

International study on **Cost-Effective Earth Observation Missions**

EDITOR: RAINER SANDAU



International Study

**Cost Effective Earth Observation
Missions**



IAA Commission IV Study Group

Commission IV: System Operation & Utilisation

International Academy of Astronautics

October, 2005

POSITION PAPER CONTRIBUTORS

Principal Editor:

Rainer Sandau

Redaction Committee:

Jaime Esper
Larry Paxton
Rainer Sandau

Authors (contributions to chapters):

Briess, Klaus (Germany)	4.1.3, 7.1, 8.4.2
Bartholomé, Etienne (Italy)	7.9
Belward, Alan (Italy)	7
Boshuizen, Chris (Australia)	8.1.1, 8.1.2
Carmona-Moreno, Cesar (Italy)	7
Contant, Jean-Michel (France)	4.4
Cutter, Mike (UK)	4.1.1
Esper, Jaime (USA)	3.2.4, 4, 4.1.2, 4.5, 5, App. 3
Hsiao, Fei-Bin (Taiwan)	8.3, 8.4
Ince, Fuat (Turkey)	7.5
Jacobs, Martin (South Africa)	5 - 5.2.3
Kayal, Hakan (Germany)	4.2, 4.3
Kawashima, Rei (Japan)	8.5.3
Klimov, Stanislav (Russia)	8, 8.1, 8.5.1
Konecny, Gottfried (Germany)	3.2.1, 7.8
Krischke, Manfred (Germany)	7.2
Lee, Chris (UK)	3.1.2, 3.2.3, 4.1.1, 4.2
Neumann, Andreas (Germany)	7.4
McCouston, Doug (USA)	4.5
McKenna-Lawlor, Susan (Ireland)	3.2.1.1 – 3.2.1.7, App. 1, 2
Mostert, Sias (South Africa)	5
Olsson, Håkan (Sweden)	7.3
Parlow, Eberhard (Switzerland)	7.6
Paxton, Larry (USA)	1, 2, 3.1.3, 3.2.5, 3.2.7, 7.5, 9
Sandau, Rainer (Germany)	1, 3, 3.1.1, 3.2.2, 3.2.6, 3.2.8, 3.2.9, 3.2.10, 8.4.4, 8.4.5, 9
Scherer, Dieter (Germany)	7.7
Squibb, Gael (USA)	3.2.11
Taylor, Emma A. (UK)	3.2.11
Wertz, James (USA)	6
Wynne, Randolph (USA)	7.3
Yasaka, Tetsuo (Japan)	8.5.3

Further Contributors:

Kusnierkiewicz, David (USA)
Milne, Garth (South Africa)
Ovchinnikov, Michael (Russia)
Thyagarajan, K. (India)
Wei, Sun (UK)

LIST OF CONTENT

Position Paper Contributors	iii
List of Abbreviations.....	ix
Summary.....	1
1 Introduction.....	3
2 Definition of cost-effective Earth Observation Missions	11
3 Background Material and Organizational Support.....	13
3.1 Studies	13
3.1.1 IAA Studies	13
3.1.1.1 IAA Position Paper on Inexpensive Scientific Satellites	13
3.1.1.2 IAA Position Paper: The Case for Small Satellites.....	14
3.1.2 COCONUDS	15
3.2 Organizations and Programs.....	16
3.2.1 United Nations.....	16
3.2.1.1 Introduction to UN/COPUOS.....	16
3.2.1.2 Background to UN/COPUOS.....	16
3.2.1.3 UN Conferences on the Peaceful Use of Outer Space	17
3.2.1.4 UNISPACE III/ Small Satellite Missions for Earth Observations.....	18
3.2.1.4.1 Definition of Small Satellites.....	18
3.2.1.4.2 Philosophy of Small Satellites	18
3.2.1.4.3 Complementarity of Large and Small Satellite Missions.....	19
3.2.1.4.4 Small Satellite Management	19
3.2.1.4.5 Scope of Small Satellite Applications.....	19
3.2.1.5 Recommendations of UNISPACE III.....	20
3.2.1.6 Conclusions	20
3.2.1.7 Useful Background Reading.....	21
3.2.2 CEOS.....	21
3.2.2.1 General Information	21
3.2.2.2 Structures and Activities related to the position paper subject	22
3.2.3 ESA Smallsat Initiatives	23
3.2.4 NASA	25
3.2.4.1 NASA's Faster, Better Cheaper Paradigm.....	25
3.2.4.2 Examples of NASA Missions	26
3.2.5 COSPAR.....	26
3.2.5.1 General Information	26
3.2.5.2 Structures and activities related to the position paper subject	27
3.2.6 IAF.....	28
3.2.6.1 General information.....	28
3.2.6.2 Structures and Activities related to the position paper subject	28
3.2.7 Operational Agencies (NOAA, EUMETSAT)	29
3.2.8 International Academy of Astronautics IAA	32
3.2.8.1 General Information	32
3.2.8.2 Structures and activities related to the Position Paper subject.....	32
3.2.9 ISPRS	36
3.2.9.1 General Information	36
3.2.9.2 Structures and Activities related to the position paper subject	37
3.2.10 EARSeL.....	38
3.2.10.1 General Information.....	38
3.2.10.2 Structures and Activities related to the position paper subject	39
3.2.11 ISO TC20/SC14 "Space systems and operations"	39
4 Mission Cost Drivers.....	45
4.1 Space segment	45
4.1.1 Payload	45
4.1.2 Spacecraft	47
4.1.3 Quality Assurance.....	47
4.2 Ground segment.....	48

4.3	Mission Operations.....	51
4.4	Access to Space	53
4.5	Management and Organizational Approach	56
4.5.1	Industry Approach – The Earth Orbiter 1 (EO-1) Experience.....	56
4.5.2	Government Agency or Organization.....	56
5	Cost estimation and modeling.....	59
5.1	Definitions and Background.....	59
5.1.1	Lifecycle Phases.....	59
5.1.2	Work Breakdown Structure.....	59
5.1.3	Costing Models.....	59
5.2	Current Best Practice, Comments and Examples	60
5.2.1	Best Practice from Micro-satellite experience.....	60
5.2.2	Cost models and Mission Costs: a self fulfilling prophecy?.....	60
5.2.3	Pooling of Contribution and Funding.....	61
6	Achieving Cost Effective Missions.....	63
6.1	Is Cost Reduction Real?	63
6.2	Determining Goals and Objectives.....	64
6.3	General Methods for Reducing Space Mission Cost.....	66
6.4	Using Non-Space Assets	71
6.5	Data Sharing, Cost Sharing, and Income Generation	74
7	Application Fields, Status quo and Prospects	75
7.1	Disaster warning and support	76
7.1.1	Status quo	76
7.1.2	Prospects.....	80
7.2	Agriculture.....	83
7.2.1	Status quo	83
7.2.2	Prospects.....	86
7.3	Forestry.....	86
7.3.1	Status quo	86
7.3.2	Prospects.....	88
7.4	Ocean and Coastal Zone	89
7.4.1	Status quo	89
7.4.2	Prospects.....	91
7.5	Atmosphere	93
7.5.1	Observations of the Earth’s Atmosphere and Ionosphere Status quo	93
7.5.2	Prospects.....	95
7.6	Weather and Climate	96
7.6.1	Status quo	96
7.6.2	Prospects.....	97
7.7	Ice and Snow	97
7.7.1	Status quo	97
7.7.2	Prospects.....	99
7.8	Mapping and Geographic Information System Applications	100
7.8.1	Status quo	100
7.8.2	Prospects.....	102
7.9	Land Use/Cover Change.....	103
7.9.1	Status quo	103
7.9.2	Prospects.....	104
8	Training and Education	107
8.1	UN initiated activities.....	107
8.1.1	The Space Generation Advisory Council (SGAC) and its projects	107
8.1.2	The Space Generation Congress.....	108
8.2	International Space University	111
8.3	ITC in Holland.....	111
8.4	Examples of Student Programs.....	111
8.4.1	Program of scientific-educational microsatellites «Space to Youth, Youth to Space».....	111
8.4.2	The PICO-Sat program.....	112

8.4.3	UNISEC (Japan).....	113
8.4.4	ESA Activities	115
8.4.5	IAA	116
9	Conclusions and Recommendations	117
9.1	General Facts	117
9.2	Conclusions and Recommendations Drawn from the Background Material in Chapter 3	118
9.3	Additional Recommendations from this Study.....	119
9.4	The Future of Cost-Effective Earth Observation Missions.....	124
9.4.1	New capabilities	124
9.4.2	Challenges	125
9.4.3	Success and Failure of Cost-effective Missions	126
Appendix 1	Small Satellite Application Aspects drawn from UN Documents.....	1
1	Telecommunications.....	1
2	Earth Observations	1
3	Scientific Research on Small Satellites	2
4	Technology Demonstrations.....	3
5	Academic Training	3
6	Low Cost Launches	4
7	Launch Access.....	4
8	Ground Segment.....	5
9	Economic Benefits.....	5
10	International Cooperation	6
11	Economic and Social Commission for Asia and the Pacific.....	6
Appendix 2	Cooperating IAA subcommittees and joint IAA/UN Workshops	1
1	IAA Subcommittee on Small Satellites for Developing Nations.....	1
2	IAA Subcommittee on Small Satellites for Countries Emerging in Space Technology	1
3	UN/IAA Workshop (Brazil, 2000)	2
4	UN/IAA Workshop (France, 2001)	4
5	UN/IAA Workshop (Houston, 2002)	5
6	UN/IAA Workshop (Bremen, 2003)	8
7	UN/IAA Workshop (Vancouver, 2004)	10
Appendix 3	Examples of NASA Missions.....	1
1	The Earth Science Enterprise	1
2	Earth System Science Pathfinder.....	5
3	The Explorers Program.....	5

LIST OF TABLES

Table 4.1-1:	Payload and Platform Advances Appropriate to Small Satellite Implementation	46
Table 4.4-1:	Micro Launchers.....	54
Table 4.4-2:	Small Launchers	54
Table 4.4-3:	Medium Launchers.....	54
Table 4.4-4:	Intermediate Launchers	55
Table 4.4-5:	Heavy Launchers	55
Table 4.4-6:	Super Heavy Launchers.....	55
Table 6.1-1:	Ratio of Actual Cost to Projected Cost for 10 Case Study Missions.....	63
Table 6.2-1:	Representative Cost Data for Reduced Cost Space Missions.....	64
Table 6.3-1:	Summary of the Cost Reduction Methods Used by the Case Study Missions of	
	Tables 6.1-1 and 6.2-1.....	68
Table 6.3-2:	Methods Used by Specific Case Study Missions.....	69
Table 6.4-1:	Summary of Effects and Recommendations Associated with the Space Environment.	72
Table 6.4-2:	Alternatives to a Dedicated Launch.....	73
Table 7.2-1:	Use of the different spectral bands	85
Table 7.4-1:	Spatial resolution, field of view, and sampling frequency requirements for sensors.....	
	for coastal waters and regional applications/monitoring.....	92
Table 7.4-2:	Spectral requirements for coastal waters optical observation and monitoring.....	92
Table 7.8-1:	Status of World Mapping 1990.....	101
Table 7.8-2:	Annual Update Rates of World Mapping 1990	102
Table 7.8-3:	Relationship between pixel size and the possible mapping scale in planimetry.....	103
Table 9.3-1:	Cost Reduction Methods	120
Table 9.3-2:	Alternatives to Dedicated Satellites.....	122

LIST OF FIGURES

Figure 3.1-1:	Global coverage versus resolution.....	15
Figure 3.2-1:	Structure CEOS	23
Figure 3.2-2:	Structure of the IAA Study Group “Small Satellite Mission for Earth Observation”.....	35
Figure 4.2-1:	Traditional Ground Segment	49
Figure 4.2-2:	Future Smallsat Ground Segments	51
Figure 6.2-1:	The Space Mission Analysis and Design Process.....	66
Figure 6.3-1:	Schedule Compression Without Changing the Rules or Requirements is a Lot	
	Like Getting a Cat to Move a Piano Up the Stairs	70
Figure 7.4-1:	Spatial and temporal requirements for coastal studies (after Hoepffner).....	91
Figure 8.1-1:	Delegates at the Space Generation Congress in Vancouver Canada 2004	110
Figure 8.1-2:	Delegates at the Space Generation Summit held at the World Space Congress in 2002 ...	110

LIST OF ABBREVIATIONS

ASAP	Ariane Structure for Auxiliary Payloads
ASIM	application specific micro-instrument
CEOS	Committee on Earth Observation Satellites
COCONUDS	Co-ordinated Constellation of User Defined Satellites
COPUOS	Committee on Peaceful Uses of Outer Space
COSPAR	Committee on Space Research
COTS	Commercial Off-The-Shelf
DLR	Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
DMC	Disaster Monitoring Constellation
EARSel	European Association of Remote Sensing Laboratories
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FAA	Federal Aviation Authority
FCC	Federal Communication Commission
FMA	Failure Mode Analysis
GEO	Geostationary Orbit
GEO	Group on Earth Observation
GEVS	General Environmental Verification Specification
GMES	Global Monitoring for Environment and Security
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HEO	High Earth Orbit
HST	Hubble Space Telescope
IAA	International Academy of Astronautics
IAC	International Astronautical Congress
IADC	Inter-Agency Space Debris Co-ordination Committee
IAF	International Astronautical Federation
ISAS	Institute of Space and Aeronautical Sciences
ISO	International Organization for Standardization
ISPRS	International Society for Photogrammetry and Remote Sensing
ISU	International Space University
ITAR	International Traffic in Arms Regulations
ITC	International Training Center
JPL	Jet Propulsion Laboratory
L 1	Lagrange Point 1
LANDSAT	Land Remote Sensing Satellite
LEO	Low Earth Orbit
MEMS	micro-electromechanical system
Met Op	Meteorological Operational Service
MMS	Multi-mission Modular Spacecraft
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
SAR	Synthetic Aperture Radar
SGAC	Space Generation Advising Council
SPOT	Systeme pour l'Observation de la Terre
TRL	Technology Readiness Level
UAV	Unmanned Air Vehicle
UN	United Nations
UNISEC	University Space Engineering Consortium
UoSAT	University of Surrey Satellite
VHF	Very High Frequency

SUMMARY

This study was performed by an IAA study group, formed in 2002. The members of the study group represent different entities like governmental organizations, space agencies, academia, industry, as well as different disciplines like science, engineering, application oriented professions, and management. The geographic distribution of the 36 authors of this study covers 15 countries on five continents. Under these circumstances there was a unique opportunity to generate a study unbiased in every aspect, intended to serve the information needs of the target groups: Governments, space agencies, academia, industry, which rely on good overview information concerning status and possibilities/prospects of cost-effective Earth observation missions in the very broad variety of applications.

Cost-effective missions can be achieved by using different approaches and methods.

One of the possible approaches is taking full advantage of the ongoing technology developments leading to further miniaturization of engineering components, development of micro-technologies for sensors and instruments which allow to design dedicated, well-focused Earth observation missions. At the extreme end of the miniaturization, the integration of micro-electromechanical systems (MEMS) with microelectronics for data processing, signal conditioning, power conditioning, and communications leads to the concept of application specific integrated micro-instruments (ASIM). These micro- and nano-technologies have led to the concepts of nano- and pico-satellites, constructed by stacking wafer-scale ASIMs together with solar cells and antennas on the exterior surface, enabling the concept of space sensor webs.

Further milestones in the cost-effective Earth observation mission developments are the availability and improvement of small launchers, the development of small ground station networks connected with rapid and cost-effective data distribution methods, and cost-effective management and quality assurance procedures.

Since the advent of modern technologies, small satellites have also been perceived to offer an opportunity for countries with a modest research budget and little or no experience in space technology, to enter the field of space-borne Earth observation and its applications. This is very much in line with the charter of the IAA Study Group on Small Satellite Missions for Earth Observation. One of its intentions is to bring within the reach of every country the opportunity to operate small satellite Earth observation missions and utilize the data effectively at low costs, as well as to develop and build application-driven missions. In this context the study group supports all activities to develop and promote concepts and processes by various user communities to conduct or participate in Earth observation missions using small, economical satellites, and associated launches, ground stations, data distributions structures, and space system management approaches.

More generally cost-effective Earth observation missions are supported by four contemporary trends:

- Advances in electronic miniaturization and associated performance capability;
- The recent appearance on the market of new small launchers (e.g. through the use of modified military missiles to launch small satellites);
- The possibility of 'independence' in space (small satellites can provide an affordable way for many countries to achieve Earth Observation and/or defense capability, without relying on inputs from the major space-faring nations);
- Ongoing reduction in mission complexity as well as in those costs associated with management; with meeting safety regulations etc.

The advantages of small satellite missions, complementing the large complex missions are:

- more frequent mission opportunities and therefore faster return of science and for application data
- larger variety of missions and therefore also greater diversification of potential users
- more rapid expansion of the technical and/or scientific knowledge base
- greater involvement of local and small industry.

This Study provides a definition of cost-effective Earth observation missions, information about background material and organizational support, shows the cost drivers and how to achieve cost-effective missions, and provides a chapter dedicated to training and education. The focus is on the status quo and prospects of

applications in the field of Earth observation. Finally, conclusions and recommendations are summarized in terms of

- more general facts that drive the small satellite mission activities,
- outcomes from the background material used in the study which show that good work have been done before and the lessons learned process started soon after beginning of the small satellite activities,
- additional outcomes of the study which go beyond the information of the background material, and
- some visions concerning the future of cost-effective Earth observation missions.

In brief, our position is that developing cost-effective Earth observation missions is within the means of many nations. The development of small satellite technologies bears with it enormous opportunities to do more with less, address local and global needs, focus the development of the technical infrastructure of a country, and reduce risk inherent in the use of space.

1 INTRODUCTION

At the beginning of the space age all space projects were small, if you neglect the huge initial efforts to provide the necessary infrastructure. The incredible increase of knowledge coming from these small space missions induced a huge amount of new questions and the space projects were growing bigger and bigger. This was due to the growing complexity of the missions leading to increasing costs and development times. This trend became true not only in the US and the Soviet Union but also in the other regions entering the space field like Western Europe and Asia. The space programs run into a kind of cost spiral: higher costs led to fewer missions which led to the demand for higher reliability which again leads to longer schedules and higher costs.

The return to smaller missions was initiated by

- the restriction to dedicated missions with only single instruments or sensor systems optimized to observe specific physical phenomena
- the reduction in space budgets.

The International Academy of Astronautics (IAA) since 1988 called attention to the potential for small inexpensive satellite missions through studies, symposia at the IACs and stand-alone conferences, which were organized by IAA committees (see chapter 3.2.8.2). Also UN focused on this matter through UN-COPUOS and the UNISPACE conferences which are strongly supported by the IAA committees (see chapters 3.2.1.6 ... 3.2.1.12).

This study was performed by an IAA study group, formed in 2002. The members of the study group represent both, different entities like governmental organizations, space agencies, academia, industry, as well as different disciplines like science, engineering, application oriented professions, and management. The geographic distribution of the 36 authors of this study covers 15 countries on five continents. Under these circumstances there was a unique opportunity to generate a study unbiased in every aspect, intended to serve the information needs of the target groups: Governments, space agencies, academia, industry, which rely on good overview information concerning status and possibilities/prospects of cost-effective Earth observation missions in the very broad variety of applications.

Cost-effective mission according to the formula given in chapter 2 can also be complex mission, missions using GEO satellites, and so forth. This study focuses on small satellite missions in LEO, and, where ever possible, on small satellites of sizes and weights to be transported into LEO with small inexpensive launchers or even as secondary or so-called piggy-back payload systems. The small satellite mission philosophy may be described as a design-to-cost approach with strict cost and schedule constraints, combined with, as far as possible, a single mission objective. For the purpose of this study we use the generic term small satellite for space craft weighting under the 1000 kg limit. We propose a simplified nomenclature for subsets of small satellites:

- mini satellites < 1000 kg
- micro satellites < 100 kg
- nano satellites < 10 kg
- pico satellites < 1 kg

It should be noted that there is as yet no universally adopted definition of small satellites. For instance ESA defines small having a mass of 350–700 kg, mini 80–350 kg and micro 50–80 kg. Similarity, at University of Surrey (UK) satellites with masses of 500–1000 kg are “small” and masses of 100–500 kg belong to “mini”. Concerning the small satellite related costs the figures differ considerably. At UNISPACE III, the costs of developing and manufacturing a typical mini-satellite was indicated to be US\$ 5-20 million, while the cost of a micro-satellite was correspondingly US\$ 2-5 million. The cost of a nano-satellite could be below US\$ 1 million (prices of 1999).

Cost-effective missions can be achieved by using different approaches and methods.

One of the possible approaches is taking full advantage of the ongoing technology developments leading to further miniaturization of engineering components, development of micro-technologies for sensors and instruments which allow to design dedicated, well-focused Earth observation missions. At the extreme end of the miniaturization, the integration of micro-electromechanical systems (MEMS) with microelectronics for data processing, signal conditioning, power conditioning, and communications leads to the concept of application specific integrated micro-instruments (ASIM). These micro- and nano-technologies have led to the concepts of nano- and pico-satellites, constructed by stacking wafer-scale ASIMs together with solar cells and antennas on the exterior surface, enabling the concept of space sensor webs.

Further milestones in the cost-effective Earth observation mission developments are the availability and improvement of small launchers, the development of small ground station networks connected with rapid and cost-effective data distribution methods, and cost-effective management and quality assurance procedures.

Since the advent of modern technologies, small satellites have also been perceived to offer an opportunity for countries with a modest research budget and little or no experience in space technology, to enter the field of spaceborne Earth observation and its applications. This is very much in line with the charter of the IAA Study Group on Small Satellite Missions for Earth Observation. One of its intentions is to bring within the reach of every country the opportunity to operate small satellite Earth observation missions and utilize the data effectively at low costs, as well as to develop and build application-driven missions. In this context the study group supports all activities to develop and promote concepts and processes by various user communities to conduct or participate in Earth observation missions using small, economical satellites, and associated launches, ground stations, data distributions structures, and space system management approaches.

More generally small satellite missions are supported by four contemporary trends:

- Advances in electronic miniaturization and associated performance capability;
- The recent appearance on the market of new small launchers (e.g. through the use of modified military missiles to launch small satellites);
- The possibility of ‘independence’ in space (small satellites can provide an affordable way for many countries to achieve Earth Observation and/or defense capability, without relying on inputs from the major space-faring nations);
- Ongoing reduction in mission complexity as well as in those costs associated with management; with meeting safety regulations etc.

The advantages of small satellite missions are:

- more frequent mission opportunities and therefore faster return of science and for application data
- larger variety of missions and therefore also greater diversification of potential users
- more rapid expansion of the technical and/or scientific knowledge base
- greater involvement of local and small industry.

But of course, generally applicable rules of space law continue to apply, where relevant, also in the area of small satellite missions.

After some years of global experience in developing low cost or cost-effective Earth observation missions, one may break down the missions into categories like:

- Commercial – Requiring a profit to be made from satellite data or services
- Scientific/Military – Requiring new scientific/military data to be obtained
- New technology – Developing or demonstrating a new level of technology
- Competency demonstration – Developing and demonstrating a space systems competency
- Space technology transfer/training – Space conversion of already competent engineering teams
- Engineering competency growth – Developing engineering competence using space as a motivation
- Education - Personal growth of students via course projects or team project participation

The first three categories are usually executed in leading nations by mature space organizations with high quality standards and concomitant overhead costs and salaries. The major means of competing in lower-cost projects is by minimizing non-recurring engineering through re-using existing designs and processes. Since project evaluation is based on hard reviews of operational, scientific or technological merits, there is limited

freedom to adapt missions to meet subsidiary mission goals. The remaining categories are represented by developing organizations comprising nations, businesses, or individuals that often have goals of becoming mature space organizations. The developing organizations are often centered in educational or research institutes or are in countries that are not yet leaders in space technology. These institutes or countries are motivated by organizational or national development aims, and are prepared to contribute manpower, funds, and alternatively funded facilities to a spacecraft project. Such development efforts are characterized by the inclusion of engineers of the owning country participating in the development team, but having little previous experience of spacecraft development. Some projects are done with the help of a technology transfer organization. Projects done without technology transfer partners are usually initiated by organizations with well-developed technology bases.

Small satellite missions provide an attractive, and low-cost, means of demonstrating, verifying and evaluating new technologies or services in a mission environment at a level of acceptable risk - prior to using these technologies in more expensive, full-scale, missions. Small mission platforms can flight-demonstrate and qualify new equipment, sensors and systems cheaply and derive meaningful results in a short time (relative to what pertained in the case of early, essentially large, missions). NASA's "faster, better, cheaper" approach, as well as the program of the Institute of Space and Aeronautical Sciences (ISAS) Japan in mounting a plethora of scientific missions of 'small' class, are examples of the philosophy in action at Space Agency level. A reduction in the size of satellites has been seen among commercial Earth Observation missions, - with fewer, smaller instruments custom configured to provide full services for specific, and national, user communities (as compared with, say, the large Land Remote-Sensing (LANDSAT) satellites; ESA's ENVISAT and Meteorological Operational (MetOp) Service and the French Systeme pour l'Observation de la Terre (SPOT) type satellites).

UNISPACE III (see chapter 3.2.1.4) concluded that small spacecraft, through exploiting advanced technology (featuring larger payload mass in relation to the total mass of the spacecraft; reduced development time and that reduction in launch costs accruing to the reduced size and mass of the satellite bus), provide an attractive solution in the matter of serving the needs of Developing Countries. Of course, this conclusion is applicable to businesses and developed countries as well.

In this study we consider large satellite missions and small satellite missions being complementary rather than competitive. The large satellite missions are sometimes even a precondition for cost-effective approaches. Small satellites provide an attractive, and low-cost, means of demonstrating, verifying and evaluating new technologies or services in an orbital environment at a level of acceptable risk - prior to using these technologies in more expensive, full-scale, missions. Also, small satellites provide more frequent and varied mission opportunities; more rapid expansion of the relevant technical knowledge base; greater involvement of local industry and greater diversification of potential users. Some problems are, however, better addressed using large platforms. For example, geo-stationary satellites were, in 1999, tending to increase in mass. This was because the number of positions available in geo-stationary orbit is limited and because it was perceived at the time that a longer spacecraft lifetime would increase the financial return on the investment level concerned. On the other hand, some applications, can be better solved through the use of distributed systems (e.g. by employing constellations of either micro-satellites or small satellites suitably configured to achieve global cover). Yet other situations call for centralized systems (for example: the measurement requirements of a large optical instrument such as the Space Telescope; using high power, direct broadcast, communications systems etc.).

It was noted at UNISPACE III that experience shows that small teams (25 persons) working in close proximity, having good communications and lead by well informed responsive management, provide the best structure for producing a small satellite within budget while also successfully meeting performance and delivery targets. Such teams are typically found in small companies or research groups rather than in large aerospace organizations - which latter find it difficult to modify those in-house procedures put in place and, generally, required for large projects.

Completion of a satellite development project is an easily countable (though not necessarily reliable) indicator of a country or organization's technological capability. Funding can often be motivated for a first satellite as a demonstrator, but further projects typically need solid utilization plans and are funded by national agencies since few small satellites projects will attract commercial financing. Funding level has a

direct impact on the success of development spacecraft. Where a government agency or research institute initiates, or is responsible for the project, or the payload, sufficient funds and regulatory support is normally provided to allow the project leadership to focus on technical issues. Without such support, project leadership is at risk of being deflected to attend to fund-raising, political, and regulatory issues, with undesirable technical consequences for the project. Many small spacecraft projects emerge from developing nations, and are motivated by technical development goals. The payloads are often selected by engineering teams without a corresponding science/data interpretation team. Engineering teams often have to make the selections because scientists regard own satellites as risky developments and prefer to spend their resources on lower-risk activities. Government has a significant role to play in making funding available to both science and engineering teams conditional on full participation by both disciplines.

Further opportunities exist where organizations motivated by satellite engineering and organizations motivated by science research combine in joint projects, with each organization funding and delivering its bus and payload contributions. With this approach, payloads are likely to produce data that will be well used, and will be calibrated before flight to the levels necessary to extract science value.

Such science/engineering interactions can, and have occurred at international level, and increasing globalization should encourage such cooperation. For success however, it is highly recommended that the project be supported by government agencies on both sides, which should ensure that sufficient funding is available to make the mission a success. It is particularly important that teams not be financially stressed in the final phases of spacecraft and mission preparation, because of the impact on mission reliability. One issue, of the many that face the international cooperation, is technology transfer.

The satellite itself is often the most visible aspect of a satellite mission. However, the ground segment makes the mission possible. The ground segment fulfils three distinct functions:

- (1) operations which include status and health monitoring of the satellite, as well as necessary command preparation and validation;
- (2) tracking telemetry and commanding which are realized by the telecommunications station, possibly in association with the operations center;
- (3) data reception and the transmission of data to the user(s) - for processing and further distribution.

At UNISPACE III it was noted that the ground station can be based on a simple, very high frequency (VHF), antenna - as in the case of the University of Surrey's UoSAT satellite series. An Earth Observation mission can require, however, more complex support - due to the associated requirement to collect a large volume of data. Small satellites tend to be willing to trade risk for cost and rely on on-board autonomy and safe modes. This choice reduces their need for continuous ground monitoring - thereby simplifying, as well as reducing the overall cost of, the ground segment. The availability of on-board navigational autonomy through using the Global Positioning System (GPS) encourages this tendency.

The cost of mission operations constitutes a major element in the overall cost of a small satellite mission. Thus, although major agency tracking networks may be required during the launch and early operations phase, it is more cost-effective to, thereafter, employ national facilities (ideally utilizing a single ground station), during routine operations. A major driver is the cost of human resources. The high reliability and power of modern, personal, computers can make automation an affordable solution (with respect for example to antenna tracking; pass set-up and close-down; data reception/ storage; conversion of raw data; and status checking). Also, small satellites with modest telemetry and availability requirements might utilize mobile communications constellations to provide a global data relay system.

It was recommended that, although a ground system for a small satellite program should feature low cost, its reliability should remain sufficient to ensure that satellite passes/data transmissions are not missed. The system should further offer a fast return of critical data, as well as a rapid response to critical commanding. For bulk data, a regular return could be adequate, depending on the application concerned. However, direct down-linking to user terminals and portable ground stations can be beneficial (especially in the case of remote sensing data).

At times the major obstacle faced by satellites, large and small, has been getting into space. Large satellites tend to require very large boosters whose cost can approach 500M US\$. These large launch vehicles are often

not readily available and require special launch support. Small satellites have more opportunities for space access. Opportunities for small satellites to access space include: launch on a dedicated, expendable launch vehicle and launch as a secondary (piggyback) satellite, or as one of two spacecraft on a 'dual mission', on a single expendable launch vehicle. A launch service offered by the Space Shuttle ("get-away specials") was temporarily suspended in 2003 due to the grounding of the Space Shuttle following the loss of Columbia.

To make a choice between different launch opportunities involves weighing up the requirements of a desired mission against the capabilities, costs and constraints characterizing a particular option. At UNISPACE III it was recommended that, if a shared launch is considered, flexibility with regard to the date of launch/orbit attainment and also the value of the spacecraft itself should be carefully taken into account by the secondary partner. A further important consideration is the reliability record of the potential launch vehicle (those launching a series of low-cost payloads might be willing to risk using a relatively low-cost vehicle with an unproven record).

Over the past decades, many countries have invested in the development of indigenous launch capability. The small class of expendable launch vehicles has stimulated the largest entrepreneurial activity in the United States and in other countries (including airborne launchers such as Pegasus). Such vehicles can deliver payloads weighing between 25 kg and 1500 kg to LEO. The launch of two or more small satellites on the same expendable launch-vehicle ('dual manifesting') is also feasible. Long-range and intercontinental missiles from military arsenals of the cold-war rival super powers are, in addition, presently available for civilian space launches.

The specific cost per kilogram into orbit of small launchers is higher than for larger launch vehicles. However, their absolute cost is much lower. Some operators offer lower prices on newly introduced launchers (launch on a test flight might even be free of charge). Often, the perception of risk is that it is better to distribute the programmatic risk over more than one launch – thus the mission becomes distributed across multiple spacecraft.

Manufacturers of large expendable launch vehicles are interested in offering the option of flying secondary (piggyback) payloads on missions where the primary payload does not fully utilize the capability of the launcher. Such possibilities were exploited, for example, during some United States Delta launches, and in the case of Russian Federation Soyuz and Tsyklon launches associated with the (main payload) Resurs and Meteor satellites. Although the small payload owner enjoys the benefit of a cost-effective alternative to the purchase of a dedicated, (small) expendable launch vehicle, the schedule of the primary payload is, in such situations, agreed to be unaffected by the requirements/best interests of the secondary payload. While in 1999 shared launch opportunities were relatively rare, the growing requirement for multiple launches into Low and Medium Earth orbit posed by telecommunication satellites can be expected, in the future, to generate more frequent opportunities for piggyback launches.

Also in Europe, the Ariane 4 launcher featured a special supporting structure (The Ariane Structure for Auxiliary Payloads ASAP), which was specifically designed to support the simultaneous launch of several small satellites. The mass of an individual participating satellite (up to seven per launch can be lofted together) was limited to 50 kg. The more powerful Ariane 5 is designed to launch several 50-100 kg piggyback satellites into geo-stationary transfer, as well as into low polar, orbits.

Access to a launch may be achieved either: on a purely commercial basis; through participation in an international agreement or through using national launch capability.

At UNISPACE III it was noted that utilization of launch services provided by an international commercial source can be preferable to engaging in a cooperative arrangement, particularly for countries preparing for a first launch. In such cases the launch plan should constitute an integral part of a country's long term strategy to implement its space program, and arrangements for the development of national expertise in managing launch activities should, in addition, be catered for.

Cooperative missions are feasible where there is a mutual desire between the parties to maximize unique national resources/funding. However, each participating country must assume full financial and technical responsibility for its portion of the cooperative effort. Clear and distinct managerial and technical interfaces must also be established in the associated agreement.

In connection with international co-operation it must be noted that in several countries and regions there exist restrictions to export materials, components, services, software ...

The most severe restrictions come from ITAR (International Traffic in Arms Regulations) of USA [1]. In accordance with the Arms Export Control Act, the President of USA is authorized to control the export and import of defence articles and defence services. The President shall designate which articles shall be deemed to be defence articles and defence services. The items so designated constitute the United States Munitions List. As an example, the list includes also military and space electronics. If an article or service is placed on the United States Munitions List, its export is regulated exclusively by the Department of States.

This study is subdivided into nine chapters, this introduction being one of them. The intentions and content of chapters 2 to 8 are:

Chapter 2: Definition of cost-effective Earth observation missions

A mission can be cost-effective regardless of its size. In the past there were fewer options for developing and implementing large, complex missions: they tended to be implemented as monolithic systems wherein the mission was deemed cost-effective only if all of it worked. Small satellite technologies offer a robust path for implementing large or small missions in a cost-effective manner.

Chapter 3: Background material and organizational support

This chapter gives high level information about the major studies done at IAA and at other places and organizations IAA is aware of, concerning their contents, outcomes and recommendations. More studies are implicitly addressed in the subchapter dealing with organizations and programs. The main focus of this subchapter is to inform about the major organizations and programs dealing with Earth observation used for both research and applications. Besides a more general introduction, the structures and activities are presented which are of relevance for this study; where applicable outcomes and recommendations are summarized.

Chapter 4: Mission cost drivers

Starting from the types of satellites under consideration and cost effective approaches in general, all relevant segments of a cost-effective mission are addressed: space segment with spacecraft and payload, ground segment, mission operations, launch, and management.

Chapter 5: Cost estimation and modeling

This chapter gives a background information on which parts of the mission has what weight or influence in terms of costs and efforts to the entire mission.

Chapter 6: Achieving cost effective missions

The first part deals with the question: Is cost reduction real? With other words, can we meet the overall broad mission objectives at substantially reduced cost with respect to a traditional mission? Another issue is the determination of goals and objectives. Trading on requirements is a standard part of the low-cost space mission design process. Furthermore, general methods for reducing space mission cost are discussed, for instance the system engineering methods and the programmatics methods. Also the use of non-space assets is reflected in chapter 6, which can considerably contribute to space mission cost reduction. The last focus is on data sharing, cost sharing, and income generation.

Chapter 7: Application fields, status quo and prospects

There is an increasing need for cost effective Earth Observation (EO) missions to meet the information requirements of an almost ever growing range of applications. This is perhaps most clearly seen in the many current moves for international co-operation in the field of environment where measurements from Earth Observing satellites are an essential element. This is especially so where we need to acquire, analyse and use data documenting the condition of the Earth's resources and environment on a long-term (permanent) basis. As can be seen from the list of topics addressed in chapter 7, uses range from essential mapping activities to global climate, with information needs arising because of legislation and through international commitments.

Hazards, agriculture, land degradation, desertification, deforestation, sustainable forest management, climate, our cryosphere and others topics are all highlighted here. For the different Earth observation application fields the mission requirements are summarized, and the status quo of implementation. The given prospects show how the current situation can be improved. These improvements are results of the measures and approaches described in the preceding chapter.

Chapter 8: Training and Education

Cost-effectiveness also depends on the quality and engagement of the specialists participating in planning and implementing an Earth observation mission. Countries taking their first steps in space need to learn relevant techniques from more experienced space users, thereby acquiring a cadre of appropriately trained personnel before going on to establish a national agency and to maintain a presence in space. Technology transfer through small satellite related training programs has been successfully implemented between Surrey University in the U.K. and customers in Chile, Malaysia, Pakistan, Portugal, the Republic of Korea, South Africa and Thailand.

Small satellite programs provide a natural means for the education and training of scientists and engineers in space related skills since they allow direct, hands-on, experience at all stages (technical and managerial) of a particular mission (including design, production, test, launch and orbital operations).

Chapter 9: Conclusions and Recommendations

The conclusions and recommendations derived from chapters 2 to 8 are summarized. In brief, our position is that developing cost-effective Earth observation missions is within the means of many nations. The development of small satellite technologies bears with it enormous opportunities to do more with less, address local and global needs, focus the development of the technical infrastructure of country, and reduce the risk inherent in the use of space.

[1] www.epic.org/crypto/export_controls/itar.html

2 DEFINITION OF COST-EFFECTIVE EARTH OBSERVATION MISSIONS

Defining “cost effective” in any quantitative way is difficult. Here, we develop a heuristic approach to defining cost effective to serve as a means of capturing some of the ideas developed in this position paper.

We tend to recognize a mission that was cost effective more by what came out of it than how much money went into it: this judgement arises after the fact, however. This tendency to ignore “sunk costs” is due to the simple fact that there is nothing that can be done about money that has already been spent. The concern of program managers is to reduce the total expenditure or “bottom line”, and to manage current year costs at all times during the program. Their sponsors and customers may take a different view.

During the development phase of a mission the perceived cost of a mission involves an assessment of the monetary costs as well as some weighting given to the probability and extent of a possible failure. This last factor, $f(R)$, is a function of the perceived risk R and is generally highly subjective at the management level while at the engineering level risk can be quantitatively calculated. For example, a failure mode analysis (FMA) can be performed on a board, box, instrument, satellite, or mission level and be quantitative. However, management reserves, whether they are held at 10% or 30%, are determined based on experience and in response to external customer requirements (i.e. the sponsors perception of risk). One of the challenges of small satellite missions is to manage true risk and the perception of risk.

During the initial phase of the mission, from concept to implementation, a mission is cost-effective only as long as it is seen as cost effective. For many missions this means that they must fit within an externally imposed cost cap. For example, NASA’s Office of Space Sciences has defined cost caps for small- and medium-class explorers. A successful mission must be seen to have a reasonable expectation, at all times, of making it to launch with its core science mission addressed and within the cost cap. If there is a perception that it will not then a termination review is held.

For these times up until launch we can define a quantity C_e such that

$$C_e = C/B*f(R) \tag{1}$$

Where C is the cost to date (or projected cost to completion), B is the budgeted cost and $f(R)$ is a factor that takes into account the risk that C is incorrect. If C_e is much greater than 1 the mission will be viewed as not being cost effective. If C_e is near 1 or less than 1 it is deemed cost effective.

The mission cap is usually viewed as strictly monetary but there is always an implicit calculation of the cost of failure that is added to the sunk costs. That cost of failure can be lost revenues from the current mission, from future missions, or to prestige and confidence in the mission partners. An example of the complexity inherent in the assessment of cost is the NASA Hubble Space Telescope program. HST launch was delayed due to the loss of the Space Shuttle Challenger. Even after HST was built and delivered, the costs, C , continued to increase because HST could not be launched. In the case of HST the storage costs alone were more than \$10M/month. This was in addition to the hidden cost of keeping the team together so that when the mission is launched there are trained, experienced personnel (thus, reducing the risk of on-orbit failure) available. In this case, consideration of the sunk costs made it difficult to even consider canceling the program. The cost of failure was deemed to far outweigh the cost to get to launch. Thus it was still viewed as cost effective even though it exceeded the initial cost cap. The sponsoring organization, NASA, had relatively large financial reserves and was able to absorb these costs as well as the unexpected costs to service HST and correct a serious design flaw.

The HST scenario has no counterpart in the small satellite community. Small satellite programs can not withstand the loss of key personnel or the loss of a launch opportunity because their budgets are proportionally smaller and generally have fewer advocates for the continuation of a program that is no longer seen as “cost effective”. Large programs tend to continue on due to the fact that they are so large and visible that cancellation is avoided. Oddly enough there is a certain robustness associated with small programs: the sponsor can and will often tolerate more risk. This factor, not generally found in large programs, helps small satellite programs maintain their cost effectiveness.

After launch

$$C_e = C/E \quad (2)$$

where C is the perceived cost and E is the perceived earned value of the project. After launch C is largely mission operations and data analysis and distribution costs. Note that cost and earnings are not necessarily monetary, particularly at this stage. For governments, this equation tends to be evaluated every year: there is, typically, no memory of the sunk costs except in the perceived value of the project. In other words, if a mission doesn't cost too much to run in any given year, provides some return, and was once a large program it may continue to be operated. There are many examples of this philosophy in NASA where satellites continue to be operated long after their original design life. An extreme example of this is Pioneer 10 which was operated for over 30 years. This philosophy is counter to one of the tenets of effective small satellite design: no satellite must be unique or you are trapped in the mode of continued support, with aging equipment, of a mission that returns a lower C_e yet ties up funds. A cost effective small satellite is designed to optimize the return on the current investment.

In Chapter 4 we discuss the mission cost drivers, C, of Eqn. (1) and Eqn. (2). Particular attention is paid to those factors which reduce B and $f(R)$ in Eqn. (1). Chapter 5 provides insight into the means of estimating costs and managing the perception of $f(R)$ in Eqn. (1). Chapter 6 discusses means of increasing the value of E in Eqn. (2). Chapter 7 reviews the status quo and prospects for new measurements that again, if properly implemented, will increase E in Eqn. (2). Chapter 8 provides a few examples of how E can be increased in a less tangible way: that is, by providing educational and training that could not be achieved any other way.

3 BACKGROUND MATERIAL AND ORGANIZATIONAL SUPPORT

The main purpose of this chapter is to show, that there are already activities in the area of small satellite missions for Earth observation which in many cases led to cost-effective solutions. This Position Paper makes use of the already existing experiences and tries to go one or two steps further, especially in the wide field of applications. In this context, this chapter gives high level information about the major studies done at IAA and at other places and organizations IAA is aware of, concerning their contents, outcomes and recommendations. More studies are implicitly addressed in the subchapter dealing with organizations and programs. The main focus of this subchapter is to inform about the major organizations and programs dealing with Earth observation used for both research and applications. Besides a more general introduction, the structures and activities are presented which are of relevance for this study; where applicable outcomes and recommendations are summarized.

Especially the UNISPACE III conference summarized many small satellite mission aspects which are already commonly adopted and, of course, basic material for this study. In UNISPACE III many inputs are used coming from IAA and its different Committees and Study Groups. The main activities directly related to cost-effective Earth observation missions come from the IAA Study Group on Small Satellite Earth Observation Missions which is the umbrella for related IAC sessions, the biannual stand-alone Symposia on Small Satellites for Earth Observation, and also the IAA Study Group preparing this Position Paper on Cost-Effective Earth Observation Missions.

3.1 Studies

3.1.1 IAA Studies

Since the IAA actively dealt with the subject of small satellite mission – the first special session on inexpensive scientific satellites was organized in 1988 at the IAC in Bangalore – a lot of sessions, stand-alone symposia, position papers and documents dealing with the different aspects of small satellite missions for various applications have been organized and generated. As reference documents and background material for the position paper on Cost Effective Earth Observation Missions two position papers are considered to be suitable, both results of the activities of the IAA Committee on Small Satellites:

- Inexpensive Scientific Satellites [1], [2]
- The Case for Small Satellites [3].

These two position papers are shortly characterized, in order to give the status quo coming from the IAA and to provide basis information for the position paper under subject. General information of IAA, history and activities of the Small Satellite Committee and Study Groups, which have been created in the course of restructuring of the IAA Committees, are described in chapter 3.2.8. There you may find also the lists of publications related to small satellite missions.

3.1.1.1 IAA Position Paper on Inexpensive Scientific Satellites

After the first special session on Inexpensive Scientific Satellites took place at the IAC in Bangalore, 1988, an IAA Study Team was formed which held a workshop in May 1989 in Bordeaux that resulted in a report distributed to all members of the Academy in 1990 (for final version see [1], [2]).

The content of the Position Paper covers the feasibility, measures to achieve inexpensive satellite missions, scientific needs and technological demonstrations as well as recommendations. This Position Paper was intended to contribute to the creation of an awareness that other, more cost effective ways are still possible, that they coexist with methods developed for big programs, and that they are highly recommended for the implementation of the many more modest objectives that exist in great abundance in the scientific community.

The Position Paper concludes that “inexpensive” scientific satellites, despite the non-precise definition of this notion, must fill the gaps between the major programs of the great space agencies, that they can be developed with short lead-times, and that the rules of management and technical implementation differ considerably

from those applied in the major programs. The advantage of such class of satellites is obvious: it allows for higher flight frequencies and shorter times in implementing new technological developments. Ideally the lead-times can be made to correspond with the educational cycle of space science students. For many countries, no other than “inexpensive” satellites in this sense are conceivable for budgetary constraints. Hence there is a commonality between the programs of such nations and those which have the possibility of sending man into space and explore other planets.

This Position Paper provides excellent information, and many of the management recommendations are also applicable to cost-effective earth observation missions.

Management Recommendations

- Start a program with clearly identified specifications
- Minimize program duration
 - Reduce number of models
 - Avoid technical risk in mission-critical areas
 - Minimize team size
 - Minimize number of external interfaces
 - Avoid unnecessary administrative loads
 - Find new methods for achieving geographical distribution e. g. by multiple sub-satellites
 - Adopt innovative engineering solutions
 - Don't be constrained by existing methods (but don't reject them simply on principle)
 - Be innovative without pushing the frontiers of technology (interact with technologists)
 - Adopt simple, well-defined subsystems interfaces
 - Use off-the-shelf equipment
 - Encourage modular design
 - Make use of multiple-satellite or piggyback launch opportunities
 - Identify reliable flight opportunities
 - Adopt standard mechanical interfaces
 - Use a well-proven primary structure in which other users have confidence
 - Streamline launch campaign to minimize impact on primary payloads
 - Make use of local expertise and centers of excellence
 - Research establishments
 - Small industrial companies
 - Product Assurance (PA)
 - Develop a PA plan which is just technically adequate
 - Avoid high-reliability components unless justified
 - Restrict documentation to the absolutely necessary
 - Avoid component level testing and inspection unless really necessary
 - Emphasize box-level and system-level tests.

3.1.1.2 IAA Position Paper: The Case for Small Satellites

The purpose of this Position Paper [3] is to provide a rationale for considering small satellite missions as means of satisfying the needs of developed as well as developing countries.

For those who have not yet had experience working in space activities, it is also intended to provide a guide as to how and where to begin to get the technical support needed, and to indicate the initial thought process necessary to put together a space mission. Since each entity will have its own political structure, there is no attempt made to provide a path to available funding within a particular country. There are, of course, various potential international sources of funding, for example, the World Bank and the United Nations.

Points are provided for orbit selection and launch possibilities. There is a brief description of the components required to build a spacecraft, key management techniques, and decisions that must be made. Suggestions for possible missions are included.

The Position Paper concludes that there is a rationale for considering small satellite missions as a means of satisfying the needs of developed as well as developing countries. Governments and research institutions of

all countries are urged to study, undertake and support small satellite programs for research, educational and applications purposes in accordance with their current technical and financial capabilities. The industrialized countries should take the lead in gathering and disseminating information, the developing nations should undertake to accede to, and to increase, such information. Particular encouragement should be given by the industrialized countries to projects that provide education motivation and launch opportunities should be made available by the operators of launch systems at reasonable conditions; raw data from Earth observation should be made available on a non-discriminatory basis for research and civilian applications to all countries.

[1] Acta Astronautica, Vol 31 (1993), pp 145-167
 [2] www.iaa.net.org/p_papers/inex_sat.html (2005)
 [3] Acta Astronautica, Vol. 31 (1993), pp. 101-144

3.1.2 COCONUDS

In 1998 The European Commission sponsored a Concerted Action to explore the feasibility of developing a CO-ordinated CONstellation of User Defined Satellites (COCONUDS) to take European environment monitoring forward into the information society [1]. Led by four connected user-driven groups (SciSys Ltd and NRI from the UK, NLR from the Netherlands and Geosys from Spain) it addressed the suggestion that a large number of users have need for timely, reliable and appropriate information to improve local environmental decision making and that this could be satisfied through a constellation of low-cost satellites matched to low-cost local PC reception.

To test the COCONUDS hypothesis three primary objectives were explored:

- To establish users' needs before trying to deflect mainstream Earth Observation development onto a new path.
- To assess technical feasibility of meeting these needs through a suitable constellation of micro-satellites.
- To assess economic viability through an exploration of pertinent financial, political, social and institutional issues.

In particular COCONUDS noted that while much current attention is on high resolution satellite systems, there are a considerable body of users who would welcome a more modest – but more frequent – imaging capability (that is 30-50m; 4 band). Invariably these users are quasi-operational, locally focused and resource-poor (either in funding or equipment).

One key finding has been in the dissemination of appropriate data. Broadly speaking COCONUDS confirms the user-attractiveness of low cost direct data reception of a local region. This concept, championed by NOAA

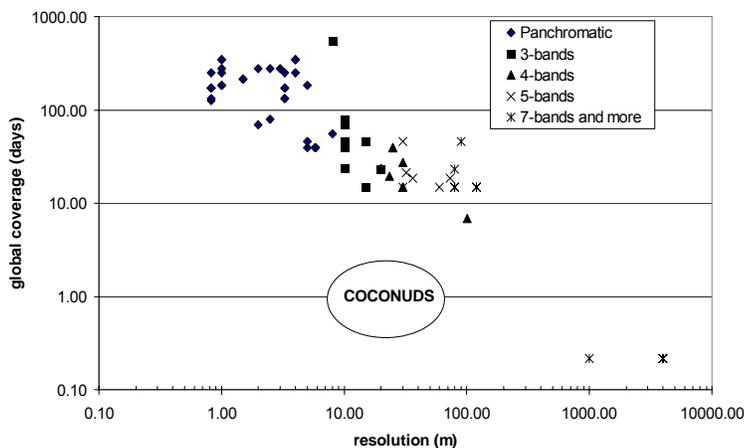


Figure 3.1-1: Global coverage versus resolution

meteorological satellites for many generations, has limited profile in more classical earth observation satellites because of their large data sets. COCONUDS however concludes that many users simply require local data and would additionally be satisfied with compressed imagery. As a result low cost reception is entirely valid.

The Programme was completed in 2001 and various related initiatives have subsequently taken the concept forward – most notably the UK SSTL Disaster Monitoring Constellation.

[1] www.dlr.de/iaa.symp/archive_3/pdf/0901.pdf

3.2 Organizations and Programs

3.2.1 United Nations

In the United Nations a number of organizations are involved in the use of satellite imagery

- the UN/COPUOS (United Nations committee on the Peaceful Uses of Outer Space) in Vienna follows conference activities, such as Unispace, and conducts seminar and training programs in the area of actions for catastrophic events,
- FAO, Rome, has since decades a program on food security sponsoring meteorological satellite uses and land cover monitoring,
- the UN Secretariat, New York, has a cartography unit helping to homogenize digitization and exchange of cartographic products between UN organizations,
- UNEP, Nairobi and UNEP-GRID in various locations around the globe (e. g. Arendal, Norway) makes extensive use of satellite data for monitoring purposes of the environment

Because of the direct relevance of the UN/COPUOS materials for the subject of this position paper, the following parts of the chapter give a comprehensive summary of the UN/COPUOS activities, documents and derived findings.

3.2.1.1 Introduction to UN/COPUOS

The United Nations Office for Outer Space Affairs constitutes that office of the United Nations responsible for promoting international cooperation with regard to developing the peaceful uses of outer space. The focal point of the activities of the United Nations in this regard is its Committee on the Peaceful Uses of Outer Space (COPUOS.). This Committee was established in 1959 to: review the scope of international cooperation in the matter of developing the peaceful uses of outer space; devise associated programs to be undertaken under United Nations auspices; encourage continued research and dissemination of space-related information and consider legal issues arising from the exploration of outer space.

UN/COPUOS and its two standing subcommittees - The Scientific and Technical Subcommittee and the Legal Subcommittee respectively address such issues as: benefits from space activities; the definition and delimitation of outer space; geo-stationary orbit applications; the implications of remote sensing; space-sciences; space-based communications; navigation and meteorological systems; nuclear power sources in outer space; space debris and the spin-off benefits of space technology.

3.2.1.2 Background to UN/COPUOS

In 1958, shortly after the launching of the first artificial Earth Satellite (Sputnik-1), the UN General Assembly (UN/GA) established an ad hoc Committee on the Peaceful Uses of Outer Space to consider:

- The activities and resources of the United Nations, the specialized agencies and other international bodies relating to the peaceful uses of outer space;
- International cooperation and programs in the field that could appropriately be undertaken under United Nations auspices;
- Organizational arrangements to facilitate international cooperation in the field within the framework of the United Nations;
- Legal problems which might arise in programs to explore outer space.

Practical proposals advanced at the time to promote international co-operation included: exchange of information on space research; co-ordination of national space research programs and assistance in the realisation of these programs.

In 1959 the General Assembly established the above mentioned Committee as a permanent body and reaffirmed its mandate under GA Resolution 1472 (XIV). In 1961, considering that the United Nations should provide a focal point for international co-operation in the peaceful exploration and use of outer space, the General Assembly requested this Committee to:

- Maintain close contact with governmental and non-governmental organisations concerned with outer space matters;
- Provide for the exchange of such information relating to outer space activities as governments may supply on a voluntary basis; supplementing, but not duplicating, existing technical and scientific exchanges;
- Assist in the study of measures for the promotion of international co-operation in outer space activities.

These tasks were specified to be performed in co-operation with the Secretary-General - using UN office facilities. The Secretary General was, in addition, personally requested to maintain a Public Registry of Launchings, based on the information supplied by States launching objects into orbit or beyond.

These terms of reference have since provided general guidance for the activities of COPUOS in promoting international co-operation in the peaceful uses and exploration of outer space.

At the time of writing (mid 2003) COPUOS incorporates 65 Member States. In addition to these States, a number of international organisations, including inter-governmental and non-governmental organisations, have observer status with respect to COPUOS and its Subcommittees.

The decisions of the General Assembly relating to the peaceful use of outer space and of COPUOS are implemented by the United Nations Office for Outer Space Affairs (OOSA) which co-ordinates all space-related activities of the United Nations and carries out the United Nations Program on Space Applications. This Office, which is located at the United Nations premises in Vienna, Austria, organises an annual Inter-Agency Meeting on Outer Space Activities which is open to all organisations of the United Nations system and deals with such issues as exchanging information, preventing duplication and arranging joint activities of common interest.

Detailed information on the work of COPUOS and its Subcommittees are contained in Annual Reports, which can be readily accessed through the web-site of the UN Office of Outer Space Affairs.

Since the advent of modern technology, particularly of microelectronics, small satellites have been perceived to offer an opportunity for countries with a modest research budget and little or no experience in space technology, to enter the field of space research and its applications. Against the background of this philosophy, the COPUOS Scientific and Technical Subcommittee routinely includes this issue in its deliberations.

The Committee for Space Research (COSPAR) collaborates with the International Astronautical Federation (IAF) in organising various meetings. In particular, COSPAR and the IAF mount annual (biennial from 2003) joint symposia held during the scientific and technical sessions of the UN/COPUOS and these symposia are organised by OOSA. Only those symposia relating to small satellites for Earth Observation, with special regard to the requirements of Developing Countries, will be mentioned here. Such a COSPAR/IAF symposium entitled Space Technology in Developing Countries making it happen was convened in 1992 and a further symposium entitled Utilisation of micro and small satellites for the expansion of low-cost space activities taking into special account the needs of Developing Countries was held in 1996. The proceedings of these events are available on the COSPAR/IAF website.

3.2.1.3 UN Conferences on the Peaceful Use of Outer Space

The Office for Outer Space Affairs provided the substantive secretariat for three United Nations Conferences on the Peaceful Uses of Outer Space (UNISPACE I, II and III), held in 1968, 1982 and 1999 respectively. Reports on the proceedings of these individual conferences are available on the United Nations website. The

organization of UNISPACE III was recommended by the General Assembly in its resolution 47/67 of 14 December 1992. At that time, in the newly established post cold-war era with its profoundly changed circumstances with regard to space and security, it was recognized that bold and innovative thinking on the part of the UN and its Member States was required to derive maximum benefit for everyone from the new situation. The primary aims of UNISPACE III (held in Vienna from 19-30 July, 1999) were defined to be as follows:

- To promote effective means of using space technology to assist in the solution of problems of regional or global significance;
- To strengthen the capabilities of Member States, in particular Developing Countries, to use the applications of space research for economic and cultural development;
- To provide Developing Countries with opportunities to define their needs for space applications for development purposes;
- To consider ways of expediting the use of space applications by Member States to promote sustainable development;
- To address the various issues related to education, training and technical assistance in space science and technology;
- To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;
- To strengthen international co-operation in the development and use of space technology and its applications.

In consequence of related discussions during the meeting itself, a resolution, currently referred to as The Space Millennium Vienna Declaration on Space and Human Development, was formulated which constitutes the nucleus of a strategy to address outstanding global challenges in the space arena. The text of this declaration is contained in the “Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space” (UN document A/CONF. 184/6).

3.2.1.4 UNISPACE III/ Small Satellite Missions for Earth Observations

In preparation for UNISPACE III, the Office for Outer Space Affairs of the UN Secretariat compiled a set of twelve background papers to provide Member States participating in the Conference (as well as in various regional preparatory meetings), with information on the latest status and trends in the use of space-related technologies. These papers were based on inputs provided by: international organisations, space agencies and by experts from all over the world. They are available through the UN Office of Outer Space website and should be read collectively. Only paper nine (Small Satellite Missions) which was discussed under the aegis of a dedicated Technical Forum during UNISPACE III, will be described below.

3.2.1.4.1 Definition of Small Satellites

It was noted in the above mentioned paper on Small Satellite Missions that there is no universally adopted definition of a small satellite. An upper limit of about 1000 kg is, however, usually observed and this was the limit adopted for UNISPACE III. Further, spacecraft of >100 kg were referred to as mini-satellites; those between 10-100 kg as micro-satellites and those below 10 kg as nano-satellites. (It is recalled for comparison that, at the University of Surrey in the U.K., spacecraft between 500-1000 kg are classified as ‘small’ while those between 100-500 kg are classified as ‘mini’ satellites. Also, at the European Space Agency (ESA), spacecraft between 350-700 kg are referred to as ‘small’ while those between 80-350 kg and those between 50-80 kg are called “mini” and “micro” satellites respectively).

At UNISPACE III, the cost of developing and manufacturing a typical mini-satellite was indicated to be between US\$ 5 - 20 million, while the cost of a micro-satellite was correspondingly between US\$ 2 - 5 million. The cost of a nano-satellite could be below US \$ 1 million (prices of 1999).

3.2.1.4.2 Philosophy of Small Satellites

The small space mission philosophy was described to require a design-to-cost approach (within strict cost and schedule constraints), combined with, as far as possible, a single mission objective. This focused approach was noted to be supported by four contemporary trends:

- Advances in electronic miniaturisation and associated performance capability;

- The recent appearance on the market of new small launchers (e.g. through the use of modified military missiles to launch small satellites);
- The possibility of ‘independence’ in space (small satellites can provide an affordable way for many countries to achieve Earth Observation and/or defence capability, without relying on inputs from the major space-faring nations);
- Ongoing reduction in mission complexity as well as in those costs associated with management; with meeting safety regulations etc.

Small mission platforms can flight-demonstrate and qualify new equipment, sensors and systems cheaply and derive meaningful results in a short time (relative to what pertained in the case of early, essentially large, missions) NASA’s “faster, better, cheaper” approach, as well as the program of the Institute of Space and Aeronautical Sciences (ISAS) Japan in mounting a plethora of scientific missions of ‘small’ class, were cited as examples of the philosophy in action at Space Agency level. A reduction in the size of satellites was further noted among commercial Earth Observation missions, - with fewer, smaller instruments custom configured to provide full services for specific, and national, user communities (as compared with, say, the large Land Remote-Sensing (LANDSAT) satellites; ESA’s ENVISAT and Meteorological Operational (MetOp) Service and the French Systeme pour l’Observation de la Terre (SPOT) type satellites).

Overall it was concluded that small spacecraft, through exploiting advanced technology (featuring larger payload mass in relation to the total mass of the spacecraft; reduced development time and that reduction in launch costs accruing to the reduced size and mass of the satellite bus), provide an attractive solution in the matter of serving the needs of Developing Countries.

3.2.1.4.3 Complementarity of Large and Small Satellite Missions

The new methodologies and techniques developed for small satellites are often later flown on major missions. Also, small satellites provide more frequent and varied mission opportunities; more rapid expansion of the relevant technical knowledge base; greater involvement of local industry and greater diversification of potential users.

Some problems are, however, better addressed using large platforms. For example, geo-stationary satellites were, in 1999, tending to increase in mass This was because the number of positions available in geo-stationary orbit is limited and because it was perceived at the time that a longer spacecraft lifetime would increase the financial return on the investment level concerned.

On the other hand, some applications, can be better solved through the use of distributed systems (e.g. by employing constellations of either micro-satellites or small satellites suitably configured to achieve global cover). Yet other situations call for centralised systems (for example through: the employment of: a large optical instrument such as the Space Telescope; using high power, direct broadcast, communications systems etc.).

3.2.1.4.4 Small Satellite Management

It was noted at UNISPACE III that experience shows that small teams (25 persons) working in close proximity, having good communications and lead by well informed responsive management, provide the best structure for producing a small satellite within budget while also successfully meeting performance and delivery targets. Such teams are typically found in small companies or research groups rather than in large aerospace organisations - which latter find it difficult to modify those in-house procedures put in place for large projects.

3.2.1.4.5 Scope of Small Satellite Applications

Already in 1999 it was usual to consider solving problems in the areas of: Telecommunications; Earth Observations; Agricultural Land Use; Environmental Protection; Testing/validation of new technologies and Academic Training by means of small satellites. Appendix 1 summarises the following application aspects given in the UN documents:

- Telecommunication
- Earth Observation
- Scientific Research on Small Satellites

- Technology Demonstration
- Academic Training
- Low Cost Launches
- Launch access
- Ground Segment
- Economic Benefits
- International Cooperation
- Economic and Social Commission for Asia and the Pacific

3.2.1.5 Recommendations of UNISPACE III

The general recommendations of UNISPACE III are articulated in a resolution entitled The Space Millennium Vienna Declaration on Space and Human Development and these recommendations were endorsed by the General Assembly of the United Nations in its resolution 54/68 of 6 December 1999.

It was in particular recommended, inter alia, that the joint development, construction and operation of a variety of small satellites offering opportunities to develop indigenous space industry should be undertaken as a suitable project for enabling space research, technology demonstrations and related applications in communications and Earth Observations.

To establish a means to realize this recommendation, the OOSA substantially extended its existing cooperation with the Subcommittee on Small Satellites for Developing Nations of the IAA. Information about the cooperating IAA subcommittees and the joint Workshops are given in Appendix 2, summarising the following cooperative activities:

- IAA Subcommittee on Small Satellites for Developing Nations
- IAA Subcommittee on Small Satellites for Countries Emerging in Space Technology
- UN/IAA Workshop (Brazil, 2000)
- UN/IAA Workshop (France, 2001)
- UN/IAA Workshop (Houston, 2002)
- UN/IAA Workshop (Bremen, 2003)
- UN/IAA Workshop (Vancouver, 2004)

3.2.1.6 Conclusions

The Committee on the Peaceful Uses of Outer Space (COPUOS) set up by the General Assembly in 1959 currently forms the focal point of United Nations activities in the field of outer space. This Committee (with its two Subcommittees) has, since its inception, promoted international co-operation in developing the peaceful exploitation of outer space, in this regard functioning successfully against the changing political background characterising the transition from the pre to the post cold-war era.

The Office for Outer Space Affairs provided the substantive secretariat for three United Nations Conferences on the Peaceful Uses of Outer Space (UNISPACE I, II and III), held in 1968, 1982 and 1999 respectively. At UNISPACE III, it was recommended, inter alia, that the joint development, construction and operation of a variety of small satellites offering opportunities to develop indigenous space industry, should be undertaken as a suitable project for enabling space research, technology demonstrations and related applications in communications and Earth Observations.

Countries ‘Emerging in Space Technology’ are defined to be those with a technical knowledge base and some space experience which are striving for small satellite missions to exploit the new, cost effective, possibilities they offer. An IAA Subcommittee was formed in 1997 to support the aspirations of this multi-national community. Structures within COPUOS to support these countries in their efforts to gain access to space using small economical satellites, still require to be established.

Since UNISPACE III, five Workshops held respectively in Brazil, 2000, France, 2001, the U.S.A. 2002, Germany, 2003 and Canada, 2004, aimed at progressing the general theme of Small Satellites in the Service of Developing Countries, have been jointly mounted by the UN/OOSA and the Subcommittee on Small Satellites for Developing Nations of the IAA within the framework of the IAC. These Workshops have acted

as tools to progress the aspirations of Developing Countries with respect to the acquisition of small satellite technology. The individual workshops considered in this regard the Latin-American Experience, the African Perspective and how, in general, small satellite programs contribute to the development within particular countries of their indigenous scientific and applications programs. Recommendations for future work were, on each occasion, formulated.

3.2.1.7 Useful Background Reading

Acta Astronautica, Vol. 43, 1998, contains selected papers from the Workshop on Small Satellites for European Countries Emerging in Space Technology (Maynooth, 1996). See S. McKenna-Lawlor, pp. 545-555 for an account of those circumstances attending the setting up of a Subcommittee of the IAA to cater for the needs of countries emerging in space technology

Background Paper (No. 9) Small Satellite Missions - for the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space. United Nations Document A/CONF. 184/BP/9

Proceedings of a Workshop of the IAA on *Small Satellites for European Countries Emerging in Space Technology* held at St. Patrick's College, Maynooth, Ireland, 7-10 May, 1996, Vols. 1-2. Ed. S. McKenna-Lawlor Published by Space Technology Ireland, Ltd., 1996

Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (Vienna, 19-30 July 1999). United Nations Document A/CONF. 184/6

Report of the Committee on the Peaceful Uses of Outer Space, General Assembly, Official Records, Fifty--Seventh Session, Supplement No. 20. United Nations Document (A/57/20)

Report of the United Nations/International Academy of Astronautics Workshop on Small Satellites at the Service of Developing Countries the Latin American Experience (Rio de Janeiro, Brazil, 5 October, 2001). Document A/ AC 105/745

Report of the Second United Nations/International Academy of Astronautics Workshop on Small Satellites at the Service of Developing Countries the African Perspective (Toulouse, France, 2 October, 2001). Document A/ AC 105/772

Report of the Third United Nations/International Academy of Astronautics Workshop on Small Satellites at the Service of Developing Countries Beyond Technology Transfer (Houston, U.S., October 12, 2002). Document A/ AC 105/799

Report of the Fourth United Nations/International Academy of Astronautics Workshop on Small Satellites at the Service of Developing Countries: a contribution to sustainable development (Bremen, Germany, 19 September, 2003. Document A/AC, 105, 813

Report of the Fifth United National/International Academy of Astronautics Workshop on Small Satellites at the Service of Developing Countries: current and planned small satellite programs (Vancouver, Canada, 5 October, 2004). In press

Acknowledgement; The author thanks the United Nations Office for Outer Space Affairs at Vienna for kindly making the report of the Fifth Workshop in the series on *Small Satellites at the Service of Developing Countries* available in advance of publication.

3.2.2 CEOS

3.2.2.1 General Information

The Committee on Earth Observation Satellites (CEOS), established in 1984, is charged with coordinating international civil spaceborne missions designed to observe and study planet Earth. Comprising 43 space agencies and other national and international organizations, CEOS is recognized as the major international forum for the coordination of Earth observation satellite programs and for interaction of these programs with users of satellite data and information worldwide. CEOS works on the principle of "best efforts"

contributions and is managed through a permanent Secretariat, Plenary meetings, and a number of Working Groups. The CEOS Chairmanship rotates annually among its Members.

The goals of CEOS are to:

- Optimize the benefits of spaceborne Earth observations through cooperation of its Members in mission planning and in the development of compatible data products, formats, services, applications and policies;
- Aid both its Members and the international user community by inter alia serving as the focal point for international coordination of space-related Earth observation activities, including those related to global change;
- Exchange policy and technical information to encourage complementarity and compatibility among spaceborne Earth observations systems currently in service or development, and the data received from them; issues of common interest across the spectrum of Earth observations satellite missions are addressed.

For detailed information about CEOS, its history, activities, structure and documents, visit the CEOS Web site: <http://www.ceos.org>

3.2.2.2 Structures and Activities related to the position paper subject

CEOS's Subsidiary Groups comprise three Working Groups and the SIT (see Figure 3.2-1).

Working Group on Information Systems and Services (WGISS)

The objective of WGISS is to facilitate and coordinate Earth observation data and information management and services, which are essential elements of successful Earth observation programs, throughout CEOS agencies. WGISS seeks to furnish data providers and users with harmonized and coordinated data and information systems, on a global scale, that easily and efficiently supply access to data, information, and services.

WGISS has two subgroups:

- Technology and Services Subgroup
- Projects and Applications Subgroup

Working Group on Calibration and Validation (WGCV)

WGCV is the second standing Working Group. The ultimate goal of the WGCV is to ensure long-term confidence in the accuracy and quality of Earth observation data and products.

WGCV has two specific tasks:

- sensor-specific calibration and validation, and
- geophysical parameter and derived product validation.

WGCV has the following subgroups:

- Atmospheric Chemistry Subgroup
- Infrared and Visible Optical Sensors (IVOS) Subgroup
- Land Product Validation (LPV) Subgroup
- Microwave Sensors (MS) Subgroup
- Synthetic Aperture Radar (SAR) Subgroup
- Terrain Mapping (TM) Subgroup

Working Group on Earth Observation Education and Training (WG-EDU)

The goals of the ad hoc working group on Earth Observation Education and Training (WGEdu) are as follows:

- Enable CEOS to promote and facilitate activities that substantially overarch and enhance international cooperation in education and training.

- Maximize benefits of the use of Earth observing satellite data and information in the sustainable management of natural and managed resources, global change research, weather and ocean state databases, ocean color applications, and basic and applied research to foster new knowledge.
- Facilitate the improvement of data availability and access, the transfer of satellite data processing and data interpretation methodology, the integration of satellite-derived data with other geospatial data streams, and the improvement of the training infrastructure necessary to support operational and strategic decisionmaking.

The Strategic Implementation Team (SIT)

The CEOS Strategic Implementation Team (SIT) was created in 1996 to advance the involvement of CEOS in the development of the Integrated Global Observing Strategy (IGOS). The SIT comprises CEOS Member Principals with the authority to commit agency support to initiatives as they unfold. The SIT’s purpose is to define, characterize, and develop the vision for CEOS’s participation in IGOS, to define and coordinate the space component of IGOS, and to address, with the relevant IGOS Partners, the interface between the space component and the in situ component.

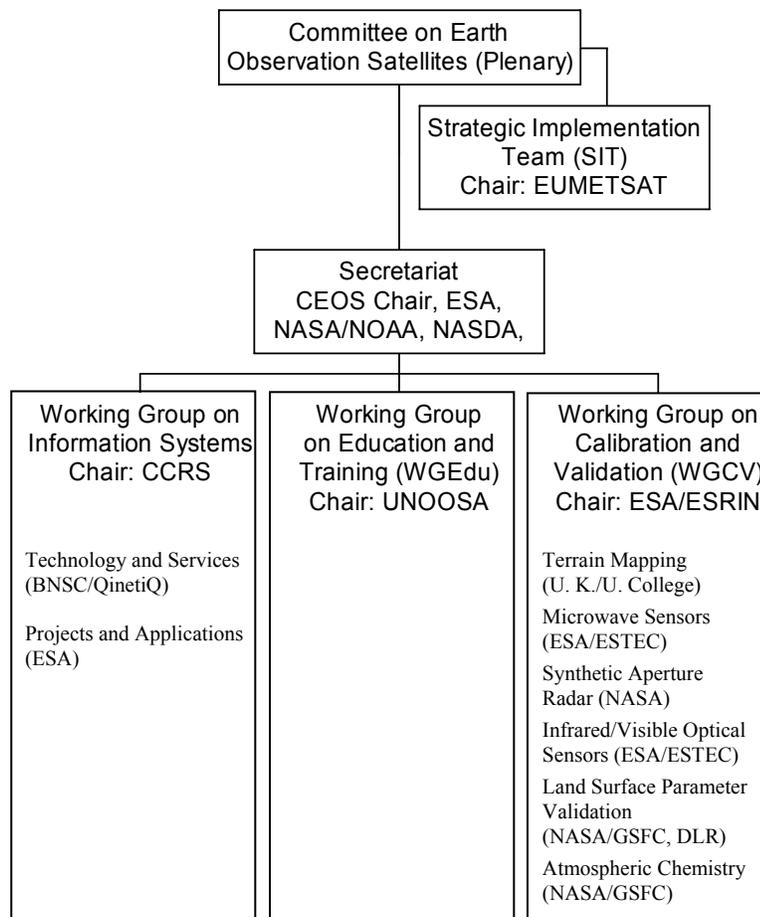


Figure 3.2-1: Structure CEOS

3.2.3 ESA Smallsat Initiatives

ESA has for many years surveyed the possible market for Smallsat missions (for example the Smallsat Mission Opportunity study conducted in the early 90’s) but they have yet to embrace the development of such a mission -with the notable exception of the Technology Satellite Proba 1, believing such technology to be more appropriate for individual member states. However in the late 90’s ESA’s new Earth Observation Envelope Programme undertook a new approach to programme development with the creation of their Earth Explorer and Earth Watch initiatives.

Taking each in turn:

Earth Explorer

Earth Explorer is targeted very much at quick science through coordinated academic, industrial and Agency developments to deliver single shot missions that can answer challenging earth science questions. While costs for such missions have tended to be larger than initially anticipated (due often to more complex instrumentation than the satellite) they have successfully demonstrated a fast-track approach versus previous “traditional” systems such as ERS and Envisat. However programmes such as Cryosat, GOCE and AEOLUS cannot truly be said to be “small”.

Nevertheless as the promise of faster missions becomes accepted (nominally a mission every 1-2 years) earth science expert groups are now proposing smallsats for their data collection. This has led to two genuine smallsats being assessed at Phase A for a future Explorer. These are the ACE+ and SWARM mission initiatives:

ACE+

The Atmosphere and Climate Explorer mission (ACE+) would measure variations and changes in atmospheric temperature and water vapour distribution. Comprising 4 microsatellites flying as two pairs in the same orbital plane but at two different altitudes, ACE+ will demonstrate a highly innovative approach using radio occultation to establish accurate global profiles of temperature in the troposphere, and water vapour in the troposphere and stratosphere.

The use of two satellites in each of the two non-sun synchronous orbits is designed to maximise geographical coverage. The satellites in the 650 km orbit will counter-rotate with respect to the satellites in the 850 km orbit. The counter-rotation is needed for cross-link occultations between the low Earth orbit (LEO) satellites of the ACE+ mission, also called LEO-LEO cross-link. Consequently, the orbits all have a 90° inclination.

Each satellite carries instrumentation in order to fulfill the two main functions:

- a precision L-band receiver and related antennas for GNSS occultations,
- a precision X/K-band transmitter or receiver and related antennas for LEO-LEO occultations.

SWARM

The objective of the Swarm mission is to provide a survey of the geomagnetic field and its temporal evolution. The concept consists of a constellation of four satellites in two different polar orbits between 400 and 550 km altitude. High-precision and high-resolution measurements of the strength and direction of the magnetic field will be provided by each satellite. In combination, they will provide the necessary observations that are required to model various sources of the geomagnetic field. GPS receivers, an accelerometer and an electric field instrument will provide supplementary information for studying the interaction of the magnetic field with other physical quantities describing the Earth system – for example, Swarm could provide independent data on ocean circulation.

The multi-satellite Swarm mission will be able to take full advantage of a new generation of magnetometers enabling measurements to be taken over different regions of the Earth simultaneously. Swarm will also provide monitoring of the time-variability aspects of the geomagnetic field.

As with Earth Explorer, ESA’s EarthWatch - intended to support operational, multi-year, multi-mission user needs - has garnered interest from more “traditional” satellite developers. Met-Op for Eumetsat and TerraSAR are current examples. However in its first call for ideas, many of the proposals actually suggested constellations of smallsats and one of these – Feugo – has survived through a series of ESA internal studies. There is every expectation that should another EarthWatch call be made, smallsats would feature even more strongly.

FUEGO

FUEGO would be designed to monitor the precursor conditions that give rise to wild fires. It would also provide information to help fight such fires. It is conceived as a constellation of 9-12 smallsats in an orbit designed to cover the Mediterranean areas (as well as parts of USA and Australia) frequently. (23 minutes for the equator). Instrumentation is expected to include thermal and middle infrared modes for fire identification, and visible / near infrared channels for fire control.

Fires will be detected on board the satellite and positions downlinked using low data rates to local reception stations and relayed to the relevant control locations via networks and onto the world fire web.

3.2.4 NASA

The National Aeronautics and Space Administration (NASA) has, besides the general “Faster Better Cheaper Paradigm”, a number of programs and projects dedicated to Earth observations. The bulk of missions are carried out by the Earth Science Enterprise, which by definition concentrates on measurements within the Earth’s atmosphere. As the scope of Earth observations are more broadly defined here to include magnetospheric and upper atmospheric observations, programs and projects relevant to the Space Science Enterprise are also introduced. It is the latter Enterprise that has found more widespread use for small satellites and their inherent low costs, although that historical trend has seen significant changes over that past few years.

3.2.4.1 NASA’s Faster, Better Cheaper Paradigm

Large organizations must address challenges not found in small organizations. In a large organization, faced with a task as complex as building a high-visibility mission, risk is generally avoided at all costs. With the dispersal of the elements of the project team, management and communications become a major concern. Documentation requirements and reviews are imposed to insure the delivery of a product, community input is sought (a process that tends to broaden mission scope rather than focus it) to ensure continued support, and the cost growth thus incurred leads to a lengthening out of the schedule. NASA Earth Observing System (EOS) was one such large system. Conceived and developed in the 1980’s it reflected the heritage and attitudes of the manned space program: bigger was better, better safe than sorry, it costs as much as it costs. Satellite programs, which were the life’s blood of the scientific research community endured decades long development to flight times and under the guise of the requirement for simultaneity of the missions brought all instruments onto one platform. For NASA the path was even more restricted as the commitment to the Space Shuttle mandated the elimination of NASA support for small launchers aside from a very limited sounding rocket program.

By 1992 NASA needed a change. A small satellite program was considered to be anything less than \$300M US in 1992 dollars. Because of the enormous costs, there were few missions in any discipline and technology had to be frozen in early in the program. The NASA Administrator, Dan Goldin, called upon NASA to change the manner in which the organization dealt with satellite programs. Goldin coined the term “faster, better, cheaper” known as FBC as the new NASA approach. There was considerable resistance to this approach as many felt that one could only implement two of the three terms but could never achieve all three in a given project.

FBC reflected a management approach that intended to stimulate innovative development and application of technology, to streamline policies and practices, and to find a way to do new missions safely and successfully in an era of diminishing resources. The key ideas were that one must:

- Distribute risk by moving from single high-cost, long-development time missions to multiple low-cost, shorter development time missions
- Empower the project teams by making them responsible for a mission’s success
- Incorporate appropriate new technologies and develop new technologies required for future missions.

This was a large paradigm shift for NASA. In some instances, the principles were applied well and resulted in mission success. Programs such as Explorers, Discovery, Earth Science System Pathfinder, and New Millennium, were reinvented to capitalize on smaller, less costly, and technologically challenging approaches to achieve the scientific and technological objectives. In other instances, notably Mars ’98, Lewis, and Clark, attempts to apply these principles resulted in mission failure.

FBC was intended to promote prudent risk taking to push the technical and programmatic boundaries. Many of the tenets of small satellite design were applied to large programs that were risk averse. This would lead to problems and confusion as resources were highly constrained and guidance on the boundaries of innovation and risk taking was lacking.

By many measures, FBC was an enormous success. FBC resulted in a threefold increase in the number of programs and projects, particularly in small science payloads. The same cultural dynamics that allowed FBC to be proposed would also lead to problems. The success of FBC required more project managers and systems engineers. At the same time, however, the entire US government work force was being reduced. NASA reduced its civil service workforce by 24 percent from Fiscal Year (FY) 1993 through FY 1999, causing both a loss in corporate knowledge and a substantially increased workload on the remaining employees. Losses also occurred within the aerospace industry workforce. In addition, instruments became more complex and because mission operations costs were slated for reduction, the technical complexity of the missions and their associated software increased. Spacecraft autonomy was introduced to hold down operations costs – this led to, among other things, the near loss of the NEAR spacecraft. Any one of these changes in practice, skills, and knowledge of the workforce would have presented a serious challenge. Couple this with the demand for the inclusion of innovation in aerospace science and technology, and the problem is further compounded.

Despite these challenges, NASA's overall mission success rate in the 1990's remained high. However, the success rate for missions that represented a radical departure from the old way of doing business, stimulated by the FBC approach, was approximately two out of three. This failure rate seemed large: when the Mars '98 failures occurred, other failure investigations and more formalized assessment of Agency practices resulted. Generally, the FBC approach is still seen as valid. The Mars '98 projects did provide a case study of the limitations of FBC. The Mars '98 missions were over-constrained by the simultaneous existence of fixed resources, schedule, and science requirements that were not revisited as the mission development progressed. Rather than re-scope the mission to match resources and schedule, risks were accepted. Some of those risks were as simple as not fully documenting interfaces or project communications and assumptions. The lessons learned from the problems with FBC, at least those relevant to this position paper is that FBC principles are valid when applied to an appropriately sized program. NASA has begun to realize this by developing criteria to judge when risk can be accepted and when it can not. Clearly manned spaceflight is one area where risk must be minimized. The loss of the Shuttle Columbia led to a reluctance to accept even modest risk. NASA's satellite work is and will continue to be inherently risky. Therefore, the goal is to strive for the intelligent and meaningful management of risk. The issue for NASA and any other space faring organization is to provide adequate guidance for decision-making and risk management for all projects.

3.2.4.2 Examples of NASA Missions

There is a good number of NASA programs with an enormous number of missions which need to be mentioned in the context of this study. The related information is given in Appendix 3 referring to NASA programs:

- Earth Science Enterprise
- Earth System Science Pathfinder
- Explorer Program

3.2.5 COSPAR

3.2.5.1 General Information

COSPAR is the Committee on Space Research. Founded in 1958 by the International Council for Science (ICSU), at the time the International Council of Scientific Unions, it is an international organization charged with encouraging international collaboration and information exchange in space research. The principal focus of COSPAR is the biennial meeting or Scientific Assembly, held in even number years. This week long meeting attracts several thousand scientists spanning many disciplines (a list of the sessions at a representative meeting follows). Anyone can attend, and anyone can propose a session. In addition, COSPAR will sponsor COSPAR Colloquia or other co-organised/co-sponsored meetings. A list of such meetings can be found at the COSPAR site. In addition to the meetings, COSPAR has a journal, *Advances in Space Research (ASR)*, which is now fully refereed and produced by Elsevier Science. ASR is organized as a series of thematic issues, consisting of papers relating to the presentations made at the COSPAR meetings. The Colloquia are published as independent proceedings. COSPAR also has an Information Bulletin sent to members of COSPAR. The Bulletin lists meetings, reports on meetings, news of space programs, lists recent launches and other items of interest to the space community. The Bulletin is published three times a year. The organization is divided into "scientific commissions" that cover broad areas of scientific research. Individuals may propose specific focused sessions within a scientific commission or that span multiple disciplines. The

leaders of the Scientific Commissions are elected from those attending the meetings. COSPAR's highest body is the Council. The Council is comprised of the Committee's President, Representatives of Member National Scientific Institutions and International Scientific Unions, the Chairs of COSPAR Scientific Commissions, and the Chair of the Finance Committee. The Council meets at the Committee's biennial Scientific Assembly. Between Assemblies the Bureau runs COSPAR.

3.2.5.2 Structures and activities related to the position paper subject

Scientific Commission A: Space Studies of the Earth's Surface, Meteorology and Climate

A0.1 Trends in Research and Operational Satellite Missions for Earth System Science

A0.2 Early Warning of Natural Hazards Using Space Technology

A1.1 Atmospheric Remote Sensing: Earth's Surface, Troposphere, Stratosphere and Mesosphere

A2.1 Biological and Physical Oceanographic Processes from Satellite Data

A3.1 Biological and Physical Processes on Land

Scientific Commission B: Space Studies of the Earth-Moon System, Planets, and Small Bodies of the Solar System, consists of 18 sub-commissions.

Scientific Commission C: Space Studies of the Upper Atmosphere of the Earth and Planets including Reference Atmospheres

Sub-commissions of interest are:

C0.1 Standards in Space Environments for ISO

C0.2 Advances in Remote Sensing of the Middle and Upper Atmosphere and Ionosphere

C1.1 Mesosphere, Thermosphere and Ionosphere Research: Coordinated Ground and Space Observations

D3.2/C1.3 Magnetosphere-Ionosphere Coupling: An Interdisciplinary Approach

C2.1 Coupling Processes in the MLT Region

D2.1/C2.2/E3.1 Influence of the Sun's Radiation and Particles on the Earth's Atmosphere and Climate

C2.3 Long-term Changes of Greenhouse Gases and Ozone and their Influence on the Middle Atmosphere and Lower Thermosphere

C2.4 Atmospheric electrodynamics and climate change

C2.5 Structure and Dynamics of the Arctic and Antarctic Middle Atmosphere

C3.1/B0.7/D3.3 Planetary Upper Atmospheres, Ionospheres and Magnetospheres

C4.1 CIRA: The Development of a New Generation of COSPAR International Reference Atmospheres

C4.2 Advances in Specifying Plasma Temperatures and Ion Composition in the Ionosphere

C5.2/D4.2 Artificial Aurora: Predictions, Observations and Interpretation

There are 9 further sub-commissions with non Earth related subjects.

Scientific Commission D: Space Plasmas in the Solar System, including Planetary Magnetospheres,

Consists of 18 sub-commissions.

Scientific Commission E: Research in Astrophysics from Space,

Consists of 19 sub-commissions.

Scientific Commission F: Life Sciences as Related to Space,

Consists of 30 sub-commissions.

Scientific Commission G: Materials Sciences in Space,

Currently consists of 1 sub-commission.

G0.1 Low Gravity Phenomena in Physico-Chemical and Bio-Processes

Scientific Commission H: Fundamental Physics in Space,

Consists of 5 sub-commissions.

Panels (Satellite Dynamics, Scientific Ballooning, Environmentally Detrimental Activities, Research in Developing Countries, Standard Radiation Belts, Space Weather, Planetary Protection, Capacity Building) and Special Sessions

Panels of interest are:

PCB1/PSRDC2 The Way Forward in Capacity Building in Developing Countries

PEDAS1/B1.6Space Debris

PSB1 The Next Generation of Scientific Balloon Missions

PSD1/B2.1 Satellite Dynamics in the Era of Interdisciplinary Space Geodesy

PSRB1/F2.9 Physics and Design Issues for Radiation Environmental Models

PSRDC1 Developing Countries Space Missions, Results and Future Prospects

PCB1/PSRDC2 The Way Forward in Capacity Building in Developing Countries

SPECIAL SESSION 1 The Public Understanding of Space Science

SPECIAL SESSION 2 Space Science Education and Outreach

There are further 6 Panels and sessions dealing with non Earth related subjects.

3.2.6 IAF

3.2.6.1 General information

The International Astronautical Federation (IAF) was founded in 1951. IAF is a non-governmental association with members drawn from government organizations, industry, professional associations, and learned societies from all over the world. Today IAF has 165 members from 44 countries.

IAF encourages the advancement of knowledge about space and the development and application of space assets for the benefit of humanity. It plays an important role in disseminating information, and in providing a significant world-wide network of experts in space development and utilization of space.

Together with its associates – the International Academy of Astronautics (IAA, see also chapter 3.2.8) and the IISL (International Institute of Space Law) – the IAF organizes an International Space Congress IAC which is held each year in a different country.

The IAF also organizes other symposia, workshops and events around the world. In close cooperation with the United Nations (UN, see also chapter 3.2.1), it organizes an annual Space Workshop for Developing Nations and seminars on space activities at meetings of the UN such as those at Unispace III.

The IAF, together with the Committee on Space Research (COSPAR) and the IISL, also conducts an annual survey of highlights in space for the United Nations.

The homepage of the IAF www.iafastro.com provides details about the structure and the programs.

3.2.6.2 Structures and Activities related to the position paper subject

There are 13 Technical Committees from which seven have some relevance to the Position Paper (PP) subject. They are listed here (http://www.iafastro.com/feder/fed_cad.htm) with extracts of their terms of references. These committees are primarily dealing with the organization of sessions and symposia at the annual IAC which is organized in close cooperation with IAA and IISL.

Earth Observation

The Committee's activities shall include all aspects of Earth observation from space, especially observation related to the Earth's environment. The scope of these activities includes mission planning, microwave and optical sensors, requirements and systems for land, oceanographic, and atmospheric applications, ground data-processing systems, and requirement for measuring and monitoring renewable resources.

Space Propulsion

The Propulsion Committee addresses sub-orbital, earth to orbit, and in-space propulsion. The general areas considered include both chemical and non-chemical rocket propulsion, air-breathing propulsion, and combined air-breathing and rocket systems. Typical specific propulsion categories of interest are liquid, solid and hybrid rocket systems, ramjet, scramjet, and various variations of air-breathing and rocket propulsion and nuclear, electric, solar and other advanced rocket systems. The Committee is concerned with component technologies, the operation and application of overall propulsion systems and unique propulsion test facilities.

Space Systems

The Committee shall deal with systems, subsystems, software and components for spacecraft and ground systems. This includes the engineering and technologies of vehicles configurations, size, power, interconnections, payloads, orbital environment, orbital and attitude control, constellations, and formations, mission duration, services, and operational aspects, as well as technologies such as orbital assembly, remote manipulation, on-orbit testing and servicing, docking and retrieval, cable tethering, autonomy and software, fluid management; thermal control, cryogenic and radiative cooling, measurement of physical parameters, gravity simulation, and communications, and data management, particularly, as they concern the design, the operation and the performance of the overall system.

Space And Natural Disaster Reduction

The focus of the committee's interest will be on natural disasters, i. e., those which occur through the agency of natural phenomena. Those disasters of sudden onset (e. g. earth quakes) as well as long-term disasters (e. g. drought) will be considered. The purview will include all aspects of disaster reduction including prevention (e. g. avoidance through improved land-use practices), preparedness (e. g. disaster forecasts and warnings), and relief. All potential contributions of space technology will be considered including remote sensing, communications, data relay and search and rescue.

Education

The committee's scope will include all matters pertaining to the effects of space activities on the formal and informal education and outreach and vice-versa. These include specific student activities and supervised youth experiments, the use for educational purposes of communication satellites, Earth observation satellites; manned and unmanned spacecraft, and ground laboratories, the many educational techniques developed to motivate the learning of scientific and other disciplines and the activities of groups intended to raise public awareness of the benefits of space activities.

Space Power

The committee shall concern itself with the production of power, storage and conversion of energy, and the generation and transmission of power for spacecraft, space vehicles, artificial satellites, space stations and surface bases on planets or satellites. The committee shall also consider the technical, economic, environmental and societal issues that will influence the realization of space power systems.

Space Transportation

This committee's activities are devoted to different types of transportation systems (the system and for the propulsion stages, expandable or reusable, manned or unmanned) and to their safety and support operations.

- Launch and Re-entry Systems
- Space Transfer Systems
- Advanced Concepts - Systems
- Advanced Concepts – Technologies
- Surface and Flight Operations.

3.2.7 Operational Agencies (NOAA, EUMETSAT)

Operational systems differ from research systems at the most fundamental level: operational systems must enable the continual monitoring of the Sun-Earth system. The two best known systems for monitoring the Sun-Earth system are EUMETSAT and NOAA. Their primary focus is on gathering meteorological data. Satellite observations are an essential input to numerical weather prediction systems and also assist the human forecaster in the diagnosis of potentially hazardous weather developments. A long-term database of stable well calibrated observations is required for monitoring.

Both of these operational programs are very large. The spacecraft, themselves, are large massing over one metric ton and measuring 2 meters or more in length. The spacecraft are procured in groups and, as a consequence, embody old technology and because of the time between procurement and flight, which can readily exceed a decade, preserve that old technology as an operational asset. The longevity of the programs mean that heritage data formats and data products must be preserved in order to meet the expectations of their customers and to maintain their organizational capability to provide a long-term database of measurements suitable for intercomparison.

Europe's Meteorological Satellite Organization

EUMETSAT is an intergovernmental organization created through an international convention agreed by 18 European Member States: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, and the United Kingdom. These States fund the EUMETSAT programs and are the principal users of the systems. EUMETSAT also has seven Cooperating States: Slovak Republic, Hungary, Poland, Croatia, Republic of Serbia and Montenegro, Slovenia and Romania.

EUMETSAT's primary objective is to establish, maintain and exploit European systems of operational meteorological satellites. EUMETSAT is responsible for the launch and operation of the satellites and for delivering satellite data to end-users as well as contributing to the operational monitoring of climate and the detection of global climate changes.

The first Meteosat satellite by the European Space Agency in 1977. EUMETSAT inherited the Meteosat satellite program from the ESA in 1987. In 1991 it initiated a new programme, the Meteosat Second Generation (MSG), to ensure continuity of observations from geostationary orbit until the latter half of the second decade of the 21st century. A Meteosat Transition Programme was also commenced to ensure continuity between the then current Meteosat Operational Programme and MSG. This included one further satellite of the same design as its predecessors and a completely new ground system. In 1995 Meteosat operations were transferred to the new ground system and a dedicated Mission Control Centre in EUMETSAT's headquarters in Darmstadt.

In the 1990s the EUMETSAT Polar System (EPS) was implemented. This is a joint venture with the US National Oceanic and Atmospheric Administration (NOAA) by which EPS will provide data from a sun-synchronous orbit with an equator crossing time of 09:30h and the US satellites from the afternoon orbits. This program, known as NPOESS, is described below.

EUMETSAT's Meteosat system is intended primarily to support the National Meteorological Services (NMS) of Member States. In addition to providing images of the Earth and its atmosphere every half an hour in three spectral channels (Visible, Infrared and Water Vapour), a range of processed meteorological parameters is produced. Meteosat also supports the retransmission of data from data collection platforms in remote locations, at sea and on board aircraft, as well as the dissemination of meteorological information in graphical and text formats. EUMETSAT does, also, support the direct broadcast of data to licensed users that operate their own small ground stations. The Meteosat Second Generation system (MSG program) will be spin-stabilized like the current generation, but with many design improvements including a new radiometer which will produce images every fifteen minutes, in twelve spectral channels. This user driven change will aid the weather forecaster in the swift recognition and prediction of dangerous weather phenomena such as thunderstorms, fog and the development of small but intense depressions which can lead to devastating wind storms. The first of these new generation satellites was launched in August 2002.

While geostationary satellites provide a continuous view of the earth disc the instruments on polar orbiting satellites, flying at a much lower altitude, provide more precise details about atmospheric temperature and moisture profiles, although with a less frequent global coverage. Polar orbiting satellites also provide observational coverage in parts of the globe, particularly the Pacific Ocean and continents of the southern hemisphere which are not well-served by the current geosynchronous constellation.

EUMETSAT is currently preparing the European component of a joint European/US polar satellite system. EUMETSAT plans to assume responsibility for the "morning" (local time) orbit and the US will continue with the "afternoon" coverage. It is planned to carry EUMETSAT instruments on the Metop satellite, developed in cooperation with ESA, for a launch in 2005. Metop-1 will be the first of a series of operational satellites providing service well into the second decade of the 21st century.

NOAA and DMSP

The US National Oceanic and Atmospheric Administration (NOAA) currently operate two types of satellites that make Earth observations: the Polar Operational Environmental Satellites (POES) for long term forecast information and the Geosynchronous Operational Environmental Satellites (GOES) for synoptic observations. Both types of observations are deemed necessary.

A new series of GOES (GOES-I through M) has been developed for NOAA by the NASA. The new series provide higher spatial and temporal resolution images and full-time operational soundings (vertical temperature and moisture profiles of the atmosphere). The newest polar-orbiting meteorological satellites (that began with NOAA-K in 1998) provide improved atmospheric temperature and moisture data in all weather situations. This new technology will help provide the National Weather Service the most advanced weather forecast system in the world. NASA produces the next generation sensors for NOAA: NOAA has no organic sensor development capability.

NOAA supports a broader user community through direct transmission. For users who establish their own direct readout receiving station, the GOES satellites transmit low resolution imagery in the WEFAX service. WEFAX can be received with an inexpensive receiver. Highest resolution Imager and Sounder data is found in the GVAR primary data user service which requires more complex receiving equipment.

The POES satellite system makes nearly polar orbits roughly 14.1 times daily. Since the number of orbits per day is not an integer the sub orbital tracks do not repeat on a daily basis, although the local solar time of each satellite's passage is essentially unchanged for any latitude. Currently the satellites orbit in a morning and afternoon plane, which provides global coverage four times daily. Data from the POES series supports a broad range of environmental monitoring applications including weather analysis and forecasting, climate research and prediction, global sea surface temperature measurements, atmospheric soundings of temperature and humidity, ocean dynamics research, volcanic eruption monitoring, forest fire detection, global vegetation analysis, search and rescue, and many other applications.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) will converge existing polar-orbiting satellite systems operated by NOAA and the US Defense Meteorological Satellite Program (DMSP) under a single national program. The program is managed by the tri-agency Integrated Program Office (IPO) utilizing personnel from the Department of Commerce, Department of Defense and NASA. The current NPOESS mandate extends to the year 2018.

On December 12, 1999, the U.S. Air Force successfully launched the first of the next block of military weather satellites, the DMSP Block 5D-3, aboard a Titan II rocket, from Vandenberg Air Force Base, California. A NOAA/USAF/contractor launch team at NOAA's SOCC supported the launch of a DMSP satellite for the first time ever. DMSP, operated by NOAA, is used for strategic and tactical weather prediction to aid the U.S. military in planning operations at sea, on land, and in the air. Equipped with a sophisticated sensor suite that can create visible and infrared images of cloud cover, the satellite collects specialized atmospheric and oceanic information, as well as data about the sun's effects on the Earth in all weather conditions. Control of the new DMSP spacecraft was transferred on December 23, 1999, to the NPOESS Integrated Program Office. A joint launch team operating from NOAA's SOCC will support the next launch of a DMSP satellite in October 2002.

Later this decade, launch and operations of the remaining POES and DMSP spacecraft will cease. Instead, the converged NPOESS spacecraft will be launched beginning in early 2009, after NOAA and the USAF have both exhausted the satellites currently in the "pipeline." Full operational capability of the NPOESS constellation is expected by 2013. Satellite operations for NPOESS will be conducted from Mission Management Centers located at NOAA's SOCC and at Schriever Air Force Base.

The NPOESS development and acquisition plan is designed to make best use of production and existing POES and DMSP assets, to reduce risk on critical sensor payloads and algorithms, and to leverage civil, governmental, and international payload and spacecraft developments. The planned evolution from the current POES and DMSP programs to NPOESS will take place over several years. Currently the U.S. is operating two POES and two DMSP primary satellites. With the launch in 2005 of the first polar-orbiting

Metop satellite by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), there will be one POES, one Metop, and two DMSP satellites in four orbital planes. The first converged NPOESS satellite must be available for launch by 2008 to back-up the last launches of the current DMSP and POES satellites. The agencies participating in the NPOESS development have agreed upon a fully defined set of integrated operational requirements that will meet the needs of the nation's civil and military users for satellite data. The established requirements for 55 atmospheric, oceanic, terrestrial, climatic, and solar-geophysical data products are guiding the development of advanced technology visible, infrared, and microwave imagers and sounders that will provide enhanced capabilities to users and improve the accuracy and timeliness of observations.

Small Satellites and Operational Systems

Small satellites may provide an attractive option for demonstrating new technologies or maintaining a capability in an aging fleet. New technologies can be demonstrated by flying in tandem with an operational satellite. This allows the new technology and its associated data products to be introduced to the system. A core responsibility of an operational system is to maintain the continuity of a data product. When a primary sensor fails on an operational sensor, a new, replacement satellite must be launched. This requirement has the immediate cost of launching a replacement satellite that is redundant with the one already in orbit except for the one primary sensor which has failed. In addition, there is a large cost associated with maintaining the capability to launch that replacement on short notice. Small satellites configured so as to be able to carry any of the primary sensors into orbit, could possibly provide an important cost reduction and reduce programmatic risk as well.

3.2.8 International Academy of Astronautics IAA

3.2.8.1 General Information

The International Academy of Astronautics was founded 1960 in Stockholm during the 11th International Astronautical Congress. Since that time, IAA has brought together the world's foremost experts in the disciplines of astronautics on a regular basis to recognize the accomplishments of their peers, to explore and discuss cutting edge issues in space research and technology, and to provide direction and guidance in the non-military use of space and the ongoing exploration of the solar system. The purposes the IAA, as stated in the Academy's statute are:

- to foster the development of astronautics for peaceful purposes,
- to recognize individuals who have distinguished themselves in a branch of science or technology related to astronautics,
- to provide a program through which the membership can contribute to international endeavors and cooperation in the advancement of aerospace science, in cooperation with national science or engineering academics.

IAA has about 1100 Full and Corresponding Members in approximately 65 countries. IAA is divided into four sections: Basis Sciences, Engineering Sciences, Life Sciences, Social Sciences.

The Academy prepares cosmic planning studies with some of its 28 scientific committees and subcommittees, and is developing a linguistic data base and organizes international specialists' symposia.

The IAA continues to enjoy and appreciate its close relations to IAF (see also chapter 3.2.6) and COSPAR (see also chapter 3.2.5), and its participation in the IAC (together with IAF and IISL) and COSPAR Congresses by sponsoring and co-sponsoring sessions, symposia, round tables and outlook papers. In addition to the proceedings of its scientific meetings, the Academy publishes the journal *Acta Astronautica* and a quarterly Newsletter.

The Academy's homepage www.iaanet.org provides all details about the history, structure, programs and activities.

3.2.8.2 Structures and activities related to the Position Paper subject

Special activities in the field of the IAA Small Satellite Committee were initiated in 1988 by Prof. G. Haerendel when he organized a special session on Inexpensive Scientific Satellites at the IAC in Bangalore. The purpose of the Committee is to develop and promote the concepts and processes required by various user

communities to gain access to space using small, economical satellites and associated launches. The Committee will concern itself not only with programs in countries already involved in space activities, but also with ways of including developing nations in future space activities for the benefit of mankind. Use of small satellites for education purposes will also be considered. The main objectives of the committee are:

- Organize symposia at the IAF Congress, COSPAR and other international meetings.
- Have workshops pertinent to expanding world-wide knowledge of small satellites.
- Coordinate Cosmic Studies.
- Make presentations to countries and organizations throughout the world as appropriate.
- Identify new, simplified approaches to space system management and hardware fabrication techniques that will permit universities, developing countries and commercial entities throughout the world to have routine entry into space. Key issues also include cost control and acquisition of funding.
- Work together with other professional society groups to expand our knowledge base contacts, e. g., COSPAR and the IAF.
- Search for ways to cooperate with other international organizations having similar goals, e. g., the United Nations and the International Space University.

Among other activities partially performed in coordination and cooperation with the subcommittees, the Committee organized the Small Satellite symposia at the annual IACs and the 1st International IAA Symposium on Small Satellites for Earth Observation which took place 1996 in Berlin.

Publications of the IAA Committee on Small Satellites (see also chapter 3.1.1):

- Position Paper: Inexpensive Scientific Satellites (1990), Acta Astronautica, Vol. 31 (1993), pp. 145-167 and http://www.iaa.net.org/p_papers/inex_sat.html
- Position Paper: The Case for Small Satellites, Acta Astronautica, Vol. 31 (1993), pp. 103-144. This study was presented at the 1st World Space Congress 1992 in Washington.
- Small Satellites for Earth Observation, Digest of the International Symposium of the International Academy of Astronautics, Berlin, November 4-8, 1996, Walter de Gruyter Berlin & New York.
- Acta Astronautica, Vol. 39, Issues 9-12, pp. 631-1042 (12 November 1996), Selected Proceedings of the IAA International Symposium on Small Satellites for Earth Observation.

Due to the high level interest and the overall purpose and goals, four Subcommittees have been created:

The Subcommittee on Planetary Missions was established in 1993. It organizes sessions at the annual IAC. In 1994 it started a series of stand-alone conferences on Low-Cost Planetary Missions, the 5th IAA International Conference took place at ESA/ESTEC in Noordwijk, September 2003. Selected Proceedings are published in the IAA journal Acta Astronautica.

The Subcommittee on Coordination of Activities with Developing Nations was established in 1993. The purpose of this subcommittee is to assess the benefit of small satellites for developing countries and to develop awareness on the subject in both developed and developing countries. The IAA Subcommittee publishes its findings and disseminates relevant information through workshops and symposiums. In order to realize its goals, the IAA Subcommittee cooperates with: the United Nations and its Committee on the Peaceful Use of Outer Space, the IAF and its Committee for Liaison with International Organizations and Developing Nations, and the International Space University.

The most important activities and publications of the subcommittee are already covered in chapter 3.2.1.

The Subcommittee on Small Satellites for Countries Emerging in Space Technology was established in 1991. Such countries were formally defined to be those with a technical knowledge base and some space experience which are striving for small satellite missions to exploit the new, cost-effective possibilities they offer. Activities and publications of the subcommittee are already covered in chapter 3.2.1.

The Subcommittee on Low Cost Earth Observation Missions was established in 1998. The objectives of this subcommittee are adopted from the parent committee objectives:

This subcommittee organized sessions at the annual IACs and continued to organize the stand-alone conferences in Berlin with the 2nd International IAA Symposium on Small Satellites for Earth Observation in Berlin, April 1999.

Publications:

- Small Satellites for Earth Observation, Digest of the 2nd International Symposium of the IAA, Berlin, April 12-16, 1999, Wissenschaft & Technik Verlag Berlin, ISBN 3-89685-561-1.
- Acta Astronautica, Vol. 46, Issues 2-6, pp. 55-440 (January - March 2000), Selected Proceedings of the 2nd IAA International Symposium on Small Satellites for Earth Observation.

Beginning 2000 the IAA started an IAA Committee Restructuring program. In that restructuring process the existing committees have been consolidated into six Academy Commissions; Program Committees and Study Groups replace the subcommittees.

The new IAA Commissions are:

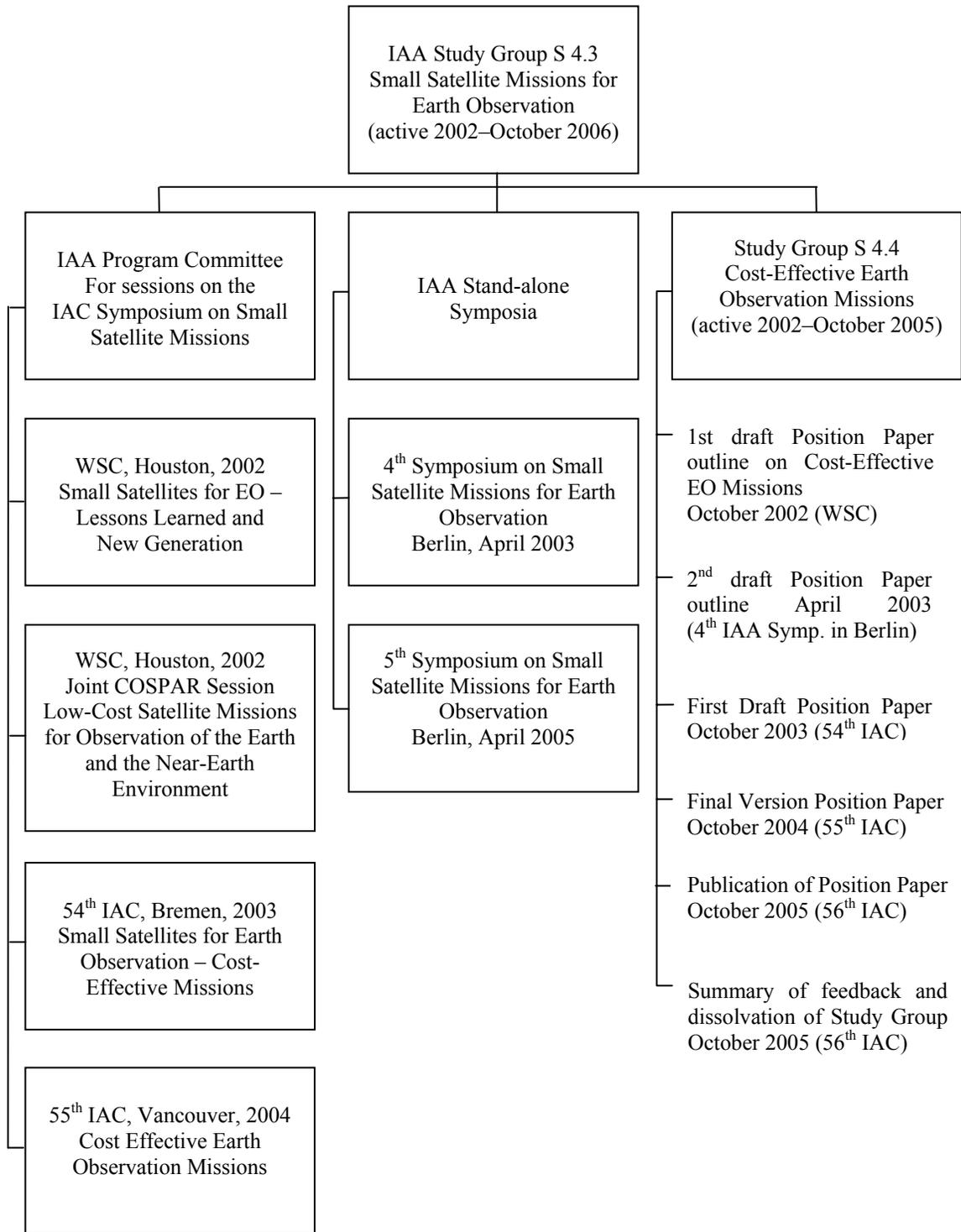
- Commission 1: Physical Science
- Commission 2: Life Sciences
- Commission 3: Technology & System Development
- Commission 4: System Operation & Utilization
- Commission 5: Policies, Law & Economics
- Commission 6: Society, Culture & Education.

In connection with this process, the subcommittee on Low Cost Earth Observation Missions transformed into the Study Group “Small Satellite Missions for Earth Observation” under the umbrella of IAA Commission 4.

It is the intention of the IAA Study Group on Small Satellite Missions for Earth Observation to bring within the reach of every country the opportunity to operate small satellite Earth observation missions and utilize the data effectively at low costs, as well as to develop and built application-driven missions. In this context the study group supports all activities to develop and promote concepts and processes by various user communities to conduct or participate in Earth observation missions using small, economical satellites, and associated launches, ground stations, data distributions structures, and space system management approaches. Small satellite missions for Earth observation can easily be tailored to the particular solutions of a country or a group of countries concerning the geography, economical and environmental needs. Novel types of constellations of small satellites are currently being designed that could serve the application needs and economical possibilities of countries and user communities by sharing the contributions and the costs. The use of low-cost satellite missions for educational purposes will also be considered.

The IAA Study Group on Small Satellite Missions for Earth Observation have the following general goals which are partially adopted from the Terms of References of the former Committee on Small Satellite Missions:

- 1) Organizing symposia at the International Astronautical Congresses, COSPAR and stand-alone symposia in Berlin.
- 2) Organize a study on “Cost-Effective Earth Observation Missions”.
- 3) Making presentations to countries and organizations throughout the world.
- 4) Working together with other professional society groups to expand our knowledge base and contacts, e. g. COSPAR and IAF.
- 5) Searching for ways to cooperate with other international organizations having similar goals, e. g., the United Nations and the International Space University.
- 6) Prepare a White Paper “Small Satellite Missions for Earth Observation” in order to provide information for decision makers, scientists, engineers, and managers about the general situation in the field of small satellite missions for Earth observation and possibilities to generate optimized/improved system designs.



- 56th IAC, Fukuoka, 2005
- 57th IAC, Valencia, 2006

Figure 3.2-2: Structure of the IAA Study Group “Small Satellite Mission for Earth Observation”

In order to further the study group's Objectives it is intended to pursue also the following specific goals:

- 1 Continue the series of bi-annual Symposia on Small Satellites for Earth Observation in Berlin
 - Bringing together users, provider, educators, specialists, and decision makers
 - Addressing the transition to the “past 2000” era regarding
 - user requirements
 - technology basisaccording to the needs and future development.
- 2 Organize session on the upcoming IACs on Small Satellites for Earth Observation with special topics, supporting the planned White Paper on “Small Satellite Missions for Earth Observation”.
- 3 Promote the development and use of new ideas for cost-effective Earth Observation Missions, e. g.,
 - new EO concepts
 - technologies of the new millennium
 - micro and nano satellite constellation conceptsin order to achieve EO solutions with the potential of sharing contributions and making use of
 - national and/or international cost distribution
 - national and/or international data interpretation distribution.
- 4 Create and propose ideas for commercialization of EO missions.

The organigram (Figure 3.2-2) summarizes the actual and planned activities of the study group.

This Position Paper “Cost-Effective Earth Observation Missions” is the activity of the IAA Study Cost-Effective Earth Observation Missions which works under the umbrella of the IAA Study Group “Small Satellite Mission for Earth Observation”. The generation of the Position Paper is strongly supported by the IAC sessions on Cost-Effective Earth Observation Missions and Special Sessions organized at the stand-alone IAA Symposia in Berlin 2003 and 2005.

Publications:

- Small Satellites for Earth Observation, Digest of the 3rd International Symposium of the International Academy of Astronautics, Berlin, April 2-6, 2001, Wissenschaft & Technik Verlag Berlin, ISBN 3-89685-566-2
- Small Satellites for Earth Observation, Digest of the 4th International Symposium of the International Academy of Astronautics, Berlin, April 7-11, 2003, Wissenschaft & Technik Verlag, Berlin, ISBN 3-89685-569-7
- Acta Astronautica, Vol. 52, Issues 9-12, May-June 2003, pp. 957-963, Selected Proceedings of the 3rd IAA International Symposium on Small Satellites for Earth Observation
- Acta Astronautica, Vol. 56, Issues 1-2, January 2005, pp. 1-346, Selected Proceedings of the 4th IAA International Symposium on Small Satellites for Earth Observation
- Small Satellites for Earth Observation, Digest of the 5th International Symposium of the International Academy of Astronautics, Berlin, April 4-8, 2005, Wissenschaft & Technik Verlag, Berlin, ISBN 3-89685-570-0
- Small Satellites for Earth Observation, Selected proceedings of the 5th International Symposium of the International Academy of Astronautics, Berlin, April 4-8, 2005, Walter de Gruyter, Berlin, New York (in press)

3.2.9 ISPRS

3.2.9.1 General Information

In 1910, the International Society of Photogrammetry (ISP) was founded. The Society changed its name in 1980 to the International Society for Photogrammetry and Remote Sensing (ISPRS).

Except for interruptions for World War I and II, the Society has carried on its activities continuously since its founding. These activities culminate every four years in the ISPRS Congress. The Congress includes the

presentation of scientific and technical papers, technical tours, scientific and commercial exhibits, meetings to conduct the business of the Society, and a social program.

Objectives and activities

The International Society for Photogrammetry and Remote Sensing is a non-governmental organization devoted to the development of international cooperation for the advancement of photogrammetry and remote sensing and their applications. The Society operates without any discrimination on grounds of race, religion, nationality, or political philosophy. The official languages are English, French and German. The Society's scientific interests include photogrammetry, remote sensing, spatial information systems and related disciplines, as well as applications in cartography, geodesy, surveying, natural, Earth and engineering sciences, and environmental monitoring and protection. Further applications include industrial design and manufacturing, architecture and monument preservation, medicine and others.

The principal activities of the Society are:

1. Stimulating the formation of national or regional Societies of Photogrammetry and Remote Sensing.
2. Initiating and coordinating research in photogrammetry and remote sensing.
3. Holding international Symposia and Congresses at regular intervals.
4. Ensuring worldwide circulation of the records of discussion and the results of research by publication of the International Archives of Photogrammetry and Remote Sensing.
5. Encouraging the publication and exchange of scientific papers and journals dealing with photogrammetry and remote sensing.
6. Promoting cooperation and coordination with related international scientific organizations

Members

There are different types of members:

- Ordinary Members (countries or a region thereof)
- Associate Members (organizations)
- Regional Members (multi-national associations)
- Sustaining Members (individuals, organizations, institutions, or agencies)
- Honorary Members (individuals).

Other than Honorary and Sustaining Members, individuals are not eligible to become members of ISPRS. An individual usually participates in the activities of the Society through affiliation with one of the member organizations.

Publications

- The International Archives of Photogrammetry and Remote Sensing (IAPRS) Contain the proceedings and the scientific and technical presentations of each congress, and of the Technical Commission Symposia.
- The ISPRS Journal of Photogrammetry and Remote Sensing is the official publication of the Society.
- The ISPRS Highlights is the official bulletin of the Society.

The homepage www.isprs.org provides all the details about the history, structure, programs, and activities.

3.2.9.2 Structures and Activities related to the position paper subject

There are two structure categories: Technical Commissions and ISPRS Committees.

Technical Commissions

The scientific and technical work of the ISPRS is accomplished by seven organizations for the four-year period between congresses, and responsibility is re-designated by the General Assembly at each Congress based upon proposals submitted by the Members. The direction of a Technical Commission (TC) is the responsibility of a President and Secretary, acting with the support of the sponsoring Member, and under the general direction of the Council. TCs organize Working Groups, and each TC arranges a Symposium between Congresses, for which it is entirely responsible. The culmination of TC's operation is the selection of papers to be presented at the Congress held at the conclusion of the four-year period.

- Commission I: Sensors, Platforms and Imagery
Homepage: www.commission1.isprs.org
- Commission II: Systems for Data Processing, Analysis and Representation
Homepage: www.commission2.isprs.org
- Commission III: Theory and Algorithms
Homepage: www.commission3.isprs.org
- Commission IV: Spatial Information Systems and Digital Mapping
Homepage: www.commission4.isprs.org
- Commission V: Close-Range Vision Techniques
Homepage: www.commission5.isprs.org
- Commission VI : Education and Communications
Homepage: www.commission6.isprs.org
- Commission VII: Resource and Environmental Monitoring
Homepage: www.commission7.isprs.org

ISPRS Committees

There are three Committees which are appointed by the Council to report on special topics or to address issues in support of Council. The membership of a Committee consists of a Chairperson appointed by the president and additional members are selected by the Chairperson with the approval of the President.

ISAC – International Scientific Advisory Group

The ISAC (www.isprs.org/structure/isac.html) has been established to support the Council and the ISPRS General Assembly in identifying and addressing important S&T trends which impact the scope of the ISPRS Commissions and the activities which should be addressed by ISPRS Working Groups. The ISAC has 12 members who have broad experience and knowledge of the state of the sciences and technologies, and are respected experts and visionaries in the three primary disciplines embraced by ISPRS: Geospatial Information Sciences, Photogrammetry, and Remote Sensing.

IPAC – International Policy Advisory Committee

The IPAC (www.isprs.org/structure/ipac.html) was established to support Council in addressing important issues relevant to Society affairs with intergovernmental organizations, especially those that relate to ISPRS collaborative activities with various elements of the United Nations, the International Council of Science (ICSU), the Committee on Peaceful Use of Outer Space (COPUOS), the Committee on Earth Observation Satellites (CEOS), and other similar organizations. Members are selected based on their knowledge of international and national policy and legislative activities related to the mission and objectives of the Society. To ensure proper representation, the IPAC Chair will strive to maintain active participation representing both public, private and academic sector perspectives as well as global/regional perspectives on policy issues relevant to the Society.

ICORSE – The International committee on Remote Sensing of Environment

The ICORSE (www.isprs.org/structure/icorse.html) has been established to foster the use of remote sensing to address priority issues of the environment. ICORSE will convene a biannual conference in alternating years with the ISPRS Commission Symposia. The conference will focus on remote sensing of the environment and will bring together scientists, technologists and environmental users of remotely sensed data. The conference proceedings will be made available to the ISPRS community as part of the continuing series of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (IAPRSSIS). The ICORSE will also provide an annual report on the state of remote sensing of environment for publication in ISPRS Highlights.

3.2.10 EARSeL

3.2.10.1 General Information

EARSeL is a scientific network of European remote sensing institutes, coming from both academia and the commercial/industrial sector. EARSeL is unique in that it represents the interests of these institutes rather than individuals, although individual membership is possible. Currently, there are about 300 member laboratories.

EARSel was founded in 1977 under the auspices of the European Space Agency, the Council of Europe and the Europe Commission. These agencies as well as others, are supporting its activities. EARSel is run by a Council of elected national representatives from each country where there are member laboratories and an executive Bureau, elected by the Council.

The principal activities are:

- stimulating and promoting education and training related to remote sensing and Earth observation,
- initiating and co-ordinating application-oriented research,
- forming a bridge between technology and applications of interest to the wide user community,
- assisting the sponsoring agencies in the development of new sensors and systems and in any technical matters of relevance,
- providing a network of experts for the agencies in Europe,
- promoting co-operation between remote sensing experts and the environmental managers and decision-makers, and between western and eastern European institutes.

URL: <http://www.earsel.org/>

3.2.10.2 Structures and Activities related to the position paper subject

The main scientific efforts of EARSel are concentrated in Special Interest Groups (SIGs). These SIGs form the foundation of the activities of EARSel and its 'raison d'être'. They encourage co-operation and foster innovative applications of remote sensing. The science is at its highest level, the state-of-the-art is well established and advances are being made and are foreseen.

The SIGs are very valuable to the scientific community and they are also of great value to the sponsoring bodies. They represent a means to understand and evaluate the major problems to be tackled in the future by the scientific community, their importance and their influence for the citizens in Europe. SIGs can be instrumental in the design and the definition of future space missions.

The SIGs organise workshops and specialist meetings, the reports and proceedings of which are published. The conclusions and specific recommendations are presented to the sponsoring agencies and other relevant institutions.

Present SIGs

- Data Fusion
- Developing Countries
- Forest Fires
- Geological Applications
- Imaging Spectroscopy
- Land Ice and Snow
- Land Use / Land Cover
- Lidar Remote Sensing of Land and Sea
- Multilateral Environmental Agreements (MEA)
- Remote Sensing of the Coastal Zone
- Self-Organised Criticality in the Environment
- Urban Remote Sensing
- 3D Remote Sensing

3.2.11 ISO TC20/SC14 "Space systems and operations"

Background

The International standards Organisation Technical Committee "Aircraft And Space Vehicles" Sub-Committee "Space Systems And Operations" (known as ISO TC20/SC14) is currently engaged in the development of standards to address implementation of measures associated with debris mitigation, as identified in recent international-level discussions. This activity is in response to recent international discussions, and interagency agreements, on the need for mitigation of space debris.

An overview of the ISO activities on this topic, and the complementary international-level discussions, is provided below. A brief overview of the influences of these activities on the development and operation of small, low cost Earth observation missions is provided.

Recent discussions on measures associated with debris mitigation

Discussion of the need for, and scope of, measures associated with the mitigation of debris (generation of, and effects of) has been carried out at an inter-governmental level (United Nations Committee for the Peaceful Uses of Outer Space Scientific and Technical subcommittee - UN COPUOS STSC). The scope, and nature, of the measures have been discussed at interagency level (at the International Telecommunications Union, and within the Inter Agency Space Debris Co-ordination Committee (IADC), a federation of eleven space agencies, representing space-faring nations. The space agencies represented in the IADC defined an agreed set of high-level debris mitigation guidelines in 2002, and, at the time of this writing (2004), they are currently discussing updates to these guidelines, with an estimated release of these updated IADC-agreed guidelines in early 2006.

These current, or future, measures, when implemented (current, or future) by national law, national licensing or regulation, or national implementation of international agreement on principles, would generally be applicable to all space missions, covering space vehicles and space launchers. A government can choose to limit the scope of its implementation of these measures at a national level, or tailor their implementation on a case-by-case basis to different missions. Some national space agencies have implemented standard practices, or standards, to expand, and define more clearly, the scope of implementation, at national level.

An example of a recent national-level regulation, building on recent international agreements is the June 2004 new ruling by the United States Federal Communication Commission (FCC), on the subject of mitigation of orbital debris (“Second Report and Order in the Matter of Mitigation of Orbital Debris”). Note that launch licensing in the US is covered by the Federal Aviation Authority (FAA). The Federal Communications Commission (FCC) licenses the frequencies for commercial launches. US government launches, are licensed by different US authorities.

Future measures would complement existing United Nations Treaties on the use of outer space (United Nations Treaty on Principles Governing the Activities of States in exploration and Use of Outer Space, including the Moon and other Celestial Bodies, January 1967 “Outer Space Treaty”; United Nations Convention on International Liability for Damage caused by Space Objects, 1972; the Principles relating to the Use of Nuclear Power Sources in Outer Space , 1992), noting that some treaties have not been signed by all space-faring nations.

A recent UN COPUOS publication (Technical Report on Space Debris [1]) provides an overview of debris mitigation measures and associated scientific research.

Recent activities by ISO on the development of standards for orbital debris mitigation

ISO TC20/SC14 discussions on this topic were initiated in 2001. In May 2003 the formation of the Orbital Debris Co-ordination Working Group (ODCWG) was agreed by the ISO TC20/SC14 Heads of Delegation at the TC20/SC14 annual plenary meeting.

The tasks of the ODCWG include:

- establishing and maintaining external liaisons with a range of agencies involved in space debris mitigation (e.g. IADC, UN COPUOS, IAA)
- developing and maintaining links within ISO TC20/SC14:
 - with the working group convenors who are responsible for the development of the standards
 - with the TC20/SC14 Heads of Delegation that:
 - Represent nine national standards bodies in total,
 - vote on the initiation of each standards project, and its progress through the development standards to the production of an ISO International Standard, Technical Specification or Technical Report).

The first draft of the Programme of Work for the Development of Standards for Orbital Debris Mitigation (Debris Standards Plan) was released internally to ISO TC20/SC14 in October 2004, and included a preliminary analysis of the IADC guidelines to identify

- (i) internationally-agreed measures that could be translated into measurable and verifiable requirements in standards.
- (ii) topics noted in the IADC guidelines that might need standards for their implementation.

Development of a framework for the development of orbital debris mitigation standards is made more difficult by the task of predicting the scope and impact on the ISO activity of the anticipated near-future changes in international agreements on debris mitigation, whether the changes are predicted at the IADC (changes to existing agreements) or at UN COPUOS level (possibility of new agreements on debris mitigation). However, the debris mitigation measures within the IADC guidelines are divided into the following topics:

- Limit debris during normal operations
- Minimise the potential for on-orbit break-ups
- Post-mission disposal
- Prevention of on-orbit collisions

and it is not anticipated that there will be any major changes to these overarching themes.

As of October 2004, one standards project has been agreed at ISO level “Unmanned spacecraft remaining useable propellant mass estimation” and another known as the “Top Level Standard” is up for vote as a new project (currently in the three month voting period) “Routes to compliance and management for debris mitigation”, alternative title, “Space Debris Mitigation Standard”

Over the period October 2004-May 2005, preparatory material to support potential New Work Item Proposals (NWIP) will be developed on the following topics:

- Orbital Conjunction Assessment Data and Information Exchange: Common Data Format for Collision Avoidance
- Launch Window Estimation and Collision Safety Verification
- Re-entry Safety Control for Unmanned Spacecraft & Launch Vehicle Orbital Stages
- Process Based Implementation of Meteoroid and Debris Environmental Models
- Population Models for Re-entry Risk Assessment
- Disposal manoeuvres (GEO)

These potential projects will be reviewed in the run up to, and at the next ISO TC20/SC14 Plenary meeting (May 2005) meeting, and may be put forward for vote as new projects following that review. Note that titles, and the scope inferred by these titles, of the proposed projects may change. Other topics may also be developed for consideration at this meeting.

Following agreement at the next ISO plenary, in May 2005, a public version of the ODCWG Programme of Work for the Development of Standards for Orbital Debris Mitigation (Debris Standards Plan) may be released on the public part of the TC20/SC14 website [2].

Additional reference information may also be provided in the public part of the website [2] following the May 2005 meeting.

Issues specific to small satellites

Cost-effective small satellites engaged in Earth observation missions are generally perceived to pose a different problem than traditional multi-payload, large platforms.

Some recent discussions on small satellites and the space debris issue have focussed on the mission concept of using large numbers of small satellites, either uncontrolled or formation controlled. These constellation designs may have individual satellites with relatively low reliability, but an overall system reliability to meet mission requirements. The use of disposable elements of a constellation, which may be linked to the use of

low-cost parts (lower reliability), and/or relatively high-volume satellite manufacturing processes (decreasing costs per unit satellite) and exploiting many of the benefits of a low cost, small satellite philosophy, is sometimes perceived to be against the underlying principles of debris mitigation.

In addition, the use of very small satellites, whether singly or as part of a constellation, has raised specific problems regarding the ability of ground-based networks to track via optical or radar, their position regularly and accurately – tracking information being an essential part of any in-orbit collision avoidance programme.

For Earth Observation missions – typically LEO orbits, altitude of 600-800km – there is a specific class of issues associated with debris mitigation, related to the relatively high density of debris objects of all sizes, and the relatively long lifetimes of post-mission satellites in that orbit. Above a certain altitude (600-650 km), dependent on satellite characteristics and other aspects, post-mission non-operational spacecraft will not de-orbit naturally within the current maximum lifetime disposal limits (25 years in the current IADC guidelines). Small satellites are perceived as less likely to have on-board propulsion systems available for post-mission disposal manoeuvres (lowering perigee to bring the lifetime of the natural decay orbits within the 25 year limit). Some recent studies of the characteristics of a range of small satellite missions indicate that most have natural post-mission orbital lifetimes above the 25 year limit.

It should be noted that a number of characteristics of cost-effective small satellite missions for Earth observation mean that they have additional benefits, when considering their impact on the orbital environment, and their likelihood of generating unwanted debris:

- Given the large number of debris objects above the 10 cm size already in some orbits, the release of constellations small satellites, may not significantly increase the underlying risk
 - Note that additional measures may need to be taken to avoid intra-constellation collisions, and avoidance of collision with other actively-controlled satellites/constellation may need to be addressed
 - The additional risk posed by constellations will need to be quantified
- Small satellites are typically not likely to survive re-entry, and therefore will not need additional propulsion systems for a risk-reducing controlled (targeted) re-entry on the ground.
 - If the natural decay lifetime of post-mission small satellites is above the agreed threshold, post-mission disposal measures will still need to be considered, which may imply the use of an on-board propulsive system
- Small satellites generally are smaller in size and therefore present a lower collision risk to other active satellites, and a lower risk of catastrophic collision which would lead to releasing large debris objects. In addition their probability of collision with damage-causing debris objects (assuming a similar approach to structural design and thermal control as larger satellites, where structural and thermal materials provide shielding against impact) is lower
 - Depending on the risk assessment, small satellites may still need to carry on-board propulsion systems for collision avoidance manoeuvres and to support regular orbit maintenance
 - Small satellites may not have the benefit of traditional structural/thermal systems (honeycomb panels, multi-layer insulation) or be using materials or systems which may be proportionally more vulnerable to impact damage (e.g. silicon-based systems, tethers)
- The shorter timescale for development, and the higher level of innovation applied to the design concepts implemented, allows designers to implement post-mission disposal system solutions (e.g. drag-enhancement devices, autonomous de-orbit systems)
 - Technological improvements may need to be implemented to allow for more accurate orbit control, or improved tracking capability, as well as, potentially, on-board propulsion systems to carry out collision avoidance manoeuvres

The development of ISO standards associated with debris mitigation may support the development of cost-effective small satellite missions for Earth observation, by ensuring acceptance of standardised processes for establishing debris risk, and the effectiveness of implementing agreed requirements, where derived from debris mitigation measures. ISO standards topics that may be of particular use to mission designers and operators of cost-effective small satellites include:

- Debris (and meteoroid) impact risk calculation methods

- Common (orbital) data formats for collision avoidance
- Re-entry risk assessment methods
- Spacecraft reliability and functionality under debris impact
- Assessment of collision risk

These topics are within the scope of the current ISO activity to prepare a Programme of Work for the Development of Standards for Orbital Debris Mitigation (Debris Standards Plan), and to initiate, and manage, the development of these standards.

[1] Technical Report on Space Debris, 1999, A/AC.105/720, ISBN 92-1-100813-1, available on <http://www.oosa.unvienna.org/>

[2] <http://isotc.iso.ch/livelink/livelink.exe?func=ll&objId=292628&objAction=browse&sort=name>

4 MISSION COST DRIVERS

Different approaches to cost-effectiveness need to be applied depending on the spacecraft and application. In order to ascertain whether a space mission is “cost-effective”, it helps to first classify missions into two major groups: Low Earth Orbiting (LEO) and Geostationary (GEO). Although there are other types, such as MEO, HEO, L1, and L2, we will assume that those missions do not belong to the “mainstream” Earth observation categories, and hence will not be addressed here. Within each of these categories, spacecraft satisfy different requirements. How the space mission is implemented, and which methods are used to achieve an efficient utilization of available cost and schedule resources, depend on its particular application. Nonetheless, we may be able to extract general aspects of space mission design and development based on past and current practice. It is also useful to split these practices into the different elements of the mission life cycle. In this context, all relevant segments of a cost-effective mission are addressed: space segment with spacecraft and payload, ground segment, mission operations, launch, and management. Integration and test (I&T), a key activity that ties the space segment together and with the ground segment and operations is a major contributor to mission cost, outside of a protracted flight.

Important contributions to I&T were made during development of the NASA Multi-mission Modular Spacecraft (MMS), in the 1970’s. In the early days at the NASA Goddard Space Flight Center (GSFC), complete prototype spacecraft were produced and tested to environmental levels greater than those expected under operational conditions, in order to demonstrate design margins of safety. After proving hardware so tested would not be degraded, GSFC developed the “protoflight” concept. Instead of building an entire copy for testing alone, protoflight hardware was built and tested to prototype levels but for durations normally used to test flight hardware. This saved the cost of producing hardware intended for testing alone. Protoflight testing was usually applied to the first unit in a series, but not to the production units. Many concepts developed during MMS were incorporated into the Goddard’s General Environmental Verification Specification (GEVS) for Shuttle and expendable launch vehicles. Today, GEVS continue to provide important guidelines for the testing of space systems, and is used by space agencies around the world, including ESA and NASA. In practice, projects are expected to modify those guidelines to suit a particular application or need, and satisfy specific programmatic constraints of cost and schedule. Nonetheless, the “fly-as-you-test” approach remains an important key to success. For the most part, the first unit in a production line undergoes a rigorous flight qualification process, and subsequent production units are exposed to a reduced set of testing requirements. NASA’s Space Technology 5 (ST5) for instance, takes a selective testing approach, where critical components (e.g. communications package) are exposed to qualification levels more stringent than non-critical components (e.g. magnetometer). The take-away message is to use judicious testing at the component level, but not to skimp on the system-level testing of at least the first production unit. Depending on the quantity of spacecraft to be produced in a particular mission, verification testing may gradually decrease to minimal levels, or remain at some reduced, but sustained level for production units.

Other practical considerations, such as the active participation of operations personnel in design, and in the integration and test phases, can help save costs in training, and correct design implementations that prove impractical or unsafe to operate during flight. In addition, a common ground system used for testing as well as flight has remained common practice at NASA, since at least 1990.

4.1 Space segment

4.1.1 Payload

The classic approach for payload development places emphasis on:

- high reliability (often achieved by redundancy)
- good stability
- often ambitious measurement and calibration accuracies
- significant emphasis on the use of interface control documents (ICD) as a contractual entity (which can lead to non-optimal subsystem specification margins and a tendency to over-engineer)
- highly detailed performance budget analyses, resulting from the ICD breakdown.
- multiple models (BB, STM, EM, QM, FM etc)

- synergy with either additional payloads on the same platform or payloads on other platforms
- political balance (geographical returns etc)

These items are generally desirable, or at least justifiable in principle, and can, in cases of significant new payload development, provide low risk solutions. However, for instance in Europe this approach leads to payloads with high price tags, large international engineering and management teams, slow decision chains, long schedules, and long periods between missions. From today’s perspective they give the impression, to many, that they are not optimal in cost effectiveness.

Other solutions should be considered. Less ambitious payloads launched on smaller sized platforms can achieve:

- shorter mission turnaround
- risk reduction by use of multiple platforms
- wider coverage and faster revisits by use of constellations
- faster learning cycle and scope for applying new ideas in a shorter time frame
- greater mission overlap
- more continuous data streams by using multiple platform concepts
- better utilisation of the engineering and science personnel (i.e less lumpy business)
- lower costs.

Additional benefits include a more cohesive labour force and greater enthusiasm from engineers who experience the design-to-flight life cycle in a much shorter period, typically 3-5 years compared to the current 8-10 year period.

To capitalise on the small platform approach it is beneficial to operate small integrated teams, with good technical experience and short decision chains. In addition, the small satellite mission is more suited to national and bilateral/trilateral teams.

Small payloads, appropriate for small satellites, of course generally have limitations that cannot always be offset by the above benefits, but these will be dependent on payload type, technology status, user requirements and the user’s willingness to be flexible with respect to the implementation of the requirements. The obvious impacts of using small satellites are related to the limited platform resources, which can for example affect payload duty cycles (and thus ground coverage), on-board calibration capabilities and pointing stabilities (thermo-elastic distortions). Ultimately, ground sampling distances will be limited by feasible payload size.

Ten years ago the concept of viable small satellite missions offering either good science or service missions was largely a dream of the future. Today, advances in payload and platform technologies, such as indicated in Table 4.1-1, can make the dream a reality, as credible small satellite missions are planned.

Table 4.1-1: Payload and Platform Advances Appropriate to Small Satellite Implementation

Payloads	Platforms
Detectors	GPS receivers
Low power electronics	Autonomous miniature star trackers
FPGAs	CMGs solutions
Solid state memories	Battery technology
Advanced materials	Downlink speeds

In time the technology will advance further bringing more small satellite mission concepts to the market place. Nevertheless, there will also be a case for a mixture of the two approaches to meet the objectives of the users as demanded by the requirements

4.1.2 Spacecraft

Modularity versus integration, broad applicability versus one-of-a-kind design, these are typical trades carried out in deciding the best implementation approach for a particular mission. Whereas modularity is typically associated with design and system re-usability for a variety of missions (hence reducing cost), integration is normally associated with highly specialized designs for specific unique applications. This line however, can be blurred when modularity is defined in terms of *levels of integration*. Then unique application spacecraft may result from a fine de-composition of the module. But this is the way of the future. Today, cost-effectiveness in spacecraft procurement can be usually associated with heritage designs such as those found in the NASA's Rapid Spacecraft Development Office (RSDO) "Rapid II" catalogue. This menu list of pre-qualified spacecraft busses provides a set of options and capabilities servicing instrument payloads. A designer would in principle simply select which pre-canned bus would best satisfy the requirements of a particular payload and mission. Each bus in turn, offers a series of "options", performance enhancements applied to suit. In a very real sense, the Rapid II catalogue presents a series of system-level modules (the bus) that can be interchanged depending on mission objectives. The RSDO also promises the advantage of competitively awarded, fixed price delivery orders in 30 to 90 days. Drawn-out procurements can add substantial costs from mission selection, and in practice streamlined contractual venues can be just as important as non-recurring engineering savings.

An important advance in spacecraft design that goes hand-in-hand with the modular, levels of integration approach is the development of (plug-and-play) interface standards. These interface standards are key in ensuring module compatibility and interchangeability. Instead of having non-recurring engineering (NRE) costs associated with a complete spacecraft bottoms-up design, modules connected through standard interfaces would only incur NRE in the development of technology improvements, and those can be absorbed through the establishment of a sound technology development program. Such program would buffer individual projects from the need to update module technology, and provide a current, common system to a variety of missions. Bus design and production itself is not inherently costly, but the accommodation of varying and unique component and instrument interfaces complicates the implementation, and necessitates extensive and detailed ICD specifications. Today, these ICDs must be uniquely developed for each component, subsystem, bus, and instrument that must be integrated into a complete spacecraft/observatory.

4.1.3 Quality Assurance

There is a direct proportion between the acceptable level of risk, and the cost of the mission. This recently became evident after the failures of the NASA Mars bound spacecraft, and the subsequent changes that were implemented to correct the situation. Each project must specify the level of risk that is acceptable. Commercial spacecraft slated for geostationary orbits (GEO) are generally fully redundant, as the return on investment hinders on successful operations over a period of 10 years or more. On the other hand, small LEO spacecraft with focused application requirements can in some cases afford a significantly higher level of risk. In proportion, the "cost per unit mass" is significantly higher for high end spacecraft.

The Quality Assurance of the space segment determines the mission performance, mission risks and the mission costs essentially. The objective of the quality assurance of the space segment consists in assuring the mission performance parameters as good as required with a low risk and within a certain budget frame. For cost effective Earth observation missions the top level requirements should be:

1. To keep within the cost budget frame
2. To keep the mission risks low
3. To achieve acceptable mission performance parameters (not as good as possible, but as good as necessary)

The quality assurance programme meeting these requirements is characterized by:

- A tailored Quality Management System (according to ISO 9000, ECSS, a.o.) to the mission objectives and mission constraints especially the cost constraints
- A dedicated risk management system (MIL-STD-882D, ECSS)
- A tailored (mostly hybrid) model- und test philosophy
- An individual and tailored space qualification programme for parts, components, units and system elements.

A key point to assure a high mission performance according to the requirements in a cost effective way are the component and EEE-part selection. The selection of Commercial-of-the-shelf (COTS) EEE-parts and components for building the space segment opens the door to flexibility and high performance parameters of the space segment to affordable prices. For instance compared to qualified radiation immune components modern VLSI technology provides at least 10 times higher performance, 10 times less power dissipation, 10 times higher integration, and 100 times lower costs /Behr et al.: Failure Tolerance and COTS, Proc. DIAS 2003/. These figures justify why COTS components already became an enabling technology for future small satellite missions with high demands on computing power and complex functionality. Regarding the total budget of a satellite mission, the lower costs of the COTS is not the only one advantage and not the major issue. The benefits of using COTS technology mainly counts if the advantages of high performance and functionality and low power consumption of modern VLSI components can be exploited.

Using COTS parts and units instead of space or MILK qualified parts and units the total power consumption and also the total mass of the system can be decreased essentially. But on the other side some additional measures for the quality assurance has to taken into account. An individual and tailored space qualification programme for parts, components, units and system elements has to be carried out to keep the risks low.

4.2 Ground segment

Introduction

There is considerable promise in the use of small satellites as low cost platforms for the collection of Earth Observation data. To date such systems have focused on either space segment or end-user aspects for fairly obvious reasons (for example whether capable imaging performances could be attained; in-orbit cost vs complexity; user applications that could be satisfied).

This is expected to change for the next generation of smallsats. While space and end user investigations will continue, an emerging focus on operational aspects will address the vital “glue” needed to establish and maintain a service chain tasked with offering information to users. Simplistically what are required will be flexible, modular, low cost technologies delivered in a Cost Effective Ground Architecture (CEGA).

Specifically, “traditional” ground segments split the functions of the data chain into monitoring and control, image reception and archiving, and image production and dissemination. These functions are often supplied separately, with considerable effort required to integrate them, with a “bottom line” of several million euros. Shrinking such systems for smallsats is not usually cost effective and so more bespoke or ad hoc developments litter the current developer community.

It is envisaged however that new missions will return to first principles of ground segment design, tempered with unique insights gained from the development of cost-conscious operational (meteorological) ground systems as well as the current generation of smallsat infrastructure. Using a modular, open architecture based on a data distribution “backbone” and “handlers” to isolate the system from changes and variations in mission protocols and service output requirements, a ground system that would meet the cost, functionality and flexibility requirements of a small satellite mission can be characterised. This thinking is now permeating mission designers and will embrace both Mission Control and Data Processing within a common infrastructure.

Ground Systems Today (Mission Control to Data Distribution)

A satellite Ground Segment is comprised of the following components:

- Satellite communications, TT&C, locate & track satellite
- Satellite command and control
- Mission planning
- Data Processing
- Data Archive & Inventory
- Data Dissemination

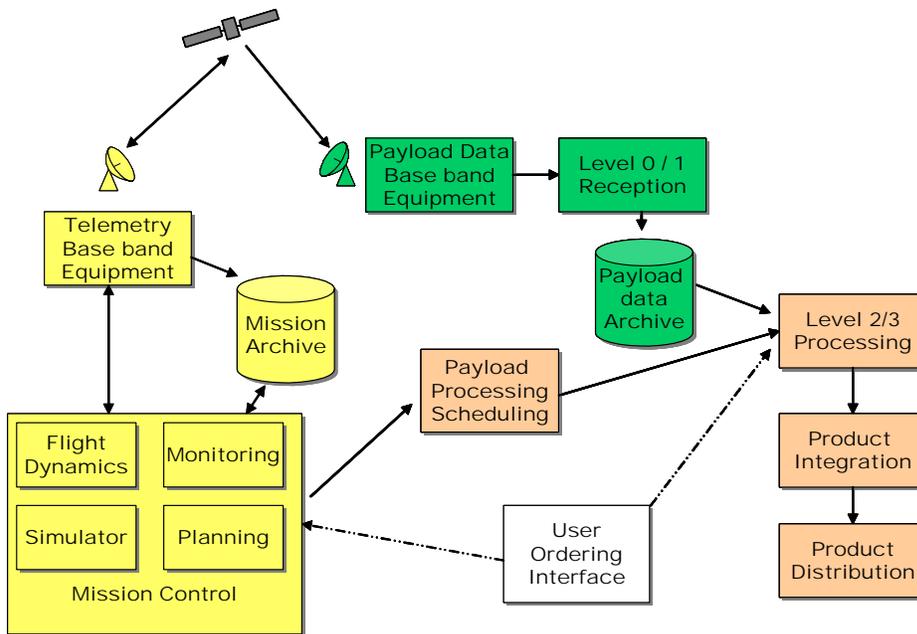


Figure 4.2-1: Traditional Ground Segment

Figure 4.2-1 shows a high level breakdown of the components of a traditional mission. The different colours represent the groupings of functions that are manufactured, and/or procured, from different sources, and frequently run from different sites. The yellow objects are concerned with the monitoring and control of the satellite in a “mission control” role. The green objects are concerned with the download and pre-processing of the payload data. The orange objects represent the value added product production, which is sometimes scheduled by mission control.

Unfortunately the design phase for most small satellites still considers the space segment in advance of the ground segment, rather than treating them together in the context of the user requirements and service needs. This leads to disconnects with the infrastructure illustrated above and often open questions remain about ground segment implementations until the last moments before launch. For example, both the UK Topsat and DMC missions have open ground segment issues well into the build phase of the satellite. While such problems are usually solved, they are often bespoke and ill-suited for rapid and cost-effective deployment. The problems are especially compounded when a constellation of such satellites are espoused.

There are some signs that this space dominated design approach is changing. Customers for smallsats are often very open to changes on the spacecraft to improve the capability of the system, examples being the amount of storage and on-board processing to reduce the downlink bandwidth and thereby simplify the ground segment. Furthermore the business plan for small satellite missions is increasingly a joint venture, risk sharing approach, where ground segment manufacturers join a partnership, to access downstream revenues (eg RapidEye).

It is not surprising to find Smallsat Ground Segments utilising more “advanced” technologies or making better use of non-space information technologies than their mainstream cousins.

Emerging Ground Segment Technologies - Opportunities and Challenges

Open systems

Ground segments for smallsats are now implementing architectures that follow open standards. The requirements for re-use of existing facilities and integration of mission specific modules can only be efficiently fulfilled using open systems. Platform independence and the ability to implement a system over heterogeneous operating systems to allow specific applications to be integrated can only be accommodated by the use of open systems.

The current generation of technologies, such as Java and XML, can be virtually free to deploy. Currently COTS are either expensive monoliths that may have high functionality but are inflexible and require a lot of configuration effort; or they are expensive general-purpose tools (e.g. DBMS) that tie solutions to 3rd party vendors and platforms. Next generation software offers interoperable components that can be used to assemble a mission specific system.

However, some open systems do come at a price – licence fees for existing software functions can drive up deployment costs in comparison to bespoke software and have been considered by some smallsat ground segment developers as a key obstacle.

Automation

The drive towards more automation is often driven by operators who perceive long term costs (e.g. staff) vs short-term cash-flow shortages from space segment cost over-runs or faltering business revenue. This experience is clear from the telecommunications sector (which has led the way with automation ground segment technologies – at least in Europe). However automation has an associated cost. It is logical to attempt to reduce staffing costs and provide systems that can run unattended, as long as the system is running within tolerance. Indeed smallsat ground segments (particularly those supporting constellations) are already attempting to seek to implement such automation.

Internet Technology

Much that involved specialist hardware and software ten years ago is now available as standard. The connectivity and access afforded by the Internet is very evident in smallsat ground systems now under development (e.g. DMC, Rapid Eye), especially in the user facing ordering and distribution areas. Increasingly these systems take advantage of e-commerce systems and image management for the simpler missions.

Some Internet technologies that are becoming standard are expected to be included in future systems–specifically XML, which is a flexible and powerful description language and used where its verbosity is not a disadvantage. Similarly, GML is becoming a standard that facilitates interchange of map information and reduces the requirements for data management if used carefully. Additionally, technologies such as JAVA provide for portable internet-enabled client applications.

More imaginative developers are even espousing the benefits of technologies that, while offering some considerable advantages in the medium term, are untested and could be overtaken relatively rapidly. Good examples are “GRID” (e.g. OGSA) and WSDL that builds upon SOAP.

Distributed Ground System

Many ground systems today are making use of the Internet to allow distributed connectivity. For example, instrument operations may now be planned and controlled from locations remote from the Mission Operations Center (MOC), such as at their home institutions. Instrument command loads may be prepared there where science and engineering support is readily available, and forwarded via the Internet to a command queue at the MOC for uploading at the appropriate contact time.

Downlinked data products, both science data and spacecraft engineering data, may be pulled from the data archive at any time for processing and analysis. Real-time data during a contact may also be distributed to these remote payload operations centers for instantaneous evaluation.

Network security issues must be addressed, but can be easily implemented with standard firewall and encryption techniques.

Data reception, distribution and archiving

Hand-in-hand with the inception of IP communications in space, data availability promises to increase considerably. A computer connected to the internet is all that is needed in order to receive data directly from the node in space. Of course, firewalls and protection schemes must then be implemented, as availability always comes with safety considerations needed to preserve the integrity of the data and the space asset.

Emerging Smallsat Ground Segments: Functional and Inexpensive

It has become clear in recent smallsat programmes that downsizing “traditional” ground segments are not able to provide the reductions in cost required by the market. Much of the cost in a ground segment is in the interfacing between processes and segments, and down-sizing does not reduce this. Some significant equipment cost savings have however been made in reception system equipment (for example the UK/NL Rapids and US Skyview systems). It seems increasingly likely that future systems will adopt the emerging and current technologies discussed above and in so doing achieve a modular, “plug-and-play” architecture as illustrated in Figure 4.2-2 below.

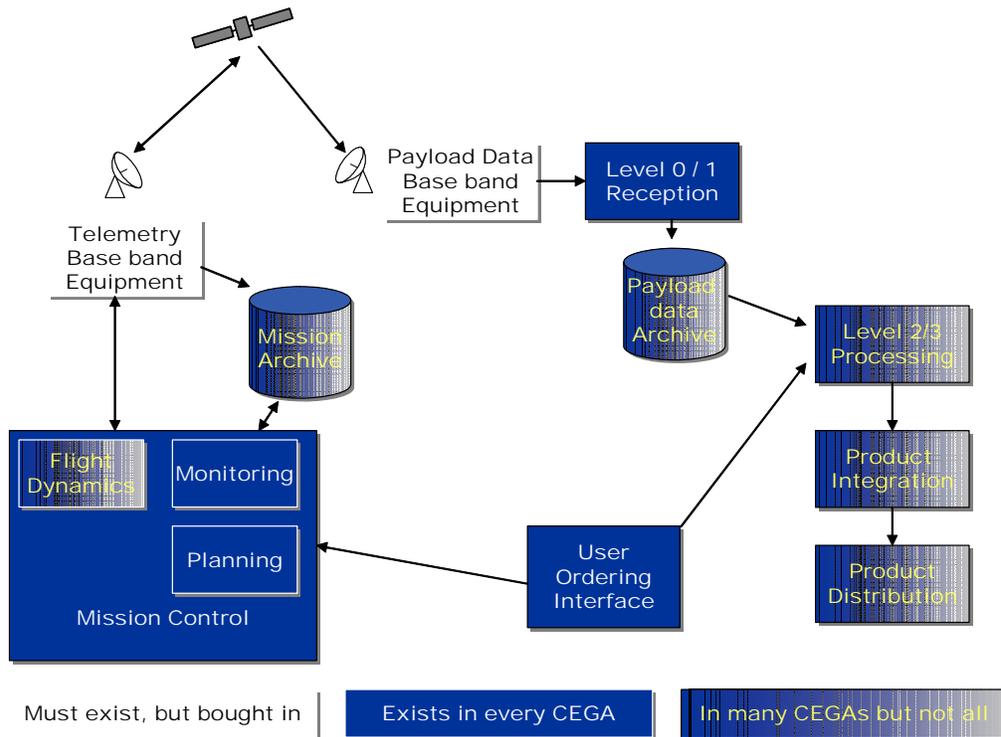


Figure 4.2-2: Future Smallsat Ground Segments

4.3 Mission Operations

The routine operations phase of a typical earth observation mission consists of the following periodic tasks:

1. Planning and scheduling of observations
2. Coordination of observation requests with spacecraft and ground station activities
3. Command loading & execution
4. Spacecraft monitoring and telemetry analysis
5. Reception, processing, archiving and dissemination of payload data

The first step is naturally to set priorities for the utilization of the payload instruments. In most cases, different interests, coming from various sources, regarding the targets for observation exists. A dedicated team must be responsible for setting priorities for these targets, taking into account specific rules for the selection. Natural disasters for example will mostly have higher priority than long-term observations.

The Utilization plan of the payload needs to be in compliance to other, non-payload related activities onboard the spacecraft and ground station schedule, especially in a multi mission environment. Examples can be software updates, periodic checks or redundancy management of satellite bus subsystems. The harmonization of these two categories of activity results in an overall satellite operations plan including ground segment resources.

In the third step the overall operations plan is implemented by means of generating command loads for subsequent upload to the satellite. Depending on the mission, the number and size of commands to be uplinked can be different.

Monitoring of satellite status is one of the most fundamental tasks of every mission operations, independent of mission type. In the case of earth observation, one common important aspect is that in the routine operations phase, the satellite can only be accessed during ground station contact, which is for about 10 minutes for low earth orbits. Depending on the number and location of ground stations, more or less telemetry must be stored and downlinked within the contact periods. The mission may require from time to time this data to be analyzed offline between two subsequent passes in order to plan new commands until the second contact. This means, that the provision of online and offline telemetry to experts is very important, especially in contingency cases but can be handled as described in chapter 4.2 by means of a distributed ground system.

Payload data reception, processing, archiving and dissemination closes the nominal cycle of a chain of mission operations tasks starting with the payload utilization plan for earth observation. One additional task may be required especially if the observation is related to fast changing phenomena such as natural disasters. In this case, a fast feedback on the results of a specific observation may be required in order to adapt the payload operations plan. An example is to change targets depending on the result of the downlinked data between two passes and upload new targets to the satellite at the second pass. This action requires the ability to process and evaluate the payload data by experts immediately after the first pass, give a feedback to the operations team, which possibly has to generate a new sequence of commands and upload them at the second pass. Besides the time, which is needed to process the data, it is also very important to have fast communication links between the different positions, especially if they are geographically distributed.

If we ask, what specific aspects of the scenario described above are relevant for cost effectiveness of mission operations, then the following should be considered:

Increasing onboard autonomy

There is a clear trend towards increased onboard autonomy to reduce planning and operations efforts. Increased onboard autonomy, in the area of planning, satellite control as well as intelligent onboard data processing, has the potential to become a key issue when we think of future earth observation missions including the commercial ones. The relevance of onboard autonomy will increase even more in conjunction with small satellite constellations for earth observation.

One example for this approach is ESA's PROBA mission. Only a single command, setting target coordinates for each image is needed in this case. All required actions to make the desired observation, such as scheduling and attitude maneuvers are done by the satellite itself.

Another good example is NASA's TIMED spacecraft, which autonomously activates the repetitive scientific observations by means of a autonomous planning system mainly based on onboard navigation data and an adapted messaging system between satellite bus and payload instruments. Observations are initiated by appropriate messages on navigation-based events, received by payload instruments from the satellite bus.

Other demonstrators for onboard autonomy, which are not directly related to earth observation, such as NASA's demonstrator for autonomous rendezvous technology mission, DART indicates that autonomous spacecraft control is becoming increasingly available and will help to reduce the cost of operations.

Onboard processing of earth observation data will additionally support the trend for more onboard autonomy. Reducing the amount of data, which has to be downlinked by transmitting only the results of an onboard image processing will decrease cost of ground segment effort and provide relevant data to the end user in a much shorter time. A demonstration of onboard generation of thematic fire maps was successfully done by the BIRD satellite of DLR.

Multi mission operation

Operation of different spacecrafts from a single, modular and multi mission capable control center has become a common practice in the recent years. Using common equipment, standards (e.g. CCSDS) and operators for different missions is an efficient way to make mission operations more cost effective. Besides

expensive equipment, this method makes more adequate use of the intellectual capacity and expertise of satellite operators, which is an important factor especially for the safety of satellite operations. In a real multi mission scenario, operators are capable of controlling more than one satellite, which is only possible with adequate trainings. Inclusion of expertise of such mission centers can be of big value and shorten development efforts for new missions, re-using similar operations concepts, significantly.

Training of operations personnel

An important aspect of successful mission operations is the training of operations personnel. Besides lecture of spacecraft documents and tutorials, execution of extensive practical trainings on a spacecraft simulator is an essential training method. Simulations of nominal and contingency operations with either simulators or an engineering model of the satellite has an enormous learning effect for the operations crew. In this context, a combined spacecraft checkout and control system is of big value, because the operators can become familiar with all aspects of spacecraft operations in a very early phase using their familiar operations environment, which would not change after the launch of the satellite.

The role of ground station network configuration

One of the most important issues, especially in the LEOP phase of every satellite mission is to have contact periods as long and frequent as possible. The ability to have frequent contacts is of big advantage in the operational phase of earth observation missions. Due to the increased number of downlink periods, data can be downlinked more frequently. Especially in the case of disaster monitoring, this can lead to shorter reaction times. Missions operations planning can be significant more flexible and relaxed, because of increased number of downlink opportunities. Calling in mind, that most of the earth observation satellites are on polar orbits, the advantage of including at least one polar ground station to mission operations is obvious and should be considered seriously in early planning phases.

Cost effective earth observation missions can only be efficient with an adequate operations concept. Following a brief description of current operations methods, some of the key issues such as onboard autonomy, the role of multi mission control centers, training of operations personnel as well as the geographical distribution of ground stations were discussed here. Thus, special attention should be paid to operations concepts for upcoming near and mid-term earth observation *constellations*, considering these discussion points as early as possible in the planning phase.

4.4 Access to Space

Commercial launch services are now available on most launch systems, many of which are new vehicles designed or modified specifically for international commercial market. The most dramatic shift has been the entry of the Russian and Ukrainian launch systems commercially operated by joint ventures with US or European companies. New launch systems around the world are even beginning to use major components built in other countries, further blurring national divisions.

Access to space of small satellites for Earth observation is a very limited portion of the access to space in general. The first limitation is related to the orbit characteristics as most of the Earth observation is performed at low altitude. Access to space for communication satellites is mostly using the geostationary orbit; consequently since the market is dominated by communication satellites the offer for Earth observation is limited for any secondary payload or piggy-back launch option. The comparative study below provides launcher characteristics and tentative indication of launch price in M\$ (as released or estimated by FAA) for the total flight by launcher category. Cost for secondary payloads or piggy back launch is significantly lower. For instance, secondary payload for the Kosmos 3M typically range from 0.5 to 1.5M\$. In addition, the variation of the US\$ against foreign currencies introduce an additional 30 % uncertainty.

For comparison reasons, the following tables show also launchers which are no longer in operation (e.g. Athena 1, Athena 2, Titan, Atlas 2 and 3, Delta 3).

Table 4.4-1: Micro Launchers

Launcher	Country	Lift-Off M (t)	PL Mass LEO	Per/apo km	Inclin. degrees	Price M\$
Pegasus XL	USA	22	440	200/200	28.5	10/15.
Shavit	Israel	23	225	370/370	143.4	10/15
Volna	Russia	36	120	200/200	63	nc
Minotaur	USA	36	640	185/185	28.5	12.5
SHTIL	Russia	40	430	200/200	63	0.5
START 1	Russia	47	450	300/300	90	5/10.
VLS 1	Brazil	51	280	400/400	25	6/7.
Athena 1	USA	66.5	700	370/370	28.5	14/17

Table 4.4-2: Small Launchers

Launcher	Country	Lift-Off M (t)	PL Mass LEO	Per/apo km	Inclin. degrees	Price M\$
Taurus	USA	73	1250	400/400	28.5	18/26
CZ1-D	China	79	900	300/300	28.5	10
Rockot	Russia	107	1850	370/370	63	12/15.
Cosmos	Russia	109	1400	400/400	51	10/14.
Athena 2	USA	127	1900	180/180	28.5	22/26
M5	Japan	129	1800	250/250	31	40/60
Vega	Europe	130	1500	700/700	90	20
Angara 1.1	Russia	145	1700	200/200	90	10/15

Table 4.4-3: Medium Launchers

Launcher	Country	Lift-Off M (t)	PL Mass LEO	Per/apo km	Inclin. degrees	Price M\$
Delta 2 7325	USA	152	2700	185/185	28.5	40/55
Delta 2 7425	USA	166	3100	185/185	28.5	40/55
Angara 1.2	Russia	170	3400	200/200	90	nc
Tsiklon 3	Ukraine	190	2900	600/600	82.5	20/25
Titan 2	USA	190	2180	185/185	90	30/40
CZ 3	China	204	4500	370/370	31	35/40
CZ 2C	China	213	1800	630/630	86	20/25
CZ 2D	China	233	1700	400/400	60	10/15
CZ 4	China	249	4000	180/180	70	20/30
Dniepr	Russia	268	4100	200/200	90	10/20
PSLV	India	283	4100	200/200	90	15/25
Molnya	Russia	306	1800	820/820	99	30/40
Soyuz	Russia	310	5800	200/200	97	30/50

Table 4.4-4: Intermediate Launchers

Launcher	Country	Lift-Off M (t)	PL Mass LEO	Per/apo km	Inclin. degrees	PL Mass GTO	Price M\$
Atlas 2A	USA	187	7300	180/180	28.5	3070	75/85
Delta 2 7925	USA	232	5141	185/185	28.5	1870	50/60
Atlas 2AS	USA	234	8600	180/180	28.5	3720	90/105
CZ 3A	China	240				2500	45/55
CZ 3C	China	345				3700	55/75
CZ 2E	China	460				3500	45/55
Zenit 2	Ukraine	460	13700	200/200	51		35/50
Atlas 3A	USA	221	8600	180/180	28.5	4050	70/105
Delta 4M	USA	250	7700	407/407	51.6	3900	65/90
Delta 3	USA	300	8300	185/185	28.5	3900	75/90
Atlas V 501	USA	334	10300	185/185	28.5	4100	70/110
GSLV	India	402				2500	25/45
Angara 3A	Russia	478	14000	200/20	63	2000	nc

Table 4.4-5: Heavy Launchers

Launcher	Country	Lift-Off M (t)	PL Mass LEO	Per/apo km	Inclin. degrees	PL Mass GTO	Price M\$
CZ 3B	China	425	13600	180/180	28.5	5000	60/70
Zenit3SeaLauncher	Ukraine	466				5900	75/95
Atlas 3B	USA	225	10700	185/185	28.5	4500	75/105
H2A 2022	Japan	315				4250	75/90
Delta 4 M/4.2	USA	320	9000	500/500	90	5300	65/100
Delta 4 M/5.2	USA	320	7800	500/500	90	4350	70/100
Atlas 5-400	USA	334	10750	185/185	90	5000	70/90
Delta 4 M/5.4	USA	405	10300	500/500	90	6120	75/110
Atlas 5-552	USA	542	17000	185/185	90	8200	85/110

Table 4.4-6: Super Heavy Launchers

Launcher	Count.	Lift-Off M (t)	PL Mass LEO	Per/apo km	Inclin. degrees	PL Mass GTO	PL Mass GEO	Price M\$
Proton K	Russia	690	21000	200/200	51.6	4500	2100	70/98
Ariane 5	Europe	710	18000	550/550	28.5	5950		150/180
Titan 4B C	USA	940	21700	180/180	28.5		5800	350/450
Ariane ECA	Europe	770				10500		120
Shuttle	USA	2040	21500	250/250	28.5			300/425
H2A 222	Japan	525	23000			9500		80/140
CZ 3B (A)	China	630				7000		60/70
Proton M	Russia	700	22000			6500	3000	85/112
Delta 4 H	USA	734	20500	500/500	90	12000		130/170
Ariane ECB	Europe	790		550/550	28.5	12000		170/190

4.5 Management and Organizational Approach

Management goes hand-in-hand with the type of organization developing the space mission: government, or private industry, national or multi-national organizations or consortia. Appropriate management styles also depend on the final application, whether it is commercial or scientific. In spite of organizational complexity, cost effective missions require a simple management implementation approach. Both industry and government experiences may be leveraged, and lessons learned.

4.5.1 Industry Approach – The Earth Orbiter 1 (EO-1) Experience

The Management Concept proposed for the programs identified here may be based on one implemented for the EO-1 program. The primary focus was to bring together a team with a common vision, and required the elimination, to the maximum extent possible, of all organizational boundaries. The key characteristics of this management concept were as follows:

- Senior management commitment to providing the resources needed to meet the requirements of the program.
- A mutual respect for each team member's capability and core competencies. This included sharing technical data as required.
- Complete trust by the team members that all efforts will be made to achieve the goals of the program. This included enabling each Technical Lead to communicate freely outside their organization.

These key characteristics were instituted from the start of the program. Program managers from the teaming organizations needed to agree on the mutual scope of the organizations involved and provided uninhibited communication between them. This management philosophy facilitated a quick response to changes in mission requirements, especially mandatory for satellite programs that incorporate new technologies or are unique in mission design.

The implementation of this management strategy in a practical sense results in a flatter organizational structure and the assignment of technical leads spanning all phases of the program. For instance, in EO-1 the (program) manager from a major supplier was assigned as the Deputy Program Manager to the Prime Contractor, thereby facilitating direct interface with the customer. This continuity is furthered during the Integration and Test Phase where the Deputy Program Manager is assigned as the Deputy I&T manager with direct responsibilities for activities at the Prime Contractor facilities. A further example of this implementation strategy can be found in the assignment of technical leads. Commitment by the functional organizations requires that these leads be assigned to the core team, ensuring their participation from the concept phase through the launch campaign phase, and into the operational phase as necessary. Typical organizations disperse key members of the team at different phases of the program for cost efficiency; however for small spacecraft programs this is inefficient in the long term. This long term assignment and commitment by the functional organizations is important for stability and consistency of the program, thereby making it more cost effective in the long run. Furthermore, this enhances ownership by the technical leads for their designs and final products on the program.

4.5.2 Government Agency or Organization

National or inter-governmental projects or programs are generally complex in nature. National or regional agencies must be responsive not only to financial stakeholders (the public), but to political sensitivities. Aside from the greater role of public service or scientific investigations, a principal role of government agencies is also to encourage industry participation, and maintain their economic viability. It would be fairly accurate to say that these organizations must be first *effective* in guaranteeing success, and second must be *efficient* in resource utilization and cost reduction. Nonetheless, agencies such as NASA or ESA have been seeking ways of reducing space mission costs (and improving efficiency) through a number of actions. Outsourcing of products and services is the first common strategy. This strategy however, could either work in favor or against the purported objectives. Small projects or technology missions such as EO-1 are better done entirely by either a designated government center, or by a prime contractor who has been given broad responsibilities ("outsourced"). As projects grow and more organizations are included in the mix, interfaces become more complex and efficiency drops proportionately. Outsourcing does very little to improve this situation. For all practical purposes, small satellite missions managed under the paradigm structure described

in Section 5.6.1 are specially suited for cost effective implementations. On the other hand, large projects become expensive due to their very nature, and different models must be applied to reduce their cost.

Notwithstanding the drawbacks to large multi-agency organizations, there is one special consideration where they may become a reasonable answer: *cost sharing*. In spite of the fact that the combined, or Total Mission Cost (TMC) may be higher, *each* individual organization or country has a net reduction in its investment. Cost effectiveness in this case is only relative to *local investments*, not relative to TMC. Cost-sharing in combination with sound management approaches is a practical answer to large projects. Cost sharing in general, is not the answer for fast-paced, focused investigations.

5 COST ESTIMATION AND MODELING

This chapter on cost estimation and modeling briefly reviews the definitions of some of the ways in which earth remote sensing programmes are cost modeled for background reference purposes. Two solutions to cost effective EO missions are then discussed, the one being starting with a modest expectation from the outset and the other examining some international collaboration models.

5.1 Definitions and Background

Costing models are used to estimate costs of the various phases and elements of the space mission. This section defines the lifecycle phases and work breakdown structure before discussing the cost estimating approaches.

5.1.1 Lifecycle Phases

Total space mission costs are determined as the sum of the costs of all lifecycle phases of the mission. The following phases are defined:

Technology development

Technology development is indicated as a separate phase to clearly distinguish it from RDT&E.

Research, Development, Test and Evaluation (RDT&E)

This includes the design, development and testing of breadboards through to qualification models. RDT&E is often referred to as the non-recurring costs. As a rule of thumb [8881, p.809] the RDT&E costs are two to three times the unit production costs (for high-tech programmes factors of five or six are used).

Production

Production incorporates the costs of producing and launching flight models.

The Theoretical First Unit [TFU] is defined [1] as the first flight qualified satellite off the line (for single satellite missions the TFU is the flight article). For multiple units, for instance components of a constellation, production costs are estimated using a learning curve factor [1, p.809] to reduce the production cost of subsequent production units.

Operations and Maintenance (O&M)

This phase refers to ongoing operational and maintenance costs including replacement satellites and software maintenance.

5.1.2 Work Breakdown Structure

The work breakdown structure is an important tool during cost estimation. Each lifecycle phase is broken down into constituent elements [1] e.g.

- Programme level
- Space segment
- Launch segment
- Ground segment

The optimization of each of the elements have significant contribution to the cost of a remote sensing mission, but in combination (e.g. Lower mass and hence lower launch cost) one sees the most significant cost savings.

5.1.3 Costing Models

The following are widely used approaches to estimating satellite mission costs:

Bottom-up

Bottom-up estimation relies on a detailed breakdown of the system into low level components. The costs of each component are estimated individually. This method is well suited to instances where detailed system information is available, either from previous projects or a detailed design of the system under review. Bottom-up estimating is therefore rarely appropriate during the preliminary studies.

Top-down or Parametric

The top-down approach does not rely on detailed knowledge of the system. Parametric estimating, for instance, is performed on the basis of system requirements and top-level design specifications. These models relate mission costs to mission parameters, thereby eliminating the need for low level information.

Typical input parameters include mass, design life, pointing accuracy and knowledge, propulsion, power and solar array area. A database of cost and technical information obtained for various missions serve as foundation for developing the cost estimating relationships (CERs). Statistical regression techniques are used to quantify and qualify these relations.

A widely referenced costing model for smaller satellites is the Aerospace Corporation's Small Satellite Costing Model (SSCM), available for Excel [2].

Numerous input parameters allow the SSCM to generate most likely cost estimates and distribution curves for life cycle stages, subsystems and programme elements.

The SSCM is predominantly based on government missions and a correcting factor of 0.8 should be applied when evaluating RDT&E costs of commercial programmes [1, p.799].

Parametric models are growing in popularity and have been indicated as the preferred method of proposal estimating by the US DoD [1, p.787].

Analogy-based estimating

The cost of similar items are used and adjusted for differences in size and complexity.

In its simplest form, analogy-based estimating may be used to derive rough order-of-magnitude (ROM) costs from data of existing systems [1, p.807-809].

Collaborative costing models

Collaborative models are used to estimate the costs of projects executed by a group of participants. As an example, consider a consortium launching a constellation of satellites. Members are assumed to be collectively responsible for RDT&E costs, while individually responsible for the Production and O&M costs of their respective units. Other collaborative modalities are discussed later in the chapter.

5.2 Current Best Practice, Comments and Examples

5.2.1 Best Practice from Micro-satellite experience

From the successful execution of micro satellite projects (MOST, Sunsat, Uosat) it has been found that small teams, as few different organisations as are required and limited budgets all contribute to innovative ways of lowering the cost of satellite programmes.

Reviewing the standard practice, it is found that bottoms-up estimation is only useful if there are a number of missions that repeatedly uses the same components. A top-down costing model is dependent on the improvement of technology that allows new technology advances to provide performance gains for the same mass or budget. Collaborative missions have been shown to achieve significant gains for the contributing partners and a number of missions and modes of sharing the cost are described in the last sections.

5.2.2 Cost models and Mission Costs: a self fulfilling prophecy?

Viewing the complete cost of space programmes, Carroll and Stibrany from Dynacon argue that "*High cost is such an endemic part of space programs, that it sometimes seems inevitable.*" [3]

They describe the concept of a "death spiral" and how it escalates space programme costs. The initial perception that a space programme has a high cost has two consequences.

Firstly, promises are made to entice stakeholders and secure funding. This leads to adding mission objectives and increasing mission demands. Furthermore, heightened awareness and the perceived high price of the mission leads to an increased risk aversion on the part of mission designers and managers. This creates an impetus to eliminate risk rather than taking calculated risks, which increases complexity of the system and associated processes.

Secondly, a consortium of suppliers is put together which guarantees a burden of documentation, staff and miscommunication that increases costs to a higher category.

A large staff has a tendency to enlarge itself through organisational dynamics. All these consequences have the effect of igniting a "cost expansion bonfire" which necessitates an early round of cost cutting and in turn leaves the project more fragile to cost overruns. In this way additional cost adds a diminishing return of value.

5.2.3 Pooling of Contribution and Funding

It is desirable to have an integrated global Earth observation system. Many efforts have been made to bring various national space agencies together, such as CEOS and IGOS and ESA GMES concept, however, it is not an easy task to bring different national Earth observation programme under one umbrella.

Effective and operational observations from space require many different sensors with various resolutions and constellations of many satellites, therefore, pooling of contribution and funding has been continuing international efforts despite of the difficulties. Some successful efforts are listed below:

1. Bi-lateral Cooperation in an EO mission Brazil and China have been working together to build and launch EO missions together. Another example is Sunsat that was a joint mission between NASA and Stellenbosch University where the launch and science instruments was contributed by NASA and the satellite bus and imaging payload by Stellenbosch.
2. Pooling of existing EO satellites for international disaster monitoring ESA, CNES and Canadian Space Agency etc. have contributed their existing EO satellites to support international disaster monitoring
3. Sharing military EO missions French and Germany MoD agreed to share their EO assets.
4. Public-Public-Private Partnership Rapideye is funded by German and Canadian governments plus private investments
5. Novel International Partnership - independent owners but in a co-ordinated constellation Disaster Monitoring Constellation (DMC) comprises 5 to 7 satellites. Each satellite is owned by different nation (UK, China, Nigeria, Algeria and Turkey, etc), however, it is built at the same design, launched into the same orbit and operated in a constellation.
6. New Regional Partnership - independent owners but in a co-ordinated constellation and the African Resource Management Constellation (ARM) comprises 3 to 5 satellites with compatible payloads and ground segments. The satellites are constructed by each partner and co-ordinated in the constellation.

References

- [1] Wertz JR, Larson WJ, Space Mission Analysis and Design, Kluwer Academic Publishers, Boston, 1999
- [2] <http://www.aero.org/software/sscm/features.html>
- [3] http://www.dynacon.ca/pdf/files/newspdf_63.pdf, Stibrany P, Carroll KA, The Microsat way in Canada, Dynacon Enterprises

6 ACHIEVING COST EFFECTIVE MISSIONS

One could argue that the Hubble Space Telescope, approaching \$10 billion in total cost, has been a cost effective mission because of the large volume and high quality of the scientific results that it produced. However, in keeping with the discussion in Chapters 1 and 2, we will use cost effective in the sense of small missions or missions with substantially reduced cost relative to traditional missions.

There are many methods available for reducing the cost of space missions. We will begin by asking whether any of them actually work (and what it means to “reduce cost”), much like asking whether modern diets truly help people lose weight. Even though many techniques may be effective, they are not all equally applicable to different programs. Which are most appropriate for a particular mission will depend in large measure on the goals and objectives of the program. Thus, we next look at the impact of goals and objectives on selecting the proper approach. We then look at the general techniques that have been used to reduce cost in prior missions, i.e., what distinguishes cost effective missions from their more traditional counterparts. Finally, we will look at broad techniques that go beyond how the mission is conducted or the spacecraft built - i.e., use of non-space assets, use of income as “negative cost,” and alternative approaches to data sharing or becoming part of a larger network.

6.1 Is Cost Reduction Real?

No organization sets out to build a space mission that isn't cost effective. Programs are normally run so as to create the lowest cost design consistent with the mission requirements and constraints. In addition, most spacecraft designers and builders are very good at what they do. Past systems have not on the whole been wasteful, poorly engineered, or designed to cost more than the minimum that was required to get the job done. All of this tells us that it would be foolish to expect to build the same spacecraft as last time, under more or less the same rules, for dramatically less money. In the broadest sense, nearly all missions to date have been “cost effective.”

Table 6.1-1: Ratio of Actual Cost to Projected Cost for 10 Case Study Missions.

Because bus and payload are often not separated in small spacecraft in the same manner as traditional spacecraft, the space segment (= bus + payload) cost often provides a better representation of the cost ratio. (See Ref. [1], p. 348–350 for further discussion of the data and the table.)

	<i>Bus</i>	<i>Payload</i>	<i>Space Seg.</i>	<i>Launch</i>	<i>Grnd Seg</i>	<i>Ops + Main</i>	<i>Total Prog</i>
AMSAT							
AO-13	2.8%	in spcraft	1.8%	0.4%	N/A	N/A	1.0%
AO-16	0.9%	in spcraft	0.5%	0.2%	N/A	N/A	0.3%
Average	1.8%	in spcraft	1.1%	0.3%	N/A	N/A	0.7%
Other LEO							
<i>Ørsted</i>	31.8%	27.1%	29.8%	12.1%	4.2%	33.9%	19.6%
<i>Freja</i>	28.2%	18.5%	24.1%	7.2%	0.7%	4.1%	9.0%
<i>SAMPEX</i>	82.2%	41.1%	64.7%	93.9%	14.2%	109.2%	51.1%
<i>HETE</i>	16.3%	59.4%	35.1%	42.2%	1.4%	in payload	14.4%
<i>RADCAL</i>	12.3%	in spcraft	8.2%	73.3%	in spcraft	N/A	14.7%
<i>ORBCOMM</i>	42.7%	in spcraft	24.9%	18.1%	0.2%	6.1%	4.2%
<i>PoSAT-1</i>	4.4%	1.9%	3.3%	1.6%	0.7%	4.2%	2.2%
Average	31.1%	28.9%	26.9%	35.5%	3.6%	31.5%	16.5%
Interplanetary							
<i>Clementine</i>	88.5%	24.0%	72.2%	32.1%	1.9%	54.1%	36.3%
<i>Pluto Express</i>	19.8%	18.0%	19.7%	7.6%	in spcraft	14.0%	15.8%
Average	54.2%	21.0%	46.0%	19.9%	1.9%	34.0%	26.1%
Avg - All exc. AO	36.3%	27.1%	31.3%	32.0%	3.3%	32.2%	18.6%
Avg - All Missions	30.0%	27.1%	25.8%	26.2%	3.3%	32.2%	15.3%

Nonetheless, it is certainly the case that not all missions have been low-cost and there is continuing pressure around the world to reduce space mission cost. But if we cannot get the same product for less money, what does it mean to “reduce cost.” Dramatically reducing mission cost means that the resulting systems will be fundamentally different in at least some aspects. Consequently, what we really mean by reducing cost is, Can we meet the overall broad mission objectives at substantially reduced cost with respect to a traditional mission?

Fortunately, this is a question for which at least some evidence exists. Table 6.1-1 shows the actual cost vs. the projected cost for 10 case study missions. In this case, “projected cost” refers to the cost estimate from the Unmanned Spacecraft Cost Model (USCM) which is a widely used empirical cost model based on data from many traditional space programs.

Specific cost data from 4 of the case study missions is shown in Table 6.2-1. In this case, “expected cost” is the same as “projected cost” above and is again based on the USCM model. Both projected and actual costs are given in FY96\$ using standard inflation tables. In addition, the cost estimate from The Aerospace Corp. Small Satellite Cost Model (SSCM) is given, although this model only covers the space segment. From both the cost ratios and actual cost data, it is clear that the actual cost for some missions is well below the expected cost. It would appear that cost reductions of 50% to over 90% are possible and that the cost is reduced in all aspects of the space mission — spacecraft bus, payload, launch, ground segment, and operations. In addition, the anecdotal evidence suggests that the reliability of very low-cost missions is comparable to or higher than that of more traditional missions. This is consistent with the idea that low-cost missions are generally simpler, with less demanding requirements and, in general, simple systems tend to be more reliable than complex ones.

Of course, we have no way of knowing what these same missions would cost or how long they would live if built by the more traditional rules and processes. Nonetheless, it seems reasonable to conclude that the “preponderance of the evidence” suggests that it is possible to dramatically reduce cost (i.e., by a factor of 2 to 10) without significantly impacting reliability. However, as we will see below, it does require dramatically changing the way we do business in space.

6.2 Determining Goals and Objectives

It is likely that the lowest cost approach to acquiring a space mission is to buy the mission intact and on-orbit from one of the low-cost space system prime contractors, such as Surrey Satellite Technology Limited, Swedish Space Corporation, or Aero-Astro. However, it is often the case that a primary or secondary objective of the mission is to provide training and expertise within the organization that is funding the project. This can still be accomplished via the low-cost prime contractors, but requires a different approach than simply buying assets on-orbit.

Table 6.2-1: Representative Cost Data for Reduced Cost Space Missions.

See text for discussion. (See Ref. [1], p. 348–350 for further discussion of the data and the table.)

RADCAL – 92 kg military test satellite:

	Expected Cost	Small Spacecraft Model	Actual Cost*
<i>Spacecraft Bus</i>	\$35.8M	\$7.8M	\$4.4M
<i>Payload</i>	\$18.0M	\$0.7M	Incl. in spc cost
<i>Launch</i>	\$16.6M	\$7.1M	\$12.2M
<i>Ground Segment</i>	\$37.8M		Incl. in spc cost
<i>Ops. + Main. (annual)</i>	\$4.5M		N/A
Total (through launch + 1 yr)	\$112.7M		\$16.6M + O&M

*An inflation factor of 1.106 has been used to inflate to FY1995\$ [SMAD, Table 20-1].

†Includes cost of 2 ground stations; ‡Estimate based on Scout launch vehicle cost.

Freja – 256 kg magnetospheric and auroral research satellite:

	Expected Cost	Small Spacecraft Model	Actual Cost*
<i>Spacecraft Bus</i>	\$44.4M	\$12.8M	\$12.5M
<i>Payload</i>	\$32.4M	\$6.0M	\$6.0M
<i>Launch</i>	\$66.4M	\$6.6M	\$4.8M
<i>Ground Segment</i>	\$118.2M		\$0.8M
<i>Ops. + Main. (annual)</i>	\$9.8M		\$0.4M
Total (through launch + 1 yr)	\$271.2M		\$24.5M

*An inflation factor of 1.000 has been used to inflate to FY1995\$ [SMAD, Table 20-1].

Pluto Express – Two 103 kg interplanetary probes:

	Expected Cost	Small Spacecraft Model	Actual Cost*
<i>Spacecraft Bus</i>	\$1,140M	\$12M	\$226M
<i>Payload</i>	\$50M	\$1M	\$9M
<i>Launch</i>	\$565M	\$332M	\$43M
<i>Ground Segment</i>	N/A		Incl. in spc cost
<i>Ops. + Main. (annual)</i>	\$40M		\$6M
Total (through launch + 1 yr)	\$1,795M		\$284M

*Initial expected cost is based on the buy of 2 additional, unmodified CRAF/Cassini spacecraft.

**The Small Spacecraft Model does not include interplanetary spacecraft and is not intended for this application.

† Does not include cost of the Russian “Drop Zond” to be deployed to the surface of Pluto.

†† Ground segment development cost was incorporated into spacecraft cost to facilitate cost trades during mission definition.

‡ An inflation factor of 1.000 has been used to inflate to FY1995\$ [SMAD, Table 20-1].

AMSAT-OSCAR-13 (AO-13) – 140 kg amateur radio satellite:

	Expected Cost	Small Spacecraft Model	Actual Cost*
<i>Spacecraft Bus</i>	\$34.4M	\$7.0M	\$0.96M
<i>Payload</i>	\$18.0M	\$0.7M	Incl. in spc cost
<i>Launch</i>	\$66.4M	\$9.8M	\$0.28M
<i>Ground Segment</i>	\$7.6M		N/A
<i>Ops. + Main. (annual)</i>	\$1.1M		N/A
Total (through launch + 1 yr)	\$127.4M		\$1.24M

*An inflation factor of 1.377 has been used to inflate to FY1995\$ [SMAD, Table 20-1].

Consequently, before looking at low-cost options, it is important to first articulate with care the real primary and secondary objectives of the mission. In doing so it is particularly important to include the so-called *hidden agenda* of political or other non-technical objectives. The process of defining objectives and preliminary requirements is defined in detail in *Space Mission Analysis and Design* or *SMAD III* [2] and is summarized in Fig 6.2-1.

Some of the non-technical issues that should be addressed as part of the definition of objectives include the following:

- What political purpose does the project serve?
- Is it intended as to generate cooperation and interchange among multiple countries, or meant to serve the needs of a single organization or country?
- Is the project intended to provide training for people associated with the sponsoring organization? How much of the follow-on activities and mission operations should the sponsoring organization be able to do on its own?
- Is the project intended to make money for the sponsoring organization?
- What are the political and economic consequences of a launch or system failure? (i.e., is insurance required?)

Typical Flow	Step	Section
	Define Objectives { <ol style="list-style-type: none"> 1. Define broad objectives and constraints 2. Estimate quantitative mission needs and requirements 	1.3 1.4
	Characterize the Mission { <ol style="list-style-type: none"> 3. Define alternative mission concepts 4. Define alternative mission architectures 5. Identify system drivers for each 6. Characterize mission concepts and architectures 	2.1 2.2 2.3 2.4
	Evaluate the Mission { <ol style="list-style-type: none"> 7. Identify critical requirements 8. Evaluate mission utility 9. Define mission concept (baseline) 	3.1 3.3 3.4
	Define Requirements { <ol style="list-style-type: none"> 10. Define system requirements 11. Allocate requirements to system elements 	4.1 4.2–4.4

Figure 6.2-1: The Space Mission Analysis and Design Process

(from Ref. [2].) This process is highly iterative, as symbolized by the arrows on the left. A key element is to be sure that all of the objectives have been articulated and that trading on requirements is allowed and encouraged.

A key issue here is the distinction between *objectives*, which are broad non-quantitative statements of what the mission must do to be useful, and *requirements*, which are the quantitative statements of what is to be achieved. This is an area in which small, cost-effective missions typically diverge substantially from their more expensive, traditional counterparts. Typically sponsoring organizations define rigid, formal requirements and go to great lengths (i.e., expense) to meet those requirements. It is this process that leads to Hubble Space Telescope or the GPS constellation. In contrast, nearly all small, low-cost missions engage in *Trading on Requirements*, which is the process of trying to find a reasonable compromise between what we would like and what we can afford.

Trading on requirements is a standard part of the low-cost space mission design process. Thus, our basic objective might be to explore and characterize deforestation in some part of the world with a secondary objective of creating multi-national political agreements to slow deforestation where it is perceived to be too rapid. The requirements will define how well it must be done, how often, and with what resolution. But the requirements of a low-cost mission can and will be adjusted as function of what can be achieved at what price. For example, if our original requirement was to achieve a ground resolution of 10 m, it might turn out that achieving a ground resolution of 20 m is better than the alternative of not being able to fly the mission. Thus, the first part of the process in working with any of the low-cost prime contractors, is to understand several basic issues:

- What are the cost and performance drivers for the missions?
- What are the key trades between what can be achieved and how much it will cost?
- Are there ways to reduce cost by bringing in other investors or selling parts of the output?

Trading on Requirements is a process that will go on throughout the mission definition process. In the end, we are looking for the same outcome that all of us make in personal decisions — finding the best compromise between what we would like to achieve and what is reasonable within budget constraints.

6.3 General Methods for Reducing Space Mission Cost

Certainly one of the first lessons in reducing mission cost is to avoid reinventing the wheel by making use of the experience base in the astronautics community. Fortunately, there is a long history of low-cost space missions (relative to traditional, large-program cost experience) that can provide background knowledge and experience on which to draw. Although specific cost information is not widely distributed, the masses of nearly all

spacecraft are widely known and published in many sources, such as the journal *Spaceflight* published monthly by the British Interplanetary Society. While not universally true, most spacecraft weighing less than 200 to 300 kg are small missions built on limited budgets. With this list as a starting point, literature or personal contacts can provide a wealth of information relevant to proposed future programs.

In addition, there have been three well-documented and widely distributed studies on processes for reducing various aspects of space mission cost. In 1992–93 at Maxwell Air Force Base, then Lt. Col. John R. London III undertook an extensive study on the reasons for high launch costs and methods to reduce them. His report was subsequently published as *LEO on the Cheap, Methods for Achieving Drastic Reductions in Space Launch Cost* [3]. This document is currently available at no cost on the web at http://www.dunnspace.com/leo_on_the_cheap.htm. This report remains the most authoritative to date on launch cost reduction methods. John London has since retired from the Air Force and is now a member of the senior staff at NASA's Marshall Space Flight Center.

A second key study was undertaken for NASA by Liam Sarsfield of the Rand Corp. on methods for reducing the cost of science missions. The final report on this study was published as *The Cosmos on a Shoestring* [4] in 1998. The most extensive study on reducing all aspects of mission cost was done by James Wertz and Wiley Larson under contract to the US Air Force Academy specifically for creating a book on this topic. The result, *Reducing Space Mission Cost* [1] was published in 1996 and includes both methods for reducing cost in all mission areas and 10 case study missions of specific programs from many fields which achieved cost reductions of 50% to more than 90% with respect to traditional cost models. A summary of the study was also published in a paper presented at the Utah State University Small Satellite Conference in 1996 [5]. Most of the conclusions presented here are from this study.

Finally, although not directly a study on reducing cost, it is worth noting the outstanding success record of the Amateur Radio Satellite Corp., AMSAT, which has successfully launched more than 40 “ham radio” communications satellites with an exceptional success record and at very low-cost — even given that the labor was free for the actual construction. The process that AMSAT uses for building these satellites is very well documented in *The Radio Amateur's Satellite Handbook* [6] by Martin Davidoff. This volume comes as close as any book available to giving a specific recipe on how to build a low-cost, but still very competent satellite.

Tables 6.3-1 and 6.3-2 from Ref. [5] summarize the general methods used by the 10 case study missions in Ref. [1] to achieve drastic cost reduction. A review of the two tables will show that the methods used by different groups have very little in common. Some use low-cost parts, while others use the best available parts. Some make cost data known and others maintain the cost data hidden. The point is that there is no single, accepted, broad method for reducing mission cost. Instead, the builders of low-cost missions are aggressive competitors, just like their more expensive colleagues who create large programs for ESA, NASA, or the US Department of Defense. Each low-cost program has found a set of solutions to fill its particular need and programmatic style.

As shown in these tables, the evidence to date strongly suggests that there is no single solution for reducing mission cost and that each program must find the combination of approaches most appropriate to its specific needs. We should not be surprised by this result. If there were specific technical approaches that gave better results at less cost on a continuing basis, then essentially all space programs would have adopted these approaches. For example, satellite builders have long ago concluded that aluminum or light-weight composite materials are best for satellite structure because of the high cost of launch. All satellite builders have adopted this approach and no one builds satellites out of steel or other heavy metals.

Generally the cost reduction methods that have been identified fall into four major groups — systems engineering, programmatic, personnel, and technology. Each of these is discussed below.

Table 6.3-1: Summary of the cost reduction methods used by the case study missions of tables 6.1-1 and 6.2-1

(from Ref. [5]) See text for discussion. Not all methods were used by all of the case study missions as shown in Table 6.3-2

Method	Mechanism	Comments
Programmatic		
Schedule Compression	Reduces overhead of standing army; forcing program to move rapidly does drive down cost	Often results in a poor design due to lack of up-front mission engineering; must reduce work required to be consistent with schedule
Reduce Cost of Failure	Allows both ambitious goals and calculated risk in order to make major progress	Fear of failure feeds cost-growth spiral; major breakthroughs require accepting the possibility of failure—particularly in test
Continuous, Stable Funding	Maintains program continuity; maintains team together	Program delay will be funding break + 2–4 months
Minimize Documentation	Reduces programmatic overhead for creating, reviewing, and maintaining	Critical to document reasons for key decisions and as-built design
Personnel		
Improved Interpersonal Communications	Dramatically reduces errors and omissions; conveys understanding as well as data	Large programs use formal, structured communications through specified channels
Small Team	Clear, nearly instantaneous communications; high morale; strong sense of personal responsibility	Problem if a key person drops out — but in practice it rarely happens.
Co-located Team	Improves communications	Best communications are face-to-face, but AMSAT and others don't seem to need it
Empowered Project Team	Rapid decision making; strong sense of personal responsibility; can make “sensible” decisions	Eliminates a major function of the management structure
Systems Eng.		
Trading on Requirements	Eliminates non-critical requirements; permits use of low-cost technology	Makes traditional competition difficult
Concurrent Engineering	Allows schedule compression; reduces mistakes; increases design feedback	High non-recurring cost relative to lowest cost programs
Design-to-Cost	Adjusts requirements and approach until cost goal has been achieved;	Spacecraft have rarely used it
Large Margins	Reduces testing; better flexibility; reduces cost of eng, manufac., and ops	Margins traditionally kept small for best performance — drives up develop. cost
Technology		
Use COTS Software	Immediate availability; dramatically lower cost; tested through use	May need modification and thorough testing; typically not optimal
Use COTS H/W	Same as software	Same as software
Use Existing Spares	Reduced cost; rapid availability; meant for space	Only works so long as spares exist — not applicable for operational programs
Use of Non-Space Equipment	Takes advantage of existing designs and potential for mass production	Typically not optimal; must be space qualified
Autonomy	Reduces operations costs	Can increase non-recurring cost
Standardized Components and Interfaces	Reduces cost and risk by reusing hardware; standardization is a major req. for other types of manufacturing	Has been remarkably unsuccessful in space; sub-optimal in terms of weight and power
Extensive Use of Microprocessors	Minimizes weight; provides high capability in a small package; allows on-orbit reprogramming	Problem of single-event upsets; high cost of flight software; very difficult to manage software development
Common S/W for Test and Ops	Reduces both cost and schedule; avoids reinventing the wheel	May be less efficient, user-friendly than ops group would prefer

Table 6.3-2: Methods Used by Specific Case Study Missions

(from Ref. [5].) Methods listed are those from Table 6-3. A dot indicates that the method was used and a star indicates that the method was regarded as important by the author of that particular case study (Ref. [1]). Missions are: Ør = Ørsted, Fj = Freja, Sx = SAMPEX, He = HETE, Cl = Clementine, PE = Pluto Express, Ra = RADCAL, Or = ORBCOMM, Am = AMSAT, Po = PoSAT-1, Br = BremSat.

Method	Ør	Fj	Sx	He	Cl	PE	Ra	Or	Am	Po	Br
<u>Programmatic</u>											
Schedule Compression			•	•	*	•	*	•	•		
Reduce Cost of Failure			•	*	•	•		•	•	•	•
Continuous, Stable Funding	•	•	•		•		•			•	
Minimize Documentation	•	•	•	•	•	•			•		
<u>Personnel</u>											
Improved Interpersonal Communications	•	•	•	•		•			*	•	•
Small Team	•	•	*	*	*	*	•	•	•	•	•
Co-located Team			•		•	•	•			•	•
Empowered Project Team	•	*		*	*	•		*	•	•	*
<u>Systems Engineering</u>											
Trading on Requirements				•	•	•	•		•	*	•
Concurrent Engineering		•	*			•	•		•		•
Design-to-Cost	•		•	•		•	*		•	*	•
Large Margins	•	•									•
<u>Technology</u>											
Use COTS Software	•	•						•	•	•	
Use COTS Hardware		•			•		•		•	•	•
Use Existing Spares						•			*		
Use of Non-Space Equipment									*		•
Autonomous Systems			•			•		•		•	•
Standardized Components and Interfaces		•	*				•			•	•
Extensive Use of Microprocessors		•		*	•	•		•		*	•
Common S/W for Test and Operations	•							•			*

System Engineering Methods. These approaches focus on the way that a program is designed and how the requirements are defined. Modern, high cost space missions work to pre-defined requirements and are optimized to maximize the performance at minimum mass. Unfortunately, minimizing the mass and mass margins tends to maximize cost. Reducing margins also adds “hidden cost” by driving up the cost of integration, test, and operations and extending the schedule. In contrast, *large margins* provide better system flexibility and drive down the cost of engineering, manufacturing, integration, test, and operations.

Section 6.2 provided a brief summary of *trading on requirements*, an approach used by many low-cost programs. Related to trading on requirements is the approach of *design-to-cost* in which both the requirements and the system design are adjusted until specific cost objectives are achieved. If the cost constraints are severe, then the overall performance will be reduced relative to traditional missions, but still may be sufficient to meet the top level system objectives.

Concurrent engineering is another widely used approach, but its implementation is substantially different in small and large organizations. In large organizations (i.e., ESA, NASA, or the major prime contractors for either), concurrent engineering involves a large and relatively expensive software system that allows interaction between all of the various aspects of a system design. For example, use of a new, larger transmitter would automatically increase the power budget and adjust the thermal, structural, and control requirements appropriately. In smaller organizations, the same effect is achieved by having people work closely together. This is effective because in a small organization, the entire spacecraft is typically built by less than 30 people and program communications is a much easier task.

Programmatic Methods. These approaches center around the way a program is run or managed. In traditional programs, the fear of failure can dramatically drive both cost and schedule and lead to spiraling growth in both areas. *Reducing the Cost of Failure* allows for more significant programmatic risk. Note, however, that in all programs, “failure becomes more expensive” as the program gets closer to launch. This should be taken into account in the mission design process.

One way to dramatically reduce cost is to significantly *compress the schedule*. However, schedule compression must be coupled with a real reduction in the amount of work that must be done. Requiring the same level of documentation, review, and approval cycles as on a traditional mission, but in half the time, leads to poorly done work and kills the responsible engineers, much like getting a cat to pull a piano up the stairs, as shown in Fig. 6.3-1.

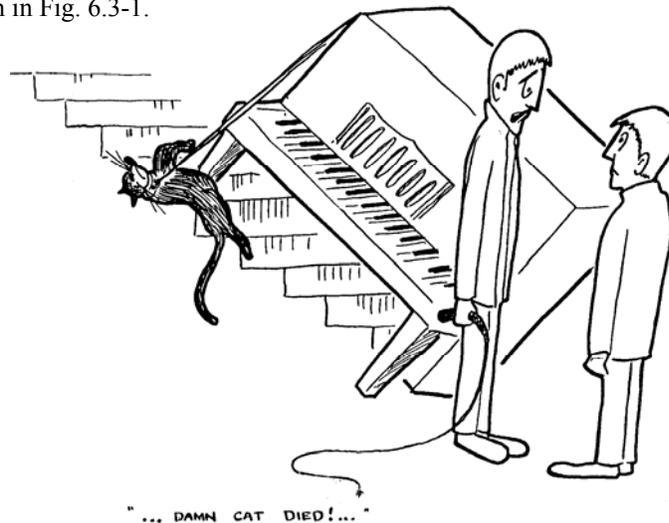


Figure 6.3-1: Schedule Compression Without Changing the Rules or Requirements is a Lot Like Getting a Cat to Move a Piano Up the Stairs (from Ref. [1].) The whip doesn't help much.

A critical programmatic element for nearly any low-cost program is *continuous, stable funding*. This is not so much to reduce cost as to keep cost and risk from growing substantially. If there is a break in funding then personnel on a small program will either be reassigned or may leave the organization entirely. Restarting the program will require both retraining and some degree of “backing up and starting over.” This, in turn, leads to increased cost, risk, and schedule. However, the funding organization will typically not want to take responsibility for this increase, thus leading to a high probability of cost and schedule overruns on any program for which there has been a significant break in funding.

Personnel. Large program organizations want to depend on regulations, process, and technology as a means of getting things done, from achieving objectives to reducing cost. Nonetheless, experience has shown that *highly-motivated personnel* are perhaps the single most important aspect of achieving good results for less cost. This is fostered by *small, co-located teams* that are *empowered* to make programmatic decisions. This is particularly difficult to achieve within a large organization and is one of the key reasons that small organizations often have a substantial advantage in creating effective, low-cost space missions. Although there was certainly no unanimity of opinion, the majority of the case study authors ranked personnel issues as the most important aspect of reducing space mission cost.

Technology. In contrast to personnel issues, the case study groups regarded technology as the least important aspect of mission cost reduction, although it can still play a significant role. Use of non-space equipment will be discussed further in Section 6.4. Use of *autonomy* in space systems can serve to reduce operations cost, but at the expense of increased non-recurring development cost.

One change that is occurring throughout the space program is the increased use of *on-board software and microprocessors*. This can serve to reduce cost by replacing hardware functions with software and also allows small, low-cost spacecraft to do far more than was previously possible. Except for very large communications satellites, nearly all other types of spacecraft and space payloads are becoming both smaller

and more capable. This trend is tending to reduce the cost of all missions. Software systems are certainly subject to failure, both in the software itself and in the microprocessor on which the software is running. Nonetheless, a major advantage of software-driven systems is that, unlike hardware, software can be changed or repaired after a spacecraft is on orbit. Experience has shown that this occurs in a large fraction of missions of all types which suggests that a major component of reducing the cost of failure is to plan for easy and rapid software reprogramming once a spacecraft is on orbit.

6.4 Using Non-Space Assets

Virtually any component built exclusively for space will be expensive because very few of them will be produced. This means that the non-recurring development cost will be amortized over fewer units and there will be little or no learning curve to drive down production costs. This suggests that use of non-space hardware and software can have a substantial impact on system cost. Specifically, one can consider use of commercial off-the-shelf (COTS) software, non-space hardware, and alternatives to a dedicated space launch.

COTS Software. A large variety of commercial software is now available that provides a number of advantages for low-cost space missions:

- Dramatically lower cost
- Immediate availability
- Regular upgrades available
- User support often available

In contrast, custom software has a very high non-recurring cost, high support cost, and often takes months or years to develop.

The commercial software market has greatly expanded due to interest from the consumer marketplace. For example, the wide-spread availability of low to moderate cost digital cameras has led to substantial growth in digital image processing software that is now dramatically more sophisticated than software of even a few years ago. There is both general image processing software, such as Photoshop, and a number of software programs specifically for processing astronomical imagery. The later has come about because of the development of digital cameras specifically for amateur astrophotography.

Another example of the importance of commercial software is the Hubble Guide Star Catalog. Originally developed at substantial cost by NASA for use with the Hubble Space Telescope, the catalog contains 19 million stars and non-stellar objects and is contained on two CD-ROMs. However, because the information is useful to the amateur astronomy community, the Hubble Guide Star Catalog is now commercially available for \$79.95. Further, any or all of the 19 million objects can be plotted and analyzed by most of the approximately ten sky plotting programs.

Commercial software is available for nearly all aspects of a space mission, including mission planning and visualization. The most widely used of these commercial tools is Satellite Tool Kit (STK) from Analytical Graphics. Because commercial software changes rapidly, the best approach for a prospective program is to define the types of analyzes or processes for which software is needed and then conduct a survey of what is commercially available at that time and what can be potentially modified to meet specific program needs.

Non-Space Hardware. For nearly all elements of space hardware, there is a fundamental choice of using space-qualified components or industrial components. Generally, industrial components provide much lower cost, newer technology, and immediate availability. Frequently, they will have better performance as well. However, the fundamental problem of using non-space hardware is answering the basic question, Will it work in space?

Since low-cost space programs often use non-space hardware, this is a question that is addressed many times in any low-cost mission. Table 6.4-1 is a summary of the principal space environment effects and what can be done to mitigate problems or test for space functionality. Testing is an absolutely critical part of this process for both low-cost and traditional, higher cost missions. For low-cost missions, the engineer systematically goes through Table 6.4-1 for each non-space component. Wherever there is a problem or issue, mitigation techniques are applied and the system is tested to ensure functionality in the space environment.

Table 6.4-1: Summary of Effects and Recommendations Associated with the Space Environment
 The objective of this process is to unambiguously answer the question, Will it work in space?

Environment	Effects	Things to Do	Things to Avoid
<i>Launch</i>	Vibration Dynamic and static loads Acoustic energy Shocks Decompression	Determine loads, energy spectrum and minimum critical frequencies from launch agency In general, design and procure all components to meet the launch agency's requirements. Do spacecraft vibration tests to ensure compliance Do spacecraft thermal and vacuum test to ensure out-gassing compliance	Unrepeatable manufacturing processes Large surface areas Overly constraining margins Unsuitable vacuum materials
<i>Free Fall</i>	Fluid, primarily propellant, management	Provide for passive or active means of propellant management, e.g., spin stabilization, bladders.	Uncontrolled fluids
<i>Vacuum or Neutral Atmosphere</i>	Outgassing Cold-welding Atomic oxygen	Check all spacecraft materials against outgassing data	Materials with known outgassing properties Bare metals in moveable mechanisms in direct contact
<i>Thermal</i>	Conduction is the primary means of moving heat within the spacecraft. Radiation is the only way to remove heat from the spacecraft	Ensure enough conduction paths are established to move heat away from hot components Ensure there is enough area to radiate waste heat into space.	Extremities on the outside of the spacecraft Heat-dissipating components in the center of PCBs Materials that "age" with thermal cycling
<i>Radiation</i>	Charged particles cause single-event phenomenon, which disrupts operation of electronic components Build-up of charged particles on spacecraft surfaces can lead to uneven charging and damaging discharges	Provide layered redundancy for suspect components Provide bit-error-correction code in spacecraft software Test new components to determine rad-hardness Use rad-hard components Ground the spacecraft's exterior surfaces	Don't use rad-soft components in high-radiation orbits Exposed components electrically isolated from the rest of the spacecraft Certain types of plastic components that break down under exposure to radiation

The principal problems associated with the space environment are the following:

- Launch loads provide very high mechanical stresses
- 0-g makes fluids behave poorly and eliminates convection cooling
- Outgassing in vacuum creates a microenvironment that can cause arcing in high voltage components
- Exterior thermal environment (including solar arrays and antennas) can go from -100 °C to +100 °C in 2 minutes as the spacecraft goes from full sunlight into eclipse and vice versa
- Radiation environment is principally responsible for preventing terrestrial computers from working in space

Alternatives to a Dedicated Space Launch. If the entire space mission cost is intended to be less than, for example, \$20 million, then it is clear that the program cannot afford \$25 million for a dedicated small launch vehicle. Fortunately, as summarized in Table 6.4-2 there are a number of far lower cost alternatives to a dedicated launch.

The first question to ask is whether an orbital flight is critical to the mission at hand. Many missions are intended to test various space equipment, but do not necessarily need to be in orbit. Virtually all of the environmental aspects of space, except for the high velocity, can be provided at a much lower cost and much

more quickly via several of the approaches listed in the table. For example, drop towers can provide 5 to 10 seconds of 0-g in a vacuum environment and experiments can be run twice a day for as long as needed to obtain the necessary results. Parabolic aircraft flights provide moderate quality 0-g for approximately 25 seconds, with up to 40 parabolas per day. In addition, the experimenter can ride along to run the experiment and see whether the equipment is working as expected and what might be done to solve problems that arise.

Table 6.4-2: Alternatives to a Dedicated Launch.

(from Ref. [1].) Although each has limitations, dramatic reductions in cost are possible for missions such as equipment testing that do not necessarily need a long period on orbit.

Option	Characteristics	Mass Limits	Principal Constraints	Approximate Cost	Sources
Balloon Flights	Hours to days at \approx 30 km altitude	Up to 70 kg for low-cost flights	Not in space, not 0-g, weather concerns	\$5K to \$15K	U. of Wyoming, USAFA, NSBF
Drop Towers	1 to 10 sec of 0-g with immediate payload recovery	Up to 1,000 kg	Brief "flight," 5 to 50 g landing acceleration, entire experiment package dropped	\approx \$10K per experiment	ZARM, JAMIC, NASA LeRC and MSFC, Vanderbilt U.
Drop Tubes	1 to 5 sec of 0-g with immediate sample retrieval	<0.01 kg	Brief "flight," 20 to 50 g landing acceleration, instrumentation not dropped with sample	\approx \$0.02K per experiment	ZARM, JAMIC, NASA LeRC and MSFC, Vanderbilt U.
Aircraft Parabolic Flights	Fair 0-g environment, repeated 0-g cycles	Effectively unlimited	Low gravity is only 10^{-2} g	\$6.5K to \$9K per hour	NASA LeRC and JSC, Novespace
Sounding Rockets	Good 0-g environment, altitude to 1,200 km, duration of 4 to 12 minutes	Up to 600 kg	Much less than orbital velocities	\$1M to \$2M	NASA GSFC, NRL, ESA/Sweden, OSC, EER, Bristol Aerosp.
GAS Containers	Days to weeks of 0-g on board the Shuttle	Up to 90 kg	Very limited external interfaces	\$27K for largest container	NASA GSFC
Secondary Payloads	Capacity that is available in excess of primary's requirements	Up to \approx 1,000 kg	Subject to primary's mission profile	<\$10M	Ariane, OSC, MDA, Russia
Shared Launches	Flights with other payloads having similar orbital requirements	Up to \approx 5,000 kg	Integration challenges	Up to \approx \$60M	Ariane, OSC, Russia

Real, in-space performance at low-cost can be achieved with suborbital or sounding rocket flights that can reach altitudes of up to 1200 km and provide up to 10 minutes of excellent 0-g, vacuum environment. At apogee, energetic suborbital vehicles can reach beyond low-Earth orbit to the lower reaches of the Van Allen belts and can provide a view of the Earth identical to what is seen from a satellite, except for the horizontal velocity. Payloads may or may not be recoverable, depending on the specific vehicle and mission profile.

Finally, if a launch all the way to orbit is critical, a variety of secondary opportunities or shared launches are available. The most widely used is the Ariane Structure for Auxiliary Payloads, or ASAP ring, flown previously on the Ariane 4 and now available on the Ariane 5. The ASAP ring on the Ariane 5 has 6 platforms, each able to hold up to 100 kg, and two adjacent platforms can be used for a single payload. The ASAP ring has provided the launch mechanism for many small satellites. Of course with any ride as a secondary payload, the orbit to which the launch vehicle goes is normally determined by the primary payload.

6.5 Data Sharing, Cost Sharing, and Income Generation

Thus far, the discussion has focused on ways to reduce cost. However, an equally important approach is to find ways to share cost or data or to generate income to offset some or all of the cost. Once again, the key issue in looking at cost sharing or income generation is the fundamental objective of the mission and whether that objective is consistent with selling product or sharing costs or data.

There are several mechanisms for sharing cost. The simplest is to buy data from an existing on-orbit system to satisfy the mission need. However, this may or may not meet the non-technical objectives of the mission that often involve gaining experience, national prestige, or education and training in space systems.

A second approach to cost sharing is to find another organization that can benefit from the same mission. For example, a forest fire detection system in low-Earth orbit can meet the needs of multiple countries, either in one region or around the world, as has been shown with the technology demonstration microsatellite BIRD (Bi-spectral Infra-red Detection) [7]. Thus, an international “FireWatch” satellite program might be appropriate as a means of reducing the cost burden on any one country or organization (Ref. [3]). An example of this approach is the Disaster Monitoring Constellation, organized by SSTL. Each participating country flies its own satellite, but has access to the data of all satellites in the constellation (Ref. [8]).

A third approach is to put additional equipment on board the spacecraft that can make use of the same spacecraft bus and mission orbit (Ref. [2]). This occurs on a regular basis on both small and large programs and is a well-established approach for sharing some elements of cost (Ref. [4]). A related approach is to complete existing large satellites with additional equipment placed on small satellites to provide additional data, additional viewing directions, or combined vertical and limb sounding (Ref. [9]).

Finally, it may be possible to generate income to offset some or all of the system cost. A good example would be navigation systems such as those provided by the American GPS or the Russian GLONASS systems. In this case, the systems are provided by the respective governments, but the signals are provided to the world at no cost. An alternative would be to license the signal and collect royalties from the relatively small number of receiver manufacturers. Similar approaches could be used for weather data, Earth observation data, or communications channels.

References

- [1] Wertz, J.R. and W.J. Larson (eds). 1996. *Reducing Space Mission Cost*. Dordrecht, The Netherlands and Torrance, CA: Kluwer Academic and Microcosm Press
- [2] Wertz, J.R. and W.J. Larson (eds). 1999. *Space Mission Analysis and Design* (3rd ed.). Dordrecht, The Netherlands and Torrance, CA: Kluwer Academic Publishers and Microcosm Press
- [3] London, Lt. Col. John R. III. October 1994. *LEO on the Cheap—Methods for Achieving Drastic Reductions in Space Launch Costs*. Maxwell Air Force Base, AL: Air University Press
- [4] Sarsfield, Liam. 1998. *The Cosmos on a Shoestring: Small Spacecraft for Space and Earth Sciences*. Santa Monica, CA: Rand Corp
- [5] Wertz, J.R. and Simon Dawson. September 1996. *What’s the Price of Low Cost?* 10th Annual AIAA/USU Conference on Small Satellites
- [6] Davidoff, M. 1998. *The Radio Amateur’s Satellite Handbook*. Newington, CT: ARRL
- [7] Briess, K., W. Baerwald, E. Gill, H. Kayal, S. Montenbruck, W. Halle, W. Skrbek, H. Studemund, T. Terzibaschian and H. Venus: “Technology Demonstration by the BIRD Mission.” *Selected Proceedings of the IAA International Symposium on Small Satellites for Earth Observation, April 7–11, 2003*, in: *Acta Astronautica* 56(2005)57–63
- [8] da Silva Curiel, A., L. Boland, J. Cooksley, M. Bekhti, P. Stephens, W. Sun and M. Sweeting: “First Results from the Disaster Monitoring Constellation (DMC).” *Selected Proceedings of the IAA International Symposium on Small Satellites for Earth Observation, April 7–11, 2003*, in: *Acta Astronautica* 56(2005)261–271
- [9] Drescher, A. and R. Sandau: “Tandem Satellites Concepts for Earth Remote Sensing.” IAA-00-IAA.11.4.07, 51st IAC, Rio de Janeiro, 2000

7 APPLICATION FIELDS, STATUS QUO AND PROSPECTS

There is an increasing need for cost effective Earth Observation (EO) missions to meet the information requirements of an almost ever growing range of applications. This is perhaps most clearly seen in the many current moves for international co-operation in the field of environment where measurements from Earth Observing satellites are an essential element. This is especially so where we need to acquire, analyse and use data documenting the condition of the Earth's resources and environment on a long-term (permanent) basis. As can be seen from the list of topics addressed in this chapter, uses range from essential mapping activities to global climate, with information needs arising because of legislation and through international commitments. Hazards, agriculture, land degradation, desertification, deforestation, sustainable forest management, climate, our cryosphere and others topics are all highlighted here.

The international community is addressing these needs. Not just through environmental conventions such as the UNFCCC and its Kyoto Protocol, but also through commitments entered into at the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg. The heads of state of 191 nations called for improved global observations for better decision-making, and emphasised the key role of satellites in providing these. This call for international co-operation was certainly heard at the G8 Summit in France in June of 2003 and the first Earth Observation Summit which followed in Washington, July 31st 2003.

The G8 Summit in Evian, June 2003, resulted in the G8 Action Plan on Science and Technology for Sustainable Development. The Summit clearly expressed the need to develop close international co-ordination of global observation strategies for the next ten years. This includes the need to identify new observations and to minimise data gaps by building on existing work to produce reliable data products on atmosphere, land, fresh water, oceans and ecosystems.

At the first Earth Observation Summit, Washington DC, 31st July 2003 the European Commission and 34 nations adopted a Declaration promoting the development of a comprehensive, coordinated, and sustained Earth Observation system or systems to understand and address global environmental and economic challenges. For this purpose, an ad hoc Group on Earth Observations (GEO) was established to prepare a 10-year implementation plan. Among many other activities areas it is worth noting that the 9th Conference of the Parties to the UN Framework Convention on Climate Change have asked the GEO to treat global climate monitoring as a priority and to work with the Global Climate Observing System's secretariat to build a 5 – 10 year implementation plan.

The year 2001 represented a turning point for space policy in Europe, when the EU and ESA Councils emphasised the strategic importance of permanent access to global information relating to environmental management and monitoring, risk surveillance and the enhancement of safety and civil security. In this context and spirit the European Green Paper consultation (Towards a European Space Policy) was launched in January 2003 and the White Paper on Space setting out eh policy in November 2003. In this framework, a European capacity for global monitoring of environment and security to support the Union's political goals regarding sustainable development and global governance will be established by 2008.

Regional/Continental initiatives such as the joint European Commission – European Space Agency's Global Monitoring for Environment and Security (GMES) initiative aim to provide timely and quality data, information, and knowledge through EO systems. GMES will be one of the means whereby Europe fulfils its commitment to the Earth Observation Summit Declaration. The global dimension of GMES will both provide Europe's policy makers with information they need and form an explicit European contribution to international environmental monitoring endeavours.

The global vision and commitments illustrated here show how much importance our political leaders place on global environmental information. In this chapter, we illustrate how cost effective earth observation missions can help meet real users' real information needs and we conclude that there is an actual need for sharing information coming from different systems in order to assure and optimize data continuity, compatibility and reliability.

In the agricultural domain, governments and international institutions are using EO systems for measurements of status, vigour, damage and disease assessment, soil moisture, erosion and other parameters

influencing the crop production. Observations are also used for comparison with official production declarations made by farmers. This information is currently being integrated in the decision-maker processes; and, since the current high costs of this technology represent a major obstacle for a wide use at commercial level, the potential market is very attractive.

EO systems are also widely used by national and international forestry services (EU forest services and the Joint Research Centre of the European Commission, Global Forest Inventory – FAO, Global Forest Watch – World Resources Institute, Forest Survey of India, ...) for obtaining maps that have proven valuable for ecological modelling and forest biodiversity assessment. This information is important as far as it documents the status and rates of change of the world's forests cover. The UNFCCC and Kyoto protocol are also interested in this thematic information as they have an impact on the evaluation of the terrestrial carbon sink. Forest fires (both natural and anthropogenic) which are mapped by EO systems can be also recurrent drivers of boreal and tropical forest cover changes.

Geostationary and polar platforms are being used to provide a global scale view of atmospheric dynamics and cloud-top temperatures which allow the scientist to better understand atmosphere and climate.

National and regional thematic cartography constitute the basis of a spatial data infrastructure. This information is essential for an optimised exploitation resource policy, for planning the natural and socio-economic environment and for a rapid response in case of natural hazards with catastrophic consequences for the population.

Ice and snow cover extent and duration are not only the result of the climatic conditions of a certain region, but are also strong climatic controls which can be measured by EO systems from space.

This chapter deals with these and other applications where cost effective earth observation missions are providing with valuable information in these essential domains which are closed to both natural (Earth's resources and environment) and socio-economic areas.

References

COM (2001) 718 final “Towards a European Space Policy”, European Commission and European Space Agency Joint Task Force Report

COM (2001) 264 final Communication from the Commission “A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development”

White Paper – “Space: A New European Frontier for an Expanding Union”

2001/C 350/02 Council Resolution of 13th November 2001 on the “Launch of the Initial Period of Global Monitoring for Environment and Security (GMES)”

<http://www.earthobservationsummit.gov/declaration.html>

“Global Monitoring for Environmental Security: A manifesto for a new European course of action”, Baveno, Lago Maggiore, Italy, May 1998

7.1 Disaster warning and support

7.1.1 Status quo

Disaster Warning and Support is an important application field of cost effective Earth observation missions. Governmental organisations, private companies and international organisations are investigating the status and the prospects in these fields with regard to their specific contributions. The main application fields of small satellites related to disaster warning are:

- Cyclones and storms,
- El Nino,
- floods,
- fires,
- volcanic activities,
- earthquakes,
- landslides,
- oil slicks,
- environmental pollution,
- industrial and power plant disaster.

The status quo of the disaster warning and support are different in the mentioned fields.

Cyclones, Storms and El Nino

Nearly 100 Tropical Cyclones occur each year on seven regions around the world related with important damages in a lot of countries. Tropical Cyclones get their energy primarily from evaporation of the sea, in the presence of high winds and the condensation in convective clouds concentrated near their centre. Resulting floods caused by the heavy rain, strong winds and bad sea conditions produce huge human and economic losses. A strong Tropical Cyclone (wind speed is greater than 33 m/s) is also called hurricane or typhoon. Wind observations over oceans made by ships are generally insufficient for determination of accurate position and details of storms and cyclones. Satellite visible and infrared images may help to locate storms but do not reveal the surface intensity. Only an active microwave sensor, a Scatterometer, has the capability of measuring both wind speed and direction of the local wind field with high spatial resolution. Combining this data with wave height measurements from an altimeter and wave spectra data give interesting information for warning and support centers. This information up to now available from big satellites (like ERS-1) only.

The similar situation is happen to the other weather related types of disasters like storms and El Nino phenomena. The status quo is characterized by establishing of warning systems basing on information fusion of different sources. These sources deliver ground data, sea buoy data, atmospheric data and data of meteorological satellites. The methods of weather prediction in combination with observation of detected weather phenomena are used for disaster warning systems. These combined systems work successfully with an acceptable warning time in these regions, where sufficient data are available for the well established weather forecast methods. The space segment of these methods is able to deliver important parameters in regional scale like:

- wind vector fields (speed and direction),
- sea surface temperature,
- air pressure,
- area extent of weather phenomena,
- characteristics of eddy currents,
- other.

But this is not given at any time and for any place in the world. It is a need for additional activities and support to gain local and global data for the improvement of the prediction of these disaster types by means of small satellites. Up to now, no dedicated small satellite system for warning and support in these fields exists.

Flood

Flood severely affects the life and environment at different places in the world each year. It causes considerable damage to buildings, bridges, roads, villages, towns and agriculture. Often floods cause also a high loss of human or animal life. Heavy rains, snow smelts or typhoons are reasons for the generation of floods. Rapid identification and response to flooded areas can help to save life and to protect some important

areas. Real-time flood monitoring with high resolution images in the optical wavelength range are desirable but usually not possible because of the cloudy and rainy weather conditions at this time. Because of their independency of weather and light conditions Synthetic Aperture Radar data are used for these purpose. Up to now small satellites do not help with this kind of instruments.

After the floods a precise assessment of the damaged area can help local authorities in planning and organising the reconstruction and future protection measures. Basing on precise satellite data insurances can assess the damage more precisely. Data from optical instruments in different spectral channels are very helpful in precise assessment of the situation and the damages. In this field of work small satellites with optical instruments can give the needed information within a short response time. But up to now bigger satellites like SPOT or LANDSAT are used data sources for this purpose. And satellite data in general are to less used for flood monitoring because potential users are not familiar with the procedures for receiving, processing and interpreting the data.

Fires

Vegetation fires

Vegetation fires associated with increasing human population density, economic activities and other multiple vegetation stresses in the tropics and in the boreal zone have led to a change of natural and anthropogenic fire regimes. In the last two decades it was observed that wildfires in many locations cause considerable damage to vegetation cover, biodiversity, landscape stability (erosion), and productivity.

Current spaceborne sensor systems can be used to generate products of fire susceptibility evaluating time-series of vegetation state data, occurrence and coarse location of active fires, as well as smoke and burnt areas (fire scars). However, existing and planned operational space-borne sensors show serious limitations (e.g. partly channel saturation leading to reduced high temperature event discrimination, spatial resolution worse than 1 km) if accurate geophysical parameters have to be obtained. The German small satellite mission BIRD (Bi-spectral InfraRed Detection) of DLR demonstrates the feasibility of recognition and quantitative characterisation of High Temperature Events (HTE) on the surface of the Earth by means of small satellites since it's launch in 2001. The EU funded FUEGO-study has investigated in detail a space borne forest fire alert system – with main emphasis on the Mediterranean region. Some main features are:

- time to detect fire outbreaks of less than 15 minutes in average, (over a total South Europe area of surveillance of around 30 Mha), including automatic alarm generation,
- automatic detection and geo-location of fire alarms with 300-500 m accuracy,
- automatic monitoring/mapping of detected outbreaks, with generation of the fire perimeter and burned area evaluation, for all outbreaks of larger than 25 ha,
- geo-location accuracy of the fire perimeter shall be around 50 m.

But it is up to now fare from the space implementation.

Uncontrolled fossil fires

Uncontrolled fossil fires are, for instance, coal seam fires and peat swamp fires. Coal seam fires are reported from nearly all parts of the world where coal is or was mined, but the most severe coal seam fires are observed in China and India. There is a large economical and ecological damage caused by coal fires. The coal fire problem in China, the world's largest producer and consumer of coal, is much higher than has ever been previously assumed by anyone outside of China. The 1992-estimate amount of CO₂ released from Chinas coal fire burning was about 2-3 % of the amount of the total world carbon dioxide emission.

Peat swamp fires in Indonesia emitted in the El Nino year 1997 1-2 Giga tons (Gt) carbon into the Earth atmosphere (see "Nature", Vol. 420, 7 November 2002). This is an amount of released carbon in the same order of magnitude as the yearly European carbon emissions from industrial and transport consumption of coal, oil and gas. The investigation of the relate parameters from space are not solved in sufficient accuracy up to now.

Volcanic activities

About 50-100 volcanoes erupt every year. The term "volcanic activity" encompasses a broad range of different phenomena including hot springs, lava effusions, and explosive eruptions. The conditions for effusive or explosive activity are mainly determined by the physical properties of the magma which in turn depend on the chemical composition, viscosity and volatile content. The average duration of an eruption is about 60 days, encompassing many different events. Time series data of volcanic gas outputs could be of extraordinary use in developing geo-chemical eruption precursor models for restless volcanoes world-wide. The volcanogenic carbon dioxide issue is particularly important with respect to (a) long lead time precursor recognition and (b) the global carbon inventory assessment in the context of *climate change*. But interesting parameters of volcanic activities like surface temperature, locations and area extend of activities, event temperatures, spectral signatures of volcanic plumes, temperature and smoke particle profiles of the plumes, and other can not be investigated from space in sufficient manner because of the lack of appropriate satellite systems.

Earthquakes

More than 50,000 earthquakes occur each year. Many of them are with severe consequences like loss of life and damage to human settlements. Forecast and prediction of Earthquakes are subjects of science and research. The investigation of the suitability of satellite data for earthquake prediction is part of the Earthquake research. Satellite data can measure fine changes in the earth's surface. These are often precursors of an earthquake. Such data is produced by the Synthetic Aperture Radar (SAR) instrument flown onboard the ERS satellites. Monitoring earthquake danger regions with ERS SAR can assist in the evaluation of earthquake-associated risks and forecasting of earthquakes. No small satellites are involved now. But satellite data helps to get an overview to the degree of damage and to find possible ways for supporting efforts. Basing on precise satellite data insurances can assess the damage precisely. Data from optical instruments in different spectral channels help in evaluation of the consequences of the Earthquake.

Landslides

Landslides are happen each year in most of the regions of the world. They are caused by several reasons: heavy rains, snow smelts, erosion by rivers and glaciers, wild fires, earthquakes, volcanic eruptions, anthropogenic impacts (like mass tourism). Satellite data can help to assess the situation and in planning and organising the reconstruction and future protection measures.. There are needs for high resolution data in the optical wavelength range and for SAR data because of the weather independency. The needed data can be given by big satellite missions with a certain delay time. A number of small satellites with optical instruments could give the needed information within a short response time. But up to now small satellites delivering precise data for land slide evaluation are not in orbit.

Oil slicks and environmental pollution

Each year smaller or larger oil disasters and pollution damages caused by ships or industries occur in many parts the world. The biggest problems are related with tanker accidents when oil are spilled into the sea, but also illegal oil and waste discharges by ships in the sea or natural oil seepage in off-shore regions cause environment damages. It is difficult to evaluate the damaged area especially in the sea. Satellite data can help to evaluate the area extent of the slick and sometimes to predict the disaster movement and development. The Synthetic Aperture Radar (SAR) instruments are preferred data sources for detection and evaluation of oil on water surfaces. Not only because of their independency on weather and light conditions but also because of the high detection quality basing on the damping effect of the oil on the backscattered signals. But these types of instruments are on small satellites up to now, they are on ENVISAT and ERS-2.

But different other types of environment pollution, like water pollution by waste water, forest damages caused by acid rain or by other reasons, atmosphere pollution by industry smoke and industry dust and other can be detected and investigated by means of spectrometers in the optical and infrared wavelength range. These instruments are flying usually on larger satellites and on small satellites for scientific research and technology demonstration. They are not used operational up to now.

Industrial and power plant disasters

Industrial and power plant disasters can damage or contaminate villages, urban areas and complete regions. Usually the area extent of the disaster and of the contamination can be evaluated by ground and airborne systems. But large scale damages can be better evaluated from space. Monitoring affected regions with space sensors can assist in the evaluation of associated risks and in managing of supporting actions. Satellite technologies also help to detect and evaluate industrial and power plant disasters in hidden regions where the disaster should be kept secret. High-resolution multi-spectral cameras and spectrometers on board of LEO satellites are suitable tools for these tasks. Nuclear power plant accidents and the area extent of contamination can be detected and evaluated by high resolution infrared sensor systems with a high system d*-detectivity. These systems are non-operational up to now but they already have demonstrated their performance capability from space on different small satellites.

7.1.2 Prospects

Cyclones, Storms and El Nino

Because the lack of dedicated small satellite systems for warning and support in these fields several new system solutions are under development. The prospective warning systems are basing on 2 fundamental approaches:

- Filling the data gaps by improvement of the time coverage and spatial resolution of satellite data
- Improve the prediction accuracy by fusion of different information using ground based, air based, sea based and space based data sources.

For filling the data gaps and gain more information by means of prospective small satellites the following parameters are of high importance:

- wave high,
- wave front direction,
- vertical temperature profile of the atmosphere,
- vertical wind dynamics of the atmosphere,
- sea surface temperature,
- eddy currents,
- other.

The progress in sensor and satellite technology allow to build small satellites with high performance sensors dedicated to investigate the mentioned parameters. Small satellites with dedicated sensor systems will supplement the existing satellite systems with new data and will improve the repeating time of data from existing systems.

One interesting new approach consists in the VOLNA-TC rocket-space system based on SSN-18 missile for sounding of tropical cyclones “, announced by Rosaviacosmos [1]. The basic idea consists in the reception and transmission of detailed data on dynamics of vertical processes and vertical profile of the atmosphere in the whole volume of a tropical cyclone (TC) to customers. After detection the tropical cyclone will be investigated in atmospheric profile and in detail by radiosondes on parachutes which are launched by submarine missiles into the cyclone.

Flood

Using Synthetic Aperture Radar instruments for data takes under cloudy and rainy weather conditions will be extended. New SAR technologies will allow to decrease the mass and power requirements of SAR instruments so that they can be implemented on small satellites. Another important prospect consists in the space implementation of several small passive SAR satellites flying in formation with an active SAR instrument on a large satellite. The formation will improve the performance of the SAR system dramatically. Small satellites with optical instruments in different spectral channels help authorities and insurances in the precise assessment of the damaged area and in planning and organising support and reconstruction by authorities. The difficulties in learning the use of satellite data for flood assessment, flood prediction and flood management will be solved stepwise.

Fires

Among the ten recommendations of the Committee on Earth Observation Satellites (CEOS) Report of the Fire Hazard Team - issued in 2000 - there is one directly related to active fire recognition: "Develop an operational satellite wild land fire detection and monitoring system with an ultimate fire detection time of 5 minutes, repeat time of 15 minutes, spatial resolution of 250 meters, maximum of 5% false alarms, with real time data transmission to local ground stations or information networks". Basing on the gained know-how in infrared sensor technology and in advanced technologies for small satellites and for a user oriented ground segment this challenging task will be solved in the near future. The following geophysical variables and data products are of main interest for prospective space borne recognition of coal seam fires and peat swamp fires: maps containing fire area, fire temperature, Fire Radiative Energy release, column content (density) and profile of CO₂, CO, including the CO/CO₂ ratio to characterise the combustion efficiency.

Volcanic activities

Basing on the experience with fire observation systems also a prospective solution for space observation of volcanic activities will be developed in the future. Because of lot of similar requirements to the fire investigation system a prospective volcanic activity monitoring system can be combined with a spaceborne fire investigation system. The following geophysical variables and data products are of main interest for space borne volcanic activity observation: surface temperature images of volcanoes with < 0.5 K accuracy, maps of summit crater radiance and near-vent surface temperatures, maps of the activity locations such as hot springs, lava effusions, and explosive eruptions containing the hot event areas, the hot event temperatures and maps of geothermal anomalies. Additionally will be investigated from space in the future: radiance maps and spectral signatures of volcanic plumes, temperature and smoke particle profiles of the plumes, volcanic gas species column content (especially SO₂ flux estimates), estimation of non-SO₂ gas species flux / content, (using the ratio with SO₂ flux /content).

Earthquakes

An important task for the future consists in Earthquake prediction with a certain warning time. New research results show that some fine changes in the Earth's surface and atmosphere are precursors of an Earthquake. The detection and evaluation of these Earth surface and atmospheric parameters and the extraction of precursor features by means of small satellite technologies will be tested and demonstrated in the near future. For assessment of the damaged area, for finding ways for supporting actions and for planning of reconstruction small satellite data in different channels of the optical and infrared wavelength range will be operational available.

Landslides

A future formation of small operational SAR satellites with a high repetition rate can give the precise information about the extent of landslides in a very fast response time at each weather. These data can be used for immediately support and action. In the future a number of small satellites with optical instruments will give further detailed information for precise assessment of damaged areas and planning of reconstruction.

Oil slicks and environmental pollution

Small satellites with SAR instruments, other small satellites with multi-spectral cameras, spectrometer and hyper-spectrometer will monitor with a high area and time coverage sea and ocean regions. They will look for oil spills and oil discharge as an operational service. Main areas of interests are the coastal zones all over the world but also off-shore regions, open sea and ocean areas. In the future it will be possible to implement spectrometers and hyper-spectrometer on small satellites for operational tasks.

Industrial and power plant disasters

The constellation of the already mentioned fire monitoring system can be used for the detection and monitoring of industrial and power plant disasters, too. Nuclear power plant accidents, for instance the thermal pollution of connected lakes or rivers or the area extent of contamination can be detected and evaluated in detail by the infrared sensor system dedicated for fire evaluation from space. This system will be

an operational system consisting of several small satellites. The space demonstration of the critical technologies are just done.

General Prospects of Earth observation missions for disaster warning and support

Looking into the segments of a space mission from the point of view “disaster warning and support” some general prospects can be recognized. An overview to these general prospects of cost effective Earth observation missions for disaster warning and support gives the dedicated United Nations/Romania Regional Workshop on the Use of Space Technology for Disaster Management for Europe, 19-23 May 2003 in Poiana-Brasov, Romania. The results can be structured into in the following 3 main topics:

1. Trends in the space segment (includes the payload and spacecraft bus) with regard to the disaster management
2. Trends in the ground segment including communication, ground stations, mission operations, data processing, archiving and distribution with regard to the disaster management
3. Trends in the programme segment of a space mission with emphasis of
 - New applications: tele-medicine, tele-education, disaster information centers, ...
 - New data products for disaster management by data fusion (SAR, optical, active, passive, spaceborne, airborne and ground-based data)

Trends in the space segment

The trends of technology development in the space segment relevant for disaster management are characterized by:

- Higher performance of micro-satellites busses due to new developments on the component and subsystem level like in board computers, data handling systems, transmitters, solar arrays, batteries, GPS-receiver and other,
- Higher performance of optical payloads for small satellites suitable for disaster monitoring tasks (high geometric and radiometric resolution, more spectral channels),
- Investigation of the feasibility of passive Radar (SAR) micro-satellites flying in formation with an active Radar satellite,
- Low-cost satellite technology makes operational satellites affordable for dedicated constellations,
- Novel international partnerships show new ways for new space nations to achieve effective systems through collaboration,
- Building of disaster monitoring constellations with small and micro-satellites,
- Increasing the repeating time for monitoring tasks by using of different satellites and constellations,
- Experimental on-board remote sensing data processing till a high level data product.

Summarizing it can be expressed, that the technology developments in the space segment offer new perspective to get data better in time and better fitting to different user requirements for disaster management also from small and micro-satellites.

Trends in the ground segment

The trends of technology development in the ground segment relevant for disaster management are characterized by:

- Increasing the flexibility of mission operations of satellites by a flexible ground segment,
- Building of networks of ground stations for increasing the satellite operational performance and data access without time delay,
- Fast response time in imaging according to user requirements,
- Data processing and distribution to the final user without delay,
- Data policy is in many cases to much restricting for fast disaster response,
- Distribution of data and algorithms for support of disaster management will be easily possible,
- Distributed permanent GNSS stations with radio links for fast data transmission are available to a certain extent and have to be extended,
- Very small ground stations for in-situ measurements with data transmission facilities via satellites are available and they are independent on existing infrastructure,

- Data processing and modeling of disaster conditions by experts are in progress, but there are gaps in the information extraction process for decision makers,
- The disaster information has to be simplified for the users,
- The education related to use space technologies has to improved.

It can be summarized, that the technology developments in the ground segment go to networking, fast response time and user oriented space segment control. The education in using spaceborne data has to be improved but also the information extraction process for decision makers has to tailored and optimized to their needs.

Trends in the programme segment

The trends in the programme segment of cost effective Earth observation missions for disaster warning and support are focused on new applications and new data products. Some key points are:

- Tele-health applications are important for disaster management and should be extended,
- Medical weather maps should be integrated in tele-health applications,
- Tele-education should be build up for disaster applications,
- The national disaster preparedness should be improved and should include the appropriate use of the space segment,
- New monitoring applications using space technologies (GPS) should be applied to rescue teams and people in high risk areas,
- For disaster management not only the use of the ground segment and of the space segment are helpful but also the use of sensor systems between like airborne systems,
- For data acquisition with airborne systems new platform developments in view like UAVs (Unmanned Air Vehicle) or transportable tethered balloons or dirigible airships (EU proposal),
- Integration and fusion of data from all different platforms and the development of models related to disaster conditions are progressing on an expert level,
- Multi-temporal analysis of regional changes and conditions basing on already existing satellite data is done by experts and can be improved,
- Basing on the expert knowledge the development of new and simplified tools to support decision makers should be improved.

It can be summarized that the tele-health and tele-education applications should be included in the disaster management programme. New platforms between space and ground like UAVs, balloons and airships will be used for data acquisition. Integration and fusion of data and temporal analysis on expert level are going on but the development of new simplified tool for decision makers should be encouraged.

7.2 Agriculture

7.2.1 Status quo

Agriculture is one of the most important activities of human mankind and one of the largest economical markets. Agricultural crops cover nearly 10% of the land surface of the Earth. An ever increasing world population, shrinking arable surface and growing environmental concerns put a large pressure on improving the methods for growing crops. On a world wide scale it will be more and more important to increase yields and to reduce the required input and prevent land erosion.

Remote sensing can play a very important role with respect to that target since it is the only means to efficiently determine in near real time the actual status of the crops in a spatial manner. This in combination with navigation on the ground allows to specifically react to the needs of the plants which are inhomogeneous even within individual fields. In addition the collection of information on the current status of the vegetation is important for a whole range of applications from subsidy control to commodity broking.

Since the launch of Landsat in 1973 and its preparations more than three decades of intensive research concerning the application of remote sensing in general and agricultural use in particular have passed.

Hundreds of research projects were conducted by private companies and governmental organizations like the JRC (EU), USDA, NASA, ESA and other national agencies and research bodies.

Today the technology is well established and many applications have taken the step from research to operational products. The following list shows some major examples of remote sensing applications which have proven their potential by today:

- Measurement of crop status (leaf area index, chlorophyll content, leaf brown pigment and nitrogen status, protein content)
- Measurement of crop vigor
- Detection of crop hydric stress
- Determination of soil colors
- Measurement of soil moisture
- Detection of soil erosion
- Crop yield prediction
- Crop identification
- Weed detection
- Crop residue detection
- Field boundaries detection and field size measurement
- Damage assessment (hail, multiple peril).

Often remote sensing data do only perform part of the job since typically end user products are a result of a combination of remote sensing data, ground truthing and intelligent agronomic modeling.

Today the major users of satellite based remote sensing for agricultural applications are governments throughout the world. Typical examples are the EU with the MARS program and within the US the USDA in its organizations like the Farm Service Agency (FSA), the Foreign Ag Service (FAS), the National Ag Statistics (NAS), and the Risk Management Agency (RMA).

Potential commercial customer groups for agricultural remote sensing applications are:

- Farmers and farming companies
- Consultants
- Cooperatives
- Food companies
- Machinery suppliers
- Agrochem and seed suppliers
- Insurance
- Cooperatives
- Commodity traders.

Although many applications would be available for those commercial customers today, the actual use of this technology within these customer groups is almost negligible. Most studies explain this with certain deficiencies of the current remote sensing satellite systems and the organization of the industry. Most often the following deficits are quoted:

- Unreliable availability of current and accurate data
- Products that are not designed for specific needs of the customers
- High cost
- Inefficient and therefore time consuming value adding chain
- With respect to high in-orbit investments insufficient funds for market development activities.

From many sides market studies have been performed to identify the current remote sensing market and most of them have concluded that the agricultural market segment will be the one developing the most dynamically. The ERSIS study for example which was funded by ESA and performed in 2000 by a large industrial consortium predicted for 2004 an accessible market for satellite based remote sensing image data of 100 Million Euro which would grow to almost 700 Million Euro until 2015. The market for the derived information services will a multiple of these values..

The major technical characteristics of most remote sensing instruments are:

- The selection of the spectral channels (and therefore which part of the electromagnetic spectrum is detected in how many separated bands). Typical mission profiles are:
 - Multi-spectral (3 to 15 channels) in the visible and near infrared regime (VNIR)
 - Hyper-spectral (up to hundreds of channels in VNIR)
 - Short wave and thermal infrared missions (SWIR and TIR)
 - Radar (typically X- and L-band)
- Source of the illumination energy (optical versus radar)
- The achievable ground resolution
- The capacity (swath, memory, data transport etc.)
- The radiometric sensitivity
- The geometric accuracy.

Most of the currently existing applications of remote sensing for agriculture do rely on multi spectral instruments mainly in the VNIR. The use of the different spectral bands is shown in the following table:

Table 7.2-1: Use of the different spectral bands

Spectral Band	Usability
Blue	<ul style="list-style-type: none"> • Separate bare soil from vegetation • Differentiate between broad-leaf tree and conifers • Measurement of plankton in coastal waters
Green	<ul style="list-style-type: none"> • Measures vitality of plants • Green peak at 550 nm
Red	<ul style="list-style-type: none"> • Chlorophyll absorption varies between plant species, hence one uses red to separate different plants • Detection of iron-rich stones
Red Edge	<ul style="list-style-type: none"> • Measurement of plant development, biomass and maturity. Because plant development is closely link to water content of the plant (wet biomass), the red-edge band can partly offset the need for a thermal infrared for plant remote sensing.
Near infrared	<ul style="list-style-type: none"> • Measurement of biomass • Detection of coast lines
Short wave infrared	<ul style="list-style-type: none"> • Differentiate between clouds and snow • Geological mapping • Water content of soil and plants
Thermal infrared	<ul style="list-style-type: none"> • Measures temperature emitted from the earth, i.e. mapping of heat distribution and circulation of fresh air in cities • Stress and water content of plants

Research shows that multi-polar, multi-frequency radar has also some potential for agricultural use but the development of applications is still in the scientific stage and for many applications it will probably rather play a complementary role to optical data.

Most of the agricultural applications with major commercial potential (like e.g. Precision Farming) do require ground resolutions between 5 and 10 meters. Some studies show that 20 – 30 m might still be acceptable for many of the applications. For global assessments of the vegetation status even resolutions with hundreds of meters do provide useful data.

For many agricultural applications the capacity of the system must be large enough to allow regular coverage of the vegetation areas.

The radiometric sensitivity of optical instruments must be sufficient to measure small changes in the reflectance of the crops for each spectral band.

In order to use the information for more efficient production methods the geo location of the imagery is important. Only if the navigation on ground does sufficiently coincide with the measured parameters from space the data are useful. Since often multi temporal imagery is required it is also necessary to be able to accurately overlay different images from different times with ideally sub-pixel accuracy.

7.2.2 Prospects

Today, the most commonly used satellite systems for agriculture are the American Landsat, the French Spot, and the Indian IRS systems. In the last two to three years also the American high resolution systems IKONOS and Quickbird have been used for certain agricultural applications. From a satellite technology point of view these systems have mainly two deficiencies which hinder a major commercial use for agriculture. These are the limited revisit capabilities over the target area and the limited capacity which together do prevent from reliably and repetitively monitoring large areas because only a few cloud free days per month are available.

Data availability, the time and cost efficient data handling and delivery, and the establishment of customer specific dedicated products are keys for a breakthrough of agricultural remote sensing applications. Therefore some new concepts have emerged during the last decade. The two best known examples for system and service concepts which are dedicated to the agricultural market are

- Resource 21 (USA).
- RapidEye (D).

In principle both concepts foresee a combination of short term revisit with very large imaging capacity which is realized through a constellation of several satellites. Both concepts will provide with a high probability the regular monitoring of the world's agricultural areas with sufficient data quality. In addition both companies follow a different business concept than the existing players by integrating large part of the value adding chain to offer customer dedicated services with short delivery times and at low cost.

Also radar is often mentioned as a candidate to overcome the problem of the data availability since radar satellites can penetrate clouds. In order to receive information which are comparable to the optical information multi-polar, multi frequency radar systems and advanced data processing are required. High complexity and cost put this alternative more in the medium and long term perspective. In addition, radar data too are sensitive to environmental conditions like soil wetness and atmospheric humidity which does create additional problems for the commercial usability of the data.

Another way to improve the situation is sometimes seen by improving the interoperability of different existing system to increase the chances to get sufficient data. Nevertheless this poses many open issues like data compatibility and organizational problems.

The potential market for agricultural remote sensing applications is very attractive. Therefore in conclusion it can be expected that industry and agencies will continue to work to overcome the current limitations. Since the market is large enough several solutions will eventually find their place and will prove that remote sensing can play some important role to overcome two of the most urgent problems of mankind: Human starvation and the destruction of the natural environment.

7.3 Forestry

7.3.1 Status quo

Optical satellite remote sensing is today used operationally by many national authorities and international organizations for obtaining overviews and improved statistics about the state and rate of change of forest resources. These studies are not only interesting for the environmentalists but also for the Global Change community. Mostly are medium resolution sensors with spatial resolution in the order of 30 m, down to 5 m, used. With this resolution, we get a "many trees per pixel" viewing situation, which means that most pixels are composed of sunlit and shadowed canopy and sunlit and shadowed ground among a group of trees. This gives a mean spectral signal, which is quite easily analyzed in combination with field plot data and/or using a chronosequence of scenes. The medium resolution data also provides a "many pixels per stand" viewing situation, which allows rough delineation of stand shape. Among the most important medium-resolution sensors are Landsat ETM+, SPOT HRG and IRS LISS III. Some examples of operational uses are listed below.

Due to variations in solar illumination, atmospheric scattering and absorption, etc., each satellite image has a unique scaling between image digital values and reflectance. In forestry remote sensing, this difficulty is usually overcome by combining the imagery with a set of field plots with known location. The Finnish National Forest Inventory has since 1991 on a national scale combined Landsat TM data with national forest inventory field sample plots (Tomppo, 2000). Similar methods are also being introduced in Sweden, USA and other countries (e.g., McRoberts et al. 2002a). By use of empirical relationships, which in the cited Finnish and U.S. cases is inverse distance weighting in spectral space, each forest pixel is assigned a vector of forest variables, weighted from a pre-defined number of spectrally close plots. This method provides a raster data base of forest variables used for an overview of forest resources. When the raster data for a certain area is averaged, statistics for smaller areas than when the field sample plots are used alone can be computed. Such raster maps have also proven valuable for ecological modeling and forest biodiversity assessment (Puimalainen et al., 2002, McComb et al, 2002).

An alternative way to use satellite data for improving the estimates of the National Forest Inventories is to use the images for stratification. In the post stratification approach the satellite data are used for providing additional information of how representative a sparse sample of objective field plots is. The satellite images are segmented and labeled into a number of discrete classes using spectral data. Plots located within these polygons can then be assigned to each stratum and stratified estimates of population totals with improved accuracy can be calculated. Post stratification has been tested and will be operationally implemented in the Swedish National Forest Inventory (Nilsson et al., 2001). In the United States Forest Inventory and Analysis program, pre stratification for forest area estimation, traditionally performed using aerial photographs, is now done using Landsat TM-derived strata in some regions (e.g., Wayman et al. 2001, McRoberts et al. 2002b).

The Forest Survey of India started in 1987 to carry out the forest cover assessment of India using visual interpretation of Landsat MSS data at 1:1000 000 scale. Since 1989, the forest cover has been assessed on a biennial cycle, principally using visual interpretation of satellite data, initially from Landsat TM, and since 1995 from IRS 1B LISS II, for all of India, at 1:250 000 scale and a minimum mapping unit of 25 ha. In 2001, the latest official forest statistics of India were developed with the aid of digital analysis of a nationwide set of IRS LISS III scenes (Forest Survey of India, 2001). Currently, the Forest Survey of India is also using LISS and PAN data to identify patches of trees outside forest areas for inventory.

The Swedish Forest Administration is yearly delineating all, approximately 50 000, clearfelled areas in Sweden, using yearly and country wide Landsat ETM+ or SPOT HRG datasets. The analysis is done at the local district offices, using digital change detection techniques. In a similar manner, the Department of Forestry in the Commonwealth of Virginia, USA, now annually monitors changes in riparian forest buffers for which a landowner has been given a tax credit via annual analysis of Landsat ETM+ data.

In addition to the above examples on national level, satellite remote sensing is also widely used for global forest inventories, for example those coordinated by FAO (e.g., Zhu and Waller, 2003). Another example is that the non-governmental organization Global Forest Watch (www.Globalforestwatch.org) has under the leadership of World Resources Institute, Washington, made an interpretation of undisturbed forest areas in the whole boreal forest zone. The map, which was presented at the Johannesburg Summit 2002, was based on interpretation on 3199 medium resolution images (Landsat TM and ETM+, Terra Aster, and Resurs-01 MSU-E), as well as 771 MSU-SK images with a spatial resolution of approximately 200 m. In this same perspective, other example is the TREES project funded by the European Commission and developed by the Directorate General Joint Research Centre in collaboration with local partners who interpreted the imagery over simple sites. This project estimated the changes in humid tropical forest cover from satellite sensing imagery, with better global consistency and greater accuracy than previously available, in order to understand their implications for the global carbon budget (Achard et al, 2002).

In conclusion, medium resolution optical satellite data has proven operationally useful for forest authorities, ecological and global change researchers and NGOs. However, both the commercial market and the willingness among single governments to pay for operational satellite systems is weak. Thus, there is currently a deficit of firm future plans for operational monitoring using medium resolution data, which is prohibitive for new authorities that are evaluating the technology. Cloud cover which makes it difficult to obtain yearly imagery within a specified season of the year is also problematic in some areas.

7.3.2 Prospects

We do not have to wait for technical innovations in order to get remote sensing that is useful for forestry. The current bottleneck is instead the political willingness to establish an operational monitoring service. The number one priority from the forestry point of view should be to establish a basic medium resolution remote sensing service which should:

- have pixel sizes in the order of 20 m;
- have only a few spectral bands, preferably blue (optional but useful for atmospheric correction), green, red, NIR, and also the shortwave infrared, which makes the sensor more expensive but is essential for forest volume (e.g., Gemmell, 1995) and biomass (e.g., Horler and Ahern, 1986) retrieval;
- have large scenes, preferably in the order of 200 * 200 km or more, both for increasing the chance of obtaining cloud free data, and including as many field sample plots as possible within one image;
- have a good signal to noise ratio and stable mechanics, which probably means a push-broom CCD array design;
- be reliable and operational, meaning at least two satellites in space and a spare ready for launch at any time (preferably accomplished by international cooperation);
- be as free as possible from additional features that make the satellite more expensive, such as many spectral bands; pointable optics etc.;
- have an efficient data dissemination system (for example, cloud free data retrievable in geo-corrected form over the Internet);
- provide long term archiving of cloud free scenes.

The use of along track forward and after looking sensors might be a defensible add-on for forestry sensors. One reason is that the BRDF will vary slightly with forest type and leaf area (e.g., Wu et al. 1995). Another reason is that the possibilities for atmospheric correction using image data only will improve. The within-scene atmospheric differences are particularly important to remove when field plots from the full scene are used.

With the above indicated fleet of medium resolution monitoring satellites, operated in international cooperation, the use of satellite remote sensing in forestry will mature in a fashion similar to what has been the case in meteorology. The use of statistical designs for national inventories, where field sampling and image data are used in a truly integrated way, will develop. In addition, techniques for analyzing the development of forests using a long sequence of images will mature, and we will create invaluable databases of images for future generations.

In addition, high resolution commercial imagery will be beneficial to forestry in case they are sold at an affordable price. When the spatial resolution increases to 2 m or better, we have a “many pixels per tree” situation. Such imagery will, if analyzed in a correct way, improve the estimates of forestry parameters marginally. However, these types of sensors could not be recommended for forestry at the cost of not having large scenes and frequent revisits, as described above.

Acknowledgements

Mats Rosengren, at Metria Miljöanalys, Stockholm, is acknowledged for providing technical comments on sensor design priorities.

References

Achard, F., H.D. Eva, H.J. Stibig, Ph. Mayaux, J. Gallego, T. Richards and J.P. Malingreau. “Determination of Deforestation Rates of the World’s Humid Tropical Forest”. *Science*. Vol. 297, No. 5583, pp. 885-1080. 9 August 2002.

Forest Survey of India, 2002. State of Forest Report 2002. Ministry of Environment and Forests, Dehra Dun, India.

Gemmell, F.M., 2002. Effects of forest cover, terrain, and scale on timber volume estimation with Thematic Mapper data in a Rocky-Mountain site. *Remote Sensing of Environment* **51**(2):291-305.

Horler, D.N.H. and F.J. Ahern, 1986. Forestry Information Content in Thematic Mapper Data. *International Journal of Remote Sensing* **7**:405-428.

McComb, W. C., McGrath, M. T. Spies, T.A. Vesely, D. 2002. Models for mapping potential habitats at landscape scales: An example using northern spotted owls. *Forest Science* **48**(2):203-216.

McRoberts R.E., M.D. Nelson, and D.G. Wendt, 2002a. Stratified estimation of forest area using satellite imagery, inventory data, and the k-Nearest Neighbors technique. *Remote Sensing of Environment* **82**(2-3):457-468.

McRoberts R.E., M.D. Nelson, D.G. Wendt, and M.H. Hansen, 2002b. Using a land cover classification based on satellite imagery to improve the precision of forest inventory area estimates. *Remote Sensing of Environment* **81**(1):36-44.

Nilsson, M., Folving, S. Kennedy, P., Chirici, G., Corona, P., Marchetti, M., Olsson, H., Ricotta, C., Ringvall, A., Ståhl, G., and Tomppo, E. Combining remote sensing and field data for deriving unbiased estimates of forest parameters over large regions. In proceedings from IUFRO conference, Palermo, 2001.

Pummalainen, J., Angelstam, P., Banko, G., Brandt, J. Caldeira, M., Estreguil, C., Folving, S., Garcia del Barrio, J.M., Keller, M., Kennedy, P., Köhl, P., Marchetti, M., Neille, P., Olsson, H., Parviainen, J., Pretzsch, H., Ravn, H.P., Ståhl, G., Tomppo, E., Uuttera, J., Watt, A., Winkler, B., and Wrba, T. Forest Biodiversity, assessment approaches for Europe. European Commission, Joint Research Centre, Institute for Environment and Sustainability, EUR Report 20423 EN, 2002.

Tomppo, E. Remote sensing requirements to support forest inventories. In: Verstraete, M., Menetti, M. and Peltoniemi, J (ed) *Observing Land from Space: Science Customers and Technology*. Advances in Global Change Research **4**, 151-160, 2000.

Wayman, J.P., R.H. Wynne, J.A. Scrivani, and G.A. Reams, 2001. Landsat TM-based forest area estimation using Iterative Guided Spectral Class Rejection. *Photogrammetric Engineering & Remote Sensing* **67**(10):1155-1166.

Wu, A.H., Z.Q. Li, and J. Cihlar, 1995. Effects of land-cover type and greenness on Advanced Very High-Resolution Radiometer bidirectional reflectances: Analysis and removal. *Journal of Geophysical Research-Atmospheres* **100** (D5):9179-9192.

Zhu, Z.L., and E. Waller, 2003. Global forest cover mapping for the United Nations Food and Agriculture Organization Forest Resources Assessment 2000 program. *Forest Science* **49**(3):369-380.

7.4 Ocean and Coastal Zone

7.4.1 Status quo

The global ocean and the coastal zones are the largest ecosystem of the Earth, two thirds of the Earth's surface are covered with water. Through their role in matter cycles (most important water and CO₂) and their thermal capacity the oceans are essential components of the "global ecosystem Earth" heavily determining long-term and global processes (climate) as well as regional to local phenomena (weather). The Abundance of biomass in the oceans is estimated to equal that of the vegetation on land. The largest portion is due to the Phytoplankton, forming the begin of the marine food chain and through photosynthesis being a major factor for the global CO₂-balance.

On the other hand oceans and coastal zones are the ecosystem of most socio-economic importance for the mankind: estimated 70 % of the world's population is living in coastal zones, the largest part of human activity (industry, agriculture, fishery, transport, recreation) is taking place in these areas. Hence, it is not only important to understand the role of the ocean for the climate but, even more important, the impact of human activities on the coastal and open ocean systems needs to be understood, monitored and managed to assure sustainability of this essential living resource for mankind.

As a third, due to the fact that major human activities concentrate in coastal and shelf regions there are also several threats coming from the ocean: floods and storms are destroying coastal constructions and settlements, coastal erosion leads to significant land loss in many regions, harmful or toxic algal blooms cause significant damage to aquacultures or fishery, ships are damaged or sunk by storms or waves etc.

This overview illustrates that oceans and coastal zones need a very complex approach to describe the interdependency of anthropogenous and natural, biological and physical processes on timescales ranging from hours to centuries and spatial scales ranging from local to global.

To understand the state and dynamical process in the oceans and coastal zones as well as possible changes induced directly by human activity or possibly indirectly through climate changes a complexity of physical, bio-geophysical and bio-geochemical parameters and processes needs to be observed by remote sensing:

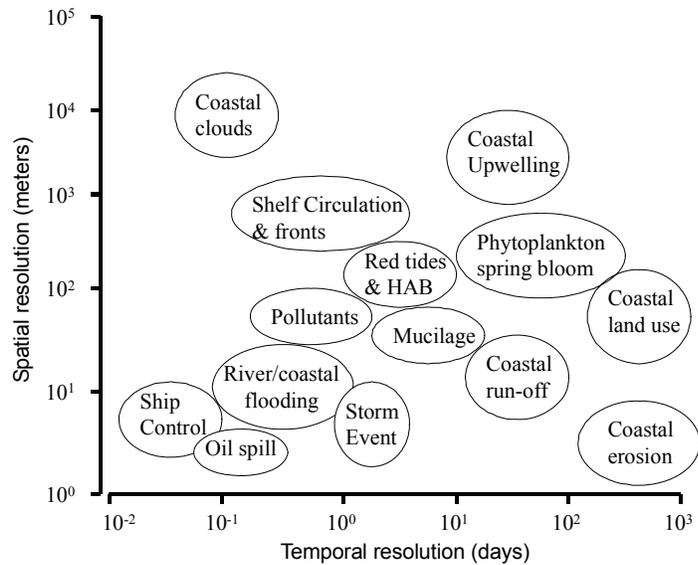
- wind fields
- wave fields and currents
- surface temperature (SST)
- sea level
- water constituents (mainly phytoplankton, inorganic suspended matter, dissolved organic material)
- primary production and CO₂-fixation by phytoplankton
- ecological indicators for water quality (e.g. clarity, eutrophication)
- pollution
- ice cover and ice state (see chapter 7.7)
- coastal morphology and erosion
- land use in coastal zones.

This wide variety of parameters leads to corresponding variety of remote sensing technologies used to realise these observations:

- microwave altimetry
- microwave scatterometry
- synthetic aperture radar (SAR)
- passive microwave sounding
- thermal infrared imaging
- hyperspectral optical imaging (ocean colour)
- spatial high resolution multispectral imaging (land use, coastal morphology).

Thus, it is clear that ocean and coastal zone observations always have to rely on a constellation of different satellites providing different technologies, resolutions and observational scenarios.

The technologies have well developed during last 25 years, most have reached a level of maturity to be used operational. Scatterometers, and microwave radiometers and thermal imagers are operated on several meteorological or other remote sensing satellites (e.g. NOAA-series, European remote sensing satellites ERS-1/-2 or ENVISAT). Synthetic aperture radar technology has mainly been pushed by the European ERS and Canadian RadarSat. Due to the size and high energy consumption SAR-satellites are comparably large, i.e. have masses larger than 1 ton. During the past ten years numerous ocean colour satellites have been launched, e.g. SeaWiFS by the USA, IRS-P3 and IRS-P4 by India, ROCSAT of Taiwan and other missions by China and Korea. All these satellites are small satellites (mass \leq 500 kg) dedicated more or less exclusively to ocean colour observations. Exclusions are ESA's ENVISAT and NASA's Terra and Aqua satellites which are large multi-instrumented platforms to allow synergetic use of several observation technologies. For spatial high resolution imaging typical "land"-satellites are used (e.g. Landsat, SPOT, IRS-P6, Ikonos and others). So one can conclude that currently existing satellites are already providing most of the necessary observations as far as the global oceans and regional scale coastal phenomena are concerned. The data are provided by the space agencies to the users either free of charge or at low cost.



Spatial and Temporal Requirements for Coastal Studies
(after Hoepffner)

Figure 7.4-1: Spatial and temporal requirements for coastal studies (after Hoepffner)

7.4.2 Prospects

The positive summary given above, however, is somewhat misleading. There are several open issues with respect to ocean and coastal zone observations.

Most critical are the continuity and consistency of observations on a long term. For none of the currently operated missions a continuation after the lifetime of the satellites is guaranteed or even planned. Taking into account the necessary timeframe from political decision until the launch of a new satellite (typically longer than 6 years), there might well be a disruption of some observations in a few years. Also, with instruments having different technical parameters on different satellites, the derived parameters are not always consistent with each other. This is, in particular, true for ocean colour observations. The international Ocean Colour Coordinating Group IOCCG of SCOR and CEOS has addressed this problem and issued recommendations to the space agencies. The change of instrument characteristics for new satellites (which may be well justified by additional applications and new technology available) may result in inconsistencies in long-term observations. Because most important ocean-related processes have a strong long-term component the consistency issue is critical.

Another problem to be addressed by future developments is the monitoring of processes and environmental state on smaller scales, going down to local scale basins and estuaries, aiming to provide detailed information for environmental management. This task demands for new technologies in orbit, such as spatial high resolution super-/hyperspectral imaging and high resolution multi-mode SAR systems. Currently several systems for such requirements are under development (e.g. TerraSAR-X) or under study (e.g. ESA's SPECTRA).

As far as optical observations are concerned, Table 7.4 1 gives an overview on the spatial and temporal requirements for satellite sensors. The corresponding spectral requirements are summarised in Table 7.4 2.

Table 7.4-1: Spatial resolution, field of view, and sampling frequency requirements for sensors for coastal waters and regional applications/monitoring

Applications / Issues	Spatial Resolution x Extent	Temporal Resolution
River plumes, outfalls	(30 m – 1 km) x (300 m – 100 km)	hours - weeks
Tidal plumes, jets, frontal dynamics	(100 m – 1 km) x (1 km – 10 km)	hours
Harmful algal blooms, aquaculture, coastal water quality	(100 m – 1 km) x (1 km – 100 km)	days - weeks
Bathymetry and shallow benthic habitat: distribution, status	(1 m – 30 m) x (1 km – 100 km)	weeks to months
Maritime operations: navigation, visibility.	(30 m – 1 km) x (30 km – 100 km)	Hours to days
Oil spills.	(100 m – 1 km) x (1 km – 100 km)	Hours - days
Operational fisheries oceanography	1 km x 1000 km	days
Integrated regional management	(30 m – 300 m) x (30 km – 300 km)	days

Table 7.4-2: Spectral requirements for coastal waters optical observation and monitoring

Subject	Spectral requirements
- retrieval of water constituents - discrimination of species composition - harmful algal blooms (HABs)	- spectral high resolution ($\Delta\lambda \sim 5$ nm, 400-800 nm) - VIS/NIR superspectral imager (15..20 channels) or hyperspectral imager
- account for atmospheric influence over case-2 waters, atmospheric correction algorithms	- extended spectral range (800 – 1000 nm, SWIR), water vapour channels
- coastal land use (vegetation, catchment areas, snow/ice cover)	- spectral range VIS/NIR + SWIR - VIS/NIR/SWIR superspectral imager (15..20 channels) or hyperspectral imager
- primary production in coastal waters - coastal currents, water masses discrimination	- thermal infrared
- up-down-scaling of physical variables, data merging	- compatibility of selected spectral channels with other missions

Because oceans and in particular coastal waters are high dynamic (similar as the weather) a short repetition rate of observations is demanded. Current systems, in the best case, depending on geographical latitude, allow measurements twice a day (e.g. Terra/Aqua satellite constellation). To improve this situation for future systems also the geostationary orbit is in discussion for dedicated ocean instruments (but not suitable for SAR). Another approach could be the proper adjustment of orbits and observations for several “national” satellites forming together an optimal constellation or observation system.

References

Robinson I.S.: Satellite Oceanography, John Wiley & Sons, 1997, ISBN 0-471-95424-1

Barale V., Schlittenhardt P.: Ocean colour: Theory and Applications in an Decade of CZCS Experience, Kluwer Academic Publishers, 1993, ISBN 0-7923-1586-3

Yoder J.A. (Ed): Status and Plans for Satellite Ocean Colour Missions: Considerations for Complementary Missions, published by IOCC

7.5 Atmosphere

7.5.1 Observations of the Earth's Atmosphere and Ionosphere Status quo

Observations of the Earth's atmosphere must cover a range of number densities from the surface at around 3×10^{19} molecules per cm^3 to about 10^2 ions per cm^3 at the top of the atmosphere (about 600 km). Remote sensing is the most effective means of making these observations. As one can readily imagine this vast range in density dictates different approaches for different parts of the atmosphere. Number density is, however, only one of the parameters that must be measured: temperature and wind fields are also important quantities to sense from the surface to the exobase (the level in the atmosphere where the distance between collisions is equal to the vertical distance for a decrease in the atmospheric density by a factor of $1/e$ – this last quantity being known as the atmospheric “scale height”). Aerosols and trace constituents are important as tracers of atmospheric motion, signatures of human-induced and natural change, and they alter the radiative properties of the atmosphere. All of these quantities vary as a function of location, time of day, season, and geophysical conditions (this is particularly true of the upper atmosphere (above about 80 km) and the ionosphere).

The enormous potential for atmospheric observations from space was demonstrated as long ago as 1947 when captured German V2 rockets were used to obtain cloud images from space by US experimenters. Many of the early satellite experiments that gave us our first insight into atmospheric conditions were characterized by the same qualities that mark cost-effective small satellite missions today. For instance Sputnik-1, launched on October 4, 1957 massed about 83 kg and returned the first information on the density of the Earth's upper atmosphere by measuring the effects of the atmospheric drag on the satellite's orbit. The first US mission, Explorer 1 launched January 31 1958, measured the temperature of the upper atmosphere and massed about 5 kg. Since that time the observations of the Earth's atmosphere have, generally speaking, followed two paths: low Earth orbit and geostationary (GEO) orbit. This is driven by the requirement to minimize cost while maximizing return for observations of a system that has been driven to a very great extent by basic research interests. GEO platforms have been used, until relatively recently primarily as a means of providing a global-scale view of atmospheric dynamics and cloud-top temperatures. There the driver was repetitive coverage of an area to support operational use of the data. The relatively large altitude meant that, until spacecraft pointing and stabilization systems could become very sophisticated, observations of the Earth's atmosphere in a limb viewing geometry could not be effectively achieved. Atmospheric profile information is achieved from HEO by using observations from different emission bands or using atmospheric absorption features to sound the atmosphere over a limited altitude range. The need for height information from a global perspective drove the design of multispectral instruments, an improvement over the panchromatic images of the first TIROS satellites but with an associated data downlink and ground processing penalty. More data means greater costs. This desire from height information also drove an expansion into new technologies – in particular the use of microwave technology both active and passive – to determine the state parameters of the atmosphere.

The Earth's atmosphere and ionosphere can be remotely sensed or sampled via in situ techniques. Atmospheric drag limits the use of space-borne in situ sampling to altitudes above about 130 km. This frontier is to be explored, however, in an upcoming NASA mission – Geospace Electrodynamics Connections – which will conduct dipping campaigns to explore the Earth's ionosphere. The mission consists of four identical satellites, carrying propulsion and flying in formation, that repeatedly dip to as low as 130 km. This is something of an exception, however, and in situ measurements are most commonly achieved either by circular orbits above 600 km or through use of elliptical orbits that allow one to reach below 200 km.

Remote sensing satellites generally prefer to have a circular orbit as then all parts of the Earth are available for measurement with the same viewing geometry. The exception is found in aeronautical studies of the auroral region where highly elliptical orbits are frequently used. These orbits may have an apogee height of 7 Earth radii (R_E). The line of apsides is arranged in such a way that the polar regions are viewed from apogee. This highly elliptical orbit permits continuous imaging of auroral phenomena for much of the day. Once again, as from geosynchronous orbit, the emphasis is on column integrated measurements.

Remote sensing of the Earth's atmosphere from space has two general approaches: active and passive. The active techniques encompass lidars and sounders (radio and microwave). The passive techniques span almost the entire spectrum from x-rays to microwaves. Small passive remote sensing missions to study the Earth's

lower atmosphere have been relatively rare during the last twenty years. This may be due, in part, to the desire to have simultaneous coverage of a relatively large number of parameters for scientific analysis – leading to very large platforms – or the desire for global coverage at high temporal and spatial resolution – leading to large instruments at geosynchronous altitude. The NASA Earth System Science Program (ESSP) was intended to break new ground in this area. These satellites are, generally speaking, unique in their design and measurement requirements but they do offer lessons for cost effective small satellite missions. At the other end of the design spectrum, new information is becoming available from the observation of GPS satellites in occultation. The occultation technique allows for a significant scientific and operational return on a rather modest investment.

Consider the ESSP Cloudsat mission design. Cloudsat is designed to measure the influence of clouds on the Earth's radiation budget. The Earth's radiation budget is controlled by a number of factors that preclude a small satellite approach – there are just too many free parameters that must be constrained in order to make scientific progress. The Cloudsat mission is focused on relatively narrowly defined measurement objectives and consequently achieves a relatively low cost especially as it augments a much more complex mission by flying in formation with it – thus illustrating that simultaneity of measurements does not require that the payload be manifested on one large bus. This also serves to illustrate another key problem with these measurements: in order to completely specify the parameter space one must have continuous measurements. In the event of the failure of a single instrument it is much more cost effective to be able to launch a single, failed instrument on a small satellite than to choose between foregoing the measurement or sending the entire complement into orbit again.

GPS occultation provides information on water vapor profiles in the lower atmosphere and ionospheric electron number density in the upper atmosphere. Occultation experiments, in which the change in the level of a signal source is measured as it passes through the atmosphere yield height resolved profiles of a constituent's density. In the optical spectrum, ozone is one of the more commonly measured parameters and the signal source is the sun.

SAC-C, a joint Argentina, US, Brazil, Italy and France mission with CONAE and NASA as the major partners, was one of the first spacecraft to use GPS occultations for atmospheric characterization. TiungSat-1 was a microsatellite built by SSTL for Malaysia and implemented, among other instruments, the Experimental Microsatellite GPS, an SSTL/ESA collaboration. GRACE, an ESSP mission, uses advanced GPS receivers to provide sounding information as well. This new sensor approach means that a cost effective solution for this particular type of measurement is to incorporate such dual frequency GPS receivers on a satellite and provide for the downlink of the data. Since GPS is now used to provide spacecraft position and velocity information, incorporating these receivers, if done during the initial design of the mission, proves to be cost effective.

Multipoint measurements require the use of more than one satellite. ACE makes extensive use of microsat technology and consists of 6 satellites. These satellites take advantage of the use of a satellite bus that had been designed for another mission (SMART) and replicate as many subsystems as possible. This mission serves to illustrate another trend in small satellite design for Earth remote sensing missions: the use of more than one platforms to decrease the revisit time or to remove the spatial-temporal ambiguity that is inherent in sampling a system that has structures that change as a function of time and space (the atmosphere has tides and waves that control temperature, density and velocity). In this case the principal component of the satellites is the GRAS GPS receiver which is used to monitor temperature, pressure, and humidity.

“Space weather” is a recently coined term that refers to changes in the near-Earth environment. These changes can lead to increased drag on satellites in Earth orbit due to a heating of the upper atmosphere during geomagnetic storms, ground-induced currents which can lead to the loss of high voltage power transmission lines, and increases in the near-Earth radiation environment that are of concern to astronauts or high altitude aircraft on polar flight paths, or the increase in high energy particles that can damage spacecraft subsystems, to name the major areas of concern.

The NASA TIMED mission (www.timed.jhuapl.edu) is indicative of a new approach to Earth missions at NASA. In order to lower the mission costs and implement it on a faster schedule TIMED, which is relevant to the space weather initiative, was outsourced. The mission is managed and operated by The Johns Hopkins

University Applied Physics Laboratory (JHU/APL). The TIMED spacecraft and ground system are at JHU/APL which also handles all mission operations. To reduce costs, the spacecraft was designed to support autonomous or “lights out” operations. Instrument commands are forwarded directly from the instrument teams. Once the data are received on the ground they are distributed to the individual teams for processing and these teams support the archive and distribution of their own data. This mission focuses on the upper atmosphere: 60 to 180 km in altitude.

7.5.2 Prospects

New technologies for atmospheric and ionospheric remote sensing still need to be developed and improved. These new techniques require flight demonstration before relatively large investments will be made in an operational system. The US Space Shuttle program had been very useful for enabling the flight demonstration of new technologies (e.g. passive microwave sounding on the Microwave Atmospheric Sounder payload on the CRISTA SPAS mission and the first spaceflight demonstration of a lidar on the LITE mission). Since launch costs associated with the Shuttle were not charged to the individual project access to space was inexpensive and the instruments could be returned to Earth for rework, further testing or additional development. The loss of the Shuttle Columbia is sure to impact the pace of development of new Earth remote sensing instruments for the US investigators as the International Space Station is slated to occupy the payload capacity of the remaining orbiters. The question for the US program for remote sensing of the lower atmosphere is: where will the new measurement techniques be flight proven? Small satellite missions will prove to be the only cost-effective means of meeting this requirement in the next decade. This may well be achieved through “piggyback” launches of secondary payloads on the next generation of expendable launch vehicles.

Human-induced global climate change studies are international in scope and provide the impetus for much of the curiosity driven research into the physics and chemistry of the lower atmosphere. At the top of the atmosphere there are new programs to study “space weather”. One of the most prominent programs is the International Living with a Star (ILWS) Program which includes NASA’s Living with a Star (LWS) satellites and associated research efforts. This program plans to use “flights of opportunity” as well as new small satellites to meet the LWS requirements of determining the underlying mechanisms that drive changes in the upper atmosphere and the near-Earth environment and result in societal impacts.

Since geospace encompasses the volume out to about 8 Re, one of the major difficulties is providing adequate sampling of this region. In situ measurements are still required to address many issues and this proves to be the driver for mission concepts that include several to even dozens of satellites. The challenges inherent in managing such constellations have yet to be fully addressed but will provide valuable lessons for other Earth missions.

One of the first constellations is the ROCSat 3 mission which is planned to consist of six small satellites. The Republic of China National Space Program Office (NSPO) and the US University Center for Atmospheric Research (UCAR) have jointly sponsored a mission to collect data for operational use in weather forecasting and ionospheric (space weather) research and geodesy. ROCSat 3 makes use of GPS occultations to provide information about the atmosphere and ionosphere. All six satellites are planned for a single Minotaur launch in 2005.

The US University Nanosatellite Program (UNP) has great promise for demonstrating some very low-cost satellites and constellation management technologies though its future seems uncertain due to issues within the US Space Shuttle program. The premise was that universities would be funded to produce small satellites that could then be used to make useful measurements as well as to validate key technologies. The innovative aspect of this approach was to use a shared launch capability to place the satellites in orbit and manage costs by constraining the mission lifetime by placing them in a relatively short lifetime orbit.

Measurement technologies continue to evolve. One technique that may make observations more cost-effective is lidar. In Light Detection and Ranging or lidar a pulse of laser light is sent into the atmosphere and the return signal is analyzed to produce information about the distance to the backscatter point, physical state or composition. The term lidar is used generically to describe a number of techniques. The three most relevant to remote sensing of the Earth’s atmosphere are the direct time-gated measurement of the backscatter signal, which measures the aerosol density and composition as a function of altitude, differential

absorption or DIAL which determines composition as a function of altitude as does Raman and Doppler Wind Lidar which measures the Doppler shift of aerosols to get the global tropospheric wind field. Each technique has its advantages and disadvantages but all can operate day or night and provide precise measurements of the vertical distribution. Unfortunately, while these techniques have been demonstrated on the ground and in aircraft flights they have yet to be used on a continual basis from space. This may yet occur as issues relating to eye safety and power can be resolved.

New geosynchronous orbits may also be explored. As the geostationary belt, that is geosynchronous orbits with an inclination of 0 degrees, becomes more crowded there may be some value in considering placing satellites in orbits that have the same period as the Earth but do not appear stationary. The principle advantage of such an approach is improved high latitude coverage (GEO satellite don't image above 60 degrees latitude very effectively) and reduced signal interference. This orbit may prove more cost effective for some customers than relying on LEO satellites with long revisit times or poor coverage from existing GEO assets.

Even further on the horizon is the use of solar sails, basically very thin highly reflective material that absorbs momentum from sunlight, to propel satellites in non-Keplerian orbits. One of the more intriguing concepts is to use these solar sails to place satellites in "pole sitter" orbits. There a satellite maintains a fixed Earth-Sun orientation at all times. This is being considered for future space weather and meteorological imaging satellites.

7.6 Weather and Climate

7.6.1 Status quo

Meteorological and climatological research, application and service cover a wide range of requirements for the use of Earth Observation (EO) satellite data. Depending on the meteorological application these requirements span the range from high spatial resolution for e.g. urban climate studies (resolution of a few meters) to global coverages of data needed for global circulation models (GCM) or numerical weather prediction (NWP) (resolution of several kilometers). Correlated to these spatial features are specific requirements in the temporal and spectral domain. For NWP a high frequency of data is required and the IFOV of the sensor must cover atmospheric processes like cyclons or tropical storms (several 1000 km). For local studies, e.g. for the urban climate, high resolution data of a few decameters are needed. Therefore climate research is a prime user of EO data to retrieve information from the Earth surface, cloud coverage and cloud physics, spatial distribution and concentrations of gases (water vapour, ozone, trace gases etc.). That implicitly means that remote sensing for meteorological applications is far more than a "fair weather system". In recent years a world weather watch could be established with a circumglobal monitoring every 30 minutes covering the Earth surface approx. between 80 degrees northern and southern latitude.

Many of these requirements for the weather and climate community are fulfilled and various satellite systems have been implemented very successfully since many decades. A series of satellite platforms are offering information on many meteorological variables. There are near-polar orbiting systems available and geostationary systems which offer very frequent observations (like the GOES- or METEO-SAT-series).

On a global perspective the national weather services are well organized since decades through the World Meteorological Organisation (WMO) and the use of remotely sensed weather information from satellites for weather prediction has an operational status in most member countries of WMO. In Europe EUMETSAT maintains the geostationary satellite METEOSAT. Recently a first platform of a new series of geo-stationary satellites was launched successfully, built by ESA and operated by EUMET-SAT: METEOSAT Second Generation (MSG) broadens the scope of meteorological research and applications with 12 spectral bands in the solar and terrestrial spectrum. Having a spatial resolution of 3 km in 11 bands and 1 km in 1 band combined with a repetition cycle of 15 min the systems enables to analyse rapidly developing dynamic features in the atmosphere. In addition to an improved separation of low clouds and stratus as well as water and ice clouds it offers the quantification of ozone, water vapour and carbon dioxide. This is far more what weather forecast re-quires. Data can be used by the climate change community as well.

A classical work horse for weather forecast is the NOAA-AVHRR series: a set of multiple satellites in near polar orbit, enabling several overpasses per day with a nadir resolution of approx. 1 km. This data can easily be downloaded at many stations worldwide which enables a fast access to important satellite information like (surface properties, albedo, NDVI, surface temperatures etc.) for many operational and re-search activities.

The strategy of a set of polar orbiting satellites for meteorological purposes is already decided for the years to come and also Europe will get into this business in the near future.

Due to the political importance of the consequences of global climate change many satellite sensors have been launched from various countries to explore the concentrations and spatial distribution of atmospheric greenhouse gases in the troposphere, stratospheric ozone depletion especially over polar regions, landuse changes world-wide, pollution and dynamics of oceans, changes in terrestrial vegetation cover due to natural and anthropogenic impacts and their consequences for fluxes of radiation, heat, momentum and matter between of the Earth-Atmosphere-System and many other aspects. Most of these investigations are aiming at monitoring these processes on a high repetition cycle and on a global basis. Two satellite platforms play an important role in this context:

- The European ENVISAT launched by the European Space Agency ESA offering a unique set of sensors for various kind of environmental monitoring and research
- EOS-TERRA/AQUA also providing the community with a set of sensors like e.g. MODIS

ENVISAT was launched in 2002 by ESA and offers a unique combination of sensors in the various wavelengths. It fulfills many requirements of the climate change community and of atmospheric physics and chemistry as well: GOMOS, SCIAMACHY, MIPAS, ASAR, AATSR, MERIS. The advantage of ENVISAT is that many sensors are flown parallel and therefore an in-depth analysis of atmospheric properties and processes can be carried out. The system is made mainly for meso- to macro-scale investigations. High resolution sensors except the ASAR, the Advanced Synthetic Aperture Radar as a follow-on for ERS-1 and ERS-2, are missing.

There is a similar situation with TERRA-MODIS. The system collects data in 36 spectral bands for land and aerosol properties, ocean colour, phytoplankton and bio-geochemistry, atmospheric vapour, ozone, atmospheric temperature, cloud properties and surface temperature in 250 – 1000 m grid size. NASA does a lot of data pre-processing and corrections and offers the research community many derived products which can be downloaded from the internet. This is a key aspects for these data to be used worldwide and European data policy is far from being so progressive. But again the high-resolution sensor is not available and research in very heterogeneous and highly fragmented landscapes is quite problematic.

7.6.2 Prospects

Generally speaking research in climatology and meteorology can rely on many EO sensors for a wide range of applications and research. Sensor strategy for the future is on the one side driven by the requirements of national weather services and by the needs of the global climate change community on the other. There is normally no need for complains.

But since the failure of LANDSAT-ETM the situation has changed and has to be seen from a different point of view also: all those who need high resolution satellite data in the thermal infrared wavelength have a problem to get data. This is a long list of candidates like urban climatologists, ecologists, hydrologists etc. The alternative to choose the thermal bands of ASTER with a 90 m resolution only partially closes this gap and is not satisfactory, since ASTER is not recording continuously (only a couple of minutes per orbit) and although the satellite is flying the appropriate orbit and hits the right place of investigations there is no guarantee that data are really recorded. Therefore the ASTER data archive shows many geographical gaps and only a few data sets of a specific region are available. Nevertheless one advantage of ASTER data and one reason that they are used intensively is the data policy of NASA/ NASDA. Data can be downloaded from the internet free of charge from the ASTERweb or for a very small price. The failure of LANDSAT-ETM is a real drawback for many applications and it is very much recommended to think about having a successor of LANDSAT-7-ETM in the very near future.

7.7 Ice and Snow

7.7.1 Status quo

The cryosphere is commonly subdivided in land ice, sea ice and snow cover. Land ice is further subdivided in the ice sheets of Antarctica and Greenland, (mountain) glaciers, permafrost, lake and river ice. The presence of ice and snow is confined to cold climates either at high altitudes or high latitudes (or a combination of both). In many cases, ground-based observations of ice and snow properties are difficult to obtain in the respective regions due to lacking infrastructure and complex topography, harsh climates or the lack of daylight during the polar winter. Thus, remote sensing provides access to information on the cryosphere not available from other data sources.

The cryosphere is an important component of the climate system carrying information on the other system components. For instance, changing positions of the ice fronts or equilibrium lines of ice sheets and glaciers are related to changing climatic conditions affecting the mass balance by changing accumulation and ablation rates. Perturbations of the mass balance have, in turn, influence on ice volume, ice-covered area, ice thickness, flow velocity, ice temperature and surface topography, also controlled by bedrock topography and other boundary conditions. For this reason, ice and snow monitoring by remote sensing is highly relevant not only to glaciological but also to climate research, a fact stressed both by ESA's Living Planet Programme (ESA, 1998) and the Earth Observing System (EOS) Science Plan (NASA, 1999). Today, there is no doubt that the climate trends measured all over the world during the last century have resulted in a significant reduction of the global ice volume due to negative mass balances observed during a majority of the years in a majority of the regions. Hence, the observed increase in mean sea level during the same period is partly caused by the cryospheric response on changing climates. This explains the large number of research projects utilizing remote sensing as a tool to monitor and study mass balance of ice sheets and glaciers or the spatial and temporal evolution of the snow cover, to mention just two prominent examples. A further, rather important aspect of contemporary climate research addresses the problem of quantifying sources and sinks of greenhouse gases in permafrost regions like Siberia or Canada. The vastness of these regions, in combination with complex, small-scale spatial patterns of the underlying surface structures and processes make remote sensing a prerequisite for this kind of research.

Ice and snow properties are not only the result of the climatic conditions of a certain region, but are also strong climatic controls playing an important part in several global and regional feedback mechanisms of the climate system, as the well-known example of the positive ice/snow-albedo feedback demonstrates. Spatially distributed data on ice and snow are used for initialization, calibration and validation of global or regional climate models. Such models not only enable studying the (still insufficiently known) present climate; moreover, they can answer questions or, at least, give additional information concerning past and future climates. In any case, comprehensive data on present conditions of the cryosphere as provided by remote sensing systems are essential to create a baseline for quantifying future changes.

The strong interactions between the cryosphere, solar radiation and the atmosphere are not only acting on longer time scales of years up to millennia, which are relevant for the climate system and the dynamics of ice masses, but manifest themselves also in day to day variations of local and regional weather conditions. This forms the scientific background for employing remote sensing data on ice and snow in numerical weather or hydrological forecast systems. In this respect, spatial distributions of snow properties like snow-covered area (SCA), snow depth or snow water equivalent (SWE) are of utmost importance.

Ice and snow, storing most of the Earth's freshwater, are important components of the hydrological cycle. For instance, over one billion people depend on water resources originating from snowmelt runoff (Goodison et al., 1999). The presence of glaciers often ensures river runoff and ground water recharge throughout the year in climates of strong seasonality in precipitation. Meltwater runoff is extensively used for hydropower generation, irrigation or freshwater supply, which partly requires intermediate, managed storage in reservoir lakes, particularly in semiarid climates.

The positive aspects of ice and snow, particularly as freshwater reservoirs or as natural basis of tourism (skiing, mountaineering, skating, ice fishing, etc.) go in hand with a large number of natural hazards like

- floods due to jökulhaups, intense or long-lasting snowmelt or the outburst of subglacial lakes,
- slushflows, snow avalanches, drifting snow on roads and railroads,
- ice fall, advancing or calving ice shelves and glaciers, glacier surges,
- rock and debris avalanches, rockfalls and debris flows in areas of deglaciation or permafrost melt,
- sea ice and ice bergs on ship routes,
- damages to agricultural, horticultural or forestial stands due to heavy ice and snow loads.

This list of natural hazards is by far not complete, but clearly shows the large number of research disciplines and application fields related to the cryosphere. Since most of the relevant processes are acting on time scales of less than a day up to a few years, monitoring of ice and snow by remote sensing systems is of great interest

in this respect. Detection of critical ice or snow conditions based on (or aided by) remote sensing data is widely used in early-warning systems. Typically, the respective data sets have to be acquired within short time to ensure data homogeneity, and to allow (near) real-time applications and high repetition rates, which are of particular importance for operational purposes. Therefore, remote sensing has received increasing significance over the last two decades, since it is the only feasible way for acquisition of such data sets.

Previous reviews on remote sensing of the cryosphere have been made by a large number of authors (e.g. Hall and Martinec, 1985; Foster et al., 1987; Rott and Mätzler, 1987; Bernier, 1987; Massom, 1991; Bindschadler, 1998; König et al., 2001). As early as in 1982, a Plan of Research for Snowpack Properties Remote Sensing (PRS)² was worked out to identify critical research topics and to outline a research strategy for developing the scientific understanding, models and techniques required to make remote sensing of snow a useful operational tool (NASA, 1982). Despite the huge technological and scientific improvements achieved since that time, the description of general approaches and many of the recommendations are still valid. More recently, the EOS Science Plan (NASA, 1999) comprehensively describes the current state of knowledge, the unsolved problems and new possibilities and strategies of ice and snow research by remote sensing systems.

7.7.2 Prospects

The large number of research topics and applications that can be successfully addressed by remote sensing of ice and snow is justifying the enormous efforts of installing and maintaining the respective air- and spaceborne systems acting as platforms for the required imaging and non-imaging optical, thermal infrared, active and passive microwave sensors. However, there is an increased need of cost effective Earth observation missions for a number of reasons discussed in the previous chapters of this report. Thus, the question arises, whether cost effective missions are meeting the specific requirements of cryospheric research and applications or not.

From the author's viewpoint, two types of Earth observation missions are of major interest for the future of cryospheric research and applications:

1. Long-term global monitoring missions providing highly accurate data at moderate spatial and temporal resolution to address the slow processes in and long response times of the cryospheric subsystems.
2. Application-specific operational missions ensuring repetitive acquisition of ice or snow data within very short time at high spatial resolution.

Missions of type 1 require satellite platforms, while missions of type 2 could also be carried out by airborne systems if the area of interest is clearly defined and small (a maximum extend of tenths to hundreds of square kilometers).

Moderate spatial resolutions suitable for missions of type 1 are ranging between 50 and 1'000 m, while moderate temporal resolutions range from a few weeks up to one year. With some restrictions, such missions are already existing (e.g., NOAA-AVHRR, Landsat). The multi-year ICESat mission (Schutz, 1998), using the Geoscience Laser Altimeter System (GLAS) for measuring mass balance trends of the ice sheets as inferable from ice thickness changes, can be cited as one of the most promising approaches in this respect. In particular, the mission is planned to continue for 15 years or longer (the current satellite launched in the beginning of 2003 has an expected lifetime of three years and will be followed by similar systems). The total duration of the mission will significantly depend on proven cost-effectiveness of the employed systems.

Cryosat, the first Earth Explorer Opportunity Mission planned for launch in 2004, employs a set of advanced techniques for cryospheric observations from space (ESA, 2003). Despite its high scientific and technological level, the mission has a serious drawback inherent to most of ESA's Earth observation missions: a short mission duration of only a few (in this case, of three) years. It is a great pity that ESA does not ensure long-term continuity for its extremely valuable and successful systems like ERS-1/2, ENVISAT, and the ones so far planned for the future.

The set-up of operational services for cryospheric applications based on Earth observation data acquired by remote sensing systems is not a question of scientific and technological developments but mainly depends on reliable data provision over long times. Earth observation missions, even the cheapest ones, usually require

initial investments of several tenths to hundreds of millions EUR, and subsequent funding for maintenance, product generation and dissemination. Since the prices for single products have to be marketable, and the number of potential users is limited, the costs are only balanced if the missions continue over a long time.

Certainly, there are a number of problems related to ice and snow that need to be further studied, for instance:

- radiative transfer models suitable to correct high-resolution VNIR and SWIR imagery for topographic, adjacency and BRDF effects,
- accurate retrieval of ice and snow properties from remote sensing data (in particular SWE at high spatial and temporal resolution),
- subpixel analysis algorithms (e.g. for retrieval of snow properties in forested areas or for detection of cloud contaminated pixels).

However, the existence of huge data sets like remote sensing data from other systems or high-resolution digital elevation models essential for data pre-processing, information retrieval and numerical modelling of Earth system processes relevant to many cryospheric applications, in combination with the availability of appropriate sensor technologies and instrument platforms, forms a solid basis for the design of cost effective Earth observation missions.

Political and socio-economic decision makers have to be convinced that the benefits (not only measured in monetary terms) of well-designed Earth observation missions will be greater than the costs, and that there is no reason to wait for future scientific and technological developments.

References

- Bernier, P.Y.. "Microwave remote sensing of snowpack properties: potential and limitations". *Nordic Hydrology*. Vol. 18, pp. 1-20. 1987.
- Bindschadler, R.. "Monitoring ice sheet behaviour from space". *Review of Geophysics*. Vol. 36 (1), pp. 79-104. 1998.
- Foster, J.L., D.K. Hall, and A.T.C. Chang. "Remote sensing of snow". *EOS Trans. AGU*. Vol. 68 (32), pp. 682-684, 1987.
- ESA. "The science and research elements of ESA's Living Planet Programme". ESA SP. Nr. 1227. 1998.
- ESA. "CryoSat science report". ESA SP. Nr. 1272. 2003.
- Goodison, B.E., R.D. Brown, and R.G. Crane. "Cryospheric systems". In: NASA, *EOS Science Plan*. 1999.
- Hall, D.K., and J. Martinec. "Remote sensing of ice and snow". 1985.
- König, M., J.-G. Winther, and E. Isaksson. "Measuring snow and glacier ice properties from satellite". *Reviews of Geophysics*. Vol. 39 (1), pp. 1-27. 2001.
- Massom, R.. "Satellite remote sensing of polar snow and ice: Present status and future directions". *Polar Record*. Vol. 31 (177), pp. 99-114. 1995.
- NASA. "Plan of research for snowpack properties remote sensing-(PRS)". 1982.
- NASA. "EOS science plan". 1999.
- Rott, H., and C. Mätzler. "Possibilities and limits of SAR for snow and glacier surveying". *Annals of Glaciology*. Vol. 9, pp. 195-199. 1987.
- Schutz, B.E.. "Spaceborne laser altimetry: 2001 and beyond". In: Plag, H.P. (ed.), *Book of Extended Abstracts, WEGENER-98*, Norwegian Mapping Authority, Honefoss, Norway. 1998.

7.8 Mapping and Geographic Information System Applications

7.8.1 Status quo

Topographic Mapping constitutes the basis of a Spatial Data Infrastructure. About 90 % of information concerning the earth surface are spatially related. Topographic maps are the spatial link to this information.

Topographic maps depict on a chosen reference system (a defined reference ellipsoid and its projection onto a plane surface) the important features describing the terrain

- settlements
- the transportation network
- the extent of vegetation

- the hydrography
- the toponymy
- the administrative boundaries
- the hypsography of the terrain.

Since the beginning of the 19th century military survey units have been established in the countries of the world with the aim to provide base data for strategic and tactical operations of the armed forces. The military still maintains a strong interest in base mapping until today. In the 20th century governments of the countries around the globe recognized, that base mapping was a prerequisite for exploitation of resources, for planning the natural and the socio-economic environment and for the rapid reaction to catastrophic events. For these reasons national mapping agencies were established with an allocated national budget of 0.1 % of the GNP as a world average.

It was generally realized, that mapping was not only an expensive, but also a time-consuming task. The technologies of the late 19th century with surveys on the ground (triangulation, plane tabling) were only capable to create adequate mapping systems in densely populated Europe and in some regions of Asia but they failed in the vast and mostly “empty” continents of the former colonial world.

With world war I and later with world war II aerial mapping technology was able to make progress in the developing parts of the globe. This technology is still prevalent. The requirements for base mapping are scale dependent: Global issues require a base map in a scale range 1 : 200 000, national (e. g. resource and environmental) issues require a scale range of 1 : 25 000 and larger.

Mapping the environment is, of course, not a static issue, but it requires continuous updating of all changes, at least at periodic intervals.

The UN Secretariat has until recently conducted official surveys of the status of world mapping and its updating. The results of the last survey conducted in 1990 and published in 1993 are contained in tables 7.8-1 and 7.8-2.

These tables show, that a global topographic map coverage now exists for global needs at the scale 1:200 000, at least in analog form, but the annual update rate of 3.4 % suggests that this map coverage is on the average 30 years old.

The situation is even more severe at the national planning level 1 : 50 000, in which only 2/3 of the land surface (65.6 %) was mapped. The average age of that map coverage is over 40 years (update rate of 2.3 %).

Table 7.8-1: Status of World Mapping 1990 [1]

Scale range	1 : 25 000	1 : 50 000	1 : 100 000	1 : 200 000
Africa	2.9 %	41.4 %	21.7 %	89.1 %
Asia	15.2 %	84 %	56.4 %	100 %
Australia and Oceania	18.3 %	24.3 %	54.4 %	100 %
Europe	86.9 %	96.2 %	87.5 %	90.9 %
Former USSR	100 %	100 %	100 %	100 %
North America	54.1 %	77.7 %	37.3 %	99.2 %
South America	7 %	33 %	57.9 %	84.4 %
World	33.5 %	65.6 %	55.7 %	95.1 %

Table 7.8-2: Annual Update Rates of World Mapping 1990 [1]

Scale range	1 : 25 000	1 : 50 000	1 : 100 000	1 : 200 000
Africa	1.7 %	2.2 %	3.6 %	1.4 %
Asia	4.0 %	2.7 %	0 %	1.9 %
Australia and Oceania	0 %	0.8 %	0 %	0.3 %
Europe	6.6 %	5.7 %	7.0 %	7.5 %
Former USSR	0 %	0 %	0 %	0 %
North America	4.0 %	2.7 %	0 %	6.5 %
South America	0 %	0.1 %	0 %	0.3 %
World	5.0 %	2.3 %	0.7 %	3.4 %

At the UNCED Conference 1992 in Rio de Janeiro Agenda 21 and its chapter 40 expressed the requirement of mapping for the purpose of environmental monitoring, and the expansion of basic topographic mapping into various systematic thematic mapping coverages for sustainable development. Examples for such thematic map coverages are the national thematic map series at the scale 1 : 50 000 of Mexico for 7 themes (topography, vegetation, geology, land cover, land use potential etc.) or the national map 1 : 50 000 of New Zealand. In Europe the CORINE program of the EC established land cover monitoring at the scale 1 : 100 000, and in 10 states of Eastern Africa the FAO-initiated Africover project provides land cover information.

The present topographic and thematic mapping efforts are geared to digitization and homogenization of the existing topographic and thematic maps into raster and vector form.

To increase the efficiency of new map data or its updating to a satisfactory update cycle of at least 10 years the use of satellite imagery is a must. This was already successfully demonstrated by the use of Spot-imagery for CORINE and by the use of Landsat-imagery for Africover.

Other international initiatives for the updating and homogenization of topographic and thematic maps have been the “Global Mapping Forum”, which intends to provide a global coverage in a number of themes in the scale 1 : 1 000 000 by the year 2007. Another effort is expressed by “Digital Earth” supported by the International Cartographic Association with the intent to look at larger scales (1 : 200 000).

7.8.2 Prospects

While the mapping and map updating progress at smaller scales 1 : 100 000 and 1 : 200 000 can greatly be pushed ahead by the use of existing satellites such as Landsat, Spot and IRS with ground pixel resolutions ranging from 30 m to 5 m, the current high resolution satellites with pixel resolutions between 0.6 m and 1.8 m Ikonos, QuickBird, Orbview and Eros cannot provide a homogeneous extended area coverage of the terrain other than for limited areas.

This gap between present satellites aimed at global issues and those of the high resolution satellites looking at local issues can well be filled by small satellites aimed at pixel resolutions between 1 m and 5 m. Table 7.8-3 lists the relationship between pixel size and the possible mapping scale in planimetry.

Another aspect to consider is the provision of elevation data in the form of a digital elevation model, which is part of the topographic base data. Elevation data are customarily provided by a sequence of stereoscopically overlapping images. The accuracy of the height determination greatly depends on the intersection angle of rays at a terrain point, the elevation of which is to be determined. Despite of the high resolution of the 1 m pixel size satellites these do not offer a favorable base height ration close to 1 : 1 (they are only 1 : 10). Thus the elevation accuracy is limited to the 5-m range. Other stereo-systems such as Spot 5 are more favorable but their acquisition capacity is limited.

On the other hand, radar interferometric systems offer very efficient and inexpensive elevation data, as the SRTM mission has shown promise of this technique in the 5-m accuracy range.

Table 7.8-3: Relationship between pixel size and the possible mapping scale in planimetry

Pixel size	possible mapping scale in planimetry
0.6 m	1: 6 000
1 m	1: 10 000
2.5 m	1: 25 000
5 m	1: 50 000
10 m	1: 100 000
30 m	1: 250 000

Nevertheless, the methodology is greatly affected by radar shadows and by foreshortening in mountainous areas, deteriorating the DEM accuracy beyond tolerances.

It is in these mountain areas of the world, where small satellites with stereo sensors with a favorable base-height ratio could offer an optical complement to the radar interferometric area to be operating reasonable well in relatively flat areas.

In this way mapping using satellite imagery from small satellites could greatly speed up the process of updating regionally useful geographic information systems at the 1 : 50 000 scale level. The desired update rate is at least 5 years, during which a global coverage could be reached by small satellites.

Reference

[1] UN Secretariat, "The Status of World Mapping 1990", World Cartography 1993, UN Cartographic Conference, Beijing, paper prepared by A. Brandenberger and S. Ghosh

7.9 Land Use/Cover Change

7.9.1 Status quo

The production and use of information on land cover and land use has dramatically increased during the last 50 years in relation with the development of spatial planning policies on one hand and of remote sensing and GIS techniques on the other hand. Yet spatial planning is not the only area where land cover information is needed. Indeed, environmental policies and international agreements signed after the Rio Earth summit in 1992 (i.a. the Framework convention on Climate Change, the Convention on Biodiversity and the Convention to Combat Desertification) not only have established a legally binding framework for environmental assessment, management and reporting, but also have given scientists a strong impetus to improve their understanding of the mechanisms governing changes, such as the interactions between the Earth's surface, in our case the land masses, and the atmospheric and climatic processes. It can be easily understood that in a world of steady population increase, anthropogenic actions on the environment, such as deforestation and increase of cropland, can influence the functioning of the climate system [1] (Shukla & al. 1990).

The definition and understanding of the differences and connections between land cover and land use is still a critical aspect that impacts the information production. Land cover is the observed (bio)-physical cover on the Earth's surface, whereas land use is determined by the human activities undertaken in a given land-cover type to exploit it economically, to maintain it or change it [2] (Di Gregorio & Jansen, 2000). Thus a piece of land covered by, say, grass can be from the land-use point of view a football ground, a meadow or a natural reserve. So far both concepts have often been mixed in land cover/use map legends to answer specific user needs, in particular at large and medium scales. Yet a clear separation between land use and land cover is better from the map producer point of view. Indeed, as land cover exclusively refers to the physiographic aspect of landscape, it can be assumed that its identification is feasible by remote observation techniques only, whereas land use type cannot be derived simply from remote observation, but also requires access to other information collected with other means.

A tremendous effort has been produced by several organizations to come up with standardized land cover definition schemes. Without trying to inventory all these exercises, it is worth mentioning the CORINE land cover nomenclature developed in the eighties in Europe to produce land cover/land use maps at 1/100 000 scale across European countries using a legend compatible with categories used in classical statistical records [3], whereas the IGBP land cover legend [4] aimed at small scale global mapping was established according functional and physiognomic properties of vegetation and non vegetated areas [5] (Running & al 1994) in agreement with the needs of climatic models. Di Gregorio & Jansen [2] proposed a land-cover classification system that allows the user to define land cover classes according a set of measurable structural properties, such as, for vegetation, vegetation height, cover percentage, leaf type and life cycle, etc...

Historically land cover and land use mapping was preceded by topographic and later by vegetation maps. Right from the beginning topographic maps depicted a number of land cover classes of use for military purposes. This is for instance the case of one of the first large scale topographic maps, the Ferraris "cabinet" map of the Austrian Low Countries produced more than two centuries ago (ca 1775) at an approximate scale of 1/11 500. More recently, in particular after World War I, vegetation maps were prepared in many regions of the world from field survey completed and generalized with air photographs. With the advent of satellite imagery the balance between field survey and image analysis was reversed, and field survey was increasingly used only for training and validating the interpretation based on digital data classification and analysis. One of the visible consequences of this change is that vegetation maps, typically based on the identification of a number diagnostic plant species and associations, are progressively abandoned for current land cover maps that focus more on vegetation landscape physiography.

In the past, chorographic scales including global maps were typically obtained by the generalization of larger scale maps. They can now directly be obtained through the classification and interpretation of low resolution satellite imagery, leading in principle to more spatially homogeneous products.

During the last 20 years most parts of the world have been covered by land cover mapping exercise at scales ranging between 1/50 000 and 1/500 000. It is not the purpose here to provide a complete inventory, but it is worth mentioning some examples, such as the National Land Cover Characterization Project for the US [6] (Vogelmann & al, 2001), the above-mentioned CORINE land cover map for Europe, the AFRICOVER project for Eastern Africa, just to mention exercises at sub-continental scale. Such projects made use of high resolution satellite imagery (i. a. the American Landsat MSS & TM, the French SPOT HRV or the Indian IRS).

At global scale the IGBP 1km land cover product [7] (Loveland & al, 1999) and the University of Maryland version [8] (Hansen & al, 2000) were both derived from AVHRR data acquired in the early nineties, Boston University is producing the land cover information from MODIS instrument [9] (Strahler & al 2003), whereas the Joint Research Centre has coordinated the production of a reference land cover dataset for the year 2000 (Global Land Cover 2000) from data acquired with the VEGETATION instrument onboard SPOT satellite [10] (Bartholomé & al 2002).

Radar imagery has also been used, alone or in combination with optical data (e. g. TREES map of Africa, [11] Mayaux & al., 2000).

In summary, owing to the advent of space technology it was possible to produce land cover maps of many parts of the world at various scales. Needs in land cover and land use information arise from applications in environmental management, environmental reporting as well as scientific research. Partial efforts of nomenclature standardizations took place; they tried in first place to fulfill specific user requirements. A wide range of sensors have been used and are currently available for land cover/land use mapping, with spatial resolutions ranging between one meter and several kilometers. The methods used to exploit data ranged from pure visual interpretation to fully automated processes. It can be observed that the final quality and accuracy is a direct function of human interaction in the production process.

7.9.2 Prospects

Needs in land cover and land use information will remain high. Experience has shown the capacity of spaceborne observing systems to provide adequate input data and of remote sensing experts to extract relevant information with a high level of accuracy. Yet a number of improvements can still be expected.

Requirements increase for monitoring of changes of land cover categories of “strategic” importance. This is the case for instance of forest surfaces, in relation with carbon storage and carbon flux assessment in the framework of climate change analysis and monitoring. Accurate change measurement cannot be achieved by simple comparison of land cover maps at different dates. Ad hoc methods need to be developed and accepted whereby input data are combined and analyzed together. This implies that input data are inter-compatible (in other words “inter-operable”) under several aspects: radiometry, atmospheric correction, geometric co-location for instance.

Not all properties of satellite measurements are used for land cover identification. Currently the classification process consists in the delineation of areas of similar spectral and/or temporal behaviour, and in a second step in the association of those areas with field information to identify their nature. The combination of more measured parameters should allow the identification of a larger set of diagnostic criteria of land cover classes. This involves the combined operation of a set of different yet complementary instruments operating in various areas of the spectrum (visible, thermal microwave), both with passive and active devices (radar, lidar), and with various viewing angles.

Such an approach is for sure not yet feasible for a number of reasons. In the meantime it will be useful to focus on the building up and maintenance of time series of data acquired with existing instruments and on definition of pre-processing standards as well as their systematic application to alleviate the work of the analysts.

The development of automated and semi-automated classification procedures will further emphasise the purely physiographical component of land cover characterization, leading possibly to a more explicit separation between land cover and land use products.

For what regards access to data, land cover mapping applications have a lot in common with other activities described elsewhere in the text, such as agriculture, forestry, etc... It can thus be expected that the space segment will be covered for the years to come.

On the land cover specific application side, the situation is somewhat more complex. There is currently no requirement for yearly updates of land cover maps, excepted in very rare and specific cases. The update frequency is rather in the 5-10 years range. As a result land cover production is most often the result of ad hoc projects established for a limited period. As a result there is a high risk of skill loss between projects, with possible impact on quality standards safeguarding. It would thus be most useful to preserve these capacities by enhancing the aspects of operational change detection, whereby between two full-scale mapping exercises hot spots of fast land cover /use change are identified and monitored, in order to produce partial updates if necessary.

References

- [1] Shukla, J., C. Nobre, and P.J. Sellers, (1990). Amazon deforestation and climatic change. *Science*, 247:1322-1325
- [2] Di Gregorio A, and Jansen L.J.M., 2000. Land Cover, Classification System, concepts and user manual, GCP/RAF/287/ITA Africover (Food and Agriculture Organization of the United Nations Publishing Service, Viale delle Terme di Caracalla, 00100, Rome, Italy). 179 pp
- [3] Anonymous, 1995, CORINE Land cover - Part 1: Methodology Published by: Commission of the European Communities OPOCE (Office for official publications of the european communities) http://reports.eea.eu.int/COR0-part1/en/tab_abstract_RLR
- [4] BELWARD, A. S., ESTES, J. E., and KLINE, K. D., 1999, The IGBP-DIS global 1 km land cover data set DISCover: A Project Overview, *Photogrammetric Engineering and Remote Sensing*, 65, 1013 - 1020.
- [5] RUNNING, S. W., LOVELAND, T. R., and PIERCE, L. L. 1994, A vegetation classification logic based on remote sensing for use in global scale biogeochemical models, *Ambio*, 23, 77-81.
- [6] Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, N. Van Driel, 2001. Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic

- Mapper Data and Ancillary Data Sources, *Photogrammetric Engineering and Remote Sensing*, 67:650-652.
- [7] LOVELAND, T., ZHU, Z., OHLEN, D. O., BROWN, J. F., REED, B. C., and YANG, L., 1999, an analysis of the IGBP Global Land Cover Characterization Process. *Photogrammetric Engineering and Remote Sensing*, 65(9), 1021-1032
- [8] HANSEN, M., DEFRIES, R., TOWNSHEND, J. R. G., and SOHLBERG, R., 2000: Global land cover classification at 1km resolution using a decision tree classifier, *International Journal of Remote Sensing*, 21(6-7), 1331-1365
- [9] Strahler, A.H., Schaaf, C.B. and M.A. Friedl 2003. Albedo and land cover from MODIS on Terra and Aqua, Abstracts from the Annual meeting of the Association of American Geographers, March 5-8, 2003, New Orleans, LA.
- [10] BARTHOLOMÉ, E., BELWARD, A.S., ACHARD, F., BARTALEV, S., CARMONA-MORENO, C., EVA, H., FRITZ, S., GRÉGOIRE, J.-M., MAYAUX, P., and STIBIG, H.-J., 2002, GLC 2000 - Global Land Cover mapping for the year 2000 - Project status November 2002. Publications of the European Commission, EUR 20524 EN, Luxembourg: Office for Official Publications of the European Communities, 55 pp
- [11] Mayaux P., G.F. De Grandi and J.P. Malingreau, 2000, Central Africa Forest Cover Revisited: a Multi-Satellite Analysis, *Remote Sens. Environ.*, 71, pp. 183-196

8 TRAINING AND EDUCATION

Cost-effectiveness also depends on the quality and engagement of the specialists participating in planning and implementing an Earth observation mission. Countries taking their first steps in space need to learn relevant techniques from more experienced space users, thereby acquiring a cadre of appropriately trained personnel before going on to establish a national agency and to maintain a presence in space. Technology transfer through small satellite related training programs has been successfully implemented between Surrey University in the U.K. and customers in Chile, Malaysia, Pakistan, Portugal, the Republic of Korea, South Africa and Thailand.

Small satellites programs provide a natural means for the education and training of scientists and engineers in space related skills since they allow direct, hands-on, experience at all stages (technical and managerial) of a particular mission (including design, production, test, launch and orbital operations).

ESA provided insight into many of the educational and outreach activities and opportunities that ESA provided for European young people and may serve as an example for the increasing emphasis which is given nowadays to this aspect. As a basic policy, ESA committed one per cent of its budget to education and outreach (current NASA's requirement is 2-3 % for all space missions). That level of commitment translated into a large number of ESA-sponsored educational activities for young people, ranging from dedicated web pages and educational newsletters to opportunities to carry out experiments on parabolic flights. Through such programs, ESA aimed to challenge and motivate gifted youth and in turn strengthen the space workforce in Europe. Most of the programs were for Europeans only.

8.1 UN initiated activities

Introduction

In its resolution 54/68 of 6 December 1999, the General Assembly endorsed the resolution entitled "The Space Millennium: Vienna Declaration on Space and Human Development", which had been adopted by the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III). UNISPACE III had a strategy to address global challenges in the future. Part of that strategy called for actions to create a consultative mechanism to facilitate the continued participation of young people from all over the world in cooperative space-related activities. UNISPACE III proposed the organization of a series of symposia to promote the participation of young people in space activities as part of the program of workshops, training courses, symposia and conferences. The objectives of the symposium were: (a) to continue to enhance the participation of youth from all over the world in space activities; (b) to identify some recommendations of UNISPACE III for implementation by youth groups.

The United Nations, on behalf of the co-sponsors, invited developing countries to nominate suitable candidates under the age of 35 for participation in the symposium. Selected participants were required to have a university degree or well-established working experience in a field related to the overall theme of the meeting. The selected participants should also be working in programs, projects or institutions that conducted education or outreach activities or with space-related companies. Students without university degree or professional working experience were accepted if they were actively involved in space-related activities in their home countries or if they had been actively involved in the work of UNISPACE III. The symposium focused on the participation of youth in space activities. Particular emphasis was placed on how developing countries could use education as a cornerstone in developing their space activities.

Several projects were proposed as a result of discussions in the working groups of previous symposiums. The symposium of UNISPACE III recommended that the regional groups should establish local working groups that would develop action plans for implementing the projects and noted that, to be successful, the groups would need to find access to telecommunications and some amount of funding

8.1.1 The Space Generation Advisory Council (SGAC) and its projects

The Space Generation Advisory Council (SGAC) is an international non-profit organisation which represents the views of youth on space issues to the United Nations and other bodies. SGAC organises many activities and programmes, including the annual Space Generation Congress which takes place for instance in Fukuoka, Japan in 2005, and Valencia, Spain in 2006.

SGAC's primary work is in advancing space policy making, representing the world's youth on space policy to the United Nations and other international organisations. This goes back to the roots of the Council at the UNISPACE III conference in Vienna 1999 where participants made several recommendations which were incorporated in to Vienna Declaration on Space and Human Development.

SGAC continues to present youth input to the UN through our Observer Status with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). SGAC has also been represented at the Space Policy Summit - a meeting of government representatives and heads of space agencies to discuss the future exploration of space. In addition SGAC has contributed to the European Green Paper on Space Policy.

The SGAC initiated a world space outreach project called "Yuri's Night", which is a celebration of the first flight into space by Yuri Gagarin. Yuri's night celebrations are diverse, with events ranging from dance parties attended by 1,500 people to three-day space-related conferences. Yuri's Night was celebrated in over 70 cities in more than 30 countries. It was estimated that 10,000 people attend Yuri's Night activities annually and that, through extensive media coverage, the event reaches around 25 million people.

The SGAC has partnered with the not-for-profit organisation Cosmos Education and organised the project "Under African Skies". The project involved an international team of youth from 13 countries and 5 continents travelling from Johannesburg to Nairobi during a 4 week period. It reached 34 schools, educating 4,000 students on a variety of space-related topics from astronomy to history and culture. The highlight of the 2001 expedition was a three-day conference that coincided with a solar eclipse.

The aim of the SGAC project entitled "Global Space Education Curriculum" is to develop a global space curriculum for primary, secondary and tertiary schools. The curriculum would respond to the educational initiatives of the United Nations aimed at incorporating space science and technology into the educational systems of all countries.

The activities of the SGAC are consolidated and expanded upon at the annual Space Generation Congress, which is the premier international event for young space professionals.

www.spacegeneration.org

8.1.2 The Space Generation Congress

The Space Generation Congress began in 1999 as the Space Generation Forum, organized by the United Nations Office of Outer Space Affairs (UN OOSA) and held at UNISPACE-III. This forum was the first gathering of the world's young space professionals and from this grew the Space Generation Advisory Council (SGAC), in support of the United Nations Program on Space Applications. The SGAC is the only body that represents students' and young professionals' views to the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS).

In 2002, the alumni of the Space Generation took on the organization of the congress themselves, and held a special event that year as part of the World Space Congress, called the Space Generation Summit. The name Space Generation Congress was adopted for the follow-on event held in Bremen in 2003, and again in Vancouver in 2004, by which time the Space Generation Congress had secured its place as the premier event for emerging space professionals. The year 2005 will see the culmination of this effort, with cooperation between the International Astronautical Federation's IAC congress, and the associated Student Outreach program allowing an effective, sophisticated event to be held.

SGC runs for 3 days every year, and is open to delegates from a diverse range of backgrounds, including professional engineers, scientists, lawyers, artists, entrepreneurs, business managers, environmentalists, and educators, as well as students in these areas, but all with one common factor: an intense desire to reach out into space.

SGC allows delegates to meet internationally, create networks, make enduring friendships for their professional careers, and most importantly, allow them to contribute directly to the industry that they are

passionate about. No other event gives young people such an opportunity outside of their professional careers.

It provides crucial leadership training, and develops the initiative and problem-solving skills of delegates. It brings its delegates to the International Astronautical Congress, where they can interact with professionals, and gain valuable insight into their own work as well as their SGC project.

The table below shows the breakdown of delegates by region for past congresses and the expected attendance to 2005.

	Total delegates	The Americas	Asia and Oceania	Africa and the Middle-East	Europe
2002	140	28%	17%	15%	40%
2003	50	26%	28%	18%	28%
2004	90	59%	19%	3%*	19%
2005 (projected)	160	20%	35%	20%	25%

* A large number of African and Middle-Eastern delegates were unable to obtain visas for Canada in 2004.

The SGC 2005 will be the first event officially held in conjunction with the International Astronautics Congress (IAC). This association provides the SGC with a host of new opportunities, and illustrates how far the actions of young professionals have come from the first meeting in 2002. SGC 2005 aims to generate new visions on enhancing humanity through space exploration. It will inspire a new generation of young people to be leaders and explorers, develop implementation plans for current and future SGAC projects, and pass on these ideas to the wider space community at the IAC and beyond.

The SGC 2005 theme “*Explorers wanted: Out of the cradle, into action*”, captures the new spirit of exploration in space industry. As individuals and corporations make their first steps into a new era, we make a call to all explorers who dream of leaving our “cradle,” Earth, to explore the solar system and beyond. The theme takes its inspiration from the words of Konstantin Tsiolkovsky, a Russian space founder:

*“The Earth is the cradle of humanity,
but mankind cannot stay in the cradle forever”*

The congress theme aptly ends with a move to action, and is a call to all explorers who ultimately will leave the cradle of earth and explore the solar system and beyond.

The program has two tracks. The first is to identify where the Space Generation can make active contributions to the space industry and apply space technology for the benefit world citizens. This includes enhancing the worldwide operations of the SGAC and providing input to the United Nations Action Teams on Space Applications. The second track focuses on creating new projects for the Space Generation community and expanding a number of our existing, successful projects. Delegates will generate the content of each of these tracks themselves by participating in online discussions before the congress. At the congress, they will be able to work face to face and complete the work started online. By collocating SCG with the IAC, delegates have access to a large number of professionals who can advise them and help develop their ideas.

Space Generation Congress: a catalyst for on-going and future projects

Since its inception, the SGAC has created a range of successful projects that illustrate the scope impact and diversity of the Space Generation. The annual congress is the catalyst of these projects and presents a valuable opportunity for delegates to take advantage of new opportunities and aim for new targets.

Yuri’s Night, for example, is a worldwide event to rally interest and awareness about the space adventure. Every April 12th, people around the world celebrate Yuri Gagarin’s historic first flight into space in the vessel Vostok, by holding event ranging from public evenings of stargazing to celebrity parties. The events have been a phenomenal success, taking place on every continent, and even on the International Space Station.

The Moon Mars Workshop is another example. With the ultimate goal of this workshop being to help in the project to send humankind to the planets, SGC 2002 developed a series of workshops designed around the

exploration of the Moon and Mars. The main goal of the workshop is to provide a mechanism for international collaboration on relevant research topics for young academics, who can then publish their findings. Ever since 2002 the Moon Mars Workshop has held a stand-alone event every six months on a range of topics including exploration, Mars Habitats, and Lunar research.

The SGAC also takes an administrative role in Space Generation activities worldwide providing the legal framework for all space generation undertakings, as well as support, mentoring, networks, industry connections, and alumni resources.

www.explorerswanted.com



Figure 8.1-1: Delegates at the Space Generation Congress in Vancouver Canada 2004



Figure 8.1-2: Delegates at the Space Generation Summit held at the World Space Congress in 2002

8.2 International Space University

The International Space University serves as an international forum for the exchange of knowledge and ideas about challenging issues related to space and space applications. ISU also held Symposia relating to nano/micro satellites technology development and their applications. The recent one is concerning the “Symposium on Smaller satellites: bigger business? concepts, applications and markets for micro/nanosatellites in a new information world”, organized by Rycroft, M. and Crosby, N. The Symposium's broad ranging theme is analysed and discussed from many viewpoints - engineering, science, policy, law, business, finance and management. Different ways in which small satellites may create larger business opportunities are examined, ranging from telecommunications systems to Earth observation applications and technology demonstrators. Information satisfying the needs of consumers is the key to success. Small satellites, which are Responsive, Adaptable and Cost Effective, will define the new space RACE.

www.isunet.edu

8.3 ITC in Holland

The International Institute for Geo-Information Science and Earth Observation, established in 1950 under the name International Training Centre for Aerial Survey (hence ITC), seeks to promote the sound application of geo-information technology through programmes of research, education and project services. To provide the scientific framework and basis for realizing the strategic goal, a solid new research programme has been developed that fits ITC's knowledge field, is problem- and output-oriented, is inter- and multi-disciplinary in character, and is embedded in the national and European scientific network. This programme comprises five, partly overlapping spearheads with the shared overall aim of strengthening civil society. The names of these spearheads are: Geoinformation Science and Earth Observation for

1. strengthening civil society
2. improving planning and management of multifunctional use of space
3. disaster management
4. better understanding of Global Change
5. water management, food security, and the environment

8.4 Examples of Student Programs

8.4.1 Program of scientific-educational microsattellites «Space to Youth, Youth to Space»

Objectives and Tasks

The main objective of the Program «SPACE TO YOUTH, YOUTH TO SPACE» is to teach schoolchildren and students based on the development, launch of micro-satellites and their operation by using of the ground control, data receiving and processing complexes. In the course of the Program implementation a wide range of educational, scientific and technological tasks will be solved [1, 3]. The Program foresees a design and launch of five satellites within 2003-2008.

Work Organization and Cooperation.

The program is presented by a noncommercial Interregional Public Organization “Association of Specialists and Young People for Creative Research in Space Technologies “Microsputnik” (IRPO “Microsputnik”) united highly qualified scientists and engineers from the Russian scientific, design and production organizations of rocket and space technology. Nine major organizations participated in the realization of the first micro-satellite “Kolibri-2000”(“Kolibri-1”) [2] (the English translation of Kolibri is hummingbird).

IRPO “Microsputnik” is engaged in implementation of the research and educational micro-satellite projects equipped with scientific hardware to perform fundamental and application studies of the near-earth space. Simultaneously, it develops and introduces methodical materials developed on basis of scientific and technical information obtained in the course of implementation of projects in the educational program.

The launch of the Russian – Australian micro-satellite “Kolibri-2000” (Project “Kolibri-1”), which was delivered to orbit on the 26th of November 2001 by the “Progress” cargo vehicle is the first implemented Program project. After a four-month stay onboard the International Space Station in the night from 19th into 20th of March 2002 following “Progress” separation the micro-satellite was launched, by use special transport

and launch container, in the autonomous flight. “Kolibri-2000” made 711 orbits around the Earth and on the 4th of May 2002 made a destructive reentry over the Pacific Ocean area.

The “Kolibri-2000” was composed of the instrumentation module, gravitational device, solar arrays, antennas (http://www.iki.rssi.ru/kolibri/mission1_e.htm). “Kolibri-2000” total mass was 20.5 kg, power consumption was up to 30 W. The scientific hardware (total mass 3.5 kg) consisted of two instruments:

- Three-component flux-gate magnetometer (“Mag-Sensors”, IKI);
- Particle and field analyzer (SINP, IKI).

The analysis of the first micro-satellite flight results confirmed a challenging Program implementation and gave full grounds to use micro-satellite “Kolibri-1” as a baseline for all series of micro-satellite in the Program frame.

At present time the second Program phase, “Kolibri-2” is at the implementation stage.

The Program was introduced at the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space held its fortieth session at the United Nations Office at Vienna from 17 to 28 February 2003 (<http://www.oosa.unvienna.org/COPUOS/stsc/2003/presentations/Tamkovich/sld001.htm>).

The Subcommittee continued to express its concern over the still limited financial resources available for carrying out the United Nations Programme on Space Applications and appealed to Member States to support the Programme through voluntary contributions.

References

1. Klimov, S.I., M.N.Nozdachev, G.M.Tamkovich, O.R.Grigoryan, A.N.Zaitzev, The research objectives in the frame of the program of scientific-educational micro-satellite. COSPAR Colloquium “Plasma processes in the near-Earth space: Interball and beyond, 5-1- February, 2002, Sofia, Bulgaria, Abstracts, p.82, 2002
2. Klimov, S.I., Yu.V.Afanasyev, N.A.Eismont, E.A.Grachev, O.R.Grigoryan, V.A.Grushin, D.S.Lysakov, M.N.Nozdachev. Result of in flight operation of scientific payload on micro-satellite “Kolibri-2000”. *Small Satellite for Earth Observation*. 4th International Symposium of the International Academy of Astronautics (IAA) Berlin, April 7-11, 2003. Editors: H.P.Roser, R.Sandau, A.Valenzuela, p. 95-98, 2003
3. Klimov, S.I., G.M.Tamkovich, V.N.Angarov, Yu.I.Grigoriev, O.R.Grigoryan, M.B.Dobriyan, M.N.Nozdachev, A.P.Papkov, I.V.Pharnakeev, V.V.Radchenko, S.I.Vasiliev, L.M.Zelenyi. Aerospace education program realization by means of the micro-satellite. *Small Satellite for Earth Observation*. 4th International Symposium of the International Academy of Astronautics (IAA) Berlin, April 7-11, 2003. Editors: H.P.Roser, R.Sandau, A.Valenzuela, p. 387-390, 2003

8.4.2 The PICO-Sat program

Status quo

Pico Satellites are small satellites with a total mass from 0.1 kg to 1 kg. CUBESATs are a standardized class of pico satellites characterized by a total mass of 1 kg and a particular dimension of 10cm x 10cm x10cm to fit in a special on orbit deployment device. They are defined from the Caltech Institute. It is a container for 3 CUBSAT spacecrafts. They can be released into orbit from an upper stage of the launcher or from another spacecraft. There first pico satellites from different nations (USA, Japan, Norway and other) are already in orbit. They were primarily developed by universities including students in all parts of development, qualification, implementation, test, launch and mission operations. The mission objectives are technology demonstration, education, or to solve some atmospheric or Earth remote sensing tasks.

Prospective

The pico satellite performance parameters like power, thermal control, duty cycle, attitude stabilisation and control or down-link bit rate are not comparable with parameters from larger satellites up to now. But in the future the implementation of parts and components of COTS mass production from different industry branches will allow to increase the performance of the spacecraft dramatically and keeping the costs low. Micro Electro-Mechanical Systems (MEMS) and micro machined structures will allow current missions to be done with pico satellites or to supplement with pico satellites for increasing the time coverage. Advanced

microcomputer technologies allow the implementation of high processing capabilities on-board of the satellites.

Advanced miniaturization technologies like MEMS enable also to build new sensor concepts or to increase the performance of small payload packages for pico-satellites. Payload instruments like cameras in the ultra-violet, visible or infrared wavelength region, imaging spectrometers in different wavelength ranges or atmospheric sounders, magnetic field sensors and others will be developed by means of high integrated technologies for pico satellites.

Increasing the spacecraft performance parameters of pico satellites and simultaneous decreasing the total costs by using mass products open new prospective for pico satellite missions. After a technology demonstration and development phase characterized by many single pico satellite missions in a next step a combination of many pico satellites to a multi pico satellite mission will begin. The multi pico satellite missions will be characterized by different approaches:

- to supplement a large satellite mission by several pico satellites for improving the mission performance by increasing the time coverage or additional spectral channels or additional instrument data or other observation angle (stereo capability)
- formation flying of pico satellites with different instruments and payloads for remote sensing of one target at the same time by different instruments
- forming multi mission concepts with a swarm of pico satellites with different payloads
- flying of different pico satellites in a satellite cluster what can build up a spacecraft formation on demand
- forming a "virtual satellite" by a network of co-orbiting satellites
- building a sparse aperture with a formation of pico satellites to overcome the small aperture of one pico satellite instrument for Earth remote sensing or extra terrestrial research
- other options.

The benefits of the prospective clusters of pico satellites can be summarized to:

1. New high performance capabilities
2. The performance of single pico satellites can be increased by using parts and components of the most advanced technology level. The performance of a cluster will be essentially improved by the multi-mission capability and the formation building opportunity. In the future large effective aperture sizes can be accomplished by flying a formation of high performance pico satellites. With pico satellite formations seems to be possible to build much larger apertures as with fixed or folding structures.
3. Reduced life cycle cost
4. The mass produced identical satellites reduce the manufacturing cost dramatically. Also the launch costs can be reduced.
5. Improved reliability
6. The single pico satellite should have an improved reliability because of a failure tolerant design and the implemented countermeasures against degradation. The constellation and cluster has a redundancy implemented and it shall be reconfigurable on demand.
7. Inherent adaptability
8. The cluster of pico satellites can be supplemented easily by new elements to accommodate changes in requirements. This assures a functional adaptability. Future technology advances can be integrated in a cost effective manner and assure a technological adaptability to the state-of-the-art technology level.

8.4.3 UNISEC (Japan)

In this chapter, brief introduction of UNISEC will be described, followed by Pico-satellite training projects and student-oriented real satellite projects supported and coordinated by UNISEC.

Background

UNISEC (University Space Engineering Consortium) is a non-profit organization that aims at facilitating student-oriented real space activities in Japan, such as development of nano-satellites and hybrid rockets. UNISEC obtained the status of legal entities from Japanese government in 2003, and has supported student space activities at university level in many ways including funding support, technological and legal problem consultation, organizing workshops or other collaborative activities, etc. UNISEC's primary objective is education for students, but also aims for activating Japanese space development by performing intensive

research into nano-satellite and hybrid rocket technologies and public outreach. Currently, UNISEC has 30 groups from 21 universities and colleges, and this number is continually growing, because more and more universities are getting interested in student-oriented hand-made space activities as effective educational opportunities.

Mission

UNISEC is committed to three missions:

1) Human Resource Development

UNISEC aims to contribute to human resource development in the space engineering field, providing participants with opportunities to cultivate technical skills and project management attitudes. Students and supporters can develop their human interaction skills as well as technical skills through thoughtful collaboration in pursuing real projects.

2) Technological Innovation

UNISEC continuously challenge participants to reach new heights of technological innovation. With fresh ideas generated by students and many hands available in many universities, "trial and error" methodology works effectively.

3) Outreach

UNISEC's important activities include the bridging between the space development pursued by the professionals and the general public, with the following two strong points. First, students are standing just at the middle point technologically and mentally between the general public and the professional. Secondly, universities are located in diverse areas, and it is effective for each university to collaborate with local communities. Diverse efforts have been considered and attempted to improve public awareness in collaboration with other communities and organizations.

Important Policy in UNISEC community

UNISEC respects the students' real-projects and outreach activities, not the paper projects, discussions without any implementations or criticism. Even though the barriers and obstacles apparently seem to be too big to tackle, challenges are encouraged and respected. The success is shared among other universities with the adulation, and the failures resulted after the challenges are also shared with others as important lessons learned.

Activities

UNISEC has supported students' real space projects in many ways, which include the following activities.

- Fund raising and financial support to student organized space projects.
- Planning and promotion of collaborative development and research among universities.
- Technical support for students' space projects.
- Assistance and negotiation for using ground test facilities of national institutions and private companies.
- Acquisition of launch opportunities in Japan and foreign countries, and arrangement of clustered launches.
- Acquisition of frequency permission through domestic and international negotiation.
- Acquisition of launch sites and safety assurance.
- Consulting legal matters to facilitate hand-made satellite and rocket activities.
- Building ground station networks in collaboration with universities all over the world.
- Outreach activities through organizing workshops open to the public, lectures and training classes.

Two examples of UNISEC activities and their outcomes are described in the following.

1) Pico-satellite Training Program - CanSat

CanSat is a juice-can sized satellite for training. It is launched up to 4 km using an amateur rocket, and fallen down with parachute. It takes 15-20 minutes to get to the ground, and the flight time of 20 minutes provides students with opportunities to perform various experiments such as communication with ground station, GPS experiment, camera mission, etc.

UNISEC has facilitated CanSat activities by offering financial supports for travel fees to US, publishing their activities on the web, and organizing workshop where students can exchange their experiences and knowledge. In order to provide more effective opportunities, UNISEC has organized “Comeback competition,” where a machine (a kind of satellite model) with a certain steering mechanism such as parafoil is to, after release in high altitude, come back to a target point autonomously without human interaction, and the one which comes nearest to the target point wins the competition.

2) Student-oriented Real Project – CubeSat

The highlight of UNISEC activities in 2003 was the success of two CubeSat nano-satellites developed by the students at University of Tokyo (<http://www.space.t.u-tokyo.ac.jp>) and Tokyo Institute of Technology (<http://lss.mes.titech.ac.jp>). These two satellites were the first successful on-orbit CubeSats in the world, and have been surviving for more than 18 months.

UNISEC has supported the projects by offering partial financial supports, organizing lectures and symposia open to general public, and publishing anecdotes about CubeSat projects on the web.

This success gave lots of incentives to the students of other universities in Japan, from which some groups plan to launch their first satellites in 2005.

Future Vision

UNISEC is a loose community where participants can be energized and motivated by participating the real activities, respecting each university’s features and strength generated by the diverse location and the unique background.

In the future, with a big project such as “sending CubeSat to the moon” or “global ground station network,” a taskforce will be formed and make an achievement in the real world.

<http://www.unisec.jp>

8.4.4 ESA Activities

Background Information on the Programme

The ESA Education Office has generated a series of activities targeted at primary, secondary and higher education and can be seen on the ESA Education Website [1].

The European Space Agency is committed to its mandate to encourage the youth of Europe to actively prepare for, and participate in, the building of their future through a better knowledge of (space) technology and sciences, with the aim of ensuring an appropriately skilled workforce into the 21st century.

The ESA Education Office coordinates all the education activities proposed by the various ESA Directorates and the Education Office itself. The aim is to help young Europeans, aged from 6 to 28, to gain and maintain an interest in science and technology by organising or informing them about various activities designed for their specific age group.

ESA's Education Office has a number of external partners. These can be national agencies, industry, associations working with young people, universities, editors, broadcasting channels, museums, etc. In order to be listed, organisations should have special activities or agreements with ESA in the field of education.

EDUnews

EDUnews will help you to keep up to date with all the latest news and events in the space-related educational field, both in Europe and beyond. The publication is free of charge and can be sent either in hard copy or direct to your email address.

IAF Student Participation Programme

The annual Student Participation Programme to the IAF Congress is one of the ESA Education Office main activities. It is an annual programme that started in 1999 bringing over 450 students from all over Europe to the IAF Congress in Amsterdam.

More than 1000 students have enjoyed this unique Education programme and participated in the numerous congress sessions and social events bringing about a "generation handover" of the space expertise in all the parts of the world.

Throughout the Congress, the students have the chance to interact with professionals, and learn from their expertise and listen to their views on the future of space. The students are incorporated into the congress as

normal participants, bringing an appreciated element of youthful energy into the Congress rooms. The Congress mainly attracts students majoring in space studies. However, past years have involved a large fraction of students who are not studying core space topics but subjects in related fields (e.g. engineering, law, medicine, etc.). For many students this is a lifetime opportunity and results in strong motivation towards their studies and future career path. The students are invited to propose papers. Abstracts will be judged and high quality papers's authors will have the opportunity to either present their paper in a technical or student session or present a poster at the ESA Student Stand in the exhibition area.

COSPAR 2004

ESA's Education Office started a new initiative to enable top students to participate in the Scientific Assembly of the Committee on Space Research, in Paris in July, 2004.

In collaboration with the directorate of Earth Observation and the directorate of Space Science, the Education Office provided grants to 19 European students (13 students from universities in ESA member states, six students from Russia, Ukraine, Poland or the Czech Republic) to enable them to take part in the 35th Committee on Space Research (COSPAR) Scientific Assembly.

The selection was based on the scientific content of the abstracts submitted by students through the regular process on the COSPAR web page.

[1] <http://www.esa.int/export/esaED/index.html>

8.4.5 IAA

At the 4th IAA Symposium on Small Satellites for Earth Observation, April 7-11, 2003, Berlin, IAA started a new event: The Student Prize Paper Competition. In response to the call for student papers, the authors needed to submit extended 4-page abstracts. The best six papers have been selected by an Student Paper Evaluation Committee (SPEC) with distinguished judges from academia, industry and government coming from three continents. The six finalists presented their papers on a special session of the symposium. The prizes of the best papers have been funded by different international entities (space agencies, industry, academia). Travel funds were provided by DLR and NASA.

The Student Prize Paper Competition was continued at the 5th IAA Symposium on Small Satellites for Earth Observation in Berlin, April 4-8, 2005. The SPEC was extended to distinguished judges coming from five continents now.

www.dlr.de/iaa.symp

9 CONCLUSIONS AND RECOMMENDATIONS

This study was performed by an IAA study group, formed in 2002. The members of the study group represent different entities (governmental organizations, space agencies, academia, industry) as well as different disciplines (science, engineering, application oriented professions, and management). The geographic distribution of the 36 authors of this study covers 15 countries on five continents. Under these circumstances there was an opportunity to generate a study unbiased in every aspect, intended to serve the information needs of the target groups: Governments, space agencies, academia, industry, which rely on good overview information concerning status and possibilities/prospects of cost-effective Earth observation missions in the very broad variety of applications.

In this study we have presented the state of the art of small satellite missions and examined the factors that enable one to produce a cost-effective small satellite mission for Earth observation. We find that, while there are several examples of such missions flying today, the lessons that must be learned in order to produce cost-effective small sat missions have neither been universally accepted nor understood by all in the space community. In this study we intend to point out how a potential user can produce a cost effective mission. One of the key enablers of designing a cost-effective mission is having the key expertise available. As the number of successfully space-faring nations grows, the pool of expertise available to meet the challenges of small mission grows.

9.1 General Facts

Cost-effective missions can be achieved by using different approaches and methods.

Since the advent of modern technologies, small satellites have also been perceived to offer an opportunity for countries with a modest research budget and little or no experience in space technology, to enter the field of space-borne Earth observation and its applications. This is very much in line with the charter of the IAA Study Group on Small Satellite Missions for Earth Observation. One of its intentions is to bring within the reach of every country the opportunity to operate small satellite Earth observation missions and utilize the data effectively at low costs, as well as to develop and build application-driven missions. In this context the study group supports all activities to develop and promote concepts and processes by various user communities to conduct or participate in Earth observation missions using small, economical satellites, and associated launches, ground stations, data distributions structures, and space system management approaches.

More generally small satellite missions are supported by four contemporary trends:

- Advances in electronic miniaturization and associated performance capability;
- The recent appearance on the market of new small launchers (e.g. through the use of modified military missiles to launch small satellites);
- The possibility of 'independence' in space (small satellites can provide an affordable way for many countries to achieve Earth Observation and/or defense capability, without relying on inputs from the major space-faring nations);
- Ongoing reduction in mission complexity as well as in those costs associated with management; with meeting safety regulations etc.;
- the development of small ground station networks connected with rapid and cost-effective data distribution methods
- and cost-effective management and quality assurance procedures

One of the possible approaches is taking full advantage of the ongoing technology developments leading to further miniaturization of engineering components, development of micro-technologies for sensors and instruments which allow to design dedicated, well-focused Earth observation missions. At the extreme end of the miniaturization, the integration of micro-electromechanical systems (MEMS) with microelectronics for data processing, signal conditioning, power conditioning, and communications leads to the concept of application specific integrated micro-instruments (ASIM). These micro- and nano-technologies have led to the concepts of nano- and pico-satellites, constructed by stacking wafer-scale ASIMs together with solar cells and antennas on the exterior surface, enabling the concept of space sensor webs.

The advantages of small satellite missions are:

- more frequent mission opportunities and therefore faster return of science and for application data
- larger variety of missions and therefore also greater diversification of potential users
- more rapid expansion of the technical and/or scientific knowledge base
- greater involvement of local and small industry.

But of course, generally applicable rules of space law continue to apply, where relevant, also in the area of small satellite missions.

After some years of global experience in developing low cost or cost-effective Earth observation missions, one may break down the missions into categories like:

- Commercial – Requiring a profit to be made from satellite data or services
- Scientific/Military – Requiring new scientific/military data to be obtained
- New technology – Developing or demonstrating a new level of technology
- Competency demonstration – Developing and demonstrating a space systems competency
- Space technology transfer/training – Space conversion of already competent engineering teams
- Engineering competency growth – Developing engineering competence using space as a motivation
- Education - Personal growth of students via course projects or team project participation

In this study we consider large satellite missions and small satellite missions being complementary rather than competitive. The large satellite missions are sometimes even a precondition for cost-effective approaches.

9.2 Conclusions and Recommendations Drawn from the Background Material in Chapter 3

The background material reviewed in Chapter 3 summarizes the key conclusions and recommendations that are also applicable to cost-effective Earth observation missions.

IAA Position Paper on Inexpensive Scientific Satellites

The IAA Position Paper on Inexpensive Scientific Satellites provided some particularly useful background material on management. In particular, the program must be started with a clearly identified specification and the program duration must be minimized. To achieve control over the program duration one must reduce the number of models of the subsystems, avoid technical risk in mission-critical areas, and minimize the total number of people on the team. To hold the team size to a minimum one must minimize the number of external interfaces and minimize the administrative burden. That Position Paper pointed out that innovative engineering solutions should be sought out but care must be taken to only count on or implement technologies with an acceptable risk. Risk can be reduced by reducing complexity – and interfaces add complexity. Therefore one should adopt simple well-defined subsystem interfaces, encourage a modular design and use “off-the-shelf” solutions where practical. These should be tested at the box- and system-level. The cost to launch and the reliability of the launcher has long been recognized as a key to whether the mission will be cost-effective. Part of that process is the identification of reliable flight opportunities, especially shared rides (with the proviso that the interface as a secondary payload must not interfere with the primary payload and must use a well-proven interface to that primary payload). That report also identified the need for a robust infrastructure that could provide local expertise to solve problems and pointed out that small companies and universities can provide assistance at times.

IAA Position Paper: The Case for Small Satellites

The Position Paper concludes that there is a rationale for considering small satellite missions as a means of satisfying the needs of developed as well as developing countries. Governments and research institutions of all countries are urged to study, undertake and support small satellite programs for research, educational and applications purposes in accordance with their current technical and financial capabilities. The industrialized countries should take the lead in gathering and disseminating information, the developing nations should undertake to accede to, and to increase, such information. Particular encouragement should be given by the industrialized countries to projects that provide education motivation and launch opportunities should be made available by the operators of launch systems with reasonable conditions; raw data from Earth observation should be made available on a non-discriminatory basis for research and civilian applications to all countries.

EC Study COCONUDS

COCONUDS noted that while much current attention is on high resolution satellite systems, there are a considerable body of users who would welcome a more modest – but more frequent – imaging capability (that is 30-50m; 4 band). Invariably these users are quasi-operational, locally focused and resource-poor (either in funding or equipment).

One key finding has been in the dissemination of appropriate data. Broadly speaking COCONUDS confirms the user-attractiveness of low cost direct data reception of a local region. This concept, championed by NOAA meteorological satellites for many generations, has a limited audience among the more classical Earth observation satellites because of their large data sets. COCONUDS, however, concludes that many users simply require local data and would be satisfied with compressed imagery. As a result low cost reception is entirely feasible.

Recommendations of UNISPACE III

It was in particular recommended, inter alia, that the joint development, construction and operation of a variety of small satellites offering opportunities to develop indigenous space industry should be undertaken as a suitable project for enabling space research, technology demonstrations and related applications in communications and Earth Observations.

Conclusions from UN Activities

The Committee on the Peaceful Uses of Outer Space (COPUOS) set up by the General Assembly in 1959 currently forms the focal point of United Nations activities in the field of outer space. This Committee (with its two Subcommittees) has, since its inception, promoted international co-operation in developing the peaceful exploitation of outer space, in this regard functioning successfully against the changing political background characterising the transition from the pre to the post cold-war era.

The Office for Outer Space Affairs provided the substantive secretariat for three United Nations Conferences on the Peaceful Uses of Outer Space (UNISPACE I, II and III), held in 1968, 1982 and 1999 respectively. At UNISPACE III, it was recommended, inter alia, that the joint development, construction and operation of a variety of small satellites offering opportunities to develop indigenous space industry, should be undertaken as a suitable project for enabling space research, technology demonstrations and related applications in communications and Earth Observations.

Countries ‘emerging in space technology’ are defined to be those with a technical knowledge base and some space experience which are striving for small satellite missions to exploit the new, cost effective, possibilities they offer. An IAA Subcommittee was formed in 1997 to support the aspirations of this multi-national community. Structures within COPUOS to support these countries in their efforts to gain access to space using small economical satellites, still need to be established.

Since UNISPACE III, five Workshops, held respectively in Brazil (2000), France (2001), the U.S.A. (2002), Germany (2003), and Canada (2004), aimed at advancing the general theme of Small Satellites in the Service of Developing Countries, have been jointly mounted by the UN/OOSA and the Subcommittee on Small Satellites for Developing Nations of the IAA within the framework of the IAC. These Workshops have acted as tools to advance the aspirations of Developing Countries with respect to the acquisition of small satellite technology. The individual workshops considered in this regard the Latin-American experience, the African perspective and how, in general, small satellite programs contribute to the development within particular countries of their indigenous scientific and applications programs. Recommendations for future work were, on each occasion, formulated.

9.3 Additional Recommendations from this Study

The situation in the field of small satellite missions for Earth observation has matured in the last ten years. This may be, for instance, observed from the topics and the quality of contributions to the series of, to date, five biannual IAA Symposia on Small Satellites for Earth Observation in Berlin, Germany. The 5th Symposium took place in April, 2005.

We propose a simplified nomenclature for subsets of small satellites:

- mini satellites < 1000 kg
- micro satellites <100 kg
- nano satellites <10 kg
- pico satellites <1 kg.

At UNISPACE III, the costs of developing and manufacturing a typical mini-satellite was indicated to be US\$ 5-20 million, while the cost of a micro-satellite was correspondingly US\$ 2-5 million. The cost of a nano-satellite could be below US\$ 1 million (prices as of 1999). Whereas the development and production time for large satellites is observed to be 15+ years, the corresponding time for minis should be 3 – 5 years, for micros 1.5 years, for nanos about 1 year, and for picos less than 1 year. Of course, cost and duration figures are to be considered ball park figures. They are based on the usage of state-of-the-art technology by professional teams. They may deviate considerably if key technology is to be developed and/or the implementation teams are at the beginning of the learning curve.

There is no single, accepted, broad method for reducing mission cost. Instead, the builders of low-cost missions are aggressive competitors, just like their more expensive colleagues who create large programs for ESA, NASA, or the US Department of Defence. Each low-cost program has found and have to find a set of solutions to fill its particular need and programmatic style. Table 9.3-1 gives a summary of cost reduction methods which are selectively used by the builders of low-cost missions.

Table 9.3-1: Cost Reduction Methods

Method	Mechanism	Comments
Programmatic		
Schedule Compression	Reduces overhead of standing army; forcing program to move rapidly does drive down cost	Often results in a poor design due to lack of up-front mission engineering; must reduce work required to be consistent with schedule
Reduce Cost of Failure	Allows both ambitious goals and calculated risk in order to make major progress	Fear of failure feeds cost-growth spiral; major breakthroughs require accepting the possibility of failure—particularly in test
Continuous, Stable Funding	Maintains program continuity; maintains team together	Program delay will be funding break + 2-4 months
Minimize Documentation	Reduces programmatic overhead for creating, reviewing, and maintaining	Critical to document reasons for key decisions and as-built design
Personnel		
Improved Interpersonal Communications	Dramatically reduces errors and omissions; conveys understanding as well as data	Large programs use formal, structured communications through specified channels
Small Team	Clear, nearly instantaneous communications; high morale; strong sense of personal responsibility	Problem if a key person drops out — but in practice it rarely happens.
Co-located Team	Improves communications	Best communications are face-to-face, but AMSAT and others don't seem to need it
Empowered Project Team	Rapid decision making; strong sense of personal responsibility; can make “sensible” decisions	Eliminates a major function of the management structure

Systems Eng.		
Trading on Requirements	Eliminates non-critical requirements; permits use of low-cost technology	Makes traditional competition difficult
Concurrent Engineering	Allows schedule compression; reduces mistakes; increases design feedback	High non-recurring cost relative to lowest cost programs
Design-to-Cost	Adjusts requirements and approach until cost goal has been achieved;	Spacecraft have rarely used it
Large Margins	Reduces testing; better flexibility; reduces cost of eng, manufac., and ops	Margins traditionally kept small for best performance — drives up development cost
Technology		
Use COTS Software	Immediate availability; dramatically lower cost; tested through use	May need modification and thorough testing; typically not optimal
Use COTS H/W	Same as software	Same as software
Use Existing Spares	Reduced cost; rapid availability; meant for space	Only works so long as spares exist — not applicable for operational programs
Use of Non-Space Equipment	Takes advantage of existing designs and potential for mass production	Typically not optimal; must be space qualified
Autonomy	Reduces operations costs	Can increase non-recurring cost
Standardized Components and Interfaces	Reduces cost and risk by reusing hardware; standardization is a major req. for other types of manufacturing	Has been remarkably unsuccessful in space; sub-optimal in terms of weight and power
Extensive Use of Microprocessors	Minimizes weight; provides high capability in a small package; allows on-orbit reprogramming	Problem of single-event upsets; high cost of flight software; very difficult to manage software development
Common S/W for Test and Ops	Reduces both cost and schedule; avoids reinventing the wheel	May be less efficient, user-friendly than ops group would prefer

To reduce cost, alternatives to dedicated launches of satellites should also be taken into consideration (see Table 9.3-2). Although each of the alternatives has limitations, dramatic reductions in cost are possible for missions such as equipment testing that do not necessarily need a long period on orbit.

Table 9.3-2: Alternatives to Dedicated Satellites

Option	Characteristics	Mass Limits	Principal Constraints	Approximate Cost	Sources
Balloon Flights	Hours to days at \approx 30 km altitude	Up to 70 kg for low-cost flights	Not in space, not 0-g, weather concerns	\$5K to \$15K	U. of Wyoming, USAFA, NSBF
Drop Towers	1 to 10 sec of 0-g with immediate payload recovery	Up to 1,000 kg	Brief "flight," 5 to 50 g landing acceleration, entire experiment package dropped	\approx \$10K per experiment	ZARM, JAMIC, NASA LeRC and MSFC, Vanderbilt U.
Drop Tubes	1 to 5 sec of 0-g with immediate sample retrieval	<0.01 kg	Brief "flight," 20 to 50 g landing acceleration, instrumentation not dropped with sample	\approx \$0.02K per experiment	ZARM, JAMIC, NASA LeRC and MSFC, Vanderbilt U.
Aircraft Parabolic Flights	Fair 0-g environment, repeated 0-g cycles	Effectively unlimited	Low gravity is only 10–2 g	\$6.5K to \$9K per hour	NASA LeRC and JSC, Novespace
Sounding Rockets	Good 0-g environment, altitude to 1,200 km, duration of 4 to 12 minutes	Up to 600 kg	Much less than orbital velocities	\$1M to \$2M	NASA GSFC, NRL, ESA/Sweden, OSC, EER, Bristol Aerosp.
GAS Containers	Days to weeks of 0-g on board the Shuttle	Up to 90 kg	Very limited external interfaces	\$27K for largest container	NASA GSFC
Secondary Payloads	Capacity that is available in excess of primary's requirements	Up to \approx 1,000 kg	Subject to primary's mission profile	<\$10M	Ariane, OSC, MDA, Russia
Shared Launches	Flights with other payloads having similar orbital requirements	Up to \approx 5,000 kg	Integration challenges	Up to \approx \$60M	Ariane, OSC, Russia

Cost-effectiveness also depends on the quality and engagement of the specialists participating in planning and implementing an Earth observation mission. Countries taking their first steps in space need to learn relevant techniques from more experienced space users, thereby acquiring a cadre of appropriately trained personnel before going on to establish a national agency and to maintain a presence in space. Technology transfer through small satellite related training programs has been successfully implemented between Surrey University in the U.K. and customers in Chile, Malaysia, Pakistan, Portugal, the Republic of Korea, South Africa and Thailand.

Small satellites programs provide a natural means for the education and training of scientists and engineers in space related skills since they allow direct, hands-on, experience at all stages (technical and managerial) of a particular mission (including design, production, test, launch and orbital operations).

Different Earth observation applications need different approaches for cost-effective missions. The individual prospects are shown in chapter 7 "Application Fields, Status Quo and Prospects". The general prospects for disaster warning and support (chapter 7.1) may serve as an example. They can be grouped into the following main topics: **space, ground, and program segment**:

Trends in the space segment

The trends of technology development in the space segment relevant for disaster management are characterized by:

- Higher performance of micro-satellites busses due to new developments on the component and subsystem level like onboard computers, data handling systems, transmitters, solar arrays, batteries, GPS-receiver and others,
- Higher performance of optical payloads for small satellites suitable for disaster monitoring tasks (high geometric and radiometric resolution, more spectral channels),
- Investigation of the feasibility of passive Radar (SAR) micro-satellites flying in formation with an active Radar satellite,
- Low-cost satellite technology makes operational satellites affordable for dedicated constellations,
- Novel international partnerships show new ways for new space nations to achieve effective systems through collaboration,
- Building of disaster monitoring constellations with small and micro-satellites,
- Decreasing the revisit time for monitoring tasks by using different satellites and constellations,
- Experimental on-board remote sensing data processing to produce a high level data product.

In summary, one can say that small satellites can provide data more quickly with a better match to user needs.

Trends in the ground segment

The trends in technology development for the ground segment relevant to disaster management are characterized by:

- Increasing the flexibility of mission operations of satellites by building a flexible ground segment,
- Building of networks of ground stations for increasing the satellite operational performance and data access without time delay,
- Improving response time in imaging according to user requirements,
- Data processing and distribution to the final user without delay,
- Data policy is in many cases to restrictive for fast disaster response and must be addressed beforehand,
- Distribution of data and algorithms for support of disaster management using COTS products running on personal computers will enable better use of the data,
- Distributed permanent GNSS stations with radio links for fast data transmission are available to a certain extent and have to be extended,
- Very small ground stations for in-situ measurements with data transmission facilities via satellites are available and they are independent on existing infrastructure,
- Data processing and modeling of disaster conditions by experts are in progress, but there are gaps in the information extraction process for decision makers,
- The disaster information has to be simplified for the users,
- The education related to use space technologies has to improved.

In summary, technology developments in the ground segment address networking, improving response time and providing user-oriented space-segment control. The education in using spaceborne data has to be improved but also the information extraction process for decision makers has to tailored and optimized to their needs.

Trends in the programme segment

The trends in the programme segment of cost effective Earth observation missions for disaster warning and support are focused on new applications and new data products. Some key points are:

- Tele-health applications are important for disaster management and should be extended,
- Medical weather maps should be integrated in tele-health applications,
- Tele-education should be built up for disaster applications,
- National disaster preparedness should be improved and should include the appropriate use of the space segment,

- New monitoring applications using space technologies (GPS) should be applied to rescue teams and people in high risk areas,
- For disaster management, space sensors are part of the spectrum of sensors that includes ground- and aircraft-based systems,
- New airborne platforms such as UAVs (Unmanned Air Vehicle) or transportable tethered balloons or dirigible airships (EU proposal) may augment the space segment,
- Integration and fusion of data from all available sources and the development of models related to disaster conditions are progressing on an expert level,
- Multi-temporal analysis of regional changes and conditions basing on already existing satellite data is currently done by experts and can be simplified or improved,
- “Expert systems” need to be developed to aid decision makers; these new and simplified tools must be improved and/or developed to make the data useful.

In summary, tele-health and tele-education applications should be included in a disaster monitoring program. In addition, the entire spectrum of assets, from ground to space, must be integrated into an environment that provides the information needed to make decisions. This “expert system” needs to be developed: too much of the data is of meaning to, and accessible to experts and too little is in a form that can be used for disaster relief and mitigation.

9.4 The Future of Cost-Effective Earth Observation Missions

In this study we have considered the past experience of the global small satellite community and reviewed and incorporated the work of other studies and bodies that deal with disseminating information about small satellite missions and in promoting the appropriate use of such technology and we have surveyed the state of our current knowledge. This study brings to light new capabilities as well as challenges that must be addressed in order to produce successful, cost-effective small satellite missions.

9.4.1 New capabilities

There are three new developments that may prove to greatly enhance the capabilities of small satellite missions. These are:

- 1) the convergence of data acquisition and data visualization technologies
- 2) the ready availability of new small launchers and the rise of “space tourism”
- 3) the development of smaller, lighter, lower power satellites that can act as a constellation or independently

While there are many other developing technologies that hold promise, these factors may well transform the small satellite enterprise in the next ten years. A mission can be cost-effective and achieve all its measurement requirements without having to actually make all the measurements itself. To put this in concrete terms, NASA has a series of research satellites (Aqua, CloudSat, CALIPSO, PARASOL, Aura, and OCO) called the “A Train” that fly in formation. These satellites make individual measurements that support cross platform science. Many of the instruments that image the surface also use ancillary information, such as digital elevation maps, to add context to their products. One could readily envision a small satellite mission that was intended to provide some niche product, such as crop yield forecasting, in a particular region. Such a small satellite could produce a very specific measurement, say normalized difference vegetative index (NDVI), which would be corrected for aerosols and clouds using data from the A Train. With such a tightly defined measurement requirement, the spacecraft resource requirements could be quite small and the data system could be designed for “store and forward” operations with the data pushed to the analysis site over the internet. Another approach, as evidenced in SSTL’s DMC, is to decrease the ground repeat delay by forming a cooperative that shares data which are produced among the elements of the constellation. Membership is acquired by contracting for the production of an element of the constellation. Each member of the cooperative then gets the benefit of a much shorter revisit time. In short, the economies of scale begin to operate as more members join the cooperative.

Getting into space is still a challenge. During the last ten years there have been more small launchers available and at prices that are quite reasonable compared to the cost of a small satellite. One of the newest and, potentially, most vigorous areas of development of small launchers has come about under the impetus of “space tourism”. On October 4th, 2004, Burt Rutan and Paul Allen, built and flew the world’s first private

spacecraft to the edge of space to win the \$10 million Ansari X PRIZE. Perhaps the early history of the development of commercial aviation presages the next twenty years of space access. At the turn of the century, air travel was relatively risky and quite expensive. As the commercial market for air transport grew costs dropped as did risk. Now, air transport is so cost-effective that it is used to ship bulky agricultural goods, such as apples, half way around the world at prices that are competitive with local transport and production. To make space tourism viable the cost of putting a person in space will have to be reduced to the order of \$1M. At those kinds of costs for mass to orbit, small satellite missions will no longer be strongly constrained by launch costs. If we step back from the purely speculative, commercial launch services are now available on most launch systems, many of which are new vehicles designed or modified specifically for international commercial market. The most dramatic shift has been the entry of the Russian and Ukrainian launch systems operated as joint ventures with US or European companies. New launch systems around the world are even beginning to use major components built in other countries, further blurring national divisions. This international trend is important because some nations still insist on the use of a “national” launch capability. The increasing availability of these low-cost launchers and the development of dispensers has opened up possibilities for single launches of a constellation as well as individual payloads. The launch of the NASA / DLR GRACE satellites used Eurokot Launch Services, the joint venture owned by Astrium and the Russian company Khrunichev, to place two satellites in a closely controlled formation via a dispenser. This launch was the first commercial use of the Russian SS-19 ICBM which provides the two booster stages for the ROCKOT launch vehicle with a heritage of 150 flights. At the other end of the cost and mass spectrum, Ariane 5 has been used to launch 6 auxiliary payloads along with the primary Helios satellite. This included Nanosat, Spain's first small satellite, built by the country's INTA national space agency (Instituto Nacional de Técnica Aeroespacial), with a mass of less than 20 kg. In another example, the Cluster mission formed a constellation of four satellites, flying in formation, using two separate launches.

Once the spacecraft are in orbit, the remaining costs are largely associated with operating the spacecraft (including monitoring its health and safety) and collecting the data. As the number of spacecraft increases in a constellation there would be, without a change in the operations paradigm, a concomitant increase in the costs to operate the constellation. In order to have a cost effective constellation of micro- or nano-satellites the operations costs have to be low on a per satellite basis especially since some of these constellations are envisioned as consisting of tens or even hundreds of micro- or nano-satellites. Powerful, cheap, microprocessors provide the means for increased autonomy at the individual satellite level and across the constellation. At issue, though, is developing the software to perform these operations and subsequently testing the software so that its operation can be verified before flight. Qualifying these systems for spaceflight will be a challenge that must be addressed.

9.4.2 Challenges

The biggest long-term challenge for the small satellite community is that of developing a robust commercial market that supports the infrastructure that has been developed to produce small satellites. Small satellites have appealed to some nations as an instrument of national pride and as a means to focus and enhance the industrial base as well as providing a means of attracting students to a high tech industry. This is, of course, a finite market. After the first few satellites there has to be reason other than becoming a space-faring nation to invest in, develop, and fly the next space mission and continue the development and training of students. To develop a robust market, small satellite manufacturers must remain relevant and cost-effective. It appears that in many markets space technology has entered the era of diminishing returns – for example, if you can achieve imagery from space with a spatial resolution of about one meter, do you really gain anything marketable by imaging at one centimeter? This plateau effect means that more vendors can aspire to provide the same product. How many suppliers can the market support? It may be that the market can support more suppliers of imagery if revisit time is a key driver. The user then must draw products from several sources and understand enough about each independent data source so that the desired product can be produced. Raw data products, though, are not likely to capture many more users: tailored products that address specific needs can be supplied by small satellites. The vertical integration of the industry, to provide instruments, data and integrated data products, is likely to spur significant growth.

Until that robust commercial market has been developed, government support will continue to be the financial mainstay of the small satellite community. This situation will remain in force until some economies of scale can be achieved. At this time, SSTL and RapidEye are two notable examples of commercial ventures

that have achieved some stability. They did this by identifying and cultivating a niche market that they are able to address. Much of the small satellite community is still tied to education and research activities – activities that rely on government support. Inter-government cooperative agreements provide the means of broadening the opportunities available to the community. Bureaucracies are averse to risk, however, and small organizations and cooperative agreements are often viewed as risky.

Managing risk is a key problem, then. Since no complex system can be designed and tested against all failure modes, experience is often the best and only guide to making trades. Large organizations tend to have more restrictions on what can fly and may have stringent risk assessment processes. In NASA terms the confidence in a subsystem or system is called the Technology Readiness Level or TRL of the item. Higher TRLs mean the element has significant flight experience. The highest TRL is assigned to elements with direct flight heritage. Small satellites can be quite effective as platforms to raise the TRL of an element to be used in a latter design. The challenge faced by the small satellite community is to gain a broader acceptance of the notion that TRLs can be raised as an integral part of a mission rather than by implementing a dedicated mission such as the JPL-led Deep Space missions.

Making small satellites more cost-effective calls for new technologies but who then pays to certify these new technologies for spaceflight? There is certainly a higher risk associated with unproven technology. For example, the ready availability of large format detectors at relatively low cost shifts the design choices from being driven by the detector resolution to being driven by other factors such as the interplay between spacecraft stability and off-nadir pointing capability or downlink bandwidth and onboard storage, etc. Can a system be designed that can use these new detectors? How do they behave in space? A small mission is arguably the best way to perform a flight verification because even a failure to operate on orbit, or even to achieve orbit, can still be a successful demonstration from an educational or developmental viewpoint. Cost-sharing between a larger richer, risk-averse partner and a smaller, poorer more risk-tolerant partner may prove beneficial to both parties.

9.4.3 Success and Failure of Cost-effective Missions

In this study we have examined both what we know about small satellites and their uses for Earth observation. What makes a mission cost effective? The simplest answer is that the desired end is achieved for a price that is acceptable to all parties. While some mission objectives may only be achieved by the large, complex instruments and spacecraft, there are many uses for small missions. For many potential customers the best price point is established by sharing risk. If the risk is borne broadly, even a failure to achieve launch can still yield a cost-effective mission because the partners view the educational and infrastructure return as sufficiently high and the other shared aspects of the partnership yield some of the required information. To remain cost-effective in the commercial arena, small missions must be able to incorporate new technologies that reduce costs and improve performance. Small satellite missions face growing competition in regional markets from GPS-based solutions, UAVs, balloons, and sensor webs, for example. The chief advantage of satellites is their global access. Exploiting that, and successfully marketing that advantage will hold the long-term key to keeping small satellites cost-effective.

Assessing whether a mission is successful or not involves many different measures. Assuring that a small-satellite mission is considered successful means that these differing measures must be addressed and considered in the design of the mission. Some of these measures of success are, in fact, much more likely to be fulfilled by a small-satellite mission than a large one. For example, students are much more likely to be involved in a small satellite mission. The experience gained in the design, construction, test, flight, operation, and data analysis phase of the mission will guarantee “success” in terms of the educational experience of the students. Small satellites can demonstrate new technologies or measurement techniques. If they achieve these goals they are “successful” even if the scope of the goal is small (for example, a small satellite mission need not inventory the global carbon budget but it could provide a measure of the amount of carbon produced in boreal forest fires). In terms of impact at the national level, a small satellite that is produced by a country may well evoke more pride of ownership than an instrument or participation in a large-scale investigation. In this study we have laid out the reasons how to design and implement a small cost-effective Earth-observation mission. In the end, success is subjective: the true measure is whether the program continues and flourishes.

Appendix 1

Small Satellite Application Aspects drawn from UN Documents

1 Telecommunications

Telecommunications activity potentially involves many applications. In the position paper prepared for UNISPACE III, related discussions were restricted to those remote and mobile communications (including messaging, electronic mail and localization), that could be established using small satellites in Low Earth Orbit LEO.

Utilization of LEO enables the introduction of many services for example communications between a portable terminal similar to that employed in cellular telephone communications and a normal telephone located in an existing, fixed, telecommunications network. This latter solution can be attractive to users in remote areas/regions lacking communications infra-structure. In addition, communications can be established between a mobile user and the user of a fixed network system located anywhere in the world.

Use of automatic data collection platforms in conjunction with the two-way characteristics of LEO communications, allows the installation in space of a collection network featuring wide coverage and a 'real-time' service. Further, LEO communication systems can usefully determine the location of any user of a mobile terminal (in 1999 the location accuracy was ~ 100m). In addition, the facility can be usefully coupled to a facsimile machine for the transmission of graphical data (e.g. an electro-cardiogram)

Telemedicine is an application that allows the transmission of information obtained by cheap, simple sensors sited in remote areas to complex processing units in large medical centers - where these data can be interpreted by specialists. An example of this process is provided by the HEALTHNET project which employs a 60 kg micro-satellite (HealthSat) flown in LEO to relay medical data recorded in a number of African countries to North America.

Mobile communications can play an important role in the circumstance of a large natural disaster. In such situations, help can be summoned to reach the disaster victims with minimum delay; also mobile communications can provide rescue teams with important logistical support.

Since in 1999 LEO communications systems were specifically configured to exploit the large market for this service present in Developed Countries, it was perceived at UNISPACE III that efforts should also be made to use this technology to solve problems pertinent to those populations occupying large remote areas within Developing Countries. Lest the costs concerned would turn out to be prohibitive, Developing Countries that could benefit from the technology were encouraged to carefully establish their minimum needs as an input to required processes of international co-ordination - such as appropriately regulating the radio frequency spectrum. It was foreseen that the carefully considered introduction of this technology would, thereafter, bring the benefits of education and social development to needy regions.

An example of 'needs definition' by a Developing Country is provided by the ECO-8 project conceived in Brazil. Most of this latter country is in the tropical zone where it was realized that eight (or possibly twelve) small satellites in low inclination orbits would be sufficient to meet Brazil's need for communications coverage rather than utilize the expensive services offered at the time by the Iridium (66) and Globalstar (48) satellite constellations.

2 Earth Observations

Earth Observation applications cover activities related to data collection and to imagery. Already by 1999, low cost small satellites could provide affordable multi-satellite networks that allowed observations to be made anywhere on the Earth's surface with a cadence of about twelve hours. The special topographical features of each country required dedicated observation scenarios to be set up in order to derive maximum benefits from the technology. At the time of UNISPACE III, Brazil and the Republic of Korea were already in course of developing customized national programs, while Latin America and South-East Asia still required the acquisition of a variety of related indigenous capabilities/technical expertise.

Sustained development within a country can be supported through local monitoring, and control of the exploitation, of its natural resources (e.g. through obtaining regular, global, satellite information concerning the depletion of the Rain Forest, a long term strategy to sustain this resource can be put in place, while installing, in parallel the logistics necessary to contemporaneously support human land settlement and employment).

Remote sensing using low-cost space systems which allow direct down-linking of data to various, small, ground stations, eliminates the need for a centralized processing and distribution system while yet providing the advantages of: real-time access to the observations concerned; small size databases and easy information distribution within areas not well served by communications systems. In some Developing Countries, monitoring of: forest and brush fires; pollution; fishing and storms are a sine qua non. In the area of disaster prevention, demands exist for earthquake forecasts, early detection of tropical storms and predictions of volcanic activity.

Constellations of polar orbiting, and geo-stationary, meteorological satellites were noted at UNISPACE III to potentially allow for cost sharing between partners and for the comparison of complementary data taken within particular regions. Also, advances in sensor technologies presented interesting possibilities to equip the constituents of new small satellite constellations with, say, payloads featuring only a single instrument - thereby reducing the impact of the failure of an individual member of a particular constellation. A philosophy associatively proposed was commercialization, whereby the private sector could assume the role of building, launching and operating environmental monitoring satellites while the measured data were made available for purchase through organizations such as national meteorological and hydrological services.

3 Scientific Research on Small Satellites

Examples of small scientific satellites launched by Developing Countries are provided by FASat (Chile) which monitors ozone depletion, and KITSAT from the Republic of Korea which monitors geo-magnetically trapped particles.

A special advantage accruing to the availability of low cost, small, satellites is the possibility they offer to measure simultaneously particular physical parameters at a variety of spatial locations. Pre-UNISPACE III, the solution of a large (mother) and a small (daughter) sub-satellite had already been successfully used to separate the time and space components of variations in key geo-physical parameters within the framework of a number of scientific space projects including Aktivny, Apex and Interball. In addition, the Czech-made Magion sub-satellites (~ 50 kg mass) had, from a controlled distance, been used to complement scientific data gathering by a mother satellite.

Many ongoing co-operative scientific programs in the area of solar and space-plasma physics illustrate the advantage of using a coordinated group of satellites to obtain multi-point measurements of various phenomena. A particular case is provided by the International Solar-Terrestrial Physics program, which involves the co-ordination of data from the Solar and Heliospheric Observatory (SOHO) spacecraft of ESA; the WIND and POLAR spacecraft of NASA and the Geotail spacecraft of ISAS. Since UNISPACE III, the four members of CLUSTER-2 (launched by ESA in 2000), and the upcoming twin spacecraft Double Star Equator and Double Star Polar spacecraft (to be launched by CSSAR, China in 2003 and 2004 respectively), constitute additional constellation members suitable for contributing to the above mentioned multi-point measurements. It is noted that not all members of this coordinated group of spacecraft can be categorized as small (for example. the total mass of the SOHO spacecraft is 1850 kg).

During the last decade of the twentieth century, considerable progress was made in the northern hemisphere in the matter of studying both the global behavior of the upper terrestrial atmospheric regions and in establishing how these regions respond to changes in the interplanetary medium. At UNISPACE III it was recommended that Developing Countries, which in many cases are located in the southern hemisphere (in particular in the tropical zone), should plan to join in the international effort to increase such knowledge. Already some countries of the southern hemisphere contained the human resources, skills and motivation to carry out such studies - which would be for the benefit of all mankind.

Several important natural phenomena that occur in the tropical and southern hemispheric zones are presently not adequately understood (e.g. those ionospheric plasma depletions/bubbles present over South America

which strongly affect radio communications; also the large fluxes of energetic, charged, particles associated with the South Atlantic geo-magnetic anomaly, which can cause severe physical damage to, or even the failure of, various kinds of transiting satellite systems).

Further, the southern hemisphere is an important region for mounting studies of significant celestial objects not visible to astronomers in the northern hemisphere. In this respect, satellite observations could usefully complement those ground based studies of the southern sky already carried out over many years by a number of southern based groups in Developing Countries.

Examples of small satellite expeditions to the planets cited during UNISPACE III, were the highly innovative and successful Discovery and New Millennium programs mounted in the United States; various planetary and lunar missions developed in Japan by ISAS and a low-cost lunar mini-satellite proposed by the University of Surrey - all of which missions illustrate the benefits of the "faster, better, cheaper" philosophy. It is noted here that, since UNISPACE III, the launch of ESA's Mars Express Mission (2003), and ongoing Agency preparations for a Venus Express Mission, provide further important examples of the genre.

4 Technology Demonstrations

Small satellites provide an attractive, and low-cost, means of demonstrating, verifying and evaluating new technologies or services in an orbital environment at a level of acceptable risk - prior to using these technologies in more expensive, full-scale, missions.

Such technology demonstrations were mounted aboard: NASA's Discovery and New Millennium Programs; on spacecraft in Japan's Hypersat Class and on ESA's Project for On-Board Autonomy (PROBA). Further, the Centre National d'Etudes Spatiales (CNES) in France was already in 1999 developing a universal platform Proteus aimed at various applications in space research, remote sensing, telecommunications and technology demonstrations. The first launch of this platform in association with the Jason1 ocean monitoring spacecraft, took place in 2001. CNES is, in addition, developing a micro-satellite (100 kg) family for technology, science and application missions.

The NASA Discovery program provides examples of missions designed to demonstrate technologies suitable for Solar System exploration (e.g. Lunar Prospector, Mars Pathfinder, NEAR etc.). The latter program is well known because of its association with high profile, media coverage, Less known missions (launched for example by the U.K.) have also been successfully flown to collect important data concerning material and equipment behavior in those particle radiation regimes characterizing both LEO and geo-stationary transfer orbits.

5 Academic Training

Countries taking their first steps in space need to learn relevant techniques from more experienced space users, thereby acquiring a cadre of appropriately trained personnel before going on to establish a national agency and to maintain a presence in space. Technology transfer through small satellite related training programs has been successfully implemented between Surrey University in the U.K. and customers in Chile, Malaysia, Pakistan, Portugal, the Republic of Korea, South Africa and Thailand.

Small satellites programs provide a natural means for the education and training of scientists and engineers in space related skills since they allow direct, hands-on, experience at all stages (technical and managerial) of a particular mission (including design, production, test, launch and orbital operations). At the 1999 UNISPACE III meeting, it was noted that universities and schools of engineering in several countries in Europe had already developed, launched and operated their own small satellites. Also that groups in Japan, South Africa and the United States (NASA's University Explorer Mission program) were engaged in the same activity.

Development of a low-cost, rapid time-scale, mission within an academic setting provides an approach attractive to countries wishing to establish expertise in space technology. Such a program can be a purely national one although, more generally, co-operative endeavor involving technology transfer is involved. participants who do not, thereafter, continue to work in the space industry, take with them into the national community, in addition to technological know-how, valuable skills - including the ability to organize within an industrial milieu and employ state of the art management methods.

6 Low Cost Launches

Opportunities for small satellites to access space include: launch on a dedicated, expendable launch vehicle and launch as a secondary (piggyback) satellite, or as one of two spacecraft on a 'dual mission', on a single expendable launch vehicle. A launch service offered by the Space Shuttle ("get-away specials") was temporarily suspended in 2003 due to the grounding of the Space Shuttle following the loss of Challenger.

To make a choice between different launch opportunities involves weighing up the requirements of a desired mission against the capabilities, costs and constraints characterizing a particular option. At UNISPACE III it was recommended that, if a shared launch is considered, flexibility with regard to the date of launch/orbit attainment and also the value of the spacecraft itself should be carefully taken into account by the secondary partner. A further important consideration is the reliability record of the potential launch vehicle (those launching a series of low-cost payloads might be willing to risk using a relatively low-cost vehicle with an unproven record).

Over the past decades, many countries have invested in the development of indigenous launch capability. The small class of expendable launch vehicles has stimulated the largest entrepreneurial activity in the United States and in other countries (including airborne launchers such as Pegasus). Such vehicles can deliver payloads weighing between 25 kg and 1500 kg to LEO. The launch of two or more small satellites on the same expendable launch-vehicle ('dual manifesting') is also feasible. Long-range and intercontinental missiles from military arsenals of the cold-war rival super powers are, in addition, presently available for civilian space launches.

The specific cost per kilogram into orbit of small launchers is higher than for larger launch vehicles. However, their absolute cost is much lower. Some operators offer lower prices on newly introduced launchers (launch on a test flight might even be free of charge). It is recalled here that the disastrous loss of ESA's CLUSTER constellation on the 'free' first flight of the Ariane 5 launch vehicle in 1996 constitutes a cautionary case.

Manufacturers of large expendable launch vehicles are interested in offering the option of flying secondary (piggyback) payloads on missions where the primary payload does not fully utilize the capability of the launcher. Such possibilities were exploited, for example, during some United States Delta launches, and in the case of Russian Federation Soyuz and Tsiklon launches associated with the (main payload) Resurs and Meteor satellites. Although the small payload owner enjoys the benefit of a cost-effective alternative to the purchase of a dedicated, (small) expendable launch vehicle, the schedule of the primary payload is, in such situations, agreed to be unaffected by the requirements/best interests of the secondary payload. While in 1999 shared launch opportunities were relatively rare, the growing requirement for multiple launches into Low and Medium Earth orbit posed by telecommunication satellites can be expected, in the future, to generate more frequent opportunities for piggyback launches.

Also in Europe, the Ariane 4 launcher features a special supporting structure (the Ariane Structure for Auxiliary Payloads ASAP), which is specifically designed to support the simultaneous launch of several small satellites. The mass of an individual participating satellite (up to seven per launch can be lofted together) is limited to 50 kg. The more powerful Ariane 5 is designed to launch several 50-100 kg piggyback satellites into geo-stationary transfer, as well as into low polar, orbits.

7 Launch Access

Access to a launch may be achieved either: on a purely commercial basis; through participation in an international agreement or through using national launch capability.

At UNISPACE III it was noted that utilization of launch services provided by an international commercial source can be preferable to engaging in a co-operative arrangement, particularly for countries preparing for a first launch. In such cases the launch plan should constitute an integral part of a country's long term strategy to implement its space program, and arrangements for the development of national expertise in managing launch activities should, in addition, be catered for.

Co-operative missions are feasible where there is a mutual desire between the parties to maximize unique national resources/funding. However, each participating country must assume full financial and technical

responsibility for its portion of the co-operative effort. Clear and distinct managerial and technical interfaces must also be established in the associated agreement.

8 Ground Segment

The ground segment fulfils three distinct functions: (1) operations which include status and health monitoring of the satellite, as well as necessary command preparation and validation; (2) tracking telemetry and commanding which are realized by the telecommunications station, possibly in association with the operations centre; (3) data reception and the transmission of data to the user(s) - for processing and further distribution.

At UNISPACE III it was noted that the ground station can be based on a simple, very high frequency (VHF), antenna - as in the case of the University of Surrey's UoSAT satellite series. An Earth Observation mission can require, however, more complex support - due to the associated requirement to collect a large volume of data. Small satellites tend to rely on on-board autonomy and safe modes. This reduces their need for continuous ground monitoring - thereby simplifying, as well as reducing the overall cost of, the ground segment. The availability of on-board navigational autonomy through using the Global Positioning Navigational System (GPS) encourages this tendency.

The cost of mission operations constitutes a major element in the overall cost of a small satellite mission. Thus, although major agency tracking networks may be required during the launch and early operations phase, it is more cost-effective to, thereafter, employ national facilities (ideally utilizing a single ground station), during routine operations. A major driver is the cost of human resources. The high reliability and power of modern, personal, computers can make automation an affordable solution (with respect for example to antenna tracking; pass set-up and close-down; data reception/ storage; conversion of raw data; and status checking). Also, small satellites with modest telemetry and availability requirements might utilize mobile communications constellations to provide a global data relay system.

It was recommended that, although a ground system for a small satellite program should feature low cost, its reliability should remain sufficient to ensure that satellite passes/data transmissions are not missed. The system should further offer a fast return of critical data, as well as a rapid response to critical commanding. For bulk data, a regular return could be adequate, depending on the application concerned. However, direct down-linking to user terminals and portable ground stations can be beneficial (especially in the case of remote sensing data).

9 Economic Benefits

Direct benefits derived within a country from the use of small satellites depend on the application concerned and they include:

- Improvement of agricultural and animal productivity in medium to large-size farms owing to better weather predictions; identification of soil characteristics; improvements in communications and transportation;
- Lowering of transportation costs, made possible by the optimization of truck, bus and ship routing, location and early robbery detection, with favorable impact on the price of goods;
- Provision of communications for the basic needs of rural settlements in remote areas;
- Improvements in natural disaster detection and relief, made possible by systems that integrate scientific communications and remote-sensing satellite networks;
- Educational programs for populations in remote areas

International experience shows that investments in the space sector result in a very high multiplier effect on the gross national product (by a factor of the order of seven). In order that a country maintains within its own borders its investments in commercial space systems and services, the participation of national industry in contracts for the provision of space systems/services should be fostered. This requires the development of local expertise. As shown in Section 3.5.5, projects to develop small and micro-satellite systems provide a powerful means to acquire such national expertise.. Technology transfer, through education programs and formal training should be built in when setting up any commercial contract to acquire a new space system (as was, for example, done in Korea when setting up the Koreasat telecommunications satellite program).

10 International Cooperation

According to the tenets of the Charter of the United Nations, and other agreements concerning international co-operation relating to the exploration and peaceful uses of outer space, each country has the right to participate in space activities. Further, each space faring country has an obligation to co-operate in efforts to share existing information and adequate technology so as to help others to plan, develop, launch and operate satellites.

At the time of UNISPACE III, international co-operative space activities involving small satellites were only just beginning. It was thus considered highly desirable to define opportunities that would widen the scope of such co-operative efforts so that more countries could gain access to space and to the benefits derivable from space technology. Small satellites were cited, in this regard, to provide the best available opportunity for Developing Countries to initiate their own space programs in the most cost-effective way.

Already, an example of a successful co-operative program where engineers received training in small satellite design, production and operations was provided by the UoSAT commercial program of the University of Surrey. Also, the Republic of Korea had initiated programs to produce small Earth Observation satellites, with the support of various industrialized countries. Further, the Technical University of Berlin had provided the Tubsat-C platform to support a Moroccan initiative to build its first national micro-satellite (for messaging and remote sensing). In addition, co-operative agreements between Argentina and NASA as well as between Argentina and Brazil for the development of small satellites programs were in existence, while yet other countries were contemplating setting up co-operative arrangements to similarly develop national space capability.

A process whereby a national team acquires during its first satellite project sufficient technology transfer to enable it to produce a further generation of national small satellites independently, was defined at UNISAPCE III to constitute a criterion of success (transfer of know-why as well as of know-how). It was noted that, to achieve successful technology transfer:

- Persons of sufficient technical and scientific background should be involved;
- Access to appropriate infra-structure to support the application of the technology should be available;
- A long term development plan with scheduled objectives and proper financing should be in place.

11 Economic and Social Commission for Asia and the Pacific

At the time of UNIAPACE III, despite the wide range of economic and technological diversity in the 'Asia and Pacific' region, no previous experience in relation to co-operation in space related fields existed. Thus, a supportive framework was proposed by the Economic and Social Commission for Asia and the Pacific (ESCAP) with a modus operandi based on the principle of percentage contribution, such that countries participating in space projects would share the related expenses flexibly - based on their level of participation.

ESCAP considered that the technology required to pursue a space related project can be sub-divided into 'already published technology' and 'new technology'. Use of 'already published' technology attracts no transfer fees. New technologies developed for a project were deemed, on the other hand, to involve participation that could be at one of four levels:

Host-level participation: for countries that have the technologies to build common payloads and are willing to offer such technologies for the project, but without making any financial contribution to it. Host countries should not charge for the use of their technologies within the project. **Owner-level participation:** for countries that put common payloads on their own satellites and operate them, covering all the necessary expenses for manufacturing payloads of their own. If new technology is required, the owner-level country should cover expenses relating to the necessary research and development activity.

Partner-level participation: for countries that participate in manufacturing all, or part, of common payloads. Once common payloads are in orbit, host-level, owner-level and partner-level countries can use the concerned constellation of satellites freely, based on prior arrangements.

Analysis work-level participation: for countries that do not participate in manufacturing common payloads but perform analysis and research using data gathered from the common payloads, access to data and to other related information is guaranteed to be free of charge. If specific hardware or software is required, it should be developed at the expense of each participating country.

Expenses involved in attending meetings and seminars concerning a particular project should be covered by each participating country. When host or owner-level countries needed to provide manpower training to participating countries, this should be offered to the participating countries at marginal cost.

Appendix 2

Cooperating IAA subcommittees and joint IAA/UN Workshops

1 IAA Subcommittee on Small Satellites for Developing Nations

The International Academy of Astronautics created a Subcommittee entitled Small Satellites for Developing Nations in 1993 with a brief to assess the benefits of small satellites for Developing Nations in the fields of education, space science, communications, earth observation and medical care.

This Subcommittee should work to provide access to advanced technology and management techniques for Developing Nations; to foster international co-operation and to identify mechanisms for the provision of technical, as well as financial, support for its constituents. The Subcommittee should, in addition, develop general awareness in respect of these matters and report and disseminate relevant information through workshops, congresses and publications.

Further, the Subcommittee was directed to liaise with the United Nations and with COPUOS; with the International Astronautical Federation (IAF) - through its Committee for Liaison with International Organisations and Developing Nations (CLIODN) - as well as with such other international organisations as might be appropriate to enable it to fulfil its objectives. In particular, it should organise a yearly session and hold a yearly meeting of the Subcommittee within the framework of the International Astronautical Congress (IAC).

At the 1999 meeting of the IAA Subcommittee, it was agreed that the occasion of the 51st IAC which was to be held at Rio de Janeiro, Brazil in October, 2000, would provide an ideal opportunity to review the status and advancement of small satellite programs in Latin America. It was further agreed that this review would take place within the context of a Workshop on Small Satellites at the Service of Developing Countries mounted jointly by the UN/OOSA and the Subcommittee on Small Satellites for Developing Nations of the IAA, and that this Workshop would be open to participants from other regions. Moreover, that the situation in Latin America would be used as a general example of how Developing Countries could benefit from small satellites and that this topic should, consequently, constitute the core of the discussions.

Based on the ensuing positive response to the Brazil Workshop (see Section 3), a second Workshop aimed at encouraging the development of small satellite technology in Africa was held in Toulouse, France during October, 2001. Further Workshops in the series were held at Houston, U.S.A. in October 2002 on the occasion of the World Space Congress, and during the IACs in Bremen (2003) and Vancouver (2004).

These Workshops have served to progress the program concerning Small Satellites in the Service of Developing Countries conceived at UNISPACE III. A summary of the recommendations for future work arrived at during each of the individual Workshops appears in Sections 3 - 7).

2 IAA Subcommittee on Small Satellites for Countries Emerging in Space Technology

A further Subcommittee of the International Academy of Astronautics was formed in 1997 to cater for the needs of countries Emerging in Space Technology. Such countries were formally defined to be those with a technical knowledge base and some space experience which are striving for small satellite missions to exploit the new, cost effective, possibilities they offer. The formation of this Subcommittee was predicated on the outcome of an IAA Workshop entitled Small Satellites for European Countries Emerging in Space Technology held at Maynooth, Ireland (7-10 May 1996) which was attended by representatives from twelve countries and which, in addition, had messages of support and interest from representatives of a further five countries.

At this Workshop it was concluded that the problems and objectives of Developing Nations in gaining access to space using small satellites are fundamentally different from the corresponding problems and objectives of countries 'Emerging' in space technology. The experiences of the workshop confirmed the existence of a community of European countries in the 'Emerging' category and it was recommended to the IAA by the participants that the interests and needs of this community should be fostered by the creation of a dedicated

Subcommittee. The Proceedings of the Maynooth Workshop were published in two volumes in 1996. Further, Acta Astronautica Volume **43**, 1998 contains a selection from the technical papers presented.

The requested Subcommittee was set up by the IAA in 1997 with a brief to provide a support structure to develop and promote the concepts and processes of 'space emerging' countries. At the first meeting of the new Subcommittee which was titled Small Satellites for European Countries Emerging in Space Technology and held during the 48th International Astronautical Congress at Turin Italy (October, 1997), a wish was expressed by those present to extend the remit of the Subcommittee to include representatives of, not only European, but of all countries in the world. This was subsequently agreed by the IAA and the group was then assigned the more general name Subcommittee on Small Satellites for Countries Emerging in Space Technology.

As is clear from the present text, COPUOS documents refer in particular to the problems and objectives of 'Developing Nations' in gaining access to space. At the time of writing, means remain to be found within COPUOS to formally include within its remit the special needs of technically 'emerging' countries and this topic should be further pursued.

3 UN/IAA Workshop (Brazil, 2000)

The first joint workshop of the United Nations and the Subcommittee on Small Satellites for Developing Nations of the IAA held within the framework of the International Astronautical Congress (entitled Small satellites at the service of Developing Countries - the Latin American Experience), was mounted at Rio de Janeiro, Brazil on 5 October 2000. One of the objectives of this Workshop was to review the advances made in Latin America with regard to the development and utilisation of small satellites in the aftermath of two earlier workshops organised by the IAA Subcommittee (one on Small Satellites for Latin America held in Brazil during June 1994 and the other on Small Satellites at the Service of Developing Countries held during UNISPACE III at Vienna in July 1999).

It was demonstrated during the Brazil workshop of October, 2000, that Latin America's experience in the field of small satellites had grown substantially since 1994. In this connection, in addition to several projects concluded or under development in Argentina, Brazil and Chile, national activity was also reported by Mexico and Peru.

Ten papers were presented in the Workshop, dealing, in general, with the current situation and with advanced projects in Latin America and other regions.

Among these, the first paper described the benefits arising from the Brazilian Data Collection Satellite (SCD) system which consists of two small spacecraft (SCD-1 and SCD-2), supported by a set of data collection platforms distributed throughout Brazil (especially in the Amazonian and north-east area of the country). Among accruing benefits, the development of Brazilian capability in the areas of spacecraft design, manufacture, testing and operations was noted. Examples were given of socio-economic benefits in fields such as: hydrological monitoring and electrical power generation; agriculture; fisheries; flood monitoring and warning; monitoring and prevention of fires and other natural disasters, together with transportation and water resource management (for water supply and water quality control). It was demonstrated overall how a developing country can take advantage of space technology for general advancement and environmental protection.

A presentation concerning the national technological heritage of Brazil which can be exploited to develop new satellite architecture for telecommunications systems, provides an example of a program that can be used to fulfil a representative need within developing countries.

Given the geographical position of Brazil close to the equator, the Amazon Rainforest Observation System satellite (SSR) can support a local effort to develop an innovative solution that will dramatically increase the re-visit time of spacecraft to this region and associatively allow near real-time data transmission.

Two co-operative space programs have been entered into by Brazil. The first, undertaken with France, was to develop a low-cost micro-satellite to fly Brazilian and French scientific and technological experiments. A perspective towards a longer term partnership and new opportunities is already in view in this connection.

The second co-operative program was with Argentina. This Argentine-Brazilian Satellite (SABIA3) is dedicated to the monitoring of water, food production and the environment.

It was noted that Argentina and Spain are in the process of studying Cesar, a co-operative remote sensing programme. Also, that Argentina, Brazil and Spain are in parallel considering the possibility of merging SABIA3 and Cesar in a trilateral programme.

In the universities of Cordoba and Neuquen in Argentina, privately supported projects involving small and inexpensive satellites devoted to scientific and technological experiments are presently mounted as a means of (a) promoting good education in space engineering and technology and (b) to attract talented young people to the subject. Similar projects are underway in Mexico. In Brazil, university involvement in space is through expert groups that collaborate to solve technical problems.

In Chile, the Satellite de la Fuerza Aerea (FASat) has been developed with a British university as part of a programme of hands-on training, leading ultimately to the national development and operation of small satellites. Among the onboard experiments is one that, since August 1998, has allowed ozone concentration profiles over the territory of Chile to be monitored. In addition, daily global maps of atmospheric ozone concentrations, showing the formation and extent of the ozone 'hole' over Antarctica, have been generated onboard FASat, thereby demonstrating that small satellites can provide valuable scientific data.

Peru, through the small remote sensing satellite of the Comision Nacional de Investigacion y Desarrollo Aerospacial (ConidaSat), has, in the context of a hands-on training program supported within Europe, initiated a project to develop that national capability and infra-structure required to design and build a satellite. The selection of a remote sensing task for this spacecraft represents a step towards achieving monitoring of the territory of Peru. However, some scientific experiments might also be included in the mission.

Conclusions and Recommendations

The participants in the Workshop recognised that small satellite projects in Latin America promote international co-operation within this region, as well as with European partners. Also, it was noted that several satellite projects developed in Latin America could potentially be of interest in other regions, especially Africa.

While acknowledging that the proposals made during UNISPACE III were fully applicable to Latin America, the Workshop made a number of additional conclusions and recommendations that were more focused on the specific needs of the region.

In this connection, it was recognised that the route of international co-operation is a very promising one and that it should be further explored so as to foster the use of small satellite systems for the benefit of Latin American and other Developing Countries - especially through the promotion of a large number of regional projects. It was associatively specifically recommended that:

- Co-ordinated activities be initiated to identify significant problems that are common to different countries in a region that could be addressed through the use of small satellite technology.

It was noted that efforts had already been made to develop space systems devoted to improving the quality of life in Developing Countries. To provide maximum benefit to the populations of such countries it was further recommended that:

- These programs be established in such a manner as to ensure continuity and sustainability

The importance of Earth Observation programs for Developing Countries was particularly highlighted, as well as the benefits of international co-operative efforts. It was associatively recommended that:

- Long term strategic co-operation agreements be prepared to ensure the definition and development of sustainable programs

Also, the importance of space development in education curricula, especially for motivating and training students, was recognised. In line with recommendations previously made at UNISPACE III, it was proposed that:

- Each country would recognise the important role that space assets could play in education and the need to incorporate space into education, and to develop among the population, and among decision makers, an awareness of the benefits offered by space.

The importance of collaboration across regions, especially the potential benefits accruing to facilitating Africa to have access to space systems of a kind already developed, or similar to those developed, in Latin America, was identified. It was recommended that:

- Another workshop be organised to review the needs of African countries and the benefits that small satellite systems could bring to those countries to suit their needs.

4 UN/IAA Workshop (France, 2001)

The second workshop jointly organised by the United Nations and the International Academy of Astronautics (IAA), entitled Small Satellites at the Service of Developing Countries - the African Perspective, was held at Toulouse, France on 2 October, 2001 during the 52nd IAC.

Six papers were presented in the Workshop, which generally described advanced projects in Africa and other regions.

Among these, the first paper gave an overview of the results already achieved during workshops held at UNISPACE III and in Latin America, stressing the applicability of the results and conclusions arrived at to African countries. A presentation by the Director of the Office for Outer Space Affairs in Vienna, underlined the importance of small satellites in the use of space technology for sustainable development. Emphasis was placed on capacity building through technology transfer and training programs. Financing and intellectual property rights associated with technology transfer were highlighted.

South Africa, based on its successful SUNSAT programme, reported that it was seeking further development of its space activities in the context of the needs of African countries. An example could be the provision of low cost data for better decision making. In particular, the SUNSAT programme has demonstrated that high-resolution remote sensing data recorded aboard small satellites has applications in areas such as agriculture, water resource management and disaster mitigation. Existing technological capabilities developed for SUNSAT could be reconfigured to execute a completely new programme that would provide economic benefits for Africa, not only in an applications area, but also in education and training and in the development of industrial and spin-off enterprises.

A world-wide Disaster Monitoring Constellation (DMC) consisting of five small satellites was described. This has the potential to allow daily revisits to a particular region to monitor rapidly changing conditions during disasters. It was foreseen that each satellite would be contributed by a different country. Algeria, which was already building its first satellite (Alsat-1) as part of a know-how and technology transfer program mounted between Algeria and the UK was also in this connection, a partner in DMC. The other four partners are Nigeria, China, Thailand and the UK. (see an account of the later expansion of this consortium in Section 5). In addition to its primary mission as a component of the DMC constellation, each satellite can be used to support the specific needs of individual partners. In the case of Algeria, monitoring of agricultural land use and of industrial and marine pollution; verification of cartography for infra-structure development as well as the more regional application of intensive monitoring of desertification, constitute applications of national importance.

Tunisia expressed an interest in space activities, possibly in co-operation with other countries from the Magreb region. A preliminary study has already been undertaken in co-operation with France of a potential small satellite mission for climatic data collection and the remote monitoring of lakes and dams. Other applications in the area of telecommunications and in the facilitation of access to the information society, are also goals for Tunisia. .

Brazil presented an equatorial mission developed from the Amazon Rainforest Observation system (see Section 3) for a possible co-operative program. This project would be directed towards the specific needs of low-latitude regions and based on a small satellite placed in an equatorial orbit to increase the re-visit frequency and provide near real-time data transmission. Applications would include: monitoring of deforestation; forest fires; flooding; desertification; mineral exploitation and various sea activities. It was noted that the siting of the receiving station and transmission centre in Africa could serve users in the African equatorial region and preliminary contacts to explore this possibility were already in train.

Conclusions and Recommendations

This workshop clearly demonstrated the tremendous benefits that can accrue through introducing space activities to a region through a small satellite program. In this context, the importance of placing the main focus on those applications that would provide sustainable economic benefits for Developing Countries in Africa was highlighted.

The participants, while recognising that the proposals made during UNISPACE III were fully applicable in the case of Africa, considered that the route of international co-operation should be further explored, in order to foster the use of small satellite systems for the benefit of African and other Developing Countries - especially through the promotion of regional projects. For this purpose it was recommended that:

- Co-ordinated action be initiated to identify significant problems that were common to different countries in the region and that could be addressed through the use of small satellite technology. Partnerships should then be developed between regions with common needs - such as the equatorial regions of different continents.

Efforts had already been made to develop space systems devoted to improving the quality of life in Developing Countries. To provide maximum economic and social benefits to the populations in such countries it was recommended that:

- Relevant programs be established in such a manner as to ensure continuity and sustainability.

The workshop stressed, in particular, the importance of Earth Observation programs for Developing Countries and the benefits of international co-operative efforts. It was associatively recommended that:

- Long term strategic programs be developed to ensure the acquisition and processing of the data needed for monitoring environment and natural resources, as well as for decision making.

The benefits were recognised of small satellite programs vis-a-vis the acquisition of space related technology and the development of spin-off enterprises. It was, therefore, recommended that:

- Space activities be an integral part of any national program devoted to technology acquisition and development

In considering the importance of space development in education curricula, especially for motivating and training students and having regard to recommendations made at UNISPACE III, it was proposed that:

- Each country would recognise the important role that space assets could play in education and the need to incorporate space into education, and to develop among the population, and among decision makers, an awareness of the benefits offered by space technology applications.

5 UN/IAA Workshop (Houston, 2002)

The third workshop jointly organised by the United Nations and the International Academy of Astronautics (IAA), entitled Small Satellites at the Service of Developing Countries: Beyond Technology Transfer, was held at Houston, Texas on 12 October, 2002 during the World Space Congress. The emphasis was: on operational aspects of the use of small satellites; on existing and proposed applications and on associated benefits for Developing Countries.

Seven papers were presented at the Workshop which mostly dealt with applications in the field of remote sensing and Earth observations.

The first paper dealt with ALSAT-1 (the first Algerian satellite), which was developed as part of a know-how and technology transfer program between Algeria and the UK. This satellite is one of the first to be launched by several co-operating countries as part of a Disaster Monitoring Constellation (DMC). This consortium had, since the time of the previous Workshop in France (Section 4) enlarged from five to seven partners, namely Algeria, China, Nigeria, Thailand, Turkey, the UK and Viet Nam. Satellites from these countries were to be put into the same orbit in order to form the first international constellation dedicated to monitoring natural and man-made disasters. This would enable the seven countries to have daily access to global images for disaster mitigation, national remote sensing applications and space commercial exploitation. This program constitutes a representative case of international co-operation between developed and developing countries.

As part of DMC, ALSAT-1 contributes to mitigating disasters through early warning, event monitoring and analysis. When not used for DMC purposes, it is employed in national applications. The vast land area of Algeria (2.5 million square km) requires multiple kinds of monitoring from space (see Section 4), with particular consideration of the accelerating desertification occurring at the boundaries of the Sahara. The launch of a second satellite (ALSAT-2) is currently being planned.

Also as part of DMC, Nigeria is developing its first satellite (NigeriaSAT-1) under the aegis of a National Space Research and Development Agency (NASRDA). This programme constitutes an important component of the national strategy for socio-economic development through space applications. Among the objectives of the Agency are the development of indigenous capability in the areas of space science and technology. The use of these capabilities as tools for natural resource management; infra-structure development; environmental monitoring and sustainable development is then foreseen. The NASRDA programme is built around the following themes: development of human resources and capacity building; management of natural resources; study of the Earth and its environment; defence; national security and law reinforcement; space communication applications as well as education and training. The promotion of international co-operation is an integral part of the space programme in Africa, in particular within the Economic Community of West African States (ECOWAS).

Plans to develop a communications satellite (NigeriaSAT-2) are in train. Ineffective communications currently represent the greatest local barrier to socio-economic development, and this spacecraft will be configured to contribute to providing an adequate telecommunications system throughout Nigeria, as well as regional coverage to ECOWAS countries.

It was noted that a core objective of the New Partnership for African Development, which is a mandated programme of the African Union, is to give impetus to Africa's development through successfully bridging existing gaps in priority sectors (that include information and communications technologies) and eliminating the digital divide. It was perceived that the utilisation of small and micro-satellites provides one of the most appropriate instruments for realising these objectives.

Against the background of the successful SUNSAT programme in South Africa, it is mooted to develop an African Resource Management (ARM) constellation through an African co-operative programme (see also Section 4). The application of these satellites could contribute to meeting the needs of African countries in a sustainable manner, while also addressing the solution of problems such as: the 'brain drain'; lack of access to space technology and data; poverty and food insecurity; disasters; poor infra-structure; refugees and unsustainable development. In the light of current satellite developments, space engineering capability is becoming accessible within Africa, and a commitment to long-term research and development is perceived to only be sustained through repeatable development and the utilisation of technology and know-how. It is envisioned that the establishment of an ARM constellation would contribute to the fulfilment of certain of the key aims of the New Partnership for African Development.

The maritime status of Indonesia is a driving factor for development activities and business ventures and these, together with the need to manage a wealth of natural resources (both terrestrial and marine) are presently considered to warrant the use of space technology. On the premise that a satellite would make significant contributions to solving problems related to national economic development, as well as provide an

input to the education of students in the areas of spacecraft design and manufacturing, a plan to launch a micro-satellite for resource monitoring (Ganesyasat-CXM) has been conceived. This satellite would follow a low equatorial Earth orbit to achieve optimum temporal resolution and provide inputs to environmental observations and geographical information. Also, it would support scientific studies associated with meteorological and volcanic activity surveillance.

Argentina's Satellite de Aplicaciones Cientificas (SAC-C) was launched in November 2000. SAC constitutes an international Earth observing satellite developed by the Argentina Comision Nacional de Actividades Espaciales in partnership with the United States. In addition, inputs in the areas of instrumentation and satellite development were provided by Brazil, Denmark, France and Italy.

The satellite was built in Argentina to carry a payload of ten instruments that study: the evolution of desertification processes; the prediction of agricultural production and the monitoring of flood areas and of coastal and freshwater regions. Other investigations involve: monitoring the condition and dynamics of the terrestrial and marine biosphere and environment; studies of the Earth's magnetic field and related Sun-Earth interactions; development and utilisation of Global Positioning System (GPS) techniques designed to measure atmospheric phenomena on a global scale for the study of weather, seasonal, inter-annual and long-term climatic change.

SAC-C forms a member of the so-called 'Morning Constellation', along with three satellites from the United States (Landsat-7, EO-1 and Terra). This constellation permits the quasi-simultaneous acquisition from the four satellites of images of various geometric and spectral resolution in different spectral bands; the carrying out of autonomous navigation experiments and the testing of the capability of the GPS satellite constellation for atmospheric studies; navigation and attitude and orbit control. The main application areas are hydrology; desertification; urban planning; precision farming; forestry; ecology; atmospheric and ionospheric studies and cloud properties. Data from the four satellites yield information on land use; native forest resources and floods and fires.

A novel application of the Brazilian data collection satellites SDC-1 and SDC-2 concerns the precision farming of orange crops. In this regard, data collecting platforms located on the ground collect data relating to soil moisture and the height of the fruit (important parameters for the flowering process leading to fruit production). These data are then transmitted to users via the spacecraft. Such an application is only valid for perennial crops. However, the application could be extended to other types of agricultural data for government or private use.

A small satellite project for space weather monitoring is being jointly developed by Brazil and the Russian Federation. Also, a joint Russian-Ukrainian mission combining a Russian Interball satellite and a Ukrainian Prognoz satellite is under consideration. Brazil could provide a third satellite in a highly elliptical orbit. By mounting a constellation of these satellites in different orbits, it would be possible to monitor inter-planetary and magnetospheric phenomena with variable temporal and spatial characteristics. Such data could be used to improve space weather forecasting and monitoring.

Conclusions and Recommendations

The workshop recognised that avenues of international co-operation should continue to be explored in order to foster the use of small satellite systems for the benefit of Developing Countries through the promotion of regional projects. For this purpose it was recommended that:

- Co-ordinated action be continued to identify significant problems that are common to different countries in a region and that could be addressed with the help of small satellite technology. In addition, partnerships should be developed between regions with common needs, such as the equatorial regions of different continents.

Efforts had been made to develop space systems devoted to improving the quality of life in Developing Countries. To provide maximum economic and social benefits for the populations of such countries it was recommended that:

- Programs should be established in such a manner as to ensure continuity and sustainability.

The Workshop highlighted the growing importance of Earth Observation programs for Developing Countries and the associated benefits of international co-operative efforts. It was recommended that:

- Long-term strategic programs be developed to ensure the sustainable acquisition and processing of data needed for monitoring the environment and natural resources; for the mitigation of man-made or natural disasters and for decision making.

The benefits of small satellite programs for the acquisition, development and application of space science and technology and the associated development of a knowledge base and industrial capacity was recognised. It was thus recommended that:

- Space activities should be a part of any national program devoted to the acquisition and development of technology and capacity-building.

The importance of space development in education curricula was confirmed, especially for motivating and training students. In line with the recommendations of UNISPACE III it was recommended that:

- Each country recognise the important role that space assets could play in education and the need to incorporate space science and technology in curricula.

The need to develop among the general public, as well as among decision makers, an awareness of the potential benefits of space technology applications was emphasised. In particular, the important role that a dedicated organisation or agency could play in the definition and implementation of a space program was stressed. It was thus recommended that:

- Every country or group of countries consider the attainment of a minimum level of space capabilities as they could be invaluable in enhancing socio-economic development and the quality of life of populations.

6 UN/IAA Workshop (Bremen, 2003)

The fourth workshop jointly organized by the United Nations and the International Academy of Astronautics (IAA), entitled Small Satellites at the Service of Developing Countries: a contribution to sustainable development, was held in Bremen, Germany on 30 September 2004.

One of the aims of the Bremen workshop was to review the benefits of small satellite programs, with emphasis on the contribution that small satellites can make to sustainable development. The agenda opened with an overview of the results of previous workshops (at Vienna, Rio de Janeiro, Toulouse and Houston, see above). Six papers were then presented.

The first was provided by students of science and law from France and Singapore who were, at that time, pursuing their studies in Canada and the United Kingdom. The theme of the presentation, 'an analysis of small satellites for developing countries', incorporated a political and policy analysis. The text started from the concept of sustainable development and went on to explore the potential for co-operation between developing and developed countries from technical, as well as from legal, viewpoints. It was concluded that, against a general background of technology transfer, the success of such programs requires (a) a long term relationship between the two participating countries and (b) a coordinated approach within these countries in the matter of science and technology education. Space treaties were noted to be useful in enabling developing countries to gain equal access to space. The acquisition of space technology can benefit developing countries through allowing access to relevant knowledge and through the overall internal betterment of socio-economic conditions.

The second paper was prepared by students from the International Space University. A detailed analysis was presented of those conditions indicating an outbreak of malaria and it was demonstrated how, by employing space technology, long-term climatic predictions and short term in situ measurements can contribute significantly to improving the monitoring and prediction network presently in place. It was concluded that small, low-cost, satellites with data collection capability could be utilized to play a valuable role in

establishing a space based monitoring system that would more successfully support the combating of this disease than is presently the case.

The next contribution highlighted the Disaster Monitoring Constellation (DMC) as a showcase of international collaboration, with participation by Algeria, China, Nigeria, Thailand, Turkey and the United Kingdom (see also Section 5). Several satellites in this series have already been launched and now provide data for international co-operation in the areas of natural and manmade disaster monitoring, as well as with regard to remote sensing applications. Key features of this program are (a) long term commitment to space by associated governments; (b) the rapid establishment for participating countries of a national asset in space supported by well trained ground staff; (c) planned investment downstream in second and third satellites and in related national facilities.

Next it was explained how the African Resource Management constellation (ARM) is intended to address African needs with regard to space technology development and applications. The baseline payload comprises a 2.5 m panchromatic and multispectral imager. A hyperspectral focal plane will be added later. Resource management priorities were taken into account in the design since many disasters in Africa could be prevented through better management. Collaboration with a number of countries in the matter of related technology transfer and development is foreseen to take place downstream.

The Brazilian experience with respect to an Undergraduate Orbital Student Satellite (UNOSat) was then presented, associatively highlighting related project management, short schedule pressure and technical problem solving. It was noted that important lessons were associatively learned and an indelible impression conveyed by the explosion of this satellite on the launch pad.

The final contribution concerned the educational opportunities accruing to the building and launching of Russia's 29-kilogram Kolibri-2000 satellite. Valuable experience was gained and school children had benefited from the program. A new launch opportunity for a 29-kilogram satellite planned to attain a 450 km circular orbit is being organized and this program will feature further educational benefits.

Conclusions and Recommendations

The Workshop was deemed to have clearly demonstrated the tremendous spin-offs that can be gained through introducing space activities in developing countries through a small satellite program. The participants recognized that small satellites comprise a useful tool for acquiring and developing technology and contributing to education and training. The importance of placing the main focus on applications that provide sustainable economic development for individual developing countries was emphasized.

Practical results, such as those described in the presentations, were noted to demonstrate the effectiveness of small satellites in addressing regional problems. New programs are expected to provide benefits such as those arising from remote sensing, especially in such fields as disaster mitigation, agriculture, desertification, forest monitoring and infra-structure development. Improving public health is a new and important application that will require further attention in the future.

Small satellite programs are already promoting, through bilateral and multilateral agreements, international co-operation within individual regions and world-wide. Small satellite projects could result in fruitful co-operation between different countries in the planning, implementation and maintenance of a constellation of satellites, as well as in the effective utilization of the data thereby acquired. Such an approach can provide a useful means of sharing satellite development costs, information and data.

Within a particular country, a small satellite program can stimulate an interest in science and technology; enhance the quality of life and the quality of education; promote research and development and result in better linkages between government agencies, educational institutions and industry. With this in mind, the participants emphasized the need for greater awareness of the benefits of space programs among both the public and decision makers.

The participants also recognized the contribution of students to the Workshop and considered that the interest in the subject of small satellites shown by students and young professionals constitutes a positive sign of growing public awareness.

While recognizing that the proposals made during UNISPACE III are fully applicable the participants made, or reconfirmed, the following conclusions and recommendations:

- Avenues of international co-operation should continue to be explored in order to foster the use of small satellite systems for the benefit of developing countries, including through the promotion of regional projects. For that purpose the Workshop recommended that coordinated action be continued in order to identify significant problems that are common to different countries in a region and that could be addressed with the help of small satellite technology. The Workshop also recommended that partnerships be developed between regions with common needs, such as the equatorial regions of different countries.
- Efforts have been made to develop space systems devoted to improving the quality of life in developing countries. To provide maximum economic and social benefits to the populations of such countries, the Workshop recommended that programs be established in such a manner as to ensure continuity and sustainability.
- The Workshop in particular highlighted the growing importance of Earth observation programmes for developing countries and the benefits of international co-operative efforts. It was, therefore, recommended that long term strategic programmes be developed to ensure the sustainable acquisition and processing of those data needed for monitoring the environment and natural resources, for the mitigation of man-made and natural disasters and as inputs for decision making.
- The Workshop recognized the benefits of small satellite programs in the acquisition, development and application of space science and technology and the associated development of a knowledge base and industrial capacity. The Workshop thus recommended that space activities be made an integral part of any national programme devoted to the acquisition and development of technology and capacity building.
- The Workshop confirmed that it recognised the importance of space development in educational curricula, especially for motivating and training students. In line with the recommendations of UNISPACE III, the Workshop recommended that each country recognize the important role that space assets can play in education and the need to incorporate space science and technology in curricula.
- Finally, the Workshop emphasized the need to develop among the general public, universities and decision-makers an awareness of the potential benefits of space technology applications. In particular it recognized the important role that a dedicated organization or agency can play in the definition and implementation of a space program. The Workshop recommended that every country, or group of countries, consider the attainment of a minimum level of space capability, as this could be invaluable in enhancing socio-economic development as well as the health and quality of life of populations.

7 UN/IAA Workshop (Vancouver, 2004)

The fifth workshop organized jointly by the UN Office of Outer Space Affairs and the IAA was held in Vancouver, Canada on 5 October, 2004 under the title Small Satellites in the Service of Developing Countries: current and planned small satellite programs. In consequence of a re-organization of the internal structure of the IAA, the responsibility within this organization for the activity was assumed by IAA Commission 4. The Workshop formed an integral part of the contemporaneous International Astronautical Congress.

One of the aims of the Vancouver Workshop was to review the benefits of small satellite programmes, with particular emphasis on the contribution that small satellites can provide in support of scientific Earth observation and telecommunication missions. Emphasis was placed on international co-operation, education and training and the benefits of such programs in the service of developing countries.

The agenda opened with an overview of the results of previous workshops and six papers were then presented and discussed.

The first, which concerned Argentina's Pehuensat-1 program, highlighted the successes of an ongoing university program that incorporates various practical elements. This program, which includes experiments performed aboard the Space Shuttle, illustrates the importance of the Space Shuttle to Developing Countries for the mounting of short term space experiments. The latest satellite in the program was 'fit checked' to the Brazilian launcher that was destroyed in the accident of 2004 and it was noted that this accident made a deep impression on the team from Argentina.

The next contribution concerned the Malaysian University program, which provides an opportunity for hands-on student training. The technical details of this satellite were presented, as well as an account of the challenges of executing a resource limited university program in parallel with the national Malaysian program.

A description was then provided of how local small satellite expertise has been successfully applied with regard to one of the crucial sub-systems for high resolution imagery (namely the Attitude Determination and Control System/ADCS) constructed for Korea's large satellite Kompsat-2.

The fourth paper concerned the South African SUNSAT-2004 mission and showed how advances in COTS technology is presently leading to micro-satellites with a performance that can be operationally applied for remote sensing. The 40-kg satellite described, with its multi-spectral payload (having of the order of 6m ground spacing, was conceptualized and is presently in development at Stellenbosch University. The advances associatively achieved were so technically significant that they were transferred to industry before the university mission was itself completed.

Also described were the challenges of mounting a resource constrained university program. Key factors in determining the success of a university satellite program in the absence of a national program, but with a growing space capability in industry in its vicinity, were discussed. The deduced importance of mounting an holistic program that would incorporate university, industrial and national interests was emphasized.

The next contribution was provided by Surrey Satellite Technology, Ltd. from the United Kingdom and it described the progress made in developing the ground infra-structure supporting the micro-satellites of the Disaster Monitoring Constellation (DMC). The ground stations of the various participating countries are being inter-connected to facilitate information exchange and arrangements put in place whereby partners can order data sets from other constellation participants. The advantages of working together in flying a constellation so as to achieve increased temporal resolution for individual countries, as well as the benefits of sharing necessary resources, were highlighted.

The final paper constituted an overview of the Brazilian program over a period of twenty five years, thereby covering the results, perspectives and consequences of the space program of a particular developing country. This program included Brazil's Data Collection Satellites (CDS-1 and CDS-2) that monitored remote weather stations in the Amazonian forest. Also, international collaboration with China with regard to the China Brazil Earth Remote Satellite (CBERS-1 and CBERS-2) series, that combined resources to achieve large satellite capability. Collaboration with the International Space Station program is presently expected to yield long term benefits. Access to space programs is important for Brazil because of its geographic location, which is appropriate for launching satellites into equatorial and polar orbits. Brazil has an ongoing resolve to achieve small launch vehicle capability.

Conclusions and Recommendations

The Workshop was deemed to have again demonstrated the tremendous spin-off benefits to be gained through mounting small satellite programs. In particular the participants of the Workshop: recognized that small satellites provide a useful tool for acquiring and developing technology and contributing to education and training. The Workshop stressed the importance of placing the main focus on applications that provide sustainable economic benefits for Developing Countries.

- Three trends could be identified in the Workshop papers. The first is that the benefits of utilizing outer space for developing countries is now poised to extend beyond the technology demonstrations and national missions for gaining first access to space, to utilizing micro-satellites for operational remote sensing applications.
- Representatives of four countries discussed and evaluated a resource limited micro-satellite programme at a university. Growth in the capability of micro-satellites should lead to a further interest in this technology. University research and development missions should be better funded in conjunction with national programmes to not only provide operational satellites, but also produce significant human resource development.
- The third trend derived from the Workshop was the clear benefit to be gained from collaborative programs, in the first instance within large, bilateral, satellite programmes (Brazil and Korea) and in the second instance from participation in a constellation that provided increased temporal resolution. It was recommended that other developing countries seek also to gain benefits through international collaboration.

Appendix 3

Examples of NASA Missions

1 The Earth Science Enterprise

NASA's Earth Science Enterprise (ESE) missions fall into three classifications: Systematic, Exploratory, or Operational Precursor & Technology Demonstration. In support of enabling climate and weather prediction capability, ESE also builds and launches spacecraft for NOAA's Polar Operational Environmental Satellite (POES) and Geostationary Operational-Environmental Satellite (GOES) programs. New measurements from space are necessarily exploratory. Many exploratory measurements prove sufficiently valuable to science that they become systematic, i.e., data continuity spanning multiple mission lifetimes is required. Mature systematic measurements that are outside NASA's research mission, such as for weather forecasting, are transitioned to operational satellites operated by other agencies (such as the National Oceanic and Atmospheric Administration, NOAA).

Systematic Measurement

Systematic measurements of key environmental variables are essential to specify changes in forcings caused by factors outside the Earth system (e.g. changes in incident solar radiation) and to document the behaviour of the major components to the Earth System. Systematic is not necessarily synonymous with continuous measurement, and gaps in time series may be tolerable when short-term natural variability or calibration uncertainties between discontinuous records do not mask significant long-term trends. ESE aims for continuity in systematic measurements, but does not plan for instantaneous replacement in case of premature sensor or spacecraft failure.

Over the next decade, NASA will transition a number of environmental parameters from research-oriented programs to operationally-oriented ones. The transition presents a challenge requiring careful planning for calibration, retrieval algorithms, and reprocessing of data sets to assure consistency to assure the ability of data from operational entities to address long-term global change questions. A number of systematic measurement missions will be cited, for spacecraft that fall within the 1000kg range.

The *Active Cavity Radiometer Irradiance Monitor III* (ACRIM III) instrument measures the total solar irradiance from the Sun. The ACRIM III package is flying on a spacecraft called ACRIMSAT. The spacecraft was launched on December 20, 1999 as a secondary payload on a Taurus launch vehicle. ACRIMSAT data will be correlated with possible global warming data, ice cap shrinkage data, and ozone layer depletion data. It is theorized that as much as 25 percent of the earth's total global warming may be solar in origin due to small increases in the Sun's total energy output since the last century. By measuring incoming solar radiation and adding measurements of ocean and atmosphere currents and temperatures, as well as surface temperatures, climatologists will be able to improve their predictions of climate and global warming over the next century.

The *Global Precipitation Measurement* (GPM) is a joint mission with the National Space Development Agency (NASDA) of Japan and other international partners. Building upon the success of the Tropical Rainfall Measuring Mission (TRMM), it will initiate the measurement of global precipitation, a key climate factor. Its science objectives are: to improve ongoing efforts to predict climate by providing near-global measurement of precipitation, its distribution, and physical processes; to improve the accuracy of weather and precipitation forecasts through more accurate measurement of rain rates and latent heating; and to provide more frequent and complete sampling of the Earth's precipitation. GPM is envisioned to consist of a primary spacecraft to measure precipitation structure and to provide a calibration standard for the constellation spacecraft, an international constellation of NASA and contributed spacecraft to provide frequent precipitation measurements on a global basis, calibration/validation sites distributed globally with a broad array of precipitation-measuring instrumentation, and a global precipitation data system to produce and distribute global rain maps and climate research products. The core GPM spacecraft is scheduled for launch in 2009.

The *Ice, Clouds, and Land Elevation Satellite* (ICESat) provides a subset of the large Earth Observing System (EOS) spacecraft measurements, primarily land, ice, and sea ice altimetry products with secondary products being cloud/aerosol lidar and land/vegetation altimetry. In particular the mission determines decadal variation of ice sheet thickness over Greenland and Antarctica, altitude and thickness of clouds, vegetation heights, land topography, and ocean surface and sea ice altimetry. The main scientific objective is to understand the role of polar regions in the Earth's climate and sea-level variations.

Jason is an oceanography mission to monitor global ocean circulation, improve global climate predictions, and monitor events such as El Nino conditions and ocean eddies. The Jason-1 satellite carries a radar altimeter, and it is a follow-on mission to the highly successful TOPEX/Poseidon mission. It is a joint mission between France and the USA. The Delta vehicle was shared with another NASA mission, TIMED. Jason was launched in 2001.

The *Quick Scatterometer* (QuikSCAT) mission is intended to record sea-surface wind speed and direction data for global climate research and operational weather forecasting and storm warning. It replaces the data lost by the failure of the Advanced Earth Observing Satellite in June 1997.

The *Solar Radiation and Climate Experiment* (SORCE) is a NASA-sponsored project which will provide Total Irradiance measurements and the full Spectral Irradiance measurements required by climate studies. The spectral measurements include ultraviolet, extreme ultraviolet, and the visible to near infrared. SORCE represents the merging of the EOS Solar Stellar Irradiance Comparison Experiment (SOLSTICE) and the Total Solar Irradiance Mission (TSIM). SORCE observations provide understanding of the roles of Sun's variations on Earth's climate. SORCE was launched in 2003.

NOAA Satellites

Where practical, mature systematic measurements that are of use outside NASA's research mission, such as for weather forecasting, are transitioned to operational satellites operated by other agencies. This is exemplified by the history of the POES satellites that NASA builds for NOAA. The first weather satellite, TIROS was launched into polar orbit in 1960. This was NASA's first experimental step to determine if satellites could be useful in the study of the Earth. The TIROS Program, with participants from NASA, the US Army and Navy, RCA, and the U.S. Weather Bureau, proved extremely successful, providing the first accurate weather forecasts based on data gathered from space. Over the next 5 years, 10 TIROS spacecraft were launched to provide data continuity. Between 1965 and 1970, NASA built, launched, and operated an improved series of polar weather satellites to the newly created National Oceanic and Atmospheric Administration (NOAA) - final home of the U.S. Weather Bureau. After handover from NASA, the satellites became designated as NOAA with a number. This tradition has continued through NOAA-16, launched in September 2000. Similarly, NASA builds and launches the geostationary operational weather satellites (the GOES satellites), for NOAA. NASA gives the GOES and POES satellites a letter designation; NOAA then gives them a number designation at handover.

Exploratory Measurement

Exploratory missions that can yield new scientific breakthroughs are a significant component of ESE's program, in conformity with the strategic mission of NASA to promote research and development. Each exploratory satellite project is expected to be a one-time mission that can deliver conclusive scientific results addressing a focused set of scientific questions. In some cases, an exploratory mission may focus on a single pioneering measurement that opens a new window on the behavior of the Earth system. Included in this class of missions are *small university-led missions* which seek to train the next generation of scientists at the same time scientific information is obtained. No commitment for long-term measurement is made with this class of mission, although it is possible that the results of an exploratory project could lead to introducing a new systematic measurement or transition to an operational application program. Sample exploratory spacecraft under 1000kg include:

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) will provide key measurements of aerosol and cloud properties needed to improve climate predictions. The CALIPSO mission is led and managed by NASA's Langley Research Center for the NASA Earth System Science Pathfinder (ESSP) program and collaborates with the French space agency Centre National d'Etudes Spatiales (CNES),

Ball Aerospace and Technologies Corporation, Hampton University and the Institut Pierre Simon Laplace in France. CALIPSO is scheduled for launch in 2004.

Challenging Mini-Satellite Payload for Geo-scientific Research and Applications Program (CHAMP) performs the following three tasks: 1) Mapping of the Earth's global long to medium wavelength gravity field and temporal variations with applications in the geophysics, geodesy and oceanography; 2) Mapping of the Earth's global magnetic field and temporal variations with applications in geophysics and solar terrestrial physics; 3) Atmosphere/ionosphere sounding with applications in global climate studies, weather forecasting, disaster research and navigation. This is a cooperative project with Germany. Energy forecasting and water management. CHAMP was launched in 2000.

CloudSat is an experimental satellite that will use radar to measure the vertical structure of clouds and cloud properties from space. Launch is planned for no earlier than January 2005 from Vandenberg AFB in California. CloudSat will fly in orbital formation as part of a constellation of satellites including Aqua, CALIPSO, PARASOL, and Aura.

The *Gravity Recovery and Climate Experiment* (GRACE) is a cooperative mission with Germany. Its primary goal is to obtain accurate global and high-resolution determination of both the static and the time-variable components of the Earth's gravity field. GRACE was launched in 2002 from the Plesetsk Cosmodrome, Russia.

The *Hydrosphere State Mission* (HYDROS) will provide the first global views of Earth's changing soil moisture and land surface freeze/thaw conditions, leading to breakthroughs in weather and climate prediction and in the understanding of processes linking water, energy, and carbon cycles. HYDROS is scheduled to launch in 2009.

Total Ozone Mapping Spectrometer (TOMS)-*Earth Probe* (EP) provides global measurements of total column ozone and its variation on a daily basis. Together with TOMS aboard Nimbus-7 and Meteor-3, it provides a long-term data set of daily ozone over about two decades. TOMS-EP was launched in 1996.

Operational Precursor and Technology Demonstration

Requirements for more comprehensive and accurate measurements place increasing pressure on operational environmental agencies and require major upgrades of existing operational observing systems. In order to enable such advances, NASA invests in innovative sensor technologies and develops more cost-effective versions of its pioneer scientific instruments that can be used effectively by operational agencies. ESE has identified several operational precursor or "bridging" missions that will lead to future operational deployment in low Earth orbit or geostationary orbit during the next decade, principally within the framework of the NPOESS and GOES programs. Active participation of operational agencies in the definition and development of the new systems, and their commitment to transition to operational status, are essential for the success of such operational precursor developments. In this regard, the determination of the partner agency to continue a new observation when technological readiness is demonstrated is a major element of choice in NASA's decision to invest in operational precursor missions. The first such investment was the highly successful Earth Orbiter 1 (EO-1).

The New Millennium Program *Earth Observing-1* (NMP EO-1) mission included three advanced land imaging instruments and five revolutionary cross cutting bus technologies in a 529kg spacecraft. The three advanced imaging instruments has led to a new generation of lighter weight, higher performance and lower cost Landsat-type Earth surface imaging instruments. The hyperspectral instrument was the first of its kind to provide images of land-surface in more than 220 spectral colors. Local to regional land cover and land cover change and atmospheric constituents - agricultural competitiveness, air quality, carbon management, coastal zone management, invasive species management, water management and conservation, public health, energy forecasting, and aviation safety. EO-1 was launched in November 2000.

NASA's Earth Science Enterprise has had a long history of collaboration with international partners. As the Earth system knows no boundaries, it is important to secure collaboration with world countries in order to facilitate scientific discovery. Table provides a summary list of international contributing partners, and their working relationship with the ESE.

Table 1: International contributing partners, and their working relationship with the ESE

Contributing Partner	Contribution Type	Project or Instrument	Date	Vehicle
Argentina	Spacecraft, instrument, mission operations and data analysis (MO&DA)	SAC-C	November 2000	Delta II
Australia	Spacecraft, launch, MO&DA	FEDSAT	February 2002	Japanese H-2A
Belgium	Hitchhiker Instrument	SOLCON	Up to 4 flights planned	Space Shuttle
Brazil	CCD Imaging Camera	CIMEX	TBD	Space Shuttle
Brazil	NASA Aircraft overflight support and in-situ measurements	LBA	Ongoing 6 year Campaign	N/A
Brazil	Instrument on Aqua	HSB	July 2001	Delta II
Canada	Instrument on Terra Spacecraft	MOPITT	December 18, 1999	Atlas II AS
Canada	SAR instrument/spacecraft	RADARSAT-1	November 4, 1995	Delta II
Canada	Atmospheric Chemistry Experiment	SCISAT	Mid 2002	Pegasus XL class
Canada	Cloud radar components	CloudSat	March 2003	Delta II
Canada	Satellite data collection; instruments; aircraft; PIs	BOREAS	Ongoing Campaign	N/a
Denmark	Magnetic mapping payload	SAC-C	November 22, 2000	Delta II
Denmark	Spacecraft; instruments; MO&DA	Oersted	February 23, 1999	Delta II
ESA	Provision of scientific data	ERS-1/ERS-2	1991/1995	Ariane-4
ESA	Provision of scientific data	ENVISAT	June 2001	European Ariane-5
France	Platform; portions of instrument; spacecraft operations	PICASSO-CENA	March 2003	Delta II
France	Spacecraft; instruments; validation; science	Jason	May 2001	Delta II
France	MO&DA	Oersted	February 23, 1999	Delta II
Germany	Spacecraft & launch	CHAMP	July 15, 2000	Russian COSMOS
Germany	MOS ocean color sensor	IRS-P3/MOS	March 1996	Indian Polar Satellite Launch Vehicle
Germany	Launch	GRACE	June 2001	Russian Rocket
Germany	X-SAR instrument	SRTM	January 2000	Space Shuttle
India	Access (with NOAA) to data from meteorological sensors on Indian INSAT satellites and in-situ measurements	INSAT	Ongoing launches and data collection	1990 Delta launch and all others via European Ariane vehicles
Italy	Flight and ground support equipment	Triana	October 2001	Space Shuttle
Japan	Instrument on EOS PM-1	AMSR-E	December 2000	Delta II
Japan	Spacecraft; instruments; launch	ADEOS II	February 2002	Japanese H-II
Japan	Spacecraft, instruments; launch	JERS	February 11, 1992	Japanese H-II
Japan	Instrument on Terra Spacecraft	ASTER	December 18, 1999	Atlas II AS
Japan	Launch; precipitation radar instrument	TRMM	November 28, 1997	Japanese H-II
Japan	Data analysis	QuikSCAT	June 19, 1999	Titan II
Netherlands	Instrument on EOS Aura	OMI	December 2002	Delta II
Over 30 countries	In-situ data collection	Aerosol Robotic Network	Ongoing	N/A
Over 80 countries	VLBI/SLR/GPS system investment and operation	NASA-led Space Geodesy Program	Ongoing	N/A
Russia	Spacecraft; launch	SAGE III/Meteor-3M	December 2000	Russian Zenit
South Africa	Spacecraft; instruments; MO&DA	SUNSAT	February 23, 1999	Delta II
United Kingdom	Subsystems for instrument on EOS Aura	HIRDLS	December 2002	Delta II

2 Earth System Science Pathfinder

The Earth System Science Pathfinder (ESSP) Project is a component of the Earth Science Enterprise (ESE) that addresses unique, specific, highly-focused mission requirements in Earth science research. The ESSP program is an innovative approach for addressing Global Change Research by providing periodic "Windows of Opportunity" to accommodate new scientific priorities and infuse new scientific participation into the Earth Science Enterprise.

The ESSP missions are the cornerstones of a dynamic and versatile program consisting of multiple Earth system science space flights. The ESSP program is characterized by relatively low to moderate cost (less than US\$125M in FY01 dollars), small to medium sized missions that are capable of being built, tested and launched in a short time interval. These missions are capable of supporting a variety of scientific objectives related to earth science, including the atmosphere, oceans, land surface, polar ice regions and solid earth. Investigations include development and operation of remote sensing instruments and the conduct of investigations utilizing data from these instruments. Some missions funded through the ESSP program were already cited above, and include GRACE, CloudSat, and HYDROS. Additional ESSP missions are the *Orbiting Carbon Observatory* (OCO) and *Aquarius*.

3 The Explorers Program

Explorer-class missions are characterized by relatively moderate cost, and by small to medium sized spacecraft that are capable of being built, tested and launched in short time intervals compared to large observatories (EOS-class). Although the Explorer Program Office is part of NASA's *Space Science Enterprise* (SSE), there can be missions developed to study the near-Earth environment, and thus qualify as "Earth observation missions" from the standpoint of this position paper. A sample of programs and missions are summarized next.

Small Explorers (SMEX)

SMEX Mission investigations are characterized by definition, development, launch service, and mission operations and data analysis costs not to exceed US\$120 million, including launch vehicle. SMEX missions are the closest SSE relative to the ESE ESSP missions in size and scope.

SMEX yielded a rather prolific number of spacecraft. The *Solar Anomalous and Magnetospheric Particle Explorer* (SAMPEX) was successfully launched by a Scout rocket in 1992. It investigated the composition of local interstellar matter and solar material and the transport of magnetospheric charged particles into the Earth's atmosphere. The *Fast Auroral Snapshot Explorer* (FAST) was launched August 21, 1996 aboard a Pegasus XL vehicle. FAST objective was to determine the physical processes that produce aurorae. The *Submillimeter Wave Astronomy Satellite* (SWAS), was launched in 1999 aboard a Pegasus XL, and was designed to measure the amount of water, molecular oxygen, carbon monoxide and atomic carbon, in interstellar clouds. The *Transition Region and Coronal Explorer* (TRACE) was launched in 1997, and observed the connection between the Sun's magnetic fields and coronal heating. The *Wide-Field Infrared Explorer* (WIRE) was launched in 1998. WIRE used a cryogenically-cooled telescope and arrays of highly sensitive infrared detectors for the study of galaxy evolution. Unfortunately, a manufacturing error in one of its electronic boxes caused the cryogen to bleed off the instrument, resulting in the loss of its science mission. In addition to the previous spacecraft, HESSI (High Energy Solar Spectroscopic Imager), and GALEX (Galaxy Evolution Explorer), are also SMEX derivatives.

Medium-class Explorers (MIDEX)

MIDEX mission investigations are characterized by definition, development, launch service, and mission operations and data analysis costs not to exceed US\$180 million, including launch vehicle.

The *Imager for Magnetopause-to-Aurora Global Exploration* (IMAGE) uses neutral atom, ultraviolet, and radio imaging techniques to: identify the dominant mechanisms for injecting plasma into the magnetosphere on substorm and magnetic storm time scales; determine the directly driven response of the magnetosphere to solar wind changes; and, discover how and where magnetospheric plasmas are energized, transported, and subsequently lost during substorms and magnetic storms. IMAGE was launched in 2000.

The *Aeronomy of Ice in the Mesosphere* (AIM) satellite mission will explore Polar Mesospheric Clouds (PMCs), also called noctilucent clouds, to find out why they form and why they are changing. Results from this mission will provide the basis for study of long-term variability in the mesospheric climate.

University-class Explorers (UNEX)

UNEX investigations are characterized by definition, development, launch service, and mission operations and data analysis costs not to exceed US\$15.0M (real year dollars). UNEX missions will be launched by a variety of low cost methods.

The *Student Nitric Oxide Explorer* (SNOE) was a small scientific spacecraft designed, built, and operated by the University of Colorado at Boulder, Laboratory for Atmospheric and Space Physics (LASP). Its scientific goals were to measure nitric oxide density in the terrestrial lower thermosphere (100-200 km altitude) and analyze the effects on its abundance from solar and magnetospheric forcing factors. SNOE was launched in 1998 by a Pegasus XL into a 580km altitude sun-synchronous orbit.

The *Cosmic Hot Interstellar Plasma Spectrometer* (CHIPS) will help scientists determine the electron temperature, ionization conditions, and cooling mechanisms of the million-degree plasma believed to fill the local interstellar bubble.