Chapter 11

Remote Sensing for Natural or Man-made Disasters and Environmental Changes

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62183

Abstract

Disasters can cause drastic environmental changes. A large amount of spatial data is required for managing the disasters and to assess their environmental impacts. Earth observation data offers independent coverage of wide areas for a broad spectrum of crisis situations. It provides information over large areas in near-real-time interval and supplementary at short-time and long-time intervals. Therefore, remote sensing can support disaster management in various applications. In order to demonstrate not only the efficiency but also the limitations of remote sensing technologies for disaster management, a number of case studies are presented, including applications for flooding in Germany 2013, earthquake in Nepal 2015, forest fires in Russia 2015, and searching for the Malaysian aircraft 2014. The discussed aspects comprise data access, information extraction and analysis, management of data and its integration with other data sources, product design, and organisational aspects.

Keywords: Satellite Based Crisis Information, Environmental Changes, Natural Disaster, Man-made Disaster

1. Introduction

The impact of disasters on the environment has become more severe over the last decades. Moreover, the reported number of disasters has dramatically increased, as well as the costs to the global economy and the number of people affected (see Figure 1 for natural disasters) [1,2]. The reasons for these disasters are manifold, and the impact can be found in the increasing vulnerability of societies, infrastructure, and population. Furthermore, extreme weather events have become more common and severe [3].

The increasing occurrences of natural and man-made disasters lead to a growing demand for up-to-date geographic information, especially timely material on rapidly evolving events. This includes comprehensive, near-real-time Earth observation data, which offer independent coverage of wide areas for a broad spectrum of civilian crisis situations [4]. Satellite imagery can serve as a source of information in disaster situation. Accordingly, remote sensing can provide information on various domains of the disaster management, from risk modelling and vulnerability analysis to early warning and damage assessment [5].

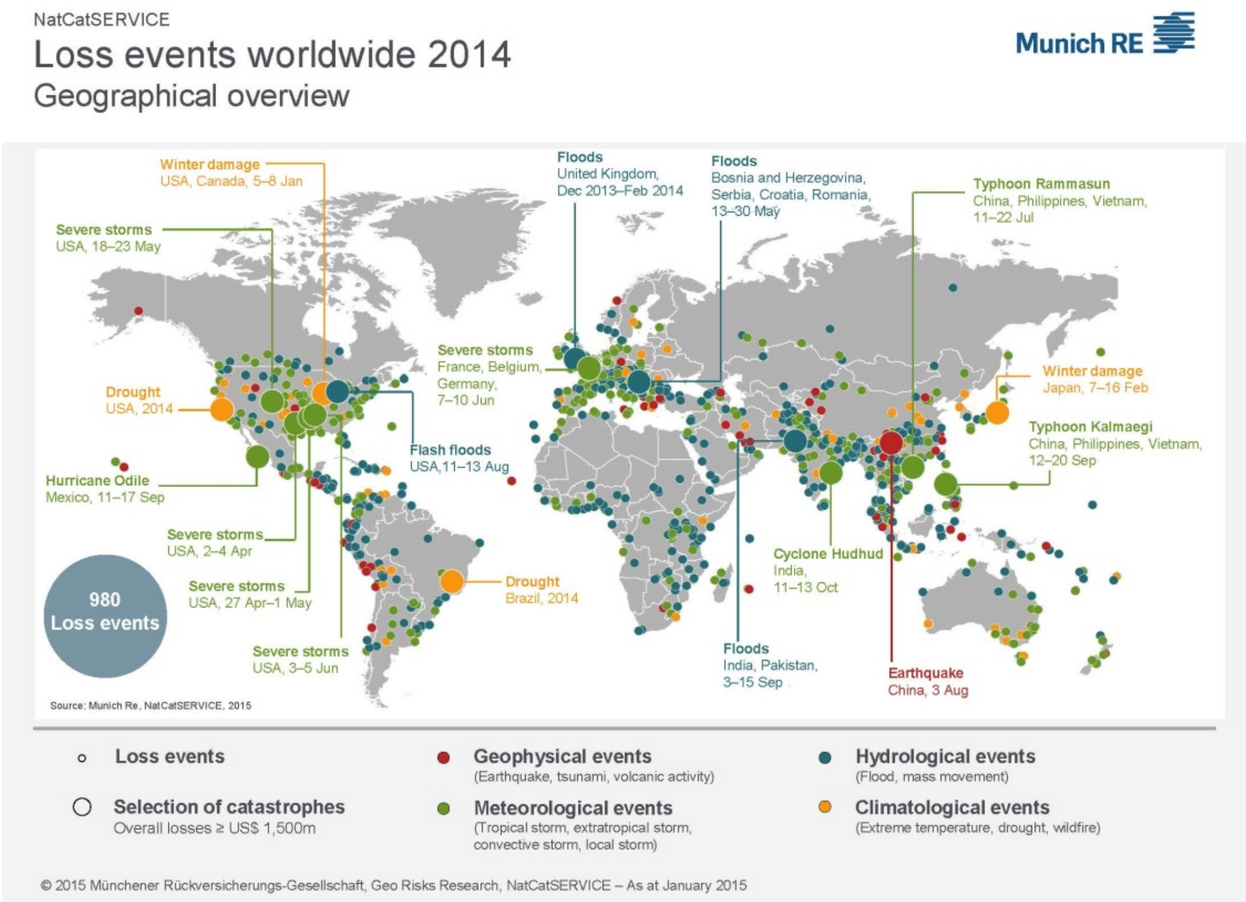

Figure 1. World Map of Natural Disasters 2014 [2]

2. Disaster management and remote sensing

2.1. Disaster types and their environmental impact: A brief overview

There are several ways to classify disaster types [1,6]. One common classification is natural and man-made disasters. Severe geo-physical or climatic events, such as volcanic eruptions, floods, cyclones and fires that threaten people or property, are termed as natural disasters. Man-made disasters are events which are caused by human activities (e.g. industrial chemical accidents and oil spills). Sometimes, natural disasters that are accelerated by human influence are termed human-induced disasters [6]. In addition, the Centre for Research on the Epidemiology of Disasters [7] divides the natural disaster category into six sub-groups, which in turn include 17 disaster types, and 33 sub-types (see Table 1). The technological disaster category is segregated into three sub-groups which in turn include 15 disaster types (see Table 2). Besides, disasters can be categorised as acute (e.g. earthquake) or slow (e.g. drought) based on their onset.

Natural disaster sub-group					
Climatological	Geophysical	Hydrological	Meterological	Biological*	Extraterrestrial*
Natural disaster types and sub-types					
Drought	**Earthquake**	**Flood**	**Storm**	**Animal accident**	**Impact**
Glacial Lake Outburst	Ground Shaking	Coastal food	Extra-tropical cyclone	**Insect infestation**	Airburst
Wildfire	Tsunami	Riverine flood	Tropical cyclone	Grasshoper	**Space Weather**
Forest fire	**Mass movement**	Flash flood	Convective Storm	Locust	Energetic particles
Land fire	**Volcanic activity**	Ice jam flood	**Extreme temperature**	**Epidemic**	Geomagnetic storm
	Ash fall	**Landslide**	Cold wave	Viral disease	Shockwave
	Lahar	Avalanche (snow, debris, mudflow, rockfall)	Heat wave	Bacterial disease	
	Pyroclastic flow	**Wave action**	Severe winter conditions	Parasitic disease	
	Lawa flow	Rogue wave	**Fog**	Fungal disease	
		Seiche		Prion disease	

Table 1. Natural disasters categorisation after [7]; *not being considered below

Man-made disaster sub-group		
Industrial accident	Transport accident	Miscellaneous accident
Man-made disaster types		
Chemical spill	Air	Collapse
Collapse	Road	Explosion
Explosion	Rail	Fire
Fire	Water	Other
Gas leak		
Poisoning		
Radiation		
Other		

Table 2. Man-made disasters categorisation after [7]

There are many effects that result from disasters, whether natural or man-made. For instance, the impacts of disasters have a human and an environmental dimension. UNEP concludes that 'environmental conditions may exasperate the impact of a disaster, and vice versa, disasters tend to have an impact on the environment' [8, p.1]. Reference [9] discusses down the environmental impacts for different types of disasters in detail. They raise the interesting point that while most environmental impacts are negative, some are positive. For example, 'floods can help rejuvenate floodplain vegetation and are important drivers of many ecological processes in floodplains' [9, p. 55]. In Table 3, a selection of environmental impacts for different types of disasters is listed.

Natural disasters	Climatological	Drought	Droughts generally damage ecological systems: depletion of water resources, loss of plant and animal life, deterioration of soil, fire
		Glacial lake outburst	Flooding, destruction of plant life, landslide, erosion
		Wildfire	Loss of plant and animal life, erosion, flooding, mud slides, long-term smog
	Geophysical	Earthquake	The dominant losses from earthquakes and mass movements are to structures and potentially to humans. Nevertheless, both disasters can also result in adverse environmental consequences: flora and fauna damaged by the shocks, shifts in land surfaces, alterations in local hydrologic systems.
		Mass movement	
		Volcanic activity	Loss of plant and animal life, deterioration of soil, air and water pollution, long-term smog
	Hydrological	Flood	Major floods have varied effects on river-floodplain ecosystems: e.g. negative impact on trees if they are too long submerged; polluted water infiltrate floodplains and contaminate ground water aquifers; positiv impact like rejuvenate floodplain vegetation
		Landslide	Destruction/loss of plants, erosion, depletion of water resources
		Wave action	Modifies the dynamics of coastal marine communities e.g. the influence the structure of biological communities on rocky shores
	Meterological	Storm	The dominant losses from storms are to structures and potentially to humans. The environmental effects are: e.g. destruction of plants, forest fire, flash flood.
		Extreme temperature	Avalanche, snow melt, loss of plants and animals, flash floods, flooding, drougth, erosion, fire
		Fog	Loss of plant and animal life, decreasing the UV radiation, damages to health for humans, animals and vegetation
Man-made disasters	Technical	Chemical spill Collapse Explosion Fire Gas leak Poisoning	There are several effects on the environment depending on the detailed subtype and dimension of the disaster. Some general impacts are for example: Negative health outcomes from accidental releases of toxins, Loss of plants and animals, Water/soil/air pollution, Damages to health for humans, animals and vegetation, Destruction of plants, Erosion, Flooding, Fog, etc.
	Transport	Air Road Rail Water	
	Miscelleanous	Collapse Explosion Fire	

Table 3. Disasters and their environmental impacts [modified after 9]

The impact of disasters can be reduced through a proper disaster management [10]. The process of disaster management is often interpreted as a cycle consisting of four main phases: mitigation, preparedness, response and recovery (see Figure 2 and for more information [10]).

2.2. Earth observation for disaster management: potential and limitations

The Earth is being imaged each day by a constellation of remote sensing satellites. Two complementary types of Earth observation satellites are particularly relevant to disaster management. 'Geostationary Earth observation satellites' are placed at an altitude of approximately 35,800 kilometres. At this altitude, one orbit takes 24 hours, the same length of time as

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Figure 2. Disaster management cycle

the Earth requires to rotate once on its axis [11,12]. In effect, it means that satellites in this orbit remain stationary above the ground and view the whole Earth disk below. Their spatial data resolution is very low but is collected at the same point every 15 minutes. With these kinds of data, the evolution of atmospheric phenomena can be observed, ensuring real-time coverage of meteorological events such as severe local storms and tropical cyclones [13]. The importance of this capability has been exemplified during several hurricane events.

The great advantage of ‘polar-orbiting satellites’ is the provision of relatively high spatial resolution data (up to 0.3 meter for optical imagery and 1 meter for radar imagery) [11], which is very important for mapping disaster damages in detail, such as affected infrastructure or buildings after an earthquake [13]. Most of the Earth observation satellites are in a low and ‘near-polar’ orbit with an orbital period of approximately 90–100 minutes and an orbit inclination near 90 degrees. This allows the satellite to see virtually every part of the Earth as the Earth rotates underneath it. However, no spot on the Earth's surface can be sensed continuously or at any point of time from a satellite in a polar orbit. The time elapsed between observations of the same point on the Earth (revisit time) is limited to once every few days with the same sensor parameters or maximum once a day for steerable satellite. Moreover, most satellites do not continuously collect data due to limitations in power and memory. Some offer regular and reliable data acquisition while others may be more ad hoc, collecting only 5 or 10 minutes' worth of data in a 90-minute orbit. Data are stored on board the satellite until it is in sight of a ground station to downlink the data. The time between an image being taken and being available to download can range between a month to a few minutes and is getting faster all the time. Thus, the collection of high-resolution data has some limitations regarding acquisition time, data provision and image extent.

The Earth observation satellites have their own special systems of imaging sensors which make use of the visible, infrared, microwave and other parts of the electromagnetic spectrum [11]. The characteristics of some sensors that are commonly used to support disaster management are listed in Table 4.

Data type	Sensor	Nadir spatial resolution (m)	Bands	Swath (km)	Revisit Frequency
Optical (multispectral)	Worldview-3	0.31 1.24 3.7 30	Panchromatic 8 Multispectral 8 SWIR 12 CAVIS (Corrects for Clouds, Aerosols, Vapors, Ice & Snow)	13.1	1.1 days at 1 m GSD or less 4.5 days at 20° off-nadir or less
	Worldview-2	0.46 1.84	Panchromatic 8 Multispectral	16.4	1.1 days at 1 m GSD or less 3.7 days at 20° off-nadir or less
	Pleiades-1A / 1-B	0.70 2.00	Panchromatic 4 Multispectral	20	Daily
	SPOT-6 / -7	1.50 6.00	Panchromatic 4 Multispectral	60	Daily
	RapidEye	6.5	5 Multispectral	77	Daily
Thermal	ASTER	15 30 90	4 Multispectral 6 SWIR 5 TIR	60	4-16 days
	MODIS	250 500 1,000	36 bands (VIS, NIR, SWIR/ MWIR, LWIR)	2,330	Daily
Synthetic Aperture Radar (SAR)	TerraSAR-X / TanDEM-X	1 3 18	Spotlight Stripmap ScanSAR	10 30 100	11 days
	Cosmo-SkyMed	<1 3-15 30-100	Spotlight Stripmap ScanSAR	10 40 100-200	1.5 days
	Radarsat -2	3 25 8 8 25 25 50 100	Ultra-fine Fine Quad-pol fine Standard Quad-pol standard ScanSAR narrow ScanSAR wide Extended high	20	Every few days
	ALOS	10 100	PALSAR (Fine) PALSAR (ScanSAR)	40-70 250-350	Several times per year as per JAXA acquisition plan

Table 4. Examples of sensors and their characteristics to support disaster management [modified after 16]

'Optical data' are of great importance for disaster management support, because they can be used nearly for all disaster types and for all phases of disaster management. For example, they are used for planning the logistics of relief actions in the field immediately after an earthquake or tsunami [13–14]. Optical images are easy to understand and interpret even for non-specialists, particularly when it consists of the three visual primary colour bands (red, green and blue) and the bands are combined to produce a 'true colour' image. However, the interpretation of false colour composite images is not intuitive and requires expert knowledge; likewise, all advanced analysis techniques need comprehensive know-how. To select the most appropriate data type for the needs of the individual disaster situation, the characteristics of the sensor are of great importance [15]. Particularly, temporal and spatial resolutions are key factors. For example, for mapping an earthquake in an urban area optical data with a spatial resolution of <0.5 meters are most valuable. The most crucial point for the use of optical images is their availability. Due to cloud coverage, haze and other atmospheric conditions useful optical images could not obtained by every satellite overpass. Aggravating this situation, there are some disasters such as wildfire or severe storms which are characterised by clouds and smoke.

The 'thermal imagery' offers excellent possibilities for automated extraction of anomalous high temperature or hot spots caused by wild fires or information about volcanic eruptions. However, due to the fact that energy decreases with increasing wavelength, thermal wavelength have relatively low energy levels and consequently thermal image data have a lower spatial resolution than optical data. [16]. Techniques for automatic fire detection from the space are operational and are accepted by the users (e.g. European Forest Fire Information System) [17].

'Microwave sensors' are of great value for the fast response mapping and analysis tasks, as they allow imaging at wavelengths almost unaffected by atmospheric disturbances such as rain or cloud. Most modern synthetic aperture radar (SAR) sensors are designed to acquire data from various ground resolution elements (see Table 4). In most applications, only the relative variability of backscatter intensity within the image is used. Nonetheless, backscatter intensity and the phase of SAR images can be utilised. Phase information of a single SAR data set has no value, but the comparison of phases between two SAR images acquired at distinct times are utilised in SAR interferometry or INSAR. Moreover, with modern satellites (e.g. TerraSAR-X and Radarsat-2) it is possible to acquire simultaneous data with more than one polarisation [16]. SAR systems can be used to map flooding or to measure earth deformations before and during earthquakes or volcanic eruptions, particularly when post-event imagery can be jointly analysed with archived reference imagery for change detection or interferometric coherence or displacement measurements [15, 13].

Table 5 summarises the remotely sensed data types and image processing techniques for information extraction about natural disasters.

In general, the availability of appropriate data with respect to acquisition time, image extent, spatial as well as temporal and spectral resolution is an important consideration for most applications in the disaster context [18]. Particularly, there are numerous examples for the importance of the necessity of fast availability of remote sensing data like damage assessment maps for earthquakes, landslides or flooding. However, for monitoring the spread of an oil spill or the extent of flooding the revisit time is relevant too [13].

Remote sensing has proven to be useful for a range of applications. Especially high spatial resolution data and remote sensing techniques are being deployed in the context of the disaster

Data type	Sensor examples	Technique	Application
Optical (multispectral)	Worldview, Pleiades, Quickbird, Ikonos, RapidEye, SPOT, ASTER, Landsat, ALOS	Manual interpretation	Infrastructure and property damage due to flooding, earthquakes, landslides, etc.
		Spectral classification	Location and extent of flooding, landslides, volcanic debris, fire scars
		Semivariogram analysis and other textural classifiers	Damage due to earthquakes; location of landslides
		Image thresholding (including band ratios)	Location and extent of flooding, landslides, volcanic debris, fire scars
		Image differencing	Location and extent of flooding, landslides, volcanic debris, fire scars
		Postclassification change detection	Location and extent of flooding, landslides, volcanic debris, fire scars
		DEM generation	DEM is used as a supplementary information in variety of studies
Thermal	ASTER, MODIS, AVHRR	Split window	Crater lake temperatures, lava flow, precursor to earthquake activity, temperature and size of fire hotspots
		Dual band	Crater lake temperatures, lava flow, precursor to earthquake activity, temperature and size of fire hotspots
Synthetic Aperture Radar (SAR)	TerraSAR-X, TANDEM-X, Cosmo-SkyMed, Radarsat-1/2, JERS-1, ERS-1/2, ENVISAT, ALOS	Coherence	Coherence Change detection due to landslide, flooding, fire, etc.
		Backscatter intensity	Coherence Change detection due to landslide, flooding, fire, etc.
		Interferometry/DEM generation	Change detection due to landslide, flooding, fire, etc.
		Differential interferometry	Surface deformation due to volcanic or tectonic activity; velocity and extent of slow moving landslides
		Polarimetry	Landcover classification and change detection

Table 5. Remotely sensed data types and image processing techniques for information extraction about natural disasters [modified after 13]

management domain, from risk modelling and vulnerability analysis to early warning and damage assessment (see Table 6). A broad assessment of several remote sensing sensors (optical, thermal, SAR, etc.) and their utility for providing information about natural disasters is given in Ref. [13, p. 200–201].

Reference [19, p. 2-3] concludes that 'the most evident parts are preparedness (warning for storms, cyclones, floods, etc.,) and response (mapping of all types of crisis impact and situations), while applications of satellite information during the phases of recovery and mitigation prevention are being still further developed'. Additionally, the authors give the following main reasons for a drastically increased demand for rapid satellite data analysis for all kinds of disaster and phases over the past years:

- accessibility of very high resolution optical (up to 0.3 meter) as well as radar imagery (up to 1 meter) from space has risen significantly over the past years even for the civilian domain
- relief agencies rapidly gain a better understanding on what these new geoinformation technologies can bring to their work in the fields of mission planning, logistics, situation awareness and even mission security

			Mitigation	Preparedness	Response	Recovery
Natural disasters	Climatological	Drought	Risk modelling; vulnerability analysis; land and water management planning	Weather forecasting; vegetation monitoring; crop water requirement mapping; early warning	Monitoring vegetation; damage assessment	Informing drought mitigation
		Glacial Lake Outburst	Mapping glacial lake outburst-prone areas; glacial monitoring; delineating flood-plains; land-use mapping	Weather forecasting; glacial monitoring, lake outburst detection; early warning	Flood mapping; evacuation planning; damage assessment	Damage assessment; spatial planning
		Wildfire	Mapping fire-prone areas; risk modelling	Fire detection; predicting spread/direction of fire; early warning	Coordinating fire fighting efforts	Damage assessment
	Geophysical	Earthquake	Building stock assessment; hazard mapping	Measuring strain accumulation	Planning routes for search and rescue; damage assessment; evacuation planning; deformation mapping	Damage assessment; identifying sites for rehabilitation
		Mass movement	Hazard mapping	Measuring strain accumulation	Planning routes for search and rescue; damage assessment; evacuation planning; deformation mapping	Damage assessment; identifying sites for rehabilitation
		Volcanic activity	Risk modelling; hazard mapping; digital elevation models	Emissions monitoring; thermal alerts	Mapping lava flows; evacuation planning	Damage assessment; spatial planning
	Hydrological	Flood	Mapping flood-prone areas; monitoring fuel load; delineating flood-plains; land-use mapping	Flood detection; early warning; rainfall mapping	Flood mapping; evacuation planning; damage assessment	Damage assessment; spatial planning
		Landslide	Risk modelling; hazard mapping; digital elevation models	Monitoring rainfall and slope stability	Mapping affected areas; and slope stability	Damage assessment; spatial planning; suggesting management practices
		Wave action	Risk modelling; vulnerability analysis	Wave action detection; early warning	Mapping affected areas	Damage assessment; spatial planning
	Meterological	Storm	Risk modelling; vulnerability analysis	Early warning; long-range climate modelling	Identifying escape routes; storm surge predictions; cyclone monitoring; impact assessment; crisis mapping	Damage assessment; spatial planning
		Extreme temperature	Risk modelling; vulnerability analysis	Weather forecasting; long-range climate modelling; early warning	Crisis mapping; evacuation planning; damage assessment	Damage assessment; spatial planning
		Fog	Risk modelling; vulnerability analysis	Weather forecasting; long-range climate modelling; early warning	Crisis mapping; evacuation planning; damage assessment	Damage assessment; spatial planning

Table 6. Remote sensing applications for disaster management [complemented after 12]

- media and the public raise the demand for up-to-date easy-to-understand visual information on disaster areas and ongoing relief work

The following sections focus primarily on the contribution of remote sensing to the response phase, in particular, giving a brief overview of the workflow from an emergency call or request for assistance, through satellite tasking, data acquisition, analysis, map provision and furthermore explaining some existing operational services, and finally a number of case studies are presented.

2.3. Rapid mapping workflow

No decision maker or relief worker can work with raw satellite imagery. To generate the required situation maps, reports or statistics, which can be read and understood by non-satellite expert users, experts in remote sensing and cartography are necessary. In 2004, German Aerospace Center (DLR) was one of the first institutions, which has set up a dedicated interface called Center for Satellite Based Crisis Information (ZKI) to facilitate the use of its Earth observation capacities in the services of national and international response to disaster situations [18]. ZKI's function is particularly 'rapid mapping' – the rapid acquisition, processing and analysis of satellite data and the provision of satellite-based information products. Analyses are tailored to meet the specific requirements of national and international political bodies or humanitarian relief organisations. In order to provide up-to-date and relevant satellite-based cartographic information and situation analysis, it is necessary to establish efficient and operational data flow lines between satellite operators, receiving stations and distribution networks on the one hand and the decision makers and relief workers on the other hand. Service lines and feedback loops have been created to allow best possible data and information provision, as well as optimised decision support [20]. In order to meet with users' demands and service requirements in crisis situations, ZKI set up a rapid mapping workflow (Figure 3) ensuring a fast access to available, reliable and affordable crisis information worldwide.

Schedules for the full cycle from the emergency call (mobilisation phase), satellite tasking (data acquisition), pre-processing, analysis and interpretation, map production and data provision to the end-user are tight (as fast as possible). Hence, rapid mapping is still a complex task [15].

After the mandatory decision process, whether satellite analysis is appropriate for the respective crisis or not, the area of interest has to be defined and cross-checked to avoid false geolocation. Following this iterative process, it has to be assured that all applicable satellites are programmed for data acquisition. Furthermore, an enquiry for corresponding archive imagery has to be set up for documentation of the pre-disaster situation and change detection analysis. Besides the procurement of satellite data, it is necessary to check and prepare supplementary geodata such as population and infrastructure data, road network, contour lines and administrative boundaries. Experience of several activations and user feedback shows that additional geoinformation increases the satellite data analysis significantly. This includes place names, critical infrastructure, transportation network or further detailed specifications. Availability and access to accurate and up-to-date spatial data, particularly in remote regions, are the most crucial problems [18].

After receiving the archived and recently recorded satellite imagery, essential pre-processing has to be done. This includes geo- and ortho-rectification as well as radiometric corrections and data format conversions. Data re-projection is necessary due to varying demands and standards. In the majority of activations, a Universal Transverse Mercator (UTM) projection

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is used due to global applicability and following international standards. Depending on user's needs, crisis type and extent, different analysis process chains have to be applied [18].

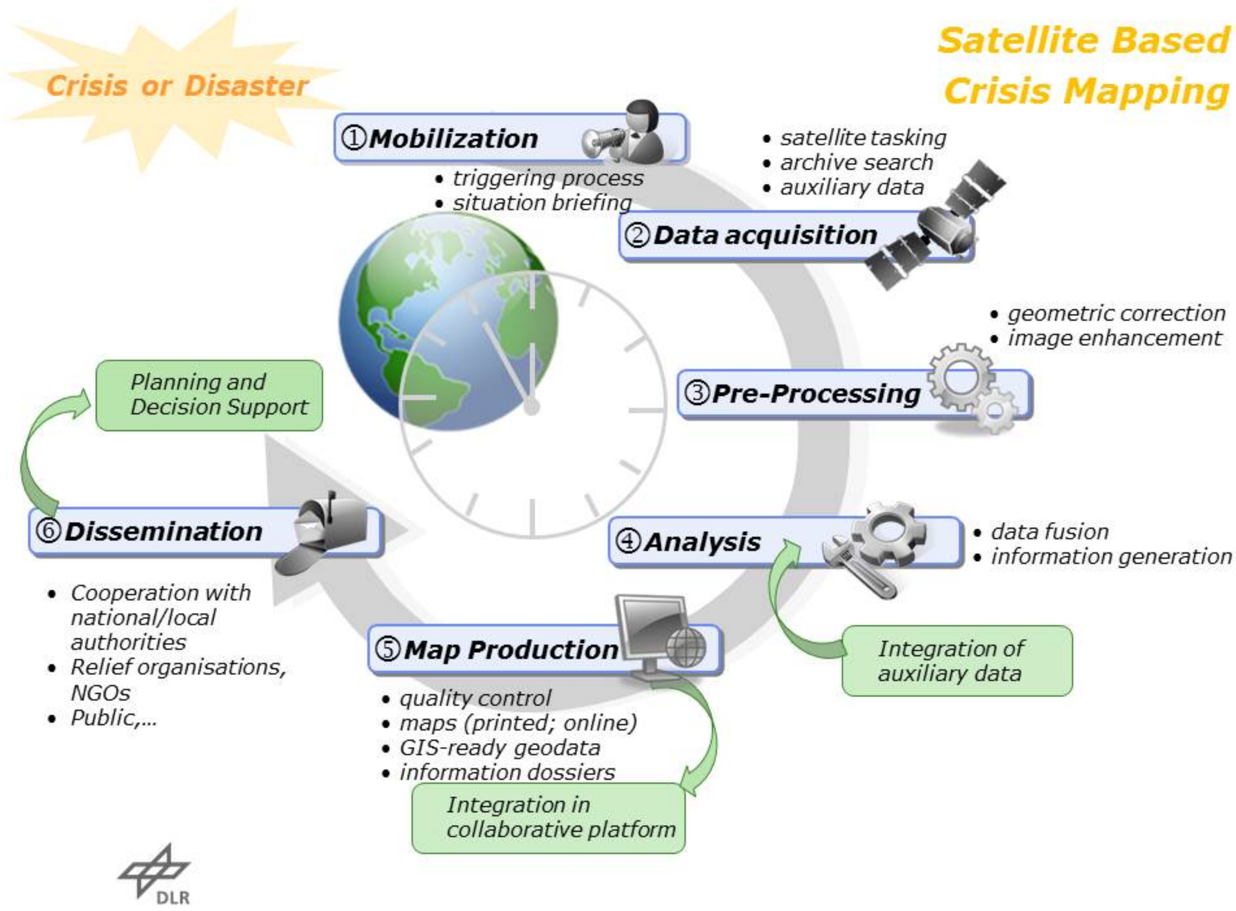

Figure 3. Rapid mapping workflow

Derivation of water surfaces or general damage assessment is dependent on input data type, scale and possible availability of archived satellite imagery. Before and after image comparison allows the quantification of affected areas. This change detection method can either be applied for optical or radar imagery in order to detect areas where significant change can be identified. Furthermore, general image classification and differencing methods allows quantification of flooded areas, fire scars or damaged areas [19].

Situation and damage maps are generated in order to translate complex satellite information in readable and coherent crisis information. Following this map compilation, an adapted map generation process is applied. A settled quality control process takes place after each single product generation step as well as before publishing. Delivery is accomplished via Internet, intranet, ftp, e-mail or satellite communication. Furthermore, printed and laminated maps will be sent via express delivery on request. User feedback from field units has proved to be an important source for optimisation. Maps are updated when new and improved data are available or knowledgeable feedback is received even though the maps are published and delivered [18].

In order to fulfil its tasks, DLR-ZKI is involved in international, European and national mechanisms providing space-based information supporting the disaster relief (e.g. International Charter Space and Major Disaster). The understanding of the organisational frameworks of these mechanisms, their activation procedures and workflows are a prerequisite to take advantage of the products provided by these mechanisms.

2.4. Mechanisms of providing satellite-based crisis information

2.4.1. International Charter 'Space and Major Disasters'

For providing fast and reliable image access on archive or new post-event imagery effectively, there is a need for more than a single research-oriented or commercial system. Thus, 'effective and well-balanced coordination among the different observing systems is required in order to allow best service to the civil-protection and humanitarian relief community' [18, p. 1527].

With the installation of International Charter Space and Major Disasters in 1999, from now onwards referred to as 'Charter', a globally functioning mechanism was established to provide a unified system of rapid space data acquisition and delivery in case of natural or man-made disasters [21]. The Charter is a consortium of space agencies and satellite data providers. Each member agency of the Charter has committed resources to support relief organisations as well as civil protection and defence organisations with free of charge satellite (raw) data in order to help mitigating effects of disasters on man life and environment. Its members, conscious of the need to improve its access globally, have adopted the principle of 'Universal Access': any national disaster management authority will be able to submit requests to the Charter for emergency responses [21]. Proper procedures have to be followed, but the affected country does not have to be its member as it was before. A registration process is available for national authorities to express interest in participating in the Charter. Universal Access implementation started in September 2012 and is being implemented gradually [21].

Since its inception in 2000, the Charter has been activated for more than 470 disasters (as end of September 2015), in more than 110 countries. In 2014, the Charter was activated 41 times for disasters in 30 countries. In the same year, more than 75% of Charter activations were based on weather-related disasters such as flooding, ocean storms and landslides, while solid Earth-related hazards (e.g. earthquakes, volcanic eruptions) represented 10% of Charter activations; activations for man-made disasters (e.g. oil spills) are marginal (<5%; see Figure 4) [21].

Comparing Charter activations with occurrence of disasters of hazard types reported by emergency events database (EM-DAT), proportions of both fit together to some extent (see Figure 5). One obvious difference can be recognised in category "Others" which incorporates particularly all man-made disasters. Nevertheless, the Charter covered 7 of the 10 most severe disasters by fatalities 2014 as reported by EM-DAT (Table 7).

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Top 10 Disasters – Number Killed – 2014					
Country	**Disaster type**	**Date**	**#killed**	**#Affected people**	**Total Damage (000' $)**
China P Rep	*Earthquake*	*3/8/2014*	*731*	*1,120,513*	*5,000,000*
Nepal	*Landslide*	*2/8/2014*	*450*	*184,894*	-
Afghanistan	*Flood*	*24/4/2014*	*431*	*140,100*	-
Pakistan	*Flood*	*1/9/2014*	*367*	*2,470,673*	*2,000,000*
India	*Flood*	*8-9/2014*	*298*	*275,000*	*16,000,000*
Nepal	Flood	12/8/2014	217	28,279	-
India	Landslide	30/7/2014	209	-	-
Sri Lanka	*Landslide*	*29/10/2014*	*196*	-	-
China P Rep	*Storm*	*7/4/2014*	*128*	-	-
Philippines	Storm	15/7/2014	111	4,654,966	820576

Table 7. Ten most severe natural disasters by number of fatalities in 2014 based on EM-DAT statistics [7] and events covered by Charter activations (indicated in bold and italics) [source 21; p.49]

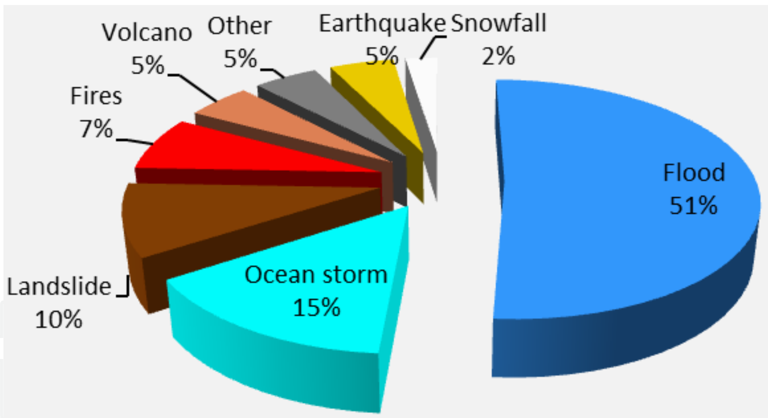

Figure 4. Percentage of hazard-type Charter activations in 2014 [21, p.24]

Due to user feedbacks and meaningful statistics, it can be concluded that a meaningful satellite observation information capacity was established for a variety of non-expert users.

However, it should be mentioned, that the Charter does not concern the whole disaster management cycle (see Figure 2) and not for long humanitarian crisis as well. Moreover, the rapid mapping value-adding activities (see the following section) are not primary in the mandate of the Charter. The analysis of the satellite (raw) data and map production are often entrusted to associated value-adders. Today there is no other operational capacity playing such

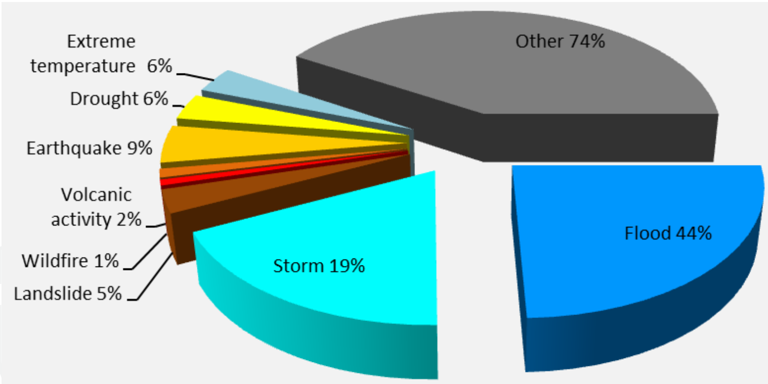

Figure 5. Occurrence of disasters in 2014 in percentage, by hazard type [data source 7]

an important role on a worldwide basis. However, other space-based initiatives are available providing new capacities to other users.

2.4.2. Sentinel Asia

Another collaboration between space agencies is the so-called Sentinel Asia initiative. It has a regional focus and was established in 2005, as a collaboration between regional space agencies and disaster management agencies, applying remote sensing and Web-GIS technologies to assist in disaster management in the Asia-Pacific region. Until today multiple national agencies of about 25 countries in the region have joined and benefited from the disaster support services provided by Sentinel Asia. It intends to expand efforts like the Charter and make relevant data available to all countries and many more people in the region [22].

Sentinel Asia also cooperates with the Charter: since its inception Sentinel Asia provides a regional enhancement to the Charter, as it allows any country in the region to join their network and request disaster-relevant information, regardless of their membership of the Charter (even before the Universal Access was implemented). Moreover, Sentinel Asia built up an expert team with different knowledge base, such as disaster management agencies, space agencies, as well as relevant regional and international entities. They created a network with so-called data provider nodes (DPNs), where several regional space agencies and related institutes providing satellite data from their national satellite systems to the so-called data analysis nodes (DANs) [23]. These DANs analyse raw image data together with their own geospatial data. Moreover, they implemented specific technical working groups, which aim to accelerate and optimise information analysis process (e.g. expand utilisation of satellite-derived products for tsunamis or wildfires). In parallel with the activities above, capacity building for technical and emergency-response agencies users of the Sentinel Asia system is realised [22–23].

In summary, Sentinal Asia is a direct and active collaboration with regional disaster management agencies, and great regional network of data providers, data analysis nodes and users. With regard to the fact that Asia comprises 39% of the worldwide total disasters, Sentinel Asia is a very valuable initiative [22].

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2.4.3. Copernicus Emergency Management Service

Yet another service which collaborates with the Charter is the Copernicus Emergency Management Service (EMS). Copernicus EMS is intended as an operational service offered to authorised users active in the field of crisis management in the EU member states, the European civil protection mechanism, the Commission's Directorates-General (DGs) and the participating executive agencies and international humanitarian aid [24]. The service started its operations in April 2012 and is implemented by the European Commission DG Joint Research Centre (JRC). The scope of the service is the provision of timely and accurate geospatial information derived from the satellite remote sensing and completed by the available in situ or open data sources. Copernicus EMS is provided free of charge for the users, during all phases of the disaster management cycle, and in two temporal modes [25].

EMS service and all other Copernicus services such as land monitoring or atmosphere monitoring are based on the provision of satellite imagery from contributing missions that are made available through the Copernicus Space Component Data Access (CSCDA) system operated by European Space Agency (ESA) since 2008. In future, the service will also be supported by all the Sentinels; for Sentinel 1-A first maps were already produced [26].

Analysis products are standardised and depend on the set of parameters chosen by users when placing the service request. For rapid mapping, the following product categories are offered: reference maps, delineation maps (providing an assessment of the geographic extent of the event) and grading maps (providing an assessment of the damage grade and its spatial distribution) [25].

Unlike the Charter analysis and map, production is explicitly within the mandate of Copernicus EMS. Therefore, an agreement has been set up to exploit the advanced crisis mapping capability of the EMS to support Charter requests pertinent to European policy sectors. Another important advantage of Copernicus EMS is the opportunity to request geospatial information in support of disaster management activities not related to immediate response. This is of particular importance for activities dealing with prevention, preparedness, disaster risk reduction and recovery phases [25]. For this purpose, there are three categories of maps offered: reference maps, pre-disaster situation maps and post-disaster situation maps.

In summary, Copernicus EMS is a fully operational service with a predefined and standardised product portfolio, covering the whole disaster cycle, which is free of charge for authorised users. In contrast, satellite data providers as well as value adders have paid service contracts with the European Commission, which leads often to a faster and guaranteed product delivery, but not necessarily to better products. Some restrictions are given for the service: only large-scale disasters and crises are within the scope of the service and the request should not be related to an existing on-going conflict or crisis with EU military operations or in politically sensitive areas [25].

2.4.4. UNITAR Operational Satellite Applications Programme (UNOSAT)

UNOSAT is the United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme which was created in 2000 [27]. UNOSAT provides maps, reports as well as geographic information system (GIS) compatible data layers for natural hazards, complex emergency situations or conflict crises – at no cost to the user. The users are entities of the United Nations systems such as OCHA, UNHCR, UNICEF, WFP, UNDP, WHO, IFRC, ICRC; International and national NGOs and the governments of affected countries. UNOSAT is covering the response and recovery phase and is working worldwide. UNOSAT collaborates with several partners (e.g. other services, satellite data providers, UN entities, companies like Google and ESRI) [28].

2.4.5. SERVIR

SERVIR mechanism is a joint venture between NASA and the United States Agency for International Development (USAID) [29]. It integrates satellite observations, ground-based data and forecast models to help developing nations in Central America, East Africa and the Himalaya region to assess environmental threats and to respond to and assess damage from disasters of natural origin. SERVIR is a multi-agency and multi-government mechanism with over 30 partners and collaborators and is endorsed by governments in Central America, Africa and the Hindu-Kush Himalaya region of Asia. The coordination office is located in United States and is supported by three regional centres: The Regional Centre for Mapping of Resources for Development (RCMRD) in Kenya, the International Centre for Integrated Mountain Development (ICIMOD) in Nepal and the Water Centre for the Humid Tropics of Latin America and the Caribbean in Panama [28].

Program supports not only national governments, but also universities, non-governmental organisations, and the private sectors. Users of SERVIR are government officials, disaster managers, scientists/researcher, students and the general public [29]. SERVIR serves as a source for satellite imagery and information provider during extreme events. The SERVIR mechanism is intended to respond to needs for satellite-based geoinformation in Mesoamerica, Africa or the Himalaya [28].

2.4.6. ZKI service for federal agencies

One of the first national operational services providing rapid space data acquisition and delivery in case of natural or man-made disasters is the so-called ZKI Service for Federal Agencies (ZKI-DE). ZKI-DE was established in January 2013, based on a framework contract between German Federal Ministry of the Interior (BMI) and the German Aerospace Center (DLR), coping all phases of the disaster management cycle. It enables German national authorities and other authorised users to order products of DLRs Center for Satellite Based Crisis Information (ZKI), even for requests at regional scale and for users like national security authorities (with the option of arrangements of confidentiality). Moreover, aiming at a better and more customised use of the products by public authorities, the service includes not only the provision of maps and dossiers in case of a disaster but also user trainings, a consulting service and continuous further developments based on user requirements and new technical capabilities [30]. This cooperation is not limited to BMI and its special agency (e.g. like 'Federal Office of Civil Protection and Disaster Assistance' or 'Federal Criminal Police Office'). As a first institution, the German Red Cross also uses ZKI-DE products for their emergency operations worldwide [30]. As a matter of fact, due to licence and safety regulations products could often not be published.

2.4.7. Other initiatives

There are more and more actors gathering/providing further space-based disaster information such as private companies (e.g. Digital Globe, Google, ESRI). Other interesting and upcoming actors are volunteer organisations like Map Action and crowdsourcing crisis mapper (e.g. Open Street Map initiative–OSM, Tomnod owned by Digital Globe). In this context, data acquisition and reliability are often critical aspects. Depending on the expertise of volunteer's equipment and raw data quality, analysis can vary considerably. Nevertheless, changing data policies in case of (major) disasters and new techniques in image analysis can facilitate the access to satellite data, as well as the dissemination of rapid-mapping products.

3. Examples for applying satellite-based information in disaster management: Case studies

In this section, a number of examples of satellite imagery application for disaster relief intend to highlight swift and synergistic use of state-of-the-art processing techniques and rapid data access. These rapid-mapping results could be achieved by building on existing scientific results, long-term engineering experience in the domain of satellite data processing and last but not least operational data access mechanisms. It is not indented to report major generic methodological research results or method comparison here.

3.1. Flooding in Germany 2013

Extreme flooding in Germany and other parts of the Central Europe began after several days of heavy rain in the late May and early June 2013 [31]. Flooding and damages primarily affected southern and eastern German states as well as Czech Republic and Austria. Switzerland, Slovakia, Belarus, Poland, Hungary and Serbia were affected to a lesser extent [31].

German Joint Information and Situation Centre (GMLZ) tasked Charter, Copernicus GIO EMS (Precursor of Copernicus EMS) and national Service ZKI-DE with the provision of satellite data and the creation of satellite and aerial image-based situation information covering the regions most affected by the current floods in Thuringia, Saxony, Bavaria and Baden-Wuerttemberg [32-34]. GMLZ is a facility of the German Federal Office of Civil Protection and Disaster Assistance (BBK). Charter and Copernicus EMS provided fast and cost-free access to satellite images covering a disaster area; moreover, Copernicus EMS delivered 38 maps (reference and disaster). National ZKI-DE service complemented the response products with up-to-date airborne data and more than 50 products such as supplementing monitoring maps or web services (see Figure 6).

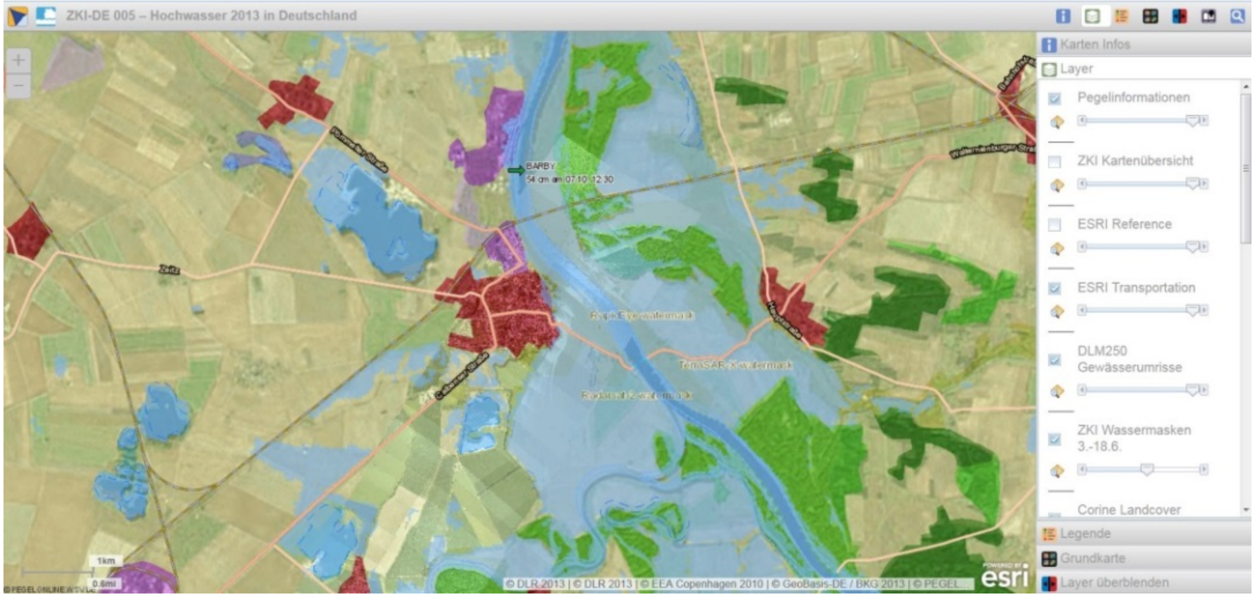

Figure 6. Flooding in Germany 2013 – ZKI-DE Web service [32]

Figure 7. Flooding in Germany 2013, Passau – first situation map 10 h after acquisition [34]

ZKI-DE was able to present the first situation map products to the users. The products based on the German radar-satellite TerraSAR-X and were delivered 10 hours after acquisition. The maps show the flood extent derived from the radar data, as backdrop serves as a topographic map (see Figure 7). Derivation of flood extent from TerraSAR-X data and map production/ dissemination just took 4 hours (6 hours for data downlink and pre-processing, respectively). These fast rapid-mapping results could be achieved by building on existing operational organisational structures (24/7) with trained staff, (semi-) automated image analysis procedures, and several templates as well as models/macros for the map products and their dissemination.

Nearly all the products were published for everyone on websites and were used in the disaster response phase by several users in Germany – from decision makers in the situation centres as well as local or top-ranking politician. Moreover weeks and months after the disaster, vector data sets of the disaster extent were requested several times by environmental and research institutes. These entities work in different phases of the disaster management cycle. Following up the experiences of the flooding 2013, several actions were implemented to reduce the impact of such heavy weather conditions [35].

In general, optical as well as radar satellite remote sensing have proven to provide essential large-scale information on flood situations. For optical input data, the standard semi-automatic method is (unsupervised) classified [36]. If the spectral resolution of the sensor and/or the cloud coverage does not allow clear semi-automatic classification, the flood information can be extracted via visual interpretation. Change detection analysis is used if pre- and post-disaster satellite data are available [34]. Even though, optical data provide positive result information on inundation, radar data are a preferred input for flood detection. Fortunately, the number of automatic image processing algorithms to derive flooding from high-resolution SAR data (TerraSAR-X, Radarsat-2, Cosmo–SkyMed) has increased in the last years. One thing in common in these algorithms is that they make use of automatic thresholding algorithms for the initialisation of the classification process [36–39].

3.2. Earthquake and Landslide in Nepal 2015

On 25th April 2015, a 7.8 magnitude earthquake hit the Himalayan region. The epicentre was located near Kathmandu, the capital of Nepal. In addition to Nepal, India, China and Bangladesh were affected. The event and several aftershocks caused wide-ranging destruction. The earthquake triggered several landslides, an avalanche on Mount Everest. More than eight million people were affected by the earthquake [40]. Several actors were involved in producing useful information as a response to the disaster. Copernicus EMS was activated by European Commission's Humanitarian aid and Civil 40 products were published at the EMS webpage [41].

The International Charter on Space and Major Disasters was activated by several organisations (e.g. Indian Space Research Organisation – ISRO), and a plenty of maps were made available on webpage of the Charter in the aftermath of the earthquake [42]. Moreover, Sentinel Asia, ZKI-DE and several other actors [43] delivered a number of standard maps (see Figure 8) and innovative products such as a 3D-Animation flight over Kathmandu before the earthquake, based on 10 cm airborne data (see Figure 9) [42,44]. Even the National Geospatial-Intelligence

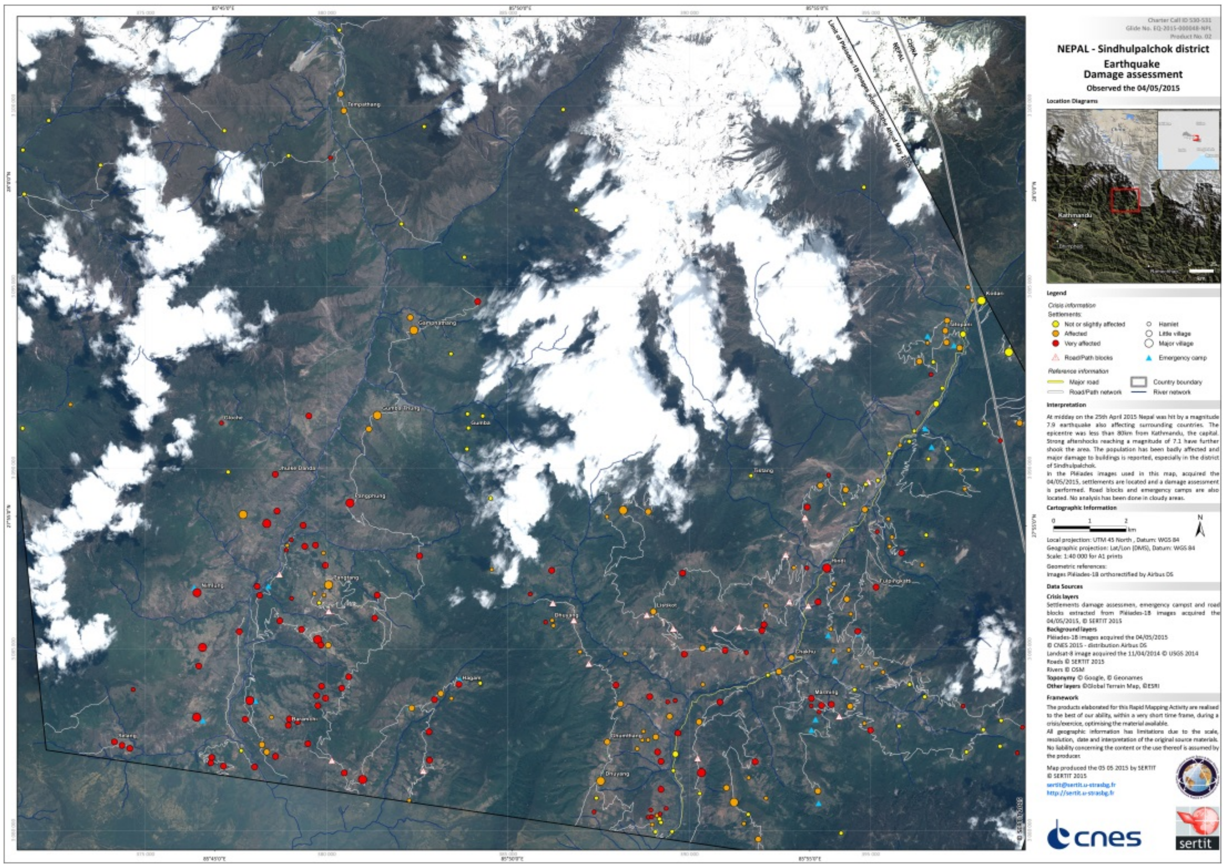

Figure 8. Earthquake in Nepal—Damage assessment map based on Pléiades data and visual interpretation [42]

Agency released unclassified geospatial intelligence data, products and services [42]. Within the crowdsource community also several initiatives were working on the Nepal earthquake such as Tomnod and Open Street Map (see Figure 10), Map Action, Micromappers [45].

Various methodologies have been proposed for earthquake damage assessment using optical and radar Earth observation data. For estimating infrastructural damages based on SAR, methods exploiting changes in backscattering intensity and the related image correlation coefficient [47] or a combination of backscatter intensity, phase changes and/or ancillary data are often used [48]. Reference [15] stated that 'most SAR-based change detection approaches suffer from a lack of archive data with the same acquisition parameters as the post crisis imagery'. Consequently, only very few of the SAR or optical-based approaches have been targeted for the use in an operational rapid mapping environment. For analysing optical satellite data several analysis methods were used to detect damages. Several authors applied either semi- or fully automatic change detection methods for earthquake damage assessment [49,47]. However, for various reasons, such methods have rarely been applied during rapid mapping activities [15]. For instance, automatic change detection approaches will potentially detect changes that are not related to earthquake damages (e.g. vegetation changes, different illumination, etc.). Moreover, in case of cloud coverage, haze or radiometric and spectral problems just manual extraction methods like visual interpretation and grid interpretation can be performed. The

Figure 9. Earthquake in Nepal—Screenshot of a 3D-Animation flight over Kathmandu before the earthquake based on 10 cm airborne data (sensorDLR MACS) [44]

selection of the method depends on the requested information. For instance, if single (small-scale and heterogeneous) objects (e.g. houses, streets, ships and other relevant objects) have to be identified only visual interpretation is possible. Otherwise, the grid analysis allows the interpretation in specified areas (grid cells) and takes the relation of the neighbourhood into account by spatial aggregation of the thematic information content to be provided [18].

In summary, a fast activation of several mechanisms has taken place and resulted in large amounts of satellite imagery and airborne data. Nearly all results are based on optical data and visual interpretation. Many useful maps and visualisations facilitated a general understanding of the situation as well as the assessment of detailed aspects of the disaster and the relief work, including damage overview, road and infrastructure accessibility, gathering areas, strategic holding areas etc. According to several users' feedback, the maps and layers (streets, damage etc.) provided vital information with respect to evacuation planning, general

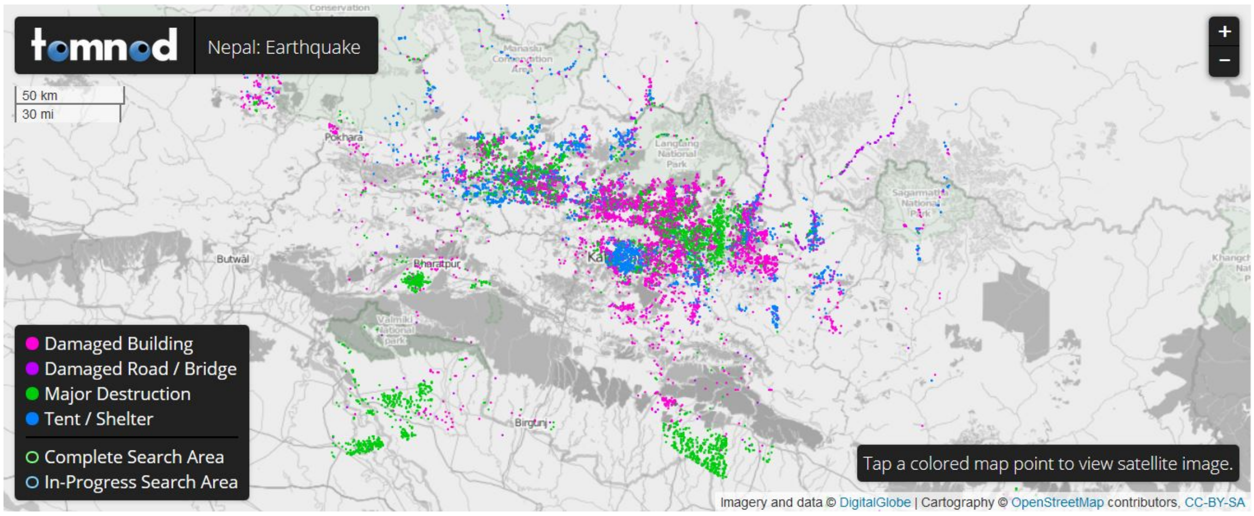

Figure 10. Earthquake in Nepal—Online damage map created by tomnod/OSM based on WorldView-1,-2,-3 and GeoEye [46]

pathfinding to get a better overview and understanding of problems on site. In addition, these maps proved to be very useful for making decisions on logistics and joint operations among relief organisations. Nevertheless, a multitude of websites and platforms hosted the maps, which resulted for some users in an overflow of mapping and imagery. During such extreme events, the authors of source [15] recommended a better coordination and harmonisation of global mapping efforts. As a consequence, an International Working Group on Satellite based Emergency Mapping (IWG-SEM) was initiated in 2012 resulting from the experiences of the Haiti earthquake in 2011. The IWG-SEM is a voluntary group of organisations involved in satellite-based emergency mapping which supports disaster response by improving international cooperation in such mapping activities. The group was founded to improve cooperation, communication and professional standards among the global network of satellite-based emergency mapping providers.

3.3. Forest fire in Russia

In July 2015, a heat wave in Russia's Siberian district started with over one hundred forest fires in the Buryatia and Irkustkaya Republics. Fires spread to an area of approximately 100,000 hectares [50].

After a request from the Russian Federal Space Agency (ROSCOSMOS) together with the Agency for Support and Coordination of Russian Participation in International Humanitarian Operations(EMERCOM), the Charter was triggered [Charter]. Burned area was mapped using the Russian satellite Resurs-P and its multispectral sensor with 12 meter resolution data (see Figure 10) and furthermore with SPOT-7 and GAOFEN-1 for another area [50]. In addition, fire hot spots were detected using RapidEye, GAOFEN and SPOT 7 [e.g. see Figure 11]. Burnt area analysis and fire hot spot detection was obtained by visual interpretation.

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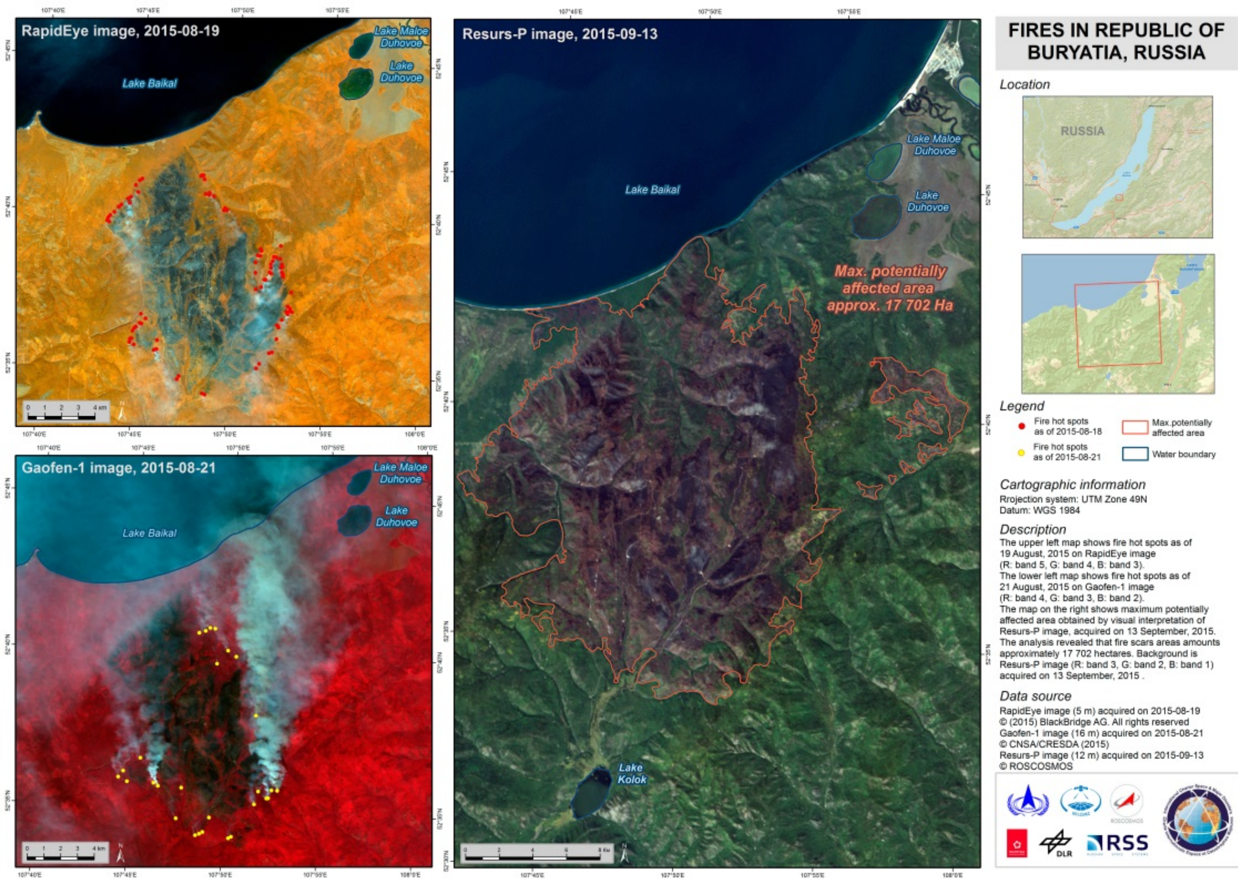

Figure 11. Forest Fires in Russia 2015 – Mapping hot spots and burned areas created by Research Center for Earth Operative Monitoring (NTs OMZ) [48]

In general, to identify fires and/or burnt areas optical data are the best choice and either semi-automated methods or visual interpretations can be applied [51]. In case of cloud coverage or direct fire effects such as smoke plumes or haze, visual interpretation usually gives better results. If the area is completely covered with clouds, radar data is an option. First positive results were gathered using SAR data for burnt area detection, applying backscatter coefficient analysis [52–53]. Nevertheless, optical satellites are commonly the main data source used for burnt area mapping in a rush-mode. In addition, fire hot spots can be detected automatically with optical data and appropriate methods. For instance, based on data of the NASA-owned MODIS sensors on board of the Terra-1 and Aqua-1 satellites, active fires can be detected [54].

3.4. Search for Malaysia Airlines Flight 370

On 11th March 2014, China Meteorological Administration requested the Charter for supporting search for Malaysia Airlines Flight 370 (MH370) [55]. The aircraft disappeared from radar on March 7th 2014 with 239 people on board. Soon an international search began in the South China Sea, the last known location of the aircraft. A few days later the search area has been expanded several times (e.g. to Indian Ocean). Satellite imagery was used to search for any evidence of the aircraft. Satellite images have revealed suspected debris or oil spill of missing aircraft in a number of locations (see example in Figure 12), but despite efforts to search an area of the southern Indian Ocean no trace of the plane has been found [55].

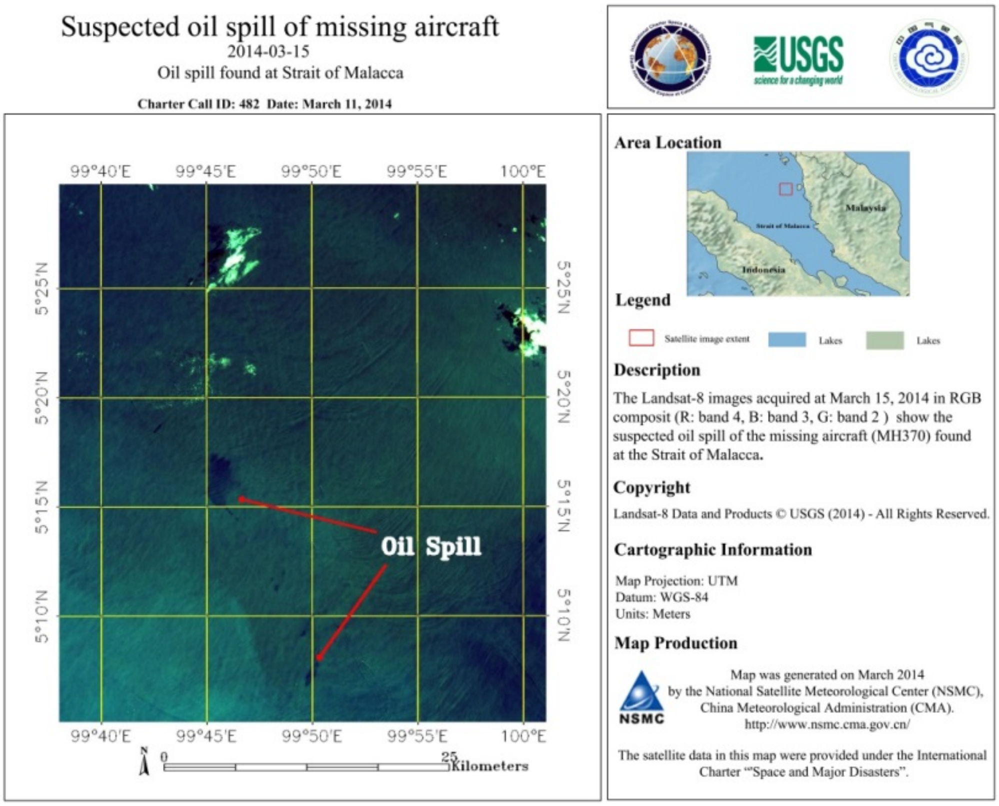

Figure 12. Searching for Malaysia Flight 370—Suspected oil spill of missing aircraft; created by National Satellite Meteorological Center (NSMC), China Meteorological Administration (CMA) [55]

Tomnod, a company owned by the satellite provider DigitalGlobe, started a crowdsourcing campaign in which over two million volunteers have studied WorldView-2 images of the area. The search area was sliced up in many small images which every user was able to see and tag with four types: Wreckage, Oil slick, Life raft and Other. Like other microtasking platforms, Tomnod uses triangulation to calculate areas of greatest consensus by the crowd [56]. The results are illustrated in Google Earth (see Figure 13).

Even though crowdsourced satellite information gave some reliable results or even misjudgements for this disaster, this way of data provision and processing information has been useful in man-made disasters before [56-57] and is a powerful new approach of producing crisis information based on satellite data. Nevertheless, Tomnod has to improve their infrastructure such as adding server capacity. Due to the huge volume of traffic (an estimated 100,000 views per minute), the site was down for several hours on March 11th and 12th.

However, the information provided by the Charter was also wrong. It is very difficult to search small items even if the imagery has a spatial resolution of 0.5 meters in an unspecific area with the current Earth observation technology. However, still there are a lot of data (e.g. SAR or other complex information) and several applications in disaster management which need advanced image analysis procedures. Therefore, remote sensing experts and specific tools are mandatory.

Figure 13. Searching for Malaysia Flight 370 – Online damage map created by tomnod based in Worldview-2 data and illustrated in Google Earth [56-57, visualisation in GoogleEarth]

4. Conclusion and outlook

The increasing occurrence of natural disasters and humanitarian emergency situations cause a growing demand for timely and up-to-date geoinformation for an effective disaster management. Within the last 10–15 years, a promising and considerable development has taken place to improve and accelerate the provision of Earth observation-based disaster information. Accordingly, remote sensing technology plays an important role in disaster management, especially during the preparedness and response phase.

Examples could be shown of how operational mechanisms (e.g. Charter, Copernicus EMS, ZKI-DE, etc.) serve rapid mapping based on Earth Observation data. In addition, a number of potential remote sensing data sources (TerraSAR-X, SPOT, RapidEye, WorldView and airborne data) and new (semi-automated) algorithms as well as visual interpretation results could be showcased for different disaster types.

Nevertheless, there are still some limitations with respect to the rapid availability of imagery and the reliability of the rapid image analysis in case of a disaster. Even if the imagery has a spatial resolution of 0.5 meters, geometric resolution is often still too coarse to assess damage or other important disaster information. Moreover, compromise must be found between the time spent on an analysis and the mapping accuracy that needs to be achieved. These aspects also have to be evaluated against user requirements during an emergency.

Further effort and scientific work is needed to derive even better, faster and more standardised crisis information from space-based imagery. In addition, in case of extreme disasters, a more structured and coordinated way of collaboration is needed to achieve most powerful results [15]. The International Working Group on Satellite based Emergency Mapping provides an important framework in this context.

Within the next years, new data sources (better geometric, spectral and temporal resolution), new tools, modified data policies (open access or strictly regulated) and new actors/collaborations (crowdsourcing crisis mapper, national services, inter-organisational cooperation) will influence the potential of remote sensing for natural or man-made disasters.

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