15

Remote sensing and the disaster management cycle

Karen E. Joyce[1], Kim C. Wright[1], Sergey V. Samsonov[1], and Vincent G. Ambrosia[2]
[1]GNS Science
New Zealand
[2]California State University – Monterey Bay
United States of America

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).

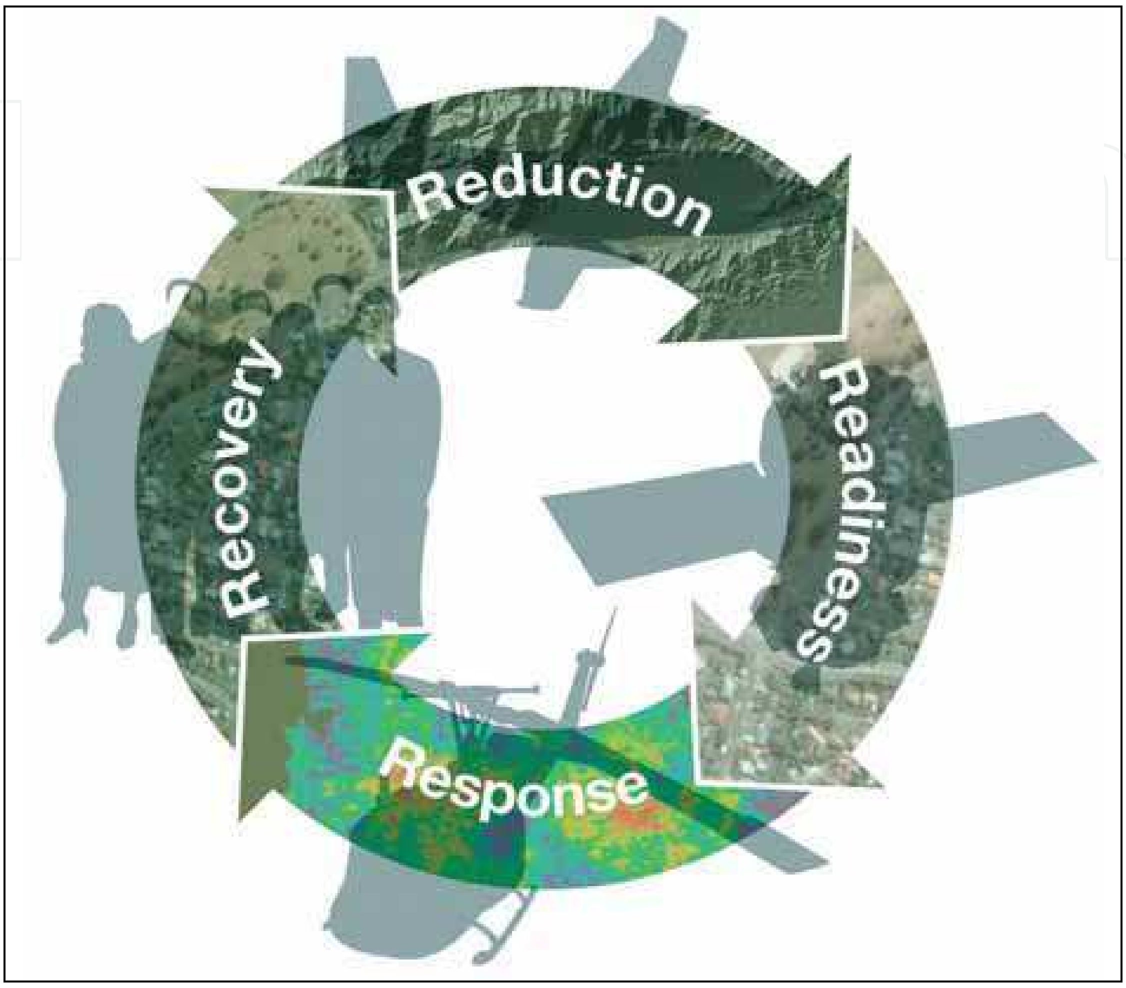


Fig. 1. The disaster management cycle

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

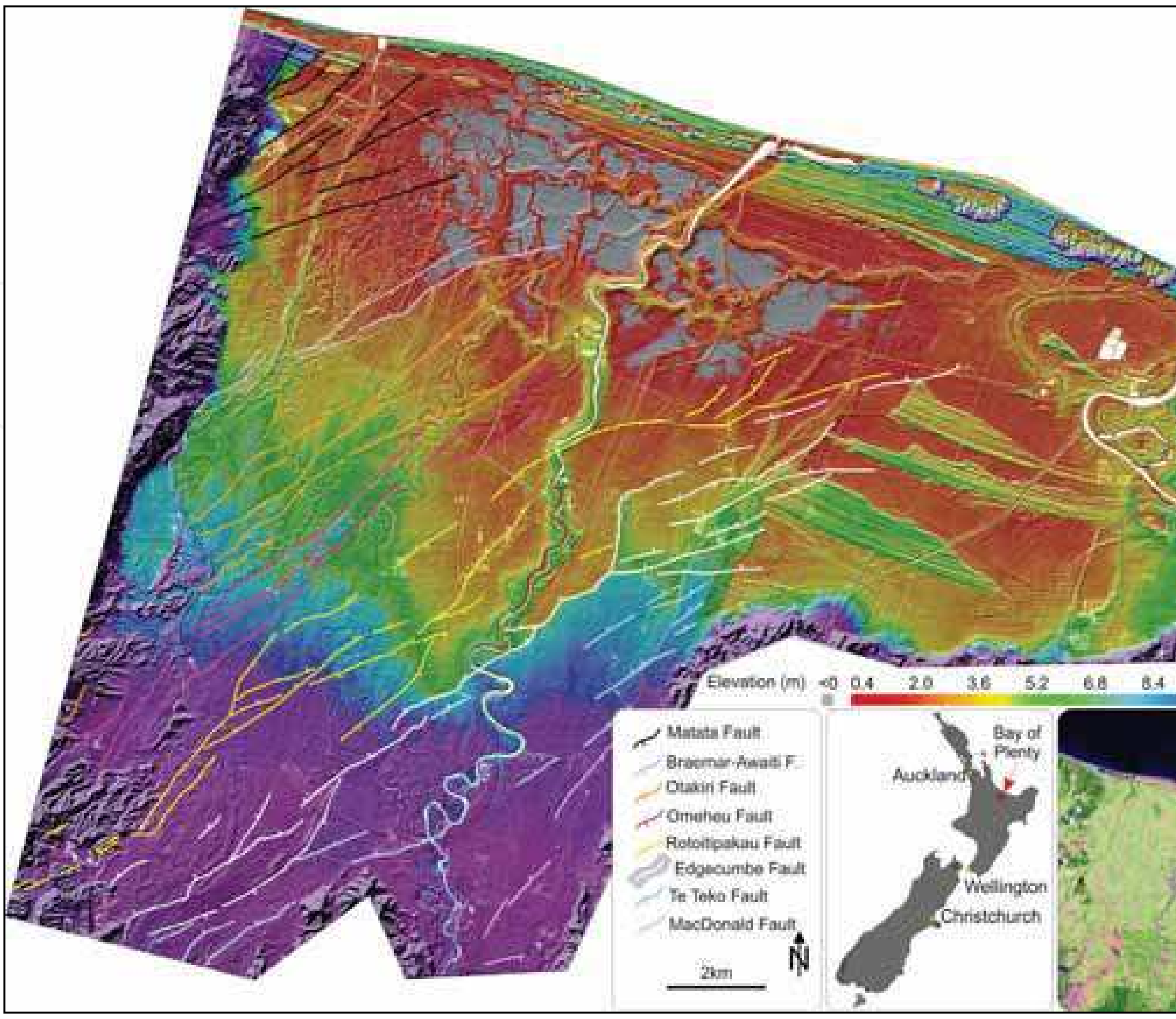


Fig. 2. Identification of known and new active faults using high resolution airborne LiDAR data acc
Mouslpoulou 2009 in press). Landsat ETM+ false colour composite (5,4,2) acquired in 2001 is inset fo
the site. Of the active fault traces shown here, approximately 85% were unknown before undertaki
also is the discovery of a large inland area that is below sea level (elevation <0m) and is a potent
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.

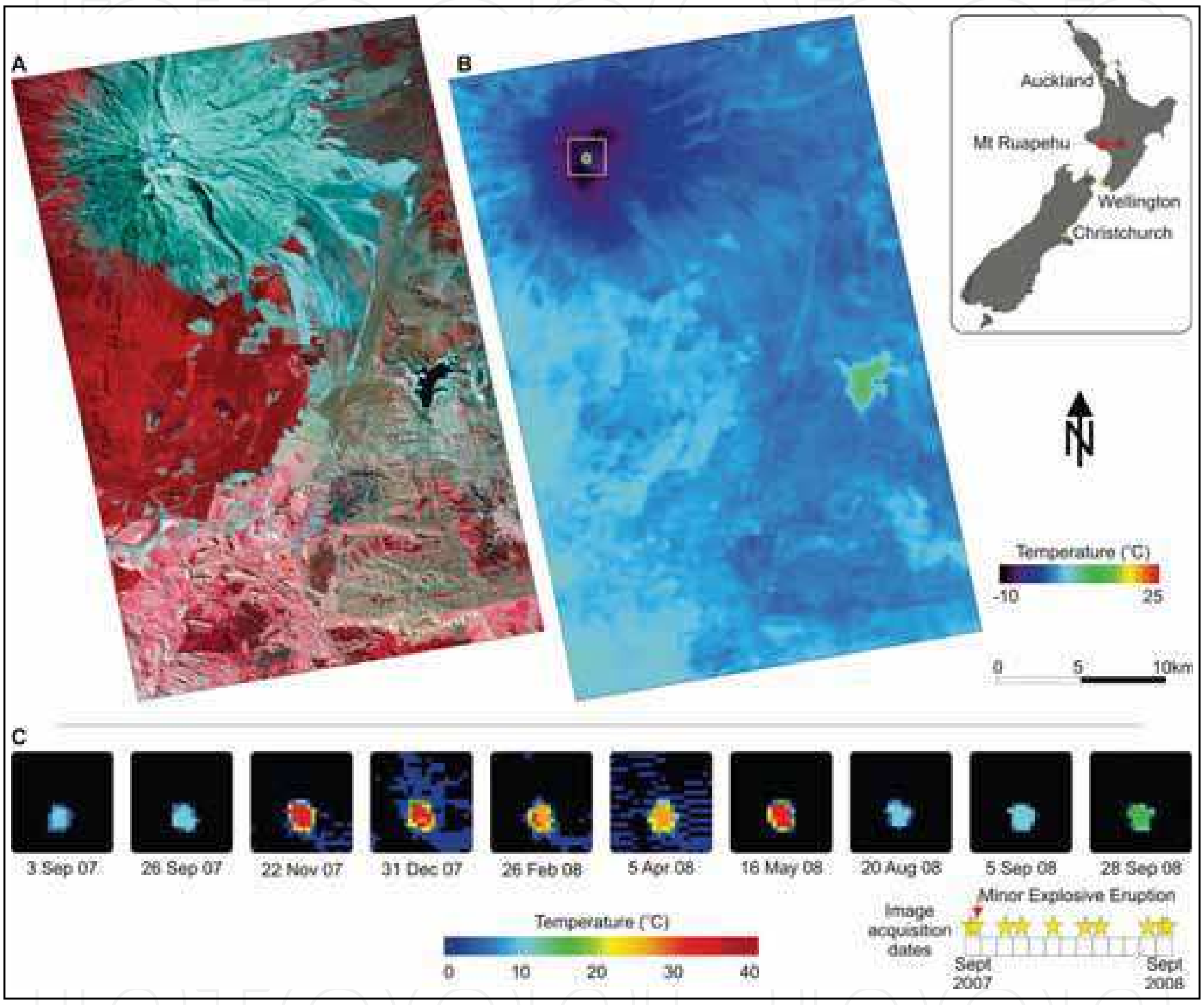


Fig. 3. Thermal monitoring of Mt Ruapehu. (a) SPOT-5 image obtained 15 March 2008 demonstrates land cover for contextual purposes; (b) Average temperature image calculated from night-time ASTER thermal data between 3 September 2007 and 28 September 2008; and (c) Mt Ruapehu Crater lake subsets using ASTER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

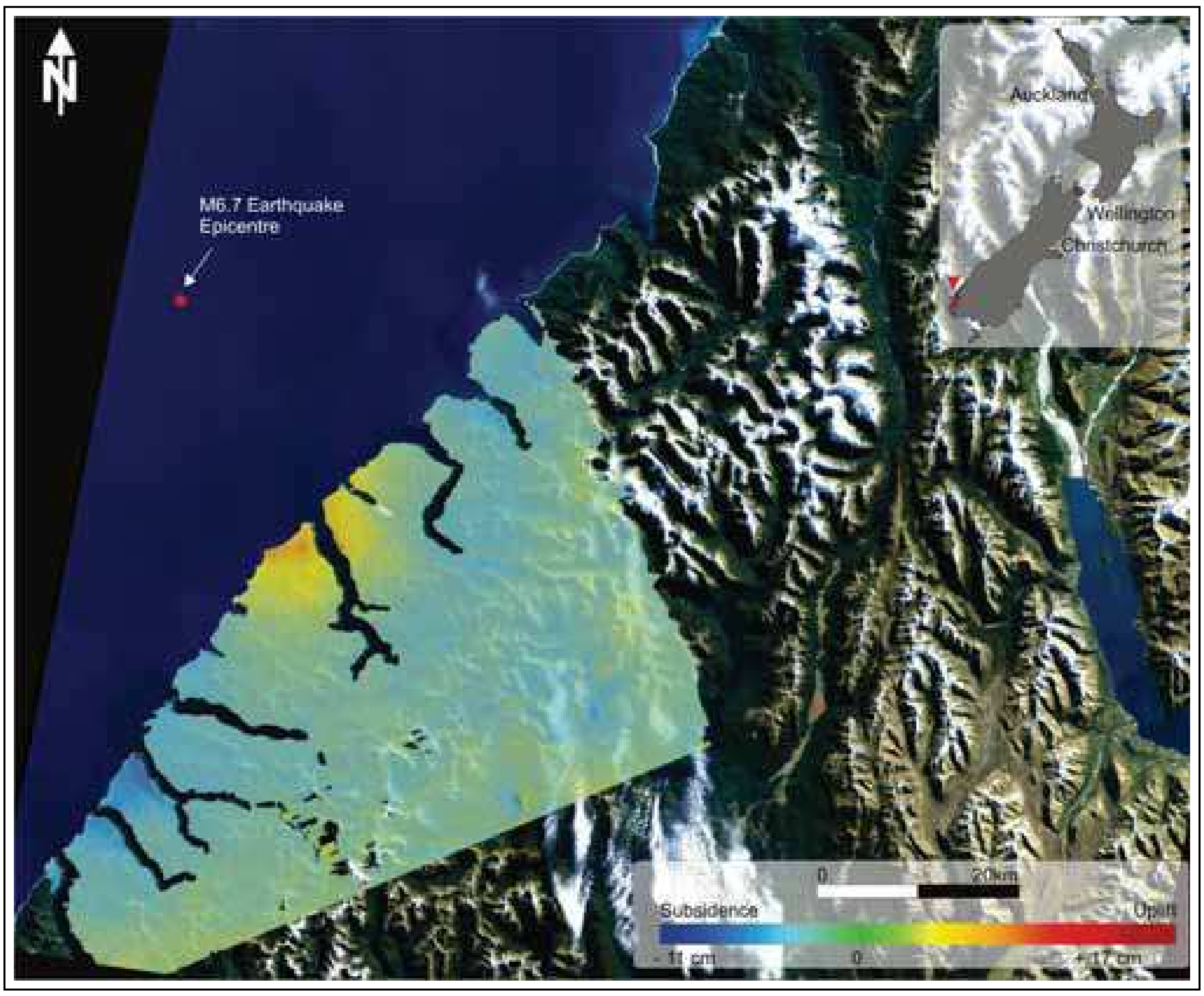


Fig. 4. Ground deformation following George Sounds earthquake in October 2007.
Background image is a Landsat 7 ETM+ true colour composite scene

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).

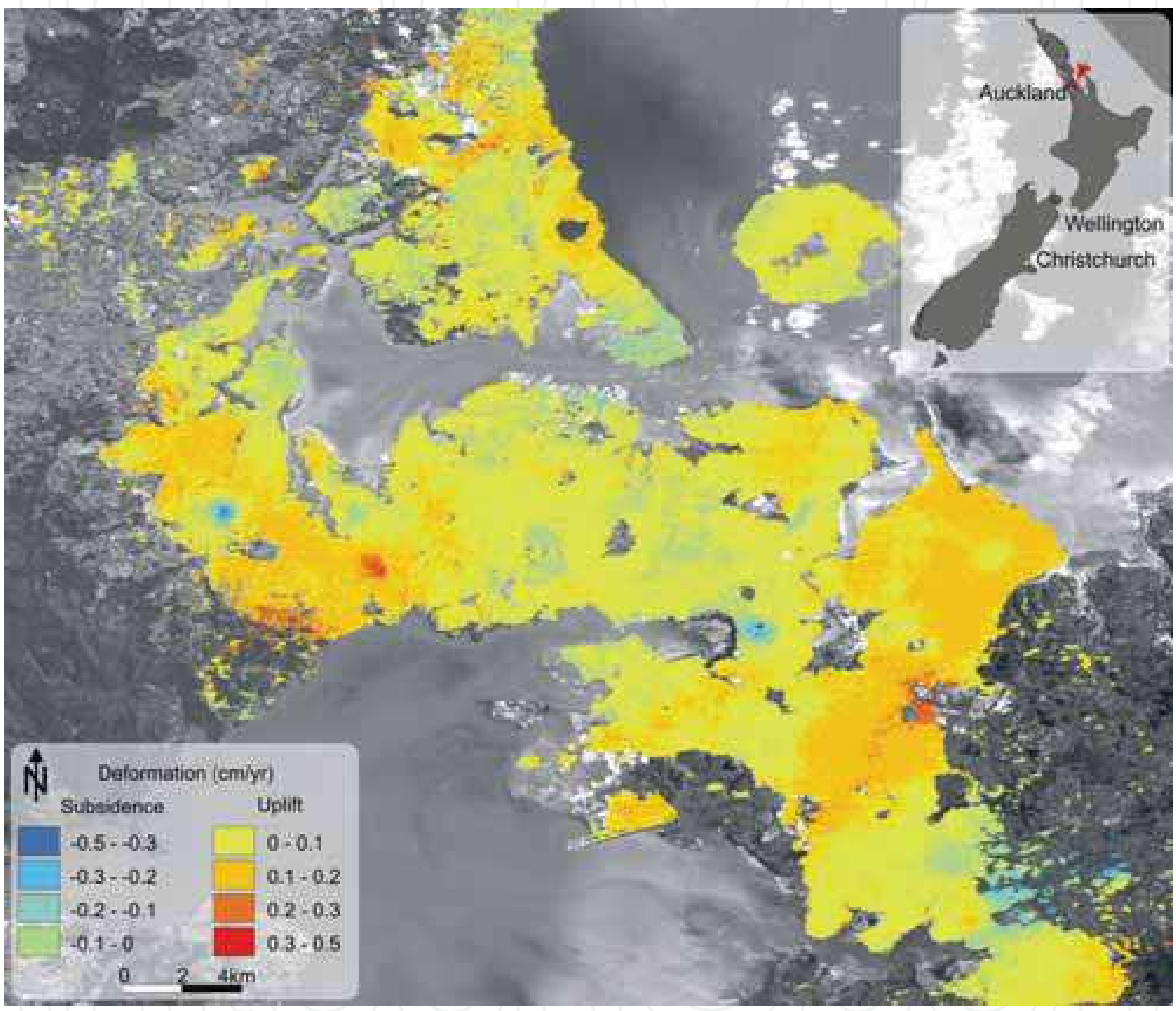


Fig. 5. Monitoring uplift and subsidence in Auckland. Background image is a green band grey scale mosaic of SPOT-5 and Landsat 7 ETM+ imagery.

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 hazard behaviour (e.g. fire front approaches, water level rises). Other examples of the use of remote sensing during the response phase are given in Table. 3. Ideally, recovery activities commence when the response phase begins, to ensure an integrated process for holistic recovery. This means that damage assessments undertaken via remote sensing during the response phase will also be integral to the recovery phase.

Type of information	Data required	Sensor example	Application example
Inundation	SAR, optical	Radarsat, SPOT, ASTER Quickbird, Ikonos	Determine magnitude, location and duration of impacts. Use SAR when cloud cover is still problematic
Widespread storm or earthquake induced landslides	SAR, moderate – high resolution optical	Radarsat, SPOT, ASTER Quickbird, Ikonos	Determine magnitude, location and duration of impacts.
Volcanic ash and gases	Shortwave infra red, thermal infrared	GOES, TOMS/OMI, MODIS	Highly temporally variable, so minimum of daily imagery required. Used for volcanic ash advisories and to warn airlines of hazardous flight paths
Public information during events	High resolution optical imagery	Quickbird, Ikonos	Assist those at risk to personalise hazard threat
Ship location	SAR	Terra SAR-X, Cosmo Sky-Med	Locating ships in the ocean during storm
Co-seismic and post-seismic deformation	InSAR	ERS-1/2, ENVISAT ASAR, ALOS PALSAR	Confirming magnitude of earthquake and forecasting possible aftershocks

Table 3. Examples of information and data requirements during the response phase

During the response phase, the temporal relevancy of remote sensing information is crucial to allow disaster managers to plan effective mitigation strategies on dynamic situations. In the case of wildfire events, it is critical to have current and timely intelligence on the fire location, fire-front, and fuel conditions. Near-real-time information allows the fire management team to plan fire attack appropriately, consequently saving resources, time and possibly lives. Concurrently, the information must be of sufficient spatial resolution to allow detailed tactical assessments and decisions to be made on the wildfire condition, and be spectrally-relevant to the phenomenon being observed or measured.

Despite the spectacular nature of imagery often captured during a disaster event, the use of remote sensing during the response phase has experienced mixed levels of success, particularly in the case of satellite platforms. Regional scale imagery of effects associated with the development of fire fronts (hot spot detection), volcanic eruptions (gas and ash emissions), or tropical cyclones (inundation) is generally successful where the area of impact is sufficiently large. For example, the wildfire management agencies in the United States currently utilize thermal-infrared (TIR) satellite data provided by MODIS to provide synoptic, 2-4 times-daily hot-spot detection of fire at continental scales (U.S. Forest Service 2009). The spatial resolution of MODIS is low / moderate (1000 meters), and is used to derive a regional estimate of fire distribution. Although the temporal frequency of the MODIS data is sufficient for regional fire assessment, its spatial resolution is insufficient for more localised events, or for assessing the specific on-ground impact. Conversely, polar orbiting satellites with appropriately high spatial resolution generally do not have the overpass frequency or data relay capability to provide imagery quickly enough to be of use for immediate response. The space science community is attempting to address this issue with the launch of satellite constellations such as Rapid Eye and the Disaster Monitoring Constellation (International collaboration between Algeria, China, Nigeria, Turkey and the UK). There are also avenues for collaboration between international organisations for data acquisition and provision in the event of disasters, such as the International Charter for Space Based Disasters (Ito 2005), and Sentinel Asia (Kaku et al. 2006). While potentially providing a considerable amount of data, neither of these tools can yet be used for immediate or first response due to the current time delay between requesting and receiving data. As such, research into airborne platforms has proven to be of greater utility for rapid data and information provision.

In 2006, 2007 and 2008, the National Aeronautics and Space Administration (NASA) and the U.S. Forest Service collaborated to evaluate and demonstrate the use of long-duration, large Unmanned Airborne Systems (UAS), innovative sensing systems, real-time onboard processing, and data delivery and visualisation technologies to improve the delivery and usefulness of remote sensing data on wildfire events. The objectives were to demonstrate the capabilities of providing sensor-derived, GIS-compatible, geo-rectified, processed data on wildfire conditions to incident management teams within 15-minutes of acquisition from the sensors on the UAS. The characteristics of this system render it ideal for emergency response that is not just isolated to wildfire events.

During the 2006, 2007 and 2008 U.S. wildfire season, a series of missions were flown over wildfires in the western U.S. to demonstrate the integration of the above-mentioned technologies to provide near-real-time information to disaster managers. The missions were flown on the NASA *Ikhana*, a modified General Atomics – Aeronautical Systems, Inc. Predator-B (MQ-9) Unmanned Aerial Vehicle (UAV), designed specifically for supporting NASA science missions. The *Ikhana* is capable of medium / high altitude and long-duration (24-hours) operations, making it an ideal platform for disaster event monitoring. The *Ikhana* UAS flew missions with the NASA AMS-Wildfire sensor onboard, which can be remotely operated and provides autonomous data processing capabilities (Ambrosia & Wegener 2009).

The use of the *Ikhana* and accompanying systems has proven successful over a number of events. In October 2007, four missions were flown over the Santa Ana wildfires in a five-day period (Figure 6a) and the resultant information was used to deploy fire fighting resources. In late June 2008, lightning storms in northern California ignited thousands of fires, that grew together to become over 25 major incidents covering millions of acres of forestlands. The national airborne remote sensing assets were overwhelmed and with a state emergency declared, the *Ikhana* and AMS-Wildfire were requested to support wildfire data collection operations. During the remainder of the summer, the *Ikhana* flew four missions in California, providing near-real-time data on numerous wildfires. The AMS-Wildfire real-time data were used effectively to locate a major fire surge encroaching on Paradise, California (Figure 6b). The data was used to support the emergency evacuation decision of the entire population of the community, an effective demonstration of the criticality of near-real-time remote sensing information supporting disaster management operations.

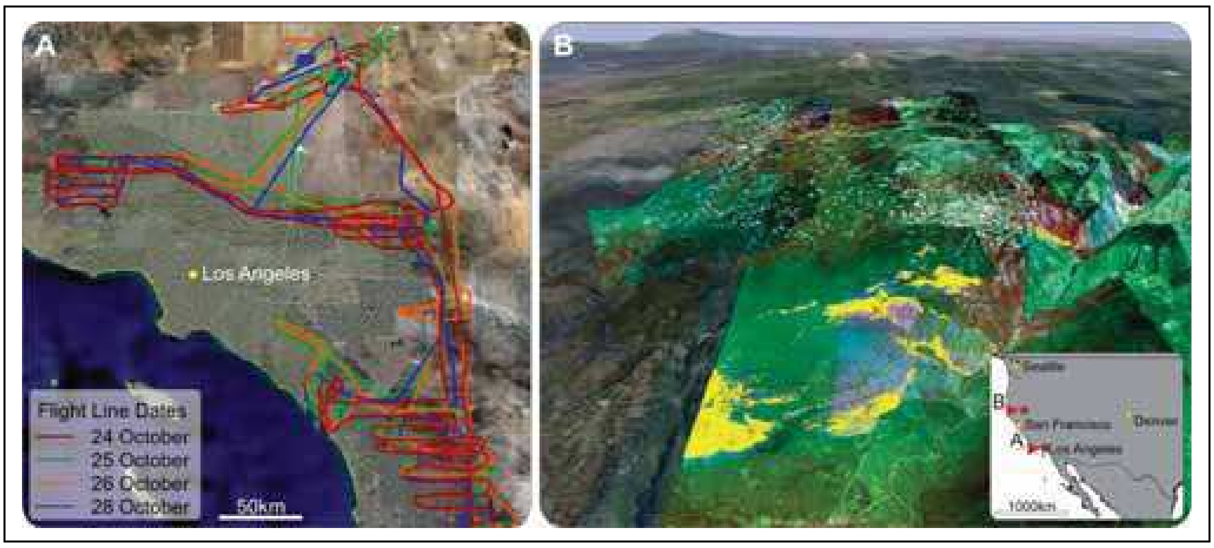


Fig. 6. (a) Flight routes required to cover 11 major wildfires California over four days in October 2007; and (b) AMS-Wildfire 3-band graphic image overlay and fire hot-spot detects (yellow areas) of the Canyon Complex fire approaching Paradise, California. The data was acquired on 8 July 2008. The hot-spot detect data, showing the fire moving rapidly towards Paradise, assisted in the evacuation determination for residents in the vicinity. This north-viewing 3-D data is displayed on Google Earth background information.

One of the key factors to the success of this system is the provision of not only data, but information that can be ingested and utilised immediately by emergency managers to aid their decision making. Part of this speed of information delivery is attributed to the autonomous processing onboard the UAS to create geo-rectified image raster products (GeoTIFF) and hot-spot detection vector files (*.shp* files). An emergency situation is not the time to be experimenting with new algorithms or processing techniques, thus it is necessary to ensure robust techniques have been thoroughly trialled and considered operational pre-event (Joyce et al. 2009a). The vector and raster products generated with this system are transmitted via the *Ikhana* telemetry system, through a communications satellite to servers on the ground, where they are automatically processed into Keyhole Markup Language (KML) files, compatible with Google Earth and made available in near-real-time at NASA servers. The combination of the near-real-time imagery and the simple Google Earth visualisation capabilities are a powerful tool that requires minimal (or no) training in its employment. Embedding a remote sensing specialist within the emergency management team can further assist with data integration, information understanding, and fielding specialized requests.

Although the Western States UAS Fire Imaging Missions were focused on demonstrating remote sensing capabilities to wildfire management entities, they resulted in direct emergency support to national incidents in all three years. Those missions allowed a comprehensive assessment of the technologies and resulted in the adaptation and integration of various components into operational use. The key components to the "usefulness" of the data were the timeliness of the data (from acquisition to product delivery) and the simple format which the data was available for visualisation and decision-making. While these factors are important at all stages of the disaster management cycle, they become particularly critical during the response phase, where rapid decision making is most important. The provision of simple hotspot information also means that the emergency management team is not overwhelmed with too much data or too many visualisation options. The choice of using Google Earth as a "front-end" display of the data was a careful decision to provide information in a format and software system that was easily operated and readily available to the fire management community. Fire Incident Command team members do not have the time to "learn" new software capabilities or new tools while they are in the midst of a major wildfire management activity. Google Earth provided a user-friendly capability to allow quick data integration, zoom capabilities, 3-D visualisation and ease of use.

The use of UAVs presents opportunities as well as risks. UAVs provide increased range and flight time and the ability to penetrate environments that might be too hazardous for piloted aircraft (Henson 2008). Mission and platform costs currently precludes immediate adaptation of UAS systems by disaster management agencies, but the disaster support missions we showcased are major steps forward in demonstrating UAS utility and sensor and processing capabilities available right now! These technologies need not be considered for use only with unmanned vehicles, but can be adopted for piloted aircraft, and hopefully for satellite platforms in the future. Autonomous onboard processing has been trialled with Hyperion for identifying hotspots associated with volcanic eruptions (Davies et al. 2006), though the challenge remains to progress these techniques to operational status.

4.4 Recovery

The use of remote sensing to aid or monitor disaster recovery is perhaps the least developed application of this technology. However, this is an area where the remote sensing community could contribute a great deal through the provision of objective time series analysis over large areas with both high and medium levels of spatial detail. In other specialisations, time series analysis of remotely sensed data is an established technique. Environmental applications such as deforestation and urban sprawl are common targets. In each case, the monitoring objective is clear. In disaster recovery, there are often some very clear indicators that can easily be measured and monitored with remote sensing imagery. Some of these indicators include construction and subsequent removal of medium and long-term emergency shelters; debris removal; commencement and completion of new construction or reconstruction (buildings, bridges, roads); vegetation regrowth; and reduction of siltation from waterways after flooding events (Table 4).

Type of information	Data required	Sensor example	Application example
Rate of recovery e.g. debris removal, vegetation regrowth, reconstruction	Moderate to very high resolution imagery in a continuous time series	Aerial photography, Quickbird, Worldview, Ikonos	Compare the effectiveness of different recovery strategies; Determine if aid funding is being used appropriately; Wildlife habitat recovery (eg after fire); Identify 'residual risk' – areas not recovered are more vulnerable to future events
Infrastructure and facilities locations	Very high resolution imagery	Aerial photography, Quickbird, Worldview, Ikonos	Create new baseline maps
Revised DEM	InSAR, LiDAR	ERS-1/2, ENVISAT ASAR, ALOS PALSAR	Necessary after large earthquake or volcanic eruption if the local and regional elevation changes
Status Quo	Very high resolution imagery	Aerial photography, Quickbird, Worldview, Ikonos	Plan areas for funding allocation

Table 4. Examples of information and data requirements during the recovery phase

Using high spatial resolution the amount of housing reconstruction can at least be visually identified by the presence and absence of blue tarpaulins covering roofs following Hurricane Katrina (Hill et al. 2006). Conceivably an automated detection method could be developed to identify these quickly and repeatedly in a time series dataset. The authors also provide a list of other recovery related features observable over time with Quickbird data. In Figure 7, the progression of recovery in a small area of New Orleans can be seen with high resolution data. Notable features in the image acquired a week before the hurricane are a large car park, sporting fields, and residential housing (Figure 7a). The progression clearly shows inundation in this area (Figure 7b), and remaining sediment shortly after the water subsidence. By March 2006, temporary housing is evident in the location of the car park, and is still visible three years after the event, though the number of roofs covered in blue tarpaulins has decreased. An analysis of the relative rate of change is given in Figure 7k, demonstrating that impervious surfaces and lines of communication such as roads moved towards recovery quite quickly after the event, while mature vegetation takes somewhat longer. Some roofing damage and a swimming pool appear to remain in an unrepaired state three years after the event. The key here is that a time series of data is vital to determine if any change is occurring, and to further extract rates of change.

Recovery rates following a widespread landsliding event in northern New Zealand can also be seen from a series of SPOT-5 and ALOS AVNIR-2 imagery (Figure 8). Here the landsliding is apparent as bright scars in the colour infra red imagery acquired four months after the event (Figure 8b). One year later, recovery of many of the grassy slopes on the eastern portion of the image can be seen, while the landslides in the western region are also becoming overgrown (Figure 8c). This recovery becomes even more apparent in the series of NDVI images, which highlight the contrast between landslides (black) and surrounding vegetation (various shades of grey) (Figure 8d-f). In an area that was covered with many thousand landslides (Joyce et al. 2008a), satellite remote sensing is the only time and cost effective manner of data collection for understanding recovery in the area. Similar techniques could be used to look at native habitat regeneration following bushfires.

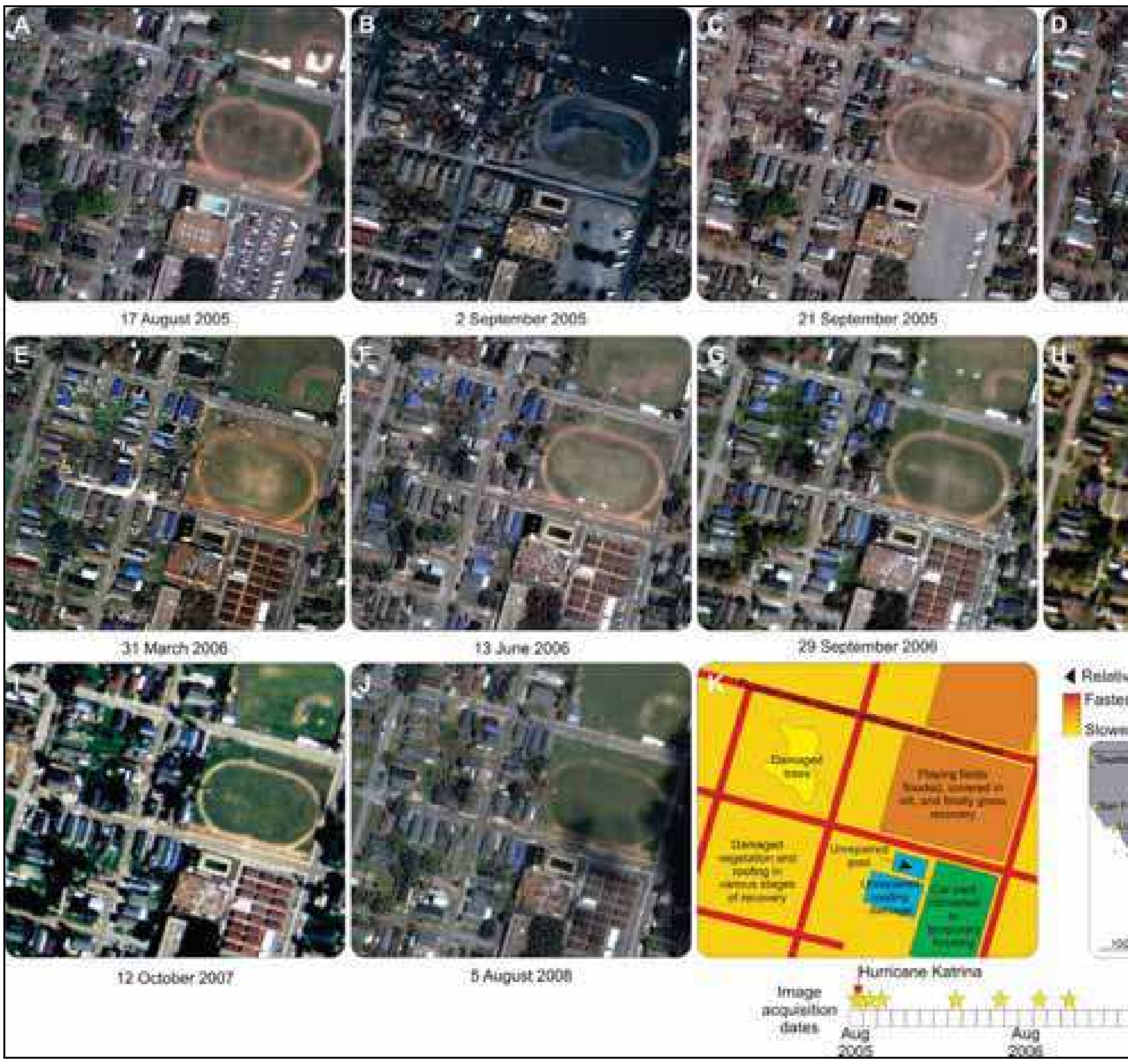


Fig. 7. Time series of high resolution imagery in New Orleans (a) Before Hurricane Katrina; (b) Soo
(c-j) Various time intervals following the recovery process; and (k) Interpreted rate of recovery. In
Google Earth 2009.

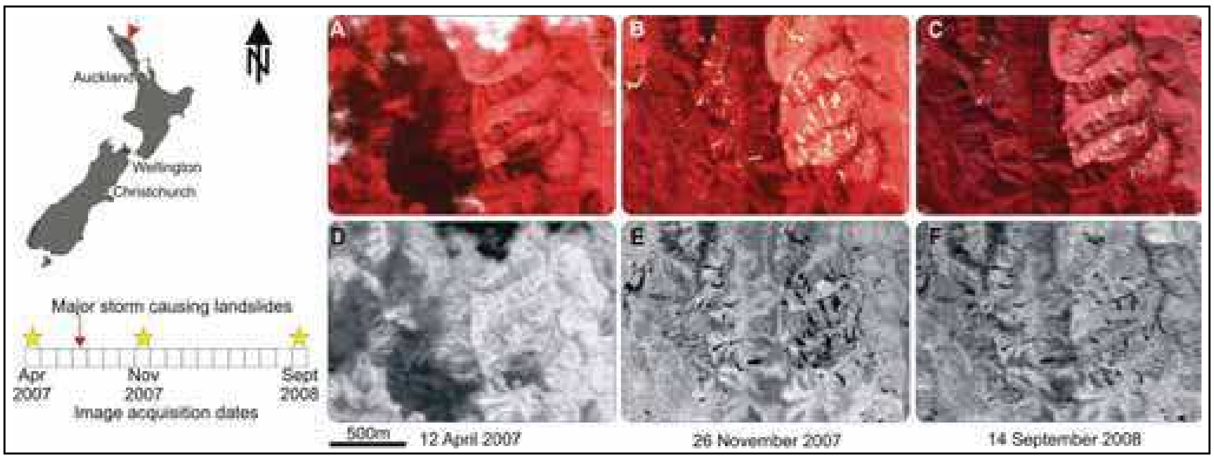


Fig. 8. Recovery of vegetation after a widespread landsliding event in northern New Zealand, July 2007. (a) SPOT-5 CIR obtained before the event; (b) SPOT-5 CIR obtained shortly after the event; (c) ALOS AVNIR-2 CIR imagery obtained one year later; and (d-e) NDVI images of the aforementioned data.

Analysis of time series imagery could also help to monitor the effectiveness of different recovery strategies. By extracting recovery rates from data acquired at appropriate time intervals, this assessment could help guide recovery plans for future events of a similar nature. This would also help identify areas of residual risk that require ongoing monitoring until the physical recovery process completed.

5. Conclusions

Remote sensing can be used to inform many aspects of the disaster management cycle. An exhaustive coverage of all potential applications would be impossible in a single book chapter, however we have shown several good examples from which inspiration can be sought for future use. It is important to consider all aspects of disaster management, rather than focussing on emergency response. By incorporating remote sensing into reduction and readiness activities, this can also educate both emergency management staff and the community about this type of information so that they are familiar with its use under a response and inherently pressured situation.
The key elements to facilitate the usefulness of remote sensing data in support of the disaster management community are being able to provide the appropriate information in a spectrally, temporally, and spatially relevant context. Additionally, one must be aware of the information requirements of that disaster management community, and tailor the remote sensing information to meet those needs. That can only come through close collaborations between the disaster management community and the remote sensing / geospatial community.

6. Acknowledgements

All SPOT 5 imagery used in this chapter is © CNES. This manuscript incorporates data which is © Japan Aerospace Exploration Agency ("JAXA") (2008). The data has been used in this manuscript with the permission of JAXA and the Commonwealth of Australia

(Geoscience Australia) ("the Commonwealth"). JAXA and the Commonwealth have not evaluated the data as altered and incorporated within the manuscript, and therefore give no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose. Environment Bay of Plenty provided the licence to use the LiDAR data. Thank you to Andy Gray for assistance with graphics and to Phil Glassey and David Johnston for chapter review.

7. References

Ambrosia V. G. & Wegener S. S. (2009). Unmanned airborne platforms for disaster remote sensing support. In: *Advances in Geoscience and Remote Sensing*, 317-346 - this book, IN-Tech Publishing, Vienna

Barnes P. (2002). Approaches to community safety: risk perception and social meaning. *Australian Journal of Emergency Management*, 17, 1, 15 - 23

Becker J., Saunders W., Hopkins L., Wright K., & Kerr J. (2008). Pre-event recovery planning for use in New Zealand: An updated methodology. GNS Science Report 2008/11. GNS Science

Begg J. G. & Mouslpoulou V. (2009 in press). Analysis of late Holocene faulting within an active rift using lidar, Taupo Rift, New Zealand. *Journal of Volcanology and Geothermal Research*

Board on Natural Disasters (1999). Mitigation emerges as major strategy for reducing losses caused by natural disasters. *Science*, 284, 1943-1947

Burby R. J. (2001). Involving citizens in hazard mitigation planning: Making the right choices. *Australian Journal of Emergency Management*, 16, 45 - 51

Burby R. J. (1998). Natural hazards and land use: An introduction. In: *Cooperating With Nature: Confronting Natural Hazards with Land Use Planning for Sustainable Communities*, Burby RJ (Ed.), 1 - 26, Joseph Henry Press, Washington D.C.

Carrivick J. L., Manville V., & Cronin S. (2009). A fluid dynamics approach to modelling the 18th March 2007 lahar at Mt. Ruapehu, New Zealand. *Bulletin of Volcanology*, 71, 153-169

Cloude S. R. & Papathanassiou K. P. (1988). Polarimetric SAR Interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, GE36, 1551 - 1565

Cutter S. L. & Finch C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 7, 2301-2306, 00278424

Davies A. G., Chien S., Baker V., Doggett T., Dohm J., Greeley R., Ip F., Castano R., Cichy B., Rabideau G., Tran D., & Sherwood R. (2006). Monitoring active volcanism with the Autonomous Sciencecraft Experiment on EO-1. *Remote Sensing of Environment*, 101, 4, 427

Donner W. & Rodriguez H. (2008). Population Composition, Migration anti Inequality: The Influence of Demographic Changes on Disaster Risk and Vulnerability. *Social Forces*, 87, 2, 1089-1114, 00377732

Elachi C. (1987). *Introduction to the Physics and Techniques of Remote Sensing*, John Wiley & Sons, New York

Franceschetti G. & Lanari R. (1999). *Synthetic Aperture Radar Processing*, CRC Press, New York

Galley I., Leonard G. S., Johnston D., Balm R., & Paton D. (2004). The Ruapehu lahar emergency response plan development process: An analysis. *Australian Journal of Disaster and Trauma Studies*, 1

Giglio L., Csiszar I., Restás Á., Morisette J. T., Schroeder W., Morton D., & Justice C. O. (2008). Active fire detection and characterization with the advanced spaceborne thermal emission and reflection radiometer (ASTER). *Remote Sensing of Environment*, 112, 6, 3055

Godschalk D. R., Kaiser E. J., & Berke P. R. (1998). Integrating hazard mitigation and local land use planning. In: *Cooperating With Nature: Confronting Natural Hazards with Land Use Planning for Sustainable Communities*, Burby RJ (Ed.), pp 85-118, Joseph Henry Press, Washington D.C.

Granger K. (2000). An information infrastructure for disaster management in Pacific Island Countries. *Australian Journal of Emergency Management*, 15, 1, 20 - 32

Gregg C. E. & Houghton B. F. (2006). Natural Hazards. In: *Disaster Resilience: An Integrated Approach*, Paton D, Johnston D (Eds.), pp 19-39, Charles C. Thomas Publishers Ltd, Springfield

Hancox G. T. H. & Wright K. (2005). Analysis of landsliding caused by the 15-17 February 2004 rainstorm in the Wanganui-Manawatu hill country, southern North Island, New Zealand GNS Science report. Institute of Geological and Nuclear Sciences (64)

Hanssen R. F. (2001). *Radar interferometry: data interpretation and error analysis*, Kluwer Academic Publishers

Henson R. (2008). *Satellite observations to benefit science and society: recommended missions for the next decade*, National Research Council, National Academies Press, National Acadamy of Science, 0-309-10904-3

Hill A. A., Keys-Mathews L. D., Adams B. J., & Podolsky D. (2006). Remote sensing and recovery: A case study on the Gulf Coasts of the United States, *Proceedings of the Fourth International Workshop on Remote Sensing for Post-Disaster Response*, Cambridge, UK

Ito A. (2005). Issues in the implementation of the International Charter on Space and Major Disasters. *Space Policy*, 21, 2, 141

Joyce K. E., Belliss S., Samsonov S., McNeill S., & Glassey P. J. (2009a). A review of the status of satellite remote sensing image processing techniques for mapping natural hazards and disasters. *Progress in Physical Geography*, 33, 2, 1 - 25

Joyce K. E., Dellow G. D., & Glassey P. J. (2008a). Assessing image processing techniques for mapping landslides, *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium*, Boston, MA

Joyce K. E., Samonsov S., & Jolly G. (2008b). Satellite remote sensing of volcanic activity in New Zealand, *Proceedings of the 2nd Workshop on the use of remote sensing techniques for monitoring volcanoes and seismogenic areas*, Naples, Italy

Joyce K. E., Samsonov S., Manville V., Jongens R., Graettinger A., & Cronin S. (2009b). Remote sensing data types and techniques for lahar path detection: A case study at Mt Ruapehu, New Zealand. *Remote Sensing of Environment*, 113, 1778 - 1786

Kaku K., Held A. A., Fukui H., & Arakida M. (2006). Sentinel Asia initiative for disaster management support in the Asia-Pacific region, *Proceedings of the SPIE*,

Laska S. & Morrow B. H. (2006/7). Social vulnerabilities and Hurricane Katrina: An unnatural disaster in New Orleans. *Marine Technology Society Journal*, 40, 4, 16-26

Leonard G. S., Johnston D. M., & Paton D. (2005). Developing effective lahar warning systems for Ruapehu. *Planning Quarterly*, 158, 6-9

Massonnet D. & Feigl K. (1998). Radar interferometry and its application to changes in the Earth surface. *Reviews of Geophysics*, 36, 4, 441 - 500

Mileti D. S. (1999). *Disasters By Design: A reassessment of Natural hazards in the United States*, Joseph Henry Press, Washington D.C.

Nirupama N. & Simonovic S. (2007). Increase of Flood Risk due to Urbanisation; A Canadian Example. *Natural Hazards*, 40, 25 - 41

Norman S. (2004). Focus on Recovery: A Holistic Framework for Recovery. In: *NZ Recovery Symposium Proceedings 12-13 July, 2004.*, Norman S (Ed.), 31-46, Ministry of Civil Defence and Emergency Management, Wellington

Oppenheimer C. (1993). Infrared surveillance of crater lakes using satellite data. *Journal of Volcanology and Geothermal Research*, 55, 117 - 128

Oppenheimer C. (1997). Remote sensing of the colour and temperature of volcanic lakes. *International Journal of Remote Sensing*, 18, 1, 5-37

Paton D. (2006). Disaster resilience: Integrating individual, community, institutional and environmental perspectives. In: *Disaster resilience: An integrated approach*, Paton D, Johnston D (Eds.), 320, Charles C Thomas Publisher, 0-398-07663-4, Springfield

Paton D. & Johnston D. (2001). Disaster and communities: vulnerability, resilience and preparedness. *Disaster Prevention and Management*, 10, 270-277

Pertrow T., Thieken A., Kreibich H., Merz B., & Bahlburg C. H. (2006). Improvements on flood alleviation in Germany: Lessons learned form the Elbe flood in August 2002. *Environmental Management*, 38, 717-732

Petersen T., Beaven J., Denys P., Denham M., Field B., Francois-Holden C., McCaffrey R., Palmer N., Reyners M., Ristau T., Samonsov S., & Team T. G. (2009 in review). The Mw 6.7 George Sound earthquake of October 16, 2007: response and preliminary results. *Bulletin of New Zealand society for earthquake engineering*

Phinn S. R. (1998). A framework for selecting appropriate remotely sensed data dimensions for environmental monitoring and management. *International Journal of Remote Sensing*, 19, 17, 3457 - 3463

Phinn S. R., Joyce K. E., Scarth P. F., & Roelfsema C. M. (2006). The role of integrated information acquisition and management in the analysis of coastal ecosystem change. In: *Remote sensing of aquatic coastal ecosystem processes: Science and management applications*, Richardson LL, LeDrew EF (Eds.), 325, Springer-Verlag

Pottier E. & Ferro-Famil L. (2008). Advances in SAR polarimetry applications exploiting polarimetric spaceborne sensors, *Proceedings of the 2008 Radar Conference*, pp. 1 - 6, Rome, Italy

Quarantelli E. L. (1997). Ten criteria for evaluating the management of community disasters. *Disasters*, 21, 1, 39-56

Quarantelli E. L. (1985). What is Disaster? The Need for Clarification in Definition and Conceptualisation in Research. In: *Disasters and Mental Health Selected Contemporary Perspectives*, Sowder B (Ed.), 41-73, Government Printing Office, Washington

Ronan K. R. & Johnston D. M. (2005). *Promoting community resilience in disasters : the role for schools, youth, and families*, Springer, 0387238204, New York

Rosen P., Hensley P., Joughin I., Li F., Madsen S., Rodriguez E., & Goldstein R. (2000). Synthetic aperture radar interferometry. *Proceedings of the IEEE*, 88, 3, 333-382

Samsonov S. V., Tiampo K., Gonzalez P., Manville V., & Jolly G. (2009 in review). Modelling deformation occurring in the city of Auckland, New Zealand mapped by differential synthetic aperture radar. *Journal of Geophysical Research*

Shrestha R. L., Carter W. E., Satori M., Luzum B. J., & Slatton K. C. (2005). Airborne Laser Swath Mapping: Quantifying changes in sandy beaches over time scales of weeks to years. *ISPRS Journal of Photogrammetry & Remote Sensing*, 59, 222 - 232

Slovic P., Fischhoff B., & Lichtenstein S. (2000). Cognitive Processes and Societal Risk Taking. In: *The perception of risk*, Slovic P (Ed.), 32-50, Earthscan Publications Ltd, London

Trunk L. & Bernard A. (2008). Investigating crater lake warming using ASTER thermal imagery: Case studies at Ruapehu, Poás, Kawah Ijen, and Copahué Volcanoes. *Journal of Volcanology and Geothermal Research*, 178, 2, 259 - 270

van Zyl J. J., Zebker H. A., & Elachi C. (1990). Polarimetric SAR applications. In: *Radar Polarimetry for Geoscience Applications*, 315 - 360, Artech House, Nomood

Wisner B. (2004). Assessment of capability and vulnerability. In: *Mapping Vulnerability: Disasters, Development and People*, Bankoff G, Frerks G, Hilhorsdt D (Eds.), 183 - 193, Earthscan, London

Wisner B., Blaikie P., Cannon T., & Davis I. (2004). The challenge of disasters and our approach. In: *At Risk: Natural Hazards, people's vulnerability and disasters*, Wisner B, Blaikie P, Cannon T, Davis I (Eds.), 3-48, Routledge, London & New York

Wright R., Flynn L., Garbeil H., Harris A., & Pilger E. (2002). Automated volcanic eruption detection using MODIS. *Remote Sensing of Environment*, 82, 1, 135

Wright R., Flynn L. P., Garbeil H., Harris A. J. L., & Pilger E. (2004). MODVOLC: near-real-time thermal monitoring of global volcanism. *Journal of Volcanology and Geothermal Research*, 135, 1-2, 29-49

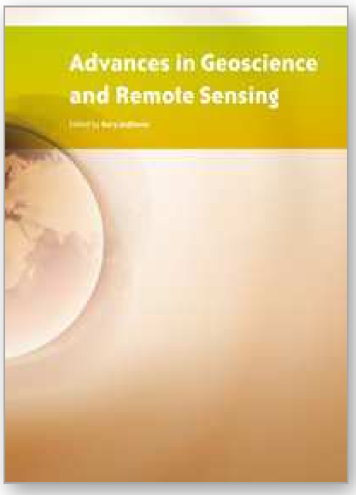
8. Glossary

Note that the satellite sensors listed here and within the text are simply examples of the types of instruments that can be used, rather than being a complete listing of all possibilities.

ALOS AVNIR-2	Japanese Space Agency (JAXA) Advanced Land Observing Satellite Advanced Visible and Near Infrared sensor. Useful for local to regional scale mapping and monitoring
ALOS PALSAR	Japanese Space Agency (JAXA) Advanced Land Observing Satellite L Band SAR satellite. Useful for deformation monitoring in regions of dense vegetation
ASAR	C Band Advanced Synthetic Aperture RADAR
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer on board NASA's Terra satellite. Useful for monitoring volcanic activity
AVHRR	Advanced Very High Resolution Radiometer (NOAA – National Oceanic and Atmospheric Administration). Useful for regional to national scale applications
CIR	Colour Infrared – three band standard display of green, red and near infrared light displayed as blue, green and red respectively

DEM	Digital elevation model
DMC	Disaster Monitoring Constellation. International collaboration between space agencies in Algeria, China, Nigeria, Turkey and the UK for regional scale mapping (optical)
ERS	European Space Agency Satellite with a suite of SAR and optical sensors
ENVISAT	European Space Agency Satellite with a suite of SAR and optical sensors
GOES	Geostationary Operational Environmental Satellites – used for metrological applications
Ikonos	Very high spatial resolution commercial satellite (GeoEye). Useful for local scale mapping and monitoring (e.g. buildings and assets)
InSAR	Interferometric Synthetic Aperture RADAR – technique used for measuring surface deformation
KML	Keyhole Markup Language – native language for Google Earth files
LADS	Laser Airborne Depth Sounder
Landsat ETM+	Enhanced Thematic Mapper plus. Useful for long term regional scale mapping and monitoring, though technical malfunctioning limits data coverage
Landsat TM	Thematic Mapper. Useful for long term regional scale mapping and monitoring
LiDAR	Light Detection and Ranging. Used for creating very high spatial resolution DEMs
Meteosat	European geostationary meteorological satellite
MODIS	Moderate Resolution Imaging Spectrometer. Used for hotspot monitoring of fires and volcanic activity on a regional to continental scale
NASA	National Aeronautics and Space Administration
OMI	Ozone Monitoring Instrument – used for monitoring volcanic gas emissions
POLInSAR	Polarimetric Interferometric Synthetic Aperture RADAR
PS-InSAR	Permanent Scatterers Interferometric Synthetic Aperture RADAR
Quickbird	Very high spatial resolution commercial satellite (Digital Globe). Useful for local scale mapping and monitoring (e.g. buildings and assets)
RADARSAT	Canadian Space Agency C Band SAR satellite
RapidEye	Constellation of five high resolution optical satellites, the combination of which provides a daily revisit capability
SAR	Synthetic Aperture RADAR. Active sensor capable of capturing data through clouds, smoke and haze
SMAP	Soil Moisture Active Passive – scheduled for launch in 2012
SPOT	Satellite Pour l'Observation de la Terre – French Space Agency (CNES – Centre National d'Etudes Spatiales) colour infrared and panchromatic earth observation satellite

SWIR	Short Wave Infrared. Used for volcanic ash and gas monitoring and also vegetation applications
Terra SAR-X	X-band SAR satellite
TIR	Thermal Infrared, used for fire and volcanic activity monitoring
Topex Poseidon	Joint CNES / NASA satellite altimetry mission, used for studying sea level, ocean bathymetry, tides and ocean currents (now succeeded by Jason)
UAS	Unmanned Airborne System
UAV	Unmanned Aerial Vehicle
UV	Ultra Violet – non-visible short wavelength radiation, useful for volcanic gas estimation
Worldview	Very high spatial resolution commercial satellite (Digital Globe). Useful for local scale mapping and monitoring (e.g. buildings and assets). Currently only panchromatic.



Advances in Geoscience and Remote Sensing
Edited by Gary Jedlovec

ISBN 978-953-307-005-6
Hard cover, 742 pages
Publisher InTech
Published online 01, October, 2009
Published in print edition October, 2009

Remote sensing is the acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s), that is not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, buoy, or ship). In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area. Human existence is dependent on our ability to understand, utilize, manage and maintain the environment we live in - Geoscience is the science that seeks to achieve these goals. This book is a collection of contributions from world-class scientists, engineers and educators engaged in the fields of geoscience and remote sensing.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821