The Application of Remote Sensing Technologies for Disaster Management

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ABSTRACT:
This paper provides an overview of how remote sensing technologies have or could be used in the management of natural disasters. The focus is on methods to improve our understanding the built environment and its vulnerability to natural hazards, and on methods to better assess the impact of large natural disasters on urban areas. In order to demonstrate the efficacy of remote sensing technologies for disaster management, a number of cases studies are presented, including applications for the 1999 Marmara, Turkey earthquake, the 2003 Bam, Iran earthquake, and the 2004 Indian Ocean earthquake and tsunami. The paper also provides a brief discussion on possible future directions for remote sensing in disaster management.

KEYWORDS:
Remote Sensing, Disaster Response, Damage Detection, GPS, GIS

1. INTRODUCTION

In many instances, disasters act as catalysts in the adoption of new and emerging technologies. Spawned by the need to rapidly collect vital information for disaster management, technology innovations have often helped emergency responders to assess the impact of large disasters more efficiently and rapidly, and to track and monitor progress in critical response and recovery operations. Some examples of where technology implementation has been driven by the occurrence of a major disaster include Hurricane Andrew in 1992, where the lack of rapid damage or situation assessment tools hindered the deployment of federal resources and thus identified the need for near real-time loss estimation methodologies; the 1994 Northridge Earthquake where GIS took center stage during the initial response and recovery periods by providing important visual and spatial information on critical operations; the World Trade Center attacks which demonstrated the potential use of remote sensing technologies for damage assessment and recovery; and Hurricane Charley in 2004 where the deployment of GPS-based, field survey technologies helped to freeze in time the damage and destruction of this disaster so that researchers could study the effects of significant wind hazards in a more comprehensive and complete manner. All of these events underscore the opportunities that emerge when time-critical information can be delivered more efficiently to users making critical decisions during the disaster.

One technology which has had an enormous impact on disaster management has been remote sensing. In the past decade, this technology has been used extensively to explain the extent of impacts caused by earthquakes, tsunamis, hurricanes, floods, wildfires and terrorist attacks. Through high-resolution optical imagery and active sensors (e.g., synthetic aperture radar, or more commonly known as SAR, and light detection and ranging or LIDAR), remote sensing technologies have demonstrated significant efficacies in quantifying post-disaster damage, monitoring recovery and reconstruction progress after significant disasters, and more recently, in developing information on our urban infrastructure. One main reason for this rapid progress has been the introduction of high-resolution, commercially-available satellite imagery. Where these technologies used to be available to mainly government agencies (mostly military), they have now become readily accessible to the public. The impact of this development has been most noticeable – in our opinion - in the disaster management area.

This paper focuses on the integration of remote sensing technologies in all aspects of disaster management, i.e., disaster preparedness, mitigation, response and recovery. In order to demonstrate their efficacy in these four areas, cases histories and examples from recent disasters, including the Marmara, Turkey earthquake, the Bam, Iran earthquake, and the Indian Ocean earthquake and tsunami are discussed.

Finally, the paper ends with a view towards the future. What new developments can be expected in technology development and implementation, and what future challenges must be overcome to realize broader application of these technologies in future disasters.

2. INVENTORY DEVELOPMENT

Compiling a comprehensive and accurate database of existing critical infrastructure is a priority in emergency management, since it provides a basis for simulating probable effects through scenario testing, while setting a baseline for determining the actual 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, inventories are often scarce. CEOS (2001) documents a program to compile comprehensive records of urban settlements that could be affected in the event of an earthquake, to avoid a repeat of the 1998 Afghanistan earthquake, when due to unavailability of even simple maps or images, relief workers experienced extreme difficulty locating affected villages.

Although the location of urban centers is generally well documented for developed nations, interest is growing in accurate low-cost methods for characterizing the built environment in more detail. Building inventories are a primary input to loss estimation models, such as the FEMA program HAZUS®MH (Hazards-US) and California (Governor's Office of Emergency Services) system EPEDAT (Early Post-Earthquake Damage Assessment Tool). These are used as planning tools prior to an event and as a response tool once an event has occurred. Measures of interest include: building height; square footage; and structural type 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 offers a detailed inventory of both height and square footage, which through supplementing existing datasets, may lead to more accurate loss estimates.

Figure 2-1 illustrates a methodology where building height and square footage information is obtained from a combination of interferometric SAR (IfSAR) and optical imagery (see also Eguchi *et al*., 1999). Figure 2-1a shows the derivation of buildings heights, in terms of a normalized digital surface model (nDSM). Based on the method developed by Huyck *et al.* (2002), this nDEM is obtained as the difference between a SAR-derived digital surface model (DSM) and a bare-earth digital terrain model (DTM). The former DSM represents the apparent ground surface, as a composite of superimposed features, such as buildings and underlying bare earth topography. The latter DTM is solely topographic, obtained from the same base data via a sequence of filters. As shown by the flowchart in Figure 2-1b, building heights are recorded as the local maxima within footprints delineated on high-resolution aerial photography. The heights are then translated to stories, using a conversion factor that corresponds with standard loss estimation software (see HAZUS®MH, 1997). Ground level square footage is also recorded on a per building basis, as the footprint area in pixel units. Using a scaling factor based on image resolution, this value is converted to single story square footage. Finally, the total square footage for each structure is computed as the product of the number of stories and ground level area.

The efficacy of this methodology has been tested for 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 preparation). Moving forwards, methodological procedures are under development that 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 is particularly important at a city-wide scale, where the overview offered by satellite imagery can be used by planning departments to track urban growth (see DOT/NASA, 2002, 2003). Classifying imagery into vegetation, concrete, and buildings is a straight-forward task, which is readily applied to multi-temporal coverage. Growth is detected in terms of change between the scenes.
In addition to using active sensors, such as IfSAR, new building inventory development techniques are emerging from the use of high-resolution optical satellite data. Research at Stanford University and ImageCat, Inc. have focused on the development an approach for rapidly obtaining spatial and structural information from a single high-resolution satellite image, using rational polynomial coefficients (RPC) as a camera replacement model (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 area extracted by measuring the image coordinates for the corner of a building at ground level and its corresponding roof-point coordinates, and using the relationship between image-space and object-space together with the sensor's orientation. Figure 2-2 shows a 3-dimensional model of Long Beach, California that was developed using this methodology, i.e., the Mono-Image Height Extraction Algorithm, or MIHEA.

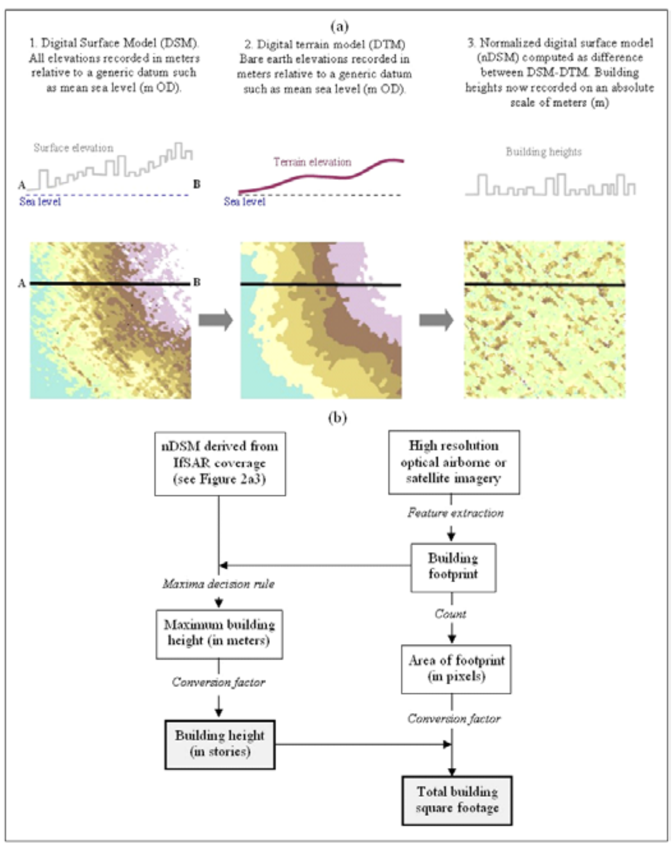

Figure 2-1 A Methodology to obtain Building Inventory Data from Remote Sensing Coverage. (a) The derivation of a normalized digital surface model (nDSM) from IfSAR data, as a basis for building height measurements. (b) Processing steps involved in computing building height (in stories) and coverage (in total square footage). Source: Adams and Huyck, 2006.

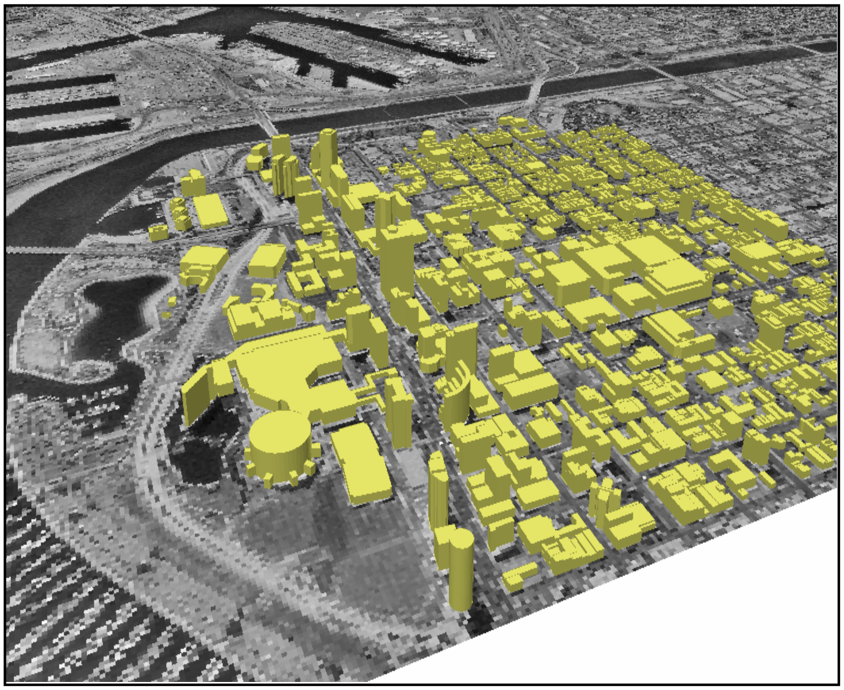

Figure 2-2 Three-Dimensional Building Inventory Model of Long Beach, California.
Source: Chung and Sarabandi, 2006.

3.0 DAMAGE DETECTION

Real-time damage detection following a natural or man-made disaster initiates the response process, providing the 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; and Tralli, 2000); and d) determine whether the situation warrants national or international aid. Of particular importance is damage sustained by urban settlements, together with critical infrastructure, such as roads, pipelines and bridges. In this section, damage detection methodologies developed from the remote sensing area are described for highway bridges and buildings, drawing on research conducted following recent earthquake events and experience gained in the aftermath of the World Trade Center attack. The methodological process follows either a direct and indirect approach. In the former case, damage is detected by directly observing the characteristics of, or temporal changes to an object of interest. In the latter case, damage is detected through a surrogate indicator.

In extreme events, such as natural disasters and terrorist attacks, the performance of critical transportation elements is a major concern. Taking the U.S. as an example, the transportation network is vast, comprising over 500,000 bridges and 4 million miles of road (Williamson et al., 2002). When a disaster like the 1994 Northridge earthquake 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 simply not an option. Taking 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. Irrespective of whether the event occurred in Indonesia or the US, earth orbiting remote sensing devices like IKONOS and QuickBird 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.

Under the auspices of a DOT/NASA initiative promoting remote sensing applications for transportation (Morain, 2001; DOT/NASA, 2002, 2003), preliminary damage detection algorithms termed *'Bridge Hunter'* and '*Bridge Doctor'* have been developed for highway bridges (Adams *et al.*, 2002). From the methodological summary in Figure 3-1, Phase 1 of the damage detection process employs Bridge Hunter to track down and compile a catalogue of remote sensing imagery, together with attribute information from Federal Highway Administration Databases (FHWA) databases. During Phase 2, Bridge Doctor diagnoses the 'health' of bridges, determining whether catastrophic damage has been sustained. In this case, the bridge damage state is quantified directly, in terms of the magnitude of change between a temporal sequence of images acquired 'before' (Time 1) and 'after' the event (Time 2). It is hypothesized that for collapsed bridges, where part of the deck fell or was displaced, substantial changes will be evident on the remote sensing coverage. However, where negligible damage was sustained, change should be minimal.

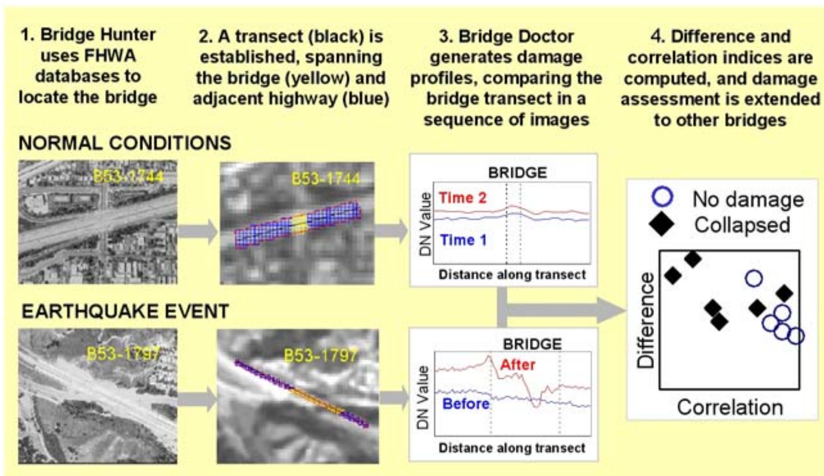

Figure 3-1 Schematic Summary of the 'Bridge Hunter' and 'Bridge Doctor' Damage Detection Methodologies, with examples of results obtained for collapsed versus non-damage bridges following the 1994 Northridge Earthquake. Source: Adams et al., 2002).

The Northridge earthquake was employed as a testbed for model development. Widespread damage was sustained by the transportation network when the 6.7 magnitude event struck Los Angeles on January 17, 1994. Six examples of bridge collapse were available for model calibration and validation. Damage profiles obtained from SPOT imagery clearly distinguish between these extreme scenarios. From the subset of results in Figure 3-1, reflectance signatures for the non-damaged example are consistent at Time 1 (before earthquake) and Time 2 (after earthquake), following a similar pattern along the highway and across the bridge. For the collapsed scenario, substantial changes are evident between the 'before' and 'after' earthquake scenes. The damage profiles no longer follow a similar trend, with abrupt divergence in signature around the collapsed span. Damage indices including difference and correlation offer a quantitative comparison. The bivariate damage plot clearly distinguishes between the low correlation and high difference associated with collapsed bridges, and high correlation and low difference of their non-damaged counterparts.

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, it 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. In the former case, building damage is recorded directly, through its signature within the imagery (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. However, moderate and minor damage states are indistinguishable from non-damage. Damage is usually quantified in terms of the extent or density of collapsed structures. In the latter case, damage may also be determined using an indirect indicator, based on the theory that urban nighttime lighting levels diminish in proportion to urban damage (CEOS, 2001). Further details of the respective methodologies are given below.

Direct approaches to building damage assessment may be categorized as multi- and mono-temporal. Following a similar theoretical basis to the bridge damage methodology described above, *multi-temporal* analysis determines the extent of damage from spectral changes between images acquired at several time intervals; typically before and after an extreme event. Figure 3-2 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 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, 2000b) 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. 3-3a-b for the town of Golcuk, demonstrates changes in reflectance due to earthquake damage (see also Estrada *et al.*, 2001a, 2001b). Areas of pronounced change are highlighted by circles. Figure 3-3c-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 Figure 3-4 (see also EDM, 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 SAR coverage (Eguchi *et al.*, 2000b), which offers advantageous 24/7, all weather viewing, and an additional index of change termed coherence (see also Matsuoka and Yamazaki, 2000a; Yamazaki, 2001; Huyck *et al.*, 2002; and Eguchi *et al.* 2003). Matsuoka and Yamazaki (2002, 2003) have recently generalized this approach, to show consistency in the trend between building collapse and remote sensing measures for the 1993 Hokkaido, 1995 Kobe, 1999 Turkey, 2001 Gujurat, India earthquakes.

At a regional scale, Matsuoka and Yamazaki (2002) detect damaged settlements within Marmara and Gujurat provinces, following 1999 and 2001 earthquakes in Turkey and India. This approach provides a quick-look assessment of the damage extent, and directs responders to the severely hit areas. For further details of multi-temporal damage detection following the Gujurat event, readers are also referred to Yusuf *et al.* (2001a, 2001b, and 2002), Chiroiu *et al.* (2002, 2003) and Chiroiu and Andre (2001). For the 2001 El Salvador earthquake, see Estrada *et al.* (2001a).

Mono-temporal analysis detects damage from imagery acquired after a disaster has occurred. It is particularly 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, it is most effective for extreme damage states, where buildings have collapsed or are severely damaged (Chiroiu *et al.*, 2002; Chiroiu, 2005; and Saito et al., 2005).

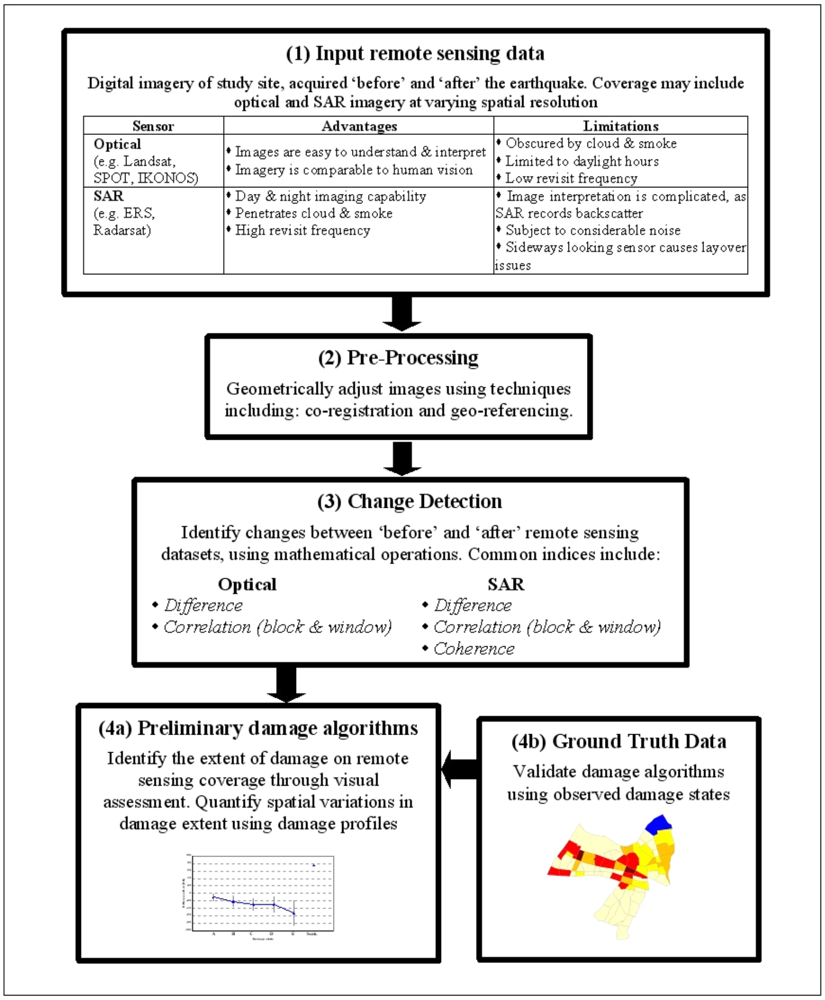

Figure 3-2 Damage Detection Methodology Employed for Buildings and Urban Settlements, using Multi-Temporal Remote Sensing Imagery. Source: Adams and Huyck, 2006.

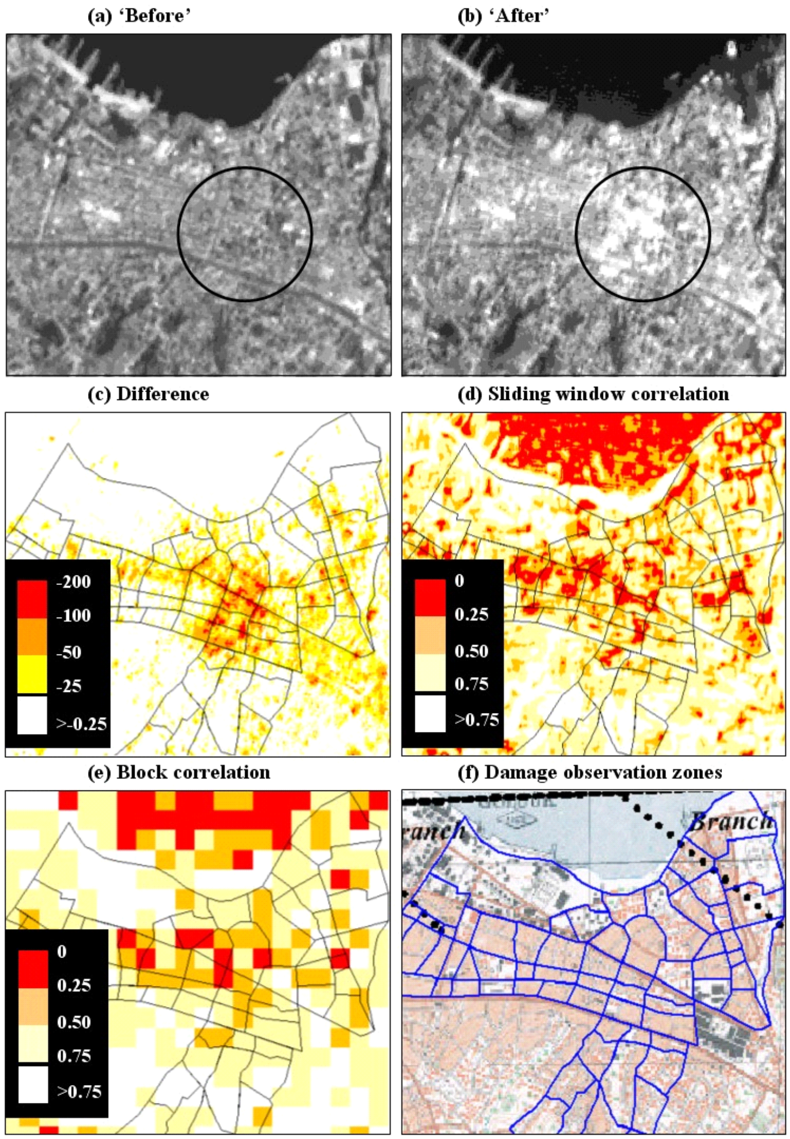

Figure 3-3 Panchromatic SPOT4 coverage of Golcuk, Turkey (1999 Marmara, Turkey Earthquake) showing (a) 'before' image; (b) 'after' image; (c) difference values; (d) sliding window correlation; (e) block correlation; and (f) ground truth zones, where the percentage of collapsed buildings was observed. Data courtesy of ESA, NIK and AIJ. Source: Huyck et al., 2004.

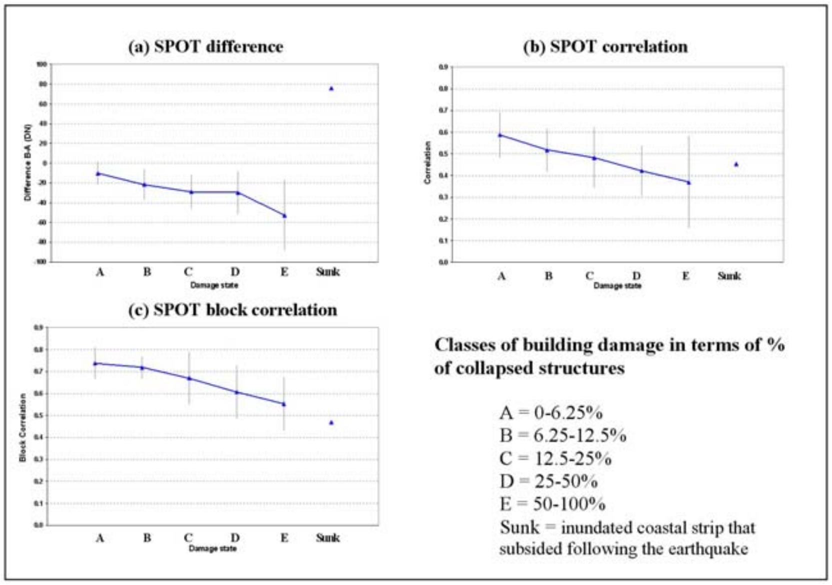

Figure 3-4 Damage profiles for Golcuk, Turkey (1999 Marmara, Turkey Earthquake) showing how values recorded in the 70 sample zones for each SPOT index of change varies with the concentration of collapsed buildings (A-E). Error bars represent 1 standard deviation about the mean. Source: Huyck et al., 2004.

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 in Kobe. A 'standard of interpretation' was devised to distinguish between collapsed, partially collapsed, and non-damage structures, based on: the occurrence of debris; level of deformation; and degree of tilt. Success of this methodological approach is judged in terms of correspondence with ground truth observations. Chiroiu and Andre (2001), Chiroiu et al. (2002) use similar criteria to interpret building damage from high-resolution IKONOS satellite imagery of the city of Bhuj, which sustained extensive damage during the 2001 Gujurat earthquake. Similar work was done by Saito et al. (2005) for 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) inventory building collapse from visual inspection of HTTV imagery for Kobe. Diagnostic characteristics of debris and structural building damage are expressed quantitatively by Hasegawa *et al.* (1999) and Mitomi *et al.* (2002). Their basic methodology recognizes collapsed and non-damage scenarios in terms of color, edge and textural information. Multi-level slice and maximum likelihood classifiers determine the spatial distribution of these classes (Mitomi *et al.*, 2001b, 2002). Although developed using imagery of Kobe, this methodology has successfully detected collapsed buildings in Golcuk, Chi Chi (Mitomi *et al.*, 2000, 2001b) and Gujurat (Mitomi *et al.*, 2001a; also Yamazaki, 2001).

An *indirect* method of mono-temporal building damage assessment is also documented in the literature. In this instance, damage to building stock is inferred using a surrogate measure. Hashitera *et al.*, (1999) and Kohiyama *et al*. (2001) compare 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.

Although examples used to illustrate the preceding methodologies are drawn from earthquake events, damage detection from remote sensing imagery also proved particularly useful in the aftermath of the World Trade Center terrorist 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 people around The World with an early visualization of the devastation at Ground Zero. The first detailed pictures were captured the following day; the Fire Department of New York (FDNY) recorded oblique shots from a circling helicopter, and Keystone Aerial Surveys vertical photographs for the New York State Emergency Management Office. From the 15-16th September until mid October, Earth-Data 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, in respect of their extended temporal coverage, further discussion of their usefulness is reserved for the following evaluation of the role played by remote sensing technology in protracted post-event monitoring.

Figure 3-5 shows an example of a damage map prepared after the 2004 Indian Ocean earthquake and tsunami. The damage map created for the town of Ban Nam Khem in Thailand was developed through 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 between 50-100% of the houses were destroyed. The degree of damage captured by the remote sensing coverage rapidly diminishes moving inland, reaching 0-30% at a distance of approximately 500m from the shorelines (see Chang, et al., 2006 for details).

Figure 3-5 Damage Map for Ban Nam Khem, developed using high-resolution QuickBird and IKONOS imagery – 2004 Indian Ocean Earthquake and Tsunami. The percentage of collapsed buildings is computed within zones at 100m intervals from the open coast and inlet shores. Source: Chang et al., 2006.

4.0 FIELD RECONNAISSANCE

GPS-based technologies have been one of the reasons why field reconnaissance efforts after major disasters have improved significantly. 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 to 3 meters 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 the Multidisciplinary Center for Earthquake Engineering Research (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, 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 logged on a spreadsheet manually. In terms of efficiency, past deployments have indicated that VIEWS significantly increases the rate at which survey data is collected (see, for example, 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 that hit the US Gulf coast in 2004 (Adams et al, 2004b, 2004c); 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 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 16-25th 2005, in order to "ground truth" the preliminary remote sensing results. VIEWS was equipped with satellite base layers including the Landsat landuse classification, the mangrove change/loss map, and the QuickBird and IKONOS satellite imagery. The damage survey of impacted areas (see screen capture of VIEWS in Figure 4-1) was conducted by a three member team from a moving vehicle, on foot, and by boat depending on vehicular access and type of landuse (for example mangrove). Fourteen (14) hours of geo-referenced digital video footage were recorded along the reconnaissance survey route that covered about 75 miles. Of this route, 50 miles were covered from a moving vehicle, 20 miles from a boat, and 5 miles as a walking tour. A library of approximately 550 digital photographs was also collected by the team.

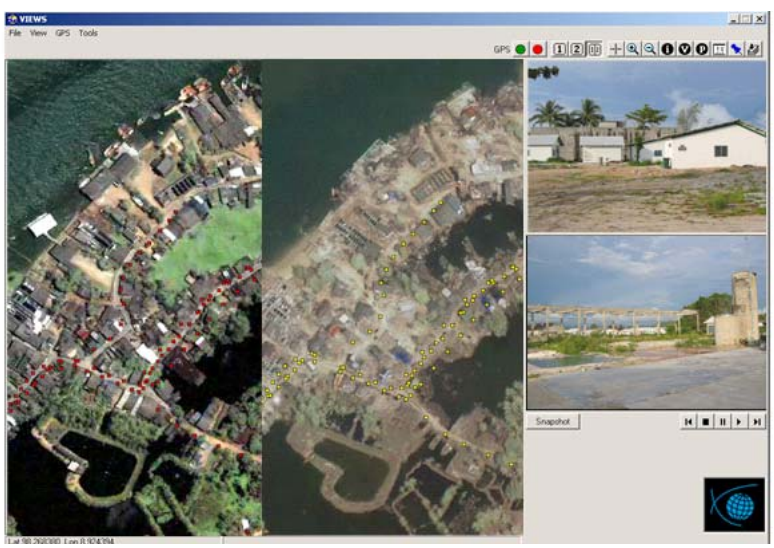

Figure 4-1 VIEWS interface showing 'before' and 'after' high-resolution imagery and part of the GPS route (illustrated by the yellow and red dots) followed by the field team in Ban Nam Khem – Indian Ocean Earthquake and Tsunami. The upper photograph shows an example of the rapid reconstruction that is occurring, and the lower digital video shows remaining building damage. Source: Chang, et al., 2006.

5. FUTURE DIRECTIONS

The following recommendations are offered with regard to future directions for remote sensing applications in natural disasters:

1. Integrate damage assessment methodologies using remote sensing into internet-based visualization platforms, such as Google Earth or Virtual Earth. By offering the results of these assessments via the internet, a much broader audience for these applications is possible.

2. Develop a set of consensus-based damage assessment criteria based on only remotely-sensed data. This is a necessary step in standardizing the results of multi-investigator or multi-event assessments.

3. Explore the feasibility of training structural and civil engineers in utilizing standard damage assessment protocols and remote sensing images to expand the resource base to perform rapid damage analyses for any large event around the world, e.g., the 2008 Sichuan, China earthquake.

4. Explore the use of remotely-sensed data to augment or validate detailed building attribute information for large urban areas. Consider various levels or scales of building inventory improvement based on type of occupancy, e.g., residential, commercial and industrial.

5. Build on current international agreements or protocols (e.g., International Charter) to strengthen the capability of non-government organizations to provide rapid, global assessments for any natural disaster around the world.

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