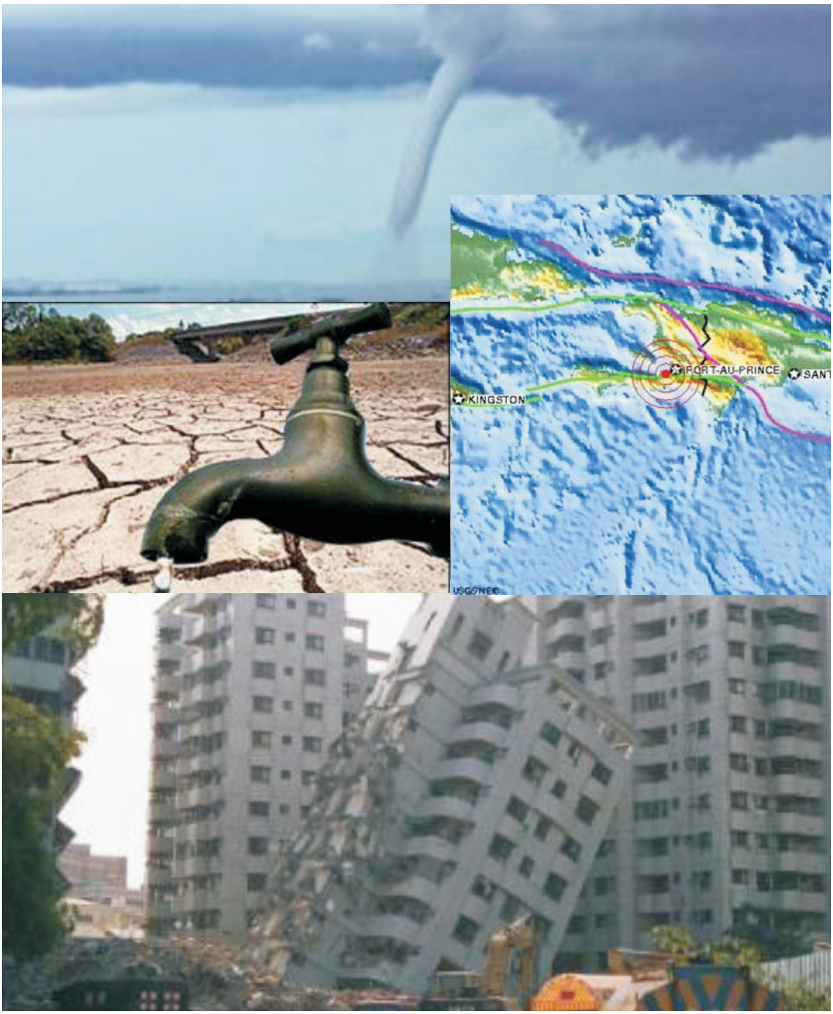
SPACE-BASED DISASTER MANAGEMENT: THE NEED FOR INTERNATIONAL COOPERATION



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-BASED DISASTER MANAGEMENT: THE NEED FOR INTERNATIONAL COOPERATION

Edited by Ranganath Navalgund, Valery Menshikov and Joseph Akinyede

Printing of this Study was sponsored by:
Indian Space Research Organisation (ISRO)
ISRO Headquarters, Antariksh Bhavan, New BEL Road
Bangalore, India - 560 231 www.isro.org

International Academy of Astronautics
6 rue Galilée, Po Box 1268-16,
75766 Paris Cedex 16, France
www.iaaweb.org

ISBN EAN 9782917761120

9 782917 761120

Cover Illustration: Disaster (source: Roscosmos, Maksimov Space Systems Research Institute, ISRO)

SPACE-BASED DISASTER MANAGEMENT: THE NEED FOR INTERNATIONAL COOPERATION

Edited by:
Ranganath Navalgund
Valery Menshikov and
Joseph Akinyede

Blank

TABLE OF CONTENTS

Page

Foreword
Gopalan Madhavan Nair, IAA President 5

Preface
Ranganath R. Navalgund, Chair, IAA WG-IV 7

Executive Summary 9

1. Scope 16

1.1 Type of disasters, their damage potential, time-scales 16

1.2 Role of space technology 23

1.3 Collaborative international efforts 33

1.4 Objectives of the study report 35

2. General Context and Status of Major Natural Disasters 37

3. Future Stakes, Issues and Potential Solutions 45

3.1 Overall short-comings in the present-day space observation systems, in-situ observation networks and modeling 45

3.2 Solutions through International efforts in place 48

3.2.1 GEOSS 48

3.2.2 UN-SPIDER 48

3.2.3 Sentinel-Asia 49

3.2.4 International Charter "Space and Major Disasters" 49

3.2.5 Disaster Monitoring Constellation (DMC) 50

3.2.6 GMES- SAFER 51

3.2.7 United Nations Geographical Information Working Group (UNGIWG) 52

3.2.8 ESCAP/WMO Typhoon Committee and WMO/ESCAP Panel on Tropical Cyclone 52

3.2.9 IGMASS (International Global Monitoring Aerospace System): Proposed 53

4. Future Perspectives for International Co-operation 54

Appendix 1 Contributors 68

Appendix 2 References and additional readings 69

Appendix 3 Heads of Space Agencies Summit 76

Appendix 4 IAA in Brief 78

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 also like to extend my thanks to 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

Preface

Space-borne remote sensing has been playing an important role in identifying disaster sites, assessing damage and risk, monitoring disaster situations and providing early warning. A large number of initiatives have been taken up by the international space agencies as well as many other multilateral forums to establish mechanisms for making available space data and its products for the managers in different phases of disasters. However, it has not been possible to provide the right type of data at the right time in the right format to the end stakeholders in mitigating the disasters at all times. For some of the disasters, early warning methods have been inadequate. In this context, the International Academy of Astronautics (IAA) has commissioned a study, through the Working Group on Disaster Management/Natural Hazards, to reach a broad consensus on international cooperation and coordination at the highest level to consider new initiatives of cooperation, avoiding any duplication of on-going efforts as well as foster closer international coordination to strengthen the effectiveness and support of global space activities.

The Working Group prepared an outline of the study report and also circulated a brief note listing a number of issues related to the theme, present state-of-the-art in various aspects of disasters, inadequacies in the observation systems, kinds of satellite constellations required, etc. Based on the reports generated by various members of the working group followed by discussions through teleconferences, a draft report was prepared and circulated within the group. The draft was also discussed at the 2nd International Symposium on Space and Global Security of Humanity organised at Riga, Latvia during July 5-9, 2010. In addition, several rounds of discussion with IAA Steering Committee members took place. Based upon these discussions as well as the feedback received from the Trustees of the IAA, this document has been generated. The document provides scope of the present study, general context and status of space technology vis-à-vis major natural disasters, *over all shortcomings in the space observations at present, in-situ observation networks, modeling, various international efforts in place and suggests future course of action required for international cooperation to effectively use space technology in various phases of disaster management including better early warning methods.*

As Chair of the Working Group, I would like to place on record my appreciation to the Co-Chair and members of the Working Group on Disaster Management/Natural Hazards, Dr. Jean-Michel Contant, IAA Secretary General, Mrs. Corinne Jorgenson, President, Advancing Space and the Co-Chair of the Steering Committee, representatives of space agencies, my colleagues at the Space Applications Centre/ISRO, and all those who provided necessary background material, in compiling this document.

Ranganath Navalgund
Chair, IAA Working Group on
Disaster Management/Natural Hazards

Executive Summary

Natural disasters are events, which are caused by purely natural phenomena and bring damage to human societies (such as geophysical – earthquake, volcano, landslides, land subsidence; hydrological – floods, avalanche, debris flow; meteorological – cyclone, snow storm, dust storms, tornado; climatological – extreme temperature, drought, wild fire; biological – epidemics, insect infestations and extra-terrestrial-meteorite/asteroid impacts). Human-induced disasters are natural disasters that are accelerated / aggravated by human influence. Natural events cannot be prevented, but potential disasters can be 'managed' to minimise loss of life and properties through disaster management. Space based Disaster Management System has the distinct advantage of being unaffected by disasters on the ground and provides unbiased, synoptic and timely information on different components of the disaster management cycle.

However, even with the availability of large spectrum of Earth Observation (EO) data, development of communication technologies, and building of international networks; availability of right information to right people at right time in right format is still a major challenge. In this context, this IAA study report on Disaster Management/ Natural Hazards outlines the current status of the space-based disaster management technology for different disasters, identifies the gap areas, and suggests possible improvements for real-time integrated solutions. One of the important aspects, which the study attempts to highlight, is the development of early warning systems, where international collaborative research effort would be necessary to develop forecasting models, in which EO data can be assimilated for more accurate warning system(s).

Present day earth observation satellites are designed to meet requirements of wide-ranging applications and do not full-fill specific requirements of disaster prediction, monitoring and mitigation. Space resources, both EO satellites as well as communication satellites, need to be pooled together for disaster management purposes. The existing *network of ground stations receiving satellite data is inadequate for global coverage, therefore countries/space agencies need to establish as well strengthen existing ground infrastructure for receiving satellite data. Current available expertise to process raw satellite data into meaningful products for disaster management is limited to a few countries/ few Institutes. Rigorous and time-tested early warning/ forecasting models need to be developed. Robust decision support systems are necessary. Operational institutional arrangements among satellite operators, remote sensing service providers, disaster management authorities and response action headquarters require to be established with standardized value added products, services and delivery channels with specific disaster response plans during disaster emergency response. There is a gap between existing information products of space agencies or remote sensing centres and the information requirement of disaster managers. There is poor networking between data provider and user agencies, thus making the utility of spatial data limited. The public Internet service is observed to be inadequate in providing access to large volume of space based information data in many countries.*

Disaster is a global phenomenon. Any disaster that strikes does not restrict itself to administrative boundary. Even if its effect is limited to a particular country, it becomes a global concern for response and relief. Hence, it is essential to have a network of various international organizations working towards disaster management, more particularly in the field of utilization of space technology for disaster management.

At present, there exist a number of international commitments of space agencies to share their space resources for disaster affected nations. Some of these initiatives are operational, some are semi-operational, while some are at initial stages of formulations. The Global Earth Observation System of Systems (GEOSS) provides platform to integrate Earth observations with other information to help planners reduce vulnerability, strengthen preparedness and early-warning measures and, after disaster strikes, rebuild housing and infrastructure *in ways that limit future risks. UN-SPIDER acts as an open network of providers of space-based solutions to support disaster management activities. This includes all types of information provided by earth observation satellites, communication satellites and global navigation satellite systems. Sentinel Asia is a "voluntary and best-efforts-basis initiatives" led by the APRSAF (Asia-Pacific Regional Space Agency Forum) to share disaster information in the Asia-Pacific region on the Digital Asia (Web-GIS) platform and to make the best use of earth observation satellites data for disaster management in the Asia-Pacific region.*

International Charter on Space and Major Disasters, initiated by ESA and CNES following the Third United Nations Conference on the Exploration and Peaceful Use of Outer Space (UNISPACE III) in 1999 has currently, ten member space agencies. The Charter is an international agreement between space agencies (not between States), making their resources available on a best effort basis to emergency operations at the request of a world wide Authorized Users base. The Charter, fully operational since November 2000, is a successful case of international cooperation and has been activated more than 265 times in 90 countries over all continents for a variety of disasters.

The Disaster Monitoring Constellation (DMC) consists of a group of satellites independently owned and controlled by a separate nation, but all satellites have been equally spaced around a sun-synchronous orbit to provide daily imaging capability. The countries involved are Algeria, China, Nigeria, Turkey, UK and Spain. The DMC has both multi-spectral sensors with 22-32 m resolution and panchromatic sensors with 4 m resolution. The DMC Consortium has agreed to consider participation in the International Charter for Space and Major Disasters, contributing daily imaging capability to fill the existing 3-5 day response gap. The European initiative GMES (Global Monitoring for Environment and Security) proposes to provide information useful in a range of issues including climate change and citizen's security, land, risks, ocean and *atmosphere. In the frame of the GMES initiative, SAFER (Services and Applications For Emergency Response) project aims at preparing the operational implementation of the Emergency Response Service (ERS). SAFER provides civil protection authorities and humanitarian relief organizations with a rapid mapping capacity when natural disasters occur and in the context of complex crises. United Nations Geographical Information Working Group (UNGIWG) is a network of professionals working in the fields of cartography and geographic information science to building the United Nations Spatial Data Infrastructure needed to achieve sustainable development and emergency responses. ESCAP/WMO Typhoon Committee and WMO/ESCAP Panel on Tropical Cyclone is an ESCAP-affiliated regional cooperation mechanism jointly working with the Tropical Cyclone Programme of the World Meteorological Organization. The International Global Monitoring Aerospace System (IGMASS) is a study proposal to create a system to provide well-timed warning to the international community about coming disasters and emergencies, natural and man-caused disasters through a global and operational forecasting with the use of scientific and technical potential of earth-based, air and space monitoring all over the world and the further development and gradual integration of navigation, telecommunication and information resources of the planet to solve the humanitarian problems of Humanity.*

An analysis of various space-based disaster management techniques and the status of different international networks showed that, the current capability is mostly at the level of post-disaster monitoring and damage assessment. Early warning is still a research issue. Even most of the international networks are limited to providing near real-time EO data for post-disaster activities. Though, it has been an important dimension, it does not suffice the complete space based disaster management requirement. Apart from this, the space technology development and applications are at different levels in different countries. Especially in developing and under-developed nations, where impact of disaster is very high, the space capability is either nil or very limited making them *more susceptible. All these necessitate strong international cooperation. In order to achieve the goals of disaster risk reduction and management, it is essential to explore and establish information sharing and product service modes and mechanisms among different countries, thereby to strengthen the exchanges and cooperation on relevant experience and to narrow the gap between developed and developing countries.*

Having considered the significant role played by space technology in all phases of disaster management and the various initiatives undertaken by the national, regional and international organizations, as well as gaps in the existing observational platforms and early warning/ forecasting methods, the Study Group recommends following:

- *Strengthen existing network of earth observation satellites (optical and radar sensors) through virtual constellations, ensuring their continuity and establish a mechanism for proper orbit allocation, satellite tasking for emergencies and meeting rush access of EO data. It is very important to not only acquire 'good' data but also to be able to disseminate as quickly as possible usable data to the end users. A possible satellite constellation of 20 EO satellites shall provide temporal resolution of 3 hrs for global coverage.*

- *Strengthen existing mechanism of International Co-operation. Efforts should be made to strengthen the UN-SPIDER, GEOSS and ISPRS Disaster Management Program for more global coverage. Every country should be encouraged to participate in such internationally recognized programs. There should be commitment from each country, to provide all possible support, in form of data sharing, capacity building, etc. to the affected nations.*

- *Strengthen collaborative efforts for developing early warning models. An international team should carry out research and modeling activity for forecasting, which should be provided with* *all forms of data support from all space organizations. This should be supported by the local governments for building technical infrastructure towards intensive field data collections. The early warning programs of GEOSS, UN-SPIDER, IGMASS and other regional/international initiatives should be supported and strengthened.*

– *Strengthen communications network by including low earth orbit communication satellites/Data Relay Satellite System (DRSS) and make available adequate band widths so that availability of data becomes easier. Attempts should be made to augment amateur radio (Ham Radio) service, which are highly useful during post-disaster activity.*

– *Create a policy for data sharing and making available all EO data in standard format, along a common framework with properly defined meta-data and processed to useful derived products with different thematic layers in the same format. The efforts of CEOSS towards data standardization should be strengthened. Sharing of value added data products at nominal cost should be through a mechanism of coordination among existing international programs/initiatives on space and disasters. It is noted that presently, all the acquired data, including VHR (Very High Resolution) data are available to all the actors in the frame of the International Charter on Space and Major Disasters. However, the users are waiting for products (maps) rather than raw data, which are totally unusable for them.*

– *Improve efforts for capacity building. There is need to develop new regional and global institutes of disaster management and to strengthen existing ones in order to effectively conduct regular courses/trainings especially for the representatives of less developed countries. IAA can play a great role by preparing brochures and bulletins in easy and multiple languages, to explain the scope of EO data for disasters management. IAA may* *facilitate preparation of a directory of relevant web sites on all phases of disaster management, which includes GEOSS, UN-SPIDER, and International Charter Web Portals.*

- *Strengthen regional/national level Networking of Stakeholders (Government and non-government). There is a need for regular interactions/ meetings/ and workshop between all partners to avoid duplication of efforts. The framework of the activities needs to be defined and responsibilities of each stake-holder should be clearly outlined. This also necessitates regular mock exercises for disasters scenarios.*

1. Scope

1.1 Type of disaster, their damage potential, time scales

Disasters are the deadly events causing miseries to mankind and they are inevitable. A disaster is a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources. A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk. Centre for Research on the Epidemiology of Disasters (CRED) defines a disaster as a "situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance (definition considered in EM-DAT); an unforeseen and often sudden event that causes great damage, destruction and human suffering".

EMDAT (CRED) the international disaster database, distinguishes two types of disasters, i.e. natural and technological. Natural disasters occur naturally and are always triggered by natural hazards. EM-DAT (CRED) and NATcatService of Munich Reinsurance Company (Munich RE) databases on natural disasters have been utilized to establish a common classification of natural disasters (Below *et al.,* 2009) and is summarized in Table 1 and 2.

Table 1: Disaster sub-group definition and classification

Disaster Subgroup	Definition	Disaster Main Type
Geophysical	Events originating from solid earth	Earthquake, Volcano, Mass Movement (dry)
Hydrological	Events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up	Flood, Mass movement (wet)

Meteorological	Events caused by short-lived /small to meso scale atmospheric processes (in the spectrum minutes to days)	Storm
Climatological	Events caused by long-lived/ meso to macro scale processes (in the spectrum from intra-seasonal to multi-decadal climate variability)	Extreme Temperature, Drought, Wild Fire
Biological	Disaster caused by the exposure of living organisms to germs and toxic substances	Epidemic, Insect Infestation, Animal Stampede
Extra-terrestrial	Events caused by Extra – terrestrial sources	Meteorite/Asteroid

The technological disasters comprise of three groups:

- Industrial accidents: such as chemical spills; collapses of industrial infrastructures; explosions; fires, gas leaks; poisoning; radiation;
- Transport accidents: by air, rail, road or water means of transport;
- Miscellaneous accidents: collapses of domestic/non-industrial structures; explosions; fires.

Natural disasters are events, which are caused by purely natural phenomena and bring damage to human societies (such as earthquakes, volcanic eruptions, cyclones). Human made disasters are events, which are caused by human activities (such as atmospheric pollution, industrial, chemical accidents, major armed conflicts, nuclear accidents, oil spill). Human-induced disasters are natural disasters that are accelerated/ aggravated by human influence. It may be noted EO satellites do not provide information on all types of disasters.

Table 2: Natural Disaster Classification

NATURAL DISASTERS					
Geophysical	**Hydrological**	**Meteorological**	**Climatological**	**Biological**	**Extra-terrestrial**
• **Earthquake** o Ground shaking o Tsunami • **Volcano** o Volcanic eruption • **Mass Movement (Dry)** o Rockfall o Landslide ➢ Mudslide ➢ Lahar ➢ Debris flow o Avalanche ➢ Snow avalanche ➢ Debris avalanche o Subsidence ➢ Sudden subsidence ➢ Long-lasting subsidence	• **Flood** o General flood o Flash flood o Storm surge/ Coastal flood • **Mass movement (Wet)** o Rockfall o Landslide ➢ Debris flow o Avalanche ➢ Snow avalanche ➢ Debris avalanche o Subsidence ➢ Sudden subsidence ➢ Long-lasting subsidence	• **Storm** o Tropical Cyclone o Extra-Tropical Cyclone (Winter Storm) o Local/Convec-tive Storm ➢ Thunderstorm /Lightning ➢ Snowstorm/ Blizzard ➢ Sandstorm/ Dust storm ➢ Generic (severe storm) ➢ Tornado ➢ Orographic storm (strong winds)	• **Extreme Temperature** o Heat Wave o Cold Wave ➢ Frost o Extreme Winter Condition ➢ Snow pressure ➢ Icing ➢ Freecing rain ➢ Debris avalanche • **Drought** • **Wild Fire** o Forest Fire o Land Fire (grass, scrub, bush, etc. …)	• **Epidemic** o Viral infectious disease o Bacterial infectious disease o Parasitic infectious disease o Fungal infectious disease o Prion infectious disease • **Insect Infestation** o Grasshopper/ Locust /Worms • **Animal Stampede**	• **Meteorite /Asteroid**

Table 3 & 4 (Westen and Soeters, 2000) provide classification of disasters on the basis of gradual scale from purely natural to purely human made and on the basis of main controlling factors.

The world has seen many disasters over the years. In the last thousand years, there were at least 43 disasters, which took more than 100,000 lives each (Hall, 2005). The deadliest earthquake in history hit the eastern Mediterranean in July 1201. Approximately 1.1 million people were killed, mostly in Egypt and Syria. The worst flood disaster was in China in 1887. The Yellow River overflowed, causing the death of about 900,000 people (some reports say it was a million that perished). The deadliest drought in recorded history was in China between 1876 and 1879. Rivers became dry, so most crops and livestock died. There was no food production in a 1-million km^2 area of 9 provinces and the drought caused the death of an estimated nine million people. In India, about ten million people lost their lives from a famine in Bengal, in 1769. In the last ten years (1994-2003), there have been at least 6145 disasters affecting the world (Source: EM-DAT, 2005). In this period, among the natural disasters 75 per cent are hydro-meteorological, followed by 16 per cent biological and 9 per cent geological. If individual disasters are considered, the frequency of occurrence is highest for floods, followed by windstorms, drought & related, epidemic, earthquake & tsunamis and landslides (Figure 1).

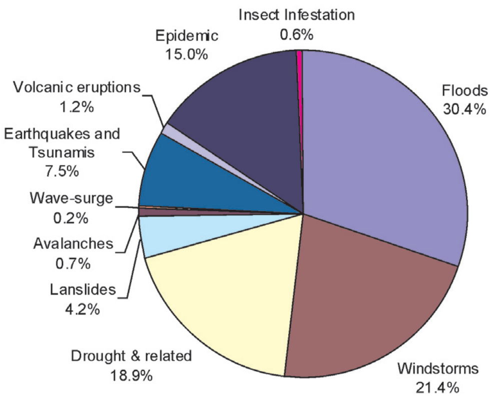


Figure 1: Worldwide distribution of natural disaster from 1994-2003 (Source: EM-DAT, 2005)

Table 3: Disasters in a gradual scale between purely natural and purely human-made and amenable to satellite based Earth Observations

Natural	Some human influence	Mixed natural/ human influence	Some natural influence	Human
Earthquake Tsunami Volcanic eruption Avalanche Glacial lake outburst Cyclone Asteroid Impact	Flood Drought	Landslides Subsidence Desertification Coal fires Coastal erosion Sea Level Rise	Crop disease Insect infestation Forest fire Mangrove decline Coral reef decline	Oil spills Water pollution Air pollution

Table 4: Main controlling factors leading to a disaster and amenable to satellite based Earth observations

Meteorological	Geomorphological/ Geological	Ecological	Technological	Global environmental	Extra terrestrial
Drought Dust Storm Flood Wind storm Cyclone	Earthquake Tsunami Volcanic eruption Landslide Avalanche Subsidence Coal fires Coastal erosion	Crop disease Insect infestation Forest fire Glacial lake outburst Coral reef decline Desertification	Oil spills Water/soil/ air pollution Pesticides Mangrove decline	Sea Level Rise El Nino	Asteroid impact

Since the turn of the century, the Emergency Events Database (EM-DAT) has recorded an average of 397 disasters each year. In the year 2008, more than 235, 000 people were killed, 214 million people were affected and economic costs were over 190 billion US$ by a total number 354 of reported disasters (Rodriguez *et al.,* 2009). The death toll was three times higher than the annual average of 66 813 for 2000-2007, mainly caused by two major events: Cyclone Nargis which killed 138 366 people in Myanmar and the Sichuan earthquake in China which caused the death of 87 476 people. Disaster costs in 2008 were more than twice the 82 billion US$ annual average for 2000-2007 and were mainly attributed to the Sichuan earthquake in China (85 billion US$) and hurricane Ike in the U.S. (30 billion US$). Asia remained the most affected continent. Nine of the top 10 countries with the highest number of disaster-related deaths were in Asia. While China, the U.S., the Philippines and Indonesia reported the largest number of natural disasters, Djibouti, Tajikistan, Somalia and Eritrea topped the list of number of victims per 100 000 inhabitants.

The deadliest disaster in 2010 was an earthquake that occurred on Tuesday 12, January, in Haiti with a catastrophic magnitude 7.0 M_w and an epicentre near the town of Léogâne, approximately 25 km (16 miles) west of Port-au-Prince, Haiti's capital. The Haitian Government reports that between 217,000 and 230,000 people have died, an estimated 300,000 injured, and an estimated 1,000,000 homeless. It was also estimated that 250,000 residences and 30,000 commercial buildings had collapsed or were severely damaged.

Another major disaster in 2010 was the 2010 Chilean earthquake which occurred off the coast of the Maule Region of Chile on February 27, 2010 rating a magnitude of 8.8 on the moment magnitude scale and it killed about 497 people.

Developing countries and least developed countries suffer more than 92 per cent of all deaths caused by natural disasters (see Table 5). Their high population densities and poor infrastructure, coupled with unstable

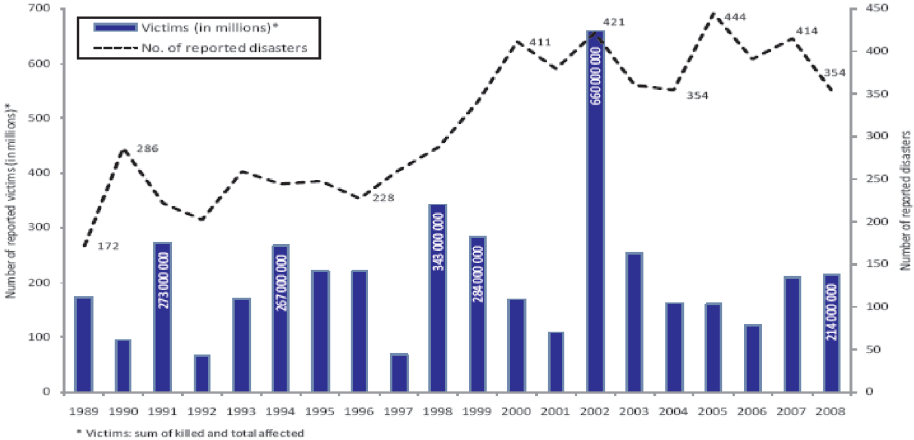


Figure 2: Number of reported disasters and victims for the period 1989-2008 (Rodriguez *et al.,* 2009)

landforms and exposure to severe weather events, makes them particularly vulnerable.

Table 5: Number of people reported killed by type of disaster and level of development (1991 - 2005) source: EM-DAT

	Flood	Wind Storm	Drought	Slide	Earthquake and tsunami	Volcanic eruption	Epide-mic	Total
OECD	2150	5430	47516	426	5910	44	442	61918
CEE+CIS	2635	512	3109	1176	2412	0	568	10412
Developing Countries	97061	65258	12599	9369	397303	900	47616	630106
Least developed countries	20127	149517	3320	1739	9247	201	70588	254739
Countries not classified	99	767	57	23	2277	0	104	3327
Total	122072	221484	66601	12733	417149	1145	119318	960502

* Drought related disasters category includes extreme temperatures

Disasters belong to the multifarious temporal- and space scales. Some of them appear on the scale of a territory, a region, a country or the planet, while the others may affect locally. Similarly the time range of occurrence disasters also vary a lot starting from minutes (earthquake, landslides) to vary slow disasters taking months to develop (e.g. drought). Figure 3 shows the spatial and temporal scales of different disasters. The disaster management will vary greatly depending upon the spatio-temporal scale of disasters.

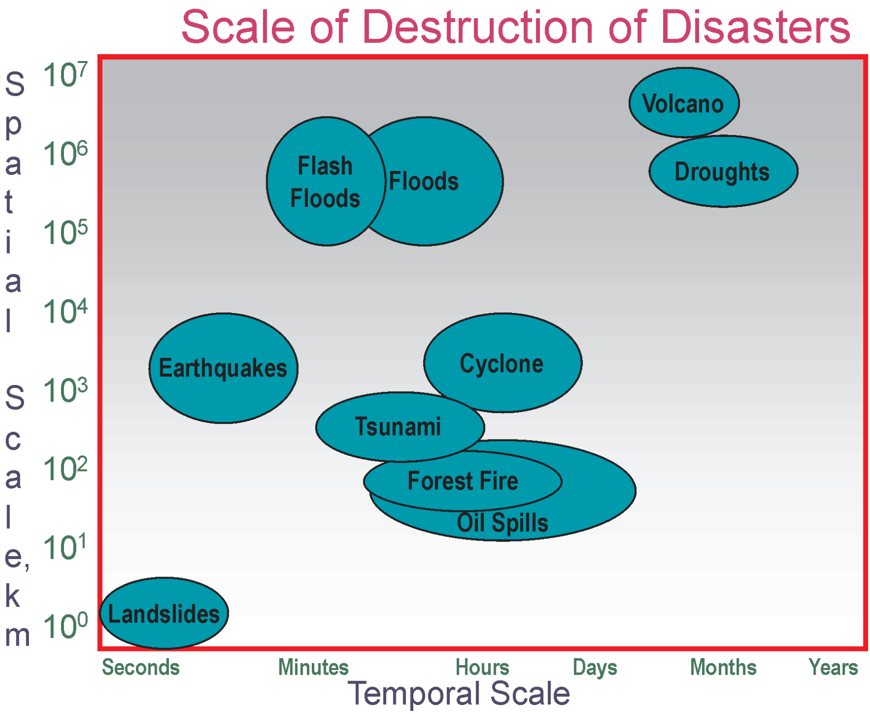


Figure 3: Spatial and temporal scales of different disasters

1.2 Role of Space Technology

Natural events cannot be prevented, but potential disasters can be 'managed' to minimise loss of life and properties through disaster management. Disaster management aims to reduce, or avoid the potential losses from hazards, assure prompt and appropriate assistance to victims of disaster, and achieve rapid and effective recovery. The Disaster management cycle illustrates the ongoing process by which governments, businesses, and civil society plan for and reduce the impact of disasters, react during and immediately following a disaster, and take steps to recover after a disaster has occurred. Appropriate actions at all points in the cycle lead to greater preparedness, better warnings, reduced vulnerability or the prevention of disasters during the next iteration of the cycle (see Figure 4, Table 6).

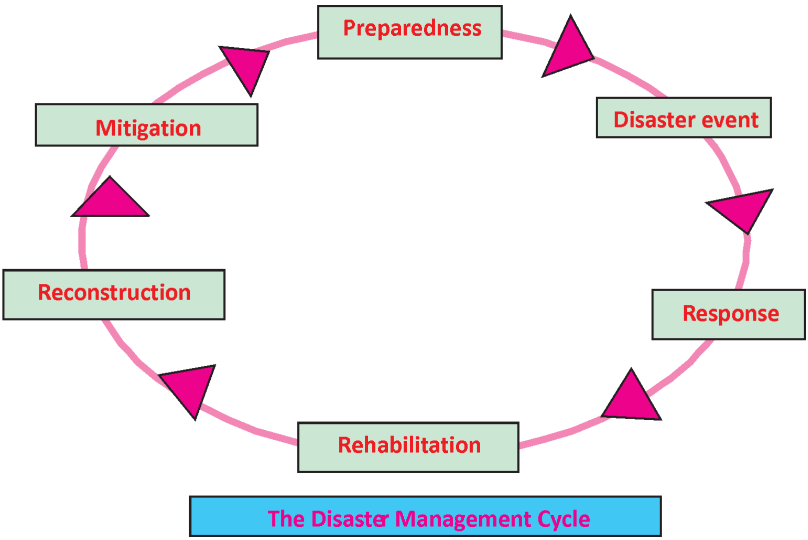


Figure 4: The disaster management cycle

The primary concern in disaster management is to prevent a hazard take the form of a disaster. Pre-disaster planning consists of disaster prevention, mitigation and preparedness. Disaster response can be divided into warning phase and emergency relief phase. Recovery is the period following relief stage, where ad-hoc measures should be consciously eschewed and strict adherence enforced to follow the recommended land use pattern and engineering design and control.

The importance of disaster monitoring and mitigation has been included in the UN Millennium Declaration of September, 2000, where the heads of State and Government have resolved (among other things) to intensify cooperation to reduce the number and effects of natural and man-made disasters.

Space based Disaster Management System has the distinct advantage of being unaffected by disasters on the ground and provides unbiased, synoptic and timely information on different components of the disaster management cycle. Space technology has demonstrated a variety of critical and valuable supports to many disaster management areas such as assessment, preparedness and mitigation planning, early warning, impact assessment and emergency communications.

Certain aspects of space and related technologies such as Geographical Information System (GIS), Global Positioning System (GPS), remote sensing, and digital photogrammetry have proven to be crucial for disaster management. The contribution of satellite remote sensing to earth observation science since the launching of Landsat in 1972, has made significant development in all dimensions ranging from high-resolution topography (using Interferrometric SAR, LIDAR, and digital photogrammetry) and geodesy to passive hyperspectral (such as ASTER, MODIS and Hyperion) and active microwave imaging have transformed the discipline (Tralli *et al.,* 2005). Applications of different spectral channels for disaster management is shown in Table 7 and a list of current and future optical sensors is presented in Table 8 and microwave sensors in Table 9.

Table 6: Applications of remote sensing in disaster management

Disaster	Mitigation	Preparedness	Response	Recovery
Cyclone	Risk modelling Vulnerability analysis	Early warning (track and intensity) Storm surge predictions Long-range climate modelling	Identifying escape routes Identify areas for providing relief/aid Crisis mapping Impact assessment Cyclone monitoring Inundation monitoring	Damage assessment Spatial planning
Drought	Risk modelling Vulnerability analysis Land and water management planning	Weather forecasting Vegetation monitoring Crop water requirement mapping Early warning and drought bulletins	Monitoring vegetation Damage assessment	Informing drought mitigation

Disaster	Mitigation	Preparedness	Response	Recovery
Earthquake	Building stock assessment Hazard mapping	Measuring strain accumulation Identifying Earthquake precursors Micro-seismic zonation	Planning routes for search and rescue Damage assessment Evacuation planning Deformation mapping	Damage assessment Identifying sites for rehabilitation
Fire	Monitoring fuel load Risk modelling	Mapping fire-prone areas Fire detection Predicting spread/ direction of fire Early warning	Coordinating fire-fighting efforts	Damage assessment
Flood	Delineating flood-plains Land use mapping	Mapping flood-prone areas Flood detection Early warning Rainfall mapping	Flood mapping Evacuation planning Damage assessment Identify areas for providing relief/aid	Damage assessment Spatial planning

Disaster	Mitigation	Preparedness	Response	Recovery
Landslide	Landslide hazard zonation Risk modelling	Monitoring rainfall and slope stability Early warning models Digital elevation models	Mapping affected areas Identify routes for providing relief/aid	Damage assessment Spatial planning Suggesting management practices
Volcano	Risk modelling Hazard mapping Digital elevation models	Emissions monitoring Thermal alerts	Mapping lava flows Evacuation planning	Damage assessment Spatial planning

Table 7: Applications of different wavebands for disaster management

Wavelength	Waveband	Useful for	Example sensors
Visible	0.4-0.7µm	Vegetation mapping	SPOT; Landsat TM, IRS - LISS, AWiFS
		Building stock assessment	AVHRR; MODIS; IKONOS; CARTOSAT
		Population density	IKONOS; MODIS
		Digital elevation model	SRTM, CARTOSAT, ASTER; PRISM
Near infrared	0.7-1.0µm	Vegetation mapping	SPOT; Landsat TM; AVHRR; IRS, MODIS IRS-LISS, AWiFS
		Flood mapping	IRS, MODIS
Shortwave infrared	0.7-3.0µm	Water vapor	AIRS
Thermal infrared	3.0-14µm	Active fire detection	MODIS
		Burn scar mapping	MODIS
		Hotspots	MODIS; AVHRR
		Volcanic activity	MODIS; AVHRR
Microwave (radar)	0.1-100cm	Earth deformation and ground movement	Radarsat SAR; PALSAR
		Rainfall	Meteosat; Microwave Imager (aboard TRMM)
		River discharge and volume	AMSR-E
		Flood mapping and forecasting	AMSR-E
		Surface winds	QuikScat radar, Oceansat-2
		3D storm structure	Precipitation radar (aboard TRMM)

Acronyms: Satellite Pour l'Observation de la Terre (SPOT); Thematic Mapper (TM); Advanced Very High Resolution Radiometer (AVHRR); Moderate Resolution Imaging Spectroradiometer (MODIS); Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER); Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM); Synthetic Aperture Radar (SAR); Phased Array type L-band SAR (PALSAR); Tropical Rainfall Measuring Mission (TRMM); Global Precipitation Measurement (GPM); Advanced Microwave Scanning Radiometer (AMSR-E); Atmospheric Infrared Sounder (AIRS)

Table 8: Main parameters of current and forthcoming optical/IR satellite and micro satellite systems with medium to high resolution (Source: Metternicht *et al.*, 2005)

Optical Satellite	Sensor	Spatial resolution (meters) and (# bands)					Swath (km)	Repeat Cycle	Year launch
		PAN	VNIR	SWIR	MWIR	TIR			
Landsat 5	MSS		80 (4)			120 (1)	185	16	1984
	TM		30 (4)	30 (2)					
IRS-IC and	LISS-III		23.5 (3)	70.5 (1)			142	24	1995
IRS-ID	PAN	5.8.					70	24	
	WiFS		188 (2)	188 (1)			774	5	1997
IRS-P2	LISS-II		36.4 (4)				74	22	1994
IRS-P3	WiFS		188 (2)	188 (1)			774	5	1996
Landsat 7	ETM+	15	30 (4)	30 (2)		60 (1)	185	16	1999
SPOT 4	HRVIR	10	20 (3)	20 (1)			60 (80)	26 (4)	1998
	Vegetation		1000 (3)	1000 (1)					
CBERS 1 and 2	HRCC	20	20 (4)				113	26	1999
	IR-MSS	80		80 (2)		160 (1)	120	26	
	WFI		260 (2)				890	3 to 5	
Ikonos 2	OSA	1	4 (4)				11	3	1999
Terra	ASTER		15 (3)	30 (6)		90 (5)	60	16	1999
KOMPSAT-1**	EOC	6.6					17	26	1999
	OSMI		1000 (6)						
EROS A1**	PIC	1.9					14	2.5 - 4.5	2000
MTI	MTI		5 (4), 20 (3)	20 (3)	20 (2)	20 (3)	12		2000
SPOT 5	HRG	2.5-5	10 (3)	20 (1)			60	26 (5)	2002
	HRS	10					1230	26	
	Vegetation 2		1000 (3)	1000 (1)			2200	1	
Quickbird 2	BGIS 2000	0.6	2.5 (4)				16	3	2001
IRS-P6									
(ResourceSat-1)	LISS-4	6	6 (3)				23.9 (70)	5	2003
	LISS-3		23.5 (3)	23.5 (1)			141	34	
	AWiFS		56 (3)	56 (1)			740		

DMC2-AlSAT1[a]	ESIS		32 (3)				600	4	2003
DMC2-BILSAT-1[a]	PanCam	12					25 (300)	4	2003
	MSIS		26 (2)				55 (300)		
	COBAN		120 (4)						
DMC2-Nigeria									
SAT 1a	ESIS		32 (3)				600	4	2003
UK-DMCa	ESIS		32 (3)				600	4	2003
ROC-Sat-2/									
FormoSAt-2[b]	RSI	2	8 (4)				24	14	2004
OrbView-3[b]	OHRIS	1	4 (4)				8	3	2003
KOMPSAT-2[b]	MSC	1	4 (4)				15	28	2004
IRS-P5									
(CartoSat-1)	PAN-F/A	2.5					30	5	2005
ALOS	PRISM,	2.5					35 (70)	46 (2)	2005
	AVNIR-2		10 (4)				70		
CBERS 3 and 4	MUX		20 (4)				120	26	
	PAN	5					60	1 - 26	
	ISR		40	40 (2)		80	120	26	
	WFI		73 (4)				866	5	
TopSatb	RALCam1	2.5	5 (3)				25	4	2005
Pleiadesc-1 and 2	HiRL	0.7	2.8 (4)				20	26 to 4	
RapidEye A-E[d]	REIS	6.5	6.5 (5)				78	1	2007
EROS B - C	PIC	0.7	2.8				11		2005 - 2008
RazakSatc	MAC	2.5	5 (4)				20	13 - 15f	2005
China DMC+4									
(Tsinghua-1)	MS DMC	4	32 (3)					600	2005
Resurs DK-1[g]	ESI	1	3 (3)				28.3	N/A	2005

[a] DMC (Disaster Monitoring Constellation of 4 satellites) of sun-synchronic circular orbit, daily revisit cycle.
[b] Circular, sun-synchronic orbit.
[c] Two-space-craft constellation of CNES (Space Agency of France), with provision of stereo images.
[d] Five-satellite constellation.
[e] Near equatorial low Earth orbit (NEO).
[f] Passes/day.
[g] Near-circular non-sun synchronous orbit.

Table 9: Main characteristics of current and forthcoming microwave satellites (Source: Metternicht *et al.*, 2005)

Satellite	ERS-1	ERS-2	Radarsat-1	JERS-1	Envisat	Radarsat-2	Alos	TerraSAR-X	Cosmo/ SkyMeda
Sensor	AMI	AMI	SAR	SAR	ASAR	SAR	PALSAR	TSX-1	SAR-2000
Space agency	ESA	ESA	Radarsat Int	NASDA	ESA	Radarsat Int	NASDA	DLR/Infoterra GmbH	ASI
Operational since	1991	1995	1995	1992	2002	2005	2.4	2006	2005
Out of service since	2000			1198					
Band	C	C	C	L	C	C	L	X	X
Wavelength (cm)	5.7	5.7	5.7	23.5	5.7	5.7	23.5	3	3
Polarization	VV	VV	HH	HH	HH/VV	QUAD-Pol[b]	A11	A11	HH/VV
Incidence angle (°)	23	23	20 - 50	35	15 - 45	10 - 60	8 - 60	15 - 60	Variable
Resolution range (m)	26	26	10 - 100	18	30 - 150	3 - 100	7 - 100	1 - 16	1 - 100
Resolution azimuth (m)	28	28	9 - 100	18	30 - 150	3 - 100	7 - 100	1 - 16	1 - 100
Scene width (km)	100	100	45 - 500	75	56 - 400	50 - 500	40 - 350	5 -100 (up to 350)	10 - 200 (up to 1300)
Repeat cycle	35	35 (3)	24	44	35	24	2 - 46	2 - 11	5 - 16
Orbital elevation (km)	785	785	798	568	800	798	660	514	619

Source: ITC's database of satellites and sensors

(Online: http://www.itc.nl/research/products/sensorsdb/A11Satellites.aspx), Connecting Earth Observation Resource: http://directory.eoportal.org/res_p1_Earthobservation.htm#note.

[a] Constellation of 4 satellites.

[b] QUAD-Pol mode (all four polarization: HH, HV, VV, VH).

With the advent of multi platform, multi sensor, multi spectral geodata and the organisation of spatial databases around a Geographical Information Systems (GIS), combined with the Global Positioning System (GPS) and photogrammetry, the process of systematic spatial information acquisition has now become much easier (Nayak and Pathan, 2005). Large developments in analytical and predictive modelling through GIS and Decision Support System (DSS) has occurred based on enhancement in computing methodologies through neural networks, fuzzy logic and hybrid soft computing techniques. There has been significant progress in managing topological change in geo-spatial databases. The web-mapping technology has matured and moved towards 3D web applications, sensor web environments, web-based services, and distributing (grid) geo-computing.

All these developments have revolutionized all aspects of the earth observation studies, including disaster monitoring, mitigation and management. While the remote sensing data has been utilized in disaster identification, damage assessment, monitoring changes over time; integration of GIS and modelling has influenced disaster mitigation and management through vulnerability zone identification, creation of spatial databases of emergency management resources, e.g. hospitals, relief centers, etc.

The first Disaster Monitoring Constellation (DMC-I), developed by Surrey Satellite Technology Limited, UK addresses the basic need for providing timely data (da Silva Curiel *et al.,* 2002). A constellation of 5 satellites is designed to offer daily coverage of any point on the globe.

1.3 Collaborative International Efforts

Under the theme "Space benefits for humanity in the twenty-first century", the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) was held in Vienna from 19 to 30 July 1999. In its resolution 1, the Conference adopted. The Space Millennium: Vienna Declaration on Space and Human Development, that was subsequently endorsed by the General Assembly in its resolution 54/68. The Vienna Declaration recommended 33 specific actions that should be taken to enable space technologies to contribute to the solution of global challenges of the new millennium. One of the recommendations put forward was the need "to implement an integrated, global system, especially through international cooperation, to manage natural disaster mitigation, relief and prevention efforts, especially of an international nature, through Earth observation, communications and other space-based services, making maximum use of existing capabilities and filling gaps in worldwide satellite coverage". The use of space-based solutions and information has increased significantly since UNISPACE-III. The use of such technologies has been proven useful in the risk assessment, mitigation and preparedness phases of disaster management. As the global community learnt from the tsunami event of December 2004, space technologies have a central role to play in providing early warning to communities that are at risk. But in order for developing countries to be able to incorporate the use of space technology-based solutions there is a need to increase awareness, build national capacity and also develop solutions that are customised and appropriate to the needs of the developing world. This was the main goal of the space technology and disaster management programme carried out by the Office for Outer Space Affairs (UNOOSA), between 2000 – 2004 (http://www.eird.org/wikien/index.php/Space_technology_and_disaster _reduction).

During the current decade, both developed as well developing countries have put concentrated efforts in utilizing and sharing space based technology like Earth Observation (EO) satellites, communication satellites, meteorological satellites and Global Navigation Satellite Systems (GNSS) in disaster risk reduction and disaster management.

Therefore, efforts to facilitate the access to space information products and services to support disaster management decision making were made among several space agencies and disaster management agencies. These efforts have resulted into several global and regional programs of International co-operation such as United Nations Platform for Space-based Information for Disaster management and Emergency Response (UN-SPIDER), International Charter on Space and Major Disasters, Group on Earth Observation (GEO) and Global Earth Observation System of Systems (GEOSS), Sentinel Asia, Global Monitoring for Environment and Security (GMES), UNOSAT, The Asia Pacific Space Cooperation Organization (APSCO) and many more.

1.4 Objectives of the Study Report

However, even with the availability of large spectrum of Earth Observation (EO) data, development of communication technologies, and building of international networks; **availability of right information to right people at right time in right format is still a major challenge.** In this context, this IAA study report on Disaster Management/ Natural Hazards is very timely. The purpose of this study report is to:

i) outline the current status of the space-based disaster management technology for different disasters,

ii) identify the gap areas,

iii) suggest possible improvements for real-time integrated solutions.

One of the important aspects, which the study attempts to highlight, is the development of early warning systems, where collaborative research effort would be necessary to develop forecasting models, in which EO data can be assimilated for more accurate warning system(s).

The report is further divided into three chapters, apart from the current chapter which deals with the scope of the study. The second chapter discusses the current status, and analyzes the role of EO data for management of individual disasters. The third chapter is on Stakes, Issues and Potential Solutions. This chapter identifies the shortcomings of the current technology and looks into the mode of activities of different international networks. Based on the above analysis, the last chapter deals with the recommendations for better space based disaster management, outlining the need for international cooperation.

2. General Context and Status of Major Natural Disasters

Natural disasters are often frightening and difficult for us to understand, because we have no control over when and where they happen. What we can control is how prepared we are as communities and governments to deal with the dangers that natural disasters bring. Places that are more likely to have natural disasters, such as the earthquake-prone Pacific Ring of Fire, or coastal areas vulnerable to hurricanes, require accurate methods of predicting disasters and warning the public quickly. A study made by Ugnar (1999) has shown that losses due to extreme events are increasing steeply specially in the last decade of the twentieth century. However, these increased losses may be either due to a real increase in the frequency of the extreme weather events or due to increased vulnerability of cities, towns and the associated infrastructure and installations, which have grown rapidly to meet the needs of a growing population.

This chapter describes some of the most damaging disasters, their genesis, spatial and temporal scales, status of space technology in mitigation, monitoring, damage assessment and early warning/ forecasting and Gap areas. Earthquakes, tsunami, wind storm/cyclones, floods, drought and landslides are the most damaging natural disasters.

Earthquake

Earthquakes are short-lived, menacing and the most feared natural hazards because of their sudden impact and devastation in a matter of few seconds inflicting immense losses of life and property. Currently, operational EO capabilities have shown use in the mitigation and response phases of earthquake risk management, but limited in the warning phase.

Mitigation includes creation of seismic zones, where various earthquake damage reduction measures can be taken and also for base mapping for emergency relief logistics, and estimation of settlement and structure vulnerability (e.g. building design) and exposure (e.g. proximity to active areas) (CEOS, 2003). Remote sensing and GIS provide a database from which the evidence left behind by disaster can be combined with other geological and topographical database to arrive at hazard maps. Satellite remote sensing plays an important role in the mapping of active faults, lineament and density of lineaments as well as liquefaction sensitivity index.

New generations of high-resolution optical satellites (IKONOS, TES, EROS, Cartosat-2/2A/2B, etc), which provide imagery with 1-meter resolution in panchromatic mode, are very useful for damage mapping. The high level of details makes possible reliable damage detection to the buildings or to other structures (Chiroiu *et al.,* 2001). In recent earthquake at Uri town, Cartosat-1 data has been utilized for damage detection and assessment. SAR interferometry such as (InSAR) also holds increasing utility for the mapping of seismic ground deformation. A number of countries such as the United States, France and Russia had launched satellites that will help to better predict earthquakes from space. However, the move represents only one effort to tap the potential to predict imminent earthquakes, other measures need to be combined with the space technology.

Tsunami

Tsunami is Japanese for "harbor wave". Tsunamis occur when large volumes of water are forcefully displaced by crustal movement of the ocean floor, usually due to an earthquake, (underwater) landslide or a volcanic eruption. Tsunamis have incredible energy because of the great volume of water affected. They bring waves of destruction capable of killing thousands of residents along the coast.

Most tsunamis originate along the Ring of Fire. The Ring of Fire is an area of volcanoes and seismic activity 24,000 mi long. Associated risks include flooding, polluted water supplies, and damaged gas lines.

Although many countries have well developed tsunami warning systems, there is need to strengthen the network of tsunami warning systems in developing countries. Denser networking of seismic stations, tide gauges, data buoys with pressure sensors along with satellite connectivity, storm surge modeling using high resolution DEM, improving forecasting time duration are some of the critical areas requiring efforts at regional and global level. In addition research related to early warning of earthquakes requires to be strengthened with newer techniques.

Cyclone/Storm Surges

Tropical cyclones are among the most devastating events in nature. Most of the damages are caused due to coastal inundation by tidal waves, storm surges and torrential rains besides the effect of wind. However, as a result of improved computer models and remote sensing techniques, the impact of cyclones on life loss has been gradually reduced. Meteorological satellites have been highly useful for monitoring and forecasting of cyclones. INSAT-VHRR, NOAA-AVHRR and METEOSAT have been used to identify cloud systems over the oceans, and also for cyclone tracking, intensity assessment and prediction of storm surges.

Though significant progress has been made in the track and intensity prediction of tropical cyclones, further improvements in these directions are needed through different R&D efforts. Enhancement of observational network over data sparse region such as coastal Doppler Weather Radar (DWR), extensive use of satellites, buoys, aircrafts and UAV etc. in the real time and the assimilation of these products is required in providing better initial conditions to the mesoscale models.

Floods

Floods are among the most recurrent natural hazards in the world, claiming more lives and causing more property damage than any other natural phenomena.

Near real time flood monitoring is only possible through satellite data, Synthetic Aperture Radar (SAR) can achieve regular observation of the earth's surface, even in the presence of thick cloud cover. Flood inundation maps have been combined with many GIS layers, such as administrative boundaries, road/rail network, settlement location, etc., for real time flood impact assessment.

GIS is used in Flood risk zoning (FRZ) to demarcate areas likely to be affected by floods of different magnitudes, probability levels, and risk associated for life and economy (Chakraborti *et al.,* 2003). The output from hydrologic models can also be combined with the socio-economic data in a GIS to forecast extent of damage under different flooding scenario.

Drought

Drought is a period or condition of unusually dry weather within a geographic area where rainfall is normally present. During a drought there is a lack of precipitation. Droughts occur in all climatic zones. However, its characteristics vary significantly from one region to another. Drought is a condition resulting from prolonged absence, deficiency, or poor distribution of precipitation.

In the past, climate and meteorological data have been the primary sources for drought information used to support decision-making. However, more recently, satellite observations have proved to be a valuable source of timely, spatially continuous data with improved detail for monitoring vegetation dynamics over large areas. Vegetation indices (VI), most commonly Normalized Difference Vegetation Index (NDVI), have been extensively used to monitor vegetation stress condition.

Landslides

Landslides pose serious threat to human settlements and structures used for transportation, natural resources management and tourism. It imparts significant damages to property, highways, railways, waterways and pipelines. The slide events were reported to have triggered mainly by rainfall, earthquake and human activities. Landslide studies can be organized into three phases (Brenan, 2005), which include detection and classification of landslides, monitoring activity of existing landslides, and analysis and prediction of slope failures in space and time. Remote sensing techniques can be and are often used in all three stages of a landslide investigation. Metternicht *et al.,* (2005) provides a review of remote sensing for landslides.

Aerial photographs, stereo images, optical and microwave images are useful for the detection and classification of landslides. Remote sensing and GIS can also play a major role in the monitoring of landslide movements, prediction of slope failures and generation of hazard zonation maps.

Avalanche

An avalanche is a rapid flow of snow down a slope, from either natural triggers or human activity. In mountainous terrain avalanches are among the most serious objective hazards to life and property, with their destructive capability resulting from their potential to carry an enormous mass of snow rapidly over large distances. One of the aims of avalanche research is to develop and validate computer models that can describe the time evolution of snow packs and predict the shear yield stress. A complicating factor is the large spatial variability that is typical.

Forest fire

Forest fires cause a wide range of global environmental impacts. The most obvious one being the destruction of forest vegetation and subsequent release of substantial amount of trace gases and particulates into the atmosphere, causing various changes to the earth (Fraser *et al.,* 2000). Satellite data and GIS have been found to be useful in forest fire management (Ajai *et al.,* 2003a).

Active fires can be detected using mid infrared (3-5 μm) bands available in NOAA-AVHRR, MODIS and ATSR (Ajai et al., 2003a). Detecting forest fires with the use of AVHRR images has been done with the use of a fire detection algorithm developed by Li *et al.,* (2000 a&b).

Volcanic Eruptions

A Volcano is a vent in the earth through which hot gases and molten rock rise to the surface. A Volcano consists of a fissure in the earth's crust, above which a cone of volcanic material has accumulated. Volcanoes pose a serious threat to persons on the ground near erupting volcanoes (due to proximal hazards such as lava flows, mud flows, ash fall, etc). Ash clouds from major eruptions endanger aircraft and airport operations over distances of thousands of kilometers. Remote sensing and GIS has become an indispensable part of the global system of detection and tracking of the airborne products of explosive volcanic eruptions. Francis (1989) has reported the results of the applications of the Landsat Thematic Mapper (TM) and other satellite systems to the identification, spectral and thermal monitoring of mudflow of active volcanoes. Recent research has also shown the potential of remote sensing and GIS for monitoring proximal hazards such as hot spots and lava flows using geostationary and polar InfraRed (IR) data (CEOS, 2003; Bertrand *et al.,* 2003). Also, Interferometric Synthetic Aperture Radar (InSAR) imagery has been used to document deformation and topographic changes at volcanoes.

Desertification

Desertification is the extreme deterioration of land in arid and dry sub-humid areas due to loss of vegetation and soil moisture; desertification results chiefly from man-made activities and influenced by climatic variations. Today about 33 per cent of the earth's land surface exhibits desert characteristics to some degree or other. It is principally caused by overgrazing, overdrafting of groundwater and diversion of water from rivers for human consumption and industrial use, all of these processes fundamentally driven by overpopulation. A major impact of desertification is biodiversity loss and loss of productive capacity, for example, by transition from land dominated by shrublands to non-native grasslands.

Remote sensing data along with GIS has been useful for desertification monitoring and assessment. The indicators of desertification amenable to remote sensing include salinity, erosion, sand sheet etc. (Ajai, *et al.,* 2003b).

Impact of Asteroids and Comets/Near Earth Objects (NEO)/ Hazardous Space Objects (HSO)

Collision of asteroids and comets on the earth's surface has the potential to cause large scale destruction and are classed as Extra-Terrestrial disasters. Asteroids and comets whose orbits bring them to the vicinity of Earth are called Near Earth Objects (NEOs). NEOs are comets and asteroids that have been nudged by the gravitational attraction of nearby planets into orbits that allow them to enter the Earth's neighborhood. The Earth has been subjected to bombardment by thousands of very large NEOs since its formation. While the great majority of NEOs are small and pose little or no danger the most damaging ones are 6 km or more in diameter, and the effects of their impact on Earth would likely cause the extinction of most life on Earth. This has occurred several times, the most recent being the impact 65 million years ago which extinguished the dinosaurs and 60% of other species, but fortunately their average impact frequency is only every 100,000,000 years. The impact of NEOs 1-6 km in diameter would result in catastrophic damage regionally or globally.

As of April 25, 2010, 6995 Near-Earth objects have been discovered (NASA, 2010). Some 805 of these NEOs are asteroids with a diameter of approximately 1 kilometer or larger. Also, 1110 of these NEOs have been classified as Potentially Hazardous Asteroids (PHAs). Potentially Hazardous Asteroids (PHAs) are currently defined based on parameters that measure the asteroid's potential to make threatening as it closely approaches to the Earth. Hazardous Space Objects (HSO) includes all types of space debris having potential to cause impact disasters on the earth's surface. Efforts are required for the timely detection and performance definition of the NEO/HSO, the timely and reliable delivery to NEO/HSO of impact modules which provide a proper declination of the hazardous object from the dangerous trajectory or to destruct it into non-hazardous fragments and development of suitable spacecraft and launch vehicles (Degtyar *et al.,* 2010).

3. Future Stakes, Issues and Potential solutions

3.1 Overall short-comings in the present-day space observation systems, in-situ observation networks and modeling

Following are some of the short-comings and issues in the present day space observation systems in the context of disaster management:

i) **Inadequate existing network of EO Satellites:** Present day earth observation satellites are designed to meet requirements of wide-ranging applications and do not full-fill specific requirements of disaster prediction, monitoring and mitigation. Overwhelming majority of existent EO satellites is dedicated to recovery efforts after natural and man-caused disasters. Information from EO satellites is not practically used for the purpose of disaster prediction. It results from absence on the board of satellites appropriate equipment from one side, and absence of reliable methods, approaches and instruments to predict disasters from other side. It is necessary to identify specific sensors with appropriate spatial, spectral and temporal resolutions. Limited satellite availability, with large gap between dates of pass is observed. The observational gaps need to be removed by providing additional network of satellites in particular radar satellites to complement the existing EO satellites. Constraint in timeliness in getting data and providing products, especially for hydro-meteorological disasters, for which cloud free optical data is difficult to obtain, is observed. Since remote sensing satellites have definite orbit and only limited maneuvering is possible, there is a need of a constellation of intelligent earth observation satellites, both optical and microwave, with daily revisit capability. Satellites/ Missions specifically designed for planetary defense against

Near Earth Objects/Hazardous Space Objects are required. Table - 7 summarizes the sensor specific wave length ranges of EO satellites for disaster management.

ii) **Lack of mechanism to share space resources:** Space resources, both EO satellites as well as communication satellites need to be pooled together for disaster management purposes. Although several International programs of global and regional co-operation have been launched during current decade, there is overlap and duplications of efforts. In addition, many less developed countries still do not have access to the space resources. Although regional co-operation programs focus to full-fill regional needs, there should be tie-up of all such programs under one umbrella so that both space resources as well expertise for disaster management may be globally shared.

iii) **Inadequate ground stations:** The existing network of ground stations receiving satellite data is inadequate for global coverage, therefore countries/space agencies need to establish as well strengthen existing ground infrastructure for receiving satellite data.

iv) **Inadequate value added services for disaster related satellite data products:** Current available expertise to process raw satellite data into meaningful products for disaster management is limited to a few countries/few Institutes. It needs to be strengthened by increasing the existing expertise and infrastructure as well by developing new expertise and infrastructure at several other countries/Institutes.

v) **Requirement of improving the quality of value added satellite data products:** Satellite data products are useful in all the phases of disaster management cycle. These value added satellite data products are: early warning /risk assessment products, disaster loss and damage assessment products, decision making support products etc. In order to generate such products appropriate satellite data processing techniques/methods or models are needed. These methods may be further improved by collaborative efforts of local, regional or global nature. Rigorous and time-tested early warning/ forecasting models need to be developed. A robust decision support system needs to be developed.

vi) **Requirement of improving the disaster response plans:** Operational institutional arrangements among satellite operators, remote sensing service providers, disaster management authorities and response action headquarters require to be established with standardized value added products, services and delivery channels with specific disaster response plans during disaster emergency response. There is non-availability of spatial database of socio-economic aspects at various scales, causing damage assessment and relief operations difficult.

vii) **Lack of data sharing policy:** Although some of the initiatives such as International Charter on Space and Major Disasters do provide access to satellite data to all member countries, requirements at grass-root level are not full-filled due to moderate to coarse resolution of the data and it is difficult to implement any action at grass-root level. There is gap between existing information products of space agencies or remote sensing centres and the information requirement of disaster managers. There is poor networking between data provider and user agencies, thus making the utility of spatial data limited.

viii) **Inadequate Internet bandwidth for accessing space information services:** The public Internet service is observed to be inadequate in providing access to large volume of space based information data in many countries.

3.2 Solutions through International efforts in place

Disaster is a global phenomenon. Any disaster that strikes does not restrict itself to administrative boundary. Even if its effect is limited to a particular country, it becomes a global concern for response and relief. Hence, it is essential to have a network of various international organizations working towards disaster management, more particularly in the field of utilization of space technology for disaster management. The activities of these international organisations are briefly described below.

3.2.1 GEOSS/GEO

The Global Earth Observation System of Systems (GEOSS) tries to integrate Earth observations with other information to help planners reduce vulnerability, strengthen preparedness and early-warning measures and, after disaster strikes, rebuild housing and infrastructure in ways that limit future risks. By making it possible to integrate different types of disaster-related data and information from diverse sources, GEOSS aims to strengthen analysis and decision making for disaster response and risk reduction by providing a better understanding of the relationship between natural disasters and climate change.

3.2.2 UN-SPIDER

There have been a number of initiatives in recent years that have contributed to making space technologies available for humanitarian aid and emergency response. UN-SPIDER is the first to focus on the need to ensure that all countries and international and regional organizations have access to and develop the capacity to use all types of space-based information to support the full disaster management cycle which will significantly contribute to a reduction in loss of lives and property. The UN-SPIDER programme is achieving this by focusing on being a gateway to space information for disaster management support, by serving as a bridge to connect the disaster management and space communities and by being a facilitator of capacity-building and institutional strengthening, in particular for developing countries. UN-SPIDER is being implemented as an open network of providers of space-based solutions to support disaster management activities. This includes all types of information provided by earth observation satellites, communication satellites and global navigation satellite systems.

3.2.3 Sentinel-Asia

Sentinel Asia is a "voluntary and best-efforts-basis initiatives" led by the APRSAF (Asia-Pacific Regional Space Agency Forum) to share disaster information in the Asia-Pacific region on the Digital Asia (Web-GIS) platform and to make the best use of earth observation satellites data for disaster management in the Asia-Pacific region. Sentinel Asia is planned to be an internet-based, node-distributed, information distribution backbone, triggering data acquisition and distributing relevant satellite and in-situ spatial information on all hazards from all available satellites in the region to all participating countries through their representative space agencies during major disasters. Major Activities of Sentinel Asia include: Emergency observation by earth observation satellites in case of major disasters: Acceptance of observation requests: Wildfire monitoring and Flood monitoring and Capacity building for utilization of satellite images for disaster management.

3.2.4 International Charter on "Space and Major Disasters”

International Charter on Space and Major Disasters was initiated by ESA and CNES following the Third United Nations Conference on the

Exploration and Peaceful Use of Outer Space (UNISPACE III) in 1999. The Charter now embraces ten member space agencies-CNES, ESA, the Canadian Space Agency (CSA), the US Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the Indian Space Research Organisation (ISRO), Argentinian Comision Nacional de Actvidades Espaciales (CONAE), the Japanese Aerospace Exploration Agency (JAXA), the Disaster Monitoring Constellation (DMC) via the United Kingdom Space Center (UKSC) and the China National Space Administration (CNSA). Moreover, Roscosmos (Russia), Kari (Korea), INPE (Brazil) and DLR (Germany) join the Charter in 2010 as full members.

The Charter is an international agreement between space agencies (not between States), making their resources available on a best effort basis to emergency operations at the request of a world wide Authorized Users base. The Charter is a simple but global data exchange mechanism relying on existing satellites resources with two fold missions: i) to task satellites in emergency situation (the Charter deals only with emergency and does not concern the prevention/rehabilitation phases), ii) to supply emergency organizations, essentially the national civil protection agencies, with a timely, free and co-ordinated access to satellites data in case of major natural or man made disaster. Each member agency commits satellite and operational resources to support the activities of the Charter and thus is helping to mitigate the effects of disasters on human life and property. The Charter, fully operational since November 2000, is a successful case of international cooperation. It has been activated more than 265 times in 90 countries over all continents for a variety of disasters. The Charter has achieved a number of objectives as a globally integrated space based EO system (Ito, 2005).

3.2.5 Disaster Monitoring Constellation (DMC)

The Disaster Monitoring Constellation (DMC) was designed as a proof of concept constellation, capable of multispectral imaging of any part of the world every day. It is unique in that each satellite is independently owned and controlled by a separate nation, but all satellites have been equally spaced around a sun-synchronous orbit to provide daily imaging capability. The countries involved in DMC include: Algeria, China, Nigeria, Turkey, UK, Spain. The DMC has both multi-spectral sensors with 22-32 m resolution and panchromatic sensors with 4 m resolution.

Although its main function is to provide independent daily imaging capability to the partner nations, all DMC members agree to provide 5% of capacity free for daily imaging of disaster areas, and this data is channelled to aid agencies. The DMC Consortium has agreed to consider participation in the International Charter for Space and Major Disasters, contributing daily imaging capability to fill the existing 3-5 day response gap.

3.2.6 GMES- SAFER

The European initiative GMES (Global Monitoring for Environment and Security) proposes to provide information useful in a range of issues including climate change and citizen's security, land, risks, ocean and atmosphere.

In the frame of the GMES initiative, SAFER (Services and Applications For Emergency Response) project aims at preparing the operational implementation of the Emergency Response Service (ERS). SAFER provides civil protection authorities and humanitarian relief organizations with a rapid mapping capacity when natural disasters occur and in the context of complex crises. Future products will also address early warning and reconstruction.

SAFER will reinforce the European capacity to respond to emergency situations: fires, floods, earthquakes, volcanic eruptions, landslides, humanitarian crisis. The main goal is the upgrade of the ERS service and the validation of its performance.

3.2.7 United Nations Geographical Information Working Group (UNGIWG)

It is a network of professionals working in the fields of cartography and geographic information science to building the United Nations Spatial Data Infrastructure needed to achieve sustainable development and emergency responses. UNGIWG was formed in 2000 to address common geospatial issues – maps, boundaries, data exchange, standards – that affect the work of United Nations Organizations and Member States. UNGIWG also works directly with nongovernmental organizations, research institutions and industry to develop and maintain common geographic databases and geospatial technologies to enhance normative and operational capabilities. Specifically UNGIWG aims to improve the efficient use of geographic information for better decision-making; to promote standards and norms for maps and other geospatial information; to develop core maps to avoid duplication; to build mechanisms for sharing, maintaining and assuring the quality of geographic information; and provide a forum for discussing common issues and emerging technological changes.

3.2.8 ESCAP/WMO Typhoon Committee and WMO/ESCAP Panel on Tropical Cyclone

The Typhoon Committee is an ESCAP-affiliated regional cooperation mechanism jointly working with the Tropical Cyclone Programme of the World Meteorological Organization. It develops activities under three substantive components: meteorology, hydrology, and disaster prevention and preparedness, and supports training and research relevant to these areas. The success of the Typhoon Committee, which focused on the West Pacific Ocean region, then led to the establishment and operation of another regional cooperation mechanism of the WMO/ESCAP Panel on Tropical Cyclones for the area of the Bay of Bengal and Arabian Sea. The experience of the Typhoon Committee and the Panel on Tropical

Cyclone highlights the fact that a framework at regional/sub-regional level brings in opportunities for greater integration of stakeholders in the overall process of disaster reduction and leads to further institutional networking.

3.2.9 IGMASS (International Global Monitoring Aerospace System): Proposed

The International Global Monitoring Aerospace System (IGMASS) is a study proposal to create a system to provide well-timed warning to the international community about coming disasters and emergencies, natural and man-caused disasters through a global and operational forecasting with the use of scientific and technical potential of earth-based, air and space monitoring all over the world and the further development and gradual integration of navigation, telecommunication and information resources of the planet to solve the humanitarian problems of Humanity. IGMASS is proposed to be a large organizational and technical system and it is intended to integrate in its structure, along with specially created, its own specialized space segment together with appropriate ground infrastructure of management and maintenance of spacecraft, receiving, processing and expansion of monitoring information.

4. Future Perspectives for International Cooperation

An analysis of various space-based disaster management techniques and the status of different international networks showed that, the current capability is mostly at the level of post-disaster monitoring and damage assessment. Early warning is still a research issue. Even most of the international networks are limited to providing near real-time EO data for post-disaster activities. Though, it has been an important dimension, it does not suffice the complete space based disaster management requirement.

Apart from this, the space technology development and applications are at different levels in different countries. Especially in developing and under-developed nations, where impact of disaster is very high, the space capability is either nil or very limited making them more susceptible. All these necessitate strong international cooperation. In order to achieve the goals of disaster risk reduction and management, it is essential to explore and establish information sharing and product service modes and mechanisms among different countries, thereby to strengthen the exchanges and cooperation on relevant experience and to narrow the gap between developed and developing countries.

Hence the major recommendations of this study group are as follows:

4.1 Strengthening existing constellation of satellites

It has been observed that disaster monitoring requires constellation of satellites with different sensor capabilities. No single satellite can cope with all these needs. Although, efforts have been made through several global and regional programs to make available data from satellites of different countries for disaster monitoring purposes, the existing constellations are not adequate. Rather, what disaster managers need is a constellation of satellites carrying a range of sensors. Crucially, different situations need data collected in different wavebands. For example, optical and near infrared data can map land use or assess droughts. But to track a cyclone's eye, or monitor flooded areas beneath cloud, microwave sensors are needed. Similarly spatial resolution requirement for different disasters will vary widely. No single country can afford to develop such complete satellite system. Hence, international cooperation is needed to develop complementary space based systems covering all aspects of data requirement for disasters.

International effort is required not only to strengthen existing constellation of EO satellites (optical and radar sensors) but also to guarantee a continuous operational availability of this virtual constellation, and also to develop a global mechanism with a twofold mission: tasking satellites in emergency response situation and providing rush access to EO data to organizations dealing with major disaster management. It is very important to not only acquire 'good' data but also to be able to disseminate as quickly as possible usable data to the end users.

Any proposed constellation should fulfill the following requirements:

i) The satellites should be sun-synchronous for identical solar imaging conditions.

ii) Retrograde polar orbits with inclination ~ 98° to satisfy global coverage and sun-synchronicity.

iii) Altitude of ~ 1000 km for avoiding effect of atmospheric drag which would shorten life of satellite and avoiding the Van Allen radiation belt.

iv) Spatial resolution of 20-30 m and swath of ~ 600 km to achieve acceptable pixel distortion at edge of swath.

v) Temporal resolution of ~ 3 hrs, which is perhaps the most important driver for disaster monitoring constellation.

vi) Multi-spectral sensors operating in green, red, NIR, SWIR and thermal regions of electro-magnetic spectrum.

vii) Microwave sensors should be a part of the proposed constellation to ensure all weather imaging capability. A possible specification for a microwave SAR sensor is to have a swath of ~ 500 km with HH polarization and 50 medium resolution. The range of incidence angles could be ~ 20-30º with C band (5.3 Ghz, 5.7 cm).

A possible satellite constellation of 20 EO satellites providing temporal resolution of 3 hrs for global coverage has been worked out (details in Supplement).

4.2 Strengthening existing mechanism of international co-operation

Disaster does not recognize political/administrative boundaries. Its short and long-term impacts can affect many countries. Existing mechanism of International co-operation needs to be strengthened. While some of the programs are well represented by several countries or space agencies and have long term well defined programs such as GEOSS, others require more representation as well clearly defined and focused programs for the future. In this connection, the role of international bodies such as UN-SPIDER and GEOSS/GEO is significant. Every country is encouraged to participate in such internationally recognized programs. There should be commitment from each country, to provide all possible support, in form of data sharing, capacity building, etc. to the affected nations. Efforts should be made to strengthen the UN-SPIDER, GEOSS and ISPRS Disaster Management Program for more global coverage.

4.3 Collaborative efforts for developing early warning models

So far most of the International programs for disaster monitoring restrict to data sharing during disasters, however efforts towards early warning mechanisms are not well established. hough, there is reasonable amount of progress in forecasting of hydro-meteorological disasters (e.g. drought, flood, etc.), the research efforts are very limited in case of geological disasters, like earthquake, landslides, tsunami etc. An international team should carry out research and modeling activity for forecasting, which should be provided with all forms of data support from all space organizations. This should be supported by the local governments for building technical infrastructure towards intensive field data collections. The early warning programs of GEOSS, UN-SPIDER, IGMASS and other regional/international initiatives should be supported and strengthened.

4.4 Strengthen communications network

Only generating earth observation data for disaster affected area is not enough. The information has to be communicated to the stakeholders. Hence, there is also need to strengthen communication networks by including low earth orbit communication satellites/Data Relay Satellite System (DRSS) and make available adequate band widths so that availability of data becomes easier. Many ground based communication networks (e.g. telephone connections) break during a disaster. Hence providing emergency communication is of utmost importance. Attempts should be made to augment amateur radio (Ham Radio) service, which are highly useful during post-disaster activity.

4.5 Creating a policy for data sharing

Real-time data sharing is a major issue for disaster management. Generally, disaster management data of high spatial resolution, i.e. better than 10 m are not usually available because of their high costs, formats and other issues. There should be international policies to make this high resolution data available to the disaster affected country. All EO data should be available in standard format, along a common framework for data sharing with properly defined meta-data and processed to useful derived products with different thematic layers in the same format. The efforts of CEOSS towards data standardization should be strengthened. Sharing of value added data products at nominal cost should be through a mechanism of coordination among existing international programs/initiatives on space and disasters.

It may be noted that presently, all the acquired data, including VHR (Very High Resolution) data are available to all the actors in the frame of the International Charter on Space and Major Disasters. However, the users are waiting for products (maps) rather than raw data, which are totally unusable for them.

4.6 Improving efforts for capacity building

One of the major tasks could be towards capacity building. There are many stakeholders with different levels of knowledge capacity. In order to bring them to single platform for disaster management, there should be consistent efforts towards capacity building at all levels. This can be achieved through regular workshops/trainings at all levels (i.e. for scientists, managers, planners, grass-root workers, media and general public). IAA can play a great role by preparing brochures and bulletins in easy and multiple languages, to explain the scope of EO data for disasters management. Websites need to be developed to provide information on disaster management. IAA may facilitate preparation of a directory of relevant web sites on all phases of disaster management, which includes GEOSS, UN-SPIDER, and International Charter Web Portals. There is need to develop new regional and global institutes of disaster management and to strengthen existing ones in order to effectively conduct regular courses/trainings especially for the representatives of less developed countries.

4.7 Strengthening regional/national level networking of stakeholders (Government and non-government)

Disaster management activity has large number of stake-holders, both government and non-government. Many times, the whole process gets affected as different authorities try shifting the responsibility from one to another. Also duplication of the activities cause loss of valuable time. Space agencies should be encouraged to avoid this. There is a need for regular interactions/ meetings/ and workshop between all partners. The framework of the activities needs to be defined and responsibilities of each stake-holder should be clearly outlined. This also necessitates regular mock exercises for disasters scenarios.

Supplement to 4.1

Design of Satellite Constellations for Disaster Monitoring

Introduction

Disasters are catastrophic, and in many cases, episodic events that can occur anywhere on the earth's surface at any time. Examples are floods, earthquakes, landslides, forest fires, hurricanes etc. Practically, only space-borne remote sensing sensors operating in different regions of the electro-magnetic spectrum provide global coverage and can effectively monitor the occurrence and location of disasters, both spatially and temporally. The satellite orbital characteristics (sun-synchronous and geostationary) as well as sensor spatial, spectral and temporal resolutions determine the extent and frequency of area coverage, of any given location on the earth's surface. It is becoming increasingly clear that existing satellite remote sensing systems are quite adequate for environmental monitoring but not for disaster detection and monitoring at any given location on the earth's surface (Igleseider *et al.,* 1995; Ward *et al.,* 1999). This is primarily because many satellite missions have high temporal resolution (~1 day) with coarse spatial resolution (~tens of kilometers). On the other hand, sensors with relatively finer spatial resolution (10m – 500m) have low temporal resolution (of the order of days). Disaster monitoring requires primarily high temporal resolution (~hours, days) and medium to high spatial resolution (30m – 500m). There is a growing consensus among the remote sensing community that small satellite constellations are the only viable alternative for global coverage with high temporal and spatial resolution, for disaster monitoring at a global scale.

Background

A simple argument (Lo, 1999) shows that a minimum of three satellites are required for instantaneous global coverage. The area of the instantaneous nadir coverage circle A(h) of a satellite sensor (also called the footprint) is given by

$$A(h) = 2*pi*R^2 *h/(R+h) \qquad (1)$$

Where h is satellite altitude and R is radius of the earth (6378.14 km). Since h/(R+h) is always < 1, A(h) is always smaller than the earth's hemispherical area, 2*pi*R2. A lower bound on the number of satellites required to provide instantaneous global coverage is obtained by dividing the total surface area of the earth (assumed to be a perfect sphere) by A(h), that is

$$N = 4*pi* R2/A(h) = 2 + 2*R/h \qquad (2)$$

Since h > 0 and finite, equation (2) shows that the required number of satellites is > 2, hence a minimum of three satellites are required for instantaneous global coverage. The per-cent coverage of the earth by satellites at different altitudes, calculated using equation 1, is given in Fig. 1.

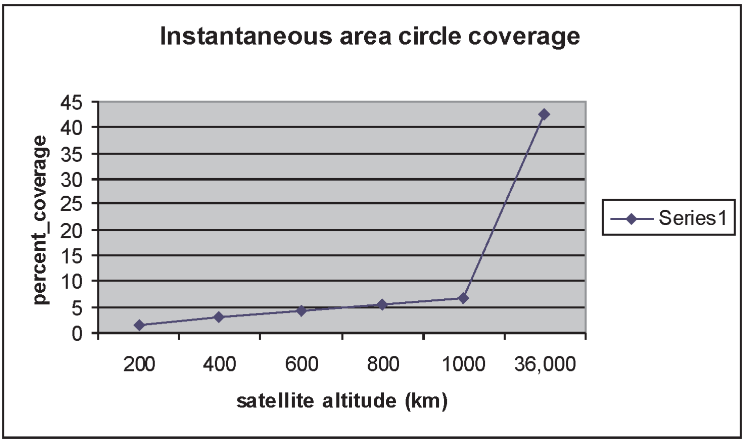


Figure 1: Percent coverage of the earth by satellites at different altitudes

From Fig. 1, it is seen that for typical low earth satellite altitudes (200 – 1000 km), the instantaneous coverage of the earth is about 4 – 6%, compared to about 42% for satellites at geosynchronous altitudes (~ 36, 000 km). This implies that, in principle, complete global coverage can be ensured with three geostationary satellites in the equatorial plane. This was pointed out as early as 1945 by the eminent science writer Arthur C. Clarke. For example, instantaneous global coverage is possible with the three satellites placed at intervals of 0, 90 and 180 degrees along the equatorial plane. In practice, due to the wide area coverage of geostationary satellites (± 81 deg latitude), there are distortions at edges of swath. For low earth orbits (LEO), the rotation of the earth beneath the satellite leads to global coverage with strips of appropriate swath. So, there is a need of satellite constellations to achieve continuous global coverage of the earth.

Satellites revolve round the earth in an orbital plane in either circular or elliptic orbits. A satellite in orbit in three-dimensional space has six associated elements, viz., three components of position and three components of velocity, in a suitably defined earth-centred co-ordinate frame. Equivalently, the orbit is characterized by six classical Keplerian orbital elements, viz., inclination angle (i), right ascension of ascending node (RAAN) (Ω), argument of perigee (ω), eccentricity (e), semi-major axis (a) and true anomaly (θ). These six elements uniquely define the satellite orbital plane. In absence of perturbations, the orbital plane is fixed with respect to the earth. In reality, a satellite revolving around the earth in an orbital plane is subject three major perturbations, atmospheric drag, sun-moon gravitational force and the earth's equatorial bulge or the earth's oblateness. If satellite altitude h is high enough (~ 600 – 1000 km), atmospheric drag is minimized and sun-moon gravitational force is not important if h < ~ 36, 000 km, which is a typical altitude for geosynchronous orbits. The perturbation effects of the equatorial bulge can be modeled through a spherical harmonics term, more precisely, the J_2 term (the second spherical harmonic) – a consequent first effect is the precession of the satellite orbital plane and the second effect is a shortening of the orbital period. These and other basic concepts related to satellite orbits are discussed in detail in Lo (1999) and Nelson (1995).

The next question is, what are the types of orbits, number of orbits and optimum number of satellites in an orbit to ensure global coverage. Firstly, circular satellite orbits are preferred over elliptical orbits since they are symmetric and comparatively easy to analyze their orbital motion. In circular orbits, satellites move with uniform speed, though their corresponding ground trace on the earth is not uniform. While all points on Earth's surface rotate at the same angular velocity around the North Pole, the actual velocity (v) of any point on the surface is given by $v = r^*\omega$, where r is the radius of latitude circle and ω is angular velocity. It follows that points at different latitude circles have different velocities, due to the variable radii of different latitudes. For disaster monitoring, or for that matter general environmental monitoring, it would be desirable to have sun-synchronous orbits, in which the satellite images the earth at approximately the same time of day at the same latitude, thus ensuring identical illumination conditions at a given location. This can be done by setting the orbital precession rate equal to the rate at which the earth revolves around the sun (~ 1° per day). This can be arranged with polar satellite orbits with an inclination of ~ 98 – 99°, orbiting the earth. For circular orbits, the time period (T) to complete a revolution is given by (Joseph, 2003).

$$T = 10^{-2}(R + h)^{3/2} \qquad (3)$$

R and h are expressed in km and T is in seconds.

To avoid atmospheric drag, LEO are generally placed at an altitude of 500 – 1000 km above the earth. The resulting time period is ~ 94 – 104 minutes and the satellite orbits the earth 15 times per day. During this time period of a single orbit, a point on the equator moves about 2800 km, so the 15 orbits do not cover the earth completely. If the sensor swath is ~ 2800 km, it follows that a single satellite can provide daily global coverage. However, such a wide swath has extreme distortion at swath edge and hence is not suitable for global surface monitoring.

Having narrowed down the choice of a satellite constellation to circular orbits (so eccentricity is zero) and polar sun-synchronous low earth orbits (thus ensuring high spatial resolution and constant illumination conditions), the question can be rephrased - what is the optimum number of polar satellites required for global disaster monitoring, with a temporal resolutions of the order of hours with ~ 10 – 30 m spatial resolution? This question leads to the study of satellite constellations, where a constellation is defined by the number of orbital planes p and number of satellites per plane, s. The optimization problem is to choose p and s to minimize the total number of satellites N, for global coverage. The Walker constellation (Walker 1970) is defined by three parameters, viz., T/P/F, where T is total number of satellites, P is number of orbital planes and F is the phasing parameter denoting the relative spacing between satellites in adjacent planes. The total number of satellites is equally divided among P planes with same inclination and the planes are equally spaced at 360/P degrees. Satellite constellations have been routinely employed for global communication (Brunt, 1996, GLOBALSTAR, 2007).

Igleseider (1995) studied the problem of small satellite constellation for disaster monitoring and generated various scenarios linking satellite elevation as function of revisit time or temporal resolution. It was concluded that a minimum of 32 satellites are necessary to cover the globe with a revisit time of 30 minutes. Ward et al made a detailed study of the use of small satellites for disaster monitoring and concluded that 7 satellites in a single orbit are required for daily global coverage.

Proposed satellite constellation

A possible satellite constellation for continuous global coverage can be designed based on foregoing considerations. The requirements are as follows:

I) The satellites should be sun-synchronous for identical solar imaging conditions.

II) Retrograde polar orbits with inclination ~ 98° to satisfy global coverage and sun-synchronicity.

III) Altitude of ~ 1000 km for avoiding effect of atmospheric drag which would shorten life of satellite and avoiding the Van Allen radiation belt.

IV) Spatial resolution of 20-30 m and swath of ~ 600 km to achieve acceptable pixel distortion at edge of swath.

V) Temporal resolution of ~ 3 hrs, which is the most important driver for disaster monitoring constellation.

VI) Multi-spectral sensors operating in green, red, NIR, SWIR and thermal regions of electro-magnetic spectrum.

VII) Microwave sensors should be a part of the proposed constellation to ensure all weather imaging capability. A possible specification for a microwave SAR sensor is to have a swath of ~ 500 km with HH polarization and 50 medium resolution. The range of incidence angles could be ~ 20-30° with C band (5.3 Ghz, 5.7 cm).

The width of the swath of a satellite (w) is given by

$$w = 2r_e\beta \qquad (4)$$

Where, r_e is radius of earth and β is earth central angle given by

$$\beta = \cos^{-1}\left(\frac{r_e}{r_{sat}}\cos\theta\right) - \theta \qquad (5)$$

with rsat = satellite height from centre of the earth and θ is satellite elevation angle given by

$$\theta = \cos^{-1}\left(\frac{r_{sat}}{r_e}\ \sin\alpha\right) \tag{6}$$

where α is the satellite nadir angle (i.e, half FOV). From the above equations, it can be computed that for α = 20°, rsat = 1000 km and θ = 67°, swath = ~ 594 km. From eqn (3), the orbital period for the satellite is 103 minutes and it completes 14 orbits per day. The total area covered by it in a day is ~ 8316 kms, with gaps due to rotation of the earth. Since the earth's circumference is 40073 km, the minimum number of satellites with identical swath required to for daily full coverage of the earth is 5. This ensures full coverage at the equator and greater overlapping coverage at higher latitudes, since the satellite orbit converges at the poles. It follows that if the number of satellites is doubled, i.e., 10 satellites in the same orbital plane, global coverage is possible two times a day. The argument can be extended to show that a minimum of 20 satellites are required for global coverage of the earth for a temporal resolution of 3 hrs. A Walker constellation with these specifications can be characterized as follows: T = total number of satellites = 20, P = number of satellites per plane = 5 and F is the inter-plane phase. The ascending nodes of the satellites are uniformly distributed along the orbit at intervals of 72° (360/5). The phase difference between the planes is given by F*2*pi/T, F=0, 1, 2, 3 which in the present case corresponds to 0, 18, 34 and 54 degrees respectively for planes 0,1,2 and 3 (Bruccoleri 2007). Table 1 summarises requirements of number of satellites vis-à-vis temporal resolution.

Table 1: A possible satellite constellation for global coverage

Number of orbital planes	No of satellites /plane	Total no satellites	Global coverage	Phase difference between corresponding satellites in different planes (deg)	Spacing of ascending node of planes (deg)
1	5	5	daily	–	–
2	5	10	12 hrs	0,72	180
3	5	15	6 hrs	0,48,96	120,240
4	5	20	3 hrs	0,18,34,54	120,240,360

Note

- Global coverage means a point on the earth's surface can be seen by at least one satellite at any given time and place.
- Satellite sensor height above earth surface assumed to be 900 km, with inclination angle ~ 98 deg sun-synchronous orbits and swath of 600 km. Satellite elevation angle and satellite nadir angle are computed to be ~ 55 deg and ± 30 deg respectively with an equatorial crossing time of ~ 1030 am.
- Spatial resolution of 60 – 70 m is possible from this height.
- It is proposed to have two SAR and three optical payloads (with green, red, NIR, SWIR sensors) out of the five satellites in a plane. One possible SAR configuration could be a ScanSar mode with ~ 600 km swath, ~ 50 m spatial resolution, operating in C band, HH polarization with 20 – 30 deg incidence angle. This ‘2 SAR – 3 optical satellite’ constellations in one plane can lead to 60% global coverage by optical payloads and 40% global coverage on a daily basis. By extension, repetition of this pattern in 4 planes can ensure the same coverage at a revisit period of ~ 3hrs. This can address the problem of non-availability of optical data due to cloud cover to a large extent.

International Academy of Astronautics

Space-Based Disaster Management: The Need for International Cooperation

Appendix 1

Contributors

Chair	:	Ranganath Navalgund, INDIA
Co-Chair	:	Valery Menshikov, RUSSIA
Rapporteur	:	Akinyede Joseph, NIGERIA
Members	:	Ciro Arevalo Yepes, AUSTRIA
		V. G. Degtyar, RUSSIA
		V. S. Hegde, INDIA
		Masanori Homma, JAPAN
		Andre Husson, FRANCE
		Igor Kabashkin, LATVIA
		Sergey Lysyy, RUSSIA
		Mikhail Novikov, RUSSIA
		Sergey Pushkarsky, RUSSIA
		Lydia Rykhova, RUSSIA
		Jeannie Seelbach, USA
		Amoldo Valenzuela, GERMANY
Additional Contributors	:	Ajay Rajawat, INDIA
		Shibendu Ray, INDIA
		V. N. Sridhar, INDIA

International Academy of Astronautics

Space-Based Disaster Management: The Need for International Cooperation

Appendix 2

References and Additional Readings

1. AIAA (2004). *Protecting Earth from Asteroids and Comets. An AIAA Position Paper, American Institute of Aeronautics and Astronautics.*
2. ASE (2008). *Asteroid Threats: A Call for Global Response. Association of Space Explorers International Panel on Asteroid Threat Mitigation*. Jessica Tok (Editor), September, 2008. Report submitted for consideration and subsequent action by the United Nations. 54p.
3. Ajai, Kimothi, M. M., Dutt, C. B. S. and Ranganath, B. K. (2003a). Forest Fire Management. NNRMS Bulletin 28, pp. 95-107.
4. Ajai, Arya, A. S. and Dhinwa, P. S. (2003b). Desertification: the creeping disaster. NNRMS Bulletin 28, pp 52-64.
5. Anonymous (2005). National Database for Emergency Management (NDEM). Technical Document. NRSA/RS&GIS-AA/NDEM/R00/Sept05. NRSA, Hyderabad
6. Below, R., Wirtz, A. and Guha, D. (2009). Disaster Category Classification and Peril Terminology for Operational Purposes, Common accord Centre for Research on the Epidemiology of Disasters (CRED) and Munich Reinsurance Company (Munich RE), Working Paper, 264. CRED/Munich RE.
7. Bertrand, C., Clerbaux, N, Ipe, A. and Gonzalez, L. (2003). Estimation of the 2002 Mount Etna eruption cloud radiative forcing from Meteosat-7 data. Rem. Sens. Environ. 87: 257-272

8. Brennan, E. M. (2005). Remote Sensing Techniques Applied to Landslide Studies. http://geosun.sjsu.edu/paula/285/285/eb_sem.htm. (Accessed 17 December, 2005).

9. Bruccoleri (2007). Flower Optimisation and Implementation, Ph.D thesis, Texas A & M University.

10. Brunt, P. (1996). IRIDIUM – Overview and Status, Space Communications, 14, pp 61-68.

11. CEOS (2003). The Use of Earth Observing Satellites for Hazard Support: Assessments and Scenarios. Final Report of the CEOS Disaster Management Support Group (DMSG), November.

12. Cervone, G., Kafatos, M., Napoletani, D. and Singh, R. P. (2005). An early warning system for coastal earthquakes Adv.Space Res. (in press)

13. Chakraborti, A. K., Bhanumurthy, V. and Chandra Sekhar, G. (2003). Remote sensing towards filling the gaps in flood monitoring, impact assessment and forecast modelling. NNRMS Bulletin 28, pp. 44-51.

14. Chen, D. Huang, J. and Jackson, T. J. (2005). Vegetation water content estimation for corn and soybeans using spectral indices derived from MODIS near- and short-wave infrared bands Rem. Sens. Environ. 98, (2-3): 225-236.

15. Chiroiu, L., André, G., and Bahoken, F. (2001). Earthquake loss estimation using high resolution satellite imagery., http://www.gisdevelopment.net/application/Natural_hazards/earthquakes/nheq0005.htm.

16. da Silva Curiel, A., Wicks, A., Meerman, M., Boland, L. and. Sweeting, M. (2002). Second Generation Disaster- Monitoring Micro-satellite Platform. Acta Astronautica. 51(1-9): 191-197.

17. Degtyar, V. G., Volkov, V. A. and Kalashnikov, S. T. (2010). Development of principles for adaptation of space and rocket

complexes to be used for mitigation of asteroids and comets threat.

18. EM-DAT (2005). The OFDA/CRED International Disaster Database. http: //www.em-dat.net (Accessed 16-December-2005)

19. Francis, P. W. (1989). Remote sensing of volcanoes. Advances in Space Research. 9(1):89-92.

20. Fraser, R. H., Z. Li, and R. Landry. (2000). SPOT VEGETATION for characterizing boreal forest fires Int. J. Rem.Sens., 21(18): 3525-3532.

21. GLOBALSTAR Inc. (2007). www.globalstarusa.com/en/content.php.

22. Hall, D. B. (2005). 66 of the world's worst disasters. http://across.co.nz/. Available on 15 December, 2005.

23. IAA (2010). Concept of the International Global Monitoring Aerospace System (IGMASS). Draft, 2010, http://iaaweb.org/iaa/Scientific%20Activity /Study%20Groups/SG%20Commission%204/sg49/sg49draft.pdf

24. IAA (2009), Dealing with the Threat to Earth from Asteroids and Comets, Ivan Bekey (Editor), Published by the International Academy of Astronautics.

25. Igleseder, H., Arens-Fischer, W., Wolfsberger, W. (1995). Small satellite constellations for disaster detection and monitoring, Advances in Space Research, 15, No. 11, pp 79-85.

26. Indian Institute of Remote Sensing (2000). Perspectives, 31-76.

27. Ito, A. (2005). Issues in the implementation of the International Charter on Space and Major Disasters. Space Policy, 21: 141-149.

28. Jeyaseelan, A. T. and Venkaratnam, L. (2003). Remote sensing towards agriculture drough monitoring – Retrospective and prospective. NNRMS Bulletin 28, pp. 30-43.

29. Joseph, George (2003). Fundamentals of Remote Sensing, Universities Press of India Limited.

30. Kimothi M. M.and Jadhav R. N. (1998). Forest fire in the Central Himalaya: an extent, direction and spread using IRS LISS-I data. Int. J. Rem. Sen., 19(12): 2261-2274.

31. Kishtawal, C. M. *et al.* (2005). Gephys. Res. Let. 32:11804.

32. Koutsias, N. and M. Karteris. (2000). Burned area mapping using logistic regression modeling of a single post-fire Landsat-5 Thematic Mapper image. Int. J. Rem. Sens. 21(4):673-687.

33. Li, Z., S. Nadon and J. Cihlar. (2000a) Satellite-based detection of Canadian boreal forest fires: development and application of the algorithm. Int. J. Rem. Sens., 21(16):3057-3069.

34. Li, Z., S. Nadon, J. Cihlar and B. Stocks. (2000b). Satellite-based mapping of Canadian boreal forest fires: evaluation and comparison of algorithms. Int. J. Rem. Sens., 21(16):3071-3082.

35. Lo, M. W. (1999), Satellite Constellation Design, Computation in Communication.

36. Majumdar, T. J., and Massonnet, D. (2002). D-InSAR applications for monitoring of geologic hazards with special reference to Latur earthquake, 1993, Current Science, Vol. 83, No. 4, 502-508.

37. Mansourian, A., Rajabifard, A., and Valadan Zoej, M. J. (2004). "SDI and Network-Based GIS for Disaster Management", Proceedings of 12th International Conference on Geoinformatics (GeoInformatics 2004), 7-9 June 2004, University of Gavle, Sweden.

38. Mansourian, A., Rajabifard, A., Valadan Zoej, M. J., and Williamson, I. (2005). Using SDI and web-based system to facilitate disaster management. Computers & Geosci. (In press).

39. Menshikov Valery A., Perminov Anatoliy N., Urlichich Yuriy M. (2010). Global Aerospace Monitoring and Disaster Management – Springer, 570 p.

40. Metternicht, G., Hurni, L., Gogu, R. (2005). Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments. Rem. Sens. Environ., 98:284-303.

41. Nayak, S. and Pathan, S. K. (2005). Annual Report of ISPRS TC IV. www.commission4.isprs.org.

42. Nelson, R. A. (1995), Satellite Constellation Geometry, Via Satellite.

43. NRC (National Research Council), (2003). Living on an active earth: perspectives on earthquake science. Committee on the Science of Earthquakes. National Academies Press, Washington, D.C. 432 pp.

44. Ouzounov, D. and F. Freund (2004). Mid-infrared emission prior to strong earthquakes analyzed by remote sensing data Advances in Space Research 33:268-273.

45. Perminov Anatoliy N., Menshikov Valery A. (2009). Space and Security of Humanity – Moscow: Space Systems Research Institute named after A. A. Maksimov, 12 p.

46. Prabaharan D. J. and Kanniah, K. D. (2000). Volcano Hazard Management Using Digital Elevation Model. Presented in Asian Conference in Remote Sensing, 2000.

47. Rajabifard, A., Mansourian, A., Valadan Zoej, M. J. and Williamson I. P. (2004). "Developing Spatial Data Infrastructure to Facilitate Disaster Management", Proceedings of Geomatics 83, National Cartographic Center (NCC), Tehran, Iran.

48. Rodriguez, J., Vos, F., Below, R. and Guha-Sapir, D., (2009). Annual Disaster Statistical Review 2008, The numbers and trends, CRED, Belgium, 25 p.

49. Sajanani, M. P. (2005). Disaster Managemnt Initiatives-Institutional, Legal and Coordinated Mechanism. In the Souvenir of National Symposium of Agrophysical Approaches in Disaster Mitigation, Resource Management and Environmental Protection. November 17-19, 2005, IARI, New Delhi, pp. 11-24.

50. Sinha, Anil (2002). Hazard and Vulnerability – an overview. Presented in Disaster Preparedness & Mitigation Workshop in Northeast Region, December 6-7, 2002.

51. Suju, L. I., Kang, Byung-Sam and Guoxiang, W. U. (2003). Collaborative development of a regional disaster management support platform on space-based information sharing and analysis, ESCAP Technical Paper, IDD/TP-09-03 (Version 1.0).

52. Tadesse, T., Hayes, M. J. and Brown, J. F. (2005). A new approach for predicting drought related vegetation stress: integrating satellite, climate and biophysical data over the US central plains. ISPRS J. Photogram. Rem. Sens., 59:244-253.

53. Tralli, D. M., Ronald, T., Blom, G., Zlotnicki, V., Donnellan, A., Evans, D. L. (2005). Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards. ISPRS J. Photogram. Rem. Sens., 59:185-198.

54. Ugnar, S. (1999). Is strange weather in the air? A study of U.S. national network news coverage of extreme weather events, Climate Change, 41,2,133-150.

55. Unganai, L. S. and Kogan, F. N. (1998). Southern Africa's recent droughts from space Advances in Space Research. 21(3): 507-511.

56. Walker, J. G. (1970). Circular Orbit Patterns Providing Whole Earth Coverage, Technical Report 70211, Royal Aircraft Establishment.

57. Ward, J., Jason, S., and Sweeting, M. Microsatellite (1999). Constellation for Disaster Monitoring. SSC – 99_V2, j.w.ward@ee.surrey.uc.uk.

58. Westen, C. J. van and Soeters, R. (2000). Remote sensing and geographic information systems for natural disaster management. In: Natural Disasters and their Mitigation, Remote Sensing and Geographic Information System.

International Academy of Astronautics

Space-Based Disaster Management: The Need for International Cooperation

Appendix 3

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 have been recognized and celebrated throughout the second half of the year with a series of symposia around the globe, and culminate with a Space Agencies Summit on November 17, 2010 at the Ronald Reagan Building and International Trade in Washington DC.

After 50 years of existence the International Academy of Astronautics (IAA) is recognized by the major space agencies as a unique elite body that can help advancing international cooperation. It have been observed that much current cooperation programs are aging such as the ISS, initiated more than 20 years ago, with only 8 countries. The world is flattening as many newcomers are joining the club of emerging space countries, the major space countries face budgetary challenges and politicians and 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 global challenges to come can only be solved by international cooperation with all countries committed to work together. However space agencies have to balance new aspirations and eventual challenge solutions with constraints of existing programs/budgets and national interests/needs. The large number of new players brings the question on how to efficiently cooperate while partners number will nearly triple? 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 any 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 Space Flight and Planetary Robotic Exploration have been assembled last year and have published those studies and recommendations for deliberation by Agencies. This is a historic and unique event as not only 24 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.

International Academy of Astronautics

Space-Based Disaster Management: The Need for International Cooperation

Appendix 4

International Academy of Astronautics

November 2010

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. Current President, Dr. Madhavan Nair, India, Past President Prof. Edward C. Stone, USA, Vice-Presidents: Mr. Yannick d'Escatha, France, Prof. H. Matsuo, Japan, Dr. Stanislav Konyukhov, Ukraine, Prof. Liu Jiyuan, China, Secretary General Dr. JM 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.

Mailing Address: IAA, PO Box 1268-16, F-75766 Paris Cedex 16, France

Secretariat: 6 rue Galilée, 75116 Paris, France, IAA Study Center in Beijing, China; IAA Secretariat Branch in Bangalore, India, 35 Regional Secretaries in all continents (see http://iaaweb.org/content/view/139/238/)

Web Site: http://www.iaaweb.org

Phone: 33 1 47 23 82 15, Fax: 33 1 47 23 82 16

email: sgeneral@iaamail.org