REMOTE SENSING FOR NATURAL DISASTER MANAGEMENT

Cees VAN WESTEN
International Institute for Aerospace Survey and Earth Sciences, ITC, The Netherlands
Division of Applied Geomorphological Surveys
Westen@itc.nl

KEY WORDS: Natural Disasters, Earthquakes, landslides, volcanoes, Remote Sensing, GIS.

ABSTRACT

Natural disasters are extreme events within the earth's system that result in death or injury to humans, and damage or loss of valuable goods, such as buildings, communication systems, agricultural land, forest, natural environment etc. The economic losses due to natural disasters have shown an increase with a factor of eight over the past four decades, caused by the increased vulnerability of the global society, but also due to an increase in the number of weather-related disasters.

For the management of natural disasters a large amount of multi-temporal spatial data is required. Satellite remote sensing is the ideal tool for disaster management, since it offers information over large areas, and at short time intervals. Although it can be utilised in the various phases of disaster management, such as prevention, preparedness, relief, and reconstruction, in practice up till now it is mostly used for warning and monitoring. During the last decades remote sensing has become an operational tool in the disaster preparedness and warning phases for cyclones, droughts and floods. The use of remote sensing data is not possible without a proper tool to handle the large amounts of data and combine it with data coming from other sources, such as maps or measurement stations. Therefore, together with the growth of the remote sensing applications, Geographic Information Systems have become increasingly important for disaster management. This chapter gives a review of the use of remote sensing and GIS for a number of major disaster types.

1. INTRODUCTION

Natural disasters are extreme events within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) which differs substantially from the mean, resulting in death or injury to humans, and damage or loss of valuable good, such as buildings, communication systems, agricultural land, forest, natural environment. They are a profound impact of the natural environment upon the socio-economic system (Alexander, 1993). This impact may be rapid, as in the case of earthquakes, or slow as in the case of drought.

It is important to distinguish between the terms *disaster* and *hazard*. A potentially damaging phenomenon (hazard), such as an earthquake by itself is not considered a disaster when it occurs in uninhabited areas. It is called a disaster when it occurs in a populated area, and brings damage, loss or destruction. Natural disasters occur in many parts of the world, although each type of disaster is restricted to certain regions. Figure 1 gives an indication of the geographical distribution of a number of major hazards, such as earthquakes, volcanoes, tropical storms and cyclones. As can be seen from this figure earthquake and volcanoes, for example, are concentrated mainly on the earth's plate boundaries.

Disasters can be classified in several ways. A possible subdivision is between:

- *Natural disasters* are events which are caused by purely natural phenomena and bring damage to human societies (such as earthquakes, volcanic eruptions, hurricanes);
- *Human-made disasters* are events which are caused by human activities (such as atmospheric pollution, industrial chemical accidents, major armed conflicts, nuclear accidents, oil spills), and
- *Human-induced disasters* are natural disasters that are accelerated/aggravated by human influence.

In table 1 the various disasters are classified according to this classification, using some intermediate classes. A landslide, for example, may be purely natural, as a result of a heavy rainfall or earthquake, but it may also be human induced, as a result of an oversteepened roadcut.

The impact of natural disasters to the global environment is becoming more and more severe over the last decades. The reported number of disaster has dramatically increased, as well as the cost to the global economy and the number of people affected (see table 2).

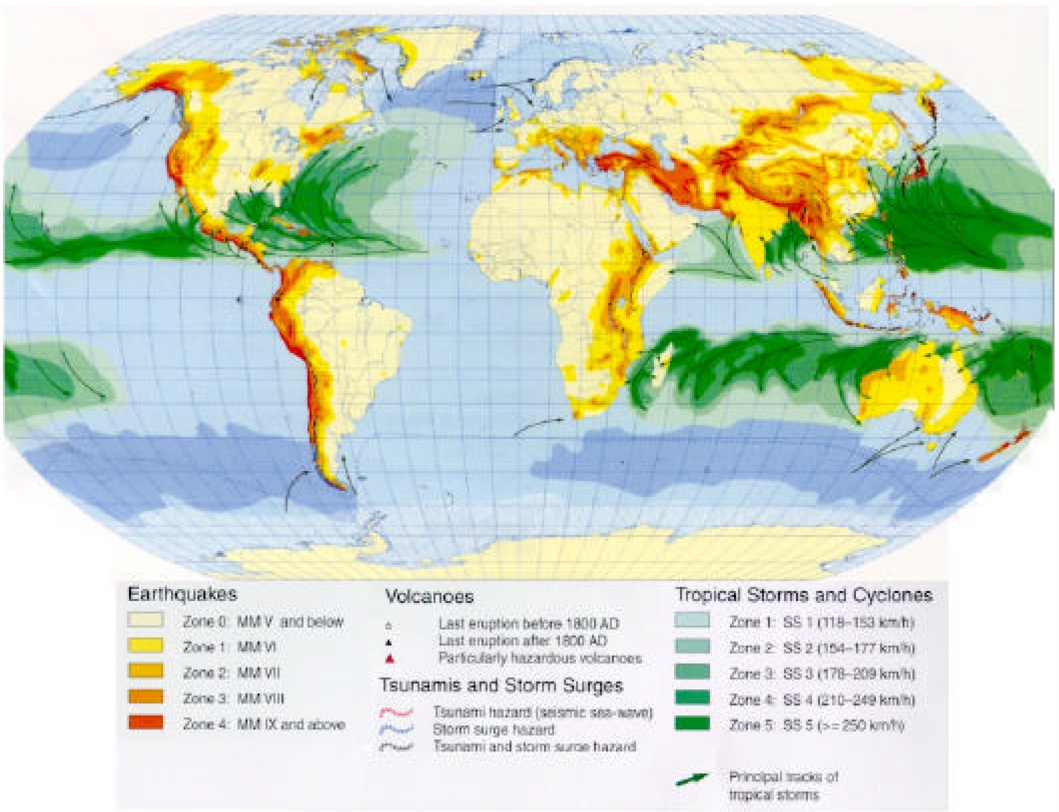

Figure 1: World map of natural disasters (Source: Munich Re., 1998a)

Natural	**Some human influence**	**Mixed natural /human influence**	**Some natural influence**	**Human**
Earthquake Tsunami Volcanic eruption Snow storm / avalanche Glacial lake outburst Lightning Windstorm Thunderstorm Hailstorm Tornado Cyclone/ Hurricane Asteroid impact Aurora borealis	Flood Dust storm Drought	Landslides Subsidence Erosion Desertification Coal fires Coastal erosion Greenhouse effect Sealevel rise	Crop disease Insect infestation Forest fire Mangrove decline Coral reef decline Acid rain Ozone depletion	Armed conflict Land mines Major (air-, sea-, land-) traffic accidents Nuclear / chemical accidents Oil spill Water / soil / air pollution Groundwater pollution Electrical power breakdown Pesticides

Table 1: Classification of disaster in a gradual scale between purely natural and purely human-made.

	Decade 1960 - 1969 US $ billion	**Decade 1970 -1979 US $ billion**	**Decade 1980 - 1989 US $ billion**	**Last10 years 1988 - 1997 US $ billion**	**Factor Last 10 : 60s**
Number of large disasters	**16**	**29**	**70**	**48**	**3.0**
Economic losses	**50.4**	**96.9**	**153.8**	**426.7**	**8.5**
Insured losses	**6.7**	**11.3**	**31.0**	**93.5**	**14.0**

Table 2: Statistics of great natural disasters for the last four decades (source: Munich Re, 1998b)

Earthquakes result in the largest amount of losses. Of the total losses it accounts for 35%, ahead of floods (30%), windstorms (28%) and others (7%). Earthquake is also the main cause in terms of the number of fatalities (47%), followed by windstorms (45%), floods (7%), and others (1%) (Munich Re., 1999).

The strong increase in losses and people affected by natural disasters is partly due to the developments in communications, as hardly any disaster passes unnoticed by the mass media. But it is also due to the increased exposure of the world's population to natural disasters. There are a number of factors responsible for this, which can be subdived in factors leading to a larger risk and factors leading to a higher occurrence of hazardous events. The increased risk is due to the rapid increase of the world population, which has doubled in size from 3 billion in the 1960s to 6 billion in 2000. Depending on the expected groth rates, world population is estimated to be between 7 and 10 billion by the year 2050 (UNPD, 1999).

Another factor related to the population pressure is that areas become settled that were previously avoided due to their susceptibility to natural hazards. Added to this is the important trend of the concentration of people and economic activities in large urban centres, most of which are located in vulnerable coastal areas. Mega-cities with a very rapid growth mostly experience the occupation of marginal land, susceptible to disasters, by the poor newcomers.

Another factor related to the increasing impact of natural disasters has to do with the development of highly sensitive technologies and the growing susceptibility of modern industrial societies to breakdowns in their infrastructure. Figure 2 shows the distribution of economic and insured losses due to natural disasters during the last 4 decades.

It is also clear that there is a rapid increase in the insured losses, which are mainly related to losses occurring in developed countries. Windstorms clearly dominate the category of insured losses (US $90 billion), followed by earthquakes (US $ 25 billion). Insured losses to flooding are remarkably less (US $ 10 billion), due to the fact that they are most sever in developing countries with lower insurance density.

However, it is not only the increased exposure of the population to hazards that can explain the increase in natural disasters. There is also a clear trend that the frequency of destructive events, related to atmospheric extremes, such as floods, drought, cyclones, and landslides is increasing. During the last 10 years a total of 3,750 windstorms and floods were recorded, accounting for two-thirds of all events. The number of catastrophes due to earthquakes and volcanic activity (about 100 per year) has remained constant (Munich Re., 1998). Although the time-span is still not long enough to indicate it with certainty, it is a clear indication that climate change shows a clear negative trend in relation with the occurrence of natural disasters, which only will be become more severe in the near future.

There seems to be an inverse relationship between the level of development and loss of human lives in the case of a disaster. About 95 percent of the disaster related casualties occur in developing countries, where more than 4.200 million people live. Economic losses attributable to natural hazards in developing countries may represent as much as 10% of their gross national product. In industrialised countries, where warning-systems are more sophisticated, it is more feasible to predict the occurrence of certain natural phenomena, and to carry out massive evacuations. The application of building codes and restrictive zoning also accounts for a lower number of casualties in developed countries.

These statistics illustrate well the importance of hazard mitigation. The International community has become aware of the necessity to increase the work on disaster management. The decade 1990-2000 was designated the "International Decade for Natural Disaster Reduction" by the general assembly of the United Nations. However, now that we are at the end of the IDNDR, we must conclude that the efforts for reducing the effects for disaster reduction during the last decade have not been sufficient, and have to be enhanced in the next decade.

2. DISASTER MANAGEMENT

One way of dealing with natural hazards is to ignore them. In many areas, neither the population nor the authorities chooses to take the danger due to natural hazards seriously, due to many different reasons. The last major destructive event may have happened long time ago, and is only remember as a story from the past. People may have moved in the area recently, without having the knowledge on potential hazards. Or it may be that the risk due to natural hazards is taken for granted, given the many dangers and problems confronted with in people’s daily lives. Cynical authorities may ignore hazards because the media exposure for their aid supply after the disaster has happened has much more impact on voters than the quit investment of funds for disaster mitigation.

To effectively reduce the impacts of natural disasters a complete strategy for disaster management is required, which is also referred to as the disaster management cycle (see figure 2).

Disaster management consists of two phases that take place before a disaster occurs, ***disaster prevention*** and ***disaster preparedness***, and three phases that happen after the occurrence of a disaster, ***disaster relief***, ***rehabilitation*** and ***reconstruction*** (UNDRO, 1991).

Disaster management is represented here as a cycle, since the occurrence of a disaster event will eventually influence the way society is preparing for the next one.

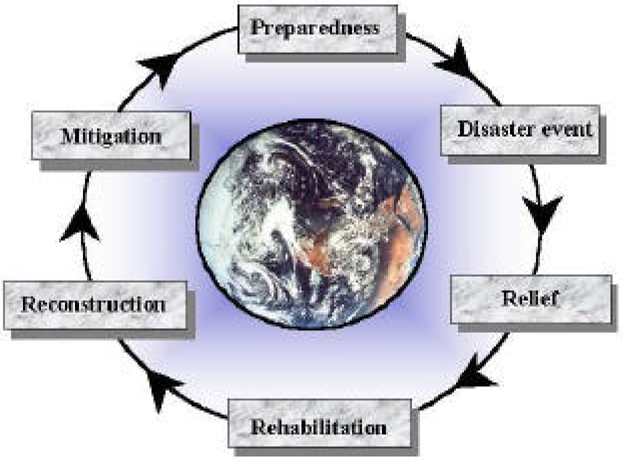

Figure 2: The Disaster Management cycle

3. REMOTE SENSING AND GIS TOOLS

Mitigation of natural disasters can be successful only when detailed knowledge is obtained about the expected frequency, character, and magnitude of hazardous events in an area. Many types of information that are needed in natural disaster management have an important spatial component. Spatial data are data with a geographic component, such as maps, aerial photography, satellite imagery, GPS data, rainfall data, borehole data etc. Many of these data will have a different projection and co-ordinate system, and need to be brought to a common map-basis, in order to superimpose them.

We now have access to information gathering and organising technologies like remote sensing and geographic information systems (GIS), which have proven their usefulness in disaster management.

- First of all, remote sensing and GIS provides a data base from which the evidence left behind by disasters that have occurred before can be interpreted, and combined with other information to arrive at hazard maps, indicating which areas are potentially dangerous. The zonation of hazard must be the basis for any disaster management project and should supply planners and decision-makers with adequate and understandable information. Remote sensing data, such as satellite images and aerial photos allow us to map the variabilities of terrain properties, such as vegetation, water, and geology, both in space and time. Satellite images give a synoptic overview and provide very useful environmental information, for a wide range of scales, from entire continents to details of a few metres. Secondly, many types of disasters, such as floods, drought, cyclones, volcanic eruptions, etc. will have certain precursors. The satellites can detect the early stages of these events as anomalies in a time series. Images are available at regular short time intervals, and can be used for the prediction of both rapid and slow disasters.
- Then, when a disaster occurs, the speed of information collection from air and space borne platforms and the possibility of information dissemination with a matching swiftness make it possible to monitor the occurrence of the disaster. Many disasters may affect large areas and no other tool than remote sensing would provide a matching spatial coverage. Remote sensing also allows monitoring the event during the time of occurrence while the forces are in full swing. The vantage position of satellites makes it ideal for us to think of, plan for and operationally monitor the event. GIS is used as a tool for the planning of evacuation routes, for the design of centres for emergency operations, and for integration of satellite data with other relevant data in the design of disaster warning systems
- In the disaster relief phase, GIS is extremely useful in combination with Global Positioning Systems (GPS) in search and rescue operations in areas that have been devastated and where it is difficult to orientate. The impact and departure of the disaster event leaves behind an area of immense devastation. Remote sensing can assist in damage assessment and aftermath monitoring, providing a quantitative base for relief operations.
- In the disaster rehabilitation phase GIS is used to organise the damage information and the post-disaster census information, and in the evaluation of sites for reconstruction. Remote sensing is used to map the new situation and update the databases used for the reconstruction of an area, and can help to prevent that such a disaster occurs again.

The volume of data needed for disaster management, particularly in the context of integrated development planning, clearly is too much to be handled by manual methods in a timely and effective way. For example, the post disaster damage reports on buildings in an earthquake stricken city, may be thousands. Each one will need to be evaluated separately in order to decide if the building has suffered irreparable damage or not. After that all reports should be combined to derive at a reconstruction zoning within a relatively small period of time.

One of the main advantages of the use of the powerful combination techniques of a GIS, is the evaluation of several hazard and risk scenarios that can be used in the decision-making about the future development of an area, and the optimum way to protect it from natural disasters.
Remote sensing data derived from satellites are excellent tools in the mapping of the spatial distribution of disaster related data within a relatively short period of time. Many different satellite based systems exist nowadays, with different characteristics related to their s*patial-, temporal- and spectral resolution.*
Remote sensing data should generally be linked or calibrated with other types of data, derived from mapping, measurement networks or sampling points, to derive at parameters, which are useful in the study of disasters. The linkage is done in two ways, either via visual interpretation of the image or via classification.

The data required for disaster management is coming from different scientific disciplines, and should be integrated. Data integration is one of the strongest points of GIS. In general the following types of data are required:

- Data on the disastrous phenomena (e.g. landslides, floods, earthquakes), their location, frequency, magnitude etc.
- Data on the environment in which the disastrous events might take place: topography, geology, geomorphology, soils, hydrology, land use, vegetation etc.
- Data on the elements that might be destroyed if the event takes place: infrastructure, settlements, population, socio-economic data etc.
- Data on the emergency relief resources, such as hospitals, fire brigades, police stations, warehouses etc.

The amount and type of data that has to be stored in a GIS for disaster management depends very much on the level of application or the scale of the management project. Natural hazards information should be included routinely in development planning and investment project preparation. Development and investment projects should include a cost/benefit analysis of investing in hazard mitigation measures, and weigh them against the losses that are likely to occur if these measures are not taken (OAS/DRDE, 1990).
Although the selection of the scale of analysis is usually determined by the intended application of the mapping results, the choice of a analysis technique remains open. This choice depends on the type of problem, the availability of data, the availability of financial resources, the time available for the investigation, as well as the professional experience of the experts involved in the survey. See also Cova (1999) for an overview of the use of GIS in emergency management.
In the following sections the use of remote sensing for 4 types of natural disaster is discussed.

4. EXAMPLE 1: FLOODING

Different types of flooding (e.g. river floods, flash floods, dam-break floods or coastal floods) have different characteristics with respect to the time of occurrence, the magnitude, frequency, duration, flow velocity and the areal extension. Many factors play a role in the occurrence of flooding, such as the intensity and duration of rainfall, snowmelt, deforestation, land use practices, sedimentation in riverbeds, and natural or man made obstructions. In the evaluation of flood hazard, the following parameters should be taken into account: depth of water during flood, the duration of flood, the flow velocity, the rate of rise and decline, and the frequency of occurrence.
Satellite data has been succesfully and operationally used in most phases of flood disaster management (CEOS, 1999). Multi channel and multi sensor data sources from GOES and POES satellites are used for meteorological evaluation, interpretation, validation, and assimilation into numerical weather prediction models to assess hydrological and hydro geological risks (Barrett, 1996). Quantitative precipitation estimates (QPE) and forecasts (QPF) use satellite data as one source of information to facilitate flood forecasts in order to provide early warnings of flood hazard to communities.
Earth observation satellites can be used in the phase of disaster prevention, by mapping geomorphologic elements, historical events and sequential inundation phases, including duration, depth of inundation, and direction of current.
Earth observation satellites are also used extensively in the phases of preparedness/warning and response/monitoring. The use of optical sensors for flood mapping is seriously limited by the extensive cloud cover that is mostly present during a flood event. Synthetic Aperture Radar (SAR) from ERS and RADARSAT have been proven very useful for mapping flood inundation areas, due to their bad weather capability. In India, ERS-SAR has been used successfully in flood monitoring since 1993, and Radarsat since 1998 (Chakraborti, 1999). A standard procedure is used in which speckle is removed with medium filtering techniques, and a piece-wise linear stretching. Colour composites are generated using SAR data during floods and pre-flood SAR images.
For the disaster relief operations, the application of current satellite systems is still limited, due to their poor spatial resolution and the problems with cloud covers. Hopefully, the series of high resolution satellites will improve this. Remote sensing data for flood management should always be integrated with other data in a GIS. Especially on the local scale a large number of hydrological and hydraulic factors need to be integrated. One of the most important aspects in which GIS can contribute is the generation of detailed topographic information using high precision Digital Elevation Models, derived from geodetic surveys, aerial photography, SPOT, LiDAR (Light detection And Ranging) or SAR (Corr, 1983). These data are used in two and three dimensional finite element models for the prediction of floods in river channels and floodplains (Gee et al., 1990).

5. EXAMPLE 2: EARTHQUAKES

The areas affected by earthquakes are generally large, but they are restricted to well known regions (plate contacts). Typical recurrence periods vary from decades to centuries. Observable associated features include fault rupture, damage due to ground shaking, liquefaction, landslides, fires and floods. The following aspects play an important role: distance from active faults, geological structure, soiltypes, depth of the watertable, topography, and construction types of buildings.

In earthquake hazard mapping two different approaches are to be distinguished, each with a characteristic order of magnitude of map scale (Hays, 1980): small scale (regional) *seismic macro zonation* at scales 1:5,000,000 to 1:50,000, and large scale (local) *seismic micro zonation* at scales of 1:50-25,000 to 1:10,000.

The most important data for seismic hazard zonation is derived from seismic networks. In seismic microzonation, the data is derived from accelerometers, geotechnical mapping, groundwater modelling, and topographic modelling, at large scales.

Satellite remote sensing does not play a major operational role in earthquake disaster management. In the phase of disaster prevention satellite remote sensing can play a role in the mapping of lineaments and faults, the study of the tectonic setting of an area, and neotectonic studies (Drury, 1987). Visible and infra-red imagery with spatial resolutions of 5-20 meters is generally used.

Satellite Laser Ranging (SLR) and Very Long Base Baseline Interferometry (VLBI) have been used for the monitoring of crustal movement near active faults. In the measurement of fault displacements Global Positioning System (GPS) have become very important. An increasingly popular remote sensing application is the mapping of earthquake deformation fields using SAR interferometry (InSAR) (Massonet et al., 1994, 1996). It allows for a better understanding of fault mechanisms and strain. However, although some spectacular results have been reported, the technique still has a number of problems which does not make it possible to apply it on a routine basis.

There are no generally accepted operational methods for predicting earthquakes. Although there is some mentioning of observable precursors for earthquakes in literature, such as variations in the electric field or thermal anomalies, they are heavily disputed.

In the phase of disaster relief, satellite remote sensing can at the moment only play a role in the identification of large associated features (such as landslides), which can be mapped by medium detailed imagery (SPOT, IRS etc.). Structural damage to buildings cannot be observed with the poor resolution of the current systems. The Near Real Time capability for the assessment of damage and the location of possible victims has now become more possible with the availability of the first civilian optical Very High Resolution (VHR) mission, IKONOS-2, though this will only make a difference if adequate temporal resolution, swath-coverage and ready access to the data can be achieved (CEOS, 1999).

6. EXAMPLE 3: VOLCANIC ERUPTIONS

The areas affected by volcanic eruptions are generally small, and restricted to well known regions. The distribution of volcanoes is well known, however, due to missing or very limited historical records, the distribution of active volcanoes is not (especially in developing countries). Many volcanic areas are densely populated. Volcanic eruptions can lead to a large diversity of processes, such as explosion (Krakatau, Mount St. Helens), pyroclastic flow (Mt. Pelee, Pinatubo), lahars (Nevado del Ruiz, Pinatubo), lava flows (Hawaï, Etna), and ashfall (Pinatubo, El Chincon). Volcanic ash clouds can be distributed over large areas, and may have considerable implications for air-traffic and weather conditions.

Satellite remote sensing has become operational in some of the phases of volcanic disaster management, specifically in the monitoring of ash clouds. The major applications of remote sensing in volcanic hazard assessment are: 1) monitoring volcanic activity & detecting volcanic eruptions , 2) identification of potentially dangerous volcanoes, especially in remote areas and 3) mapping volcanic landforms and deposits (Mouginis-Mark and Francis, 1992).

Earth observation satellites can be used in the phase of disaster prevention in the mapping of the distribution and type of volcanic deposits. For the determination of the eruptive history other types of data are required, such as morphological analysis, tephra chronology, and lithological composition. Volcanic eruptions occur within minutes to hours, but are mostly preceded by clear precursors, such as fumarolic activity, seismic tremors, and surface deformation (bulging).

For the (detailed to semi-detailed) mapping of volcanic landforms and deposits, the conventional interpretation of stereo aerial photographs is still the most used technique. The stereo image does not only give a good view of the different lithologies and the geomorphological characteristics of the volcanic terrain, but it can also be used for delineating possible paths of different kinds of flows.

One of the most useful aspects of remote sensing is the ability of the visible and infrared radiation to discriminate between fresh rock and vegetated surfaces. This is useful because vegetation quickly develops on all areas except those disturbed by the volcano or other causes (urban development, etc).

Topographic measurements, and especially the change in topography are very important for the prediction of volcanic eruptions. Synthetic Aperture Radar (SAR) sensors can provide valuable data which describes the topography. Measurement of ground deformation may eventually be achieved using SAR inteferometry.

For the monitoring of volcanic activity a high temporal resolution is an advantage. For the identification of different volcanic deposits a high spatial resolution and, to a lesser extent, also a high spectral resolution are more important.

Hot areas, e.g., lavas, fumaroles and hot pyroclastic flows can be mapped and enhanced using Thematic Mapper data. Landsat Band 6 can be used to demonstrate differences in activity which affect larger anomalies such as active block lava flows. For smaller and hotter (>100 C) anomalies the thermal infrared band can be saturated but other infrared bands can be used (Rothery et al., 1988; Frances and Rothery, 1987; Oppenheimer, 1991). Uehara et al. (1992), used airborne MSS (1.5m resolution) to study the thermal distribution of Unzendake volcano in Japan to monitor the lava domes causing pyroclastic flows when collapsed.

Volcanic clouds may be detected by sensors that measure absorption by gases in the cloud such as TOMS (Krueger et al, 1994), by infrared sensors such as AVHRR (Wen and Rose, 1994), by comprehensive sensors on meteorological satellites, and by microwave or radar sensors. Remote sensing has become an indispensable part of the global system of detection and tracking of the airborne products of explosive volcanic eruptions via a network of Volcanic Ash Advisory Centers (VAACs) and Meteorological Watch Offices (MWOs). Satellite data provide critical information on current ash cloud coverage, height, movement, and mass as input to aviation SIGnificant METerological (SIGMET) advisories and forecast trajectory dispersion models (CEOS, 1999).

7. EXAMPLE 4: LANDSLIDES

Individual landslides are generally small but they are very frequent in certain mountain regions. Landslides occur in a large variety, depending on the type of movement (slide, topple, flow, fall, spread), the speed of movement (mm/year - m/sec), the material involved (rock, debris, soil), and the triggering mechanism (earthquake, rainfall, human interaction).

In the phase of disaster prevention satellite imagery can be used for two purposes: landslide inventory and the mapping of factors related to the occurrence of landslides, such as lithology, geomorphological setting, faults, land use, vegetation and slope.

For landslide inventory mapping the size of the landslide features in relation to the ground resolution of the remote sensing data is very important. A typical landslide of 40000 m^2 , for example, corresponds with 20 x 20 pixels on a SPOT Pan image and 10 x 10 pixels on SPOT multispectral images. This would be sufficient to identify a landslide that has a high contrast, with respect to its surroundings (e.g. bare scaps within vegetated terrain), but it is insufficient for a proper analysis of the elements pertaining to the failure to establish characteristics and type of landslide. Imagery with sufficient spatial resolution and stereo capability (SPOT, IRS) can be used to make a general inventory of the past landslides. However, they are mostly not sufficiently detailed to map out all landslides. Aerial photo-interpretation still remains essential.

It is believed that the best airphoto-scale for the interpretation of landslides is between 1:15.000 and 1:25.000 (Rengers et al., 1992). If smaller scales are used, a landslide may only be recognized, if size and contrast are sufficiently large. It is expected that in future the Very High Resolution (VHR) imagery, such as from IKONOS-2, might be used successfully for landslide inventory.

Satellite imagery can also be used to collect data on the relevant parameters involved (soils, geology, slope, geomorphology, landuse, hydrology, rainfall, faults etc.). Multispectral images are used for the classification of lithology, vegetation, and land use. Stereo SPOT imagery is used in geomorphological mapping, or terrain classification (Soeters et al. 1991). Digital elevation models can be derived from SPOT or IRS images, or using airborne or spaceborne inSAR techniques.

In the phase of disaster preparedness use could be made of the following techniques for the monitoring of landslide movements: ground measurements, photogrammetry, GPS, Radar interferometry. Warning systems for landslides are only operational in a few places in the world, with a very high density of information (landslide dates as well as daily rainfall should be known in order to establish rainfall thresholds) (Keefer et al, 1987). The use of Meteosat & NOAA, combined with raingauge data for predicting these threshold is being investigated.

8. CONCLUSIONS

The decade of the 1990's, designated as the International Decade for Disaster Reduction, has not resulted in a reduction of the losses due to natural disasters. On the contrary, the statistics show a rapid increase, both related to an increasing vulnerability of large part of the earth's population, as well as to an increase in the number of weather related events.

The decade of the 1990's also showed a rapid increase in the technological capabilities and tools that can be used in disaster management. Some of these tools deal with the collection and management of spatial data, such as remote sensing and Geographic Information Systems. Although none of the new satellites was specifically designed to be used in disaster mitigation, most of them also have demonstrated their usefullness in disaster prevention, preparedness and relief.

For several types of disasters the use of earth observation techniques has become operational in the warning and monitoring phases, within a relatively short period of time. Remote sensing is used operationally in the warning and monitoring of cyclones, drought, and to a lesser extend floods.

The operational applications mainly use imagery with low spatial resolution, coming from meteorological satellites or NOAA-type satellite.

The Turn-Around-Time (TAT) is the time required between the image is obtained untill the answer should be given for the warning or monitoring of a specific hazard. This differs strongly one type of disaster to another. For example for wildfire the TAT is very short (0.5 hour), for cyclone's and floods it is 24 hours, and for drought it is weeks. The TAT depends on many factors, such as the location of the event, the satellite constellation, the weather conditions (cloud free images or radar), the data receiving aspects, data analysis aspects (e.g. visual interpretation or automated analysis) and commercial and legal aspects.

In many of the weather related disasters, obtaining cloudfree images for damage assessment is often a severe problem. For some types of disasters, such as floods, debris flows or oil spills, SAR is the solution in that case. For other types of disasters (e.g. landslides, earthquakes, wildfires) detailed optical images should be used.

In the phase of disaster relief, satellite remote sensing can only play a role in the identification of the affected areas, if sufficiently large. Structural damage to buildings cannot be observed with the poor resolution of the current systems. Near Real Time damage and the location of possible victims has now become possible with the availibility of the first civilian optical Very High Resolution (VHR) mission, IKONOS-2, though this will only make a difference if adequate temporal resolution, swath-coverage and ready access to the data can be achieved. The temporal resolution provided by individual satellites, especially considering cloud cover, will not be sufficient, and VHR will not become operational in damage mapping unless multiple satellites are used. This capability is of prime concern to relief agencies who require NRT imagery to locate possible victims and structures at risk, and also to map any changes to access that may have occurred. With the anticipated availability of VHR data, co-ordination of effort and motivation to acquire imagery will become paramount. Ideally, there needs to be a single co-ordinating body for the ordering, receiving, preparation and dissemination of data.

In most cases, the availibility of GIS databases, containing information about elements at risk, if combined with less detailed images containing the extend of the area affected, will allow for a rapid assessment of the number of persons and buildings affected.

In view of the limitations inherent to the data collection and analysis techniques and the restrictions imposed by the scale of mapping, a hazard survey will always retain a certain degree of subjectivity. This does not necessarily imply an inaccuracy. The objectivity and certainly the reproducibility of the assessment can considerably be improved by the interpretation of sequential imagery, the use of clear, if possible, quantitative description of the factors considered, as well as well defined analytical procedures and decision rules, which are applied to come to the hazard assessment. The most important aspect however remains the experience of the analyst, both with regard to various factors involved in hazard surveys, as well as in the specific conditions of the study area. Due to the difficulty of formalizing expert rules, the use of expert systems in hazard assessment is still not very advanced (Pierson et al., 1991)

REFERENCES

Alexander, D. (1993).
Natural disasters. UCL Press Ltd., University College London. 632 pp.

Barrett, E.C., (1996)
The storm project: using remote sensing for improved monitoring and prediction of heavy rainfall and related events. Remote Sensing Reviews, vol 14, 282 pp.

CEOS/IGOS (1999)
CEOS/IGOS disaster management support project. http://www.ceos.noaa.org/

Chakraborti, A.K. (1999)
Satellite remote sensing for near-real-time flood and drought impact assessment- Indian experience. Workshop on Natural Disasters and their Mitigation - A Remote Sensing & GIS perspective, 11-15 October 1999, Dehradun, India.

Corr, D. (1983)
Production of DEM’s from ERS-1 SAR data. Mapping awareness, 7, pp. 18-22.

Cova, T.J. (1999)
GIS in Emergency management. In: Geographical Information Systems, management and Applications. Longley, P.A., Goodchild, M.F. Maguire, D.J., and Rhind, D.V.

Daag, A. and Van Westen, C.J. (1996).
Cartographic modelling of erosion in pyroclastic flow deposits of Mount Pinatubo, Philippines. *ITC Journal* 1996-2: 110-124

Drury, S.A (1987)
Image interpretation in geology. Allen and Unwin, London, 243 pp.

Francis, P. and Rothery, D. (1987). Using the Landsat Thematic Mapper to detect and monitor volcanic activity. Geology 15, pp. 614-617.

Hays, W.N. (1980)
Procedures for estimating earthquake ground motions. U.S. Geological Survey Professional Paper 1114, 77 pp.

Keefer, K. et al. (1987)
Real-Time Landslide Warning During Heavy Rainfall.
Science 238, pp. 921-925.

Kesseler, M. (1995).
` Modelisation et cartographie de l'area volcanique de Vulcano (Iles Eoliennes, Italie) par un Systeme d'Information Georeferee. Publications du Departement de Geologie et Paleontologie. Universite de Geneve. pp. 1-72.

Krueger, A. et al. (1994). Volcanic hazard detection with the Total Ozone Mapping Spectrometer (TOMS), U.S. Geol. Surv. Bulletin, 2047, pp. 367-372.

Massonnet, D., K. L. Feigl, M. Rossi, and F. Adragna, Radar interferometric mapping of deformation in the year after the Landers earthquake, Nature, 369, 227-230, 1994.

Massonet, D., Feigl, K.L.and Rossi, M. (1996)
Co-seismic deformation field in the M=6.7 Northridge, California earthquake of January 17, 1994 recorded by two radar satellites using interferometry. Geophysical Research Letters, Vol. 22, pp 1541-1544.

Mouginis-Mark, P.J. and Francis, P.W. (1992). Satellite observations of active volcanoes: prospects for the 1990s. Episodes, Vol. 15, No 1. pp 46-55.

Munich Reinsurence Company (1998)
Wolrd Map of Natural Hazards. Munich Reinsurance Company,Munich,Germany , 55 pp.

Munich Reinsurence Company (1998)
Annual Review of natural catastrophes 1997. Munich Reinsurance Company,Munich,Germany , 19 pp.

Munich Reinsurence Company (1999)
A year, a century, and a millennium of natural catastrophes are all nearing their end - 1999 is completely in line with the catastrophe trend - Munich Re review. http://www.munichre.com/

OAS/DRDE (1990). Disaster , Planning and Development: Managing Natural hazards to reduce Loss. Department of Regional Development and Environment. Organization of American States. Washington, USA. 80 pp

Oppenheimer, C. (1991), Lava flow cooling estimated from Landsat Thematic Mapper infrared data; The Lonquimay eruption (Chile, 1989), J. Geophys.res., 96, pp. 21865-21878.

Rengers, N., Soeters, R. and Westen, C.J. Van (1992)
Remote sensing and GIS applied to mountain hazard mapping.
Episodes, Vol.15, No.1, March 1992, pp.36-45.

Rothery , D. et al., (1988), Volcano monitoring using short wavelength infrared data from satellites, J.Geophys.Res. 93:, pp. 7993-8008

Scofield, R.A. and Achutuni, R. (1996)
The satellite forecasting funnel approach for predicting flash floods. Remote Sensing Reviews, vol. 14, pp. 251-282.

Soeters, R., Rengers, N. and Van Westen, C.J. (1991)
Remote sensing and geographical information systems as applied to mountain hazard analysis and environmental monitoring.
Proceedings 8th Thematic Conference on Geologic Remote Sensing (ERIM), April 29-May 2, 1991, Denver, USA, Vol. 2, pp. 1389-1402.

Uehara, S., Kumagai, T. and Yazaki, S. (1992). Thermal Observations of Unzendake Volcanic Activities Using Airborne MSS. Proceedings: Workshop on Predicting Volcanic Eruptions and Hazard Mitigation Technology. March 3-6, 1992. Science and Technology Agency, Japan.

UNDRO (1991)
Mitigating Natural Disasters. Phenomena, Effects and Options. United Nations Disaster Relief Co-ordinator, United Nations, New York. 164 pp.

UNPD (1999)
United Nations Population Division, World Population Prospects.
http://www.undp.org/popin/wdtrends/wdtrends.htm

Van Westen, C.J. (1993)
Application of Geographic Information Systems to Landslide Hazard Zonation.
ITC-Publication Number 15, ITC, Enschede, The Netherlands, 245 pp.

Wen, S. and Rose, W. (1994). Retrieval of particle sizes and masses in volcanic clouds using AVHRR bands 4 and 5, J. Geophys.Res. 99, pp. 5421-5431.