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Towards more effective risk reduction: Catastrophic tsunami

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The International Union of Geological Sciences (IUGS) is evaluating whether there are additional geoscientific activities that would be beneficial in helping mitigate the impacts of tsunami. Public concerns about poor decisions and inaction, and advances in computing power and data mining call for new scientific approaches. Three fundamental requirements for mitigating impacts of natural hazards are defined. These are: (1) improvement of process-oriented understanding, (2) adequate monitoring and optimal use of data, and (3) generation of advice based on scientific, technical and socio-economic expertise. International leadership/coordination is also important.

To increase the capacity to predict and mitigate the impacts of tsunami and other natural hazards a broad consensus is needed. The main needs include the integration of systematic geological inputs - identifying and studying paleo-tsunami deposits for all subduction zones; optimising coverage and coordination of geodetic and seismic monitoring networks; underpinning decision making at national and international scales by developing appropriate mechanisms for gathering, managing and communicating authoritative scientific and technical advice information; international leadership for coordination and authoritative statements of best approaches. All these suggestions are reflected in the Sendai Agreement, the collective views of the experts at the International Workshop on Natural Hazards, presented later in this volume.

Introduction

In line with its role in promoting international, broad-based, and inter-disciplinary scientific studies relevant to the entire System Earth, the International Union of Geological Sciences (IUGS) is evaluating whether there are additional geoscientific activities that would be beneficial in helping mitigate the impacts of tsunami that have been of great international concern since the devastating Boxing Day tsunami of 2004 in Indonesia.

There is currently considerable tsunami-related research being undertaken, and huge investments have been made in tsunami warning systems, which many people have interpreted as a quick technological fix. Unfortunately, the research and one of the best warning systems in the world did not save the many Japanese who died in the major Tohoku tsunami of March 2011.

It appears that currently available information in the light of data sharing and data networking is not adequate to rule out any subduction zone hosting a magnitude 9 or greater earthquake, and therefore generating a catastrophic tsunami. It is thus important to assess what could be done to increase our capability to predict and mitigate the impacts of tsunami globally. A broad consensus on the priorities for filling knowledge gaps and how to achieve more effective communication of advice to guide decisions and policies is vital both for reducing risks and attracting the funding and expertise necessary for the additional activities.

Different stake-holders need to be involved. Academic and applied research is vital for understanding processes. Government agencies have important roles in monitoring, conducting systematic field observations, and providing advice in support of policy development and decision-making. Further, international Unions/Councils are well placed to provide leadership and to facilitate international collaboration.

IUGS sponsored the 1st International Workshop on Natural Hazards in October 2013, held in conjunction with the 2nd International G-EVER meeting in Sendai, Japan. The objective was to bring together leading tsunami researchers, representatives of government and international agencies, to discuss and agree on priorities for mitigating the risks of natural hazards – the “Sendai Agreement”. This paper summarises the introductory presentation, which set the scene for this workshop.

Consideration of priorities

There are four fundamental requirements for mitigating impacts of natural hazards:

1. Good understanding of the processes involved
2. Adequate monitoring and optimal use of data
3. Production of advice and options for mitigation based on scientific, technical and socio-economic expertise. This must include effective means of getting advice used in policies/decisions
4. International leadership/coordination.

Uncertainties remain in relation to the regions with the highest imminent risks and options for minimising impacts on people and critical infrastructure. We now discuss each of the four fundamental

requirements in turn, identifying issues that we suggest need more attention.

Good understanding of processes

Over the last decade there has been a considerable increase in research, involving geologists, seismologists, and oceanographers, into the processes and complexity of the oceanic lithosphere and other issues related to catastrophic tsunamigenic events. A summary of the main research activities is provided in Appendix 1.

There has been research in some regions aimed at recognising paleo-tsunami deposits, which can provide a good guide to the magnitude, extent and dates of previous events. This should be conducted systematically in Recent coastal sequences of all subduction zones where currently there is not sufficient information to assess tsunami risk.

Recognising tsunami deposits is not always straightforward. Tsunami deposits are deposited over sediments in low-lying areas landward of the coastline, such as lagoons and deltaic plains. Both tsunami deposits and storm deposits may have strongly erosive bases and mainly consist of sand, but major tsunamis inundate areas farther inland than storms. Furthermore, the presence of material eroded from the shelf is considered more likely to suggest a tsunami rather than a storm event due to the much greater energy and erosive power associated with individual waves in the tsunami, and the movement of very large boulders also implies a tsunami origin.

A long history of tsunami has been documented in Japan, with many significant events and several very large and destructive examples. Investigated tsunamigenic deposits provide evidence of the regional extents of their impact on coastal environments—for the major 869 AD Sanriku earthquake (Ref1) (http://en.wikipedia.org/wiki/869_Sanriku_earthquake_and_tsunami), tsunami deposits have been found over 4.5 km inland in the Sendai Plain. Two earlier deposits with similar character were also identified and dated in this area. This led to the conclusion of a recurrence interval for large tsunamigenic earthquakes along the Sendai coast of approximately one thousand years, suggesting that a repeat of this event was overdue and that large-scale inundation was very likely. Clearly, it was not a surprise to scientists when the Tohoku tsunami struck.

In this context, we suggest that systematic peer-reviewed mapping and dating tsunami deposits should be undertaken to provide updated risk maps in areas where information is inadequate. Peer-reviewed risk assessments for all subduction zones would be beneficial in raising awareness of the potential risks and potential return periods of major events. This activity should include evaluation of the significance of subducting seamounts as a major factor in collision processes in subduction zones, followed by catastrophic release of stress. Also, there is a need for systems analysis to understand other concatenated events better, e.g., mega-earthquake recurrence - tsunami – flooding.

Monitoring and applications of data

In acknowledging the considerable monitoring of events and trends using seismic and geodetic networks, ocean buoys, and so on, it is suggested that there would be benefit in detailed evaluation of the types and coverage of data being gathered, and priorities for addressing any shortcomings in these, taking account of the capabilities of emerging technologies and how these could be rolled out.

There is also a need to optimise the use of monitoring and mining data, making use of cloud and computing power to produce valuable applications. This is illustrated by the TsuDAT web application (Ref2) (<http://boundlessgeo.com/case-study/tsudat-geonode-disaster-modeling/>), which is summarised in Box 1.

Box 1. TsuDAT: Web application indicating likely impacts of tsunami

TsuDAT is underpinned by, and provides access to, pre-computed database of 70,000 tsunami events from all subduction zone sources in Pacific/Indian oceans. It draws on a pre-computed database of offshore waveforms, and only the inundation component needs to be modelled. A web-server and tsunami simulations are hosted in the Cloud, giving scalable computing resources. Spatial data is managed through a GeoNode that facilitates data uploading, editing and sharing via the web. All data is Open Geospatial Consortium compliant and all software is open-source. Given basic training, the inundation modelling can be done rapidly by non-experts, who have an option to include any available detailed local bathymetric data, to indicate the likely impacts of a tsunami.

It is suggested that there is a case to consider what other similarly innovative and practical web applications, using available data, can be developed and/or refined.

Scientific and technical advice to decision makers

It is one thing for scientists to understand risks. But it is another to have decision-makers fully informed of these risks and the options for addressing them. This is illustrated well by the situation in Japan, where no concrete actions were taken in response to the warnings of scientists that a tsunami striking the north-eastern coast of Honshu was highly likely in the foreseeable future, (Ref3) (http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami). The owner of the nuclear power plants in the coastal areas at risk, TEPCO, revised its estimates of likely tsunami heights at the Fukushima Daiichi Nuclear Power Plant to greater than 9 m, but took no immediate action. The 2011 Tohoku earthquake resulted in a wave height at Fukushima of about 15 m, well above the 5.7 m for which the plant's defences had been designed, and the impact was exacerbated by land subsidence. The inundation distance and lateral extent of the tsunami were similar to the earlier major events mapped in the region.

In general, a number of factors can distort decision-making processes, including political paralysis stemming from the overwhelming magnitude of an issue, dominating personalities, ideologies, ineptitude, and incentives for inaction. However, in this communications age, poor decisions are becoming more obvious and communities around the world are demanding better and effective actions. This creates opportunities for building mechanisms, at both national and international scales, for communicating the significance of research and observations to decision makers and working with them on options. This has not yet been achieved in many cases.

There is not a universal approach that can be applied to getting scientific advice factored into major decisions. The approach pursued

in Australia, which is summarised in Appendix 2, should provide useful guides to what is important and what can be achieved - this approach is working well and is adequately funded by Government. It is summarised below, followed by the partly different German approach.

Australian approach: Given geoscientists are commonly viewed narrowly and negatively in terms of mining and environmental disruption, there was a need at the outset to establish the geosciences' crucial applications in addressing many challenges and their complementarity with the environmental and social sciences, in part through demonstration projects. The key elements of Australia's approach to provision of scientific and technical advice into government decision makers are:

- Flexible, interactive approaches which present scientific advice along with an economic and social basis for considering/acceptance of various options
- A comprehensive information base for decision-making, with no crucial knowledge gaps that are limiting effectiveness of advice
- Multidisciplinary systems-science approaches
- Taking advantage of on-going advances in computing power, data management and access
- Dedicated advisory groups of broadly-based scientists working in/with government, which focus on practical applications of scientific data and research, can see "the big picture" and are aware of government expectations and constraints. They interact regularly with a wide range of researchers and bring together all relevant research findings, facilitate/lead research aimed at filling gaps, promote cross-disciplinary approaches, and foster linkages to social scientists and economists.

Advisory groups are understood and trusted by decision makers, with whom they have regular communication. Their main activities are approved and funded by Government (and other key clients). Their careers are not dependent on external funding and peer-reviewed publications, or subject to other potential distractions and conflicts of interest. They provide regular briefings and prepare authoritative scientific/technical papers, national approaches, guidelines, standards and options for addressing current and potential issues. Their publicly available outputs are open to peer review.

German approach: This involves less direct government involvement. Geoscientific inputs are coordinated in two principal ways. First, the senate commission of the German Science Foundation (DFG) works on future tasks and challenges that the geosciences are confronted with (Senatskommission für Zukunftsaufgaben in den Geowissenschaften; ZAG: <http://www.sk-zag.de>). This is a purely scientific and non-governmental think-tank of experts representing different fields in the geosciences. Second, the German government has set up task forces for tsunami and hazard research in its research organisations of the Helmholtz Gemeinschaft (<http://www.helmholtz.de>). Joint efforts among these organisations and universities have come to fruition in closer cooperation between the geosciences and political and administrative sciences (<http://earth-in-progress.de>), efforts in improving knowledge transfer and the introduction of governance issues in geoscience education (<http://www.geogovernance.de>).

International leadership and coordination

There would be clear benefits in enhanced international coordination and support for multidisciplinary systems-science and monitoring programs related to major global issues. There is a need to set priorities, to facilitate international collaboration, to ensure that the information for decision-making is comprehensive, and to develop/facilitate authoritative statements/guidelines for major issues.

The International Council for Science (ICSU) is well placed to provide leadership and coordination for agreed priority activities. In the case of tsunami, this should be done through ICSU's Integrated Research on Disaster Risk (IRDR) program, which is currently being revitalised. ICSU's member states and Unions support this leadership and coordination role.

Summary

A broad consensus is needed on proposals for increasing capacity to predict and mitigate the impacts of tsunami and other natural hazards. Feedback is sought on the scope for better links between various activities already in place, for conducting some activities more systematically, and for innovative applications of data to help further mitigate risks of catastrophic tsunami.

The time for action is now, given increasing public concerns about poor decisions and inaction, plus advances in computing power, data management and access make it possible to use and integrate data in ways that were not previously possible.

It is suggested that the main needs are:

- Integrated systematic geological inputs, particularly identifying and studying paleo-tsunami deposits in the recent geological records to establish the occurrence, magnitude and frequency of tsunami – peer-reviewed risk assessments are needed for all modern subduction zones.
- Optimising coverage and coordination of geodetic and seismic monitoring networks and introduction of new technologies, including remote sensing applications. Also, development of useful applications of monitoring data.
- Developing appropriate mechanisms for gathering, managing and communicating authoritative scientific and technical advice information, to underpin decision making at national and international scales.
- International leadership, coordination and authoritative statements of best approaches.

These suggestions are reflected in the Sendai Agreement, the collective views of the experts at the International Workshop on Natural Hazards, presented later in this volume.

References

- Lambert and McFadden, 2013, Episodes, v. 36 No.1, pp.2-7.
 Ref1: http://en.wikipedia.org/wiki/869_Sanriku_earthquake_and_tsunami
 Ref2: <http://boundlessgeo.com/case-study/tsudat-geonode-disaster-modeling/>
 Ref3: http://en.wikipedia.org/wiki/2011_T%20c5%8dhoku_earthquake_and_tsunami

Appendix 1

Major current and recent activities directed at mega-earthquakes and tsunami

(drawn from a report by Lambert & McFadden, 2013)

- There is on-going compilation and analyses of historical records of earthquakes and tsunamis. Japan has by far the best historical records in the world, but this wasn't enough to predict a magnitude 9 event. A basic problem is that historical records are very short in geological timescales.
- An Intergovernmental Oceanographic Commission (IOC, UNESCO) committee is tasked with identifying the subduction zones around the world that can produce giant earthquakes and tsunamis, as well as tsunami earthquakes (events that are dangerous because their slow ruptures can be misread by warning systems and coastal populations). Understandably, the IOC is very much dominated by oceanographers and meteorologists and yet the bulk of the evidence for past events is geologic in nature.
- The Global Earthquake Model (GEM) is developing global databases and global scientific consensus on the state of knowledge. This work is being done through a series of Global Components studies that will be underpinned by a computational modelling framework and tools: <http://www.globalquakemodel.org/global-components>. In particular, it is intended that the Global Active Faults and Seismic Source Database will represent the authoritative source for information on active earthquake sources, including the world's subduction zones. However, GEM is not directly addressing tsunamis and is certainly not doing paleo-seismic or paleo-tsunami studies to increase the knowledge base. GEM's work will, however, provide an excellent baseline from which to identify knowledge gaps and to expose the risks associated with them. GEM is trying to develop a global scientific consensus on Mmax for earthquake hazard calculations. This will at least help establish the state of play from a hazard/risk assessment perspective.
- The Extreme Natural Hazards and Societal Implications Project (ENHANS; <http://www.iugg.org/programmes/enhans.php>) of the International Union of Geodesy and Geophysics (IUGG) launched in 2010 is supported by several ICSU bodies including the ICSU Regional Office for Asia and the Pacific. It aims (i) to improve understanding of critical phenomena associated with extreme natural events and to analyse impacts of the natural hazards on sustainable development of society; (ii) to promote studies on prediction of extreme events reducing predictive uncertainty and on natural hazards mitigation; to bring the issues into the political and economic policies; (iii) to disseminate knowledge and data on natural hazards for the advancement of research and education in general and especially in developing countries.
- Paleo-tsunami research (including trenching etc.) is one of the essential tools in tsunami research and is covered under the umbrella of ICSU, which established a new 10-year program dedicated to disaster risk research, Integrated Research on Disaster Risk (IRDR, <http://www.irdrinternational.org/>). IRDR tries to bridge natural and social sciences, engineers and policy makers etc. to mitigate, if not fully prevent, disasters.
- In 2011, the Geological Survey of Japan (GSJ) initiated a project related to Asia-Pacific region global earthquake and volcanic eruption risk management (G-EVER, <http://g-ever.org/index.html>). The first workshop was held in Tsukuba in Feb. 2012 (<http://g-ever.org/en/gever1/index.html>) and co-sponsored by IUGG and two IUGG associations dealing with seismology (IASPEI) and volcanology (IAVCEI). One of the major topics was earthquake- and volcano-generated tsunamis.
- The first bilateral symposium on geohazards and disaster risk under the US–Russian Presidential Commission on Science and Technology was held in Moscow in July 2012. One of the important topics was joint paleo-tsunami studies.

Appendix 2

Geoscience underpinning policies and decisions addressing major challenges in Australia

The Australian Academy of Science's National Committee for Earth Sciences produced a *National Strategy for Earth Sciences* in 2003 (<http://www.science.org.au/natcoms/nc-es/documents/nc-es-strategic.pdf>), which emphasized the key-underpinning role of the geosciences in approaches to a wide range of major issues. In many cases decision-making processes require: (i) information on surface features, including through remote sensing; (ii) information on subsurface materials and processes, including through collation of information from direct sampling and integration of geological and geophysical data; (iii) systematic monitoring as required to track important trends and events; and (iv) strategic analyses involving integrated consideration and modelling of all relevant data and information. It also identified the need for integration of the efforts of academic researchers and government agencies and collaborative

approaches to sharing expertise and infrastructure needed for major research programs. This national strategy was influential in achieving wider appreciation of, and increased funding for, the vital underpinning roles of the Earth Sciences, as well as in developing important new roles for the national geological and geospatial agency, Geoscience Australia (GA: <http://www.ga.gov.au/>).

GA is currently a vibrant government agency with a strong public profile. It is a primary source of scientific and technical advice in support of policy development and major decisions on a wide range of issues requiring geoscientific and geospatial inputs. But this was not always the case. Two decades ago its predecessor organization, the Bureau of Mineral Resources (BMR) was underfunded and struggling to be seen as relevant to the government that was funding it. This motivated the agency to transform in an effort to reverse this

perception, involving it contributing to and implementing the national strategy.

In changing its attitude and culture, GA transformed from an introverted agency with poor communication channels into the main body of government to a vibrant agency with a culture that said its job is “to apply geoscience to Australia’s most important challenges” and with effective communication channels to ensure that its work is recognised, relevant, and used.

The success of the transformation from the beleaguered BMR to the present-day GA is evidenced by a 2010 review by the Department of Finance and the Department of Resources and Energy (http://www.finance.gov.au/publications/strategic-reviews/docs/strategic_review_ga.pdf). That review recognized the importance of the agency’s work to many major issues facing the nation and recommended that its funding be increased to (i) strengthen capabilities for collection of regional-scale data and for monitoring, (ii) invest in custodianship of Australia’s exponentially increasing geoscientific and geospatial data, and (iii) enable continuation of fundamental capabilities in areas such as groundwater, natural hazards, mineral resources and clean energy. This was a unique outcome for a review involving the Department of Finance, particularly at a time when the focus is on reducing government expenditure.

- Australia is a major supplier of a wide range of mineral and energy commodities to world markets. The strength of its economy is linked to its considerable mineral endowment. In 2010, recognising the falling success rate of mineral exploration in Australia, the Australian Academy of Science ran a Think Tank for young scientists to try to develop fresh approaches to exploration under cover. The Academy then drew together a representative group, now known as the UNCOVER group, from across the spectrum of academia, government agencies, and industry to develop from this Think Tank an appropriate research

and data- acquisition vision and to improve collaboration and coordination across the sector. In 2012, UNCOVER released the document *Searching the Deep Earth: A Vision for Exploration Geoscience in Australia* (<http://www.science.org.au/policy/uncover.html/>). This vision, which includes enhanced information on the subsurface through comprehensive integration and modelling of geological information and a range of geophysical datasets, has now informed strategic planning for the state geological surveys and for Geoscience Australia. It is noteworthy that enhanced understanding of sub-surface materials and processes has wider applications in relation to issues such as understanding groundwater systems, building cities and infrastructure, mitigating hazards and risks, and managing wastes.

Amongst the numerous other important geoscience contributions to high profile government policies and decisions are

- Improved water management through better knowledge of groundwater systems and their links with surface waters.
- Addressing community concerns about the rapidly growing coal seam gas sector, particularly centred on potential impacts on ground and surface waters.
- National guidelines to facilitate decisions on proposed uranium mines.
- Enhanced monitoring of environmental health and vegetation cover through developing improved remote sensing approaches.
- Establishing links between geology and bioregions.

Reinforcing Australia’s leadership role in mitigating the impacts of geohazards in its region by building fit-for-purpose tsunami warning systems, an online bushfire status system used by fire-fighting authorities and the wider public, and TsuDAT - a web application for non-experts to conduct inundation modelling to assess their own tsunami risk.