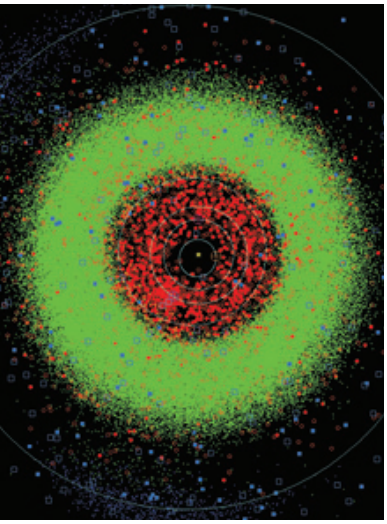

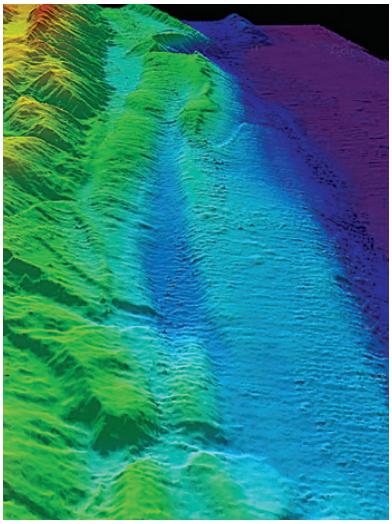
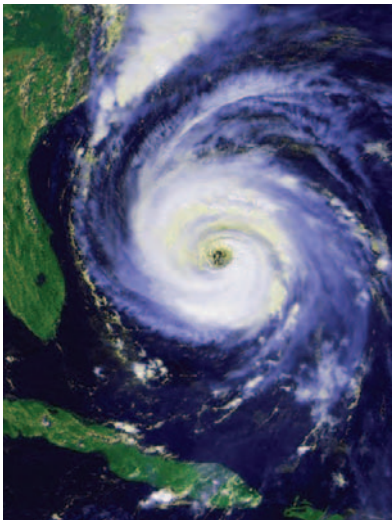

The Role of Science in Physical Natural Hazard Assessment

Report to the UK Government by the Natural Hazard Working Group
June 2005

Images on front cover

Plot of the inner solar system: Near Earth Objects
Image courtesy of the Minor Planet Center

1968 earthquake Meckering, Australia
Image courtesy of University of California/National Geographic Data Centre

Plate boundary between the Indian and Eurasian plates
Image courtesy of MOD following a survey conducted by HMS Scott in collaboration with the British Geological Survey and National Oceanagraphic Centre, Southampton

Hurricane Fran September 1996
Image courtesy: National Oceanic and Atmospheric Administration.

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Executive Summary

The Prime Minister's request

1. Following the tragic Asian tsunami on 26 December 2004, the Prime Minister asked the Government's Chief Scientific Adviser, Sir David King, to convene a group of experts (the Natural Hazard Working Group) to advise on the mechanisms that could and should be established for the detection and early warning of global physical natural hazards.

2. The Group was asked to examine physical hazards which have high global or regional impact and for which an appropriate early warning system could be put in place. It was also asked to consider the global natural hazard frameworks currently in place and under development and their effectiveness in using scientific evidence; to consider whether there is an existing appropriate international body to pull together the international science community to advise governments on the systems that need to be put in place, and to advise on research needed to fill current gaps in knowledge. The Group was asked to make recommendations on whether a new body was needed, or whether other arrangements would be more effective.

Observations and Recommendations

3. There is a renewed commitment in many countries and international organisations to undertake disaster reduction and to put early warning systems in place. Many programmes have been established or are proposed to address the threat posed by physical natural hazards.

4. However, these programmes are as yet insufficiently co-ordinated; there is an evident need for a more strategic and sustainable global approach. Greater linkage of national and international programmes is needed in order to use resources better, prevent duplication and ensure effort is focussed on gaps in the global infrastructure.

5. The Group endorses the view expressed at the Kobe World Conference on Disaster Reduction (Jan 2005) that there is a clear need for a sustainable and effective global multi-hazard early warning system building on existing capabilities and frameworks. In this context we welcome the developing Global Earth Observation System of Systems (GEOSS) and recognise the high level of effectiveness of the World Meteorological Office (WMO) hydrometeorological warning system under the coordination of the United Nations.

6. A disaster management system requires continual investment, effective governance and integration into relevant development planning processes, all aimed at reducing

the vulnerability of the population to natural hazards. The UN plays a key role in these areas. However there is duplication of effort between UN agencies, and the International Strategy for Disaster Reduction (ISDR), while generally well conceived, currently lacks the capacity and resources to play its designated role effectively, in particular to improve knowledge about disaster causes and options for risk reduction.

7. Early warning systems must be part of the broader disaster management system. Essential elements of early warning include forecasting and prediction, assessment, preparedness, effective means of communication, appropriate technology and maintenance. The robustness of these elements depends significantly on sound scientific and technological assessment of hazards, and of possibilities for risk reduction. However despite progress made in the field of science, technology and research on natural hazards it appears that scientific knowledge is often poorly applied to disaster risk management policies and programmes.

8. Before the December 2004 tsunami there was sufficient weight of scientific knowledge which, had it been effectively communicated to decision makers, should have resulted in better preparedness. There should also have been a better way to communicate the scientific experts' evidence on the risks of further events in the same region. In the event there was indeed a further major earthquake on the same fault line in March 2005, south of the initial one, though not, fortuitously, a further tsunami.

9. We are clear that there is an urgent need to improve the integration of scientific knowledge of physical natural hazards into the management of early warning. Robust communication lines between the scientific community and decision-takers must be established and strengthened to ensure effectiveness.

Key Recommendation

We recommend the establishment of an International Science Panel for Natural Hazard Assessment. The Panel would enable the scientific community to advise decision-takers authoritatively on potential natural hazards likely to have high global or regional impact. It would facilitate individual scientists and research groups pooling their knowledge and challenging each other; it would address gaps in knowledge and advise on potential future threats. It would address how science and technology can be used to mitigate threats and reduce vulnerability.

10. Our recommendation to establish such a Panel is intended to fill a gap in existing efforts to address the threat posed by natural hazards. It should not replace or duplicate existing frameworks or institutions. The Panel should sit comfortably within the overall UN disaster management framework and have close links with relevant agencies and initiatives to ensure that its findings are applied.

11. Having looked at the costs of bodies operating in a similar capacity to the proposed Panel, we are confident that its costs would be minimal compared with the benefits in terms of cost effectiveness of soundly based preparedness and mitigation measures. These measures would, in turn, bring enormous benefits both in terms of reduced economic costs and human lives lost by preventing a hazard becoming a disaster. If integrated into the framework of an existing relevant international organisation we anticipate costs would be in the region of £0.5m – £1m a year.

12. With regard to existing early warning mechanisms we are impressed by the global operational warning system used by the hydrometeorological community. This system is mature and has proven to be effective. The WMO system is supported by 187 countries and operates 24 hours a day throughout the year. However for most other natural hazards there is no single internationally recognised authority or official warning process. There is therefore a real risk of ineffective, inaccurate and conflicting warnings.

Recommendation 2

We recommend consideration of the possibility of developing the WMO framework to provide an authoritative co-ordinated warning system for other natural hazards. To do this it would need to establish effective working relationships and operational communications with other relevant bodies, including the Science Panel recommended above.

13. The Group is confident that the cost of implementing this recommendation would be small. Extending use of the WMO framework in this way would require minor upgrades of some existing systems and some additional staff. It clearly represents good value for money when set against the alternative of establishing a new, parallel early warning system.

14. For any early warning system to be effective it is essential that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation. Institutional capacities must be established to ensure that early warning systems are well integrated into government policy and decision-making processes and emergency management systems at both the national and local levels. Such early warning systems should be subject to regular system testing and performance assessments.

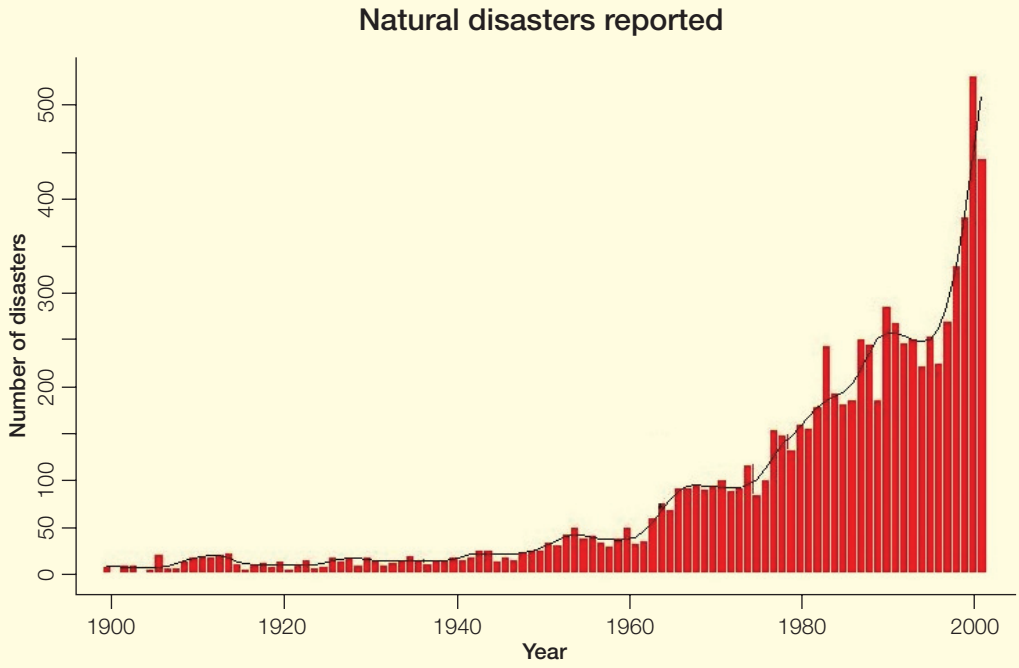
Recommendation 3

We recommend that governments and international bodies prioritise national capacity building for hazard risk management. In particular greater support should be given at the national level to the improvement of scientific and technical methods and capacities for risk assessment, monitoring and early warning.

Introduction

1. Every year the world suffers the impact of natural physical hazards of various kinds. Some of these hazards are of low frequency but have high impact, such as the Asian tsunami in December 2004, whilst others such as tropical cyclones and storm surges are more frequent but often have greater cumulative impact. Surge events, for example, have been responsible for the deaths of over half a million people in Bangladesh over the last 35 years. Natural hazards are a part of the world we live in and in most instances cannot be prevented. “But hazards only become disasters when people’s lives and livelihoods are swept away” (Kofi Annan, Oct 2003). There is indeed much that can be done – and is being done – to mitigate their impact both in terms of human lives and in economic terms. The multitude of hazards present different dangers and the differing vulnerability of populations across the world make the task of preparing and limiting their impact a difficult and complex one. However the increase in scope and frequency of natural disasters (figure 1) necessitates a step change in the efforts to address them by the global community.

"EM-DAT:
The OFDA/CRED
International
Disaster Database
http://www.emdat.net
Université Catholique
de Louvain
Brussels – Belgium



EM-DAT: The OFDA/CRED International Disaster Database
(http://www.cred.be)
Figure 1

At the time of writing this report the estimated impact of the Asian tsunami was as follows:"

- 305,276 dead or missing
- 500,000 injured
- 1.7 million internally displaced
- 4 million impoverished
- 2 million unemployed
- 410,000 housing units destroyed
- Citizens of ~ 40 countries killed and injured
- Economic losses as high as US$13.4 billion (Euro 10 billion)
- Insured losses between US$2.5 and 4 billion (Euro 1.9 – 3 billion)

2. The current heightened political attention on the subject of natural hazards provides a unique opportunity to influence government policy and decision-makers internationally to invest proactively in disaster risk management on a global basis.

3. The World Bank has determined that every dollar spent in preparing for a natural disaster saves seven in response[1]. During the 1990s, for example, the Bank estimates that economic losses due to natural disasters could have been cut by US$ 280 billion through just US$ 40 billion of appropriate advance spending. Going forward, it is reasonable to assume that the cost-effectiveness of anticipatory measures will apply at least as much to catastrophes of global extent as to local natural disasters. The potential economic losses are illustrated by the particular case a potential major earthquake in Tokyo (which geologists assess could occur within the next 100-150 years) which is expected to incur economic losses of US$3.3 to US$4.3 trillion, with potentially catastrophic implications for the planetary economy.

1. Natural Disasters: Counting the cost, March 2004.

4. The cost effectiveness of spending to mitigate economic losses is an important part of the argument for taking action on preparedness and mitigation, including early warning. However other potential consequences of a global catastrophe are manifold and incommensurable in economic terms, from large losses of life to threats to socio-political stability and security. We are faced with a stark choice when it comes to dealing with global geophysical events. Either take no action and incur the risks – potentially trillions of dollars of economic losses and millions of lives lost – or exercise precaution in the face of scientifically established global threats and take practicable measures to mitigate their impact.

5. In the wake of the Asian tsunami the Prime Minister asked the Government Chief Adviser to bring together a group of experts to advise on the mechanisms that could and should be established for the detection and early warning of global physical natural hazards. The Group[2] was asked to:

- Focus on global risks which have a low level of occurrence, but have a high impact when they do occur and for which an appropriate early warning system could be designed and/or implemented.
- Consider the global systems currently in place and under development and their effectiveness in pulling together scientific evidence and using it to put effective early warning systems in place.
- Consider whether there is an existing appropriate international body in place to pull together the international science community to advise governments, on a regular basis, on the type of systems that need to be put into place, how they can be improved and augmented over time, and also advise on future research to fill current gaps in knowledge.
- If it considered there was no appropriate international body, or that other arrangements would be more effective, the working group would make recommendations.

6. This Report represents the Group's examination of these issues and makes recommendations as appropriate.

2 Natural Hazard Working Group membership and terms of reference can be found at Annex A.

Natural Hazards

7. The Group reviewed the science relating to physical natural hazards which have significant impact, the global early warning systems in place and under development including the Global Earth Observation System of Systems, and the effectiveness of these systems in utilising the scientific evidence available.

8. Natural hazards cover enormous ranges of scale, frequency and impact. The Group focussed on high magnitude global geophysical hazards that have the capability of affecting the entire planet, either physically and directly or via 'knock-on' effects on the global economy or social fabric. These include earthquakes, volcanoes, storm surges, tsunamis and collisions with near earth objects (comets and asteroids). Examples of future hazards with potential significant impact include:

- seismic and tsunami threats from locked fault segments in South and SE Asia;
- the next major Tokyo earthquake referred to above;
- the next major Cascadia earthquake (off the coast of the U. S. Pacific North West) likely to be in the region of magnitude 9 generating major local and Pacific-wide tsunamis;
- collapse of La Palma's Cumbre Vieja volcano, posing a major tsunami threat to the Atlantic Basin;
- catastrophic failure of the Sarez lake natural dam (Tajikistan) which threatens millions of people in Tajikistan, Afghanistan, Uzbekistan and Turkmenistan;
- a very large magnitude volcanic eruption that severely impacts on a large city or region
- near earth objects with a diameter of 100m or greater (several times a year these make close approaches though none is currently predicted to impact).

9. The Group also noted the impact of higher frequency extreme meteorological events such as tropical cyclones and other windstorms, floods, heatwaves, drought and space weather (which often have greater cumulative impact than high magnitude low frequency events), and discrete abrupt climate change events linked to global warming such as Gulf Stream shutdown (or slowdown) and melting of the Greenland and West Antarctic Ice Sheets.

10. Science and technology can help us to understand the mechanisms of natural hazards and to analyse their potential transformation into disasters. However the state of understanding of differing natural hazards and their potential impact is variable. For some there is a good scientific consensus, but there are important areas of significant shortcomings in understanding and information relating to these potentially catastrophic events. Scientific knowledge of the forces of nature is made up of a wealth of information that has been learned through study, experiments, and observations of natural hazards and their impacts on mankind. The scientific and technological disciplines that are involved include basic physical and engineering sciences, natural, social and human sciences. They relate to the hazard environment (hydrology, geology, geophysics, seismology, volcanology, meteorology, atmospheric physics; space science; space engineering; earth observation; solar system studies and biology), to the built environment (engineering, architecture, and materials science) and to the policy environment (sociology, humanities, political sciences, and management science).

11. Over the last three decades, scientific knowledge of the intensity and distribution in time and space of natural hazards, and the technological means of confronting them, has expanded greatly. There have been dramatic advances in the understanding of the causes and parameters of natural phenomena, in modelling techniques for predicting their behaviour and in technological means of resisting their forces. Progress in the science and technology of natural hazards and of related coping mechanisms have made it possible over the past years to introduce significant changes in our response to natural hazards. For example major progress has been made in the development of global meteorological models and their application to large-scale weather prediction.

12. Some hazards have global or regional impacts, and require international cooperation. For example hydrometeorological events can have impacts which affect a number of countries within a region. Further examples include tropical cyclones, drought, heatwaves and trans-boundary pollutants and any threat which is air or waterborne for example nuclear, chemical, wild-land fires, and some diseases. Storm surges have killed far more people than tsunamis, for example in Bangladesh over half a million people have been killed in surge events in the last 35 years. Due to the nature of meteorologically related events international cooperation is needed to observe and then forecast the likely developments. Additionally, effects of globalisation can result in impact which goes beyond the geographical region affected.

13. Frequently a major incident of one type may result in disasters of another. For example a volcanic eruption may cause deaths very close to the volcano. However the eruption may also cause air pollution hazardous to aircraft and cause health impacts over a much larger area, and have an effect on the climate which could have an associated impact on other types of hazards. The impact of a near earth object on earth can trigger a tsunami. A tropical cyclone can cause a storm surge, or a disaster can cause health effects due to the spread of disease (some of which are affected by weather conditions).

14. Application of scientific knowledge in understanding the cause, timing and effects of hazards is an essential element of disaster risk management. This should include an understanding of the vulnerability of different countries and populations in order to assess the likely impact. Considerations should include geographical coverage; likely locations of the hazards; local infrastructure (e.g. types or locations of buildings to withstand high winds or floods) and location of settlements (e.g. in a flood plain). The effectiveness of damage limitation planning and engineering is evident from the differing impact of seismic activity depending on local planning and resources (eg. in 1988, seismic activity registering 6.9 on the Richter scale claimed 25,000 lives in Armenia, while activity in California registering 7.0 had claimed 63 lives).

Early Warning Systems (EWS)

15. Effective early warning systems (EWS) should address a chain of concerns. Essential elements include forecasting and prediction, assessment, preparedness, effective means of communication, appropriate technology and maintenance arrangements.

16. In addition to an up to date scientific knowledge base, the long term effectiveness of any early warning system will depend on the suitability and reliability of the technologies employed; maintenance of a sufficient level of funding to ensure operability; and a rigorous top to bottom risk communication network accompanied by prior education of at-risk populations. The required technologies already exist to provide warnings for most global natural hazards, and the requirements for early warning systems are generally known. However coverage of early warning systems for most natural hazards is inadequate. In particular there is a need to do more to enable developing countries to more fully utilise scientific knowledge and technology. The main global mechanisms with an early warning system role currently in place or under development are the Global Earth Observation System of Systems (GEOSS) which aims to develop a comprehensive, co-ordinated and sustained earth observation system of systems and the WMO early warning system for weather, water and climate related hazards. *Further information on both these frameworks can be found at Annex C.*

17. Maintenance is a key issue for many developing countries. Systems to mitigate infrequent but high impact events are problematic: long term maintenance of high tech systems which may be used infrequently is difficult and expensive. Ongoing maintenance seems to deter many nations from wanting to put DART (Deep Assessment and Report of Tsunamis) systems in place. When the Asian tsunami occurred, three of the six DART buoys in the Pacific Ocean early warning system were out of commission. African geological survey laboratories are littered with the non-functioning remains of high tech western donated equipment.

18. Experience shows that systems routinely used for other monitoring functions – and thus frequently tested - will be reliable in the event of an infrequent major hazard. Once a main infrastructure is in place and embedded for the early warning role it can be supplemented by instruments for other purposes, probably at minimal cost.

19. Some types of hazard are more amenable than others to prediction and warnings. Some have precursors to events which give short timescale warnings, for some the scientific understanding and nature of the event are such that we can provide reasonably accurate forecasts of the likely location, strength, timing etc of such an event (e.g. near earth objects, tropical cyclones) whilst accurate prediction of earthquakes for example is not currently possible. *Additional information on the types of natural hazard and the threats they pose is provided at Annex B.*

20. Appropriate links between organisations responsible for warnings and authorities responsible for acting upon the warnings are essential, as are appropriate mechanisms to disseminate understandable warnings to political authorities and the population. The different sectors need to work together: scientists, warning organisations, national governments and local authorities responsible for action plans. This requires good governance and identified points or channels of responsibility.

21. Warning systems can however, only be truly effective if appropriate action plans are drawn up to respond to the different types of impending events. These should include measures to educate and raise awareness among the local population so that they understand the hazards and know how they should respond to a warning and so reduce their vulnerability.

22. The influences on effectiveness of early warning systems are therefore dynamic and interconnected: scientific understanding of the hazards continually being improved, vulnerability changing, warning capability improving, governance and politics effecting links between different organisations and points of responsibility, and changing awareness of the population. By encouraging all sectors to work together on a continual basis, a virtuous cycle of continuous improvement should be better assured.

International frameworks for Early Warning Systems

23. In considering whether there is an existing appropriate international body in place to pull together the international science community to advise governments, the Group met with senior officials from the United Nations Educational, Scientific and Cultural Organization/Intergovernmental Oceanographic Commission (UNESCO/IOC) and the UN International Strategy for Disaster Reduction (ISDR). Discussions centred on the role of the UN in disaster reduction and the scope of the International Early Warning Programme – a UN led initiative to develop shared and systematic approaches to early warning systems which was announced at the Kobe World Conference on Disaster Reduction. In this context the Group considered the role of other relevant bodies including the World Meteorological Organisation, the Group on Earth Observation and the Intergovernmental Panel on Climate Change.

Details of relevant international frameworks and bodies can be seen at Annex C.

Observations

24. There are many different types of natural physical hazards which can turn into disasters if appropriate monitoring and warning systems, based on good scientific knowledge, are not in place or appropriate measures are not taken to reduce the vulnerability of the population. Some of these hazards are low frequency but have very high impact, whilst others are high frequency but can have a high impact either in a single event or through a cumulative effect of a number of events over a period of time.

25. Despite progress made in the field of science, technology and research on natural hazards it appears that scientific knowledge is often poorly applied to disaster risk management policies and programmes. Examples include:

- A hazard assessment report on Soufriere Hills Volcano, Montserrat delivered to the UK and Montserrat governments in 1986[3]. The Report emphasized the high chances of a volcanic eruption on the island by the end of the century, and identified the capital of Plymouth as an area where it would be unwise to make major capital investments. The report was lost and there is no evidence that it was used by either Government. The eruption started in 1995 and over 100 million pounds of investment in new infrastructure, including a hospital and government buildings built in the wrong place, was destroyed.
- In the Summer of 2004 Kerry Sieh, a Professor of Geology from Caltech's Tectonics Observatory in California led a team visiting the islands above the western Sumatra megathrust fault. The people he spoke to were surprised when they were informed that they were vulnerable to a possible devastating earthquake or tsunami. Government officials cancelled a meeting with Professor Sieh because of other priorities[4].
- In March 2005, in an article in Nature magazine[5], Professor John McCloskey and his team at the University of Ulster warned that there was an increased chance of another large earthquake either in the Sunda trench subduction zone, which lies off the southwest coast of Sumatra, or along the neighbouring Sumatra fault, that runs northwest southeast through the middle of Sumatra. Later that month there was indeed a further large earthquake.

3 Wadge, G. and Isaacs, M.C., 1987. Volcanic hazards from Soufriere Hills Volcano, Montserrat, West Indies. A report to the Government of Montserrat and the Pan Caribbean Disaster Preparedness and Prevention Project. University of Reading, UK.

4 TIMESONLINE 2 January 2005, TIME Asia Magazine 3 January 2005

5 Nature, vol 434, 17 March 2005

A pyroclastic flow generated during the eruption of Montserrat's Soufriere Hills volcano, September 1996.
Image courtesy of Bill McGuire

Phi-phi island (Thailand) in the aftermath of the Indian Ocean tsunami
Image courtesy of Tiziana Rossetto, Benfield Hazard Research Centre, University College London

26. There is a need to assess more systematically what the science base has to offer, and then to strengthen and improve the integration of scientific knowledge and evidence into decision making and actions. This was recognized in the Framework for Action document issued at the Kobe World Conference on Natural Disasters earlier in 2005: that there was a need to "support the development and sustainability of the infrastructure and scientific, technological, technical and institutional capacities needed to research, observe, analyse, map and where possible forecast natural and related hazards, vulnerabilities and disaster impacts."

27. However it is important to acknowledge the limits of some countries to make effective use of the knowledge and implement early warning systems, and to build on this. It should also be noted that there can be great sensitivity on the part of developing countries that a 'western' or 'developed country' solution which is not suitable for, or owned by them, is being imposed.

28. There is a need to recognise the critical importance of viewing natural disasters not as isolated hazard events but often as intrinsically linked to vulnerability which is often driven by social, economic and political factors and, therefore, part of the broader development context. Indeed, as poorer countries continue to suffer disproportionately from the impacts of natural disasters there is clear evidence of the integral links between disaster vulnerability, poverty and development (more than half of disasters occur in low human development countries even though only 11% of people exposed to hazards live there, and these countries suffer far greater economic losses relative to their GDP than richer countries).

29. It is important that global knowledge of science and technology is effectively brought to bear ie. targeted and communicated. There is a good science base but scientific knowledge about natural hazards is not always shared. This occurs for several reasons: financial; political, commercial; concerns about how the data will be used; insufficient national capacity or systems to utilise or share data. Sometimes advice and information is available that has been developed for other purposes and is only made available by default – it was not gathered for international use in the first instance. Sometimes knowledge is not shared and acted upon simply because there is no mechanism to share it. Removing some of these obstacles to sharing information could be a role for an International Science Panel on Natural Hazard Assessment (see key recommendation below).

30. Up to date databases have an important role to play in understanding and planning for natural disasters. There is significant scope for improving the quality of information contained in databases without necessarily incurring excessive cost. There is also scope to improve the sharing of information currently available, building on existing operational warning systems. Exploitation of databases involves more than simply sharing raw data. It involves intelligent interrogation and manipulation of information and an understanding of the science that lies beneath the data.

31. Scientific knowledge is necessary in all stages of an early warning system, from mapping the hazard and assessing vulnerability, through monitoring and forecasting, through dissemination of a warning in an understandable way to the relevant decision makers and the population, and development of appropriate action plans.

32. Past experience in different regions exposed to high impact hazard events has shown that attention to the scientific and technical elements of early warning systems must be matched by an equal emphasis on strengthening the national capacity to maintain systems and to receive and disseminate warning messages from the national to the local level.

33. The Kobe World Conference on Disaster Reduction agreed that there is a need for a global multi-hazard early warning system, building upon the existing capabilities and frameworks, under the coordination of the United Nations. The Group endorses this view. There is a clear need for a sustainable and effective global multi-hazard early warning system building on existing capabilities and frameworks. Current programmes are as yet insufficiently co-ordinated; there is an evident need for a more effective and sustainable global approach. Greater linkage of national and international programmes is needed to use resources better, prevent duplication and ensure effort is focussed on gaps in infrastructure. The Group welcomes the developing Global Earth Observation System of Systems (GEOSS) and recognises the high level of effectiveness of organisations such as the WMO. The UN has a key role in this area, however there is duplication between UN agencies. The International Strategy for Disaster Reduction (ISDR) while generally well conceived currently lacks the capacity and resources to play its designated role effectively.

34. The global operational warning system used within the hydrometeorological community is very mature and has been proven to be effective for different types of hazards, from short range through seasonal forecasts to climate predictions, including tropical cyclones and emergency response such as predicting the plume track and fallout from an accidental nuclear release. The same system is used to provide warnings of the spread of volcanic ash plumes in conjunction with the International Civil Aviation Organisation (ICAO). It is also being used, in conjunction with UNESCO, for the exchange of tsunami warnings within the Pacific region and is planned to be used to exchange the tsunami warnings within the Indian Ocean when this system is developed. Developing awareness and response to a high frequency event can help to prepare for response to a low frequency event with similar impact characteristics (e.g. storm surge and tsunami).

Hurricane Fran struck the state of North Carolina in September 1996, causing damage totalling US$5 billion – the third costliest hurricane in US history.
Courtesy: NOAA

35. There is a need for different sectors of the physical sciences to work together, and to work in multi-sectoral partnerships with the social and medical sciences and other sectors involved in disaster risk reduction. This is needed to ensure that scientific knowledge is properly coordinated and applied to disaster risk management policies and programmes. It would also strengthen and improve the integration of scientific knowledge and evidence into decision making regarding disaster risk reduction. Integrating different types of hazards into a common approach would be cost-effective and would help ensure consistency in the communication of warnings and in action plans.

Recommendations

36. In the course of its work and as outlined in this report, the Group has identified weaknesses and gaps in the global response to the threat of natural hazards with potentially great impact. These shortcomings relate to a range of concerns: gaps in knowledge, lack of communication and co-operation and ineffective international frameworks.

37. **The Group's key recommendation is the establishment of an International Science Panel for Natural Hazard Assessment.**

38. In an increasingly populous and interconnected world, large-scale geophysical hazards have the capability of delivering death, destruction and economic and social chaos far beyond the boundaries of a single state. Relatively low frequency, high magnitude geophysical events have so far attracted little attention from a hazard mitigation and disaster management perspective. The events of Boxing Day 2004 have demonstrated, however, that we ignore such extreme hazards at our peril. We are faced with a stark choice when it comes to dealing with them; take no action and accept without complaint the consequences – potentially trillions of dollars of economic losses and millions or tens of millions of lives – or take up the challenge now of identifying such threats, understanding the processes and mechanisms that underpin them, and developing an effective system for advance warning.

39. Scientists have a major role to play in the practical application of knowledge and understanding to help lessen the human and economic impact of natural hazards. Before the December 2004 tsunami there was sufficient weight of scientific knowledge which, had it been effectively communicated to decision makers, should have resulted in better preparedness. However there was a failure to apply what had been learned about earthquakes and tsunamis to warn vulnerable populations. There should also have been a better way to communicate the emerging scientific evidence on the risks of further events in the same region. In the event there was indeed a further major earthquake in March 2005 on the same fault line, south of the initial one, though not, fortuitously, a further tsunami.

40. We are clear that there is an urgent need to improve the integration of scientific knowledge of natural hazards into the management of early warning. Robust communication lines between the scientific community and decision-takers must be established and strengthened to ensure effectiveness.

Key Recommendation

We recommend the establishment of an International Science Panel for Natural Hazard Assessment. The Panel would enable the scientific community to advise decision-takers authoritatively on potential natural hazards likely to have high global or regional impact. It would facilitate individual scientists and research groups pooling their knowledge and challenging each other; it would address gaps in knowledge and advise on potential future threats. It would address how science and technology can be used to mitigate threats and reduce vulnerability.

41. Our recommendation to establish such a Panel is intended to fill a gap in existing efforts to address the threat posed by natural hazards. It should not replace or duplicate existing frameworks or institutions. The Panel would bring together scientists from both developed and developing countries. It would be attached to, or work closely with, international organisations whose roles include the identification and monitoring of potential large-scale natural threats. For example it could provide an international initiative to support the integration of scientific knowledge which the Group on Earth Observation (GEO) could build upon, and provide a mechanism to support GEO in promoting consensus-building about the highest priority observation needs. It could also provide a source of scientific and technical advice for GEO, complementing and working with existing scientific advisory bodies such as the International Council for Science (ICSU) and the Global Climate Observing System (GCOS).

42. The Panel's responsibilities might include:

- Assessing threats, validating forecasts and predictions, and anticipating future events
- Presenting a global exposure and vulnerability assessment on the basis of the above eg. addressing people, infrastructure, economic and social impact
- Identifying gaps in knowledge
- Identifying barriers to sharing knowledge eg. capacity, security, commercial, finance, political
- Facilitating sharing of information and data
- Building a database of potential global and para-global geophysical events and their likely impacts
- Fostering international dialogue
- Supporting the quality and number of relevant databases, electronic fora, online libraries, project tracking systems
- Promoting closer collaboration and better linkages with existing relevant programmes and systems

43. The most effective working model might be one in which the input would be pertinent science undertaken by individuals, research groups and scientific agencies, and the output would be informative products, threat identifications and warnings, recommendations and proposals for action. These would be targeted at, and designed to inform, national governments, international agencies, NGOs, civil defence and emergency groups.

44. The Group's recommendation to establish such a Panel is intended to fill a gap in existing efforts to address the threat posed by natural hazards. It would not replace or duplicate existing frameworks or institutions. The Panel as envisaged above would sit comfortably within the overall UN disaster management framework and have close links with relevant agencies and initiatives to ensure that its findings are applied. In establishing the Panel any ongoing plans for reform of the UN disaster reduction framework should be taken into consideration. However plans to reform the UN infrastructure should not delay the establishment of the Panel.

45. While not in a position to precisely cost the establishment and work programme of such a Panel, benchmarking against similar bodies indicates an annual cost in the region of £1million. If the Panel were to make maximum use of existing co-ordination systems (for example within the UN framework) the cost could be as low as £0.5m. The Group is confident that these costs would be minimal compared with the potential benefits, both in terms of economic costs and human lives.

46. As mentioned above, the global operational warning system used within the hydrometeorological community, through the WMO framework of National Meteorological and Hydrological Services (NMHSs) has been proven to be effective for different types of hazards, from short range seasonal forecasts through to climate predictions, and including tropical cyclones and emergency response such as predicting the plume track and fallout from an accidental nuclear release.

47. The WMO is involved in the development of a tsunami early warning system for the Indian Ocean. UNESCO/IOC supports the Pacific Ocean member states in the establishment and maintenance of tsunami early warning systems, in partnership with the WMO (in particular through the use of its global telecommunication system to exchange the warnings) and its NMHSs in the region (many of which have the national mandate for tsunami warnings). The WMO and IOC are also now working in partnership with the countries in the Indian Ocean and with interested donor countries, to establish a tsunami early warning system for the Indian Ocean. The possible expansion of the system to include other types of weather and water-related hazards, including for air-borne disease, wild-land fires is currently being discussed.

48. The WMO system is also used to provide warnings of the spread of volcanic ash plumes in conjunction with the International Civil Aviation Organisation (ICAO). A network of nine designated centres around the world (major NMHSs, including the Met Office in the UK) are responsible for advising international aviation of the location and movement of clouds of volcanic ash, working with other relevant organisations such as those responsible for monitoring major volcanoes. This system could be extended to provide warnings of ash fall downwind of an eruption, through improved modelling (which would benefit from closer collaboration between meteorologists and volcanologists involved in the development of models), and closer partnerships between the Volcanic Ash Advisory Centres and the organisations responsible for monitoring the volcanoes (e.g. national geological surveys), as well as those organisations responsible for such warnings within the different countries likely to be affected.

49. These examples demonstrate the potential of how the WMO system could provide a framework for the operational exchange of warnings of other types of hazards eg. geophysical hazards such as volcanoes. It would have the benefit of utilising a system which is already a 24/7 operational system which is frequently tested on different types of hazards and has members in 187 different countries. It would also have the benefit of utilising the same links with the decision makers, authorities and public, and acting as a channel for further scientific input into these links for different types of hazards. To perform this role effectively the WMO would need to establish effective working relationships and operational communications with other relevant bodies, including the Science Panel recommended above.

50. This would provide a cost-effective approach to the development of a global multi-hazard early warning system, with the same basic telecommunication and information systems being used for the exchange of different types of warnings, but with appropriate links with the organisations with the expert knowledge of the particular hazards and appropriate specific action plans for the different types of hazards. It would also have the benefit of being able to deal more effectively with the effects of one hazard on another, rather than having these dealt with in separate systems. If the hydrometeorological community is to expand its responsibilities this will require co-operation both with other national and international organisations that traditionally have dealt with geohazards and with emerging frameworks such as the Global Earth Observation System of Systems (GEOSS).

Recommendation 2

We are impressed by the global operational warning system used by the hydrometeorological community. This system is mature and has proven to be effective. The World Meteorological Organisation system is supported by 187 countries and operates 24 hours a day throughout the year. However for most other natural hazards there is no single internationally recognised authority or official warning process. There is therefore a real risk of ineffective, inaccurate and conflicting warnings. We recommend consideration of the possibility of developing the WMO framework to provide an authoritative co-ordinated warning system for other natural hazards. To do this it would need to establish effective working relationships and operational communications with other relevant bodies, including the Science Panel recommended above. The Group is confident that the cost of implementing this recommendation would be small. Extending use of the WMO framework in this way would require minor upgrades of some existing systems and some additional staff.

51. For any early warning system to be effective it is essential that national disaster co-ordination centres meet a minimum operational standard. Once an early warning of an imminent event has been issued, countries must have the means to disseminate it to those at risk and the ability to undertake timely action such as evacuation of vulnerable communities. In many countries this is not the case, or is insufficiently the case. For example, there can be lack of clear governance and infrastructure, inadequate equipment, insufficient or inexpert staff and ill-informed population.

Recommendation 3

We recommend that governments and international bodies prioritise national capacity building for hazard risk management. In particular greater support should be given at the national level to the improvement of scientific and technical methods and capacities for risk assessment, monitoring and early warning.

52. In conclusion the Group notes that although there is much being done to mitigate the impact of physical natural hazards, not least through a wide range of initiatives following the Asian tsunami of December 2004. However a recurrent theme is the existence of barriers to effective international co-operation through relevant responsible organisations. Our recommendations are intended to address some of the barriers that exist in the communication and sharing of scientific knowledge, however there remains much more to be done.

Annex A

Natural Hazard Working Group Terms of Reference

The Prime Minister has asked the Government Chief Scientific Adviser to bring together a small group of experts to advise on the mechanisms that could and should be established for the detection and early warning of global physical natural hazards.

The group will focus on those global risks which have a low level of occurrence, but have a high impact when they do occur and for which an appropriate early warning system could be designed and/or implemented.

It will consider the global systems currently in place and under development and their effectiveness in pulling together scientific evidence and using it to put effective early warning systems in place.

It will consider whether there is an existing appropriate international body in place to pull together the international science community to advise governments, on a regular basis, on the type of systems that need to be put into place, how they can be improved and augmented over time, and also advise on future research to fill current gaps in knowledge.

If it is considered that there is no appropriate international body, or that such a body could be improved or augmented, or that other arrangements would be more effective, the working group will make recommendations.

Members

Members of the Working Group served as individuals and not as representatives of their affiliated organisation

Professor Sir David King FRS (Chair)	Government Chief Scientific Adviser and Head of the Office of Science and Technology
Dr Gill Ryall	Meteorological Office
Dr David Ovadia	British Geological Survey
Professor Jim McQuaid CBFREng	University of Sheffield
Professor Bill McGuire	University College London
Dr Shamita Das	University of Oxford
Dr Colin Hicks	British National Space Centre
Professor Geoffrey Boulton FRS	University of Edinburgh
Professor David Williams	University College London
Professor Stephen Sparks FRS	University of Bristol
Professor Alan Thorpe	Natural Environment Research Council
Professor Howard Dalton FRS	Chief Scientific Adviser, DEFRA
David Peppiatt	ProVention Consortium Secretariat
Professor Ed Hill	Proudman Oceanographic Laboratory
Professor Ian Davis	Cranfield Research Centre

Secretariat

Robert Canniff	Office of Science and Technology
Helen Almey	Office of Science and Technology
Judy Britton	Office of Science and Technology

Annex B

Background note on the different types of physical natural hazard and the underlying science

Earthquakes

The earthquake Process

Earthquakes occur when crustal stresses cause strain to accumulate around faults in the Earth's crust. When the strain exceeds the material strength of the rock, frictional sliding occurs along the fault and strain energy is released, some of it in the form of seismic waves that travel out from the fault zone. It is these waves that cause the observed ground shaking during an earthquake. The size of the earthquake depends on the dimensions of the fault, the amount of slip, the accumulated strain and stiffness of the rock.

Understanding the earthquake process is one of the basic goals of seismology. To some extent, this is relatively well established, with a large volume of both observational and theoretical work that has been developed over the last hundred years or so.

Leaning apartment houses in Niigata, Japan Tilted and collapsed apartment houses following the 1964 Niigata earthquake resulting from soil liquefaction and the behaviour of poor foundations.
Image courtesy of the National Geophysical Data Centre.

Where and when earthquakes occur

On a global scale most of the world's earthquakes occur in clearly defined zones, for example around the margins of the Pacific Ocean. This distribution is closely linked to the theory of plate tectonics and the dynamic processes at work in the Earth. The Earth's outer shell, or lithosphere, is relatively rigid and made up of a number of segments, rather like the piece of a jigsaw puzzle. These plates are continually moving at rates of a few cm per year, driven by convection deep within the Earth's asthenosphere. As the plates collide, diverge or move past each other this generates strain that is released in the form of earthquakes. As a result, most of the world's earthquakes occur at plate boundaries. In the case of the recent Sumatra earthquakes, the Indo-Australian plate is being pushed underneath, or subducted, below the Burmese and Sunda plates.

Earthquake Prediction

Although a great deal is known about where earthquakes occur, a major problem is predicting when an earthquake will occur. There is currently no reliable means of predicting earthquakes on a regular basis, despite 40 years of research into the subject. Some seismologists believe that routine prediction of earthquakes will never be possible because of the inherently chaotic nature of earthquake generation.

The success and usefulness of any method proposed for earthquake prediction is judged on the basis of bounds placed on:

- the magnitude of the earthquake predicted
- its location, including depth, which is critical in determining the potential for damage
- the time of the earthquake and
- the lead time of the prediction

Earthquakes may sometimes be preceded by precursory seismic activity such as foreshocks, but generally such precursors are only identified with the benefit of hindsight. Many major earthquake zones (e.g. California, Japan) are extremely well monitored seismically, but there has been no consistent observation of precursory seismic activity in these areas of the world. Analysis of how crustal stresses shift as a result of recent earthquakes has been suggested as a basis for forecasts of the likelihood of large earthquakes in the near future, but again, without precision. This stress transfer process has been widely observed, for example along the North Anatolian Fault in Turkey. In a recent article in the journal Nature[6], Professor John McCloskey and co-workers at the University of Ulster examined the possible stress

6 Nature, vol 434, 17 March 2005

changes caused by the 26 December 2004 earthquake in Sumatra. They concluded that there was an increased chance of another large earthquake either in the Sunda trench subduction zone, which lies off the southwest coast of Sumatra, or along the neighbouring Sumatra fault, that runs northwest southeast through the middle of Sumatra. The earthquake of 28 March 2005 would appear to be confirmation of this hypothesis. However, this method can be thought of a re-mapping the seismic hazard of a region, rather than a true prediction since, although it gives a measure of which fault segments are most likely to fail, it does not tell us when this might happen.

Earthquake Monitoring

There are well-established global networks of seismic instrumentation, for example the Global Seismographic Network (GSN) operated by IRIS (Incorporated Research Institutions for Seismology). The goal of these networks is to deploy permanent seismic recording stations uniformly over the earth's surface to allow global detection of significant earthquakes. Currently the GSN consists of over 128 stations, distributed globally, which all use high quality instrumentation and most of which have near real-time communications links. There are also numerous regional and national monitoring networks, which provide useful data on regional and local seismicity.

Although the culture of 24/7 long term, systematic regional or global scale monitoring is well established in the meteorological sciences, such a culture is embryonic in the geological sciences.

Volcanoes

No volcano erupts without precursory warning signs. To make a path to the surface, fresh magna must break rock – which generates earthquakes – and make space for itself, which causes a swelling of the overlying ground surface. Provided that a volcano is being monitored, both phenomena will be detected weeks or even months before an eruption starts. However there is no way at present of predicting the scale, duration or climax of an eruption. Equally it is possible for a volcano to show signs of 'unrest' without a following eruption, so that warning signs are not a guarantee that eruptive activity is certain.

Volcanoes can be monitored by a wide range of techniques and many volcanic eruptions can be successfully forecast if sufficient technical and human resources are available. The science is far from exact and successful forecasts and warnings are typically based on a combination of multiple monitoring techniques and the availability of experienced science and technical teams.

The effectiveness and robustness of the monitoring and state of knowledge is highly variable. Some regions are extremely well covered by national structures (eg Japan

and USA) or co-operative regional arrangements (eg the Pacific Northwest by the Alaska Volcano Observatory of the USGS and the Institute of Volcanic Geology, Russia). Other areas are poorly covered (eg much of South and Central America) due to poor resourcing or low priority by Governments. Probably less than 50 of the world's 1500 plus volcanoes are adequately monitored, partly as a consequence of most of them being in resource poor countries.

1974 eruption at Ngauruhoe, New Zealand New Zealand's most active volcano in modern times, with more than 60 eruptive episodes since its first recorded eruption in 1834.
Image courtesy of the University of Colarado/National Geographic Data Center

In general the science of volcanology is developing rapidly. A major gap, in terms of knowledge of rare global scale volcanic eruptions, is that it is not well understood what

characteristics a supervolcano would show prior to a major eruption. None has been witnessed; most scientists believe that the signs will be similar to those in small and medium sized eruptions, but we do not know for sure. A major difficulty is that supervolcanoes also have many small eruptions during their lifetime and we do not understand well what are the main controls on why some eruptions develop into catastrophic super-eruptions and many others don't. It is quite likely that not all the active supervolcanoes have been recognised and the next such eruption on Earth may well be from an unexpected place. A recent study at Cambridge, on behalf of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), indicates that the best estimate for the recurrence rate of super-eruptions (defined a little arbitrarily as chose involving more than 1015 kg of magma) is about 1 in 50,000 years.

Volcanology warning systems are based on national institutes, such as geological surveys and meteorological services. There is no global system for warning about volcanic eruptions except in the context of aviation safety.

There are approximately 80 volcano observatories in the World Organisation of Volcano Observatories (WOVO), which is co-ordinated under the IAVCEI. However at present there is essentially no funding to support co-ordination, interaction, data sharing and exploitation of any resulting benefits.

Hydrometeorological hazards

The majority of natural disasters are associated with hazards of hydrometeorological origin (weather or water related).These include floods, droughts, tropical cyclones, storms, heatwaves, cold spells, mudflows and landslides, waves and storm surges, and avalanches. . The relative frequency of such events means that the impact over a period of a few years is significantly greater than for either geological or biological hazards, particularly for developing and least developed countries. The Intergovernmental Panel on Climate Change has indicated that the frequency and severity of severe weather-related events is likely to increase due to climate change. The impacts of some geological and biological types of natural hazards are also related to the weather, in particular those which involve transport of "pollutants" through the atmosphere (e.g. spread of volcanic ash), and these too can have a regional impact or even affect the global climate.

Over the past few decades substantial advances in science have resulted in improved and more efficient methods for making and collecting timely observations from a wide variety of sources, including radars and satellites. However the international scientific community is emphasizing the still very poorly observed areas as being a limiting factor in the quality of some forecasts.

Tsunamis

Tsunamis are anomalous waves most commonly triggered by submarine earthquakes that involve the vertical displacement of a large area of sea bed (up to tens of thousands of square km). Destructive and lethal tsunami may also be generated by submarine landslides, during coastal, island and submarine eruptions, by the collapse of ocean island volcanoes and – rarely – by unusual meteorological phenomena. Their destructive capacity arises from great velocities (up to 800 – 900 km in the deepest ocean), wavelengths (crest-to-crest) of hundreds of kilometres (rather than a few tens of metres for storm waves), and run-up heights that may be 30m or more for quake generated tsunami but in excess of 400m for rare ocean island collapses or large impact events. Tsunami science is limited by knowledge of the geological sources, for example earthquake rupture mechanisms, and by the detail (land and sea topography) of where tsunamis impact and there is clearer the need for more extensive mapping of the earth's oceans. Japanese scientists recently presented statistics showing the vast majority of tsunamis they have monitored typically occur within 10 minutes of the causal earthquake. An early warning system for tsunamis in the Pacific Ocean was established in 1965 but it is worth noting that it has not been tested by a major tsunami event (although there have been several false alarms). A tsunami early warning system in the Indian Ocean is in the process of being built. NOAA (National Oceanic and Atmospheric Administration) plans to have the technological element of an Atlantic Tsunami Warning System operational by 2007. This will comprise five DART buoys in the Atlantic and another two in the Caribbean.

Tropical cyclones

Tropical cyclones (also known as hurricanes or typhoons) are areas of low atmospheric pressure that form over warm tropical or subtropical waters, eventually building up into a huge, circulating mass of wind and thunderstorms up to hundreds of kilometres in diameter. The strongest have sustained winds greater than 195km/h and wind gusts greater than 280km/h. About 80 tropical cyclones form every year in certain regions of the tropics.

Not all tropical cyclones move onto land from the sea, but when they do they can cause disasters of varying severity hundreds of kilometres inland, and a single tropical cyclone can affect a number of countries. Severe damage can be caused by the strong winds, and the heavy rainfall may last for days, and frequently causes flooding, or flash floods when the cyclone moves over land. Storm surges – bulges of ocean water formed by the cyclone – can ride on top of tides; when they move up riverine estuaries, they too can start large-scale flooding (see below).

Storm surges

Storm surges are often associated with tropical cyclones (see above). They are a major natural hazard in many vulnerable coastal and island regions around the world, and large ones regularly cause tremendous destruction in the Pacific, Atlantic and Indian Oceans, the Bay of Bengal and the Gulf of Mexico. One of the most dramatic examples on record occurred in 1970, when a massive storm surge left 300,000 people dead after it swept in over the coastal wetlands of Bangladesh. In the future, the rise in sea level associated with global warming, paired with land subsidence along fragile coastlines, may mean bigger storm surges and more vulnerability to them as well as to tsunamis. There is also concern that a rise in sea-surface temperatures may increase the number of tropical cyclones reaching coastlines, and thus the number of surges.

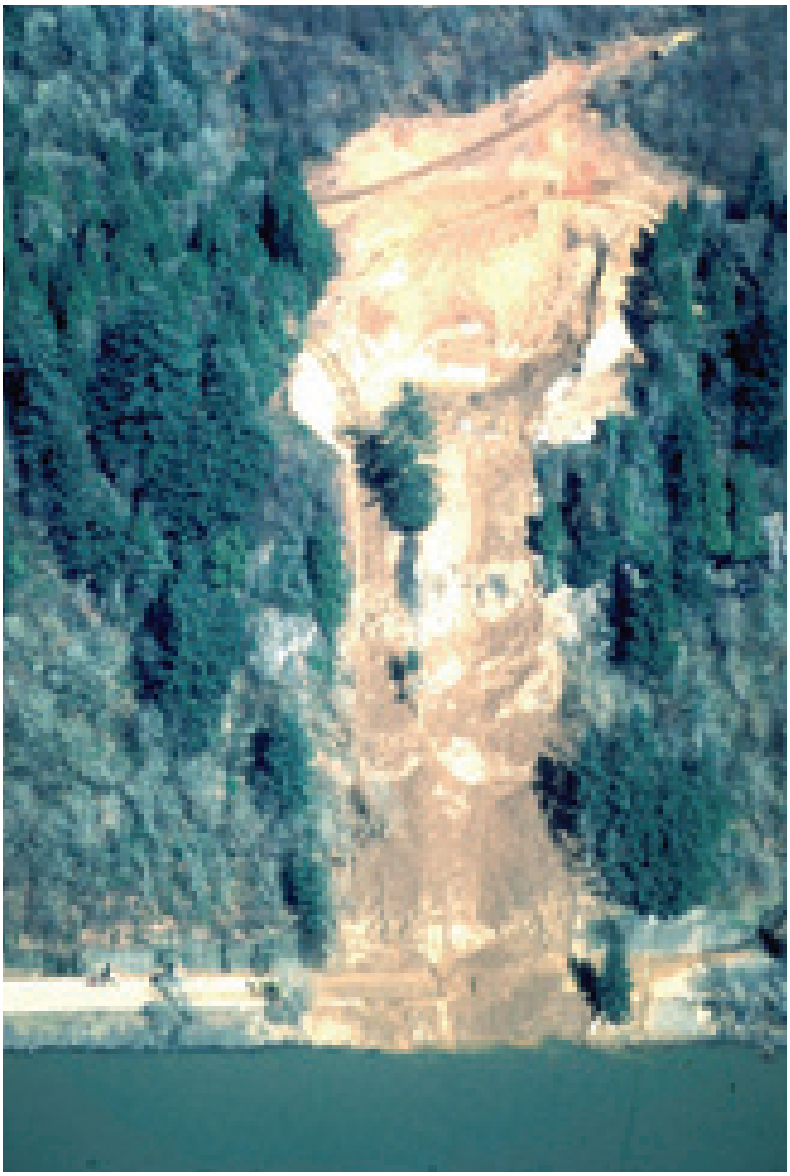
Floods

Flooding happens when rainwater or snowmelt accumulates faster than soils can absorb it or rivers carry it away. Floods come in various forms, from small flash floods to sheets of water covering huge areas of land. They can be triggered by severe thunderstorms, tornadoes, tropical cyclones and the El Nino phenomenon (where warm water in part of the Pacific sets off extreme weather elsewhere in the world). Some 1.5 billion people were affected by floods in the decade up to the millennium.

Floods are among the most common and most devastating natural disasters, and are on the rise partly due to climate change which has triggered heavier precipitation in parts of the Northern Hemisphere.

Landslides and mudflows

Weather-related landslides and mudflows cause billions of dollars in damage and thousands of deaths and injuries every year around the world, although they are generally not likely to encompass large areas. Landslides happen when heavy rain or rapid snowmelt sends large amounts of earth, rock, sand or mud flowing swiftly down mountain slopes, especially if bare or burnt by forest or brush fires. Mudflows and the coarser debris flows are essentially wet, fast-moving landslides that form when masses of loose, wet debris or volcanic deposits become unstable due to saturation from rainfall, melting snow or ice, or an overflowing crater lake.

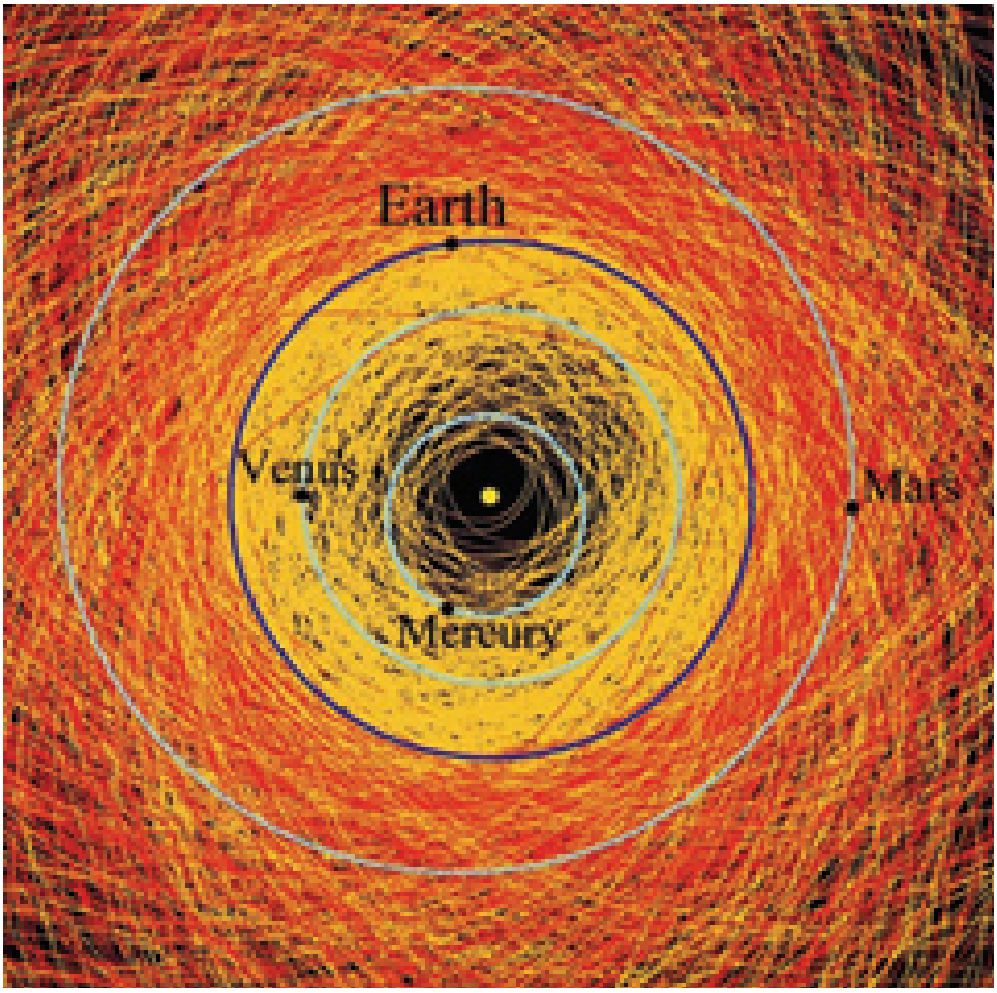


Landslide and debris flows, Stella, Washington Landslide in marine sediments over basalt, extending across Washington State Highway 4 into the Colombia River.
Image courtesy R L Schuster, US Geological Survey.

Near earth objects (NEOs)

Most near Earth object (NEO) impacts can be predicted precisely in time and location. There is a realistic chance that a predicted major NEO impact could be avoided by deflecting the NEO in its orbit. The Minor Planet Center (MPC). The MPC was set up by the International Astronomical Union and operates an effective EWS for near Earth objects by collecting observational data from telescopes world-wide and computing NEO orbits. Mechanisms for disseminating warnings of predicted NEO impacts are currently under development.

A US NASA programme to identify 90% of all NEOs of diameter larger than 1km (whose impacts would lead to global consequences)is nearing completion. However, smaller NEOs also present a hazard and their numbers are very much greater. Larger telescopes than are currently being used for NEO detection would be needed for similarly near-complete studies of the population of smaller NEOs.



Orbits of all Near Earth Objects known at the start of 2000, UK Task Force Report on Potentially Hazardous Near Earth Objects, September 2002
Image courtesy of Scott Manley Armagh Observatory Duncan Steel

In 2000 the UK Government responded to growing national and international concern about the risks associated with NEO impacts by commissioning the UK Task Force Report on Potentially Hazardous Near Earth Objects, published in September 2000 (www.nearearthobjects.co.uk). As a result of the Report the Government promoted widespread international discussions on the assessment and mitigation of risks associated with these impacts.

Space Weather

The risk from space weather relates to its ability to damage infrastructure on earth and in orbit. It can be the cause of major disruption to communication, navigation and positioning information and can also cause damage to power networks, as happened in Canada in 1989. Space weather is caused by energy surges from the sun – in effect storms from space of which the "Aurora Borealis" is one manifestation. The causes and behaviour of these storms are not yet well understood. Further scientific and technical research would improve the knowledge base and would help protect infrastructures at risk.

Annex C

International frameworks

The United Nations Educational, Scientific and Cultural Organization (UNESCO)/Intergovernmental Oceanographic Commission (IOC)

UNESCO, through the Intergovernmental Oceanographic Commission (IOC) supports the Pacific Ocean member states in the establishment and maintenance of tsunami early warning systems, in partnership with the World Meteorological Organisation (WMO) (in particular through the use of its global telecommunication system to exchange the warnings) and its National Meteorological Hydrological Services in the region (many of which have the national mandate for tsunami warnings). The IOC and WMO are currently working in partnership UN member states to establish in the first instance, a tsunami early warning system for the Indian Ocean, and in the longer term to establish a global tsunami early warning system. IOC is concentrating on the technical monitoring and forecast system, whilst WMO is working with the countries in the region to develop their communication systems.

UNESCO also has many programmes in place that have proven experience in the scientific study and mitigation of natural hazards including earthquakes, floods, volcanic eruptions, tsunamis, landslides and drought. The Organisation also works on the safeguarding and rehabilitation of educational and cultural institutions in disaster-prone countries. The UNESCO earthquake programme dates back to 1960. It promotes a better understanding of the distribution in time and space of natural hazards and of their intensity, and helps set up reliable seismological networks; it encourages rational land use plans and secures the adoption of suitable building design.

Plans have been announced to dissolve UNESCO's Earth Sciences Division, which includes programmes in Earth Observation and disaster reduction, and to cut funding to the International Geoscience Programme.

The World Meteorological Organization (WMO)

Events of hydrometeorological origin constitute the large majority of disasters. The World Meteorological Organisation (WMO) is the UN specialised agency for weather, water and climate. Through its scientific and technical programmes and its network of global forecasting centres, 40 Regional Specialized Meteorological Centres (RSMCs) and the National Meteorological and Hydrological Services (NMHSs) of its 187 Member States, it has a highly mature operational early warning system (operating 24 hours a day every day of the year) for weather, water and climate related hazards. This includes a global infrastructure for the observation, research, monitoring, detection,

forecasting, early warning and exchange of information related to hazards such as tropical cyclones, floods, droughts, severe thunderstorms, cold spells, heat waves, landslides, storm surges, sand storms, fires, locust swarms, accidental nuclear release, volcanic eruptions, air-borne diseases and chemical accidents.

International Strategy for Disaster Reduction (ISDR)

The UN International Strategy for Disaster Reduction (ISDR) is an intergovernmental process addressing natural hazards and disaster reduction, administered by a Secretariat in Geneva and supported by an Inter-Agency Task Force (IATF), comprising all relevant UN bodies and international organisations active in natural disaster reduction, thus providing a mechanism for bringing together the physical sciences with the other sectors. ISDR provides the coordination framework for all National Platforms for Disaster Reduction, which in many countries provide the forum for coordinating stakeholders (including scientific and technical expertise) and resources. UNESCO and WMO are considered to be among two of the leading agencies working within ISDR and active on the IATF in strengthening the scientific knowledge on natural hazards, particularly in relation to early warning and hazard monitoring. The IATF also includes the International Council for Science (ICSU) which has a special sub-committee on natural hazards.

The ISDR co-ordinates the International Early Warning Programme (IEWP), launched at the Kobe World Conference on Disaster Reduction. The IEWP is a vehicle by which partner organisations cooperate and develop shared and systematic approaches to advancing early warning systems worldwide. In theory the ISDR is the strategic UN agency through which the UN deals with disasters. In practice the UN acts principally through the triumvirate of UNESCO, the WMO and ISDR, of which the ISDR is very much the junior partner. Institutional reform of the ISDR including greater and more flexible funding has been signalled, although to date no proposals have been shared with the Group.

Group on Earth Observations (GEO)

The purpose of the international ad-hoc Group on Earth Observations (GEO) is to promote the development of a comprehensive, coordinated, and sustained earth observation system of systems among governments and the international community to better understand and address global environmental and economic challenges for the benefit of humankind. This is to be achieved by developing the Global Earth Observation System of Systems (GEOSS), a mechanism proposed by the United States for co-ordinating global early warning effort. GEOSS was proposed in recognition of the fragmented nature of geophysical monitoring. GEOSS implementation will enable improved monitoring of the state of the earth, increased understanding of dynamic earth processes, enhanced prediction of the earth system, and further implementation of international environmental treaty obligations. The GEO process is intended to:

- Cover the full spectrum of in situ and remotely sensed (space-based and aircraft) observations
- Provide an opportunity for all nations and international organisations to work together for a common cause, under a common agreed approach, framework, and methodology;
- Actively involve developing countries in making improved observations within their national territories, and access and use observations made by others;
- Provide a means to build on the efforts of current international initiatives and programmes to assess user requirements, identify caps in global observations, improve communication among nations and organisations with common interests in similar observation capabilities;
- Provide high-level (Ministerial) recognition of the universal need for improved earth observation and
- Promote consensus-building among participants about the highest priority observation needs, which are unmet or require significant increase in resources to provide comprehensive solutions.

The GEOSS 10-year implementation plan includes:

- Commitment of nations to make more complete long-term collection of high-priority earth observations;
- Plugging the gaps in observation capabilities;
- Capacity-building in both developing and developed countries;
- Greater interoperability and connectivity among individual component observing systems for improved exchange and sharing of data and information to commonly agreed standards.

The Intergovernmental Panel on Climate Change (IPCC)

The IPCC effectively provides a mechanism for providing a scientific consensus warning of the likelihood of human-induced climate change, its potential impacts and options for adaptation and mitigation. The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC does not carry out research nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed and published scientific/technical literature. To date the IPCC has produced 3 major scientific assessments of climate change and several special reports on specific aspects of climate change.

The IPCC has three Working Groups and a Task Force:

- Working Group I assesses the scientific aspects of the climate system and climate change.
- Working Group II assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it.
- Working Group III assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.
- The Task Force on National Greenhouse Gas Inventories is responsible for the IPCC National Greenhouse Gas Inventories Programme.

Global Monitoring for Environment and Security

The aims and vision of the Global Monitoring for Environment and Security (GMES) initiative under development by the European Commission and the European Space Agency are:

- To establish a European capacity for the provision and use of operational information for monitoring and management of the environment and civil security
- To support Europe's goals for sustainable development, environmental protection and global crisis management;
- Implementation of the environmental and civil policies of the EU
- Use of both space-borne and in-situ techniques to support science-based policies

The key thematic areas within the overall objectives are: (i) atmosphere monitoring, (ii) ocean monitoring, (iii) land monitoring, (iv) improving the risk management of environmental hazards, (v) water resources, and (vi) security.

International Council for Science (ICSU)

The International Council for Science (ICSU) is a non-governmental organization representing a global membership that includes both national academies (103 members) and international scientific unions (27 members). Through this extensive international network, ICSU provides a forum for discussion of issues relevant to policy for international science and the importance of international science for policy issues and undertakes the following core activities:

- Planning and coordinating interdisciplinary research to address major issues of relevance in both science and society;
- Actively advocating for freedom in the conduct of science, promoting equitable access to scientific data and information, and facilitating science education and capacity building;
- Acting as a focus for the exchange of ideas, the communication of scientific information and the development of scientific standards;
- Supporting in excess of 600 scientific conferences, congresses and symposia per year all around the world, as well as the production of a wide range of newsletters, handbooks, learned journals and proceedings.

ICSU also helps create international and regional networks of scientists with similar interests and maintains close working relationships with a number of intergovernmental and non-governmental organizations, including UNESCO, WMO and ISDR.

Because of its broad and diverse membership, the Council is increasingly called upon to speak on behalf of the global scientific community and to act as an advisor in matters ranging from ethics to the environment.

The International Union of Geodesy and Geophysics (IUGG) is the key ICSU Union for natural physical hazards. It not only deals with volcanoes, earthquakes, landslides and tsunamis but also with climate related hazards.

International Astronomical Union

The International Astronomical Union (IAU) has established an internationally based early warning system for near earth object impacts. The IAU's mission is to promote and safeguard the science of astronomy through international co-operation. It provides a co-ordination role for the professional research and education activities of its 9,000 strong membership.

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