The Role of Science in Preventing and Reducing Natural Disasters

Professor R S J Sparks FRS

Department of Earth Sciences, University of Bristol

Science has a central role in the forecasting and mitigation of natural hazards. It underlies technological solutions to early warning, provision of advice to authorities in areas at risk, design of effective mitigation strategies for communities, and provides critical information for policy-makers and the public to help save lives and avoid economic losses. The fulfilment of these roles for science is in practice complex and has not been entirely successful, as recent events such as the 2004 Asian tsunami, the 2005 Pakistan earthquake, and hurricane Katrina illustrate.

Natural disasters are increasing dramatically, principally because of increasing vulnerability of communities due to population growth, globalisation and environmental stresses. Some hazards, such as wildfires, droughts, floods, storm surges and hurricanes, appear to be increasing as a consequence of global warming. Risk from natural hazards can, however, be reduced by improving community resilience and the effectiveness of the application of known science. Science and engineering can help in many ways including: identifying risk, giving adequate warnings of impending natural hazards, designing buildings and structures that protect the public, giving advice to assist decision-making on issues such as land-use planning, sustainable development, mitigation strategies and responses during an emergency.

Rapid advances are being made in understanding natural hazards as a consequence of technological innovation and better models of Nature. There are now many different ways of monitoring the solid earth, oceans and atmosphere, which potentially allow hazards to be identified and forecast so that warnings can be given. Measurements of the Earth from Space provide a synoptic and global perspective that allows, for example, remote volcanoes to be monitored and tsunami waves to be tracked across the ocean. Increased computer power also allows much more sophisticated and intricate models of hazardous processes. Despite these advances the many hazards are not anticipated and the known science is not applied effectively. There are also limits to the ability of science to predict precisely due to the uncertainties that are intrinsic to most natural processes. There are epistemic uncertainties (what we don't yet know) and aleatory uncertainties (natural variability). The science that describes natural events and characterises the inherent uncertainties is complex and also provides great challenges in communication to the public and to decision-makers.

There needs to be much more integration of the social and natural sciences. Natural hazards only result in risk and disaster if there are people living on the flood plain, or next to an active volcano, or near a geological fault. Vulnerability needs to be better understood. It is a complex concept that depends on many factors including: the economy of an affected community; culture; social factors (such as demography, poverty, education, and religious perspectives); awareness of the hazard and its effects;

and politics. People's perceptions of risk also affect how they react to danger. These factors that affect vulnerability need to be combined with understanding of the hazard itself to estimate risk and develop strategies that increase community resilience and reduce risk. Such complexity calls for highly multidisciplinary research and feeding the results of such research into practical applications and methodologies.

Extreme hazards that are infrequent but have very high consequences are a particular problem. As one example the largest explosive volcanic eruptions on Earth have the potential to devastate whole nations, regions and may even threaten global civilisation. Such eruptions, however, only occur every thousand years or so. Several megacities (Rome, Santiago in Chile, and Manila for example) are built on young geological volcanic deposits from immense eruptions, that would destroy the cites were they to occur today. Extreme events are difficult to study because they are rare and the factors that control them are consequently not well understood. In general, the World is unprepared. Communities can gain experience of more frequent smaller hazards and learn to live with them, while they have no experience of infrequent extreme events.

The effects of natural disasters are particularly severe in the developing world where the ability to anticipate and respond to natural hazards is much less than in the developed world. The World Bank analysis suggests that natural disasters commonly reduce GDP in the developing world by 10 to 15%. Major disasters have long term consequences, such as setting back development by many years and even decades. The livelihoods of some poor communities may never recover with the disaster condemning the people to long-term poverty. Many countries lack the resources to support or make effective mitigation strategies, such as earthquake-resistant buildings or rehousing vulnerable communities into safer places with alternative livelihoods. Lack of human and financial resources for the development and application of natural hazard science can be acute. In general the scientists in poor countries do not have easy access to knowledge, facilities, equipment and educational resources that are taken for granted in the developed world. Mechansims to fund and support science in the developing world are completely inadequate. Those that exist are commonly due to the somewhat ad hoc arrangements with scientists from the developed world. Well-intentioned capacity-building schemes by NGOs, government aid programmes are typically too short-term to be very effective or sustainable.

The developed world in general is much more resilient to natural hazards. The same earthquake that kills a handful of people in California may kill tens of thousands in many Asian countries. However, even the wealthy nations appear ill-prepared for the more extreme events as exemplified by Hurricane Katrina and the Gloucester floods. There are also strong tele-connections. A next major earthquake in Tokyo may be the first trillion dollar disaster and the Asian tsunami caused the greatest loss of life for Sweden in its history from a natural disaster. There are more subtle, but hugely significant effects. Natural disasters hold back development and are a significant factor in the persistence of extreme poverty. Natural disasters can exacerbate conflict and cause economic migrations, which have big impacts on the developed world.

To a large extent the focus of aid agencies (such as DFID and the UNDP for example) and NGOs has been on the role of governance, ethnic tensions, sustainable and more efficient agriculture, desease reduction (eg aids and malaria), trade, and education in understanding the causes of poverty and in using funds for poverty reduction. Natural disasters have been largely seen in terms of disaster relief; most of the resources indeed go into short-term relief operations, notwithstanding the World Bank's estimates that for every $ spent on prevention $7 are saved. There are signs that this attitude is changing , but slowly.

Institutions and funding structures are a particular problem. At national levels in the developed world there remain strong barriers to the promotion of multidisciplinary projects, notwithstanding much rhetoric and warm words. Focus on specialist, discipline-based research remains dominant. International structures for science related to natural disasters and hazards are complex and in the UN system have lacked serious levels of funding. There are plenty of short-term projects and initiatives, but many of the key problems require a long-term approach and appropriate commitments. Too many programmes and initiatives have been too short-term to be effective to address chronic and often increasing problems of vulnerability in the developing World.

HOW CAN SCIENCE HELP TO PREVENT NATURAL DISASTERS BECOMING ECONOMIC AND HUMAN CATASTROPHES?

The Role of Science in Preventing and Reducing the Impact of Human-Induced Climate Change

Prof Chris Rapley CBE
Director, Science Museum

The Earth seen from space reveals a small blue orb in the inky darkness of the cosmos. The planet is unique, as far as we are aware, since it is the only location in the universe known to harbour life.

Energy from the Sun is the predominant driver of all activity on Earth. The balance between the energy intercepted and the energy radiated into space is almost exact. Small differences cause the planet to warm or cool.

The planet itself is hugely complex, with its various components – atmosphere, ocean, ice, biosphere, humans and the solid earth – all interacting, with a myriad of interconnections, many highly nonlinear. This makes it a considerable scientific challenge to understand. Progress through "reductionism" – the study of the component parts – is a necessary but insufficient part of the approach. Essential is a "systems" view, in which the planet is also considered as a whole.

A further challenge is the sheer enormity of the object of study, and the vast spread of spatial and temporal scales which need to be addressed. Even by aggregating the entire world's resources of researchers and their equipment, coverage is thinly spread, and priorities have to be sharply focused and addressed. International co-operation and co-ordination are essential.

There is no planetary "Users Manual" and the Earth is finite, without spares. All of life relies upon the "ecosystem services" it supplies free of charge. These include clean air, fresh water, food, fibre, and shelter, as well as more esoteric but high value services such as the pollination of crops. In spite of the self-evident need to care for and protect our irreplaceable "Life Support System", the state of the planet is increasingly unhealthy as a consequence of human activities.

Until the late eighteenth century, human energy use exploited the flows of wind and water and the capabilities of "beasts of burden", including other humans. The transition to fossil fuels has transformed the human condition incomparably for the better. It has also resulted in unprecedented growth in population, which, combined with an equally rapid growth in economic activity, has led to mankind constituting a force at the global scale.

Annual human emissions of carbon have risen from a few million metric tons in 1850 to more than 7 Gigatons (GtC) today (the CO_2 tonnage is 3.67 times greater). What matters to the atmosphere is the total amount of carbon that has been injected, estimated to be about 500GtC, with contributions of 320GtC from fuel burning and cement production, and 180GtC from land use change, mainly deforestation.

The lasting product of fossil fuel energy use is an increased loading of carbon dioxide in the atmosphere. Although the terrestrial biosphere (plants, trees and soils) and the oceans have absorbed roughly half of the human emissions, the atmospheric content has increased rapidly – a thousand times faster than the natural cycles of climate and carbon – and by more than 35% – a magnitude equivalent to the "natural" variations between an ice age and an interglacial.

The "Greenhouse Effect" has been known and understood since the mid-nineteenth century. The phenomenon is highly beneficial, since the Earth's surface is 30°C warmer than would otherwise be the case, making "life as we know it" possible. We have enhanced the effect, both directly and because a warmer atmosphere carries more water vapour. The upshot is an estimated net imbalance between the heat received by the surface and the heat lost to space of approximately $1.5W/m^2$.

More than 90% of the heat imbalance is absorbed by the oceans, and this can be seen in changes in the vertical temperature profiles averaged from thousands of measurements over the last 30 years. The measured warming of the land surface of some 0.7°C since pre-industrial times can also only be accounted for by the addition of human-induced forcing to "natural" variations.

The geographical distribution of warming is patchy, with parts of the polar regions showing the strongest increases. This is consistent with the amplification expected as a result of the "ice-albedo" feedback, in which the loss of ice and snow, which reflect about 90% of incoming solar radiation, exposes land or ocean which absorb about 80%. A very dramatic example of polar warming is the reduction over the last 30 years in summer sea ice extent in the Arctic. The record summer minimum in 2007 – some 25% less than the previous minimum in 2005 – caught the science community by surprise.

The Policy-Maker's summary of Working Group I of the Fourth Assessment Report of the UN's Intergovernmental Panel on Climate Change concludes that (i) current atmospheric greenhouse gas concentrations far exceed the levels of at least the last 650k years as a result of human emissions, (ii) warming of the climate system is unequivocal based on a mass of factual evidence, and (iii) the climate forcing is overwhelmingly human. These conclusions are based on an evaluation of thousands of peer-reviewed scientific publications and have been agreed by the politically appointed delegates of 113 nations, including nations whose administrations are "climate sceptic". There are indications that the conclusions of the IPCC tend to be conservative.

Comparisons of past global temperature and sea level show that whenever the world is warmer, sea levels rise. Any initial growth of the cold, high altitude interiors of the great ice sheets due to increased snowfall is more than compensated for by losses through melting and sliding around their peripheries.

Of particular concern, therefore, are the major ice discharges from the Greenland ice sheet and from the Amundsen Sea Embayment of the West Antarctic Ice Sheet (WAIS) revealed in data from spaceborne and airborne instruments. The stability of the WAIS has been a subject of speculation since the 1970s, as the bulk of it lies on bedrock well below sea level and so experiences an "Archimedian" uplift. The concern is that a retreat may accelerate and become unstoppable, resulting in sea level rise worldwide. The "trillion dollar questions" are "How Much?" and "How Quickly?" A major task of the International Polar Year 2007-2008 is to provide improved answers to these questions.

Future sea level rise has the potential to affect the lives of millions and to impact trillions of dollars worth of infrastructure. A single flooding of London would alone cost an estimated £30bn, equivalent to 2% of the UK's GDP. Could a flooded London be the future? The unthinkable can happen as we witnessed with New Orleans – for different reasons – in September 2005.

Looking ahead, the temperature projections from the IPCC show dramatic change. The UN Framework Convention on Climate Change commits nations to avoiding "dangerous" climate change. Some have adopted 2°C global mean temperature rise as the "safe" limit, corresponding to an equivalent CO_2 concentration of 450ppm.

In order to stabilise the CO_2 concentration of the atmosphere, it is necessary ultimately to stop adding it, especially as there is evidence that as the world warms the terrestrial biosphere and the ocean will weaken as carbon sinks, and may even become sources.

No single solution exists. However, multiple approaches, each seeking a reduction of ~1GtC/y by 2050 can in principle achieve the necessary reductions. These include improved energy efficiency and conservation, switching to less carbon intensive fuels, nuclear power, better management of the terrestrial biosphere, especially forests, CO_2 capture and storage, and CO_2 sequestration.

The costs are significant, but the recent Stern report concluded that an ongoing investment of 1% of GDP ($0.6Tn/y) starting now, would avoid a future 20% economic catastrophe. These figures compare well with the $3-5Tn estimated investment in conventional oil production necessary to satisfy the future projected world oil needs on a "business as usual" basis.

A worrying fact is that over the last seven years, despite much discussion, human carbon emissions have continued on the "business as usual" trajectory, which deviates strongly from the path necessary to stabilise at 450ppm. New trajectories can be drawn up, but in the end, if these are not followed, a 450ppm stabilisation level will become impossible to attain unless a means of active (and massive) CO_2 extraction and sequestration is developed.

The challenge facing the human race is unprecedented. The evidence for the problem is complex and technical with uncertainties at the detailed level. The impacts of current behaviour are distributed and distant in time and space. There is inertia in population growth, societal infrastructure and behaviour. Strong vested-interests are threatened. There are significant issues of sharing between the developed and developing world. There is a major mismatch between the jurisdiction, capabilities and motivations of existing institutions relative to what is needed. And as yet, there is no market mechanism capable of "self-correcting" the problem

Leadership is required, to a degree currently absent.

Even so, we should remain hopeful, since: "Our problems are Man made, therefore they may be solved by Man" (John F Kennedy).

HOW CAN SCIENCE HELP TO PREVENT NATURAL DISASTERS BECOMING ECONOMIC AND HUMAN CATASTROPHES?

Geohazards

Professor John F Dewey FRS

University College, Oxford

We live on a "dangerous" Earth with objective hazards of varying duration and magnitude. Hazards become dangers, and a chronic nuisance, disaster or catastrophe, when man interfaces with them. The problem is whether a hazard generates random, episodic, or periodic events. Forecasting the precise location, time, and magnitude of an event is the central issue, which can only come with continuous monitoring on local to global scales. Forecasting involves: hazard identification, monitoring / measurement, modelling, understanding the geology, assessment, risk and vulnerability analysis for the 1, 10, 100, 1000 etc year event, planning, preparedness, warning systems, pre-event mitigation, civil defence, warning, evacuation, and post-event mitigation. These are not sequential but iterative, and involve long-term commitment and money. Many live in and reoccupy, sometimes knowingly, seriously-hazardous sites. The greed and ignorance of developers should be discouraged by compensation schemes paid by those who have not given warnings. Insurance should be refused to those who ignore warnings. Knowledge and responsibility must be encouraged by national, local, and individual understanding in which data and ideas are shared, and warning systems are developed. Science is about testing ideas not about certainty, which can never be delivered to Government and the public. The following is a list of principal geohazards with sketchy notes.

1. Earthquakes: up to about magnitude 9.5, occur on strongly-coupled continental margin subduction zones (Chile 1960, Alaska 1964, northwest US "imminent", Sumatra 2004). Events, up to 8.3, occur in slightly-oblique, locking segments of motion-parallel plate boundaries (San Francisco 1906, Northridge 1994, Kocaeli 1999) and on the thrusts of continental collision zones (Assam 1950). Sophisticated monitoring is now intense in California and Japan, where the engineering standards of building codes and retro-fitting are high, but much less so in risk areas elsewhere where codes and adherence are weaker. Forecasting is still a great problem; most promising is the network-linkage model of Rundle and Turcotte of UC Davis.

2. Tsunamis and freak waves: Tsunamis result from the vertical displacement, by large earthquakes, giant landslides, or meteorite impact, of a column of water that radiates as a long wave-length, low-amplitude, wave at about 750 kph until the water shallows and the slowing column develops a massive amplitude increase. Freak (rogue) waves that impinge on rocky shores are limited in area but pack the same momentum punch (a cubic metre of water weighs a ton). Tsunamis flatten parking meters, drive wood slivers through tyres, and carry 100 ton blocks (destruction of the Adak lighthouse 1946). Monitoring and warning systems in the Pacific are pervasive but, in the Indian Ocean, non-existent (2004 disaster).

3. Floods: Mega-floods result from the rare instantaneous inundation (Black Sea 7500 BC, Mediterranean 6 my ago, Co Durham 250 my ago) of areas below sea level (42 world-wide), by the catastrophic release of glacial meltwater (Lake Missoula), and by catastrophic flows of hot water, ice, mud, and rock from lava melting ice. The greatest problem is the chronic flooding of flood plains. The economic loss and the heartache of ruined homes are profound. Mitigation comes in the form of river channel dredging and cutting of relief channels, and not "concreting and building over". The problem will be solved by the refusal of planners to allow building and of companies to insure losses in flood plains. Government and developers must compensate home-owners who have been cheated; flood plains must become no-go areas, unless developers are prepared to provide very expensive engineering solutions. Narrow valleys with large catchment areas (Boscastle, Lynmouth) are an avoidable source of catastrophic flooding. Hurricane-driven storm surges cause catastrophic flooding of coastal plains (New Orleans 2006), where building should be prohibited.

4. Landslides: Downhill creep of soil and small slow landslides on steep slopes is a chronic problem. Fast-moving catastrophic rock flows (Frank, Alberta, in 1903, Peru 1970) are infrequent killers of hundreds. Cliffed, soft-rock coastlines are greatly at risk (Dorset, Yorkshire Holbeck Hall, 1993). Behind Los Angeles, steep slopes, unstable, poorly-consolidated soils and rocks, forest fires and seasonal heavy rain, are a lethal combination that leads to disastrous mudslides and landslides.

5. Bolides/meteorites: During Earth's existence, the rate and average size of objects striking the Earth has declined exponentially as the planets swept up planetesimal junk. However, if the very rare, perhaps 50 million year, event were to occur of a bolide 10 km in diameter at 25km/sec, a surface blast of air superheated to 4000°C and a long "winter" from the global circulation of impact dust could cause a total disruption of the food chain. We might not survive such an event.

6. Volcanoes: Volcanic hazards are becoming well understood and forecasting is probably attainable. The fast flow of high-temperature basaltic lava (Hawaii, Iceland) rarely kills. As silica content increases, viscosity increases and temperature decreases to generate more explosive and dangerous volcanism. Mudflows (lahars) are destructive but fast-moving incandescent gas/ash avalanches (Mt Pelee, Martinique 1929) are incinerators. Lateral hot gas/ash surges caused by flank collapse (Mt St. Helens 1980, Soufriere 1995) are extremely fast and dangerous. Eruptions that threaten mankind on a global scale are the mega-eruptions above massive magma chambers such as Yellowstone and the Long Valley Caldera in the western US.

7. Hurricanes, tornadoes, typhoons, storms, storm surges, twisters, spouts: These are mainly seasonal and generally affect well-documented "alleys", and can be monitored and avoided, temporarily or permanently.

8. Water, hydrology, drought: Agriculture in California (Cadillac Desert), depends upon a dwindling water supply in competition with the needs of a growing population. 400,000 year old groundwater is mined! Water wars are not inconceivable.

9. Forest wildfires, coal-bed and culm-bank fires: From lightning strike, exothermic reactions in exposed coals, accident, and arson.

10. Soil erosion, overgrazing, land degradation: Deforestation and intensive agriculture, starting with the US dustbowl in the 1920's, have led to soil loss, and degradation. Overgrazing, encouraged by EU headage subsidies, has led to severe land degradation, soil instability, and landslides.

11. Land heave, subsidence and instability: Caused by seasonal variations in wetness/dryness, and by mining, quarrying, and excavation for roads and railways, and loading by buildings.

12. Gas hydrates: A water/methane combination in the sediments of continental margins. Submarine landslides release pressure causing water-methane dissociation and the massive release of methane through the water column into the atmosphere leading to vast quantities of methane in the atmosphere and, perhaps, the sinking of vessels.

13. Geology and health: Asbestos, arsenic, methylated mercury, radon, heavy metals, garbage disposal, hazardous landfill chemicals, toxic and nuclear waste are very serious environmental problems.

14. Planetary exploration/biocontacts: Astrobiology/exobiology is a subject with, as yet, no material to study. This could change if a "malevolent" bug were returned, accidentally, to Earth.

15. Climate change/global warming: Global climate has been changing for 4.55 billion years. Glacial periods (we are in one) occur about every 300 million years and have extreme and rapid variations in climate and sea level, in contrast to the warmer and more stable humid conditions with much higher sea levels of most of Earth history. In the late Ordovician and late Carboniferous, CO_2 levels were ten times those of today, both associated with unstable glacial periods. The present global climatic regime cannot be captured in "frozen time frame". That we can stop or slow climate change is absurd, as are the hysterical headlines of "save the planet" and "stop climate change now". The post-industrial revolution increase in CO_2 and GMT is clearly anthropogenic but there is no evidence that this has or will cause problematic climate change; the models have substantial uncertainties. Sea level has been rising at 1.8 mma-1 for 12,000 years with no change since the immense increase of gas, oil, and coal burning from 1945. Sea level will rise by about sixty metres when the present glacial period ends. Earth has experienced the Medieval Warming and the Little Ice Age; we are back to conditions during the reign of Augustus. Glacier shortening has been constant since long before the 1945 increase There has been no increase in severe tornados, hurricane wind-speed and landfall, in 60 years. Short-term anthropogenic climate change, if it happens, is an opportunity not a problem, and trivial compared with population growth, the shortage of clean water, food safety, obesity, disease, the greed and aggression of the human species, and the catastrophic and chronic problems 1-13 listed above. We should mitigate if possible but it is best to avoid the hazard.

In discussion the following points were made:

The main areas of concern relate to identification, forecasting, mitigation and avoidance. The question is what can politicians do to help? Reference was made to the comparison between the Titanic and Explorer disasters with both ships sunk by icebergs but the latter without any loss of life. Satellite measurements are of great assistance, but greater interaction between science and social research is needed, which raises the question of how Institutions should respond. When you do well, no one notices. In Bangladesh floods people are now trained to go up onto nearby hills whereas 300,000 people were killed previously. Hence good practice needs to be taught and long-term preparations made. Much better research and monitoring is also required.

The UK model of embedding Chief Scientific Advisers in Government Departments is a good way of getting people together to discuss issues. Transfer of responsibility to the international scene raises problems since while there are lots of good intentions at the UN there is no money. UNESCO only has $1m for support of all its science programmes. The Intergovernmental Panel on Climate Change is another potential source of funding.

Floodplain management requires awareness and knowledge based on long term monitoring, whereas it may be possible to obtain a three-year research grant but not over a longer term. Funding for interdisciplinary research is difficult to obtain. Human psychology is adapted to the best bet that tomorrow will be the same as today, and let's just hope I am not unlucky.

Diverse topics were raised such as risks from nuclear waste, the Thames Barrier and Radon. Nuclear waste is an inevitable consequence of the use of nuclear power and therefore must be dealt with effectively as nuclear power will form an integral part of the mix of power sources in the future. The exposure to radiation from the nuclear industry is insignificant in comparison to variations in the natural background and medical sources of radiation. The current estimate for sea level rise at the Thames Barrier in the next 100 years is 40cm but this takes no account of the fate of icesheets, or of rare extreme events superimposed on sea level rise. Training to respond to the dangers from tsunami in Japan forms part of every child's basic education. The history of extreme events can be very variable. More recent events may leave a clear mark in the geological record whereas older events may be under-recorded.