INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
(of UNESCO)

Thirtieth Session of the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS-XXX)

Nuku'alofa, Kingdom of Tonga, 11-15 September 2023

NATIONAL REPORT

Submitted by

AUSTRALIA

BASIC INFORMATION

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4. Tsunami Standard Operating Procedures
4.1. for a Local Tsunami

There is the potential for local tsunami to be generated by underwater slippage of sediments off the Australian continental shelf in some areas. Usually there would be insufficient time for a warning system to operate, due to the very short tsunami arrival times from such nearby sources. However, the threat from local tsunamis is very low - Australia's main threat from tsunamis, and the focus of Standard Operating Procedures, is regional/distant earthquake sources.

5. Tsunami Standard Operating Procedures for a Distant Tsunami

National Tsunami Warnings and Community Response

The Joint Australian Tsunami Warning Centre (JATWC), operated by the Australian Bureau of Meteorology (Bureau) and Geoscience Australia (GA), was formally established on 1 July 2007. The JATWC is the national authority and provides Australia with an independent capability to detect and warn of tsunamis. The Australian community is regularly advised of nil, potential or confirmed threats from tsunamis being generated by undersea subduction zone earthquakes throughout the surrounding Indian and Pacific Ocean basins.

Threat Assessment:

The JATWC operates through two 24/7 hubs. The seismic detection and monitoring hub of the JATWC, based at GA in Canberra, automatically issues seismic solutions for potentially tsunamigenic earthquakes via a dedicated high speed communications link to the tsunami warning and sea level monitoring hub of the JATWC, based at the Bureau's National Production Services (NPS) co-located in Melbourne and Brisbane (See Figure 1). For earthquakes of magnitude 6.5 and above, GA additionally issues a manually-assessed seismic solution to the Bureau.

Receipt of the manual seismic assessment automatically triggers tsunami travel time software at the Bureau. With the aid of a purposely built Decision Support Tool (DST), forecast tsunami amplitudes from pre-calculated deep ocean model tsunami scenarios are then used by highly trained and competency assessed staff to determine whether a *No Threat* Bulletin or a *Tsunami Watch* will be issued directly to the Australian community through the Bureau's dissemination systems.

The scenarios are generated by a Bureau modified version of the MOST (Method Of Splitting Tsunami) model, originally developed by the Pacific Marine Environmental Laboratory (PMEL) of the United States National Oceanic & Atmospheric Administration (NOAA). The earthquake source parameters required for the scenario database were developed in collaboration with GA. When an earthquake event occurs, the closest scenario is extracted from the database and used as forecast guidance (see Figure 2 for an example). The source locations for the scenarios are at 100 km intervals along the subduction zones within the Indian and Pacific Oceans. The South Sandwich subduction zone is also included, as tsunamis from this source can impact Australia.

Each source location has four or five scenarios associated with it, with moment magnitudes of 7.0 (for subduction zones near Australia only), 7.5, 8, 8.5 and 9. A total number of 2,069 scenarios have been generated at 521 potential locations. A scaling technique is used to

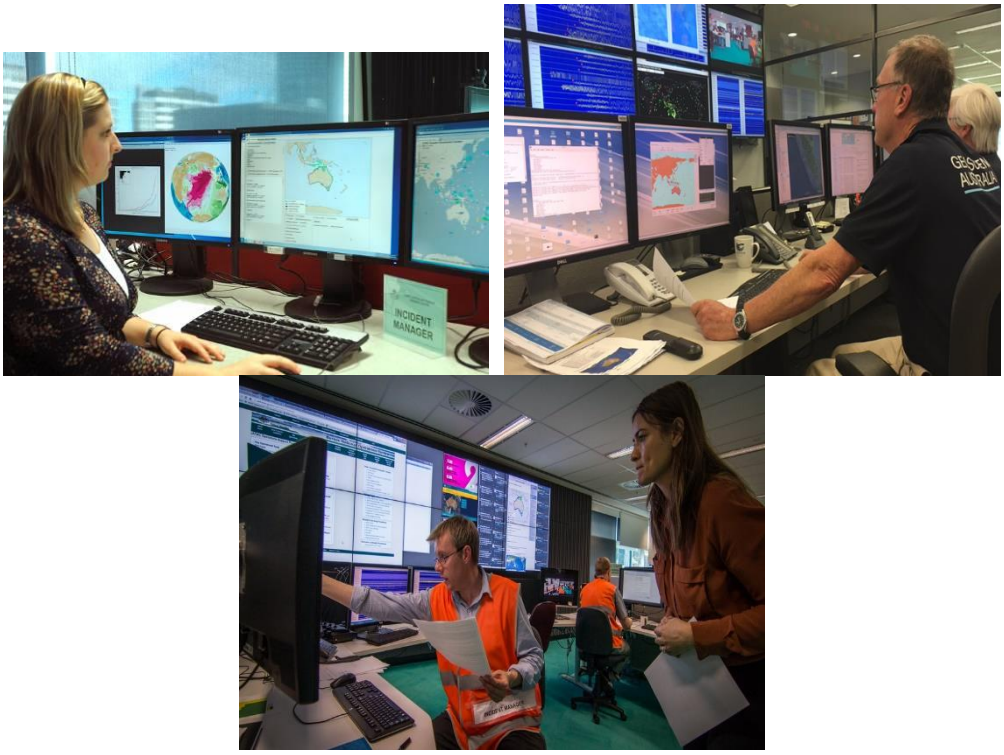

Figure 1: *Staff of the Joint Australian Tsunami Warning Centre (JATWC) operated by the Australian Bureau of Meteorology and Geoscience Australia*

provide forecast guidance for earthquakes of intermediate magnitudes (e.g. 7.8, 8.1). Each scenario has associated forecast guidance products. These model guidance products specify expected maximum wave amplitudes and arrival times at each model grid point. The values of the maximum wave amplitudes for the grid points in each Australian and Indian Ocean Coastal Forecast Zone (CFZ) are then used to determine the threat level for that zone.

In addition to providing a basis for the tsunami forecast system, these scenarios can be used as boundary conditions for detailed inundation modelling studies performed within state-based hazard assessment projects.

The model output has been calibrated against known impacts in Australia from a number of real tsunami events since 1960. The resulting threshold values of predicted tsunami amplitude offshore (deep water) for Australian coastal zones, which in negotiation with emergency response authorities are used to assign one of three threat levels, are as follows:

No Threat (to Australia):	< 20 cm (Australian Continent and Antarctica) < 10 cm (Offshore Territories)
Marine Threat (no inundation):	20 to 55 cm (Australian Continent and Antarctica) 10 to 50 cm (Offshore Territories)
Land Inundation Threat:	> 55 cm (Australian Continent and Antarctica) > 50 cm (Offshore Territories)

The threat assessment is made for individual segments all along the coast (approx. 200km long) associated with existing marine weather forecast zones that are well known to the public. Inundation modelling has been used to verify the JATWC tsunami warning strategy.

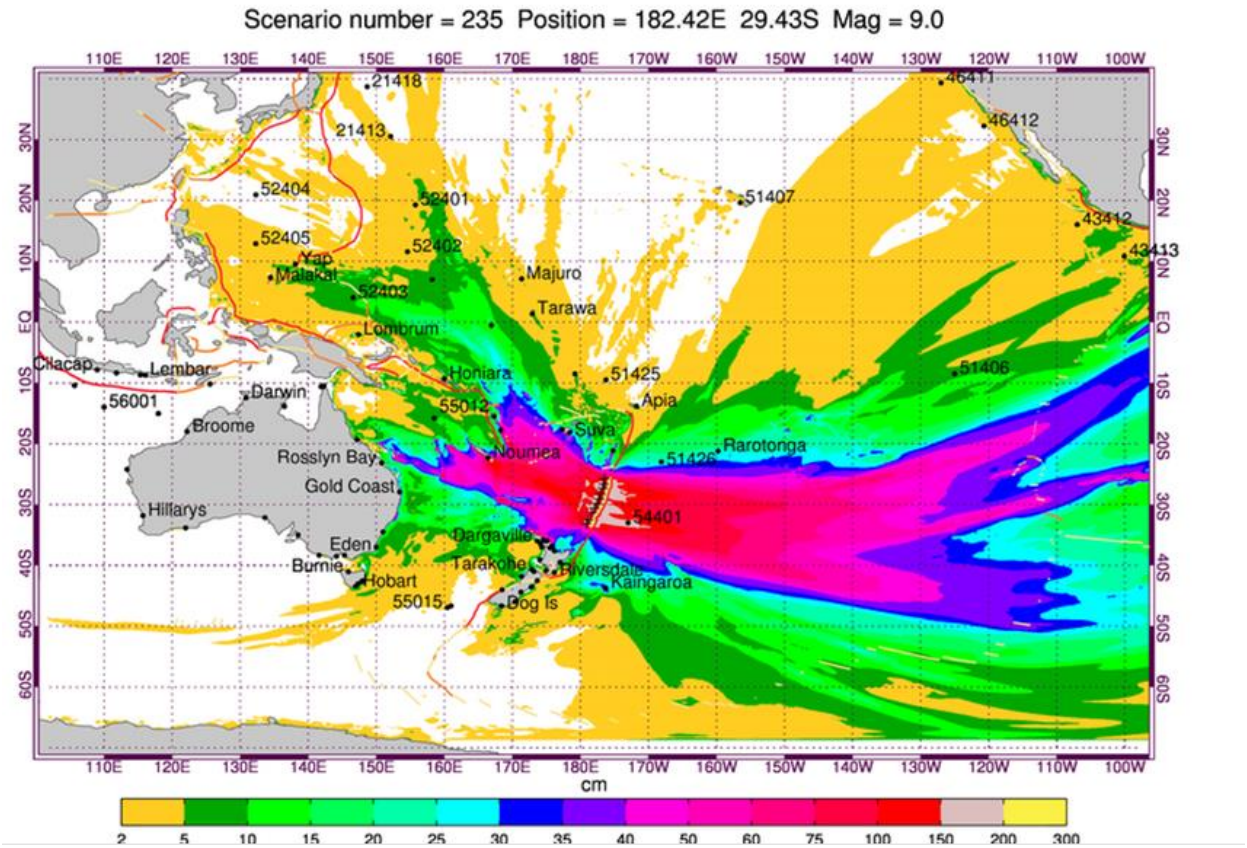

Figure 2: *An example of the maximum wave amplitudes scenario predicted for a potential Mw = 9.0 event in the Kermadec region*

Tsunami Bulletins:

Once a JATWC *Tsunami Watch* bulletin has been issued, a monitoring process begins using national and international sea-level gauges across the Pacific and Indian Oceans. If no tsunami is detected by the gauges, then a *Cancellation* bulletin may be issued by the JATWC.

If either a tsunami is confirmed, or no tsunami signal has reached a gauge but there is only 90 minutes (or less) of travel time remaining before potential impact on the Australian mainland or Offshore Territories, the JATWC will issue a *Tsunami Warning* for either a *Marine Threat* or a *Land Threat* for the relevant States and Territories, as determined by the tsunami model scenario. Approximate values extrapolated with Green's Law for expected tsunami effects (wave amplitude) in shallow water are (at approximate coastal sea-level gauge depth of 5m):

No Threat:	< 40 cm
Marine Threat:	40 to 100 cm
Land Threat:	> 100 cm

Consultations about decisions on tsunami warnings are undertaken via a dedicated video communication link between the Bureau JATWC hub in Melbourne and/or Brisbane and the GA JATWC hub in Canberra. There is also expert specialist surge/support available from the Bureaus' Environmental Prediction Services Tsunami Marine and Coastal Hazards team during the initial standing up or activation of the JATWC. The Bureau's Decision Support Offices in each state and territory, as well as the Bureau's specialist aviation and defence weather services offices, also provide further liaison and advice to state/territory emergency services, local authorities, communities, media, defence and industry users.

An example of the graphical display on the JATWC public web site for national tsunami warnings is shown in Figure 3.

Figure 3: *Example of different levels of tsunami warnings for designated coastal zones for the Australian mainland and offshore territories that may be displayed on the JATWC website during a tsunami event such as previously shown in Fig.2 for the Kermadec region.*

The standard format of tsunami warning bulletins is shown in Table 1. Key elements include: a) Message identifiers (to alert users to sequence of warnings, timing, etc); b) Advice to the media about how they should handle the warnings; c) Headline message to gain attention; d) Summary for use by the media (the full details and complexities of the warnings on the web site can be long, so a summary is also required for distribution by the media); e) Advice on appropriate community responses to the threat; and f) When the next bulletin will be issued

Table 1: *Structure of Tsunami Warning Bulletins*

Product Identifier	Identify type product/auto notifier
Media Instructions	How urgently should be broadcast. Use of Standard Emergency Warning Signal (SEWS) or not
Message Title and Issue Time	Type, date / time and number sequence of message
Headline Message	Key message; eg. No Threat, Potential Threat, Threat
Summary	What, where and when the threat is
Threat Information	Level of Threat, Coastal areas affected, time of Arrival
Community Response Advice	What action people should take
Next Update Time	When the next update will be issued
Where Public can get Further Information	Web and telephone details for further / latest information

Advice on Community Response

The nationally consistent, recommended actions for community response (Action Statements) for each level of threat (Land and Marine) as derived and agreed by the Australian Tsunami Advisory Group (ATAG) of the Australia-New Zealand Emergency Management Committee (ANZEMC) are:

Marine Threat Warning – Action Statements

Definition: Warning of potentially dangerous rips, waves and strong ocean currents in the marine environment and the possibility of only some localised overflow onto the immediate foreshore.

- Move out of the water and stay away from the waterfront of harbours, coastal estuaries, rock platforms and beaches.
- Boats in harbours, estuaries and in shallow coastal water should return to shore. Secure your boat and move away from the waterfront.
- Vessels already at sea in deep water of more than 25m should remain well offshore until further advised.
- Do not go to the coast to watch the tsunami.
- Check that your neighbours have received this advice.

Land Threat Warning – Action Statements

Definition: Warning for low-lying coastal areas of major land inundation, flooding, dangerous rips, waves and strong ocean currents.

- All Action Statements under Marine Threat plus
- Go to higher ground, at least ten metres above sea level, or if possible move at least one kilometre away from all beaches and the water's edge of harbours and coastal estuaries.
- If you cannot leave the area, take shelter in the upper storey of a sturdy brick or concrete multi-storey building.
- It will be in your own interests to walk to safety if possible to avoid traffic jams.
- Take only essential items that you can carry including important papers, family photographs and medical needs.

Warning Dissemination:

The Bureau of Meteorology component of the JATWC has national, sovereign responsibility for issuing tsunami advisories and warnings specific to Australia and its territories. This information is provided to the public, media, operational centres of state and territory emergency management organisations, and other relevant authorities via the Bureau's existing 24/7 meteorological and severe weather (multi-hazard) communications network (see Figure 4).

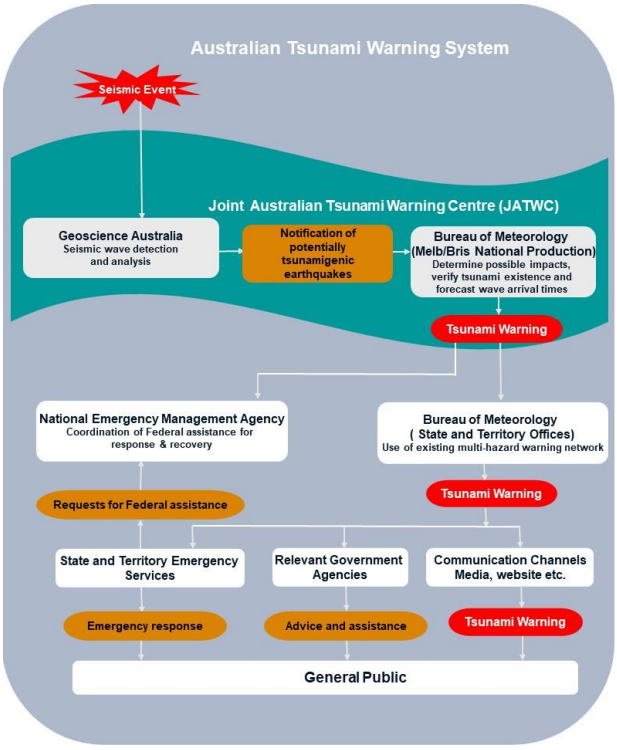

Figure 4: *Concept of Operations for the Australian Tsunami Warning System (ATWS)*

The Bureau directly promulgates public advices and warnings relevant to an event. Tsunami bulletins and warnings are distributed to the media and public by a variety of electronic media (internet, fax, SMS, push notifications and ftp). Warnings are also available to the public and media via a dedicated '1300 tsunami' phone information line.

Dissemination of warnings using latest technologies is the key to effective community response. The Bureau has developed a strategy to use social media in the warnings space. In late 2014 the Bureau commenced using Twitter to make the public aware that hazard warnings have been issued and are available on the Bureau's website. Tweeting is a manual process but has been automated as much as possible in recent years. Bureau's mobile app is another channel to alert the public if there is a tsunami warning affecting their area.

A dedicated National Media and Communications Team at the Bureau liaises and coordinates media interactions with the media groups of GA and the Department of Climate Change, Energy, the Environment and Water (DCCEEW) in Canberra. The Bureau has dedicated communications officers around the country to handle regional and local media enquiries.

The JATWC also generates its tsunami warnings using the Australian Standard version of the Common Alerting Protocol (CAP).

Business Continuity

The Bureau and GA components of the JATWC each have Business Continuity Plans in case of primary system failures to ensure 24/7 capability is not interrupted. Information from the Indian National Centre for Ocean Information Services (INCOIS) in Hyderabad, the Indonesian Tsunami Early Warning System (InaTEWS) of BMKG in Indonesia, the Pacific Tsunami Warning Centre (PTWC) of NOAA in Hawaii, and the North-West Pacific Tsunami Advisory Centre (NWPTAC) of the Japan Meteorological Agency (JMA) in Tokyo can be used as a further back-up if GA's seismic monitoring facilities and/or Bureau's tsunami warning Decision Support Tool (DST) were to still be inoperable.

Emergency Response:

Emergency management agencies of the various State and Territory Governments on receipt of tsunami warning information from the JATWC have formal jurisdiction and prime responsibility for community preparedness and emergency response prior to, and during events.

Development of nationally consistent responses and preparedness is facilitated by ANZEMC ATAG, which includes all State and Territory emergency management agencies (including Norfolk Island, Christmas and Cocos (Keeling) Islands and Australian Antarctic territories) and other national groups with roles in marine hazard management (Surf Life Saving Australia or SLSA), the technical agencies involved with tsunami warnings (Bureau and GA), the National Emergency Management Agency (NEMA) which operates the Australian Government National Situation Room (AGNSR), and the New Zealand government agencies of GNS and National Emergency Management Agency.

The AGNSR liaises with relevant State and Territory emergency management organisations to facilitate and coordinate the provision of federal resources to the states and territories for post event recovery as required. The AGNSR also coordinates communication within the Federal Government during an event to ensure senior Government officials and relevant Government Departments are aware of the situation and requirements for national support and response. The Bureau and the DCCEEW support and provide community education on all-hazards, including tsunami.

SLSA receives tsunami bulletins and then coordinates responses by local surf life-saving clubs, such as closing beaches to swimming. This is a particularly important role for Marine Threat warnings.

JATWC also issues warnings to port and maritime authorities around the country. The Australian Maritime Safety Authority (AMSA) receives and forwards national and international tsunami warning and threat information to shipping in its international area of regional responsibility as the Navigational Area X Coordinator.

An example of the ISO 9000 based tsunami warning signage used in Australia is given in Figure 5.

***Figure 5**: Australia has adopted the ISO 9000 based international standards for tsunami warning signage.*

Warning Termination:

JATWC will issue a warning *cancellation* when it assesses that either no tsunami has eventuated or the tsunami threat has passed. In the latter case, the observed wave amplitudes must be below the Marine Threat threshold for at least two hours, although abnormal sea level changes and currents may persist for many hours.

The All Clear advice on when it's safe to return to coastal areas is not made by the JATWC, but by the State/Territory emergency management authorities who have jurisdictional responsibility for public safety and response to any tsunami impacts.

Tsunami Threat Information Provided to Indian Ocean Member States

The JATWC has been operating as a designated Tsunami Service Provider (TSP) for the UNESCO Intergovernmental Oceanographic Commission (IOC) Indian Ocean Tsunami Warning & Mitigation System (IOTWMS) since 12 October 2011. India and Indonesia also operate designated TSPs for the IOTWMS. IOTWMS-TSP Australia has built on its well-developed national capability and capacity to provide tsunami threat assessments for other Member States around the Indian Ocean. TSP Australia accords with the procedures and service levels specified in the IOTWMS TSP Service Definition Document maintained by Working Group 2 of the UNESCO/IOC Intergovernmental Coordination Group (ICG) for the IOTWMS, to which Australia has been a significant contributor.

In accordance with the TSP Service Definition Document, IOTWMS-TSP Australia does not itself issue warnings for other countries, but it provides a Registered User web site for National Tsunami Warning Centres (NTWCs) of other Indian Ocean countries to access to interoperable tsunami threat information in standard formats, including the details of the expected wave amplitudes and arrival times at each designated Indian Ocean Coastal Forecast Zone (CFZ). The NTWCs then use this and information, in conjunction with similar information from the other TSPs of India and Indonesia, to decide whether to issue tsunami warnings to their own communities. TSP Australia also launched an IOTWMS public web site that reflect the tsunami warning status of the Member States based on their reporting to TSPs during the event. The website can be found at www.bom.gov.au/iotwms.

IOTWMS-TSP Australia's services consist of:

- A password-protected website (http://reg.bom.gov.au/tsunami/rtsp/) containing:
    - Service Level 1 Earthquake Bulletins
    - Service Level 2 Tsunami Threat Assessment Bulletins
    - Threat Maps showing threat status for the 572 Indian Ocean CFZs
    - Threat Table giving detailed threat data for each CFZ
    - NTWC Warning Status Reporting Form
    - Downloadable Spatial Data File (.dbf) with detailed threat data for each CFZ
    - Graphical products (see Figures 6-8)
    - Maritime product for NAVAREA Coordinators
- TSP Tsunami Bulletin Notification Messages issued to NTWCs by email, fax, GTS and mobile-phone SMS text. These messages notify NTWCs that IOWTMS-TSP Australia has updated a Tsunami Bulletin on its password-protected website.
- An IOTWMS-TSP Australia User Guide giving NTWCs full information on the services provided.
- A public website to reflect the tsunami warning status of all Indian Ocean countries (www.bom.gov.au/iotwms).

For the Indian Ocean CFZs, the threat levels are based on the ICG/IOTWMS agreed threat threshold of 50cm wave amplitude at the beach (not the deep water amplitudes used in Australia's national tsunami threat assessment). Zones with amplitudes of 50 cm or higher are set to 'threat' level.

IOTWMS-TSP Australia's tsunami modelling and threat-assessment capability is based on pre-run scenarios from the MOST (Method Of Splitting Tsunamis) forecast model, as described earlier for national tsunami warnings for Australia.

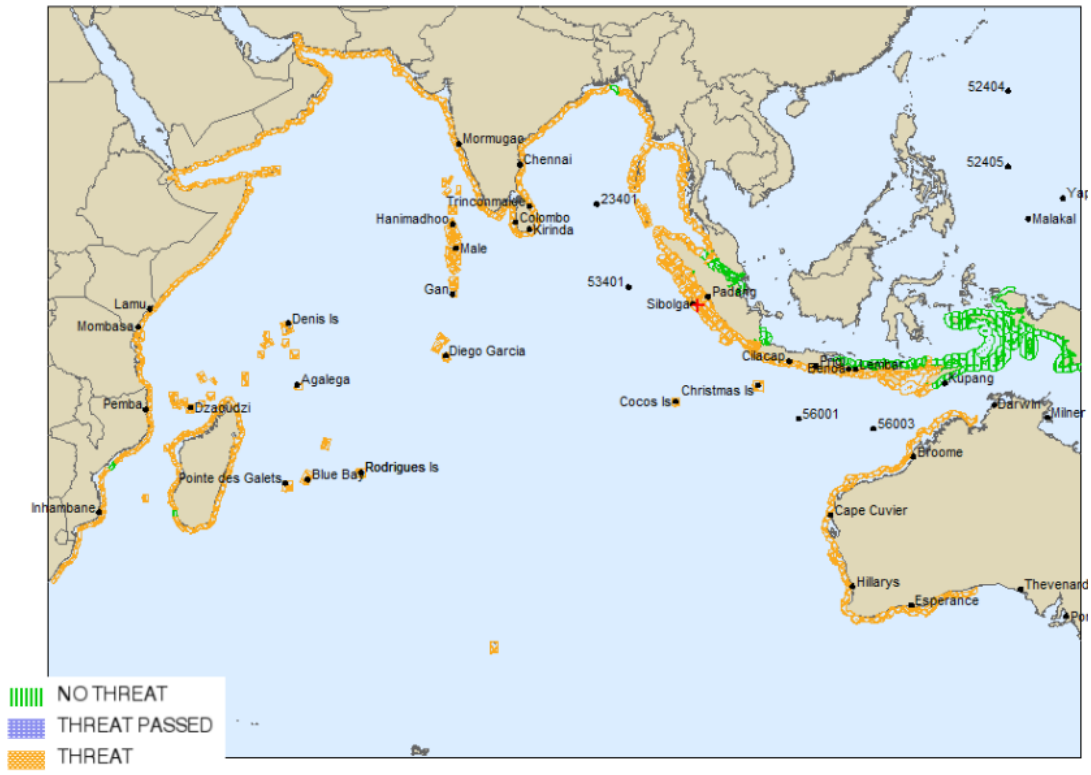

Figure 6: *IOTWMS-TSP Australia Coastal Zone Threat Map for a simulated scenario of Magnitude 9.2 Earthquake off Southern Sumatra (IOWave16).*

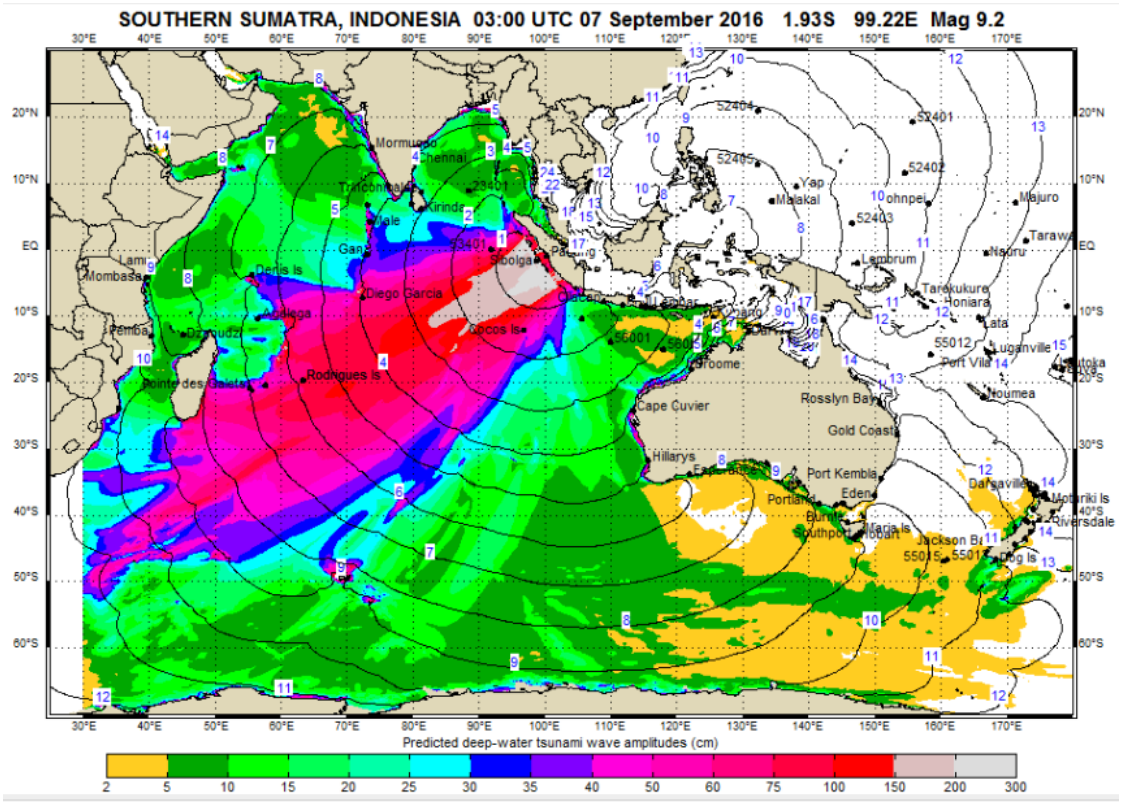

Figure 7: *IOTWMS-TSP Australia forecast of Deep-Water Maximum Wave Amplitude and Travel Time for a simulated scenario of Magnitude 9.2 Earthquake off southern Sumatra (IOWave16).*

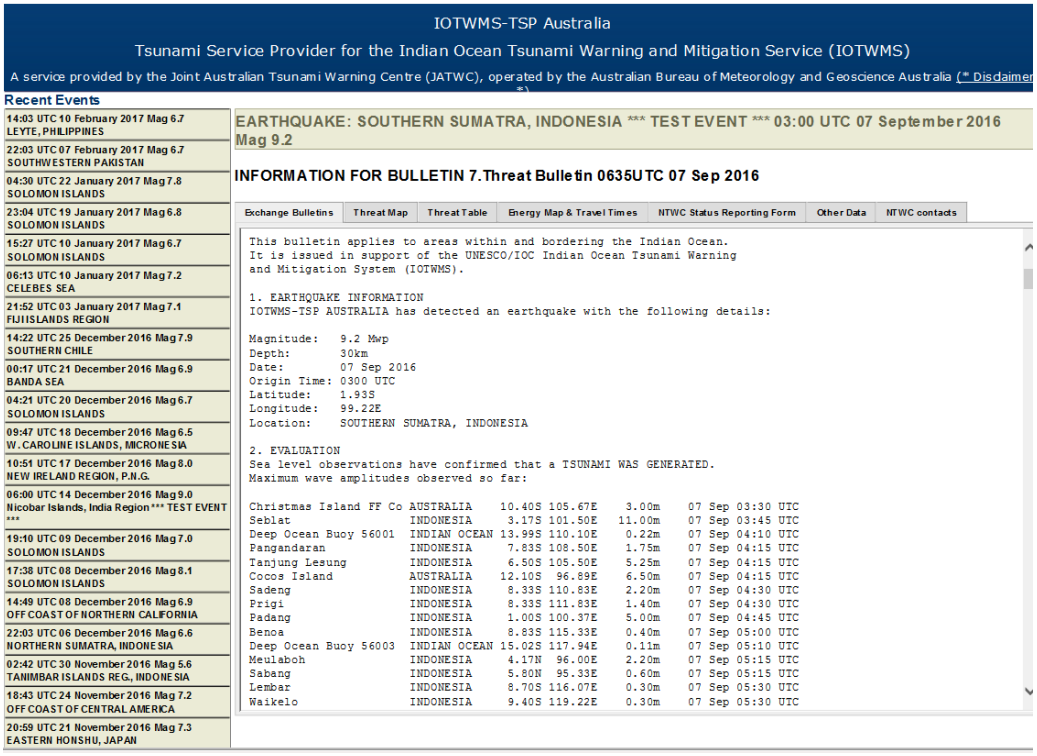

Figure 8: *IOTWMS-TSP Australia "Confirmed Threat" Tsunami Bulletin, with wave observations for a simulated scenario of Magnitude 9.2 Earthquake off Southern Sumatra (IOWave16).*

National Seismic Network

Geoscience Australia accesses real time data from Australian and international seismic stations to monitor for earthquakes that may generate tsunami (see Fig.11). Real time data from Australian stations is shared with the international community. Figure 12 shows the infrastructure for the Christmas Island (XMIS) station.

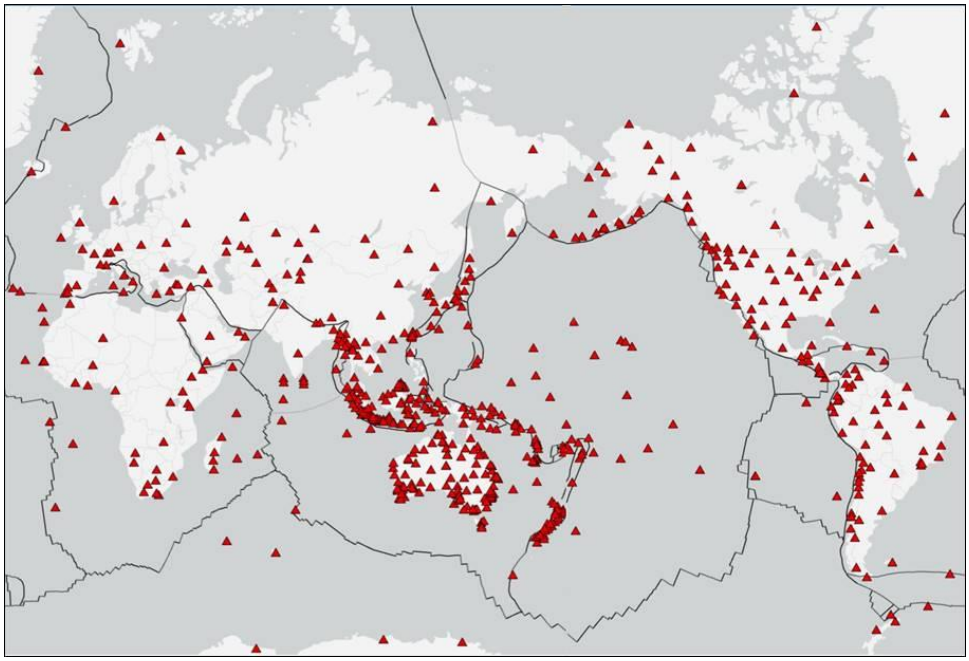

Figure 11: *Map of seismograph stations providing real-time data to Geoscience Australia's National Earthquake Alerts Centre (NEAC), a component of the Joint Australian Tsunami Warning Centre (JATWC). Geoscience Australia relies on international data-sharing arrangements with other countries and institutions to ensure JATWC can rapidly detect and characterise potentially tsunamigenic earthquakes anywhere, anytime.*

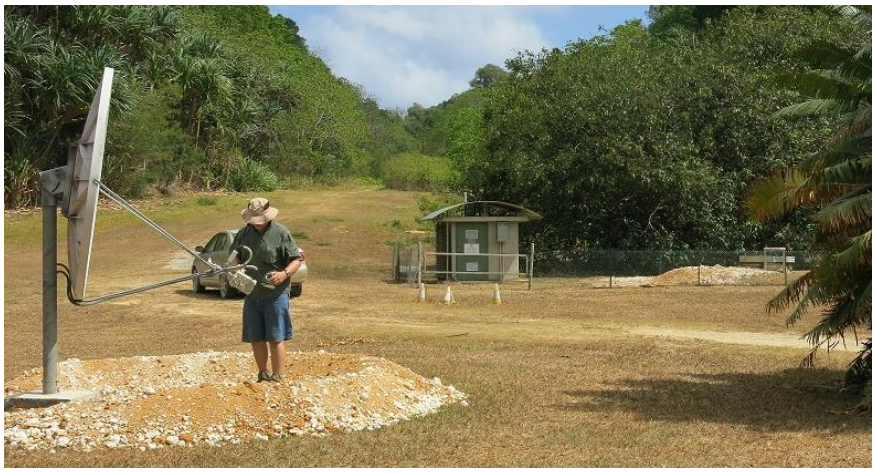

Figure 12: *The Christmas Island (XMIS) seismograph station*

6. National Sea Level Network

The sea level network has been designed to enable confirmed warning times of at least 90 minutes for the west and east mainland coasts of Australia. User and service requirements for the tsunami sea level network have led to a Zone based mode, feeding into data availability, lifecycle, and operational consideration requirements. Within each zone, a sea level site has been evaluated based on its potential contribution to an early warning and has been categorised

as either being an early warning, monitoring, or verification site. Consideration has also been given to the value of the site to model assimilation and scenario validation.

Figure 13 gives the location of existing coastal sea-level stations and tsunameters (deep ocean tsunami detection buoys) operated by the Bureau of Meteorology and used for verifying the existence of a tsunami. The composite network of 42 coastal stations and 6 deep-ocean tsunameters provides coverage for tsunamis originating from both the Pacific Ocean and Indian Ocean basins.

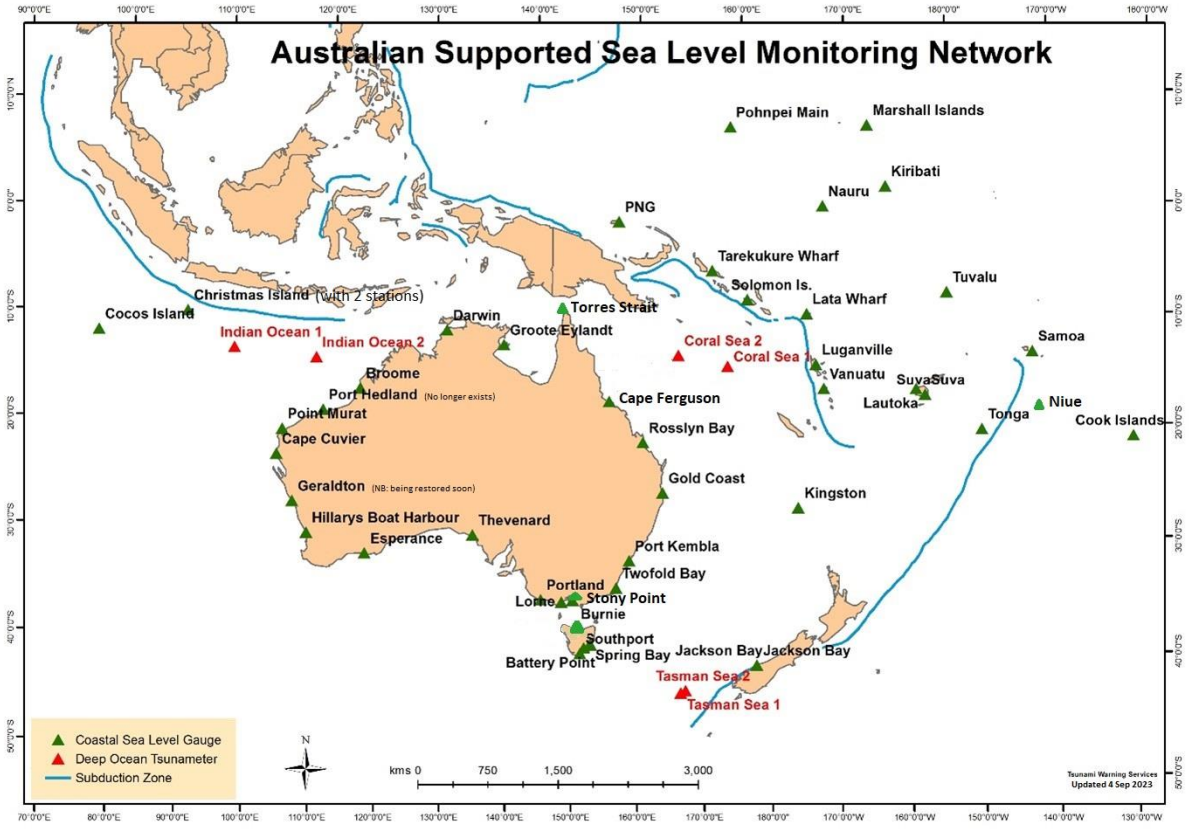

Figure 13: *Australian sea level monitoring stations operated by the Australian Bureau of Meteorology.*

The original tide gauge network was established to mainly monitor sea-level changes due to climate change. These stations report sea-level data as well as a limited set of meteorological parameters. Sea-level measurement is performed via the traditional 'Aquatrak' acoustic-in-air sensor. The stations also capture sea surface temperature, air temperature and pressure, wind speed and direction.

The newer coastal sea-level stations designed specifically for tsunami observing purposes were installed at locations deemed most suitable for tsunami monitoring (e.g. exposed to open waters). These stations utilise a radar-based water-level sensor chosen for its technical capabilities, as well as lower lifecycle cost. Six of these additional tsunami purpose-built coastal stations face the Indian Ocean, and fourteen face the Pacific Ocean.

To meet tsunami warning requirements, the data communications systems of the climate coastal sea-level station network have been upgraded to enable all the stations to report their data at one-minute intervals reliably and cost-effectively.

The Bureau of Meteorology gathers real-time data at one-minute intervals for all 42 coastal stations. Data is redistributed in real-time in the recommended Table Driven Code Form (CREX) on the WMO Global Telecommunications System (GTS) for use by other nations.

Users unable to access the GTS can use FTP to obtain the data from the Bureau. Alternatively, the Bureau can provide PDF plots of sea-level data from stations listed in Table 2 through the Bureau's webpages for Registered Users.

***Table 2**: Australian Coastal Sea Level Stations as at 4 September 2023 (*radar type gauges)*

Location	**Latitude**	**Longitude**	**Date Commissioned**	**GTS 1 min**
Australian Mainland				
Groote Eylandt	-13.86	136.42	Sep 1993	√
Darwin	-12.47	130.85	May 1990	√
Broome	-18.01	122.22	Nov 1991	√
Hillarys	-31.85	115.74	Nov 1991	√
Esperance	-33.87	121.90	Mar 1992	√
Thevenard	-32.15	133.64	May 1992	√
Portland	-38.34	141.61	Jul 1991	√
Burnie	-41.05	145.91	Sep 1992	√
Spring Bay	-42.55	147.93	May 1991	√
Port Kembla	-34.47	150.91	Jul 1991	√
Rosslyn Bay	-23.16	150.79	Jun 1992	√
Cape Ferguson	-19.28	147.06	Sep 1991	√
Point Murat *	-21.82	114.19	Dec 2007	√
Cape Cuvier *	-24.22	113.40	Nov 2008	√
Battery Point *	-42.89	147.34	Mar 2009	√
Southport *	-243033	146.97	Jun 2009	√
Two Fold Bay *	-37.10	149.93	Jun 2009	√
Gold Coast *	-27.94	153.43	Jun 2009	√
Stony Point	-38.37	145.22	n/a	
Torres Strait	-10.59	142.22	Nov 2014	√
Indian Ocean				
Cocos Islands	-12.12	96.90	Sep 1992	√
Christmas Island I	-10.43	105.67	Dec 2006	√
Christmas Island II *	-10.43	105.67	Jul 2009	
Pacific Ocean				
Lautoka, Fiji	-18.13	178.43	Oct 1992	√
Suva, Fiji	-18.13	178.43	Oct 1992	√
Tarawa, Kiribati	1.35	172.91	Dec 1992	√
Port Vila, Vanuatu	-17.75	168.28	Jan 1993	√
Nuku'Alofa, Tonga	-21.13	175.2	June 2018	√
Rarotonga, Cook Is	-21.2	200.23	Feb 1993	√
Apia, Samoa	-13.82	188.25	Feb 1993	√
Funafuti, Tuvalu	-8.38	179.21	Mar 1993	√

Location	Latitude	Longitude	Date Commissioned	GTS 1 min
Majuro, Marshall Islands	7.11	171.37	May 1993	√
Nauru	-0.53	166.9	Jul 1993	√
Honiara, Solomon Is	-9.43	159.95	Jul 1994	√
Lombrum- Manus Is	-2.03	147.36	Sep 1994	√
Jackson Bay, NZ *	-43.97	168.62	Jul 1996	√
Pohnpei, FSM	6.98	158.20	Dec 2001	√
Luganville, Vanuatu *	-15.52	167.19	Dec 2007	√
Kingston, Norfolk Is *	-29.06	167.96	Aug 2009	√
Choisuel, Solomon Is *	-6.69	156.41	May 2010	√
Lata, Solomon Is *	-10.72	165.80	May 2010	√
Niue	-19.05	-169.9	Expected Sep 2023	√

Australia has six deep ocean tsunami monitoring stations (tsunameters) deployed in locations to the NW (Indian Ocean), NE (Coral Sea) and SE (Tasman Sea) of the country. One of them is now replaced with the new generation 4G DART systems, with the intent to replace all stations with the new system in the future. See Figure 14 for examples of these deployed DART systems.

Data from the buoys have been transmitted on the GTS in real time using the CREX/BUFR Template for Transmission of Sea Level Data from Tsunameters. Data from these stations have also been made available in real time through the web site of the US National Data Buoy Centre (NDBC) and the IOC Sea Level Monitoring Facility.

***Table 3**: Australian Deep Ocean Tsunami Stations (Tsunameters) as at 4 September 2023*

Location	Latitude	Longitude	Established	Status
Indian Ocean				
Indian Ocean 1	-12.32	108.51	Oct 2008	OK
Indian Ocean 2	-15.02	117.99	Oct 2008	OK
Coral Sea				
Coral Sea 1	-15.43	158.28	Apr 2008	70% data availability
Coral Sea 2	-14.72	153.54	Sep 2009	OK
Tasman Sea				
Tasman Sea 1	-46.93	160.47	Feb 2007	BPR communication issue, to return to service Nov/Dec 2023
Tasman Sea 2	-44.85	161.73	Apr 2011	OK. 4G DART

Figure 14: *Deep ocean tsunameters deployed by Australia*

7. Information on Earthquake Events and Tsunami Occurrences

Since January 2021, 160 events have resulted in the issuing of JATWC bulletins, of which four were assessed as a Marine or Land threat to the Australian mainland or its offshore islands and territories.

An earthquake of magnitude 7.6 occurred 11 February 2021 southeast of the Loyalty Islands, New Caledonia. In response, the Bureau issued a Marine Warning for Lord Howe Island. This was the first tsunami warning issued by the Bureau of Meteorology for any Australian state or territory since 2 March 2016.

An earthquake of magnitude 7.9 occurred on 5 March 2021 near Kermadec Islands, New Zealand, preceded by two smaller but above M7.0 earthquakes in the same region on the same night. The M7.9 earthquake generated a tsunami that reached marine threat level for Norfolk Island. While tsunami waves were also expected to reach (and later observed along) the

Australian east coast and Lord Howe Island, the JATWC did not issue warnings because waves were of smaller size and below the Marine Warning threshold.

An explosive volcanic eruption of the Hunga Tonga-Hunga Ha'apai volcano (near Tonga) occurred on 15 January 2022. This eruption generated a tsunami that reached Land threat level at Norfolk Island, and Marine threat level at Lord How Island, Macquarie Island, and most coastlines of the four eastern states of Queensland, New South Wales, Victoria and Tasmania. Appropriate warnings were issued with the entire operations lasting for over 30 hours.

An earthquake of magnitude 7.7 occurred 19 May 2023 southeast of the Loyalty Islands, New Caledonia. In response, the Bureau issued at total of six Marine Warnings for Lord Howe Island, justified by the observed dangerous waves and surge in the marine environment around the island.

Table 4: *Tsunami bulletins issued by JATWC since January 2021. "ATWS Bulletin issue time" is the time in minutes between earthquake occurrence and the first ATWS bulletin being issued. Target time is 30 minutes. Events listed in blue are "felt earthquakes" – events less than the tsunami magnitude of 6.5 but felt by people within 20km of the coastline and so No Threat advice issued by JATWC. Events highlighted in green led to the JAWTC issuing ATWS Marine warnings or above.*

2021

Time	Date (UTC)	Mag	Location	ATWS Bulletin Type	ATWS Bulletin issue time
12:23	21-Jan-21	6.9	Talaud Islands, Indonesia	No Threat	18
23:36	23-Jan-21	6.9	South Shetland Islands	No Threat	16
13:20	10-Feb-21	7.6	Southeast of Loyalty Islands	Warning	21
14:07	13-Feb-21	7.1	Near East Coast of Honshu, Japan	No Threat	28
13:27	04-Mar-21	7.2	Off E. Coast of N. Island, N.Z	No Threat	15
17:41	04-Mar-21	7.3	Kermadec Islands, New Zealand	No Threat	29
19:28	04-Mar-21	7.9	Kermadec Islands, New Zealand	Warning	18
09:09	20-Mar-21	7.1	Near East Coast of Honshu, Japan	No Threat	13
14:24	*15-Apr-21*	*3.0*	*Foster, VIC*	*No Threat*	*37*
01:27	01-May-21	6.9	Near East Coast of Honshu, Japan	No Threat	11
06:57	*24-Jun-21*	*5.1*	*Offshore Broome, WA*	*No Threat*	*23*
06:15	29-Jul-21	8.2	Alaska Peninsula	No Threat	14
17:46	11-Aug-21	7.1	Mindanao, Philippines	No Threat	20
18:32	12-Aug-21	8.1	South Sandwich Islands Region	No Threat	25
11:57	14-Aug-21	6.8	Alaska Peninsula	No Threat	18
11:10	16-Aug-21	6.9	South Sandwich Islands Region	No Threat	21
10:10	18-Aug-21	6.9	Vanuatu Islands	No Threat	13
00:45	22-Aug-21	6.8	South Sandwich Islands Region	No Threat	15
21:33	22-Aug-21	7.0	South Sandwich Islands Region	No Threat	19
01:47	08-Sep-21	6.8	Guerrero, Mexico	No Threat	14
23:15	*21-Sep-21*	*5.9*	*N of Rawson, VIC*	*No Threat*	*17*
06:29	02-Oct-21	7.2	Vanuatu Islands Region	No Threat	19
16:47	*08-Oct-21*	*4.8*	*Murrayville, VIC*	*No Threat*	*31*
10:58	09-Oct-21	6.8	Vanuatu Islands Region	No Threat	16
09:10	11-Oct-21	6.9	Alaska Peninsula	No Threat	13
16:43	*02-Nov-21*	*5.7*	*Tanimbar Islands Reg., Indonesia*	*No Threat*	*22*
08:05	*05-Nov-21*	*2.5*	*Mornington, VIC*	*No Threat*	*30*

13:05	*13-Nov-21*	*5.3*	*Marble Bar, WA*	*No Threat*	*22*
03:20	14-Dec-21	7.2	Flores Sea	No Threat	14
18:25	29-Dec-21	7.3	Banda Sea	No Threat	16

2022

Time	Date (UTC)	Mag	Location	ATWS Bulletin Type	ATWS Bulletin issue time
11:35	11-Jan-22	6.6	Fox Islands, Aleutian Islands	No Threat	15
04:10	15-Jan-22	-	Hunga Tonga Hunga Ha'apai Volcano	Warning	108
21:24	*24-Jan-22*	*4.8*	*Wagin, WA*	*No Threat*	*31*
19:25	*01-Feb-22*	*6.0*	*Banda Sea*	*No Threat*	*22*
20:21	16-Feb-22	6.8	South of Fiji Islands	No Threat	28
20:50	*05-Mar-22*	*3.7*	*Mount Barker, SA*	*No Threat*	*15*
14:36	16-Mar-22	7.3	Near East Coast of Honshu, Japan	No Threat	15
08:34	*29-Mar-22*	*2.9*	*Mount Barker, SA*	*No Threat*	*165*
20:57	30-Mar-22	7.0	Southeast of Loyalty Islands	No Threat	15
05:44	31-Mar-22	6.9	Southeast of Loyalty Islands	No Threat	13
10:13	19-May-22	6.9	Macquarie Island, Southern Ocean	Watch	23
02:36	*27-May-22*	*6.3*	*Timor Region*	*No Threat*	*21*
19:17	12-Jul-22	6.8	Easter Island Region	No Threat	21
00:43	27-Jul-22	7.0	Luzon, Philippines	No Threat	12
12:59	*09-Aug-22*	*5.6*	*Banda Sea*	*No Threat*	*22*
07:09	*16-Aug-22*	*5.5*	*Macquarie Island, Southern Ocean*	*No Threat*	*54*
16:23	*01-Sep-22*	*5.1*	*Banda Sea*	*No Threat*	*21*
23:47	10-Sep-22	7.6	Eastern New Guinea Reg., P.N.G.	No Threat	15
11:04	14-Sep-22	7.0	Southeast of Loyalty Islands	No Threat	16
19:41	*17-Sep-22*	*2.4*	*Frankston, VIC*	*No Threat*	*31*
06:44	18-Sep-22	7.0	Taiwan	No Threat	12
18:05	19-Sep-22	7.4	Michoacan, Mexico	No Threat	12
06:16	22-Sep-22	6.6	Michoacan, Mexico	No Threat	14
09:38	09-Nov-22	6.8	South of Fiji Islands	No Threat	14
09:50	09-Nov-22	6.9	South of Fiji Islands	No Threat	20
10:48	11-Nov-22	7.3	Tonga Islands Region	No Threat	19
07:09	12-Nov-22	7.0	Fiji Islands Region	No Threat	19
13:37	18-Nov-22	6.6	Southwest of Sumatra, Indonesia	No Threat	11
10:05	*21-Nov-22*	*4.3*	*Derby, WA*	*No Threat*	*34*
02:03	22-Nov-22	6.9	Solomon Islands	No Threat	16
19:24	04-Dec-22	6.8	Tonga Islands	No Threat	12

2023

Time	Date (UTC)	Mag	Location	ATWS Bulletin Type	ATWS Bulletin issue time
12:32	08-Jan-23	7.2	Vanuatu Islands	No Threat	18
17:47	09-Jan-23	7.6	Banda Sea	No Threat	13
06:06	18-Jan-23	6.9	Northern Molucca Sea	No Threat	16
09:37	*17-Feb-23*	*6.1*	*Tanimbar Islands Reg., Indonesia*	*No Threat*	*16*
06:41	04-Mar-23	6.8	Kermadec Islands, New Zealand	No Threat	13
00:55	16-Mar-23	7.1	Kermadec Islands Region	No Threat	14
17:12	18-Mar-23	6.7	Near Coast of Ecuador	No Threat	16
23:23	*22-Mar-23*	*4.7*	*Flinders Region, SA*	*No Threat*	*23*
02:46	*02-Apr-23*	*2.9*	*Mount Barker, SA*	*No Threat*	*13*

18:04	02-Apr-23	7.1	New Guinea, Papua New Guinea	No Threat	14
09:55	14-Apr-23	7.0	Java, Indonesia	No Threat	16
09:02	*17-Apr-23*	*4.7*	*Offshore Broome, WA*	*No Threat*	*30*
04:07	*19-Apr-23*	*4.2*	*Macquarie Island, Southern Ocean*	*No Threat*	*41*
08:23	*22-Apr-23*	*6.2*	*Banda Sea*	*-*	*-*
00:41	24-Apr-23	7.2	Kermadec Islands, New Zealand	No Threat	15
20:00	24-Apr-23	6.9	Southern Sumatra, Indonesia	No Threat	15
16:02	10-May-23	7.5	Tonga Islands	No Threat	12
02:57	19-May-23	7.7	Southeast of Loyalty Islands	Warning	13
01:50	20-May-23	7.2	Southeast of Loyalty Islands	No Threat	19
14:56	21-May-23	6.8	Prince Edward Islands Region	No Threat	26
15:49	*24-May-23*	*6.1*	*Banda Sea*	*No Threat*	*23*
13:41	*28-May-23*	*3.8*	*NE of Sunbury, VIC*	*No Threat*	*17*
02:03	*03-Jun-23*	*2.4*	*Mornington, VIC*	*No Threat*	*24*
18:06	15-Jun-23	7.2	South of Fiji Islands	No Threat	20
15:32	*29-Jun-23*	*4.6*	*N of Rawson, VIC*	*No Threat*	*25*

8. Addresses (URLs) of national tsunami-related web sites

Table 5 *lists of web sites in Australia for national tsunami warnings (JAWTC) and related information.*

Description	Website Address
Joint Australian Tsunami Warning Centre	http://www.bom.gov.au/tsunami/
Indian Ocean Warning Status TSP Australia	http://www.bom.gov.au/tsunami/iotwms
Geoscience Australia – Earthquake Information	http://www.ga.gov.au/earthquakes/
Geoscience Australia – Tsunami Information	http://www.ga.gov.au/scientific-topics/hazards/tsunami
Australian Tsunami Warning System	http://www.bom.gov.au/tsunami/about/atws.shtml
Tsunami: The Ultimate Guide	https://knowledge.aidr.org.au/tsunami-the-ultimate-guide/#/

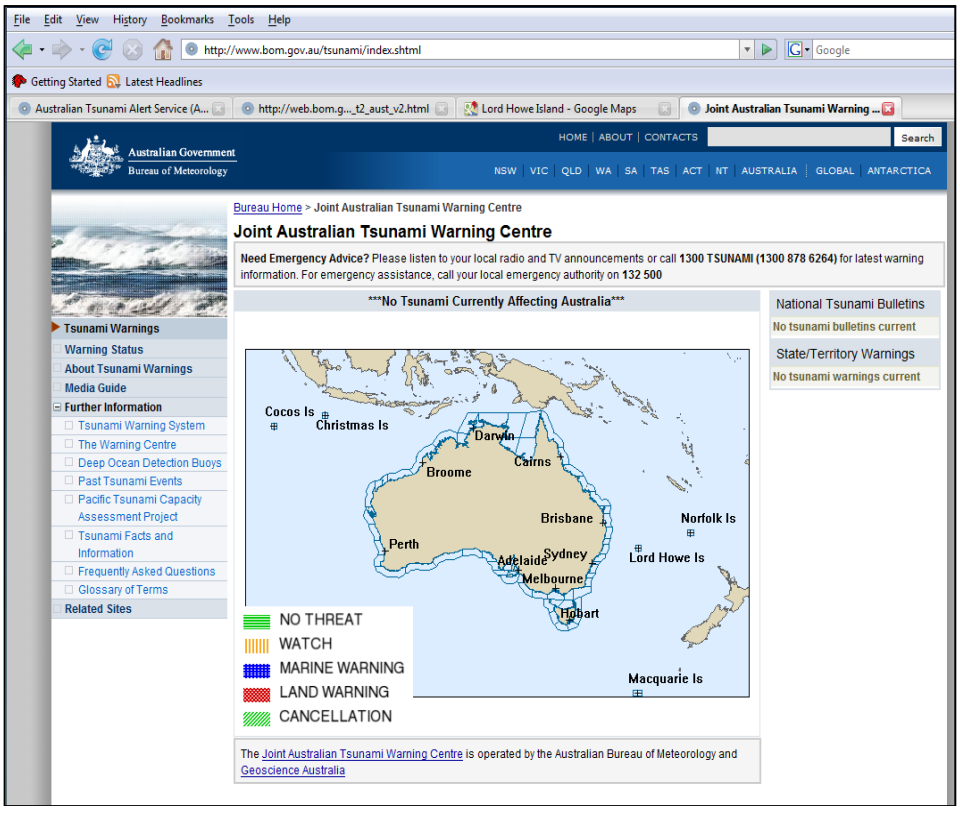

Figure 15*:* Screen shot of the official Australian national tsunami warning web site http://www.bom.gov.au/tsunami/

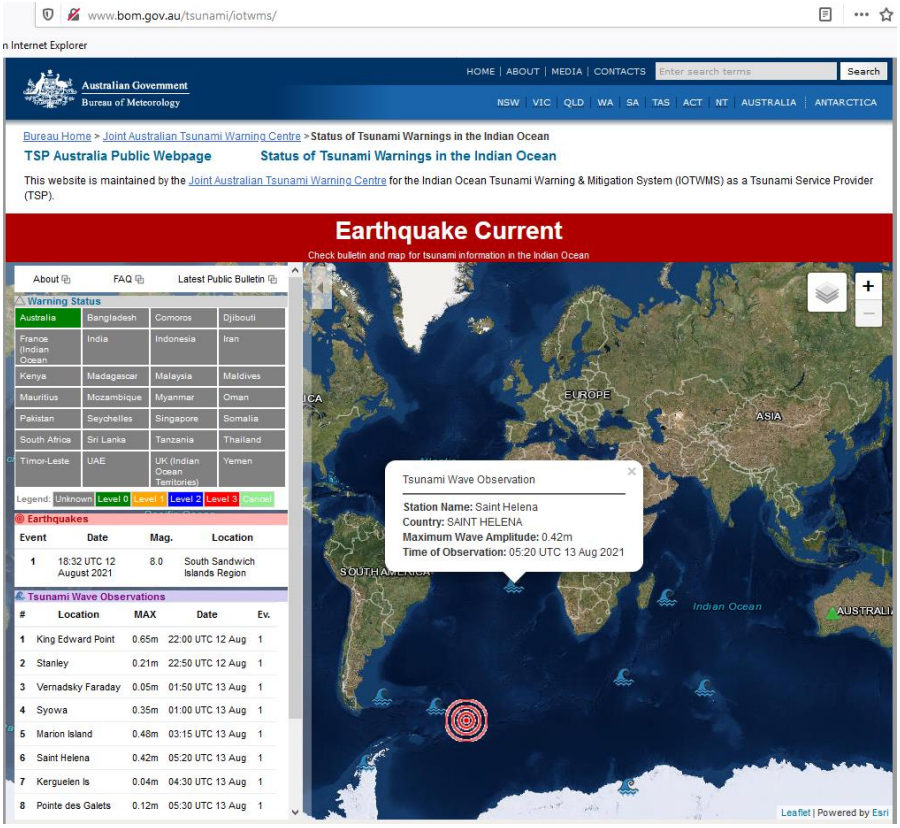

Figure 16. Screen shot of the TSP Australia Public web site http://www.bom.gov.au/iotwms/

9. Summary plans of future tsunami warning and mitigation system improvements

Tsunami Risk Assessment

The 2018 update of the national Probabilistic Tsunami Hazard Assessment (PTHA) by Geoscience Australia has been used by the State and Territory emergency management agencies to prioritise areas for more detailed tsunami inundation assessments.

Following the New South Wales State Emergency Services (SES) releasing of its tsunami evacuation mapping platform to the NSW public in 2016, Queensland Fire and Emergency Services has recently published the tsunami evacuation mapping platform to the Queensland public.

Enhanced Seismic Monitoring

Geoscience Australia's suite of software and tools used to detect potentially tsunamigenic earthquakes continues to be enhanced and refined. A w-phase estimator has been developed to produce magnitude estimates and associated focal mechanisms of large earthquakes. This development was undertaken in collaboration with the Research School of Earth Sciences of the Australian National University. The w-phase estimator is running in Geoscience Australia's real-time development environment, with outputs shared with the Bureau of Meteorology.

Enhanced Sea Level Monitoring

Efforts are continuing at the Bureau of Meteorology to sustain those core networks of coastal sea level stations and deep ocean tsunami detection DART buoys. Other efforts occurring at the Bureau include accessing additional sea level data in real-time from tide gauges operated by local port and maritime authorities around Australia, although not all these gauges were installed or have the capability for real-time monitoring.

Enhanced Tsunami Warning

The Bureau of Meteorology has updated the warning thresholds after taking into account the more recent tsunami events, enabling the separate and more accurate thresholds setting for mainland coastlines and offshore islands as listed in Section 5.

The Bureau's tsunami standard operating procedures have been updated to include procedures in handling non-seismic tsunami sources caused by volcanic eruptions and undersea landslides.

The Bureau's underpinning tsunami warning decision tool is being replaced by a global community of practice tool called TOAST together with a more robust and secure information and communication technology infrastructure.

Community Awareness and Preparedness

The national tsunami coordination body of the Australian Tsunami Advisory Group (ATAG) developed a new 3-year workplan of 2022-25, emphasising the importance of exercising the end-to-end tsunami warning system and building community tsunami awareness and preparedness.

NATIONAL PROGRAMMES AND ACTIVITIES INFORMATION

10. EXECUTIVE SUMMARY

The Joint Australian Tsunami Warning Centre (JATWC), operated by the Bureau of Meteorology and Geoscience Australia, is the national authority for providing tsunami warnings to Australia and its offshore territories. The JATWC is also a designated Tsunami Service Provider (TSP) for the Indian Ocean Tsunami Warning & Mitigation System (IOTWS), providing tsunami threat information for 28 Indian Ocean countries. Australia, through the Bureau of Meteorology, has continued to provide over AUD$400,000 per year and accommodation support to the UNESCO/IOC in support of the Secretariat Office of the ICG/IOTWMS at the Bureau's Regional Office in Perth, Western Australia.

Australia participated in two international exercises of IOWave20 and PacWave22. It also conducted a national tabletop tsunami exercise called Bombora in 2022 with 50 agencies participating, and it plans to participate in the upcoming IOWave23 exercise in October 2023.

Australia continues to operate its own national seismic and sea level monitoring networks, making all data freely available to all other countries. A new tsunami Decision Support System is also being implemented at the Bureau of Meteorology. The Bureau's tsunami warning services have been enhanced through a major transformation of the operating model and was recertified by an independent auditing agency for another three years to 2026 for operating an ISO 9001 compliant quality management system.

Australia continues to undertake national and local scale risk assessments, community preparedness evaluation and tsunami research aimed at the ongoing improvement of the Australian Tsunami Warning System (ATWS).

11. NARRATIVE

Improvements to the JATWC systems and procedures

The Bureau of Meteorology is implementing a new system called TOAST to transform the key decision supporting tool underpinning the JATWC tsunami operations at the Bureau.

The Bureau has just completed a major enterprise-wide transformation of the Bureau public service offering which has greatly enhanced the agility and resilience of tsunami operations. The enhancement is due to a new operating model where the National Production Services provide the 24/7 tsunami monitoring and initial response capability, while the Environmental Prediction Services provide the expert surge capability through the on-call tsunami restriction roster. The new incident management arrangement further enabled the enterprise-wide resource mobility and support.

The quality managed tsunami warning services through such a major transformation has been recertified by an independent auditing agency for another three years to 2026 for complying with the international ISO 9001 standards.

Tsunami research projects, tsunami mitigation activities and best practices

The nationally consistent Australian Warning System (AWS) is being considered for implementation at various States/Territories. New South Wales has implemented AWS for

riverine and tsunami hazards, and Queensland is actively pursuing similar implementation for tsunami.

Queensland Fire and Emergency Services received funding through the Coastal and Estuarine Risk Mitigation Program (CERMP) for tsunami modelling at Gladstone. The Project is due to start Mar 2024.

City of Gold Coast completed its tsunami modelling project which included submarine landslide modelling useful for local tsunami planning.

Tsunami Exercises and Communications Tests

Indian Ocean Communications Tests
Australia has assisted in the organisation and conduct of the half-yearly IOTWMS communications tests since early 2011. Australia participates as both an IOTWMS Tsunami Service Provider and as a National Tsunami Warning Centre. Australia also assists the ICG/IOTWMS Secretariat in the preparation of the official manuals and reports for the tests.

Exercise IOWave20
The Intergovernmental Coordination Group (ICG) of the Indian Ocean Tsunami Warning & Mitigation System (IOTWMS) organises Indian-Ocean-wide tsunami exercises roughly once every two years. IOWave20 took place during October 2020 against the backdrop of the COVID-19 pandemic. As a consequence, the exercise has the limited scope and objectives. It focused on three Tsunami Service Providers (TSPs) including the JATWC to exercise their Indian Ocean regional operational responsibility. Each TSP provided live simulated threat advice to National Tsunami Warning Centres in the Indian Ocean for three different scenarios, being conducted over three separate weeks.

National Exercise Bombora
Australia is at risk of catastrophic consequences following a large scale tsunami. To inform national preparedness a jointly planned exercise was undertaken on 31 August 2022 with Queensland Fire and Emergency Services (QFES), NSW State Emergency Service and the National Emergency Management Agency (NEMA). There were 150 people from 50 agencies in participation of this national tabletop discussion Exercise called Bombora.

Exercise Bombora comprised a three stage scenario developed by Geoscience Australia (GA) and examined the impact of a tsunami upon the east coast of Australia, exploring the processes and challenges during the response and early recovery phase. In the first stage a large undersea earthquake (9.4 Richter scale) ruptured 2,600 kilometres east of the Australian mainland. Stage two was triggered and Australia received confirmation that a tsunami had been generated. The third and final stage saw the initial tsunami wave hit all locations between Wollongong and the Gold Coast, resulting in widespread damage, over 10,000 casualties, destruction of 3,000 houses, tens of thousands more damaged and significant critical infrastructure destroyed or damaged.

Eight recommendations have arisen from Exercise Bombora. NEMA will lead working groups, involving states and territories, Geoscience Australia, Bureau of Meteorology, and a representative from the Australian Tsunami Advisory Group to coordinate the broader packages of work to address these recommendations.

Exercise PacWave22
The Australian participation in the exercise was limited to the JATWC receiving comms test messages from PTWC and JMA on the exercise day of 13 October 2022.

The JATWC also participated in the Pacific Island Countries and Territories Regional Exercise (PacWave22-PICT) on 9 November 2022. The 2-hour real-time tabletop regional exercise tested the Hunga Tonga Hunga Ha'apai (HTHH) PTWC Interim Procedures and the regional communication and cooperation between PICT Member States.

Exercise IOWave23
The upcoming IOWave23 exercise is scheduled to take place over a three-week period during the 4th to the 25th of October 2023. Four scenarios will be run in real time simulating Indian Ocean countries being put in a tsunami warning situation and requiring National Tsunami Warning Centres, Disaster Management Offices, and other relevant authorities in each country to activate their SOPs.

Three of the scenarios will simulate tsunamis generated by approximate magnitude 9 earthquakes originating in the Andaman, Makran and Java trenches. In addition, due to tsunamis generated by the recent 2018 Anak Krakatau and 2022 Hung Tonga-Hunga Ha'apai eruptions, the IOWave23 exercise will be the first exercise to test the response to a tsunami generated by a non-seismic tsunami source, simulating a tsunami generated by a volcanic eruption at Heard Island.

Australian participation in IOWave23 will focus on the Java Trench scenario (Day 4) as a functional exercise with large turnout of all affected States and Territories. For the non-seismic scenario (Day 3), Western Australia will conduct a local tabletop discussion exercise.

In all four scenarios, the Joint Australian Tsunami Warning Centre (JATWC) will also exercise its role as a Tsunami Service Provider (TSP) for the IOTWMS.

Date: 7 September 2023

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