PART I

# Introduction

# 1

# Extreme natural hazards and societal implications – the ENHANS project

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## 1.1 Introduction

The beginning of the twenty-first century has been marked by a significant number of extreme natural events and disasters associated with floods, hurricanes, severe storms, earthquakes, tsunamis, wildfires, landslides, volcanoes, extreme space weather, and extra-terrestrial hazard. Extreme events may cause devastation resulting in a loss of human lives, great environmental damage, and a partial or total loss of infrastructure. The principal signature of such events is that their probability decreases rapidly with magnitude, while the inflicted damage rapidly increases, and so does the cost of the respective protection measures. Extreme events and disasters remind us once again that there is a strong coupling between complex natural and social processes. A holistic approach is required to understand the natural phenomena and related social disasters associated with extreme events.

Humankind will never be able to prevent the occurrence of natural phenomena entirely. However, scientists are able to gain better understanding of the complex mechanisms of extreme natural events that cause the disasters, to study the physical and the social vulnerability of society to the extreme events, to share their knowledge with disaster management agencies who need the scientific information to be prepared to cope with such extreme events. Scientists need also a deeper understanding, based on work across disciplines, of all of the processes that are involved. They must be mindful of public concerns and the underlying risk perceptions. Communication between the various stakeholders that deal with natural hazards and disaster risk reduction needs to be strengthened.

Keeping this in mind, the International Union of Geodesy and Geophysics (IUGG) initiated the 'Extreme Natural Hazards and Societal Implications – ENHANS' project, which was enthusiastically supported by the International Council for Science (ICSU) and several international scientific unions, professional societies, and interdisciplinary and intergovernmental bodies. Among the Partners were the American Geophysical Union (AGU), the International Geographical Union (IGU), the International Society for Photogrammetry and Remote Sensing (ISPRS), the International Union of Geological Sciences (IUGS), the International Union of Theoretical and Applied Mechanics (IUTAM), the Integrated Research on Disaster Risk (IRDR) Programme of ICSU, the International Social Sciences Council (ISSC), and the United Nations International Strategy for Disaster Reduction (UNISDR) as well as the Global Ocean Observing System (GOOS) of the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Representatives of the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER), and the Munich Reinsurance Company also took part in the project. The ICSU Regional Offices for Africa (ROA), Asia and the Pacific (ROAP), and Latin America and the Caribbean (ROLAC) have been involved in the relevant parts of the project providing links to the regions. The project has been managed by IUGG and an international scientific committee: R. Abler (IGU, USA), A. Abreu (ICSU ROLAC, Brazil), O. Altan (ISPRS, Turkey), K. Alverson (GOOS, France), P. Bobrowsky (IUGS, Canada), J. U. Fucugauchi (AGU, Mexico), N. Hasan (ICSU ROAP, Malaysia), A Ismail-Zadeh (Project Leader, IUGG/AGU, Germany), E. Madela-Mntla, (ICSU ROA, South Africa), G. McBean (IRDR, Canada), and K. Moffatt (IUTAM, UK).

The principal goals of the ENHANS project have been to

(i) improve understanding of critical phenomena associated with extreme natural events and to

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analyse the impacts of the natural hazards on the sustainable development of society;
(ii) promote studies on the prediction of extreme events and on natural hazards mitigation;
(iii) disseminate scientific knowledge and data on natural hazards and disaster risks for the advancement of research and education in general and especially in developing countries; and
(iv) establish links and networks with the organizations involved in research on extreme natural hazards and their societal implications.

The goals of the ENHANS project have been achieved via scientific meetings and open forums that brought together research experts, decision makers, disaster managers, agents of the insurance industry, and mass media representatives. The project placed a special emphasis on the importance of research on extreme natural hazards and disaster risk mitigation in the most vulnerable regions of the world, particularly in Latin America and the Caribbean, Africa, the Middle East, Asia and the Pacific region.

The project contributed to and promoted research activities in natural hazard and disaster risk reduction, in particular via implementation of the IRDR Programme. The project revealed the existing knowledge, potentials, and scientific expertise in the relevant topics of extreme natural hazards and disaster risk research in many regions of the world. The project events were held around the world, each focusing on extreme natural hazards and disaster risks in a particular region (Fig. 1.1):

- Latin America and the Caribbean (Iguassu, Brazil, August 2010);
- North Africa (Cairo, Egypt, November 2010);
- North America and Europe (San Francisco, USA, December 2010);
- Sub-Saharan Africa (Pretoria, South Africa, January 2011);
- Middle East (Antalya, Turkey, May 2011); and
- Asia and the Pacific region (Melbourne, Australia, July 2011).

Moreover, the advanced school (Trieste, Italy, October 2011) and scientific session (San Francisco, USA, December 2011) on predictability of extreme events have been parts of the ENHANS project. The following sections describe the ENHANS events and results of the project.

## 1.2 Focus on Latin America and the Caribbean Region

The first ENHANS events took place at the Meeting of the Americas in Foz do Iguassu, Brazil, on 9–11 August 2010. The event consisted of a symposium and a town hall meeting. The symposium was convened by J. U. Fucugauchi (National Autonomous University of Mexico (UNAM), Mexico) and A. Ismail-Zadeh (Karlsruhe Institute of Technology, Germany/Russian Academy of Sciences, Moscow, Russia/Institut de Physique du Globe de Paris, France). The role of the ICSU Regional Office for Latin America and the Caribbean in developing research projects on natural hazards and disaster risks in the region was discussed by A. Abreu (ICSU Regional Office for Latin America and the Caribbean, Brazil) who introduced a new multidisciplinary research programme on Integrated Research on Disaster

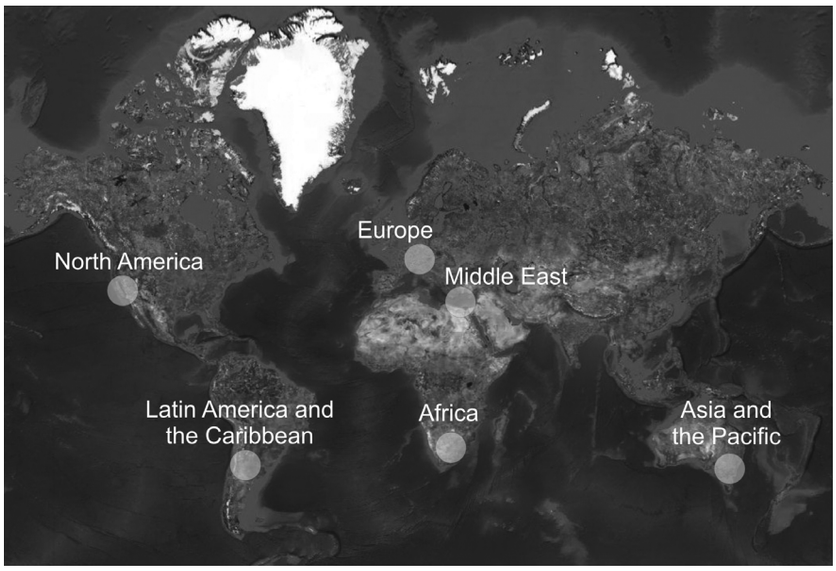


Figure 1.1. Geographical illustration of the ENHANS project meetings. For colour version, see Plates section.

Risk of ICSU and its Partners including the content and significance of the programme for Latin America and the Caribbean region. Meteorological hazards and associated risks in the Caribbean region were the subject of the talk by T. Gibbs (Consulting Engineers Partnership Ltd, Barbados), and volcanic hazards and risks in the region were presented by S. De La Cruz-Reyna (UNAM, Mexico). O. Perez (Universidad Simón Bolivar, Caracas, Venezuela) spoke on earthquake activity and associated hazards in South America and the Caribbean and on the socio-economic impact of great earthquakes in the region. The anatomy of landslide disasters was analysed by I. Alcantara-Ayala (UNAM, Mexico) with case studies from Mexico and other South American countries. O. Cardona (National University of Colombia, Manizales, Colombia) spoke on indicators of earthquake disaster risk and risk management in the Americas, while F. Romanelli (University of Trieste, Italy) presented a novel seismic hazard assessment methodology and its application to hazard evaluation in Valparaiso (Chile). Two oral sessions of the symposium were continued by a poster session with 25 papers.

The presentations by invited speakers and subsequent discussion at the town hall meeting addressed three questions: (i) How can science (both natural and social) and society form partnerships for disaster reduction? (ii) How can the science and society partnership convert natural disaster risk to opportunity? (iii) What are the urgent issues for disaster risk in Latin American and the Caribbean cities and regions under intensifying natural and social pressure? A. Lavell (Latin American Social Sciences Faculty – FLACSO and LA RED, Costa Rica) spoke on increasing the salience of disaster risk management on the political agenda. He said that 'Disaster Risk Management is still not of sufficient social and political salience given current and future predicted disaster trends and costs, and which climate change probably adds to'. The talk highlighted why this may be so and what the principal ways to place the theme more firmly on the political and social agenda are. K. Alverson (Director, Global Ocean Observing System – GOOS, Intergovernmental Oceanographic Commission) spoke on GOOS implementation in Latin America and the Caribbean. The talk focused on the importance of sustained ocean observing systems being 'in place both to prevent and mitigate disasters, where possible, as well as to rapidly bring observing assets to bear in post disaster relief efforts'. Both natural coastal inundation hazards, such as storm surges and tsunamis, as well as anthropogenic hazards, such as oil spills, were discussed, focusing where possible on Latin America and the Caribbean, including the Gulf of Mexico. P. Boccardo (Politechnico di Torino, Italy, and an ISPRS representative) discussed disaster management in the case of the 2010 Haiti earthquake. His presentation highlighted issues and challenges associated with emergencies related to disasters, particularly, data acquisition, processing, and information extraction when a humanitarian response is involved. Two panellists of the discussion, I. Alcantara-Ayala (IGU Vice-President) and M. McPhaden (AGU President), mentioned how international unions and professional societies could assist in research on natural hazards and in the mitigation of disasters. The speakers and panellists answered questions from the attendees. The discussion was moderated by J. U. Fucugauchi and A. Ismail-Zadeh.

## 1.3 Focus on Africa

The African meetings of the ENHANS project took place in Cairo, Egypt, on 1 November 2010 and in Pretoria, South Africa, from 17 to 20 January 2011. The symposium on Extreme Natural Hazards and Climate Changes in North Africa was organized by the Egyptian Academy of Scientific Research and Technology. A. Ismail-Zadeh introduced the ENHANS project and emphasized the importance of integrated research on natural and human-induced hazards and disasters. T. Beer (CSIRO, Melbourne, Australia) discussed the problems of environmental risk management that are related to climate change and geophysical hazards. H. Gupta (National Geophysical Research Institute, Hyderabad, India) discussed the problem of induced seismicity. D. Jackson (University of California, Los Angeles, USA) reported on global earthquake forecasts and how the forecasts help to understand seismic hazard. S. Riad (Cairo University, Egypt) discussed climate-related hazards and their impacts on Egypt. A round table discussion took place after the presentations.

The ENHANS International Workshop 'Extreme Natural Hazards and Disaster Risk in Africa' (Pretoria, South Africa, 17–20 January 2011) provided an opportunity for the research community of the African countries and international experts to discuss and analyse major topics related to extreme events and disaster risks. The workshop served as a platform to establish links and networks between African experts and relevant international organizations. The workshop was organized by A. Kijko (University of Pretoria, South Africa) and hosted by the Aon Benfield Natural Hazard Centre, University of Pretoria. More than 40 delegates, representing various international, intergovernmental, African, and other organizations, attended the workshop. The workshop presentations can be downloaded from http://www.enhans.org/showcasing/workshop_jan2011.php (accessed on 23 August 2013). The workshop's participants adopted the recommendation (see Appendix 1.1) to governments and funding institutions in cooperation with the relevant

Figure 1.2. Lake in the centre of Tswaing meteorite crater. For colour version, see Plates section.

ICSU bodies, United Nations agencies and other international entities. The Pretoria workshop was highlighted in the *UN SPIDER Newsletter*,[1] the *Insurance Journal*,[2] and in the *Newsletters of the University of Pretoria*.[3]

The workshop participants visited the Tswaing crater (1.13 km in diameter and 100 m deep), an extreme event site associated with a meteorite that hit the Earth some 200 000 years ago (Fig. 1.2). K. Moffatt (University of Cambridge, UK), a workshop participant, wrote a poem about the tour (see below)

*Black Swan On First Looking into the Tswaing Meteorite Crater*

In single file we climbed the narrow trail,
Through bramble thicket to the crater's rim.
Where warming sun cast shadows on the brim,
And bathed the bushveld scrub and scattered shale.

Concealed beneath the gently waving grass,
By saline lake, the haunt of duck and plover,
Lay snakes and lizards in the rain-soaked clover,
On diaplectic quartz and feldspar glass.

In prehistoric stone-age time of yore,
At hypersonic speed a chondrite fell
On thunderstruck impala and gazelle,
And vaporized upon the forest floor,

Black swans are not so rare, I heard you say!
Beware! One may befall this very day!

*Keith Moffatt*

## 1.4 Focus on North America and Europe

The symposium 'Natural Extreme Events: Modeling, Prediction and Mitigation' and related events were held at the Fall Meeting of the American Geophysical Union on 13–15 December 2010 in San Francisco, USA. The symposium consisted of three scientific sessions. The Union-wide session attracted more than 300 experts in various fields of extreme natural hazards. The session was focused mainly on North America and Europe. I. Zaliapin (University of Nevada, USA) and A. Ismail-Zadeh, organizers of the symposium, welcomed the participants and presented the ENHANS project. D. Baker (Colorado University at Boulder, USA) spoke on predictability and mitigating impacts of extreme space weather events. A storm surge, as a globally distributed risk, was the topic of the talk by H. von Storch (University of Hamburg, Germany). U. Lall (Columbia University, USA) explained why flooding was severe in 2010. He considered several case studies and discussed whether this is a coincidence or a predictable climate phenomenon and how to respond to these extremes. T. Jordan (University of Southern California, USA) spoke on new large-scale numerical simulations to forecast extreme earthquake ground motions, and S. Sparks (University of Bristol, UK) gave a talk on extreme volcanic eruptions and discussed their return period, impact, and implications. R. Douglas (Willis Research Network, UK) spoke on how (re)insurance and public science interact to manage the risk of extreme events for societal benefit. According to R. Douglas 'natural hazard modelling, married to risk, financial and economic modelling, created a new scientific and social organism – a rich and diverse community representing how nature, property and populations perform at the extremes'. N. Lin (Princeton University, USA) spoke on hurricane risk assessment related to wind damage and storm surge, while K. Klima (Carnegie Mellon University) spoke on tropical cyclones and presented her approach to a decision-analytic assessment of cyclone hazards. Extreme precipitation events in the European Alpine region were discussed by N. Awan (University of Graz, Austria). J. Rundle (University of California, Davis, USA) spoke on precursory activation and quiescence prior to major earthquakes. F. Guzzetti (University of Perugia, Italy) discussed landslide hazard, vulnerability, and risk assessment and emphasized the importance of methodology for risk assessment, its limits and challenges. K. Satake (University of Tokyo, Japan) spoke on tsunami modelling, forecasts, and early warning. A. Smith (National Oceanographic and Atmospheric Administration, USA) examined insurance loss return periods with extreme event intensity thresholds across the USA. In the poster session a variety of topics related to natural hazards, extreme events, theory, hazard and risk modelling, prediction and mitigation were presented. The culminating event of the symposium was a keynote lecture on 'Society's Growing Vulnerability to Natural Hazards and Implications for Geophysics Research' by J. Slingo (Met Office, UK).

## 1.5 Focus on the Middle East

The ENHANS Session 'Natural Hazards and Disaster Risks in the Middle East Region' was held on 7 May 2011 in Antalya, Turkey. The session was organized by A. Ismail-Zadeh and J. Rovins (USA/China, IRDR Executive Director), who introduced the IRDR programme and highlighted recent developments and preparation for the IRDR Conference in Beijing in 2011.

M. Ghafory-Ashtiany (International Institute of Earthquake Engineering and Seismology, Tehran, Iran) presented a talk on the topic of natural hazard and risks in Iran and the risk reduction capacity building in the country. Ghafory-Ashtiany said that 'to reduce and mitigate the unavoidable risk of natural hazard, scientists, engineers, government officials and the general public must all be involved in the process of finding realistic, achievable and appropriate ways of applying scientific knowledge to everyday life. Only by capacity building and working together, a nation can mitigate the impact of natural hazards on human life and society, and solve the risk puzzle'. He considered that Iran's experience in reducing earthquake disaster risk could be applied to many developing countries. Ghafory-Ashtiany argued that the main reasons for high human and property losses in the past were the significant vulnerability of the built environment, the rapid growth of population, and incompatible urban development.

C. Tuzun and M. Erdik (Bogazici University, Istanbul, Turkey) presented a new project, Earthquake Model of Middle East region (EMME), aimed at the assessment of seismic hazard, the associated risk in terms of structural damages, casualties, and economic losses and also at the evaluation of the effects of relevant mitigation measures in the Middle East region. The region is located at the junction of major tectonic plates, namely the African, Arabian, and Eurasian plates, resulting in very high tectonic activity. The speaker mentioned that 'some of the major earthquake disasters in human history occurred in the Middle East, affecting most countries in the region. Being one of the most seismically active regions of the world, the Middle East, extending from Turkey to India, is also a key region in terms of urbanization, energy reserves and industrialization trend.'

A. Al-Bassam (Saudi Arabia) presented natural hazards affecting the Kingdom of Saudi Arabia. The northwestern region of the country is prone to earthquakes and volcanic hazards, whereas the central and the western regions of the country are subject to flooding, especially during events of heavy rainfall. Landslides are a common phenomenon in the inhabited mountainous regions in the southwest. Dust storms are quite common in the central and the eastern parts of the Kingdom. Different government agencies and various universities having been working on these issues to mitigate these hazards and also to educate the people.

T. Merabtene (University of Sharjah, Dubai, United Arab Emirates) spoke on flood risk management in the Middle East and North African region (MENA region). He considered that 'the magnitude and impact of climate change increasingly take new catastrophic dimensions under the current paradigm shift of the MENA cities if disaster risk management actions and appropriate disaster policies are further delayed'. Flash floods in many countries in the MENA region have caused loss of life and have disrupted business activity resulting in great public and private economic damage. He argued that the increasing frequency of floods in the region is an indicator that urban flood management has potential implications for the sustainable development of current and future urban infrastructure in the MENA region. Merabtene emphasized the institutional deficiencies behind the current situation and discussed various strategies for keeping flood risk management high on the political agenda in MENA countries.

## 1.6 Focus on Asia and the Pacific region

Three major ENHANS events took place between 29 June and 2 July 2011 at the XXVth General Assembly of the International Union of Geodesy and Geophysics in Melbourne, Australia: (i) the symposium 'Grand Challenges in Natural Hazards Research and Risk Analysis', (ii) the symposium 'Earth on the Edge – Recent Pacific Rim Disasters', and (iii) the open forum 'Natural Hazards: From Risk to Opportunity by Partnership of Science and Society'. The events were organised by K. Takeuchi (ICHARM, Japan) and A. Ismail-Zadeh.

### 1.6.1 The symposium 'Grand Challenges in Natural Hazards Research and Risk Analysis'

Each year thousands of people across Asia and the Pacific region are killed and many more affected by floods, storms, earthquakes, drought, volcanoes and other such hazards. These hazards are only potentially damaging and the disasters occur when they impact on vulnerable communities, which are highly concentrated in poorer countries with weaker governance. G. McBean (University of Western Ontario, Canada; Chair of the IRDR Scientific Committee and ICSU President-elect) introduced the IRDR programme, which integrates research across hazards, natural, socio-economic, engineering, and health sciences disciplines and geographical regions. The research focuses on: the characterization of hazards, vulnerability, and risk; effective decision making; and knowledge-based actions leading to major reductions in future impacts and loss of lives. McBean considered that

'forensic investigations that will delve in greater depth into the root causes of disasters is one initial thrust. The second, risk interpretation and action, will examine how human actions, conditions, decisions and culture, and how people choose, or feel they have no choice but, to live and work in areas at higher risk, change vulnerabilities and contribute to disasters.'

J. Schneider (Geoscience, Australia) stated that 'effective disaster risk reduction is founded on knowledge of the underlying risk'. While methods and tools for assessing risk from specific hazards or to individual assets are generally well developed, our ability to holistically assess risk to a community across a range of hazards and elements at risk remains limited. Developing a holistic view of risk requires interdisciplinary collaboration amongst a wide range of hazard scientists, engineers, and social scientists, as well as the engagement of a range of stakeholders. Schneider presented some of the challenges sampled from a range of applications addressing earthquake, tsunami, volcano, severe wind, flood, and sea-level rise from projects in Australia, Indonesia, and the Philippines.

S. Sorooshian (University of California, Irvine, USA) considered that capturing the spatial and temporal distribution of precipitation in fine scales is critical to hydrologic, climatic, and ecological applications. The development of satellite remote sensing techniques has provided a unique opportunity for better observation of precipitation from space and overcomes some of the limitations of ground measurement. Sorooshian reviewed some of the development in satellite-based precipitation observation methodologies.

A. Kitoh (Meteorological Research Institute at Tsukuba, and Kyoto University, Japan) said that 'high-resolution models are vital to project reliable and possible future changes in weather extremes such as tropical cyclone and heavy rainfall'. He reported that unprecedented super high-resolution atmospheric models are being used for global warming projections. Kitoh described how projections on tropical cyclones reveal marked future increases in precipitation and surface wind velocity fields at the inner-core region within 150 km from the tropical cyclone centre, implying an increase in disaster risk induced by tropical cyclones in the future. He said that information on the uncertainty of future projection is significant for any decision-making processes and for various application studies on disaster prevention.

P. Linden (University of Cambridge, UK, and an IUTAM representative) presented an ongoing scientific and engineering project to prevent flooding in Venice. The construction of the flood protection gates at the entrance to the Venice Lagoon which are due to be commissioned in 2014 provides an unprecedented opportunity to manage the lagoon and its interaction with the Adriatic Sea. It also raises important questions about the scientific monitoring and decision-making process to enable the sustainable development of the lagoon and the historic city of Venice. Linden discussed the past and future monitoring and assessment of the physical and ecological states of the Venice Lagoon and described proposed structures for its management.

In the *Handbook of Disaster and Emergency Policies and Institutions* by J. Handmer and S. Dovers (Earthscan, 2007), a lack of previous focus on the policy and institutional aspects of disasters and emergencies is identified. S. Dovers (Australian National University, Canberra and an IGU representative) discussed the increasing emergence of climate change as a major influence on thinking about disasters, and the lessons from events such as the floods and cyclones in Australia. Dovers emphasized particularly the degree to which the existing agendas of policy and institutional reform, and the existing institutional capacities provide a basis for coping with what is likely to be a future punctuated by an increasing number of serious disasters and emergencies.

J. Eichelberger (US Geological Survey, and an AGU representative) discussed how several observatories in the Pacific region monitor volcanoes and warn of impending or ongoing eruptions. Many of the real-time monitoring data are available to the public through observatory websites, and citizen reports on volcanic activity and ash falls are solicited. A close link between Russian and the Alaska observatories tracks ash threatening North Pacific air routes. A challenge is to maximize the societal benefit from this expanded hazard community. Indeed, accessibility of real-time data makes the concept of cloistered observatories outmoded. Observatories will still be dedicated to monitoring a limited number of volcanoes for their neighbouring populations and will be the sole authoritative voice for hazard warnings, but must also become nodes for data and knowledge exchange for the larger scientific community. The Eyjafjallajokull eruption showed that such networking should be international in scope.

The Indian Ocean tsunami of 26 December 2004 was the most devastating in the world for the past 40 years. H. Gupta (President of the Asian Oceanic Geoscience Society, and a representative of the ICSU Regional Office for Asia and the Pacific) discussed how India planned to develop an integrated mitigation system for tsunami and storm surges in the northern part of Indian Ocean region with the ultimate goal of saving lives and property.

S. Zlatanova (Delft University of Technology, The Netherlands, and an ISPRS representative) described how 'A proper management increases the situational awareness after a disaster happened, gives a better overview of available data (especially dynamic data), facilitates the access to a desired piece of information, and contributes

to automatic data processing. Consequently the information can be used more efficient in the decision-making process'. Well-structured data can support cost-benefit analysis in the post-disaster period, provide a strong foundation for effective mitigation measures and improve preparedness. The variety of approaches reveals the complexity of the problem. Emergency response is very much nationally and even locally (district) organized. Furthermore each country is prone to a specific set of hazards and organizes its management procedures according to the recognized vulnerability. Another complicating factor is the disaster type, which may require different data sets and procedures for management. Zlatanova analysed the challenges in data management and presented some dynamic data models.

### 1.6.2 The Symposium: Earth on the Edge – Recent Pacific Rim Disasters

The symposium was dedicated to the recent disasters in the Pacific Rim region. K. Takeuchi (International Centre for Water Hazard and Risk Management, Tsukuba, Japan) introduced the total picture of the Great East Japan Earthquake and Tsunami with the latest figures for damage. He said that a concatenation of events occurred from the earthquake to the tsunami and from the tsunami to nuclear meltdown. The impact spread through the industrial supply chain first locally, then nationally, and to nation and finally internationally. He also described the newly enacted Reconstruction Law and its basic policy. He emphasized that no disaster should be 'beyond expectation' in disaster risk management however unexpected the hazards are.

The Tohoku earthquake that occurred on 11 March 2011 off the Pacific coast of northern Honshu caused the worst tsunami disaster in Japan's history. K. Satake (Earthquake Research Institute, University of Tokyo, Japan) reported that this giant earthquake was a plate boundary rupture along the Japan trench, where interplate earthquakes ($M < 8$) occurred at an interval of a few decades and that the probability of one occurring in the next 30 years was forecast as $>80\%$. The March earthquake was, however, much larger than forecast. The GPS network recorded large coseismic displacements ($>5$ m horizontal and $>1$ m subsidence), and the tsunami inundation extended several kilometres inland. The fault rupture was about 400 km long, while the aftershocks extended nearly 500 km, including three $M > 7$ events within an hour of the main shock. A similarly large earthquake and tsunami in AD 869 (called the Jogan earthquake) was recorded in a Japanese historical document, which mentioned a thousand casualties and the tsunami inundation extending several kilometres inland. Studies have clarified that the Jogan and older tsunami deposits were distributed several kilometres from the present coast with recurrence intervals of several hundreds to thousand years.

F. Imamura (Tohoku University, Japan) said that the Great East Japan Earthquake took more than 27 000 lives. Several types of tsunami impact were reported, among them inundation over a large area, destruction of buildings and infrastructure and a change of topography due to erosion and deposition. Although the observation system for tsunamis was heavily damaged along the coast, some data were recorded by the tidal gauges, GPS buoys, and deep sea pressure sensors. The extent of the affected area was quite large and limitations and difficulties for ground survey persist. Imamura reported the results of field surveys as well as satellite image analysis, which allows the extent of tsunami inundation and land use change to be identified. The distribution of tsunami run-up heights measured along the coast ranged from 7 to 15 m in Sendai and Fukushima with a simple beach geometry and from 10 to 30 m in Sanriku with the complex geometry of the Rias coast.

S. Kiefer (University of Illinois, USA) discussed how the dynamic features of the tsunami waves changed. As the tsunami approached and then flowed onto the shore of northern Honshu, the character of the waves changed several times. Deep-water waves changed to multiple shallow water waves as the tsunami approached the shore. When these waves encountered coastal cities, they broke into individual hydraulic streams channelled by the infrastructure. From videos posted on the Internet, Keifer and her group constructed hydrographs for sites in Kesennuma, Oirase, Sendai, and Kamaishi.

K. Irikura (Aichi Institute of Technology, Japan) discussed how the huge tsunami generated by the Great East Japan Earthquake led to the accidents at the nuclear reactors. When the earthquake happened, all of the reactor units at four nearby plants were automatically shut down and began to be cooled by cooling systems until they were attacked by big tsunami waves. All the units at the Onagawa and the Tokai No. 2 nuclear power plants escaped problems because the heights of the tsunami waves were lower than the altitudes of the plant sites. However, the Fukushima No. 1 and the Fukushima No. 2 plants were damaged by big tsunami waves, because the tsunami heights were much higher the altitudes of the plant sites. At the Fukushima No. 1 plant, external electric power was cut, water-tanks were broken, and all of the independent power generation systems were damaged. At the Fukushima No. 2 plant, some of the independent power generation systems were not broken because they were on higher ground, so that the cooling systems at the Fukushima No. 2 plant soon recovered. The severe accidents at the Fukushima No. 1 plant were caused by a deficiency of multifaceted protective mechanisms, not only by the tsunami.

The deadly and damaging Christchurch Earthquake of 22 February 2011 is part of the Canterbury earthquake sequence which started with the $M_w$ 7.1 Darfield Earthquake in September 2010. K. Furlong (Penn State University, USA) showed that this sequence occurred on previously unrecognized fault(s) and was significantly distant from the main components of the plate boundary system through South Island, New Zealand. The initial rupture in the September event and subsequent aftershocks have delineated a linear (nearly east–west in orientation) trend extending over 80 km from the foothills of the Southern Alps to the Pacific coast, east of the city of Christchurch. Understanding the relationships between fault segments, regional geologic structure, and crustal stresses associated with regional plate interactions is key to placing these events into a context that allows us to apply the lessons learned to future events.

N. Nicholls (Monash University, Melbourne, Australia) discussed the role of the climate and weather in the January 2011 Brisbane floods, and the potential role of climate/weather forecasts in avoiding or reducing flood damage. Since the last major floods in the Brisbane River (1974) there have been major advances in the detail, timeliness, delivery, and quality of weather and climate predictions on all these timescales. On some timescales weather and climate forecasts were not even available for previous floods. The skill of forecasts on the synoptic timescale has improved dramatically over the past few decades. The models used to make projections on climate change timescales have become more complex than those available in the early 1970s, and the likely consequences of global warming are now better appreciated.

### 1.6.3 The open forum: Natural Hazards: From Risk to Opportunity by Partnership of Science and Society

The open forum attracted the attention of not only the participants of the IUGG General Assembly but also representatives of media. S. Briceño (UNISDR Director, Geneva, Switzerland) welcomed the participants in his video message and presented key issues related to disaster risk reduction and mitigation. T. Beer (IUGG President, Australia) presented several challenges in natural hazards research and risk analysis, especially those related to climate change. R. Kuroda (ICSU Vice President, Japan) talked about the partnership of science and society. She mentioned that since 2000, science itself had changed: it had become inter- and trans-disciplinary and more competitive. Meanwhile international collaboration through mega-projects had become an inevitable part of research. The most profound change for science, however, has been its stronger interdependence with society. The outcome of science and technology very quickly spreads into our everyday life and can and has changed socio-economic structures and our way of thinking dramatically. Kuroda proposed that scientists should be educated in social literacy and the public in science literacy. A. Ismail-Zadeh and K. Takeuchi moderated the forum and discussions on topics related to natural hazards, extreme events, disaster risk and the link between science and society.

The open forum was followed by an online briefing on predicting disasters, which was organized by the Australian Science Media Centre. Four experts spoke at the news briefing: J. Goff (Australian Tsunami Research Centre and Natural Hazards Research Laboratory, University of New South Wales); A. Ismail-Zadeh (International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow); T. Jordan (Southern California Earthquake Center, University of Southern California); and Brian Kennett (the Australian Academy of Science Committee on Earth Science and Research School of Earth Sciences, Australian National University in Canberra). The briefing addressed the following questions: Can anyone really predict earthquakes, tsunamis, and volcanic eruptions? If not, why not and will we ever be able to do so? Knowing the epicentre of a shake seems to be only part of the problem, can we say how much damage will be caused? Australia has been affected before, how likely is it that it will experience another earthquake or tsunami? Can we be forewarned enough to organize mass evacuations days in advance? Or to accurately predict that an event will happen in a few-year span? The briefing can be heard at the web-page of the Australian Science Media Centre.[4]

## 1.7 Focus on education

The ENHANS project promoted the activity of the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, and coorganised an advanced school on ‘Understanding and Prediction of Earthquakes and Other Extreme Events in Complex Systems’. The need for a scientifically literate populace is increasingly recognized as critical in many countries, as they face the consequences of increasing population pressures, limited resources, and environmental degradation. Basic science literacy, coupled with scientific ‘ways of knowing – namely drawing conclusions based on observation, experiment and analysis – provides citizens with the tools needed for rational debate and sound decision-making based on scientific knowledge’ (from the 2011 report of the ICSU Ad-Hoc Review Panel on Science Education). Geoscience education, and particularly education on extreme natural events and disaster risks, is profoundly important for the basic science literacy

of the population living at risk. Moreover, special attention should be given to economically less-developed countries.

The advanced school held between 26 September and 8 October 2011 in ICTP covered a wide range of the developments in the field of natural and socio-economic extreme hazards and disaster risks. During this advanced school, prominent experts delivered lectures and gave seminars to earlier career scientists, mostly from developing countries.

## 1.8 Focus on predictability

Natural and socio-economic disasters pose an intolerable threat to society. The most damaging and least understood of these are so-called extreme events. In different contexts these events are also called critical transitions, disasters, or catastrophes. The multidisciplinary research of the last decades reveals a surprising similarity and structural universality in the development of extreme events in systems of diverse origin. The ENHANS symposium 'Predicting Extreme Events in Natural and Socio-Economic Systems' was dedicated to V. Keilis-Borok (University of California, Los Angeles, USA), a distinguished scientist who greatly contributed to research on the predictability of extreme events in natural and socio-economic systems. The symposium was organised by A. Gabrielov (Purdue University, Lafayette, USA), I. Zaliapin, and A. Ismail-Zadeh. Invited speakers covered a wide spectrum of research on predictability: earthquake forecasting and prediction by D. Turcotte (University of California, Davis, USA), V. Kossobokov (Russian Academy of Sciences, Moscow, Russia), S. Uyeda (Japan Academy of Sciences, Tokyo, Japan), P. Varotsos (University of Athens, Greece), and T. Jordan (University of South California, Los Angeles, USA); scaling laws, chaos, and predictions by C. Allègre (Institut de Physique du Globe de Paris, France); prediction of human-induced events by H. Gupta (National Geophysical Research Institute, Hyderabad, India); prediction of extreme events in socio-economic systems by M. Ghil (École Normale Supérieure, Paris, France) and M. Intriligator (University of California, Los Angeles, USA).

## 1.9 Project results and conclusion

The ENHANS project concluded that a reduction of disaster risk could be achieved through in-depth scientific research on disaster risks and through risk assessments. The ENHANS project called for the following important actions (see Appendix 1.2 for the text of the Declaration):

- the promotion of comprehensive holistic inter- and transdisciplinary approaches to natural hazard and disaster risk research, which have to integrate knowledge from natural and social sciences, mathematics, engineering, disaster management, insurance sectors, and other stakeholders dealing with disaster risk;
- assistance in networking existing regional scientific and educational centres with the aim of establishing a regional centre of excellence in disaster risk research (e.g., in sub-Saharan Africa);
- negotiations to set up a process of assessing and synthesizing the policy-relevant results of peer-reviewed published research on: the understanding of natural phenomena and the social vulnerability associated with disasters; the capability of predictive systems to disseminate the timely and accurate information needed for policy and decision making; methodologies and approaches for reducing vulnerability and increasing resilience of societies; and the overall ability of societies to reduce risk (prevent, mitigate, and prepare for the increasing impact of natural events).

The major scientific results of the ENHANS project have been broadcast via the project homepage (http://www.ENHANS.org), newsletters of UN, international and national organizations, and the Internet (as video presentations or as report presentations). The ENHANS project results are summarized in this book *Extreme Natural Hazards, Disaster Risks and Societal Implications*.

### *Appendix 1.1*

### THE ENHANS INTERNATIONAL WORKSHOP RECOMMENDATION (PRETORIA, SOUTH AFRICA, 20 JANUARY 2011)

*The following recommendation is made by attendees of the international workshop 'Extreme Natural Hazards and Disaster Risks in Africa'.*

Whereas, natural hazards are an integral component of life in the African continent, and floods, droughts, earthquakes, tsunamis, landslides, and other extreme natural events hit Africa on a regular basis resulting in tragic loss of life and property due to tremendous vulnerability of the African countries to extreme hazards;

The ENHANS International Workshop "Extreme Natural Hazards and Disaster Risks in Africa"

***Acknowledging*** the long-standing and ongoing contributions of

the American Geophysical Union (AGU);
the Global Oceanic Observing System (GOOS) of the Intergovernmental Oceanographic Commission (IOC) of UNESCO;