Remote sensing and the disaster management cycle

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1. Introduction

Disaster management planning is structured around the disaster management cycle model. The cycle consists of four stages – reduction, readiness, response and recovery. Remotely sensed data can provide a valuable source of information at each of these stages, helping to understand spatial phenomena, and providing scientists and authorities with objective data sources for decision making. The challenge with disaster management is that the inherent unpredictability and range of hazards does not allow for a single all-encompassing solution to be developed and explored. Instead, there are a multitude of different remote sensing platforms and sensors that can and should be employed for image acquisition. An extensive coverage of each, including optimal processing regimes for their data would be prohibitively long; instead this chapter aims to give some general examples of the use of remote sensing in disaster management, while directing the reader to more specific studies in the literature. The types of data required and information provision needs for each stage will be discussed including optical, thermal, and synthetic aperture radar as data sources over a variety of spatial and temporal scales.

Remote sensing can be used to assist risk reduction initiatives through identification of hazard zones associated with flood plains, coastal inundation and erosion, and active faults. It can also be used to verify hazard models by measuring the location and magnitude of actual events. Imagery is widely used by meteorologists for providing weather forecasting and warnings of potentially severe weather events, providing the public and emergency responders with information that can assist decision making around short term readiness. These images are commonly presented in print, television and on the internet, and they are well accepted by viewers around the world. Imagery of fires, volcanic eruptions and flooding are often used during the response phase for the visual impact that they provide. If people in potentially at-risk locations personalise the risk, they are more likely to take readiness actions such as making emergency plans for contact and evacuation or assembling emergency kits. Remote sensing images of similar communities experiencing hazards, or the progress of a hazard such as a fire front, can

assist with this personalisation process. For agencies that respond to emergencies, remote sensing imagery provides a rapid method of assessing the magnitude of hazard impacts, areas most affected, and where key transport and other infrastructure links have been disrupted or destroyed. Remote sensing can also be used to provide an indication of the rate of recovery in an area post disaster based on indicators such as vegetation regrowth, debris removal, and reconstruction.

There are few examples where remote sensing is incorporated seamlessly into all stages of the disaster management cycle for planning purposes. This requires a collaborative effort from emergency managers, policy planners and remote sensing technical staff that may not always be co-located, or even working for the same organisation. However, data is becoming more readily available, and some satellites and constellations are even targeting at least partially the disaster management / emergency response community in recognition of the value remotely sensed imagery can provide. If this current trend continues, integrating remote sensing and emergency management will become increasingly more commonplace.

2. The disaster management cycle

The traditional approach to hazard risk and disaster management has been one primarily focussed on response to events as they occur (Gregg & Houghton 2006), managing residual risk through warning systems and emergency management plans, and more recently attempting to reduce risk through changing the hazard process or impacts (Board on Natural Disasters 1999). Examples of attempts at hazard modification include: the use of stopbanks and levees to provide opportunities to build in areas vulnerable to flood hazard; building codes for strengthened buildings to allow development in earthquake prone locations; and building seawalls along coasts to reduce susceptibility to erosion and coastal inundation. These measures have allowed greater development in hazardous areas, and are typically designed for protection up to a certain magnitude of event, but there always exists the potential for design limits to be exceeded (Burby 1998). Because of reliance on technological solutions, risk is increasing in the developed world as infill and migration increases in "protected" areas (Mileti 1999). In less-developed nations, risk is also increasing, although the drivers differ. Reliance on decreasing natural resources, population increase, poverty, and political drivers push communities into hazardous areas traditionally left un-settled (Donner & Rodriguez 2008). The body of research into the evolution of hazards and disaster management now recognises that it is primarily social drivers that create vulnerability to hazards, and consequently increase the potential for disasters (Board on Natural Disasters 1999, Cutter & Finch 2008, Donner & Rodriguez 2008, Pertrow et al. 2006, Wisner et al. 2004). The overall focus of emergency management has shifted to consider disaster management planning as part of a broader system of planning for sustainable, resilient communities. Whether a hazardous event will become a disaster - an event that is beyond the capacity of responding agencies, resources, and community coping capacity (Quarantelli 1985), can be influenced by effective disaster management planning.

This recognition of the importance of social drivers has brought about a change in how disaster planning is considered and undertaken. Many nations now plan using a variation of the Disaster Management Cycle, an integrated, four–phase planning system. Although

the cycle can be considered as a continuum, traditionally the first phase of the cycle is considered to be reduction, followed by readiness, response, and recovery (Figure 1).
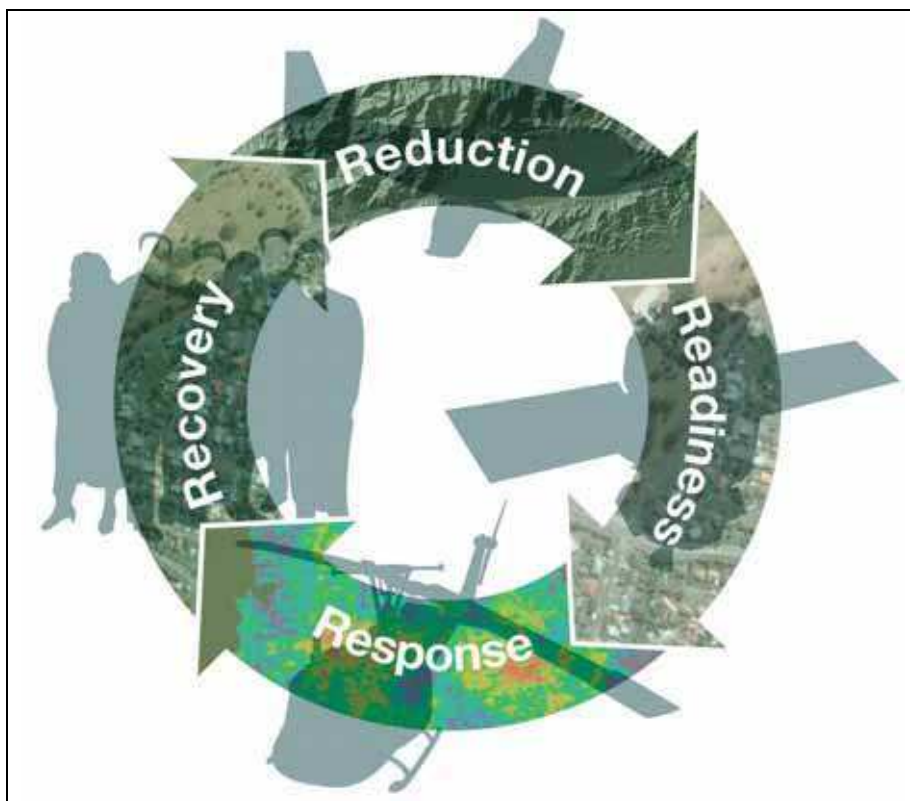

Fig. 1. The disaster management cycle

Reduction incorporates all measures and planning that reduce the likelihood of a disaster occurring. This is done through the process of risk identification and reduction; either by modifying the hazard process using traditional structural methods such as stopbanks or seawalls, or by modifying behaviours and the assets at risk (Gregg & Houghton 2006). Behaviour modification includes land use planning to: prevent development in hazardous areas; incorporate good access for response and evacuation; and foster interconnected and resilient communities (Burby 1998). In theory, land use planning can reduce all risk from disasters, but centuries of settlement in hazardous locations make this option unrealistic and impractical. Modifying assets at risk includes such methods as strengthening buildings and infrastructure and raising floor heights to reduce hazard impacts.

Readiness planning accepts that some residual risk is present for communities and that measures must be in place to ensure any response to hazards is efficient and reduces hazard impacts. Readiness planning includes: public education on hazards and their consequences, and how these consequences can be reduced; training of emergency planners and responders; installing monitoring and warning systems for hazards;

exercising response plans; and fostering community resilience through increased uptake in home preparedness such as learning first aid, having an emergency kit and an evacuation plan (Ronan & Johnston 2005).

The phase of disaster management that has traditionally received the most recognition, funding and planning effort is Response (Gregg & Houghton 2006). This fact is also reflected in the remote sensing community, with an overwhelming number of research papers dedicated to the use of imagery for disaster response, despite the fact that data often cannot be provided in the timeframe required to be of use for decision makers. The reality is that most nations do not have the capability to prevent disasters occurring; the best option for reducing the chance of a disaster is through reducing risk. However, response capability is important in any disaster as it involves the processes of coordinated effort to manage resources, including life essentials and personnel, for activities such as evacuation, relief, search and rescue and needs assessment (Quarantelli 1997).

Recovery, the fourth phase of the cycle has traditionally been focussed on restoration of lifeline utilities, and building reconstruction. There is now considerable research into holistic recovery processes, which recognise that for community recovery to be sustainable, the social, economic, built and natural environments must be considered (Norman 2004). The four environments are interlinked as communities rely on:

- Natural environment for amenity (recreation, psychological wellbeing), and resources (to provide opportunities for construction and employment);
- Built environment for lifeline utilities and structures to enable people to live, work and recreate;
- Economic environment to provide goods, services and livelihoods; and
- Social environment, to provide opportunities for political participation, community building, networking and psychological wellbeing.

The recovery phase of a disaster can be considered to have several steps, the initial restoration of lifeline essentials, and the longer term rebuilding of communities. The recovery phase is often considered to be an optimal time to include measures that will reduce the risk of future disasters (Becker et al. 2008).

The four phases of the disaster management cycle are not discreet; they are interrelated and ideally integrated throughout the planning process. Decisions about risk reduction methods will affect the degree of readiness planning and response that will be required. Readiness levels of affected communities and responders can determine whether an event becomes a disaster, as can be seen in the failure to provide evacuation options for the 20% of the New Orleans population with no vehicle or resources to leave the city prior to hurricane Katrina's landfall (Laska & Morrow 2006/7). The effectiveness of the response phase will play a significant role in how affected communities recover, both physically and psychologically. Lessons from the response phase can be incorporated into risk reduction and readiness planning. Finally, the recovery phase can include risk reduction measures to increase resilience and reduce future vulnerability.

3. Remotely sensed data types

In order to successfully use remote sensing for disaster management, physical indicators of features or attributes within the disaster management cycle that are measureable in imagery need to be identified. At that point, selection of the most appropriate remotely

sensed data set is possible by identifying the spatial, spectral, temporal, and radiometric requirements. The use of a framework for selecting appropriate remotely sensed data has been demonstrated for mapping and monitoring coastal and tropical wetlands, tropical rainforests, coastal ecosystems and coral reefs (Phinn 1998, Phinn et al. 2006). This is an approach that can be modified and applied under many different circumstances and for various environments. Here we look to apply aspects of the framework to disaster management. During the reduction, readiness and recovery phases, there may be sufficient time to develop and apply the framework as the cycle is progressing. However, as timeliness is a critical factor in the response phase, it is of most use to already have systems in place to aid with appropriate data selection so that crucial decisions need not be made under the severe time constraints that are necessitated by rapid response. Preparation may therefore involve developing a range of scenarios representing potential situations that require rapid response at a set location, and applying the principles of data selection and processing in advance. In this way, the decisions regarding remote sensing in the response phase can actually be made during the readiness phase instead. This should be done as a collaborative exercise between both remote sensing experts and emergency management agencies.

The types of satellite and airborne sensors that can be used to support phases of the disaster management cycle are many and varied. It is most important to consider the spatial scale of the hazard, in addition to determining the most appropriate data type to address the problem. For example, geostationary satellites provide data over a large area, but with minimal spatial detail, and are appropriate for monitoring weather patterns (readiness) and volcanic ash and gas distribution (response). Conversely, very high spatial resolution data (e.g. aerial photography, Quickbird, Ikonos, Worldview) are appropriate for targeting relatively small areas where they can provide a great deal of detail. Examples of their use include baseline infrastructure mapping for scenario development and model validation (reduction and readiness), building damage (response), and observations of debris removal and reconstruction (recovery).

In the disaster reduction phase, the focus for remote sensing is often on mapping landscape features such as land cover / land use, and the location of potentially hazardous features or processes to avoid when developing infrastructure (e.g. active faults, flood plains). During the readiness phase, the emphasis is on monitoring these features or processes, developing models for forecasting purposes, and using maps and model for training and education. In the response phase, the timely acquisition of data and provision of information to emergency services is critical. Much of the attention will be placed on identifying infrastructure that has been damaged or is likely to be at risk in the near future (e.g. housing in the path of a bush fire). Finally during the recovery phase, the focus will shift to long term monitoring of debris removal, vegetation regeneration, and reconstruction.

3.1 Optical

There are a large number of applications for which optical remotely sensed imagery can be used to aid the disaster management cycle. Optical data can be of particular use to the disaster management community as it is generally simple to understand and interpret raw data, particularly when collected using standard true colour spectral bands (blue, green, and red). The characteristics of the sensor are important in selecting the most appropriate

data type for use in individual situations. Consideration should be primarily given to the spatial and temporal resolution of the sensor. These factors will differ depending on the disaster management activity. For example, during the response phase, rapid acquisition of data following the event is crucial. During the recovery phase, the speed of acquisition is less important than repetition on a consistent basis. In the early stages of recovery, imagery may be useful on a monthly basis, though as time passes, an annual acquisition may suffice.

Optical data can be used for activities in all stages of the disaster management cycle, however the greatest potential contributions are for monitoring recovery, and helping to plan for reduction and readiness. The use of satellite optical data for immediate response at a local scale is currently hindered by the speed of data acquisition and delivery with polar orbiting satellites. For large events, a more regional synoptic view is possible using geostationary satellites; however the amount of detail able to be extracted from these images is reduced.

The greatest limitation of optical sensors under many hazard or disaster scenarios is the inability to obtain imagery through clouds, smoke or haze. Events such as wildfires, volcanic eruptions, and tropical cyclones or other severe storms are characterised by cloud and smoke, which can effectively obscure damage on the ground both during and immediately subsequent to an event.

3.2 Thermal

As energy decreases with increasing wavelength, thermal wavelengths have comparatively low energy levels and consequently thermal image data have a lower spatial resolution than that capable of being achieved with optical imagery. As yet there are no very high spatial resolution thermal satellite sensors commercially available. Nonetheless, thermal imagery provides a valuable source of information about volcanic eruptions and the location of wildfires. Robust techniques for automatic extraction of anomalous high temperatures or 'hotspots' have been thoroughly tested and considered operational on a global scale using MODIS, AVHRR or GOES imagery (Wright et al. 2002, Wright et al. 2004). The University of Hawai'i and Geoscience Australia both apply automated hotspot detection algorithms for the detection of volcanic activity and bushfires respectively and serve the information in near real time via the internet. These algorithms have primarily been developed to detect features above the background or average temperature values, and to avoid large numbers of false alarms, they are not sensitive to merely warm features. They are also unable to differentiate between the types of heat source, so addition spatial information or manual interpretation may be required.

Higher spatial resolution thermal imagery for analysis at local scales can be obtained using ASTER or Landsat TM/ETM+, though neither of these sensors have the ability to provide imagery of rapidly changing thermal features, as their orbits only allow them an overpass frequency of approximately 16 days. Nevertheless, both sensors are useful for tracking longer term temperature fluctuations, such as the warming and cooling cycles of volcanic lakes (Joyce et al. 2008b, Oppenheimer 1993, Oppenheimer 1997, Trunk & Bernard 2008). The higher resolution imagery can also be of use in calibrating and validating data obtained from the likes of MODIS.

As the temperature of an object increases, the wavelength of peak radiation decreases. Very hot features can therefore be seen in visible or shortwave infra red (SWIR) imagery

and often become saturated in thermal infra red data if they are sufficiently large with respect to the pixel size. This relationship has been demonstrated using forest fire size and the temperature difference between a smouldering and flaming fire that could be of use in understanding different stages of fire development (Giglio et al. 2008). Unfortunately the SWIR bands on ASTER were declared non-functional in January 2009 after experiencing technical difficulties since May 2007. These five SWIR bands fall within a similar spectral range as Landsat TM/ETM+ band 7 that could be used as an alternative.

3.3 Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) is an active microwave sensor that is capable of acquiring data in harsh weather and lighting conditions not suitable for optical sensors, such as dense cloud or smoke coverage (Elachi 1987, Franceschetti & Lanari 1999, Hanssen 2001). Most modern SAR sensors are designed to acquire data of various ground resolution elements ranging from 100s of metres to 1-3 metres, but higher spatial resolution images usually have significantly smaller spatial coverage and are limited by satellite storage and processing capacities. The incidence angle of SAR sensors can be manipulated in order to image different areas without changing the satellite orbit, thus decreasing necessary revisit time.

Both backscatter intensity and the phase of SAR images can be utilised. In most studies only the relative variability of backscatter intensity within the image is used but absolute values can be required for some multi-temporal studies. The precise interpretation of backscatter intensity can be complicated because of its dependence on the dielectric properties of the reflecting material, surface roughness, and sensor wavelength but at the same time the variety of useful information still can be easily observed (landslides, tsunami, flooding, and damage to infrastructure). Phase information of a single SAR image has no value but comparison of phases from two SAR images acquired at distinct times are utilised in SAR interferometry or InSAR. InSAR is capable of producing high resolution ground deformation maps with sub-centimetre accuracy (Rosen et al. 2000). These maps can then be used for studying the causes of deformation such as earthquakes or volcanic activity (Massonnet & Feigl 1998). Modern satellite SAR systems are capable of acquiring simultaneous data with more than one polarisation (e.g. Radarsat-2, ALOS PALSAR and TerraSAR-X). This information can be used in various studies utilising SAR polarimetry and POLInSAR techniques, such as land classification, detection of areas affected by fire or flooding (Cloude & Papathanassiou 1988, Pottier & Ferro-Famil 2008, van Zyl et al. 1990).

At present, commonly used satellite SAR data is acquired in three wavebands: X (3.1 cm); C (5.6 cm); and L (23.6 cm). Waveband selection depends on the type of application, land-cover, time span, and availability. The analysis of backscatter intensity by determining thresholds associated with certain features can be performed in standard GIS or image processing software, such as ArcGIS or ERDAS Imagine, but InSAR, SAR polarimetry and POLInSAR processing require specialised software (or add-on modules to basic packages) and extensive processing experience. The price of the data greatly varies from a few dollars per image for purely scientific applications to a few thousand of dollars for commercial applications. Several recently launched commercial satellites are available to acquire data of any hazardous event with a very short delay and deliver the data rapidly

to the user, though the cost of priority commissioned data is significantly greater than that of archived imagery (RADARSAT-2, TerraSAR-X and Cosmo-Skymed).

4. Remote sensing applications

4.1 Reduction

Disasters are social constructs in that social drivers such as migration (forced and voluntary), conflict, modification of natural buffer systems, reliance on shrinking resources, private property rights, urban intensification, artificial protection structures, and economic and political vulnerability are all contributors to people living in hazardous locations or at levels of vulnerability that make a disaster more likely. Remote sensing technology can assist with addressing some of these "disaster drivers", through providing the data required to assist land use planners, emergency managers, and others tasked with disaster management. Reduction of risk, and therefore reduction in the probability of a disaster occurring, is an important part of the disaster management cycle. Remote sensing can be applied in disaster reduction initiatives through identification and understanding of hazards (Table 1). This knowledge is then applied to mitigation activities such as land use planning, engineering structures, building codes and hazard consequences modelling to determine methods for reducing vulnerability (Gregg & Houghton 2006). Note that the sensor examples given in Table 1 and subsequent tables are indicative of current or potential instrument use. Many alternative sensors with similar characteristics could also be used.

Understanding of hazards, their magnitude, frequency, duration, location, range and manifestation (e.g. heavy rainfall, tephra, strong winds) has long been accepted as essential to disaster management. Although it is primarily social factors that amplify a hazard event into a disaster (Quarantelli 1985, Wisner 2004), improved knowledge of hazards and their potential consequences is essential for decision making about modifying hazard characteristics, or modifying vulnerability of people and assets. Remote sensing can be used directly for hazard identification (e.g. flood plain modelling, slope stability and landslide susceptibility), but can also be used to derive hazard-independent information that can be used for disaster reduction (e.g. baseline building, infrastructure, and topographic mapping). An excellent example of the use of remote sensing for hazard identification is provided with LiDAR mapping of active fault location (Begg & Mouslpoulou 2009 in press). Traditionally fault location is conducted using stereo aerial photography interpretation followed by intensive field survey. However the horizontal and vertical resolution provided by airborne LiDAR imagery provides the capability for identifying fault traces and extracting elevation offsets with digital data in an objective manner. The identification of many previously unknown faults in northern New Zealand is shown in Figure 2.

Type of information	Data required	Sensor example	Application example
Location of fault traces and rupture zones	High resolution DEM	Airborne LiDAR, SAR	Use for land use planning around active faults to reduce risk from future development in fault hazard locations
Fault displacement	Interferometric SAR	ERS1/2, ENVISAT ASAR, ALOS PALSAR	Knowledge of fault displacement rates are used in numerical models in order to forecast the magnitude of possible earthquakes
Flood plain mapping	DEM	Airborne LiDAR, ERS1/2, ENVISAT ASAR, ALOS PALSAR	Identification of flood plains can help inform changes in land use, and identify areas developing protective measures (e.g. stopbanks)
Land cover / land use	Optical and polarimetric SAR	SPOT, ASTER RADARSAT-2	Used for catchment management planning to reduce flood and landslide risk
Vegetation change	Consistent time series of data	SPOT, ASTER RADARSAT-2	Determine drought zones, inform fire hazard mapping
Determining lahar and lava flow paths	DEM, high resolution optical imagery	SAR, Airborne LiDAR, SPOT, AVNIR-2, ASTER	Hazard zonation, public awareness, determining location of safety shelters
Locating potential and actual unstable slopes	DEM, Interferometric SAR, high resolution stereo optical imagery	Airborne LiDAR, ERS1/2, ENVISAT ASAR, ALOS PALSAR, aerial photography	Hazard mapping for infrastructure planning
Baseline infrastructure maps	Very high resolution optical imagery	Aerial photography, Quickbird, Ikonos, Worldview	Assist with hazard mapping to identify key infrastructure at risk – the risk can then be addressed through mitigation or built in redundancy. Can also be used for later damage assessment post-disaster
Baseline topographic data	Moderate to high resolution optical imagery	SPOT, AVNIR-2, Aerial photography, Quickbird, Ikonos, Worldview	Hazard modelling

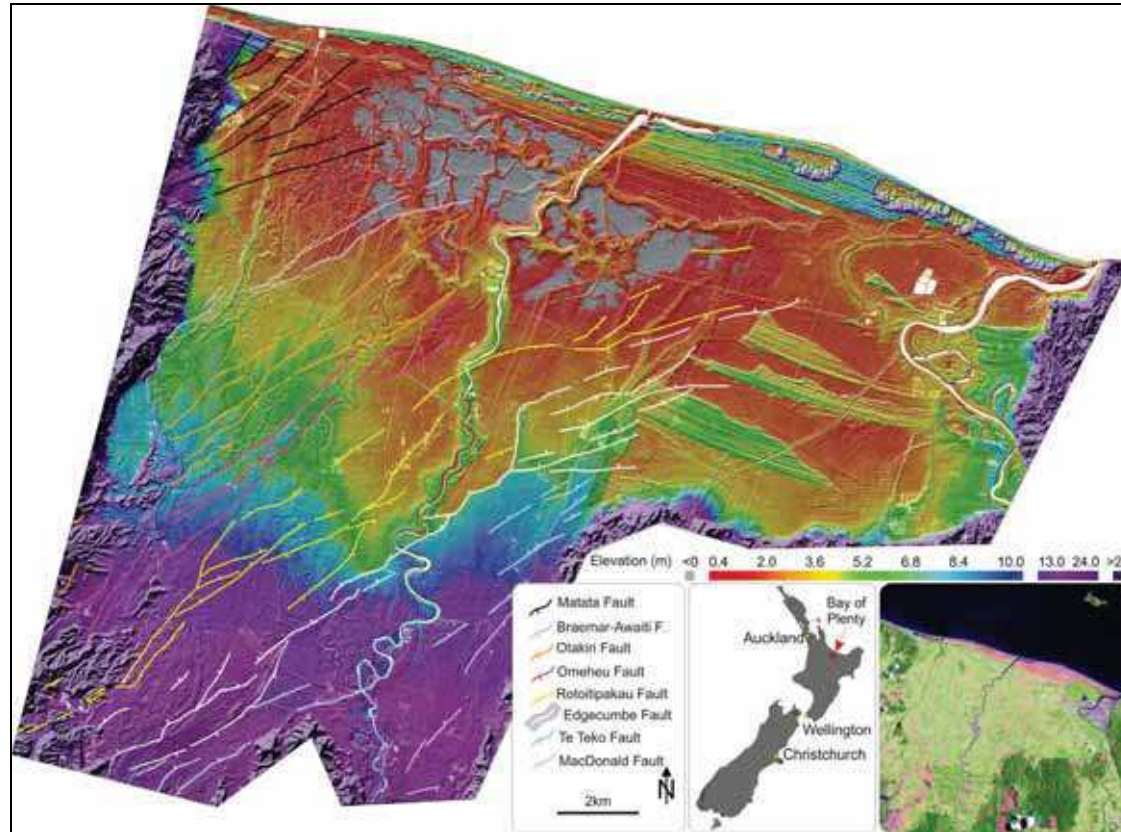Table 1. Examples of information and data requirements during the reduction phase

Fig. 2. Identification of known and new active faults using high resolution airborne LiDAR data acquired in late 2006 (Begg & Mouslpoulou 2009 in press). Landsat ETM+ false colour composite (5,4,2) acquired in 2001 is inset for a contextual overview of the site. Of the active fault traces shown here, approximately 85% were unknown before undertaking this study. Also of note also is the discovery of a large inland area that is below sea level (elevation <0m) and is a potentially hazardous region for tsunami related inundation

Remotely sensed data acquisitions can be used to inform land use planning, a key tool that authorities and communities employ to avoid or mitigate hazard risk (Burby 1998). By identifying the location and characteristics of hazards, land use planning methods can be applied to address the risk these hazards pose. Planning methods include mapping hazard zones (location and range of hazard impact) and identifying the probability of occurrence. Hazard maps are applied to developed and green field (undeveloped) land and options for risk treatment determined. Treatment options can include measures such as setback zones (no development within the hazard zone, e.g. proximal to active faults or within coastal erosion or inundation zones), or special building codes (e.g. minimum floor heights above base flood level) can be introduced to reduce the risk to assets and people (Godschalk et al. 1998). Understanding of hazard information is one of a number of critical factors influencing individual and group decision making for risk management (Paton & Johnston 2001). Where hazard information is readily available to the public in a variety of forms, including maps, there is a greater likelihood of public support for risk reduction initiatives introduced through land use planning (Burby 2001).

Other methods for land use planning based on remote sensing data include identifying changes in land use on flood plains to assist with flood hazard modelling. In the city of London, Canada, Landsat images taken over a 25 year period have been used to determine the spread of urban development (Nirupama & Simonovic 2007). The consequent increase in impermeable surface cover facilitated more rapid runoff and less natural absorption of rainfall. When compared with flood hydrographs, the rate of land use change correlates with smaller rainfall events producing flooding. The benefits to future land use planning are that it can be determined how land use changes affect the flood hazard risk, and this will guide future development in a way that mitigates the effects of continued urban sprawl.

Collecting asset data via high resolution remote sensing allows for identification of infrastructure and buildings in hazardous locations, which can then be targeted for strengthening or re-location. Asset data is also essential for hazard consequence modelling, whereby hazard data is combined with asset data and fragility (vulnerability) information to determine potential losses. Building fragility to hazards is based on such factors as construction materials (earthquake, volcanic ash fall, tsunami), engineering design (tsunami, landslide, earthquake), building height (wind), floor areas (earthquake), proximity of other structures and vegetation (fire) and roof pitch angle (ash fall, snow), and floor height (flood, tsunami). Remote sensing methods for collecting building and infrastructure data require high to very high resolution satellite or airborne imagery and is often completed using manual digitizing or more recently, segmentation and object oriented classification. Optical imagery is often complemented by LiDAR data, which can not only aid in detecting building edges, but is also used for calculating building heights. Incorporation of remotely sensed data into a GIS is vital during this phase for recording spatial attributes and combining with other data sets.

Remote sensing technology can also be applied to measure the success of risk reduction initiatives. A common method for addressing flood risk is the construction of stopbanks to contain flood waters for an event of a given magnitude. Aerial reconnaissance during major flooding events can identify whether stopbanks are performing to design standard and identify areas of weakness, overtopping or failure. Monitoring of non-structural risk reduction initiates is also possible. To address coastal hazard erosion and inundation risk,

many communities choose non-structural options such as beach renourishment and dune restoration. In Florida, airborne LiDAR captured over time has been applied to measure coastal erosion from hazards, alongside the success of non-structural beach restoration methods through determining changes to beach morphology (Shrestha et al. 2005). Another example of measuring the effects of risk reduction initiatives is analysing post-disaster images of rainfall induced landslides on land under different vegetation covers for large events. From analysis of aerial photographs (oblique and vertical) of an event in 2004 which impacted the lower North Island of New Zealand, it was determined that vegetation cover played an important role in reducing loss of productive soil, and reducing landslide hazard to assets (Hancox & Wright 2005).

4.2 Readiness

Readiness planning and activities are undertaken in the realisation that residual risk from hazards has the potential to create emergencies, and in some cases, disasters for affected populations. Readiness is the identification and development of necessary systems, skills and resources before hazard events occur. The desired outcome of readiness planning and activities is that response to hazards is more coordinated and efficient, communities experience less trauma, and recovery times are reduced (Quarantelli 1997). Examples of readiness activities include public education, preparedness activities, trainng and exercising, evacuation planning, developing hazard monitoring and public alerting systems, and putting in place state, national and international plans and agreements for assistance and aid. Readiness activities and planning are undertaken at a number of levels to increase resilience and response capability for individuals, households, organisations, and states or nations. The provision of good hazard and asset information to assist these activities is essential and examples where remote sensing can assist this phase are given in Table 2. It is important in this phase to prepare an archive of and gain familiarity with the most up to date spatial information including (but not limited to) imagery, DEMs, and vector data. This information is required to assist with damage assessment during the response and recovery phases.

At the individual and household level there are identified factors that contribute to whether people will take actions to prepare for disasters. Personalisation of risk is essential (Barnes 2002, Slovic et al. 2000), e.g. "Will it affect me?", "Do I need to do something about it", and "What can I do about it?". Other factors include belief in the benefits of hazard mitigation (outcome expectancy) and their belief that what they personally can do will make a difference (reduce negative outcome expectancy) (Paton 2006). At a community level, participation in community affairs and projects, and individual's ability to influence what happens in their community (empowerment) and the level of trust they have in different organisations (trust) have also be shown to be key predicators of resilience. Therefore, communication of risk in a meaningful way is an essential part of preparedness planning. Remotely sensed data such as LiDAR are used to produce high resolution hazard and risk maps, which are used by authorities to communicate information about location and range of hazards to their communities. If individuals believe that a hazard is likely to affect them detrimentally within an understandable and pertinent timeframe, they are more likely to take actions to prepare. These actions might include having emergency supplies in the home, an action plan for evacuation and emergency contact with other household members, first aid training or training as a civil defence volunteer. The principle of risk perception aiding preparedness applies to both static and dynamic hazards, e.g. fault trace or flood

plain mapping vs. cyclone or bushfire progression. Remotely sensed images showing the progression of a bushfire front or the track of a cyclone are commonly used by the media to inform the public of where hazards are occurring and where they are likely to impact as they evolve. As community resilience research has shown, awareness of hazards is not the only factor in triggering actual preparedness actions; however it is one significant driver (Paton 2006, Paton & Johnston 2001, Ronan & Johnston 2005).

Type of information	Data required	Sensor example	Application example
Severe weather warnings	RADAR, broadscale visible and infra red imagery	GOES, NOAA, Meteosat	Provide valuable advanced warning of severe events to the public and emergency planners via meteorologists
Movement and ground deformation	InSAR and PS-InSAR	ERS-1/2, ENVISAT ASAR, ALOS PALSAR	Rate of movement for slow moving landslides. Often acceleration of deformation rates means that a large event is about to follow. Early detection of deformation in volcanic regions is used for forecasting of possible eruptions
Soil moisture	Long wavelength SAR	SMAP	Water shortage leading to drought and agricultural productivity decline, ability of soils to retain water to indicate flood and landslide potential
Ground temperature variability	Thermal imagery, or SWIR in the case of very hot features	ASTER, MODIS, AVHRR	Monitoring heating and cooling cycles of volcanoes to understand pre-eruptive characteristics for forecasting purposes
Coastal and bathymetric mapping	SONAR, Laser depth ranging	LADS, Topex Poseidon / Jason	Tsunami hazard modelling
Display and advertisement of potential hazards	Moderate to high resolution optical imagery, often overlaying a DEM	Aerial photography, Quickbird, Ikonos - usually using black and white or true colour composites for ease of understanding	For use in public education about hazards and risks to foster greater readiness of individuals, households and organisations Use in civil defence emergency management exercises to provide realistic scenarios that will assist with staff professional development and planning
Detecting sea temperature or atmospheric pressure change in cyclone/hurricane/ typhoon generating latitudes	Broad scale thermal imagery, geostationary	MODIS, GOES, AVHRR	Advance warning of severe weather approaching to commence

Table 2. Examples of information and data requirements during the readiness phase

At the institutional level, a strong focus is placed on the development of plans and relationships. A primary way to test the effectiveness of these preparedness plans and relationship functions is through civil defence emergency management exercises. In order

for exercises to provide an effective learning experience for participants, realistic hazard scenarios must be developed. Remotely sensed data can assist this process through the creation of hazard maps, providing realism to exercise injects (new information about hazards or consequences as the exercise plays out).

At local to national scales, obtaining an overall picture of the hazardscape; identifying at risk areas, and priority hazards for resources and planning is essential. Granger (2000) discusses the development of information infrastructure for disaster management in Pacific island nations, based on remotely sensed data, and GIS interpretation. For countries with limited budgets, collaboration to purchase remotely sensed data for disaster planning is beneficial because of cost savings, the opportunities for skill and process sharing, and the consistency of data for modelling (Granger 2000).

As discussed previously, hazard modelling is important for risk reduction (section 4.1); it is also important for readiness, as for many hazards residual risk dictates that an effective emergency response will be the most practical solution for disaster management. For example, New Zealand has several active volcanoes; Mt Ruapehu is the largest of these. Ruapehu is a national park and has two commercial ski fields in operation on its slopes. Depending on the time of year, visitors to the mountain are engaged in a variety of recreational, educational and scientific activities. The greatest hazards associated with the volcano are eruptive events and lahar flow (Carrivick et al. 2009). The volcano has a crater lake at the summit which produces periodic large lahars during eruptions and tephra dam bursts. These lahars follow channels which are bridged by the main trunk railway line and State Highway 1, as well as passing through ski field and hiking areas. A lahar event in 1953, before bridges were raised and strengthened, destroyed the Tangiwai rail bridge, and a passenger train unable to stop was derailed resulting in the death of 151 people. While bridges have been modified to reduce risk, considerable readiness planning has also been undertaken to ensure that the events such as the 1953 disaster cannot happen again (Galley et al. 2004).

Following eruptions in 1995 and 1996 a large tephra dam formed on the crater rim allowing the lake to fill to higher than normal levels. The volcanic rocks of Crater Lake rim now had a weakness, a section of the rim comprised of weaker tephra, which would fail when lake levels reached a certain height. Extensive modelling of potential lahar flow paths and velocities was undertaken based on high resolution remotely sensed data (Carrivick et al. 2009). The path was verified using aerial photography, LiDAR, ASTER and PALSAR imagery after the event (Joyce et al. 2009b). The modelling provided the necessary hazard information for authorities to manage the risk through a suite of preparedness activities. A bund (levee) has been constructed to prevent lahar flow onto the main highway; and a comprehensive monitoring and alarm system was constructed to detect lahar break outs. An integrated response plan involving emergency managers, police, the fire service, road managers, railways operators, ski field staff, scientists and national park managers, was developed to stop all trains outside the hazard zone, close the highway, trigger warnings and response plans at the ski fields (move to ridges away from flow paths) (Leonard et al. 2005), and locate and evacuate any hikers or workers in hazard zones within the national park. The tephra dam burst early in 2007, and the response based on high quality modelling went as planned. The lahar was of considerable size but remained within expected channels and the only significant damage was to an unoccupied public toilet building at the Tangiwai memorial site.

Lahar flows and eruptions remain an ongoing hazard at Ruapehu. To assist with preparedness for these hazards, remote sensing is part of the suite of monitoring systems employed to detect changes in volcanic activity. A combination of synthetic aperture radar, ASTER thermal imagery (Figure 3), and OMI UV/visible imagery is acquired on a routine basis for monitoring deformation, Crater Lake temperatures and gaseous emissions respectively.
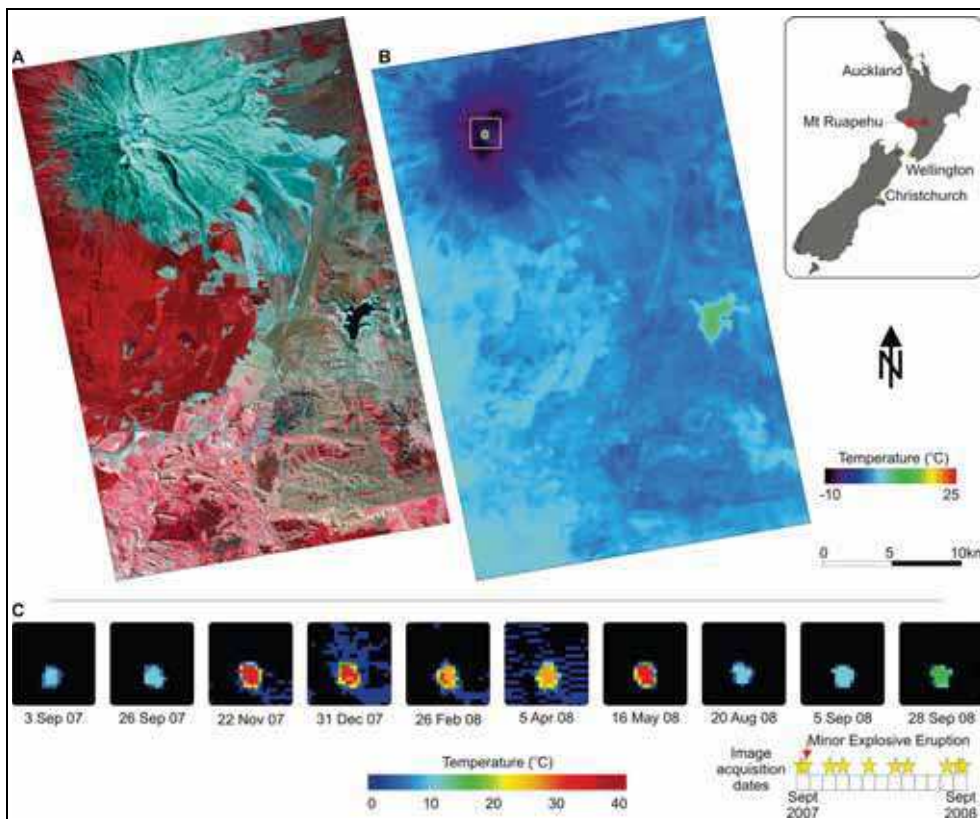

Fig. 3. Thermal monitoring of Mt Ruapehu. (a) SPOT-5 image obtained 15 March 2008 demonstrates land cover for contextual purposes; (b) Average temperature image calculated from night-time ASTER thermal data between 3 September 2007 and 28 September 2008; and (c) Mt Ruapehu Crater lake subsets using ASTER night-time thermal data. Note the temperature scale change for illustrative purposes.

The use of remotely sensed data of a previous event can be used in this phase to constrain geophysical models and help provide realistic scenarios for future events. For example, InSAR can be used to examine the deformation effects of a single event (such as an earthquake) by acquiring only two images as close in time as possible, one before and one after the event. Using this technique, the PALSAR L-band sensor on board the ALOS satellite was successfully used to map co-seismic deformation of a magnitude 6.7 earthquake

in the vicinity of George Sounds, off the coast of the lower South Island on 16th October 2007 (Petersen et al. 2009 in review). After processing two PALSAR images (22 July and 22 October 2007) displacements were apparent in the coastal region closest to the epicentre (Figure 4). Landslides were also experienced in the area (though not evidenced in this figure). The long wavelength L-band is of particular use in this region due to its ability to penetrate dense vegetation to retrieve the ground signal. The amount and location of deformation is used in modelling studies to estimate earthquake parameters in order to learn more about the tectonics of this remote region. As this is an uninhabited area of New Zealand, there was no observed infrastructure damage that may have otherwise necessitated acquisition of high resolution optical imagery for response or recovery purposes.
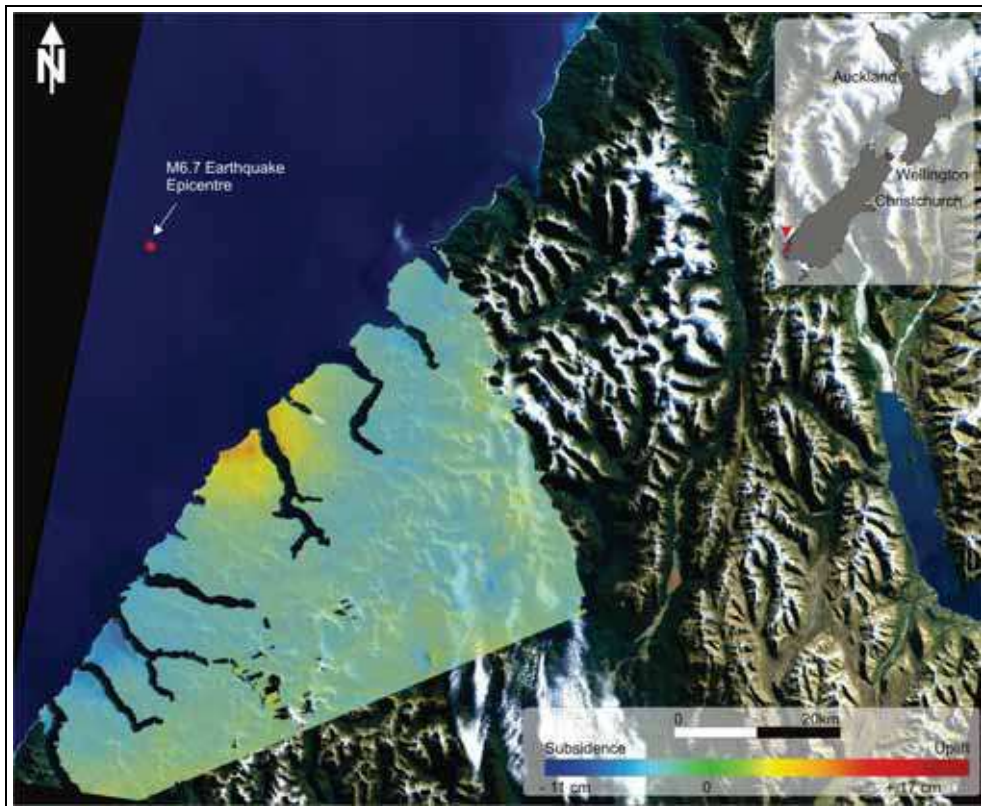

Fig. 4. Ground deformation following George Sounds earthquake in October 2007. Background image is a Landsat 7 ETM+ true colour composite scene

Monitoring longer term ground deformation effects such as that produced by ground water extraction, volcanic activity or slow moving landslides is conducted using multiple SAR images over a period of time. Using this technique it is possible to detect sub centimetre scale ground movement over large areas that could otherwise only be monitored or detected

using networks of in-situ GPS. With this method, the C-band sensor on board the ENVISAT satellite was able to detect sub-centimetre deformation in the Auckland region (Figure 5). This figure was created using a stack of 117 images, spanning the period 17 July 2003 and 9 November 2007. InSAR is used in this manner for long term monitoring and produces a rate of change over time. It is believed that most of the observed InSAR signal shown here is caused by extraction of groundwater; however the link to volcanic activity has also been investigated (Samsonov et al. 2009 in review).
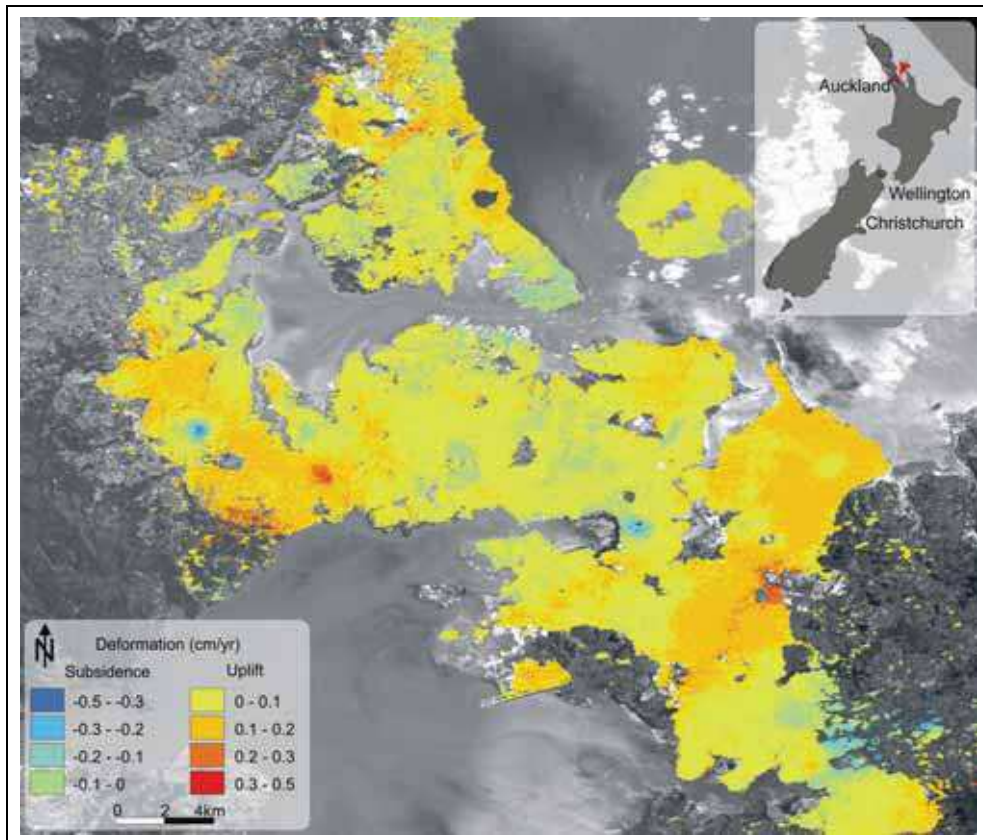

Fig. 5. Monitoring uplift and subsidence in Auckland. Background image is a green band grey scale mosaic of SPOT-5 and Landsat 7 ETM+ imagery.

4.3 Response

Response activities are primarily focussed on protecting life and property during disasters. Activities such as evacuations, search and rescue, sandbagging along riverbanks, evaluating building safety, establishing immediate emergency shelter, setting up command posts and other short-term tasks fall into the response phase. Remote sensing can be used here to provide immediate damage assessment if the data can be provided in a timely manner, and also to assist evacuation plans through the combination of observing weather patterns and

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