Chapter 15
Utilizing New Technologies in Managing Hazards and Disasters

Ronald T. Eguchi, Charles K. Huyck, Shubharoop Ghosh, Beverley J. Adams, and Anneley McMillan

Abstract This chapter introduces new and emerging technologies that have proven effective in disaster management or show promise in future deployments. These technologies are discussed in the context of the four major phases of disaster management: preparedness, response, recovery and mitigation. Examples of some technologies discussed in detail include real-time hazard warning or monitoring systems; advanced loss estimation methodologies and tools; remote sensing for response and recovery; and field data collection and visualization systems, especially those that are GIS and/or GPS-based. The chapter concludes with a brief discussion of research or implementation issues, focusing specifically on the above technologies, and including issues related to real-time event monitoring; privacy protection; and information sharing and trust management.

Keywords Remote sensing · Disaster management · Damage assessment · Loss estimation · Reconnaissance · Warning and monitoring

15.1 Introduction

Often, disasters act as catalysts for the adoption of new and emerging technologies. Spawned by the need to rapidly collect vital information for disaster management, technical innovations have helped emergency responders more efficiently and rapidly assess the impact of large disasters, and track and monitor progress in critical response and recovery operations. For example, after Hurricane Andrew struck Florida (1992), the lack of rapid damage or situation assessment tools hindered the

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R.T. Eguchi (✉)
ImageCat, Inc., Long Beach, CA 90802, USA
e-mail: rte@imagecatinc.com

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deployment of federal resources and thus identified the need for near real-time loss estimation methodologies. Following the 1994 Northridge California earthquake, use of geographic information systems (GIS) during the initial response and recovery periods provided important visual and spatial information about critical operations (Eguchi et al. 1997a). New York City's World Trade Center attacks (2001), demonstrated the potential use of remote sensing technologies for damage assessment and recovery (Huyck and Adams 2002). And, shortly after Hurricane Charley struck Florida in 2004, deployment of global positioning system (GPS)-based survey technologies helped to "freeze" in time the storm's damage and destruction so researchers could study the effects of significant wind hazards in a more comprehensive and complete manner. All these events underscore the opportunities that emerge when time-critical information can be more efficiently delivered to users who are making critical decisions during a disaster.

The last decade has witnessed technological innovations in numerous areas, including data collection and management, information visualization, smart sensors, robust communication systems (including wireless platforms), loss estimation, GIS, personal digital assistant (PDA) solutions, GPS-based technologies, and remote sensing, often collectively referred to as geographic information technologies (GIT). In many cases, these technologies have existed for many years, however, their application or deployment for disaster response or management has been nonexistent or slow. Part of the reason for the delay in their utilization is the long lead time required for response organizations to understand and embrace the efficacy of these solutions for facilitating response and recovery operations. In almost all cases, implementing these new technologies necessitates replacing "old, but tried and true" solutions. Attempts to replace these solutions, particularly during an actual disaster, are often met with extreme resistance especially if the newer solutions are not problem-free from the outset.

This chapter introduces technologies that have either proven to be effective in disaster management or are considered important components in future deployments. We begin by discussing each technology from the perspective of its maturity level, benefits, and potential drawbacks. In addition, we suggest future directions for incorporating these technologies into different phases of disaster management, i.e., preparedness, response, recovery and mitigation. We also discuss some of the barriers that exist in their deployment and utilization. One of the biggest challenges is overcoming the resistance that typically accompanies the introduction of new technologies. The chapter concludes with a discussion of other issues, some ironically caused by the availability of more powerful information technologies, e.g., privacy protection, information sharing, and trust management.

15.2 Applications to Emergency Management

The following sections describe how advanced and emerging technologies are being used to enhance disaster mitigation, preparedness and response efforts.

15.2.1 Mitigation and Preparedness

While working towards the long-term goal of disaster prevention, in the shorter term, contemporary emergency management is concerned with minimizing the extent and effects of extreme events (Garshnek and Burkle 2000). Mitigation measures serve to reduce or negate the impact of an event, while preparedness efforts facilitate a more effective response once the disaster has occurred.

Hazard Assessment. Hazard identification is a pre-event research activity where remote sensing and GIS play important roles. For example, MIKE21[1] has been used to create detailed digital elevation maps to identify areas at risk of flooding in the event of a dam break (DHI 2007); similarly fluvial and coastal flooding have been modeled using MIKE21 and HAZUS®MH (FEMA 2008). Elevation data are routinely derived from interferometric[2] synthetic aperture radar (IfSAR[3]) (e.g., Galy and Sanders 2000) and Light Detection and Ranging (LIDAR) data. Hazard maps showing landslide potential can be directly created using remotely-sensed detailed elevation readings from such instruments, and indirectly through geological, soil and moisture information from optical and radar coverage (CEOS 2002). Interferometry has also been used to track changes in topography associated with volcanic activity (JPL 1995; Lu et al. 2003), and glacial movement (JPL 2003).

Optical data are particularly useful for the visual assessment of hazards. Monitoring patterns of vegetation growth, identified through classification techniques (Campbell 1996), provides a means of detecting encroachment around energy transportation pipelines (DOT/NASA 2003). Such monitoring ensures adequate access to pipelines in case of needed repairs and/or maintenance. This process is most successful when "supervised" by an analyst, whereby a user identifies "areas of interest" to guide subsequent image-wide categorization. Multi-spectral coverage extending to longer wavelengths of the electromagnetic spectrum offers the unique opportunity to inspect features that are invisible to the naked eye. In terms of wildfire risk, the Southern California Wildfire Hazard Center (SCWHC 2003) documents the quantification of chaparral fuel content using multi-spectral data (c.f., CEOS 2002; Roberts et al. 1998).

Figure 15.1 shows how satellite imagery was used to map the extent of flooding in New Orleans after Hurricane Katrina (2005). The flood boundary shown in Fig. 15.1 was created using expert interpretation of high-resolution imagery provided by DigitalGlobe (QuickBird image captured on September 3, 2005; see Womble et al. 2006 for details on flood boundary determination). This flood boundary was visually compared with an automatically-generated spectral classification of

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[1] MIKE 21 is a professional engineering software package for the simulation of flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas and seas; http://www.dhigroup.com/Software/Marine/MIKE21.aspx

[2] Interferometry is a widely used technique where an object is observed from several angles and then digitally reconstructed as a single, more detailed image.

[3] IfSAR, or InSAR, is an aircraft-mounted sensor designed to measure surface elevation, which is used to produce topographic imagery.

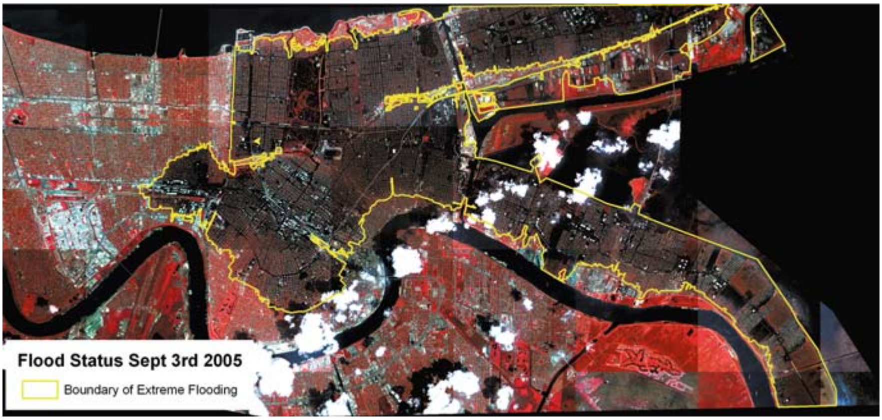


Fig. 15.1 Expert interpretation of September 3, 2005 flood limit (*yellow lines*) overlaid onto DigitalGlobe QuickBird "false color" composite of New Orleans after Hurricane Katrina
Source: Womble et al. 2006

the inundated area obtained from moderate-resolution (30 m) Landsat 5 coverage, captured on 30 August 2005 by the National Aeronautics and Space Administration (NASA), and posted by the USGS on 03 September 2005. Although comparison was precluded in some areas due to cloud cover, the degree of correspondence between the QuickBird flood line and the Landsat 5 spectral classification was generally high.

In addition to mapping the extent of flooding in New Orleans, other remote sensing technologies were used to estimate the height or depth of the flooding. The National Oceanographic and Atmospheric Administration's (NOAA) flood depth map for 31 August 2005 was developed using a combination of satellite imagery from the National Geospatial Intelligence Agency and LIDAR (Light Detection and Ranging) data from Louisiana State University and the State of Louisiana. This map (Fig. 15.2) shows that most of New Orleans was covered by at least 7–9 ft of water, with some areas exceeding 20 ft. The extent of surface flooding shown in this Figure visually appears to correspond well with the flood boundary delineations shown in Fig. 15.1.

Inventory Development. Compiling a comprehensive and accurate database of existing critical infrastructure is a priority in emergency management, since such data provide the basis for simulating probable effects through scenario testing, and set a baseline for determining the extent of damage and associated losses once an event has occurred. In the context of mitigation and preparedness, demand is increasing for accurate inventories of the built environment, in order to perform vulnerability assessments, estimate losses in terms of repair costs (RMSI 2003), assess insurers liability, and for relief planning purposes (Sinha and Goyal 2001; RMSI 2003). In lesser developed regions of the world, such inventories are often scarce. The Committee on Earth Observation Satellites (CEOS 2002) documents a program to compile comprehensive records of urban settlements at risk in the event of an earthquake. This effort is being driven by the experience of the 1998 Afghanistan

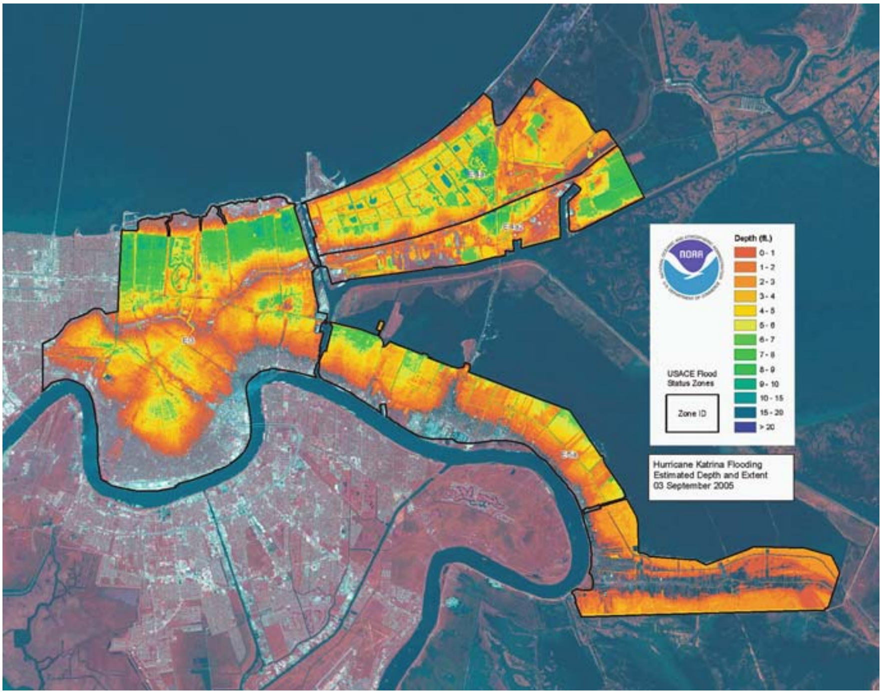


Fig. 15.2 August 31, 2005 flood depth estimation for New Orleans after Hurricane Katrina
Source: No Author 2005

earthquake, when due to the unavailability of even simple maps or images, relief workers experienced extreme difficulty locating affected villages.

Because building inventories are the primary data input into loss estimation models such as the Federal Emergency Management Agency's (FEMA) HAZUS®MH and California's Early Post-Earthquake Damage Assessment Tool (EPEDAT), the more detailed the inventory the more reliable the model output. These models are used as planning tools prior to an event and as response tools once an event has occurred. Measures of interest include: building height, square footage, and occupancy (use). To a large degree, the accuracy of loss estimates depends on the quality of input data. Default datasets are often based on regional trends, rather than local data. Research being undertaken at the Multidisciplinary Center for Earthquake Engineering Research (MCEER), suggests that remote sensing data offer a detailed inventory of both height and square footage, which, through supplementing existing datasets, may lead to more accurate loss estimates.

For example, building height and square footage information can be obtained from a combination of IfSAR and optical imagery (Eguchi et al. 1999; Huyck et al. 2002; Adams and Huyck 2005). The efficacy of this methodology has been tested on case study areas in Los Angeles, where the values for building height and coverage correspond closely with independently derived tax assessor data (Eguchi et al., in press). Methodological procedures are under development to use these results to update existing inventories within the HAZUS®MH program.

A significant advantage of remotely-derived inventories is the relative ease with which they can be updated. This attribute is particularly important at the city scale, where the overview offered by satellite imagery can be used by planning departments to track urban growth (DOT/NASA 2002, 2003). Classifying image features into vegetation, concrete, and buildings is a common task, readily applied to multi-temporal images. Growth or contraction of those features can be detected by examining change between the scenes.

In addition to using active sensors (e.g., IfSAR), new building inventory development techniques are emerging from the use of high-resolution optical satellite data. Research at Stanford University and ImageCat, Inc. has focused on the development of an approach using rational polynomial coefficients (RPC) as a camera replacement model to quickly obtain spatial and structural information from a single high-resolution satellite image (Sarabandi et al. 2005; Chung and Sarabandi 2006). Geometric information that defines the sensor's orientation is used in conjunction with the RPC projection model to generate an accurate digital elevation model (DEM). The methodology described in Sarabandi et al. (2005) shows how the location and height of individual structures are extracted by measuring the image coordinates for the corner of a building at ground level and at its corresponding roof-point coordinates, and using the relationship between image-space and object-space together with the sensor's orientation to arrive at these parameters. Figure 15.3 shows a 3-dimensional model of Long Beach, California developed using this methodology, called the Mono-Image Height Extraction Algorithm (MIHEA).

Loss Estimation. Although loss estimation studies were conducted in the 1960s, only in the 1990s did such methodologies become widely used. A major factor in this development was the emergence of GIS technology that allowed users of

Fig. 15.3 Three-dimensional building inventory model of Long Beach, California Source: Chung and Sarabandi 2006

information technology to easily overlay hazard data or information onto maps of various systems (e.g., lifeline routes, building data, population information).

Loss estimation methodologies are now a vital part of many hazard mitigation studies. These methods are typically used to forecast the potential impacts of different hazard scenarios (typically used for planning), to project losses in an actual event (when used in conjunction with near real-time sensor systems, such as the ShakeMap system deployed by the US Geological Survey), and to assess the benefits of a mitigation activity such as structural retrofit. A National Research Council report, *Impacts of Natural Disasters* (NRC 1999), also discusses the importance of relying on loss estimation modeling as a means of tracking and monitoring the costs of natural disasters. Because current government accounting systems are inadequate when it comes to totaling the costs of a disaster, the NRC report suggests that loss estimation modeling could provide a surrogate means of tracking these costs.

The Federal Emergency Management Agency (FEMA) has recognized the value of loss estimation modeling as a key hazard mitigation tool. In 1992, FEMA began a major effort (which continues today) to develop standardized loss estimation models that could be used by non-technical hazard specialists. The resulting tool, HAZUS®MH, currently addresses earthquake, flood, and wind.

HAZUS®MH is built on an integrated GIS platform composed of seven major interdependent modules. The connectivity between the modules is conceptualized by the flow diagram in Fig. 15.4. The following discussion provides a brief description of each module; detailed technical descriptions can be found in the HAZUS®MH Technical Manuals (NIBS/FEMA 2003a, b, c).

Potential Hazards (1) - This module estimates expected intensities, or the severity of, three hazards: earthquake, flood, and wind. For each of these the software estimates ground motion and ground failure potential from landslides, liquefaction, and surface fault ruptures; flood heights or depths; and wind speeds and wind-born debris. If probabilistic analysis is needed, frequency or probability of occurrence can be included.

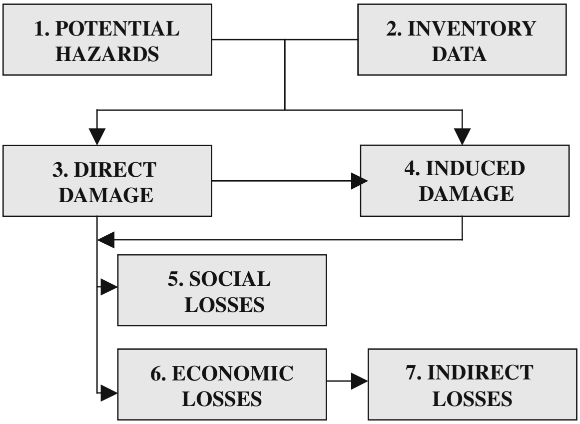


Fig. 15.4 HAZUS®MH modules
Source: (FEMA 2008)

Inventory Data (2) - HAZUS®MH provides a national-level built environment exposure database that allows preliminary analysis without the necessity of collecting local data. This database includes general building stock, essential facilities, transportation systems, and utilities. General building stock data are classified by occupancy (e.g., residential, commercial, industrial) and by model building type (structural system, material of construction, roof type, and height). State-specific mapping schemes are provided for single-family dwellings, and region-specific schemes for all other occupancy types (in all cases, the schemes are age and building-height specific).

Direct Damage (3) - Based on the level of exposure and the vulnerability of structures at different hazard intensity levels, this module estimates property damage in each of the four inventory groups (general building stock, essential facilities, transportation, and utilities).

Induced Damage (4) - Estimates are also calculated for "induced damage", which is secondary property damage occurring as a consequence of an event (e.g., fire following an earthquake).

Social Losses (5) - These losses are estimated in terms of casualties, displaced households, and short-term shelter needs. Casualties are calculated at four levels (minor injury to death), during three times of day (2:00 a.m., 2:00 p.m., and 5:00 p.m.), for four population groups (residential, commercial, industrial, and commuting). Displaced households are calculated from the number of uninhabitable structures, estimated by examining the relationship between damage to residential building stock and utility service outages.

Economic Losses (6) - Direct economic losses are estimated in terms of structural and nonstructural damage, contents damage, costs of relocation, losses to business inventory, capital-related losses, wage and salary income losses, and rental losses.

Indirect Economic Losses (7) - This module evaluates region-wide, longer-term effects by examining changes in sales, income, and employment by sector (i.e., commercial, industrial, retail).

The various modules of the HAZUS®MH software have been calibrated using existing literature and damage data from past events. Pilot studies have been conducted to assess and validate the credibility of estimated losses. Recently, the system was used to assess savings from FEMA-sponsored mitigation activities; the conclusion was that a "... dollar spent on mitigation saves society an average of $4" (MMC 2005, p. 5).

Another example of a loss estimation modeling effort is illustrated by the Early Post-Earthquake Damage Assessment Tool (EPEDAT), which was used during the 1994 Northridge Earthquake (Eguchi et al. 1997b). EPEDAT's use as a loss estimation technique in the immediate post-event context was a key development, marking a significant departure from conventional applications. Beforehand, earthquake loss studies largely addressed the pre-earthquake planning needs of utility operators, the insurance industry and government emergency response agencies. The needs of these entities generally required modeling events that would have the greatest impact on local population and economies (e.g., worst-case scenarios). Technological advances in high-speed computing, satellite telemetry and GIS altered the modeling landscape, making it possible to generate multiple-scenario loss estimates, provide nearly unlimited mapping capability, and (perhaps most importantly) develop near real-time estimates given the source parameters of the event (i.e., magnitude and location). For years, real-time broadcasts of earthquake data including magnitude, location, depth, time of occurrence, and in some cases, ground motion maps or contours, have been available in California and other western states. Access to such data in conjunction with the availability of powerful GIS-based loss estimation tools has made near real-time loss estimates a reality in many seismically-active regions of the world.

Logistical Support. In addition to inventory development, databases of critical infrastructure provide a baseline for determining the extent of damage and associated losses once an event has occurred. For example, remote sensing and GIS technologies played an important role in response efforts at Ground Zero following the 9/11 World Trade Center attack. A pre-existing very detailed base map of New York City, compiled from aerial photos and GIS data, depicted building footprints, roads, and lifelines (Cahan and Ball 2002; Huyck and Adams 2002) – data that underpinned subsequent mapping efforts.

Following the 9/11 attack, it was recognized that several remote sensing technologies were underutilized during response efforts (Huyck and Adams 2002; Huyck et al. 2003). For example, calibrated temperature readings would have been valuable for firefighters, but were unavailable until early October. To facilitate the collection of appropriate and timely data for extreme events occurring within the US, FEMA and NASA have established a Remote Sensing Consultation and Coordination Team (Langhelm and Davis 2002). This team is tasked with identifying suitable data, coordinating its acquisition, and distributing the resulting imagery (Langhelm 2002, personal communication, FEMA Region X GIS Coordinator). To support data collection through the RSCCT system, it is important to have contractual agreements in place before an event occurs. Prior agreements between the New York State Office for Technology and EarthData facilitated overflights of Ground Zero in the aftermath of the terrorist attack (Huyck and Adams 2002).

15.2.2 Response and Recovery

Following the onset of an extreme event, assessing the nature, extent, and degree of damage are priorities. Accomplishing these tasks can be problematic due to the distributed nature of natural disasters, and limited accessibility when transportation routes are disrupted. After the initial chaos has subsided, emergency efforts turn to monitoring activities and the provision of logistical support. In terms of response, advanced technologies (especially remote sensing and GIS) offer a number of distinct advantages over traditional ground-based techniques (Puzachenko et al. 1990; Garshnek and Burkle 2000).

Damage Detection. Damage detection provides information needed to: (a) prioritize relief efforts, (b) direct first responders to critical locations, thereby optimizing response times (Sinha and Goyal 2001) and ultimately saving lives, (c) compute initial loss estimates (RMSI 2003; Tralli 2000), and (d) determine whether the situation warrants national or international aid. In urban areas, building and infrastructure damage (e.g., roads, pipelines, bridges) are of particular interest. This section describes remote sensing damage detection methodologies developed from recent earthquake events and the World Trade Center attack.

The vast US transportation network includes over 500,000 bridges and four million miles of road (Williamson et al. 2002). When a disaster strikes, effective incident response demands a rapid overview of damage sustained by numerous elements, spread over a wide geographic area. Given the magnitude and complexity of transportation systems, near-real time field-based assessment is not an option. For example, during the recent Indian Ocean earthquake and tsunami (2004) centered near Sumatra, the media reported damage to roads and bridges, with a number of villages cut off. Considering the critical 48 hour period that urban search and rescue teams have to locate survivors, accessibility must be quickly and accurately determined in order to reroute response teams and avoid life threatening delays. Earth orbiting remote sensing devices such as IKONOS and QuickBird can present a high-resolution, synoptic overview of the highway system, which can be used to monitor structural integrity and rapidly assess the degree of damage.

A DOT/NASA initiative promoting remote sensing applications for transportation (Morain 2001; DOT/NASA 2002, 2003) has developed preliminary damage detection algorithms termed “Bridge Hunter” and “Bridge Doctor” for highway bridges (Adams et al. 2002). Bridge Hunter locates and compiles a catalogue of remote sensing imagery together with attribute information from Federal Highway Administration (FHWA) databases. Bridge Doctor diagnoses the “health” of bridges, determining whether catastrophic damage has been sustained by quantifying differences in the before-and-after images (Adams et al. 2002). The Northridge earthquake served as a testbed for these algorithms due to widespread damage sustained by the transportation network. Six examples of bridge collapse were available for model calibration and validation. SPOT imagery indicated substantial change between the “before” and “after” earthquake images of the bridges. A bivariate damage plot quantified the visual impression by producing a low correlation/high difference for collapsed bridges, and high correlation/low difference for undamaged bridges (Adams et al. 2002).

The use of remotely-sensed data for assessing building damage offers significant advantages over ground-based survey. Where the affected area is extensive and access limited, remote sensing presents a low-risk, rapid overview of an extended geographic area. A range of assessment techniques are documented in the literature, including both direct and indirect approaches.

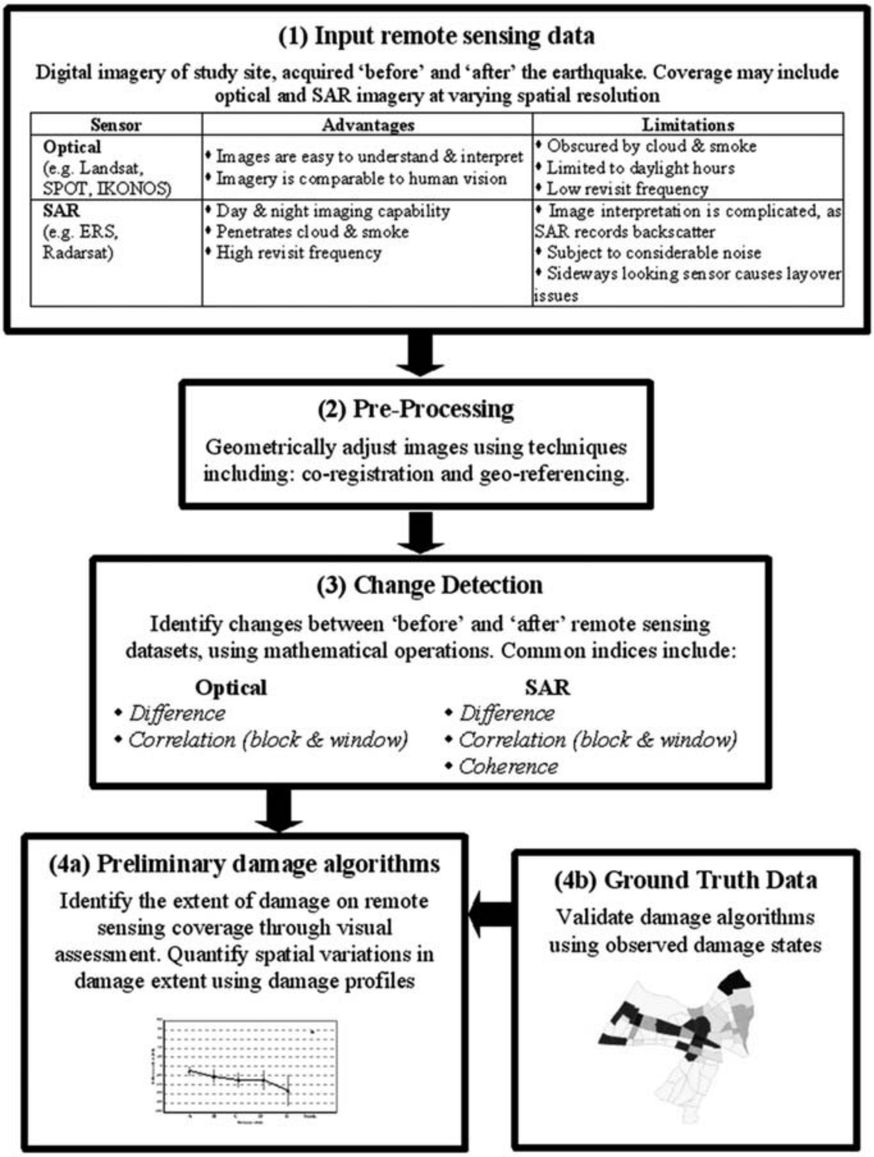
Direct approaches attempt to quantify building damage in terms of the extent or density of collapsed structures (for a useful review, see Yamazaki 2001). Research by Matsuoka and Yamazaki (1998), Chiroiu et al. (2002) and Chiroiu and Andre (2001) suggests that collapsed and extensively damaged buildings have distinct spectral signatures. Unfortunately, moderate and minor damage states are currently indistinguishable from undamaged states.

Direct approaches to building damage assessment may be categorized as multi- and mono-temporal. Multi-temporal analysis determines the extent of damage via spectral change between images acquired at several time intervals, typically before and after an extreme event. Figure 15.5 outlines the methodological process that has been employed at city-wide and regional scales for various earthquakes, using optical and Synthetic Aperture Radar (SAR) imagery.

At a city-wide scale, comparative analysis of Landsat and Earth Resources Satellite (ERS) imagery collected before and after the 1995 Hyogoken-Nanbu (Kobe) earthquake, suggested a trend between spectral change and ground truth estimates for the concentration of collapsed buildings (Aoki et al. 1998; Matsuoka and Yamazaki 1998, 2000a, 2000b; Tralli 2000; Yamazaki 2001). Similar qualitative and quantitative methods were used to evaluate damage in various cities affected by the 1999 Marmara earthquake in Turkey (Eguchi et al. 2000a, b) and the 2003 Bam earthquake in Iran (Yamazaki et al. 2005; Hutchinson and Chen 2005; Chiroiu 2005; Gusella et al. 2005; Rathje et al. 2005; and Saito et al. 2005). Visual comparison between SPOT scenes in Figs. 15.6a, b for the town of Golcuk, demonstrates changes in reflectance due to earthquake damage (see also Estrada et al. 2001a, b). Areas of pronounced change are highlighted by circles. Figure 15.6c, f shows measures of change such as difference, correlation and block correlation (see also Eguchi et al. 2003), overlaid with the zones where ground truth data were collected (AIJ 1999). Graphing the concentration of building damage by each measure generates the damage profiles in Fig. 15.7 (see also No Author 2000; Huyck et al. 2002; Eguchi et al. 2002, 2003). There is a clear tendency towards increased offset between before and after scenes as the percentage of collapsed structure rises from class A–E.

This methodology has also been implemented for ERS synthetic aperture radar (SAR) coverage (Eguchi et al. 2000b), offering 24-hour all-weather viewing, and an additional index of change termed “coherence” (Matsuoka and Yamazaki 2000a; Yamazaki 2001; Huyck et al. 2002; Eguchi et al. 2003). Matsuoka and Yamazaki (2002, 2003) recently generalized this approach to show consistency in the trend between building collapse and remote sensing measures for the earthquakes that occurred in Hokkaido and Kobe, Japan (1993 and 1995, respectively), Marmara, Turkey (1999), and Gujarat, India (2001). The authors detected damaged settlements within the Marmara and Gujurat provinces following those earthquakes. Regional approaches using SAR as a data source provide a quick-look assessment of damage extent and can direct responders to severely impacted areas. Further details of multi-temporal damage detection following the Gujurat event are available in Yusuf et al. (2001a, b, 2002), Chiroiu et al. (2002, 2003) and Chiroiu and Andre (2001).

Mono-temporal analysis detects damage from imagery acquired after a disaster has occurred and is useful where “before” data is unavailable. The methodology relies on direct recognition of collapsed structures on high-resolution coverage, through either visual recognition or diagnostic measures. As with the multi-temporal approach, mono-temporal analysis is most effective for extreme damage states, where buildings have collapsed or are severely damaged (Chiroiu et al. 2002; Chiroiu 2005; Saito et al. 2005).



(1) Input remote sensing data

Digital imagery of study site, acquired 'before' and 'after' the earthquake. Coverage may include optical and SAR imagery at varying spatial resolution

Sensor	Advantages	Limitations
Optical (e.g. Landsat, SPOT, IKONOS)	• Images are easy to understand & interpret • Imagery is comparable to human vision	• Obscured by cloud & smoke • Limited to daylight hours • Low revisit frequency
SAR (e.g. ERS, Radarsat)	• Day & night imaging capability • Penetrates cloud & smoke • High revisit frequency	• Image interpretation is complicated, as SAR records backscatter • Subject to considerable noise • Sideways looking sensor causes layover issues

(2) Pre-Processing

Geometrically adjust images using techniques including: co-registration and geo-referencing.

(3) Change Detection

Identify changes between 'before' and 'after' remote sensing datasets, using mathematical operations. Common indices include:

Optical	SAR
• *Difference*	• *Difference*
• *Correlation (block & window)*	• *Correlation (block & window)*
	• *Coherence*

(4a) Preliminary damage algorithms

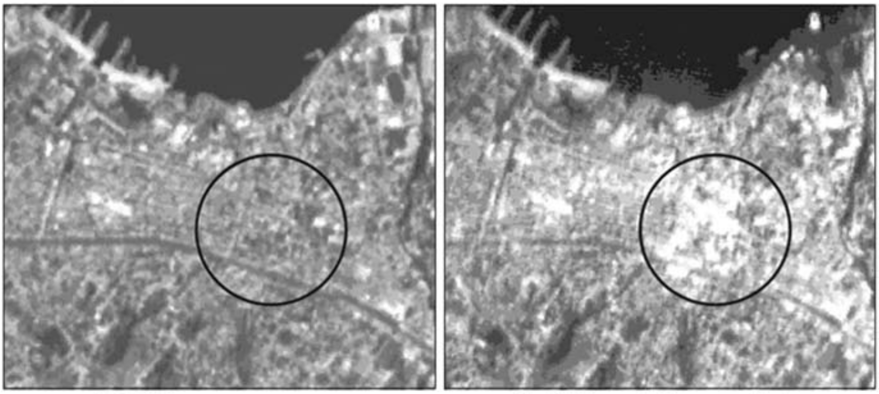
Identify the extent of damage on remote sensing coverage through visual assessment. Quantify spatial variations in damage extent using damage profiles

(4b) Ground Truth Data

Validate damage algorithms using observed damage states

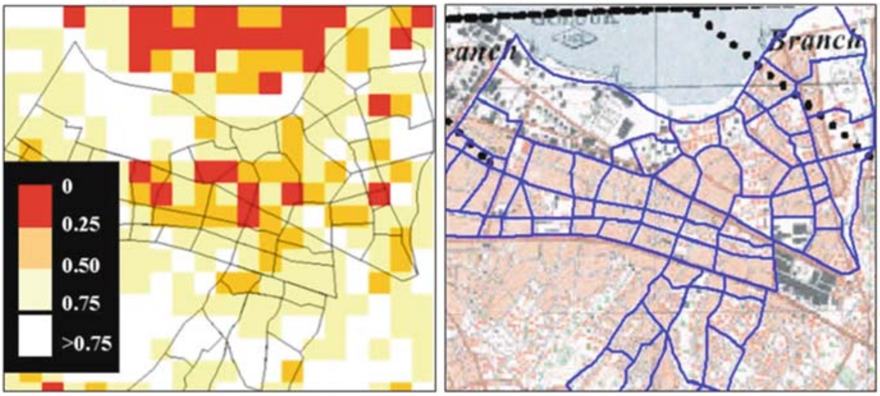
Fig. 15.5 Damage detection methodology employed for buildings and urban settlements, using multi-temporal remote sensing imagery
Source: Adams and Huyck 2005

Ogawa et al. (1999) and Ogawa and Yamazaki (2000) employ mono- and stereoscopic photo interpretation of vertical aerial photography to determine the damage sustained by wooden and non-wooden structures after the 1995 Hyogoken-Nanbu (Kobe) earthquake. A "standard of interpretation" was devised to



(a) ‘Before’ **(b) ‘After’**

(c) Difference **(d) Sliding window correlation**



(e) Block correlation **(f) Damage observation zones**

Fig. 15.6 Panchromatic SPOT4 coverage of Golcuk, Turkey (1999 Marmara, Turkey Earthquake) showing “before” image (**a**); “after” image (**b**); difference values (**c**); sliding window correlation (**d**); block correlation (**e**); and ground truth zones (**f**), where the percentage of collapsed buildings was observed (Data courtesy of the European Space Agency, NIK and Architectural Institute of Japan.)
Source: Huyck et al. 2004

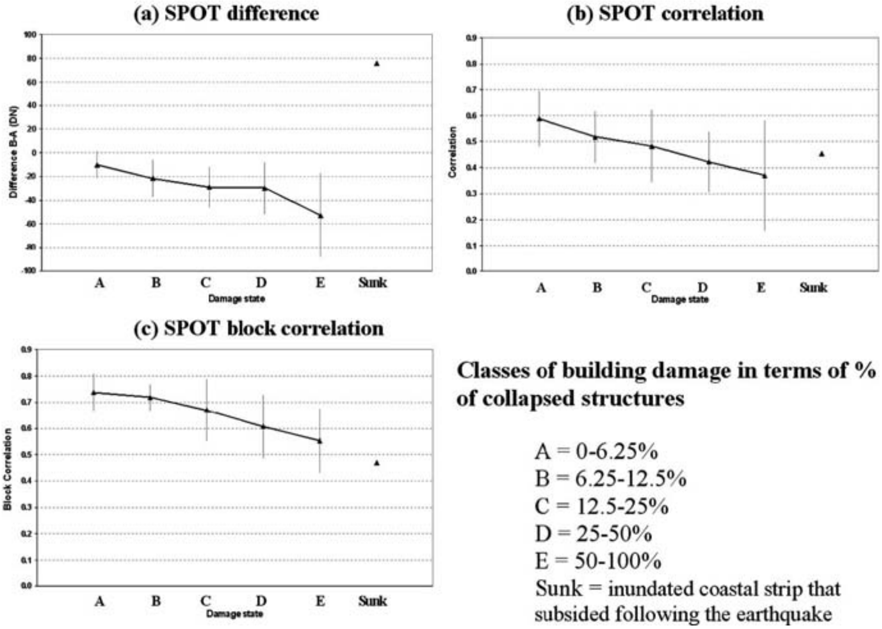


Fig. 15.7 Damage profiles for Golcuk, Turkey (1999 Marmara, Turkey Earthquake) showing how values recorded in the 70 sample zones for each SPOT index of change varies with the concentration of collapsed buildings (a–e). Error bars represent 1 standard deviation about the mean
Source: Huyck et al. 2004

distinguish between collapsed, partially collapsed, and undamaged structures based on: occurrence of debris, level of deformation, and degree of tilt. Success of this methodological approach was judged in terms of correspondence with ground truth observations. Chiroiu and Andre (2001), as well as Chiroiu et al. (2002) used similar criteria to interpret building damage from high-resolution IKONOS satellite imagery of the city of Bhuj following the 2001 Gujurat earthquake, and similar work was performed by Saito et al. (2005) after the Bam, Iran earthquake.

High speed automated aerial television is also emerging as a useful tool for mono-temporal damage assessment. Ogawa et al. (1999) and Hasegawa et al. (2000) inventoried Kobe building collapse from visual inspection of HTTV imagery. Diagnostic characteristics of debris and structural building damage are expressed quantitatively by Hasegawa et al. (1999) and Mitomi et al. (2002) by recognizing collapsed and non-damage scenarios in terms of color, edge and textural information. Multi-level slice and maximum likelihood classifiers determined the spatial distribution of these classes (Mitomi et al. 2001b, 2002). This methodology has been successfully used to detect collapsed buildings from the Marmara (Turkey), Chi Chi (Taiwan) (Mitomi et al. 2000, 2001b), and Gujurat (India) earthquakes (Mitomi et al. 2001a; Yamazaki 2001).

Indirect methods of mono-temporal building damage assessment can also be inferred using a surrogate measure. Theoretically, for example, urban nighttime lighting levels should diminish in proportion to urban damage (CEOS 2002). Hashitera et al. (1999) and Kohiyama et al. (2001) compared night-time lighting levels in US Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) imagery acquired before and after the Marmara and Gujurat earthquakes. In both cases, areas exhibiting the greatest reduction in intensity corresponded with damaged settlements, supporting the hypothesis that fewer lights shine where buildings are severely damaged (Chiroiu and Andre 2001). Operating under the cover of darkness, this damage assessment tool is a useful supplement to optically-based methodologies that are limited to daylight hours.

In addition to the earthquake events described above, damage detection from remotely sensed imagery proved useful following the World Trade Center attack (Cahan and Ball 2002; Hiatt 2002; Huyck and Adams 2002; Logan 2002; Thomas et al. 2002; Williamson and Baker 2002; Huyck et al. 2003). IKONOS coverage acquired on 12th September 2001 and posted on the Internet provided an early visualization of the damage at Ground Zero. The first detailed pictures were captured the following day when the Fire Department of New York (FDNY) recorded oblique shots from a circling helicopter, and Keystone Aerial Surveys took vertical photographs of the area for the New York State Emergency Management Office. From the 15–16th September until mid October, EarthData systematically acquired orthophotographs, thermal and LIDAR data (for a full timeline of data acquisition, see Huyck and Adams 2002). While these datasets were initially used to detect damage, they also played an important role in post-event monitoring.

Another example of a damage map, this time prepared following the 2004 Indian Ocean earthquake and tsunami, is shown in Fig. 15.8. This map was created for the town of Ban Nam Khem in Thailand using expert interpretation of high-resolution pre- and post-tsunami imagery. Of the 761 structures sampled, 449 (59%) were classified as collapsed, with 312 sustaining a lesser damage state. The degree of damage is most extreme bordering the open coast and inlet where 50–100% of the houses were destroyed. The degree of damage rapidly diminishes inland, reaching 0–30% at approximately 500 m from the shorelines (Chang et al. 2006).

Early Warning. For events such as a hurricane where ample time is available before the hazard affects an urban area, tracking or monitoring the progress of the hazard is crucial. Satellite systems have long been used to identify hurricanes and estimate when they will make landfall and where significant damage may occur. NOAA/National Weather Service has recently added "strike probabilities" – with respect to landfall – as well as projected wind speeds for all major hurricane events. This information, when used with simulation models (loss estimation) can provide important data for planning response and recovery efforts.

Several years ago, the feasibility of an early warning system for earthquakes was studied by a research team led by ABS Consulting (ABS 2000, 2001a, b, 2002). The study consisted of four phases: (a) identification of potential users of an earthquake early warning system within selected institutional sectors using a structured telephone survey; (b) review of the risk communication and hazard warning literature to identify relevant findings that apply to the design of warning systems and to the issuance of real-time and near real-time warnings, with a special emphasis

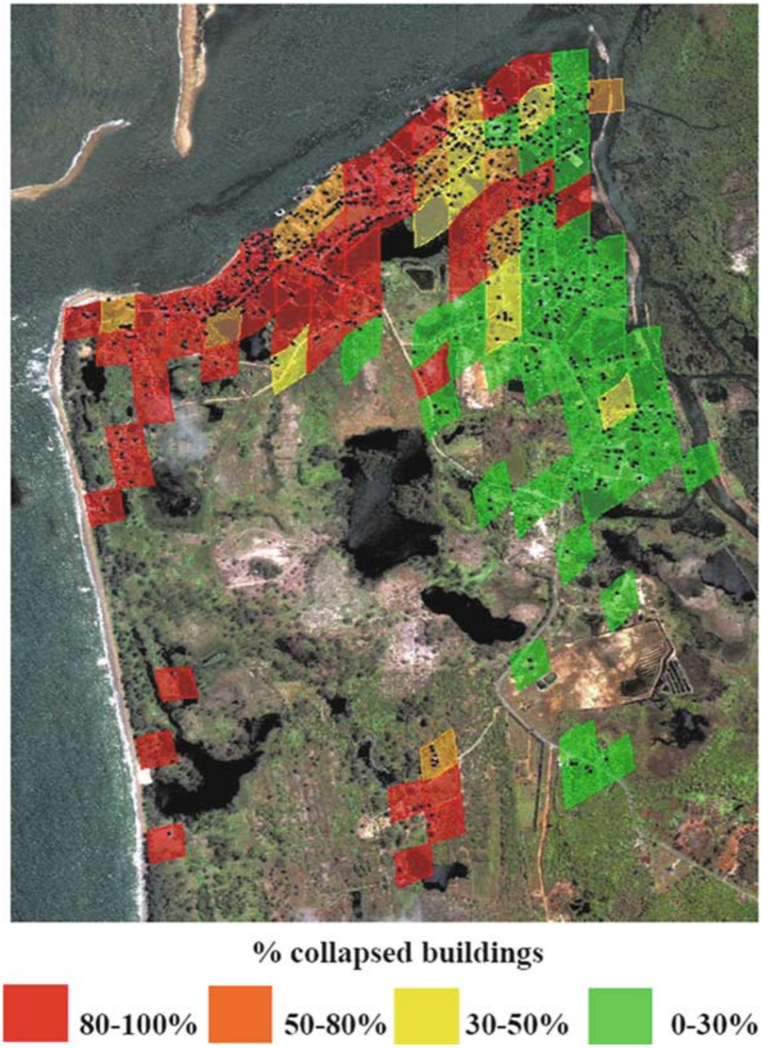


Fig. 15.8 Damage map using high-resolution QuickBird and IKONOS imagery for Ban Nam Khem, 2004 Indian Ocean Earthquake and Tsunami. The percentage of collapsed buildings is computed within zones at 100 m intervals from the open coast and inlet shores
Source: Chang et al. 2006

on the challenges associated with the dissemination of very short-term warnings; (c) identification and analysis of public policy issues associated with the earthquake early warning system; and (d) proposal to design a pilot project to introduce an earthquake early warning system to southern California. The basis for the Seismic Computerized Alert Network (SCAN) was that during an event, seismic sensors located throughout the southern California basin would detect ground motion and earthquake source information early enough to alert areas expected to experience significant ground motions. While this type of early warning system has been successfully deployed in Japan, it has yet to be implemented in the US. A key issue is whether the system provides sufficient time to prepare for impending ground motions. At best it can supply only 1 min of warning between the occurrence of a large San Andreas earthquake near the Salton Sea to the time it would reach the Los Angeles basin.

Post-Event Monitoring. As response efforts unfold following an extreme event, remote sensing is an important source of logistical support. The following section presents selected instances where remote sensing has aided response efforts in the aftermath of man-made and natural disasters (see also Mileti 1999).

In terms of man-made disasters, remote sensing data was of value following the recent explosion of the Columbia Space Shuttle. A combination of airborne COMPASS and radar satellite imagery was used to show the distribution of the debris field (No Author 2003; Oberg 2003). After the World Trade Center attack, LIDAR, thermal imagery and aerial photography acquired by EarthData gave a detailed overview of Ground Zero. Multi-temporal analysis enabled the monitoring of cleanup operations and volumetric analysis using LIDAR elevation data (Fig. 15.9) tracked progress clearing the debris pile. In several instances, the fusion of key datasets provided responders with valuable new information (Huyck and Adams 2002; Huyck et al. 2003). For example, overlaying the 3D LIDAR representation of the debris pile with a map of hazardous materials and fuel sources enabled firefighters to assess what was happening underneath the ground. The correlation between voids and the position of fuel and Freon tanks presented a focus for firefighting efforts, possibly preventing explosions that would have released toxic gases. When thermal data was overlaid with a two-dimensional 75 × 75 ft transparent reference grid established by the FDNY, it provided a common system for tracking objects and remains amongst the debris. And when fused with an orthophotograph, it facilitated strategic planning needed to consider the location of hotspots within the pile (Rodarmel et al. 2002). The thermal data were also used to evaluate firefighting strategies, by visually noting differences in a time series of images during which various chemicals were tested. Aerial photographs were also widely employed as a base-map. Applications included overlay with CAD models of floor plans for the Twin Towers, enabling search and rescue teams to pinpoint specific infrastructure, such as stairwells and elevator shafts.

Remote sensing is also increasingly employed to track oil spills. Danish and Norwegian agencies use satellite and airborne surveillance to perform reconnaissance on detected slicks. CEOS (2002) and Fingas and Brown (1997) note that optical, SAR and laser flurosensor devices are particularly useful for detecting and monitoring oil slicks. Tracking pollution and particulate debris is another emerging application. Atmospheric pollutants are recorded through increased absorption at specific wavelengths of the electromagnetic spectrum. Following the World Trade Center attack, hyperspectral imagery was recorded by the JPL Advanced Very High Resolution Imaging Spectrometrer (AVIRIS). Through studying absorption patterns in narrow bands, it was possible to map the concentration of airborne particulates surrounding Ground Zero, including concrete, cement and asbestos (Clark et al.

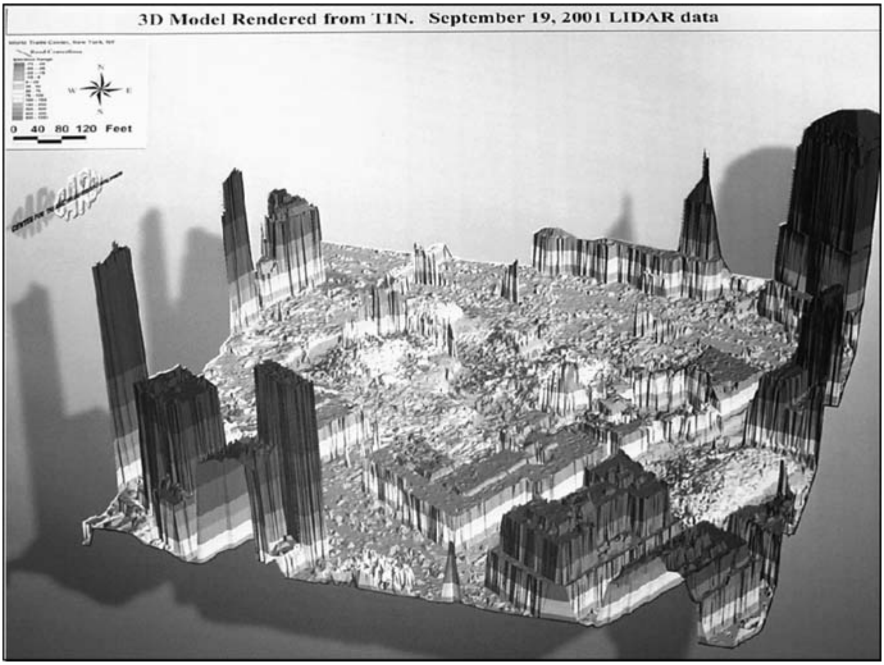


Fig. 15.9 Map showing a 3D terrain model for Ground Zero, produced from LIDAR data acquired by EarthData on September 19th 2001
Source: Adams and Huyck 2005

2001). The Airborne LIDAR Pipeline Inspection System (ALPIS) uses an infrared laser to monitor gas plumes at ground surface level (LaSen 2003). Together, these examples clearly point towards the potential application of spatial technology in response to bioterrorism, and the detection of airborne contaminants (Brown 2002).

For natural disasters, remote sensing applications typically focus on tracking the location and extent of a given hazard, using a temporal sequence of images. In the case of wildfires, the online GEOMAC service (GEOMAC 2003) integrates MODIS thermal imagery (see also Ahern et al. 2001; CEOS 2002). GEOMAC offers a reasonably timely visualization at a regional scale, but until a constellation of low earth orbiting satellites (LEOS) comes online (see Sun and Sweeting 2001), the ultimate target of real-time detection with 15 min updates (CEOS 2002) remains out of reach. For tracking floods, optical imagery has been widely used (Sharma et al. 1996; Laben 2002), despite the persistent challenge posed by cloud cover. A number of authors illustrate all weather capability through integrating optical and SAR imagery (Profeti and MacIntosh 1997; Tholey et al. 1997; Wang et al. 2003). Volcanic eruptions also represent a considerable challenge, creating a range of land- and air-based hazards. Kerle and Oppenheimer (2002) describe the use of optical and radar imagery to track fast flowing lahars. Monitoring the spread of atmospheric ash clouds is a further application area (CEOS 2002; Francis and Rothery 2000), which promises to reduce risk to aviators.

Field Reconnaissance. GPS-based technologies are one of the reasons field reconnaissance efforts after major disasters have improved. Before this technology became available to the general public, documentation of field reconnaissance activities was cumbersome and time consuming. Now, with GPS-systems offering positional accuracies of about 1–3 m anywhere in the world, it is possible to link photos and videos with actual points on the earth. This capability becomes even more important when this technology is integrated with GIS systems.

One of the field-based systems that has emerged in recent disasters is the VIEWS system developed for MCEER. VIEWS is a laptop-based portable field data collection and visualization system used during disaster reconnaissance missions to collect geo-referenced: (i) damage observations, (ii) photographs, and (iii) video footage. The system has been deployed from a moving vehicle, boat, aircraft and on foot. Through a real-time GPS feed, the geographic location of every record is overlaid on "before" and "after" remote sensing images and damage base maps. Through inbuilt GIS functionality, the field team uses the high-resolution satellite scenes to prioritize field survey activities, plan and track their route, and pinpoint damaged structures and features of interest. Traditional methods of post-disaster damage assessment typically involve walking surveys, whereby damage indicators together with the overall damage state are manually logged on a spreadsheet. VIEWS significantly increases the rate at which survey data is collected (Adams et al. 2004b). VIEWS has previously been used in reconnaissance activities following the 2003 Bam, Iran earthquake (Adams et al 2004a), Hurricane Charley and Hurricane Ivan (US Gulf coast 2004) (Adams et al. 2004b, c), the Niigata, Japan earthquake in October 2004 (Huyck et al. 2005), and Hurricanes Katrina and Rita in 2005 (Womble et al. 2006).

The Indian Ocean tsunami event constituted the first deployment of VIEWS and high-resolution satellite imagery for post-tsunami field reconnaissance (Ghosh et al. 2005). The system was deployed to study several key sites from August 16–25 2005, in order to "ground truth" the preliminary remote sensing results. VIEWS was equipped with layers including a Landsat landuse classification, a mangrove change/loss map, and QuickBird and IKONOS satellite imagery. The damage survey of impacted areas (Fig. 15.10) was conducted by a three member team from a moving vehicle, on foot, and by boat depending on vehicular access and type of landuse (e.g., mangrove). Fourteen (14) hours of geo-referenced digital video footage were recorded along the reconnaissance survey route covering about 75 miles (50 miles from a moving vehicle, 20 miles from a boat, and 5 miles walking tour). A library of approximately 550 digital photographs was also collected by the team.

15.3 Challenges

Ironically, the emergence of new technologies – especially, information technologies – has created a number of challenges that are only now being addressed by researchers and practitioners in disaster management. Whereas, the norm several decades ago was to have sophisticated modeling solutions to disaster management problems with little or no empirical data, the situation today is quite the reverse.

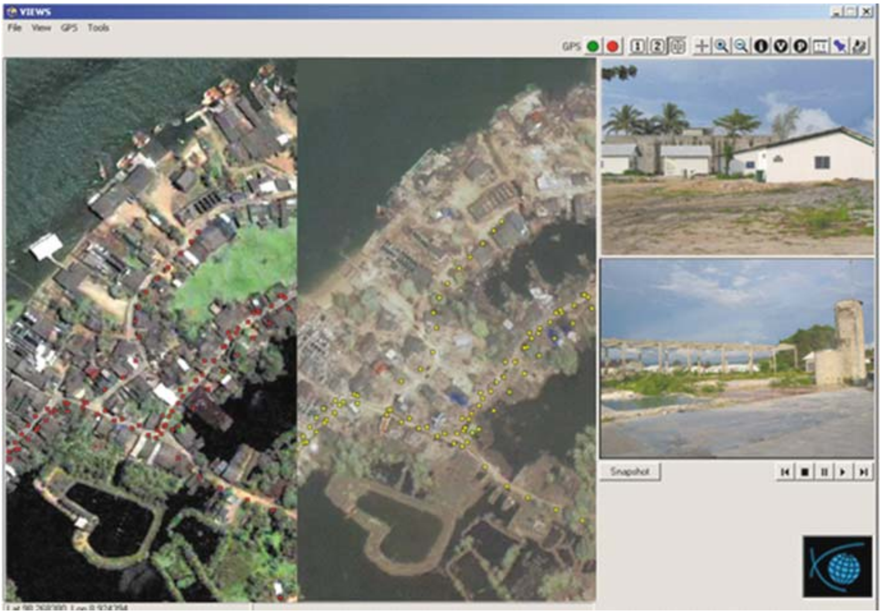


Fig. 15.10 VIEWS interface showing "before" and "after" high-resolution imagery and part of the GPS route (*yellow and red dots*) followed by the field team in Ban Nam Khem – Indian Ocean Earthquake and Tsunami. The upper photograph shows an example of the rapid reconstruction that is occurring, and the lower digital video shows remaining building damage
Source: Chang et al. 2006

Because of widespread field sensors and other data (e.g., remote sensing), the disaster management community has access to much more data than it can possibly handle. Some of the issues now arising because of the overabundance of data and information are real-time event monitoring, privacy protection, information sharing and trust management.

Real-Time Event Monitoring. As discussed earlier, some hazards are monitored through extensive field networks where information on an event as it is occurring can be sent back to some central site where the data can be analyzed. An example of this type of network is the California Integrated Seismic Network (CISN) which monitors earthquake occurrences in California and uses this data to create real-time ground motion intensity maps (http://earthquake.usgs.gov/resources/software/shakecast/). Ideally, the ground motion maps are imported into GIS-based loss estimation tools like HAZUS®MH and the impacts caused by the event can be approximated within a matter of minutes. Similar tools are available for monitoring and tracking significant hurricanes. One of the major issues arising from this process is how to disseminate this information to emergency management officials and the public. One solution being explored is providing information through online systems. By showing maps of heavily shaken areas, emergency management officials can assess where resources are needed first and eventually determine whether outside resources will be needed during the initial response period, mainly to address life safety issues. Furthermore, if these online systems are able to overlay different information layers (e.g., location of hospitals, initial damage reports, location of shelters) onto hazard or damage maps, the public can use this information to decide how best to plan for their own recovery. Some possible applications for an online GIS system include a family re-unification system, guides for where to obtain assistance or supplies, locations of highway closures, locations of hazardous conditions (e.g., fire-following, hazardous materials release; possible dam failure), and locations of utility outages.

Privacy Protection. With increasing amounts of georeferenced data available to the public, privacy protection becomes an issue. Satellite images or aerial photos of workplaces and residences are commonly accessible on the internet. Some internet applications provide photos or video at street levels, potentially capturing images of individuals without their knowledge. While there is no current law prohibiting companies or individuals from taking these photos or videos, there should be general guidelines that either limit the types of photos that can be taken, seeks authorization from individuals included in these images, or follows some protocol to obscure the identification of specific individuals in the images.

Information Sharing and Trust Management. The sharing of data between organizations has always been problematic, either because the mechanism to do so has not been developed or because the information that could be shared is either proprietary or protected under some privacy measure or law. During an emergency, certain types of data should be shared between government agencies so that effective decision-making can take place. For example, sharing damage assessment or repair information between utility companies and transportation agencies because utility companies attempting repairs need to know which roads and highways are still operational. In addition, system-wide repairs for a particular utility system may benefit greatly by coordinating the timing of these repairs with other utilities that may also have experienced damage. In this way, the restoration process can proceed in more systematic and efficient manner. Such coordination is being facilitated through Emergency Operations Centers (EOC), however, joint access to this information on a more real-time basis may provide significant benefits. In order to facilitate this type of collaboration, information sharing technologies that allow organizations to retain control over their information and to ensure the proprietary nature of some data must be developed (e.g., trust management systems).

15.4 Final Remarks

While much progress is evident from the examples given above, remote sensing and GIS technologies are not yet institutionalized into current and future emergency response programs. Disaster experts continually warn governments and the public about the possibility of “worst-case” natural hazard scenarios and their overwhelming impacts. Yet, planning for the occurrence of these events has fallen far short of need. The large earthquake that occurred off the coast of Sumatra, which resulted in one of the deadliest tsunamis ever recorded, was a painful reminder that living in some of the most desirable areas of the world includes risks.

Although predicted some years ago, the disaster in New Orleans after Hurricane Katrina seemed to surprise many, including some key government agencies. While the calamity may have been caused by the “perfect storm,” the response by key government organizations tasked with providing emergency support to New Orleans and other areas affected by the hurricane was neither timely nor effective. Whether the government’s emergency response system was overtaxed to the point where it became dysfunctional will be discussed for many years. It is hoped that such discussion will result in significant changes that will prevent such catastrophic failure from occurring again. Proper use of geospatial technologies could have alleviated some of the confusion and suffering of New Orleans’ citizens; properly applied, such technologies can help response teams alleviate, and even prevent, similar suffering in the future.

In the case of both Katrina and the Indonesian tsunami, new benchmarks were met in terms of the use of GIT to mitigate the effects of these disasters. The 2004 Indian Ocean earthquake and tsunami were among the first events where satellite and airborne imagery of all types was being captured and studied. The commercial high-resolution satellite data provider DigitalGlobe captured and immediately released images of the tsunami wave train hitting the shores of Sri Lanka. Sobering before-and-after images of Banda Aceh showed the world the level of devastation that had occurred. Had such images been captured all along Indonesia, Thailand, India and Sri Lanka in the first few days after the earthquake, a much better situational assessment could have been made and, perhaps assisted in providing a more rapid and coordinated response to the most severely affected areas. More rapid response may not have saved the majority of individuals killed in the tsunami, but could have alleviated much of the suffering and perhaps some lingering health issues that occurred weeks and months after the disaster.

Similarly, a more rapid response after Hurricane Katrina – especially understanding the extent of flooding in New Orleans and inundation areas along the Mississippi – could have provided a more realistic assessment of needs and priorities in the first few days and weeks after Katrina’s landfall. While there were many useful images of these areas taken quickly after the hurricane’s initial onslaught, these images would have been more useful if geo-referenced to a GIS.

In order for GIT to more effectively respond to the next wave of disasters, it must address the following issues or requirements:

- First-responders, and those who provide them with technical support, must have timely access to all images collected after an event. This access is especially pertinent for sensors operated at all levels of government. In addition, there must be adequate training and education for first-responders to enable them to appropriately interpret and use such information for response and recovery.
- Damage detection methodologies must become more robust, capable of working with various levels of data resolution or sensor types. Data fusion should be emphasized, and conclusions based on independent assessments.

- Emphasis needs to be placed on integrating post-event imagery and data into models that predict damage or impacts. Taking model results as the initial a priori estimate of impacts and revising or calibrating this estimate with real, post-event data should provide the basis for model re-calibration and improved output.
- Post-event imagery and event analysis should be posted on the internet as quickly as possible. Access to these data will not only improve response but provide the opportunity for additions and corrections from additional sources.
- Success and failure with respect to the use and adoption of GIT must be documented for every event, to improve its application and implementation for disaster response.
- Finally, government support is critical, especially in terms of research to design, develop and test methodologies, systems, platforms, and other components so that robust disaster response GIT can be developed and deployed not only throughout the US, but around the world.

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