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Remote Sensing and GIS Technologies for Monitoring and Prediction of Disasters

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Introduction

Sisi Zlatanova and Shailesh Nayak

Natural and anthropogenesis disasters cause widespread loss of life and property and therefore it is critical to work on preventing hazards to become disasters. This can be achieved by improved monitoring of hazards through development of observation systems, integration of muti-source data and efficient dissemination of knowledge to concerned people. Geo-information technologies have proven to offer a variety of opportunities to aid management and recovery in the aftermath. Intelligent context-aware technologies can provide access to needed information, facilitate the interoperability of emergency services, and provide high-quality care to the public.

Disaster management poses significant challenges for real-time data collection, monitoring, processing, management, discovery, translation, integration, visualisation and communication of information. Challenges to geo-information technologies are rather extreme due to the heterogeneous information sources with numerous variations: scale/resolution, dimension (2D or 3D), type of representation (vector or raster), classification and attributes schemes, temporal aspects (timely delivery, history, predictions of the future), spatial reference system used, etc.

There is a need to continuously discuss the state of the observing systems and integration of effective monitoring of disasters, development of predictions systems, integration and analysis of geo-information. Recognising the importance of use of geo-information in disaster management, several universities (Delft University of Technology, VU University Amsterdam, The Netherlands; University of Waterloo, Canada), international organisations (ISPRS, UNOOSA, EU, ICA, FIG, OGC) and vendors (Bentley, Intergraph, Oracle, PCI) have taken the initiative to organise an annual symposium, which aims at uniting the efforts of researchers, developers, data providers and users from different countries and continents. The symposium was organised first in Delft, The Netherlands (March, 2005). Three more symposia were organised under the coordination of the ISPRS WGIV/8: Goa, India (September 2006), Toronto, Canada (2007) and Harbin, China (August, 2008).

The second symposium concentrated on natural disasters as the general theme was 'Remote Sensing and GIS Techniques for Monitoring and Prediction of Disasters'. It was organised by the Indian Society of Remote Sensing, ISPRS, ISRO, UNOOSA, FIG, EC, AGILE, ICA and Delft University of Technology on 25-26th of September 2006, Goa, India. The two-day symposium has accommodated 60 participants from 12 countries.

From the originally 96 submitted abstracts (from 28 countries), 46 full papers were received. The papers were presented in 6 oral sessions and one poster session in the first day. The symposium was closed with a panel session devoted to providing timely geo-information, quality of data, use of technical expertise after a disaster and involvement of geo-specialist in efforts to predict and mitigate disasters.

There are practically no doubts about current status of technology in providing spatial data to end users. Global navigation satellites and Earth observation satellites have largely demonstrated their flexibility in providing data for a broad range of applications: weather forecasting, vehicle tracking, disaster alerting, forest fire and flood monitoring, oil spills detection, desertification spread monitoring, crop and forestry damage assessment. Monitoring and management of recent natural disasters have also benefited from satellite imagery, such as the Indian Ocean tsunami in 2004, floods (Austria, Romania, Switzerland, and Germany in 2005), hurricanes (USA in 2005), forest fires (Portugal, France in 2005), earthquakes (Pakistan in 2005, Indonesia in 2006), etc.

However, it is recognised that effective utilisation of satellite positioning and remote sensing in disaster monitoring and management requires research and development in numerous areas: data collection, access and delivery, information extraction and analysis, management and their integration with other data sources (airborne and terrestrial imagery, GIS data, etc.) and data standardization. Establishment of Spatial Data Infrastructure at national and international level would greatly help in supplying these data when necessary. In this respect legal and organisation agreements could contribute greatly to the sharing and harmonisation of data.

Quality of data in case of disaster is still a tricky issue. Data with less quality but supplied in the first hour might be of higher importance in saving lives and reducing damages compared to trusted, high quality data but after two days. Apparently a balance should be found in searching and providing data as the general intention should be increased use of accurate, trusted data.

Charters and international organizations have already launched various initiatives on the extended utilization of satellite positioning and remote sensing technologies in disaster monitoring and management. For example, the International Charter is often given as a good example of availability of data and expertise after a disaster, but still the coordination between the different initiatives at local and international level is considered insufficient. This observation is especially strong for developing countries, although some authorities in developed countries (e.g. USA in the case of Hurricane Katrina) also fail to react appropriately. Capacity building needs to be further strengthened and the governments must be the major driving factor in this process. Related to this is the role of the geo-specialist in disaster management. Geo-specialist are not directly involved in emergency response, e.g. training together with first responders or preparing monitoring and mitigation programs, but there is high understating of closer work with users.

The Second Symposium has clearly revealed regional specifics in disaster management. While the symposium in Europe addressed Spatial Data Infratsructures and cooperation between different rescue units as major challenges, the symposium in India discussed mostly availability and processing of data and put emphasis on early warning systems, realizing that the national SDI for disaster management either do not exist or are at a very early stage.

The chapters of this book reflect some of the topics mentioned above. The efforts of many researchers over the past four years to continue research and development in the area of spatial data integration for effective emergency services and disaster management have also provided guidance and inspiration for the preparation of this book.

This book consists of 14 chapters organised in three parts. The readings in this book outline major bottlenecks, demonstrate use of remote sensing technology, and suggest approaches for sharing and access of information in various stages of disaster management process.

Part 1: Use of geo-information technology in large disasters.

The first chapter of Kerle and Widarontono elaborate on use of geo-information during the earthquake on 27 May 2006 in the Yogyakarta area, Indonesia. The authors provide numerous chronological details on the work of the different local and national organisations involved and the use of remote sensing data. This particular disasters is an excellent illustration of the works completed after the activation of the International Charter ‘Space and Major Disasters’. Thanks to the almost immediate activation of the Charter, much satellite information could be quickly provided in the first two days. The authors also address some issues that need further improvement such as prices, availability of high resolution data, etc.

The second chapter is devoted to the lessons learned from the Katrina hurricane. The author Henrike Brecht has participated in the emergency response activities immediately after the water flooded the city of New Orleans. The personal observations of the author are organised in five groups of lessons namely management, technology and infrastructure, data, operational (and workflow) and map products. Clearly, many improvements have been observed in providing and use of geo-information comparing to any other disaster in USA, but problems still exist. The chapter provides a very good overview on bottlenecks and failures largely contributing to the 'what went wrong' issue. Interestingly, the lessons learned are very similar to the 9/11 experiences.

The third chapter addresses the damages on the fauna and flora on the Indian cost after the Tsunami, December 2004. Shailesh Nayak and Anjali Bahuguna present their elaborated study on the impact on major ecosystems applying high-resolution satellite imagery. As illustrated in the chapter, the applied methodology has helped to estimate the loss and help in the rehabilitation process. The damage to ecosystem (especially the coral reef and the mangroves) is critical as it directly affects fishery recourses of coastal communities.

After the first three chapters on use of remote sensing information for monitoring and damage assessment, Chapter 4 elaborates on a new initiative for developing countries that have to further ease access and sharing of satellite data. David Stevens elaborated on the tasks and activities of the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER), established in December 2006 as a program of the United Nations Office for Outer Space Affairs. Through presenting recent major meetings, conferences and assemblies, and summarizing the most important activities of various organisations, the author motivates the work of the new program.

Part 2: Remote sensing technology for disaster monitoring

The second part of this book consists of five chapters all presenting remote-sensing technologies (satellite imagery, radar technology, Global Positions Systems) applied for various hazards or phases of disaster management process.

Chapter 5 is a collaborative work of eight universities and organisations and present a broad overview on need of different technology for monitoring of hazards, response to disaster, recovery and mitigation. The authors discuss availability of remote sensing data (illustrated with useful web links), provide practical examples from case studies and report software developments within the participating organisations. Special attention is given to dynamic integration of data for geo-visualisation in virtual environments and on hand-held. The chapter concludes with thoughts about a well-recognised need for an appropriate geo-education for disaster managers.

Hedge, Shalini, Nayak and Rajawat present a satellite-image based methodology for monitoring of pollution in the shore water. According to the authors, the pollution dispersion in the near shore water is highly complex and dependent on a number of factors. Ocean Colour Monitor patterns as well as other satellite data products have helped to successfully trace sediments dispersion and understand sediment dynamics through the different seasons.

In the following chapter, Surendranath, Saibal Ghosh, Ghosal and Rajendran address mapping of landslides in the Darjeeling Himalayas in East India. Again, this chapter is an excellent illustration of use of remote sensing data for monitoring of hazards. The authors are confident that some conventional methods based on aerial photogrammetry and manual inspection can successfully be replaced by high-resolution satellite images. The chapter present details on the methodology for the derivation of accurate DEM from topographic maps, IRS pan stereoscopic satellite imagery and freely available Shuttle Radar Topography Mission elevation data. Their method is especially suitable for highly rugged hilly areas, which are constantly under the highly dynamic and active erosion processes.

Chapter 8 discusses the potential of Persistent Scattered Interferometry for detection and monitoring of land subsidence. This technology reveals high cost effectiveness compare to conventional geodetic techniques. Besides the applicability of radar technology for monitoring of deformations, this research stresses the need of incorporating supplementary geo- information sources for an improved interpretation. Swati Gehlot and Ramon Hanssen report very promising results of applying this technology in the city areas in the Netherlands.

The last chapter in this Part 2 presents an extended procedure for GPS data collection. The improved procedure makes use of special waypoint protocol. Robert Mikol discusses the waypoint naming in detail (and the consequent organisation in a database) and illustrates its applicability for rapid data collection in case of oil spill. Though the DBMS has been never used during oil spill and subsequent cleanup, the idea was accepted as successful for data collection under limited financial resources.

Part 3: System architectures for access of geo-information

This part presents different approaches for management, access and sharing of geo-information for disaster management. Though not specifically concentrated on remote sensing data, the presented systems can easily be used if remote sensing imagery is available.

Jan Herrman addresses the very important issue of access and sharing of data through web services. Access control and security (protection of information) are especially important to enforce restricted access to protected spatial data or to declare views on the relevant data for certain users/roles. The author provides a overview on existing technology and elaborates on the advantages of Geo OASIS's eXtensible Access Control Markup Language (GeoXACML).

Chapter 11 elaborates further on a Spatial Data Infrastructure for disaster management in the Netherlands. The presented system architecture is a typical example of thin client-server architecture, which should be able to serve any type of user on the field or in the commando center. The implemented services are context-oriented and follow recent standardization developments toward chaining of generic services. A spatio-temporal model for management of operational data is one of the few attempts worldwide to manage emergency operational data in DBMS.

Charles Siegel, Donald Fortin and Yves Gauthier report on their system for cooperation and collaboration during emergencies. As discussed in the chapter, real-time contact and making available all the data to all the participants in an emergency is considered a key component in every command and control system. The developed system allows live Internet geo-collaboration, which is in use in civil security operating in the Québec Ministry of Public Security. The presented case studies come from real emergency management situations.

Chapter 13 presents yet another approach to access and visualize data over Internet, this time for flood management. The authors extensively discuss the decisions taken in development of the client-server architecture, data model for management of flood information, street/road networks and other spatial information. This approach convincingly illustrates the advantage of storing and managing information in DBMS: integrated spatial analysis can readily be performed at the server. A light web-application allows for visualization and inspection of performed analysis.

The last chapter presents a usability study about new type of hardware, i.e. Multi Tangible Tabletop User Interface, for its applicability in disaster management. The tangible table does not require use of mouse and keyboard; instead, the user can touch the surface with fingers. As the name suggests, multiple many users can work simultaneously as the table 'remembers' who 'possesses which objects. The authors suggest that this technology could be very appropriate at a tactical level in commando centers, where disaster managers have to discuss steps in managing emergency situations.

The chapters in this book are aimed at researchers, practitioners, and students who apply remote sensing technology in monitoring of hazards and managing of disasters. The book itself is the result of a collaborative effort involving 37 researchers located in 8 countries.

Acknowledgements

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Previous book volumes in the series of Gi4DM

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Part 1: Use of Geo-Information technology in large disasters

1. Geoinformation-Based Response to the 27 May Indonesia Earthquake – an Initial Assessment

Norman Kerle and Barandi Widartono

Abstract

A devastating earthquake occurred on 27 May 2006 in the Yogyakarta area in Indonesia. Response activities began immediately, and included extensive ground-based mapping by Indonesian entities, as well as an activation of the International Charter "Space and Major Disasters", which led to the rapid production of image based damage maps and other assistance. The aim of this paper is to assess the Geoinformation that became available and was used in the aftermath of the disaster. It shows that some of the map products, largely because of lack of field data and communication with forces in the disaster area, were not as effective as they could have been. It further provides a preliminary quality assessment of those damage maps, using data from a house-by-house damage assessment. Disaster response and data processing are still ongoing, and further analysis will be required to determine how the use of Geoinformatics, and the utility of international assistance based on Charter products in particular, can be improved.

1.1 Introduction

At 05:54 AM local time on 27 May, 2006, a magnitude 6.3 earthquake struck eastern Java in Indonesia. With an epicenter approximately 20 km SSE of Yogyakarta near the densely populated Bantul district, close to 6,000 people died and an estimated 154,000 houses were destroyed. Despite frequent geophysical disasters in Indonesia, the affected area had not experienced an earthquake of comparable magnitude in over 100 years, and was thus ill prepared. Simple brick buildings, the principal housing type in the affected area, could not withstand the motion and readily collapsed. Despite the time of the earthquake, very early in the day on a Saturday, many people were already busy outside their homes, limiting the loss of life in one of the most densely populated areas Indonesia with >1,600 people per km^2 (BAPPENAS, 2006).

1.1.1 The earthquake event

The earthquake occurred early on 27 May, at a shallow depth of approximately 10 km, and 20 km SSE of Yogyakarta (USGS, 2006), although epicenter coordinates indicated on various maps, as well as the hypo center depth, have varied substantially. While only limited damage occurred in Yogyakarta itself, the district of Bantul to the south suffered most, with additional substantial damage in the Klaten district to the NE. Preliminary estimates of damage exceed 3 billion US$, over 50% of which attributed to housing damage (BAPPENAS, 2006). The earthquake began just weeks after sustained strong eruptions at Merapi volcano, some 45 km to the North, prompting speculations of a connection. However, the movement followed a previously identified NE-SW-trending fault, and, while Merapi's activity may have played a role, resulted primarily from the Australian plate subducting beneath the Sunda plate at a rate of 6 cm per year (USGS, 2006). Figure 1 gives an overview of the affected area and seismic intensities caused by the earthquake. Note that the epicenter (star) as determined by the USGS is more than 10 km away from the fault line (hatched line) identified by Indonesian scientists as the source of the earthquake.

1.2. Immediate response activities

The disaster led to the immediate mobilisation of a variety of response activities. An USAID/OFTA team arrived on the same day, followed quickly by other organisations over the next few days. Within Indonesia, the established disaster management hierarchy was activated, comprising of Bakornas, Satkorlak and Satlak for the national, provincial and district levels, respectively. The latter coordinated the local work, predominantly in the Bantul and Klaten districts. In addition to these efforts, the Ministry of Public Works carried out a rapid damage assessment for 300 selected public buildings to assess structural integrity, followed by an extensive house-to-house mapping campaign by the geography department of Gadjah Mada University (UGM) in Yogyakarta. About 100 staff and students carried out several ground mapping projects. After an initial survey of the emergency, a rapid building damage survey was initiated, followed by a more detailed one. Data entry and processing are still ongoing, and the large amount of data promises to be valuable in assessing the accuracy and potential limitations of purely image-based damage maps. A preliminary assessment of the parts of the UNOSAT damage maps is provided below. It is based on data for one of 8 mapped districts, Imogiri, for which alone over 14,000 houses were individually assessed for damage.

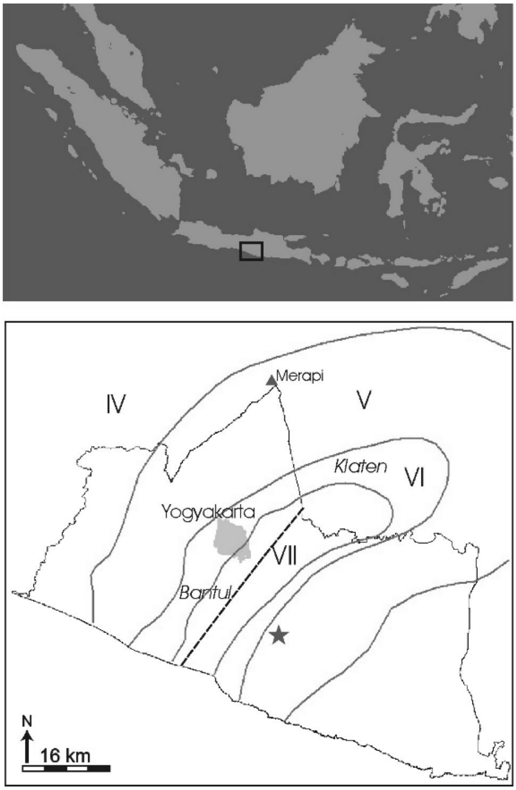

Fig. 1. Map of the disaster area, with seismic intensity zones and the mainly affected districts of Bantul and Klaten, as well as the active fault (hatched line) and epicenter (star) indicated.

The International Charter was also activated on the day of the earthquake by the German Foreign Ministry, and project management assigned to the German Space Agency, DLR. Due to favourable satellite positions and pointability, high resolution satellite data were acquired as early as 28 May, and again on 30 and 31 May, while medium resolution ASTER and SPOT images were taken on 30 May. In addition, Japans Daichi satellite passed over the area on 28 May, collecting images with the AVNIR (VNIR) and PALSAR (radar) sensors. A pre-disaster Ikonos image was also acquired on 9 May 2006, while 2 Quickbird scenes were taken in July 2003, all adding to a substantial array of data. Figure 2 shows the images and ground data that were obtained, and the damage maps produced.

Despite the abundance of images, however, there were also problems. In particular (i) the immediate availability only of lower resolution quick-looks, (ii) distribution by different vendors and organisations at different prices, (iii) availability of the actual satellite data, as opposed to quick-look or jpg-images, only to selected users, and (iv) frequent distribution in smaller tiles led to difficulties. For example, a largely cloud-free Ikonos image covering much of the affected area was acquired on 28 May and was available from CRISP in Singapore, the Asian distributor for Ikonos data. However, LAPAN, the Indonesian mapping agency only received and distributed parts of it (several tiles missing; Fig. 3), while the DLR carried out a preliminary damage assessment only on two lower resolution samples posted on the CRISP site, and later used the cloudier Quickbird image that covered a smaller area. This was because the CRISP Ikonos images are nearly 3 times the price of Ikonos imagery sold through the European vendor, exceeding the budget made available by RESPOND, the GMES service element for the use of Geoinformatics for humanitarian assistance (DLR, pers. comm.).

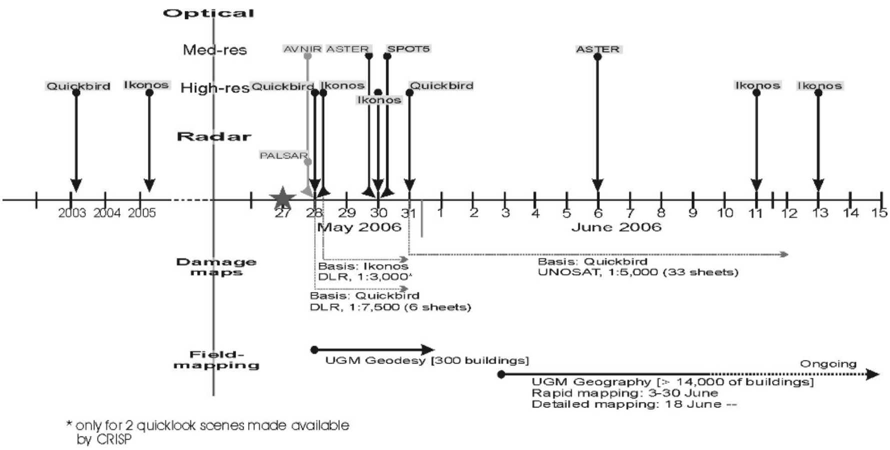

Fig. 2. Overview of high and medium resolution image data acquired before and after the 27 May earthquake. Damage maps based on those images, as well as field mapping carried out, are also indicated.

1.2 Damage Map Products

Image-based damage mapping is constrained by the spatial resolution of the available data and the average size of the destroyed objects to be mapped. If those objects are too small to be imaged individually, texture-based processing is required, by necessity resulting in lower accuracies (Kerle et al., 2008). Given the nature of the predominantly affected houses – small and distributed in clusters amidst heavy vegetation – high resolution data such as Quickbird or at most Ikonos are required. The price for such high detail, however, is not only high image cost, but also lower coverage. From Fig. 4 it is clear that, despite the seemingly extensive image database, only limited high resolution coverage of damaged areas was achieved, further hampered by clouds. Hence the substantial mapping efforts could only produce detailed damage assessment of parts of the area, a typical reality for such disasters, especially spatially extensive ones in tropical areas. Additionally, damage mapping as part of a Charter activation is carried out on a best-effort basis, typically without feedback from the field, constrained by the available or affordable data, as indicated above, and with very limited time. Therefore, focus on especially affected areas at the expense of comprehensive coverage is frequent.

Following the 27 May earthquake a large number of map types was produced by different entities, the majority of them based on field information. Reliefweb (www.reliefweb.int) lists some 50 maps for the earthquake area, primarily produced by UNOSAT, DLR, IFRC, MapAction, and OCHA. All of them are of high cartographic standard and optimised for large-scale printing, and reflect an overall increasing specialisation of different response organisations, each providing assistance according to its specific expertise and resources, and generating map products related to specific aspects of the disaster.

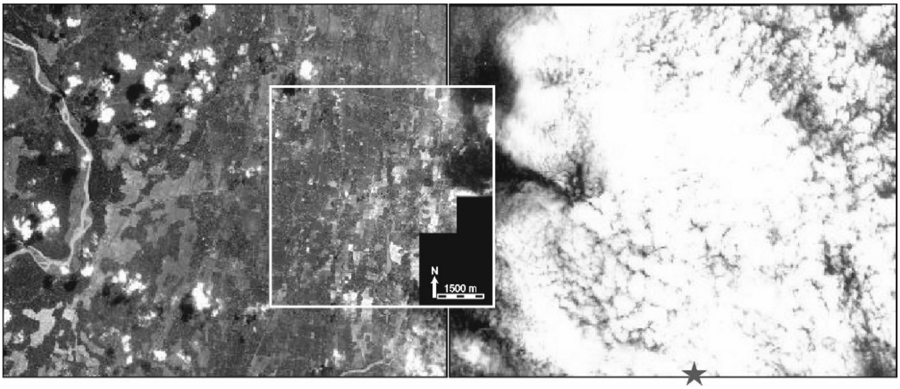

Fig. 3. Ikonos scenes of the disaster area acquired on 28 May, available through CRISP in Singapore (background), and actual scene provided to LAPAN in Indonesia, all color images reproduced here in grayscale. Star shows epicenter. For footprint of the smaller image see Fig. 4.

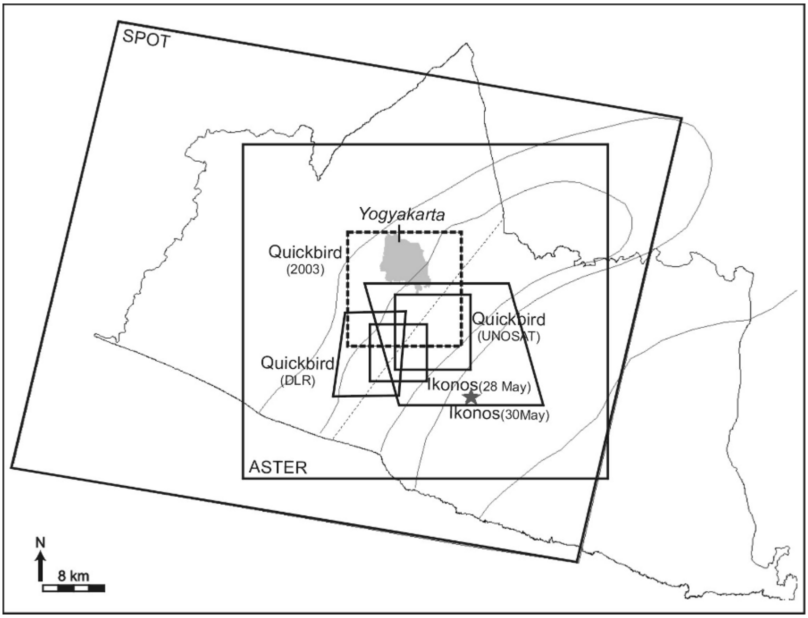

Fig. 4. Footprints of selected pre- (hatched line) and post-disaster (solid lines) satellite images that covered parts of the affected area.

For Indonesia, only DLR and UNOSAT produced image-based damage maps, which include (i) overviews, typically annotated with auxiliary information such as coordinate grids, place names, major roads, etc., (ii) pre- and post- event comparisons with or without further analysis, and (iii) stand-alone damage maps. Each of those categories can contain further sub-types (Fig. 5). All high-resolution versions can be found on Reliefweb, RESPOND (www.respond-int.org), DLR-ZKI (www.zli.dlr.de) and UNOSAT (www.unosat.org).

Maps created after a disaster are aimed at different purposes. They include simple reference maps that facilitate orientation and navigation, status-quo maps of different disaster-related aspects such as landslides or building damage, auxiliary maps showing population densities, utility lines, ethnic distributions, etc., and maps as a planning basis. Those may show possible shelter locations, or areas safe for reconstruction. Depending on their information content, the maps are needed by different users and at different times, and are ideally produced with a specific user group in mind. Especially maps prepared in the first few days after an event, however, are typically prepared far away from, and without a direct communication link to, the disaster area. This results in the risk that maps are prepared without awareness of the specific information needs of, in particular, national response forces in the affected country. Similarly, one of the limitations of the Charter is limited knowledge within potential beneficiary countries on what the Charter may provide, and when. In Indonesia this led to a situation where local institutions carried out their own damage mapping, albeit ground-based but with satellite image support. This was approached from 2 sides. First, as stated above, a limited assessment of public buildings was carried out by the Ministry of Public Works, while UGM organised a more extensive house-by-house mapping campaign that lasted over one month. In addition, bottom-up reporting worked well, where representatives from some 1,200 villages reported damage numbers to district officials, and from there further to the district. This took approximately 2 weeks to be done, longer than the initial image-based maps, but also resulted in more reliable data.

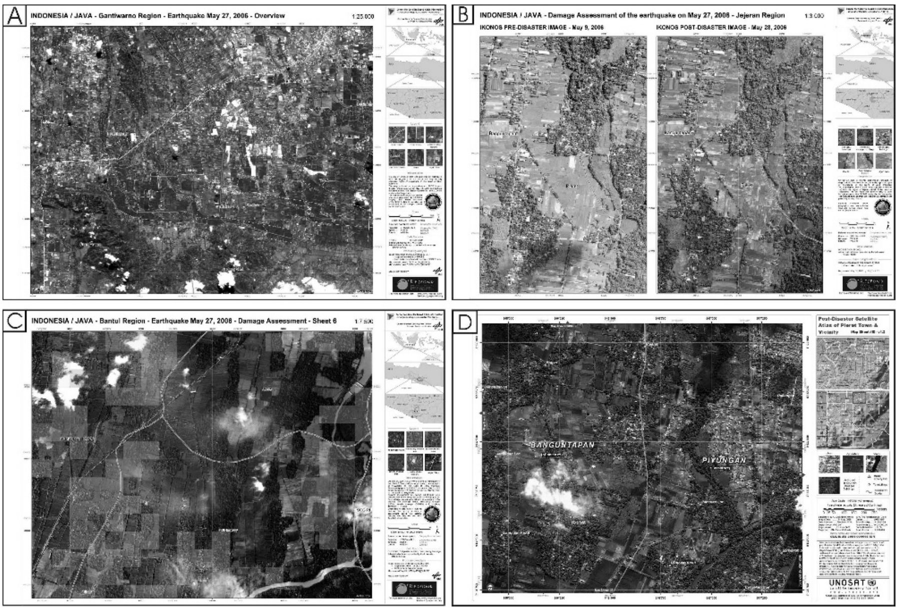

Fig. 5. Illustration of different image-based map types. A: overview map based on SPOT5 data with auxiliary data overlaid; B: damage map based on pre- and post disaster Ikonos data; C: 250m grid damage map based on Quickbird image; and D: more detailed damage mapping on the same Quickbird image (source: A-C DLR, D UNOSAT). All maps are originally on color.

This is particularly so since only a coarse damage map based on 250m grid cell was prepared by DLR at first (published on 31 May), while map results from a more detailed assessment in the area further East that was located in the highest intensity zone, were only published by UNOSAT on12 June, the same day as the map based on village reports (prepared by OCHA, available on Reliefweb).

1.3 The Response Chain and the Weakest Link

Geoinformation has a tremendous potential to facilitate all aspects of disaster management, including response. The general approach is illustrated in Fig. 6, which shows the main elements of the chain, as well as constraining factors.

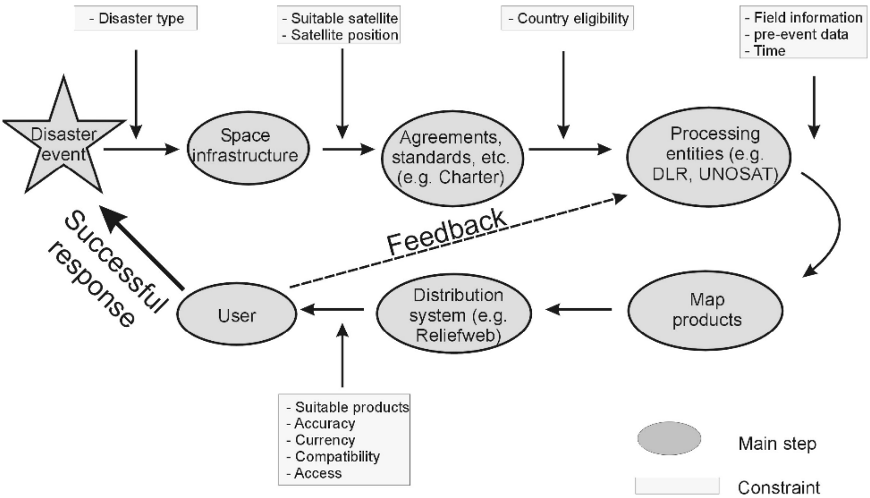

Fig. 6. The Geoinformation-based disaster response chain.

To what extent image-based information can aid in an emergency situation depends primarily on the disaster type (Kerle et al., 2008; Zhang and Kerle, 2008). Suitable sensors are then further constrained by their actual availability, a function of position and pointing capabilities. Civilian data acquisition and distribution is still a relatively slow process, hence agreements such as the Charter have been establish to speed up the process. The acquired data are made available to reference imagery, as well as more analysis time. The map products thus produced can be highly variable in quality. SERTIT, for example, when in charge of a Charter activation, attempts to produce damage maps within 12 hours of image acquisition (SERTIT, pers. comm.). Current distribution of map products is almost entirely internet-based, which allows rapid and lossless global circulation and easy reproduction. Sites dedicated to disaster management support, such as Alertnet or Reliefweb, or sites by the organisations involved in the Charter are very effective in making this information available. The most significant constraint in the chain is the link to the user. Only if map products suit the need of the user, are timely and current, accurate, compatible with existing data, and can be readily accessed, is there a potential to aid in the emergency response.

1.4 Preliminary Accuracy Assessment of Charter Damage Maps

As shown above, the damage maps prepared by DLR and UNOSAT, with the exception of 2 small Ikonos scenes, were based on cloudier or older (31 May) Quickbird data, although its higher spatial resolution also allows more detailed mapping than would have been possible with initial Ikonos data. So far only a small amount of the ground-based damage mapping data are available, which only partly overlap with the UNOSAT damage maps. Of the approximately 14,000 mapped houses in the Imogiri district (dark dots in Fig. 8), some 6500 were completely or heavily damaged, though of those less than 2000 fell into the area covered by the Quickbird image (Figs. 7 and 8). Figure 7 shows part of the 31 May Quickbird used by UNOSAT. *B* shows heavily or completely damaged areas as indicated in those maps, as well as actually heavily damaged or destroyed (squares) or moderately affected (circles) houses as mapped by the UGM campaign. *C* shows a close-up of the image, indicating the how well complete damage is distinguishable in Quickbird data. Parts of the image, in particular in well-exposed damage clusters, were accurately mapped (*D*, location shown in *B*), while more isolated houses in denser vegetation, or structures with less than total damage were harder to identify (*E*). Many more data are expected for the other areas mapped rapidly or in detail (outlines in thick solid and thinner hatched lines, respectively, Fig. 8), and will be analysed in the coming months.

1.5 Conclusions and Preliminary Lessons

Following the 27 May earthquake, extensive ground-based damage mapping was initiated by UGM, while the Charter activation made rapidly acquired high-resolution satellite data available to DLR and UNOSAT. This particular disaster was unusual insofar as a large number of multi-source data became quickly available. Conversely, it was an event quite comparable to other recent disasters such as the earthquakes in Pakistan, Gujarat or Bam, where damage was severe and widespread, confusion reigned initially, and the detailed picture of the destruction only gradually emerged.

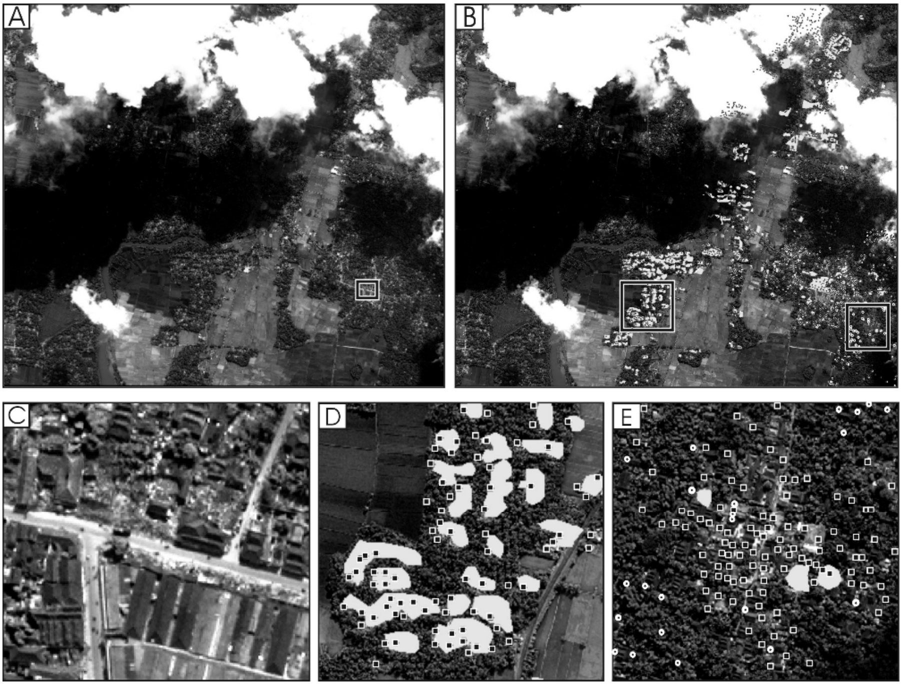

Fig. 7. Part of the Quickbird image of 31 May that was used by UNOSAT for damage mapping (A). See text for details.

Although the Charter was activated and damage maps were produced, knowledge from the field is never or scarcely incorporated in this process. In the Indonesia case it appears that local authorities did not know what products to expect, or when, and hence resorted to their own mapping, benefiting from the proximity of a well set-up university. Here the existing administrative hierarchy also facilitated the damage reporting from villages up to the province level. As illustrated in Fig. 6, the weakest link determines the use of damage maps and other information made available