GIS and Emergency Management in Indian Ocean Earthquake/Tsunami Disaster

An ESRI® White Paper • May 2006

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An ESRI White Paper

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GIS and Emergency Management in Indian Ocean Earthquake/ Tsunami Disaster

Executive Summary

This white paper addresses the utility of geographic information system (GIS) technology in support of the Indian Ocean tsunami relief efforts. ESRI, the world leader in GIS technology, continues to respond and support efforts of humanitarian aid and assistance associated with this event.

Through the course of response and recovery, ESRI served as a facilitator of information. First, it provided contact through its worldwide network of distributors in support of a multitude of GIS users who responded in rescue and rehabilitation missions. In addition, ESRI expanded its Web server, providing technical information, data, and pertinent map products.

Geospatial information remains a key element in disaster management. Investments in planning and preparedness affect the ability of agencies and aid organizations to respond, especially when time is critical. The enormity and the reach of the tsunami event illustrate the challenges of data acquisition, integration, and sharing across jurisdictions and varying data systems. Interoperability remains a vital issue that was amplified by social and political differences. In spite of best efforts, the full potential of GIS was not realized in this event, and ESRI will continue to develop solutions for quick deployment and adaptation under emergency conditions.

This paper describes the event, responses, and attempts to underscore the challenges of data sharing in a dynamic environment. In this case, lessons learned can make a difference when lives literally hang in the balance.

The Indian Ocean earthquake/tsunami disaster once more reinforced the global vulnerability to hazards. This complex, dynamic, and multidisciplinary event allowed the assessment of the technological approaches for disasters. Within these approaches, GIS is one of the high-end technologies that can help save lives and property. To better address its role, ESRI wanted to know how GIS is being used for humanitarian efforts in response to this disaster. Hence, this paper attempts to identify how GIS technology supported rescue and recovery efforts as well as continues to support rehabilitation efforts.

Since this disaster affected many countries and the world's economy, it can be deduced that the problems encountered were diverse. One main problem was that the technology level differed dramatically from country to country. Some countries made relatively good use of GIS, but some could not. Other problems were lack of data, data sharing, communication, and standardization. These problems also created duplication of data. Moreover, accessing data and up-to-date information was difficult and slow. Political obstacles in the government structure and lack of collaboration between agencies worsened the situation.

The hardware used was mainly computers, laptops, mobile phones, global positioning system (GPS) units, and tabular forms. The GIS software used was ESRI® ArcGIS® 9

and ArcView® 3.x and products from MapInfo® and ERDAS®. In particular, Maplex™ and the Military Analyst extension for ArcGIS 9 were used. Topography, census, roads, utilities, bathymetry, elevation, geology, land cover, landmarks, hydrology, administrative boundaries, tidal datum, and orthophoto are examples of data types utilized. Ground control points (GCP) were collected for new geodetic investigations. LandScan (population data), Shuttle Radar Topography Mission (SRTM), Digital Terrain Elevation Data (DTED) Levels 1 and 2, QuickBird™, IKONOS®, and SPOT® were utilized for remote-sensing (RS) analysis. Interactive maps (ArcIMS®, Manifold, DM Solutions), static maps, and Eroom® and Groove technology as well as information sharing were some of the uses of the Internet. This list of hardware, software, data, and Internet usage was compiled using questionnaires and Internet sources and shows the extent of GIS usage. GIS has many advantages, but it was not utilized as it could have been in the disaster region.

The lessons learned from a GIS perspective are

- The database should be ready beforehand.

- The imagery database should be kept up to date.

- The GIS technology usage level should be more advanced to make better use of its capabilities.

- Country-based sociopolitical issues should be handled with care when implementing actions, especially for the recovery phase.

- Government, private, and local agencies accompanied by international agencies should collaborate closely for emergency actions and employ GIS.

- International, national, and local agencies should go beyond investing in crucial life support and invest in GIS.

ESRI should consider some developments for emergency situations such as

- A special emergency installation package
- Merging different versions of the software
- Common workspace environment

A special emergency installation package would be supportive due to the problems encountered during field use of the software. Quick installation and a tutorial on using the Data Interoperability extension would enable relief workers to start working more rapidly. The emergency package could also include a business partner's products such as GPS units. Another important issue is the system integration between different versions of the software. A workspace environment in which GIS data sharing and communication is possible would also be useful. This will create solutions for the problems experienced in this disaster as well as future ones.

In conclusion, it is important to be prepared and mitigate the disaster before it occurs. Decision makers should take into account the current situation and work closely with scientists to implement the required policies. Since disasters have no boundaries, international collaboration and enhancement of technology usage should be the first steps. As for ESRI, showing the best practices of GIS utilization and promoting its usage are key issues.

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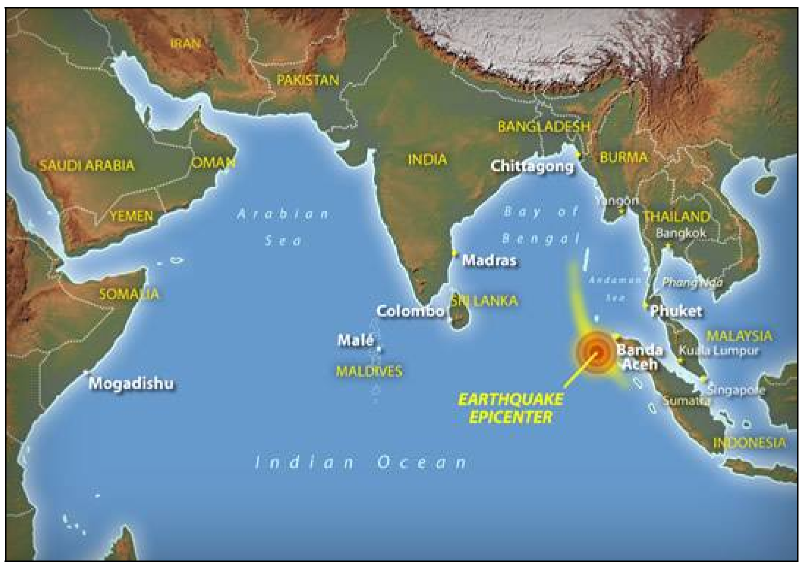
Introduction

On December 26, 2004, at 00:58:53 UTC, a magnitude 9 earthquake hit the Sumatra Andaman islands in the Indian Ocean (figure 1). The earthquake caused a secondary hazard, a tsunami, which amplified tremendously the casualties and property loss. The waves reached 18 meters in height and extended 8,000 kilometers from the quake's epicenter.

Tsunami is a Japanese word for harbor waves and refers to the natural phenomenon of a series of waves generated when water in a lake or sea is rapidly displaced on a massive scale. Earthquakes, landslides, volcanic eruptions, and the impact of extraterrestrial bodies such as meteorites can generate tsunamis, which can rapidly and violently inundate coastlines, causing devastating property damage, injuries, and loss of life.[1]

Figure 1



Indian Ocean and the Epicenter of the Earthquake on December 26, 2004

The Indian Ocean earthquake/tsunami was one of the biggest catastrophes in history. The areas most affected were Indonesia, Malaysia, Sri Lanka, India, and Thailand, respectively. Following are disaster-related statistics as of November 2005.[2]

Table 1

Deaths	**=**	**186,983**
Missing	**=**	**42,883**
Homeless	**=**	**1.7 million**

Casualty Statistics

As of February 24, 2005, the worldwide insurance company Munich Re estimates the overall economic loss at more than $10 billion[*] and the insured loss at approximately

[1] Tsunami (http://en.wikipedia.org/wiki/Tsunami).
[2] UN Office of the Special Envoy for Tsunami Recovery (www.tsunamispecialenvoy.org).
[*] All dollar amounts are U.S. dollars unless noted otherwise.

$1–2 billion. International donors acted quickly with a great amount of donations. Of the $10 billion appeal, 70 percent have already been raised. Furthermore, a total of $6.4 billion in government aid, $1.7 billion in private aid, and $1.7 billion in loans has been donated to the affected countries.[3] Such a large amount of donations coupled with a complex situation made it imperative that monies be distributed equitably according to need.

With the high death toll and large amount of donations received, effective disaster management has been crucial. To deal with this issue, not only basic activities (such as providing lifesaving supplies) but also technological solutions should be used. In these circumstances, GIS technology has become more important than before to disaster management issues. The ability to provide answers to vital questions, such as where the most affected areas are and how they can be reached, saves time in an emergency situation.

In the first few weeks following the disaster, the technological data provided from all over the world for the disaster area was sparse and unorganized. Many organizations wasted valuable time in duplicating preliminary and critical data such as damage maps. Because of a lack of coordination, some of the information released that could have supported other organizations in solving a problem was not used. The need to produce new data was significant. All these problems underscore the need for information management. Emergency management requires both static and dynamic information in different stages of an emergency. Ideally, GIS in its best practices should be used in both phases. This paper addresses GIS usage in humanitarian efforts and focuses on both stages of emergency management—response and recovery.

Objectives

The objectives of this white paper include the following:

1. Identify how GIS technology has supported rescue and recovery efforts as well as continues to support rehabilitation efforts.

2. Identify where these implementations of technology are occurring.

3. Provide a report on each deployment that includes

   a. The organizations or agencies deploying the technology, denoting a contact person whenever possible

   b. The mission they are supporting and the tasks they are attempting to complete
      i. Identify the key mapping products used to support the mission.

   c. The technology that is being used
      i. Software
      ii. Hardware
      iii. Data
      iv. Web services

   d. Screen shots and photographs if available

4. Identify barriers and issues in technology deployments.

[3] Reuters, January 11, 2005.

5. Describe and expand upon issues/problems and barriers that were pervasive or common within the overall affected areas.

6. Describe what GIS data and products were important to the rescue and recovery efforts.

7. Describe GIS data and products not available that would have been useful.

8. Describe how technology could assist in preventing catastrophic loss of life and property for this region of the world.

The following were used to gather information:

- Internet
- Questionnaires
- Conference calls
- ESRI network
- ESRI data relating to the disaster

The collected information enabled the creation of the following products:

- A poster map that shows the disaster area with relief organization locations
- An online, interactive map with the same information (using ArcIMS)
- A tsunami intensity map for the Indian Ocean and surrounding area
- An ArcGlobe™ map project showing the plate boundaries for tsunami risk areas
- Text files
- GIS data

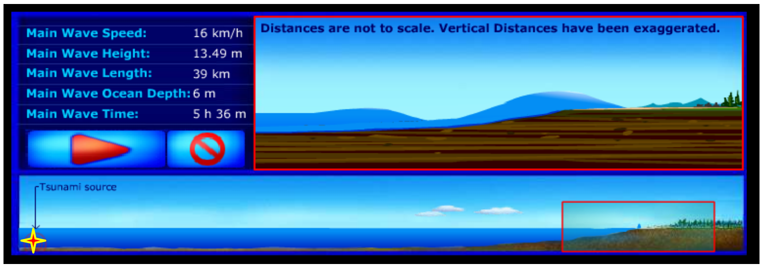
Tsunami Hazard

What Is Tsunami Hazard?

Tsunamis are large, long water waves caused by underwater earthquakes, submarine volcanic eruptions, or the impact of extraterrestrial bodies such as meteorites or landslides. As a tsunami approaches the shoreline, the enormous amount of energy that has been stored in the long wavelength is transferred to wave height with terrible consequences (figure 2). In particular, gulfs, bays, and estuaries are some of the most vulnerable coastlines. The shape of these inlets creates a funnel-shaped tsunami that amplifies into a big wall of water weighing billions of tons that crashes inland with enormous power.[4] The term *run-up* refers to the height of the tsunami measured above mean sea level. Additionally, tsunamis are generally not only a single wave but a series of waves. The first one to reach the coastline is the highest. The series of waves creates more damage than a single one. Hence, the structures and people able to escape the first wave are at risk from following waves.

[4] Kovach, R., and McGuire, B. 2003. *Guide to Global Hazards*.

Figure 2



Wave Height Rising as It Approaches the Shore

In figure 2, close to the tsunami source, the wavelength is longer and the height is lower compared to the wave properties closer to the shoreline. The energy released causes great wave heights. When a wave reaches the shore, it destroys everything in its path. Besides the number of deaths, missing people, and affected population, the effects of a tsunami can also be measured in surface, infrastructure, and agriculture damage.

Table 2

Type of Disaster	Effects on the Earth's Surface	Effects on Infrastructure	Effects on Agriculture
Seaquakes or tsunamis	Floods Salinization and sedimentation in coastal strips Contamination of water and water table	Destruction of, or damage to, buildings, bridges, roads, irrigation, and drainage systems	Localized damage of crops Destruction of coastal plantations Changes in reproductive cycles of coastal fauna and damage to fishing

Tsunami Disaster Effects on the Earth's Surface, Infrastructure, and Agriculture

On December 26, 2004, all the effects in the table shown above took place. In general, the environmental damages are

- Gouged beaches
- Crushed coral reefs
- Thousands of hectares of mangrove trees decimated
- Altered coastlines from Thailand to Somalia
- Rice paddies and vegetation flooded with salty water

The United Nations Environmental Programme's (UNEP) environmental rapid assessments have identified gaps in the Asian tsunami disaster report including

- The lack of vulnerability mapping and comprehensive risk assessment

- Minimal field assessments to date mainly restricted to areas of high population density

- The historic lack of environmental baseline data

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- The lack of environmental quality assessments and data on toxic and hazardous wastes that may be mixed with other debris
- The lack of environmental guidelines in national disaster plans (if they exist)

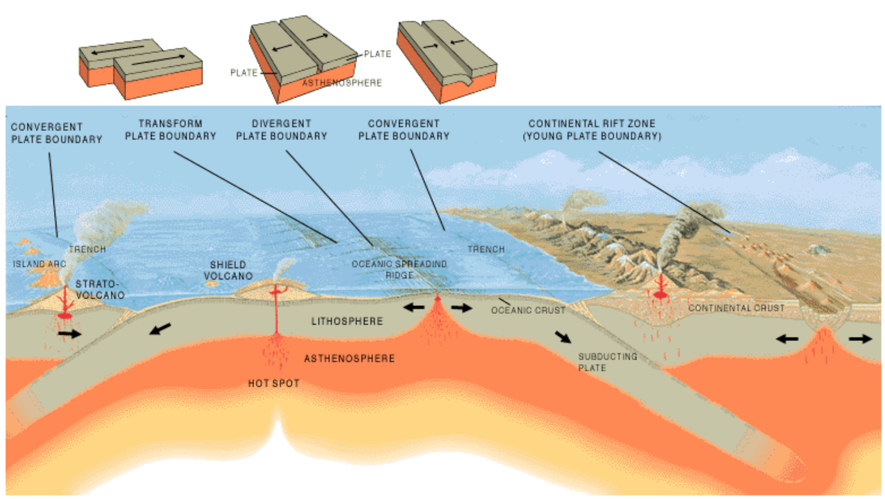
In Thailand, 80 percent of the coral reefs were destroyed. In Indonesia, Thailand, Maldives, and other countries, mangrove trees were decimated. Damage to these trees, however, is less serious than other types because mangroves have the ability to recover quickly. All the rice paddies and other vegetation/agriculture were flooded with salty water and will need two to three rainy seasons to wash away the salt.

What Is the Mechanism behind an Earthquake That Triggers a Tsunami?

Not all earthquakes create tsunamis. And earthquakes are not the only cause of tsunamis. Submarine volcanic eruptions, meteorological events, or landslides can also trigger tsunamis.

To better understand earthquakes that can create tsunamis, the processes involved should be adequately identified. Humans live outside the thinner layer—the crust—of the lithosphere, which could be likened to the shell of an egg. As with an egg, the earth's "shell" is only a small portion of the earth, and natural processes experienced on the crust have their origins far below the surface. At greater depths, the earth's temperature, density, and pressure increase. Between 100 and 2,900 kilometers deep, the heat induces convective currents. These currents can and do move the upper crust—the thin layer that is hard and rigid. Ridges are formed by plates of floating crust moving away from each other, and new crust forms as a result of the action. Trenches are formed when the plates collide or slide against each other. Three different plate boundaries could be defined according to their movements—transform, convergent, and divergent (figure 3). Plate boundaries are the highly active areas of earthquakes. In particular, convergent plate boundaries could cause tsunamis because of their ability to create sudden, high vertical movements at the seafloor. This movement will displace the water covering the seafloor vertically and horizontally and create tsunamis. As the water mass attempts to regain its balance, all of its boundaries (ocean, sea, or lake) will be affected at different levels.

Figure 3



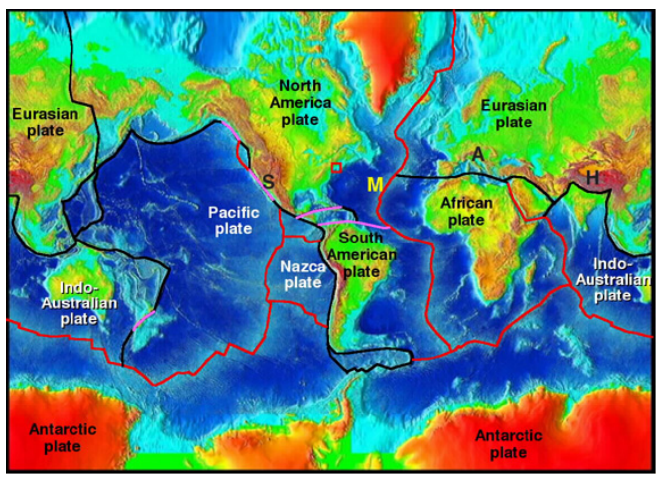
Three Types of Plate Boundaries—Transform, Convergent, and Divergent

The December 26, 2004, earthquake had several characteristics that contributed to the creation of the tsunami and magnified the catastrophe. First, it had a large magnitude (moment magnitude = 9.0), which is the largest earthquake recorded worldwide in 40 years. Second, the plate boundary was convergent. Third, it occurred off the coast in deeper water. Fourth, the earthquake had a shallow focus (generally, 0–70 kilometer depth is defined as shallow). Finally, the lateral displacement caused large vertical displacement (maximum 20 meters), and the total length of the rupture was more than 1,200 kilometers. The devastating megathrust earthquake of December 26, 2004, occurred on the interface of the India and Burma plates and was caused by the release of stresses that developed as the India plate subducted the overriding Burma plate. In the region of the earthquake, the India plate moved toward the northeast at the rate of about 8 cm/year relative to the Burma plate. As it continues to move, it results in an oblique convergence at the Sunda trench. The oblique motion creates convergence and normal faulting.[5]

Which Areas Are at Risk?

Simply put, all convergent plate boundaries have the potential to generate tsunamis because they are able to create large-magnitude earthquakes and cause large, vertical movements of the seafloor. Figure 4 shows the plates and plate boundaries around the world. Red lines represent divergent boundaries, black lines represent convergent boundaries/subduction zones, and purple lines represent transform boundaries.

Figure 4



Global Topography and Plate Tectonics

From this figure, it can be concluded that the Pacific and Atlantic oceans, Mediterranean Sea, and Indian Ocean are capable of generating tsunamis. For the other regions, it might seem that they are relatively safe, but on the other hand, tsunamis can travel long distances and still affect shores that are far from them. These are called *teletsunamis* and originate from a distant source, generally more than 1,000 km away.

Some of the deadliest tsunamis have originated from the Mediterranean and China seas, Indian Ocean, Japan Sea, and the waters off northern Chile. Over the last 1,200 years, more than 70 tsunamis have taken in excess of 100,000 lives in Japan (table 3). Though the deadliest tsunamis originated in these regions, many other regions, such as the United States, have suffered from economic damage.

[5] Earthquakes, USGS (www.usgs.gov).

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Table 3

Deadliest Tsunamis in History			
Fatalities	**Year**	**Magnitude**	**Principal Areas**
226,000	2004	9.0	Indian Ocean
100,000	1410 BC		Crete-Santorini, Ancient Greece
60,000	1755	8.5	Portugal, Morocco
40,000	1782	7.0	South China Sea
36,500	1883		Krakatau, Indonesia
30,000	1707	8.4	Tokaido-Nankaido, Japan
26,360	1896	7.6	Sanriku, Japan
25,674	1868	8.5	Northern Chile
15,030	1792	6.4	Kyushu Island, Japan
13,486	1771	7.4	Ryukyu Trench, Japan

The Deadliest Tsunamis 1400 BC–2004 AD[6]

In the United States, California, Oregon, Washington, and especially Alaska and Hawaii are the states that had damage and casualties from tsunamis. One of the most devastating tsunamis that struck Hawaii was in 1946, where run-up heights were 10–17 meters. It left 159 people dead and caused $26 million in damage. In 1952 in the USSR, an earthquake of M = 9 caused $1 million in damage to Hawaii; and in 1957, the Aleutian Islands earthquake (M = 9.1) caused $5 million in damage. In 1960, the Chilean earthquake (M = 9.5) affected the coastlines of the United States from the teletsunami. It left 61 people dead and caused $23 million in damage. Another important teletsunami was generated in the Gulf of Alaska in 1964 from an earthquake of M = 9.2. The damage totaled $84 million. In California, 13 people were killed and $10 million in damage was caused.

Overall, approximately 28 tsunamis with run-up heights greater than one meter have occurred along the U.S. west coast since 1812. On the average, there are two tsunamis per year somewhere in the world that cause damage near their source. And in the Pacific region, tsunamis happen every 15 years according to the National Oceanic and Atmospheric Administration (NOAA).

Apart from the North America Pacific plate margin, the North America-Caribbean plate boundary also has high risk of tsunamis. There is a high risk in northern Puerto Rico and the Virgin Islands as well, with active plate boundary faults creating the potential for submarine landslides. This region is particularly at risk, since its population has been growing fast. A tsunami would affect 35.5 million people, 4 million of whom are U.S. citizens.[7]

Potential Tsunami Hazard in the Atlantic Ocean

Megatsunamis are giant waves that could have run-up heights reaching 90 meters. They could be a result of the collapse of ocean island volcanoes or segments of the continental shelf or asteroid impacts with the sea. In tsunami research, much attention is given to the La Palma Cumbre Vieja volcano because it could generate a megatsunami. It is located

[6] Tsunami (http://www.infoplease.com/spot/tsunami.html).

[7] Ten Brink, U., Danforth, W., Polloni, C., Andrews, B., Llanes, P., Smith, S., Parker, E., and Uozumi, T. 2004. "New Seafloor Map of the Puerto Rico Trench Helps Assess Earthquake and Tsunami Hazards." *Eos,* Vol. 85, No. 37, September 14, 2004. 349–354.

off the northwest coast of Africa in the Canary Islands belonging to Spain. In 1949, an eruption displaced as much as 200 cubic kilometers of rock, which slid four meters seaward before grinding to a halt. The ground deformation monitoring suggested that the mass is creeping one centimeter each year. Because of this information, it is believed that it will collapse soon along with a volcanic eruption, but the time of eruption cannot be estimated. The results of such an event would be devastating. The waves could reach from 10–25 meters high on the eastern shores of the Americas and western coasts of Europe.

Managing Disasters

What Can Be Done?

Through hazard mitigation, lives and property can be saved and environmental damage can be reduced. Hazard mitigation has physical, engineering, and social aspects. The physical aspect involves the observation and collection of data and modeling.[8] Physical models attempt to predict the likelihood and outcome of a hazard; for example, they can be used to predict weather, hurricanes, and volcanic eruptions and forecast flood stage levels. Engineering, for example, is applied in designing and building structures to resist earthquakes. Social considerations include land-use planning, scientific predictions, analyzing risk, and the cost-benefit analysis. The stated goal of hazard mitigation is to reduce by 50 percent the number of people affected by disasters by the year 2015.

Disaster can be defined as the onset of an extreme event causing profound damage or loss as perceived by the afflicted people.[9] Disaster management involves three phases—predisaster, during the disaster, and postdisaster. The predisaster phase consists of risk identification, mitigation, and preparedness. During the disaster, emergency response takes place, and in the postdisaster phase, rehabilitation and reconstruction are applied. The actions create a cycle in time (figure 5).

Figure 5

Disaster Management Cycle: Predisaster, During, and Postdisaster Phases

In the predisaster phase to identify risk, hazard, risk, and vulnerability assessments are performed. *Hazard* can be defined as an interaction between humans and an extreme natural event with respect to cultural perceptions and value systems.[10] The term *risk* includes probability and could, therefore, be defined as the actual exposure of something of human value to a hazard and is often regarded as the combination of probability and

[8] See note 4 above.
[9] Risk, Hazard and Disaster (http://homepages.uc.edu/~huffwd/Volcanic_HazardRisk/Gravley.pdf).
[10] See note 8 above.

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loss.[11] These assessments help identify the characteristics of a hazard such as its frequency, magnitude, and location. *Elements at risk* are the population and assets exposed in a vulnerability assessment. Since risk is identified using vulnerability and probability of hazard, therefore

Risk = Hazard x Vulnerability

The result of the risk assessment provides a function of hazard probability and vulnerability. Hazard monitoring and forecasting use GIS, mapping, and scenario building. At the end of this phase, risk is identified and mitigated. Land-use planning and building codes related to the risk can be updated and enforced in the community. The public could be educated about risks and trained in prevention. In emergency preparedness, early warning systems, communication systems, networks of emergency responders, shelter facilities, and evacuation plan are key elements.

During the disaster phase, existing early warning systems could be used. In emergency response, humanitarian assistance, cleanup, temporary repairs, restoration of services, and damage assessment are the basic steps. After this phase, rehabilitation and reconstruction activities take place. Damaged critical infrastructure is reconstructed; budget and macroeconomic management issues are addressed; revitalization of affected sectors begins; and tourism, exports, and agriculture are managed.

Disasters or hazards are not limited to tsunamis. Others include earthquakes, volcanic eruptions, drought, famine, epidemics, floods, landslides, storms, hurricanes, avalanches, and fires. The list could be extended to include technological and man-made hazards such as pollution and land contamination. Any of these hazards could be controlled and mitigated by effective disaster management.

Technology Used in Emergency Management

Technology Used in Rescue and Recovery

Following the earthquake/tsunami disaster, months of response and relief work have passed. The ongoing humanitarian aid includes rehabilitation and reconstruction. Since the event encompassed such an immense area, the rehabilitation and reconstruction phase will be a long-term issue; months and even years will be invested. Emergency response to the area was relatively quick. What's more, the amount of donations gathered from all over the world for the relief activities was outstanding. Hundreds of international nongovernmental organizations (NGOs) rushed to the area. Local NGOs, government agencies, universities, and the public and private sectors are all working side by side to provide disaster relief.

In general, these activities can be distinguished into three areas:

- Social activities (relief work, food, shelter, etc.)
- Scientific activities that could support social activities
- Scientific activities that support research

The technology applied in these activities differs in context. For example, a better tsunami animation of the event would not be beneficial to relief workers. On the other hand, a detailed map of the damage area would be more functional.

[11] See note 8 above.

For relief work, computers, laptops, mobile phones (including satellite phones), GPS, and the Internet were used. The military and governments also used heavy equipment and technology (helicopters, planes, etc.) to clean up debris, find people, and identify usable routes. Scientific activities that supported the relief work employed computers, laptops, GPS, and the Internet. Moreover, scientists and relief workers were better able to implement GIS and RS. Preliminary usage included satellite imagery, which enabled mapping of damaged areas, and basic infrastructure data. Finally, scientific activities for research utilized high-end technology, software, and hardware. Examples of these activities are the simulations created by several university members. The following table shows the technology summary gathered from an e-mail questionnaire that was sent out to ESRI contacts who worked in the field (table 4).

Table 4

Hardware	Computers, Laptops, Mobile Phones, GPS, Tabular Forms
Software	ArcView, ArcGIS 9 (Military Analyst and Maplex extensions), MapInfo, ERDAS
Data Used	Topography, Census, Roads, Utilities, Bathymetry, Elevation, Geology, Land Cover, Landmarks, Hydrology, Administrative Boundaries, Tidal Datum, Orthophoto, GCP, LandScan (population), SRTM, DTED Levels 1 and 2, QuickBird, IKONOS, SPOT
Internet Usage	Interactive Maps (ArcIMS, Manifold, DM Solutions), Static Maps, Information Sharing for Coordination, Eroom and Groove Technology

Summary of Technology Usage in Disaster Area

Current relief work taking place in the disaster area is categorized as follows:

- Coordination and Support Services
- Agriculture and Fisheries
- Education
- Food
- Health
- Infrastructure and Rehabilitation
- Protections/Human Rights Rule of Law
- Shelter/Nonfood Items
- Water
- Sanitation
- Livelihood

These areas are being covered by 200–300 international and local NGOs in the field and also by government and private sector workers. These NGOs have been responding to categories listed above. Since the phase has changed from response to recovery and rehabilitation, some of the projects include a draft master plan for reconstruction of Banda Aceh presented by the Indonesian government that is a mapping exercise for recovery and rehabilitation from the UN Office for the Coordination of Humanitarian Affairs (UN OCHA). For these activities and the response phase, relief workers used GIS technology.

In Sri Lanka, Urban Development Authority has been active from the beginning of the emergency. Using computers donated from the United States Agency for International Development (USAID) and laptops from IBM, GPS was employed to follow up on internally displaced people (IDP) (many GPS units were donated through Trimble and

ESRI). Mobile phones and the Internet are also being used. ESRI (ArcView), MapInfo, and ERDAS software are the main source software used. Internet mapping technology based on ArcIMS was also implemented. IKONOS and SPOT were used for imagery data. Russian 1:50,000-scale topography and shapefiles, along with census information, were the main vector data used.

The United Nations Joint Logistics Centre (UNJLC), Vietnam Veterans of America Foundation (VVAF), United Nations Humanitarian Information Centre (UN HIC), Indonesia National Cartographic Section, Survey Service, national government disaster management efforts, and combined military collaborated in using GIS in Sri Lanka and Indonesia. The software used is ArcGIS 9 with the Military Analyst and Maplex extensions. Data was obtained from the UN, U.S. government (USG), commercial providers, and governments of Indonesia and Sri Lanka. It includes

- DTED 2
- Roads in 1:50,000 and 1:100,000 scale
- Bathymetric surveys
- New geodetic survey to establish GCPs to reregister all map products

In Thailand, a collaboration of the UN, Swedish Defence, Swedish government, and Swedish International Development Cooperation Agency used GIS technology. The data used is census (1:50,000), topography, and elevation that was obtained from the Internet, Swedish Land Survey, Swedish Defence, ESRI (Thailand) Co. Ltd., and Land Survey Thailand. Also, Swedish Rescue Services Agency (SRSA) collaborated with the UN, Norway and Denmark governments, ESRI (Thailand), and Ministry of Natural Resources and Environment for Thailand. They collected GIS data and used the following for 3D modeling and analysis:

- Orthophotos
- Landmarks
- Roads
- Hydrology
- Administrative borders
- Satellite images

Is There Sufficient Financial Aid to Deploy Technology?

For the first time in emergency response history, the financial aid was sufficient; it reached $9.8 billion in total. The financial aid provided could be categorized into three areas: government, private, and loans. More than 19 countries provided donations as well as government and private aid. The United States, Japan, Britain, Australia, the Netherlands, and Germany were the leading contributors. The World Bank, Asian Development Bank (ADB), and International Monetary Fund (IMF) loaned $1.7 billion. Most of the aid came from government funds—$6.4 billion—with some pledged and some provided or in process. Private aid was also a large amount—around $1.7 billion in total (table 5). Additionally, Bangladesh provided heavy vehicles; Pakistan provided military staff; and Afghanistan provided medics. India was able to donate $600 million.

Table 5

Country	Government Aid (in U.S. dollars)	Private Aid (in U.S. dollars)	Loan (in U.S. dollars)
United States	$350 million	$200 million	
Japan	$500 million		

Country	Government Aid (in U.S. dollars)	Private Aid (in U.S. dollars)	Loan (in U.S. dollars)
Norway	$183 million	$30 million	
Britain	$96 million	$466 million	
Italy	$95 million	$20 million	
Sweden	$80 million	$75 million	
Denmark	$75 million		
Spain	$68 million		
France	$66 million	$90 million	
Canada	$343 million	$75 million	
China	$83 million		
South Korea	$50 million	$13 million	
North Korea	$150 thousand		
Australia	$764 million	$77 million	
Netherlands	$343 million	$35 million	
Russia	$10 million		
Germany	$647 million	$586 million	
Qatar	$25 million		
World Bank			$250 million
European Union	$2 billion		
ADB			$500 million
IMF			$1 billion
India	$600 million		
Bangladesh	Heavy vehicles		
Pakistan	Military staff		
Afghanistan	Medics		
Total	**$6.4 billion**	**$1.7 billion**	**$1.7 billion**

Aid Types and Amounts

Organizations and Their Technology Implementations

The Internet was the main source of information for GIS technology usage in the area. Additionally, a questionnaire, phone calls, the ESRI international distributor network, and ESRI Tsunami Disaster Support Web site were other essential sources of information. The following table lists the international and local NGOs that are active in the region. Each has different goals and sometimes parallel objectives in their organizations (table 6). This list is the database from which data for the poster and the ArcIMS map was derived. Organizations were randomly selected, and most used GIS technology for their accomplishments. Information and data from different sources were also used.

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Table 6

No.	Organization Name	Main Focus
1	UNJLC	UNJLC was created to complement and coordinate the logistics capabilities of cooperating humanitarian agencies during large-scale and complex emergencies.
2	WFP	When a natural or man-made disaster strikes anywhere in the world and an official request is made for United Nations World Food Programme (UN WFP) food aid, the agency draws up an Emergency Operation (EMOP).
3	USAID	USAID's Office of Foreign Disaster Assistance (OFDA) is deploying a regional Disaster Assistance Response Team (DART) that includes USAID/OFDA regional advisors, water and sanitation experts, field officers, and information officers. USAID/DART members are located in Sri Lanka, India, Indonesia, and Thailand and coordinates the USG humanitarian response to the earthquake and tsunami emergency.
4	CARE	CARE has operated in each of the affected countries for decades and has significant capacity to provide immediate lifesaving humanitarian assistance, placing special emphasis on working with women. CARE members are responding directly or in concert with government teams and local partners in each country as the situation requires. Their focus is to ensure that the most vulnerable people are helped.
5	Red Cross	Red Cross disaster relief focuses on meeting the emergency disaster-caused needs of individuals and families. When a disaster threatens or strikes, Red Cross provides shelter, food, and health and mental health services, which address basic human needs. In addition, it helps individuals and families to independently resume their normal daily activities. This may include a referral or a way to pay for what is needed most: groceries, new clothes, rent, emergency home repairs, transportation, household items, medicines, and occupational tools.
6	UNESCO	United Nations Education, Scientific and Cultural Organization (UNESCO) focuses on four priority areas: (1) advocacy and technical support for education on disaster prevention and for sustainable development, (2) policy advice on inclusive education to meet the needs of schoolchildren physically affected by the tsunami, (3) psychosocial and pedagogical training for teachers and educational professionals, and (4) community-based educational rehabilitation. UNESCO also provides posttsunami recovery and reconstruction in the organization's other areas of expertise, namely natural science, communication, and culture.
7	Sarvodaya	This organization focuses beyond the rebuilding of homes, roads, and rail tracks. It values reestablishing social welfare services, such as health and education, or restarting commercial activities to support daily life.
8	UNICEF	United Nations Children's Fund (UNICEF) relief assistance includes providing clean, safe water and basic sanitation; emergency immunization to prevent fatal childhood diseases; feeding malnourished children and pregnant women; care for children who have endured traumatic events; shelter and protection for orphans and separated children; and education kits and temporary classrooms to get children back to school.
9	Oxfam	Oxfam's humanitarian work is not limited to crisis response but covers a full range of activities including advocacy, prevention, preparedness, direct response, and rehabilitation. The organization works in situations created by war, drought, floods, earthquakes, and famine.

No.	Organization Name	Main Focus
10	WHO	Human survival and health are the cross-cutting objectives and the measures of success of all humanitarian endeavors. The World Health Organization (WHO) goal is to reduce avoidable loss of life, burden of disease, and disability in emergencies and postcrisis transitions.
11	World Vision International	World Vision is an international partnership of Christians whose mission is to follow the Lord and Savior Jesus Christ in working with the poor and oppressed to promote human transformation, seek justice, and bear witness to the good news of the kingdom of God.
12	Save the Children	Save the Children is a leading nonprofit humanitarian relief and development organization working in more than 40 countries throughout the developing world and the United States. Its mission is to create lasting, positive change in the lives of children in need.
13	Islamic Relief Worldwide	In addition to responding to disasters and emergencies, Islamic Relief promotes sustainable economic and social development by working with local communities—regardless of race, religion, or gender. Islamic Relief works in four main sectors: emergency relief, development, orphans, and war.
14	Action Against Hunger	Action Against Hunger's mission is to save lives by combating hunger, malnutrition, physical suffering, and the associated distress that endanger the lives of children, women, and men in emergency situations of war, conflict, and natural disaster.
15	GOAL	GOAL is an international humanitarian agency dedicated to the alleviation of suffering among the poorest of the poor. It was founded by its current chief executive John O'Shea in 1977, when he invited four friends to join him in an effort to help those in greatest need worldwide.
16	BAPS Care International	BAPS Care International's mission is to serve needy individuals, families, and communities throughout the world, with a focus on India.
17	Direct Relief International	Direct Relief International works to improve the health and lives of people in developing countries and those people victimized by disaster or war. It supports locally run facilities, hospitals, and programs that provide health services with essential material resources—medicines, vitamins and nutritional supplements, supplies, and equipment. It receives most of these products through donations and ensures that they are provided in the most secure, efficient manner possible.
18	Habitat for Humanity International	Habitat for Humanity International is a nonprofit, nondenominational Christian housing organization. It welcomes all people to join in building simple, decent, affordable houses in partnership with those who lack adequate shelter.
19	AmeriCares	AmeriCares is a nonprofit disaster relief and humanitarian aid organization providing immediate response to emergency medical needs, as well as supporting long-term humanitarian assistance programs, for all people around the world, regardless of race, creed, or political persuasion. AmeriCares solicits donations of medicines, medical supplies, and other relief materials from U.S. and international manufacturers and delivers them quickly and efficiently to indigenous health care and welfare professionals around the world.
20	American Jewish World Service	American Jewish World Service sponsors programs of relief, rescue, and renewal and helps Israel address its most urgent social challenges. It is committed to the idea that all Jews are responsible for one another.

No.	Organization Name	Main Focus
21	Mercy Corps	Mercy Corps provides emergency relief services to assist people afflicted by conflict or disaster. Additionally, it develops sustainable communities that meet the needs of children and families. Integrated strategies include agriculture, economic development, health, housing and infrastructure, and strengthening local organizations. It promotes civil society initiatives in all its programs to encourage citizen participation, accountability, nonviolent conflict management, and the rule of law.

Active International and Local NGOs in the Disaster Region

Of the organizations listed above, Mercy Corps focused on good technical support and highlighted the importance of information technology in its relief efforts. Hence, its mission was to help NGOs be more effective in the area by using GIS in their relief work.

GIS and Remote-Sensing Data/ Information Providers and Coordinating Agencies

NOAA collaborates with various federal-international agencies to model data, interpret the models, and create hazard analysis tools. It uses data such as

- Elevation
- Census
- Imagery
- Geology
- Land cover
- Tidal datum models

The data sources were from federal, state, and local authorities. Like the U.S. Geological Survey (USGS), NOAA also uses ArcIMS technology for publishing dynamic maps on the Internet. It provides a tsunami events database via its Web site and includes layers such as tsunami events/run-ups accompanied by significant earthquakes for a region, hydrology, elevation, and population data.

Pacific Disaster Center (PDC) provided geospatial data processing and distribution. It has obtained and processed high-resolution satellite imagery from National Geospatial-Intelligence Agency (NGA); coordinating processing with USGS Earth Resources Observation System (EROS) Data Center, Mercy Corps, and other organizations. It also launched Indian Ocean Tsunami Geospatial Information Service, based on ArcIMS, and the corresponding Internet-based Map Viewer. ESRI provided consultative services to support high-volume/high-availability site requirements. It also provided online access to the GIS data via the Internet map service, viewer, and FTP site at Maui High Performance Computing Center (MHPCC), which enabled support of U.S. government interagencies and the international communities of interest. PDC has been one of the most important information providers for this event. Its Internet mapping Web site, based on ArcIMS and ArcMap™, includes earthquakes and their detailed information along with the probable damage areas for the United States, Landsat-derived damage areas, hospitals, and tsunami inundation zones.

SERTIT provides rapid mapping service and also specializes in crisis remote-sensing applications. It is supported by the European Space Agency (ESA) and was contracted in January 2004 by the French space agency, CNES, for three years to produce added-value Earth Observation (EO)-derived products within the framework of the international charter Space and Major Catastrophes.

UN has many divisions, but for disaster management, it can be divided into four basic branches: OCHA, the United Nations High Commission for Refugees (UNHCR), UNWFP, and UNICEF. The International Search and Rescue Advisory Group (INSARAG) and the Search and Rescue Team (SAR) work closely with these branches and mostly provide guidelines. OCHA has the Disaster Response Branch (DRB) and the UN Disaster Assessment and Coordination has On-Site Operations Coordination Center (OSOCC). UNWFP Emergency Preparedness and Response Unit (ODAP) has provided damage and population density maps with casualties information. Based on SRTM-3 digital elevation data from the National Aeronautics and Space Administration (NASA) and USGS EROS, Nicobar Islands coastal flooding tsunami hazard map was provided by Open University. For this map, the coastline data was obtained from NGA. Office of the Geographer and Global Issues, Bureau of Intelligence and Research, of the U.S. Department of State (DOS) provided political boundaries, roads, and airports of the region. The LandScan dataset is a worldwide population database compiled on a 30" by 30" latitude-longitude grid provided by Oak Ridge National Laboratory and ESRI, which was widely used. ArcWeb℠ Services provided a map, dynamically created with ESRI ArcGIS Server, which demonstrated the functionality of on-demand map publishing for Indonesia.

Remote-sensing imagery was also provided through several agencies and private companies for the relief work. Some of them are UNOSAT, USGS, MDA Federal Inc., GeoNetwork, and DigitalGlobe.

UNOSAT (a UN Institute for Training and Research [UNITAR] project) provides imagery for the areas where UN is active and to the officers who are working with UN as well as the local authorities working for territory planning and monitoring purposes. It supports activities such as disaster management, risk prevention, peacekeeping operations, postconflict reconstruction, environmental rehabilitation, and social and economic development.

USGS has provided Shuttle Radar Topography Mission DTED and Landsat® 7 satellite imagery. It has contributed to the relief work by providing images from Landsat 7 in addition to other image-derived products for damage area maps. SRTM DTED (Level 2) was used by VVAF and UN for analysis. USGS also has other satellite imagery products commercially available that can be used in relief work.

MDA Federal Inc. (formerly Earth Satellite Corporation) has donated more than 15 million square kilometers of imagery from its global NaturalVue 2000™ imagery dataset in support of tsunami disaster recovery and reconstruction efforts. Imagery datasets have been provided to UN OCHA and DOS for their organizations' use. They have also joined ESRI in creating an Indian Ocean Disaster Geospatial One-Stop portal to make a variety of resources available to anyone who needs them. These resources include many types of geographic data, map services, information about GIS projects in the region, lists of volunteers, and more.

GeoNetwork—Food and Agriculture Organization (FAO) of the United Nations—has endorsed this Web site where users can search for or share geographically referenced thematic information among different UN agencies, NGOs, and other institutions. The products are damage area data, agroclimatic information, population density data, and elevation data and imagery (SPOT 5, Landsat ETM, etc.).

DigitalGlobe has provided 60-centimeter QuickBird images, which are the highest-resolution, commercial satellite images. Companies and agencies such as PDC and ImageCat have used this imagery, which was collected in March 2002, for comparison.

Using the GIS- and RS-provided or available data, other organizations have implemented interactive maps on the Internet for the region. One of them was created by Cornell University and the Earthquake Engineering Research Centers Program of the National Science Foundation through the Multidisciplinary Center for Earthquake Engineering Research. International Water Management Institute provided the vector GIS data for the country of Sri Lanka for this Web site. The software used for creating this interactive Web site was based on Manifold IMS software technology. It includes flooded areas, transportation lines, political districts, hospitals, and topography of Sri Lanka.

USGS used ArcIMS technology to publish interactive maps in the first hours of the disaster. The online data includes transportation, disaster resources, hydrology, orthoimagery, imagery, elevation, and land cover. UNEP and its World Conservation Monitoring Centre (WCMC) endorsed tsunami information interactive map services using ArcIMS technology, which include infrastructure, sensitive areas, species, background information, socioeconomic data, and response activities in their dynamic map. This site provides information to help emergency responders coordinate more effectively. UNEP makes recommendations on how to reduce vulnerability to future coastal hazards. It also provides reports, maps, and graphics, including multimedia documents, on its Web site.

DM Solutions Group, a Web mapping solutions company from Canada, collaborated with University of Ottawa to build a Tsunami Disaster Mapping Portal that included political, infrastructure, satellite imagery, and tsunami wave height data layers.

Coordination-related information providers aim to reduce suffering and save lives. Through technology, it is possible to help aid agencies reach people in need as quickly as possible. Up-to-date information will answer questions such as

- Where are the hospitals, airports, schools, and so on? How many are there?
- How far is the airport?
- Where are the best places to establish refugee camps/command centers?
- What is the extent of the damaged area?

To answer such questions, GIS technology is key. Knowing this, many local and international agencies have focused on providing necessary GIS data. In Indonesia, NGO Bakornas provides relief activity locations and information on relief work through the Internet. UN HIC under UN OCHA provides services to the humanitarian community working in Indonesia (Sumatra), Sri Lanka, and the surrounding countries. In Sumatra, UN HIC coordinates with a number of partners including UNJLC, the United Kingdom's (UK) Department for International Development (DFID), USAID's OFDA, and the humanitarian aid department of the European Commission. It provides products, coordination tools, maps, Web site and services, technical support, survey design, and data archiving. It has been the main source of the decision-making process in Sumatra and contributed to a common framework for information management within the humanitarian community. It has provided many maps, showing information such as food sector activity, internally displaced people, camps for health and education, as well as geographic maps showing population, streets, and locations of the NGOs. Preliminary vector data was obtained from Australian maps.

UNJLC's mission is to optimize and complement the logistic capabilities of cooperating agencies within a well-defined crisis area for the benefit of the ongoing humanitarian operation. In this capacity, it has been providing the routing, infrastructure, and air operations.

The United Nations Humanitarian Air Services (UNHAS) has been coordinating disaster actions in the areas of sea, land, fuel, warehousing/commodity tracking, freight grid pipeline, field, road network, air operations, customs, and railway via its aviation service for humanitarian affairs.

USAID/OFDA has deployed a regional Disaster Assistance Response Team that included USAID/OFDA regional advisors, water and sanitation experts, field officers, and information officers.

USAID/DART members are located in Sri Lanka, India, Indonesia, and Thailand and are still coordinating the USG humanitarian response to the earthquake and tsunami emergency. USAID has been one of the sources most frequently referred to for up-to-date information about the region. One day after the disaster, it had already produced progress reports.

Center of Excellence in Disaster Management and Humanitarian Assistance (COE) is a federally funded project given a mandate by the U.S. Congress to improve the coordination and integration of the world's response to natural disasters, humanitarian crises, and peace operations. COE is a direct-report unit to the U.S. Pacific command (USPACOM), which oversees U.S. military forces and U.S. Department of Defense assets in the Asia-Pacific region. The director of COE, a civilian, reports directly to the deputy combatant commander of USPACOM. Like USAID, its progress reports were some of the main sources of information for the disaster area. It has collected information on international development and relief organizations, international assistance, politics/military, security, health/medicine, food, logistics, and coordination.

World Vision committed $10 million for the first 120 days of the response. This included relief distributions; housing; health; and income generating, microeconomic development, and livelihood programs as well as special programs targeting children affected by the disaster.

For the International Federation of Red Cross and Red Crescent Societies, apart from its disaster emergency response focus, predicting and preventing disasters and reducing their impact are central to the work of the federation's member societies around the world. So far, they have focused on logistics, basic health care, water truck provision, distribution, relief, and specialized water treatment supply. The director of the secretariat's Disaster Management and Coordination Division makes the final decision on deployment, based on the assessment report and advice from technical departments such as health, logistics, field support, and telecommunications.

ADB has committed $1 million toward the development of an early warning system for the Indian Ocean, which could be linked to other regional and global warning systems. Its contribution is more in multilateral development finance dedicated to reducing poverty in Asia and the Pacific.

Barriers and Issues in Technology Deployment

After a major disaster, decision makers, rescue agencies, and civil defense managers need quantitative estimates of the extent of the disaster when data may still not be accessible to the outside world. To overcome such an issue, technology can help in many ways. Satellite images and existing maps would be the main sources of information.
Though there are high-end technologies and databases ready to use in an emergency in many developed countries, this information is not readily available to developing countries. It is increasingly apparent that disasters are not merely country- or region-based problems; their effects could influence the entire world in terms of economic, political, and social issues.

The Indian Ocean earthquake/tsunami disaster affected 12 countries. With its magnitude and extent, it was one of the most devastating natural disasters in history. Therefore, it became a complex and difficult multidisciplinary problem for emergency management. So far, the response, relief, and recovery phases encountered several problems that could be categorized into scientific and social issues. To define these problems, interviews with relief workers and managers were conducted. Reports and the Internet were also used. The problems could be summarized as follows:

Scientific Problems

- Lack of data
- Inadequate data sharing
- Poor communication of data
- Duplication of data

Social Problems

- Political problems
- Government structure
- Relocation of people
- Inequity

In this particular event, many of the areas hit by the tsunami were developing countries. Thus, data was lacking. In particular, critical infrastructure data, such as transportation and locations of hospitals, buildings, and communications, was in great demand. Even after a couple of months, the data was not available as it should have been. The reasons for this lie also in the circumstances of the countries involved. In many developing countries, data sharing between government and nongovernment agencies is not widely applied. Moreover, knowing which data was where and how to share and communicate it was also problematic. In such an ambiguous data environment, most of the agencies started to create the data they needed, which resulted in data duplication. For example, many satellite images were provided shortly after the earthquake/tsunami, and many damage area maps were created almost at the same time.

In addition to the social problems created by the disaster, political conflicts presented new challenges. In Indonesia, the separatist rebels from the Free Aceh movement limited the amount of humanitarian aid entering some regions. Data sharing was disrupted by these incidents; a government agency worker did not want to share critical infrastructure data with an international agency officer, fearing that the data could fall into the hands of the Free Aceh movement rebels. In Sri Lanka, there have been disputes between Tamil Tiger rebels and government troops over distribution of aid to tsunami victims. During the first three days following the disaster, the rebels complained that government aid failed to reach rebel-held areas in the north and east.[12] A relief worker who was a longtime resident of Sri Lanka mentioned that newly established international NGOs with a great deal of financial aid create harm in the longer term instead of solving problems. The reason for this is that they were not taking into account the ethnic differences and conflicts between people.[13]

In addition to political problems, government structure itself creates problems. In some countries, permission is required from many levels of government. In an emergency situation, bureaucracy can be a big barrier in terms of time and data productivity.

[12] AP (http://www.infid.be/tsunami_2101.htm).
[13] Psyche Kennet, Personal Communication.

Another social problem was the difficulty in convincing people to relocate from their destroyed settlements. Many of them refused to change their living location. In particular, people who earn their living from fisheries did not want to move 200 miles inland in Sri Lanka.

Finally, inequity was another social problem. Surprisingly, in the first reports of the disaster, Yemen was not included in the damaged countries list, even though it sustained damage of more than $1 million (UNEP assessment) and two deaths from waves that reached six meters high.

Possible Technology Implementations for the Region

Neither an early warning system for tsunami nor tsunami education existed in the Indian Ocean region at the time of the disaster. If there had been, many lives and property would have been saved. An English girl's story of how she told people that the receding sea was a sign of tsunami coming to the shore in Phuket (Thailand), eventually saving many lives, reinforces the importance of education in surviving disasters.

As mentioned earlier, disaster management is a cycle in time, and the objective is to save lives and property. Thus, the goal is to be prepared for the next disaster. Hazards are region based, and this generally means that they will repeat themselves sooner or later. To be better prepared for the next one, the steps that should be taken are

- Assessment of risk
- Mapping the extent of the disaster
- Helping communities prepare
- Allocating resources
- Deploying personnel
- Monitoring emergencies in real time
- Saving lives
- Protecting property

Identifying the key issues that can be solved by GIS and applying its technology can assist in preventing catastrophic loss of life and property in the future.[14]

An example of advanced GIS technology deployment is applied by MapAction. This charity is based in the United Kingdom and supports humanitarian operations through the provision of data collection and mapping capabilities in the field. Below is the main information flow diagram that it is putting into practice.[15] While deploying staff to a disaster area, predisaster mapping data is gathered and analyzed at the UK base. At the same time, remote-sensing imagery is obtained from the Earth Observation Satellite and the information is shared through communications satellite with the Internet and telephones. The field team starts collecting information using the mobile GIS mapping

[14] Amdahl, G. 2001. *Disaster Response: GIS for Public Safety*.
[15] MapAction (http://www.mapaction.org/).

and GPS and sends the information to the base (figure 6). This fills one of the most important information gaps, namely, the location of people affected and critical infrastructures such as hospitals.

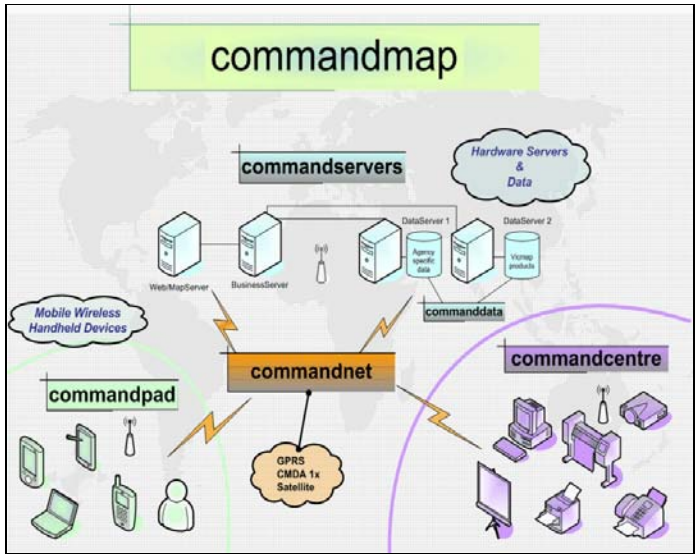
Figure 6

MapAction and Its Technology Usage Diagram

A further step in advanced technology implementation uses the satellite communications-observation data. The mobile GIS mapping and GPS connected to the hardware servers and data enables the established command center to reach decision makers, the media, and other information users. The Australia-based company Maptel is developing commandmap, a new system incorporating the use of GIS technology in real time with wireless technology to provide dynamic data exchange from field team to command center and other emergency service providers (figure 7).[16]

[16] Maptel (http://www.maptel.com.au/).

Figure 7



The Commandmap project enables advanced technology to be used in emergency management.

Many other applications are available to high-end technology users; for example, the U.S.-based company Dewberry has created a technology solution for decision makers and planners that will enable them to better prepare and respond before, during, and after a disaster.[17] The application manages and predicts debris, tracks the disaster incidents, and manages the resources. The application can work independently (PC based with MapObjects® or ArcObjects™), can be server based (allows multiple user logins and updates to the information) or Web based, and permits users to access and update information through a Web portal. Another example comes from Development Gateway foundation. This nonprofit organization has developed an open source software tool, called Local Projects Database (LPD),[18] that organizations can use to coordinate international relief and construction efforts to capture and share knowledge. Online sites such as Eroom, which is prepared by the Department of State Humanitarian Information Unit (HIU),[19] can be used to capture and share the knowledge. This site facilitates the sharing of working-level data, information, and knowledge through instant messaging, expertise directories, calendars for briefings, and online webcam discussions on specific topics and issues. This site has been used by HIU workers, the UN, and other international agencies to collaborate information. It is intended to give/produce information for midlevel authorities. Groove is another sharing point used as a virtual office.[20] The software can be used for the same purpose as Eroom but also has interactive mapping capability. Above all, there need not always be online access to work on the data. Groove has two GIS-based applications created by InfoPatterns and Black Coral; however, these applications lack the interoperability that would enable them to be more powerful tools. Overall, these technology examples help to illustrate the efficiency of emergency response if the proper tools are implemented.

[17] Dewberry (http://www.dewberry.com/).
[18] Local Projects Database Community (http://lpd.sourceforge.net/).
[19] Eroom (https://bceroom.state.gov/eRoom/HIU/).
[20] Groove (http://www.groove.net/home/index.cfm).

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Future Early Warning Systems

Tsunami warning systems have been used mostly in the Pacific, Hawaii, and Japan. Other countries, such as Chile, El Salvador, Guatemala, New Zealand, Nicaragua, and Peru, also have warning systems. The Japanese use a simultaneous announcement wireless system, which receives the signal and broadcasts through speakers, and so forth. In addition, fire trucks equipped with loudspeakers cruise the areas that are not covered by the wireless system. Television, radio, sirens, bells, telephone network, and word of mouth are also used to warn the general public. Moreover, the education system provides training on tsunami and other hazards to children in Japan.

For future technology deployments, Global Earth Observation System of Systems (GEOSS), an international effort, is under way. This initiative is being led by the United States, Japan, South Africa, and the European Commission, with dozens more nations participating at the ministerial level. Indonesia, Thailand, and India have also joined the 54 participating nations. The aim of this effort is to build a network of linked data from satellites, ocean buoys, and ground-based air and water quality monitors to take the pulse of the planet. This project will facilitate enhanced monitoring and detection, warning, and communications, which will help provide emergency responders more time to take action.[21]

Specifically, NOAA will deploy 32 new advanced technology, Deep-Ocean Assessment and Reporting of Tsunami buoys to create a fully operational tsunami warning system, scheduled for completion in mid-2007, as part of a $37.5 million expansion of the U.S. tsunami warning system.[22] These systems are based on pressure-sensitive sensors mounted on floating buoys, which are linked to satellites and monitored continuously. The buoys are highly sensitive but expensive to install and maintain. Satellite-borne radar altimetry is another potential technology that can be used for warning systems.

Additionally, UNESCO is focused on prevention and is working to establish a global early warning system to detect tsunamis before they strike. It has assessed the impact in affected countries in its recovery activities. The UN International Strategy for Disaster Reduction (UN ISDR) Platform for the Promotion of Early Warning (PPEW) will also coordinate another big-budget project for planning and determining early warning systems for the Indian Ocean.[23]

Lessons Learned

The information gathered from the Internet, interviews, and discussions was used to measure the results of emergency management and GIS usage. From these results, the following recommendations could be made for the GIS usage aspect of emergency management:

- Organized GIS database
  - Critical infrastructure data
  - Up-to-date image data bank
  - Metadata
  - Data interoperability
  - Predefined emergency response database model
  - Data sharing with media

[21] GEOSS (http://www.epa.gov/geoss/).
[22] NOAA (http://www.publicaffairs.noaa.gov/releases2003/dec03/noaa03-147.html).
[23] UN ISDR (http://www.unisdr.org/ppew/tsunami/ppew-tsunami.htm).

- Coordination in
  - Allocating resources
  - Preventing the duplication of data
  - Awareness of ongoing international/national GIS projects
- Upgrading to high-tech GIS system
  - Mobile mapping capabilities
  - Monitoring emergencies in real time

In social and general aspects where emergency management was also affected, country-based sociopolitical issues should be taken into consideration.

An organized GIS database is vital to emergency management. Time spent to create and re-create data for analysis reduces time to reach people in need. Critical infrastructure data that should be ready in advance includes transportation, political boundaries, telecommunications, electrical power, water, oil and gas, bank and finance, emergency services, and governments' continuity information. All this information should be accompanied by metadata to ensure accuracy and reliability. Moreover, in many cases, standard file types should be interoperable. In Indian Ocean countries, this data was, by and large, not ready and not being shared because of various political problems or lack of communication. The high-resolution satellite imagery, once again, proved invaluable. It enabled high-level decision makers, emergency responders, and the world media to fully understand the extent of the damage. Though remote-sensing data was quickly available and used extensively by emergency responders, this information should be kept up to date to enable faster decision making. Communicating with the media is also important; maps for public viewing should also be created to focus more attention on the situation, since public awareness raised by the media is critical to efficient fund-raising.

Coordination is a big issue that would enable solutions to many time problems in emergency matters. One of these problems was caused by data duplication—many emergency responders were trying to create the same type of information (e.g., the extent of the damaged areas) at almost the same time. In this case, data sharing and communication would have saved time and helped save more lives. For example, at an international level, an agency could have the transportation information but need to know the extent of the damaged areas, while another agency could already have this information. This lack of important data sharing among agencies could be prevented through collaboration before a disaster occurs instead of during the first critical hours following an event when all responders are working to rescue victims and save lives. Data flow could be coordinated by an appointed agency, such as in the case in the United States where Incident Command System (ICS) prepares all emergency responders to work together efficiently. The knowledge of ongoing international/national GIS projects could also help in the first phases of an emergency. In Sri Lanka, International Water Management Institute (IWMI) (www.iwmi.cgiov.org) and Cornell University published important data online that could be accessed by any user. Using Manifold interactive mapping technology, they were able to show the data interactively on the mapping portal within hours of the tsunami.

Another important lesson is that sociopolitical issues are fragile and should be handled with great care. As mentioned earlier, rebels occupying Sri Lanka and Indonesia prevented aid from reaching the affected areas. Relief agencies need to be more sensitive to a region's ethnic, cultural, and religious differences instead of focusing on their own priorities such as safety of reconstruction areas.[24]

GIS technology and RS have been used to coordinate the location of heavy military vehicles and IDP camps during response and recovery operations. Compared to GIS capabilities, the part of the technology that was used was not high end. The reason for this is that data was not available for many of the countries affected by the disaster. The developing world will eventually fulfill the digital requirements necessary to implement GIS technology. Once this occurs, the benefits offered by high-end GIS technology can be fully utilized. With GIS models and analysis, emergency vehicle dispatch and tracking, evacuation routing, tracking response, search and rescue, damage assessment, and recovery coordination are possible. Basic technologies used in the region are the Internet, satellite connection, GIS software, GPS, laptop and mobile GIS, and so forth.

In the United States, Oklahoma City's GIS Division of the Information Technology Department implemented an application that utilized Internet, ArcGIS, ArcSDE®, and Microsoft® .NET technology. The region known as "tornado alley" in Oklahoma has a high frequency and intensity of tornadoes. After a tornado passes, the software is used to help locate people hiding in private storm shelters, close to their houses, that are buried under dirt and debris. The application also depends on public response. Using the Web site, storm shelter owners entered their shelter location into a database that is saved on the server. Shortly after 3,000 private storm shelters were updated in the database, a tornado hit the region and emergency responders were able to reach the families under the storm shelters more quickly than before.[25]

The U.S. Department of State has compiled information about remote-sensing usage and pointed out some problems it encountered during the tsunami event. A unified international/national agency policy was lacking that could have addressed acquiring, processing, and disseminating data. The lack of a policy resulted in redundant, poorly documented, and largely unused products.

Like GIS data sharing, remote-sensing data sharing was not adequate. The reasons mentioned in this white paper are manpower requirements, procedural protocols, and domain security issues. Commercial imagery was widely used by the public but was of limited use to early responders and decision makers. In addition, the requests for higher-resolution imagery grew in importance in the recovery stages of the disaster.

The U.S. Department of State was advised to take action in the areas listed below, but these steps also address any other international/national agency; therefore, they should be taken into account for GIS agencies as well.[26]

- Standard operating procedures
- Mechanisms for effective interagency coordination and cooperation in humanitarian crises
- Geospatial/Imagery group devoted to diplomatic and policy activities

[24] See note 10 above.
[25] Meldrum, S. 2004. "Shelter from the Storm." *ArcUser,* January–March 2004. 16–17.
[26] Christian, C., Crawford, M., and Echevarria, F. 2005. *Lessons Learned Report: Remote Sensing and Satellite Imaging Community of Interest,* U.S. Department of State.

- Partnerships with academia and other organizations to better leverage delivery of relevant expertise to the field

Conclusion

On short notice, the Indian Ocean tsunami demonstrated the global vulnerability to disasters. The extent of the loss of human lives and damage to property was beyond imagination. Although the international and national response to the disaster was rapid and financial aid sufficient, poor coordination of the response made the task more difficult. Political and information barriers created complex, multidisciplinary problems. As a result, knowledge of emergency management and its successful applications became more important than before, and the use of existing technologies to save more lives and property proved possible.

In general, most of the coordination efforts failed because of the diversity of the levels of information in the countries impacted by the disaster. In general, the affected countries did not have the base data or technology to address their needs. Lack of information was not the only factor responsible for impeding humanitarian efforts; political, social, and economic issues were also major obstacles. Because of these obstacles, officials responsible for creating and implementing programs and policies should be sensitive to the diversity of the people in the region and enlist the help of sociologists, psychologists, and anthropologists. On an international level, the coordination of agencies responding to the disaster was inefficient. To better respond to future disasters, countries need to work together at the regional and international levels ahead of time. The use of GIS technology for these applications will enable the agencies involved to save time and improve efficiency.

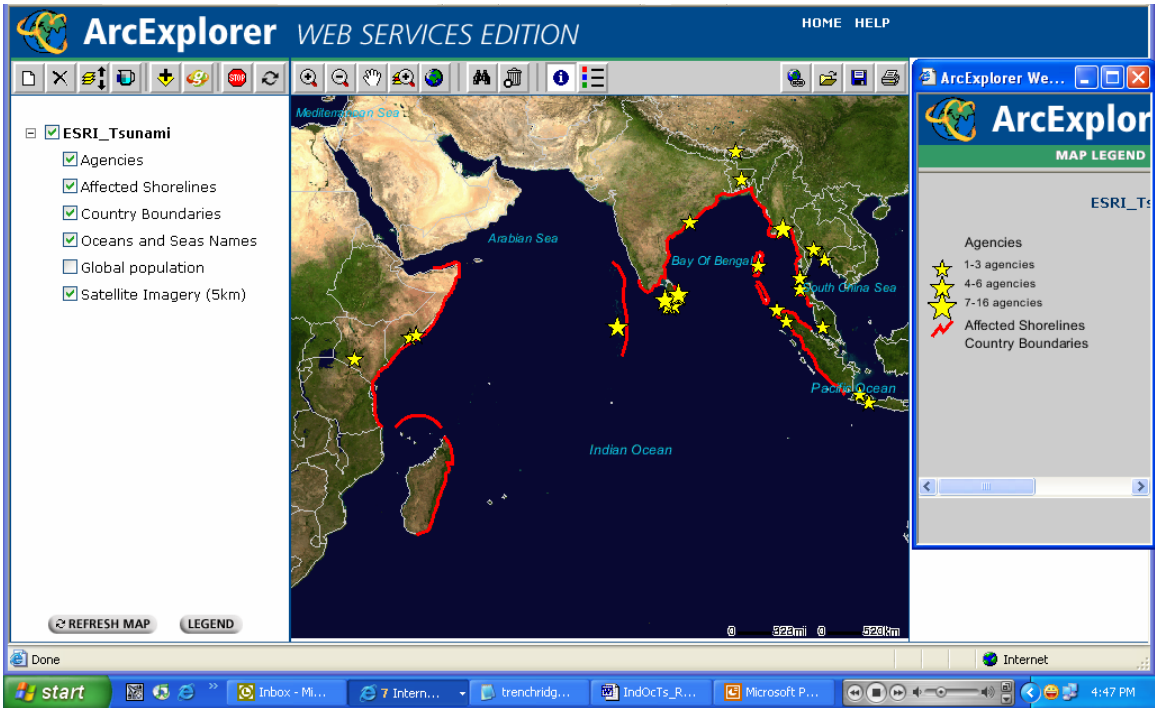
Implementation of a tsunami early warning system proved to be one of the most important steps that should be taken. Currently, global and country-based actions are under way or planned. In addition, land-use planning, coastal zone management, and structural improvements (building codes for earthquakes/tsunamis) should be applied. The huge gap in technology implementation among countries should be solved to enable interoperability in emergencies. Given the lack of interdepartmental coordination in disaster management in many countries, a central body should be established with participation from different agencies within the countries.

In all cases, basic databases for humans and their activities and habitat are a critical element in emergency preparedness and response. Consequently, through technology it is possible to identify and mitigate risk, be prepared, respond to emergencies, and recover from them. Managing the information needed for emergency matters is a challenge, and investing more in GIS technology is important to increase the effectiveness of relief work in terms of time. It can assist rescue agencies and civil defense managers in assessing damage from an event and enable them to respond more efficiently. Efforts to facilitate worldwide use of GIS technology will ensure the success of these endeavors.

Appendix A

While addressing the use of GIS in the Indian Ocean earthquake/tsunami disaster, some of the information gathered was used in map products. The *Indian Ocean Area* interactive map utilizes ArcIMS technology to show some of the NGOs in the field that had been working during the emergency response, relief, and recovery phases. The database included the locations of 21 international and local NGOs with 86 liaisons and their contact information. This map is a good example of GIS technology implementation in emergency management. The information was updated as time allowed. The map server is Geography Network℠, where many maps and information can be found and easily downloaded. The map service is ESRI_World, and ESRI_Tsunami is the image service. The image service URL is http://www.geographynetwork.com/arcexplorer/arcexplorer.html?link=20050324184616763_ESRI_Tsunami, which can be reached through any Web browser. It can also be reached through the map service by using the free ArcExplorer™—Java™ Edition software. The map with affected shorelines and agency database can be viewed on top of the ESRI_World data, which includes the world satellite image (1999 ERDAS IMAGINE® format, 1:2 kilometer scale and a database with political information. The database can be queried by the agency names, country names, liaisons, contact information, Web sites, and x,y coordinates, but it cannot be edited. In ArcMap, through the GIS servers connection, the Geography Network can be reached for viewing ESRI_World and ESRI_Tsunami maps. The map metadata can also be accessed through the Geography Network.

Figure A-1



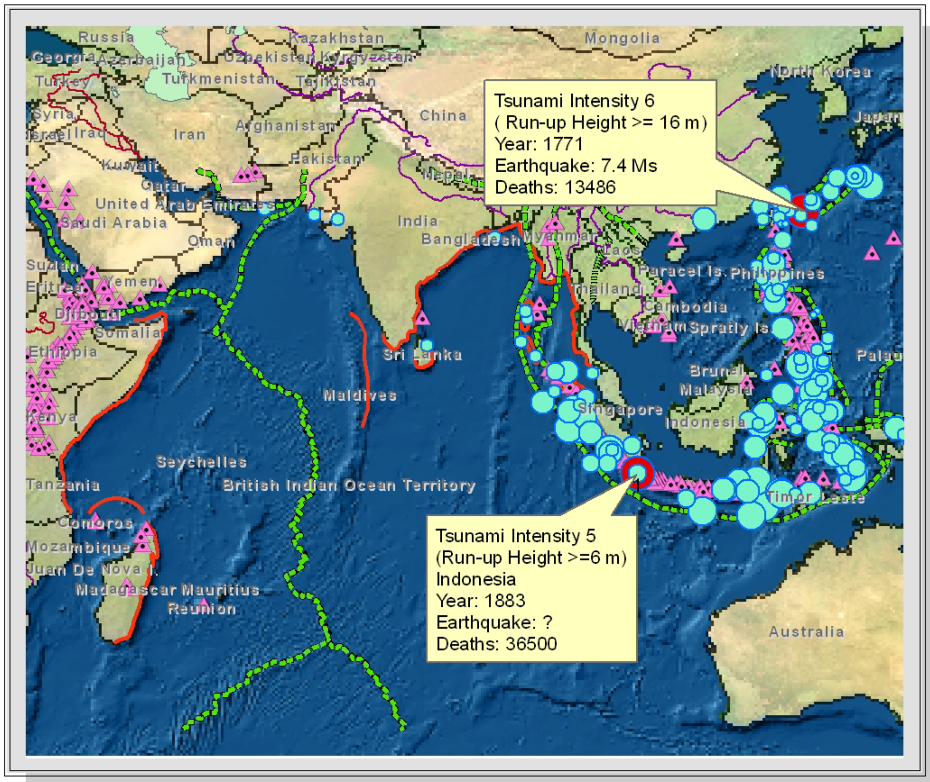
The Relief Activity Map for the Indian Ocean Earthquake/Tsunami Disaster

Appendix B

Using the data available through the Internet and data providers such as NOAA, many maps can be created. With this and some additional data, analysis/modeling could also be performed. The tsunami intensity database, along with the significant earthquakes database, was downloaded from the NOAA Web site. The map shows tsunami run-up heights, volcanoes, significant earthquakes, affected shorelines, plate boundaries, and political information. The database can be queried for the specific earthquake and/or slide information that is related to it. NOAA provided shapefiles and used ArcCatalog™ to create a personal geodatabase and feature class dataset. The geographic data area extends from the Indian Ocean to the west side of the Pacific Ocean. The spatial distribution of the tsunami events shows clustering in mainly Indonesia, the Philippines, and Japan. Several other events have occurred between the years 416 and 2004 in Pakistan, India, Bangladesh, Myanmar, Malaysia, Australia, China, Vietnam, Papua New Guinea, and Singapore. The map presents the chronology, tsunami intensity, and number of events and their spatial distribution in the area (figure B-1).

J-9543

Figure B-1

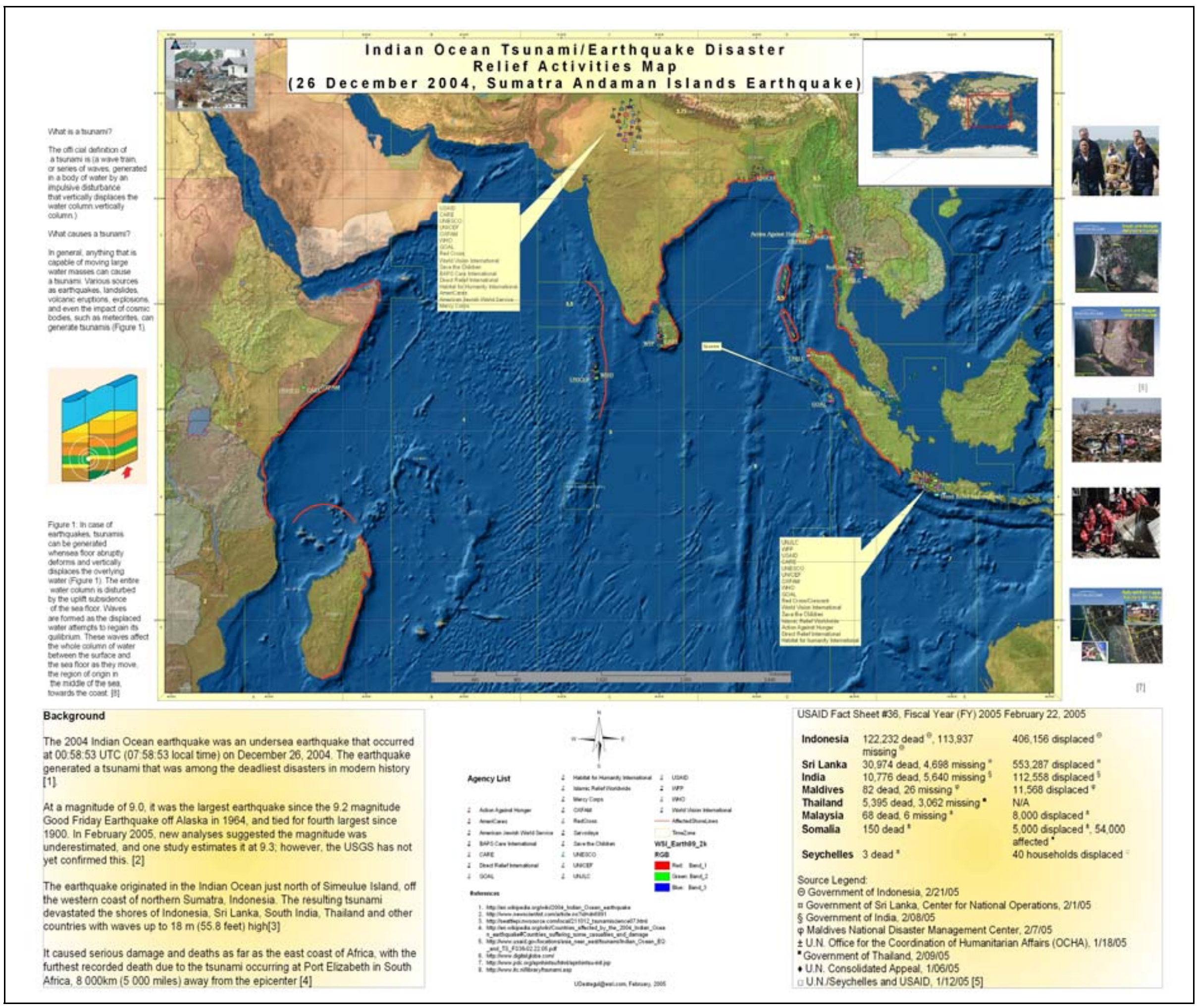


Tsunami Intensity Map for the Indian Ocean and Surrounding Areas (Years 416–2004)

Appendix C

The information from the interactive map, background of the disaster, and the casualty statistics comprise a poster. Such posters provide information at a glance. Photographs, the definition of tsunami, casualty statistics, and the background were designed around a screen shot of the *Disaster Relief Activities Map* (figure C-1).

Figure C-1

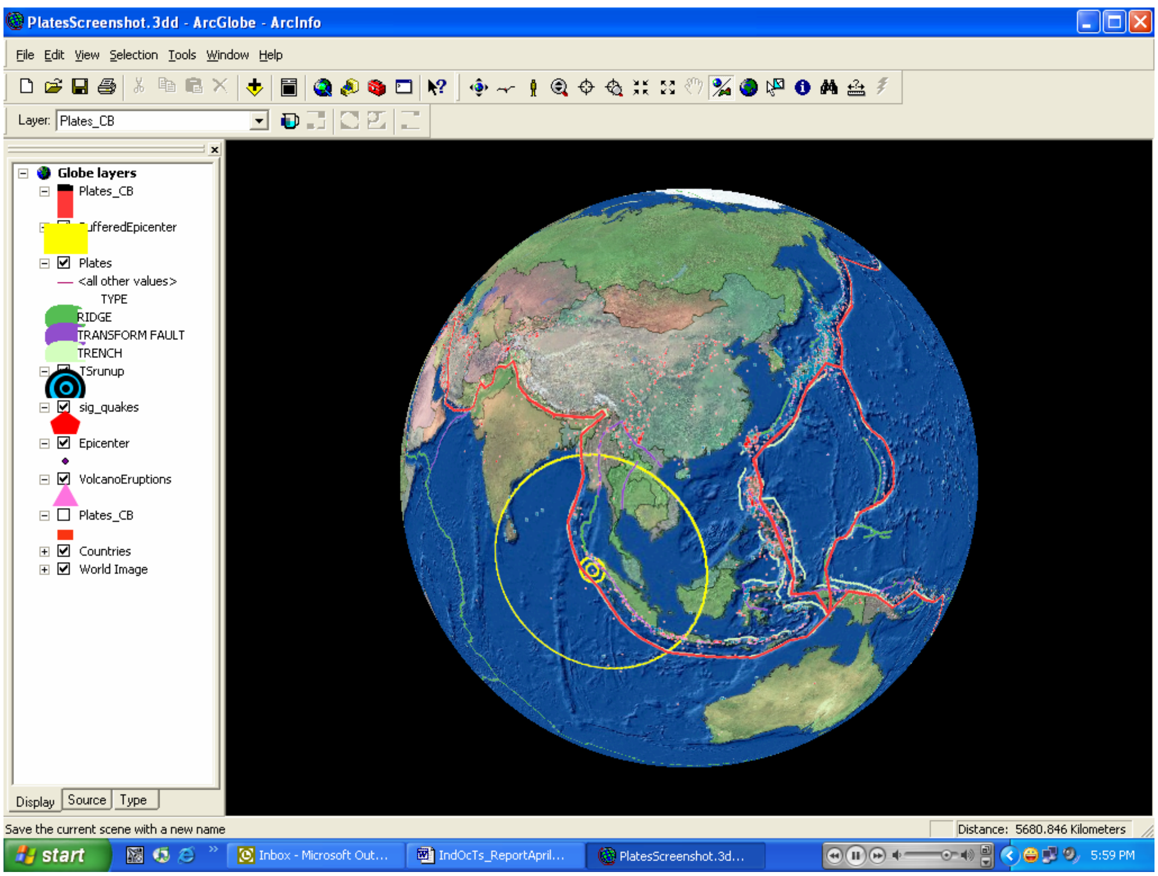


Poster Designed for Information at a Glance

Appendix D

Another product of this study is the ArcGlobe map project. On this map, plate boundaries with transform, ridge, and trench types, in addition to a convergent boundaries layer, are used to show the areas that are at risk for tsunamis. The other layers are significant earthquakes; tsunami run-up; volcanoes; epicenter of the December 26, 2004, earthquake over the countries; and the world images from the NOAA database and the book *Exploring the Dynamic Earth: GIS Investigations for the Earth Sciences.*[27] With ArcGlobe, users can view the globe in 3D and zoom in to see bathymetry, which enables them to understand the subduction zone and its form.

Figure D-1



The Screen Shot of the Map Project That Shows Plate Boundaries, Epicenter, and Significant Earthquakes

[27] *Exploring the Dynamic Earth: GIS Investigations for the Earth Sciences* (http://saguaro.geo.arizona.edu).

Appendix E: Glossary

Acronym	Definition
ADB	Asian Development Bank
Bakornas	The national coordinating body for disaster management, Indonesia
CNES	The French space agency
COE	Center of Excellence in Disaster Management and Humanitarian Assistance
DART	Disaster Assistance Response Team
DFID	Department for International Development
DOS	Department of State
DRB	Disaster Response Branch
DTED	Digital Terrain Elevation Data
ECHO	The European Commission's humanitarian aid department
EROS	Earth Resources Observation System
EO	Earth Observation
ESA	European Space Agency
FAO	Food and Agriculture Organization
GCP	ground control points
GEOSS	Global Earth Observation System of Systems
GIS	geographic information system
GPS	global positioning system
HIC	(UN) Humanitarian Information Centre
HIU	Humanitarian Information Unit
ICS	Incident Command System
IDP	internally displaced people
IMF	International Monetary Fund
INSARAG	International Search and Rescue Advisory Group
ISDR	International Strategy for Disaster Reduction
IWMI	International Water Management Institute
MHPCC	Maui High Performance Computing Center
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency (formerly NIMA)
NGO	nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
OFDA	Office of Foreign Disaster Assistance (USAID)
OSOCC	On-Site Operations Coordination Center
PDC	Pacific Disaster Center
PPEW	Platform for the Promotion of Early Warning (UN ISDR)
RS	remote sensing
SAR	Search and Rescue Team

Acronym	Definition
SRSA	Swedish Rescue Services Agency
SRTM	Shuttle Radar Topography Mission
UN	United Nations
UNDAC	United Nations Disaster Assessment and Coordination
UNEP	United Nations Environmental Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNHAS	United Nations Humanitarian Air Service
UNHCR	United Nations High Commission for Refugees
UN HIC	United Nations Humanitarian Information Centre
UNICEF	United Nations Children's Fund
UN ISDR	United Nations International Strategy for Disaster Reduction
UNITAR	UN Institute for Training and Research
UNJLC	United Nations Joint Logistics Centre
UN OCHA	UN Office for the Coordination of Humanitarian Affairs
UN ODAP	UNWFP Emergency Preparedness and Response Unit
UNOSAT	A UN Institute for Training and Research project
UNWFP	United Nations World Food Programme
USAID	United States Agency for International Development
USG	United States Government
USGS	United States Geological Survey
USPACOM	U.S. Pacific Command
VVAF	Vietnam Veterans of America Foundation
WCMC	World Conservation Monitoring Centre (UNEP)
WHO	World Health Organization