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Tsunami warning system fully operational

Major contribution to earthquake and tsunami science and warning systems

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On the morning of Sunday 26 December 2004 a large undersea earthquake generated a massive series of tsunami that combined to cause an estimated 228 000 deaths. The massive earthquake which began below the ocean off the coast of northern Sumatra and the Andaman and Nicobar Islands, has been measured at a magnitude of over 9. This was equivalent to the energy released by about 3.5 million standard atomic blasts. The tectonic plate boundary that separates the Indo-Australian Plate from the Sunda Plate deformed the seabed in a mega-thrust/uplift movement along a 1 200 kilometre long fault over a ten minute period.

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The massive series of seismic sea waves, or tsunami, devastated the immediate coastal communities of western Indonesia and far off communities in Sri Lanka, India, Thailand, Malaysia, Myanmar, Maldives, Seychelles, Somalia and Tanzania. This was the most devastating earthquake-tsunami event in recorded history. The tsunami waves were recorded by the Australian Bureau of Meteorology on tide gauges around the Australian coast and reached about one metre at Hillarys Harbour in Perth, Western Australia. Measurements of half-a-metre were measured at gauges in Tasmania and New South Wales. Over the following days, reports emerged from coastal communities in Western Australia of damage to moored boats and an increase in the number of people being rescued because of abnormally strong currents resulting from localised tsunami effects.

At the time of the tsunami, Australia relied on the existing Australian Tsunami Alert System, an arrangement between Geoscience Australia, the Bureau of Meteorology, and Emergency Management Australia which provided a limited notification and warning capability. It had no capability for confirming that an earthquake had generated a tsunami, and there were no mitigation and response strategies in place.

More recently, massive earthquakes have continued in our region, all located where the Australian tectonic plate meets the surrounding Pacific and Sunda plates (figure 1). Regrettably, more lives have been lost, along with enormous property losses, in Indonesia, Solomon Islands, Samoa and Tonga from the combined effects of the earthquakes and tsunami.

Australia's response

The day after the Indian Ocean tsunami, the then Prime Minister of Australia, The Hon. John Howard MP, pledged to '… do everything we can as a regional neighbour and regional friend to assist the countries that have been so badly affected'. Consequently, the Australian Prime Minister and Minister for Foreign Affairs and Trade were among the attendees at a Tsunami Disaster Summit organised by the Association of South East Asian Nations (ASEAN) in Jakarta on 5 and 6 January 2005. One of the key outcomes of this Summit was an agreement to establish a regional tsunami warning system.

Consequently, in its 2005–06 Budget the Australian Government provided $68.8 million to develop an Australian Tsunami Warning System (ATWS) over the next four years. The system would meet three major objectives:

1. Provide a comprehensive tsunami warning system for Australia.
2. Support international efforts to establish an Indian Ocean tsunami warning system.
3. Contribute to the facilitation of tsunami warnings for the South West Pacific.

First steps towards an Australian tsunami warning system

The Australian Government was well placed to develop an effective, reliable and durable tsunami warning system which would address Australia's needs, as well as meet regional requirements. It would utilise existing scientific and technical expertise at Geoscience Australia, the Australian Bureau of Meteorology, and Emergency Management Australia, as well as the diplomatic leadership of the Department of Foreign Affairs and Trade.

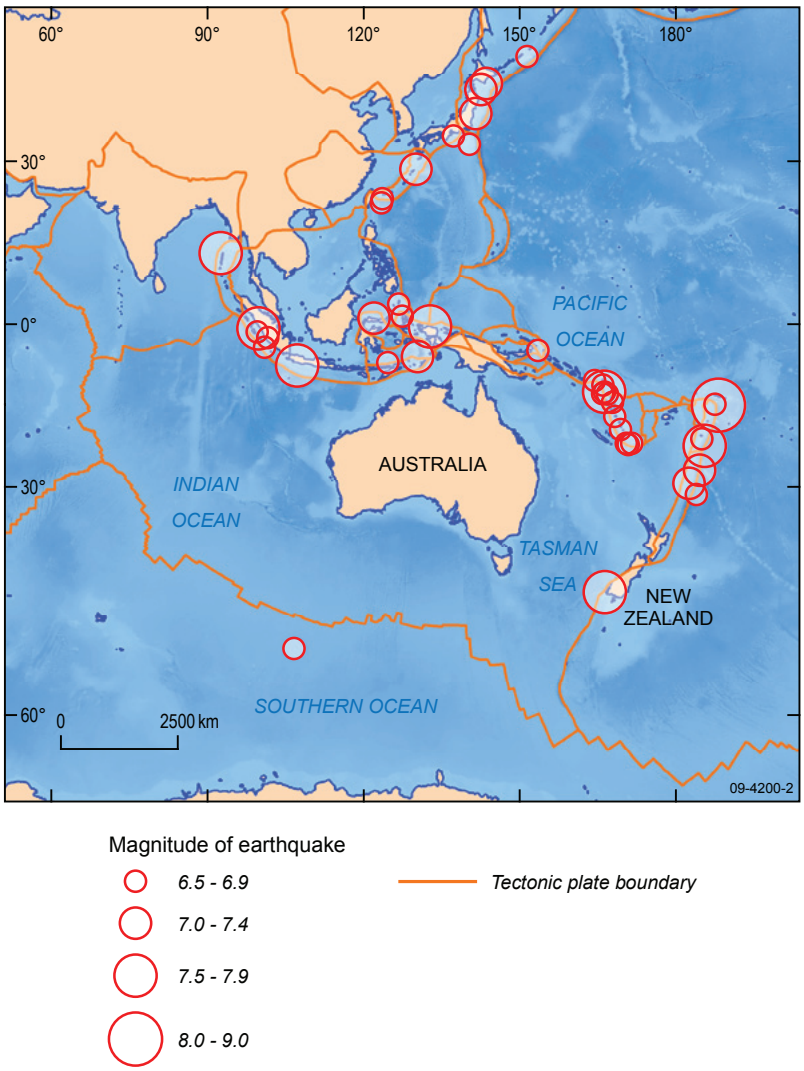

Figure 1. Epicentres of large earthquakes close to Australia's tectonic plate boundaries that have occurred since December 2004.

The Australian Tsunami Warning System (ATWS) began to take shape during the financial year 2005–06 with each of the program collaborators allocated funding over the next four years. The ATWS is defined as an end-to-end system encompassing:

- understanding the hazard through to raising community awareness and preparation
- earthquake and tsunami monitoring, detection and analysis through to public warnings
- evacuation and response.

Since the constitutional responsibilities for these activities fell within all levels of Australian government—federal, state and territory, and some local government—each would be involved in the ATWS to varying degrees.

To build on the existing domestic capabilities of Geoscience Australia's seismic monitoring and analysis systems, the agency was allocated $21 million over the four years. This was to upgrade existing seismic stations, build new seismic stations (both within Australia and overseas), and to access real-time digital seismic data from new and existing international seismic networks. Geoscience Australia would also establish a 24 hour seismic monitoring and

analysis capability to compute and advise of any earthquakes in our region that had the potential to cause tsunami within 15 minutes of the earthquake rupture occurring.

The Bureau of Meteorology was allocated $40.5 million over the four years to upgrade their existing tide gauge sea level stations, build new tide gauge stations within Australia and overseas, and to install new tsunameter buoys located in deep ocean locations near subduction zones. The Bureau of Meteorology would also develop a 24 hour tsunami warning service, with a tsunami monitoring and analysis capability. The service would advise of potential tsunami impacts at least 90 minutes before a tsunami generated from undersea earthquakes reached the Australian coastline.

Emergency Management Australia is the Australian Government agency which coordinates training and education in natural hazard mitigation and response. The agency received $7.3 million over the four years to:

- develop an understanding of the tsunami threat to Australia
- develop and present a program of tsunami awareness and preparation for emergency managers, industry and the general community
- oversee a national test of the ATWS toward the end of the four-year implementation.

Because of the substantial international scope of the Australian Government's policies to assist in the establishment of an Indian Ocean Tsunami Warning and Mitigation System and improve capabilities to receive tsunami warnings in the South West Pacific, the Department of Foreign Affairs and Trade was selected to coordinate the cross-portfolio program outlined above.

International coordination

The body responsible for coordinating international efforts in tsunami warning and mitigation is the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IOC General Assembly XXIII in Paris held in June 2005 confirmed the need to establish an interim tsunami warning system in the Indian Ocean. This would be provided through the existing Pacific Tsunami Warning Center in Hawaii and the Japan Meteorological Agency.

The Paris meeting also adopted resolutions to create three regional Intergovernmental Coordination Groups (ICGs)—for the Indian Ocean, the North-East Atlantic and Mediterranean, and the Caribbean—to establish basin-wide tsunami warning systems. The new ICGs would also contribute to the work of a global Coordination Group on tsunami in collaboration with the existing system covering the Pacific Ocean and other relevant United Nations bodies.

The first session of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System was held in Perth in August 2005. A key resolution of the meeting was that the IOTWS would be a coordinated network of national systems and capacities. It would also be a part of a global network of early warning systems for all ocean-related hazards. It was agreed that each Member State would have responsibility for issuing warnings within their respective territories.

Development of the Australian tsunami warning system

The ATWS Implementation Strategy and Plan was developed in August 2005 under the direction of the Australian Government's Department of Prime Minister and Cabinet. It was then submitted to the Cabinet Implementation Unit which oversaw the project and the participating agencies provided quarterly reports.

In 2005 Geoscience Australia monitored 33 seismic stations, known as the Australian National Seismic Network (ANSN), which had been developed for its domestic earthquake monitoring and alert

service. By October 2009, this number had increased to 192 and consisted of:

- 19 of the existing ANSN stations
- 28 ANSN stations that had been substantially upgraded
- 9 new ANSN stations within Australia
- 3 new overseas stations built by Geoscience Australia (one in Niue and two in PNG)
- 133 stations from shared international seismic networks.

To increase its robustness the network was redesigned, with digital data communications shared across three separate providers using discrete telecommunication infrastructures. In addition, in September 2008 the Comprehensive Nuclear-Test-Ban Treaty Organization approved the use of its seismic network for tsunami warning purposes.

During the initial stages of the project, the computer architecture of Geoscience Australia's earthquake monitoring, alert and analysis system was significantly upgraded. The software system is based on the Antelope software developed by Boulder Real Time Technologies in Colorado, USA. Antelope is an integrated collection of programs for data collection and seismic data analysis. Further software was developed to provide a graphical user interface to both Antelope and other software modules that were written in-house or provided by other centres. Consequently, the ATWS uses 'moment magnitude' based on P-waves (Mwp), using the algorithm from the Pacific Tsunami Warning Center in Hawaii, to provide consistency in earthquake magnitude estimates in all warnings from all centres.

The computer architecture has been designed to be as robust as possible, with two independent systems operating continuously. One is at the Operations Hub at Geoscience Australia in Canberra, and the other at a business continuity site established at the head office of the Bureau of Meteorology in Melbourne. System upgrades are rigorously controlled through a change-management regime where separate system environments have been created for each of the activities associated with research, development and testing. Once a change has been successfully tested, the upgrade is moved to both environments; firstly to the business continuity system in Melbourne and then to the primary system in Canberra. This stage was completed in July 2007 and at no time since have both systems been inoperable at the same time.

Launch of the warning service

During 2006, Geoscience Australia employed and trained duty staff for round-the-clock earthquake monitoring, analysis and reporting. This culminated in the launch of the Australian Tsunami Warning Centre Operations Hub at Geoscience Australia on 1 December 2006. The Hub detects earthquakes in the region and examines details such as magnitude, location, and depth, along with other seismic characteristics, to determine whether or not they are likely to cause a tsunami. By July 2007, Standard Operating Procedures for the Duty Seismologist which outlines the actions and timeframes expected of the duty staff when earthquakes occur had been completed.

The Australian Bureau of Meteorology and Emergency Management Australia have worked closely with Geoscience Australia to develop the ATWS. Over the four-year implementation period, the Bureau of Meteorology upgraded and installed new tide gauges across Australia and the South West Pacific, and installed six tsunameter buoys (two south of Java, two in the Coral Sea and two south of New Zealand).

In consultation with emergency management agencies in the Australian states and territories, the Bureau of Meteorology has also developed world-class tsunami warning bulletins. To support the tsunami impact forecasts in these bulletins, the Bureau of Meteorology pre-computed 2 386 deep water tsunami wave height and propagation models. These were generated by generic earthquake rupture parameters over subduction zones in the Indian and Pacific oceans and near the South Sandwich Islands in the southern Atlantic Ocean. These models have been used to develop tsunami forecast impact

levels to better inform emergency managers about likely tsunami effects in coastal zones.

The completed warning service was launched in October 2008 along with the official designation of the Joint Australian Tsunami Warning Centre (JATWC), reflecting the joint operations of Geoscience Australia for its seismic monitoring and alerting, and the Bureau of Meteorology for its sea level monitoring and tsunami warning role within the Australian Tsunami Warning System (figure 2). Emergency Management Australia has an important operational role in the warning process. The JATWC alerts Emergency Management Australia of tsunami earthquakes and receives all tsunami warning bulletins from other warning centres around the world. Emergency Management Australia uses this information to inform relevant government agencies and, in the case of significant events, informs the Prime Minister's Office.

Major contributions

In collaboration with Geoscience Australia and the Bureau of Meteorology, Emergency Management Australia conducted a program of emergency management awareness and education seminars across the nation. The program of workshops, *Introduction to Tsunami for Emergency Managers (ITEM)*, were conducted between 2007 and 2009. They provided information on the detection and warning processes, as well as the science of tsunami, and risk modelling methodology and emergency management arrangements.

Emergency Management Australia, in partnership with Geoscience Australia, has produced two nation-wide tsunami hazard assessments.

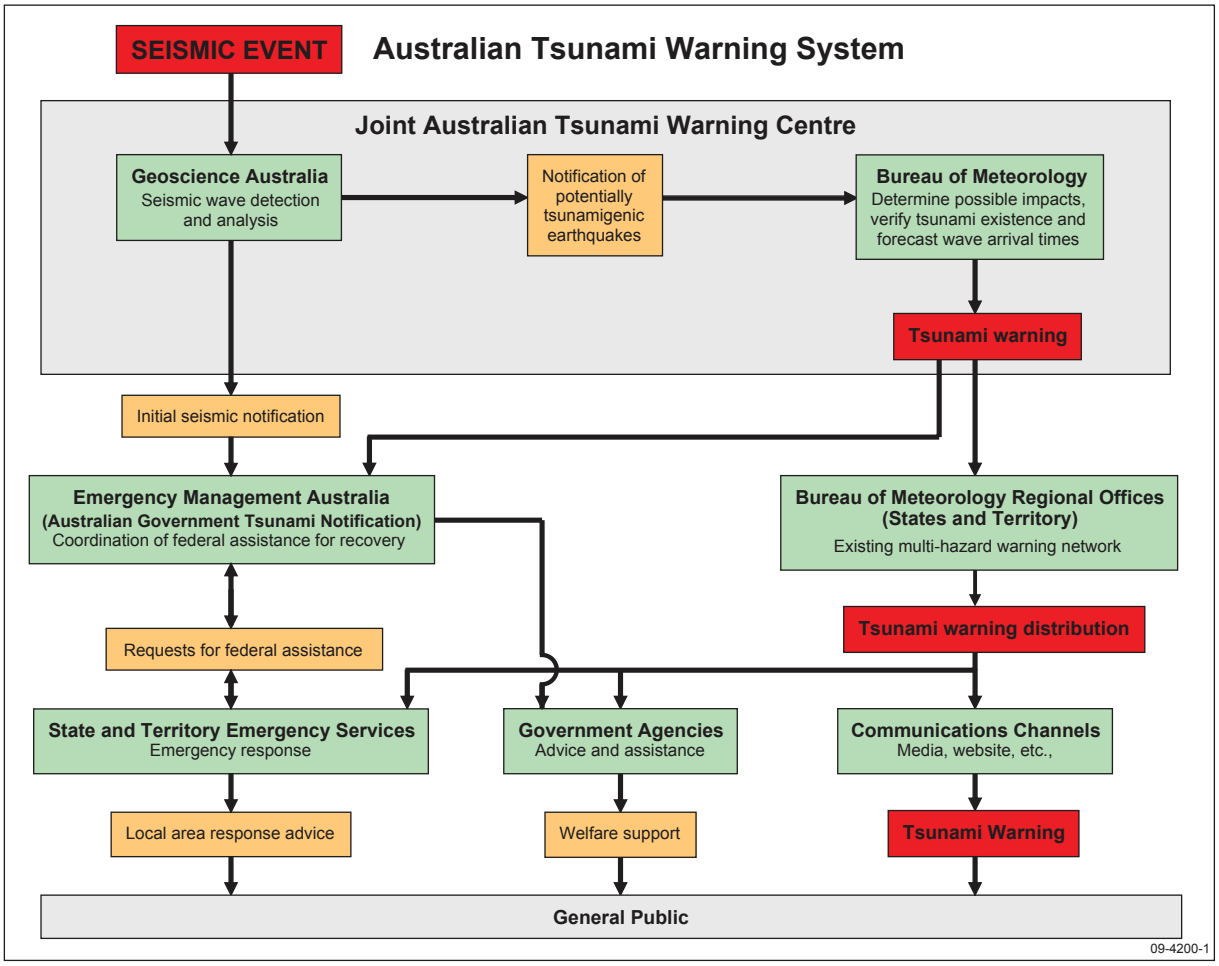

Figure 2. Flow chart outlining the roles of the contributors to the Joint Australian Tsunami Warning Centre operations.

The first assessment, published in 2007, was for a probabilistic tsunami hazard map and the second, published in early 2009, was a nearshore hazard map. In collaboration with the Fire and Emergency Services Authority of Western Australia and Emergency Management Australia, Geoscience Australia has produced tsunami inundation models for a number of communities around the Australian west coast. Geoscience Australia has also produced probabilistic tsunami hazard maps for the South West Pacific (2008) and the Indian Ocean (2009) in partnership with the Australian Agency for International Development (AusAID).

With their extensive experience in running national exercises to test emergency management processes, Emergency Management Australia have been instrumental in testing elements of the ATWS over the four years. In 2006, a test of the existing Australian Tsunami Alert Service was conducted to set a benchmark for the system to demonstrate improvements. In 2008, Emergency Management Australia held a desktop exercise to test their role in alerting government authorities. The final milestone, defined in the ATWS Implementation Strategy and Plan, was 'Exercise Ausnami' when Emergency Management Australia conducted a comprehensive test of the ATWS over two days in June 2009.

Performance measures

With the completion of the ATWS implementation in June 2009 the system became fully operational. Because the system was developed in stages over the four years, statistics on the performance of the system for those earthquakes assessed as having the potential to generate tsunamis have only been collected over the last two years.

Between July 2007, when the system developed from an alert service to a warning service, and 31 October 2009 there have been 125 earthquakes assessed as having the energy and mechanism to generate tsunamis. Not all these tsunami would have the potential to impact Australia, but they were reported internationally in line with our role in both the Indian and Pacific Oceans.

The most important performance measure for the ATWS is the requirement to provide a tsunami warning at least 90 minutes before the impact of a tsunami generated from undersea earthquakes. This measure was met for all 120 earthquakes to 31 October 2009.

The timeliness and accuracy of the earthquake alerts and the tsunami warning bulletins produced by the JATWC are another measure. The average alert time for earthquakes occurring in the Australian region is just under 11 minutes (compared to a required benchmark of 15 minutes). The average time taken to issue the subsequent tsunami bulletin is just under 20 minutes (compared to a benchmark of 30 minutes).

Other performance measures are the accuracy of the magnitude computation and the location of the hypocentre of the earthquake. The initial magnitudes computed are on average within 0.2 of the final computed solution for other centres, and the hypocentre is on average approximately 30 kilometres away from the final computed position. These results are well within expectations.

Future developments

As with all systems, new techniques are continuously developed and implemented to better improve the ATWS. A major priority is to provide a more comprehensive description of the mechanics of earthquakes rather than rely on the magnitude—a definition of the earthquake's strength—and the time and hypocentre which defines the location of the initial rupture.

Current research at Geoscience Australia involves the use of seismic arrays. These are powerful tools for the near-real time detection of the rupture length, direction and duration of very large earthquakes. They will assist to more accurately select the most appropriate tsunami propagation model for forecasting tsunami impacts, and provide more accurate tsunami warnings. Another development is the use of an automated moment magnitude calculator which is likely to improve the average response time by the Geoscience Australia Duty Seismologist.

Towards a regional tsunami watch role

An implementation plan for a system of Regional Tsunami Watch Providers (RTWP) was accepted at the fifth meeting of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System in Kuala Lumpur in April 2008. Countries which have the capacity to exchange tsunami warning information, such as earthquake and tsunami warning bulletins, have participated in RTWP trials. To date, Australia, Indonesia and India are exchanging earthquake bulletins for tsunami warning purposes.

After only four years of development, the ATWS is now a major contributor to earthquake and tsunami science and warning systems in the region.

For more information

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Related websites/articles

Asian Tsunami effects in Western Australia (University of Western Australia)
www.seismicity.see.uwa.edu.au/welcome/tsunamis_in_wa/asian_tsunami_in_wa

Intergovernmental Oceanographic Commission, United Nations Educational, Scientific and Cultural Organization
www.ioc-tsunami.org/index.php?option=com_content&task=view&id=20&Itemid=1023

Joint Australian Tsunami Warning Centre (Bureau of Meteorology)
www.bom.gov.au/tsunami/index.shtml

AusGeo News 93: Scientific expertise and emergency management
www.ga.gov.au/ausgeonews/ausgeonews200903/emergency.jsp