→ SATELLITE EARTH OBSERVATIONS IN SUPPORT OF DISASTER RISK REDUCTION

Special 2015 WCDRR Edition

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UNISDR Foreword – Resilient People, Resilient Planet

Economic development and population growth have unleashed unprecedented change in the Earth's atmosphere. Earth observation (EO) satellites have propelled not only our ability to investigate this change and to monitor the consequences in real-time but also to make issues around weather and climate more visible and understandable for the general public.

In an age when human activities threaten the planet with potentially irreversible negative changes, it is important that we have access to satellite imagery to improve our ability to understand and reduce the impact of the rise in disaster and climate risks over the coming decades. These will be decisive years in gauging the long-term sustainability of our current development models.

An understanding of key indicators around climate change, such as sea-level rise, the retreat of glaciers, permafrost and Arctic sea ice, and desertification, is enhanced by satellite imagery and is important to ensuring that decision-makers and public opinion alike are well-informed on the evolving nature of risk as we enter a year of opportunity for the global development agenda. 2015 will see the world reaching agreement on a post-2015 framework for disaster risk reduction but also of course, on a universal development agenda for the coming decades and a Climate Agreement. EO will play a key role in monitoring progress on implementation of these initiatives.

The real-time monitoring from space of natural hazards such as cyclones, floods, drought and volcanoes provides us with reliable and actionable information that is end-user friendly for planners, technical experts, business, countries, farmers, air traffic, and others; in other words for all of society. Such information must be understandable and provide the foundation for important decisions that determine how cities are planned, how communications and transport function, how farmers plant and harvest, the productivity of fisheries, public health planning and decision-making, and many other critical areas of development planning.

This informative volume provides good examples that illustrate why cooperation and collaboration between relevant stakeholders including end users will feature prominently in the post-2015 framework for disaster risk reduction which will be adopted at the 3rd UN World Conference on Disaster Risk Reduction in Sendai, Japan in March 2015.

Margareta Wahlström

Special Representative of the Secretary-General for Disaster Risk Reduction

Head of the UN Office for Disaster Risk Reduction

CEOS Message to WCDRR

The Committee on Earth Observation Satellites (CEOS) represents the civil Earth-observing programmes of more than 30 of the world's leading space agencies. These agencies are collectively investing billions of dollars in space infrastructure with the capability to provide sophisticated, continuous, and sustained observations of the entire planet. The world is familiar with the application of these observations to the task of forecasting, tracking, and alerting society to extreme weather events like cyclones, and significant progress has been made by space agencies in facilitating access to a wide range of observations in response to a much wider range of disasters. However, the space agencies represented in CEOS have resolved that more could and should be done to realise the full potential of the application of satellite EO to disaster risk management, in particular by better supporting national and local decision-makers to implement disaster risk reduction and resilience measures, during all disaster risk management phases.

This report explores how satellite EO can contribute to the main challenges of disaster risk reduction, across a range of different countries and addressing varying capacity and infrastructure. It also highlights some of the main capabilities of satellite EO, their applications, and the challenges we face in converting information collected in space to knowledge of value to societal challenges, delivered in a timely way to users at all levels of government here on Earth.

The report has been compiled in support of the 3rd United Nations World Conference on Disaster Risk Reduction (Sendai, Japan, March 2015), to assist the debates around how to better address the endemic challenges of risk reduction to ensure that future generations face fewer disasters and are better equipped to handle them. In combination with other resources (such as in-situ observations, model outputs, and socio-economic data), satellite EO is an absolutely essential tool in the development of information, providing evidence and supporting the science which underpins strategies for decision-making, and for monitoring our progress on all geographical scales as we explore new development paths aimed at sustainable management of the planet, confronting disaster risk reduction, climate change, and sustainable development in a unified manner.

We hope that this CEOS Report might serve as a valuable reference source for a variety of readers from all sectors of society, including those engaged in the Post-2015 framework for disaster risk reduction process and in the definition and execution of the main sustainable development goals tied to risk reduction, as well as decision-makers in political and socio-economic sectors.

Shizuo Yamamoto

Vice President
Japan Aerospace Exploration Agency (JAXA)
CEOS Chair for 2015

Volker Liebig

Director of Earth Observation Programmes
European Space Agency (ESA)

Part I

Space Data Supporting Disaster Risk Reduction

1

The Importance of Disaster Risk Reduction

1.1 Introduction

The 3rd United Nations World Conference on Disaster Risk Reduction (WCDRR) gathers members of the Disaster Risk Management (DRM) community such as government officials, NGOs, intergovernmental organizations, governmental agencies, scientific institutions, and the private sector to discuss strategies for disaster risk reduction (DRR).

UNISDR defines DRR as reducing the damage caused by natural hazards like earthquakes, floods, droughts and cyclones, through an ethic of prevention.

According to an October 2014 Asian Disaster Reduction Center assessment, 361 natural disasters were reported worldwide in 2013, with 23,538 lives lost and close to 100 million people affected. Economic losses from natural disasters in 2013 have been estimated at approximately US$119 billion.

The 3rd WCDRR has been convened to review implementation of the Hyogo Framework for Action (HFA) and to adopt a post-2015 framework for disaster risk reduction.

HFA was adopted in 2005, and fostered a public awareness and understanding of the importance of DRR. Countries responded to HFA by strengthening their institutional, legislative and policy frameworks, and early warning systems, and increased their disaster preparedness activities through risk assessments, education, and research.

HFA has made progress in reducing losses, but it is recognised that disaster risk is on the increase worldwide and there is a renewed sense of urgency in defining a post-2015 framework for disaster risk reduction that will provide a powerful tool to support substantial reductions in loss of life and property and societal impact on communities and countries in the coming decade and beyond.

1.2 Risk on the Increase

Natural disasters are of increasing frequency and severity in the modern world. Impacts of disaster events on human lives and the economy are increasing every year due to growing urbanisation and an increase in the number and severity of extreme weather events. Worldwide economic losses due to disasters have surpassed US$100 billion every year since 2010.

Exposure is one of the major drivers of risk, and growing urbanisation is a key factor, causing more people to be exposed to risk. Over the past 30 years, the portion of the world's population living in flood-prone river basins has increased by 114% and that of those living in coastlines threatened by cyclones has increased by 192%. Today, over half of the world's cities of 2–15 million people are in areas of seismic risk.

The 2014 revision of the World Urbanization Prospects published by the United Nations Department of Economic and Social Affairs (UN DESA) estimates that population in urban areas will increase by approximately 2.5 billion by 2050, mostly in informal settlements in cities at risk from the increasing effects of climate change.

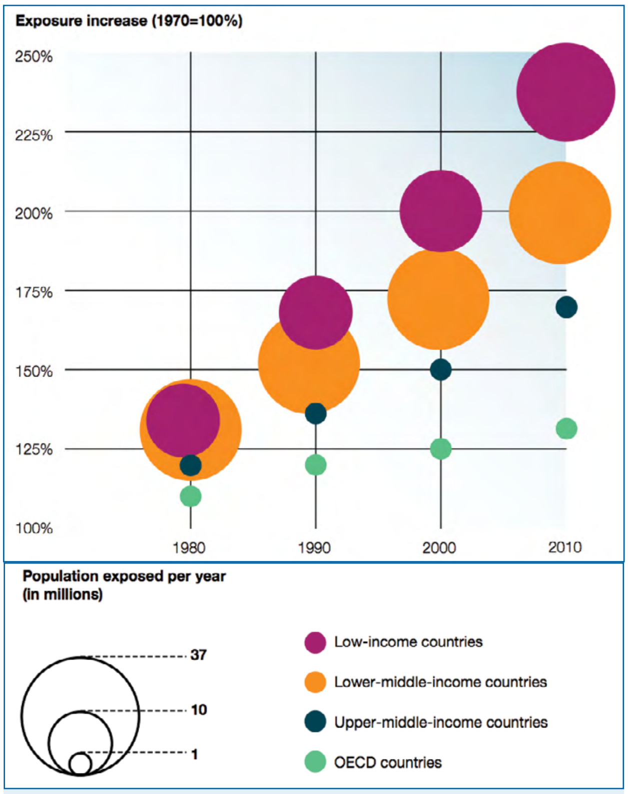


Image credit: MunichRe

These informal settlements are highly vulnerable, as they tend to be inadequately managed, planned, and suffer from environmental degradation and poverty, magnifying their susceptibility to damage and loss from natural disasters.

This was made clear by the difference in outcomes of the 2010 earthquakes in Chile (525 fatalities) and Haiti (estimates vary but possibly more than 100,000 fatalities). Urban areas with poor living conditions and infrastructure are most at risk and typically suffer high loss of life from natural disasters.

As with residential developments, there has been an increase in private and public, commercial, and industrial investments being concentrated in hazardous areas which, due to economic globalisation, also presents a risk to global supply chains, businesses, governments, and society. Damage to businesses severely effects the local population by removing public infrastructure/services and sources of employment/income. The increased exposure of people living and working in these at-risk areas is compounded by the increased hazard of extreme weather events. The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5) WG1 states that an increase in intense tropical cyclone activity is more likely than not in the Western North Pacific and North Atlantic, and that increased incidence and/or magnitude of extreme high sea level are very likely. The IPCC's AR5 WG2 has indicated that Europe is at risk of increased economic losses and people affected by flooding in river basins and coasts, driven by increasing urbanisation, increasing sea levels, coastal erosion, and peak river discharges; and Asia is at risk of increased riverine, coastal, and urban flooding leading to widespread damage to infrastructure, livelihoods, and settlements.

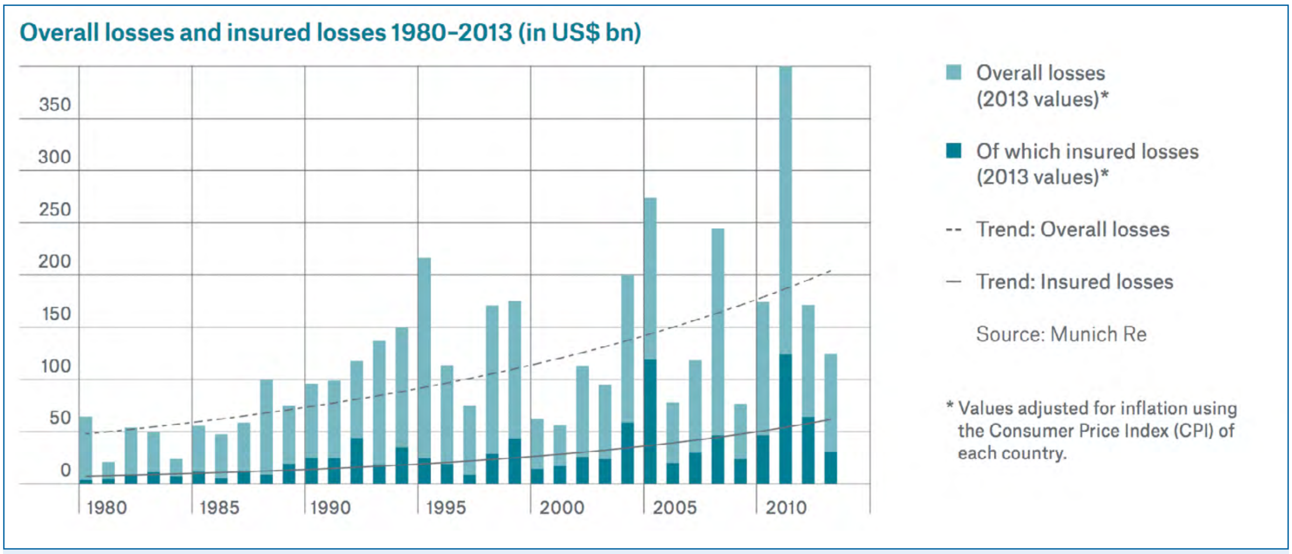
Climate change-induced sea level and temperature increases are also resulting in risks related to agriculture and food security, ecosystem degradation, and health. DRR, climate change, and sustainable development are intrinsically related and must be confronted in a unified manner.

Development patterns are increasing the exposure and vulnerability of people and property, and hazards are becoming more frequent due to climate change. The world's population has never been exposed to such a high level of disaster risk, and this is likely to grow in the coming years as the same trends continue.

1.3 Decision-making for Risk Management Requires Comprehensive Information

The post–2015 framework for disaster risk reduction will build on the successes of the existing Framework and set ambitious targets for DRR, targets against which progress can be measured in practical terms. The new framework is expected to incorporate focused actions across sectors by states at local, national, regional and global levels in the following priority areas:

- Understanding disaster risk;
- Strengthening governance and institutions to manage disaster risk;
- Investing in economic, social, cultural, and environmental resilience;
- Enhancing preparedness for effective response and building back better in recovery and reconstruction.



Overall losses and insured losses 1980–2013 (in US$ bn)

Source: Munich Re

* Values adjusted for inflation using the Consumer Price Index (CPI) of each country.

Image credit: MunichRe

The availability of information for decision-making, implementation, and monitoring is fundamental to the activities in these priority areas and the overall success of our efforts as a society to recognise, address, and reduce the increased disaster risks we are facing.

Decision/Policy-making

To respond effectively, decision- and policy-makers require up-to-date, accessible, reliable, scientific information that is complemented by knowledge from the community and other stakeholders.

The Framework will require all states and stakeholders to collect, analyse, and disseminate information and data that can help influence public policies and decision-making. Sustainable mechanisms for the generation of that information and its management are required to ensure ongoing availability of the source data.

Satellite EO can be a powerful tool to generate uniform information across a range of countries and covering a wide span of risk scenarios. It supports the generation of objective, coherent information about risk that is easy to update and difficult to challenge. This standard indicator can be linked to actual exposure to risk (by tracking populations and assets in hazardous areas), to measuring the impact of risk reduction initiatives (by measuring change of the previous indicator), or to many other indicators. Applied in a systematic way, satellite EO can help create consistent and comparable information to measure implementation of the post-2015 framework for disaster risk reduction, when measures can be concretely observed.

Implementation

The implementation of policies and activities related to DRR requires open access to science-based risk information and knowledge.

Early warning systems for natural disasters, such as extreme meteorological events, forest fires, drought, or tsunamis, all have unique data needs, must be tailored to the requirements of end users, and require large volumes of information for increased accuracy.

Responders to a disaster also require near real-time data in order to increase their situational awareness and effectiveness. An effective disaster response and recovery is enabled by accurate information on the scope, extent, and impact of the disaster event.

Monitoring

UNISDR is anticipated to provide support for the monitoring and review of the post–2015 framework for disaster risk reduction. Five global targets facilitate the assessment of global progress towards the desired outcomes:

1. Reduce disaster mortality;
2. Reduce the number of people affected by disasters;
3. Reduce economic loss from disasters;
4. Reduce damage to health and educational facilities caused by disasters; and,
5. Increase the number of countries with national and local strategies.

Assessment of these targets requires that a number of indicators be monitored. Transparent, globally consistent, and multi-scale information is a necessity for accurate assessments.

Satellite EO are a unique source of synoptic information at global, regional, and local levels; can operate in all-weather conditions, day and night; and can contribute to all disaster phases from preparedness to response and recovery. In the context of the post–2015 framework for disaster risk reduction, satellite EO can simplify consistent and comparable implementation and monitoring and can link hazards, risk, and climate. While obtaining the right spatial and temporal resolution for observations is a challenge on a global basis, systems capable of monitoring the evolution of risk are in place. Innovative partnerships between governments and the private sector may be required to deliver high-resolution global imagery to meet this challenge.

1.4 Contents

This report has been compiled in support of the 2015 WCDRR to introduce and promote the use of satellite EO in support of DRR. The report highlights some of the unique capabilities of satellite EO, though often combined with other data sources, and the related efforts of the specialist space agencies entrusted by governments to develop and operate the satellites.

Section 2 presents the role of satellite EO, highlighting some of their unique capabilities and potential contributions to DRR. This section also introduces the International Charter on Space and Major Disasters and Sentinel-Asia.

Section 3 elaborates on the purpose and disaster-related activities of CEOS.

Section 4 discusses some key future developments and challenges for space agencies and CEOS in relation to the uptake and application of EO for DRR and the challenges inherent in the post–2015 framework for disaster risk reduction.

Part II presents some case studies that demonstrate the utility of satellite EO for DRR and institutional efforts to more closely integrate satellite EO in DRR activities.

Part III highlights some space data capabilities for monitoring risk, disaster response, disaster recovery, and long-term climate monitoring.

Further information

World Conference on Disaster Risk Reduction (WCDRR):
www.wcdrr.org

UNISDR:
www.unisdr.org

EM-DAT International Disaster Database:
www.emdat.be/database

2

The Role for Satellite EO

2.1 The Big Picture

More than 40 nations are identified as having invested in EO satellites, amounting to government investment of approximately US$7-8 billion per annum, with further and increasing investment coming from the commercial sector and through public-private partnerships. Many of the biggest programmes are moving to free and open data policies, so that the data generated by this valuable infrastructure might be applied without restriction and across a whole range of societal benefit areas. The Copernicus programme of the European Commission (EC) and European Space Agency (ESA) will provide free and open access to a range of data types, both optical and radar, of direct value to DRR – amounting to thousands of images per day (equivalent to approx. 1250 DVDs of data per day). Similarly, the satellite EO programmes of the US government are operated on the basis of free and open access to data. Since the Landsat programme archive was opened in this way in 2008, some 20 million scenes have been downloaded by users all around the world.

These investments have been made with a view to numerous and diverse applications of the space-based infrastructure and the observing capabilities of the hundreds of satellites involved. Many of these satellites have substantial potential to contribute to DRM, including DRR. Indeed, for a few satellites, DRM is one of their primary functions; but for most it is a great potential that is yet to be fully realised.

As with satellite communications and satellite navigation systems, the use of a space-based infrastructure for the provision of EO in support of disasters provides several benefits:

- The infrastructure is not vulnerable to the disaster itself; surface-based infrastructure like in-situ sensors and communication systems are prone to damage and failure as a result of disasters, whereas satellites offer a robust source of near-real time and unique information to aid disaster management;
- Consistent and comparable information is collected systematically on multiple scales, from local to trans-boundary to global;
- Inaccessible and hazardous areas can be sensed without risk, including at all stages of disaster management.

Satellite observations can supply regular, detailed updates on the status of hazards on a global, regional, or national basis. EO satellite data are a complementary data source to in-situ data (as well as airborne data, socio-economic data, and model output) in many countries, but in some cases it may be the only source of information, either because of limited or lacking in-situ information or because satellites offer a unique means of monitoring that cannot be affected by the hazards observed.

More than a hundred EO satellites are in operation at any one time, hosting a diverse range of sensor types that utilise different parts of the electromagnetic spectrum and different techniques to provide a range of measurements from space. Much of these data are available freely and openly for any purpose and ready for application by the DRR community.

Some of the measurements are undertaken from geostationary orbit whereby the satellite is always above the same spot on the Earth and effectively sees a full 'disc' view of the Earth. These are typically for meteorology purposes and are the source of the familiar weather pictures shown on TV news. Most EO satellites orbit the Earth over the poles and collectively offer daily access to most points on the globe for both optical and radar imagery. These satellites are closer to the Earth's surface and can typically provide data at a higher resolution and accuracy than meteorological satellites.

Measurements from these satellites provide valuable additional input that can be used for a multitude of applications in support of disasters: tracking the path of tropical storms including typhoons, cyclones and hurricanes worldwide; monitoring changing morphology of volcanic domes in case of eruptions; tracking the dispersion of ash emitted during volcanic eruptions; mapping the geographical extent of flooded regions even under cloudy conditions; tracking the extent of forest fires and oil spills; and monitoring the effects of droughts on soils, vegetation, and crops.

As the United Nations plans for the post-2015 framework to succeed the HFA, satellite data have a critical role to play, particularly in providing information to help reduce the underlying risk factors and strengthening disaster preparedness for effective response in association with traditional methods used by the DRM community.

Satellite EO contributes primarily to the hazard and exposure components of DRR and to the following functions in particular:

- Exposure mapping to support preparedness/mitigation, early warning & response. Basic mapping underpins almost all the mapping services provided in disaster management and humanitarian aid projects using satellite EO. It provides the base layer information that users can utilise to determine key geographical attributes of a given area. Significant archives of satellite data exist, from as far back as the 1970s in some cases, that can be mined for baseline information of various kinds;
- Hazard mapping and risk assessment (geo-hazards, hydro-meteorological hazards, climatological hazards, technological hazards). For example, flood risk analysis provides information to support risk management and water resources management. Different types of information can be extracted, such as the classified distribution of the land cover and socio-economic units in areas at risk or hazard damage information based on measurements of water depth and/or flow velocity. Again, the satellite archives can provide historical data that contribute to hazard assessment, such as historical flood extents for major events over a given area;
- Critical infrastructure monitoring. Up-to-date, synoptic, and objective infrastructure information helps maintain a current status concerning assets at risk. Such data can be used to provide improved knowledge of the potential impact of natural hazards in areas at risk. For example, repeat satellite radar images can be used to measure sub-centimetre-scale changes in deformation over spans of days to years, with applications for geophysical monitoring of subsidence and structural stability;
- Early warning/alert and tracking of a range of natural hazards, including tropical cyclones, landslides, and volcanoes;
- Disaster response following natural and man-made hazards and support for Crisis Mapping/Damage Assessment, including rapid assessment and the location, scale and severity of the disaster impact;
- Support to recovery/reconstruction/rehabilitation. Satellite EO supports precise post-disaster needs assessment and evaluation of early and long-term recovery needs and priorities; this includes use to position recovery aid, identify safe and unsafe areas, prioritise infrastructure repair, monitor risks from repeat hazards, development of a spatially explicit timeline of recovery, and informing the direction of reconstruction aid.

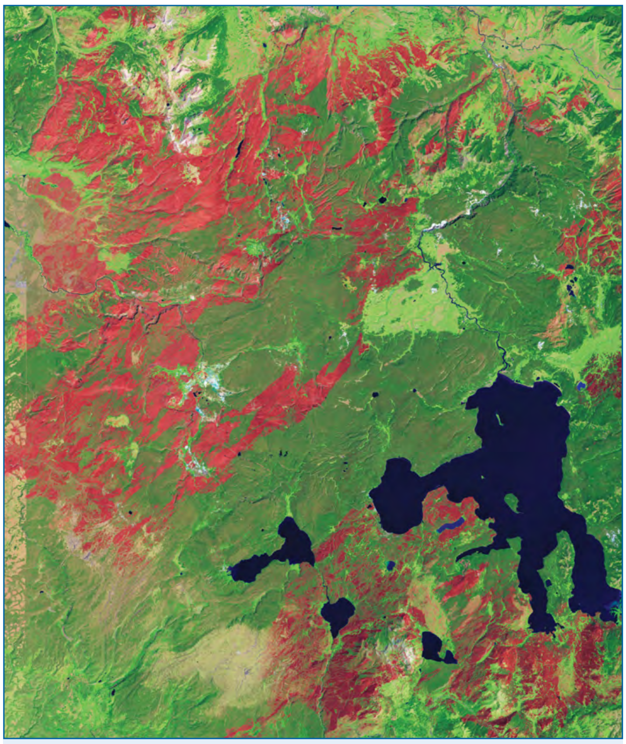


Figure 1: This 1989 image from Landsat 5 shows the extent of fire burnt area (in red) following severe fires in Yellowstone National Park.

Image credit: NASA Earth Observatory, Robert Simmon, United States Geological Survey.

2.2 How Satellite EO Helps

The language that has been developed in support of WCDRR, the post-2015 framework for disaster risk reduction, and the topic of DRR, identifies risk as a function of:

- Hazard – an act or phenomenon that has the potential to produce harm or other undesirable consequences to a person or thing;
- Exposure – the people, property, systems, or functions that could be lost to a hazard. Generally exposure includes what lies in the area the hazard could affect;
- Vulnerability – susceptibility to physical injury, harm, damage, or economic loss. It depends on an asset's construction, contents, and economic value of its functions.

Satellite EO supports a wide range of disaster types and all phases of DRM, including the very long term monitoring of climate phenomena. **Part II** of this document provides some real and practical examples of the different ways satellite EO is being applied by governments, disaster agencies, and UN bodies around the world in support of DRR.

Part III provides an overview of the contribution of satellite EO to the different phases of disasters, with a focus on the benefits to the end users. Until relatively recently, most of the activity around the application of satellite EO focussed on the immediate response phase. The DRM community, including engaged space data providers, has in recent years increased the emphasis on Disaster Risk Reduction, recognising that more lives can be saved and property can be better protected through proactive investment in risk reduction or mitigation.

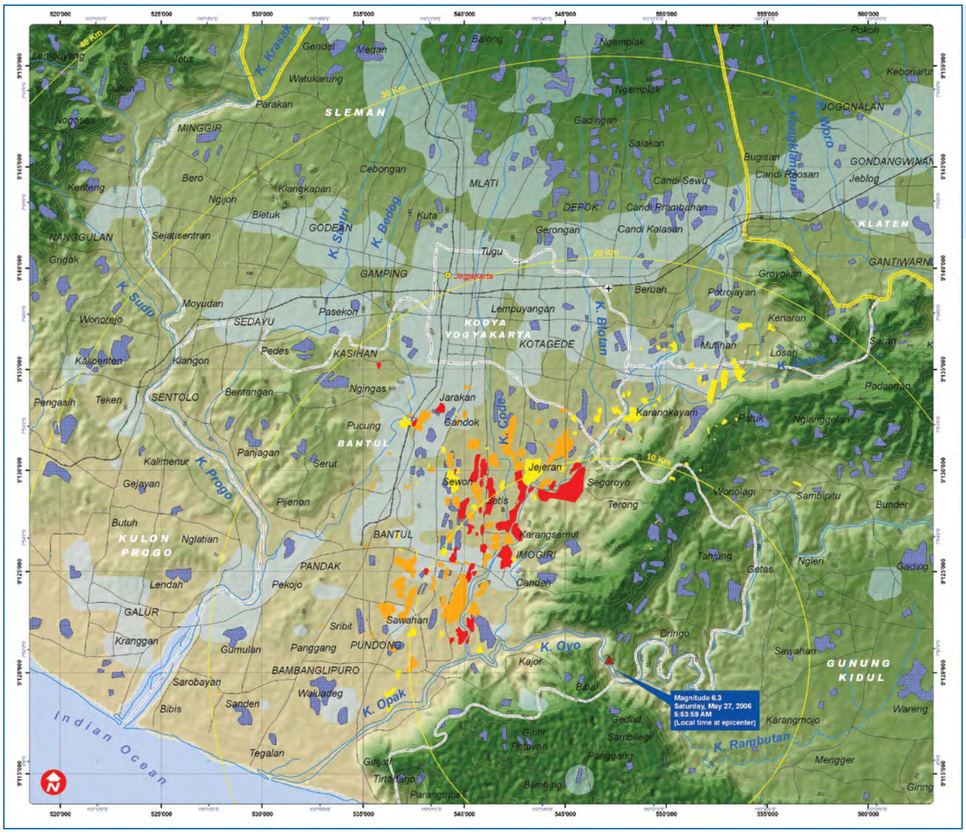
Satellite EO can support indicators to monitor progress in the implementation of DRR and support harmonisation of international standards and risk assessment practices, especially when hazards are trans-boundary in nature. It can help augment the capacity of the community to manage risks.

A number of national DRM-related agencies have already adopted satellite EO in their formal guidelines for risk mitigation, and acquire EO data routinely on a nationwide basis.

Satellite EO can help science in narrowing down the uncertainty in hazard and risk assessment and supports better informed practitioners and end users. Satellite EO also assists in educating the general public around a culture of disaster prevention and resilience.

Figure 2: The ash plume generated by the eruption of Eyjafjallajökull volcano in Iceland, as seen by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite.
Satellite EO helped track the spread of volcanic ash, assisting aviation safety decision-makers. Around 100,000 flights were cancelled due to the eruption, resulting in losses of approximately 200 million US/day.

Image credit: NASA Earth Observatory, Jeff Schmaltz, MODIS Rapid Response Team (NASA).



Magnitude 6.3
Saturday, May 27, 2006
5:53:59 AM
(Local time at epicenter)

Figure 3: Preliminary damage assessment and critical infrastructure map for Java Island, Indonesia, following a magnitude 6.3 earthquake on Saturday May 27, 2006.

Image credit: UNITAR/UNOSAT

2.3 International Coordination

Technologies such as satellite EO do not themselves result in reduced damage or losses, but their use facilitates better-quality decisions that can bring this about. The significant investment in space-based infrastructure has not yet been fully exploited for DRR. Realising the full benefits requires a solid base of political support, laws and regulations, institutional responsibility, and trained people.

A number of international coordination efforts have been pioneering the establishment of the necessary connections between data providers, information developers, and end users to ensure that decision-makers in the DRM community are able to benefit from satellite EO.

The International Disaster Charter

The International Charter on Space and Major Disasters is the main mechanism globally by which countries can access satellite EO in support of their disaster response activities. The Charter (www.disasterscharter.org), is an international collaboration among space agencies to provide a unified system to access imagery for disaster response.

With 15 members today, the Charter is able to provide rapid access to data from a virtual constellation of a series of satellites, both optical and radar, tasked in rush mode to help disaster management centres in relief actions. It is aimed to help better organise, direct, and mobilise national disaster management resources during emergencies and the international relief community concerning situations where humanitarian assistance is required.

The Charter is focused on hazards with rapid onset scenarios, on the hazard impact, and aims to service operational users during the immediate response phase. The Charter provides access to satellite data globally and at no cost to Authorized Users.

Part II of this document features a case study on the Charter.

Sentinel Asia

Sentinel Asia is a voluntary basis initiative (www.aprsaf.org/initiatives/sentinel_asia) led by the Asia-Pacific Regional Space Agency Forum (APRSAF) to support disaster management activity in the Asia-Pacific region by applying geospatial information and technologies, including EO satellite data. Its main activities include:

- Emergency observation by EO satellites in case of major disasters (with working links to the Charter as required);
- Acceptance of observation requests;
- Wildfire monitoring, flood monitoring and glacier lake outburst flood monitoring;

Figure 4: These images from JAXA's ALOS radar satellite were taken before (right) and after (left) the Great East Japan Earthquake and subsequent Tsunami. Areas flooded by water appear dark blue in the post-disaster image.
JAXA conducted emergency observations using ALOS to generate maps showing damage-area extent and severity, which helped responders search for survivors and coordinate recovery efforts.

Image credit: JAXA

– Capacity building for utilization of satellite image/data for disaster management.

The Committee on Earth Observation Satellites

The Committee on Earth Observation Satellites (CEOS; www.ceos.org) coordinates civil space-based EO programmes. More than 30 national/regional space agencies participate in CEOS coordination efforts, with these agencies collectively responsible for the operation of more than 100 current EO satellite missions.

The governments and agencies represented in CEOS have resolved to increase application of their investments in EO satellites to the global challenge of DRR. Section 3 of this document explains these in more detail, including the establishment of a Working Group dedicated to Disasters, and the progress of several thematic pilots supporting DRR.

Copernicus

In Europe, the EC, through the Copernicus programme, has established the Emergency Management Service (http://emergency.copernicus.eu) that integrates satellite data with operational value-adding services to support DRM and is currently developing new applications using satellites through its Framework Programmes for Research and Technical Development and in particular its new Horizon 2020 programme of the EU for research and innovation.

Copernicus Emergency Management Service addresses, with worldwide coverage, a wide range of emergency situations resulting from natural or man-made disasters. It covers in particular floods, earthquakes, landslides, severe storms, fires, technological disasters, volcanic eruptions, humanitarian crises, and tsunamis. There have been 95 'rush-mode' activations of the Service since its inception in 2012.

The Group on Earth Observations

The Group on Earth Observations (GEO) is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS). GEO was established in February 2005 by the Third Earth Observation Summit in Brussels. This followed calls for action by the 2002 World Summit on Sustainable Development and the Group of Eight (G8) leading industrialised countries. GEO is a voluntary partnership of governments and international organizations. It provides a framework within which these partners can develop new projects and coordinate their strategies and investments.

GEO addresses multiple societal benefit areas, including disasters. GEO aims to enable the global coordination of observing and information systems to support all phases of the risk management cycle associated with hazards (mitigation and preparedness, early warning, response, and recovery).

GEO provides an important forum for cooperation among space agencies, in-situ observations providers, governmental users, and Ministers.

World Meteorological Organization

The World Meteorological Organization (WMO) is a specialised agency of the United Nations. It is the UN system's authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the oceans, the climate it produces, and the resulting distribution of water resources. WMO has a membership of 191 Member States and Territories.

The WMO Global Integrated Observing System (WIGOS) enables the collection of data from 17 satellites, hundreds of ocean buoys, thousands of aircraft and ships, and nearly 10,000 land-based stations. Along with the communication and data-processing and forecasting systems of WMO, these observing assets are deployed in support of a range of DRR activities, including:

- The Tropical Cyclone Programme, which uses six Tropical Cyclone Warning Centres dedicated to providing tropical cyclone analysis, forecasts and alerts in support of National Meteorological and Hydrological Service operational warnings;
- International Airways Volcano Watch, which comprises international ground-based networks, global satellite systems, and in-flight air reports to detect and observe volcanic eruptions and ash cloud and pass the information quickly to appropriate air traffic services units and Meteorological Watch Offices, which provide the necessary warnings to aircraft before or during flight. The warnings are based on advisory information supplied by nine Volcanic Ash Advisory Centres designated upon advice from WMO;

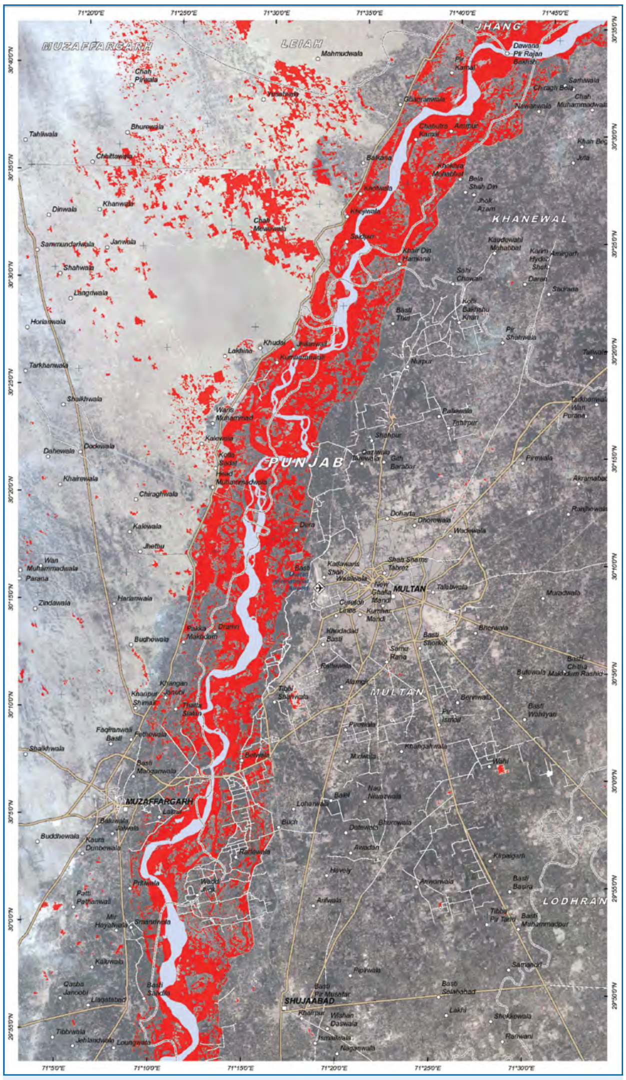


Figure 5: This map of Multan area, Punjab Province (Pakistan) was generated using Landsat-8 and TerraSAR-X data supplied under the International Charter on Space and Major Disasters. Red denotes areas that are affected by flooding.

Image credit: UNITAR/UNOSAT, NASA, USGS, DLR/Airbus

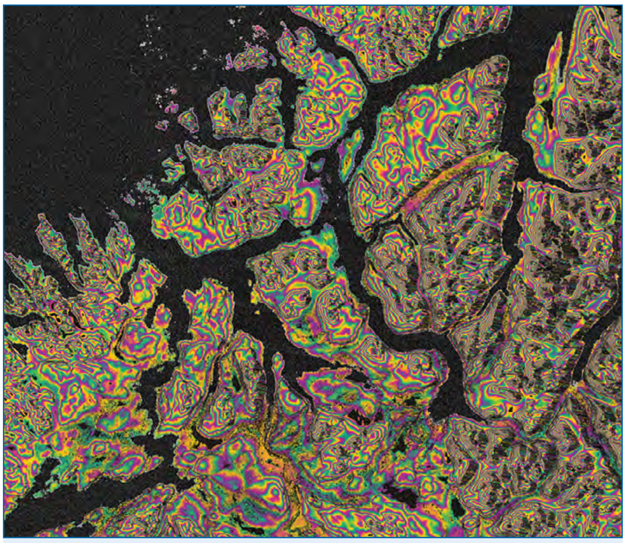


Figure 6: An InSAR image of the northern coast of Norway from Sentinel-1A in August 2014. InSAR images can detect small surface changes and are used for nationwide rockslide hazard mapping by Norwegian authorities. The unprecedented coverage offered by Sentinel-1 will significantly increase the value of InSAR data for this purpose.

Image credit: ESA

- The WMO Programme of Emergency Response Activities, established in 1986 to assist governments to respond effectively to environmental emergencies with large-scale dispersion of airborne hazardous substances from nuclear facility accidents, smoke from large fires, volcanic ash, dust and sand storms, and chemical releases from industrial accidents.

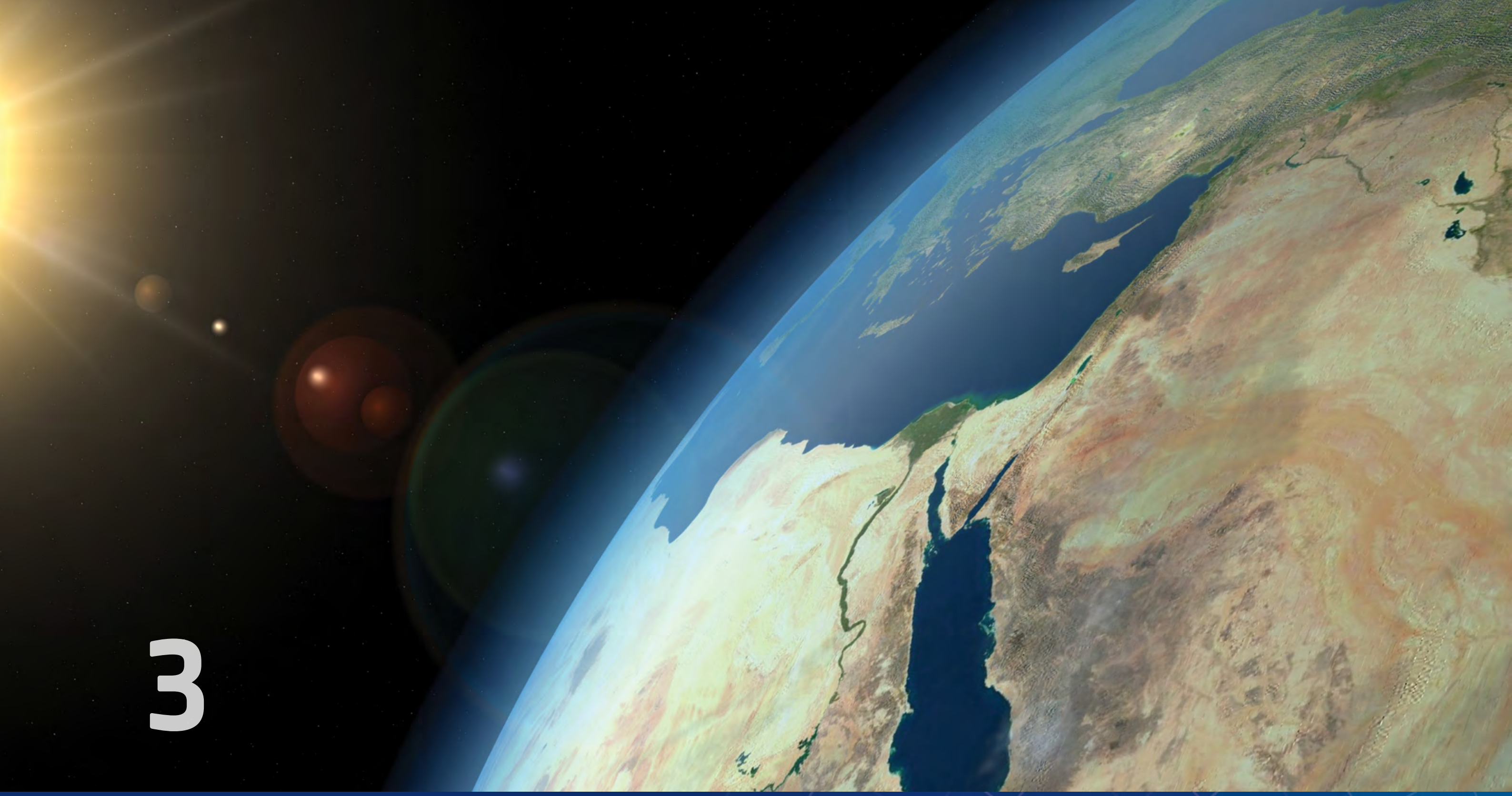
WMO's close relationship with responsible national agencies ensures effective dissemination of hazard alerts in each case.

Further information

International Charter on Space and Major Disasters:
www.disasterscharter.org

Copernicus:
www.copernicus.eu

Sentinel Asia:
www.aprsaf.org/initiatives/sentinel_asia



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CEOS

What is CEOS?

CEOS is the Committee on Earth Observation Satellites, created in 1984 in response to a recommendation by a Panel of Experts on Remote Sensing from Space, under the aegis of the G-7 Economic Summit of Industrialised Nations Working Group on Growth, Technology and Employment.

CEOS was established to provide coordination of the Earth observations being provided by satellite missions, recognising that no single programme, agency, or nation can hope to satisfy all of the observational requirements that are necessary for improved understanding of the Earth System. Since its establishment, CEOS has provided a broad framework for international coordination on space-borne EO missions.

CEOS has three primary objectives:

- To optimize the benefits of space-based EO through cooperation of CEOS Agencies in mission planning and in the development of compatible data products, formats, services, applications and policies;
- To serve as the focal point for international coordination of space-based EO activities;
- To encourage complementarity and compatibility among space-based EO systems and the data received from them.

CEOS membership had reached 31 space agency Members in 2015, comprising most of the world's civil agencies responsible for EO satellite programmes.

What Does CEOS Contribute to DRR?

CEOS is working with the user community at local/national and regional levels, with academia, civil protection, UN agencies, and operational resources management agencies to demonstrate the value of EO satellite data and to demonstrate the necessary connections required with the users of the information, as well as the many intermediary bodies.

CEOS has been actively expanding its support to all phases of DRR, building on its original emphasis on disaster response. This resolve is demonstrated through a number of important initiatives:

- Development of a **CEOS DRM strategy** and supporting **Disasters Working Group**;
- Establishment of **three thematic pilots**, covering Floods, Seismic Hazards, and Volcanoes to demonstrate an expanded coordination of space agencies in support of national users of the resulting information products;

- The creation of a **Recovery Observatory** that showcases how space agencies can improve collaboration with all DRR stakeholders in the aftermath of a major disaster on the scale of Typhoon Haiyan or the Haiti Earthquake of 2010;
- Support to the **Geohazard Supersites and Natural Laboratories initiative** of GEO. This project coordinates EO acquisitions over designated 'supersites' to ensure science users have information required to advance state-of-the-art research into EO-based risk assessment in relation to specific hazards: the volcanoes of Hawaii, four volcanoes in Iceland, the Marmara region Fault Zone in Turkey, and the volcanoes of Italy, New Zealand, and Ecuador. Eventually, the supersites project is expected to develop methodologies that can be used to monitor such hazards using EO on a global basis.

The long-term vision for the CEOS DRM strategy is:

- Global in scope, but building on strong partnerships at local/national or regional levels;
- User-driven (defined against user information needs and based on the engagement of the diverse user communities involved in DRM);
- Full-cycle (addresses mitigation/ preparedness, warning, response/recovery, etc.);
- Addressing several hazard types;
- Taking account of all relevant EO-based capabilities available or under development.

The pilots represent an important part of the CEOS DRM strategy, with an emphasis on the development of connections between the satellite data providers and national users of the resulting information products.

Flood pilot

The main goal is to demonstrate the effective application of satellite EO to the full cycle of flood management at global and regional/local scales by:

- Integrating existing near-real time global flood monitoring and modelling systems;
- Linking global systems to regional end-to-end pilots that produce high-resolution flood mitigation, warning and response products and deliver flood and flash flood related services in: the Caribbean (with particular focus on Haiti); Southern Africa, including Namibia, South Africa, Zambia, Zimbabwe, Mozambique, and Malawi; Southeast Asia (with particular focus on the lower Mekong Basin and Western Java, Indonesia);
- Developing new end products and services to better deliver flood-related information and to validate satellite EO data and products with end users, including retrospective products working from archived EO flood extent data;
- Encouraging regional in-country capacity building to access EO data and integrate into operational systems and flood management practices.

Seismic Hazards pilot

This pilot is characterised by three main objectives:

- Supporting the generation of globally self-consistent strain rate estimates and the mapping of active faults at the global scale by providing EO radar and optical data and processing capacities to existing initiatives;
- Supporting and continuing the Geohazard Supersites and Natural Laboratories initiative for seismic hazards and volcanoes;
- Developing and demonstrating advanced science products for rapid earthquake response (>Magnitude 5.8).

Volcanoes pilot

The volcanoes pilot exploits the instruments of several EO satellite missions to achieve the following objectives:

- Demonstrating comprehensive monitoring of Holocene-era volcanoes in the Latin American volcanic arc;
- Developing new protocols and products over active volcanoes where EO data collects are already taking place (Hawaii, Iceland, and Italy);
- Demonstrating operational monitoring over a large-scale eruption during 2014–2016.

Only CEOS offers the breadth of membership and sensor platforms to provide the full range of necessary data and coordination capacity to support such a broad-ranging effort that groups end users, practitioners, and satellite operators.

Through the above work, CEOS and its Agencies are committed to fostering the use of EO in support of DRR and to raising the awareness of politicians, decision-makers, and major stakeholders of the benefits of using satellite EO in all phases of DRR.

The 3rd World Conference for Disaster Risk Reduction provides an opportunity for the DRR community to better understand the benefits it can draw from the use of satellite EO and to work with the data provider agencies to help realise the full potential of this significant investment in space infrastructure in support of DRR objectives, including the plan of action outlined in the post-2015 framework for disaster risk reduction.

More information on many of the CEOS DRR activities is provided in the Case Studies of Part II.

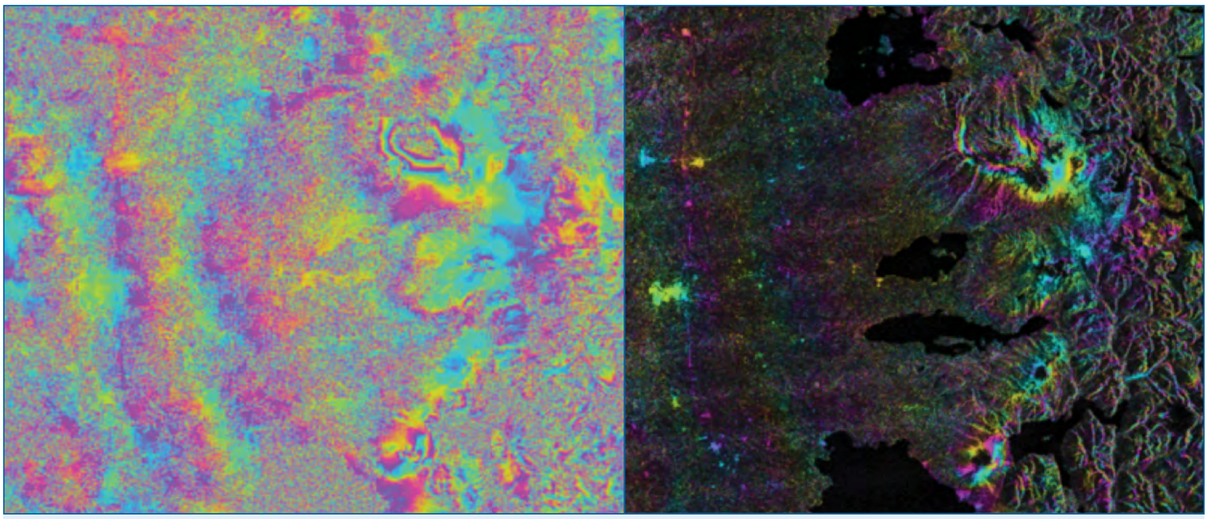

Figure 1: The Cordon Caulle volcano, Chile, erupted in 2011–2012. This interferogram shows post-eruptive inflation that would not otherwise have been known without the CEOS pilot program.

Image credit: Matt Pritchard (Cornell University)

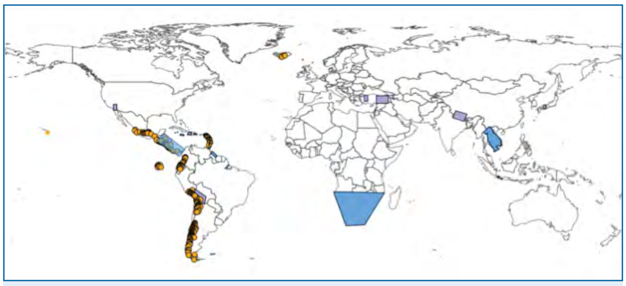

Figure 2: Overview of combined EO data polygons for three CEOS thematic pilots to be deployed over 2014–2016. Floods in blue, seismic hazards in purple, volcanoes in sienna. Areas not to scale and for indicative purposes only.

Further information

CEOS:
www.ceos.org

Earth Observation Handbook:
www.eohandbook.com

Missions, Instruments and Measurements (MIM) Database:
database.eohandbook.com

4

Future Challenges

The many governments that are investing in the space infrastructure of EO satellites are convinced as to the potential of their application to DRR. These same governments are reducing the barriers to access and application of satellite EO in response to a range of other hazard types - through mechanisms like the International Charter, Sentinel-Asia, and Copernicus. Seeking to extend similar benefits to all phases of disasters and to all kinds of hazards, CEOS has committed to addressing a number of challenges associated with application of satellite EO to the HFA objectives:

- Institutional and technical solutions are needed to facilitate access to, and application of, satellite EO at the necessary levels and by the relevant institutions, including international bodies with development responsibilities such as the World Bank, recognised national agencies, down to local government; uptake by DRR agencies requires demonstration of the value provided and a commitment to sustained, free, and open data that will be available on demand, as and when needed;
- Exemplified by the universal uptake and application of weather satellite data, the application of space-based risk assessment techniques for different hazards will require investment in suitable information systems and skills if the data are to be applied in local environments;
- Data alone cannot meet the needs of the DRR community; data must be integrated into tools specifically adapted to user needs for information: to map hazards, evaluate asset exposure, and model vulnerability. This is a challenging task given the wide range of hazards and geographies to be considered on a global basis;
- A substantial EO satellite capability, including radar, optical, and high-resolution imaging satellites, already exists in space or is planned. The collective capability offers frequent revisit and wide-area synoptic coverage. Conversion of this staggering and diverse array of data into information of high value to the DRR community requires continuous study and research.

Noting these challenges and recognising the considerable successes in the use of satellite EO for DRR, CEOS would like to communicate four key messages to the distinguished delegates of the WCDRR:

1. **Satellite EO data complement other data sources but provide unique information.** Countries have made significant investments in the space-based infrastructure of EO satellites. And space agencies have resolved to extract the maximum value from this infrastructure in support of the post-2015 framework for disaster risk reduction.

2. **CEOS is dedicated to supporting the availability of satellite data for DRR purposes and its transformation into higher-level information that can be readily applied by end users.** Technology alone does not result in reduced damage and losses, but its use facilitates better quality decisions that can bring this about. Ensuring free and open access to a range of satellite data for DRR purposes is one of the CEOS goals in coming years.

3. **Satellite data contributes on all scales, from global, through regional, to local issues.** Development banks, UN agencies, government agencies, NGOs, intergovernmental organizations, scientific institutions, and the private sector all have a role to play in DRR and all should be engaged in realisation of the benefits of the data.

4. **Space agencies seek cooperation with major stakeholders to identify the information needs of users addressing top priorities of the post-2015 framework for disaster risk reduction and to establish a plan for a sustained and coordinated response to fulfil those needs.** This will require long-term commitments from space agencies, from all relevant EO data providers, and from the practitioners who support the transformation of the observations into understandable and directly usable information that can be combined with other data sources (airborne, in-situ, model outputs, socioeconomic) as needed in support of decision-making. CEOS is committed to the necessary cooperation, including ongoing engagement of the end-user community to ensure proper specification of their needs and results that are fit for purpose.

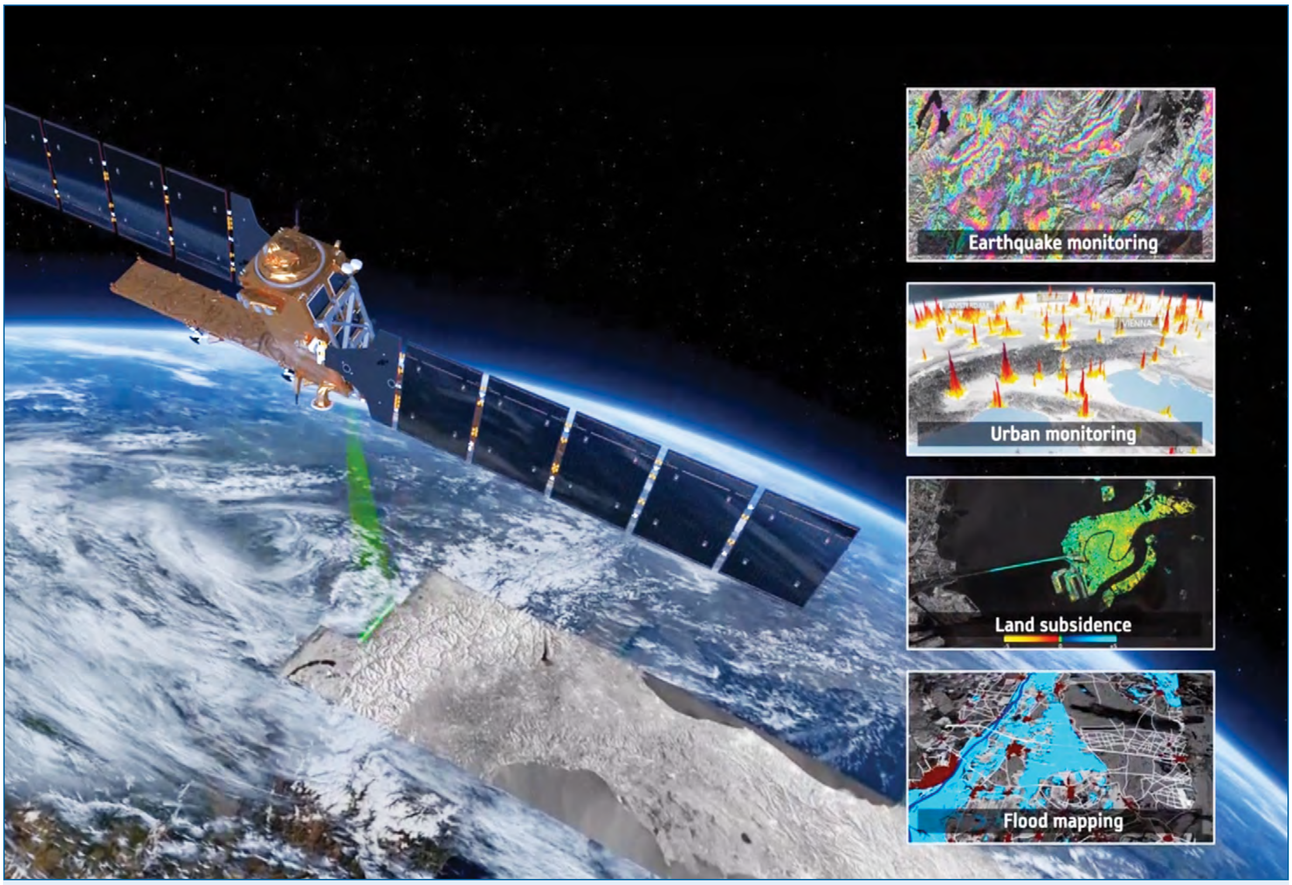

Figure 1: Risk information produced from Sentinel-1 radar data

A number of indicators have been proposed to help determine whether the post-2015 framework for disaster risk reduction is achieving its objectives of reducing disaster risk; consistent and comparable information sources will be needed if we are to compile meaningful results on different scales, including from country to country. In combination with other data sources, and with the aid of tools to combine and interpret the data, satellite EO can provide unique capabilities that might fundamentally transform the way in which the post-2015 framework is implemented and its success measured. This provides the possibility of monitoring changes in exposure to risk and providing evidence as the basis and impetus for change in policies or emphasis of the DRR community and of governments. Only satellite EO offers uniform, comprehensive global monitoring to compare risk evolution in one country to that of another and to make the connections with the datasets and indicators related to climate change. More than half of the 40+ Essential Climate Variables (ECVs) recognised as required for climate monitoring are largely or exclusively dependent on satellite EO data sources.

Satellite EO services for DRR already exist that serve users and have successfully demonstrated the cost-benefit of providing risk assessment based on the data. Additional R&D is required for some of the geo-information needs of DRR users. For other needs, such as in areas identified by the CEOS thematic pilots, the products are mature, precise, and documented. Awareness of these successes and capabilities remains a challenge. Connections between the various arms of governments (from specialised technical space agencies through to national emergency management agencies) must be established and matured and awareness must be improved of the capability of this powerful infrastructure in space for our most urgent of Earth-bound challenges in relation to DRR.

Part II of this document presents a number of examples of the practical application of satellite EO to the DRR domain. A range of hazards and data types are included. **Part III** explains in simple terms the relevance to each phase of DRR of the different types of data.

The space agencies represented by CEOS undertake the following commitments in support of the post-2015 framework:

Development of a multi-year plan for CEOS corresponding to the post-2015 framework timeframe, providing comprehensive support and coordination in relation to the role of satellite EO for the framework. Developed in partnership with the major stakeholders including UN organizations, GEO, international relief agencies, leading development banks, national civil protection agencies, and local authorities.

Support to the post-2015 framework at global and regional/local scales. In line with the Decadal Plan and in cooperation with the relevant user communities, CEOS agencies are implementing pilot demonstrators during 2014–2017 to demonstrate how satellite data and derived information can be useful to the full cycle of DRM. The long-term vision is to transition to the sustained provision of data and services.

Part II

Case Studies

1

Flood Mapping by Italian Civil Protection

The Italian system of Civil Protection has engaged a number of national agencies, in particular the Italian Space Agency (ASI), in a variety of disaster response activities. This includes cross-agency collaboration on flood-extent mapping.

The experiences of the Italian authorities demonstrates the importance of organisation, cooperation between stakeholders, and the integration of satellite data with models, informed by interaction with regional and local authorities, to produce accurate and timely flood map products in support of disaster preparedness and response.

1.1 The Italian Framework

The Italian national territory is exposed to a broad range of natural hazards, including floods, which cause fatalities and significant economic damage every year. The vulnerability of the population and built environment is often high and in some cases has been exacerbated by human activities. The National Civil Protection Service operates the Department of Civil Protection (DPC), which has activities covering prevention, forecast and assessment, early warning and alerting, and emergency response and recovery from emergency.

To address its mandate, the Civil Protection Service has organized a comprehensive system that includes a great number of both local and centralised resources. In particular, for hydrogeological risk, a national alert system is run by the DPC and regional authorities built around a network of Functional Centres (CF). One CF covering the national level is located at the DPC and one CF is located in each region. This national alert system provides services in two phases – forecast of expected flooding and then monitoring and observations of current weather and flooding conditions.

The activities of DPC are daily supported by research efforts through a network of national Competence Centres (CC), focused on the integration of technological and scientific advancements into the emergency response and management cycle. In this framework, the products based on the integration of traditional and innovative EO and ground-based (non-EO) data and technologies foster the ability of Civil Protection Authorities in flood risk management activities.

The ASI has been designated as the CC for EO within the national Civil Protection system. ASI's role is to support the DPC by developing applications based on EO data, coordinating with other space agencies, and transferring scientific and technical know-how to national authorities. In 2009 following the requirements of the DPC, ASI funded nine technological pilot projects focused on specific hazards such as floods, volcanoes, seismic risk, landslides, fires, oil spills, and air quality. These projects were strongly user driven, and have produced tools, procedures, and applications now operational and used for emergency management.

During an incident, emergency flood monitoring using EO is activated by DPC or at the request of a regional authorised user. The International Centre on Environmental Monitoring (CIMA) Research Foundation is the CC and value adder for hydrogeological risk management and ASI acts as its data provider during flood emergencies. The DPC, ASI, and CIMA work in cooperation as program managers, along with end users at the regional CFs.

Satellite capabilities include the COSMO-SkyMed (CSK) constellation, which plays an important role at a national scale, carrying out monitoring related to rapid mapping, damage estimation, and recovery. The constellation has many desirable characteristics for disaster risk management and response, including high spatial resolution, high revisit time, and day/night all-weather capability. ASI has also signed an agreement with ESA to develop the Italian ground segment for Sentinel data access and exploitation.

Two examples of these capabilities follow – the first is related to the benefits of collaboration between decision makers, end users, and hydrometeorologists and the second shows the benefits of synergy between Sentinel-1 and CSK for monitoring disasters at a national scale. The two examples refer to flood monitoring but the conclusions extend to other hazards.

1.2 Liguria Floods, November 2014

The use of satellite EO data in the mapping of flash flooding in small Mediterranean drainage basins like those in Albenga and the surrounding municipalities presents significant challenges for image acquisition planning. Water remains in these small basins for only a few hours, and with satellite imaging opportunities arising on the order of days, the acquisitions need to be planned based on weather and flood forecasts.

Flash flood mapping represents one of the biggest challenges to the limits of usability of satellites for flood monitoring. Acquisitions cannot be scheduled following a flood occurrence, as they would take place over 24 hours after the event, by which time the visible traces of water will no longer be present. Even acquisitions based on weather and flood forecasts are susceptible to failure, due to uncertainty on the location of the flash floods both in space and time.

The Liguria floods of November 2014 were used to test the potential of monitoring a flash flood using weather forecasts to pre-emptively plan acquisitions. Three factors were key to the success of this activity: extensive knowledge of the area by CIMA researchers; close collaboration with forecasters of the regional CF; and close cooperation between CIMA, CF, DPC, and ASI to minimise acquisition planning time.

Attention was focused on three flat, sparsely populated areas that are suitable for observation using SAR satellites: the floodplains of the Centa (Albenga), Entella (Chiavari-Lavagna), and Magra rivers (see Figure 1).

Forecasts issued on November 14th by CF Liguria for the three areas of interest (AOI) showed significant probability of waters exceeding flood thresholds for the Centa and Entella rivers in the late morning/early afternoon of the 15th. Upon request of the CF Liguria, the DPC, ASI, and CIMA proceeded to plan CSK acquisitions in these AOI for the evening of the 15th.

Figure 1: Area of interest and swaths of CSK images for the Liguria floods.

Image credit: DEWETRA (CIMA), Google Maps

Figure 2: Flooded area for the Centa floodplain as observed by CSK at 19:17 local time.

Image credit: DEWETRA (CIMA), ASI, Google Maps

Ultimately, only the areas of western Liguria were flooded, with no significant impacts observed on the Entella river floodplains (see Figure 2). The flooding took place in the late morning/early afternoon of the 15th, and the CSK image acquired a few hours later (19:17 local time) still indicates the presence of flooding despite the rapidly changing situation.

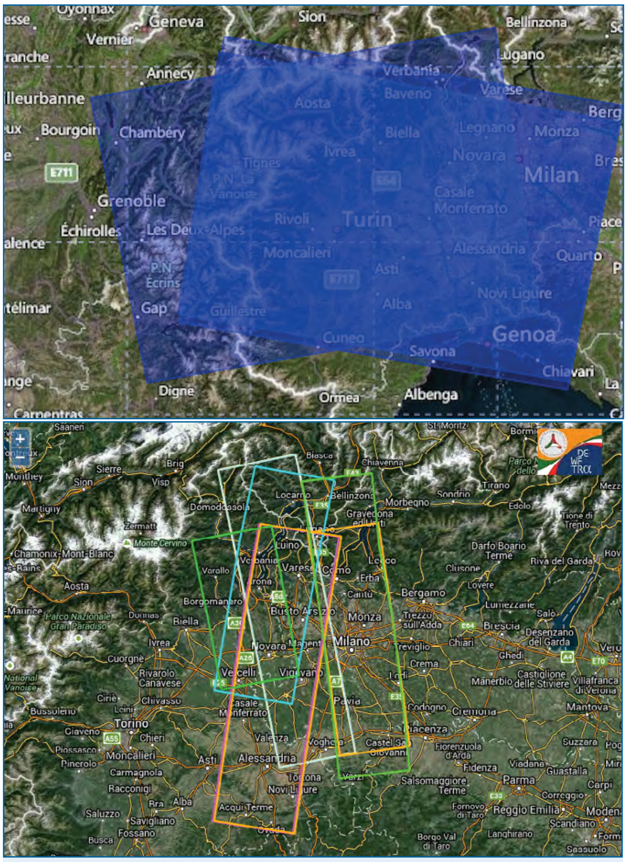

Figure 3: Spatial and temporal coverage of the AOI by Sentinel-1A (top) and CSK (bottom) for the period November 13–20, 2014.

Image credit: (top) ESA, Google Maps (bottom) DEWETRA (CIMA), Google Maps

1.3 Synergistic use of Satellites for Flood Detection

Monitoring of the flooding of the Po river and its tributaries between the 15th and 20th of November 2014 demonstrates the synergistic use of observations from multiple satellite sensors, with careful consideration of the specific space/time resolution and different revisit times of each satellite allowing for optimal integration of the observations.

Sentinel-1A provides complete spatial coverage of the area due to its large swath width (250 km), with a revisit time which provides one or two images every 12 days. For the specific AOI, two images were acquired – the first acquired on the morning of the 15th (preceding the flood event) and a second during the evening of the 16th, just the after the passage of the flood peak. The CSK acquisitions have a more limited spatial coverage (40km swath) but a higher image resolution (5m) and a high revisit frequency (ten images between the 13th and 20th).

The characteristics of the two satellites are highly complementary. Sentinel-1A provides a complete synoptic spatial coverage of the AOI, while CSK provides high-resolution space/time information on the evolution of the event at sub-areas of specific interest. Regular Sentinel-1A interferometric wide-swath mode acquisitions also allow a reliable, large-scale identification of permanent water bodies (e.g., rivers and lakes). In this case the use of Sentinel-1A acquisitions from the 4th (pre-event) allowed the identification of the Po river, shown in dark blue in Figure 4. The results obtained using Sentinel-1A (left) and CSK (right) show good agreement.

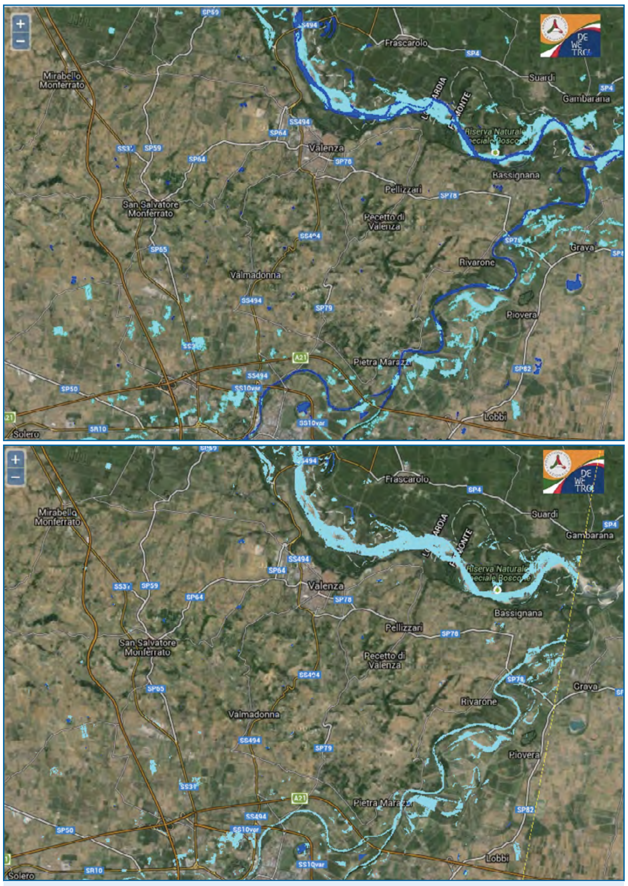

Figure 4: Comparison of the flooded areas derived from Sentinel-1A (top) and CSK (bottom) at the same time (18:22 local time) on November 16th. The dark blue color indicates permanent water bodies derived from Sentinel-1A.

Image credit: (top) ESA, Google Maps (bottom) ASI, Google Maps

1.4 Conclusions

The two cases presented are examples of how the synergistic use of different sources of information can improve the ability to monitor floods using satellites. The Albenga flood case shows how close cooperation between forecaster, end user, data provider, and value adder greatly increases the probability of detecting flash floods. In this case, the probability of successfully identifying flooded areas increased to 50%, compared to a zero probability when using images ordered after the event.

In the second example, the synergistic use of two satellite missions has been shown to produce high added value for flood monitoring. Sentinel-1A was assigned the task of covering the entire event and identifying permanent water bodies. CSK was tasked with providing high-resolution spatial and temporal information about the evolution of the event in areas of specific interest. It is anticipated that the increased revisit frequency following the launch of Sentinel-1B (down to 6 days) will greatly improve the chances of synoptic spatial coverage of events.

Case study contributors:

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Acknowledgements

The authors thank the Liguria region for providing flood forecasts for the rivers Centa, Entella, and Magra. The figures were made using the open source platform DEWETRA of the DPC. The feasibility study for the COSMO-SkyMed acquisitions was conducted using the NFS platform, developed by Acrotec s.r.l. and co-funded by ASI (Bando periodico riservato alle PMI, Bando Tematico N. 02 “Osservazione della terra”)

Further information

COSMO-SkyMed System Description & User Guide
www.e-geos.it/products/pdf/csk-user_guide.pdf

2

Use of Satellites for Flood Disasters in Southern Africa

Alongside research partners, CEOS is implementing disaster modelling and monitoring capabilities and working more closely with end users in order to build and sustain capacity for optimal flood and water management using satellite imagery. The end users include national, regional, and international agencies responsible for preparedness, disaster management, water resources management and flood/drought prediction and assessment. These projects are contributing to risk reduction in Southern Africa from disaster events in terms of people's lives and livelihoods, as well as reducing the cost for assessments and recovery. Improvements are being made around individual decision making and directly related to the introduction of satellite-based products and services, especially in the area of flooding. Advancements are also being made by local, national, regional, and international agencies in generating their own products and validating the satellite data using crowd-sourcing techniques and open source tools.

2.1 Namibia

In Southern Africa the Namibian Department of Water Affairs and Forestry and the National Water Resources Authorities are using satellite-derived products and services to warn the public of impending floods; monitor algal blooms in reservoirs; and track flood, drought, and health-related events as they unfold at the national level. The Regional Centre for Mapping of Resources for Development (RCMRD) provides disaster risk management support on a regional basis to their constituent countries using the same remote-sensing capabilities.

These flood and drought monitoring and modelling capabilities have been used by the Namibian government since 2008, when the worst flooding in two decades occurred in the northern part of the country. At that time, the affected population chose to not take action ahead of the flood because no serious flooding had occurred for a long time and flood forecasts from satellite remote sensing were not widely available. People within the areas of concern did not heed warnings by national agencies and this resulted in approximately 250,000 people directly affected, as well as significant property damage. A state of emergency was declared and many people were rescued from rooftops using boats and helicopters. During the following year, extensive use of satellite data allowed national agencies to improve their analyses and share them with news outlets. The satellite imagery analysis showed not only where to expect flooding, but also indicated potential severity, so that people within the risk areas could gauge the level of danger. This enabled effective, informed, pre-emptive action during the flood season.

In the following years, CEOS Agencies and their partners in academia and at research institutions joined forces to develop a pilot program aimed at improving these modelling and monitoring services by incorporating new satellite assets for higher spatial, spectral, and temporal resolution. These programs also include advanced capabilities for crowd-sourcing to improve validation. These advancements make use of the Internet and are based on open source tools and services that are freely available to the public.

Figure 1: Namibian hydrologists manually measure flood water depth for map validation.

The tools and services are platform-independent and are in widespread use via personal computers and smartphones. Processing services and predictive models that were unavailable in the region 5 years ago have been converted to open-source code that is now freely available. Training on installation and operation of these open-source services have been conducted in-country on numerous occasions and those training courses are available as webinars, videos, and presentations that are all posted on the Internet for public access. In April 2014, CEOS Agencies kicked off a 3-year pilot to extend this approach to Southern Africa and establish a vision for sustainable satellite-based flood services in the region.

2.2 Mozambique

The Zambezi River is the fourth largest river in Africa, sustaining biodiversity and agriculture and generating hydroelectric power. However, nearly every year, moderate-to high-magnitude floods place hundreds of thousands of people and their livelihoods at risk. The countries in the Zambezi basin, in particular the downstream country of Mozambique with its vast delta area, have limited infrastructure and resources and thus lack the capacity to establish effective flood management, mitigation, and relief services plans or a flood forecasting system. Although some local flood forecasting efforts in the Zambezi basin exist, there is currently no integrated flood warning system, primarily due to poor communication facilities and limited exchange of information and data in real-time. Furthermore, flow and water-level measurement stations are sparse in most countries in the region.

The lack of information makes emergency response such as food aid distributions by the United Nations World Food Programme (UN WFP) very challenging. Reliable maps showing infrastructure and the current state of rivers and floodplain inundation (as illustrated in Figure 1) need to be delivered in near-real time to UN WFP field officers at ground level. With composite images and flood products from the array of satellites and services outlined below, there is a dramatic increase in mapping accuracy, as well as detailed information on the rise or fall of floods on a regular basis during the emergency response. Observations of floodplain inundation over time allow disaster relief agencies like the UN WFP to identify the most significant flood events and allocate resources and direct operations accordingly.

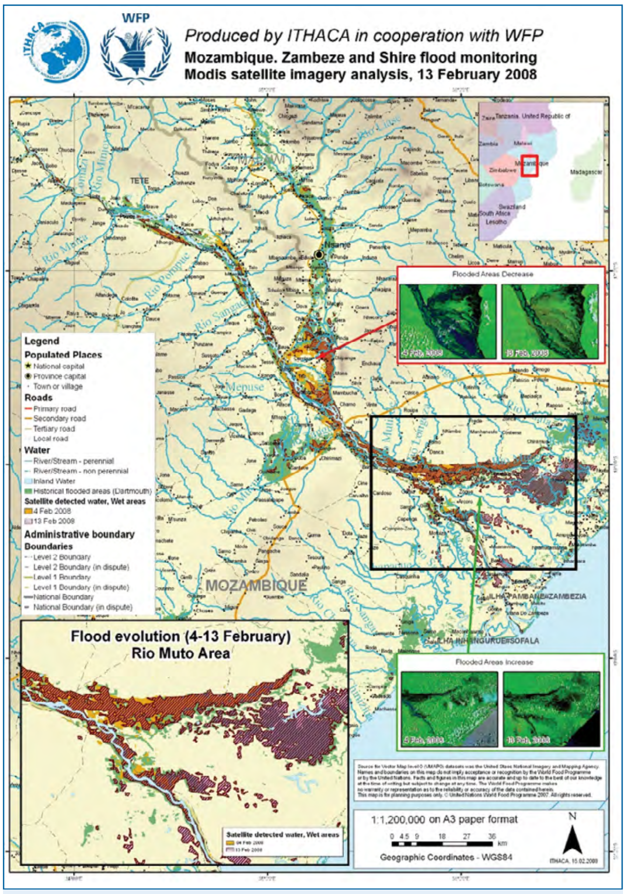


Figure 2: Map showing inundation extent in combination with infrastructure and other annotations.

The UN WFP is also involved in investigating the operational value of a flood forecasting model that derives a simple flood index to be used with regional rainfall predictions and observed antecedent and near real-time soil moisture fields as observed by NASA's upcoming Soil Moisture Active Passive (SMAP) mission. This investigation is taking place under NASA's SMAP Early Adopter program with lead investigators from the UN WFP.

2.3 Tools and Services

Flood information on both the global scale and at the local level is utilized in national and regional settings by practitioners in those areas through an integrated set of product publishers and consumer clients.

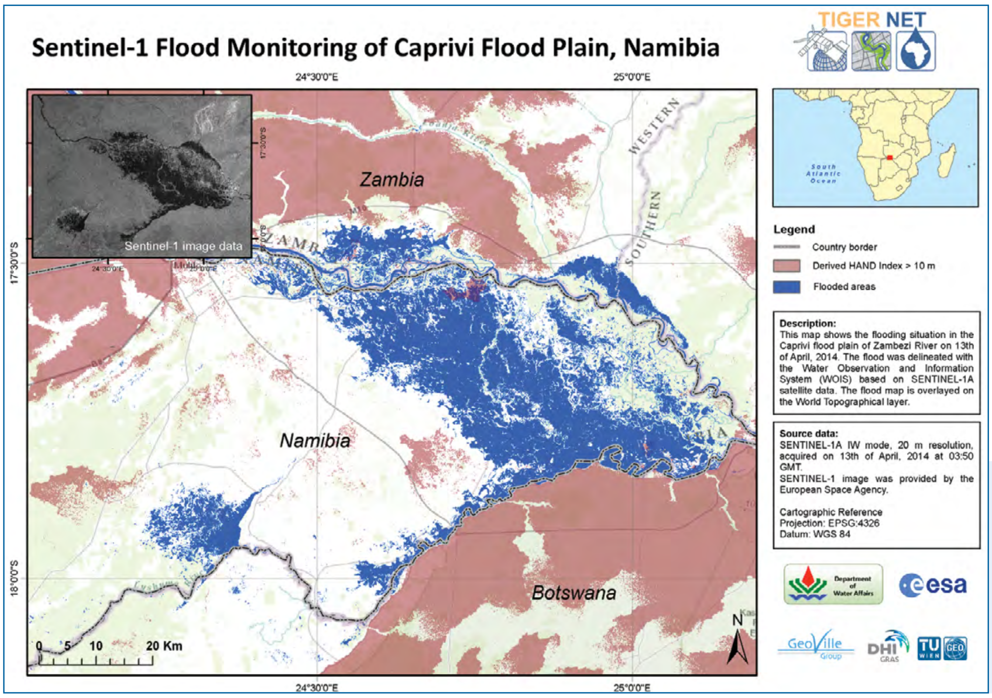
Flood maps are made freely available in near-real time every day by a unique global flood monitoring system funded by NASA and operating at both the Goddard Space Flight Center (http://oas.gsfc.nasa.gov/floodmap) and at the Dartmouth Flood Observatory hosted by the University of Colorado (http://floodobservatory.colorado.edu) using daily images from low- and moderate-resolution instruments. With composite images, NASA produces cloud-free maps showing the locations of flooded areas along rivers, where hundreds of thousands of people may be affected.

The Continuous Routing of Excess Storage (CREST) model developed by the University of Oklahoma was implemented in Namibia, at the RCMRD, and at the South African National Space Agency during early 2014 and is currently operating daily to forecast floods on a local basis in the region. CREST is supported with on-site training by NASA's SERVIR program and on-going support is being provided by the University of Oklahoma.

The University of Maryland Global Flood Monitoring System provides flood monitoring and forecasts every 3 hours at both 12-km and 1-km resolutions. The system uses satellite-based rainfall information from the Multi-satellite Precipitation Analysis system using tropical rainfall measuring mission (TRMM) and global precipitation measurement (GPM) plus conventional information and a hydrological and routing combination model (the Dominant river Routing Integrated with VIC Environment or DRIVE system). The system provides global flood detection, stream-flow estimates, and inundation-mapping images and output data at resolution as fine as 1-km and rainfall forecasts using the NASA GEOS-5 model.

The Water Observation and Information System is an open-source tool that enables African water authorities to produce and apply a range of satellite EO products needed for Integrated Water Resource Management in Africa. The system has been developed in close collaboration with eight trans-boundary and national water authorities in Southeast Africa. Each water authority has been trained in the use of the system in order to develop a local capacity for monitoring, assessing, and inventorying water resources using satellite data. In the case of Namibia specifically, the capabilities for hydrological modelling, flood forecasting, and mapping have been demonstrated (see Figure 3). The full software package (TIGER) has been publically released.

The Open GeoSocial Application Programming Interface (API) provides high resolution optical and radar imagery and turns them into flood maps on an expedited basis to supplement the products from the daily modelling and monitoring systems. RCMRD was the first to implement the API, and the second site targeted for installation is

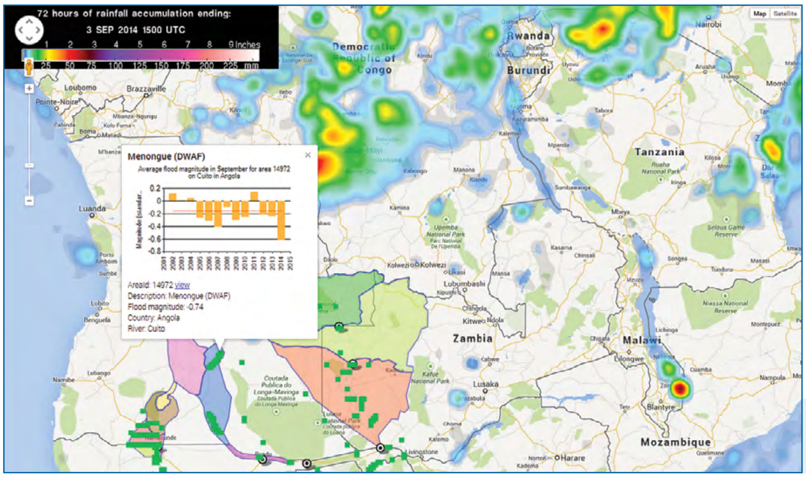


Description:
This map shows the flooding situation in the Caprivi flood plain of Zambezi River on 13th of April, 2014. The flood was delineated with the Water Observation and Information System (WOIS) based on SENTINEL-1A satellite data. The flood map is overlayed on the World Topographical layer.

Source data:
SENTINEL-1A IW mode, 20 m resolution, acquired on 13th of April, 2014 at 03:50 GMT.
SENTINEL-1 image was provided by the European Space Agency.

Cartographic Reference
Projection: EPSG:4326
Datum: WGS 84

Figure 3: As one of its first images, the Sentinel-1a mission covered the flood extent in the Caprivi plain on April 13, 2014. The Sentinel-1a Interferometric Wide Swath mode allows flood maps in high resolution of 20m.



Menongue (DWAF)

AreaId: 14972 view
Description: Menongue (DWAF)
Flood magnitude: -0.74
Country: Angola
River: Cuito

Figure 4: Namibia Flood Dashboard integrates satellite- and ground-data products for user analysis.

Namibia. The "Dashboard" node of the API is being used by the Namibia Department of Water Affairs and Forestry to post their daily flood bulletins, river gauge readouts, and emergency station (e.g., schools) status, in addition to housing the monitoring and modelling flood maps.

The approaches outlined above are being extended to two other CEOS regional pilots – South East Asia, and Caribbean/Central America – mirroring the approach taken in Southern Africa. All three regional pilots are being integrated with a global component for synchronization of records and results.

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2.4 Conclusion

The CEOS regional Flood Pilots offer a unique vehicle to federate a myriad of initiatives that independently offered increased capacity, but collectively begin to offer the perspective of a sustainable approach to flood management on a region-by-region basis. Combined with the global efforts put forward by the CEOS Flood Pilot, CEOS and its local, national, and regional end users are leading the way toward the definition of a global system for high-resolution flood and water management.

Further information

Soil Moisture Active Passive (SMAP):
https://smap.jpl.nasa.gov

Continuous Routing of Excess Storage (CREST):
http://hydro.ou.edu/research/crest

SERVIR:
https://servirglobal.net/Global.aspx

University of Maryland Global Flood Monitoring System:
http://flood.umd.edu

TIGER:
www.tiger.esa.int/page_eoservices_wois.php

Flood Maps Workshop:
https://github.com/vightel/FloodMapsWorkshop

Namibia Flood Dashboard:
http://matsu-namibiaflood.opensciencedatacloud.org

3

Australian Flood Mapping

Geoscience Australia (GA) contributes to a greater understanding of natural hazard and disaster exposure through observations of water from space. This supports Australia's capability to reduce the economic, social, and environmental impacts of flood events.

3.1 Historical Challenge: Australia's Floods

With extreme vulnerability to flooding, the management of flood hazard is a key challenge for Australian communities, governments, insurers, planners, and industries. In financial terms, floods are one of the most damaging forms of natural hazard faced by Australia.

Historically, flood studies commissioned to understand exposure to floods have focused on populated areas, which in Australia are primarily located around the coast. This is unsurprising, as these areas have the greatest potential to sustain the highest damage in the shortest period of time. However, this left a significant information gap in understanding flood hazard, and surface water behaviour more generally, particularly in Australia's extensive inland areas.

Satellite data are playing a key role in filling this gap, complementing flood studies and in-situ data to assist in decisions that can minimise loss of life, loss of property, and disruption to key economic sectors such as agriculture, mining, and energy.

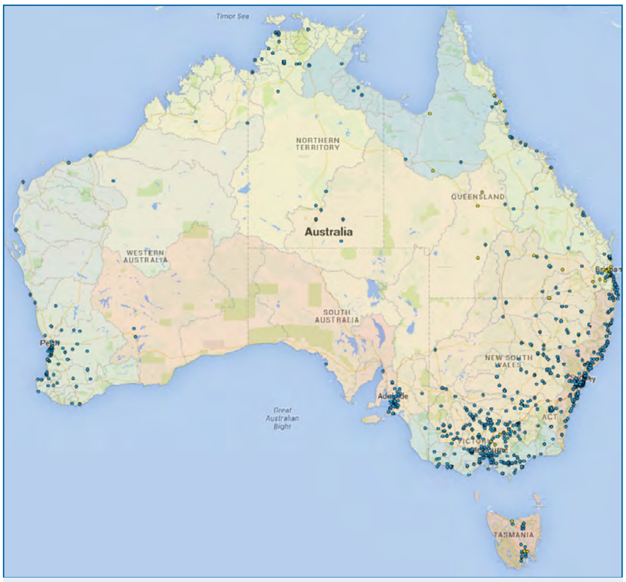

Figure 1: The Australian Flood Studies Database collates data from flood studies undertaken across Australia. This map shows the locations for which flood studies are available, and is an extract from the Australian Flood Risk Information Portal which links to the database.

3.2 Water Observations from Space

In 2011, the Australian Government commissioned the National Flood Risk Information Project (NFRIP) to increase the quality, availability, and accessibility of flood information across Australia. A key component of this project was the development of a water-observations product that capitalised on the unique capabilities of satellite observations to provide a consistent nationwide assessment of where surface water has been observed over previous decades.

WOfS was first released in 2014. Through this tool, GA has harnessed Earth observations from space, collected by the United States Geological Survey's Landsat series, to develop the world's first continent-wide map of the presence of water over a 25-year period at "paddock-scale".

The information produced by WOfS provides an easily accessible summary of how frequently surface water has been observed over the continent between 1987 and the present day. It shows where bodies of water half a football field – or larger – have always been observed, such as the presence of permanent water bodies including lakes or dams; have occasionally been observed including flooding; or have never been observed.

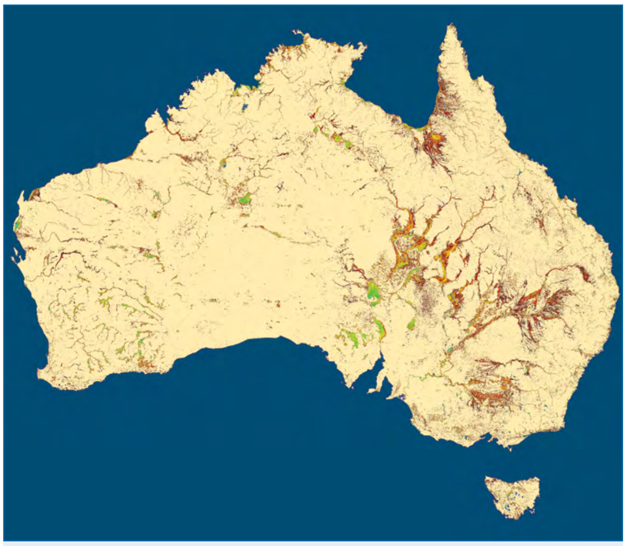

Figure 2: This WOfS summary product shows how often surface water has been observed. The colour scheme indicates frequently observed water (such as permanent lakes and dams) in purple and blue, down through greens to infrequently observed water (such as floods) in yellows, and finally to very low percentages in red.

In addition to providing this summary information, WOfS facilitates a better understanding of how water moves through the landscape over time. These insights are important, as the most appropriate mitigation approach for an area that is frequently inundated for short periods may be very different to the most appropriate approach for an area infrequently inundated for long periods.

A key feature and benefit of WOfS is the consistency and depth of data it provides. This requirement for data consistency and depth meant that WOfS was only economically viable through the use of satellite EO. The Landsat series was able to deliver consistent data across the very large Australian landmass, at regular intervals, at the decades-long time scales required for such a product. For a typical location, over 600 observations covering 27 years are used. For some locations, over 1000 observations are available.

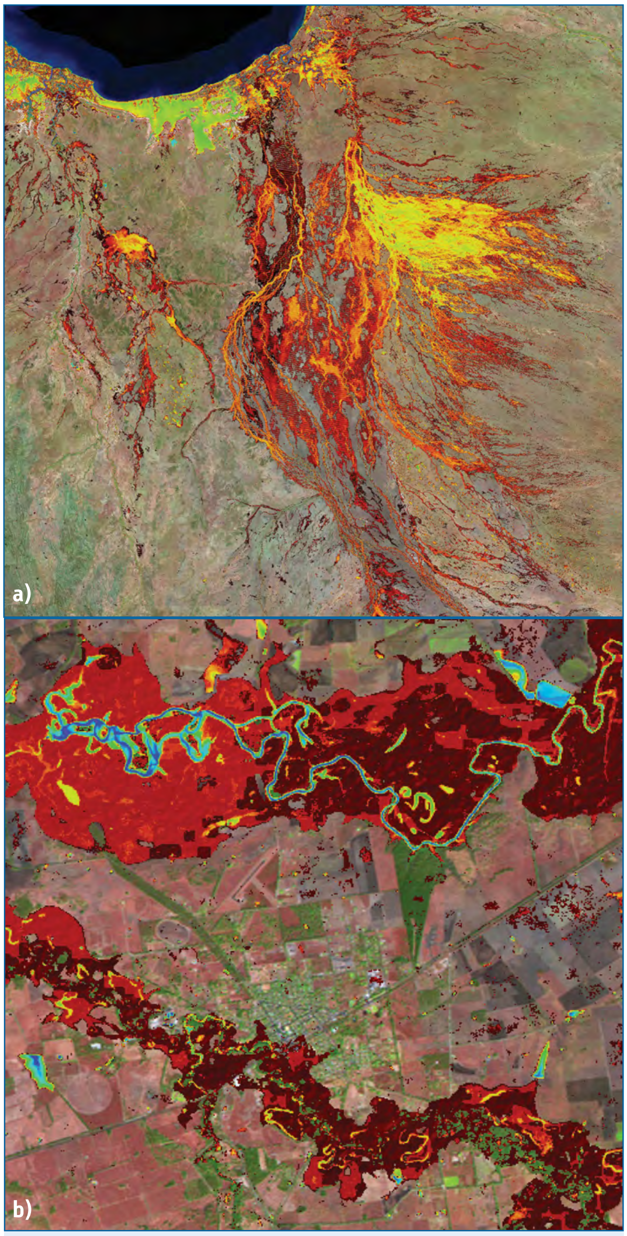

Figure 3: **a)** shows the northern Australian rivers flowing into the Gulf of Carpentaria, an important cattle-farming region. This is a broad, flat floodplain with flooding driven by the yearly wet season. The results for this region show large areas (in yellow) that are inundated regularly but also spend much time totally dry.

b) shows the area around the town of Chinchilla in southern Queensland, an important cropping region. The results here show that the neighbouring rivers are usually quite small (blue areas) but occasionally experience severe floods (in red) large enough to inundate the town itself.

3.3 Application of the Product

Although less densely populated, the inland areas of Australia are important. They are home to significant agricultural and resource industries; provide key rail and road transportation links to connect major economic centres; and house environmental assets, whose importance to communities and economic activity located considerable

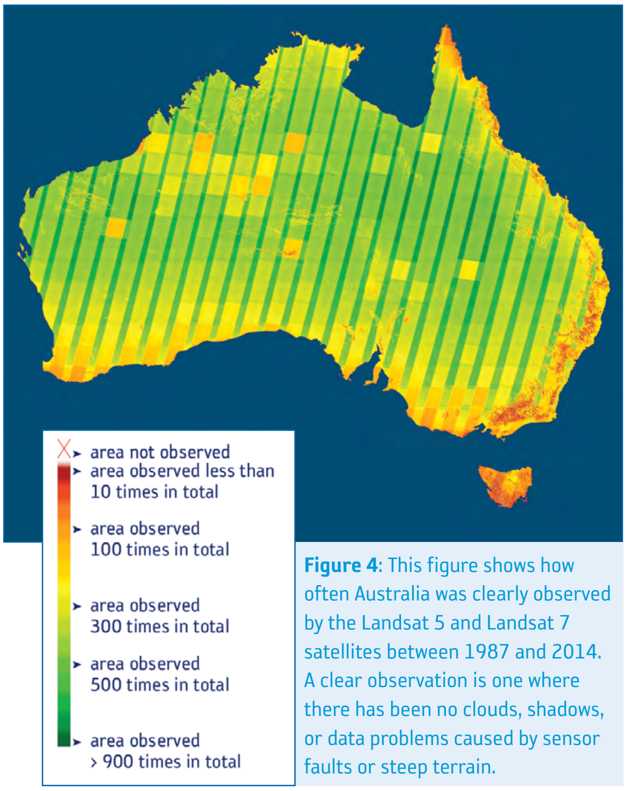

Figure 4: This figure shows how often Australia was clearly observed by the Landsat 5 and Landsat 7 satellites between 1987 and 2014. A clear observation is one where there has been no clouds, shadows, or data problems caused by sensor faults or steep terrain.

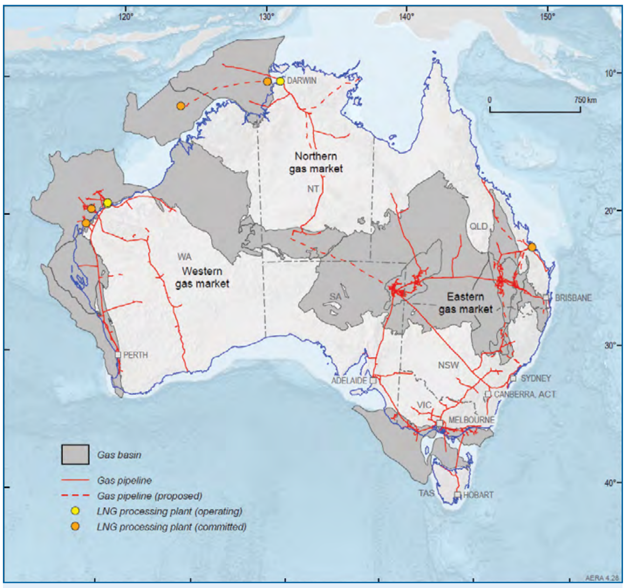

Figure 5: This map shows the location of major identified gas basins and infrastructure in Australia. Although significant gas activity occurs in offshore areas, significant inland deposits make understanding flood hazard in these areas important.

Image credit: GA and BREE, 2014, Australian Energy Resource Assessment, 2nd Ed. GA, Canberra.

distances away is only just becoming apparent. The flat topography of these inland areas makes them particularly vulnerable to flooding, which can cover very large areas, take months to dissipate, and behave in less predictable patterns.

The WOfS tool provides planners, civil protection agencies, insurers, governments, and communities with a consistent set of data that can be used to support a range of disaster mitigation applications in these important areas.

For planners, the ability to understand how water behaves in these landscapes can support improved decision making around what to build and where. Such decisions can significantly reduce the duration and extent of direct flood impact and reduce flow on economic impacts. Improved decision making can also help mitigate infrastructure reconstruction costs, which are often borne by governments.

For civil protection agencies, understanding water behaviour in the landscape can inform response planning. Modelling when, and to what extent, communities may be isolated can enhance preparatory activities, particularly in coordination and prioritisation of logistics activities (such as movement of essential supplies) to homesteads or communities that may be isolated for long periods.

For insurers, the level of understanding provided through WOfS can assist in setting insurance premiums. While the availability of appropriately priced insurance products is important to both the insurers and the insured, it is also important to governments who desire a well-functioning insurance market as a way of reducing the reliance on government in the case of a disaster.

For governments, keeping flood hazard at 'top of mind' is a key challenge. With its consistent, comparable and regularly updated quantitative data, WOfS offers a highly visual and intuitive tool for use in community education and outreach around flood hazards.

For communities, WOfS provides a freely available tool around which discussions can take place. Providing quantitative and up-to-date data can inform discussions and support decisions that can reduce exposure to risk.

In addition, the WOfS tool offers unique insights and data that may otherwise be unavailable. The consistent and quantitative nature of this product makes it a valuable tool to complement more targeted products, such as flood studies.

3.4 Making Satellite Imagery Work

Historically, satellite imagery has been difficult to use to its full potential, particularly over long time periods and very large areas, because of the large volumes of data. However, significant technical progress has been made and the technical barriers to making full use of EO from space are lowering. One example of these advances is the Australian Geoscience Data Cube, developed collaboratively by GA, CSIRO, and the National Computational Infrastructure, which underpins WOfS.

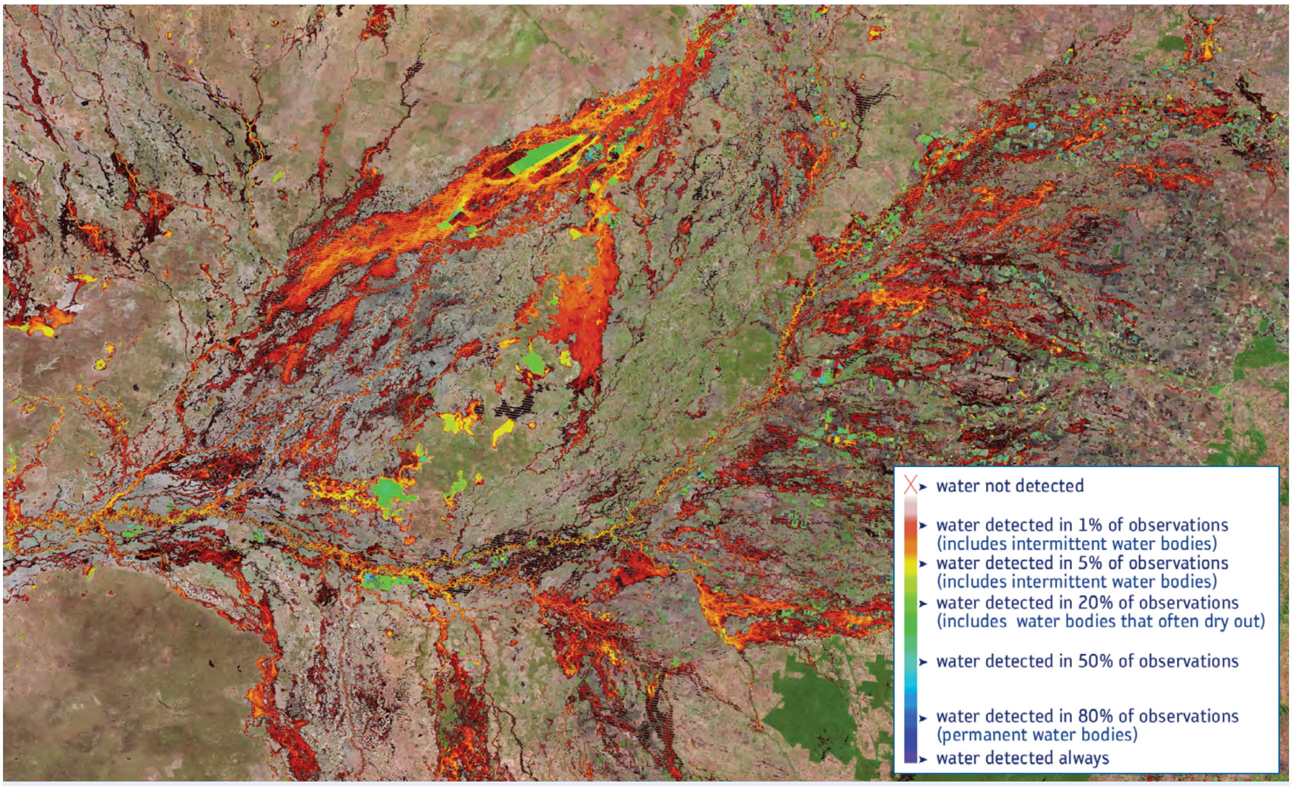

Figure 6: The Border Rivers area of northern New South Wales and Southern Queensland is one of Australia's biggest and most important cotton farming areas. This figure shows how WOfS demonstrates the broad flooding that occurs in this region.

The Data Cube enables the full archive of Landsat data for the entire Australian continent to be analysed in a matter of hours, enabling this source of data to be used in a manner not previously possible. This new approach presents exciting opportunities for the application of EO from space to other aspects of DRR, such as mapping of fire history, where a consistent national understanding of hazard behaviour over long periods is critical.

3.5 Future of WOfS

Geoscience Australia will continue developing the WOfS, with future plans including incorporation of data from new satellites, such as the Europe's Sentinel series, to provide an even richer product.

The WOfS technology has significant potential for transfer to other geographic areas, particularly developing countries with similar topography to Australia. As the product is based on the global Landsat dataset, technology transfer is simplified and it can also be adapted to local conditions with the potential for results to be shared with the international DRR community to create a global picture.

Both the WOfS tool and the Australian Geoscience Data Cube technology that underpins it are available as Open Source under Creative Commons licenses.

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Further information

WOfS is accessible from the Geoscience Australia: **www.ga.gov.au**

4

Uses of Satellite EO for Disaster Risk Assessment

Over the past two decades, the annual economic losses resulting from disasters worldwide have increased from $US50 billion to US$200 billion. Increasing emphasis is being placed on understanding and managing risk in the key financial organizations that deal with natural disasters, i.e., the re/insurance industry, and the international development banks.

EO satellites provide a wide range of valuable environmental information that is very pertinent to disaster-risk assessment and reduction. This case study explores recent assessments of the utility of EO information already carried out in close collaboration with end-users within the context of their operational activities. These end-user organisations include SwissRe, Willis, Guy Carpenter, Allianz, and PERILS from the re/insurance sector, and World Bank country operations teams from the international development sector.

4.1 Risk Assessment in the Re/Insurance Sector

The uptake of EO-based services is currently rather limited within the insurance sector. A recent survey by the European Association of Remote Sensing Companies (EARSC) shows that less than 1% of total revenues generated by EARSC members are from clients within the insurance and financial areas.

A few years ago, ESA began investigating the potential to expand the use and uptake of EO-based information in cooperation with major industry players through an informal working group. In addition to the technical discussions of what EO could deliver, innovative new business models were considered for delivery of information into the industry. The idea was to use an existing information platform developed and co-financed by the industry itself, through PERILS, an independent, Zurich-based company that provides industry-wide catastrophe data for the insurance sector, intermediaries, and other service-providing organisations.

The initial focus was on floods, as these represent a major source of disaster-related events, with approximately half of all of the activations of the International Charter on Space and Major Disasters being associated with floods. The first step was to define the industry requirements for flood information products and test the feasibility of using EO to meet these requirements through near real-time coverage of a major European flood event, supplying the insurance industry with critical information to rapidly assess exposure and potential losses, and allowing improved risk modelling.

The Insurance working group triggered the trial on Monday June 3, 2013 following the development of a major flood event in Germany, the Czech Republic, and Hungary. During the event, flood-mapping products were produced on an almost daily basis for 10 days and made available to more than 400 individuals from more than 150 organisations of the insurance sector via the PERILS web portal.

A wide range of satellite sensors was utilized for the trial, both radar (COSMO-SkyMed, TerraSAR-X, RADARSAT-2) and optical (SPOT-5/6, Pleiades, MODIS), and Landsat as historic reference data. The daily products provided a combination of low-resolution (50–100m) wide-area coverage for mapping of regions and high-resolution (0.5m) products for cities. Four weeks after the end of the flood event, a maximum flood-extent product was produced and delivered via the PERILS web portal. This product is derived from satellite observations, in-situ observations, and modeling, and delineates the maximum boundaries of the flood event.

The near real-time flood maps were used within the insurance industry mainly to continuously assess their potential losses. The maximum flood extent is used for claims management and to validate and improve existing flood models within the industry.

The general consensus was that the trial had been very useful as a hands-on demonstration of the benefits of EO for a major flood, but that the time interval from the occurrence of the event to the provision of the first flood maps has to be shortened (to within 48 hours maximum) to be fully used in loss estimation. In this flood event, such delays were encountered because, in addition to this trial, the Copernicus/GMES Emergency Service and the Charter were also activated (for Government users) with sometimes conflicting and higher-priority access to the required satellite data.

Figure 1: Rapid Flood Extent over the city of Magdeburg, Germany, derived from a Pléiades-HR data (70cm) acquired the 10th of June 2013 during the Elbe River flood event.

Image credit: SERTIT, CNES/Astrium Services/Spot Image

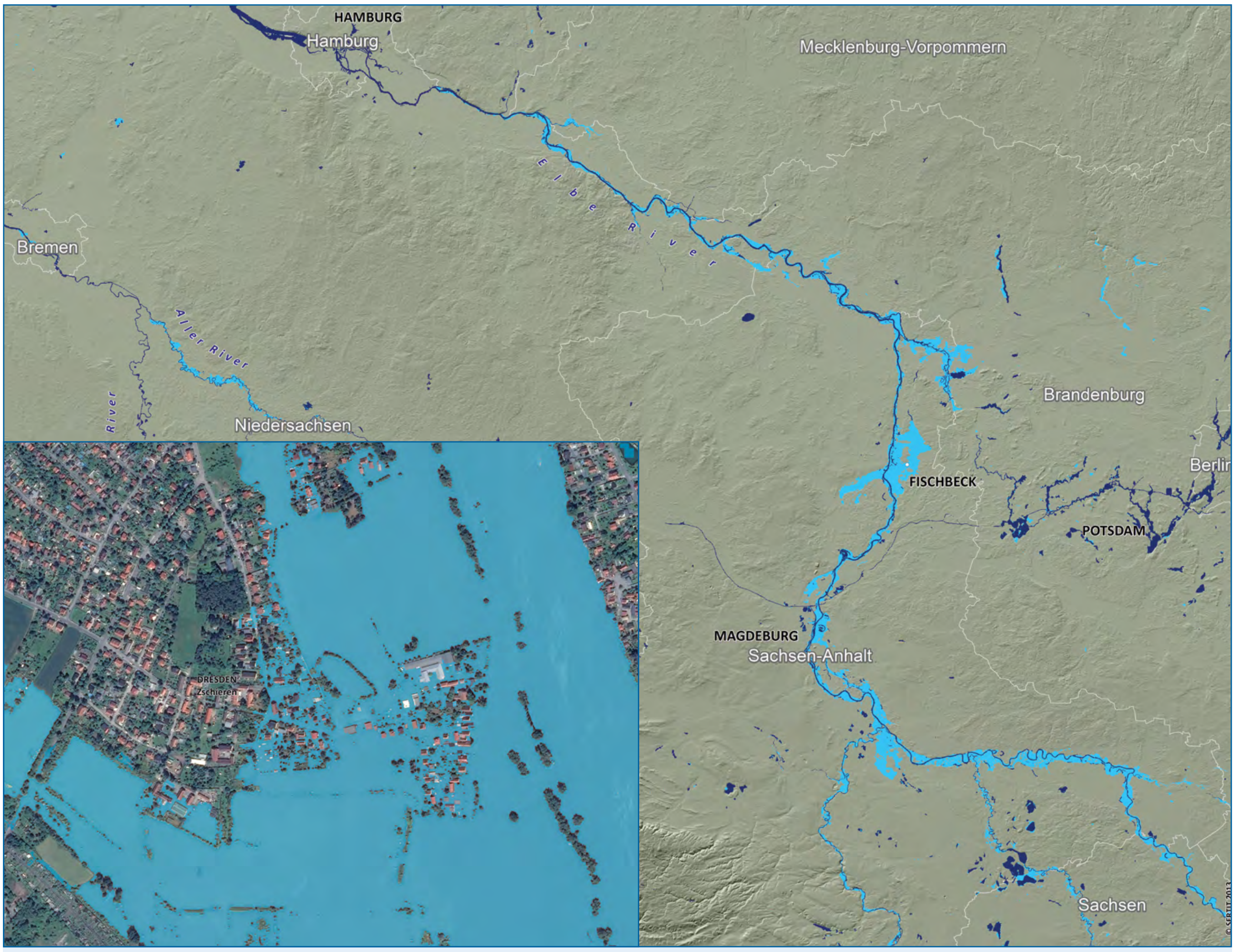

Figure 2: June 2013 Maximum Flood Extent over more than 400km of Elbe River in Germany based on Rapid Flood Snapshots. (Background: SRTM DEM)

Image credit: VISTA, SERTIT, USGS

Figure 3 (inset): Rapid Flood Extent over the area of Zschieren in Dresden, Germany, derived from a Pléiades-HR data (70cm) acquired the 5th of June 2013 during the Elbe River flood event.

Image credit: SERTIT, CNES/Astrium Services/Spot Image

4.2 Risk Assessment in the International Development Sector

Multilateral Development Banks (MDBs) provide support to developing countries to reduce poverty and stimulate economic growth. This involves dealing with the complex challenges of climate change, rapid urbanisation, threats to food security, natural resource depletion, and the risk of natural disasters. The provision of accurate and consistent geospatial information is a key component of their activities and the world expects MDBs to use the best available datasets to support strategic planning and to ensure that economic growth is achieved in an environmentally sustainable manner.

Since 2008, ESA has been collaborating with the main MDBs (World Bank, European Investment Bank, International Fund for Agricultural Development, and more recently the Asian Development Bank) to investigate the use of EO information for the planning, implementation, monitoring, and assessment of international development projects and programmes. ESA and the World Bank have jointly implemented 33 specific technical assistance activities delivering EO-based products and services to World Bank project teams and/or to local stakeholders in the countries where the projects are being implemented. The overall portfolio of projects spans all regions of World Bank operations (i.e. East Asia Pacific, Africa, Latin America & Caribbean, South Asia, and Europe & Central Asia) and a wide range of sectors such as Forestry & Agriculture, Urban Development, Water Resources Management, Marine Resources, Coastal Zone Management and Disaster Risk Management. Ten of these 33 activities concern DRR, as described in Table 1.

The rising economic impacts of disasters across the globe are attributed to the growing concentration of assets and population in areas at high risk of natural hazards. Cities of

Project Title	Hazard Type(s)	Region or Site	Main sector
Climate Change Adaptation and Natural Disasters Preparedness in the Coastal Cities of North Africa	Subsidence	Tunis, Alexandria	Urban risk
Assessing Vulnerability in the Metropolitan Area of Rio de Janeiro	Landslides, Flooding	Rio de Janeiro	Urban risk
Building Flood Defence Systems in Guyana	Coastal flooding	Guyana	Disaster Risk Management
Multi-Hazard Vulnerability Assessment in Ho Chi Minh City and Yogyakarta	Hydromet hazards, landslides, volcanoes, earthquakes	Ho Chi Minh City and Yogyakarta	Disaster Risk Management
Building Exposure Maps of Urban Infrastructure and Crop Fields in the Mekong River Basin	Flooding	Mekong River Basin, Cambodia	Integrated water resources management
Analysis of Land Subsidence in Jakarta	Coastal flooding	Jakarta	Disaster Risk Management
Risk information services for DRM in the Caribbean	Landslides	Belize, Dominica, Grenada, St Lucia, St Vincent & the Grenadines	Disaster Risk Management
Comprehensive Climate Risk Mitigation in Sri Lanka	Flooding	South Asia	Disaster Risk Management
EO Information for Hydromet and Climate Services	Several	Several	Climate Change
Sustainable development of mountain regions in the Himalayas	Landslides, Flooding, glacier lakes.	Several	Disaster Risk Management

Table 1: ESA and World Bank technical assistance activities related to DRR

the developing world accommodate more than 50% of the global population and hundreds of billions of dollars worth of assets. The projects focused on demonstrating how EO data and information can support urban risk assessment to support the formulation of better disaster-resilience strategies.

Although there are a number of highly specialized EO products and services addressing the challenges of DRM that are currently being assessed for operational use by World Bank teams, a specific example is given in further detail in the following section.

> *“This pilot shows that satellite-derived flood information has the potential to satisfy a long-standing industry need for quick and detailed flood information during and after large events.”*
>
> Eduard Held, Head of Products at PERILS

Example: Subsidence Risk in Jakarta

Jakarta is highly vulnerable to the impacts of natural disasters. The greatest risk facing the city, one that imposes very high human and economic loss, is flooding. Particularly in the north of the city, the local neighborhoods are extremely vulnerable to damages from seawater intrusion and coastal inundation. This is largely because the flood risk is aggravated by rapid land subsidence. The evidence shows that if sustained at the current rate, subsidence will result in coastal defences sinking to 4–5m below sea level by 2025, resulting in some industrial/residential areas and ports being completely submerged in the coming decades.

Land subsidence in Jakarta is largely caused by uncontrolled ground water extraction – withdrawal of underground water through deep wells to compensate for the lack of access to piped water. It is estimated that 20% of such wells are over 100m deep and often cause aquifers to collapse. Other contributing factors include heavy constructions exacerbated by fast-paced urban development, as well as the natural consolidation of soil and tectonics.

To help address the situation, the World Bank is currently implementing a flood mitigation project in collaboration with Jakarta's local municipal government (DKI) and the Indonesian Ministry of Public Works. This includes revitalization of Jakarta's drainage canals and flood retention ponds, establishment of a Flood Management Information System, and increasing the capacity of the existing hydraulic networks. Collection of detailed geospatial information concerning land subsidence patterns greatly contributed to this process.

With an archive of imagery with good spatial and temporal coverage spanning the past two decades, EO data yielded land motion information at an unprecedented level of detail and accuracy. As illustrated in Figure 1, two parallel InSAR studies from two different satellites were conducted using:

- Very High Resolution (VHR) COSMO-SkyMed radar data gathered from October 2010 to April 2011, which yielded very high spatial and temporal density of measurements in the specific constructed areas. VHR radar imagery from ASI's COSMO-SkyMed satellites provides a very dense network of terrain motion measurements over a relatively limited time period;
- High Resolution (HR) ALOS archive data from January 2007 to the end of February 2011, which provided information concerning terrain motion of higher amplitude over the 4-year period. Because of the systematic data collection over strategic areas, L-band radar imagery from JAXA's ALOS mission can provide measurements over a long time span.

Satellite EO offered a unique insight into past trends as well as state-of-the-art tools for monitoring present and future terrain deformations. The EO results revealed that the sub-districts of Penjaringan, Cengkareng, the South Center of Jakarta, and the suburban district of Cikarang are affected by strong subsidence rates. In the Jakarta Bay (District of Penjaringan), where a system of sea walls, water draining channels, canals, and water reservoirs protecting the land from sea flooding are located, the maximal detected subsidence rate is more than −15cm/year, resulting in a deformation of more than −60cm over the period of 4 years.

The benefits of the mapping products go beyond improvements in resolution and detail in comparison to alternative techniques. In fact, the use of EO was extremely useful in framing a World Bank dialogue with the local government to convey the importance of prevention actions. The occurrence of severe subsidence was relatively well known to the public in the past but it was largely unaddressed as a risk factor despite alarming figures. Institutional fragmentation as well as the absence of effective mechanisms for metropolitan coordination hindered the local government's ability to act on the policy and technical level. The unique insight offered by satellite EO gave the opportunity to raise the profile of the land subsidence problem and bring it back to light from an entirely new perspective.

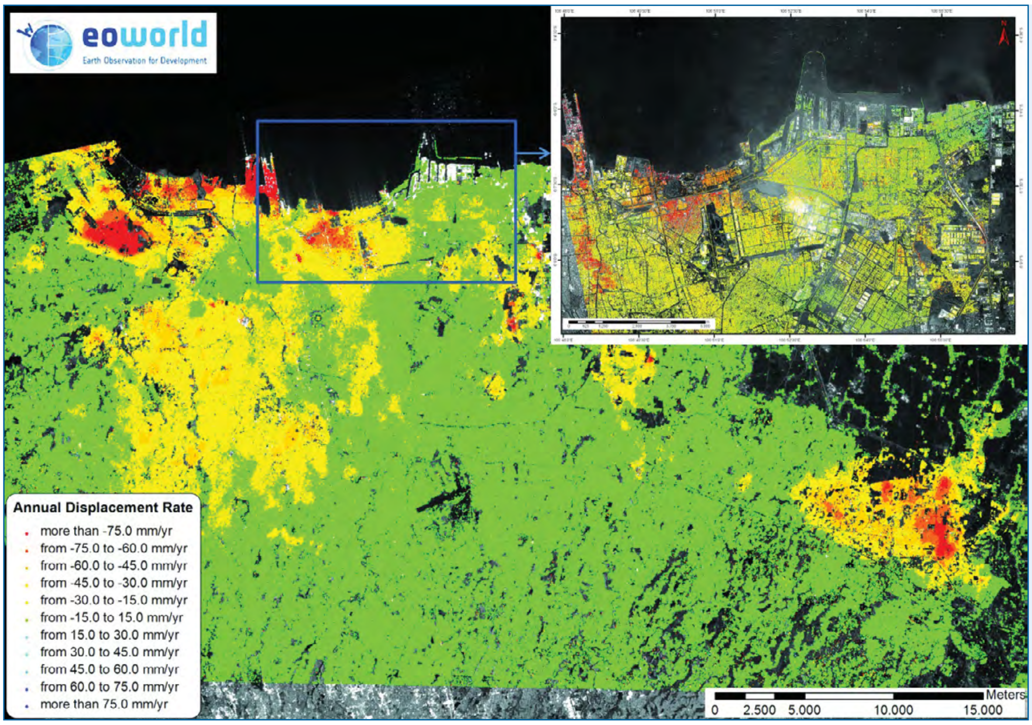

Figure 4: Top right: land deformation map over Jakarta at the scale 1:30,000 derived from the analysis of 12 COSMO-SkyMed data products acquired from October 2010 to April 2011. Background: Land deformation map over Jakarta at the scale 1:50,000 derived from the analysis of ALOS data acquired from January 2007 to February 2011. Some sectors of Jakarta Bay show an accumulated subsidence of more than 60mm.

Image credit: Altamira Information; COSMO-SkyMed data distributed by e-Geos.

> *“Previous information on subsidence was largely based on terrestrial sample point monitoring, and did not offer anywhere near the resolution, quality or timeliness possibilities offered by this analysis. This study provided much more recent, comprehensive, and encompassing information at higher resolution than previously available. It was suitable for use both to update previously available data on Jakarta’s subsidence and particularly as a means to achieve a higher sense of urgency when communicating the issue to Jakarta decision makers and stakeholders.*
>
> *The Government is implementing a World Bank-supported flood mitigation project targeted at restoring existing flood channels. The information on subsidence at a local level provides knowledge to enable a better idea of infrastructure reconfiguration needs going forward in the long-term flood mitigation efforts in Jakarta. The high-resolution analysis provides a more compelling justification for projects and greater impact in project discussions and dialogue with the authorities and stakeholders. The timeliness and relatively quick analysis provides the possibility to shorten the project preparation timeframe.”*
>
> Fook Chuan Eng, Senior Water and Sanitation Specialist, World Bank Jakarta Country Office

4.3 Conclusions

It is evident that satellite EO-derived products and services have significant potential to provide key (sometimes unique) information to support risk assessment and the formulation of better disaster resilience strategies for risk reduction.

Over the next few years, the entry into operations of the European EO programme Copernicus, headed by the EC in partnership with the ESA co-funding entity for the Sentinels programme, will see EO data delivered operationally from European and National missions on a previously unprecedented geographic scale, frequency, and quality.

The opportunity therefore presents itself to continue working with key stakeholders in the field of DRM to establish the use of satellite EO-derived information as ‘best-practice’, on a fully sustainable basis.

Case study contributors:

Stephen Coulson, Ola Grabak, Philippe Bally (ESA)

Eduard Held (PERILS)

Further information

World Bank, Earth Observation for Development:
www.worldbank.org/earthobservation

Copernicus Programme:
www.copernicus.eu

Insurance Working Group European flood trial products:
www.perils.org/web/products.html
(simple registration required)

5

Sentinel Asia – Space-Based Disaster Management Support

The Sentinel Asia initiative is a voluntary, grass-roots and best-effort-based collaboration between regional space agencies and DRM agencies for humanitarian purposes. Sentinel Asia applies remote sensing and Web-GIS (Geographic Information System) technologies to DRM in the Asia-Pacific region and aims to:

- **Promote the use of space technology for DRM;**
- **Build partnerships between DRM and space agencies in the Asia-Pacific region;**
- **Promote utilization of data products by end users;**
- **Improve public awareness and knowledge transfer through capacity building activities;**
- **Provide a platform to perform these activities.**

5.1 Emergency Observation Activities

When a major disaster occurs in the Asia-Pacific region, the Sentinel Asia team triggers emergency observations from a number of EO satellites, based on specific observation requests of the Joint Project Team (JPT) and Asian Disaster Reduction Center (ADRC) members.

The ADRC was established in Kobe, Hyogo prefecture in 1998 to enhance the disaster resilience of its member countries, to build safe communities, and to create a society where sustainable development is possible. The Center works to build disaster-resilient communities and to establish networks among countries through many programs including personnel exchanges.

The following subsections are examples of events that triggered a Sentinel Asia response and detail the corresponding actions.

Large-Scale Flood, Nepal, August 2008

A large-scale flood occurred after a dyke burst in Sunsari district in southeastern Nepal on August 18, 2008. JAXA made an emergency observation using the Advanced Land Observing Satellite (ALOS) on August 22 and 24 (see Figure 2 (b)), following a Sentinel Asia-mediated request from the Nepalese International Centre for Integrated Mountain Development (ICIMOD) Survey Department and the Department of Water Induced Disaster Prevention.

JAXA-generated products indicating the inundation area were provided immediately to the Nepalese government. By overlaying these data with census information on population and houses, it was possible to create a map of the affected area (Figure 3) as well as data on the amount of damage, the potential number of victims, and the number of houses affected. This information was used to rescue victims, create a recovery plan, and to manage relief payments.

Long-Term Deluge, Thailand, October 2010

Long-term deluges tend to occur once every 50 years in the central and northeastern parts of Thailand; the last such event occurred in October 2010. In response to a Sentinel Asia request from the Geo-Informatics and Space Technology Development Agency of Thailand (GISTDA),

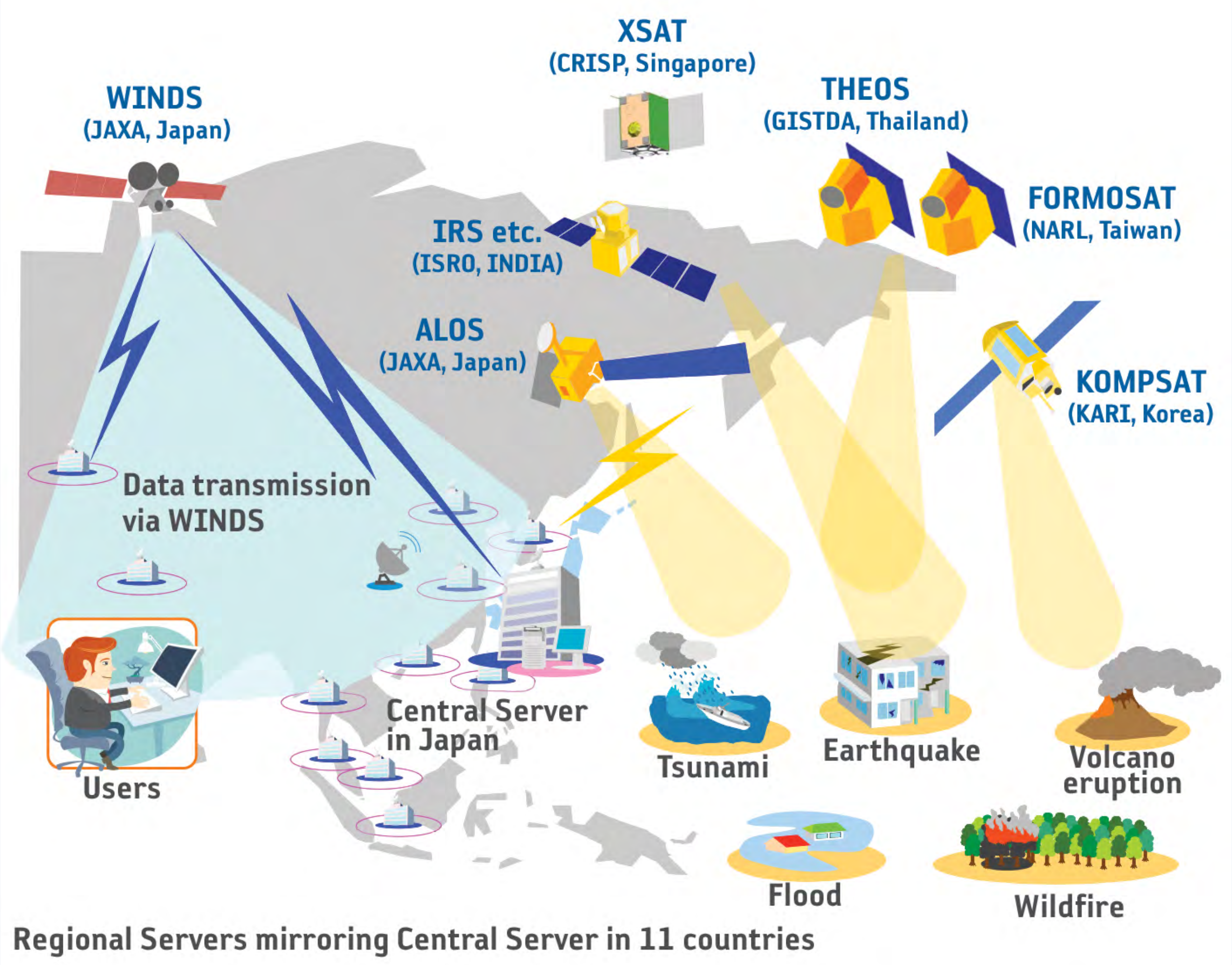

Figure 1: Conceptual illustration of emergency observation and data transmission via WINDS communications.

JAXA made emergency observations with ALOS on October 21, 2010 and provided the data to GISTDA using the Wideband InterNetworking Engineering Test and Demonstration Satellite (WINDS).

GISTDA generated inundation maps using the ALOS imagery and reported to the Cabinet Office every day. By overlaying house distribution information on a PALSAR-derived inundation map (Figure 4), the number of affected houses was counted and reported. The Thai government decided to compensate households whose homes had been directly affected and used these data to inform its relief payments.

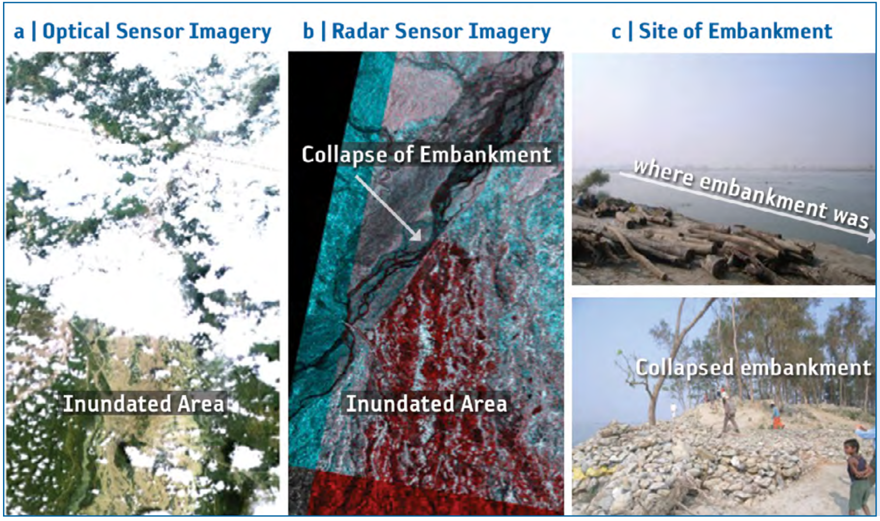

Figure 2: Flood in Nepal caused by the collapse of an embankment in August 2008. **(a)** Image from AVNIR-2 (optical sensor). **(b)** Image from PALSAR (radar sensor) aboard ALOS. Inundated area is shown in red. **(c)** Photo taken in December 2008 showing the area of collapsed bank (approximately 2–3km in length).

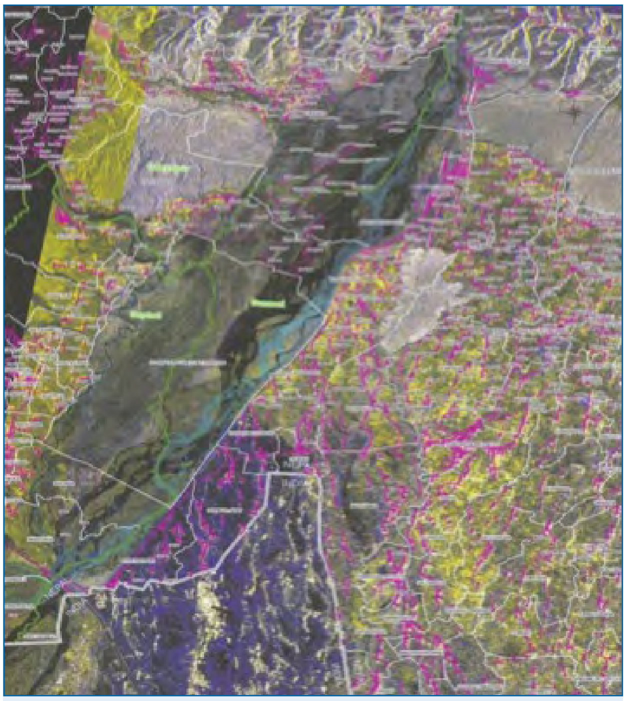

Figure 3: Map of the damaged area overlaid with census data.

Image credit: Survey Department of Nepal, JAXA

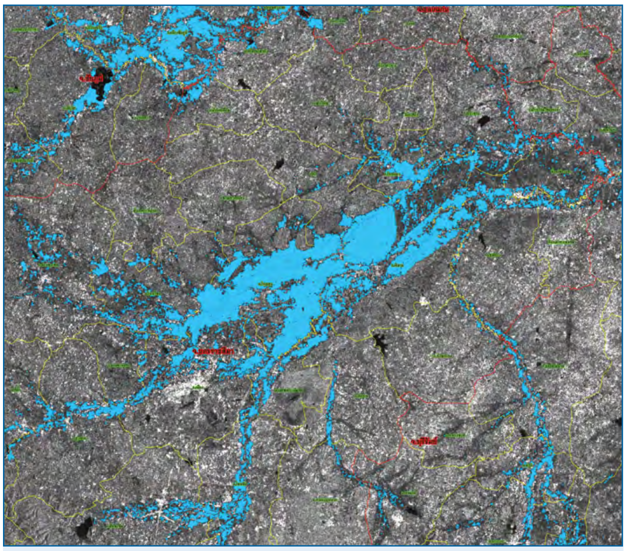

Figure 4: Flood inundation map generated using ALOS/PALSAR imagery. Blue shows the inundation area extracted from satellite imagery analysis.

Image credit: GISTDA

Great East Japan Earthquake, March 2011

A magnitude 9.0 earthquake, the strongest ever recorded in Japan and the fourth largest on world record since 1900, occurred in the Pacific Ocean near the Tohoku region at 14:46 JST on March 11, 2011. The earthquake and subsequent tsunami caused massive destruction along the Tohoku-Kanto Pacific coast of Japan.

JAXA immediately planned emergency observations using ALOS and simultaneously asked Sentinel Asia and the Charter (on behalf of the Cabinet Office) to carry out emergency observations. As a result, ALOS and other international satellites provided more than 6,000 satellite images for assessment after the earthquake. These images were processed and analyzed to facilitate their use by disaster management organizations and were provided to ten ministries, agencies, organizations, and municipalities, including the Cabinet Secretariat and the Cabinet Office for disaster management. The images helped to determine the extent of the damage over wide-ranging areas that could not be viewed from the ground or by aircraft and to plan disaster countermeasures.

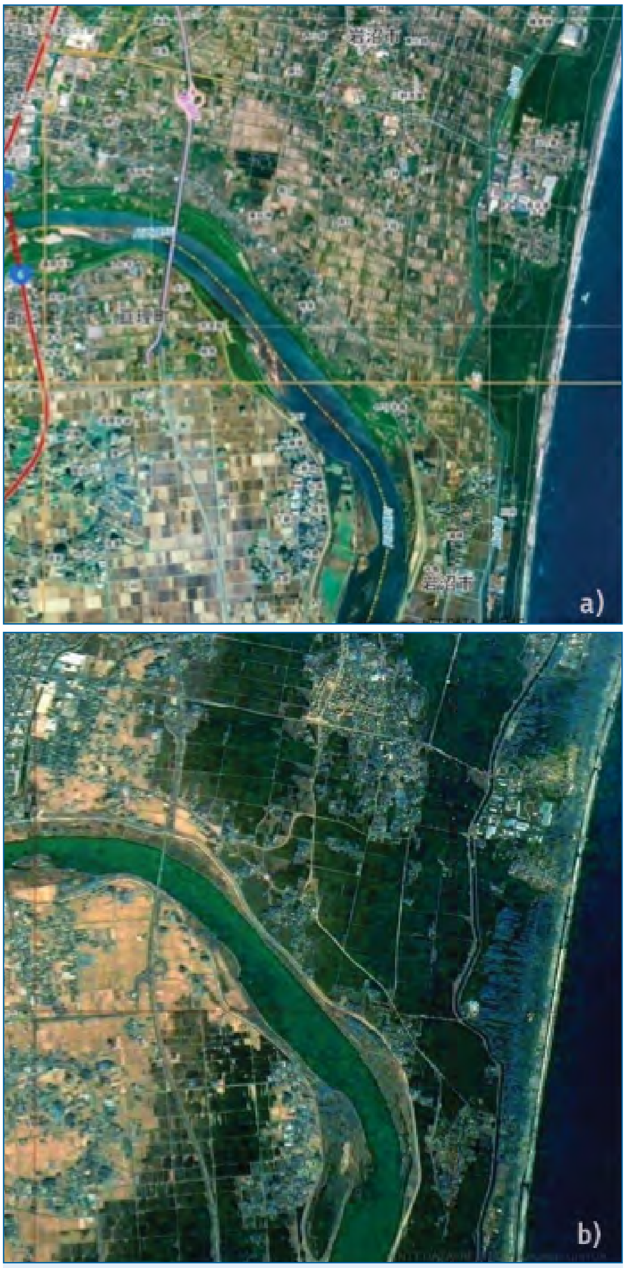

Figure 5: Satellite images of Natori: **a)** pre-earthquake observation by ALOS; **b)** March 14, 2011 by THEOS.

Image credit: JAXA, GISTDA

5.2 Improving the Connection to End Users and Becoming a Community-Operated System

Sentinel Asia Success Story (SASS) is an activity aimed at increasing:

1. Regional cooperation to promote utilization of Sentinel Asia by end users;
2. Local awareness and knowledge transfer through capacity building;
3. Human resources and human network development.

The following are examples of SASS activities.

Sentinel Asia Success Story in the Philippines

JAXA has been implementing SASS in the Philippines since 2009. ALOS pan-sharpened imagery and a Digital Surface Model (DSM) are used to map hazards related to lahars near Mt. Mayon, floods in Iloilo city, and landslides in Antique province. These products were created by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), and the Mines and Geoscience Bureau (MGB), respectively. This first phase of mapping occurred from the beginning of 2009 to March 2010. In the second phase, beginning in April 2010, Global Satellite Mapping of Precipitation (GSMaP) data have been used to produce landslide warnings in Albay; interferometry has likewise been used to monitor land subsidence in the Manila area and earthquake/volcanic eruptions at Mt. Mayon, Mt. Taal, and the Valley Fault.

Volcanic activity was recorded at Mt. Mayon in Luzon from December 14, 2009 and lava was confirmed to be flowing from the crater on December 20. About 47,000 people living near the volcano evacuated after warnings were issued by the Provincial government. JAXA made emergency observations with ALOS on December 25, 2009 at the request of PHIVOLCS through Sentinel Asia. PHIVOLCS created a lava deposit map of the eruption, which was used to inform decision makers at the National Disaster Coordinating Council (NDCC). Lava flow and lahar hazard maps were prepared beforehand using ALOS DSM in a cooperative effort between JAXA and PHIVOLCS, and these were supplemented by updated lava deposit data collected during the eruption.

GLOF Early Warning in Bhutan

The ADRC implemented the Glacial Lake Outburst Flood (GLOF) early warning system in Bhutan from 2009 to 2012, based on community cooperation in the Mo River basin with assistance from the Ministry of Home and Cultural Affairs, Bhutan. In this system, villagers living in an upstream, safe area are connected to the river-level gauging system and when they are alerted by the alarm they warn residents in downstream, hazardous areas.

After creating a map with elevation data for the upstream area of the Mo River and a hazard map using ALOS imagery based on past flood records in Punakha, community-based river-level gauges were installed for the GLOF early warning system. In addition, disaster education and training was carried out at the community level with local residents.

5.3 The Future of Sentinel Asia

Sentinel Asia's target is to provide up-to-date disaster information to end users and to help them better utilize it. JAXA has started an activity called "Mini-project" in collaboration with the Asian Institute of Technology (AIT) from 2013. This activity aims to:

1. Organize groups, including end users themselves, to make high-quality value-added data products for end users;
2. Improve pre-disaster preparedness by sharing existing hazard and risk maps, as well as ground GIS and other data, among group members and make new maps using Open Street Map;
3. Perform post-disaster evaluations.

In 2013, mini-projects were conducted in Sri Lanka, the Philippines, Bangladesh, and Myanmar. In 2014, mini-projects have been conducted in Indonesia and Vietnam. This activity will be expanded to other countries in the near future. A good human network is the foundation of the projects.

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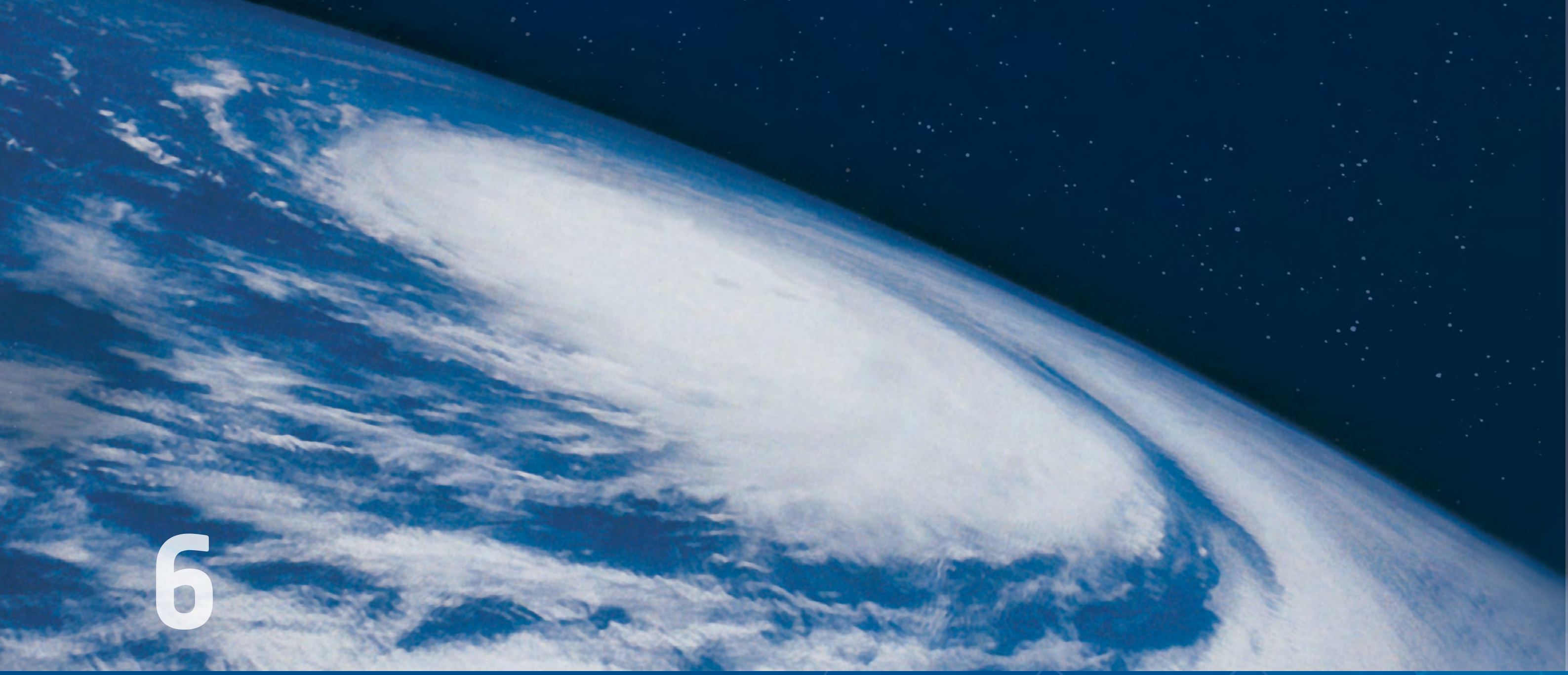
Further information

Sentinel Asia:
http://sentinel.tksc.jaxa.jp

Asian Disaster Reduction Center (ADRC):
www.adrc.asia



6

The International Charter on Space and Major Disasters

Every year, millions of people worldwide are affected by natural disasters. Increased frequency and intensity of events, along with concerns about possible links to climate change, has put disasters high on the list of modern-day challenges.

Recognizing the unique role that the combined satellite assets of many space agencies could play in support of disaster response, ESA and the Centre National d'Etudes Spatiales (CNES) initiated the International Charter on Space and Major Disasters following the UNISPACE III conference in 1999. They were joined by the Canadian Space Agency (CSA) in 2000, and together the three initial members laid down the operational foundations of the Charter. The aim was to coordinate satellite EO to support civil protection agencies in their response to disasters. Today, 15 satellite operators are members of the Charter: CNES (France), CNSA (China), CONAE (Argentina), CSA (Canada), DLR (Germany), ESA (Europe), EUMETSAT (Europe), INPE (Brazil), ISRO (India), JAXA (Japan), KARI (South Korea), NOAA (US), ROSCOSMOS (Russia), USGS (USA), UK Space Agency (UK), and DMCii (UK).

Since its foundation in 2000, the Charter has been activated 420+ times in 110+ countries worldwide.

6.1 The Charter in Action

The Charter is focused on the response phase of the DRM cycle and its functions are simple: to task satellites in response to a major disaster and to provide fast access to satellite data to support disaster response. The Charter provides satellite EO-based products as maps to assess the extent of the impact and damages caused by a disaster. the Charter responds to major disasters, addressing a portion of the 200–400 catastrophes that occur annually around the world.

First activated for landslides in Slovenia in November 2000, the Charter has brought space assets into action in well over 110 countries for over 400 natural and technological disasters, including flooding, hurricanes, tsunamis, earthquakes, forest fires, volcanic eruptions, and oil spills. Some notable Charter activations include the 2004 Asian tsunami, the 2008 cyclone Nargis in Myanmar, the January 2010 Haiti earthquake, the Deepwater Horizon oil spill in the Gulf of Mexico the same year, followed by the flooding across North West Pakistan, the 8.9 magnitude earthquake and following tsunami in Japan in March 2011, the 2012 typhoon Bopha in the Philippines, the Typhoon Haiyan that devastated the Philippines in November 2013, and the 2013 flood event in India.

In 2014, the Charter also contributed for the first time to the search for aircraft debris following the disappearance of Malaysia Airlines Flight 370 and provided imagery for the international emergency teams combating the spread of the Ebola virus. In this last case, optical satellite imagery was used to provide geocoded products of urban sprawl and infrastructure and helped support planning of evacuation routes and Ebola recovery hospitals in five African countries (Guinea, Liberia, Sierra Leone, Nigeria, and Senegal).

Charter operators are at readiness 24 hours a day to deal with requests for assistance from civil protection authorities.

Upon receiving a request, they check the identity of the caller and verify that the information needed to respond to the emergency is specified correctly. This information is then passed to an on-call officer who analyses the request and the scope of the disaster with the user to establish how to use the satellites that can provide data to the Charter to their best abilities. The final step is to prepare an acquisition and processing plan using the available space resources. Data acquisition and delivery take place on an emergency basis and a Charter Project Manager qualified in data ordering, handling, and application assists the user throughout the process.

The Charter can rely on both radar and optical satellites operated by its 15 members. Imaging radar has an all-weather capability and is particularly adapted to monitor the impact of flooding and oil spills. Optical satellites are well suited for damage mapping – medium resolution for a snapshot of overall effects, high to very high resolution to depict damage to road networks or even individual buildings – which is particularly important for organizing rescue services after an earthquake or a cyclone. The resulting products comprise maps and geocoded image overlays showing flooded surfaces, linear elements (affected roads, bridges), hot spots, burnt areas, landslide scars, or eruptive edifice, depending on the specific characteristics of each disaster.

As illustrated below, the Charter is frequently activated for weather-related disasters such as flooding and ocean storms – representing more than 70% of Charter activations – while solid Earth-related hazards (earthquakes, volcanic eruptions) represent 20% of Charter activations.

Figure 1: Example of a satellite EO-based product using optical imagery comparing an area before (GeoEye satellite) and after (SPOT satellite) the landfall of Typhoon Bopha in the Philippines in December 2012. It is worth noting the damage to buildings and tree plantations.

Image credit: Manila Observatory

Figure 2: Satellite EO-based product using very high-resolution optical imagery (WorldView satellite) to analyze the damaged structure caused by the Super Typhoon Haiyan in November 2013. In red, the destroyed structures; in yellow, structures that may be damaged. This map was elaborated by UNITAR/UNOSAT, which regularly collaborates with the Charter. The same methodology is also very useful to estimate damage after an earthquake.

6.2 The Charter User Base

The Charter can be activated by a predefined list of appointed users, known as Authorized Users (AUs). Until now AUs were typically disaster management authorities, from countries of Charter member agencies, able to request Charter support for emergencies in their own country or in a country with which they cooperate for disaster relief. Since its inception, the Charter has demonstrated a strong commitment to expanding its number of users. Initiatives include collaboration with the international humanitarian community via the United Nations Office for Outer Space Affairs (UNOOSA) and the Operational Satellite Applications Programme (UNOSAT) at the United Nations Institute for Training and Research (UNITAR), that are active in many countries and can submit requests to support in-country UN relief agencies, and Sentinel Asia, a regional network for EO-based emergency response in 32 countries. In 2012, Charter members, conscious of the need to improve Charter access globally, adopted the principle of Universal Access: any national disaster management authority is now able to become an AU and submit requests to the Charter for emergency response. Charter procedures must be followed, but the affected country does not have to be a Charter member. Universal Access follows the spirit of Charter members to enhance Charter access; it is also a response to a formal request from the intergovernmental GEO Secretariat in 2007 to make Charter requests available to more users

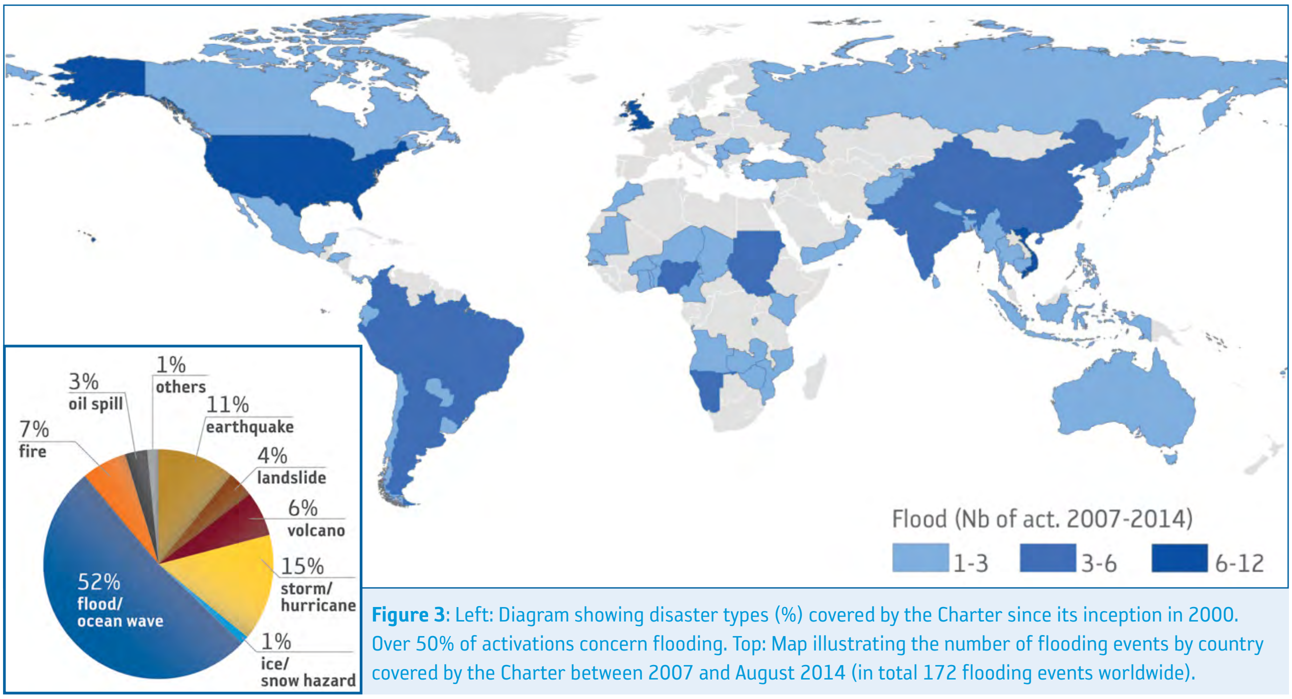


Figure 3: Left: Diagram showing disaster types (%) covered by the Charter since its inception in 2000. Over 50% of activations concern flooding. Top: Map illustrating the number of flooding events by country covered by the Charter between 2007 and August 2014 (in total 172 flooding events worldwide).

from the 89 GEO member states. The Charter works on a 6-month rotational basis. The Korea Aerospace Research Institute (KARI) has been the Primus Inter Pares since October 2014 and, as such, is the current formal interlocutor of user organisations in the Universal Access process.

Universal Access benefits national disaster management authorities previously unable to make direct requests to the Charter during emergency situations, further strengthening the Charter's contribution to disaster management worldwide. Perhaps more critically, the Universal Access principle opens the door to a global network of Charter users and value-adding specialists that will develop a capacity to effectively use satellite EO during disasters. This capacity can contribute to limiting the impact of disasters when they occur. The Charter is working with UN bodies, Sentinel Asia, and GEO to improve awareness about satellite mapping at national, regional, and international levels and to promote the Universal Access initiative.

In 2013, Geoscience Australia was granted the right to act as the AU for Australia on behalf of Emergency Management Australia (EMA). In November 2013, they activated the Charter for wildfires in New South Wales.

As a first-time user of the Charter under the new Universal Access arrangements, Geoscience Australia accessed several sources of satellite imagery and provided derived information to Australian emergency managers.

> *“The data provided broad-scale coverage of the fires that was useful for overall situational awareness and damage analysis. The assistance we received was very much appreciated.”*
>
> End user: EMA and the Rural Fire Service of New South Wales

Concerning operations, the dialogue with the user during a Charter activation is important, allowing a good understanding of the Charter-provided EO products by the user and adapting (if necessary) satellite acquisitions to the needs of the unfolding emergency. The Charter gathers feedback from users after each activation in order to assess the utility of the service and to identify areas for improvement of performance. So far, feedback from national users is showing a strong interest in the contribution that the Charter can make by providing rapid, objective, and free information to monitor an emergency and its impact.

> *“Data Access through the Charter was very valuable for map production in this crisis situation.”*
>
> End user: Federal Office of Civil Protection and Disaster Assistance (BBK) / GMLZ (German AU).

FLOOD IN GERMANY | 2013

Beyond the fundamental subject of triggering the system, the way the Charter service is provided and exploited generally requires collaboration, and local organizations can play a key role because they are close to the theatre of operations. Once an activation is requested, the Charter

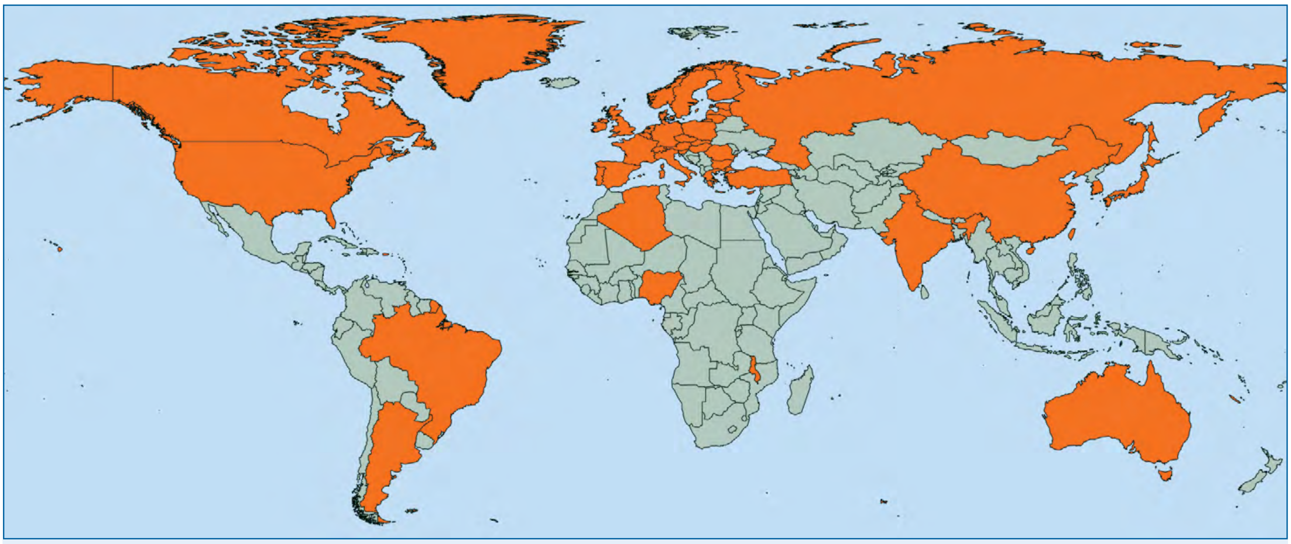


Figure 4: Map showing countries with direct access to the Charter in September 2014 (orange). Universal Access allows national users from new countries to directly submit activation requests to the Charter.

designates a Project Manager – not necessarily from a country of a Charter member – who plans for the appropriate EO acquisitions and manages their dissemination and exploitation. This aspect is also under investigation for the many countries not yet closely linked to the Charter.

> *“The value-added products provided very useful information of the flood water extent in Far Eastern Russia. The products were helpful for the purposes of disaster monitoring, destruction assessment, and relief operations.”*
>
> End user: EMERCOM (Russian AU)
>
> **FLOOD IN RUSSIA | 2013**

The Charter is a striking example of what space agencies working together can achieve. However, perhaps more importantly, the Charter has awakened the international community of practitioners of DRM and end users to the opportunities satellite EO offers, not only for disaster response, but more generally in support of the full cycle of disaster management. In that context, many of the same agencies that spearheaded the development of the Charter are working together through CEOS to demonstrate how satellite EO can be applied to risk reduction. The CEOS Working Group on Disasters has initiated pilot projects on floods, seismic hazards, and volcanoes, and is working on strategies with the international recovery community to create a Recovery Observatory. These activities primarily focus on other phases of risk management than the emergency response phase and in particular on risk assessment with the aim to better understand hazards using satellite-based observations. As far as the immediate response phase is concerned, by raising the profile of satellite EO, the Charter has greatly increased the user community's interest in satellite EO-based solutions. the Charter will continue to offer operational response services and has served a compelling role as a precursor to operational full-cycle support of satellite EO to the disaster risk management community.

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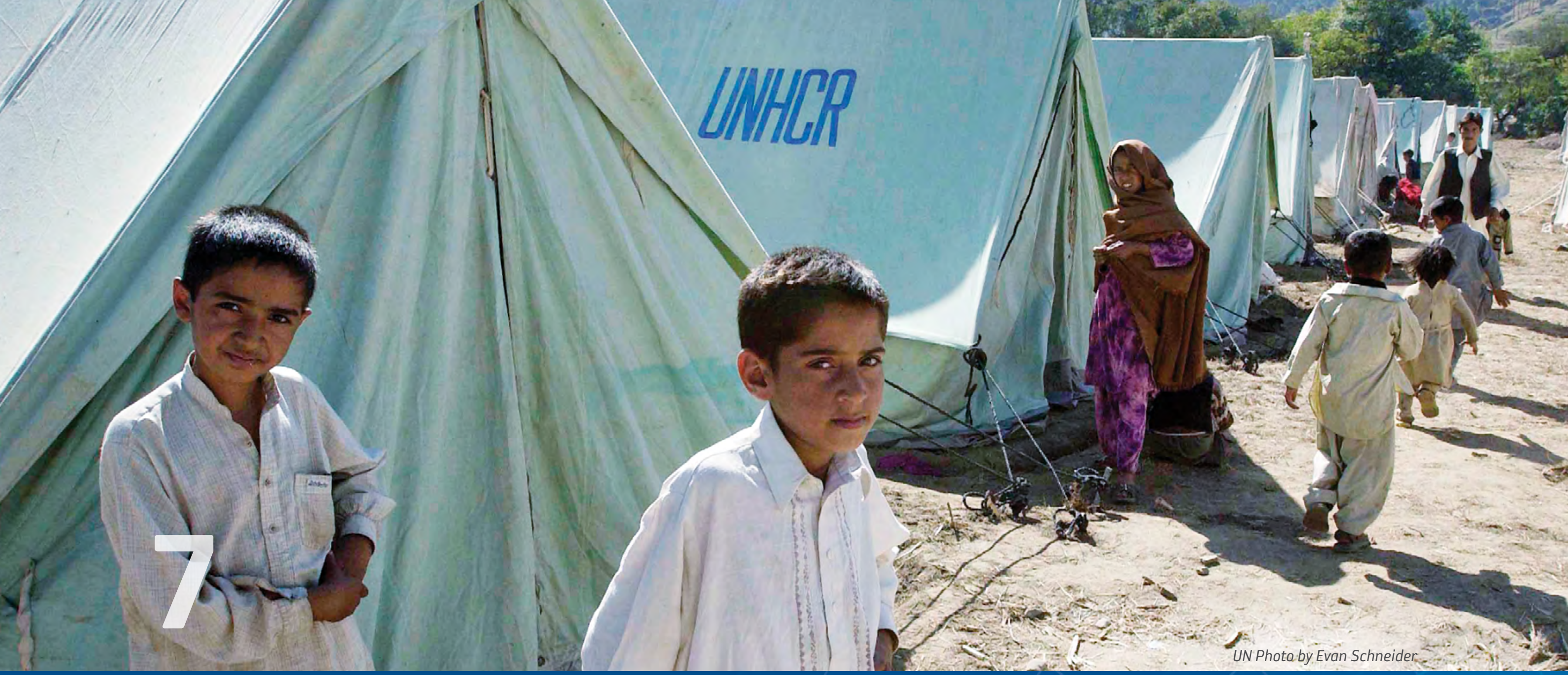
Further information

Activating the Charter:
www.disasterscharter.org/web/guest/activating-the charter



7

UN Photo by Evan Schneider

UN use of EO for Disaster Prevention and Response

The UN system has in place a range of programmes and activities to support countries in making the best use of space-based tools for disaster risk reduction. This case study illustrates the importance of capacity development, regional cooperation, and technical support in providing access to space-derived information while fostering and emphasizing the high-level intergovernmental commitment needed to effectively utilize these tools. This report will emphasize how the use of EO will be fundamental to reaching the new sustainable development goals and post–2015 framework for disaster risk reduction. It shows how EO is an enabler for reducing risks, improving response, and thus building resilience into development.

7.1 Introduction

Within their respective mandates, many UN entities routinely use space applications tools for telecommunication, positioning and navigation, or for EO. The UN system is supporting nations in developing their own capabilities to use EO tools and applications. This support includes assistance in the creation of infrastructure to acquire data, providing platforms to share and disseminate information, and integrating organised information into decision making. The result is that countries are better able to use this information for environmental and natural resource management, for socioeconomic development, and in the monitoring of national, regional and global issues. Through international agreements such as the International Charter on Space and Major Disasters (referred to below as the Charter) and the Asia-Pacific Plan of Action for Applications of Space Technology and Geographic Information Systems for Disaster Risk Reduction and Sustainable Development, 2012-2017, the UN is proactive in promoting the streamlining of space-based data and information for emergency response to DRR at the national and regional levels.

This case study presents a few initiatives of UN entities, highlighting support to nations in reaching their commitments towards the post-2015 Development Agenda and the new Framework for Action to be created at the Third World Conference on Disaster Risk Reduction.

7.2 Building Individual and Institutional Capabilities

Many governments, through commitments under the HFA and from their own national requirements, have developed policies and institutional frameworks to better prepare for disasters and to improve their response. Governments are also investing in infrastructure for data acquisition and analysis. Working with National Disaster Management Authorities, the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) Programme promotes practices to integrate EO tools and applications into those frameworks. In 2010, UN-SPIDER conducted an advisory mission to the Dominican Republic to assess its institutional framework for data collection, sharing and dissemination, human resource development strategy, and DRR and emergency response (ER) policy framework. Following this mission, the Government of the Dominican Republic developed an agreement signed by ten ministries for the coordination of actions on DRR and ER. This major achievement paved the way for increased coordination on planning and response efforts.

In another example, UNITAR's UNOSAT is developing practical knowledge and Geographic Information Systems (GIS) capacities for the Government of Chad through a multi-year programme supporting sustainable water-resource management. Likewise, the Inter-Governmental Authority on Development (IGAD) in East Africa and UNOSAT work on developing regional and national capacities in the use of GIS and EO for DRR by taking an integrated approach towards practical training on relevant applications for the region. This includes training on integrating GIS solutions for regional climate outlook, combining natural hazards with human security factors, and ensuring EO and other geographic data are available from geographic data portals.

Additionally, the UN Economic and Social Commission for Asia and the Pacific (UNESCAP) contributes to efforts in this field by facilitating the use of online geo-referenced information portals combining socioeconomic data with satellite imagery for countries with special needs to ensure that the right information is available to the right decision-makers at the right time (Figure 3) for disaster preparedness and rapid analysis/impact assessment.

UNOSAT, the Asian Disaster Preparedness Centre (ADPC), and ESCAP continue to provide practical and hands-on training on GIS and EO for disaster management, with special focus on DRR, including for government representatives in Asia-Pacific.

Figure 1: Hands-on training on use of GIS and EO for DRR within IGAD.
Image credit: UNITAR-UNOSAT

7.3 Creating Access to Data and Tools through Regional Cooperation

Besides facilitating and creating access to data at national and regional levels through specific training and awareness raising activities, the UN system has put in place dedicated data access solutions. While EO data are readily available during national disasters through mechanisms such as the Charter, the Asia-Pacific Regional Space Applications Programme for Sustainable Development (RESAP), and Sentinel Asia, providing such information for DRR purposes can be more challenging. This is an area where the UN combined efforts facilitate improved access to data and comprehensive practical solutions.

One example of this preparatory effort is the work of ESCAP in implementing the Regional Cooperative Mechanism for Drought Monitoring and Early Warning (Regional Drought Mechanism). Six countries have requested to be pilot nations under the Mechanism, specifically Afghanistan, Cambodia, Mongolia, Myanmar, Nepal, and Sri Lanka, with further interest having been expressed by other member states and international organizations. The two supporting regional service nodes presently established (in China and India) have provided specialized training, space-derived data, products, and services to the initial pilot countries of Mongolia and Sri Lanka. Further work is beginning in Cambodia, Myanmar, and Nepal in the near future.

Creating a regional platform in Central America for addressing the cross-border threat of drought, UN-SPIDER fosters collaboration for a coordinated early warning system and good practices in drought management. Drought early warning can be improved if different systems are brought together efficiently and if authorities are part of an institutional arrangement that allows for data exchange and data sharing as well as synchronising the reporting of individual systems. Figure 2 summarises the approach promoted by UN agencies in Central America and reflected in various capacity building and institutional strengthening activities in the region.

UNOSAT has also developed and made publicly available a historic flood extent GIS database. This resource helps furnish national DRR actors with precise flood-information on past events covered by UNOSAT. The data, provided in various ready-to-use GIS formats, are typically derived from Charter imagery as well as open-source data from NASA and other sources. This live database is updated each time UNOSAT produces new EO-derived flood data.

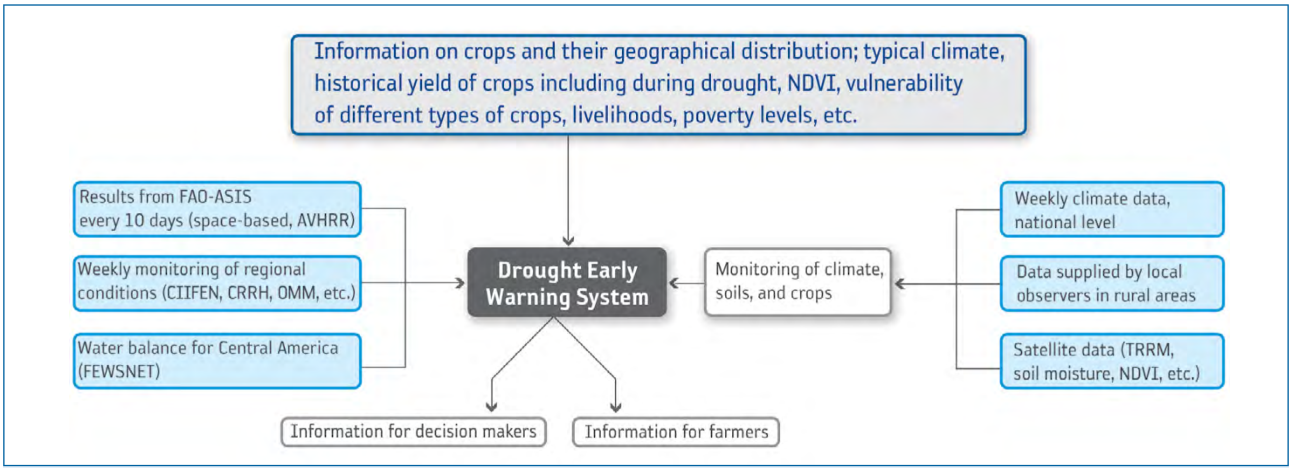


Figure 2: The approach promoted by UN-SPIDER and FAO in Central America and reflected in various capacity building and institutional strengthening activities in the region.

Image credit: UNOOSA

A dedicated digital elevation model customized for flood-modelling has been developed jointly by USGS and UNOSAT. Data for the full African and Asia continents are ready, The Americas is under development and will be ready in 2015. Test-runs show improved accuracy of flood models when taking this new dataset as input compared to previous elevation models of the same scale.

By having a fund for EO data available, UNOSAT programmes satellite imagery in advance to be prepared to provide early warning and more timely response over areas exposed to high risk of flooding. This facilitates improved preparedness by both national and international actors and ensures information will reach relevant actors in a timely manner.

Furthermore, through the RESAP network and UNOSAT, ESCAP member states can request, share, and access satellite-derived products and services. Images are provided in the spirit of regional cooperation and with the understanding that disaster mitigation is a public concern that benefits the region as a whole, for example through information systems.

UN entities wanting to increase access and use of EO in a regional context have the advantages of partnering with established regional organisations. UNOOSA/UN-SPIDER, ESCAP, and UNITAR-UNOSAT favour working with and through regional bodies as well as providing bilateral support. All are strong partners with regional mandates and a strong regional presence, building on capacities and resources at the national level. Similar organisations with expertise in remote sensing, geospatial information management, and disaster management are also collaborating with the various UN agencies for the same reasons.

7.4 The Way Ahead

The UN is working on identifying the best options for use of EO in support of DRR in a constantly changing environment, both from a technical development perspective as well as impacts from climate change and required adaptation and mitigation measures. Below are some activities that are recommended to benefit from this technology at regional, national, and local levels.

- Focus on practical capacity development, technical backstopping, and institutional awareness raising;
- Increased coordination and collaboration between various regional and international initiatives and programmes to benefit many developing countries, particularly the LDCs, LLDCs, and SIDS, which are unlikely to have an extensive space applications programme of their own;
- Taking advantage of the strong synergies among UN organizations working on GIS and EO, such as thematically focussed FAO, WFP, WMO, and WHO. This is particularly useful for impacts on food security and moving from early warning of disasters such as drought to longer-term crop monitoring;
- Opportunity for greater utilization of EO data and tools for natural resource management, in particular for sensitive regions and ecosystems;
- Working in partnerships, including with academia and private industry, to build the capacity of various sectors to better utilize EO data for disaster management and planning;
- Greater expansion of EO tools for urban planning to reduce exposure to disaster risk and also enhance the know-how and expertise of planners to develop urban areas in a sustainable manner;

– Develop multi-risks strategy models for countries to make adjustments to their policies for a more integrated approach to DRR;

– Leveraging private sector initiatives such as assessment of risk in collaboration with insurance and re-insurance agencies.

Figure 3: Example of geo-referenced information system for disaster risk management.
Image credit: UNESCAP

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Main image on page 46: *UN Photo by Evan Schneider: UNHCR refugee camp in Pakistan for victims of a major earthquake in 2005.*

Further information

UNESCAP:
www.unescap.org

UNOOSA:
www.unoosa.org

UN-SPIDER:
www.un-spider.org

UNITAR-UNOSAT:
www.unitar.org/unosat

Geographic Information Systems and Earth Observation for Disaster Risk Reduction:
www.geodrr.org

UNITAR-UNOSAT Flood Portal:
floods.unosat.org

UNEP Environmental Data Explorer:
geodata.grid.unep.ch

8

EO for the Mitigation of Geological Disasters

EO could have a significant impact on society if used more effectively as a tool to reduce the risks associated with geological hazards such as earthquakes and volcanic eruptions, which pose significant danger to life and property. EO can help to accurately assess geological hazards and inform decisions that reduce risk for affected populations. This is the objective of GEO's Geohazard Supersites and Natural Laboratories (GSNL) initiative.

Interferometric Synthetic Aperture Radar (InSAR) is a powerful satellite technique for the assessment of geological hazards. An InSAR interferogram constructed from two SAR images shows ground displacement with an accuracy of a few centimetres. A series of SAR images can measure ground velocity with an accuracy of 1mm/year or better, depending on how many acquisitions are available. Models of the underlying tectonics and volcanic processes can then be fitted to the observations and used to infer the severity of geological hazards.

8.1 Earthquake Hazards

The questions asked immediately after an earthquake are:

- Which fault or faults ruptured?
- What was the faulting mechanism?
- Were nearby faults brought closer or further away from rupturing in a new earthquake?

Satellite-based InSAR has the unique ability to answer these questions because it provides measurements of the associated ground deformation and constraints on the mechanism of the earthquake. InSAR-determined earthquake mechanisms are then fed into stress change simulations to determine the effect on nearby faults. All that is needed are suitable pre- and post-earthquake imagery.

Another key consideration in earthquake science is the hazard of future earthquakes, which requires knowledge of the long–term slip rates of the major seismic faults and their frictional behaviour.

These are not trivial questions. The subduction faults offshore Sumatra-Andaman and offshore northern Japan were classified by many scientists as partially creeping because of the relative lack of earthquakes. However, these faults eventually generated giant earthquakes in 2004 and 2011, with magnitudes 9.3 and 9 respectively. In both cases, the tsunamis generated by the sudden vertical displacement of the ocean floor killed 230,000 and 18,500 people respectively, placing them on the list of the worst natural disasters in recent times.

Continuing observations of the world's active faults with satellite-based InSAR will not only reveal the long-term rates of motion of the different crustal blocks but also resolve temporal changes in the frictional behavior, providing clues of when and where future earthquakes might occur.

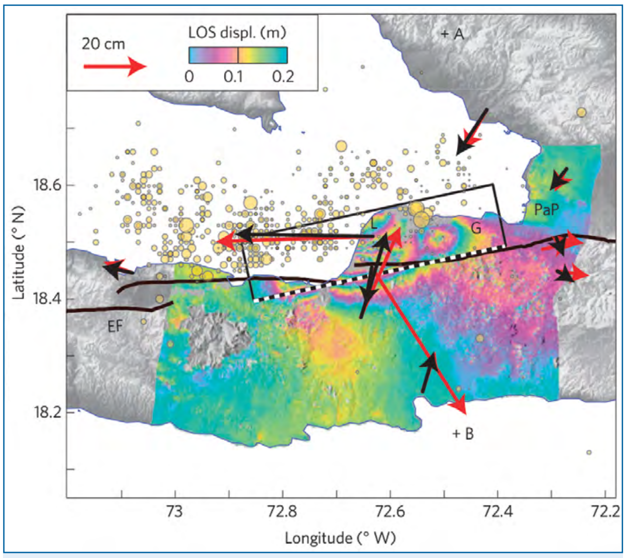

Figure 1: Map of ground deformation associated with the 2010 Haiti earthquake, observed with Japan's ALOS-1 satellite. One colour cycle represents 20cm of ground displacement. The interpretation of the ground deformation data suggested that a previously unknown fault sub parallel to the Enriquillo–Plantain Garden fault zone (EPGFZ) ruptured.

Image credit: JAXA/METI, E. Calais

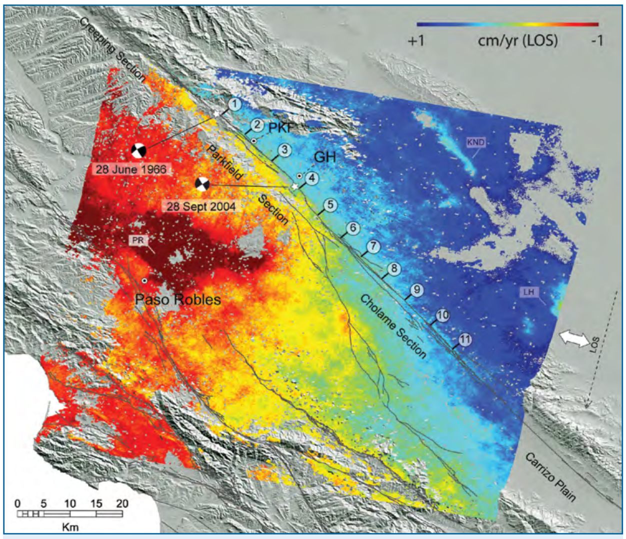

Figure 2: InSAR observations from the ERS and Envisat satellites for strain accumulation along the San Andreas fault in Central California.

Image credit: ESA, M. de Michele

8.2 Volcanic Hazards

InSAR can also contribute to volcano monitoring in two ways. An eruption is inevitably preceded by the ascent of magma to shallow levels in the Earth's crust. When magma accumulates in a reservoir, the ground surface above the reservoir inflates. Satellite-based InSAR can detect this inflation, providing early warning of forthcoming volcanic unrest long before there are any other signs of activity.

An eruption occurs when the reservoir develops enough pressure so that magma forcefully propagates towards the surface. The expansion of the magmatic conduit causes surface deformation in the summit area, which can also be detected by InSAR. Large explosive eruptions are generally preceded by significant lateral summit deformation and/or by the collapse of a lava dome. Active volcanoes do not generally have ground-based instrumentation in the summit areas, so space-based InSAR can provide unique data for early warning of volcanic activity that cannot be acquired through any other means.

The combination of moderate-spatial resolution background monitoring of all volcanoes in an arc with high-spatial resolution summit monitoring of volcanoes showing high levels of unrest forms a powerful volcano observation

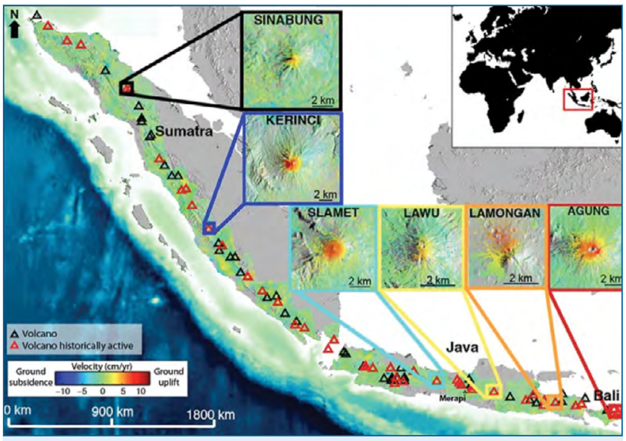

Figure 3: A 2007–2009 ground velocity map of the Indonesian volcanic arc obtained from ALOS-1 InSAR data. The insets show six volcanoes that inflated during the observation period (uplift is shown in red). Sinabung and Kerinci volcanoes in Sumatra and Slamet in Java erupted following inflation.

Image credit:JAXA/METI, E. Chaussard

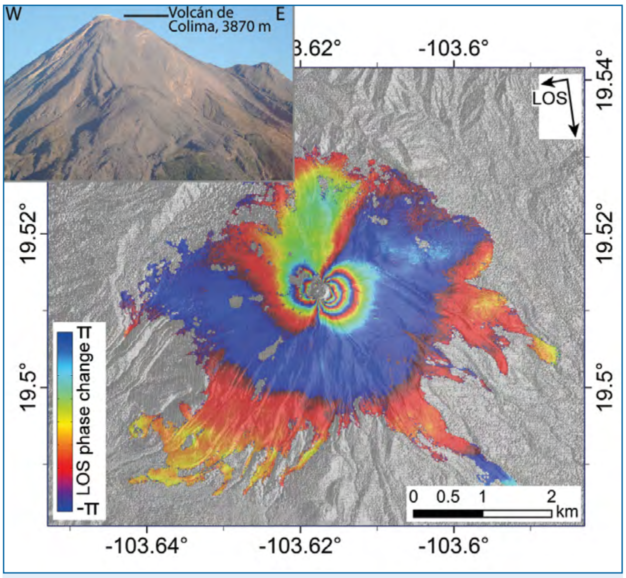

Figure 4: A TerraSAR-X interferogram of the summit of Colima volcano in Mexico that shows up to 6cm of ground displacement prior to an explosion of the lava dome in January 2013.

Image credit: DLR, J. Salzer

system that can track the movement of magma from its arrival under a volcano to its eruption from the summit. This is a process that cannot be observed using sparse ground-based measurement networks.

8.3 EO Assets

CEOS Agencies are operating several SAR satellite systems with different spatial resolutions, repeat frequencies, and wavelengths that can be combined for effective hazard monitoring. Europe's new Sentinel-1 constellation is set to observe all of the Earth's landmasses and islands every 6–12 days, ensuring the availability of pre-event imagery for virtually all seismic events. This moderate spatial resolution imagery is complemented by high spatial resolution data from Germany's TerraSAR-X, Italy's COSMO-SkyMed, Canada's Radarsat-2, and Japan's ALOS-2.

GEO's GSNL initiative pursues two broadly defined goals, aimed at advancing the scientific understanding of geological hazards and promoting the use of EO for disaster-risk assessment.

The first goal is to improve monitoring by effectively combining the assets of multiple CEOS Agencies. The time-dependent post-seismic deformation following earthquakes is best resolved using multiple SAR satellites. The COSMO-SkyMed constellation of four satellites is invaluable for monitoring volcanic eruptions.

The second goal is the integration of space-based and ground-based observations and to create societal benefit by reducing disaster risk. The initiative is developing an online infrastructure for open access to satellite and ground-based data, facilitating the application of advanced data analysis techniques to different geohazard areas around the world. Each Supersite is led by a scientist affiliated with the local monitoring agency to ensure direct interaction with CEOS.

8.4 Geohazard Supersites

'Permanent Supersites' are geographical areas in which active geological hazard(s) poses a threat to human population and/or critical facilities, and for which scientific investigations are needed to better understand the geological process narrowing down the uncertainty in hazard and risk assessment.

Event Supersites are sites affected by a major geological event (e.g earthquakes, volcanic unrest or eruption, landslides) for which a scientific forum of experts, endusers and data providers is set up during or in the immediate aftermath of the event.

The current Supersites are given below. They are among the most active tectonic and volcanic areas in the world.

Permanent Supersites: Hawai'i (USA), Iceland, Marmara Sea/North Anatolian Fault Zone (Turkey), Mt. Etna Volcano (Italy), Mt. Vesuvius/Campi Flegrei (Italy), New Zealand, and Cotopaxi and Tungurahua volcanoes (Ecuador).

Recent event Supersites: Sinabung Eruption (Indonesia), Napa Valley Earthquake (USA).

The EC has provided extra funding to advance the Supersites concept in Europe. The European Supersites will not only provide open access to the raw geophysical data streams but also to higher-level data products. This is to facilitate crisis assessment by non-experts.

Two recent geological events illustrate how EO data can be used.

8.5 2014 South Napa Earthquake

The magnitude 6.0 earthquake of August 24, 2014 that struck the southern Napa Valley northeast of San Francisco, California demonstrated the role that EO plays in response to earthquakes. This event caused extensive damage in Napa County and adjacent areas. Interferograms from both satellite and airborne systems started to become available just 3 days after the earthquake.

The early interferograms were used immediately by the United States Geological Survey (USGS) National Earthquake Information Center (NEIC) to refine models for the distribution of fault slip during the earthquake. Field teams coordinated by the California Geological Survey and the USGS used the imagery to map small surface ruptures in the field at many locations, including a fault cutting through the runway of the Napa County Airport.

After the earthquake, additional images from many SAR satellites were used to map the continuing fault movements (up to 10cm in the first 2 months after the earthquake) that caused additional damage to roads and other infrastructure. The InSAR imagery will next be used to update fault and seismic hazard maps, which will affect decisions on where and how to rebuild structures.

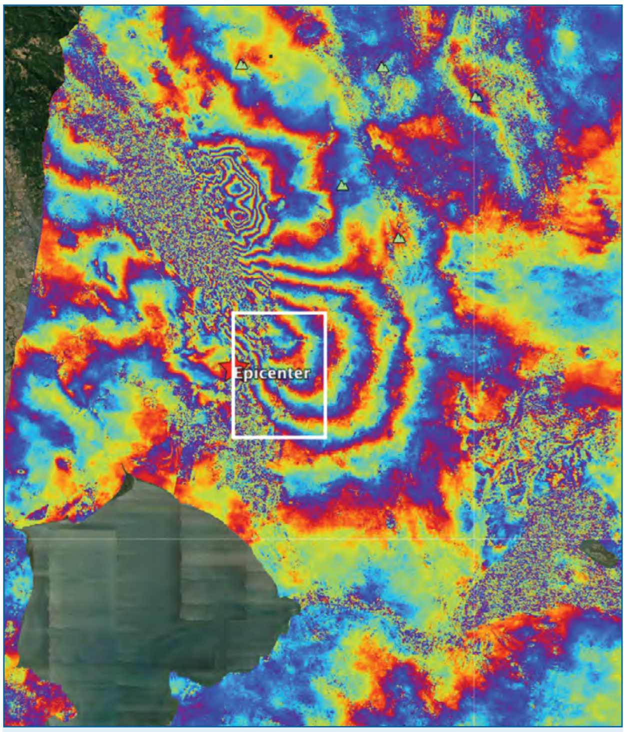

Figure 5: Map of the deformation of the Earth's surface caused by the 2014 South Napa earthquake, generated from two COSMO-SkyMed images. One colour cycle indicates 2cm of permanent surface movement and the inset map reveals a discontinuity that identifies a fault rupture cutting through the Napa County Airport.

Image credit: ASI, NASA/JPL-Caltech, Università degli studi della Basilicata, ARIA, Google Earth

8.6 2014 Eruption in the Bardarbunga Volcanic System

SAR data provided to the Icelandic volcanoes Supersite has been important in the response to the fissure eruption of the Bardarbunga volcanic system in Iceland, partly located under the Vatnajökull ice cap, that began on August 29, 2014. The eruption produced about 1km3 of lava as of November 2014, which makes it the largest lava-producing eruption in Iceland in 230 years. Air traffic remains uninterrupted because only minor amounts of ash have been generated, however volcanic gases (in particular SO2) are causing widespread pollution.

The eruptive activity was preceded by the formation of a 45km-long, 2m-wide magma-filled crack extending from the Bardarbunga caldera to the eruption site. COSMO-SkyMed and TerraSAR-X InSAR images are used together with GPS geodesy data to understand the associated ground and ice deformation. Scientists working on the EC-funded Supersite project provided daily updates on ground deformation to the Icelandic Civil Protection.

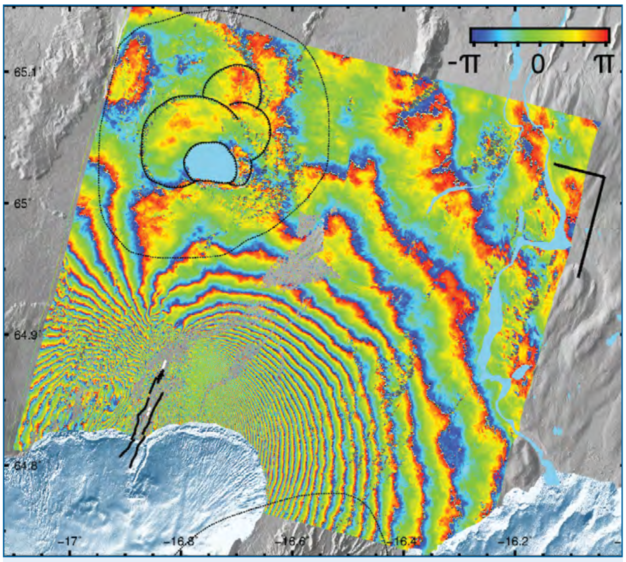

Figure 6: COSMO-SkyMed interferogram of the deformation associated with the dike of the 2014 Bardarbunga eruption in Iceland. One phase cycle corresponds to 1.6cm of ground displacement.

Image credit: ASI, S. Dumont, M. Parks

8.7 Proposed Southeast Asia Natural Laboratory for Geohazards

A new Natural Laboratory activity has been proposed for a region including Indonesia and the Philippines, which combine high levels of earthquake and volcanic hazard with high population density. According to a new report by UNISDR, volcanoes in Indonesia and the Philippines account for more than 75% of global volcanic risk. The volcanoes are currently monitored from the ground using seismic and geodetic methods. The establishment of the Natural Laboratory would lead to systematic space-based InSAR monitoring and allow stakeholders to receive state-of-the-art science data products to assist their disaster prevention and emergency response activities.

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Further information

GEO Geohazard Supersites and Natural Laboratories:
http://supersites.earthobservations.org

9

Volcanoes and Aviation

In April and May 2010, large parts of the European airspace were shut down for several days as a consequence of the eruption of the volcano Eyjafjallajökull in Iceland, with the total financial impact estimated to be €5 billion. Volcanic ash and – to a lesser extent – sulphuric gases are major hazards to aviation, with the largest threat being that volcanic ash can damage plane engines and cause them to stall. Volcanic ash can abrade windscreens, damage avionic equipment and navigation systems, and reduce the pilots' visibility. Moreover, sulphuric gases may also damage aircraft paint and windows, create sulphate deposits on and inside the engines, and might also be dangerous for the health of the passengers.

Strong winds at high altitudes present a significant difficulty in mitigating volcanic hazards to aviation as fine ash can rapidly be transported thousands of kilometres from the volcano, and in the process cross major air routes. As only a small number of the active volcanoes on Earth are regularly monitored using ground equipment, the use of space-based instruments is particularly relevant to aviation safety, as it enables the continuous and global monitoring of volcanic plumes in an effective, economical, and risk-free manner.

9.1 Volcanic Ash Advisory Centres

The International Civil Aviation Organization (ICAO) has designated nine Volcanic Ash Advisory Centres (VAACs) worldwide as a part of the International Airways Volcano Watch (IAVW). These centres are responsible for the continuous monitoring of volcanic activity within their designated areas and for issuing Volcanic Ash Advisory Statements that warn users of the presence of volcanic ash and its expected movement over a period of hours to days.

These Advisory Statements are mainly intended for the airline industry and provide the location, name, and elevation of the eruption source; details of observed ash plume location; dimensions; recent motion; general discussion of the expected path of the plume; and reference to any current aviation hazard warnings, known as SIGMETs (SIGnificant METeorological aviation hazard).

The VAACs generate their Advisory Statements by gathering information from a variety of sources, including real-time alerts from aircraft that encounter ash plumes and from ground-based radar, airborne ranging measurements (e.g. lidar), ground-based sun photometers, long-distance lightning detection networks, reconnaissance and research

Figure 1: April 2010 Eyjafjallajökull eruption in Iceland led to the worst disruption to air transport operations since World War II.

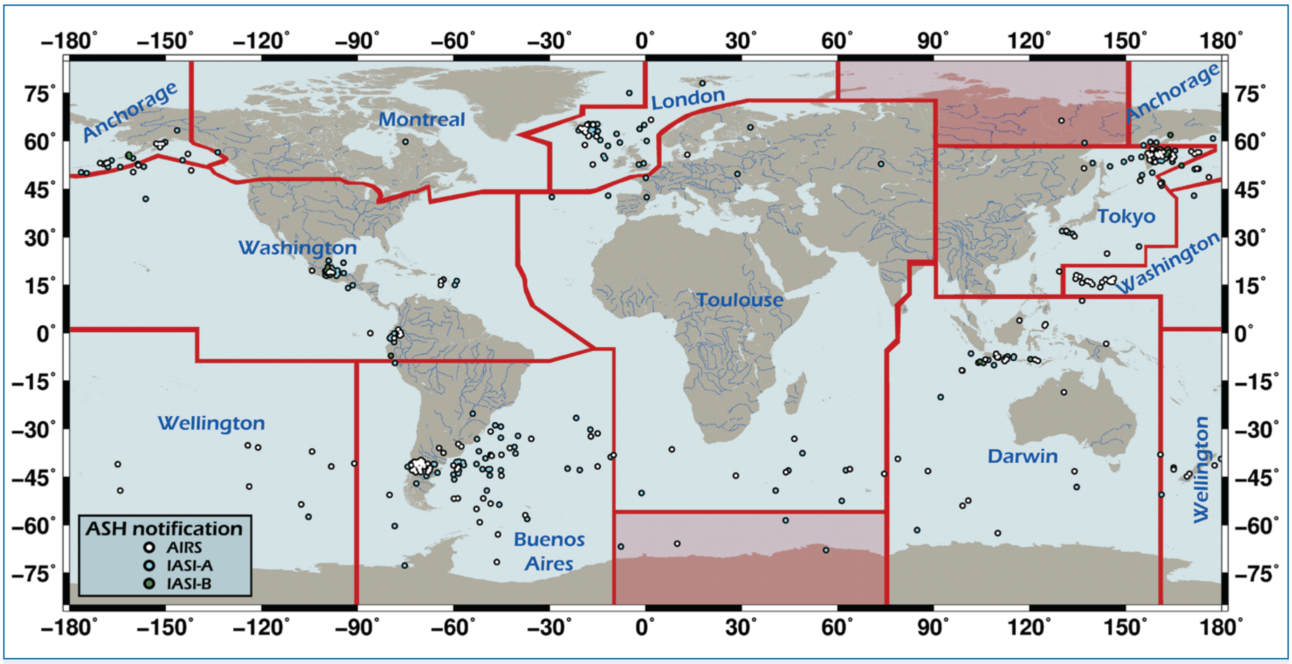

Figure 2: SACS volcanic ash notifications based on IASI and AIRS measurements from 2002–2014: Worldwide coverage of VAACs.

Image credit BIRA/IASB

aircraft, and, importantly, from satellites. The initial conditions of the eruption are input into ash dispersion models, including winds; temperature; humidity; and eruption source parameters such as the height of the plume, mass eruption rate of ash, and the size distribution of ash particles – all of which can be observed in part by satellites.

The models are run frequently (e.g., every 6 hours) to make use of the observations and the forecasts are routinely validated and verified against all available observations (satellite, radar, lidar, and research aircraft) and compared to model outputs from the other VAACs around the world.

9.2 The Role of EO Satellites

The problem of transport of ash and its interaction with aviation is a global problem and requires a global approach. Satellite data are best suited for ash detection and observation because of the global perspective, timeliness and, in the case of volcanoes, because there is no risk during acquisition.

Data for monitoring come from meteorological and non-meteorological satellites, with both visible and infrared images used to monitor large geographical areas. Geostationary satellites provide images several times an hour covering only parts of the Earth, while much lower-altitude polar-orbiting satellites provide global coverage, but at a frequency on the order of days to weeks. Multi-spectral sensors on both types of satellites provide inputs that are used to identify ash-contaminated areas. Some data can be used to provide estimations of ash particle size and height, as well as estimates of how much ash is in a vertical atmospheric column.

Satellites provide objective global coverage, which crosses national and administrative boundaries. This helps to ensure that warnings are comprehensive and provide a basis for inclusion and comparison to amongst forecasts created by the various VAACs, helping to ensure the most accurate information is available to decision makers.

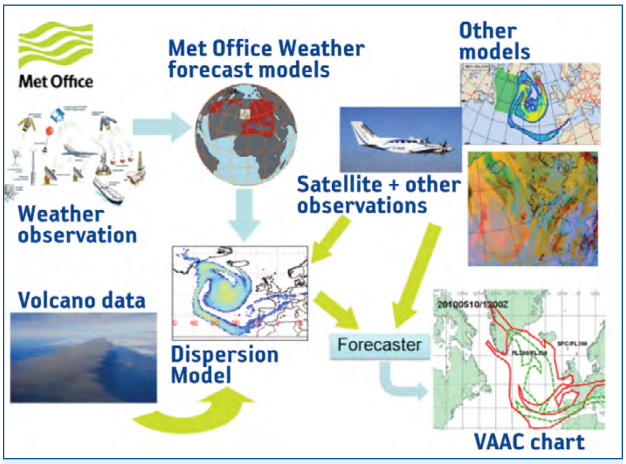

Figure 3: Volcanic Ash Forecast Process and Inputs for the London VAAC.

Image credit: UK MetOffice

9.2.1 Support to Aviation Control Services (SACS) and Volcanic Ash Strategic initiative Team (VAST)

Until recently, the ICAO applied a policy of zero tolerance to airlines regarding operations in the vicinity of volcanic ash. This policy was changed over Europe with the introduction of ash concentration thresholds following the eruption of the Icelandic volcanoes Eyjafjallajökull (April–May 2010) and Grímsvötn in May 2011. The reason for the change was that both eruptions caused partial or total closure of airspace over many European countries, with the associated disruption to societies and their economies.

The introduction of ash-concentration thresholds led to requirements for improved monitoring and forecasting services. These include the early detection and near real-time monitoring of volcanic emissions and plumes for the entire eruptive period. In addition, quantitative measurement of volcanic ash and sulphur dioxide (SO2) concentration and altitude, as well as the ash particle size distribution, are now required.

The primary objective of SACS and VAST is to address as closely as possible these enhanced requirements, in particular in support of the VAACs in their official task of informing aviation control organisations about the risks associated with volcanic activity. SACS makes use of ash and SO2 data products provided in near real-time by polar-orbiting satellites as a part of a multi-sensor warning system for volcanic emissions. The system is optimised to avoid false notifications and to date, 95% of SACS notifications have corresponded to true volcanic activity.

VAST aims to demonstrate the suitability of EO data for these types of activities and improve on the existing monitoring and forecasting services for ash transport and its interaction with aviation. With the VAST project, the following targets for service improvement will be addressed:

- Provision of a database providing satellite, ground-based, in-situ, and modelling data for six selected volcanic eruptions
- Provision of a volcanic eruption warning system based mainly on geostationary satellite data;
- Further development of dispersion forecast models (global and regional) including data assimilation, inverse modelling, and ensemble techniques to generate a measure of uncertainty of the forecast;
- Provision of an operational volcanic ash plume forecasting demonstration service at the Austrian Meteorological Office for 1 year (autumn 2014–autumn 2015).

SACS and VAST are projects funded by ESA.

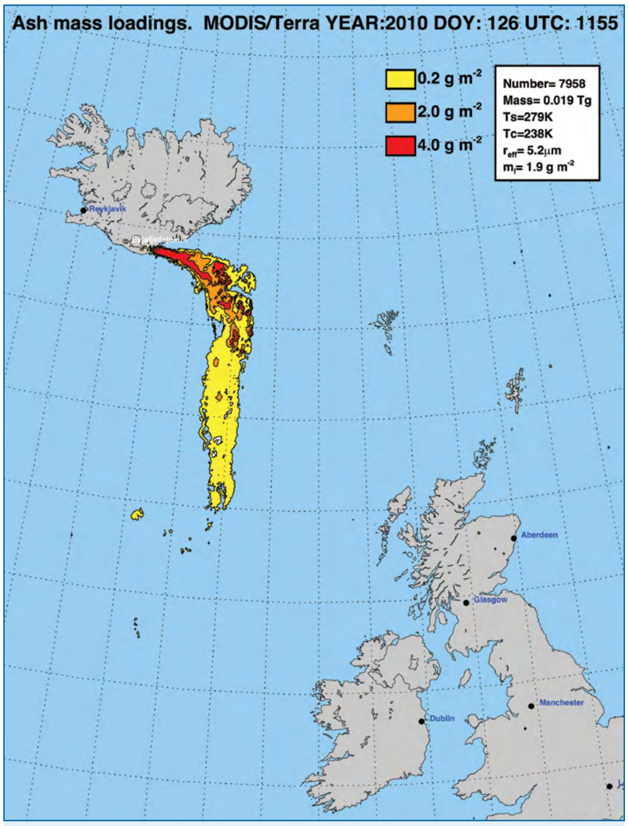

Figure 4: Three-step contours plot of Ash Mass Loadings for the Eyjafjallajökull eruption as retrieved from MODIS measurements for May 6 2010.

Image credit: NILU

9.3 Future

While the number and location of volcanic eruptions varies naturally, the number of aircraft flying is only expected to increase in the future. This will increase our exposure to the risk of both an in-flight incident, as well as to the societal and economic impacts caused by service disruptions arising from the volcanic ash hazard. By leveraging satellite observations to improve the availability of information on volcanic eruptions, global coverage can be achieved; more timely observations can be made available; and more timely, targeted, and higher fidelity warnings can be issued.

While services like SACS and VAST represent a strong first step towards increasing the amount of information available from satellites, in the future we can expect the incorporation of more sensors into ash-plume observing systems. This should improve the quality of products available and add to the range and types of parameters that can be monitored – both of which are expected to improve the quality of reporting possible.

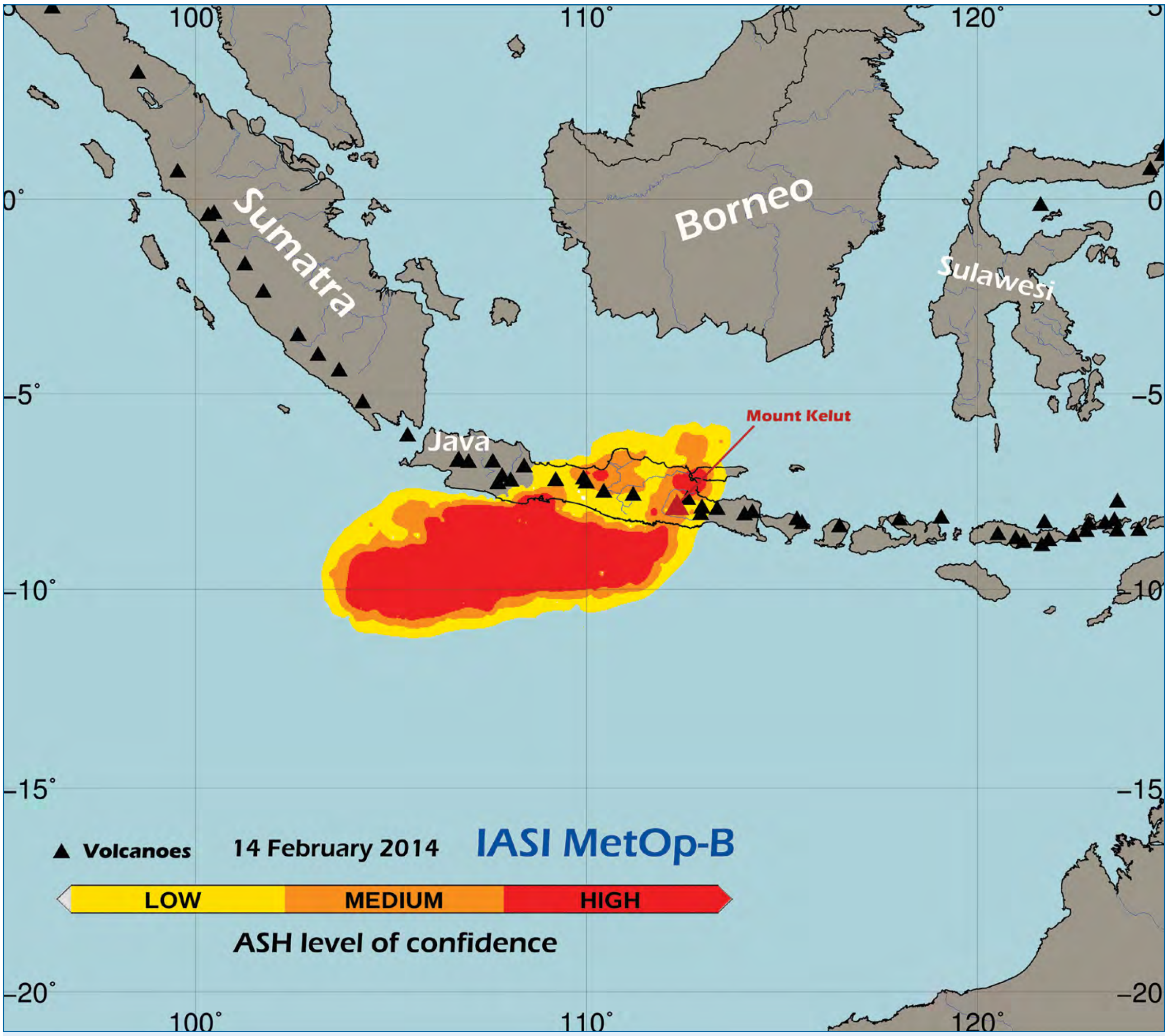

Figure 5: Kelut ash plume plot for February 14, 2014 as retrieved from IASI measurements

Image credit: BIRA/IASB

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Nicolas Theys (BIRA/IASB)

Fred Prata (NILU)

Ian Davies (easyJet)

Further information

SACS:
http://sacs.aeronomie.be

VAST:
http://vast.nilu.no

Monitoring Volcanic Ash from Space (ESA STM-280 January 2012):
http://earth.eo.esa.int/workshops/Volcano/files/STM_280_web.pdf

Earth Observations and Volcanic Ash. A report from the ESA/EUMETSAT Dublin workshop, 4-7 March, 2013:
www.nilu.no/Default.aspx?tabid=62&ctl=PublicationDetails&mid=764&publicationid=27591

Part III

Satellite EO Capabilities for Each Phase of Disaster Risk Reduction

Introduction

Part III of this document provides graphical summary descriptions of how EO satellite data support each phase of DRR:

- Mitigation and Preparedness;
- Detecting and tracking hazards (both weather–related and non–weather–related);
- Response;
- Recovery;
- Long-term climate monitoring.

The pictorial spreads describe the capabilities that the satellite data bring and the DRR functions that these capabilities support. The relevant disaster types are described and some important examples provided.

Mitigation and Preparedness

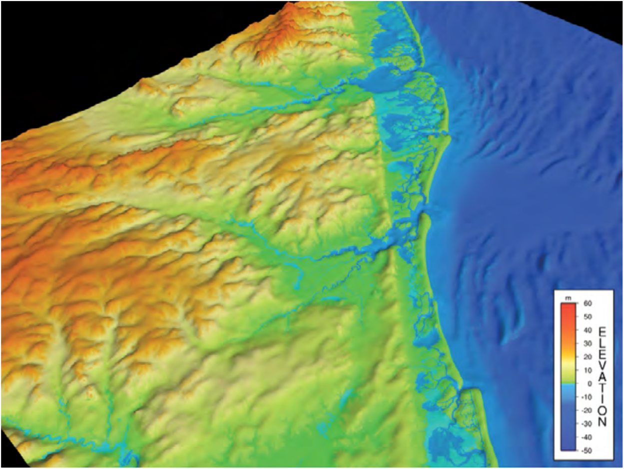
Hazard Mapping and Risk Modelling

Remote sensing provides a powerful tool for disaster mitigation and preparedness by supporting the mapping of hazards and making systematic observations as an input to risk modeling. Satellite archives contain valuable historical information and new acquisitions can help authorities narrow their focus to the areas of highest risk and optimise preparations and the pre-positioning of response assets. The relative cost effectiveness of using satellite imagery means that much broader areas and a wider range of hazards can be addressed.

For example, the assessment of wildfire fuel loads enables effective hazard reduction burns to be conducted in high-risk areas. These areas are often vast, but satellite imagery can provide cost effective methods for mapping and characterizing fire fuels quickly and accurately, supporting the best-possible mitigation outcomes.

Landslide hazard mapping requires the detailed analysis of past occurrences in relation to their geo-environmental causes. Maintenance of these hazard maps requires continual effort, frequent updates, and the collection of observations over many sites. The consistent and repetitive nature of satellite acquisitions, used in combination with high-resolution airborne images, helps to streamline and scale-up the process.

Accurate information on topography is a key input to modeling risks associated with inundation from floods and tsunamis. These models highlight the most vulnerable areas, informing those responsible for civil works like bridges and breakwaters, and enabling planning. Satellites have produced several global, high-resolution digital elevation models which are an essential input to inundation modeling.



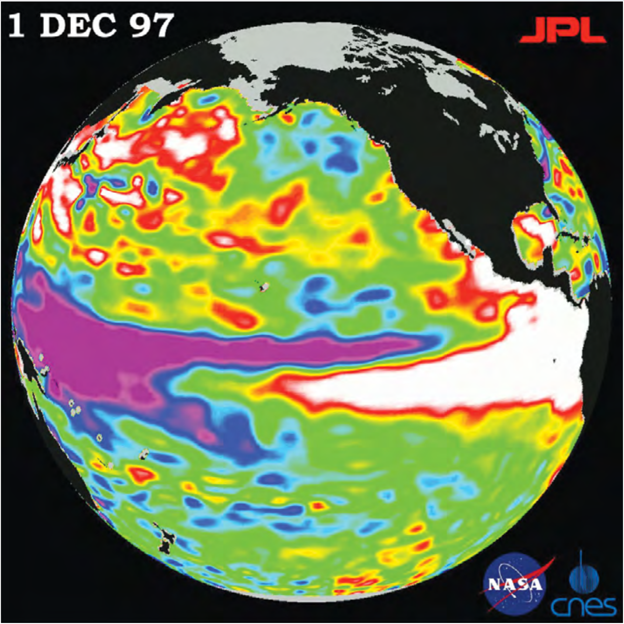
Digital Elevation Model, Atlantic City, USA

Image Credit: NOAA

Assessing Drought Vulnerability: Precipitation and Ground Water

The causes of drought are complex and can include extreme heat, reduced precipitation levels, low soil moisture, and the diminished flows of surface and ground water. To date, drought strategy has focused mainly on response management once a drought has set in, but some authorities have begun to place more emphasis on mitigation. Many of the factors governing the occurrence of drought can be measured using satellites and this supports the assessment of vulnerability that enables mitigation and preparation.

Seasonal precipitation levels across the tropics and subtropics are governed in part by the El Niño Southern Oscillation, which arises due to the effects of anomalous sea surface temperatures off the western coast of South America. Large-scale and frequent monitoring of El Niño is conducted by satellites measuring both temperature, as well as sea level that reflects changing density as seawater heats and cools. These measurements provide an assessment of precipitation for the coming season, one of the key indicators of impending drought.



The 1997 El Niño observed by TOPEX/Poseidon

Image credit: NASA/JPL

In addition to precipitation, ground water plays a major role in determining vulnerably to drought. As drought conditions worsen, the large stores of water in underground aquifers become depleted and this loss of restorative capacity can accelerate the drought impact on the water table and soils above. The amount of water stored in these aquifers is measured globally by satellites detecting small changes in the Earth's gravitational field from orbit. As aquifer levels fall, authorities can take steps to mitigate impact through water allocations, agricultural markets can adjust in an orderly fashion, and farmers can alter their cropping plans accordingly.

Producing with Confidence: Crop Insurance

Farming is a risky business, with farmers making considerable up-front investments in crop inputs, such as seed, fertilizer, fuel, and labour, to work the crop and bring it to harvest. A farmer must deal with the precarious nature of the weather, the volatility of commodity prices, and the perils of insects and disease. Crop insurance helps farmers mitigate these risks and sow crops with confidence – however these programmes need to verify claims in order to be sustainable. Farms are often spread across the countryside and in many cases cover vast areas, making on-site inspection costly or infeasible.

Both medium- and high-resolution satellite imagery is employed by government agencies and companies offering crop insurance to verify whether a claim is warranted. Satellite data can provide evidence, helping determine if a crop was planted at all, and if it was, identifying where in the growing cycle issues may have arisen. There are also instances where satellite images support a producer's claim, for example where the forces of disease, drought, and weather make the claim appear out of the norm.

Satellites make a significant contribution to the mitigation of farmer's risk relating to extreme weather, drought, and other disasters by helping provide the evidence required to make crop insurance programs viable.

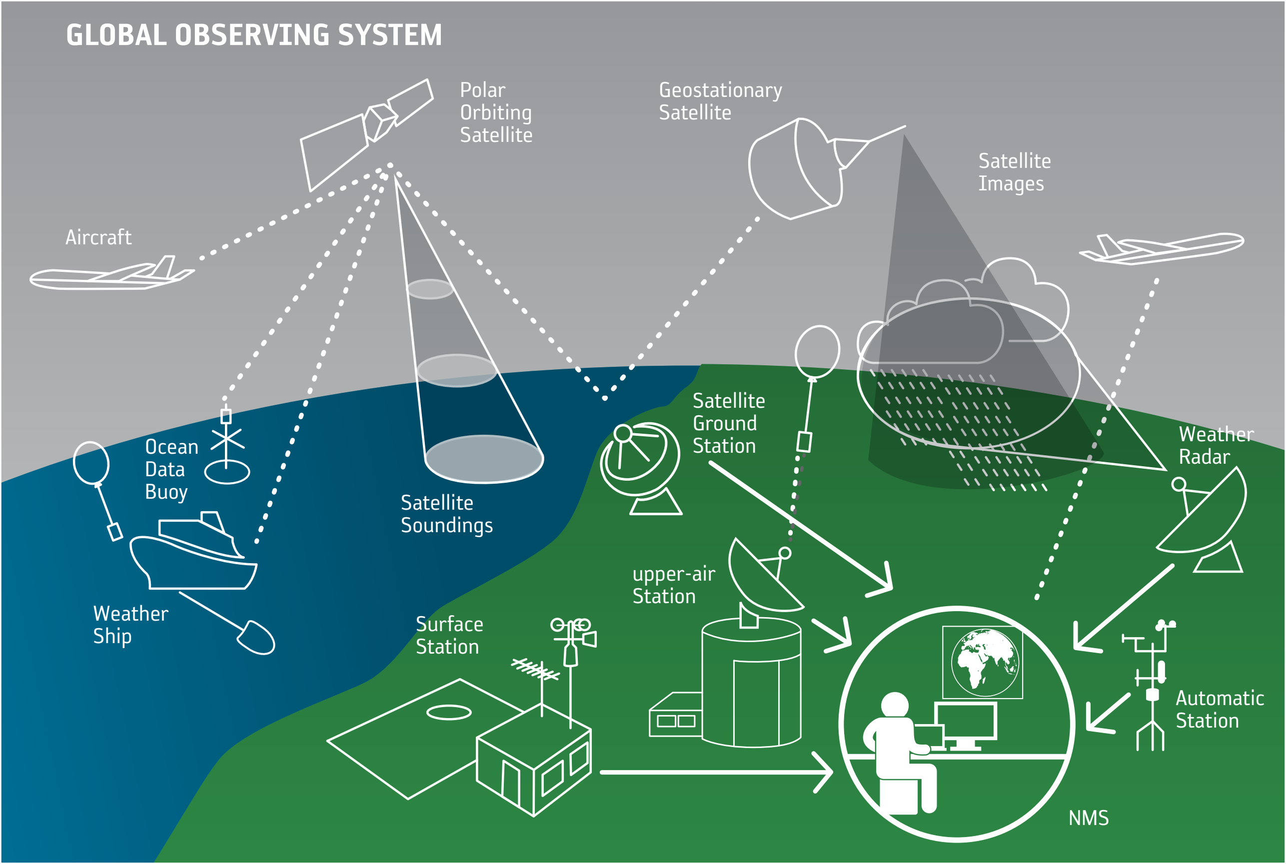
Monitoring Risk – Weather Hazards

The Global Observing System

A large portion of disasters – over 90% by some assessments – are linked to hydrometeorological hazards. Climate change is expected to lead to an increase in the intensity and frequency of some of these hazards.

Satellites operated by the world's space and meteorological agencies underpin the space segment of the Global Observing System (GOS), which is coordinated by the WMO. These satellites provide unique meteorological and environmental observations that enable warnings of extreme weather events on a global scale.

The established dissemination channels of the GOS provide information to decision makers at the local level and serve as a useful model for the timely transmission of disaster information.

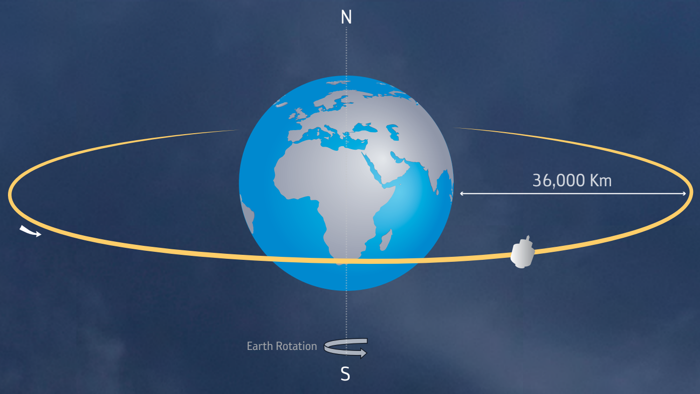


Space-Based GOS

Satellite observations from the GOS space segment provide unique global weather data that cannot be gathered from terrestrial sources. These observations greatly improve extreme weather forecast accuracy, coverage, and range, including tropical storms such as hurricanes, typhoons and cyclones, severe rain and storm activity, and tornadoes.

Forecasts of these extreme weather events allow authorities to issue warnings, coordinate evacuations, and manage the response to major incidents. In the aftermath of major incidents, satellite observations support timely damage assessments and the monitoring of resulting hazards such as flooding.

A new generation of geostationary satellites, the first of which was launched in 2014, is expected to further improve the quality and timeliness of data, producing more than 50 times the information provided by the current systems. This will include a wider variety of unique observations of the environment, with particular emphasis on hazardous weather, and will be able to provide tropical storm-scale regional observations every 2.5 minutes.



Space Data Capabilities

Operational Polar Satellites	Temperature, humidity, water vapour, wind speed, and direction	Enhanced weather forecast skill – out to 5 days with reliability
Operational Geostationary Satellites	Near real-time tropical storm imagery	Today's 48-hour forecast is as accurate as those issued for a 24-hour prediction of 10 years ago
Next-generation Operational Geostationary Satellites	Improved accuracy and expansion of application areas with advanced sensors	High frequency (every 2.5 minutes) regional tracking of tropical storms, active fire detection
Research and Development Capabilities	Measurement of physical storm intensity markers	Direct measurement of precipitation type and volume, lightning strikes

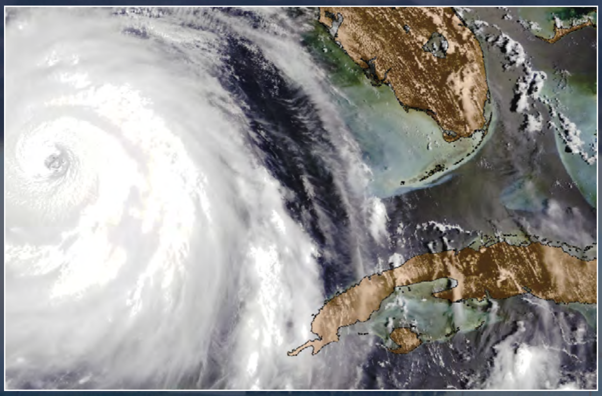
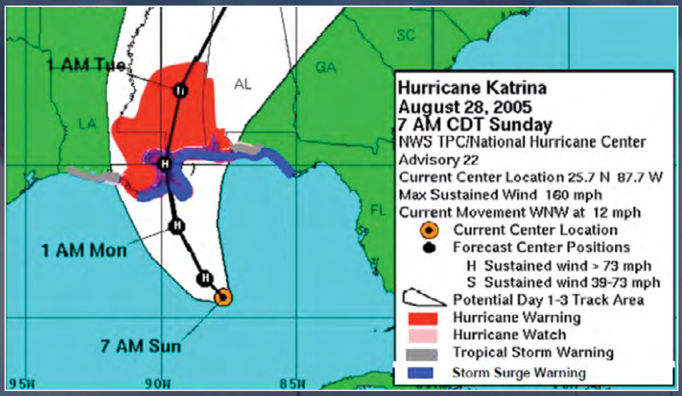


Image credit: NOAA/National Hurricane Center



Example of Proposed new Storm Surge and Hurricane Warnings

Monitoring Risk – Wildfires, Volcanoes, and Geohazards

Wildfires

Fire is a force of nature that humans have harnessed to heat our homes, cook our food, and clear land. But though we employ it regularly to our benefit, fire can very easily become a destructive force through carelessness and mistakes or via natural means.

Satellite observations can provide valuable information about wildfire risk conditions, which can help emergency managers and firefighters identify potential fire ignitions in even the most remote areas and reduce response times. For example, the level of drought stress in vegetation can be assessed and mapped, enabling the identification of drier areas of greater fire risk. And, from 2015, a new generation of lightning-mapping instruments on geostationary satellites will provide near-continuous hemispheric monitoring for lightning flashes – one of the leading natural causes of wildfires.

Once wildfires have taken hold, satellite observations help in providing information on fire extent, intensity, and hot spots over broad regions, including in remote areas that are not otherwise systematically observed. In addition, both meteorological and land-surface imaging satellites provide observations of smoke conditions, which is an important input to air quality monitoring.

Volcanoes

As discussed in the Part II case study on Volcanoes and Aviation, tracking the course of a volcanic eruption takes constant monitoring. In addition to helping track volcanic ash plumes, satellites provide a valuable tool for observing the ground around volcanoes for signs of deformation (see InSAR inset). Ground deformation can indicate that magma is flowing, which can be a valuable marker for a potential eruption.

The study of satellite data collected over volcanoes since the 1990s has shown that while deformation is not a certain indicator of impending eruption, a lack of deformation is an important indicator that no eruption will occur, with fewer than 10% of volcanoes that did not deform still erupting.

InSAR cannot replace existing field-monitoring methods, but does provide a useful addition to volcano-monitoring capability. In particular, InSAR is useful for keeping an eye on volcanoes that are difficult to access or that do not have ground-based instruments installed.

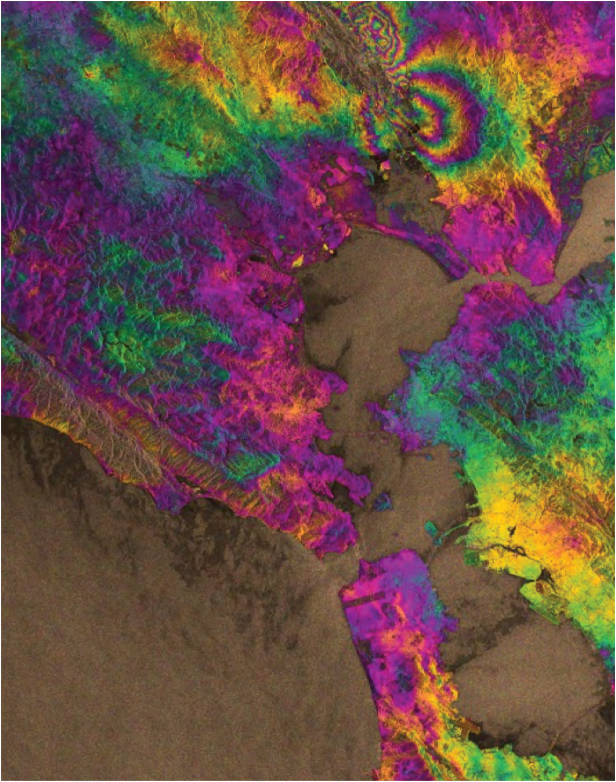
Geohazards and InSAR

Geohazards include a range of geological phenomena that present the risk of widespread damage over the short and long term, locally and more broadly – in particular earthquakes and landslides. InSAR is a powerful tool for monitoring the risks associated with geohazards.

InSAR uses two or more radar images in combination to detect surface changes over large areas. Small changes on the ground modify the reflected radar signal and lead to the rainbow-coloured fringes in the interferogram.

Unlike other techniques that rely on measurements at a few points on the ground, InSAR produces a spatially complete map of ground deformation with centimeter accuracy in a timely manner, and without subjecting field crews to hazardous conditions on the ground. The capability that satellites bring in this area represents a major leap forward in the way we will be able to monitor catastrophic geohazards in the future.

InSAR is used in some areas to track rates of subsidence, which can be a marker of potential landslide risk. It is also valuable for identifying the surface break of an earthquake and providing a guide to where rupture has not yet been detected or mapped.



Interferogram from Sentinel-1 / Napa Valley, CA, US

Image credit: ESA

Disaster Response

International Charter on Space and Major Disasters

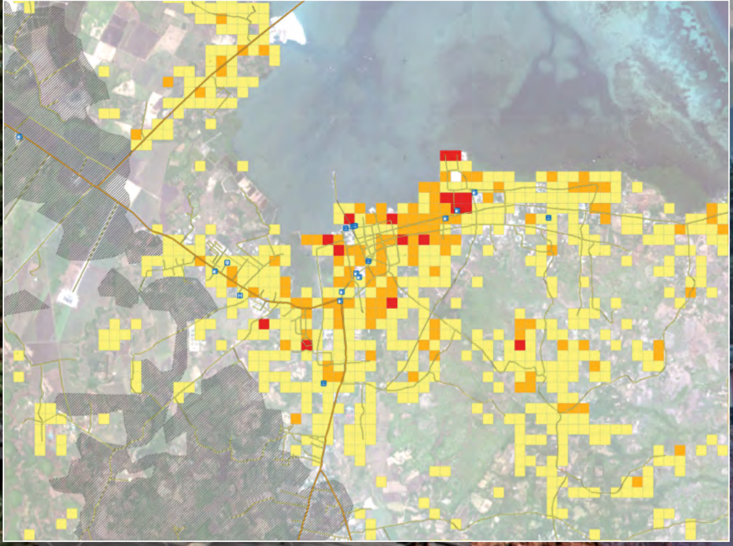
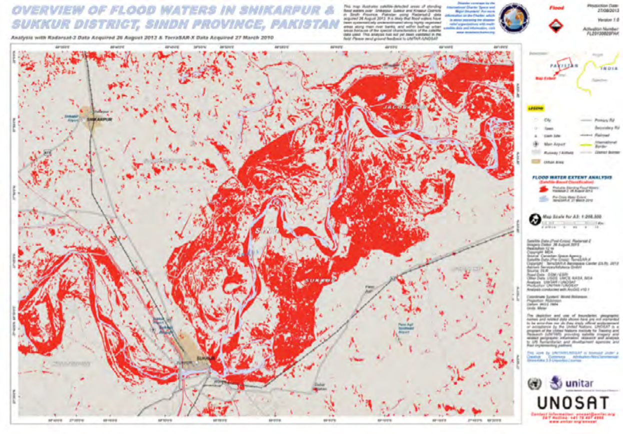


Image credit: Charter on Space and Major Disasters

The Charter (see detailed case study in Part II) is a partnership of space agencies that provides a mechanism for the rapid tasking of satellites for immediate response to disasters. It was declared formally operational in 2000 and, as of the end of 2013, has been activated for 402 disasters in 110 countries. The Charter has addressed tropical storms, earthquakes, floods, wildfires, landslides, oil spills, and volcanic eruptions, with different satellite data types better suited to different disaster types. Taken together, the satellites coordinated by the Charter provide global all-weather day-night response capability.

For example during Typhoon Haiyan in November 2013, the strongest ever to hit the Philippines, more than 1,000 high-resolution images were provided freely through Charter activation. These images were used to provide before/after imagery to assess damage to structures, houses, oil facilities, and other infrastructure. They were also used to underpin mapping and analysis in support of situational awareness and for the planning of resource deployment across the many islands of the Philippines. When the tropical storm Haiyan went on to impact the coast of Vietnam, the Charter was again activated to provide a variety of satellite data to produce estimates of affected areas and potential flood and storm inundation risk.

Flood Mapping



In 2013–2014, the Charter was activated for flood disasters more than once a month on average and accounted for more than half the activations during this period. These activations were spread across the globe, in countries with mature technical capabilities, and in those with very little national capacity to utilise satellite data. In the vast majority of these activations, satellite radar imagery was employed to produce flood-extent maps. Radar imagery enables all-weather, day-night response, which is particularly well suited to the cloudy and rainy conditions associated with flooding, as well as for detecting areas of standing floodwater.

In August of 2013, monsoon rains lead to widespread flooding in the Punjab and Sindh Provinces of Pakistan, where over 130 people were reported killed and government reports indicate that as many as 1 million may have been affected. During the floods, multiple assessments were generated using radar data captured over a 10-day period covering the flooding itself, as well as pre- and post-assessments of risk exposure and then damage.

Earthquakes

In the aftermath of a major earthquake, local infrastructure is often degraded or destroyed, including systems used by emergency managers to rapidly assess damage and the roads that enable access to sometimes remote disaster areas. Satellites help planners work around the loss of local infrastructure and can provide rapid damage assessments based on before/after imagery, comparing archives to new post-incident acquisitions.

These images – often high resolution – can provide detailed assessment of structural loss, damage to houses, and damage to critical transport infrastructure like roads, rail, and airports. In addition, satellites can effectively monitor for landslides, including in remote areas. Post-earthquake landslides can often block waterways, causing the formation of barrier lakes that themselves present a flood hazard after the initial earthquake hazard has subsided.

Unlike hazards such as tropical storms, it is not yet possible to predict earthquakes, so the ready capacity and global coverage of satellites makes them a uniquely powerful tool for earthquake response managers.

Disaster Recovery

Recovery Resource Management

The initial, frenetic disaster-response phase is often followed by a longer, more methodical recovery process involving the deployment of temporary humanitarian aid and logistics support while a more permanent recovery is organised and implemented. The complete disruption or severe degradation of local information sources can hamper the effective deployment and management of temporary aid and infrastructure. Satellites can provide imagery that plays a critical role in rapidly identifying newly formed hazards resulting from the disaster, supplementing and updating national and local geospatial information, and objective monitoring of the effectiveness of humanitarian efforts.

Post-Disaster Assessment

Active wildfires present a clear and direct danger to people, wildlife, property, and infrastructure – but beyond their immediate impact, they have significant long-term impacts on forests that need to be assessed and managed as a part of the recovery process. These impacts include damage to often remote infrastructure like forest roads and bridges, stress induced on delicate ecosystems, updates to forest inventories used by industry, and impacts on the risk profile for future fires. Satellites play a valuable role by enabling the collection of burn-scar imagery in the immediate aftermath of the fire, which can be used to prioritise urgent recovery steps. By their nature, satellites provide systematic revisit over the burnt areas in the months and years following the incident, which allows for an on-going assessment of the recovery of forests and monitoring as the risk of future fires builds with regrowth. This is of particular value in remote forested areas that are not easily accessible to forest managers and national authorities.

Like wildfires, floods also present a clear and direct danger as the waters rise, with most flooding taking place over coastal or low-lying land. Once the danger begins to recede, a rapid assessment of damage is required in order to initiate and direct recovery. This assessment is usually made on site, but in the aftermath of a major flood, damage in the field can pose risks to investigators and often the scale and vastness of the flooded areas would require too many human and material resources to allow for a timely assessment. Satellite imagery provides a viable alternative for a fast and large-scale survey of the flooded region. Archived pre-flood imagery can be used in combination with new acquisitions, enabling recovery managers to rapidly access the scope of inundation. These early assessments can be used to position recovery aid, identify safe and unsafe areas, prioritise infrastructure repair, and monitor risks from repeat flooding.

Monitoring Recovery

As the recovery process proceeds, satellites can provide practical and systematic measures of progress. For example, in the case of recovery from major storms, storm surge, or tsunamis, high-resolution satellite images can be used to determine the condition of individual buildings. When collected at regular intervals, these images can be used to generate a spatially explicit timeline of the recovery and inform the direction of reconstruction aid. In some cases, ocean surges can completely denude coastal settlements of all structures, and so pre-disaster images combined with progressive post-incident images can enable authorities to rapidly and objectively assess recovery.

In the case of the January 2010 Haitian earthquake, civil authorities lacked adequate maps of Port-au-Prince, which sustained heavy damage and frequent aftershocks. As a part of the response process, high-resolution satellite imagery was utilised by groups like the Humanitarian OpenStreetMap Team (HOT) to create new pre- and post-incident maps. These satellite-derived maps helped guide first responders and also provided a practical geospatial framework to be utilized by the Government of Haiti during the long recovery process.

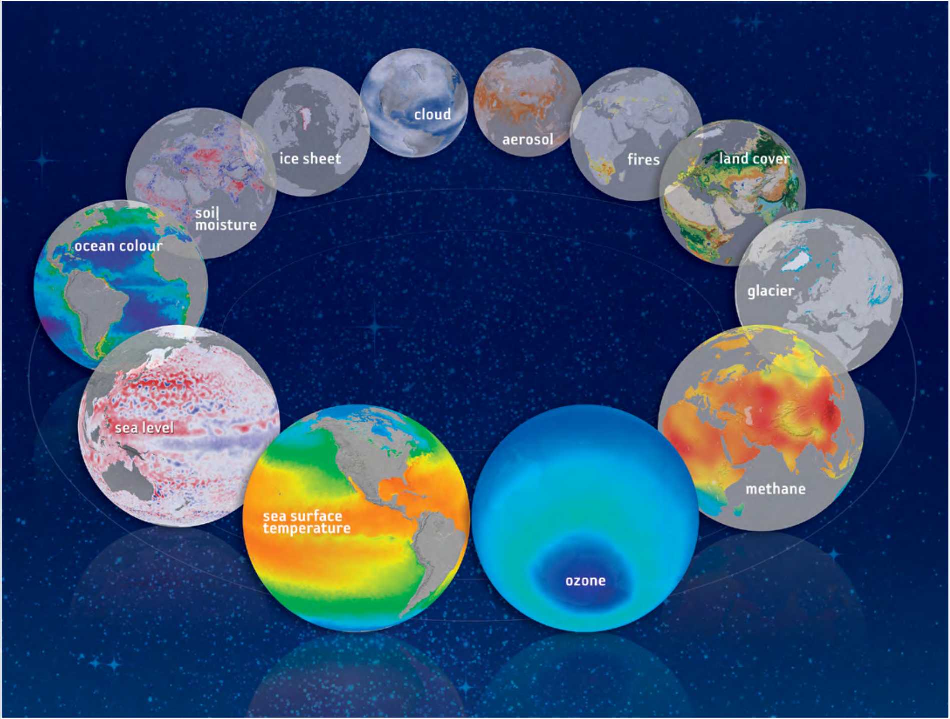
Long-Term Climate Monitoring

Climate Trends, Models, and Observations

There is growing evidence from models and observations that climate change amplifies the risk factors for extreme weather events, causing more intense tropical storms, heavier rainfalls and flooding, more severe and quicker onset drought, increasing numbers of lightning strikes, and increased conditions for wildfires and dangerous heat waves. The monitoring of long-term trends in climate variability is vital to our understanding of how this intensification will impact weather-related DRM.

With climate models continually evolving in complexity, evaluating the quality and accuracy of their results is critical. Satellites play an essential role here – there is simply no other way to make the globally consistent and comparable observations required to bridge measurements collected on the ground and from planes and ships.

A unified approach to the collection, merging, and analysis of information relating to climate change, sustainable development, and DRR will only be possible thanks to the global datasets collected by satellites.



The Global Climate Observing System

The Global Climate Observing System (GCOS) was established as a long-term, user-driven operational system capable of providing the comprehensive observations required for monitoring the climate system. GCOS has defined 50 ECVs that are technically and economically feasible for systematic observation, in large part due to the capacity of satellites. A detailed global climate record depends critically on a coordinated observing system with a strong satellite component. Of the 50 ECVs identified, 27 are exclusively or largely dependent on satellite observations.development, and DRR will only be possible thanks to the global datasets collected by satellites.

Radiation Budget, Temperature, and Storm Intensity

The Earth Radiation Budget ECV quantifies the overall balance between the incoming energy from the sun and the outgoing energy from the Earth. The radiation balance at the top of the atmosphere is a fundamental driver of the climate system and it can only be measured from space.

The atmospheric and sea-surface temperature ECVs are key predications of climate models and observations are needed to validate the results. Atmospheric temperature observations collected by satellite microwave, infrared, and GPS radio occultation instruments have become key elements of the climate record. When used in combination with aircraft measurements, satellites enable global calibration and scaling to provide a comprehensive record of atmospheric temperatures.

Global sea-surface temperature ECV data sets include a variety of localised measurements from surface drifters, moored buoys, and ships. Satellite measurements enable cross-calibration between these data sources, preserving accuracy while enabling the derivation of globally consistent records.

The Earth's radiation budget bounds the overall energy balance of the climate system and is reflected in the temperature of the atmosphere and sea surface. In turn these temperatures are linked to the intensity of extreme weather events and the hazards that disaster risk managers need to anticipate and prepare for in the future.

Precipitation and Sea Level

The general view is that the changing climate will drive changes in rainfall patterns, with rainy areas to become wetter, drier areas to become drier, and downpours to become heavier. These changes will have a significant impact on the occurrence of flood disasters. The precipitation ECV is critical to our understanding of these trends.

Observations from surface rain gauge and radar networks lack the density required to create a global record, in particular over the oceans and in countries without radar networks. Satellites can observe rain, ice, and snow and are a key input to constructing long-term, globally consistent records.

Changes in the glaciers and ice caps ECV provide some of the clearest evidence of climate change. Their decline would cause serious impacts on the many societies that are dependent on glacier meltwater, while the resulting sea-level rise would amplify flooding and ocean surge hazards in coastal regions. A century's-long time series of in situ glacier measurements has been combined with satellite imagery and elevation models to form a comprehensive global record that can be updated at scale as new satellite observations become available.

Sea level ECV measurements from tidal gauges constitute a significant historical climate data record, but local sampling does not enable global coverage. Satellite altimetry provides repeated, consistent, global coverage putting tidal measurements into context and allows data from sites around the world to be directly compared.

Global sea level has been rising for decades and this trend is expected to continue beyond the end of this century. This will expose our densely populated coastlines to increasing risk from flooding and storm surge.

CEOS Working Group on Disasters (WGDisasters)

The overarching goals of WGDisasters are to increase and strengthen satellite Earth observation contributions to the various Disaster Risk Management (DRM) phases, and to educate politicians, decision-makers, and major stakeholders on the benefits of using satellite Earth Observations in each of those phases. To achieve these goals, CEOS Agencies have agreed to a series of objectives and supporting actions that will improve the coordination of satellite acquisition and data distribution, and foster the use of satellite data by DRM users. Objectives include:

- Define a global satellite observation strategy for DRM, including a detailed assessment of needs, gaps, and satellite Earth observation requirements and the development of a strategy;
- Ensure the appropriate inclusion of satellite Earth observations in the Post-2015 framewor for disaster risk reduction process;
- Continue other supporting actions, including DRM Outreach & Evaluation of CEOS DRM Actions, satellite Earth observation capacity building for DRM, and satellite Earth observation DRM Projects Database.

Further reading and contacts for WGDisasters can be found on the CEOS website:

www.ceos.org/ourwork/workinggroups/disasters

EO Handbook Online

The full text of this report is available on the Earth Observation Handbook's website at **www.eohandbook.com/wcdrr**. A supporting database of the satellite missions, instruments and measurements is available at **database.eohandbook.com** and contains powerful search and presentation tools, with the ability to export customised tables and timelines in support of analyses of current and planned provision of observations in support of different applications and measurements.

CEOS, the Committee on Earth Observation Satellites, coordinates civil spaceborne observations of the Earth. Participating agencies strive to address critical scientific questions and to harmonise satellite mission planning to address gaps and overlaps.

www.ceos.org

ESA, the European Space Agency, is Europe's gateway to space. It is an international organisation with 22 Member States. ESA's mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world.

www.esa.int

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