SPACE-APPLICATIONS IN CLIMATE CHANGE AND GREEN SYSTEMS: THE NEED FOR INTERNATIONAL COOPERATION

International Academy of Astronautics

The International Academy of Astronautics (IAA), an independent nongovernmental organization recognized by the United Nations, was founded in 1960. The purposes of the IAA are to foster the development of astronautics for peaceful purposes, to recognize individuals who have distinguished themselves in areas related to astronautics, and to provide a program through which the membership can contribute to international endeavours and cooperation in the advancement of aerospace activities.

Study on SPACE APPLICATIONS IN CLIMATE CHANGE AND GREEN SYSTEMS: THE NEED FOR INTERNATIONAL COOPERATION

Edited by John C. Mankins, Max Grimard, and Dr. Yasushi Horikawa

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Foreword

I am pleased to welcome the present International Academy of Astronautics (IAA) study that will support discussions during the historic Heads of Space Agencies Summit on November 17, 2010 in Washington DC, USA. Prepared during a record time of one year with an unprecedented support, this study constitutes one of the four pillars of the Summit dialogue.

In addition four successful IAA conferences contributed to the input of the four studies, namely: the Academy Day in Bremen on planetary robotic exploration, the IAA conference in Riga on disaster management, IAA conference in Nagoya on climate change and the Academy Day in Prague on human spaceflight.

I would like to thank the Study Group members who have prepared this study and the Trustees of the Academy who have reviewed it. I would like to particularly thank the Summit Coordinator, Dr. Jean-Michel Contant, IAA Secretary General, who has coordinated these four studies and remarkably secured the 25 Heads of Space Agencies, as of October 1st, 2010.

I would like also to extend my thanks the Co-Chair of the Steering Committee and Summit Program Manager, Mrs. Corinne Jorgenson, President, Advancing Space and the Co-Chair of the Steering Committee, Mrs. Mary Snitch, Director, Lockheed Martin Corporation for their valuable contributions to the studies and Summit preparation.

After 50 years of existence the International Academy of Astronautics is recognized by space agencies as a unique elite body that can help advancing international cooperation. It has been observed that much current cooperation programs are aging such as the International Space Station (ISS) initiated with just a few countries. Many newcomers are joining the club of emerging space countries and more than half of the current space agencies did not exist at the beginning of ISS. The result is a need to enlarge significantly the circle of the current partners for international space cooperation.

The IAA with members from all over the world is engaged in extending the frontiers of knowledge in space exploration and also its applications to solve the day-to-day problems of humankind. Academicians have worked in unison to achieve the set goals of the Academy and it is inspiring to note the many IAA emerging activities. In view of the Summit achieving successful concrete preliminary results, many space agencies have already welcomed the Academy serving as catalyst for years to come with several subsequent implementation meetings and studies.

Gopalan Madhavan Nair
President
International Academy of Astronautics

Executive Summary

The future activities of the global space community can make significant contributions to monitoring and understanding both the causes and the consequences of Climate Change, as well as to mitigating its effects through the advancement of green systems and technologies (including new sources of energy), and through improvements in the integration of space systems and ground operations.

Over the past half-century, space systems and activities have made crucial contributions to the study and understanding of climate change, through the multi-decade accumulation of vast quantities of scientific data concerning the atmosphere, the oceans, the lands, and the mechanisms of exchanges between these domains. Moreover, technologies that were developed for space applications (e.g., PV arrays, fuel cells, etc.) have found significant terrestrial value in diverse energy and transportation applications worldwide. And, increasingly space assets (e.g., weather observing systems, space-based navigation systems, etc.) are improving the efficiency of energy consumption. In the future, the spectrum of contributions made by space activities and systems to solve the challenges of climate change and the development of increasingly green systems should be even broader and more important. The following three domains address key challenges for the space community:

- Observing Earth from Space
- Leveraging Space-Ground Systems Integration
- Enabling New Green Systems & Energy

As a part of the commemoration of the 50th anniversary of the founding of the International Academy of Astronautics (IAA), an IAA study group examined during 2009-2010 these challenges and formulated a series of recommendations for the global space community as to how better it might approach them. In each of the above thematic areas, proposals were made as to how space activities can contribute to solving them through international coordination and cooperation.

The key findings and recommendations for the international space community are summarized below.

Observing Earth from Space: Challenge & Recommendations

Key Challenge: How best can the international space community cooperate to deliver critical data in a timely way and improve the understanding and continuous monitoring of the potential drivers for, and effects of global climate change?

Recommendations: Global Space Agencies, Companies, Universities and Non-Governmental Organizations, and other international bodies already acting for the coordination of space agencies in the area of climate monitoring (e.g., GEO, CEOS, etc.) should work together to:

- Guarantee over time the continuous operational availability of the space sensors and datasets that are necessary for the monitoring of the space dependent ECVs (Essential Climate Variable). A good programmatic coordination of the Earth Science programs worldwide shall prevent any gap in the delivering of ECV data from space.
- Recognize that the responsibility for ensuring the continuity of climate measurements should be the role of those organizations and national entities with policy responsibility for managing climate change, and not that of development agencies addressing the problem as part of their research agenda.
- Develop and deploy increasingly higher resolution and more frequent measurements of ECVs to better inform international climate change modelling and simulation efforts, and develop measurements of climate-related variables not yet available from space sensors (for example wind, sea-air fluxes).
- Guarantee the data sharing from space agency missions on a full and open basis to benefit users, in all countries, whether they be space faring or developing countries.
- Ensure the transfer of capacity to developing countries to allow the full benefit of satellite data to be available to all, locally, to inform policy decisions.
- Foster technology development and the deployment of space systems to pursue improved detection of GHG emissions from space, as a means to monitor the international commitments at regional level, for climate treaty verification.
- Support the development of a reliable, objective and verifiable observation system from space to provide the necessary data for the establishment of national Monitoring, Reporting and Verification (MRV) mechanisms related to efforts to reduce emissions due to forest loss and degradation (known as “REDD").
- Define common standards for climate data storage, exchange, and processing, allowing the implementation of a global worldwide data base for climate monitoring
- Provide increasing support for the current coordinated efforts for the global inter-calibration of Earth observation space sensors.
- Ensure that the commercial sector is allowed to provide data (similar to commercial imagery business model) provided it meets calibration/validation standards.

Leveraging Space-Ground Systems Integration: Challenge & Recommendations

Key Challenge: How best can the international space community cooperate to improve the pace and thoroughness with which services and data provided by space systems are integrated with the ongoing / evolving design, development and operations of those ground systems and infrastructure that are contribute to global climate change and its mitigation?

Recommendations: Global Space Agencies, Interested, non-Space Government Agencies, Companies, Universities and Non-Governmental Organizations should work together to better:

- Define international regulations and standards, for data exchange and processing, for interoperability in telecommunications and positioning, in order to allow the use of integrated applications worldwide (e.g. for air, sea, road traffic management, sensitive industrial infrastructure monitoring, search and rescue management, etc.)
- Promote of closer cooperation among space organizations and non-space organizations (for example, FAO, ICAO, IAE, and others) in the maturation and deployment of new technologies and systems for terrestrial green systems that take better advantage of the assets and information available from space systems and activities.
- Support the development of commercial business in downstream integrated applications services related to climate change and environment, to capture the interest of the private sector. Financial investment from the private sector shall guarantee the continuity of the services for the benefit of the citizens from all countries.

Enabling New Green Systems & Energy: Challenge & Recommendations

Key Challenge: For the farther term, how best can the international space community cooperate to develop and demonstrate transformational new green systems and energy technologies?

Recommendations: Global Space Agencies, Companies, Universities and Non-Governmental Organizations should work together to:

- Foster technology programs and flight tests, to demonstrate the feasibility of space-based solar power generation and transmission to ground.
- Foster common developments and exchanges of technologies between the space sector and the energy sector, to facilitate transfer of technologies leading to new green energy systems on Earth (energy conversion, transmission, and storage).
- Foster offsetting of space technologies that might enable development of green systems on Earth, e.g. closed environmental life support systems.
- Provide reliable information from space-based observations to allow the better optimized future deployment of renewable energy mechanisms, such as tidal, wind and solar power.
- Foster technology R&D (through flight testing) to demonstrate the feasibility of so-called green propellants, which can reduce the potential harm to the environment and thereby significantly reduce the associated costs.
- In a long-term vision of the space-era, implement for any deep space exploration mission an objective of search for new resources that might enable mitigation of the resources gap on Earth.

Summary thoughts

The global space community has already done much to foster understanding of the looming risk of climate change and to develop and deploy new technologies and green systems that can mitigate and allow us to respond more effectively to those risks. All of these have a direct and enduring impact on global culture, on our understanding of the world and the relationship of humanity with natural systems, and on the education of future Earth scientists, space engineers and technologists, social scientists, and others.

During the coming years and decades that community can do much, much more: now is the time to start.

Chapter 1

Introduction

Background

The evolution of Earth's climate towards overall global warming, accompanied by increasingly severe episodes in local weather is now a fact that is generally acknowledged by the scientific community, national and international decision makers, and the public. Following the release in 2007 of the 4^{th} Assessment Report of the UN Intergovernmental Panel on Climate Change (IPCC), substantial coverage by the international media has informed the development of increased awareness by all stakeholders, and "Climate Change" is now considered a challenge for humankind and governments around the world. It is therefore a key domain for international discussions, hard negotiations (as demonstrated at COP15 Copenhagen), and hopefully coordination.

During the past six decades, space systems and activities have made innumerable and critical contributions to the study and understanding of Climate Change, through the multi-decade accumulation of vast quantities of scientific data concerning the atmosphere, the oceans, the lands, and the mechanisms of exchanges between these domains. Moreover, technologies that were developed for space applications (e.g., photovoltaic arrays, fuel cells, etc.) have found significant terrestrial value in diverse energy and transportation applications worldwide. And, increasingly space assets (e.g., weather observing systems, space-based navigation systems, etc.) are improving the efficiency of energy consumption.

Intensive international cooperation has already been implemented, in particular for the monitoring of climate variables, through various international organizations (e.g. WMO, GCOS, GEOSS, CEOS), but all experts recognize that coordination and cooperation could be improved, in particular to guarantee the continuous coverage of climate monitoring. In the domains of mitigation and adaptation, the role of space applications has been less preeminent up to now, thus leading to a lower focus for international cooperation.

Overall, space has been, and will continue to be, a key to the solution for Climate Change – not a part of the problem.

The spectrum of contributions made by space activities and systems to address the challenges of climate change and the development of increasingly green systems should be even broader and more important in future years. These contributions should involve goals such as monitoring the Earth, preventing and/or mitigating the effects of climate change, and enabling more effective adaption to changes as they occur. Moreover, these efforts can be expected to both provide, and result from, continuing and new areas for international cooperation.

The International Academy of Astronautics

The International Academy of Astronautics (IAA) is a global community of experts in space science, engineering, technology and related disciplines committed to expanding the frontiers of space and the benefits of space to humanity. It is a non-governmental organization established in Stockholm (Sweden) on August 16, 1960.

The IAA works to promote the development of astronautics for peaceful purposes, recognize individuals who have distinguished themselves in a related branch of science or technology and provide a program through which members may contribute to international endeavors for the advancement of aerospace science. It works closely with the International Astronautical Federation (IAF), national and international space agencies.

2010 is the 50th anniversary of the formation of the IAA. As part of the commemoration of this seminal historical event, and in looking forward to the future of global space endeavors, the Academy organized several activities and events, structured around four major themes:

- Human Space Flight
- Space Exploration
- Disaster Management
- Climate Change / Green Systems

These activities included a series of IAA studies addressing the four major themes for the future of space, and a several international precursor event, including a major international symposium on the topic of "What Can We Do for Our Mother Earth?" held 30-31 August 2010 in Nagoya, Japan, and culminating in a first-of-a-kind "Heads of Space Agencies Summit" in Washington, DC on 17 November 2010. [1] (The IAA study activities provided key background research and preparation for the Heads of Space Agencies Summit.)

This document is the final report for the 2009-2010 International Academy of Astronautics Climate Change / Green Systems study group.

The IAA Climate Change / Green Systems Study

During 2009-2010, the IAA pulled together an international team of volunteers to conduct an initial study of Climate Change / Green Systems (CCGS). The objectives of this Academy Study Group were to:

- Develop a comprehensive list of domains where space activities can provide value to goals related to informing our understanding climate change, or to the development, deployment and operation of green systems.

[1] The CCGS Study Group expresses its appreciation for the efforts of Prof. Seishiro Kibe of JAXA, and the other members of the local organizing committee in orchestrating the Nagoya Conference quickly and successfully.

- Delineate the respective roles of governments, and research institutes and/or universities, non-profit organizations, and industry, in developing, implementing and operating the future systems for Climate Change mitigation, and the associated services.
- Identify a range of possible mechanisms for international cooperation in pursuing shared goals with respect to climate change and green systems; these may include global versus regional approaches, potential systems-of-systems approaches with coordinated building blocks, exchanges of data, and others.
- Identify potential CCGS data-related policies and/or regulations; including data collection and distribution (e.g. standards), data access and rights of use (e.g. treaty monitoring, carbon market), allocation of tasks for data processing (e.g. essential climate variables), etc.
- Identify and/or develop documentation of specific relevant case studies concerning the relevance of space activities to climate change and/or green systems.
- Develop summary findings and recommendations, including inputs to the overall IAA space summit planning and preparatory process.

Study group members included members of the International Academy of Astronautics, various subject matter experts and scientists, and additional professionals from various organizations across the international space community. (The membership of the Study Group is provided in Appendix B of this document.)

The study was conducted primarily by means of on-line tools (i.e., email exchanges), teleconferences (as needed), and selected working meetings (which involved a subset of the full study group membership), including: (a) a working meeting in Paris during 23-25 March 2010 (in the context of the planned IAA meetings during that week); (b) a major international conference on Climate Change and Green Systems held in Nagoya, Japan at the end of August 2010; and, (c) working discussions among CCGS Study Group members during the 2010 International Astronautical Congress (27 September 2010 - 1 October 2010) in Prague, the Czech Republic.

Structuring its analysis in light of a space capabilities point of view, the Study Group focused on three topics:

- *Observing Earth from Space*: Earth observation systems are global, systemic, and accurate enough to allow precise monitoring with a variety of applications to solve climate change issues, both for mitigation and adaptation.
- *Leveraging Space-Ground Systems Integration*: beside the Earth observation systems, or in combination with them, space based telecommunications or positioning are efficient tools for use by ground systems, in order to improve their efficiency and/or reduce their carbon footprint (transport, land use, energy, crisis warning and response).
- *Enabling New Green Systems & Energy*: a wide range of space technologies may be transitioned beginning in the near term to new applications that improve the efficiency of terrestrial systems, and new energy technology options may be developed and

demonstrated, including in the far-term novel global energy solutions using systems based in space.

Each of these themes is explored in greater detail in the chapters that follow, with an emphasis on international cooperation status and perspectives. The report concludes with summary perspectives on Climate Change/Green systems, reviewing the results of the Study Group, and presenting selected conclusions from the effort, including several integrated scenarios for international CCGS cooperation, and several appendices.[2]

[2] The Appendices that are part of this document present supporting materials, such as a glossary of acronyms, identification of study group members, etc. In addition, a separate volume of proceedings from the International Conference in Nagoya, Japan (mentioned above) is being published.

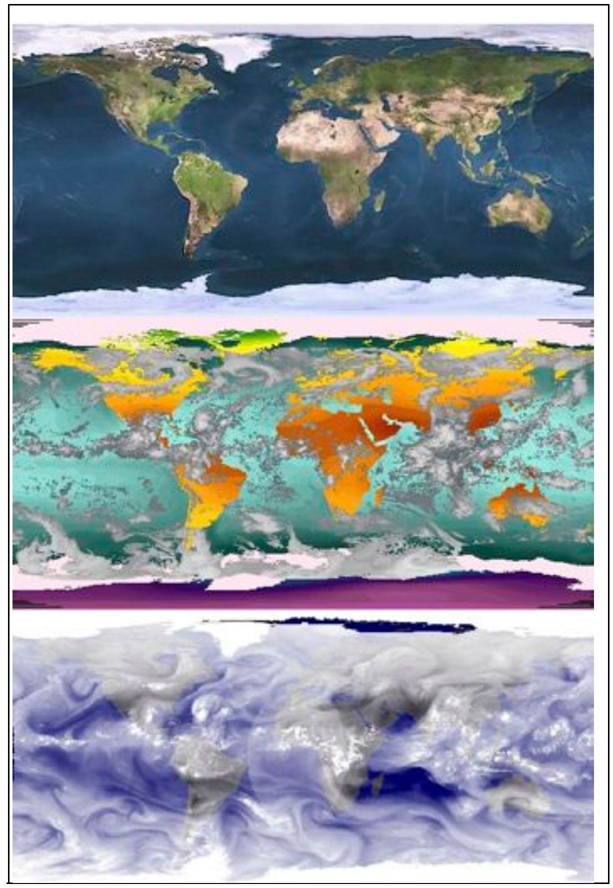
Chapter 2

Observing Earth From Space
(CCGS – Theme 1)

Introduction

Earth observation from space can assist in addressing all aspects of climate change, including:

- Modeling and prediction of climate change;
- Mitigation, for example through monitoring the reduction of emissions due to deforestation worldwide, carbon capture and storage, alternative power management;
- Adaptation, for example by supporting coastal defense management, disaster preparedness;
- Attribution, through the identification of sources of agents of climate change, for example CO_2 emissions; and,
- Timely validation of the end-to-end effect of climate change mitigation efforts.



Earth in 3 Views:
Integrated Terrain & Vegetation (Top),
Cloud Cover (Middle), and Water Vapor (Bottom)

Intensive international cooperation related to satellite-based Earth observation has already been implemented, in particular for the monitoring of climate variables as inputs to general circulation models, through various international organizations (e.g. GCOS, CEOS).

However, all experts recognize that coordination and cooperation could be improved, in particular to guarantee sustainable long-term support for the observations critical to climate. In the domains of mitigation and adaptation, the role of space applications has been less pre-eminent up to now. An exception is the case of the International Charter for Space and Disasters, which has operated for over a decade to integrate the capabilities of space agencies worldwide in response to natural disasters, particularly hydro-meteorological events that are expected to increase as a consequence of climate change. It is expected that this role of satellite data in mitigation and adaptation should increase in the future and will increasingly demand new areas for cooperation. Attribution of the responsibility for the agents of climate change requires a complex interaction of observations and models but will become increasingly important as these capacities are developed.

Well-defined requirements for observations in all these areas have been documented by the Global Climate Observing System (GCOS), comprising data from satellites and from other sources. Specific statements of need or satellite data observations have also been produced by GCOS; these are a crucial starting pointing in assessing the current capacity of space based observations for climate and allow a formal requirements dialogue between GCOS and space agencies.

The Current Situation

A general framework for the international cooperation of space agencies has already been implemented. Established in 1984, the Committee on Earth Observation Satellites (CEOS) coordinates civil space-borne observations of the Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit. Currently 28 space agencies along with 20 other national and international organizations participate in CEOS planning and activities. This coordination covers all aspects of satellite observation from space.

The Global Climate Observing System (GCOS) was established in 1992 and focuses on satellite and *in situ* observations for climate in the atmospheric, oceanic, and terrestrial domain. GCOS is intended to meet the full range of national and international requirements for climate and climate-related observations. As a system of climate-relevant observing systems, it constitutes, in aggregate, the climate-observing component of the Global Earth Observation System of Systems (GEOSS).

Requirements are captured through a number of Essential Climate Variables (ECVs), 44 in all, off which some 28 are primarily derived from satellite data. (See Table 1 below for details). The ECVs have been defined by GCOS (Global Climate Observation System), to support the work of UN FCCC and IPCC. The objective is to define internationally a set of environmental variables related to climate change that will be used as indicators of the state of environment. They are aimed at defining undisputed indicators of climate change to monitor the situation. The list of 44 ECVs (soil moisture not yet formally in the list) is accepted, and standardization of measures in progress. The full list of ECVs is presented in Table 1 below.

Climate is but one of the nine Societal Benefit Areas Supported by the Group on Earth Observations (GEO). Established in 2003, the emerging public infrastructure (GEOSS) is interconnecting a diverse and growing array of instruments and systems for monitoring and forecasting changes in the global environment. This "system of systems" is designed to support policymakers, resource managers, science researchers and many other experts and decision-makers in various Societal Benefit Areas (SBA).

Table 1 – Essential Climate Variables (By Area of Observation)

Domain	Essential Climate Variables	
Atmospheric	**Surface**	Air Temperature, Precipitation, Air Pressure, Surface Radiation Budget, Wind Speed And Direction, Water Vapor
	Upper air	Earth radiation budget (ERB), Upper-Air Temperature, Wind Speed and Direction, Water Vapor, Cloud Properties
	Composition	Carbon dioxide (CO2), Methane (CH4), Ozone, Other Long-Lived Greenhouse Gases, Aerosol Properties
Oceanic	**Surface**	Sea-Surface Temperature (SST), Sea-Surface Salinity, Sea Level, Sea State, Sea Ice, Current, Ocean Color, Carbon Dioxide Partial Pressure
	Sub-surface	Temperature, Salinity, Current, Nutrients, Carbon, Ocean Tracers, Phytoplankton
Terrestrial		River Discharge, Water Use, Ground Water, Lake Levels, Snow Cover, Glaciers And Ice Caps, Permafrost And Seasonally-Frozen Ground, Albedo, Land Cover, Fraction Of Absorbed Photosynthetically Active Radiation (FAPAR), Leaf Area Index (LAI), Biomass, Fire Disturbance, Soil Moisture (not yet part of ECVs)

Source: IPCC

GEO is a voluntary partnership of governments and international organizations. Currently, GEO's members include 81 Governments and the European Commission. In addition, 58 intergovernmental, international, and regional organizations with a mandate in Earth observation or related issues have been recognized as Participating Organizations.

Following the establishment of GEO, CEOS has been considered as the arm of GEO for implementation of the space observation of GEOSS and has strengthened its activity, in particular in the climate area. In 2006, CEOS published a report entitled "Satellite observation of the climate system: the CEOS response to the GCOS implementation plan", in order to foster the coordination of space agencies in their activities for the observation of climate. More recently, in April 2010, CEOS has implemented a CEOS Climate Working Group in order to ensure the coherent production of Fundamental Climate Data Records (FCDR) and Essential Climate Variables (ECV) among CEOS agencies in response to the defined needs of GCOS. This builds on previous efforts among meteorological space agencies to coordinate the production of specific ECVs among their programs. In addition, the Virtual Constellations of CEOS provide a coherent mechanism for responding to the climate needs in specific topical areas, and have already achieved significant progress in, for example, the coordination of observations of sea level. Note that these activities comprise not only coordination of mission and the space infrastructure, but also the processing and algorithm development needed to generate coherent ECVs in response to the needs of GCOS.

Current interests in climate have lent considerable emphasis to the need for observations, and particularly satellite observations, in order to address the societal aspects of climate change. Until recently, modeling and prediction of climate tended to concentrate on timescales of the order of centuries (the state of climate in 2100 was a frequent reference point). As a result, the initial conditions, i.e. what we get from today's observations, is of less importance than the details of the model itself in terms of what the ultimate state of the climate might be expected to be. However there is increasing interest, for societal and political reasons, in the state of the Earth's climate in ten or twenty years from now; these are timescales within the purview of current politics and form the basis for today's discussion on emissions limitations. The modeled predictions of climate change on a decadal timescale are much more heavily dependent on the initial state of the system and hence on the observations of climate today. This focus on shorter timescales gives a new emphasis to the need for high accuracy ("climate quality") observations of the Earth system.

We now also have sufficiently long time series of measurements of some aspects of the Earth system to be able to check the predictions made some time ago – decades or more. As an example, the rise in sea level by 2010 predicted in the mid-nineties can now be compared with the latest observations from satellites to a level of precision meaningful in confirming the validity of the original prediction – and indeed the observations are exactly in line with the predictions. This capacity for checking progress against predictions will increase in future as the timescale of prediction baselines increases and the ability to make detailed measurements of the earth system, mainly from space, improves.

Furthermore, through the discussion at UN FCCC Conference of the Parties, nations are now considering how to mitigate anthropogenic changes to climate. Mitigation activities also require improved knowledge of the state of the Earth and how this might be managed to improve climate outcomes. A good example is the desire to define and implement a mechanism for reducing emissions from deforestation in developing countries. Such a mechanism is likely to involve the net transfer of very considerable amounts of funding from developed to developing countries, set against a validated reduction or prevention of deforestation in the latter. In order to achieve this national forest inventories will be required which form the basis of a Monitoring, Reporting and Verification (MRV) system under the Convention. Such a system can only be based on complete and comprehensive observations of forest state from satellites. A demonstrator program involving ten countries is currently being developed by GEOSS in response to the needs of UNFCC parties, based on satellite data, working also with agencies such as the Food and Agriculture Organization (FAO). This demonstrator will need future support though improved and continuing measurements, but also through the development of skills in developing countries, and access to the necessary data, to allow full benefit to be secured from satellite data in consolidating the national forest inventories which must, by definition, be developed and reported by the individual nations themselves.

Another important example of a critical issue in which observations from space can play an important role is that of water cycle monitoring. Specific observations include changes in glaciers and snow packs, monitoring of river and dam / reservoir levels, cloud generation, rainfall, and others. The obverse side of this observation – drought prediction, detection and monitoring is no less important.

Among examples of developing capabilities to monitor aspects of the climate system from space we should also mention the critically important observations of carbon dioxide (CO2) and methane (CH4). These will be critical for all aspects of the problem, from modeling sinks and sources accurately to allowing eventually the direct attribution of emissions under any regime of treaty verification yet to be developed. Current systems have been able, for only a few years, to make direct measurements of total CO2 in the atmosphere from space but these will need to be improved in accuracy, resolution and timeliness in order to satisfy requirements of attribution. This will require not only the improvement of passive systems for CO2 and CH4 measurement, but also the introduction of active LIDAR-based technologies for differential absorption measurement of CO2 adequate to give direct reference to local emissions.

In the limited scope of this document, a comprehensive catalogue of the capacities of space observations to support the understanding and management of climate change is clearly impossible, but while the foregoing demonstrates the progress that has been made in creating a more coherent partnership among space agencies in providing the observations necessary for climate modeling, mitigation and adaptation there is no doubt that there remains significant scope for improvement. Services related to the data generation, processing and distribution will be developed, and the derived information will provide key inputs for the monitoring of relevant worldwide treaties. Climate Change is already increasing extreme phenomena endangering the life of the citizens (floods, cyclones, etc.). Specific prospects comprise a range of Earth observation and science objectives, such as…

- *Climate Monitoring*, including long-term Earth observations to understand better long-term / large-scale developments in the climate, to improve climate modeling and prediction, and to better inform the deliberations of policy makers. (The understanding of feedback process in climate system will improve the prediction of Climate Change.)
- *Natural Resources Management*. Using space-based data, various natural resources policies and developments that directly affect greenhouse gas (GHG) concentrations – for example, those related to de-forestation – may be monitored more effectively and rapidly.
- *Extreme Weather Observation and Forecasting*. Earth-observations from space can provide real time data on weather, and to inform increasingly capable weather modeling.
- *Green House Gas (GHG) Monitoring*. Based on space-based data together with the ground-based monitoring data,[3] global GHG emission distribution can be monitored, evaluated by the so-called Inverse Model, and managed more effectively. The emission from forest fires, unknown sources such as methane from permafrost and/or methane

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3 Monitoring of GHG emissions and sinks is an area where the integration of space measurements with ground measurements and numerical modelling will be necessary to monitor effectively the international commitments at regional level.

hydrate, and other non-stationary emissions can be detected from space, and thereby enhance countermeasure activities.

- And Other Areas.

Based on space-based data, in particular for GHG emissions or forest management, information from space sensors could provide valuable support to the development of the carbon trade market, which is considered today a key enabler to prevent a further degradation of the climate.

Summary Challenge and Recommendations

Key Challenge: How best can the international space community cooperate to deliver critical data in a timely way and improve the understanding and continuous monitoring of the potential drivers for, and effects of global climate change?

Recommendations: Global Space Agencies, Companies, Universities and Non-Governmental Organizations, and other international bodies already acting for the coordination of space agencies in the area of climate monitoring (e.g., GEO, CEOS, etc.)[4] should work together to:

- Guarantee the continuous operational availability of the space sensors and datasets that are necessary for the long-term monitoring of the space dependent Essential Climate Variables (ECVs). A good programmatic coordination of the Earth Science programs worldwide shall prevent any gap in the delivering of ECV data from space.
- Recognize that the responsibility for ensuring the continuity of climate measurements should be the role of those organizations and national entities with policy responsibility for managing climate change, and not that of development agencies addressing the problem as part of their research agenda.
- Develop and deploy increasingly higher resolution and more frequent measurements of ECVs to better inform international climate change modelling and simulation efforts, and develop measurements of climate-related variables not yet available from space sensors (for example wind, sea-air fluxes).
- Guarantee the data sharing from space agency missions on a full and open basis to benefit users, in all countries, whether they are already space faring or still-developing countries.
- Redouble efforts – including special symposia, workshops and on-line tools – to better ensure the timely and effective communication of Earth observing requirements, acquired data and the subsequent results of scientific studies based on those data among the several

[4] 'GEO' is the international Group on Earth Observations; it is coordinating efforts to build a Global Earth Observation System of Systems, or GEOSS. 'CEOS' (established in 1984) is the Committee on Earth Observation Satellites (CEOS). It coordinates civilian observations of Earth from space, and currently involves some 84 organizations (83 countries and the European Union).

global space agencies and the distributed international climate change research community.

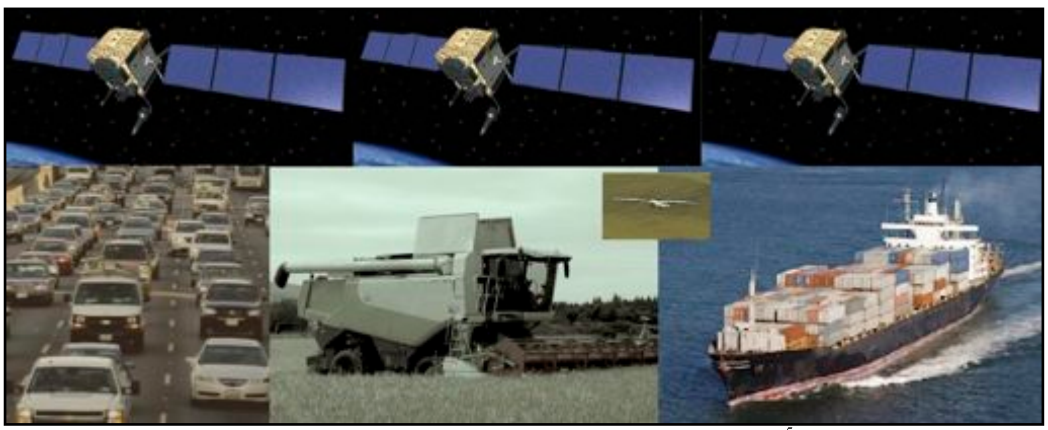
- Ensure the transfer of capacity to developing countries to allow the full benefit of satellite data to be available to all, locally, to inform policy decisions.
- Foster technology development and the deployment of space systems to pursue improved detection of GHG emissions from space, as a means to monitor the international commitments at regional level, for climate treaty verification.
- Support the development of a reliable, objective and verifiable observation system from space to provide the necessary data for the establishment of national Monitoring, Reporting and Verification (MRV) mechanisms related to efforts to reduce emissions due to forest loss and degradation (known as “REDD").
- Define common standards for climate data storage, exchange, and processing, allowing the implementation of a global worldwide database for climate monitoring.
- Provide increasing support for the current coordinated efforts for the global inter-calibration of Earth observation space sensors.
- Ensure that the commercial sector is allowed to provide data (similar to commercial imagery business model) provided it meets agreed-to calibration/validation standards.

Chapter 3

Leveraging Space-Ground Systems Integration
(CCGS - Theme 2)

Introduction

The concept of integrating space and ground systems has been already addressed in chapter 3, for what concerns the joint use of space-based sensors together with ground, sea, or airborne sensors, in order to achieve the best monitoring of Essential Climate Variables. The objective of the following chapter is to address another topic: how better to the use of the full spectrum of space-based applications to support various ground operations (beyond remote sensing), with the goal of mitigating the causes and reducing the impact of climate change.



A Powerful Tool for Improving Energy Efficiency:[5]
Continuing Improvements in the Integration of Space and Ground Systems

Space systems are generally characterized by the delivery of specific capacities: Earth observation or scientific data from remote sensing satellites, bandwidth and data transmission capacity from telecommunications satellites, and positioning and timing signals from navigation constellations. In and of themselves, each of these single capacities are already providing very useful services, but they can open a substantially broader spectrum of applications when used jointly, and when integrated with other systems (ground, sea, and air). Applied to ground operations, these services play an important role in mitigating climate change (including, better

5 The figure presents the concept of position, location and navigation satellites (in this figure, US Global Positioning Satellites are shown), and the potential to benefit key terrestrial operations, including: trafic management, guidance of day/night farming opérations, use for précision location of unmanned air vehicle imaging, and guidance of global shipping opérations.

carbon efficiency of transports, agriculture, land use, better energy management, etc.), or in adaptation (including vulnerabilities assessment, crisis warning and response, etc.).

There are innumerable applications in these fields, answering to the needs of a very large variety of users and market segments. In the frame of this report, we will discuss some of the most relevant to the climate change problem:

- *Satellite-based management of terrestrial transportation*: space assets may be increasingly employed to better manage various ground transport systems, to increase fuel efficiency, and reduce environment impact
- *Satellite-based land use*: geo-information services using remote sensing and navigation data from space, can support sustainable land use, including agriculture, ocean use, coastal use, etc.
- *Satellite-supported management of natural resources*: water, forests
- *Space-based monitoring and management of terrestrial Renewable Energy Systems (RES)*: space remote sensing, in combination with positioning and tele-communications, may be used to better manage "smart grid" systems, for instance vis-à-vis solar and wind assets (e.g., anticipating transient overcast, etc.)
- *Assessment of vulnerabilities*: space remote sensing, combined with geo-information can support the evaluation of vulnerabilities from climatic events (floods, sea raise, cyclones, desertification, etc.)
- *Disaster management*: both at the level of disaster warning and disaster response, space-based telecommunications, navigation, and geo-information are providing efficient tools

Present Situation

Most of the effort to mitigate a further degradation of climate is concentrating on reducing the emissions of Green House Gases (GHG), in particular CO_2 and CH_4. Transport, land use (in particular agriculture and forestry), and energy supply are together contributing to about 70% of the emissions, and are therefore extremely important areas for improvement.

<u>Transport of Goods and People</u>. Terrestrial and air transports represent 14% of GHG emissions. Space-based navigation, combined with geo-information services and telecommunications, is providing an efficient means to optimise transports on ground, on sea, and in the air. Making the traffic more fluid, finding the most efficient routes, and preventing traffic jams, will lead to better energy efficiency and lower emissions.

For instance, removing toll-based ground infrastructure (e.g. toll booths with transponders) through the use of satellite-based systems, using positioning information combined with telecommunications, would allow better ground network management and thus reduce congestion and improve fuel efficiency.

The use of positioning data and ground/space communications can also support multimodal transport of goods (road, rail, sea, air), through the tracking of containers and periodic confirmation of their cargo. By optimizing the use of multimodal transport nationally and internationally, overall fuel efficiency per unit weight shipped can be reduced, thereby significantly reducing the carbon footprint.

For sea transport, ocean current routing services have been developed for the commercial shipping industry. Using data from satellite altimeters and models, information can be given to optimise the routes based on favourable real-time currents. A saving of 1-2 hours per day can be achieved, leading to reductions in fuel consumption: 1% to 5% savings have been gained in the frame of pilot projects.

A similar application could be envisioned for air transport. There are some planned scientific missions, such as the European Space Agency's (ESA) Aeolus satellite, for the measurement of high altitude winds using lidar technology. After demonstration of feasibility, a global operational infrastructure with a constellation of satellites, could allow a sustainable frequent measurement of jet streams, which could be used by airlines to better optimize their transatlantic routes.

More generally, activities are underway for the inclusion of space-based navigation and telecommunications in the future Air Traffic Management (ATM) systems. Both Europe and USA have started huge modernization programs (SESAR in Europe and NextGen in the US) which will revolutionize their traffic control procedures, making traffic safer and more fluid (i.e. consuming less gasoline/diesel). In June 2010, European and American authorities formed an agreement on the interoperability between their future ATM systems, which should allow the airlines to optimize their international flights.

This non-exhaustive list of space based applications for ground, sea or air transport shows that the user market is very fragmented, with different demands for these downstream services, thus leading to a classical business approach with private services actors. The laws of the free market, supply and demand, will be the primary drivers of the development of downstream services supporting further reduction of GHG emissions coming from transport. However, international cooperation at the government level has already been active with regard to several large infrastructures enabling these downstream services. After years of political confrontation when Europe announced the Galileo program, USA and Europe have come to an agreement in June 2004. It will allow the coexistence of both GPS and Galileo through the use of different frequencies. A common civil signal (L1C) will also be implemented in both Galileo and next GPS III, allowing new receivers to utilize both systems to improve accuracy. International cooperation at government level can also lead to regulations and standards which might be applied worldwide, thus further enabling the development of these downstream green services. Another action might be to finance, directly or indirectly (e.g., through public private partnerships, incentives, etc.), the transition from some science satellites to operational satellites enabling new green services.

Sustainable Land, Ocean, Coastal Use. Agriculture, land use change, and forestry are responsible for 31% of GHG emissions. The use of space remote sensing, combined with space-based navigation (such as GPS and Galileo), can very efficiently contribute to better land use, in particular for a sustainable and environment friendly agriculture.

The combination of good crop monitoring using space remote sensing, and precision farming with GNSS (Global Navigation Satellite System), can provide substantial savings in both fertilizers and fuel, while improving the crop yields. An initial operational service implemented in France (FARMSTAR) has demonstrated 30 to 50% savings in fertilizers. In Australia, the application of GNSS for machine guidance has shown fuel and oil costs reduction by 52%, and annual yields increase by 10%.

More globally, agricultural statistics may provide decision-makers with detailed figures, for a better land management: utilized agricultural areas and non-agricultural land, national distribution of cropped area yield forecast for each type of crop, changes from one year to the next and identified trends.

In the field of sustainable agriculture at present, there is no real international cooperation. A variety of services have been developed and proposed by private operators, but generally at local level, since they are very often developed in close cooperation with agriculture actors of their nation. Some specific international actions are implemented under the umbrella of support program to developing countries (e.g. by European Commission), or in the frame of the Food and Agriculture Organization (FAO), but they are still limited, in particular for this goal of reducing the carbon footprint of agriculture practices.

For what concerns the ocean use, a combination of satellite navigation and telecommunications, allows fishing boats to transmit in real time the quantity of fish species caught in specific areas, thus allowing the administrations to updates reports on the resource, and then to draw guidelines on fishing quota. In the field of maritime surveillance, the tracking of unauthorized tanks cleaning and oil leakages can be made by satellite remote sensing, coupled with AIS and localization, and prevent ocean pollution.

Natural Resources Management. As already explained in Chapter 2, space-based remote sensing is an efficient tool for the monitoring of key natural resources. Beyond the monitoring, the coupling of remote sensing with navigation can support the implementation of concrete resources management actions. For instance, in the case of forest management, the mapping analysis can drive the policies of countries regarding the priority areas for deforestation prevention or reforestation.

There are some regions where the hydrological resources are quite dependent on snow cover and water content in the mountains (e.g. in South America). Remote sensing combined with GNSS (e.g. for measurement of water level in isolated lakes) can improve the accuracy of the currently used models, which is low for isolated regions (variations up to 60%). This better assessment of water reserves can lead to water management guidelines for the prevention of water gaps during the hot/dry seasons.

Energy Management. Production of electricity represents 26% of GHG emissions. One way of reducing this carbon footprint is to increase the ratio of Renewable Energy Sources (RES). Space applications can play various roles in that field.

Remote sensing can effectively support the selection of the best locations for implementation of large windmill infrastructures (topography analysis and wind mapping) or Concentrating Solar Power (CSP) power plants (solar radiation forecasting).

But the most promising domain for a combined use of remote sensing data with communications, positioning and very high precision timing, is the connection of these RES to the grid and the evolution towards the SmartGrid concept. Wind, solar, and even hydrological are variable energy sources, and thus require an accurate forecast, for their balanced integration in the grid.

For wind energy production, a combined use of remote sensing and GNSS atmospheric tomography allows to provide real-time, accurate wind measurements on the surface, with the objective of improving by 10% the accuracy of current forecasting. In the case of isolated wind farms (e.g. off-shore), satellite communications can link them with grid management centers.

In a similar way, remote sensing can deliver a solar radiation forecasting from areas of 2,000 km (radius) around a solar power plant, thus allowing significantly improved predictions of expected daily electricity generation (hour by hour).

For hydrological energy, the above-mentioned combined GNSS/remote sensing measurement of water reserves will allow a better forecast of energy potential delivery to the grid.

The evolution towards the SmartGrid concept will request grid active and real-time monitoring, distributed management of small power plants (in particular for RES), and cost effective communication coverage. Space based telecommunications and high precision timing from GNSS for precise synchronization of terrestrial assets shall be efficient contributors to the SmartGrid.

These various applications are on-going pilot projects implemented by ESA in the frame of its Integrated Applications Program.

Another domain of application of the combination of space positioning, data collecting, and remote sensing is the monitoring of oil and gas production and transport infrastructures. In particular for gas transport: each leakage or explosion of gas pipes leads to the direct release of GHG in the atmosphere, and there is a high interest to have an early warning system identifying such failures, including remote isolated areas. Space systems have unique capabilities for this target.

Climate change is already creating various recurring vulnerabilities for the populations (food scarcity, drought, water depletion, fires ...), and generating extreme phenomena endangering the lives of citizens (floods, cyclones ...). Even if humankind is adopting mitigation measures to prevent further degradation of the climate, there will be a need to adapt to inescapable changes.

Space systems and related downstream services can provide efficient support to this adaptation goal at both the level of assessment of vulnerabilities and the level of management of the crisis from natural disasters.

<u>Vulnerabilities Assessment</u>. Space remote sensing can support the analysis of vulnerabilities of coastal zones against sea rising, tsunamis, cyclones, or of interior zones against floods from extreme precipitation, desertification, or fires. From these analyses, reasonable land/urban management policies could be developed, limiting the potential impacts of natural hazards.

Space remote sensing combined with tools simulating the impacts, is very efficient for identifying and recording those areas which will be affected by the rises in sea level or by natural disasters related to climate change (e.g. floods, typhoons). This vulnerability assessment will support more efficient urban management, and may allow anticipating or even preventing natural disasters. As an example, Thailand is using data from its THEOS satellite in combination with data from Landsat, Radarsat and ALOS to assess areas of vulnerability through the delivery of forest fire maps, drought risk maps, flood and landslide risk maps, etc. [10].

The systematic monitoring of hydrologic basins, using global surveillance from satellites in combination with local measurement, shall allow anticipating water shortage issues in critical regions.

For the assessment of population vulnerabilities related to food scarcity, coming from weather impact on crop conditions, the FAO is driving the international cooperation, as a UN agency. Its Environment and Natural Resources Service (SDRN) relies heavily on geo-spatial and remote sensing data from ground and satellite observations to make land cover analyses, crop forecasting, desertification assessments, meteorological forecasting, ... all topics which are important for food security. For instance, the Advanced Real Time Environmental Monitoring System (ARTEMIS) is using data from European Meteosat, French Spot Vegetation instrument and Japanese GMS [5]. The global coverage and regular revisit offered by the space systems are highly efficient in gathering agro-climatic data and computing statistics, but also for the FAO's Global Information Early Warning System (GIEWS) on food and agriculture. Joint recommendations have been issued by FAO and GEO, during a common workshop in 2007, asking for the creation of a GEOSS for agricultural monitoring, providing improved observations, continuity of the satellite data record, and better coordination of the data [6].

Following the example of what FAO is doing in close cooperation with the space remote sensing community for food security, a global international effort could be promoted under the umbrella of UN-funded programs, to make a systematic worldwide assessment of other vulnerabilities coming from climate change (coastal zones, desertification, deforestation, etc.).

Disaster Management. Space-based telecommunications, positioning and imagery are providing efficient tools for the management of natural disasters, in particular when the ground infrastructures have collapsed.

In terms of international cooperation, the most impressive initiative has been the International Charter on Space and Major Disasters [7], which is focusing on delivering geo-information services on very short notice after a disaster occurrence, through the mobilization of space remote sensing capabilities all over the world. The International Charter on Space and Major Disasters aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through authorized users.

As a complement to the already existing international cooperation established by the Disaster Charter, at least two additional fields can be considered where increased international cooperation would draw large benefits.

First, a warning system targeted to serve the needs of endangered populations could be implemented thanks to the use of mobile satellite telecommunications systems. It would be activated when a disaster has been identified for a close occurrence (e.g. a tsunami). A regional cooperation system has been already implemented in Asia, gathering 29 countries, which is focused on monitoring [9], and might be extended to a warning system, if connected to a telecommunications network. International cooperation should define a standard for these communications, and an obligation for the telecommunication operators to implement this standard in their services.

Second, space-based services mixing mobile telecommunications, positioning, and geo-information are critical to disaster response operations, when all ground means have collapsed. In case of large disasters, the rescue teams are often coming from different nations, and thus using different supporting means. International coordination should be implemented to define common interfaces standards for these satellite telecommunications and for data exchanges, in order to assure the highest level of interoperability between the international rescue teams.

The table on the following page provides a summary of the some of the potential opportunities for improvements in the degree of integration of space and ground systems operations to contribute to green systems / energy goals in the coming years.

A common problem for all these integrated applications services is to make them sustainable over time. This is a key condition for their efficiency and effectiveness in providing long-term, high quality datasets regarding climate evolution. The sustainability will rely mainly on identifying a robust business model, which will allow private sector players and government agencies to maintain, operate and eventually replace the necessary space infrastructures. The definition and prototyping of a new integrated service very often comes from research institutes or space agencies. Then the question becomes how much investment is needed to switch to an operational, reliable and sustainable system, with various options.

If the infrastructure is huge and/or the stakes are strategic, the governments are generally taking the lead for the funding, but also on defining requirements. This is the case, for instance, in Air Traffic Management with large-scale initiatives in Europe (SESAR) or in the USA (NextGen).

Table 2: Examples of Opportunities for Space – Ground Integration Improvements

Space-Ground Integration Improvement Opportunity	Green Systems / Energy Benefit Potential (Examples)		
	Improvements in the Efficiency of Energy Use	Mitigation of Climate Change	Adaptation to Climate Change Impacts
Satellite-Based Management of Terrestrial Transportation	Personnel and Freight Energy Efficiency Improvements	Personnel and Freight Energy Efficiency Improvements	
Satellite-Based Land Use		Satellite Data Supported Agriculture, Aquaculture, etc.	Satellite Data Supported Agriculture, Aquaculture, etc.
Space-Supported Management of Natural Resources	Satellite-Based Monitoring of Water Assets (Snow Packs, Lakes, Rivers, etc.)	Satellite-Based Monitoring of Forests	Satellite-Based Monitoring of Water Assets
Space-Based Monitoring and Management of Terrestrial Renewable Energy Systems	Solar Power Generation / Wind Power Generation		
Assessment of National/Community Vulnerabilities			Monitoring of Climate Change Events (e.g., sea level rise) Informing National Decisions based on Climate Change Risks
Disaster Management	Identification of Disaster-Driven Energy Emergencies		Monitoring of Disaster Events Early Warning of Impending Events Monitoring / Guiding Responses to Disasters

If the application deals with a specific economic sector (e.g. agriculture) or addresses a fragmented market with a lot of users with different needs (e.g. transport), a business case has to be made to enable investment by the private sector. For the initial phase, up to the maturation of the market, governments and their space agencies might play a role, through regulation, standards definition, federation of users, or initial support to business implementation. For instance, this is one of the goals of the recently created Integrated Applications Promotion (IAP) program by ESA.

Even if the laws of the free market – supply and demand – remain the primary drivers for the development of downstream services, nevertheless an increased international cooperation could enable their implementation. A summary of the key challenge and some selected recommendations follows below.

Summary Challenge and Recommendations

Key Challenge: How best can the international space community cooperate to improve the pace and thoroughness with which services and data provided by space systems are integrated with the ongoing / evolving design, development and operations of those ground systems and infrastructure that are contribute to global climate change and its mitigation?

Recommendations: Global Space Agencies, Interested, non-Space Government Agencies, Companies, Universities and Non-Governmental Organizations should work together to better:

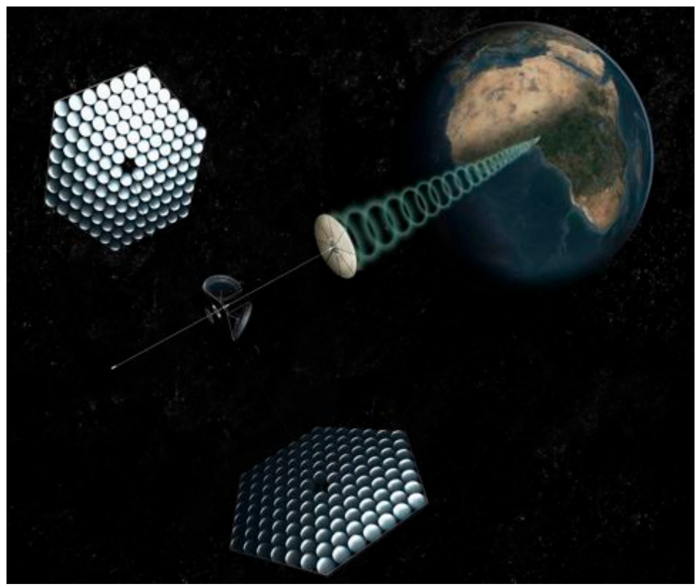
- Define international regulations and standards, for data exchange and processing, for interoperability in telecommunications and positioning, in order to allow the use of integrated applications worldwide (e.g. for air, sea, road traffic management, sensitive industrial infrastructure monitoring, search and rescue management, etc.)
- Promote of closer cooperation among space organizations and non-space organizations (for example, FAO, ICAO, IAE, and others) in the maturation and deployment of new technologies and systems for terrestrial green systems that take better advantage of the assets and information available from space systems and activities.
- Support the development of commercial business in downstream integrated applications services related to climate change and environment, to capture the interest of the private sector. Financial investment from the private sector shall guarantee the continuity of the services for the benefit of the citizens from all countries.

Chapter 4

Enabling New Green Systems & Energy
(CCGS – Theme 3)

Introduction

A wide range of space technologies may be developed and transitioned to new terrestrial applications that can improve the efficiency of ground-based systems. Also, new energy technology options may be developed and demonstrated, beginning in the near term, and including in the far-term, novel global energy solutions using space-based systems. Advances in space systems have already played a key role in sustainable energy technologies; for example, photovoltaic (PV) solar arrays, fuel cells, and high-efficiency power management systems.



One Visionary Option for New Green Systems:
The Concept of Solar Energy Delivered from Satellites in Space

In addition, component-level advances resulting from space program research and development (R&D) have been applied in diverse ways, including novel materials, new lubricants, and others. Moreover, the inherent difficulty of some space program goals has often inspired the search for, and development of new technologies and systems concepts that have later proven to be significant in terrestrial applications.

As a result, for many years various space agencies have placed some focus on the transfer of new technologies development for their programs to other, typically commercial operations. However, there is insufficient focus on the specific development and transfer of key systems and technologies that are inherently "dual purpose" – i.e., technologies that hold the promise of significant value for future space missions and which might enable new green systems and energy sources.

Looking forward, proactive research and development, and the accelerated transfer of the resulting advanced technology to novel applications of terrestrial applications could provide substantial benefits in the timely development of green systems. Examples include:

- *Energy Conversion*. Improvements in space energy conversion technologies – including thermal energy, solar energy, and nuclear power – could be transferred to further advances in terrestrial energy conversion devices and systems.
- *Energy Storage*. Advanced energy storage technologies remain an enduring challenge for diverse space missions – including exploration missions, Earth orbiting satellites, and others. These could be highly beneficial for a range of improved terrestrial energy storage systems for transportation, load-leveling and other applications.
- *Advanced Materials*. A wide range of novel materials – for example new coatings and improved tribology – might be applied to improve the efficiency and operations of diverse green energy systems (e.g., wind energy or solar power systems).
- *Green Propellants*. Opportunities exist for the introduction of new classes of so-called "green propellants" for a range of space applications – for example new ETO booster propellants – that might be applied to reduce the environmental footprint of space programs.

Looking to the longer term, advanced space systems might also provide alternative approaches to green systems and renewable energy. For example, solar-based space power stations could – if they prove to be economical viable – deliver vast amounts of carbon-neutral energy to markets worldwide. Space systems also have the potential in the far term to provide substantial carbon-neutral contributions to the global economy through the development and utilization of space resources. Technology options include:

- *Integrated Closed-Loop Eco-Systems*. Closing various "resource loops" (e.g., water, oxygen, etc.) is a key technical goal for R&D in support of future long duration human missions. In the farther term, these R&D objectives include not only physical-chemical processing, but also bio-regenerative life support systems. These technologies, and the integrated modeling of self-sufficient, closed-loop space systems, may find a wide range of applications in future green systems, including waste management, recycling, agriculture in regions with minimal fresh water and others.
- *Space Solar Power*. Advanced technology R&D may enable future space systems that could deliver solar power from orbit in the longer term – providing enormous amounts of carbon-free energy for developed and developing countries.
- *Space Computing Resources*. Terrestrial data systems (servers, data farms, etc.) require continuously increasing power. High capacity computing resources placed in space, or long-term data storage on the Moon, could provide tremendous global data services, based entirely on space-based, carbon-neutral solar energy.
- *Space Resources Development*. A long-term vision of the space era – the development and utilization of *in situ* resources, including the Moon and near Earth objects – could provide vast new resources for space and terrestrial economies with virtually zero climate impact.

Current Situation

There are numerous examples in which technologies that were initially invented or developed, and/or demonstrated for space systems and missions were later transferred to, and adopted for applications in diverse terrestrial markets. In many cases, the initial R&D and transition to non-space applications occurred so early that the role of space programs in the development of the technology is now little recognized.

A classic example is that of photovoltaic (PV) arrays. Space programs pioneered the development and use of photovoltaic cells for spacecraft, beginning as early as the 1950s-1960s. These same agencies have worked actively in support of various government and commercial efforts to expand Earth applications of the technology. Although it has only been recently that PV arrays have started to approach market competitive prices for produced electricity, a wide variety of earlier, high-leverage applications of the technology were developed. These included PV systems tailored for use at remote communications installations to operate large microwave repeaters, TV and radio repeaters, rural telephones and small telemetry systems that monitor environmental conditions. For more than 30 years, PV arrays have also been used to power agricultural water pumping systems, railroad signals and air/sea navigational aids; and, to provide electricity for isolated villages and medical clinics in the developing world. (And, PV arrays have long been used to power many types of military systems.)

Another well-cited example is that of fuel cells, used to exploit the energy stored in chemicals to directly generate electricity: a fuel cell combines a fuel (i.e., hydrogen or another chemical that is a source of hydrogen) with an oxidizer (i.e., oxygen or air) to produce electrical power. Fuel cells were used in a number of famous space systems: both the Gemini and Apollo spacecraft used hydrogen-oxygen fuel cells for electrical power generation, as does the Space Shuttle. Selected commercial uses for the fuel cells include recreational vehicles, stand-alone regenerative power systems, rural electrification, and use as a power source for underwater vehicles. As yet, the costs of fuel cells have not dropped to the point where their large-scale use for commercial power and energy storage is cost-competitive.

Also, in the early 1980s solar power generation by means of a Stirling cycle heat engine, combined with a large parabolic dish that concentrated incoming sunlight was considered to be an attractive option for future space stations or other large space platforms – particularly those that might be positioned in low Earth orbit (LEO) where the regular passage of the spacecraft through Earth's shadow could make regular PV arrays plus battery systems prohibitive. R&D conducted at the time resulted in the development of prototype modules that with good efficiency, and applicability to both terrestrial markets and prospective space systems.

Numerous space technologies have been successfully transitioned over the past five decades into a wide variety of terrestrial applications – many of which have involved renewable energy systems or improvements in energy efficiency. Typically, these have involved component or subsystem level technologies, rather than systems level applications.

There are, however, good opportunities for space systems and technologies to play an even more significant role in the future; these can be categorized into (a) opportunities that exist in the near-term, and (b) opportunities that may exist beginning in the mid- to far- term.

Nearer Term Opportunities

Historically, global space activities have been both the beneficiaries and the enablers for terrestrial applications of a wide range of advanced technologies. During the coming 3-6 years, proactive research, development, and transfer of advanced space technology to accelerate novel applications of terrestrial green systems could provide substantial benefits in the timely development of green systems. Several of the key opportunities include: application of space power systems to renewable energy; smart grids (discussed previously as "SmartGrid"); and, technology breakthroughs in key areas of energy storage (for example, batteries, fuel cells, etc.). The following paragraphs summarize some of these opportunities.

Energy Conversion. Improving the efficiency with which energy is converted from one form to another (for example, from chemical energy to electricity) is an ongoing goal for global energy R&D programs. Significant improvements in space energy conversion technologies will be essential to achieving a wide range of ambitious future space program goals, including future human missions beyond low Earth orbit (LEO), missions to the moon of the Outer Planets, and others. Some of the key areas for space technology R&D include thermal energy conversion, solar energy conversion, and nuclear power systems. It is critical, however, to accelerate the transfer of emerging new energy conversion technologies for space applications to terrestrial energy conversion devices and systems.

Energy Storage. Although various renewable power generation technologies – particularly wind and solar power – were increasingly deployed during 1990-2010, the efficient, flexible and affordable storage of huge amounts of green energy continues to be a signficant barrier to market penetration. Advanced energy storage technologies remain an enduring challenge for diverse space missions – including exploration missions, Earth orbiting satellites, and others. These could be highly beneficial for a range of improved terrestrial energy storage systems for transportation, load-leveling and other applications.

Advanced Materials. The durability, mean time between failure (MTBF), and maintenance / servicing requirements are significant drivers of the life cycle cost (LCC) of various green energy systems. A wide range of novel materials – for example new coatings and improved tribology – might be applied to improve the efficiency and operations of diverse green energy systems (e.g., wind energy or solar power systems).

Green Propellants. A number of the propellants in common use in the space industry involve an environmental footprint that is larger than desired. Also, in order to limit the risks for the population in case of a flight failure, the use of large amount of toxic propellants have to be avoided. Japan, USA, Europe and in a near future Russia and China will also adopt for their main liquid stages LOX associated to LH2 or Hydrocarbon, propellants with a minimum impact on the environment (when using modern engines in the case of LOX/kerosene). Opportunities exist for the introduction of new classes of so-called "green propellants" for a range of space applications

– for example new ETO booster propellants – that might be applied to reduce the environmental footprint of space programs. Also, the low cost access to space needed for space solar power (SSP) in the farther-term (discussed below), could take advantage of the benefits of R&D of potential high performance new hybrids or new solids green propellants for boosters

The following table provides a summary of the some of the potential opportunities for space technology R&D to contribute to various terrestrial green systems / energy applications in the nearer term.

Table 3: Examples of Space Systems / Technology Opportunities (Nearer-Term)

Technology Opportunity	Green Systems / Energy Applications (Examples)		
	Energy Use Efficiency	Sustainable Systems	New Energy Sources
Solar Power Generation (PV, CPV, etc.)			Advanced PV Cells (e.g., using Nano-technology)
Power Management and Distribution (PMAD) Systems	Modular / Intelligent PMAD SmartGrid Subsystems		
Energy Storage	Fuel Cells, Batteries, Flywheels, etc.	Electric / Hybrid Vehicles	
Advanced Materials	Insulation (e.g., Aerogels, TPS)	High Efficiency Heat Rejection	Thermo-Electric (TE) Conversion Materials

Mid- to Far- Term Opportunities

Looking to the longer term, during the coming 10-20 years, transformational new space systems might also provide alternative approaches to green systems and renewable energy. For example, solar-based space power stations could – if they prove to be economical viable – deliver vast amounts of carbon-neutral energy to markets worldwide. Space systems also have the potential in the far term to provide substantial carbon-neutral contributions to the global economy through the development and utilization of space resources. Technology options include space solar power (SSP); space resources development and utilization; and, space-based information and computing resources. The following paragraphs summarize some of these opportunities.

Integrated Closed-Loop Eco-Systems. Closing various "resource loops" (e.g., water, oxygen, etc.) is a key technical goal for R&D in support of future long duration human missions. In the farther term, these R&D objectives include not only physical-chemical processing, but also bio-regenerative life support systems. These technologies, and the integrated modeling of self-sufficient, closed-loop space systems, may find wide range of applications in future green systems, including waste management, recycling, agriculture in regions with minimal fresh water and others.

Space Solar Power. Solar energy, harvested in space and delivered via wireless power transmission (WPT) to markets on Earth could provide "green energy on demand", almost continuously to both developed and developing countries. Depending on the level of investment in, and success of Space Solar Power (SSP) R&D, space solar power represents a mid- to far-term opportunity for delivering green energy into terrestrial markets. First proposed in the 1960s, SSP was the subject of a major effort in the US in the 1970s, and a topic for continuing (albeit low-level) international R&D during the past 30 years. The results of this research have been impressive: the technical feasibility of SSP is now generally acknowledged and diverse technologies have been tested at the component level (including several tests of WPT).

However, Space Solar Power is still at an embryonic stage, and has not yet led to a real global international cooperation. Specific local cooperative efforts have been implemented between research institutes or universities to build joint demonstrations of technologies, in particular in the domain of energy transmission through microwaves or lasers. These cooperation examples are still limited and have not yet been relayed by an effort at a higher scale that would allow a decisive step in this field.

Space Computing & Information Resources. There is substantial debate regarding the energy costs of global computing and communications networks. Although the specific power requirements are hard to extract, it is clear that terrestrial data systems (servers, data farms, etc.) will require continuously increasing power during the coming decades. High capacity computing resources placed in space, or long-term data storage on the Moon, could provide tremendous global data services, based entirely on space-based, carbon-neutral solar energy. Depending on the level of investment in, and success of relevant R&D (including the successful development of extremely low cost solar power in space – see above), transformational new space computing and communications systems represent a mid- to far- term opportunity for delivering green information services for terrestrial markets.

Space Resources Development and Utilization. The development and utilization of *in situ* space resources is an enduring vision for the extension of human activity and commerce into space – including the resources of the Moon and near Earth objects (NEOs), typically asteroids. The resources that are believed available in space could provide vast new resources for space and terrestrial economies with virtually zero climate impact on Earth.

The timing when space resources might make a meaningful contribution to terrestrial energy and/or green systems depends not only on the space resources development (SRD) technologies, but also on the development of nearer term space systems, such as SPS. As a result, SRD represents a far- term opportunity for contributing to terrestrial markets.

The following table provides a summary of the some of the potential opportunities for space technology R&D to contribute to various terrestrial green systems / energy applications in the nearer term.

Table 4: Examples of Space Systems / Technology Opportunities (Mid- to Far-Term)

Technology Opportunity	Green Systems / Energy Applications (Examples)		
	Energy Use Efficiency	Sustainable Systems	New Energy Sources
Integrated Closed-Loop Eco-Systems	High-Efficiency Air / Water Purification,	Closed-Loop Waste Management	GHG Capture Systems
Space Solar Power	Higher Efficiency Use of Traditional Green Energy (e.g., Solar)		Delivery on Demand via WPT of Solar Power to Markets
Space Computing & Information Resources		Minimal Terrestrial Energy Use for High-End IT Services	
Space Resources Development and Utilization		Minimal Terrestrial Energy Use for High-Value Metals, etc.	Rare Earth Materials for Traditional Green Energy (e.g., Solar)

Summary Challenge and Recommendations

Key Challenge: For the farther term, how best can the international space community cooperate to develop and demonstrate transformational new green systems and energy technologies?

Recommendations: Global Space Agencies, Companies, Universities and Non-Governmental Organizations should work together to:

- Foster technology programs and flight tests, to demonstrate the feasibility of space-based solar power generation and transmission to ground.
- Foster common developments and exchanges of technologies between the space sector and the energy sector, to facilitate transfer of technologies leading to new green energy systems on Earth (energy conversion, transmission, and storage).
- Foster offsetting of space technologies that might enable development of green systems on Earth, e.g. closed environmental life support systems.
- Provide reliable information from space-based observations to allow the better optimized future deployment of renewable energy mechanisms, such as tidal, wind and solar power.
- Foster technology R&D (through flight testing) to demonstrate the feasibility of so-called green propellants, which can reduce the potential harm to the environment and thereby significantly reduce the associated costs.
- In a long-term vision of the space-era, implement for any deep space exploration mission an objective of search for new resources that might enable mitigation of the resources gap on Earth.

Chapter 5

Summary and Conclusions: Future Perspectives For International Cooperation

As discussed in the preceding chapters, intensive international cooperation has already been implemented in several key areas, in particular for the monitoring of climate variables, through various international organizations (e.g. WMO, GCOS, GEOSS, CEOS). However, all experts recognize that coordination and cooperation could be improved, in particular to guarantee a continuous coverage of climate monitoring.

In the domains of mitigation and adaptation, the role of space applications has been less preeminent up to now, thus leading to a lower focus on international cooperation to achieve these goals. However it is expected that this role should increase in the future and require again new areas for cooperation.

There are a number of opportunities where the global space community could pursue, or contribute to improvements in international cooperation in the fields of climate change and green systems. The large spectrum of space systems applications in relation to climate change, as described above, shows that there is not a single model for international cooperation in this domain. Depending on the nature and scale of the action (large infrastructure to be jointly developed, coordination of satellite projects from different nations, organisation of data gathering and distribution, or specific downstream service to be offered or promoted worldwide), the role of various actors, governments, space agencies, climate organizations, and the private sector, will be quite different. In some cases a real institutional international cooperation is needed, generally under the umbrella of the United Nations or their acting specialized agencies. In other cases, the free market tools are sufficient or even more efficient, and in others, the best way is to rely on the action of NGOs networks.

Different scenarios can be envisaged, depending on the topic, for the role of institutional players, including space agencies. Illustrative examples are given hereafter:

- *Climate variables monitoring*: The end-users are science community, IPCC, UN, and the countries' decision makers. Space international cooperation should be fostered at this level, and then applied by the space agencies in the frame of organisations such as GEO, WMO and CEOS
- *Space remote sensing for Emission Trading or forest monitoring*: the rules of the implementation mechanisms are decided internationally in the frame of the COPs, through CDM and REDD+ programs. The role of space systems, and the rules of associated business, will come from the development of a specific market in these domains. The environment for business development is a mix of institutional drivers and commercial trading levers. A key point for the space community will be its ability to bridge with other sectors (energy, forestry, land use, etc.) in order to promote the use of space means.

- *Integrated applications for reduction of transport carbon footprint*: government and associated agencies have a key role to play through initial R&D, but also through setting regulations and standards. In that respect, international cooperation is a must in order to guarantee that these standards and regulations can be applied worldwide. As an example the ATM regulations are discussed in the frame of ICAO, which means that the implementation of new standards supporting the use of space means should be promoted at this level.
- *Development of new energies / green systems*: here again the key for international cooperation will be to establish strong connections between space sector an other sectors, in particular energy, in order to establish the appropriate partnerships worldwide. In particular, the space based solar power should be pursued. There are two options: a classical government-to-government multilateral cooperation scheme, similar to the ISS, should be promoted, or private initiatives with international partners from the energy sector could be envisioned if they can afford the huge level of investment and its inherent risks.
- *International cooperation through NGOs*: one should not neglect the interest of NGO networks, gathering around a common initiative, as is the case for Planet Action [11]. Since its launch by Spot Image in June 2007, Planet Action has initiated 390 projects with a lot of NGOs worldwide, in 8 areas related to climate change: ice & snow cover, oceans & coastlines, drought & desertification, forest & deforestation, freshwater resources, biodiversity & conservation, human issues & habitations, awareness

The above non-exhaustive discussions of the three themes – Observing the Earth From Space, Leveraging Space-Ground Systems Integration, and Enabling New Green Systems & Energy – have resulted in three sets of recommendations concluding each relevant chapter. As a general summary, some key recommendations for increased international cooperation have been derived, which could be implemented both within and beyond the space community.

Recommendations: Cooperation within the Space Community

For improved international cooperation within the space community, the CCGS study group recommends that the space community consider the following steps:

- Rely on the existing international bodies (GEO, GCOS, CEOS, WMO), and foster an increased cooperation between the space agencies for a coherent programming of Earth observation missions addressing ECVs, to fill the present gaps and guarantee the continuity of data availability on the long term
- Set international standards for space system interfacing and integration, interoperability, data exchange, data processing
- Identify flagship projects justifying international cooperation in R&T/R&D, for the surveillance of international protocols (e.g. GHG sources detection)
- Foster a large international cooperation in Space Based Solar Power, for instance as a follow-on of ISS beside the planetary exploration

Recommendations: Cooperation Beyond the Space Community

For improved international cooperation beyond the space community, the CCGS study recommends that the space community should consider:

- Raising the profile of space applications at the level of non-space organizations dealing with climate change and its consequences, in particular UN, IPCC, COP, G8, G20, for example in demonstrating their efficiency for monitoring of protocols implementation
- Including the space enabling infrastructures in the discussion of funding mechanisms for implementation of climate change actions: World Bank, REDD, CDM, in order to facilitate the transition from scientific missions to operational monitoring and surveillance missions
- Developing the awareness of space capabilities of end users outside the space-community, in establishing partnerships with the actors of these sectors, in particular through NGO networks or international organizations (e.g. FAO)
- Identifying and fostering international actions (regulations, funding/trading mechanisms, incentives…) enabling the development of space related green business, in particular in downstream services
- Developing the awareness of the public regarding the use of space systems for the solving climate change issues, through targeted outreach (e.g. using existing instrument such as UN sponsored World Space Week)

Beyond these various actions, we consider also that the space community has also a strong role to play in developing the awareness of the public and policy makers regarding the climate change issues.

Closing Thoughts

The technical activities of the space community related to climate change / green systems include efforts to understand Earth from space, to integrate information from space in the operation of green systems, to transition space technology to enable new green systems on Earth, and to enable the development of new green energy sources in space. All of these have a direct and enduring impact on global culture, on our understanding of the world and the relationship of humanity with natural systems, and on the education of future Earth scientists, space engineers and technologists, social scientists, and others.

Images of the Earth from space have had, and will continue to have a profound impact on our appreciation of the interconnectedness of our world, and the consequences of human actions. In addition, meeting the challenges of climate change / greens systems can inspire and engage future generations of students in the sciences, in aerospace engineering, and in a wide range of technology disciplines of importance to humanity's future.

The global space community has already done so much to foster an improved understanding of the looming risk of climate change and to develop and deploy new technologies and green systems that can mitigate and allow us to respond more effectively to those risks. During the coming years and decades that community can do much, much more: now is the time to start.

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Appendix 1

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Appendix 2

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Appendix 3

Glossary of Acronyms

Glossary of Acronyms

ATM	Air Traffic Management
CCGS	Climate Change / Green Systems
CDM	Clean Development Mechanism
CEOS	Committee on Earth Observation Satellites
CNES	Centre National d'Etudes Spatiales
COP	(Climate Change) Conferences of the Parties
CSP	Concentrating Solar Power
CPV	Concentrator PV
EADS	European Aeronautic Defense and Space Company
ECV	Essential Climate Variable(s)
ESA	European Space Agency
FAO	Food and Agriculture Organization
GCOS	Global Climate Observing System
GEO	Definition 1: Geostationary Earth Orbit
GEO	Definition 2: Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GHG	Green House Gas(es)
GIEWS	Global Information Early Warning System
GNSS	Global Navigation Satellite System
GPSS	Global Positioning System System
IAA	International Academy of Astronautics
IAC	International Astronautical Congress
IAF	International Astronautical Federation
IAP	Integrated Applications Promotion (Programme; of ESA)
ICAO	International Civil Aviation Organization
IPC	International Program Committee
IPCC	Intergovernmental Panel on Climate Change
IPP	(NASA) Innovative Partnerships Program
ISRO	India Space Research Organization
JAXA	Japan Aerospace Exploration Agency
LCC	Life Cycle Cost

LIDAR	Light Detection and Ranging (aka, "Laser Radar")
MTBF	Mean Time Between Failure
NASA	National Aeronautics and Space Agency
NGO	Non-Governmental Organization
PV	Photovoltaics
R&D	Research and Development
RIHN	Research Institute for Humanity & Nature
SBA	Societal Benefit Areas
SESAR	(ESA) Single European Sky Air traffic management Research
SG	Study Group
SSP	Space Solar Power
TBD	To Be Determined
TE	Thermo-Electric (Energy Conversion)
TPS	Thermal Protection System
TTPO	(ESA) Technology Transfer Programme Office
WMO	(The) World Meteorological Organisation
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US	United States

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Appendix 4

Heads of Space Agencies Summit

Heads of Space Agencies Summit

November 17, 2010, Washington DC, USA.

This year the International Academy of Astronautics (IAA) marks its 50th Anniversary since its founding in Stockholm. In the past five decades, the Academy has brought together the world's leading experts in disciplines of astronautics on a regular basis to recognize the accomplishments of their peers, to explore and debate cutting-edge issues in space research and technology, and to provide direction and guidance in the non-military uses of space and the ongoing exploration of the solar system.

The 50th Anniversary of the IAA has been recognized and celebrated throughout the second half of the year with a series of symposia around the globe, and culminating with a Heads of Space Agencies Summit on November 17, 2010 at the Ronald Reagan Building and International Trade Center in Washington DC.

After 50 years of existence the International Academy of Astronautics is recognized by space agencies as a unique elite body that can help advancing international cooperation. It has been observed that much current cooperation programs are aging such as the International Space Station (ISS) initiated with just a few countries.

The world is flattening as many newcomers are joining the club of emerging space countries. In the meantime the major space countries face budgetary challenges and politicians as well as decision-makers face competing priorities. In addition, the USA and Russia can no longer exclusively taxi the growing international space community to low Earth orbit. The result is a need to enlarge significantly the circle of the current partners for international space cooperation.

A consensus widely recognized is that future global challenges can only be solved by international cooperation with all countries committed to work together. However space agencies have to balance new aspirations with constraints of existing programs/budgets and national interests/needs. The large number of new players brings the question: how to efficiently cooperate while the number of partners significantly increases? Confidence, trust, transparency, best practice sharing will have to be the key points for reducing impediments while promoting a safe and responsible use of space. It is anticipated that the ISS experience will be used to leverage new cooperation.

To serve as the foundation for discussion among the Summiteers, four IAA study groups composed of renowned international experts in climate change/green systems; disaster management/natural hazards; human spaceflight and planetary robotic exploration have been assembled and have published these studies and recommendations for deliberation by agencies. This is a historic and unique event as not only 25 Heads of Space Agencies have confirmed their participation in the Summit as of October 1st, 2010, but also the IAA has thorough studies that support their discussions and provide background expert documentation.

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Appendix 5

IAA in Brief

International Academy of Astronautics

A Brief Description

Founded: 16 August 1960, Stockholm, Sweden by Theodore Von Karman. The IAA became an independent organization in 1983 and a nongovernmental organization recognized by the United Nations in 1996. President: Dr. Madhavan Nair, India, Past President: Prof. Edward C. Stone, USA, Vice-Presidents: Mr. Yannick d'Escatha, France, Prof. Hiroki Matsuo, Japan, Dr. Stanislav Konyukhov, Ukraine, Prof. Liu Jiyuan, China, Secretary General: Dr. Jean-Michel Contant, France.

Aims: Foster the development of astronautics for peaceful purposes; recognize individuals who have distinguished themselves in a related branch of science or technology; provide a program through which members may contribute to international endeavours; cooperation in the advancement of aerospace science.

Structure: Regular Meeting, Board of Trustees, four Sections: Basic Sciences, Engineering Sciences, Life Sciences and Social Sciences.

Activities: Encourage international scientific cooperation through scientific symposia and meetings and the work of specialized Study Groups and Program Committees coordinated by six Commissions: on Space Physical Sciences, D. Baker (USA), on Space Life Sciences, P. Graef (Germany), on Space Technology and System Development, J. Mankins (USA), on Space Systems, Operations and Utilization, A. Ginati (Germany), on Space Policies, Law and Economics, S. Camacho (Mexico) and on Space and Society, Culture and Education, P. Swan (USA). A major initiative of the Academy is the development of a series of "Cosmic Studies" and Position Papers dealing with the many aspects of international cooperation (see http://iaaweb.org/content/view/229/356/).

Events: Establishment of cooperation with national academies in UK (2008), Sweden (1985), Austria (1986, 1993), France (1988, 2001), Finland (1988), India (1990, 2007), Spain (1989), Germany (1990), Netherlands (1990, 1999), Canada (1991), U.SA (1992, 2002), the U.S. National Academy of Engineering (1992, 2002), Israel (1994), Norway (1995), China (1996), Italy (1997), Australia (1998), Brazil (2000), the U.S. National Institute of Medicine (2002), Czech Republic (2010).

Publications: Acta Astronautica (monthly) published in English; IAA e-Newsletter; Proceedings of Symposia, Yearbook, Dictionaries and CD-ROM in 24 languages.

Members: 1243 Members and Corresponding Members in four Trustee Sections and Honorary Members in 89 countries.

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