Real-time Earthquake Monitoring at the Joint Australian Tsunami Warning Centre

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Abstract

Since November 2006, Geoscience Australia has been monitoring, analysing and alerting for potentially tsunamigenic earthquakes that could threaten Australia and its Territories coastlines, on a 24/7 basis. At the time of the 2004 northern Sumatra earthquake and Indian Ocean tsunami, the Australian National Seismic Network (ANSN) consisted of 36 seismic stations. With the implementation of the Australian Tsunami Warning System (ATWS), 12 new stations have been brought into operation and 28 stations have been significantly upgraded; Geoscience Australia now operates a total of 63 seismic stations across the region for tsunami warning and earthquake monitoring purposes. A further 136 international seismic stations from shared international networks are also now monitored. More recently, 26 strong motion stations have been replaced as part of the Joint Urban Monitoring Program (JUMP).

With an average data latency of 20 seconds, the seismic system used by the Joint Australian Tsunami Warning Centre (JATWC) is able to automatically determine an initial origin time, location and body magnitude (m_b) of large earthquakes within 5 minutes. Following analysis of the earthquake by an on-duty seismologist, a reviewed earthquake alert containing an initial estimate of the moment magnitude of the P-wave (M_{wp}) can be generated within a further 5 minutes. An alert is sent via a dedicated data line to the Bureau of Meteorology hub of the JATWC, where a tsunami bulletin is prepared and published on the Bureau's website and sent to emergency managers, the media, harbourmasters and other relevant stakeholders.

This paper describes this process, the methodologies employed and the systems used to perform this critical 24/7 monitoring role. It also highlights some of the future

development activities that are planned to enhance the accuracy and timeliness of Geoscience Australia's earthquake information.

Keywords: seismic, design, yield, curvature, displacement, performance

1. Introduction

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. 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. 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 the Attorney-General's Department 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.

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.

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 the Attorney-General's Department, as well as the diplomatic leadership of the Department of Foreign Affairs and Trade.

Building the Australian Tsunami Warning System

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 government within Australia – 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.

With its role in the national coordination of emergency management, the Attorney-General's Department coordinated the 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; and
- 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.

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 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.

2. Real-time Earthquake Monitoring at the JATWC

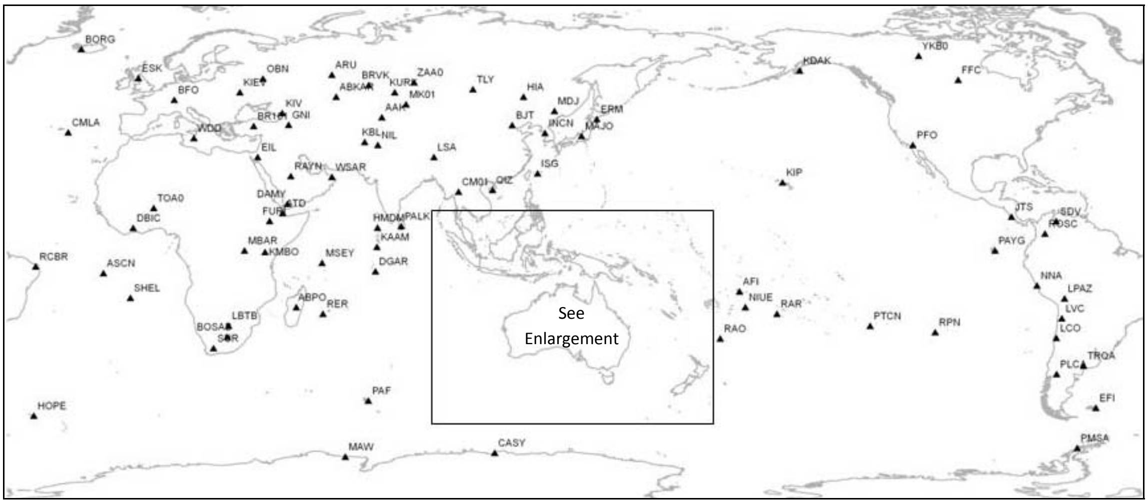
In 2005 Geoscience Australia monitored 33 seismic stations, known as the Australian National Seismic Network (ANSN), which had been developed for its domestic earthquake monitoring and alert service. By November 2010, this number had increased to 221 and consisted of:

- 19 of the existing ANSN stations;
- 28 ANSN stations that had been substantially upgraded;
- 9 new ANSN stations within Australia;
- 26 strong motion stations have been replaced as part of the Joint Urban Monitoring Program (JUMP)

- 3 new overseas stations built by Geoscience Australia (one in Niue and two in PNG); and
- 136 stations from shared international seismic networks (and includes 7 seismic arrays).

The seismic network is depicted in figure 1.

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.



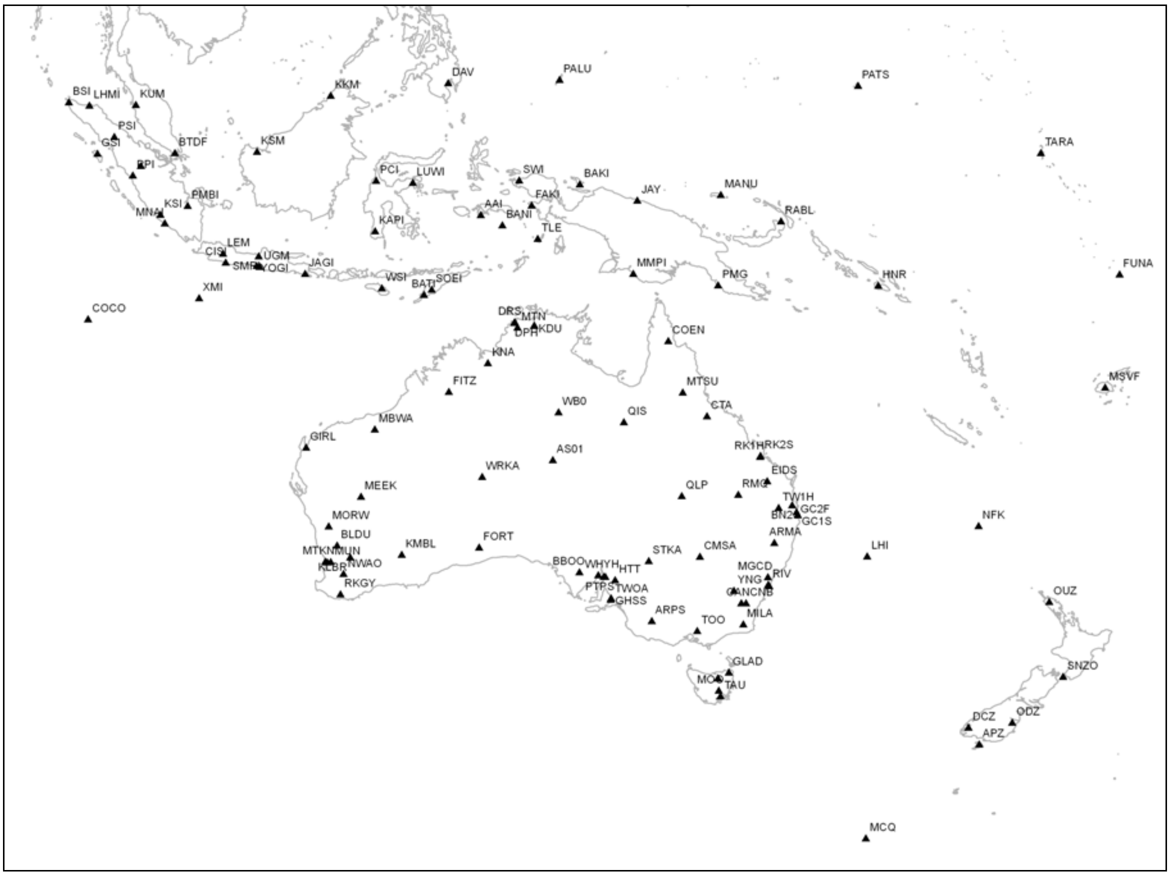


Figure 1. The location of seismic stations monitored by the JATWC. Station codes have been added as labels.

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 (M_{wp}), using an algorithm from the Pacific Tsunami Warning Center in Hawaii, to provide consistency in earthquake magnitude estimates in all warnings from all centres. This magnitude calculation takes the form (Tsuboi, et al, 1995):

$$M_{wp} = \frac{\log M_0 - 9.1}{1.5}$$

where:

$$M_0 = \max\left(\int u_z(x_r,t)dt\right)\frac{4\pi\rho\alpha^3 r}{F^P}$$

where $u_z(x_r,t)$ is the vertical component of far-field *P*-wave displacement at receiver, x_r; ρ and α is the average density and average *P*-wave velocity along the propagation path; r is the epicentral distance between the source and the receiver and F^P is a radiation pattern due to the double-couple source mechanism.

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, testing and production. 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.

3. 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 three years.

Between July 2007, when the system developed from an alert service to a warning service, and 1 November 2010 there have been 174 earthquakes assessed as having the potential 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. Five of the earthquakes generated tsunami warnings for Australia. Figure 2 shows the epicentres of these alerted earthquakes in the Australian region since July 2008.

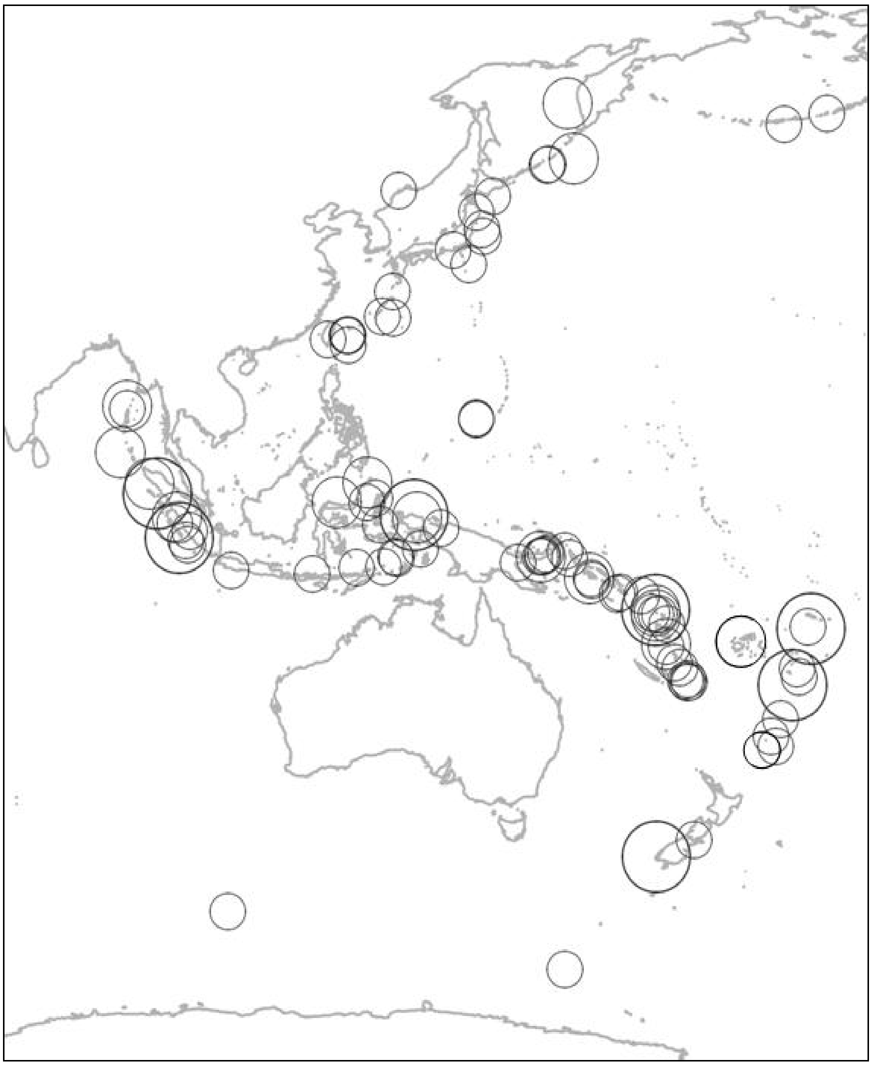


Figure 2. Epicentres of potentially tsunamigenic earthquakes alerted by the JATWC in the Australian region since July 2008

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 earthquakes to 1 November 2010.

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.

4. 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, time and hypocentre.

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.

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 watch 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.

References

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