TECHNOLOGY RESOURCES FOR EARTHQUAKE MONITORING AND RESPONSE (TREMOR)

Final Report

International Space University
Summer Session Program 2007

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Abstract

Earthquakes represent a major hazard for populations around the world, causing frequent loss of life, human suffering, and enormous damage to homes, other buildings, and infrastructure. The Technology Resources for Earthquake Monitoring and Response (TREMOR) proposal is designed to address this problem. This proposal recommends two prototype systems integrating space-based and ground technology. The suggested pilot implementation is over a 10-year period in three focus countries – China, Japan, and Peru – that are among the areas in the world most afflicted by earthquakes.

The first proposed system is an Earthquake Early Warning Prototype System that addresses the potential of earthquake precursors, the science of which is incomplete and considered controversial within the scientific community. We recommend the development and launch of two small satellites to study ionospheric and electromagnetic precursors. In combination with ground-based precursor research, the data gathered will improve existing knowledge of earthquake-related phenomena.

The second proposed system is an Earthquake Simulation and Response Prototype. An earthquake simulator will combine any available precursor data with detailed knowledge of the affected areas using a Geographic Information System (GIS) to identify those areas that are most likely to experience the greatest level of damage. Mobile satellite communication hubs will provide telephone and data links between response teams, while satellite navigation systems will locate and track emergency vehicles. We recommend a virtual response satellite constellation composed of existing and future high resolution satellites. We also recommend education and training for response teams on the use of these technologies.

The two prototypes will be developed and implemented by a proposed non-profit non-governmental organization (NGO) called the TREMOR Foundation, which will obtain funding from government disaster management agencies and NGOs. A for-profit subsidiary will market any spin-off technologies and provide an additional source of funding. Assuming positive results from the prototype systems, Team TREMOR recommends their eventual and permanent implementation in all countries affected by earthquakes.

Faculty Preface

An old Indian fable tells the story of six blind men who wanted to find what an elephant looked like. The first man approached the elephant's broad and sturdy side, and he concluded that the elephant was like a wall. The second man touched the tusk; after feeling it so round, smooth and sharp he figured that the elephant was much like a spear. The story goes on and each of the blind men created their vision of the elephant based on the limited part of it that they were able to touch and feel. Afterwards they discussed loud and long what the elephant looked like without coming to a universal conclusion. Although each one was partly right, they all were wrong… they all were missing the big picture.

Our understanding of earthquakes is a bit like the story of the six blind men. We experience the symptoms of earthquakes but do not understand fully their mechanics. Today our knowledge is limited by our narrow research scopes: geophysicists study the solid Earth; atmospheric scientists study the atmosphere; ionospheric scientists study the ionosphere. Over the past decade controversial research has indicated that anomalous phenomena can be observed prior to an earthquake - not only in the Earth's surface but also in the lower atmosphere and ionosphere. Yet, no one understands the origins and complex interaction of the Earth's lithosphere, atmosphere, and ionosphere that give rise to these earthquake precursors.

The International Space University's 3-I concept (International, Intercultural & Interdisciplinary) provides a unique approach to clarifying the mysteries associated with these devastating natural disasters. The students of this team project (TP) have studied the possible earthquake precursor phenomena from a multidisciplinary vantage point and propose a global, integrated study of earthquake precursors in an attempt to provide early warning for earthquakes. They also propose a Prototype Simulation and Response System that makes better use of the existing satellite systems and incorporates satellite systems which are expected to provide service in the immediate future. This report was prepared by a team of 36 highly intelligent and motivated students from 13 countries. This report contains innovative ideas that we hope will enable humanity to reduce the worldwide losses of life and property from earthquake damage.

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Student Preface

"Yet we are the movers and shakers of the world for ever, it seems"

- Arthur O'Shaughnessy, 1844–1881

In Beijing over the summer of 2007, thirty-six professionals from around the world met to help reduce the devastation caused by earthquakes. Organizing our group and reconciling thirty-six different visions of this final paper was a difficult task, but we succeeded because of good advice, and because we listened to each other. Early brainstorming revealed the methods our team would use to tackle this problem: by having global application, by developing a realistic solution with a significant impact, and by being innovative. We believe we have succeeded in all of these areas.

Over the course of the team project, the advantages of having a large group became apparent. We were able to create entire presentations and reports seemingly overnight, we were always in good company during late nights in the computer lab, and we had a range of expertise to draw upon through the challenges we faced. We are grateful to our visiting experts, whose advice greatly improved our team project. We are also grateful to our chair, Ray Williamson and faculty shepherd, Scott Madry, whose patience and direction were indispensable. Finally, we are grateful to our TA, Juan Carlos Fernandez Diaz, for his positive attitude and optimism, and for continuously reminding us that in his eyes, we are the "Best Team Ever".

We hope that the ideas presented here by Team TREMOR will be adopted by the international community to save lives all over the world.

Team TREMOR
Beijing, China, 2007

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List of Acronyms

A

ADPC	Asian Disaster Preparedness Center
ADRA	Adventist Development Relief Agency
ADRC	Asian Disaster Reduction Center
AIST	National Institute of Advanced Industrial Science and Technology
ALOS	Advanced Land Observation Satellite
APFM	Associated Program on Flood Management
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVL	Advance Vehicle Locating

B

BB	BroadBand

C

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CBERS	Satélite Sino-Brasileiro de Recursos Terrestres
CEA	China Earthquake Administration
CEOS	Committee on Earth Observations
CFAB	Climate Forecast Applications in Bangladesh
CNES	Centre National D'Etudes Spatiales (France)
COPUOS	Committee for Peaceful Use of Outer Space
CWS	Church World Service

D

DEMETER	Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions
DC	Direct Current
DiMSIS	Disaster Management Spatial Information System
DMC	Disaster Monitoring Constellation
DMS	Disaster Management System(s)

E

EEW	Earthquake Early Warning (Japan)
ELF	Extra Low Frequency
EMF	Electromagnetic field
ENVISAT	Environment Satellite
EO	Electro-Optical
EQ	Earthquake
ERC	Emergency Relief Coordination
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESAT	Earthquake Satellite
EWS	Early Warning System

F

F-Net	Full Range Seismograph Network of Japan

G

GEO	Group on Earth Observations
GEWRN	Global Emergency Warning And Relief Network
GDACS	Global Disaster Alert and Coordination System
GDP	Gross Domestic Product
GNP	Gross National Product
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GSI	Geographical Survey Institute
GSN	Global Seismic Network

H

HF	High Frequency

I

IAHV	International Association of Human Values
ICT	Information Communications Technology
IGP	Instituto Geofísico del Perú (Geological Institute of Peru)
INDECI	Instituto Nacional de Defensa Civil (Peru)
InSAR	Interferometric Synthetic Aperture Radar
IR	Infra-red
iSTEP	integrated Search for Taiwan Earthquake Precursors
ISU	International Space University
ITU	International Telecommunications Union

J

JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JERS	Japanese Earth Resources Satellite
JMA	Japan Meteorological Agency

L

LAIC	Lithosphere Atmosphere Ionosphere Coupling
LAN	Local Area Network
LEO	Low Earth Orbit
LIDAR:	Light Detection And Ranging

M

MAN	Metropolitan Area Network
MEDAS	Modular Environmental Data Acquisition System
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MIC	Ministry of Internal Affairs and Communication (Japan)
MODIS	Moderate Resolution Imaging Spectroradiometer
MRI	Magnetic Resonance Imaging
MS	Multi-spectral

N

NASA	National Aeronautics and Space Administration
NCAR	National Centre for Atmospheric Research
NDSN	National Digital Seismic Network (China)
NIED	Earth Science and Disaster Prevention
NOAA	National Oceanic and Atmospheric Administration (United States)
NGO	Non-Governmental Organization

P

PDA	Personal Digital Assistant
POC	Point of Contact

R

RADAR	Radio Detection and Ranging
RCSC	Red Cross Society of China (China)
REMSAT	Real-time Emergency Management via Satellite
ROM	Rough Order of Magnitude
RS	Remote Sensing

S

SAR	Synthetic Aperture Radar
SINADECI	Sistema Nacional de Defensa Civil (National System of Civil Defense)
SM	Strong Motion
SP	Short Period
SPOT	Satellite Pour l'Observation de la Terre
SSO	Sun Synchronous Orbit
SSTL	Surrey Satellite Technology Limited
STEC	Slant Total Electron Content
SWOT	Strength-Weakness-Opportunity-Threat

T

TEC	Total Electron Content
TIR	Thermal Infra-Red
TREMOR	Technology Resources for Earthquake Monitoring and Response

U

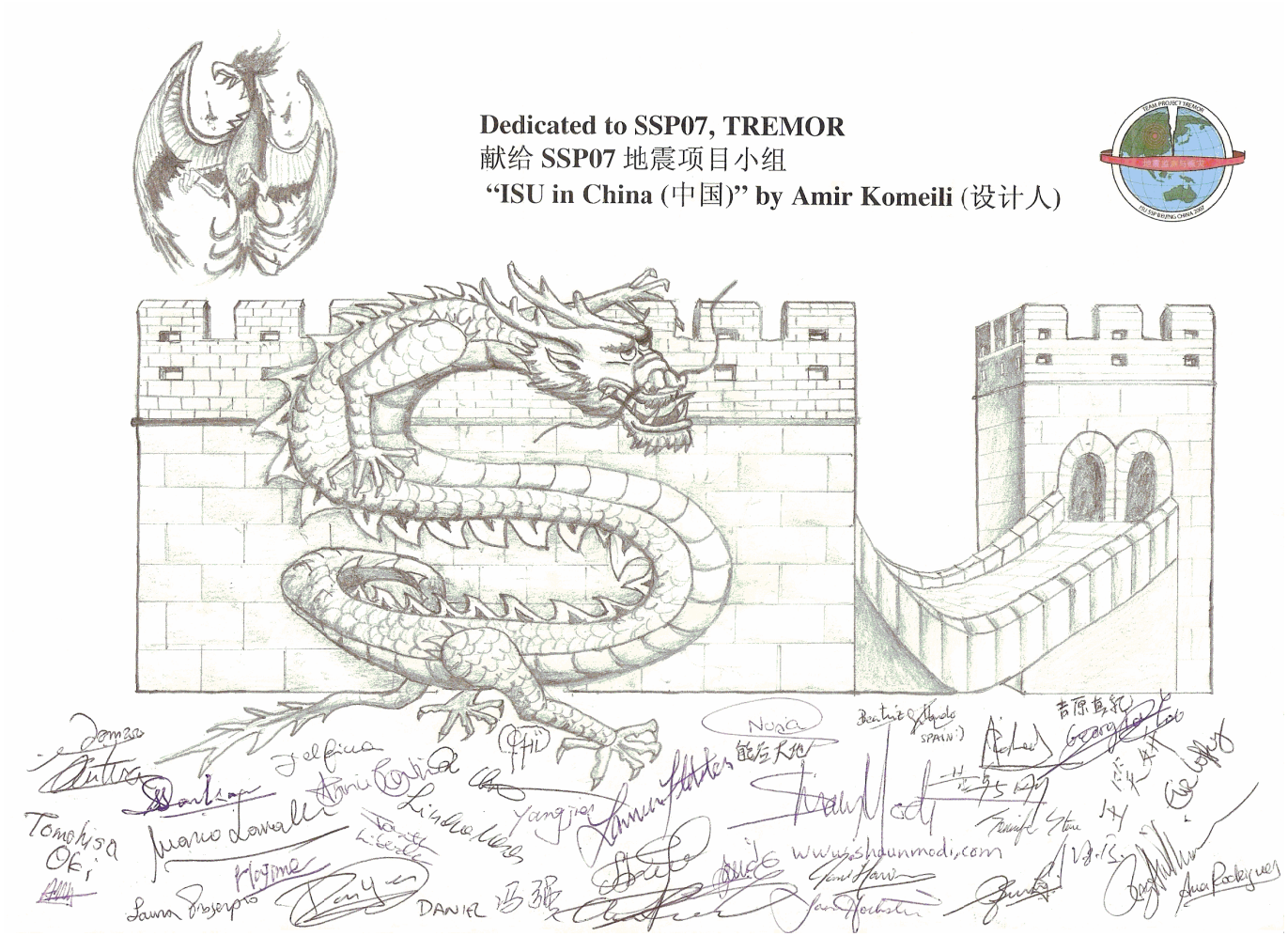
ULF	Ultra Low Frequency
UN	United Nations
UNISDR	United Nations International Strategy for Disaster Reduction
UN-OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNOOSA	United Nations Office for Outer Space Affairs
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Early Response
USD	United States Dollars
USGS	United States Geological Survey

V

VENTEN	Vehicle through Electric Network of disaster geographical information
VLF	Very Low Frequency
VNIR	Visible and Near Infra-Red
VOIP	Voice Over Internet Protocol
VSAT	Very Small Aperture Terminal

W

WAN	Wide Area Network
WGET	Working Group on Emergency Telecommunications
WHO	World Health Organization
WMO	World Meteorological Organization



Dedicated to SSP07, TREMOR
献给 **SSP07** 地震项目小组
"ISU in China (中国)" by Amir Komeili (设计人)

Chapter 1
Introduction

The Earth's crust is divided into numerous tectonic plates, in gradual motion with respect to one another. Occasionally, friction between the plates interrupts this motion, causing deformation of the contact surface and stress build-up. When stress reaches a critical point the plates suddenly shift and release enormous amounts of energy. These earthquakes cause devastation to many parts of the world each year. Since 1990, earthquakes have killed more than 300,000 people and caused over USD 250 billion worth of damage.

Space systems play a crucial role in understanding earthquakes and in mitigating their level of destruction. For SSP 07, Team TREMOR was tasked with assessing the present utilization of satellites in earthquake-related activities and with identifying possible areas of future utilization. In this report, we present our findings and recommend the creation of a new integrated space- and ground-based system to reduce the losses inflicted by these natural events.

1.1 Motivation for the TREMOR Project

Remote sensing satellites are presently used for many earthquake-related activities, including ground-motion observation, risk evaluation based on building locations, and damage assessment in the immediate aftermath of an earthquake. There is presently a gap in terms of temporal resolution (*i.e.*, revisit time for observing a given area) that, in some cases, can be as much as several weeks. This is of particular concern for earthquake response, where timely data are critical. There is also currently no reliable method for forecasting the occurrence of earthquakes from space (or from the ground for that matter) more than a few minutes before the event happens. Several claims of earthquake precursors have been put forward, such as ionospheric changes, electromagnetic effects, and ground heating. The science behind these is far from complete, and in fact is considered controversial in many quarters. The prospect of being able to forecast earthquakes with a suitably long lead time (*e.g.*, days or even weeks) is something that Team TREMOR nevertheless feels should be investigated further.

Navigation satellites (*e.g.*, GPS) are used for some ground motion studies, and are also used by response personnel for position determination in the disaster zone. One area where this technology could be further utilized is in vehicle tracking during response efforts to co-ordinate the availability of critical vehicles such as fire trucks, ambulances, and diggers. Some organizations have made use of this technology, but it has not been universally applied.

Telecommunications satellites are used during a disaster situation where normal methods of communication (*e.g.*, landline or cellular networks) are disrupted or otherwise unavailable. The application of satellite communication technology in practice is limited by the availability of satellite telephones and by the level of training of ground response personnel in their use. Mobile satellite ground stations can be used to handle cellular phone traffic when the normal cellular systems are inoperative. Other applications for satellite communications at a disaster site include teleoperated robots to help rescue teams and telemedicine.

The mission statement of Team TREMOR is as follows:

> *"To develop an integrated terrestrial and space-based global system for mitigating the effects of earthquakes, and improving response."*

1.1.1 Historical Context

Figure 1-1 shows the geographical location of all major earthquakes from 1963 to 1998. Earthquakes typically occur along tectonic plate boundaries, but some occur along fault lines in the middle of the plates as well. Countries around the Pacific Rim are heavily affected, as are many countries in the Mediterranean region and western and southern Asia. China, while not lying directly on a plate boundary, nevertheless has many seismic faults and its large population makes it particularly vulnerable.

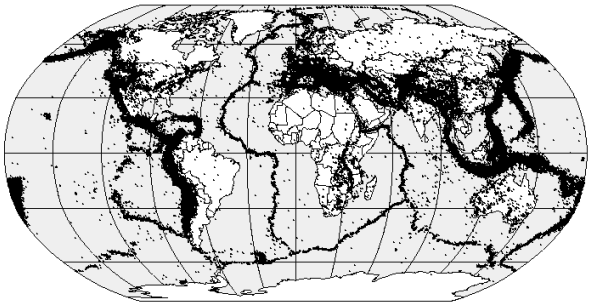


Figure 1-1 Occurrence of Earthquakes Globally (DTAM, 2002)

Figure 1-2 shows the number of fatalities and the economic damage resulting from earthquakes occurring between 1990 and 2006 in all countries. Note that this figure includes data only from land-based earthquakes and does not account for deaths from tsunamis and other earthquake after-effects. The large peak in 1995 damage results primarily from the Kobe, Japan earthquake. The peaks in fatalities in 1999, 2001, 2003, and 2005 represent major earthquakes in Turkey, India, Iran, and Pakistan respectively.

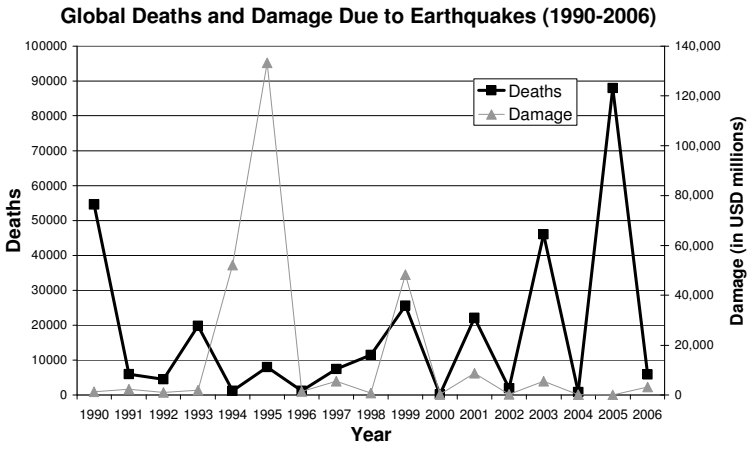


Figure 1-2 Global Deaths and Damage Due to Earthquakes (1990-2006) (NGDC, 2007)

1.2 TREMOR System

In accordance with our mission statement, Team TREMOR proposes the creation of a two-tiered system to address the mitigation and response aspects of earthquakes.

The mitigation aspect will be addressed by an Earthquake Early Warning Prototype System, which over a 10-year period will assess several possible earthquake precursors and establish whether a reliable earthquake early warning system is feasible. The validation of these precursors will be performed using both space- and ground-based technologies. The space segment will consist of two new small satellites performing ionospheric soundings and electromagnetic measurements to observe any potential earthquake precursor effects. Existing satellites will support this work through evaluation of thermal-infrared and InSAR precursor possibilities. If a reliable early warning system can be validated, then this system can be applied globally. If it cannot be established, the development of this prototype will nevertheless contribute significantly to our understanding of earthquakes.

The response aspect will be addressed by a second prototype system that will build upon the first. If an early warning of an earthquake is possible, the effects of that earthquake on the local area can be simulated. This simulation can provide valuable information to response teams, potentially in advance of the event or shortly thereafter, by identifying the areas that will be most at risk of damage. Other aspects of the Simulation and Response Prototype System include the provision of mobile telecommunication hubs that use satellite links to maintain communication between different response teams to help them better coordinate their activities, and training of response personnel in the efficient use of this technology. Finally, we recommend creation of a virtual satellite response system by coordinating data collection from existing and future high resolution multi-spectral and Synthetic Aperture Radar Systems.

These two prototypes will be developed in three focus countries -- China, Japan, and Peru -- under the umbrella of a non-profit, non-governmental organization (NGO) called the TREMOR Foundation. The Foundation will obtain the appropriate funding for the prototypes from governments and response agencies in each of the focus countries. The Foundation will also act as a liaison with each of these organizations to correctly implement the prototype systems and to involve the organizations at each stage in the system development. A for-profit subsidiary will also be created to find commercial markets for any spin-off capabilities obtained during the development of these prototypes. This subsidiary would be fully owned by the Foundation and any profits can be used to assist with overall funding.

1.3 Organization of the Report

This report provides background and details of the proposed prototype systems and their implementation. Chapter 2 reviews the science behind earthquakes and introduces several of the possible precursors that will be studied for the Earthquake Early Warning Prototype System. Chapter 3 reviews the current status of disaster management systems in general. Chapter 4 specifically reviews the existing systems for earthquakes. Chapter 5 presents a gap analysis, indicating where improvements can be made to the present systems. Chapter 6 describes the proposed Earthquake Early Warning Prototype System, including both technical and policy aspects. Chapter 7 describes the proposed Simulation and Response Prototype System from a technical, policy, and education standpoint. Chapter 8 presents the business plan and the legal and policy issues for the TREMOR Foundation, including a rough order of magnitude (ROM) cost estimate, description of the proposed subsidiary, and an examination of the legal agreements to be made with the focus countries. Chapter 9 examines in detail how the two prototype systems would be applied in each of the three focus countries.

Chapter 2
Scientific Background

A major reason earthquakes are so devastating is that, at present, we are unable to reliably predict their occurrence to provide advanced warning. The difficulty in making a meaningful earthquake prediction lies in specifying the area, time, and magnitude of an event. In order to forecast earthquakes, we must understand what causes them and where they occur. In this chapter, we discuss seismology - specifically plate tectonics and types of earthquakes associated with different plate boundaries - and the status of earthquake precursor science.

2.1 Seismology

Seismology is the study of earthquakes, with a focus on the propagation of seismic waves through the Earth's crust, and the movements of tectonic plates.

2.1.1 Plate Tectonics and Types of Plate Boundaries

The theory of plate tectonics evolved from the hypothesis of continental drift and was proposed by Alfred Wegener in the early part of the 20th century (Skinner *et al.*, 1999). According to this theory, the outer surface of our planet can be viewed as a cracked shell. This 'shell' is composed of seven major tectonic plates with several smaller plates, as well as a few areas of complex plate tectonic structure as shown in Figure 2-1 (Skinner *et al.*, 1999). Tectonic plates are constantly moving relative to each other at different rates. For example, the fault known as the East Pacific Rise at the boundary of the Pacific and Nazca Plates has a rate of motion of 15 cm per year (Kiger, 1996).

Tectonic plate boundaries can be divided into three types: divergent, convergent, and transform. Divergent plate boundaries can be found in mid-ocean environments where the dominant force is tension (*e.g.*, Mid-Atlantic ridge). Convergent plate boundaries are also known as subduction zones because of the process by which collision of crustal plates results in one plate being drawn down or overridden by another. Major mountain ranges such as Cordillera in South America can be found in these zones. Transform plate boundaries can be found along fault lines between adjoining plates that are sliding against one another. These are located mostly in the ocean; however, some occur on land such as along the San Andreas Fault zone in California. Although earthquakes occur in all tectonic plate boundary settings, those along convergent and transform plate boundaries are of most concern to human populations.

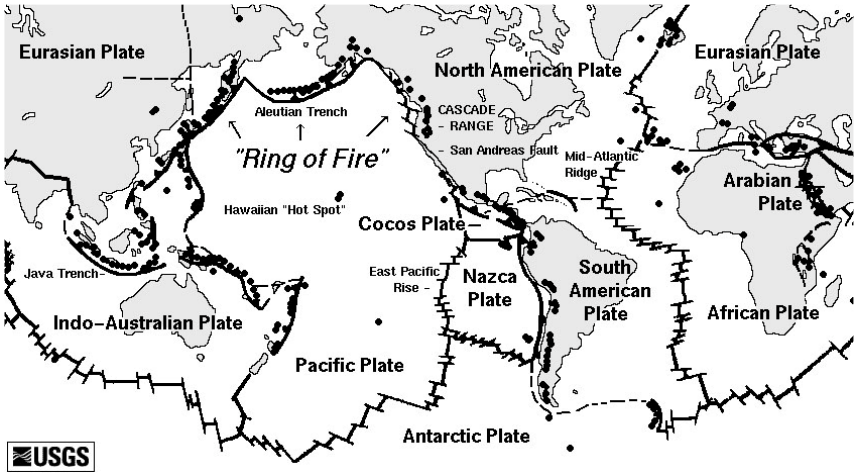


Figure 2-1 Plate Tectonics Map of the World Including "Ring of Fire" and Locations of Frequent Earthquakes (Black Dots) (USGS, 2007)

2.1.2 Types of Earthquakes and Their Causes

Most earthquakes occur along tectonic plate boundaries; however, intraplate and volcano-related earthquakes have also been known to occur. In all cases, earthquakes can be generated at different depths from shallow (<40 km), intermediate (40 to 300 km), to deep (>300 km) (Gutenberg and Richter, 1954). Energy released from shallow and intermediate depth earthquakes down to 70 km can have devastating effects on human activity because of their proximity to the surface (Kirby *et al.*., 1996; Frohlich, 1989).

The cause of earthquakes along the transform plate boundary can be explained by the elastic rebound theory. This theory states that rocks along different parts of a fault plane do not slide smoothly past each other, but rather lock together. This causes the fault to bend and store elastic energy. Once the elastic limit is exceeded, the fault catastrophically fails and releases massive amounts of energy in the form of an earthquake (Skinner *et al.*, 1999). Most of the earthquakes along convergent plate boundaries are caused by either (1) instability in frictional contact between subducting and overriding plates, (2) the growth of a shear crack in either subducting or overriding plates, or (3) dehydration of the subducting slab (Harker *et al.*, 2003).

Intraplate earthquakes can be caused by stress concentrations, zones of weakness, or high heat flow (Finnigin, 1999). Stress concentrations can either result from non-homogeneities in continental crust that cause local stress concentrations, or intrusion of magma into the bedrock. Zones of weakness can appear in the crust from a previous seismic activity. Approximately half of all intraplate earthquakes occur in close proximity to ancient failed faults (Finnigin, 1999). Higher than average heat flow can be generated by high temperatures at depths that weaken the upper mantle and lower the crust, thus creating an instability in upper crust strength. For example, the most devastating intraplate earthquake in New Madrid, Missouri, in 1811-1812 is believed to have been caused by higher than average heat flow.

The main cause of volcano-related earthquakes is magma activity. The magma ascent from the magma chamber causes the rock surrounding the chamber to crush due to high stress (Kubotera & Uni, 1965). Shallow earthquakes, or micro-tremors (< 1 km depth), occur in a limited region beneath the active crater and shallow volcanic vent, while deeper earthquakes can be detected up to 10 km below the volcano base.

2.1.3 Earthquake Magnitude and Richter Scale

The magnitude of earthquakes is measured on the Richter Scale, which was invented by Charles Richter in 1935 (Gutenberg & Richter, 1954), and detected, recorded, and measured by seismographs. The Richter Scale is logarithmic, so each successive number on the scale equates to an increase in magnitude by a factor of ten. The data on seismographs reflect shaking of the ground surface beneath the instrument caused by vibrations produced by earthquakes. The two general types of vibrations produced by earthquakes are surface waves, which travel along the Earth's surface, and body waves, which travel through the Earth. Surface waves usually have the strongest vibrations and cause most of the damage done by earthquakes.

2.2 Precursor Science

A large number of earthquake precursors of varying timescales have been proposed, including ground deformations, crustal stress, foreshocks, groundwater level changes, abnormal animal behavior, earthquake "clouds", atmospheric thermal anomalies, and ionospheric anomalies (Pulinets, 2006). Short term precursors include ground, atmospheric, and ionospheric anomalies that occur over a period ranging from hours to weeks. Longer timescale precursors are the magnetic field and ground displacements occurring over a period of months to years (mid-term precursors). The longest term precursors are associated with seismic activity lasting several years (Ouzounov 2007, pers. comm., 9 August).

The science of earthquake forecasting is controversial, mainly because of the paucity of data, the opportunity to use hindsight after an event to modify previous predictions, and the random chance of making a correct prediction when a large number of forecasts are made. Traditional precursor signals such as pre-earthquake seismic activity, acoustic ground waves, tectonic plate deformation, and ground thermal profile changes have provided limited success in earthquake prediction; however, interesting results from ground-breaking research are improving the standing of earthquake precursor science. Some of the most promising precursors are anomalies in air temperature and humidity due to ground processes, atmospheric anomalies, and ionospheric anomalies (Pulinets, 2006). It would seem that all of these precursors are linked and may be explained by the theory of Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) (Pulinets & Boyarchuk, 2004).

2.2.1 Lithosphere-Atmosphere-Ionosphere Coupling

LAIC describes a complicated series of processes involving many physical interactions that begin beneath the Earth's surface and finally manifest themselves in the ionosphere. The region on the ground in which precursory phenomena associated with an impending earthquake are first observed is termed the "earthquake preparation zone" (Dobrovolsky *et al.*, 1979). Mechanical and geochemical processes in the Earth's crust within this zone result in gas discharges, including radon, carbon dioxide, and volatile metals (Dobrovolsky & Voitov, 1994).

Radon production occurs continuously throughout the Earth's crust, but when an earthquake is imminent the production of radon decreases in the compression zone near the epicenter and increases in stretching zones away from the associated fault. The release of radon ionizes the surrounding air and creates near-Earth plasma in the form of long-living ion clusters. These changes can be detected by both ground- and satellite-based instruments. Low frequency seismo-electric emissions are also observed in seismically active zones prior to an earthquake, and may result from particle acceleration and instabilities in the near-Earth plasma (Nagao, 2002; Kikuchi, 2001).

Ionospheric anomalies are caused by the anomalous electric field penetrating the ionosphere and creating irregularities in electron concentration. Joule heating[1] in the F-region[2] of the ionosphere generates acoustic gravity waves and creates small-scale density irregularities (Hegai *et al.*, 1997). Large scale irregularities in electron density have also been observed in the F-region (Legen'ka and Pulinets, 2003). Electric field penetration of the ionosphere occurs when the earthquake preparation zone exceeds 200 km in diameter (Pulinets *et al.*, 2000). This implies a magnitude threshold of 5.0 on the Richter Scale at which ionospheric anomalies may be used as earthquake precursors (Dobrovolsky *et al.*, 1989). These anomalies may be studied using topside sounding, tomography, and radio occultation techniques. It is important to note that ionospheric variations also occur due to other phenomena such as solar flares, coronal mass ejections, and cosmic rays. It is therefore necessary to be able to distinguish these anomalies from earthquake precursor signals. It has been shown that ionospheric variations due to seismic activity have unique features and can be differentiated from geomagnetic storms (Pulinets *et al.*, 2003).

Tests of the LAIC theory include ground- and satellite-based measurements of atmospheric and ionospheric variations prior to and during the 7.8 magnitude Colima, Mexico earthquake of 2003 (Pulinets *et al.*, 2006). This work concluded that these variations were caused by radon ionization within the earthquake preparation zone, as proposed by the model. Validation of LAIC will require more comprehensive ground and satellite measurements before we can fully comprehend every process in the model. Such data may improve our ability to accurately forecast earthquakes.

[1] Joule heating is the process by which heat is generated from passage of an electric current through a conductor

[2] The F-region is the uppermost region of the ionosphere (120–400 km above the Earth's surface)

Current Situation in Disaster Management: Policy and Education

This chapter provides a brief introduction to current practices in disaster management, how disaster management is affected by policy and legal considerations, and the role of education in disaster management.

3.1 Disaster Management Cycle

Disaster management is defined by the United Nations as "the body of policy and administrative decisions and operational activities which pertain to the various stages of a disaster at all levels" (UN, 1992). Literature suggests that disaster management occurs in a cycle of four interrelated phases: planning, mitigation, recovery, and response (Roper *et al.*, 2005). Within the disaster management community, however, there is a disparity in the ways in which the disaster management cycle is defined (ISU, 1999). For example, the International Space University reports that "the terms and phases used by the Committee on Earth Observations (CEOS) differ from those used by the Australian Emergency Management Glossary or those used by the US Federal Emergency Management Agency" (ISU, 1999). In the TREMOR report the four phases will be understood as the Disaster Management Cycle shown below in Figure 3-1.

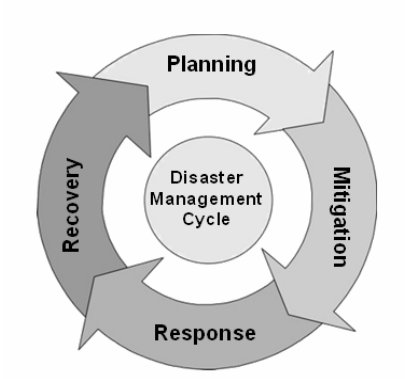


Figure 3-1 The Disaster Management Cycle

3.1.1 Planning Phase

The planning phase consists of efforts to prepare for the eventual occurrence of a disaster. Planning involves activities to analyze and document the possibility of an emergency or disaster and the potential consequences of or impacts on life, property, and environment

(Johnson, 2000). This phase includes: planning of actions to be taken when a disaster event occurs; the training of special disaster management teams; the preparation and education of the population concerning possible disasters; testing of disaster response and management scenarios (UN, 1992).

3.1.2 Mitigation Phase

Disaster mitigation can be defined as "measures taken in advance of a disaster aimed at decreasing or eliminating its impact on society and environment" (UN, 1992). It includes the development of plans to minimize the impact of a given disaster and measures to enhance disaster response operations. Actions taken to warn the public of an impending disaster, such as hurricane warnings, are also included in the mitigation phase.

3.1.3 Response Phase

Disaster response is defined by the United Nations as the "sum of decisions and actions taken during and after disaster, including immediate relief, rehabilitation, and reconstruction" (UN, 1992). Actions taken during this phase are intended to provide emergency assistance for victims, to stabilize the situation and reduce the probability of secondary damage, and to speed recovery operations (Johnson, 2000).

3.1.4 Recovery Phase

The disaster recovery phase includes the activities, both short- and long-term, that are necessary to return society to normality after a disaster. Short-term recovery activities restore vital life-support systems to minimum operating standards; long-term recovery activities may continue for years after the earthquake (Johnson, 2000).

An additional term often used in the disaster management community is *disaster reduction.* Disaster reduction can be defined as "the conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development" (UNISDR, 2003).

3.2 What Happens When a Disaster Occurs

When a large scale emergency event or disaster occurs (*e.g.,* tornado, earthquake) the first entities to respond in the minutes and hours immediately following an event are local emergency services, including police, fire, and emergency medical departments of the localities affected by the disaster. For large scale disasters, local first responders are reinforced by units from other jurisdictions and from the private sector as time increases after the disaster. Additional responders might include those from national government agencies, national militaries, and various international and national NGOs.

This pattern of response - beginning with local and expanding to include state, national and private responders - leads to immense coordination and management difficulties in response operations (Bostian *et al.*, 2002; Cutter, 2003; Roper, 2005). Disaster response is characterized by heterogeneity in actors and systems. Each responder entity brings different sets of communications technology and response equipment. The communication systems of the local first responders may not be able to talk to those systems of the entities responding from the state and national level. In fact, the systems of local fire departments may be different from those of local police departments. Interoperability of systems and data, and effective communications become major concerns (Roper, 2005).

After the 1999 Marmara Earthquake in Turkey, which had a magnitude of 7.4 on the Richter Scale and killed 17,480 people, more than 200 national and international relief agencies participated in the on-the-scene response. As a result, during the response effort coordination became an issue as "cross-matching the demand for relief and the supply for

needs in a harmonious, efficient and effective way arose as a problem" (Turkish Red Crescent Society, 2006). Responders encountered difficulty in five general areas: "customs, service provision and freedom of movement, logistics and emergency shelter, and coordination" (Turkish Red Crescent Society, 2006). The difficulties encountered in the response to the Marmara Earthquake were related in some ways to policies in place in Turkey.

3.3 Policy and Law

The present legal framework for space-based disaster response is covered in the International Charter on Space and Major Disasters. Provisions related to the use of emergency telecommunications during disaster response are described in the Tampere Convention.

3.3.1 International Charter on Space and Major Disasters (1999)

The International Charter on Space and Major Disasters resulted from the Unispace III conference hosted by the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) and the International Telecommunications Union (ITU) with the goal of providing timely satellite-based data acquisition and delivery to disaster-stricken member states. The Charter established a process by which a state can contact a 24-hour hotline to obtain space-based imagery in the event of a disaster in their state. The process mobilizes space-based and associated ground-based facilities of Charter Members to gather the data. The Charter has been frequently activated with response times of as little as a few hours. The Charter's activities are conducted on a voluntary basis and its membership consists of both public and private sector space actors (Ito, 2005).

3.3.2 Tampere Convention (1998)

The Tampere Convention established a framework for simplifying the deployment of emergency communication systems in disaster stricken areas. The Convention was agreed upon in 1998 and signed by 60 states. The member states agreed to streamline border procedures, eliminate unreasonable tariffs on essential communication equipment, and develop procedures to rapidly issue emergency radio licenses. The Convention also defined the legal status of disaster relief organizations and personnel involved in telecom assistance by establishing their privileges and immunities. National sovereignty was maintained by allowing the host nation to reserve the right to direct, control, and supervise telecom assistance. The equipment, however, is prohibited from being redirected to non-disaster relief efforts. Finally, under the Convention the host nation is responsible for the physical protection of the telecommunication disaster relief personnel (Tampere Convention, 1998).

One of the key attributes of the Tampere Convention is the establishment of the Working Group on Emergency Telecommunications (WGET) that meets twice per year and develops best-practices and 'model legal agreements' negotiated by all member states in advance (Tampere Convention, 1998). In this manner, at the time of a disaster, the 'pre-negotiated' agreements with standardized language can be used by disaster relief agencies as a basis for contracts to enter into a country to provide assistance. The intention is to speed up the process of providing disaster relief. The Convention provides an excellent framework for future, broader agreements that could be implemented in a similar manner to cover all aspects of disaster relief.

3.3.3 National Laws

National laws and polices play a significant role in disaster management. Examples from the three focus countries as discussed in the following section.

China

The Law of the People's Republic of China on Protecting Against and Mitigating Earthquake Disasters (1998) is the base law for China's earthquake disaster mitigation. It explains the basic principle of disaster mitigation, defines the organizational structure for earthquake disaster mitigation, details the rights and legal liability of relevant organizations, and confirms the technology architecture. Each province has also enacted their own regional laws for disaster mitigation in accordance with the national laws.

In addition to the Law, a number of principles were issued in 2006 as described below (He, 1999):

1. *Earthquake monitoring and management principle*: The principle confirms the establishment and management of earthquake monitoring stations.
2. *Earthquake prediction and management principle*: The principle confirms the protocols for issuing earthquake warnings to the public.
3. *Earthquake security and management principle*: The principle confirms inspection procedures for compliance to earthquake-related building codes.
4. *Emergency in devastating earthquake management principle*: The principle confirms the formal national disaster management organizational structure.

According to the national laws and principles, some provincial Congresses have issued regional laws related to earthquakes. Earthquake agencies in China have established some implementation methods related to these laws.

Japan

In Japan, disaster countermeasures are taken based on the Disaster Countermeasures Basic Act (1961) and other laws related to management disaster. Under this law it is a national priority to protect national land as well as citizens' lives, livelihoods, and property from natural disasters.

Japan's disaster management system addresses all of the disaster phases of prevention, mitigation and preparedness, emergency response, and recovery and rehabilitation. With clear roles and responsibilities for the national and local governments, the relevant stakeholders of the public and private sectors cooperate in implementing various disaster countermeasures.

Japan also has a Disaster Management Planning System that includes the following components:

- *Basic Disaster Management Plan*: This plan is a basis for disaster reduction activities and is prepared by the Central Disaster Management Council based on the Disaster Countermeasures Basic Act.
- *Disaster Management Operation Plan*: This is a plan made by each designated government organization and designated public corporation based on the Basic Disaster Management Plan.
- *Local Disaster Management Plan*: This is a plan made by each prefecture and municipal disaster management council, subject to local circumstances and based on the Basic Disaster Management Plan.

The Basic Disaster Management Plan cites comprehensive and long-term disaster reduction essentials such as disaster management related systems, disaster reduction projects, early and appropriate disaster recovery and rehabilitation, and scientific and technical research. The plan was revised entirely in 1995 based on the experiences of the Kobe earthquake. It now consists of various plans for each type of disaster, where tangible countermeasures to be taken by each stakeholder - such as the national and local governments, public corporations,

and other entities - are described for easy reference according to the disaster phases of prevention and preparedness, emergency response, and recovery and rehabilitation (Government of Japan, 2007).

Peru

Like China and Japan, Peru has specific legislation and a defined organizational structure for disaster management within the national territory. The most recent Political Constitution of Peru (29 December 1993) re-affirmed in article 163 that "the State guarantees the security of the nation through a System of National Defense." This provided the continued support of the Decreed Law 19338 established in 1972 that created the National System of Civil Defense (Sistema Nacional de Defensa Civil – SINADECI) as an integral part of National Defense. The purpose of the creation of SINADECI was to protect the population, prevent damages, provide opportune and adequate help, and to assure rehabilitation in case of disaster or calamities of all types, whatever their origin. This national system is managed by the National Institute of Civil Defense (Instituto Nacional de Defensa Civil – INDECI) which was created under article 4 of the same law. The Institute was charged with organizing, directing, and managing SINADECI as well as organizing the population and coordinating, planning, and controlling the activities of Civil Defense. In order to efficiently manage the Peruvian territory, the INDECI hierarchy includes the national office located in Lima, followed by regional, sub-regional, provincial, and district offices. Laws and regulations are established at the national level and flow down to the lower levels, which are then supplemented as required with additional regional and local laws and regulations.

The National Plan of Prevention and Response to Disasters (Plan Nacional de Prevención y Atención de Desastres) was published in January, 2004, by INDECI as part of SINADECI, and became the guide to disaster management in the Peruvian territory. A national policy for the prevention and response to disasters reads as follows: "To optimize the management of disasters at a national level, to incorporate the concept of prevention in the process of development, and to obtain an integrated, ordered, efficient, and decentralized system with participation of the authorities and general population, eliminating or reducing the loss of life, material goods, and environment and thus the socio-economic impact." The National Plan implements this policy in all phases of disaster management, including preparation for emergencies during and immediately after the event, and in long-term post-event recovery, reconstruction, and re-planning activities to reduce the impact of future events. The Geological Institute of Peru (Instituto Geofísico del Perú – IGP) is charged as the legal organization responsible at the national level for the service and investigation of seismic activity of the country. Additional responsibilities of the IGP include the development of seismicity maps, catalogs of seismic events, seismic zoning maps, and seismic predictions.

3.4 Disaster Management Actors

Many entities are involved in all phases of disaster management. For example, the 200 plus relief agencies involved in the response to the 1999 Marmara Earthquake represent only a small subset of these actors. Disaster management actors can be classified into three general categories: international bodies (*e.g.,* United Nations), non-governmental organizations (*e.g.*, Red Cross, Red Crescent Movement), and national agencies.

3.4.1 United Nations

The United Nations (UN) contributes to all phases of the disaster management cycle through its agencies, with a focus on the response phase. In general, the UN's role is to provide coordination, training, and information to improve disaster management practices rather than becoming operationally involved in any sort of on-the-scene disaster response. The UN also provides a discussion forum for disaster management practices. There are many UN agencies that contribute to disaster management; however, the main office responsible is the

UN-OCHA (United Nations, 2007). The head of the UN-OCHA is known as the Emergency Relief Coordinator (ERC).

3.4.2 Non-Governmental Organizations

Numerous NGOs are involved in disaster management activities. Team TREMOR has identified over 600 NGOs working in areas related to disaster management. Most organizations work in disaster response, though a few organizations, such as the Asian Disaster Preparedness Centre, work to reduce the potential effects of disasters.

A major NGO involved in disaster relief is the International Red Cross and the Red Crescent Movement. The Red Cross is capable of providing total post-disaster infrastructure support, which includes food, shelter, and medicine. The Red Cross has both an international headquarters and 187 national chapters located within the national borders of individual nations (Red Cross, 2007). For example, the Red Cross Society of China (RCSC) is the only Red Cross chapter in the People's Republic of China. Founded as a humanitarian social relief organization on 10 March 1904, the RCSC has become an important organization through its assistance in every earthquake disaster response in China since its establishment.

Smaller NGOs, such as Doctors without Borders, often specialize in a particular aspect of disaster relief, such as medical treatment. These smaller NGOs are also critical to disaster response. Because of a need for closer collaboration, the SPHERE project (a Humanitarian Charter and Minimum Standards in Disaster Response) was established by a group of humanitarian NGOs and the Red Cross in 1997. SPHERE's purpose is to outline a set of guidelines and standards for disaster response, to enhance collaborations between responder organizations, and to guarantee a minimum quality and accountability of the assistance rendered. They have developed a handbook and several other tools to serve as guidelines for responders (Sphere Project 2004). Figure 3-2 shows the areas in which selected smaller NGOs contribute to the disaster management cycle. Relatively few NGOs focus their activities in the mitigation phase.

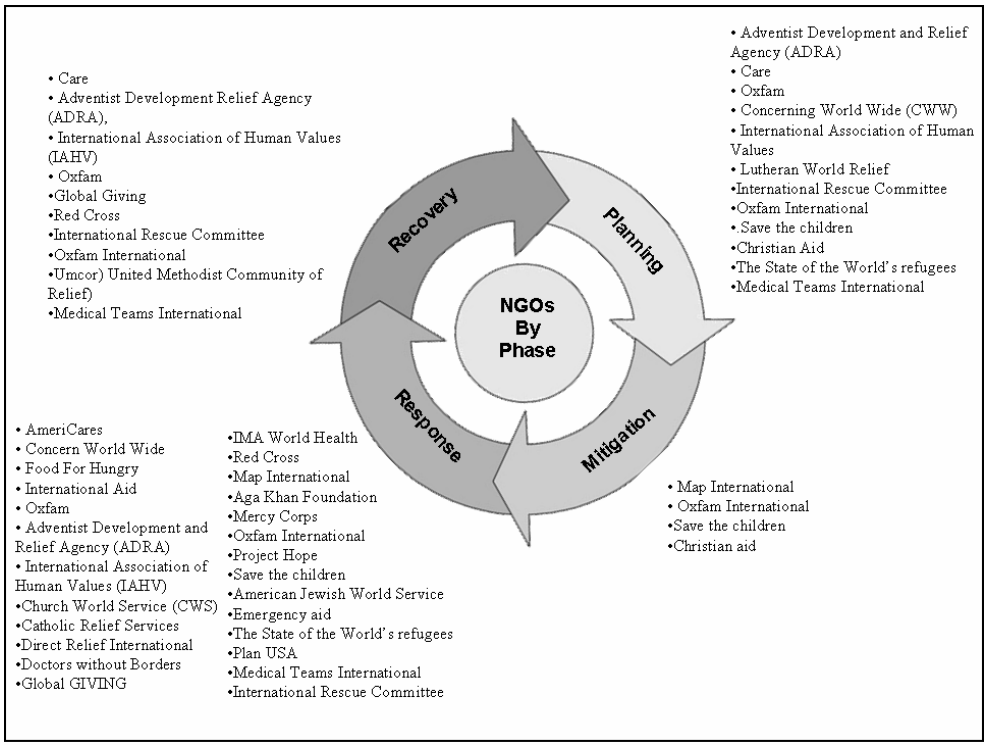


Figure 3-2 Selected NGOs by Phase of the Disaster Management Cycle

3.4.3 National Governmental Agencies

Federal governmental agencies are often the first line of disaster management in terms of preparation and response. The extent to which government agencies are involved in disaster management is related to socio-economic development and risk of disaster occurrence.

For example, in China the China Earthquake Administration (CEA), a department of the China State Council, is the national agency of China responsible for earthquake management. China also has Earthquake Administrations at the provincial and local levels. China's earthquake agencies are shown below in Figure 3-3.

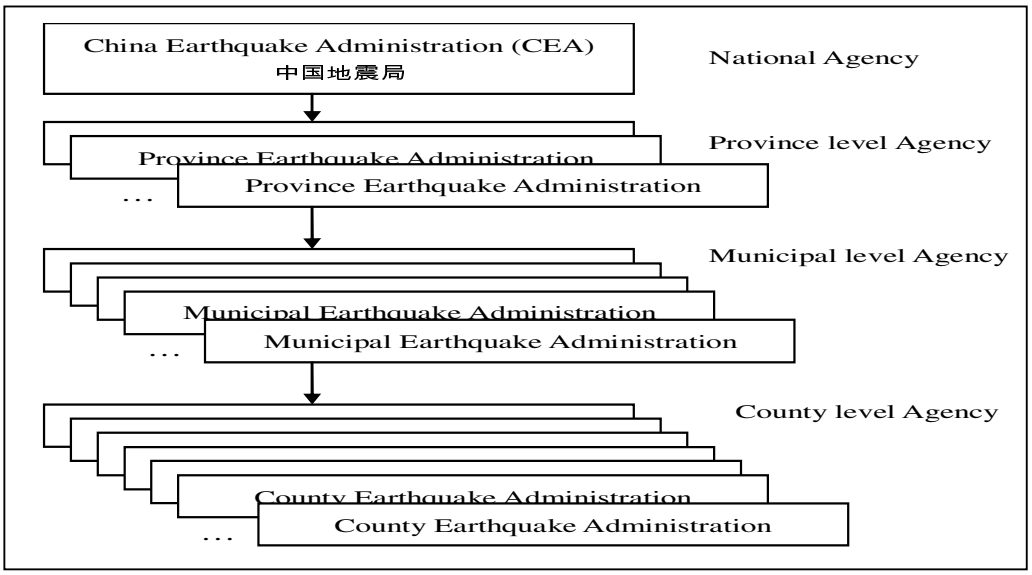


Figure 3-3 China's National Earthquake Agencies

Similar but not identical governmental structures are found in both Japan and Peru. The TREMOR prototypes systems proposed in this report must function within the context of these national government frameworks. In many cases these government agencies will be the users of the services provided by the TREMOR Foundation.

3.5 Existing Disaster Management Systems

A disaster management system (DMS) is a collection of data and/or processes that provide tools for improving disaster management across any or all of the four phases (see Section 3.1). Myriad disaster management systems exist today. Some of these address disasters generally, while others focus on individual disaster types (*e.g.,* floods, tsunamis). A discussion of selected disaster management systems follows.

3.5.1 General Disaster Management Systems

Asian Disaster Preparedness Center (ADPC)

The ADPC is not a disaster management system in itself. It is a non-profit organization that finances and implements several programs and projects with the objective of improving the disaster risk management in countries in the Asia-Pacific region. Its goal is to reduce the impact of disasters by teaching good practices, increasing the awareness of communities of disasters, and creating the necessary capacities, frameworks, institutions, and mechanisms for disaster management. Examples of their projects include the Regional Flood Management and Mitigation Center Mekong Delta, and the Climate Forecast Applications in Bangladesh (ADPC, 2007).

Disaster Monitoring Constellation (DMC)

The DMC is a constellation of five small earth observation satellites. Five countries are represented in the Constellation (Algeria, China, Nigeria, Turkey and the United Kingdom) and the individual satellites are owned by either government or private sector actors. Operating in concert, the five satellites are able to provide daily imaging of almost any point on the globe. DMC members agree to provide 5% of the capacity of their individual satellites free of charge for daily imaging of disaster areas, and provide this data to aid agencies. All data from the Constellation is shared equally among the members (DMC, 2007). The DMC represents a novel combination of developing and developed countries, as well as public and private actors, working cooperatively (Stephens *et al.*, 2007).

Global Disaster Alert and Coordination System (GDACS)

GDACS uses a subscription-based internet interface to provide near real-time disaster alerts to users around the world. In order to coordinate responses to disasters, GDACS offers a Virtual Operations Center. The system automatically collects data on presently occurring natural disasters from a wide variety of sources. It then processes the data through a simulation model in order to classify a given natural disaster according to the likelihood of requiring humanitarian intervention. GDACS also provides impact and loss estimates for a given disaster event. The system is funded by the European Commission Office for Humanitarian Aid (GDACS, 2007).

UN Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER)

UN-SPIDER is currently being developed within the United Nations Office for Outer Space Affairs (UNOOSA). The Platform's objective is to "ensure that all countries have access to and develop the capacity to use all types of space-based information to support the full disaster management cycle" (UNOOSA, 2007). When operational, UN-SPIDER will provide a gateway for accessing space-based information and will improve coordination of communication between the disaster management and space communities (UNOOSA, 2007).

3.5.2 Specific Disaster Management Systems

Climate Forecast Applications in Bangladesh (CFAB)

The CFAB project, in its pilot phase of implementation, provides residents of rural areas of Bangladesh with up to 10 days advance notice of floods. The system uses a combination of weather forecast models, satellite observations, river gauges, and hydrologic modeling techniques to predict when major rivers will crest in selected regions of Bangladesh (NSF, 2007). The CFAB program is sponsored by the U.S. National Center for Atmospheric Research (NCAR) and the Georgia Institute of Technology. It is conducted in cooperation with the Asian Disaster Preparedness Center and a number of other partners (CFAB, 2007).

Real-time Emergency Management via Satellite (REMSAT I & II)

The European Space Agency's REMSAT project (in cooperation with several Canadian agencies and universities) focuses on demonstrating the use of an integrated system using space technology for disaster management. During the first phase, a pilot project was implemented to target fire hazard management in British Columbia, Canada. However, the system is "designed to be compatible with the generic needs of other types of emergencies such as earthquakes, floods, exceptionally heavy weather conditions, or hazardous materials related emergencies" (ESA 2007). In the second phase of the project, fire hazards, telemedicine, and flood management capabilities were integrated into the system, as well as the capability of mobile, deployable command centers (ESA, 2007; ISU, 2005).

The Pacific Tsunami Warning and Mitigation System

The Pacific Tsunami Warning and Mitigation System serves to detect earthquakes in the Pacific Ocean and Indian Ocean basins (on an interim basis), to determine whether a tsunami has been generated from a detected earthquake, and to issue and disseminate warnings and advisories to those nations that might be at risk. Data used in this system originate from an integrated network of seismometers and sea level buoys. The individual sensors in the data network are owned by several nations. The system's primary operations are conducted at a National Oceanic and Atmospheric Administration (NOAA) facility in Hawaii. The system uses a variety of pre-existing communication networks and methods to disseminate tsunami bulletins and warnings, and does not operate its own dedicated communications system. Warnings and bulletins are issued using a graduated system of urgency, depending upon the level of potential threat or severity of any given tsunami. A dedicated tsunami warning system for the Indian Ocean is currently being developed along similar lines (UNESCO, 2006).

3.6 Education

The role of education in earthquake disaster management is mainly in the planning phase, although attitude, knowledge and skills relating to earthquake disasters is intended to have an impact in all of the other three phases. Promoting awareness of the importance of disaster reduction can influence many aspects of disaster mitigation at all levels of society.

3.6.1 General Discussion of Education Systems

At the national or international level, education awareness can assist in the allocation of resources for: research, science, and monitoring programs; public education programs; and infrastructure and organizations that increase the ability to respond to earthquakes. At a regional level, an appreciation for the effects of earthquake related disasters helps to develop policies that promote safer building practices. Economic pressures caused by the desire to decrease the costs of damage can foster inquiry into understanding structural vulnerabilities and give rise to organizations that lead to their correction. Education of emergency response organizations at the local level can play a major role in response and recovery. At the general public, family, or small business level, education programs inform vulnerable populations about how to make their environments safer, how to communicate with one another, how to organize themselves in the event of a disaster, and how to plan and prepare to meet their basic needs if they are injured or cut off from services after an earthquake.

Existing education methods for the general public include: school curricula, museum exhibitions, internet sites, and television and other media. In most of these cases, the funding for such programs must come from government sponsored educational initiatives or non-profit public service organizations since the potential for generating income from these activities is minimal. For professionals such as scientists and engineers, more technical education and information is usually obtained through the distribution systems of universities, government departments, institutes, and associations.

3.6.2 Examples of Organizations with an Educational Component

A number of international and national organizations exist to assist in earthquake education. Four examples are discussed below and more information is provided in Annex A.

United Nations International Strategy for Disaster Reduction – (UNISDR)

UNISDR targets building disaster resilient communities by promoting increased awareness of the importance of disaster reduction as an integral component of sustainable development. The office has the goal of reducing human, social, economic and environmental losses resulting from natural hazards and related technological and

environmental disasters. The ISDR promotes the following two objectives related to education as tools towards reaching disaster reduction.

- *Increase public awareness to understand risk, vulnerability and disaster reduction globally*
  Prevention begins with information: the more people, regional organizations, governments, NGOs, and others that know about risk, vulnerability, and how to manage the impacts of natural hazards, the more disaster reduction measures will be implemented in all sectors of society.
- *Improve scientific knowledge about disaster reduction*
  The more we know about the causes and consequences of natural hazards and related technological and environmental disasters, the more we are able to prepare ourselves to reduce risks. Bringing the scientific community and policy makers together allows them to contribute to and complement each other's work (UNISDR, 2007)

The World Health Organization (WHO)

Effective disaster management relies more on solid human resources than on equipment and technology. The frequent turnover of staff at the country level demands ongoing training and education efforts to maintain the required levels of awareness, skills and commitment to risk reduction. WHO, the directing and coordinating authority for health within the United Nations, is responsible for providing leadership on global health matters, shaping the health research agenda, and providing support for training and education efforts for disaster reduction. WHO actively supports a variety of training opportunities, including those aimed at senior disaster experts to enhance management skills and to improve knowledge and capacity in new areas such as planning, assessment of health needs, preparedness for chemical accidents, risk reduction for health services and more.

United States Geological Survey (USGS) Earthquake Hazards Program

USGS Earthquake Hazards Program has several existing activities focused on earthquake education. These programs include:

- **Earthquakes for Kids.** This area of activity is focused on fun, educational resources targeted at children. Science fair ideas, online games, and photos as well as more general information on earthquake science and scientists are provided.
- **Resources for Students.** This area of activity provides a web-based portal to educational resources for students in elementary, middle, high school, and college.
- **Resources for Teachers.** This area of activity provides web-based educational resources for teachers. The portal is searchable by grade level and/or earthquake topic.

The above organizations are used to illustrate the range of educational activities for some of the larger organizations. There are numerous other international and national organizations addressing earthquakes and other disasters with educational components. A selection of these and their web addresses for further information is found in Annex A.

Chapter 4

Existing Technologies and Systems for Earthquakes

This chapter provides a general overview of the existing technologies and related techniques that have been used for the monitoring of earthquakes. Some of those technologies are specifically designed for earthquakes, and some of them are used in the broader domain of the disaster management process. Each of the following subsections deals with a different technology and briefly explains how that technology works. The reader will gain an understanding of why a specific existing technology is important for the earthquake management process.

4.1 Space-based Technologies

There are different space systems and technologies used for earthquake management. Table 4-1 summarizes the technologies used for the observations and measurements that are briefly explained in the following paragraph of this section.

Table 4-1 Summary of Space-Based Technologies Used for Observations and Measurements

Technology/System	Description
GNSS	Global Navigation Satellite System (GNSS) is the standard generic term for satellite navigation systems that provide autonomous geospatial positioning with global coverage.
SAR	Synthetic Aperture Radar (SAR) is an active remote sensor based on the principle of radio detection and ranging (RADAR). It emits electromagnetic pulses in microwave wavelengths to calculate the range of a distant target by measuring the time delay between transmission of a pulse and detection of the reflected signal.
Electro-optical	Electro-optical sensors are passive remote sensing systems that collect electromagnetic radiation reflected from targets on the Earth that have been illuminated by the sun.
Electro-magnetic	Electro-magnetic sensors measure electric and magnetic field as well as plasma characteristics to gather information about various precursor phenomena.
Thermal infrared	Thermal infrared sensors are used to detect the long-wave infrared radiation emitted from natural objects on the ground. They can be used to monitor for possible changes in ground temperature before an earthquake.
GIS	A Geographic Information System (GIS) is a computer-based information system that can integrate information about features on Earth to provide a layered and highly interactive interface by capturing, managing, analyzing, and displaying all forms of geographically referenced information. This information can be used for multiple applications.
Telecommunications	Telecommunications is the transmission of information by wire, radio, optical cable, electromagnetic signals, or other means.

4.1.1 Global Navigation Satellite Systems, (GNSS)

GNSS is the generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage (*e.g.*, Global Positioning System, GPS). The working principle involves measuring the time delay of electro-magnetic signals between the ground terminal and several satellites. GNSS is used in both mitigation and response phases of earthquake disaster management.

During the mitigation phase, GNSS has two different applications. First, GNSS is used to measure the displacement of ground stations during the interval between earthquakes. This is done by recording millimeter-scale slip on faults that are difficult to measure using other methods. This small-scale fault motion may help to predict where and when an earthquake will likely occur (Segall, 2004). In the second case, GNSS is used to measure ionospheric perturbations. The signals from GPS satellites travel through the ionosphere. The earthquake induces an ionospheric anomaly in the form of a variation of the Total Electron Content (TEC). By measuring the change of direction and speed of GNSS signals it is possible to measure the anomaly, and from this it is possible to derive the information of pre-earthquake ground displacement (Liu, 2004).

During the response phase, GNSS has two different applications. First, it is used to estimate the magnitude of the earthquake. The total distance that a station has moved in an earthquake is computed by comparing its position prior to the event with its position following the event (Massironi, 2001). Second, GNSS can be used to assist Search and Rescue services (*e.g.*, MEOSAR, Galileo). GNSS provides accurate spatial information without relying on ground infrastructure that could be damaged in the event of an earthquake. GNSS could be used to pinpoint persons in distress and in need of rescue and evacuation. For example, after an earthquake personnel on the ground could provide the exact location of severely injured individuals for helicopter evacuation. GNSS could also be used to track logistical assets moving to and from the affected area. In this case, trucks carrying supplies and personnel could be monitored in real-time and plans made with a specific arrival time in mind.

4.1.2 Synthetic Aperture Radar, (SAR)

SAR is an active remote sensor based on the principle of Radio Detection and Ranging (RADAR). The SAR instrument emits electromagnetic pulses in microwave wavelengths and detects the radiation from illuminated objects. By measuring the duration of the travel, the range can be measured.

There are different modes of SAR data collection. The most frequently used modes for earthquake monitoring are the Fine Beam (or Fine Resolution mode) providing high resolution imagery, and ScanSAR which is able to illuminate a large area (about 400 km) with a lower resolution. Both of the two modes can be used to map the ground deformations of the Earth's surface using the Interferometric SAR technique (InSAR). InSAR combines two or more SAR images to generate maps of topography deformations. The phase difference of the electromagnetic field in the two images is processed to obtain motion information of the Earth's surface (Massonnet, 1998; Burgmann, 2000).

A SAR sensor designed for InSAR techniques represents a valuable instrument to monitor surface ground deformation. Because SAR penetrates cloud cover and canopy, SAR images can be used in the response phase to detect damage during day and night, and under all weather conditions, and to obtain information about the underlying terrain deformation. InSAR techniques may also be used to identify the epicenter of an earthquake, and SAR images make it possible to quickly identify the most damaged areas. This information can be used during relief efforts.

Current space-borne SAR missions are: Radarsat-1, Envisat, ALOS, TerraSAR-X and Cosmo-Skymed. While ERS1, ERS2, and JERS data are still used, these satellites are no longer operational (Wright, 2002). Missions with planned launches over the next few years are Radarsat-2, CRYOSAT-2, RISAT and one satellite of ESA's Sentinel constellation, which will also carry a SAR sensor.

4.1.3 Electro-Optical Sensors

Electro-optical sensors are passive remote sensing systems that collect electromagnetic radiation reflected from targets on the Earth that have been illuminated by the sun. Elements sensitive to electromagnetic energy focus energy onto a sensor plane and a prism divides the energy into specific wavelengths. An electrical signal equal to the energy is produced. These images are recorded by high resolution cameras from satellites in low Earth orbit operating in the visible and near infrared spectral ranges (VNIR). This method requires a cloud-free area because visible and VNIR cannot penetrate cloud cover. There are two broad categories of scanners: *optical-mechanical* scanners that scan across-track, and *optical-electronic* scanners that scan along-track (Cracknell & Hayes, 1991).

The output is an image composed of pixels recorded in multiple bands. Types of electro-optical systems are: panchromatic (a single channel detector sensitive to radiation within a broad range of wavelengths); multispectral (MS) (a multichannel detector with a few spectral bands in a narrow range of wavelengths); and hyperspectral (an imaging spectrometer that acquires images in about a hundred or more contiguous spectral bands in a narrow range).

High resolution optical images are used in all phases of disaster management. Particularly in the mitigation phase, monitoring of landscape changes is performed and input data are provided to be integrated into GIS. The high resolution imagery can be employed for fault mapping that can play a meaningful role in the planning phase. In the response phase, the comparison of images taken before and after the earthquake is used for damage assessment, to determine both the extent and the severity of damage. This provides information for appropriate scaling and prioritization of relief efforts. Images are visually compared and analyzed or processed by change detection software. In the case of high resolution images, textural analyses are carried out to extract finer information like damages suffered by individual buildings. This information may be used in generating damage assessment maps which are validated with ground observations. Optical remote sensing imagery is also used for monitoring the recovery phase operations over an extended period of time.

Some of the existing earth observation satellites carrying onboard high resolution electro-optical sensors, are: QuickBird (0.6 m panchromatic/PAN, 2.4 m MS); IKONOS (1 m PAN, 4 m MS); CARTOSAT-2 (1 m PAN); Orbview-3 (1 m PAN, 4 m MS); SPOT 5 (2.5 m PAN, 10 m MS); and IRS P6 (5 m PAN, 23 m MS). New satellite missions that will be launched in 2007 are the Rapid Eye constellation, CBERS-2b, GEOEYE-1, and Worldview-1. The French Pleiades mission will be launched in 2009.

4.1.4 Electro-Magnetic Sensors

Satellite missions dedicated to earthquake precursor science carry sensors to measure various phenomena. These include perturbation in the Earth's electric and magnetic fields, changes in plasma characteristics, VLF emissions, energetic particle precipitations, and oscillatory variations of electron density in the ionosphere and other ionospheric perturbations. These satellites are usually microsatellites in low-Earth orbit. The sensors include topside sounders, mass-spectrometers, magnetic field sensors and optical spectro-photometers (Kodama, 2000; Pulinets, 2006). In the mitigation phase, these measurements could provide data on earthquake precursors as the basis for early warning systems.

Currently three satellite missions are dedicated to detection and interpretation of earthquake precursors: DEMETER (France), Compass-2 (Russia), and Quakesat (USA.). Measurements

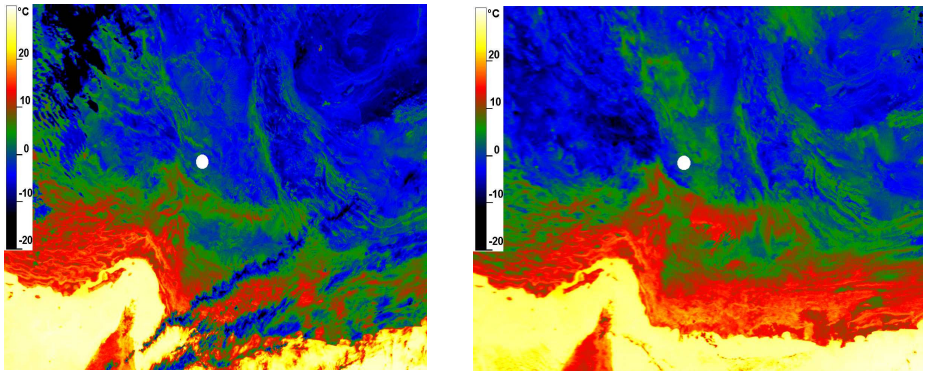
from the COSMIC constellation (Chinese Taiwan/USA) are also relevant. Within the next several years numerous satellite missions dedicated to detecting earthquake precursors will be launched, including: CANOPUS (Russia, 2006-2010), COMPASS-3 (Russia, 2007), UNAMSAT-3 (Mexico, 2007-2009), ESPERIA (Italy), SESS (China, 2008-2010), LEAP (Chinese Taiwan, 2008), IONOSATS (Ukraine, 2009) and Kazakhstan Satellite (Kazakhstan, 2010). Measurements of the European mission SWARM (2010) will also be useful. A description of the existing satellite mission, DEMETER, as well as an additional precursor research project is provided in the following section. The DEMETER satellite is similar to the satellites of our proposed constellation for the early warning system.

DEMETER, launched 29 June 2004, stands for "Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions" and it is a project of the Centre National D'Etudes Spatiales (CNES). The scientific goals of the mission are to detect and investigate ionospheric perturbations connected with both natural and anthropogenic geophysical phenomena on Earth, and to study the Earth's geomagnetic environment. Notably, DEMETER is the first mission to measure the characteristics of ionospheric perturbations on a large scale. The Chinese Taiwanese "integrated Search for [Chinese] Taiwan Earthquake Precursors" (iSTEP) Project is one of the largest in precursor research (Pulinets, 2004). Started in 2002, the project is focused on the study of seismological variations, variations of the geomagnetic and gravity fields, surface deformation, ionospheric anomalies, and other earthquake precursors (Tsai, 2004).

4.1.5 Thermal Infra-Red, (TIR)

TIR sensors are passive remote sensing sensors used to detect the long-wave infrared radiation emitted from objects. These sensors allow the mapping of temperature in the atmosphere or on the Earth's surface. They can monitor the precursor information by recording temperature changes both in the atmosphere and in the ground before earthquakes. Currently, there are three kinds of infrared remote sensors on-board different satellites: the Moderate Resolution Imaging Spectroradiometer (MODIS), and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

Thermal anomalies are relevant for the mitigation phase because they appear about 6-24 days before and continue for about a week after an earthquake (Tronin , 1996; Xu, X. *et al.*, 2000; Xu, X., 2000; Qiang *et al.*, 1997). They can appear as precursors to earthquakes with magnitude greater than 5 on the Richter scale (Qiang *et al.*, 1997; Xu H. & Xu X. *et al.*, 2000). The larger the magnitude of the earthquake is, the larger the temperature increase and the area of the temperature anomaly. The thermal infrared anomaly region differs from the surrounding area by having an increased temperature of 2 - 10℃ (Qiang *et al.*, 1997; Xu X., *et al.*, 2000; Tronin , 2006; Ouzounov , 2006). The size of such a thermal anomaly is about 500 km in length and 50 km in width (Qiang *et al.* 1991; Liu *et al.* 1999, Ye *et al.*, 1995). An example of this type of anomaly is shown in the Figure 4-1. The white circle is the epicenter of the Bam earthquake that took place on 26 December 2003.



23 Dec 2003, background 25 Dec 2003, anomaly

Figure 4-1 Example of Thermal IR Data Application, Iran Earthquake, 26 December 2003 (Tronin, 2006)

TIF anomaly information can be collected by: geostationary meteorology satellites, such as GOES, Meteosat, FY-2, FY-4; polar orbit satellites, such as NOAA-KLM, FY-1, FY-3; and high resolution sensors like Aster on NASA's Terra and Aqua satellites.

4.1.6 Geographic Information System, GIS

A Geographic Information System (GIS) is a computer-based system that can integrate data about features on Earth to provide a layered and highly interactive interface for all types of users by capturing, processing, managing, analyzing, and displaying all forms of geographically referenced information.

GIS uses various databases like population, topography, transportation, infrastructure, utilities, housing, and communication along with various imagery data like optical, SAR, and LIDAR. The data are processed and merged in interactive maps generated using GIS packages. GIS has applications in all four phases of earthquake disaster management. In the pre-disaster phases of planning and mitigation, GIS can be used to identify the hazards, evaluate the consequences of potential earthquakes, and prioritize the mitigation efforts by layering the hazard data (faults, soil) over the map data (streets, businesses, storage facilities, pipelines, power lines, residential areas). The values at risk, such as key bridges, hospitals, and hazardous material storage, can be displayed quickly and efficiently. This helps in developing mitigation measures, such as legislation that limits building in earthquake prone areas, identifies buildings in need of relocation or reinforced construction, and supplements building codes.

In the post-disaster phases of response and recovery, GIS coupled with GPS provides details such as which disaster management units have to be selected, routed, and dispatched to the disaster area in the shortest possible time. Advance Vehicle Locating (AVL) can be used to track the location of incoming disaster management units in real-time, and determine the closest mobile law enforcing personnel so that they can reach the disaster area as early as possible to minimize secondary disasters. GIS provides emergency personnel with critical information, such as the location of electrical panels, hydrants, hazardous materials, and floor plans of buildings to provide faster response to reduce the effects of the disaster.

A GIS implementation presently used in disaster management is the Disaster Management Spatial Information System (DiMSIS). Internet-based GIS systems include the Vehicle through Electric Network of disaster geographical information (VENTEN) developed by the Asian Disaster Reduction Center (ADRC) and the Internet GIS-based disaster recovery program (GISDRP) by the American Red Cross. Examples of advanced GIS technology deployment include MapAction, which provides for data collection and mapping capabilities

in the field of response phase, and CommandMap, a new system incorporating the use of GIS technology in real-time with wireless technology to provide dynamic data exchange from field teams to the command center and other emergency service providers. It uses satellite communications, mobile GIS mapping, and GPS.

4.1.7 Technologies for Telecommunications

Two main types of telecommunications are used in disaster preparation and response: terrestrial-based and space-based. Space-based communications consist of a space segment and a ground segment (ground stations to receive and transmit signals); terrestrial-based communications do not include a space segment and use wired and wireless technologies. Satellite telecommunications provide global coverage, are less affected by terrestrial geographic hurdles, and are less affected by terrestrial disasters. Terrestrial telecommunications, on the other hand, have a network infrastructure that can be easily built, but cover a relatively small geographical area.

Telecommunications play a key role during the entire disaster management cycle, especially during the response phase. When an earthquake occurs, the terrestrial communications setup often becomes unavailable and hence the space based communications using mobile equipment (*e.g.*, satellite phones) are the only means of communication. The reliable and fast transmission of voice, text, video, imagery, and data related to the disaster is critical for response phase activities. This is especially important during a disaster since the bandwidth requirements increase significantly and networks become congested from the intense traffic. Some of the existing and planned satellite telecommunication systems include: Inmarsat, GlobalStar, and Iridium.

4.2 Ground-based Technologies

There are many ground based technologies dedicated to all earthquake disaster management phases; in particular, several types of ground motion sensors are presently in use. They typically sense translational acceleration or velocity, but can also sense displacement, strain, and force. Other types of sensors are used to measure physical properties related to earthquake precursor phenomena. They include gas sensors, temperature and pressure sensors, and electrical dipole instrument. Table 4-2 summarizes the most important ground-based technologies presently used for the observations and measurements of earthquake related phenomena.

Table 4- 2 Summary of Ground-Based Sensors Presently Used

Instrument	Description
Seismometer	The seismometer is a device used to measure and record the size and force of seismic waves using the inertia principle and the flexibility principle. It provides information related to the magnitude and the frequency of seismic activity.
Accelerometer	Accelerometers register the ground accelerations caused by the passing of seismic waves through the accelerometer station. Data on seismic accelerations are indispensable for probabilistic risk assessments of seismic danger for planning and mitigation.
Magnetometer	A magnetometer measures the strength and/or direction of the magnetic field. Earthquakes induce changes in the Earth's magnetic field, which can be measured by magnetometers. Magnetometers can provide precursor data.
Gas sensor	Networks of gas sensors can be used to detect variations in terrestrial gas emissions related to fault activity, such as hydrogen, radon and carbon dioxide, which may be useful for predicting seismic activity (Wakita, 1995). Information from gas sensors may provide data concerning precursor effects.
Electrical dipole instrument	An electrical dipole instrument is able to measure the Earth's electric field resistance. Electrical and geological properties of the Earth can be derived from this data.
Temperature and pressure sensors	High resolution monitoring of temperature and pressure are carried out since thermal and hydrologic anomalies typically appear before an earthquake.

Chapter 5
Gap Analysis

The goal of this chapter is to list and discuss the main unsolved issues arising during the disaster management of earthquakes. This is the starting point of our proposed prototype because the system strives to fill some of the gaps that will be outlined in the following subsections. The chapter discusses the science and technology gaps, addresses the open issues in the policy and law domain, and deals with the education gaps. When possible, each gap is discussed in relation to the four phases of the disaster management cycle.

5.1 Science and Technology

The first obstacles to having an efficient disaster management system are the main gaps that exist from a scientific and technological point of view. These gaps, detailed below, have a strong impact on the performance of disaster management and represent the starting point for the proposed prototype early warning and response systems.

5.1.1 Temporal Resolution of Monitoring Systems

The temporal resolution of a monitoring system indicates how often the system measures the target under observation. Better temporal resolution results in better reliability of collected data. The existing system for mitigation and planning of earthquakes does not provide sufficient temporal resolution. The precursors need to be measured repeatedly in order to fulfill the technical requirements for an earthquake early warning system (Ouzounov, 2007). The response phase also requires space-based systems (*i.e.,* remote sensing satellites) that can provide images within a few hours after the occurrence of an earthquake and before the deployment of rescue units (Hill & Keys-Mathews, 2005).

5.1.2 Spatial Resolution of Monitoring Systems

The spatial resolution of an imaging sensor is the ability to distinguish details in the output data (*e.g.*, optical image from a satellite). We need high spatial resolution images because they are extremely valuable in accurate damage assessment and post-event rescue and relief planning. However, for given orbital and sensor parameters, high resolution requirements compete with the swath coverage needed for high temporal resolution. Today's highest resolution optical sensors have a spatial resolution between 1 m and 5 m, while SAR sensors acquire data with a resolution between 5 m and 10 m. Due to mission constraints and acquisition planning, the availability of data with high resolution is limited. Research is in progress to improve the resolution of data for the emergency response phase (Langhelm & Davis, 2002; Saito & Spence, 2003; Eguchi *et al.*, 2003).

5.1.3 Global Coverage of Data

There are only a few existing and planned space missions dedicated to earthquake monitoring and they are limited in capability. In particular, they do not provide suitable global coverage of the Earth's surface. In order to achieve early warning of earthquakes, global coverage is an important requirement to understand the validity of precursors and to find relationships among them. Additionally, during the response phase, the rescue units that provide first aid usually do not have actual imagery of the affected disaster zone.

Knowing, for example, which bridge is broken, which street is closed, and which buildings collapsed will facilitate the prioritization and identification of the target region.

5.1.4 Integration of Data from Different Sensors

Combining different and complementary information coming from various sensors (data fusion) remains a challenging task. The scientific community believes that data fusion is critical for extracting useful information about earthquakes; however, suitable mathematical models and systems do not yet exist. More specifically, different precursors are measured at different locations, and hence the integration is not possible. In the case of remote sensing satellites, there are both optical and SAR sensors on-board existing satellites but new techniques and algorithms are required to properly combine the different information sources.

5.1.5 Long Term Measurement of Precursors

The long term and continuous measurements of precursor data represents a large scientific gap for the early warning of earthquakes. A long-term data archive would allow scientists to assess the precursor's validity and to improve the reliability of early warning systems. Presently, the only data available (by request) is from the French satellite DEMETER. DEMETER's operational phase only started three years ago in July 2004; thus, this precursor research still lacks the historical data desired by researchers.

5.1.6 Computational and Storage Resources

The need for more powerful computational resources and data storage has been driven by improved performance of sensors, the increased number of satellites, and the need to integrate data from multiple sources. There is also a substantial amount of existing unprocessed data from potential precursors that needs to be analyzed. Presently, there are not enough systems available to manage large datasets and to process them in a short time. For the response phase we need a fast and powerful system to provide data comparison before and after an earthquake.

5.1.7 Global Map of Seismic Activity

The mapping of global seismic activity is feasible but not yet available. This requires establishment of a global seismic network and the employment of advanced remote sensing techniques like InSAR and LiDAR for mapping of the entire world. Also, a detailed global map of fault lines coupled with GIS data would enable a more accurate simulation of the effects of an earthquake on the human population. The propagation of earthquake waves can be simulated by selecting the likely magnitude and epicenter based on the latest movements of the tectonic plates. This is extremely useful for the planning and mitigation phases.

5.1.8 Geographic Information System, (GIS)

The potential of GIS for disaster management has been recognized globally but only a few nations and disaster management organizations have GIS implementations. However, even when a GIS infrastructure is available, there will still be gaps that need to be filled in order to maximize its potential use. In particular, the essential databases of population, utility location, administrative information, topographic information, satellite imagery, elevation maps, and building plans need to be regularly updated with the most current information. Some of that information is not available, especially in developing countries and sparsely populated areas, and it requires cooperation among the nations of the world to get the information. During the response phase, remote sensing images need to be received in real time because the first few hours of a disaster critical for saving lives. Interaction between the disaster response users and the GIS packages has to be made more user-friendly and easy to operate. GIS data sharing is also complex and requires expertise and a standardized format for sharing information among organizations.

5.1.9 Telecommunication

Telecommunication is a key element in managing an emergency. The communication among the different layers of decision-making and between the on-site operational teams plays an important role in ensuring a rapid response (Phillips *et al.*, 2005). The breakdown of telecommunication systems often happens after an earthquake because of damaged equipment and the overload on the system when everybody tries to use it at the same time. Space- and ground-based communication technologies need to work together within a new platform to ensure the maintenance of all components of a communication system including mobile phones, transmission towers, telecommunication satellites, and bandwidth availability. In short, the main telecommunication gap is the lack of strategies and coordination using multiple telecommunication technologies in order to have a system that can be relied upon in the event of an earthquake.

5.1.10 Global Navigation Satellite System (GNSS)

GNSS is presently used by some organizations to track response vehicles such as fire trucks, ambulances, supply vehicles, helicopters, and buses. (Karimi *et al.*, 2004; Antenucci *et al.*, 2003). Tracking all vehicles *during* the emergency management and coordinating their deployment will help to better allocate resources and to reduce time delays. Using GNSS would improve the efficiency of the dispatching process by ensuring that every area is adequately covered by rescue units.

5.1.11 Robotics

Search and rescue units have several difficulties investigating areas that are highly damaged. In order to assure the safety of personnel searching for survivors, robotic devices can be helpful (Nagatani *et al.*, 2007; Young, 2006). Teleoperated robots have the ability to search for people in dangerous environments. Further development of search and rescue robotics technology, however, is still required. In particular, units integrated with advanced sensors such as thermal infrared or vibrations sensors would be extremely valuable to search for survivors. An additional gap is communication with such robots which are limited by the availability of the frequency bandwidth.

5.1.12 Telemedicine

From the medical point of view on emergency response, telemedicine is an interesting option to help the limited number of on-site physicians. Telemedicine could improve the evaluation of patients and the treatment of certain medical events that require a specialist. Computer-based tools such as portable computers for patient information databases coupled with telemedicine can also be integrated into a system to maximize the information obtained from patients and determine the treatment of those injured (Garshnek & Burkle, 1999). According to the lessons learned from the Bam earthquake in Iran, there is a need for an integrated medical response system within an international cooperative program covering aspects from rescue to treatment (Abolghasemi *et al.*, 2006).

5.2 Policy and Law

In order for the proposed Earthquake Early Warning and Response Prototype Systems to be effectively implemented around the world, a sufficient legal framework must exist to address current political barriers. This section will outline the legal gaps that presently exist in international policies, organizations, and disaster management systems that could hinder the effectiveness of the proposed system.

5.2.1 International policy

The International Charter on Space and Major Disasters (1999) outlines the framework for a unified system that allows for the acquisition and delivery of space data to areas affected by disasters. The Charter provides processed, value-added optical and SAR imagery of disaster-stricken areas at the request of an affected country. A country may activate on behalf of non-member country that is affected by a disaster. While this process works well (Ito, 2005) for disaster response; there is not analogous process for the other phases of disaster management.

The Tampere Convention (1998) represents an effort to simplify the legal measures involved in establishing emergency communication systems in zones affected by disasters. Through the Convention, members agree to streamline border procedures, minimize legal barriers, eliminate unreasonable tariffs, and assist in the issuance of emergency operator licenses. Provisions are also made to improve the definition of the status of disaster relief organizations and personnel involved in establishing and using emergency telecommunications, including their privileges and immunities. Unfortunately, the Tampere Convention agreement only covers ground-based telecommunications. No international agreement currently exists covering the use of satellite communications during a disaster. Additionally, the Convention has not been updated as technology has advanced. The ability of emergency personnel to communicate during a disaster could be significantly improved with the inclusion of space-based telecommunication systems.

The Geneva Mandate (1999) and its fostering documents, the Yokohama Strategy (1994) and the strategy "A Safer World in the 21st Century: Risk and Disaster Reduction" (1999) offer excellent objectives and plans of action for countries trying to improve their ability to respond to disasters. Because of the non-binding nature of these documents, it is extremely difficult to quantify the progress being made on a global scale. The importance of countries conducting regular reviews of actions taken is emphasized, but these reviews must be made on a state-by-state basis.

Within the realm of existing international agreements there is currently no policy that specifically deals with either the use of GNSS by emergency personnel or the use of comprehensive GIS for disaster-stricken areas. There is also a need for agreements that would allow for improved telemedicine capabilities while response missions are conducted. Specifically, provisions need to be created that would permit equipment such as portable ultra-sound and x-ray machines to clear immigration customs without unnecessary delays.

5.2.2 International Disaster Management Systems

Many disaster management systems (DMS) currently exist around the world; however, the majority of these only address the needs of nations after a disaster has occurred - in other words, during the response and recovery phases. If the international community is seeking long-term solutions for mitigating the effects of disasters, such as earthquakes, more systems need to be developed that focus on the planning and mitigation phases. Also, the DMS are not well coordinated with each other, if at all, nor do they use all of the available resources when responding to disaster situations. If a more efficient response is desired, then DMS need to cooperate, and pool their resources. More effort should subsequently be made to implement more advanced technologies and techniques within those systems. Finally, among all of the DMS currently operating, no one system exists that specifically addresses earthquakes at an international level. Such a system would be beneficial in tailoring the type of data, technology, and response techniques required in the event of an earthquake.

5.2.3 International Organizations

The organizations and agencies that exist at the international level are able to provide a plethora of data and information to other organizations, including various levels of

government, in the event of a disaster. However, in many cases there is little or no training provided for these users on how these data can best be employed by an affected state to mitigate the possible effects of a disaster, or how respond in the event of a disaster.

5.2.4 Individual Countries

Significant gaps exist at the level of individual countries as well. For example, in Peru several gaps in the country's disaster management have been noted by officials in Peru's National Plan for the Prevention and Response to Disasters. These include:

- Uneven coordination and participation of regional and local agencies in organizing disaster management activities
- A lack of an integrated national communication systems for disaster response
- A lack of trained professionals in disaster management
- NGOs acting without coordinating with the national agency responsible for disaster response (Government of Peru, 2004)

At the national levels, gaps are often country-specific and related to a nation's development status. The ability of a developing country, such as Peru, to effectively implement its national disaster management plans may be significantly less than that of a developed country.

5.3 Education

Even if a disaster management system fills the gaps in technology and policy outlined above, it cannot work properly if the population is not aware of an impending disaster and appropriate protection measures are not taken. This section addresses the education gaps associated with the disaster management process.

5.3.1 Government Commitment

Many disaster response organizations obtain financial resources from governments, who view them as only one of many conflicting priorities. An increased awareness of decision-makers about the importance and effectiveness of disaster management systems would help to ensure that sufficient resources are available.

5.3.2 Cooperation Between Disaster-Focused Organizations and Governments

Numerous organizations exist worldwide which have excellent educational resources; however, much of the world's earthquake-vulnerable population remains unaware of methods to prepare for and protect against earthquake disasters. A global strategy for storing and sharing information and educational resources between organizations and governments is missing. This strategy would allow research of the best practices and procedures for building codes, public preparation, disaster management, and other related subjects to be available for dissemination to organizations worldwide.

5.3.3 Public Distribution and Access

Although many of the educational methods described above are disseminated through modern technology, a gap exists in the ability of existing education systems to reach remote areas, particularly in developing countries. In many areas, people may not have regular access to contemporary media such as television and Internet, and may not have the education or language skills necessary to access existing information even though the equipment and communication links might be available.

5.3.4 Response Training within Local Communities

Disaster response by off-site national or international organizations takes time. In the intervening period, chaos and disorganization can often lead to consequences for inhabitants

that are worse than the initial earthquake. Local community volunteers in vulnerable regions where limited emergency resources exist should be trained to organize a response, including first aid skills, communication, and the use of remote sensing technology. Such training could help communities to begin to manage themselves and prevent secondary damage caused by fire, the outbreak of disease, or profiteering.

Chapter 6

Earthquake Early Warning Prototype System

This chapter proposes a prototype for an earthquake early warning system.

6.1 Rationale for Prototype System

Several phenomena have been suggested as earthquake precursors. Recent studies in precursor science show that earthquake early warning could be a reality in the near future. Nevertheless, part of the scientific community is still skeptical and argues that further research is required (Geller, 1997). There is a need to obtain precursor data from simultaneous repeated monitoring in one focus region over a long period of time, and to process and integrate these precursor data with data from other sources. These sources include historical data and data from ground-based units and other space-based systems.

Existing and planned dedicated space missions for monitoring earthquake precursors (see Sections 2.2.1 and 4.1) are insufficient for resolving the precursor issue. Their performance does not satisfy the requirements of an earthquake early warning system in terms of spatial and temporal resolution (Pulinets & Boyarchuk, 2004).

This chapter describes a prototype for a space-based system to address the above mentioned deficiencies. On one hand, this system will provide a definitive assessment of whether reliable earthquake early warning is possible through precursor monitoring. On the other hand, it will form the basis for an operational early warning system once precursors are validated. The warning will identify the expected time and magnitude of the earthquake and the position of the epicentre, which can be determined using precursor data (Dobrovolsky *et al.* 1979, Pulinets 2004).

The Prototype consists of a small satellite constellation, which is described in Section 6.2, and a ground segment that performs the integration and processing of data and delivers the warning. The space segment's primary target is the monitoring of ionospheric precursors and seismo-electromagnetic emissions.

A disaster early warning system can be defined as a system of data collection to monitor a particular disaster in order to provide timely notice when a disaster threatens and thus to elicit appropriate response (Davies *et al.*, 1991). Its ultimate purpose is to protect lives and property from the damaging effects of the disaster.

Some of the most relevant functional requirements for an Earthquake Early Warning Prototype System are as follows:

- Real-time monitoring and processing: decisions based on collected data must be made quickly
- Timeliness: depending on the region, there is a fixed timeframe in which the decision whether or not to trigger an alarm must be made

- Persistent storage: the historical data shall be stored in order to give information about seismic activities over time

The proposed Earthquake Early Warning Prototype System will meet the above requirements. The flow chart in Figure 6- 1 describes the prototype. Precursor data and other kinds of data are gathered from multiple sources, specifically from a proposed satellite constellation, ground-based measurement units, and historical databases. A data analysis module will integrate and process the data to deliver a watch and, if necessary, a warning after the watch is verified. Lessons learned from the prototype performance will be extracted and recorded in the regional knowledge and historical databases, both in case of a false alarm and a confirmed warning.

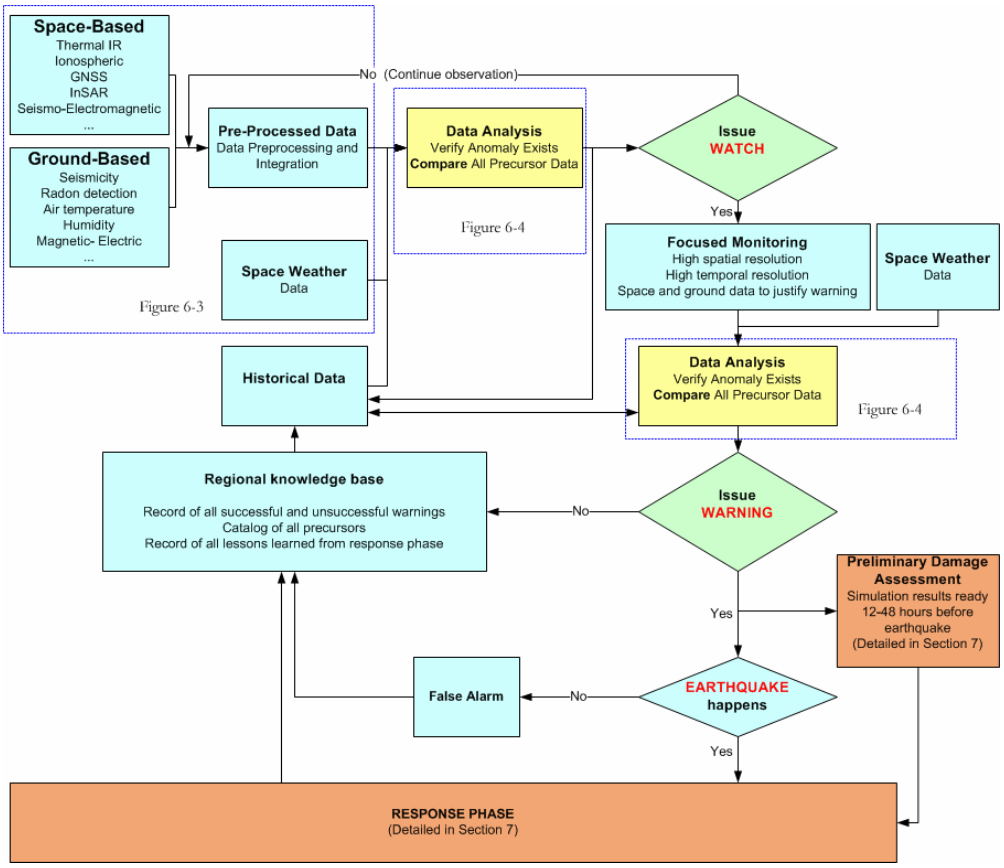


Figure 6- 1 Earthquake Early Warning Prototype System.

6.2 Space Segment

The space segment of the system consists of a constellation of small scale satellites (100-150kg). A constellation of satellites is required since it is not possible to provide adequate spatial and temporal global coverage for the required precursor measurements with only one satellite (Pulinets, 2006).

Ideally, the constellation of payloads should allow the sensing of multiple precursors, as requested by the scientific community (see Section **Error! Reference source not found.**). A full sensor suite would include SAR, thermal IR, optical sensors and sensors for ionospheric measurements; however, such a satellite constellation would be cost-prohibitive. The down-selection of sensors is the result of a trade-off between performance and cost for the proposed prototype. The proposed constellation focuses on the most promising precursors: ionospheric precursors and seismo-electromagnetic emissions (Hattori &

Hayakawa 2007; Kodama *et al.*, 2000; Pulinets, 2004; Pulinets & Boyarchuk, 2004; Pulinets, 2006). Sensors for thermal IR precursors (Ouzounov *et al.* 2007) are not included since there are enough existing remote sensing satellites to provide the required thermal precursor data (Pulinets 2006). If the mission proves succesful, improvements are also envisioned in the future (*e.g.*, increased number of satellites, monitoring of other precursors, etc.).

There are several proposals for a similar dedicated space mission for earthquake early-warning (Hayakawa *et al.*, 2000; Jason *et al.*, 2003; Pulinets, 2006; Pulinets & Boyarchuk 2004). Three proposals are presented below. The main difference between the first two proposals is that the first constellation, 2ESAT (Earthquake Satellite), is lower in cost and performance as compared to the second constellation, 4ESAT. These constellations are not fully designed and many details of their configuration have not been addressed. For instance, the final number of satellites and their payloads could be changed depending on the participating countries and institutions and the available funding. A larger number of satellites and sensors would bring down revisit time and increase the possibility of timely detection of precursors. An in-depth study should be made for achieving an optimized trade-off among cost, number of satellites, revisit time and global coverage, access to ground stations, launching constraints, etc., which is beyond the scope of this report.

6.2.1 First Option: Constellation 2ESAT

The preliminary design of the constellation 2ESAT is based on the proposal from Pulinets (2006). Both satellites are located in the same orbital plane having an inclination of 83º. The upper level satellite, 2ESAT-U, would be placed at an altitude around 960 to 1000 km (higher than the transition height of the ionosphere, which is usually at 750 km). This limitation in altitude is due to the radiation hazard at altitudes above 1000km from the Earth's surface. The lower level satellite, 2ESAT-L, would be placed at an altitude around 500 km (below the transition height of the ionosphere). The satellite bus could be based on a standardized, commercially available 100 kg low-cost platform from Surrey Satellite Technology Limited (SSTL).

The payload of 2ESAT-U consists of a topside sounder, a mass-spectrometer, a local plasma spectrometer, a ULF/ELF/VLF wave complex, a particle spectrometer, and a drift meter. 2ESAT-U and 2ESAT-L are identical except for the fact that 2ESAT-L has no topside sounder (2ESAT is similar to the DEMETER Satellite, see Section 4.1.4). Payload improvements are also proposed, like including a topside sounder in the lower level satellite or an optical spectro-photometer, a radio-beacon and/or a GPS receiver in one or both satellites. The system can be upgraded in the future by deployment of additional satellite pairs to improve revisit time.

The 2ESAT option has been selected as the space segment for the TREMOR Earthquake Early Warning Precursor System.

6.2.2 Second Option: Constellation 4ESAT

The preliminary design of 4ESAT is based on the proposal from Surrey Space Centre, University of Surrey (UK), for ionospheric precursor research purposes (Jason *et al.*, 2003; Boyarchuk, 2004; Pulinets, 2006). In this proposal, all the satellites are identical. The bus is a standardized, commercially available 100 kg low-cost platform (based on the TopSat satellite) from SSTL. Each satellite's payload consists of a topside sounder, a mass-spectrometer, and a magnetometer, weighing together no more than 25 kg. The total mass of each of the small satellites is 125 kg. For an enhanced performance, the satellites' payload could include other equipment, as stated in the previous section.

Statistical analysis shows that earthquake ionospheric precursors appear on average within a 5-day interval prior to the event. Within this period, the precursors can show up daily or only once, and they usually last for four hours. This requires a revisit time of four hours or

less, which can be achieved by a constellation of four satellites in a high inclination or Sun-Synchronous Orbit (SSO) (Pulinets, 2006). The 4ESAT constellation is thus much more ambitious than 2ESAT.

There are several proposed orbits for the satellites, with inclinations ranging from 70º to 85º and an altitude ranging from 800 to 1000 km (Jason *et al.*, 2003). Pulinets recommends that the orbit inclination should be around 83º or higher, and that the altitude should be around 1000 km (2006), provided that the topside sounder is the main instrument on board the satellite. The minimum orbit inclination is defined to allow proper global coverage and adequate measurements of the ionospheric precursors. Satellites in low inclination orbits can not provide coverage of higher latitude areas. Furthermore, the sensor sweep direction resulting from satellite motion of low-inclination orbits is not suitable for the monitoring of ionospheric precursors (Pulinets & Boyarchuk 2004), where a north /south sweep direction is preferred.

6.2.3 Third Option: Constellation TSATS

The third proposed constellation configuration consists of four identical satellites in two highly inclined elliptical orbits with two satellites per orbit (see Figure 6-2). This system is referred to as TSATS, for TREMOR Satellites.

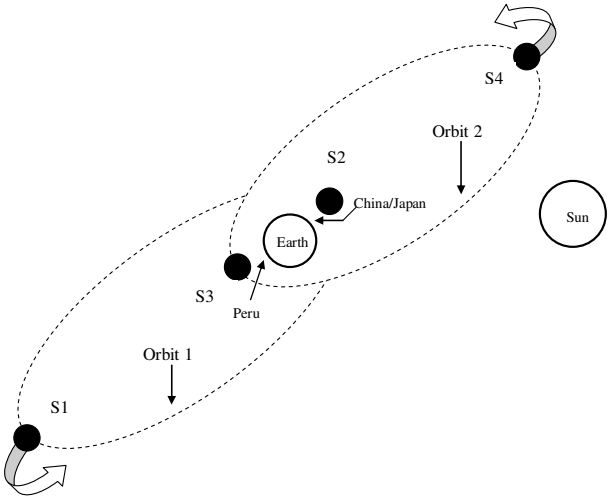


Figure 6-2 Proposed Configuration of Satellite Constellation.

The proposed configuration would serve the purpose of precursor monitoring as well as form an integral part of the response system. As shown above, Satellite1 (S1) and Satellite2 (S2) are in orbit1 while Satellite3 (S3) and Satellite4 (S4) are in orbit2. The satellites would be phased such that when Satellite1 is at apogee, Satellite2 is at perigee. Similarly, when Satellite3 is at perigee, Satellite 4 is at apogee. The orbital period for each of these satellites is 24 hours with the orbits and their inclinations chosen to facilitate maximum coverage of China/Japan and Peru (the focus countries). The choice of perigee and apogee is dictated primarily by the spatial resolution and telecommunication requirements, respectively.

Each satellite will have identical bus and payloads onboard. The proposed instruments (in keeping with the project requirements) can be Synthetic Aperture Radar (SAR), Electro-optical (EO) camera systems with imaging capabilities in visible and near infra-red (VNIR), thermal infra-red (TIR) instrument (optional), Magnetometers for sensing electro-magnetic signals, and Telecommunication antennas and transponders.

The operational strategy will be as follows. At a given instant of time (say, T_0) S1 and S4 will be at apogee; S2 and S3 will be at perigee. Assuming that at T_0, China/Japan is sun-lit and it is night-time in Peru, SAR on S3 can be used for imaging (along with other instruments for precursor studies) while Telecom and TIR instruments on S1 can cover Peru. Similarly, for

China/Japan S4 will provide the telecom and TIR coverage while the EO camera and SAR on S2 can be used for imaging purposes. After twelve hours, it is Peru that will be sun-lit and China/Japan will be under night cover. The various instruments on the four satellites can be switched on appropriately. The monitoring cycle repeats every 24 hours.

6.2.4 Link Budget

Data transmission can either be performed using a store-and-forward philosophy or data relay downlink. For the first option, more complex data storage devices are necessary on-board the satellites, along with more complex data handling systems and increased power requirements. For the second option, a low-cost system is proposed using relay satellites and only one ground station. The relay could be a chain of other LEO satellites or a single GEO satellite (Pulinets, 2006). The possibility of using the ground stations that are currently serving the DEMETER mission should also be considered.

6.2.5 Small Satellite Constellation Construction

The development of the platforms and payloads of the satellites to be included in the constellation would be contracted out via a competitive bidding process, with cost being a crucial factor. Wherever possible, the involvement of a number of organizations from the participant countries, for instance universities (involving the participation of students) or research centers, would be fostered. The participation of science teams from those countries would also be important, as they would possess specialized knowledge of the seismic environment in their respective countries and would be directly concerned with the results of the prototype systems. Candidate countries to participate in the project are those located in earthquake prone areas (Brocko, 2007) (e.g. Argentina, China, Egypt, India, Japan, Peru, Turkey, Bangladesh, Indonesia, and Thailand). The Disaster Monitoring Constellation (DMC) approach (see Chapter 3) should be taken into account as an example of the decentralized development and management of a constellation of satellites.

6.3 Ground Segment

The proposed prototype will integrate precursor data from space and ground-based systems for improved earthquake warning capability (see Figure 6-3). Apart from acquisition and integration, three more steps of data handling in the ground segment must be considered: processing, visualization and interpretation.

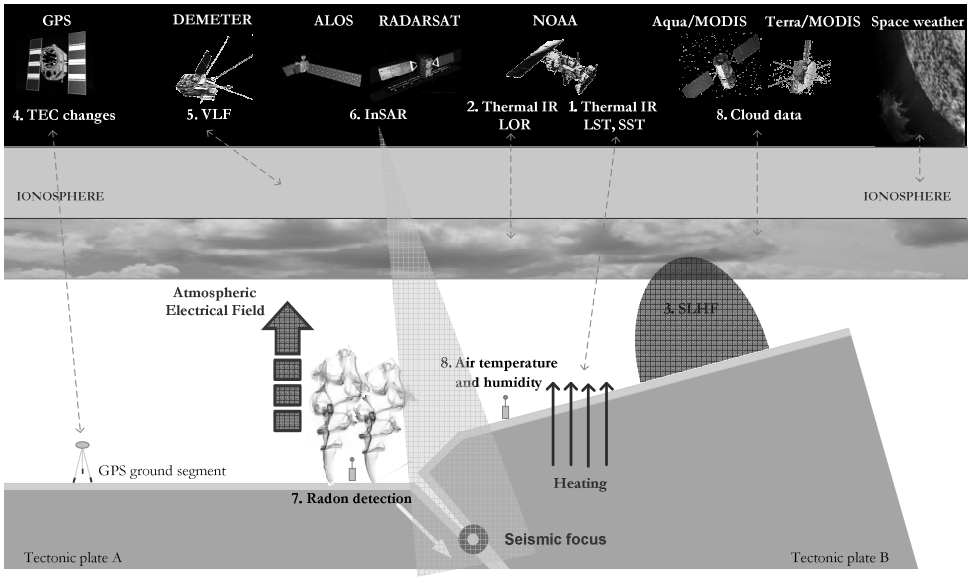


Figure 6-3 Earthquake Precursors and Their Monitoring Systems (Team TREMOR, 2007)

6.3.1 Ground-based Measurements

Ground-based measurements are used to enhance accuracy and to validate measurements from satellites. The main disadvantage of ground-based stations is that they are stationary and therefore restricted to a limited area of coverage within their local environment. Ground-based units can be used to measure radon concentration and other gas concentrations (by LIDAR or spectroscopic measurements); the change in water well levels; gravitational and magneto metric disturbances; atmospheric parameters such as temperature, relative humidity, air pressure, precipitation or wind; information about the vertical electric field (by a network of field mills); atmospheric emissions (study of the bottom layer of the ionosphere by a ground-based ionosonde); movement of the ionospheric layers (by Doppler measurements); metallic ions in the E-layer of the ionosphere (by LIDAR); and crustal deformation (by GPS ground receivers, like in GEONET) (Sagiya, 2004).

Ideal precursor monitoring systems have been proposed earlier (Pulinets & Boyarchuk 2004). As stated in these proposals, a preferably regular and large network of ground stations is required - for instance, a network of GPS ground receivers (ideally at a distance of about 100 km from each other) and ground-based ionosondes, for ionospheric mapping. The countries in earthquake prone areas should deploy adequate ground-based measurement units in their territories to improve the prototype performance. The prototype will be able to integrate and use the data coming from any kind of useful ground-based source to forecast earthquakes. The prototype's performance improves as more data are used (*e.g.*, more reliable is the warning).

6.3.2 Historical Data

Historical precursor data and other kinds of data from related systems (*e.g.*. past earthquakes, fault maps) will be integrated and processed by the prototype.

6.3.3 Data from Other Sources

Complementary data are necessary for the statistical significance to permit precursor validation and for improved prototype performances. We recommend the use of precursor data coming from multiple sources, together with the data that are obtained from the proposed satellite constellation, ground-based precursor measurement units and historical databases. The required data are mainly SAR and optical imagery, thermal IR and GNSS data (*e.g.*, GPS TEC) (Liu *et al.,* 2004). These data can be obtained from other systems such as balloons or airplanes (e.g., they could be used to determine the vertical electric field and air conductivity), which would be required in an ideal system (Pulinets & Boyarchuk, 2004).

6.3.4 Data Processing

The existing space and ground technologies for earthquake precursor monitoring generate a large volume of data. Processing resources are presently insufficient to store and process available precursor data and a major part of the data remain unprocessed. (Pulinets & Boyarchuk, 2004). This hinders the final validation of the precursor-based advance warning methodology.

The volume of data is increasing as new technologies provide better sensor resolution and higher data acquisition rates. Processing requirements are also taxed by the development of new, complex algorithms for extracting meaningful precursor information from the raw data.

The nature of information coming from different sensors is complementary and the utility in merging them has been widely demonstrated (Hall & Llinas 1997). Thus it is important to merge earthquake precursor data from space and ground segments, but this also aggravates the problem of having limited processing capabilities. The data acquisition rate becomes even larger and the data integration becomes more complex and challenging. There is a need

for powerful processing resources in coordination with storage and data management resources.

Data Analysis and Integration Module

A data analysis and integration module is proposed to process the data and generate the watch or warning. Figure 6-4 represents a top-level architecture of the data analysis module that acts as a processing core of the TREMOR Earthquake Early Warning Prototype. It is organized into two layers: the first one performs all real-time computations, while the second layer is executed offline and takes care of the data archiving, further post-processing, and distribution. A similar system has already been applied in the context of space weather (Space Environment Information System, described in Moura *et al.* 2004).

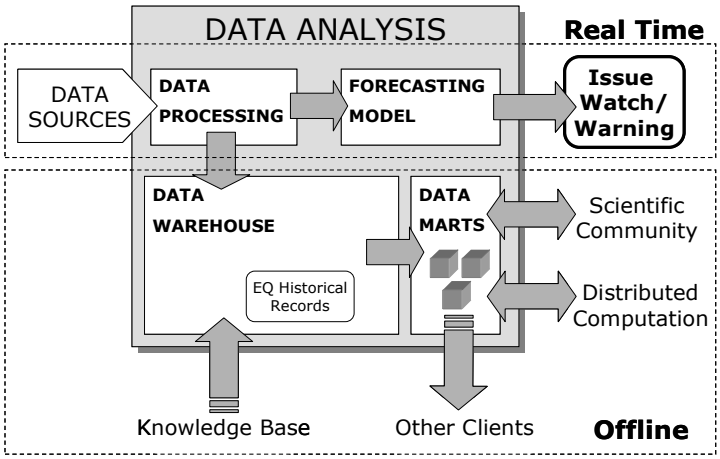


Figure 6-4 System Architecture of the Data Analysis and Integration Module.

In the first layer, data are received from external space and ground-based data sources. These data are pre-processed and fed into a forecasting model that identifies trends that can lead to the issue of an alarm.

The forecasting model is the key element of the system. In order to develop a good forecasting module, extensive processing of past precursor data crosschecked with historical records of earthquakes is required. Historical records must be divided into a learning set and a training set. The first is used to develop the model, the second to validate it. Data mining algorithms will be used to establish trends and correlations between different precursors and historical records of seismic events. Data mining could be defined as "…the nontrivial extraction of implicit, previously unknown, and potentially useful information from data…" (Penedones, 2007). Two approaches can be used in order to recognize patterns and perform an analysis of the data: a human-driven approach using the experience and understanding of the physical phenomena, and a data-driven approach using machine learning algorithms to find new unknown patterns.

In the second layer, the "offline" layer, data are stored in an archive based on data warehousing technologies (Cabibbo *et al.* 2001; Chaudhuri, 1997). A data warehouse has the following characteristics: data are organized with a subject-oriented philosophy, it is integrated to provide a comprehensive view, it is time invariant in the sense that all historical data are maintained, and it is non-volatile- meaning nothing is erased and data are not directly accessible by users. The data warehouse also includes available historical records of all known earthquakes. This information is further processed in "data marts" (more compact sets of specific data) to make it more accessible to end-users and potential clients. The most time-consuming part of the initial development is the implementation of all tools, protocols and processes (for data extraction, transformation, loading, and cleansing) surrounding the data warehouse, including the data mining algorithms.

The offline layer serves the data to several end-users or clients:

- The scientific community: researchers can access the contents of the marts (raw or pre-processed data) to further analyze the data, for earthquake research or other purposes, as it is done with astronomy data in the Virtual Observatory (Williams *et al.*, 2004)
- Other clients: organizations may request data for commercial or government processes. Additional processes can be designed to access and manage the information, such as query, reporting or monitoring tools (e.g.: a web-based query tool to obtain a report of the crust temperature over a definite spot of the Earth for a certain period of time)
- General public for distributed computation: users around the world can download sets of data for processing using the spare time on their personal computers, in an approach similar to that of BOINC (Anderson, 2004). This philosophy can be useful to further validate the forecasting model. Having the computation distributed saves costs and helps involve the public

The system can be expanded to include new types of precursor data as necessary. Other types of data can be stored in the warehouse such as geological information, soil, and building types of different regions. This could be useful for simulation and more advanced reporting and warning tools, as proposed in Chapter 7.

The forecasting model is improved by making comparisons with historical earthquake data (worldwide through distributed computation) and by using the knowledge base that comes from correct and incorrect forecasts of current earthquakes. As and when additional precursor information is added to the warehouse and new correlations found with these new data sets, the model should be updated to consider the new variables.

Access to Data by End Users

The proposed expandable archive solves the problem of the increasing data volume and the difficulties of accessibility and integration. Similar archives have already been created in other scientific fields such as astronomy.

The archive should not be seen merely as data storage. The offline layer of the system offers multiple access possibilities to the scientific community. It will integrate analysis tools and computational services to improve the sharing of expertise, data exchange, and interoperability (Hanish & Quinn 2003). Such an archive will provide an excellent tool for scientific research. The accessed data may also serve purposes other than those of earthquake precursor science or disaster management research. In the field of astronomy, the development of more powerful data mining and analysis tools has enabled new scientific discoveries using only historical data (*e.g.*, discovery of Kuiper Belt Objects). Some data sets can also be used for purposes that were not intended at the time a given mission was developed (Quinn *et al.*, 2004).

The physical implementation of the data warehouse is still in the design process. Taking into account the nature of space-based measurements that exist in large data sets, the gap between the end user and source of the data has to be bridged in terms of processing and accessing capabilities. Each institution may extract the desired data and create their own data processing tools addressing a specific topic of their interest. The collaborative approach of the proposed system is in keeping with the notion of democratization of science since valuable data will be accessible to scientists all around the world independently of the economic resources of their respective institutions.

The increased efficiency from the use of a proper archiving system will improve the TREMOR forecasting system and will advance scientific knowledge in related fields.

6.4 Policy Considerations

In order to properly implement the proposed systems a number of policy considerations must addressed. These are presented in the following section.

6.4.1 Liability

The TREMOR Foundation accepts no liability for actions taken as a result of watches and warnings issued by its systems; nor does it accept liability in cases where earthquakes occur that were not forecast by TREMOR Systems. Actions taken as a result of the watches and warnings issued by TREMOR are the responsibility of the national governments which are clients to TREMOR; the TREMOR foundation serves only in an advisory role.

Specific provisions concerning liability will be included in the agreements that the TREMOR Foundation makes with the users of its systems. Close involvement of the clients in the operations of the TREMOR Foundation, in relation to the early warning system, will be important in ensuring that liability concerns do not become an impediment to the effective operation of the system.

6.4.2 Data Policies

In order to research patterns in earthquake precursor data it is necessary to obtain as much historical seismic and real-time precursor data as possible. Nations currently undertaking earthquake precursor missions such as France or Russia would be encouraged to provide their data, both historical and real-time, to the TREMOR Foundation. This data will allow research to begin on the integration of ground and space based measurements during the preparation of a dedicated space asset to measure earthquake precursors. Once the TREMOR space segment is providing data, the data feeds from other organizations will be supplemental.

Transfer of Information to TREMOR

Contracts between the TREMOR Foundation and the agency/organization providing earthquake data, such as the United States Geological Survey, will be signed. All data transfer contracts should provide for the following:

- Historical seismic and precursor data will be provided to the TREMOR Foundation within six months of the contract signing
- Seismic and precursor data will be provided to the TREMOR Foundation in real-time using an encrypted connection. This data feed will commence within nine months of the contract signing
- Data provision to the TREMOR Foundation will be at the discretion of the nation undertaking the measurements
- By releasing data to the TREMOR Foundation, the providing agencies understand that these data may be distributed without limitation to third parties involved in research and development for the TREMOR Foundation. Accommodations will be made where export of data is not desired by individual agencies
- Data will be provided to the TREMOR Foundation at no cost
- An optional subcontract between participating organizations and the TREMOR Foundation will be prepared to allow the TREMOR Foundation to develop a publicly accessible earthquake database
- Any data sent to the TREMOR Foundation will be without liability to the provider. However to ensure data accuracy the following conditions must be met

- Data sent to the TREMOR Foundation must follow format requirements set out in the initial contract
- Calibration data from the various organizations will be sent periodically to the TREMOR Foundation

Distribution of Data to Clients

The TREMOR Foundation will cooperate with leading earthquake precursor researchers and institutions. Part of this cooperation will involve sharing data acquired from national agencies and organizations for research and development purposes. However, should an organization choose not to share its data with a particular third party, accommodation will be made to respect its request. A goal of the TREMOR Foundation will be to develop a publicly accessible database of earthquake information. This database will be available over the World Wide Web and directly from the TREMOR Foundation. An optional subcontract between the TREMOR Foundation and all cooperating organizations can be negotiated for access to data available in this database.

Interface with Existing Disaster Management Systems

Several different DMS exist today (see Chapter 3.5). The information gathered and produced by the TREMOR earthquake Early Warning Prototype will be provided to those DMS whose areas of activities include earthquakes, for example the Global Disaster Alert and Coordination System . It is our belief that information from the TREMOR system will improve the ability of existing DMS to contribute to effective data management.

6.4.3 Watch and Warning Issuance

The TREMOR Foundation's Prototype Earthquake Early Warning System will issue earthquake watches and warnings. The watches and warnings will be distributed to a single national authoritative agency responsible for earthquake disaster management in each of the client countries. The concept of a single national authoritative agency is used with success by the Pacific Tsunami Warning System (UNESCO, 2006). This ensures a single point of contact for early warning information and reduces confusion. For the pilot phase of the TREMOR Foundation early warning system, watches and warnings will be issued to China, Peru and Japan. Table 6-1 shows the national authoritative agencies for each of these countries.

Table 6-1 National Authoritative Agencies for Earthquake Management

Country	National Authoritative Agency for Earthquake Management
China	China Earthquake Administration
Japan	Director-General for Disaster Management, Cabinet Office
Peru	Instituto Nacional de Defensa Civil

Earthquake watches and warnings will be issued by the TREMOR Foundation based on specific criteria. As an example, an Earthquake Watch could be issued by the TREMOR Foundation when there is an elevated probability (greater than 50%) of a medium or high magnitude earthquake occurring within the next 14 days in a certain geographic area. An Earthquake Warning, on the other hand, could be issued by the TREMOR Foundation when, after warning verification, there is a high probability (greater than 90%) of a medium or high magnitude earthquake occurring within the next 12 to 48 hours, with an epicenter within 100-200 km of a particular geographic point, defined by latitude and longitude coordinates. The actual trigger criterion will be defined once the system has functioned for a sufficient period of time to have acquired adequate data for forecasting purposes.

In order to build confidence in the Prototype Earthquake Early Warning System, and to encourage transparency, representatives from the client countries will be involved in the operation of the system. This will help to ensure both that processes leading to the watches

and warnings are clearly understood by the TREMOR Foundation's clients, and that local institutional and cultural conditions are taken into account in implementing the system.

6.4.4 Recommendations on Actions During a Watch or Warning

The TREMOR Foundation will only provide watch and warning information to the governments of the client country; it will not provide information to the general public. This is left to individual governments. However, the TREMOR Foundation does provide general recommendations as to what actions should be taken in a watch or warning situation. These recommendations are discussed in this section. Some of the recommendations presented here, in particular those intended for the local level, are based on procedures already in place in Japan (City of Hamamatsu, 2007).

The TREMOR Foundation recommends that the early warning system is not operationally used to provide public information in a given country until a minimum threshold of confidence (90% is suggested) in forecasts over a respective geographic area has been achieved by the system.

Recommended Actions upon Issue of Watch

When a watch is issued it is recommended that the following actions be taken:

At the international level:

- Satellite resources should, at the request of the nation(s) potentially affected, be targeted on the areas covered by the watch. Pre-event remote sensing imagery can be used to help plan the response. Additional earthquake precursor observations can be provided to the TREMOR system and used to refine forecasts to help determine whether a warning should be issued.
- Disaster response equipment and teams should be prepared for deployment and pre-positioned wherever possible.

At the national government level:

- Distribute the watch to local agencies and to the public
- Preposition national disaster response equipment, including the TREMOR Simulation and Response Prototype deployable unit (described in Chapter 7)
- Prepare customs procedures for rapid entry of equipment/personnel. If a party to either WGET or the Tampere Conventions, ensure that customs officials and border guards are aware of the provisions of those agreements
- Prepare for rapid activation of professional licensing (medical, radio, *etc.*) procedures
- Review/update plans for regional evacuations
- Review and update disaster management and response plans

At the local government level:

- Provide refresher training to local emergency personnel
- Test and preposition disaster equipment
- Increase the number of on-call response personnel
- Prepare community shelters and increase canned food/water supplies
- Provide regular radio/TV warnings/broadcasts with preparation information

Recommended Actions upon Issue of Warning

When a warning is issued it is recommended that the following actions be taken:

At the international level:

- Continue watch activities

At the national government level:

- Continue watch activities
- Issue warning to the public and local agencies and actors

- Prepare to activate the International Charter on Space and Major Disaster

At the local government level:

- Continue watch activities
- Evacuate hospitals, especially the critical care population
- Safe mode for non-essential infrastructure (nuclear reactors, transportation, etc.)
- Close non-essential commercial and entertainment venues
- Close schools
- Continue regular radio/TV warnings/broadcasts with preparation information
- Turn off natural gas system
- Evacuate tsunami and landslide at-risk areas

The actions recommended in this section are merely suggestions. In the end national authorities must review which actions are most appropriate and/or feasible in their jurisdictions. It is not the role of the TREMOR Foundation to dictate actions to national governments, nor is the TREMOR Foundation in the best position to be able to make the most appropriate recommendations for any given locality.

It is particularly important that national governments give careful consideration to what actions they recommend that the public take in reaction to earthquake watches and warnings. In order to avoid panic at watches and warnings it will be necessary to conduct a thorough public education plan regarding the warning system and what to do in preparation for earthquakes.

6.5 Spin-offs and Other Benefits

Technological and methodological spin-offs and other benefits would arise as a consequence of the development, implementation, and operation of the proposed prototype.

Several benefits have been identified for the scientific community. Although the satellite constellation is devoted to the study of the distribution of seismo-ionospheric variations, other kinds of ionospheric variations, such as changes in atmosphere electron content, can be sensed. Ionospheric temporal and spatial variability are related to phenomena of scientific interest such as the 11-year solar activity cycle, magnetic storms and space weather effects. The data acquired by the satellites can therefore be used by the scientific community to enhance its knowledge by studying the effects of various phenomena in the ionosphere.

The advancement in the knowledge of ionospheric variations would also benefit certain satellite applications and other technologies. One such example is GNSS, since the positioning signals are altered by ionospheric effects leading to positioning errors. The understanding of these effects and the ionospheric variations would improve the accuracy of GNSS (Daghay, 2005). Ionospheric disturbances can also disrupt high frequency radio transmission in polar regions, which causes a hazard for polar airline flight.

The interaction between the participants through international cooperation provides other types of benefits that are essentially common for all kinds of international projects. These include technology and knowledge transfer, networking, and fostering further international cooperation. Cultural benefits can also be derived from the participation of youth on satellite constellation preparation (through universities) or data processing (through volunteer analysts units), by fostering the interest of youth in science and technology (Wertz & Larson, 1999). Participating universities in turn benefit from access to applicable research opportunities for their students, and the prestige associated with contributing meaningfully to international projects.

Chapter 7

Earthquake Simulation and Response Prototype System

Team TREMOR proposes a Simulation and Response Prototype that coordinates the main components of the response phase to reduce the time delays of response operations, increase the level of precision in the data collected, facilitate communication among teams, and enhance rescue and aid capabilities. The main goal of this prototype is to increase the level of performance seen in current response systems in order to decrease the loss of life following an earthquake. Consequently, the same prototype could be valid in the future for other type of disasters.

As illustrated in Figure 7-1, the Simulation and Response Prototype is linked with the Early Warning Prototype (see Chapter 6) forming an integrated solution to aid in disaster management; however, even in the absence of a functioning early warning system, the Simulation and Response Prototype will be able to improve disaster response significantly.

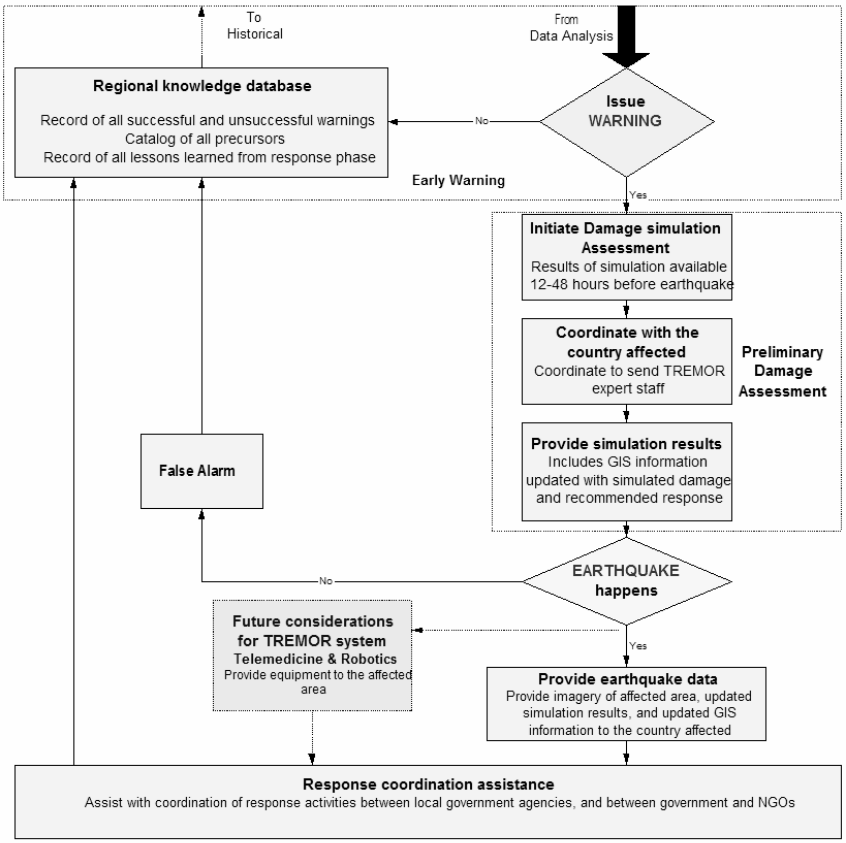


Figure 7-1 Simulation and Response Prototype System

The Simulation and Response Prototype is activated as soon as the Early Warning Prototype System issues a "Warning" (see Chapter 6). Following the issuance of an earthquake warning, the TREMOR Foundation's *Simulation Tool* (see Section 7.2.1) will perform initial damage assessment estimations. Coordination with the affected country during the planning phase is essential for obtaining the necessary inputs for the simulation, such as information on soil types and health centers networks. After the earthquake occurs, the system will also be used to optimize the allocation of resources. Trained TREMOR Foundation personnel will be sent to the site of the earthquake to support local response personnel in deploying the TREMOR mobile telecommunication unit. An enhanced communications infrastructure (see Section 7.2.2) will help in the coordination of all response activities.

Finally, simulation results, images and GIS data (see Section 7.2.3) will be delivered to help the client government in the decision-making process prior to and after the disaster.

7.1 Justification of the Simulation & Response Prototype

Lessons learned from previous earthquake disasters indicate a need to find a solution to increase the level of performance of emergency response teams, particularly by reducing time delays (Abolghasemi *et al.*, 2006). When an earthquake occurs, there is a limited amount of time for coordination teams to prepare and to perform all the tasks associated with response. These tasks include decision-making processes relating to the coordination of search and rescue teams, medical teams, supply teams, and volunteers.

Countries differ in the organization and degree of development of their disaster management systems. To accommodate these differences, we adopt a cooperative approach whereby the TREMOR Foundation offers assistance to local organizations and government agencies for coordination purposes, if requested, without interfering in regional decision-making processes.

Tracking systems will play an important role in helping search and rescue teams to coordinate their operations and ensuring that emergency, military, and supply vehicles are effectively deployed.

Other technologies that may increase the capabilities of the Simulation and Response Prototype System include telemedicine and advanced robotics. Telemedicine allows medical doctors to perform evaluations (teleconsultation), surgery (telesurgery), and many other services from a distance. For example, after the 1985 Mexico City earthquake, voice communication via satellite was used to assist emergency rescue teams (NASA News, 1985). Research is ongoing on the use of teleoperated robots during the aftermath of an earthquake (Mora Vargas *et al,* 2006). Teleoperated robots can investigate environments too dangerous for humans and send signals when casualties are found. Presently, there are some policy and cost limitations that make the use of telemedicine and robots unfeasible in the currently proposed prototype; however, we anticipate that these barriers will eventually be overcome.

7.2 Description of the Simulation & Response Prototype

7.2.1 Simulation Tool

Earthquake damage can be dramatically reduced by using a disaster simulation tool capable of estimating the damage produced in a particular area based on local conditions. A comprehensive disaster simulation system can also be used to develop guidelines for actions to be taken by the public following an earthquake, and provide resource allocation recommendations to emergency professionals such as fire brigades, ambulance teams, and police forces. Similar simulation systems are being implemented for government preparedness in the event of terrorist attacks, because these types of events are also unpredictable in nature (Alvares & Shaw, 2006).

The requirements for this system include:

- *Integrated solution*: The secondary effects caused by earthquakes, such as floods and fires, must be taken into consideration, along with combinations of effects. Evacuation of a population might be another hazard considered by the tool. A solution based on the effects caused directly by an earthquake is not enough, since decisions have to be made based on the combination of the effects.
- *Effective data presentation*: The amount of information processed by an integrated system will be enormous. An efficient data-mining system will present only data relevant to the decision making process.
- *Human behavior simulation*: To understand better the secondary effects produced by earthquakes, models of human behavior will be considered in order to identify problems such as bottlenecks in evacuation plans.
- *Continuous connection to local government services*: Simulation tools will assist in planning over the longer term recovery phase by providing recommendations related to logistics, relief delivery, shelter management, waste disposal, urgent repair, and post-earthquake reconstruction.

The simulation system will consist of two interrelated parts. The *infrastructure damage assessment model* will be used to predict the operational status of key infrastructure, such as buildings, roads, and hospitals, required during the response phase after the earthquake. The *resource allocation optimization model* will be used to estimate and best allocate available personnel, material, and equipment. The simulation will use input from the Prototype Earthquake Early Warming System.

The framework for the simulation system should be as generic as possible, with the ability to customize the parameters of the simulation for each earthquake-vulnerable region. This will allow the system to take into account regional variations in characteristics including availability of different data (Alvares and Shaw, 2006).

In the field of seismic damage assessment, some simulation models have already been implemented. Two of the most important inputs for a good estimation are soil and infrastructure information. This approach also considers the use of a learning algorithm that uses multiple earthquake events to improve the representation of the cyclic soil behavior that affects the accuracy of the prediction (Tsai & Hashash, 2007).

The two main sources of uncertainty in assessing damage to structures are the diversity of the structures themselves and the randomness of the ground excitations. Presently, this problem is addressed by estimating the damage caused by a family of seismic waves of different fundamental frequencies to a structure to determine the worst case scenario. Uncertainty can be reduced if earthquake fault models are available for the area under consideration (Lignon & Jézéquel, 2006).

Models for optimizing resource allocation are currently being developed for large-scale catastrophic events including earthquakes. They deal with many different areas that have impact on the response strategy, such as operational performance of hospital emergency departments, human behavior during building evacuation, emergency communications infrastructure, travel times after an earthquake, and the availability of trained personnel (Lignon & Jézéquel , 2006; Nakanishi . 2004; Joshi M. *et al.,* 2005; Lignon & Jézéquel, 2006; Ohboshi *et al.*, 1998). The simulation will give an optimized solution that provides an estimate of the initial response time, including the arrival of trained personnel and other material resources, and the impact if the necessary resources are not available (Lignon & Jézéquel, 2006).

7.2.2 Communications Infrastructure

An emergency communications network is intended to provide reliable communications to emergency response personnel and citizens. The ability to set up and maintain communications is a critical task in order to optimize disaster relief efforts. Emergency communications systems will need to be easy to transport, assemble, and use; require minimum power; have scalable architecture in order to manage the increased demand during the relief process; have the ability to bypass the existing network; and must support voice, data, and video applications.

The proposed system will include:

- *Geographic redundancy*: When possible, the proposed system will provide a secondary telecommunications infrastructure placed at a location distant from the damaged primary infrastructure. A dedicated hard-link should be provided to connect both in order to update the backup infrastructure in real time.
- *User terminals*: the proposed system will have the ability to integrate a wide variety of communication technologies and will allow for the use of mobile satellite phones, VoIP handheld units, laptops, PDAs, webcams, VSATs, and HAM radios. This will allow flexibility for optimal use of locally available equipment, and allow for mobility of the users.
- *Broadband*: the proposed system will provide enough bandwidth to meet the requirements of the disaster relief applications.

The architecture of the proposed system will provide global coverage in order to meet regional and international communications requirements. This will include tactical communications among relief workers on the disaster site with province and state administrators, and strategic communications between the affected area and the outside world. When possible, terrestrial infrastructure will be integrated in the proposed system, including cellular terrestrial systems and VHF/UHF/HF terrestrial radio systems.

Communication Units Coordination

As Figure 7-2 depicts, coordination is assisted by a deployable on-site unit. It is controlled by local services and supported by TREMOR Foundation representatives.

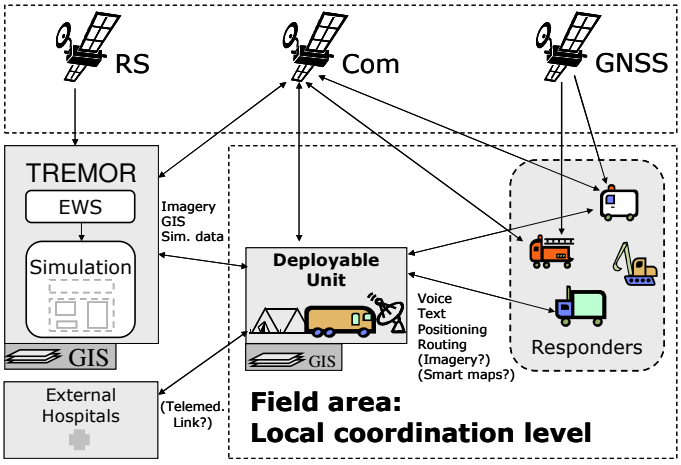


Figure 7-2 Schematic Diagram of the Deployable On-site Unit

In order to provide necessary information to governments in the aftermath of an earthquake, communications must be reliable. The proposed systems will provide the following communication links:

- *Deployable unit to mobile responders via radio and satellite*: Necessary services include voice, text, imagery, and routing. The term 'responder' makes reference to both field personnel and emergency vehicles.
- *Deployable unit to TREMOR central offices*: This will be a satellite link, although traditional mobile and fixed network could be used if available. This link is crucial for the TREMOR response system, since it permits the exchange of simulation data, damage assessment imagery, and GIS data.

An optional link to consider for future versions of the proposed system is the telemedicine link between the deployable unit and external hospitals. A direct communication link between responders and TREMOR central offices via satellite can also be considered in order to alleviate the deployable unit communications load.

One of the most important tasks in the coordination process is the GNSS-based vehicle tracking subsystem. The existence of multiple uncoordinated tracking systems for each of the response organizations (*e.g.,* Red Cross and Red Crescent, NGOs, military, police) can sometimes lead to inefficient management of resources and delays in the reaction time. The TREMOR proposal provides an integrated system based on GPS tracking to monitor all existing vehicles from the response teams that enter an affected area. The use of such a system from the deployable unit center can provide a more efficient and coordinated response.

The system will provide vehicle tracking, safe routing information, coordination among teams, intercommunication, and interoperability. This will result in reduced delays in the treatment of medical emergencies, and faster search and rescue operations. The information gathered from all vehicles by the control center has the additional benefit of real-time mapping of drivable roads and areas accessible by vehicle and could be processed to generate useful maps of the area or improve existing ones.

Several examples of systems using vehicle tracking for disaster management exist. For example, ESA's Real-time Emergency Management via Satellite (REMSAT I and II) has been used in cooperation with several Canadian universities and agencies to target forest fire hazards in British Columbia, Canada (ESA, 2007).

The vehicle terminals normally consist of a GNSS receiver, a microprocessor and a transceiver or transmitter to send the information to the command centre. A simple user interface is required to present processed information, messages and maps of the area. GNSS receivers and transmitters compatible with existing GNSS systems should be used. This may require establishing guidelines and recommendations in the design of GNSS receivers and data exchange protocols, to allow for the possibility of a universal transmitter.

Geographic Information Systems (GIS)

An organized GIS database is vital to emergency management. The GIS system will include pre-existing layers of information with soil types, building types, infrastructure and population. Critical infrastructure data that will be collected in advance of an earthquake include those on transportation, political boundaries, telecommunications, electrical power, water, oil and gas utilities, bank and finance, emergency services, and government continuity.

New layers of data that are updated during the response phase will include remote sensing imagery and vehicle and resources tracking. A component for handling vehicle tracking and routing through GNSS needs to be integrated. Data collection and updated mapping capabilities in the field are provided by the TREMOR central office. Distribution of local maps to responders in the area is one of the most important applications for the data stored in the GIS system. The basic workflow is described in ESRI, 2006. Pre-disaster mapping data is gathered and analyzed at the TREMOR central office. At the same time, remote-

sensing imagery is obtained from Earth observation satellites. The deployable on-site unit collects additional information using the mobile GIS mapping capabilities and information from GNSS, and sends the information back to the central office.

Follow-up Work: Telemedicine and Robotics

Although telemedicine is not included in the first version of the TREMOR Foundation's response and simulation system, it will be considered for future versions because of its importance during the response phase.

On-site medical personnel can communicate with supporting hospitals in unaffected regions using communication satellites, ground-based antennas, and the internet. This can involve real-time communication for teleconsultation. For example, a physician in a hospital in Beijing can use a video and sound data link to evaluate the condition of a patient in rural China. There are also some diagnostic devices, such as ultrasound, that can be directly connected to a computer to send the images automatically to an off-site physician in real-time. This concept also includes store-and-forward telemedicine which uses a communication link to send data such as those from a CT scan, MRI, or blood sample results when further evaluations are needed by specialists. Another important element is the use of portable computers by medical teams.

Next generation teleoperated robots may be able to greatly facilitate the work of search and rescue operations. The design of the telecommunication system includes a requirement that a communication link has to be available for the use of such robotics. A network of robots could be used to search for victims over a specific area. One conceptual design is to send a teleoperated vehicle into a damaged area that would then deploy smaller robots to perform a more exhaustive search of the area (Yoshida *et al.*, 2005). The robots would use wireless communications and satellite-based IP communication links.

7.2.3 Constellation of SAR and Optical sensors

There is a need to have rapid availability of remote sensing images of an area after it is affected by an earthquake. This can be achieved by providing a multi-satellite remote sensing system with a short revisit time (less than one day). The requirements for individual satellites are discussed below followed by a brief outline of issues affecting the constellation in general. The requirements for ground segment as well as the high-level data processing system are also described.

Space segment

Satellites in the constellation will be capable of acquiring data at different wavelengths, both from active and passive sensors. The most important requirement of optical sensors being used for operation within the response phase is a high spatial resolution in order to assess damage accurately. After an earthquake, the planning of rescue operations is based both on a simulated scenario of the disaster and actual images of the affected area. The radar sensor will be able to provide images during the night and under most weather conditions that can be used to create large maps of ground deformation.

Current high-resolution electro-optical and SAR systems together with near-future planned high-resolution systems could create a virtual satellite response system. Current systems include: TerraSAR-X (Germany), Cosmo-SkyMed (Italy), SPOT (France), Radarsat 1 (Canada), QuickBird (US), and IKONOS (US). The following satellites are among those planned for launch within the next two years: CBERS-2b (China/Brazil), HY-1,-2,-3 (China), GEOEYE-1 (US), Pleiades (France), Radarsat-II (Canada), Rapideye (Germany), and Worldview-1 (US). Table 7-1 summarizes the main characteristics of on-board sensors for earthquake monitoring and response applications.

These satellites will provide the resources necessary for targeted observation of an area under a TREMOR watch or warning, without the need for additional TREMOR-specific satellites. To get the most utility out of these systems, it is important that operators of new satellites take part in the International Charter for Space and Major Disasters.

Table 7-1 Summary of Main Characteristics of Optical and SAR Sensors for Earthquake Monitoring

Payload	**Main Characteristics**	
Visible and Near Infrared Radiometer	Spatial resolution	< 5 m
	Number of channels	4
	Bands	Range: 0.42-0.89μm
	Acquisition mode	Steering beam
Synthetic Aperture Radar	Spatial resolution	< 10 m (Fine Res. mode)
	Acquisition modes	Fine Resolution, ScanSAR
	Average swath width	50 km (Fine Resolution) 200 km (ScanSAR)
	Band	L band

Ground Segment and Data Processing System

The data processing ground segment for the remote sensing component can be divided into two main parts: individual processing capability for each sensor, and an overall processing capability to integrate the data and extract useful response information. The ground segment processor receives the data directly from the satellites, analyzes their quality, and performs all the necessary steps and algorithms to transform the raw data into useful products. From the scientific side, there is still a lack of suitable models to extract the full information content from the data. As discussed in Section 6.3, there is a need to develop software to interpret the data and to quickly generate easy-to-use products for distribution.

7.3 Policy Implications

The clients for the TREMOR Earthquake Simulation and Response Prototype System are presumed to be the same national authoritative agencies identified in Chapter 6.

7.3.1 Data Policies Associated with Simulation System

The TREMOR Foundation's earthquake simulation activities will be conducted at the Foundation's headquarters when triggered by an earthquake watch, and will require the use of potentially sensitive data (*i.e.,* detailed maps, building plans, and infrastructure capacity) from the individual client countries. Provision of these data to the TREMOR Foundation will be covered in the individual contracts the Foundation makes with its client countries. For its part, the Foundation will not make any of these data public or available to anyone apart from the national authoritative agency of the client country. The TREMOR Foundation will retain non-public archival copies of all data and simulation results. Results of simulations will be provided only to the client country affected. Simulations and associated data will be made available to other entities beyond the national authoritative agency only at the request of that agency. At the request of a client country, the TREMOR Foundation will run simulations for areas where no watch or warning is in place for planning purposes. However, areas with active watches or warnings will receive processing priority for simulation activities. It is the responsibility of the client country to provide feedback to the TREMOR Foundation regarding the value and accuracy of simulations. This feedback will be used by the Foundation to improve its simulation process. Procedures for providing feedback will be covered in the agreements between the TREMOR Foundation and the client country.

7.3.2 Role of TREMOR Foundation in Client Countries

As with the early warning system, the TREMOR Foundation acts only in an advisory role during the response phase of disaster management, as related to the use of the Simulation and Response Prototype.

Training Prior to Earthquake

The prototype mobile response unit will be pre-deployed to the client country so that it can be activated rapidly in the event of an earthquake. Pre-positioning of the equipment is also beneficial because it avoids the customs delays that often plague disaster response. The TREMOR Foundation will provide training to the client country on the use and operation of the response unit. The intent of this training is that the client country will be able to deploy and operate the system in response to an earthquake event without requiring any direct involvement of TREMOR Foundation personnel at the disaster site.

Advisory Team during Disaster Response

When an earthquake occurs in a client country, the TREMOR Foundation will deploy a small rapid-response team to the site. The purpose of this team is to serve in an advisory role to the operation of the Simulation and Response Prototype. In no way will this team be involved in operational decision-making concerning disaster response. This is the responsibility of the governments of the jurisdictions affected by the disaster. In order to expedite the TREMOR response team's arrival at the disaster site, it will be important that the Foundation and the client country form a prior agreement as to customs and immigration clearances and visas for the response team members. The TREMOR Foundation will suspend the response team service at the request of any individual client country. It is the client country's responsibility to provide protection for TREMOR Foundation personnel and equipment while in-country. This stipulation is similar to a provision found in the Tampere Convention (Tampere Convention, 1998).

Related Telecommunications Policy

The 1993 ISU Report GEOWARN (Global Emergency Warning and Relief Network) also refers to the existing resources and data processing centers that are linked together via a computer network and communication satellites to perform global disaster management support. Many existing disaster management systems, such as the Pacific Tsunami Warning System, rely on the current telecommunications infrastructure to provide services and information. Communications technologies are important to government and non–government organizations at the local, national and international levels.

Each potential client country for the TREMOR system has its own set of national communications infrastructure and policies. The existing situation in a given country will effect the implementation of the TREMOR prototypes. For example, in Peru there is no communication system at a national level to provide guaranteed emergency telecommunications in the case of an earthquake. In China, the China Telecommunication Corporation is the main organization responsible for emergency communication. It is a public/private partnership (China Telecommunication Corporation, 2007). In Japan, communication policies originate from the MIC International Affairs Department Telecommunications Bureau. Currently, MIC is focusing on developing information communications technologies and a safe and secure network society (Government of Japan, 2007). There are numerous gaps in current international efforts to apply telecommunications to earthquake disaster management. The following examples suggest policies to meet these gaps. The development of TREMOR Simulation and Response Prototype system takes many of these suggestions into account.

Chapter 8
TREMOR Foundation

To implement the Earthquake Early Warning and the Earthquake Simulation and Response Prototypes discussed in Chapters 6 and 7, Team TREMOR recommends the creation of a new international organization. The TREMOR Foundation, as this organization is referred to in the context of this report, will operate as a non-governmental organization (NGO) with an international headquarters and a single branch office in each of the target countries that are heavily affected by earthquakes.

The near-term objective of the TREMOR Foundation is to develop and support prototypes of an Earthquake Early Warning System and an Earthquake Simulation and Response System for three focus countries: China, Japan, and Peru. The long term goal of the TREMOR Foundation is to become a sustainable entity that will provide technology and support to all countries that are suffering from earthquakes. In this role, it will incorporate the results and lessons learned from the pilot projects in its goal of reducing the loss of life and damage to property and environment caused by earthquakes. By providing special support to those developing countries that are most vulnerable to earthquakes, the TREMOR Foundation also hopes to enhance the economic and social well-being of these less affluent regions.

To explore the business opportunities deriving from the Earthquake Early Warning System and Response System, the TREMOR Foundation will establish a for-profit spin-off subsidiary, which, during its first years of operation, will concentrate on two areas/products: a disaster recovery plan for large companies (*e.g.* IT companies, logistics management, financial institutions), and services for the natural disasters insurance market.

8.1 Business and Management Plan

The TREMOR Foundation will operate as a not-for-profit NGO. This will allow it to implement humanitarian strategies aimed at reducing loss of life as well as material damage, and to provide special support for developing countries. A more complete rationale behind the selection of an NGO model is given in Section 8.7.

8.1.1 Organization

The structure of the Foundation is shown in Figure 8-1. The different branches will interface with clients and partners as shown.

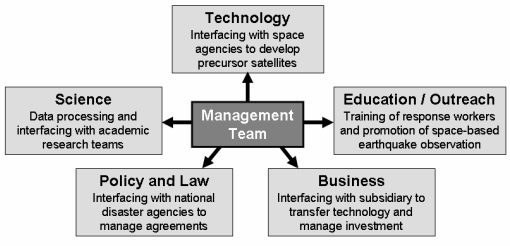


Figure 8-1 TREMOR Foundation Organizational Structure (Main Office)

8.1.2 Market Research

For the year 2007 the Global Risk Network of the World Economic Forum has identified 23 "core" global risks to the international community over the next 10 years.

In the report, the risk of earthquakes is driven by basic geophysics, so the risk remains the same as compared with the previous year, in terms of likelihood and severity. Meanwhile, slight increases in the exposure of populations are offset by slight reductions in the vulnerability of assets; however, risks do not manifest themselves in isolation: their drivers, triggers, and consequences are interconnected, as shown in Figure 8-2.

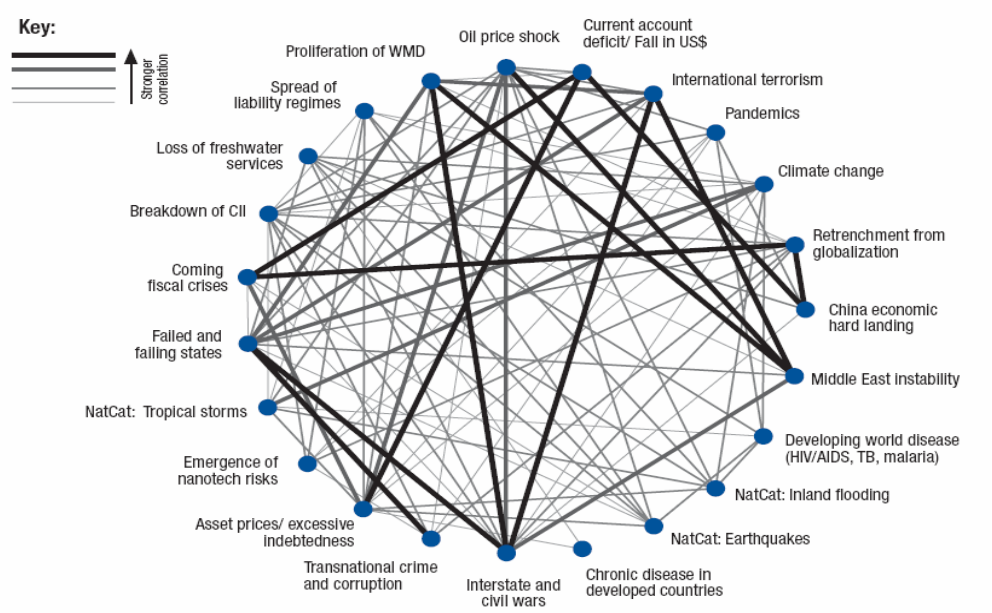


Figure 8-2 Correlation Matrix for 23 Core Global Risks (World Economic Forum, 2007)

By identifying and providing early warning of the risk of earthquakes we suggest that better mitigation strategies can be developed to reduce the number of deaths and also to achieve better management of the other "core" risks (*e.g.,* loss of freshwater services, breakdown of critical information infrastructure).

As described in Section 3.4.2, many NGOs are involved in disaster management activities. They are, however, typically not specialized in earthquake response and none are known to be developing an Earthquake Early Warning Prototype. In addition, none of them are providing a global standardized approach for the processing of earthquake-related data. The gaps in the co-ordination of the response to earthquakes (see Chapter 5) will be addressed by the TREMOR Foundation Earthquake Simulation and Response Prototype System.

8.1.3 Products, Services, and Clients

The main products and services to the clients include:

Early Warning Prototype System

For the pilot phase, the Foundation will provide all elements of the Earthquake Early Warning Prototype System, as described in Chapter 6, to the national governments in the three focus countries. The Foundation will continue to act as a liaison with these national governments to update them on the progress and results of the Early Warning Prototype.

Simulation and Response Prototype System

For the pilot phase, the Foundation will provide all elements of the Simulation and Response system, as described in Chapter 7 to the national governments in the three focus countries. The Foundation will continue to liaise with these national governments to update them on the progress and results of the response prototype.

Satellite Communications Products

The Foundation will provide earthquake response teams with mobile satellite-based communication hubs to maintain co-ordination between response organizations when local communications services are disrupted or otherwise unavailable.

Education and Outreach

The Foundation will offer training services to response teams so that team members can better understand and make more effective use of satellite-based technology in disaster situations. Examples include interpretation of satellite imagery and use of satellite communication equipment.

Research Grants

The Foundation will offer grants on a competitive basis to academic institutions and other organizations for earthquake-related research. Of particular interest will be research aimed at better understanding possible earthquake precursors and the development of new tools designed at making better use of space-based technologies for reducing earthquake hazards.

Satellite Technology Development

During the pilot period, the Foundation will fund the development of two small satellites to study ionospheric and electromagnetic precursors. This corresponds with the 2ESAT constellation as described in as described in Section 6.3.1. These data will be correlated with ground-based studies of other possible earthquake precursors. Ultimately the Foundation would fund additional earth observations satellites (*e.g.*, optical and SAR) to improve response capabilities; however, this is not envisioned for the pilot period.

The clients for these products and services will be national disaster response agencies, local civil authorities, and NGOs (*e.g.,* International Red Cross and Red Crescent Movement) that are presently involved in earthquake response efforts.

The Foundation can also provide services to the UN and other internal organizations such as the World Bank and Inter-American Development Bank; specifically, the Inter-American Bank gives international disaster financing to each member country to develop tools that will help them understand probable losses due to natural hazards, and to plan and to cope with risk - including the sustained budgetary resources necessary to reduce those potential damages.

Nonetheless, a significant amount of information from the provided services can also be used by private entities directly (*e.g.* insurance companies) as well as indirectly (*e.g.,* disaster risk management). Therefore, in order to exploit this significant market, a spin-off subsidiary will be established. The details of this subsidiary are given in Section 8.6.

8.2 Strength, Weakness, Opportunity, Threat (SWOT) Analysis

A Strength-Weakness-Opportunity-Threat (SWOT) analysis is one of the most commonly used techniques for organizing the information collected from the business environment in relation to the strategic capability of the organization (Ennew *et al.*, 1998). Table 8-1 illustrates the opportunities and threats (business environment), and strengths and

weaknesses (strategic capability) for the TREMOR Foundation. The purpose of the SWOT is to identify the strengths, weaknesses, opportunities and threats and then use them to yield findings that can contribute to formulation of a strategy (Johnson & Scholes, 1999). Opportunities should be well-matched with strengths, while threats should be converted into opportunities and weaknesses into strengths.

Table 8-1 TREMOR Foundation SWOT Analysis (Adapted from Ennew *et al.*, 1998)

Threats	Opportunities	Strengths	Weaknesses
1. Competition from other NGOs 2. Introduction of alternative technologies 3. Delays in client payments 4. Political control of product services 5. Complex legal environment	1. Need for reduction of earthquake damage 2. Applicability of products and services to other disasters types 3. No other organizations providing the Early Warning Prototype 4. Gap in satellite coverage 5. Gap in training for base response technology	1. Global coverage of earthquakes 2. Innovative technology solution 3. Low cost services 4. Commercialization of specific products through spin-off company 5. Offering standardized approach	1. New technology that has not been validated yet. 2. No previous experience 3. Needs time to build trust with the customers
Conversion →	↔ Matching ↔		← Conversion

8.3 Strategy

Although it will operate as a humanitarian, non-profit NGO, the TREMOR Foundation must nevertheless build and sustain a competitive strategy to survive as an entity in the presence of other NGOs providing related services. According to Porter (1985) there are two basic strategies: low-price and differentiation. The Foundation will implement the low price strategy. As described in Chapter 6 and 7, the entity will follow the cost-driven system by using standardized, commercially available low-cost technology, with only two small-scale satellites for the precursor prototype and using existing satellites for the response prototype.

8.4 Costing

Team TREMOR conducted a rough-order-of-magnitude (ROM) cost estimate for the TREMOR Foundation, the details of which are presented in Annex B. This estimate covers the 10-year pilot period and includes the cost of the Earthquake Early Warning Prototype, Simulation and Response Prototype, other products and services, and the overhead cost in running the Foundation. These costs are summarized in Table 8-2. These do not incorporate the costs of the subsidiary, which is treated as a separate entity.

Table 8-2 Annual Costs for TREMOR Foundation during Pilot Period

Year	Annual cost (US$)	Year	Annual cost (USD)
1	9,500,000	6	8,500,000
2	9,900,000	7	8,700,000
3	10,100,000	8	9,000,000
4	10,400,000	9	9,200,000
5	10,800,000	10	9,400,000
		Total	**95,500,000**

To place these numbers in context, the reported global earthquake damage for the period 1997-2006 was USD 272 billion, of which USD 135 billion occurred in the focus countries: USD 2 billion in China; USD 133 billion in Japan; no detailed numbers available for Peru. The World Economic Forum estimates the global cost of earthquakes for the next 10 years to be between USD 50 billion and USD 250 billion (World Economic Forum, 2007) which does not even factor in the indirect economic costs resulting from injury and loss of human life or the high but non-quantifiable costs of social disruption.

Without knowing *a priori* the validation results of the Earthquake Early Warning and Response Prototypes, it is difficult to quantify any reduction in future damage costs that would result from the full implementation of such a system. Assuming an approximate cost of USD 150 billion for the focus countries over the period 2007-2016, if even 1% of the damage costs can be saved from an early warning system (*e.g.* securing/removal of property and goods following a warning) then the estimated cost of the prototype is only 7% of the estimated savings. In this context, the risk associated with investing in this prototype system is acceptably low.

8.5 Pricing

A very important aspect that should be considered for the costing of the prototype systems is the relationship between socio-economic development and the effects of natural disasters. Horwich (2000) points out that the critical underlying factor in any economy's response to a natural disaster is the level of wealth. Albala-Bertrand (1993) suggests that the people most affected by disasters are those who have weaker economic and political bases. Moreover, there is a resource gap between potential losses of natural disasters and the capacity of poor countries to finance reconstruction and recovery (Inter-American Development Bank). For these reasons, the Foundation will apply a different pricing policy for each region/country based on gross domestic product (GDP) per capita.

8.6 Spin Off Subsidiary

The spin-off subsidiary will operate as a private company, 100% owned by the TREMOR Foundation. The entity's strategy and products are presented below.

8.6.1 Spin-Off Strategy

To survive in the market, the spin-off subsidiary must build and sustain a competitive advantage in the presence of other organizations providing related services. Competitive advantage is the plan of action that demonstrates how the entity uses its resources and distinctive competencies to gain an economic lead over its rivals (Hills & Jones 1998; Johnson & Scholes, 1999). The strategies in this level are called generic and aim to satisfy specific groups of customers' needs, which have been selected after market segmentation (Hills & Jones 1998). The approach we used is based on the principle that companies achieve competitive advantage by addressing their customers' needs more effectively than competitors and in ways that their competitors find difficult to imitate (Porter, 1985).

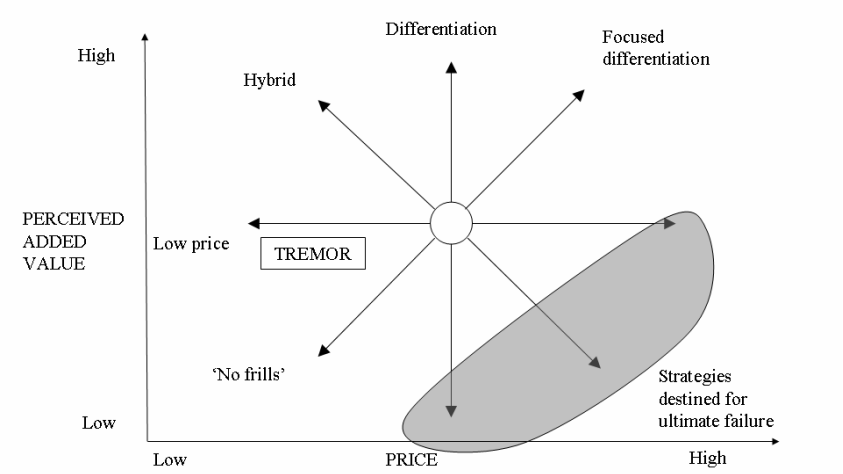


Figure 8-3 The strategy clock: Bowman's competitive strategy options (Johnson & Scholes, 1999)

As shown in Figure 8-3, the entity has the options of "no-frills strategy", low price strategy, hybrid strategy, differentiation strategy, and focused differentiation strategy.[3]

The spin-off subsidiary will implement the same low price strategy as the TREMOR Foundation. The spin-off subsidiary will also invest in innovation, efficiency, and quality superiority to achieve economies of scale and the experience curve effects that help it to sustain and win a price battle if necessary.

8.6.2 Products

During the first years of operation the spin-off will concentrate on two areas/products: a disaster recovery plan and the natural disasters insurance market.

Disaster Recovery Plan

The need for a disaster recovery plan - and in general for business continuity - is increasing in the business community. Even if until now there have not been many laws[4] to oblige companies to implement a disaster recovery plan, a workable plan should be devised to reduce the domino effects in the stock market. According to Fontana & Connor (2001), 85% of large organizations have some form of disaster recovery plan, but only 25% of them have a broader business recovery plan and only 10% to 15% of those are up-to-date.

Some of the main impacts of natural disasters on businesses are in the domains of:

- Human resources (deaths or injuries of employees, customers)
- Physical resources (loss or damage of facilities, other assets)
- Business continuity (impact on the company's ability to perform the business, impact in general on the business environment)

The spin-off entity will provide disaster risk management indicators and detailed disaster risk assessment for earthquakes and other specialized data for disaster recovery plans. Moreover, the spin-off will advise the customers in choosing the disaster recovery centre (*e.g.,* hot site, warm site, cold site). The main customers will be large companies that are dealing with departments such as information technology, logistics management, and financial

[3] The **"no frills" strategy** combines a low price, low perceived value, and a focus on a price-sensitive market

[4] Although the Sarbanes – Oxley Act in the U.S. doesn't specifically require a disaster recovery plan, the loss of financial information might have significant implications to the company (e.g., lack of financial control and in general business control, fraud issues).

institutions. According to Hoffer (2001), of the companies that had a major loss of computerized records, 43% never reopened, 51% closed within two years, and only 6% survived long-term.

Natural Disasters Insurance Market

One of the most important influences on insurance rates is the accumulated number of claims paid compared to the revenues from the premiums. The higher the difference between claims paid and revenues, the higher will be the premiums.

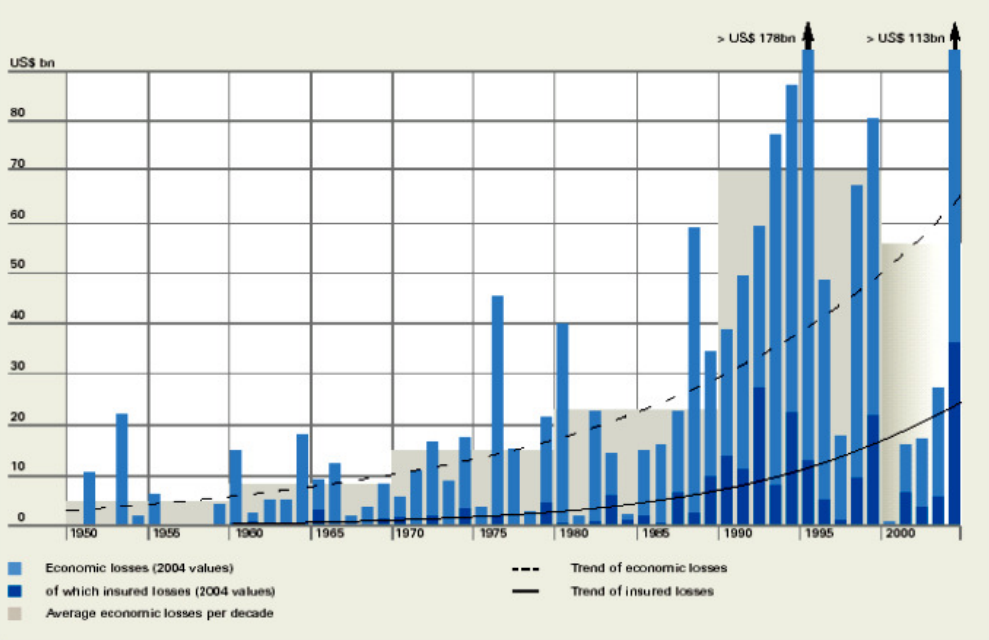


Figure 8-4 Economic Losses due to Natural Catastrophes Worldwide (Munich Re, 2005)

As can be seen in Figure 8-4 there is a significant increase in economic losses and in insurance, especially since 1985. According to the insurance company Swiss Re, preliminary estimates of natural and man-made catastrophes triggered total economic losses of around USD 40 billion[5]. (Swiss Re, 2007). Of the USD 40 billion of losses worldwide, only USD 15 billion were actually covered by insurance. Moreover, the insurance market is under immense pressure to cut its costs; therefore, the spin-off subsidiary using the resources and the know-how of TREMOR will concentrate in providing specialized services for the natural disaster insurance market (*e.g.,* earthquake insurance). This market has significant potential for increase. For example, on 1 June 2007 Swiss Re obtained USD 100 million protection against earthquake risk in Turkey, Greece, Israel, Portugal and Cyprus. It was the first time that an earthquake bond was issued in these countries in order for the earthquake risk to be secured in the capital market.

8.7 Legal and Policy Environment

As an organization with international scope, the structure and operation of the TREMOR Foundation is shaped by laws and policies at both the national and at international levels. These laws and policies have driven the selection of the business model and the way in which the Foundation interacts with its clients. Team TREMOR considered three business models for the TREMOR Foundation: a non-profit NGO, a private for-profit company, and an intergovernmental agency (*e.g.,* under the umbrella of the United Nations). For a number

[5] The most significant catastrophes are earthquakes, cold spells, windstorms and shipping disasters. It is estimated that in 2006, 30,000 people lost their lives in catastrophes.

of important reasons, the non-profit NGO option was ultimately selected. A successful early warning system could potentially save millions of dollars each year through damage reduction and thus be financially self-supporting. During the pilot period, however, the performances of these systems are not yet demonstrated and are less likely to attract private investment. Government support, particularly from the countries most affected by earthquakes, will be essential while the technology is being evaluated. The Foundation can accommodate commercial spin-off opportunities through a for-profit subsidiary, providing additional funding to the Foundation. The top level of the Foundation must remain dedicated to the goal of reducing earthquake fatalities, and, in particular, must address the gap between developed and developing nations.

The NGO option also has advantages over an intergovernmental agency option. As an NGO the TREMOR Foundation is not dependent on a single funding source, but can instead select from a wider range of options. It can be set up without the lengthy and difficult treaty-based process required for an intergovernmental organization. It can more easily obtain commercial licenses for satellite data and, depending on its country of operation, would also benefit from favorable tax laws. Finally, as an NGO, the Foundation can conduct its own international arrangements. For example, the Foundation could seek to have observer status at COPUOS, consultative status at ITU and WMO, and participation in the Committee on Earth Observing Satellites (CEOS) and the Group on Earth Observations (GEO) (ISU, 2005).

8.8 Conclusions

The proposed TREMOR Foundation will be responsible for the creation of both the Earthquake Early Warning and Response Prototype Systems. As a non-profit NGO, the Foundation will be in a position to raise funds from a variety of sources, including the governments of the focus countries and other NGOs involved in earthquake response efforts. The cost to implement the systems is estimated to be on the order of USD 100 million over the 10-year pilot period, which is a small fraction of the expected earthquake damage costs over the same period. The Foundation will also take advantage of spin-off opportunities from the prototype system by creating a for-profit subsidiary. This subsidiary will market these spin-offs commercially and be another potential source of funding for the Foundation.

Chapter 9

Application of Prototype Systems in Focus Countries

For the pilot phase of implementation, the TREMOR Foundation has studied the potential application of the proposed prototype systems in three focus countries: Japan, China, and Peru. These countries were selected because of their vulnerability to earthquakes and because they represent a cross-section of developing, rapidly developing, and developed nations. We have assessed the current abilities of these countries to manage earthquakes, have identified gaps therein, and have worked out how the TREMOR prototypes offer solutions for each of the countries.

9.1 Rationale for Focus Country Selection

Japan, China, and Peru are ideal for studying the impact of the TREMOR systems for several reasons. Earthquakes occur with regularity in each of the three countries, as shown in Figure 9-1.

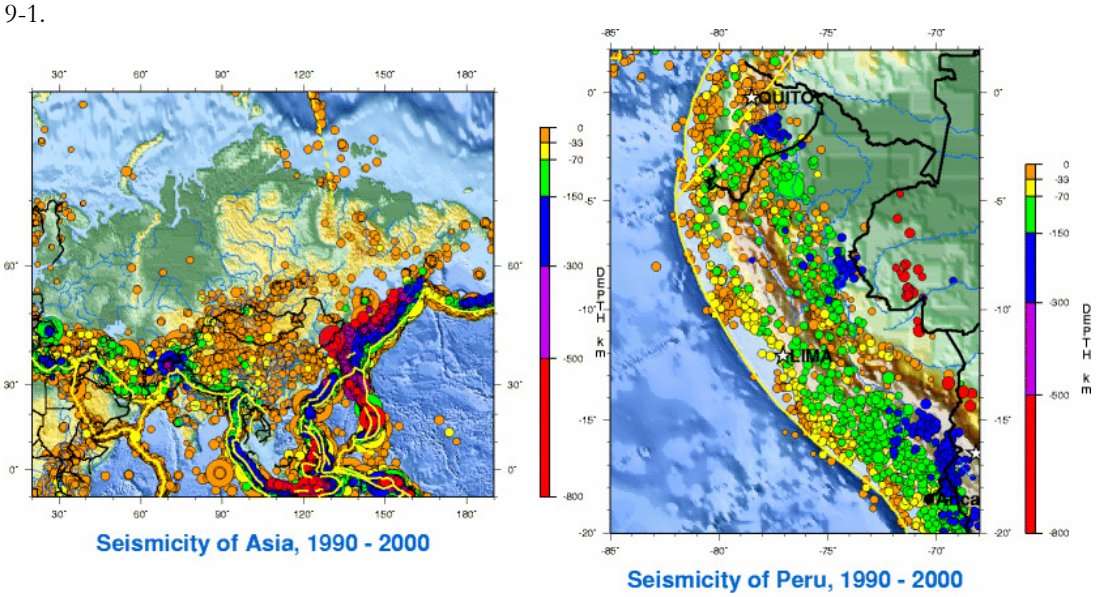


Figure 9-1: Occurrence of Earthquakes in Focus Countries (Source: USGS)

The figure shows the earthquakes that have occurred in these regions over the 10 year period between 1990 and 2000. Each dot indicates an earthquake: the larger the dot the bigger the magnitude.

Japan and Peru are both situated along tectonic plate boundaries, while China is characterized by earthquakes that occur along intraplate faults. Japan, as the most developed country of the three, is important as a focus country because it has a very advanced system for detecting earthquakes and for managing their effects. China is presently experiencing rapid economic growth, which opens up new financial possibilities for augmenting existing

earthquake measures. The consequent social upheaval - and in particular, the rapid urbanization of the country - has increased the vulnerability of its population to earthquakes. Peru was selected because of its status as a developing country, which presents additional challenges for earthquake response. Its geographic separation from China and Japan also allows the global applicability of our systems to be demonstrated.

9.2 China

9.2.1 Disaster Management in China

To reduce the severity of earthquake disasters in an effective manner, the State Council of the People's Republic of China founded The China Earthquake Administration (CEA). The CEA has put forward a policy for preparedness and reduction of earthquake damage in China. The Department of Earthquake Disaster Emergency Management, which belongs to the CEA, is engaged in the earthquake information service and disaster emergency response. The China Earthquake Disaster Prevention Center is under the authority of the China Earthquake Administration. It is responsible for implementing the China Earthquake Administration's education duties by providing training and seismic safety evaluation for engineers, as well as continuing education and technical guidance for engineering work (CEA, 2007). Governments at various levels should pay great attention to popularizing the knowledge of preparedness and reduction of earthquake disaster.

Under leadership from the CEA, China has established a national digital seismic network and a crustal movement observation network, and has upgraded the seismic precursor observation network. Seismic intensity zoning, and earthquake-resistant design and construction of dwellings, buildings, and other projects have increased. Some provisional earthquake monitoring stations and networks monitor seismic activities. When an earthquake occurs, the government builds temporary shelters and victims receive food and medicine. At the same time, the communications infrastructure is reinstated at the earliest possible moment and injured persons are moved to hospitals.

9.2.2 Case Study

On June 3, 2007, a magnitude 6.4 earthquake occurred in Ning'er County, in the southern part of China's Yunan province, killing three persons and injuring 346. More than 90,000 homes collapsed, more than 270,000 were damaged, and some 180,000 persons had to be evacuated. In all, more than 1 million people were affected by the disaster.

Because of the lack of an effective warning system, the people were not prepared for the earthquake. After the earthquake, the Chinese government tasked a special group to manage the response. The group set up a seismic monitoring system to observe possible aftershocks. A disaster investigation and damage assessment work were also begun, with the local governments forming teams to check the county houses, public infrastructure and facilities. Nevertheless, more effective countermeasures are needed for immediate response to earthquakes, and to alleviate the resulting conditions.

9.2.3 Application of Prototype Systems to China within the Context of Existing Systems

Technology and Data

China has specific legislation related to earthquake prediction, such as the Stipulation for Issuing Earthquake Prediction. (He, 1999). Accordingly, significant attention has been given to research in precursor studies in China. Earthquake precursors are routinely monitored in China including: crustal deformation, groundwater changes, geomagnetism, geoelectricity,

and animal behavior (He, 1999). Objectives of precursor research in China are as follows (Chen, 2001):

- Improving the study of commonly used earthquake analysis and prediction methods
- Searching out new short-term and imminent prediction indicators. Study of application of high technology observation data (e.g., GPS and digital seismic observation)
- Study of earthquake preparation process (e.g., by numerical simulation of precursor data)

Despite these research activities described here, precursors have, nonetheless, been identified as one of the areas of earthquake research in need of advancement in China. (Chen, 2001)

The early warning prototype proposed by the TREMOR Foundation would address the areas needing improvement. The TREMOR Foundation's early warning system could use the data from China's endeavors in earthquake precursor investigation. China's existing ground based measurements, when combined with TREMOR's database of space-based precursor information, would potentially increase the fidelity of TREMOR's early warning system with regard to China. Chinese earthquake researchers will be involved throughout the process in performing ground-based science for validation of the prototype.

China also operates an extensive network of seismometers. The country has constructed the "National Digital Seismic Network" (NDSN). The NDSN includes both the "National Digital Seismic Standard Network", which consists of 75 stations, and 20 regional digital telemetry centers consisting of 353 substations. The NDSN also includes 80 sets of mobile digital seismic sensors and 240 sets of strong earthquake observation instruments. Prior to construction of this system, an analog seismometer network existed. It comprised 742 stations in total, including 388 on-duty stations and 25 regional telemetry seismic networks with 353 substations (He, 1999; Zhu, 2002; Chen, 2002). China also operates the Crustal Movement Observation Network, which consists of 25 GPS continuous observation stations, complemented by 56 regular observation stations and a regional network with 1000 irregular stations (He, 1999; Zhu, 2002; Chen, 2002). Data from these networks are distributed over the Seismic Communication Trunk Network, and the National Seismic Communication Network. Data are processed using the China Seismic Computer Network (He, 1999; Zhu, 2002; Chen, 2002). Data processing and analysis is handled by agencies of the China Earthquake Administration. China is also soon to launch a constellation of environmental monitoring satellites. A number of these satellites will carry SAR payloads. Data from this constellation will contribute to existing data on earthquake related phenomena.

Planning

The TREMOR Foundation's historical database can use data from the above-mentioned networks. This will improve both the simulation system and the prototype early warning system. The need both to plan for earthquakes in terms of building codes and standards, and to quickly assess damage after an event has been noted in China. The importance of earthquake forecasts in urban areas, for planning purposes, has also been noted (He, 1999). To this end GIS has been increasingly employed in China as a tool for disaster management. Several cities in China have operational GIS for disaster management, which include specific functions for response to seismic events (Tang *et. al*, 2002).

TREMOR earthquake simulations can be applied to address these needs and to advance the existing technologies. The current use of GIS for earthquake disaster management in China ensures the availability of data sets necessary for TREMOR simulations as well as the existence of the institutional and technological frameworks in China that can use the simulation results. TREMOR simulation systems could easily interface with existing GIS in China. Results of simulations would potentially help China to pre-plan emergency response in cities, as well as to update building codes. These measures are expected to improve

China's disaster management capabilities significantly (He, 1999). Chinese authorities are very much interested in pre-planning disaster response activities. The TREMOR simulation system can be immensely helpful in supporting this activity.

In the context of earthquake disaster planning in China, the importance of educating the public about earthquake preparedness and mitigation activities has been identified. Several key areas of earthquake education have been recognized by Chinese policy makers (He, 1999). The training component of the TREMOR response prototype will contribute to earthquake education efforts in China by ensuring that the right personnel in the China Earthquake Administration and its subsidiary organizations are trained in the use of the TREMOR system. TREMOR will also provide supplemental information concerning recommended actions during earthquake watches and warnings. If the early warning system is implemented in China, authorities will have to educate the public on these recommendations as they apply to China specifically.

Response

In the response phase there is a need to strengthen capabilities and procedures in emergency command and search and rescue regarding earthquakes. This calls for necessary improvements in technical capabilities for on-site response. To this end, China has developed the National Disaster Reduction Center which has as its objective "to assess and analyze the occurrence and development of major disasters, and provide services on forecast, assessment and supporting disaster reduction decisions and information; to collect and analyze disaster reduction information both at home and abroad for information sharing; to provide technical assistance and supporting decisions for major emergency relief work; to organize international disaster reduction exchanges and cooperation." (Government of China, Date Unknown). The TREMOR Foundation's prototype response system could potentially be integrated into this framework. The TREMOR response system, if deployed to an earthquake site in China, would link to the National Disaster Reduction Center. This link between the TREMOR system and the Disaster Reduction Center would facilitate the coordination functions of the Center by providing connectivity to the on-site responders.

Policy and Law

China's policy and legal framework for disaster management, mitigation and response is well defined (Chen, 2001). Since 1998 the National Natural Disaster Reduction Plan of the People's Republic of China for 1998 -2010 has been in place. This plan has been reviewed and updated at regular intervals. Laws and policies specific to earthquakes have also been implemented. These include the Emergency Response Act of Destructive Earthquakes and the Law of Preparedness and Reduction of Earthquake Disasters of People's Republic of China. Chinese policy and law regarding earthquake disaster management focuses on four main aspects: (1) earthquake monitoring and prediction; (2) prevention of earthquake disaster; (3) emergency response; (4) rescue of the victims and reconstruction of earthquake-stricken regions (He, 1999). China's policy makers have noted that certain gaps in the policy frameworks are the result of a lack in technological ability (Government of China, Unknown). The TREMOR Foundation's prototype system can address this shortcoming through interactions with existing Chinese systems as described in the preceding sections.

9.3 Japan

9.3.1 Disaster Management in Japan

The Cabinet Office is responsible for securing cooperation and collaboration among related government organizations. The Director-General for Disaster Management is mandated to undertake the planning of basic disaster policies and to respond to large-scale disasters. Japan's disaster management system addresses all of the disaster phases: prevention, mitigation and preparedness, emergency response, recovery and rehabilitation. The National

Research Institute for Earth Science and Disaster Prevention (NIED) is responsible for the organization of Japan's seismological systems and for the development of recommendations for improvements in disaster prevention. The relevant stakeholders of the public and civil organizations co-operate in implementing various disaster countermeasures.

9.3.2 Case Study

Japan is one of the most seismically active regions in the world and accounts for more than 20% of the world's earthquakes (magnitude 6 or greater), as well as producing some of the most severe events. At 5:46 AM on January 17, 1995, the Hanshin-Awaji earthquake struck near Kobe with a magnitude of 7.3 on the Richter Scale. This event killed more than 6400 people and caused more than USD 130 billion in damage. Kobe residents were lucky that this event occurred just before the start of the major rush hour. Not nearly as many people were killed as could have been had the earthquake occurred an hour later during the peak rush hour with more crowded freeways. Even so, a more than 1 Km long section of the elevated free-way toppled over from the force of the earthquake.

After this disaster, the government restructured the Basic Disaster Management Plan to include the development of new special countermeasures for earthquakes, enhancement of building codes including retrofit of existing structures, and the establishment of a Disaster Reduction and Volunteer Day. Taking into account the lessons learned from the 1995 Kobe earthquake, many seismological organizations were established and the scientific field of seismological measurement was significantly strengthened. The NIED was established to coordinate these activities. These are discussed in more detail in the following section.

9.3.3 Application of Prototype Systems to Japan within the Context of Existing Systems

Technology and Data

As a well-developed, modern society, Japan has significant technology resources in ground and satellite systems, sufficient to provide data for all phases of the disaster management cycle. Ground systems include a variety of seismic sensor nets; Range Seismograph Network of Japan (F-Net); high sensitivity meters (Hi-Net) and broad-band meters (K-Net); strong motion meters (triaxial accelerometers); ground-water change (levels and chemical properties) measurements; geomagnetic condition monitoring; ground displacement measurements (GPS and strain-meters); and atmospheric and ionospheric measurements. Satellite-based systems for Japan include ground motion, strain and angle, and thermal infrared emissions.

Data from the F-Net, Hi-Net and K-Net can be obtained automatically and are available within about 2 minutes. These systems help researchers to better understand earthquake behavior, with the end goal of being able to forecast earthquakes. Satellite data contribute to the understanding of the mechanisms of earthquakes and help research into earthquake precursors. Atmospheric and ionospheric data can be obtained through the National Agencies for both ground and satellite data.

Japan has a broad-based technology and data infrastructure for monitoring the many types of precursor signals. One of the signature systems to be implemented in October, 2007 is an "urgent earthquake bulletin" early warning system. The plan is for the Japanese Earthquake Early Warning (EEW) information system to have the capability to provide up to one minute of warning prior to an earthquake (Government of Japan, 2007). However, the EEW relies on seismic signatures as potential precursor signals in order to predict epicenter, magnitude, and the time of occurrence. This limits the capability of the system to provide advanced warning of only a minute or two. The integration of data from other precursor signals would significantly improve the existing EEW system by increasing the warning time before the event, thereby allowing the population more time to prepare. Additional data sets required

for earthquake planning purposes have not been developed consistently throughout all levels of the government and society, though there is a good coordinated effort to identify what data are needed and who should be developing them.

In the response phase, a system for damage assessment via satellite imagery is in place, as is a disaster information sharing platform which provides "a common information system with a standardized information format" (Government of Japan, 2007). Governments, responding organizations, and residents are free to access this system. A specific, automatically activated Earthquake Disaster Information System provides an estimation of "the approximate distribution of seismic intensity and scale of damage (human suffering and building damage) within 30 minutes" of a given earthquake (Government of Japan, 2007).

Planning

In Japan, the education of the various levels in the disaster management cycle is fractured. Most local government emergency management personnel do not receive systematic training, and are normally trained on-the-job (Fukasawa, 2003); however, while formal training is not provided, Fuji Tokoha University, a relatively new campus in Shizuoka Prefecture, established a course of disaster management training within its Environment and Disaster Prevention Faculty in the year 2003. As of 2003, that was the only professional level program in the country. On the other hand, front line responders, primarily fire, search and rescue, and medical personnel, are all trained and certified through their professional certification agencies. In addition to individual skills assessment and certification, Japan conducts full-scale simulated drills to prepare coordinated emergency response teams for an actual disaster. The general population also has well developed programs. Primary and secondary schools have specific curricula in order to teach disaster knowledge from childhood. Social education includes many different activities in order to educate and prepare the local communities. These include town-watching, hazard-mapping, community based volunteer disaster reduction organizations, community volunteer firefighting teams, Disaster Reduction and Volunteer Day (January 17 each year) and Week (January 15-21st each year), the Yearly Disaster Reduction and Volunteer Forum, Community Disaster Reduction Fairs, and community-based drills to provide basic emergency response skills and training for how to plan for and respond to a disaster

The national disaster management plan requires the development of seismic risk and zoning maps including soil types and building structural information. This information is used to introduce building retro-fit codes and seismic building codes in order to reduce the death toll and economic losses estimated in future earthquakes. Specific products required to be developed are The Map of Weak Subsurface Layers Nationwide, and methods for developing community-specific Earthquake Disaster Hazard Maps. The latter have been developed but have not been widely distributed and much work remains to be done in order to develop these maps. Also required is a database of local resources and response and contingency plans. The response plans develop designated emergency response teams for the management of disasters which are organized according to the severity and scale of the disaster. The response plans mobilize the National Police Agency, Fire and Disaster Management Agency, Japan Coast Guard, Self-Defense Forces, and a wide-area medical transportation system for dispatching disaster medical assistance teams and ambulance parties.

Based on the country's seismic history, Japanese authorities expect, with a high degree of certainty, large magnitude earthquakes to occur in three specific regions: Tokai, Tonankai and Nakai. It is predicted that up to 9,200 people might be killed in a Tokai Earthquake and up to 18,000 in Tonankai and Nakai Earthquakes (Government of Japan, 2007). Given this scenario, Japanese authorities are greatly interested in taking actions to reduce the potential impacts of these events. Specific "Countermeasure Plans" have been drafted for each of these potential earthquakes (Government of Japan, 2007).

Response
Japan already has a well developed infrastructure and system for responding to earthquakes, a large portion of which was developed after the 1995 Kobe event. Major communications systems include the Central Disaster Management Radio network, the Fire Disaster Management Radio Network (which serves to connect countrywide firefighting organizations), and the local and municipal disaster management radio communications networks, which exist countrywide to connect local disaster management organizations and residents. Japan has also developed a satellite communications system as backup to the terrestrial radio networks.

Japan has a full range of professionally trained responders and has the capability to quickly mobilize the Self-Defense forces and Coast-Guard in the event of extreme events. Community Volunteers are also organized and trained with some limited skill sets for immediate response while waiting for professionally trained personnel to arrive, as well as to assist as needed throughout the disaster management cycle. Japan has a full range of equipment needed for response to most disaster events including the capability to quickly mobilize additional assets from other parts of the country as needed. This includes the establishment of emergency management bases in key parts of the country in order to be ready for the implementation of disaster management plans close to the affected areas. Japan has planned to develop the capability to track resources during the response phase in order to ensure effective and efficient use of available resources and to aid in the determination of what additional resources may be required throughout the disaster management cycle.

Policy and Law
Disaster management in Japan is a fluid process based on the principles outlined in the Disaster Countermeasure Basic Act of 1964. As new disasters occur in Japan, these basic laws are re-evaluated and new laws or existing laws are added or modified respectively to address new understandings in the disaster management process. On the other hand, there are more than 200 separate pieces of legislation pertaining to hazard and disaster management, enacted to address specific problems (Britton 2004). This means that specific legislative requirements often conflict with other legal needs resulting in little being done because of bureaucratic concerns that solving an emerging problem will only cause new problems for the existing systems. While Japan's exposure to a number of natural disaster risks is among the most serious in the world, this has not resulted in an 'all-hazards approach' to disaster management and loss mitigation. Bureaucratic tangles aside, Japan remains committed to proper disaster management. About 5% of the GNP is dedicated to disaster management for science and technology research, disaster prevention and preparedness, national land conservation, and disaster recovery and rehabilitation. This is up from 1962 when the approximate spending on disasters was less than 0.5% of the GNP. This changes year by year depending on the need, as in the year 1995 when the spending rose to about 11.5% of the GNP because of the Kobe earthquake.

Participation and Coordination of NGOs
Japan actively participates at the world level in the Disaster Reduction and International Strategy for Disaster Reduction. It develops and participates in international cooperative projects such as the Asian Disaster Reduction Center and has already integrated large NGOs such as the Red Cross into its disaster management planning system.

9.4 Peru

9.4.1 Disaster Management in Peru

As described previously, Peru established the National Plan for Civil Defense via the National System of Civil Defense (SINADECI) which is implemented and managed by the National Institute of Civil Defense (INDECI). The INDECI is charged to protect the

population, prevent damages, provide opportune and adequate help, and to ensure rehabilitation in case of disaster or calamities of all types, whatever their origin. The Geological Institute of Peru (Instituto Geofísico del Perú – IGP) is charged as the legal organization responsible, at the national level, for the service and investigation of the seismic activity of the country. These two organizations are the main organizations across the four phases of disaster management. All country assets as previously described belong to these organizations.

9.4.2 Case Study

One of the most dangerous geological faults in Peru is the Tacna-Arequipa fault line. It is approximately 600 km in length, and is located along the edge of the Nazca-South American plates. Geological history has determined that this fault line has significant events about every 100 years. In 1868, this fault had an earthquake with an estimated energy release of more than 9.3 Megawatts (Mw) in which there was a displacement along the entire fault line with vertical displacements of more than 1 meter in some parts. More recently, on June 23 2001, an earthquake occurred along this fault-line in which only about 200 km of the fault experienced displacement but still resulted in an energy release of magnitude 8.4 Mw in the second largest city of Peru, Arequipa, which has a population of about one million. An estimated 150 people were reported missing or dead, more than 60,000 homes were destroyed or damaged, and more than 220,000 individuals were homeless throughout the region.

The country was little prepared for such large scale devastation in 2001, and because of that event, the Peruvian National Plan for Civil Defense was restructured in 2004. The updated plan included specific recommendations for the pitfalls that were discovered. Some of those recommendations have been implemented, but many of them are yet to be realized. Some of the shortcomings identified included a lack of coordination, participation, of continuity at all levels of the management chain, of trained personnel (management, front line responders, and the local community), and of an integrated emergency communication system. These are discussed in more detail in the following section.

9.4.3 Application of Prototype Systems to Peru within the Context of Existing Systems

Technology and Data

Technology assets, both national and through international collaborations only provide information that can be used for the precursor prototype system. Information required for the response phase, which relies primarily on satellite based technology, would have to be coordinated with the International Charter on Space and Major Disaster as well as with the UN SPIDER system which is expected to be operational in the next several years.

Current Peruvian technology assets that can be used for the precursor system include systems for seismic monitoring (Radiotelemetric and Wide Band seismic sensor nets, and Triaxial Seismometers - though only two of the latter exist in the whole country), tectonic plate displacement (Strain-meters, GPS sensor net, Laser Satellite Tracking system), ionosphere (Jicamarca Radio Observatory), and meteorological data (via the NCDC of NOAA and SENAMHI of Peru). What is missing for the application of the precursor system is primarily data from the more modern space-based technologies that are expensive and difficult to access by developing nations.

Data sets are required in order to make the precursor system function properly. Data sets from existing technologies for Peru are actually quite extensive with more than 60 years of data compiled for many of the data sets, though limited in geographical area sampled. In addition to the newer space-based data sets required, additional ground assets are needed to be installed in order to provide wide area coverage.

Planning

The pre-disaster planning phase is one of the most important to ensure that responders and the community are prepared for eventual disaster events. The National Plan for the Prevention and Response to Disasters for Peru establishes specific requirements for education and outreach in all phases of disaster management, including the development of professional management (those who manage the disaster at both the national and local governmental levels as well as within UN and other NGOs based in Peru), front line responder resources (*e.g.*, search and rescue, fire-fighters, medical personnel); and, finally, within the general population to ensure that it is properly informed on how to plan for and respond to disasters at home and in the community at large.

INDECI has several agreements with Peruvian universities to provide certificate training and/or masters level diplomas in disaster management. Certificates could be for specific skills such as vulnerability and risk analysis or damage assessment, while the masters programs typically prepare professionals for disaster management careers. Most of these programs are fairly expensive by Peruvian economic standards and generally none of them have the highly trained and qualified personnel to provide this type of training. Technical level training for first line responders can only be obtained as part of the Volunteer Fire Fighters of Peru (an organization that requires its volunteer staff to be university trained prior to acceptance and which are only located in major metropolitan areas because of economic limitations); as part of the National Police (which only provides search and rescue training to its core of personnel); or through an NGO such as Fire Fighters United without Borders (which is expensive and beyond the means of the common resident). Unfortunately, this leaves the majority of residents without appropriately trained responders in the case of a disaster.

In 2006, Peru implemented an educational program as a pilot project in the primary and secondary school levels in which pamphlets and classroom training are given as part of the curriculum in order to teach the students how to plan for and respond to a disaster. However, this program addresses only 6 communities within the major metropolitan areas, leaving the bulk of provinces unattended and uninformed. One of the strengths listed in the plan is the current system of printing and distribution of information to the general public on how to act in the event of disasters; however, it is acknowledged that this is not consistently applied throughout the country or at all levels of society. Web-based information provided on the INDECI website is difficult to locate, is not widely distributed, and is not accessible in most of the provinces among the many Andean communities that have little education and high illiteracy.

Another important aspect in planning is the development of specific information sets in order to assess and improve the general community infrastructure, and provide the needed information for the post-disaster response phase. This includes seismic risk and zoning maps (including soil types and building structural information), a database of local resources (emergency response, medical, fire-fighting, etc.), and response and contingency plans. All of these components are clearly identified within the requirements of the national plan for Peru, but the scarcity of highly trained disaster management personnel in Peru is one of the weakest links of the plan. Without this, the validity of the information developed is likely to be insufficient for disaster planning and response. Further, these data sets are not consistently developed throughout the risk zones.

Response

The response phase is the least prepared portion of the disaster management cycle in Peru. The harsh economic reality of a developing nation leaves Peru without critical resources and infrastructure required for response to the many types of disasters subjected to this country. The plan specifically states that there is no integrated system of communications at the national level that guarantees efficient communications before, during, and after an

emergency generated by a disaster. Strong communication lines are critical to the effective management of and response to a disaster needed by the managerial staff, emergency staff and community volunteers. There is also a lack of basic equipment in Peru for disaster response as well as a lack of capability to track resources (personnel and equipment) during the response phase.

Policy and Law

The national policy and law of Peru is the strongest of the components of disaster management in the country. It is well developed at a conceptual level, though not as complete as the system employed in Japan. Peru works hard to engage in international collaborations through bilateral agreements and treaties, though there are a few weaknesses in the national policy and law. The first deals with the coordination and importation of resources in response to a disaster. While the treaties and mechanisms exist to allow tax-free importation of goods and equipment required for the response, Peru has a cumbersome bureaucratic customs agency. Even with all of the right documentation and proper signatures for tax-free importation, it can still take days to weeks to get emergency supplies and equipment through the customs process. The other weakness in the implementation of the public policy and national plan really lies in the lack of interest at all governmental levels (as stated by the national plan) coupled with a lack of economic resources.

Participation and Coordination of NGOs

One of the most important components to effective disaster response in Peru is the participation of NGOs; however, as stated in the national plan, this can also become problematic because some NGOs refuse to coordinate with INDECI, which is the legal entity in Peru charged with disaster management. This leads to delays in aid and response as well as mismanagement of disasters when the single authoritative agency is ignored or marginalized.

In summary, while Peru has a well thought-out and promising National Plan for Civil Defense and disaster management (very similar in scope and breadth to Japan), it generally lacks the properly trained personnel as well as the hard and economic resources required for effective disaster management. The TREMOR system has the potential to fill in many of the gaps required to turn a good plan into a good planning and response system.

9.5 Conclusions

The early warning and response prototypes proposed by Team TREMOR offer tangible benefits to the three focus countries selected. Earthquake researchers in each country will have the opportunity to participate in the early warning prototype development, and the level of understanding of precursor science in each case is expected to rise as a result. The response prototype will provide better coordination between earthquake response teams in China and Peru, where there are presently multiple organizations with overlapping responsibilities. Even Japan, which already has an extremely sophisticated system for the study of and response to earthquakes can benefit from the more detailed evaluation of precursors. The advanced techniques developed in Japan can be incorporated into the design of both prototypes, thus benefiting the other focus countries as well.

Chapter 10
Conclusions

In 1868, the entire 600 km-long western fault along the Peruvian Coast slipped in what was the largest earthquake in the last several hundred years in South America. The estimated 8.1 magnitude earthquake left tens of thousands of people dead and hundreds of thousands of people homeless. Geological history has shown that this fault has major slips every 100-150 years. On June 23rd, 2001, 200 km of the central part of this fault slipped, hitting the same areas with an earthquake of magnitude 7.9 and affecting more than 220,000 people. On August 15th, 2007, during the final preparation of this report, the northern part of this fault once again slipped, producing an earthquake with a magnitude of 7.9. As of the time of writing, hundreds of deaths have been confirmed and thousands of people have been left homeless (La Republica, 2007). Sometime in the next few years, the southern portion will also slip, causing equal or greater damage. What difference would an early warning system have made for the residents of southern Peru on the 15th of August? What difference would a more effective response system now be making as the recovery efforts proceed?

In this report, Team TREMOR has reviewed the present and future use of space- and ground-based systems to monitor and respond to earthquakes. We have identified gaps in the scientific, technological, legal, policy, and educational aspects of these systems. Based on the gap analysis, we have proposed an Earthquake Early Warning Prototype System. Realizing that early warning is important but not sufficient for reducing the impact of earthquakes, we have also developed an Earthquake Simulation and Response Prototype System as a complement to the Early Warning Prototype System.

Findings:

Potential earthquake precursors are measured separately from each other and are not measured with sufficient temporal and spatial resolution in the areas most susceptible to earthquakes.

As a result, the available data on possible precursors is presently scarce and far from conclusive. Ongoing satellite missions such as DEMETER are providing additional data on earthquake-related phenomena, but with coverage and revisit times not yet adequate for proper validation of forecasting models. As an understanding of these precursor phenomena is critical for effective early warning, this is a significant gap.

There is lack of coordination among the many organizations and agencies responding to earthquakes.

Communication among actors at a disaster scene is a significant problem as communication systems of different organizations may not be interoperable. Policy and institutional barriers also often limit coordination of activities among different organizations. Enhancing the coordination of on-the-scene responders would significantly improve disaster response.

There is a lack of effective international sharing of earthquake-related data, especially for developing nations and those without satellite resources.

This problem is particularly acute in the disaster planning and mitigation phases. An effective policy and business framework to facilitate data exchange would improve global earthquake management.

Proposals:

We have proposed an Earthquake Early Warning Prototype System.

This system is based upon a rigorous analysis of two particular types of precursor data from new and existing sources, in combination with an historical database. The prototype provides a systematic approach to the analysis of earthquake precursors, integrating information on many precursors into a warning signal that provides estimated time, location and magnitude of forecast earthquakes. This warning is transmitted to specified national authorities responsible for earthquake disaster management and relevant NGOs. Although the science of earthquake forecasting is still immature, the system accuracy will improve over time through the collection of additional data, scientific study producing new earthquake models, and through feedback on its accuracy.

We have also proposed an Earthquake Simulation and Response Prototype System.

This system will assist the various existing relief agencies and organizations in executing a rapid and coordinated response following an earthquake by providing information, from satellites and ground-based sources, mobile satellite-based communication hubs, and GNSS-based tracking of resources. Prior to any disaster event, the TREMOR Foundation will provide education and training for response crews in the use of these technologies. The proposed simulation capability included with the response Prototype will merge data from both the Earthquake Early Warning Prototype System and from GIS to better estimate the location and distribution of earthquake damage, and to help relief organizations to focus their efforts accordingly.

We have proposed implementation strategies for these systems.

To implement these prototypes we have proposed the creation of the TREMOR Foundation as a NGO. Its operations will facilitate the exchange of necessary data to develop and operate both of the proposed systems. The TREMOR Foundation will work with clients from all countries to implement the system in the most effective way possible, given local conditions and frameworks. The implementation strategy allows for possible spin-off commercialization through a for-profit subsidiary.

Future Directions:

The development of an international policy framework for pre-event data sharing should be studied.

International treaties, where they exist, are focused on the response phase of disaster management; providing data and services after a disaster event. As the TREMOR Earthquake Early Warning Prototype System validates the use of earthquake precursor data for pre-earthquake preparation, new multilateral agreements may be necessary to facilitate the effective international sharing of these types of data.

The possibility of applying the two TREMOR systems to assist with the forecasting of and response to other disasters should be studied.

The Earthquake Early Warning Prototype System may be applicable for monitoring several other types of natural disasters, with reasonably minor changes, mainly in software components. For instance, because weather monitoring will be incorporated as part of the precursor system, extreme weather conditions could be observed and appropriate warnings issued through the same organizations. Many of the same seismic and thermal precursors appear for volcanic eruptions as for earthquakes. These can be easily monitored using the Earth-observation data collected by the TREMOR Foundation, and can be similarly used to generate a forecast and to provide a warning. The Earthquake Simulation and Response Prototype System could also be adapted to incorporate new models for other disaster types into the simulation, and to adapt the currently proposed earthquake response for other uses.

One of the most important aspects of the proposed TREMOR Foundation is that it will function as an international, intercultural and interdisciplinary organization. It is our belief that this approach offers the best opportunity to use global data, technology, and human resources to help solve this global problem. Ultimately, the intent of any earthquake monitoring or response system is to minimize the loss of life, injury, and damage to property that these disasters cause. It is our firm opinion that the solutions proposed in this report will contribute in a significant way towards this goal.

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Annex A

Educational Services

The following list of organizations provides some educational services relating to earthquake disaster management for further information.

- **Earthquake Education Center**

http://www.csuniv.edu/Academics/Quake/quake.html

- **Center for Earthquake Research and Information (US)**

http://www.ceri.memphis.edu

- **International Strategy for Disaster**

http://www.unisdr.org/eng/about_isdr/isdr-mission-objectives-eng.htm

- **Southern California Earthquake Center –SCEC**

http://www.scec.org/education

- **Center for Earthquake Education and Technology Transfer**

http://quake.ualr.edu

- **Education and resources**

http://www.greentreks.org/education/resources_educationanddiscovery.asp

- **EarthScope**

http://www.earthscope.org

- **Earthquake Education Services (US)**

Working To Promote Literacy in Earthquake Science and Earth Science

- **Seismological Society of China**

http://www.ssoc.org.cn/ssc_en/index.html

- **China Earthquake Data Center (China)**

http://www.smsd-iem.net

- **Institute of Earthquake Science China Earthquake Administration (China)**

http://www.seis.ac.cn/BalanceOA/nets

- **The Institute of Crustal Dynamics (China)**

http://www.eq-icd.cn

- **Institute of Geophysics, China Earthquake Administration (China)**

http://www.cea-igp.ac.cn/English.files/index.htm

- **The 921 Earthquake Museum of Taiwan (China)**

http://www.921emt.edu.tw
http://www.taiwanfun.com/south/chianan/articles/0306/0306Diversions.htm

- **Earthquake Research Institute, University of Tokyo (Japan)**

http://www.eri.u-tokyo.ac.jp/index.html

- **Seismological Society of Japan**

http://wwwsoc.nii.ac.jp/ssj/introduction.html

- **The Headquarters for Earthquake Research Promotion(Japan)**

http://www.jishin.go.jp/main/index-e.html

- **The coordinating committee for earthquake prediction(Japan)**

http://cais.gsi.go.jp/YOCHIREN/ENGLISH/ccephome.e.html

- **Earthquake Information Center(Japan)**

http://wwweic.eri.u-tokyo.ac.jp/index-e.html

- **Active Fault Research Center (Japan)**

http://unit.aist.go.jp/actfault/english/activef.html

Detailed Cost Estimate

MAIN

Total labour rate (NA)	$ 100	/person-hour	Assumption; includes overhead costs
Total labour rate (China)	$ 40	/person-hour	Assumption; includes overhead costs
Total labour rate (Japan)	$ 150	/person-hour	Assumption; includes overhead costs
Total labour rate (Peru)	$ 40	/person-hour	Assumption; includes overhead costs
Working weeks per year	41		
Working hours per week	40		
Working hours per year	1640		
Annual rate of increase	3%		Assumed for North America / Europe
Pre-launch period	5	yr	
Satellite mission life	5	yr	
Total prototype period	10	yr	

LEGEND
Inputs
Constants
Outputs

EARLY WARNING SATELLITES

Number of satellites	2		
Spacecraft mass	125	kg	
ROM per spacecraft cost	$ 10,550,000		Includes payload, bus, and software
Total spacecraft cost	**$ 21,100,000**		
Launch cost per unit mass	$ 15,000	/kg	
Total launch cost	**$ 3,750,000**		Assumes satellites launched on same LV
Number of ground stations (GS)	2		
Purchase cost of each GS	$ 100,000		Amateur-radio-type ground stations (Source 1)
Total purchase cost of all GS	$ 200,000		
Operations staff per satellite per GS	3		
Total GS operations staff	12		
Mission lifetime	5	yr	
GS labor cost	$ 9,840,000		Assumes NA labour rate
GS maintenance cost	$ 100,000		10% of purchase cost per year (Source 1)
Total ground operations cost	**$ 10,140,000**		
TOTAL SPACECRAFT SYSTEM COST	**$ 35,000,000**		

ROM satellite costing based on average of following experimental satellite missions (Source 1)

Satellite	Cost per unit mass ($K/kg)
RADCAL	54
PoSAT-1	24
AMSAT AO-13	12
Freja	89
Orsted	243
Average	84.4

Source 1 Wertz & Larson, Space Mission Analysis and Design, 3rd Ed, Microcosm, 1999
Source 2 Tuli, Orr, & Zee, Low Cost Ground Station Design for Nanosatellite Missions, AMSAT, 2006

RESEARCH GRANTS

Pre-launch research period	2	yr
Post-mission research period	1	yr
Total research period	10	yr
Number of science team members	20	
Researcher annual stipend	$ 20,000	
TOTAL RESEARCH GRANTS	**$ 4,000,000**	

OPERATIONAL COST

Prototype period: 10 yr

	Main	China	Japan	Peru
Number of staff	10	3	3	3
Office overhead cost	$ 6,560,000	$ 1,968,000	$ 1,968,000	$ 1,968,000

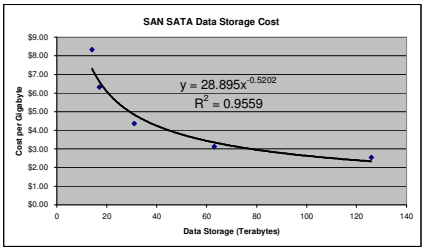
TOTAL OPERATIONAL COST $ 12,500,000

DATA PROCESSING

Data storage required	100	TB	Selected to be high-end; no detailed estimate available, but is not a cost driver
Data storage cost per GB	$ 2.63	/GB	Based on empircal curve in graph (Source 3)
Data storage cost	**$ 269,602**		
Data processing staff	10		
Total data period	10	yr	
Data processing labor cost	**$ 16,400,000**		
TOTAL DATA PROCESSING COST	**$ 16,700,000**		

NOTE: Data storage cost obtained from curve (see graph) based on empirical data (see table). These data obtained from Source 2.

Disk size (TB)	Cost per GB
14	$8.33
17	$6.33
31	$4.36
63	$3.13
126	$2.55



Source 3 http://www.its.monash.edu.au/staff/systems/dsm/technical/cost-recovery/cost-comparison-das-san.html Accessed 12 Aug 2007

TOTAL COSTS

Total Cost For Each Component

	Spacecraft System	Research Grants	Data Processing	Operational
Subtotal	$ 35,000,000	$ 4,000,000	$ 16,700,000	$ 12,500,000
Margin	20%	20%	20%	20%
Total	$ 42,000,000	$ 4,800,000	$ 20,040,000	$ 15,000,000

NOTE: Spacecraft costs are assumed to be higher during development phase, lower during operations. Data processing is assumed to be lower during development phase (ground-based data only) and higher during operations (ground and space data). Cost of mobile telecom and education outreach not individually estimated; assumed absorbed by operational costs.

Spread of Component Costs Over Pilot Period

Year	Spacecraft System	Research Grants	Data Processing	Operational
1	15%	10%	5%	10%
2	15%	10%	5%	10%
3	15%	10%	5%	10%
4	15%	10%	5%	10%
5	15%	10%	5%	10%
6	5%	10%	15%	10%
7	5%	10%	15%	10%
8	5%	10%	15%	10%
9	5%	10%	15%	10%
10	5%	10%	15%	10%

Cost By Year

Year	Spacecraft System	Research Grants	Data Processing	Operational	Total
1	$ 6,300,000	$ 480,000	$ 1,002,000	$ 1,500,000	$ 9,282,000
2	$ 6,300,000	$ 480,000	$ 1,002,000	$ 1,500,000	$ 9,282,000
3	$ 6,300,000	$ 480,000	$ 1,002,000	$ 1,500,000	$ 9,282,000
4	$ 6,300,000	$ 480,000	$ 1,002,000	$ 1,500,000	$ 9,282,000
5	$ 6,300,000	$ 480,000	$ 1,002,000	$ 1,500,000	$ 9,282,000
6	$ 2,100,000	$ 480,000	$ 3,006,000	$ 1,500,000	$ 7,086,000
7	$ 2,100,000	$ 480,000	$ 3,006,000	$ 1,500,000	$ 7,086,000
8	$ 2,100,000	$ 480,000	$ 3,006,000	$ 1,500,000	$ 7,086,000
9	$ 2,100,000	$ 480,000	$ 3,006,000	$ 1,500,000	$ 7,086,000
10	$ 2,100,000	$ 480,000	$ 3,006,000	$ 1,500,000	$ 7,086,000
All	$ 42,000,000	$ 4,800,000	$ 20,040,000	$ 15,000,000	$ 81,840,000

Cost By Year (Net Present Value, Rounded)

Year	Spacecraft System	Research Grants	Data Processing	Operational	Total
1	$ 6,500,000	$ 500,000	$ 1,000,000	$ 1,500,000	$ 9,500,000
2	$ 6,700,000	$ 500,000	$ 1,100,000	$ 1,600,000	$ 9,900,000
3	$ 6,900,000	$ 500,000	$ 1,100,000	$ 1,600,000	$ 10,100,000
4	$ 7,100,000	$ 500,000	$ 1,100,000	$ 1,700,000	$ 10,400,000
5	$ 7,300,000	$ 600,000	$ 1,200,000	$ 1,700,000	$ 10,800,000
6	$ 2,500,000	$ 600,000	$ 3,600,000	$ 1,800,000	$ 8,500,000
7	$ 2,600,000	$ 600,000	$ 3,700,000	$ 1,800,000	$ 8,700,000
8	$ 2,700,000	$ 600,000	$ 3,800,000	$ 1,900,000	$ 9,000,000
9	$ 2,700,000	$ 600,000	$ 3,900,000	$ 2,000,000	$ 9,200,000
10	$ 2,800,000	$ 600,000	$ 4,000,000	$ 2,000,000	$ 9,400,000
All	$ 47,800,000	$ 5,600,000	$ 24,500,000	$ 17,600,000	$ 95,500,000