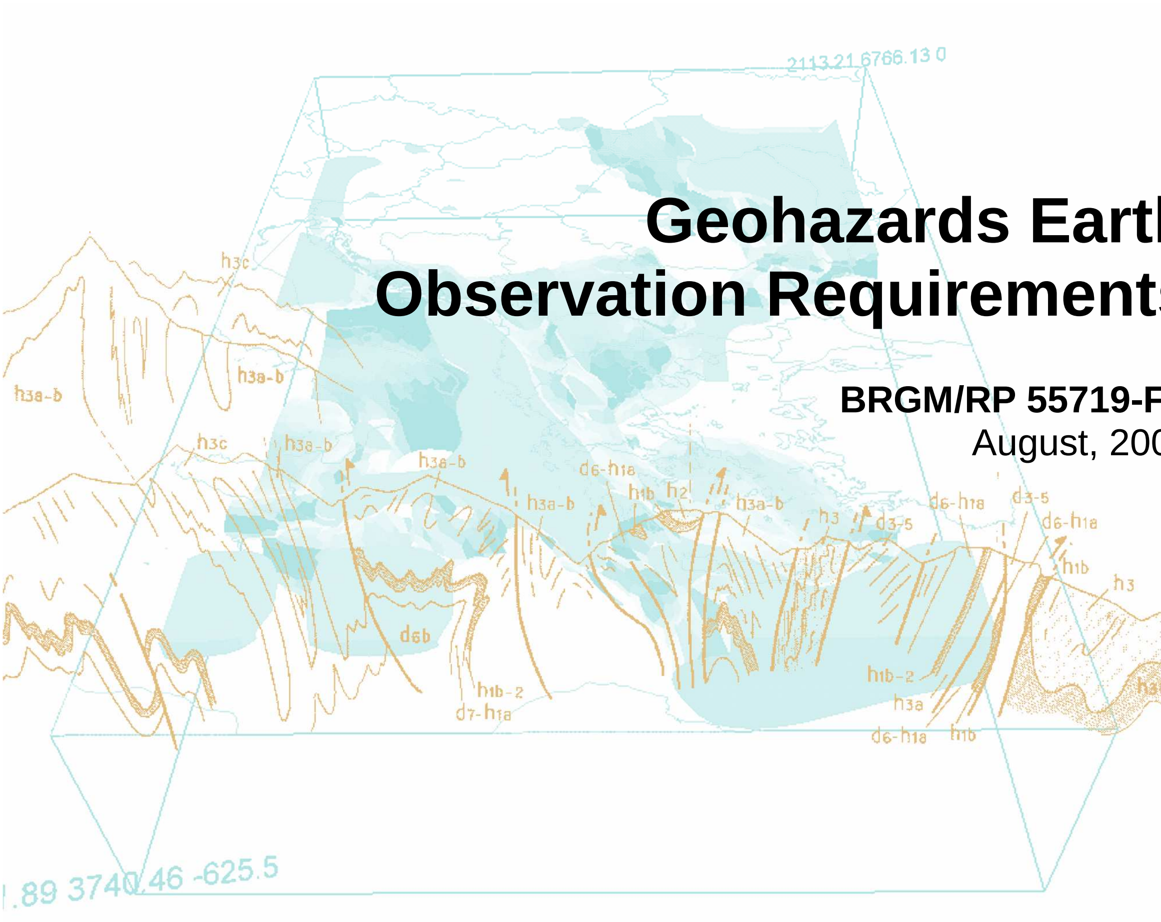

Geohazards Earth Observation Requirements

BRGM/RP 55719-FR

August, 2007

Public document

Geohazards Earth Observation Requirements

BRGM/RP 55719-FR
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Study carried out by the ESA-BRGM jointly funded IGOS Geohazards Bureau

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Synopsis

The IGOS Geohazards Bureau is jointly funded by the European Space Agency (ESA) and the BRGM. This office has been established in September 2004. As part of the contractual agreement signed by both parties (ESA ESRIN Contract No. 18349/04/I-IW), observations requirements must be produced by the Bureau and submitted to the Joint Committee for approval.

While this report was originally intended to contribute to the IGOS observational database requirements, it supports also the Global Earth Observation (GEO) initiative as a contribution to the User Interface Committee work to collect user requirements and to the user group of the GEO task DI-06-09: “Virtual Constellation for Risk Management”. IGOS Geohazards participates to GEO as its “Geohazards Community of Practice”.

IGOS Geohazards members are presently (july 2007):

- The United Nations Educational, Scientific and Cultural Organization, UNESCO
- The European Space Agency, ESA
- The National Aeronautics and Space Administration, NASA
- The Japanese Space Agency, JAXA
- The French Space Agency, CNES
- The United States Geological Survey, USGS
- The British Geological Survey, BGS
- The French Geological Survey, BRGM
- The Federation of Digital Seismological Networks, FDSN
- The World Organization of Volcanoes Observatories, WOVO
- The Global Geodetic Observing System, GGOS
- The International Consortium on Landslides, ICL

GEO participates to the IGOS Geohazards Joint Committees as permanent observer. A process is undergoing to admit other members within the partnership.

This report replicates largely parts of the IGOS Geohazards Theme report 2007, which has been submitted for review to members of the IGOS Geohazards initiative. These reviewers are the UNESCO (Robert Missotten); ESA, the European Space Agency (Marc Paganini); JAXA, the Japanese Space Agency (Chu Ishida); CNES, the French Space Agency (Steven Hosford); BGS, the British Geological Survey (Stuart Marsh, Helen Reeves, Andy Gibson and Kay Mc Manus);, The French Geological Survey, BRGM (Hormoz Modaressi, Gonéri Le Cozannet and Jérôme Salichon); WOVO, the World Organization of Volcanoes Observatories (Warner Marzocchi); and GGOS, the Global Geodetic Observing System (Hans-Peter Plag).

This report is based on a two steps approach: Firstly, end users needs are analysed for each hazard and for each step of the disaster management cycle. Secondly, corresponding data needs are provided or each hazard and for each step of the disaster management cycle. The final section of this document provides suggestions on the way forward to improve these observation requirements. It is proposed to further extend the present requirements on hazards to the assessment of vulnerability and exposure.

The need to collect user requirements is increasing, especially in the context of the GEO initiative. As the IGOS Geohazards partnership is growing, the IGOS Geohazards Bureau seeks to offer the possibility to IGOS Geohazards members to comment on and participate to this user requirement process. IGOS Geohazards members are invited to comment on this document to contribute to the next versions of these Geohazards user requirements.

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1. Introduction

One of the objectives of IGOS Geohazards is to better identify communities of practices and their interactions in an attempt to improve Earth observation information produced (data flow) and needed (requirements) by the different actors involved in geohazards management. These groups can be gathered in five main categories that are detailed in the following paragraphs: exposed populations, end users, in-sector providers, data providers and facilitators. Figure 1 summarizes and sketches their relationships with regards to the data and requirements exchange and expectation.

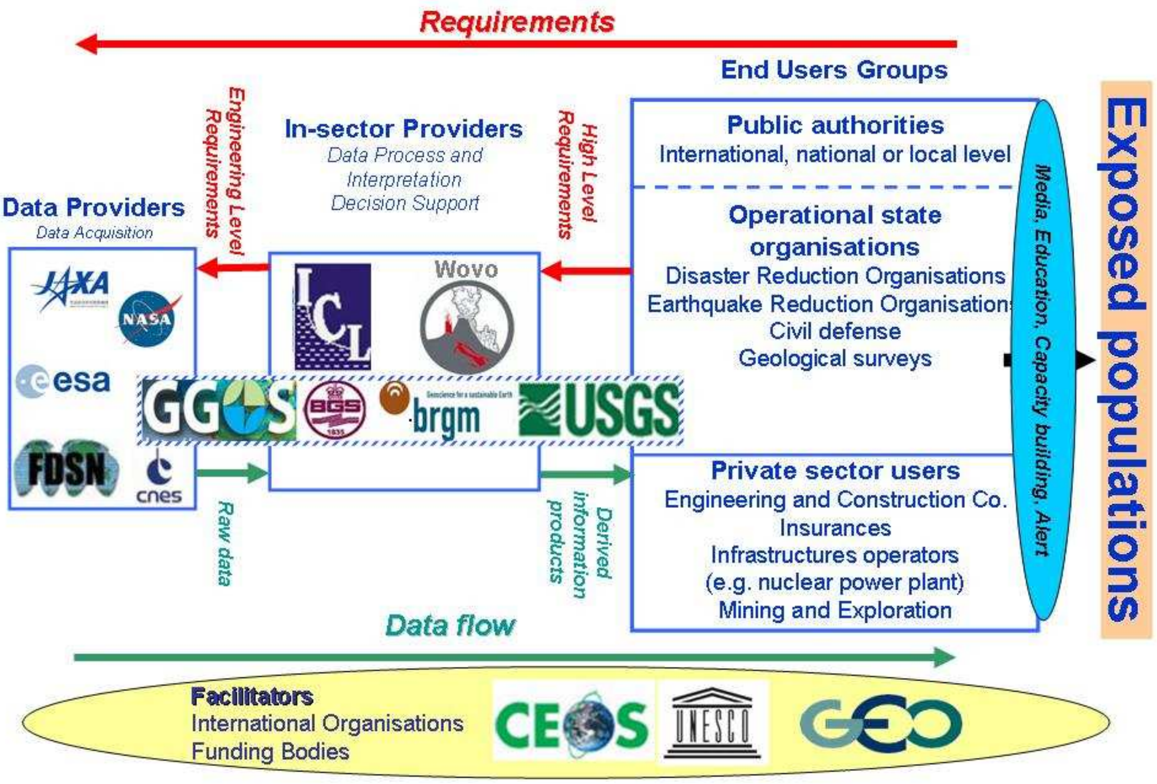

Figure1: End to end chain between data providers to users targeted by IGOS Geohazards. This sketch is an overview of the different actors involved in geohazards. Data flow (green arrows) corresponds to the observations and products regarding geohazards. Data providers provide in situ and space data to engineering, scientific and state organizations (called here "in-sector providers"). These data are analysed and/or assimilated in order to provide information to end user groups such as public authorities and private sector users.

Members of the IGOS Geohazards Partnership are represented on this sketch. They are mainly data providers and in-sector providers, but responsibilities of some partners may overlap various groups. As an example, BRGM operates a seismometers network, analyzes the data and reports to the State Authorities about the seismic activity. This is part of a contractual agreement with french ministeries. USGS, BGS and

GGOS are also overlapping across the entire data and information flows. Facilitators are international bodies and funding organizations that help organizing or funding the geohazards communities of practices.

The organizational aspects of the geohazards communities of practices are described in details in the 2nd IGOS Geohazards Theme Report, 2007.

This approach is used to spot the strengths and gaps in the current IGOS Geohazards membership. It allows also to identify two levels of requirements:

- Firstly, high level requirements (that correspond to the information needs of end users) are analysed for each hazard and for each step of the disaster management cycle

- In a second step, engineering level requirements (that correspond to the *in situ* and space data needs of the “in-sector providers”) are analysed for each hazard and for each step of the disaster management cycle

These requirements are analysed in the two next chapters. The high level and engineering level requirements have been refined in many studies such as for example MUSCL[1], RESUM[2] or Terrafirma[3] for InSAR and Permanent Scatterers methodologies, within FDSN and International Association of Seismology and Physics of the Earth’s Interior (IASPEI) for seismic data, or within GGOS for geodetic data. However, this is not the purpose of IGOS Geohazards to detail more these requirements. The purpose of this report is to provide an overview of high level and engineering level requirements for each hazard and for each step of the disaster management cycle.

[1] MUSCL: Monitoring Urban Subsidence, Cavities, and Landslides by remote sensing, project funded under the FP5. http://dude.uibk.ac.at/Projects/MUSCL/start.html

[2] RESUM: Reseau de suivi de subsidence urbaine et minière: BRGM project funded by the French ministry of research. http://resum.brgm.fr/

[3] Terrafirma: Global Monitoring for Environment and Security (GMES) Service Element (GSE) project funded by ESA. http://www.terrafirma.eu.com/

2. High level requirements

2.1. DEFINITIONS AND TERMINOLOGY

2.1.1. Geological hazards

The ISDR has proposed a terminology for disaster[4], which defines geological hazards as “Natural earth processes or phenomena that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.” It adds that “Geological hazard includes internal earth processes of tectonic origin, such as earthquakes, geological fault activity, tsunamis, volcanic activity and emissions as well as external processes such as mass movements: landslides, rockslides, rock falls or avalanches, surfaces collapses, expansive soils and debris or mud flows. Geological hazards can be single, sequential or combined in their origins and effects.”

2.1.2. Disaster management

According to ISDR, disaster management is defined as “the systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping[5] capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards.” These actions can be represented on a disaster management circle, which comprises the pre-disaster phases, crisis management and post disaster phases.[6]

2.1.3. Caracteristics of each geological hazards

End users need to acquire basic knowledge about the potential threatening natural hazards in order to prevent, mitigate, prepare, respond and finally recover from a disaster. One of the purposes of IGOS Geohazards is to identify some connections between earthquakes, landslides, volcanoes and tsunamis hazards and to propose a global approach using information supports usually delivered by scientists and geological survey agencies. Nonetheless, each hazard has its own distinct characteristics in terms of event occurrence, prediction likelihood, time and spatial extent and effects that are briefly summarised in Table 1.

[4] http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm

[5] Coping capacities are defined as “the means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster.” (ISDR)

[6] See 2nd Geohazards Theme Report, 2007

	Earthquakes	Landslides and land subsidence	Volcanoes	Tsunamis
Hazard description	- Sudden ground ruptures occurring from an epicentre and propagating along fault lines - The fault rupture triggers tremors of the earth's surface: the seismic waves	- Ground instabilities (deformation and displacement) under direct influence of gravitational forces acting on the surface or at shallow depth - Heterogeneous types of movements such as rock falls, failure of slopes, debris flow, swelling or shrinking of clay subsoils…	- Opening or vent in the ruptured Earth's surface or crust through which molten rock, ash and gases are extruded from depth -Volcanic hazard depends on the nature of volcano and the type of eruption making hazard unique for each location and event	-Series of catastrophic ocean waves generated by submarine movements. - The waves may travel at speeds up to 800 kilometres per hour and become dramatic with increasing height, up to 30 metres, when approaching shallow water along coasts
Prediction	The sudden break from an epicentre and the propagating rupture cannot be predicted yet	Possible to anticipate: The triggering factors are well known: weather conditions or another major natural disaster or human induced origin such as mining, blasting, digging or pumping.	Possible to anticipate: Warning of impending volcanic event with gradual awaking from a dormant to an active period. Precise warning is nevertheless complicated as the alert might persist many months before the major event	Possible to anticipate at distance: Alert systems monitoring triggering events (earthquake, landslide…) and ocean surveys. The local tsunamis are very difficult to predict
Time and Spatial extent	-Minute scale ruptures and tremors -Ruptures can extend as far as about 1000 kilometres along faults. -Ground shaking decreases quickly with distance but seismic waves travel far from the source.	Very variable in time and spatial extent. A landslide can be reactivated after many years, or huge landslides can be suddenly triggered by another event such as an earthquake.	-Time extent is highly variable and eruption may occur for decades. -The spatial extent of an eruption is generally limited. The location of the volcanic area, its geological history, and the affected regions are generally identified. There might be distant effects such as ash clouds.	Very variable spatial extent: Capability of causing disaster up to thousands of kilometres away from the source a couple of hours after initiation.
Distinct Characteristics	"Site effects" generated by a local amplification of ground motion even far from the source.	Soil properties such as geological or hydrological conditions are strongly related to landslide occurrence.	Different types of volcanism make eruptions inoffensive or on the contrary critical.	"Site effects": The amplitude of the tsunami wave strongly depends on the morphology of the coast.
Relationships to other natural hazards	Earthquakes often trigger Landslides, land subsidence and permanent topographic changes. Most of the tsunamis waves are generated by earthquakes	Landslides may trigger tsunamis when coastal or offshore locations	- Volcanic activity combines various hazards such as earthquakes, lava flows, ground explosions, landslides, lahars, tsunamis, gas emission and meteorological phenomena. - Hazards occurrence such as landslides while no ongoing volcanic activity is reported.	Various triggering factors due to other natural hazards mainly large earthquakes but also volcanic eruptions, and landslides along the coast or beneath the ocean.

Table 1: Geohazards characteristics

2.2. USER NEEDS AMONG ALL PHASES OF THE DISASTER MANAGEMENT CYCLE

Once natural hazards are identified for an area, the main requirement of the end users is to be provided with realistic answers to critical questions: what will happen, when, how and for how long? Survey agencies endeavour to address these questions at any phase of the hazard or the disaster, using *in situ* and space based Earth observations data, modelling and socio-economic studies. Depending on the phase of a disaster cycle (mitigation, crisis management or response)[7] the end users will have different approaches and requirements where one can distinguish:

- The mitigation and preparedness policies during the pre-emergency phases, that demand information on exposure of population or infrastructures in addition to information on hazards. While mitigation will focus on land use policies, preparedness will focus on developing operational tools for crisis management.

- Short term to very short term mechanisms in a time range from minutes to days enabling crisis management emergency phase to assess or face an impending hazard. This phase is critical for the end users though not operational yet for many types of natural hazards such as earthquakes.

- The crisis response where disaster management and post-emergency concerns aim at supplying end users with critical information to reduce consequences of a disaster and to monitor the extent of the damages.

These approaches need to be specified for all geohazards: earthquakes, landslides, volcanoes or tsunamis. Each geohazard and exposed site present specific features that are critical to identify in order to provide the most relevant products that satisfy end users requirements at each phase of a disaster management cycle. As an example during a pre-emergency phase for landslide hazard[8], a mitigation policy can aim at:

- **Reducing hazard** through specific measures such as reinforcement of the slope, reforestration, etc... Observations allows here to perform an inventory of existing landslides and the level of threat.

- **Reducing exposure** where observations provide inputs to alert systems and information to land use planning.

- **Reducing vulnerability** where observations contribute to the assessment of systemic and physical vulnerabilities, through e.g. the provision of inputs information for inventories of vulnerable elements.

The end users demand is therefore not only focused on the hazard itself, but also on the vulnerability of exposed elements. For instance, the structural engineers evaluating the building vulnerability to earthquakes for which additional products can be available require *in situ* observations such as noise measurements using portable seismometers to identify site effects or

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[7] The different phases of the disaster cycle are described in the 2nd IGOS Geohazards Theme Report, 2007

[8] USGS landslide hazard program has developed intensive real-time monitoring in the US at several critical locations such as highways, or cities: http://landslides.usgs.gov/monitoring/ and "*National Landslide Hazards Mitigation Strategy – A Framework for Loss Reduction*" by E.C. Elliot and P.L. Gori, USGS Circular 1244, 2003.

space and airborne observations to retrieve building parameters (such as building heights, or 3D models) and to map the different typology classes for large urban areas.

One of the approach of IGOS Geohazards is to outline end user most common products to all geohazards. This multi-hazards approach is expected to improve the efficiency of information provision to end users, and to identify issues that should be taken into account for developing new Earth observation services for the benefit of exposed populations. Four types of products have been identified:

- Hazard maps and risk maps are a source of input information for pre-disaster phases of the disaster management cycle

- Scenarios help authorities to prepare to the crisis, as it helps them to produce automated procedures

- Forecasting and early warning systems

- Response mechanisms, such as rapid mapping, which is addressed by the international charter "Space and Major Disasters". Generic end users products for the pre-disaster phases

2.3. PRE-DISASTER PHASES: PREVENTION AND MITIGATION

2.3.1. Hazard maps

Scientists can help end users to identify threatening hazards and the best land-use strategy through hazard maps that are the first step in the evaluation of risk. This represents a critical requirement to mitigate risk and a useful product for local to national authorities, land use planners and building companies that are developing new infrastructures. Table 3 indicates the different characteristics of earthquake, volcano, landslide and tsunami hazard maps.

End users need to integrate different hazard maps into a multi-hazards approach in order to become resilient to any potential catastrophic event. More precisely, land use planners need scientific support to establish priorities between different hazards that exhibit different spatial and time scales and various triggering factors. However, it is very difficult to perform appropriate comparisons of probabilities of occurrence between different hazards. As an example, the earthquakes hazard map of Switzerland developed by the ETH[9] (Figure 2) shows the level of horizontal ground motion expected to be reached in a period of 475 years, with 10% chance of exceedance in 50 years. Volcanic hazard can be expressed very differently: For example, the lava flow hazard can be expressed using the location and frequency of past eruptions, the topographic features and the assumption that future eruptions will be similar[10]. While seismic hazard maps focus on the greatest event in the next 475 years, volcanic hazard map focus on the next event, as volcanic features such as topography might have changed completely after the next event[11].

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[9] Swiss Federal Institute of Technology Zürich, http://www.ethz.ch/index_EN

[10] We take as an example the Lava flow hazard zone maps performed by USGS for the island of Hawaii: http://pubs.usgs.gov/gip/hazards/maps.html , Reference: "Volcanic and seismic hazards of the island of Hawaii", on line edition, U.S. Dpt. of the Interior and USGS.

[11] See for example the hazard assessment in Mount St Helens after the 1980 eruption, which completely changed the topography. http://vulcan.wr.usgs.gov/Volcanoes/MSH/Hazards/OFR95-497/OFR95-497.html, Reference: E. W. Wolfe

Finally, this example shows that if an end user has to establish a land use strategy, he will need to compare probabilities that can not be easily compared. The task of producing practical multi-hazards maps is therefore very challenging because of the characteristics of each natural disaster. A certain degree of harmonisation in the terminologies across all geohazards is therefore needed. With better homogenised information, public and private organizations can chose between different land use options to minimise the risk once the infrastructure is built. In the specific case of landslides, it is even possible to reduce the hazard itself through e.g. reforestation. Finally, the complexity of the information provided through hazard maps clearly shows that land use planners should be assisted by multi-hazards experts to take the best decision before planning new infrastructures in high risk areas.

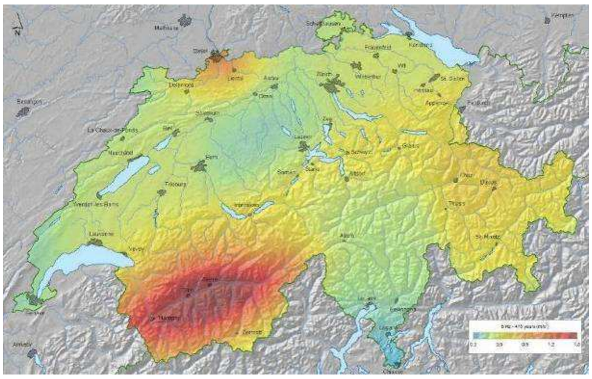

Figure 2: Seismic hazard map of Switzerland depicts the level of horizontal ground motion (in units of the 5% damped acceleration response spectrum at 5Hz frequency) expected to be reached in a period of 475 years (10% exceedance chance in 50 years).[12]

and T. C. Pierson, *Volcanic-Hazard Zonation for Mount St. Helens, Washington*, U.S. Geological Survey Open-File Report 95-497, 1995.

[12]Source: http://www.earthquake.ethz.ch/research/Swiss_Hazard/Maps_plots/Hazard_Maps/hazard_map.pdf, ETH Zurich (Switzerland), Earthquake statistics group.

Earthquakes	Volcanoes	Landslides and subsidences	Tsunamis
The relevant identification of the seismic or potentially seismic areas is critical for end users to evaluate the seismic hazard of a country, a region or a city. The availability of earthquake frequency maps is the minimum requirement in order to reduce exposure. For improved assessment of the seismic hazard, seismic zoning is implemented to obtain quantitative information for design, construction, and planning of the built areas. These maps provide end users with inferred ground motion intensity and, but not systematically, an earthquake return period.	Volcano hazard assessment and zonation maps are the main tools to address the questions of long-term planning and mitigation of volcanic hazards for all the monitored and identified sites. It requires information on the magnitudes, patterns and frequencies of the past eruptions. Thus, volcanologists dedicate a large amount of work to produce various maps to inform end users specifically on each type of volcanic related hazards. These documents need to be constantly updated with permanent studies and acquisition of new data related to the activity of the volcano. This information is produced by a wide range of science fields such as meteorology, geochemistry, geology or geophysics and hydrology.	Landslides and ground instability hazard maps are based on inventory of all types of ground instabilities, their possible evolution and their triggering factors. A hazard map may propose only the locations of old landslides to indicate potential instability, or may be more complex and then based on variables such as rainfall, slope angle or soil type. As it is often impossible to make an exhaustive inventory of all cavities in a specific region, geological maps, expertise, and inventories of existing cavities are used to draw maps showing the probability of existence of cavities, their probability of collapsing and the zones likely to be affected. Hazard maps of swelling or shrinking of clay subsoils are based on the analysis of already existing geological maps.	Tsunamis are rare events making their behaviour difficult to determine and dependant on extensive research activities. End user requirements for the tsunami hazard mitigation are basically inundation maps that take into account the topography of the sea shore and the amplitude of the waves. More complex hazard maps are likely to consider the historical tsunami and earthquakes recordings in addition to the local specificity of the bathymetry, and the characteristics of the coast that influences amplitudes of the hazardous waves. This needs integrated studies of different scientific fields such as oceanography and seismology.

Table 2: Geohazard map processing; After IGOS Theme report 2004

2.3.2. Risk maps

End users need risk maps as improved indicators offering a combination of hazard and vulnerability and providing therefore an estimation of a level of damage. The risk depends on the hazard, but also on the elements at risk and their vulnerability. For instance, the world process of urbanisation increases geological risk, unless appropriate land-use policies are applied. In many cases, areas of low or moderate seismicity can be even more vulnerable to earthquakes than high seismic zones. For similar reasons to those developed above, multi-risks[13] assessment is a matter of concern for end users concerned with mitigation and preparedness to disasters, building renovation and insurance companies. All these users need to know which elements and populations are at risk, and to estimate their vulnerability to various events. The lack of information received by exposed populations is a socio-economical component of vulnerability and can strongly increase the risk. The accessibility to vulnerability databases can be very different pending

[13] Such methodologies are proposed and applied in “Grünthal et al. (2006): Comparative risk assessments for the city of Cologne – storms, floods, earthquakes. - in Natural Hazards” or “Pierre Thierry et al (2007) An example of multi hazard risk mapping and assessment on an active volcano: the GRINP project on Mount Cameroon – in Natural Hazards”

on the considered country. As an example, the CEDIM[14] was able to estimate the value of exposed elements in Germany and the expected losses in case of floods, earthquakes or storms.

However, the situation is often far less favourable, even in developed countries. In those cases, earth observation can play a key role in performing rapid automated inventories of exposed elements and their discrimination by their vulnerability to each kind of hazard. In order to do this, building engineers and earth observation scientists need to exchange information on the parameters retrieved using observations that allow the estimation of the vulnerability for hazards. In France, for example, many parameters are used in the determination of building vulnerability, to earthquakes, among them the height of the building and their construction date. One of the expected benefits of a multi-risks approach is to save costs through mutualising the vulnerability assessment to many hazards. However, it is imperative that specificities of each hazard should be taken into account. As an example, fragility curves are an essential parameter for vulnerability assessment to earthquakes as the strongest losses are not due to the earthquake itself, but to from damage to buildings. On the other hand, vulnerability assessment to volcanic hazards might not focus on retrieving building parameters, but rather on the exposed populations, the possibility to evacuate them rapidly, and possible cascading effects due to the industrial environment. This shows that despite the potential to save costs through vulnerability assessment to hazards exists, vulnerability parameters remain specific to each hazard.

In addition, interpreting risk maps implies understanding the types of vulnerability that are addressed. In fact, there are infinite possibilities of risk maps as one can consider the vulnerability of buildings, of populations, of the GDP (Gross Domestic Product), of building value, etc… Nevertheless some research efforts are made such as the ARMONIA project[15] where new methodologies for multi-risks assessment and harmonisation of different natural risk maps are investigated.

Finally, only direct losses due to a disaster can be mapped. The deficiency or the collapse of vital infrastructures after a natural disaster such as transport may result in indirect losses that are impossible to map, and often difficult to even quantify. Disaster scenarios can help understanding these effects.

2.3.3. Disaster scenarios

Disaster scenarios are based on a simulated event and on an estimation of the vulnerability to help understanding what will be the challenges during a crisis triggered by a hazard. The scenarios usually combine information provided by the hazard maps, observations and modelling of possible consequences. Building a disaster scenario therefore in the inference of a chain of events based on modelled ongoing hazards that lead to losses with an associated frequency and severity. This contributes to end user requirements to identify and understand disaster triggering and cascading effects, such as the occurrence of an earthquake and the associated landslides or tsunami waves. This kind of tool allows the identification of possible weaknesses in the response mechanisms. Table 3 presents the different characteristics of disaster scenarios for natural hazards.

Nevertheless, end users have to be very cautious when using this product. In order to build a scenario, scientists must choose a certain number of parameters, such as the scale of the event considered, possibly its location and the cascade effects. It is therefore necessary to make

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[14] CEDIM: Centre for Disaster Management and Risk Reduction Technology http://www.cedim.de/english/13.php

[15] Applied Multi-Risk Mapping Of Natural Hazards for Impact Assessment, European Community Project n°511208, see http://www.armoniaproject.net

different scenarios of various probable events. As a consequence scientists have to interact with users to define the probability of occurrence of an event scenario that fits the end user requirements. The issues related to the interpretation of scenarios further stress the need to support scientific advisory of decision making.

Earthquakes	Volcanoes	Landslides	Tsunamis
Earthquake scenarios provide end users with information about potential damages to buildings, human loss, or effects on urban activities. Earthquake risk scenarios require many types of information such as geodesy, geology, historical and instrumental seismology, but also geotechnical parameters and engineering designs. Such studies are performed at present on many cities[16].	Eruption scenarios can be implemented according to the available knowledge of the past volcanic episodes. Examination of several possible eruption scenarios can help identify the possible vent location, the potential hazardous areas and the different types of eruptions. Nevertheless there are still many active volcanoes for which the lack of information on their eruptive history has to be addressed. The accuracy and robustness of such scenarios critically depends also on the integration of realistic volcano modelling and enhanced volcano instrumentation or monitoring such as gas or geodetic measurements.	The estimation of damage and loss according to a risk scenario is based on observations and modelling of the ground instabilities. These scenarios provide predictive tools on the ground displacement and their effects to environment, urban areas, or infrastructure in terms of spatial, temporal extent and damage. A large field of science is required to produce such scenarios: earth sciences (geology and geomorphology, geophysics), water sciences (hydrology and hydraulics), and engineering sciences (civil and mining engineering, forest and agricultural engineering).	Tsunami scenarios are simulated given multiple conditions such as seismological, geographical or societal conditions. The results of a hypothetical tsunami inundation scenario should include meaningful information about the wave height and the current speed as a function of location, as well as time series of wave height at different locations indicating waves arrival time. Tsunami scenario simulations are being performed by survey centres such as the NOAA centre for Tsunami research.

Table 3: Geohazards Scenarios; After IGOS Theme report 2004. This table does not depicts subsidence scenarios. Such scenarios exist (for example, geomechanical scenarios in mining areas), and identifying them would allow to establish a strategy to better integrate earth observation datas in these models. This could be a task for a next Geohazards Earth Observation requirement process.

2.4. EARLY WARNING, AND RESPONSE

2.4.1. Early warning

During the preparedness phase of the disaster management cycle, end-users prepare the crisis management, based on the existiong information (e.g. hazard maps, risk maps, and scenarios). Furthermore, efficient crisis management policies require some additional inputs that can be provided by real time *in situ*, airborne or space based earth observation systems. Data are integrated to acquire the relevant information for forecasting, for alerts or for response mechanisms in order to reduce the risk of exposure of societies.

ISDR defines early warning as “the provision of timely and effective information, through identifying institutions, that allow individuals exposed to a hazard to take action to avoid or reduce their risk

[16] See the Central United States Earthquake Consortium Six Cities Study using FEMA ‘s HAZUS software: http://www.cusec.org/Hazus/sixcities/six_cities.htm

and prepare for effective response" [17]. Table 4 attempts to summarise the end users' needs for information for early warning. The lack of operating information is As an example, according USGS reports, only about 20 of the 550 historically active volcanoes in the world are monitored adequately. Examples of *in situ* instrumentation for landslide monitoring and tsunami early warning are presented in figures 3 and 4 respectively

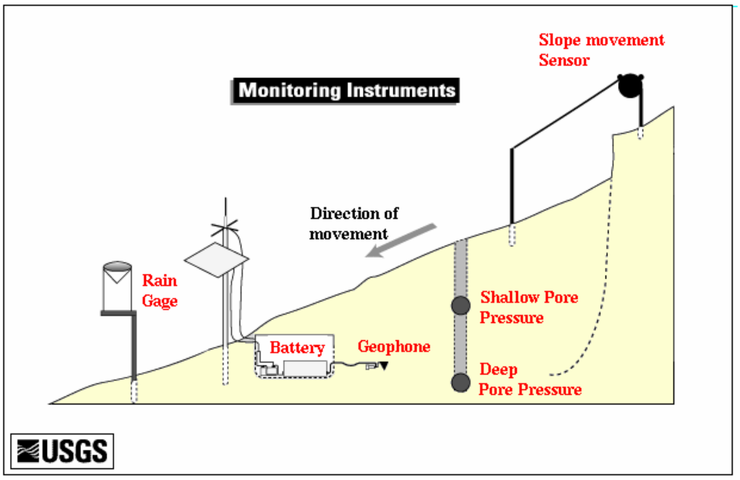

Figure 3: Real time Landslide Monitoring–Landslide Instrumentation[18]

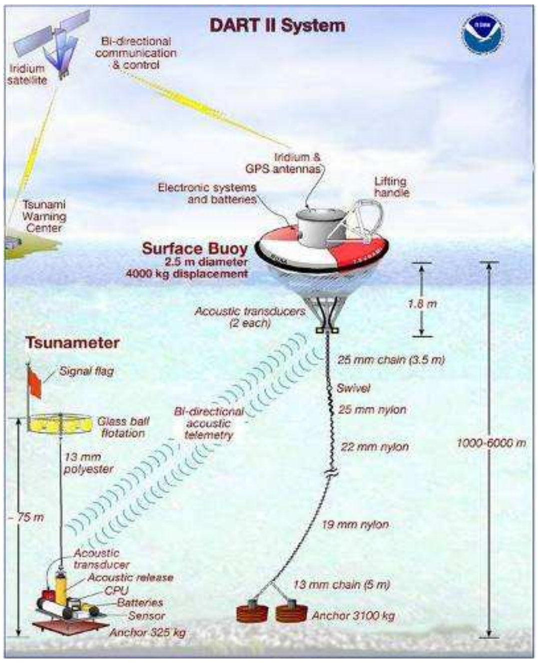

Figure 4: The Deep-ocean assessment and reporting of tsunamis (DART) buoy system is an instrument for the early detection, measurement, and real-time reporting of tsunamis in the open ocean. Developed by the US NOAA Pacific Marine Environmental Laboratory, the DART system consists of a seafloor bottom

[17] ISDR 2004 Terminology: basic terms of disaster risk reduction. http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm, International Strategy for Disaster Reduction secretariat, Geneva.

[18] Source USGS Landslide hazard program, http://landslides.usgs.gov/monitoring/hwy50/rtd/

pressure recording system capable of detecting tsunamis as small as one cm, and a moored surface buoy for real-time communications[19].

Earthquakes	Volcanoes	Landslides	Tsunamis
Existing early warning systems rely on a measure of the time delay (up to tens of seconds) between arrivals of earthquake's first waveforms and the most destructive ones. This delay is used to shut down critical facilities and to trigger emergency activities[20]. New methods based on the monitoring precursory phenomena, such as foreshocks, ground property changes or on precursory phenomena in the atmosphere[21] remain a research area.	Early warning systems have been set up for hazardous volcanoes such as Etna or mount St Helens. End users usually require the volcano observatory to provide them with the current activity of the volcano. The level of the threat is represented by a certain alert level. Earthquakes are precursory phenomena of volcanic eruptions. The ground deformation, hydrogeologic changes and the analysis of gas are also used to monitor an eruption.	End users may have access to: - The occurrence of various triggering factors such as regional or local weather and soils conditions or human activity such as mining - Appearance of precursory evidences monitored over hazardous unstable areas such as the rapid increase of ground slide velocity or cracks initiation.	Efficiency of early warning systems for tsunami depends mainly on the distance between the tsunami's triggering factors, generally an earthquake, and the exposed population. The time delay before the waves' arrival can range from a few minutes to ten or more hours. Therefore, close to the source the early warning relies only on the population and authorities' awareness of tsunami potential occurrence immediately after an earthquake ground shake or a brutal sea recession. At distance, implementation of tsunami warning centres such as the Pacific Tsunami Warning Centre is critical in making possible alerts on potentially ongoing waves.

Table 4: Geohazard forecasts; After IGOS Theme report 2004

2.4.2. Response

As soon as a natural disaster occurrs, a crisis response requires a large involvement of end users in charge of damage assessment, and relief operations. Therefore, international and national organizations, government officials, and the potentially affected population must be informed, even partially, by the scientific community and the survey agencies about the damages caused by the disaster and about the level of of the threat. Table 5 is an attempt to summarise the needs of end-users during the crisis response. In any case, rapid and continuous mapping is necessary for all types of disasters and is addressed by the international charter "Space and Major Disasters"[22] that aims to provide a unified system of space data acquisition and delivery to affected countries.

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[19] Source NOAA National Data Buoy Center, http://www.ndbc.noaa.gov/dart/dart.shtml

[20] Refer for example to the USGS Advanced National Seismic System (ANSS) : http://earthquake.usgs.gov/research/monitoring/anss/

[21] DEMETER, Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions, is a scientific mission of CNES, the French Space Agency.

[22] See http://www.disasterscharter.org/main_e.html

	Earthquakes	**Volcanoes**	**Landslides**	**Tsunamis**
Critical needs of end users during crisis response	Critical needs are: -Rapid evaluation of the damages -Location and the magnitude of the event. -Likelihood of induced effects such as tsunami or landslides. -Extent of the fault rupture. -Time frame of the aftershock sequence.	Critical needs are: -Rapid evaluation of the damages -Real time assessment of the ongoing eruption -Rapid deployment of intensive survey.	Critical needs are: -Rapid evaluation of the damages -Updated maps of the affected areas. -Real time scenarios of ongoing instabilities.	Critical needs are: -Rapid and overall assessment of the extent of the tsunami disaster -Estimation of loss and damage to structures.
Brief overview of the response mechanism	Immediately after an earthquake some products can be available to end users such as damage assessments models. In densely instrumented areas such as California (USA) shake maps that are quickly generated within a couple of minutes after an earthquake, which allows to estimate the intensity of the ground shaking and the expected damages in the area surrounding earthquake location thanks to the dense and permanent networks of *in situ* instrumentation.	A volcanic crisis is highly variable and can last from hours to years. Volcanic areas therefore must be intensively monitored using different *in situ* and remote instrumentations according to the diversity of the volcanic hazards such as ash clouds monitored by meteorological satellites or lava flows observed with thermal imagery.	Rapid information supply requires important effort to integrate various observations provided with space, aerial and *in situ* instrumentations in order to deliver effective disaster imagery with different resolution and timescale to support disaster reduction relief efforts.	The evaluation of the loss and the extent of damages are performed through *in situ* local reporting where possible but also through space and aerial observations that map the detail of sea shores detailed and overall changes such as soil conditions, topography or damage to structures.
Possibilities to improve the current procedures	Integration of more instrumentation such as geodetic Global Positioning System, strong motion monitoring systems or satellite radar or optical imagery would improve and complete such near to real time maps with additional information like co-seismic deformation, or structural damages.	Improvement of the volcanic crisis response can be promoted by initiatives such as the USGS Volcanic Disaster Assistance Program that is a unique mobile volcano-response team that helps to quickly deploy *in situ* portable survey equipment on a developing volcanic crisis and already succeeds in reducing fatalities.	Information and analysis of the disaster requires a global and integrated input of various scientific domains such as meteorology, geotechnics, geophysics or hydrology.	An efficient global monitoring is able not only to provide an extensive imagery of the inundation but also is likely to give insights for more complete understanding of tsunami behaviour, effects and impacts on coastal shores.

Table 5: Geohazard crisis response; After IGOS Theme report 2004. It is recognised that the most urgent need is a seemless damage assessment in all cases. However, to improve knowledge on the hazard itself, in situ and space observation are also required.

3. Data requirements

3.1. INTRODUCTION

The previous chapter stressed the need of earth observation information for geological disaster management.

The most commonly required information and the monitoring tools that allow their monitoring are provided in the tables 6 to 9 below for each geological natural hazards that concerns the IGOS Geohazards partnership. In a second paragraph, an attempt to present these requirements together is proposed, in order to enable users to identify how each data can be used for various hazards.

These data requirements are based on the work undertaken under the IGOS theme Report 2004. This work was focused on the observation of the hazard itself, and was not extended to the vulnerability assessment and to the estimation of damages.

With respect to the evaluation of vulnerability, earth observations data can certainly play a major role. However, few litterature was found in this field, and it was not possible to assemble a comprehensive and seemless spectrum of requirements on this topic in the 2004-2007 period. In order to improve these observation requirements, it will be necessary to assemble in a holistic way the current research being currently undertaken in this field.

With respect to the estimation of damages, it is recognised that remote sensing plays a major role in rapid dammages assessment. However, these aspects have been the scope of the International Space Charter for Major Disasters.

Therefore, the most required observations provided bellow do not include observations for vulnerability assessment.

3.2. MOST REQUIRED OBSERVATIONS FOR EACH TYPE OF GEOHAZARD

3.2.1. Volcanic hazard

REQUIRED OBSERVATIONS	BACKGROUND MONITORING/ASSESSMENT	DURING AND AFTER THE CRISIS
Characterise seismicity of volcano or group of volcanoes (magnitude, 3-D location, and type of earthquake)	Individual volcanoes require at least 3-6 seismometers, ideally with 3-directional sensors, to detect and locate earthquakes of magnitude 0.5, with digital data relayed/processed in real time	Repairs as needed and feasible
	Regional network good enough to detect and locate earthquakes of Magnitude 2.5, data relayed and processed in real time	Additional stations, deployed near or on the volcano, to detect and locate earthquakes of Magnitude 0.5
Characterise deformation of volcanic edifice (horizontal and vertical); monitor changes in gravity; characterise topography; determine location of faults, landslides and ground fractures	EDM and/or permanent GPS network of stations, either continuously transmitting or reoccupied as necessary	Additional GPS stations as needed to capture deformation; more frequent occupation (if data not continuously transmitted)
	Levelling and tilt networks surveyed as needed. Borehole strainmeters (continuous recording). Gravity surveys (1-5 years)	More frequent occupation (if not continuously recorded and transmitted)
	SAR interferometry	Request more frequent tasking plus search data archives for additional possible image pairs
	Map existing geologic structures on volcanoes using high spatial resolution satellite, aerial photography, aerial surveys and geological and geophysical ground surveys as needed.	Request repeat overflights to check for new cracks; possibly install strainmeters across selected cracks
Characterise gas and ash emissions of volcanoes by species (SO_2, CO_2) and flux (tons per day)	COSPEC, LICOR surveys at regular intervals (weekly, monthly or annually).	More frequent surveys, perhaps using small aircraft if plume not accessible by road
	Routine checks through appropriate satellite imagery. (LEO and GEO)	Additional requests tasking for higher-resolution data, check archives for usable Imagery
Characterise and monitor thermal features of volcanoes (their nature, location, temperature, possibly heat flux)	Map and monitor hot springs, fumaroles, summit craters, crater lakes, and fissure systems for temperature variations using ground-based instruments and high spatial resolution satellite data.	More frequent observations, including visible and IR photography and pyrometry as appropriate
	Systematic acquisition and analysis of imagery from airborne digital IR cameras, moderate resolution to higher-resolution resolution satellite imagery for thermal background and thermal flux.	More frequent overflights with digital IR camera; additional requests tasking for higher resolution satellite data, check archives for time series of thermal data
Characterise eruptive style and eruptive history of volcanoes	Characterise, map and date all young eruptive deposits of the volcano	Observe eruption columns, plumes and surface deposits (using overflights with visible and IR photography, video). Monitor their motions (speed, direction, areas covered and threatened), character, and thickness. Update maps

Table 6: Volcanic hazard observations most commonly required and the best available observational systems. (After IGOS Theme report 2004). This table only include data needed for hazards observations. The assessment of dammages through remote sensing means falls within the scope of the Interational Charter "Space and Major Disasters". Due to the lack of holistic scientific litterature in this field the data requirements for the assessment of vulnerability could not be presented in these users requirement document.

3.2.2. seismic hazard

REQUIRED OBSERVATIONS	BACKGROUND MONITORING/ASSESSMENT	DURING AND AFTER THE CRISIS
Characterise seismicity of seismically active region (magnitude, 3-D location, and type of earthquake**)**	Global monitoring network including ocean bottom seismometers able to characterise earthquakes of Magnitude 3.5 with data relayed and processed in real time	Network is being put in place, developed to verify the Comprehensive Test Ban Treaty
	Regional network of strong-motion detectors, capable of surviving ground motions	If none deployed, add stations afterwards to capture aftershock sequence
Characterise baseline topography and ongoing deformation of region (horizontal and vertical)	EDM and/or permanent GPS network of stations, either continuously transmitting or reoccupied as necessary	Additional GPS stations as needed to capture post-earthquake deformation; more frequent occupation (if data not continuously transmitted)
	Borehole strainmeters (continuous recording) Strainmeters on critical structures such as dams, bridges, etc	More frequent occupation (if not continuously recorded and transmitted); additional strainmeters on critical structures to monitor their structural integrity during aftershock sequence
	SAR interferometry	Request more frequent satellite tasking plus search archives for additional possible image pairs
Characterise thermal signature of region	Obtain and process time series of low/medium resolution IR imagery from polar and geostationary satellites for thermal background characterisation	Evaluate time series for possible thermal anomalies
Determine location of faults, landslides and ground fractures. Characterise historical seismicity and palaeo-seismicity of a region	Map existing structures in the region using high spatial resolution satellite and airborne imagery, aerial photography and geological and geophysical ground surveys. Study and date features that provide evidence for major previous earthquakes	Request over-flights to check extent of ground breaking and offset, for new cracks, landslides, patterns of liquefaction and building collapse, etc

Table 7: Earthquake hazard observations most commonly required and the best available observational systems (After IGOS Theme report 2004) This table only include data needed for hazards observations. The assessment of dammages through remote sensing means falls within the scope of the Interational Charter “Space and Major Disasters”. Due to the lack of holistic scientific litterature in this field the data requirements for the assessment of vulnerability could not be presented in these users requirement document.

3.2.3. Landslide hazard

REQUIRED OBSERVATIONS	BACKGROUND MONITORING/ASSESSMENT	DURING AND AFTER THE CRISIS
Characterise deformation with high accuracy and frequency (horizontal and vertical)	GPS network of stations continuously transmitting or reoccupied as necessary	Additional GPS stations as needed to capture deformation. More frequent occupation (if data not continuously transmitted)
	Satellite, airborne and ground-based SAR interferometry at various wavelengths. Frequency depending on the type of ground instability (1 month to 1 year)	Request more frequent satellite tasking plus search archives for additional possible image pairs
	Other surveys e.g. levelling, laser scanning (terrestrial and airborne), aerial photography and high-resolution stereo satellite data, borehole inclinometers. Frequency depending on the type of ground instability (1 month to 1 year)	More frequent occupation of all ground-based instrumentation (if data not continuously recorded and transmitted)
Map landslides, geomorphology, land-use, land cover, geology, structures, drainage network	Map existing landslides, depositional/erosional processes, geologic structures, landuse and land cover using high spatial resolution satellite and airborne imagery, aerial photography and geological and geophysical ground surveys	Request over-flights to check extent and distribution of landslides
Topography/Elevation (incl. slope angle, slope length, slope position)	High quality DEM from LiDAR, photogrammetry or high-resolution satellites	Rapid local update needed of how the landscape has changed
Soil strength parameters and physical properties (incl. pore water pressures)	Regularly updated when necessary. Geotechnical field logging and sampling, *in situ* and laboratory tests to determine specific site conditions and engineering parameters Variation of pore water pressure is monitored by piezometers over time	Request more frequent observations and if possible continuous recording of soil moisture
Climate Trigger precipitation (rainfall, snow, magnitude, intensity, duration), temperature	Meteorological data field measurements. Meteorological satellites data	Continuous recording
Seismic Trigger magnitude, intensity, duration, peak acceleration. Decay of shaking level with source distance (source, propagation shaking and site effects)	Accelerometer network monitoring. (Frequency: continuous or reoccupied as necessary) Models (Pseudo-static stability, Dynamic instability…)	Continuous recording

Table 8: Ground instability hazard observations most commonly required and the best available observational systems (After IGOS Theme report 2004) This table only include data needed for hazards observations. The assessment of dammages through remote sensing means falls within the scope of the Interational Charter "Space and Major Disasters". Due to the lack of holistic scientific litterature in this field the data requirements for the assessment of vulnerability could not be presented in these users requirement document.

3.2.4. Tsunami hazard

REQUIRED OBSERVATIONS	BACKGROUND MONITORING/ASSESSMENT	DURING AND AFTER THE CRISIS
Characterise seismicity of tsunami prone region (magnitude, location, and type of earthquake)	Global monitoring network able to characterise earthquakes with data relayed and processed in real time to make possible alerts and early warning.	Permanent networks to ensure aftershocks survey and possible tsunami alerts
	Broadband ocean bottom seismometer networks to complete seismological survey networks	
Ensure early detection of tsunamis and acquire data critical to real-time forecasts	Tsunami waves survey according to sea level height observations with deployment of buoys networks in all the oceans such as Deep-ocean Assessment and Reporting of Tsunamis (DART) Stations in Pacific-	Develop extensive buoy networks within all oceans and seas prone to tsunamis for permanent survey
Determine location of faults, landslides or volcano edifices likely to trigger tsunamis	Map existing structures in the region using high spatial resolution satellite and airborne imagery, aerial photography, geological and geophysical surveys. Study and date features that provide evidence for previous historical tsunamis.	Request over-flights and permanent *in situ* survey to check extent of ground breaking and offset, for new cracks, landslides, etc..
Determine coastal areas exposed to tsunami waves	Extensive topographic mapping of coastal areas using high spatial resolution satellite, airborne imagery, aerial photography, radar altimetry and *in situ* monitoring (levelling, GPS)	Request over-flights and additional satellite tasking to monitor extent of tsunami damages

Table 9: Tsunami hazard observations most required and the best available observational systems. This table only include data needed for <u>hazards</u> observations. This table only include data needed for <u>hazards</u> observations. The assessment of dammages through remote sensing means falls within the scope of the Interational Charter "Space and Major Disasters". Due to the lack of holistic scientific litterature in this field the data requirements for the assessment of vulnerability could not be presented in these users requirement document.

3.3. INTEGRATED APPROACH

IGOS Geohazards seeks an approach to assess the feasibility of integrating the primary users' requirements into a multi-hazards observation system, in order to ensure interoperability of data, an easier access to observations, and a reduction of data acquisition costs. Improvement of observation system capacities are critical to support mitigation of geohazards and to provide relevant information to private sector users, operational state organizations and public authorities. For instance, the Committee on Earth Observation Satellites (CEOS) supports the idea of new observation systems made of constellation of satellites that could be dedicated to specific needs such as geohazards. As another example based on a "system of systems" approach, the international charter mechanism "Space and Major Disasters", is already in place for enhanced crisis response. However, new developments are necessary to move toward operational services. To achieve this, the primary users (research scientists, survey agencies and service providers) have to closely interact with data providers in order to address their engineering requirements in terms of observation needs and technical issues.

One of the main challenge of an integrated global system is to identify and promote the more relevant observation systems that firstly, provide relevant data in order to inform and improve ground models and secondly, ensure a better monitoring of geohazards. The integrated approach must include a geological framework (usually GIS), attributed, where possible, with hazard and geotechnical information. Within this geological framework, links between ground-based and remote instrumentation must be established, to ensure that the monitoring systems are feeding into a ground model, providing focussed and relevant information. Table 10 is an attempt to present an integrated multi-hazards approach and the existing key systems as well as their use at each phase of a disaster cycle. The most commonly required observations are:

- The topography and the active ground deformation monitoring of seismically active areas, of the volcanoes shapes, of the landslide prone areas, and of the morphology of coastal shores, continents or sea beds.
- The geological monitoring, which is critical to identify and to characterise the type, the activity or the level of threat of earthquakes, volcanoes or landslides and additionally provide a permanent survey on triggered, induced or ongoing hazards.
- The meteorological observations presenting critical issues for scientists to infer climatic triggering factors for ground instabilities, to assess the threats of a volcano such ash clouds or lahars or to provide early warnings on tsunami waves.

In addition, new observation data and demonstrator systems, whose efficiency is still under assessment, have been included in the table.

			Pre-Emergency	Emergency	Crisis Response
Most Required Instrumentation			Hazard maps and Disaster Scenarios	Forecasting / Early Warning Systems	Disaster Response
Topography	**In situ**	**Levelling**	Inventories, base maps and Digital Elevation Models: -Geometric properties of faults and volcanic areas -Assessment of sea shorelines and landslide prone areas		-Rapid Mapping and inventories of affected areas for damage assessment - DEM and measurement of the permanent ground deformation such as shorelines and volcanoes edifices.
		GPS stations			
	Remote	**High Resolution Optical Stereo Imagery**			
		Radar Altimeter			
Active Deformation Monitoring	**In situ**	**Inclinometer /Tiltmeter arrays**	- Inventories and hazard surveys with updated deformation maps: Active faults, landslide areas or volcanic edifices - Archive data acquisition	- Real time deformation maps for precursory events and ongoing hazards such as landslides -Warning for cascading effects such as Lahars.	- Post disaster monitoring such as induced landslides - Real time survey on continuous hazards such as volcanic eruptions - DEM and measurements of the permanent ground deformation - Characterisation of the event size - Damage assessment
		Extensometer arrays			
		Temporary or Permanent GPS Network			
		Strain Meter Networks			
	Remote	**Very Long Baseline Interferometry & Satellite Laser**			
		Differential Interferometric SAR or Persistent Scatterers Interferometry (Band L,C)			
		High resolution imagery (image correlation)			
Geological Classification and Surveys	**In situ**	**Fieldwork**	- Hazard zonation maps - Hazard assessment - Continuous monitoring of geological, geophysical or geochemical parameters - Characterisation of geological, environmental background with determination of type, size and recurrence intervals over different time scales - Archive data acquisition	- Real time monitoring of geological, geophysical and geochemical parameters - Warning for precursory events, triggering factors, ongoing hazards and induced effects such as tsunami	- Post disaster monitoring such as aftershocks survey - Real time survey on continuous hazards such as volcanic eruption -Characterisation of the event size and type - Damage assessment
		Hydrologic monitoring systems			
		Continuous gas monitoring			
		Piezometer arrays			
		Shallow Boreholes			
		High Resolution Optical Imagery			
		Broadband Worldwide Seismometer Permanent Networks			
		Ocean Bottom Seismometer Temporary Networks			
		Short Period Regional Permanent Networks			
		Really Short Period Regional or Local Seismometer Networks			
		Local Temporary Portable Seismometer Arrays			
	Remote	**High Resolution Optical Imagery**			
		Hyperspectral Imagery			
		Synthetic Aperture Radar			
New Observation Data	**In situ**	**Experiments on Active Faults (boreholes)**	- Characterisation of geological, geophysical, geochemical parameters related to hazard occurrence	- Research on relevant triggering factors or precursory evidences	- Characterisation of geological, geophysical, geochemical parameters related to hazard occurrence
	Remote	**Global Strain Fields Measurements**			
		Earth's Gravitational Field Measurements			
		Infra-Red Imagery			
		Earth's Electromagnetic Field Measurement			
Meteorological monitoring	**In situ**	**Meteorological stations**	- Continuous monitoring of geophysical or geochemical parameters - Characterisation of triggering factors such as weather conditions for landslides or volcanic eruptions	- Real time monitoring of geophysical and geochemical parameters - Warning for precursory events, triggering factors, ongoing hazards and induced effects such as tsunami	- Post disaster survey on induced or cascading effects such as volcanic ash clouds
		Deep-ocean assessment and reporting Tsunamis "DART" Buoys			
		Sea Level Gauges			
	Remote	**Radar or Optical Meteorological Imagery**			

Table 10: Requirements of the primary user (research scientists, survey agencies and service providers) during disaster phases. In the Table, the in situ *instrumentation relies on ground based instrumentation. Remote instrumentation relies on space and aerial instrumentation.*

3.4. GAP ANALYSIS

This user requirement process allowed to identify gaps in the current systems. In order to improve the current geohazards observations, IGOS Geohazards therefore recommends to support:

- An extensive deployment and continuous recordings of space and ground based instrumentation. This includes
  - the deployment of seismological digital broadband networks, under the coordination of FDSN
  - the long-term, precise monitoring of the geodetic observables, under the leadership of GGOS, is also a priority
  - the development of the GNSS (Global Navigation Satellite System)
  - the public release of high resolution digital elevation model such as SRTM 30 is needed.
- Space and airborne instrumentation with high temporal and spatial resolution to efficiently complement the *in situ* observation systems or replaced them in poorly equipped areas. Among others, the Interferometric Synthetic Aperture Radar techniques, especially L band[23], and the high resolution imagery play a major role in the hazard assessment, global survey and rapid disaster responses.
- Standards in inventories proposed in the GEO architechture committee should be implemented to perform geohazards data inventories. In this perspective, the WOVOdat project to build a worldwide volcanic unrest database should be supported.
- Future and ongoing progress that rely also on new relevant scientific instrumentation in the electromagnetic, thermal, or gravitational domains that benefit from the advances in space technologies and will document, infer or find out possible precursors to earthquakes, or volcanic eruptions.

[23] The ALOS system provides Geohazards experts with L band SAR data since late 2006.

4. Perspectives for Geohazards Requirements

The present report is an extent to the initial scope of IGOS Geohazards:

- Firstly, while the initial scope of IGOS Geohazards was the hazards observations, this report is an attempt to address the exposure and the vulnerability of exposed elements.

- Secondly, while the initial scope of IGOS Geohazards was prevention, the entire disaster management cycle has been addressed in this report.

This concluding chapter summarises the reasons that led to this choice to extend the scope of IGOS Geohazards. It also formulates some recommendations for future earth observation requirements collections.

4.1. FROM MULTI-HAZARDS TO MULTI-RISKS APPROACH

Geohazards are complex phenomena that can be often triggered by one another such as earthquakes and tsunamis or volcanoes and landslides. Data acquired for the assessment of one of these hazards can help to assess another hazard. As an example of this, GPS networks are used to monitor ground displacements, as well as for tsunami early warning[24].

Moving from hazard assessment to a comprehensive risk assessment is a challenge since different risks can be appropriate calculated differently. This leads scientists to a multi-hazards and multi-risks approach.

Additional facts drive geohazards communities to a multi-risks approach:

- first, vulnerability studies include tasks such as the assessment of building stock or population density and these can be used in the evaluation of risk induced by diverse hazards.

- secondly, it is necessary to help end users to establish priorities among the threats: this requires to establish methodologies that enable comparing the risks associated with various hazards[25]. Multi-risks approaches have the advantage of enabling end users to prioritise the threats, which is a prerequisite of mitigation actions.

[24] See Rapid determination of Earthquake magnitude using GPS, a role for space geodesy in tsunami warning, G. Blewitt, C. Kreemer, W. Hammond, H.-P. Plag, University of Nevadan Reno, S. Stein, E.A. Okal, Northern Univsersity, 2006.

[25] Such methodologies are proposed and applied in “Grünthal et al. (2006): Comparative risk assessments for the city of Cologne – storms, floods, earthquakes. - in Natural Hazards” or “Pierre Thierry et al (2007) An example of multi hazard risk mapping and assessment on an active volcano: the GRINP project on Mount Cameroon – in Natural Hazards”

4.2. COOPERATION WITH METEOROLOGICAL COMMUNITIES

Parallel to this multi-risks approach for geohazards, cooperation mechanisms with the meteorological community are needed for the following reasons:

- First of all, there are triggering mechanisms and cascading effects that bring together both communities. Landslides can be triggered by heavy rainfall and volcanic ash can have an impact on weather of an entire region and be an obstacle for airlines. Meteorological organizations have developed reliable monitoring, modelling and forecasting tools, nevertheless some meteorological episodes such as extreme precipitations remain still difficult to predict.

- In addition, this cooperation is expected to avoid duplication of investment dedicated to common disaster management infrastructure, for example, in the domain of early warning. Such measures are already in place in many countries.

- Finally, certain aspects of vulnerability assessment can be cautiously mutualised among many hazards.

The implementation of a multi-risks approach faces many challenges. There is a general lack of consensus among the various communities with regards to risk terminology. In addition, the large variety of methodologies used to estimate risk accounts for their beeing highly heterogeneous. This causes conflict in the relationship between information providers and end users.

4.3. EARTH OBSERVATION REQUIREMENTS FOR EXPOSURE AND VULNERABILITY ASSESSEMENT

Risk is a combination of hazard and vulnerability of exposed elements. While the present report reviews *in situ* and space hazard observations, it only partly assesses how earth observation can be useful for vulnerability assessment and for the identification of exposed elements. This is mostly due to lack of litterature and references in this field. Therefore, the IGOS Geohazards Bureau proposes, in the next three years, to better analyse how earth observations data can help mapping the vulnerability of exposed elements in order to enable end users to get knowledge on the geological risks to which populations and properties are exposed.

4.4. CONCLUSIONS AND RECOMMENDATIONS

One of the concerns of IGOS Geohazards is to support the establishment of reliable Earth observation services for the benefit of populations exposed to geohazards. This implies breakthroughs in Earth observation science and techniques, but also that the information routinely provided to end users and decision-makers are unambiguous and well understood. The user requirement process has been put in place to fulfill this need. In order to sustain this process and allow other organizations to participate to it, IGOS Geohazards recommends to:

- Strengthen the partnerships between geohazards communities of practice concerned with geohazards observations

- Support the emergence of an efficient process to collect user requirements within GEO

In addition, following this geohazards earth observation requirement process, IGOS Geohazards recommends to:

- Promote the reduction of gaps in earth observations (see 3.4)

- Adopt progressibely the multi-risks approach, in order to ensure that Earth observation services are properly integrated into risk management

- Identify how Earth observation can be used for identification of exposed elements and for vulnerability assessment and stimulate projects on this topic

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Acronyms and Abbreviations

The following acronyms and abbreviations have been used in the present report as well as in the IGOS Geohazards Theme report 2007:

ARMONIA Applied Multi-Risk Mapping Of Natural Hazards for Impact Assessment
ALOS Advanced Land Observing Satellite
ASAR Advanced Synthetic Aperture Radar
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer
COSPEC Correlation Spectrometer
DART Deep-ocean assessment and reporting of tsunamis
DAPHNE Deployment of Asia Pacific Indian Ocean Hazard Mitigation Network for Earthquake and Volcanoes
DEM Digital Elevation Model
DEMETER Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions
DInSAR Differential SAR Interferometry
EDM Electronic Distance Measurement
ENVISAT ENVironmental SATellite
EO Earth Observation
ERS European Remote Sensing
GDP Gross Domestic Product
SRTM Shuttle Radar Topography Mission
VENUS Victoria Experimental Network Under the Sea
GEOWARN Geo-spatial warning system
GLOBVOLCANO Satellite Monitoring in Support to Early Warning of Volcanic Risk
GNSS Global Navigation Satellite System
GPS Global Positioning System
InSAR SAR Interferometry
IR Infra Red
LEO Low-Earth-Orbiting
LiDAR Light Detection and Ranging
NEPTUNE Ocean Observatory Network
RADARSAT RADAR SATellite
SAR Synthetic Aperture Radar
Sentinel Asia Disaster management support system in the Asia Pacific region
SLR Satellite Laser Ranging

Organizations, Networks and Programmes

The following organizations, networks and programmes have been mentionned in the present report and in the IGOS Geohazards Theme report 2007:

ADPC Asian Disaster Preparedness Center
ANSS Advanced National Seismic System
APEC Asia Pacific Economic Cooperation
ASEAN Association of South East Asian Nations
BGS British Geolo gical Survey
BRGM Bureau de Recherche Géologique et Minière
CEDIM Center for Disaster Management and Risk Reduction Technology
CIDA Canadian International Development Agency
CIMA Centro de Investigaçao Marinha e Ambiental (Portugal)
CNES Centre National d'Etude Spatiale
CCOP Coordinating Committee for Geosciences Programmes in East and South East Asia
CCRS Canadian Center for Remote Sensing
CEOS Committee on Earth Observation Satellites
CRED Centre for Research on the Epidemiology of Disasters
CSIRO Commonwealth Scientific & Industrial Research Organization
CSA Canadian Space Agency
CTBT Comprehensive Test Ban Treaty.
CUSEC Central United States Earthquake Consortium Six Cities Study
EC European Commission
EM-DAT OFDA/CRED Emergency Events Database
EMSC European Mediterranean Seismological Centre
ESA European Space Agency
Eurogeosurveys Association of the European Geological Surveys,
FDSN Federation of Digital Seismograph Networks
GARS Geological Applications of Remote Sensing
GEO Group on Earth Observations
GEOSS Global Earth Observation System of Systems
GGOS Global Geodetic Observing System
GSHAP Global Seismic Hazard Assessment Program
GSN Global Seismic Network
GTOS Global Terrestrial Observing System
IAG International Association of Geodesy
IASPEI International Association of Seismology and Physics of the Earth's Interior
IAVCEI International Association of Volcanology and Chemistry of the Earth's Interior
ICL International Consortium on Landslides
ICSU International Council of Scientific Unions
IDNDR International Decade For Natural Disaster Reduction
IGOS Integrated Global Observing Strategy
IGS International GPS Service
ILP International Lithosphere Program
INGV Istituto Nazionale di Geofisica e Vulcanologia
IPL International Programme on Landslides
IOC Intergovernmental Oceanographic Commission
IOTWS Ocean Tsunami Warning and Mitigation System
IRIS Incorporated Research Institutions for Seismology
ISDR International Strategy for Disaster Reduction
ITC International Tsunami Center
IUGG International Union of Geodesy and Geophysics
IUGS International Union of Geological Sciences
JAXA Japanese Aerospace Exploration Agency
JPL Jet Propulsion Laboratory
NASA National Aeronautics And Space Administration
NEIC National Earthquake Information Center
NOAA National Oceanic and Atmospheric Administration
OECD Organization for Economic Co-operation and Development
OFDA Office of Foreign Disaster Assistance (US)
ORFEUS Observatories and Research Facilities for European Seismology
PTWC Pacific Tsunami Warning Center
SAARC South Asian Association for Regional Cooperation
SPIDER UN platform for Space Based Information for Disaster Management and Emergency Response
Terrafirma
UN United Nations
UNAVCO The University NAVSTAR Consortium
UNEP United Nations Environment Program
UNESCO United Nations Educational, Scientific and Cultural Organization
UNOOSA United Nations Office for Outer Space Affairs
UNOSAT United Nations programs for access to satellite imagery
USAID US Agency for International Development
USGS United States Geological Survey
SERTIT Service Régional de Traitement d'Image et de Télédétection
VDAP Volcano Disaster Assistance Program
WMO World Meteorological Organization
WOVO World Organization of Volcano Observatories

IGOS Geohazards contributions to this report

As part of the IGOS Geohazards Theme report 2007, this report has been reviewed by the following members of the IGOS Geohazards partnership.

- Andy Gibson, BGS
- Steven Hosford, CNES
- Chu Ishida, JAXA
- Kay Mc Manus, BGS
- Warner Marzocchi, WOVO
- Robert Missotten, UNESCO
- Hormoz Modaressi, BRGM
- Marc Paganini, ESA
- Hans-Peter Plag, GGOS
- Helen Reeves, BGS
- Kaoru Takara, ICL

In addition, this paper was reviewed by IASPEI (Domenico Giardini, Robert Engdahl, Mohsen Ashtiany, and Peter Suhadolc. IASPEI proposed to participate in the IGOS Geohazards initiative, in order to contribute to the next theme report.

The members of the IGOS Geohazards partnership are presently:

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