Meeting of the IHO North Indian Ocean Hydrographic Commission (NIOHC) to be held in Bangladesh, March 2016.

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UNESCO/IOC Indian Ocean Tsunami Warning and Mitigation System (IOTWMS)

1 Status

Australia is a founding member of the IOTWMS and continues to actively participate through the Intergovernmental Coordination Group (ICG) under the auspices of UNESCO's Intergovernmental Oceanographic Commission (IOC). There are 28 countries involved in the IOTWMS, being states in and bordering the Indian Ocean basin. Australian representatives from the Bureau of Meteorology and Geoscience Australia provide leadership roles and contributions to the Working Groups and Task Teams of the ICG. Australia through the Bureau also hosts and financially supports the UNESCO/IOC Secretariat for the ICG at the Bureau's Regional Office in Perth (see Section 4 for contact details).

The ICG/IOTWMS meets regularly, with its next meeting to be held in Malaysia in the first quarter of 2016. Reports from its past ten Sessions can be downloaded from the site of the Intergovernmental Oceanographic Commission (IOC) of UNESCO at http://www.ioc-tsunami.org/ . The last meeting of the ICG was held in Oman, March 2015. A symposium on "Reducing Tsunami Risk in the Western Indian Ocean" was also held in Oman 22-23 March 2015, just prior to the 10th Meeting of the ICG/IOTWMS. Outcomes from the last ICG and associated symposium included:

- Now technical components of the warning system are operationally implemented, focus will be on sustaining the system.
- Greater focus to be placed on community awareness and preparedness to ensure communities are aware of the risks and know what to do when they receive warnings. To signify this extra focus, the "M" for "Mitigation" is no longer silent in the acronym (previously IOTWS and now IOTWMS).
- Details of the tsunami warning service for the Indian Ocean region were defined and agreed, developed in coordination with the three other tsunami warning & mitigation systems being implemented under the UNESCO/IOC banner in the Pacific Ocean (PTWS), NE Atlantic and Mediterranean Seas (NEAMS), Caribbean and Adjacent Seas (CARIBE-EWS)
- The UNESCO/IOC Indian Ocean Tsunami Information Centre (IOTIC) (see iotic.ioc-unesco.org/), which is located in Jakarta and is funded and supported by the Indonesian Government, was officially endorsed.
- The Oman National Tsunami Warning Centre (NTWC), operated by the Omani national weather service was officially launched. (see www.met.gov.om/opencms/export/sites/default/dgman/en/home/)

- Outcomes from the Indian Ocean wide tsunami exercise and drill in September 2014 (named IOWAVE14) were reviewed. The exercise highlighted both the strengths and weaknesses of the IOTWMS, identified areas requiring further attention, and provided a benchmark of the present status of the system. The three (3) designated TSPs and all twenty-four (24) Member States with nominated Tsunami Warning Focal Points (TWFPs) participated, with two (2) countries taking the exercise down to the community level, with all countries providing feedback via a post-exercise survey.
- The risks, potential tsunami threats and past tsunami events for the NW Indian Ocean (such as Makran Trench 1945) were discussed, highlighting the need for this part of the Indian Ocean to be ready. A NW Indian Ocean Working Group was established by the ICG to enable countries in this region to work more closely together on risk assessment, seismic and sea level monitoring, warning and mitigation activities. As well as protection of lives, there are many shipping, offshore and coastal industrial and defence facilities that may be impacted by tsunami activity in this region.

2 Coastal and Deep-Ocean Sea Level Data

The IOTWMS continues to rely on sea level data provided in real-time from coastal and deep-ocean sea level stations around the Indian Ocean to verify if a tsunami may have been be generated by undersea earthquakes (see Figures 1and 2). Not all earthquakes generate tsunamis, so it's vitally important (if time permits before arrival at the shore) to verify if a tsunami was generated and size before warnings are issued. This helps reduce the possibility of false alarms.

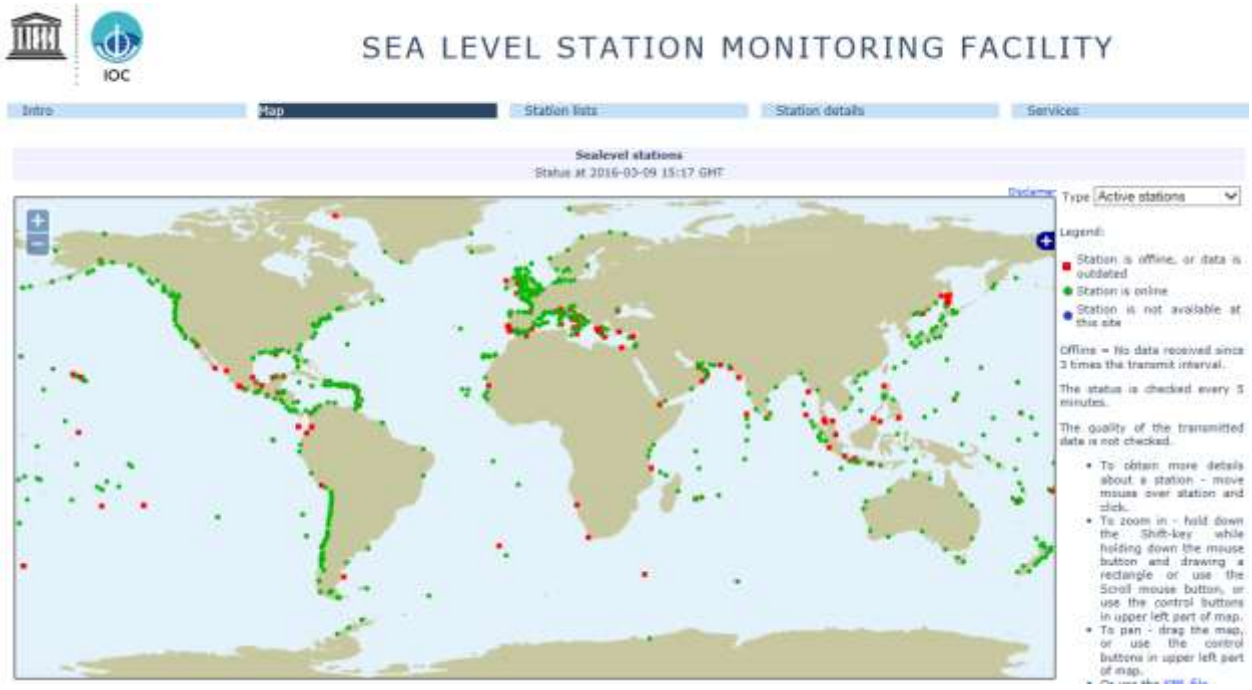

Figure 1: ***Coastal sea level stations reporting in real-time to TSPs and NTWCs on the Global Telecommunication System (GTS) of the World Meteorological Organisation (WMO as at 9 March 2016).***

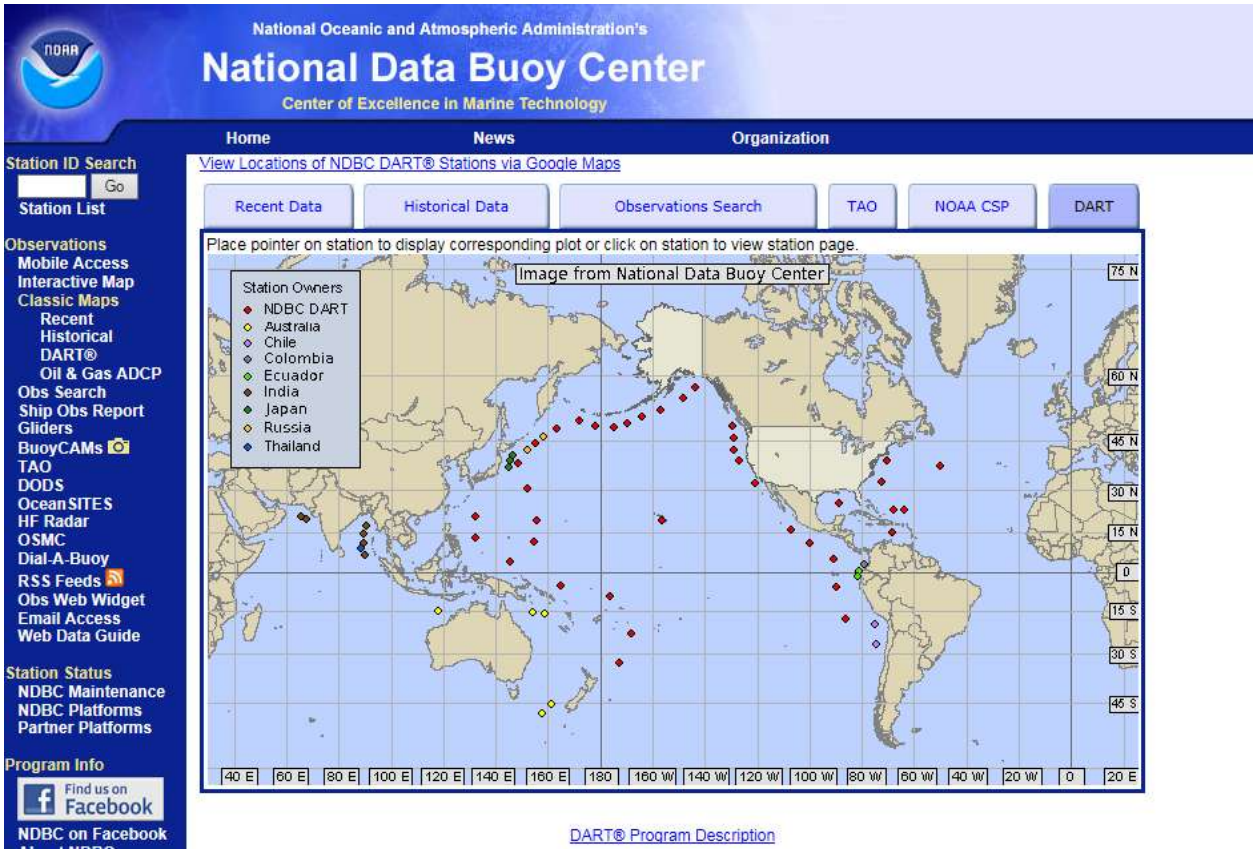

Figure 2: ***Locations of deep-ocean tsunami buoys providing critical sea level data in real-time to TSPs and NTWCs to assist tsunami warning decisions (as at 9 March 2016).***

2.1 Greater Access to Tide Gauge Data in Real-Time to Support Tsunami Warnings

There still remains much more sea level information potentially available for assisting tsunami warning decisions than shown in Figure 1. This information is often collected with tide gauges by port and maritime authorities for shipping and navigation operations and not necessarily available in real-time. All port and maritime authorities are encouraged to make their sea level data available in real-time to ensure safety of maritime operations and minimise interruptions to trade routes. Please contact the UNESCO Intergovernmental Oceanographic Commission (IOC) Sea Level Station Monitoring Facility (info@ioc-sealevelmonitoring.org) if you have sea level data you would like to share in real-time for tsunami warning purposes. Also note the sparse data around the east African coast and lower data density is some other areas.

2.2 Vandalism of Deep-Ocean Tsunami Monitoring Buoys

In general damaged ocean observing systems cause loss of critical ocean data, degraded forecasts of high seas and coastal weather, ocean temperature and currents for navigation and safe operation of vessels at sea. Damages can result in high cost of repair or replacement and undermine confidence in tsunami warning systems. This could result in significant loss of life and property, as well as costly evacuations and dangerous future complacency of communities in response to false tsunami warnings.

The tsunami warning community are deeply concerned that the rate of damage continues to be relatively high to deep-ocean tsunami monitoring buoys (often referred to as tsunameters or DARTS), but the situation shows promising signs of improvement in the Indian Ocean. All efforts to help improve the situation are very much appreciated. The tsunameters are not only used to help warn communities directly in the path of a passing tsunami, but all buoys are used by tsunami warning centres to verify the generation and propagation of a tsunami across the entire Indian Ocean during an event. They are all compared to the basin-wide forecasts to help validate the forecast model, as well as the initial assumptions of the sea floor deformation due to the undersea earthquake that generally causes tsunamis.

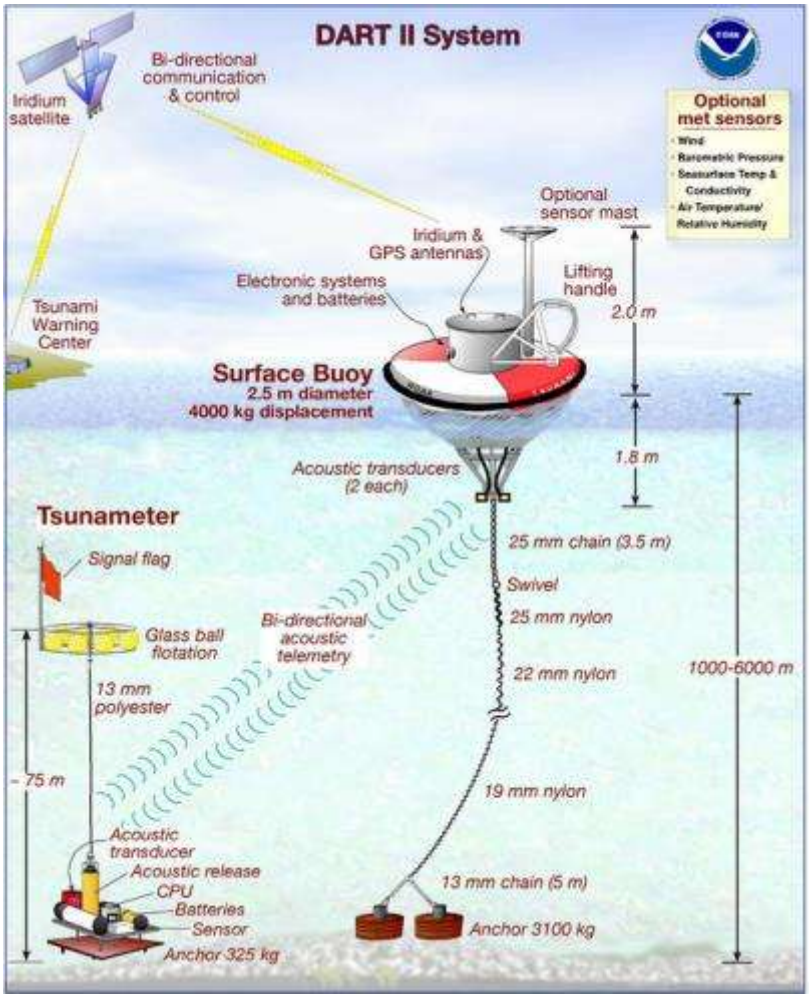

Figure 3: ***Typical deep-ocean tsunami monitoring buoy***

The deep-ocean tsunami monitoring buoys mostly consist of a bottom pressure sensing unit deployed on the sea floor (at a depth of between 2000 – 6000 m) that measures the tsunami wave-height and a surface buoy with satellite telecommunication capability to transmit the information to tsunami warning centres around the world (see Figure 3). Damage can take many forms including ship impact damage, incidental damage (e.g., fouling from fishing lines, nets or cables), damage from direct exploitation of moorings as fish aggregation

devices, intentional damage, and theft of entire systems or component parts. Accidental damage or vandalism often happens to the surface buoy, rendering the system non-operational. Fish often aggregate around the surface buoys feeding on the marine growth, which in turn attract he fishermen. Vessels tying up to the buoys can accidently or purposefully (after fish collected) damage the surface buoy and its instrumentation. The surface buoys are moored to the sea floor, so fishing lines can also snag and cut these mooring lines, leaving the surface buoys to float well out of range of the subsurface units.

Consistent efforts by India to sensitize this issue through an awareness campaign to fishermen, workshops in fish landing centres, distribution of pamphlets describing importance of tsunami buoys, involvement of Coast Guard & BOBP-Intergovernmental Organization, change in buoy design, promulgation of buoy location by National Hydrographic Office, regional coordination and many other efforts have resulted in NIL vandalism of Indian Tsunami Buoy System over the last 12 months.

In 2015 Australia replaced a surface buoy for one its two deep-ocean tsunami monitoring buoys in the waters between Indonesia and Australia, which was suspected of being damaged by vandalism in late 2014. Both buoys are presently operational. Indonesian authorities have provided briefings to the large tuna fishing industry and other fisheries on the importance of the buoys in this region.

The 2009 UN General Assembly Resolutions on Oceans and Law of the Sea (64/71, para 172) and on Sustainable Fisheries (64/72 para 109) called on States and appropriate UN agencies to take appropriate action to address intentional and unintentional damage to ocean observing systems. The community is encouraged by action of the Western and Central Pacific Fisheries Commission and the Inter-American Tropical Tuna Commission to protect moored ocean observing systems.

The IOC of UNESCO continues to urge Member States to recognize damage to ocean observing systems in national statutes, harmonize their approaches as appropriate, and cooperate to prevent, detect, deter, report, investigate and prosecute such acts of damage. Recalling the 26th Session of the IOC Assembly, Paris, 22 June - 5 July 2011 invited:

- The IOC and WMO to promote the systematic capture and exchange of records of damage to ocean observing systems and to conduct comprehensive cost benefit assessments taking into account both economic and social impacts of damage to ocean observing system;
- The FAO and regional fisheries management organizations, especially those with the competence to manage highly migratory fisheries, to adopt binding measures to prevent and minimize damage to ocean observing systems;
- The FAO, IOC and WMO to cooperate directly to develop means to promote effective enforcement of measures adopted by regional fisheries management organizations to protect ocean observing platforms, and to develop education and outreach programs to bring greater awareness to fishing communities of this problem.
- UN agencies, including IOC, WMO, IMO, and FAO, working with Member States and industry, to share information and foster education and outreach to safeguard human lives and property through protecting the ocean observing system.

3 Regional Tsunami Threat Information for Indian Ocean

An enhanced system of three Tsunami Service Providers (TSPs - operated by Australia, India and Indonesia) officially replaced the Interim Advisory Service (IAS) operated by the USA and Japan on 31 Mar 2013. The IAS was quickly established in early 2005 after the Indian Ocean Tsunami of 26 December 2004. The three TSPs are now solely responsible for providing official tsunami threat information to the 28 National Tsunami Warning Centres (NTWCs) in the Indian Ocean. The NTWCs use this information to determine and issue warnings for their coastal communities at risk, as is their sovereign responsibility. The three TSPs do not issue tsunami warnings for other countries other than their own, in their capacity as also NTWCs. The TSPs will publicly on their web sites only reflect the warning status decided by each NTWC. This helps to avoid conflicting information being issued to communities, which may lead to inappropriate responses. In some countries the NTWCs are simply national Tsunami Warning Focal Points (TWFPs) with no analysis capability, which refer the TSP threat information to the emergency response authorities for national action.

The TSPs each provide much more detailed tsunami threat information for Indian Ocean countries than the former IAS (see Figure 4). This helps countries to better prepare national tsunami warnings, save lives and reduce the frequency of false alarms. Although the assessments are independent, the three TSPs have worked together under the ICG/IOTWMS to ensure the information provided for agreed coastal zone for each country is at least the same type and in standard formats (i.e. interoperable).

Australia's contribution as a TSP is provided through the Joint Australian Tsunami Warning Centre (JATWC), which is operated by the Bureau of Meteorology and Geoscience Australia. The JATWC has extended the capability for state-of-the-art, comprehensive tsunami threat assessment and advice it has provided for Australia since 2008, to include provision of threat information to the 27 other countries bordering the Indian Ocean from 2011.

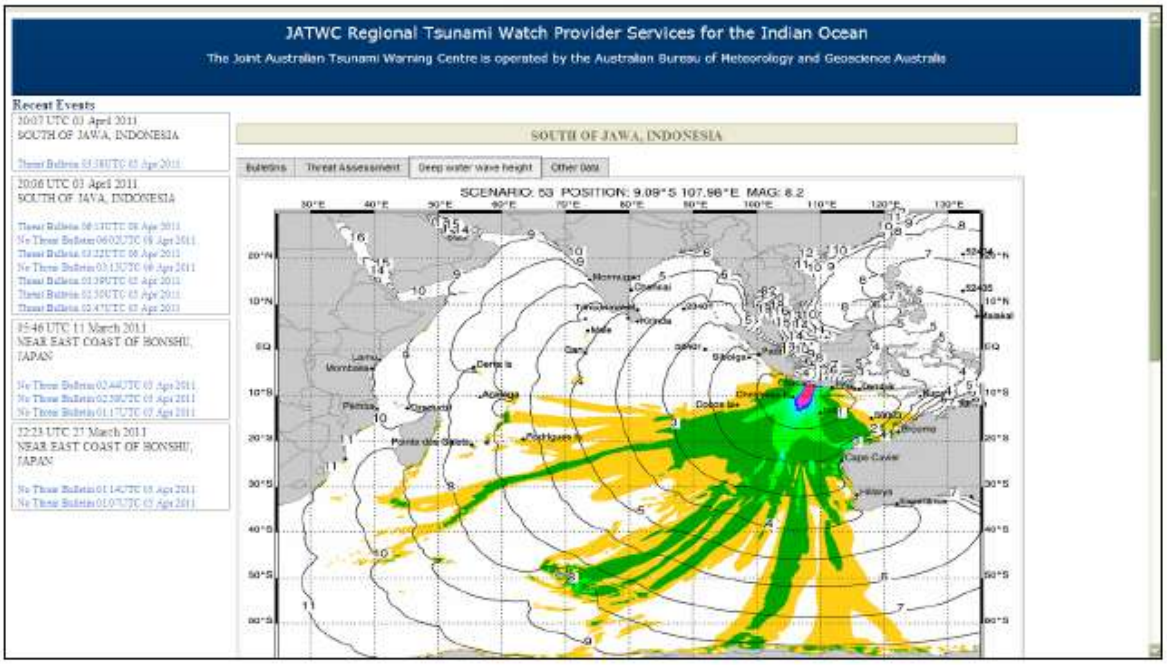

Figure 4: ***Example of more detailed tsunami threat information being provided to National Tsunami Warning Centres (NTWCs) in the Indian Ocean by Tsunami Service Providers (TSPs). This map shows the deep water energy and its directivity.***

Once NTWCs in each country have analysed the potential tsunami threat information from all available sources they choose to consider (from every/selected TSPs and/or own NTWC), as mentioned above they will decide and issue warnings to their national, regional and local authorities and communities as part of their sovereign responsibility. Port and maritime authorities will usually be in receipt of national tsunami warnings and will be involved in deciding and organising an appropriate response for port and shipping operations. For promulgation of tsunami threat information and warnings to ships on the high seas, please Section 3.4

3.1 Undersea Earthquake and Tsunami Events Since March 2015

Fortunately undersea earthquakes, which generate tsunamis large enough to create significant impacts, are relatively rare in the Indian Ocean. However, as 26th December 2004 demonstrated, they are possible and can be catastrophic (over 200,000 people lost their lives and over one million were displaced from their homes across the Indian Ocean). The risk is therefore low, but the potential consequences are major or even extreme. This makes it very difficult to maintain community awareness and preparedness. Also not all undersea earthquakes generate tsunamis. Those along major undersea tectonic plate subduction zones (where a plate moves under an adjacent plate, occasionally resulting in a large buckling under the pressure) have the greatest potential to sufficiently deform the sea floor, and usually only if their magnitude is greater than 6.5 and with an epicentre less than 100km below the sea floor.

Since this time last year there have only been three undersea earthquakes over the magnitude 6.5 threshold in the Indian Ocean region requiring analysis and threat interpretation by the TSPs and NTWCs. Two did not have the potential to generate any tsunamis and therefore were deemed "no threat". These included a magnitude 6.6 undersea earthquake just north of Timor-Leste on 4th November 2015, which had a depth of 3km and felt by the local communities, but fortunately had relatively small magnitude and was not located on a subduction zone. The other was an undersea earthquake of magnitude 7.2 on the Southeast Indian Ridge on 4th December 2015, which had of depth 137km and was also far away from any subduction zones.

The third undersea earthquake had a magnitude of 7.8 located to the southwest of Sumatra (Indonesia) and occurred on 2nd March 2016. It had a depth of 0km (i.e. sea floor), but fortunately was not on a subduction zone. However, it was felt by local communities and did generate a small tsunami as a result of the strike-slip motion of the earthquake. Communities in Indonesia close to the earthquake source therefore had no choice but to respond to the natural warning signs (large earthquake felt near the coast) and evacuate nearby low lying coastal communities. This is one of the most difficult tsunamis to forecast, as the sea floor deformation is relatively small compared to the magnitude of the earthquake. For earthquakes on subduction zones where the motion is strike-thrust, it is possible to at least make reasonable assumptions (but still not always precise), based on historical records and geo-mechanics, of how much the sea floor will be deformed and accordingly how much water will be displaced to generate a tsunami. As model forecasts could therefore not be used accurately, TSP-Australia (JATWC) assumed a relatively small tsunami of 0.5m amplitude at the beach would be generated and potentially threaten coasts (at marine threat level, i.e. no inundation, but possible dangerous currents and rips) within approximately 1000km of the earthquake centre (parts of west Sumatra (Indonesia), Cocos and Christmas Islands (Australia), Sri Lanka, Nicobar and Andaman islands of India) (see Figures 5 and 6). Australia

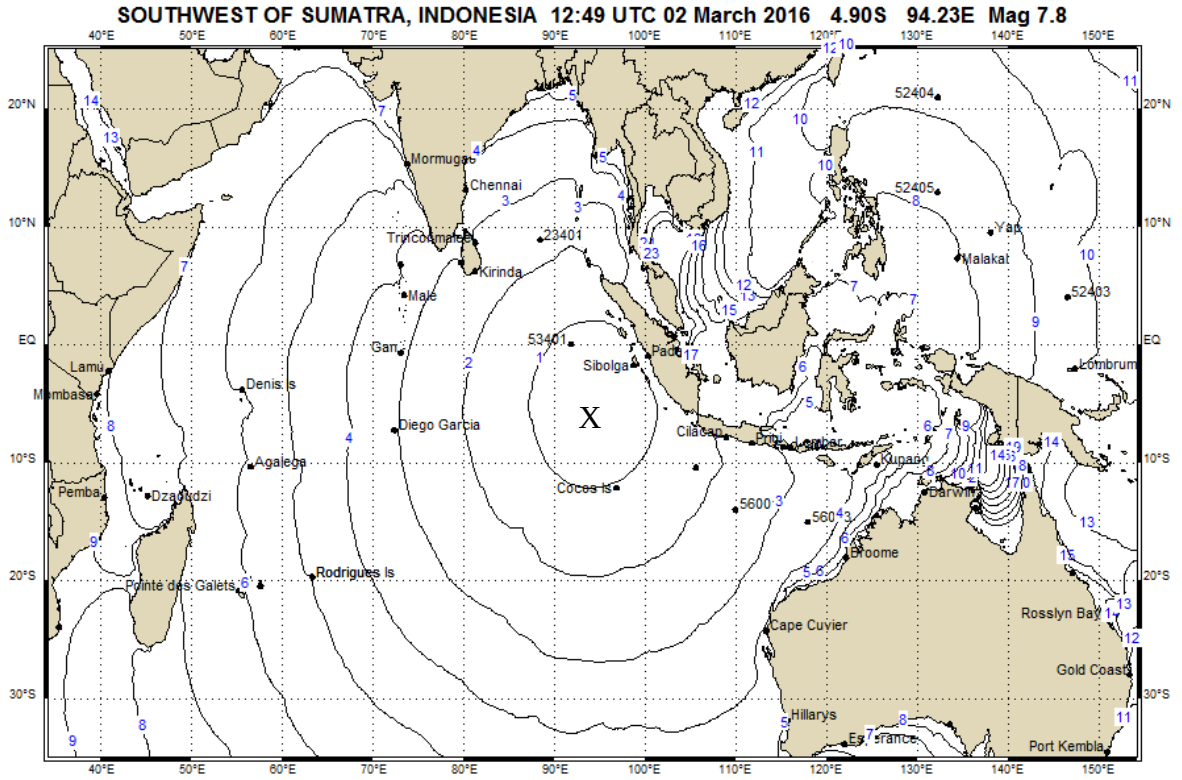

Figure 5: ***TSP-Australia estimated travel time map for small tsunami generated southwest of Sumatra on 2 March 2016***

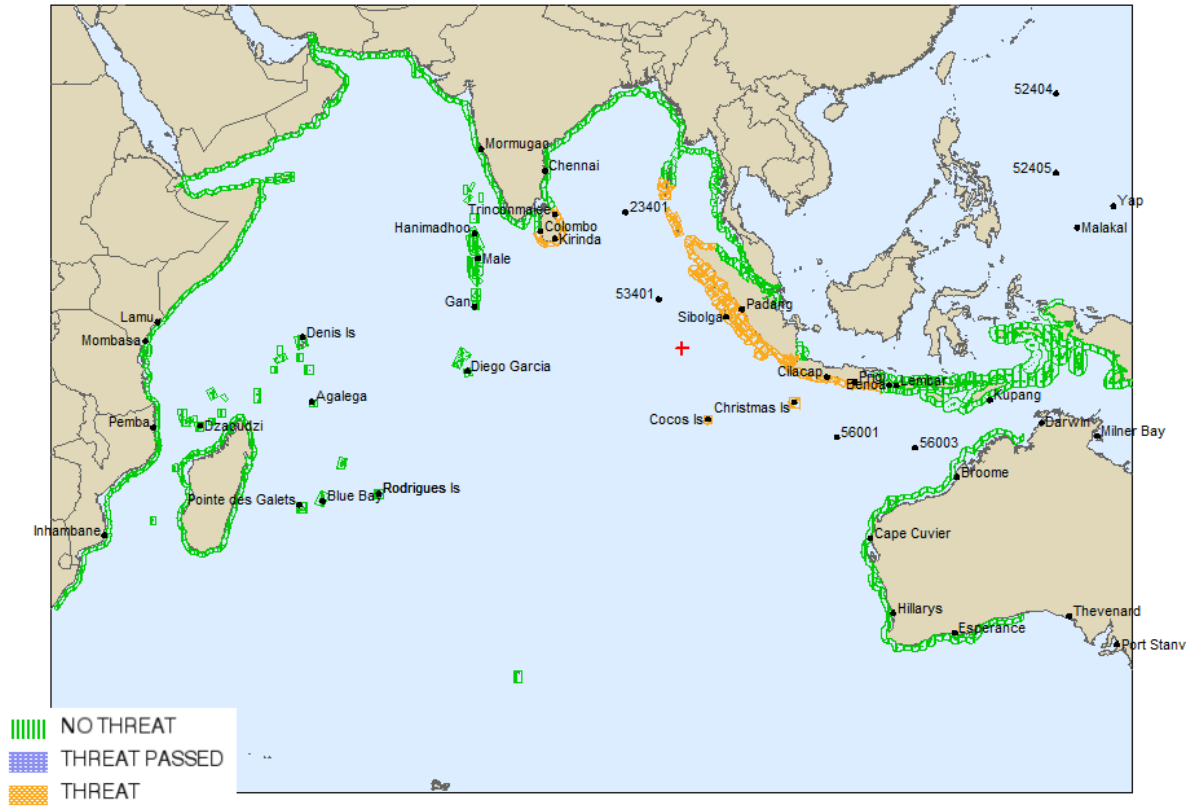

Figure 6: ***TSP-Australia map showing where tsunami threat is greater than an amplitude of 0.5m for the small tsunami generated southwest of Sumatra on 2 March 2016***

(JATWC) accordingly issued marine tsunami warnings for its offshore territories of Cocos and Christmas Islands. TSP-India estimated tsunami amplitude of up to 4.0m for parts of Sumatra in Indonesia and 0.5m for Mauritius. TSP-Indonesia estimated tsunami amplitude of 1.0m for parts of the coast of west Sumatra. Fortunately only very small tsunami waves (amplitude less than 10cm) were detected by tide gauges on the coasts of Sumatra, Cocos and Christmas Islands. The two Australian tsunameters between Indonesia and northwest Australia also detected a small tsunami in open waters, which helped to confirm a tsunami had been generated and also reduce the warning levels (see Figure 7). Given the magnitude and nature of the earthquake, and given it was felt by many coastal communities, the conservative forecasts and warnings were very much warranted.

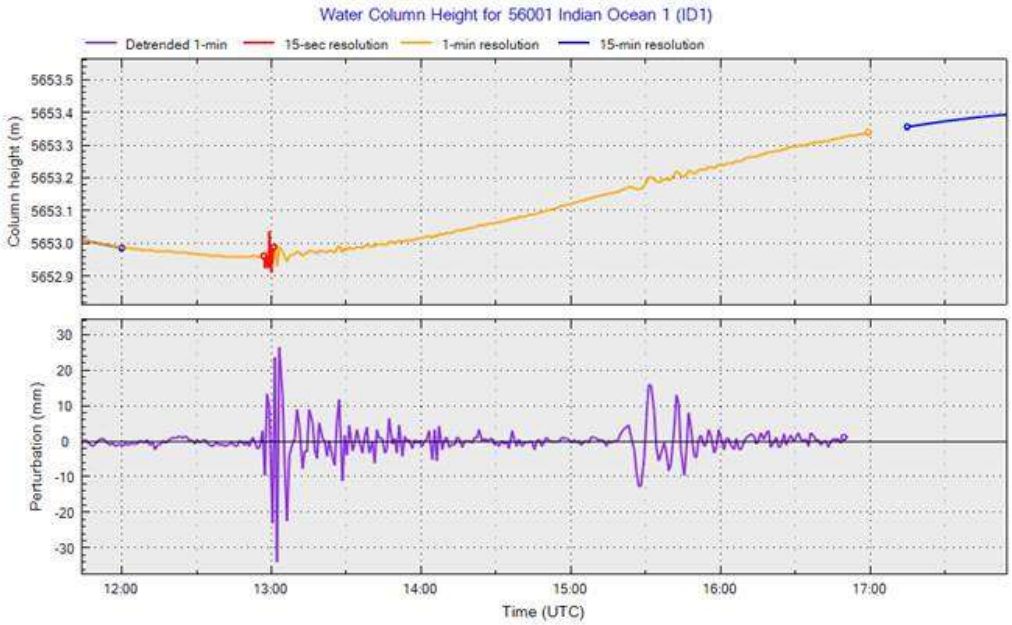

Figure 7: Record from Australian tsunameter (l3° 59' 27" S and 110° 05' 49" E) showing detection of small tsunami generated from southwest of Sumatra on 2 March 2016. The purple traces are water column height de-trended to remove tide. You can see the initial seismic signal that triggered higher reporting rate of our systems, followed some time later by the resultant deep water-level disturbance. The disturbance was about +/– 12 mm. From these plots, speed of propagation was roughly 800 km/h.

3.2 Training Workshops

Each year the ICG/IOTWMS organises a Standard Operating Procedures (SOP) Workshop for NTWCs and DMOs from each country around the Indian Ocean. It can also include national or regional media. The objective is to train national authorities through desktop exercises how to make best use of information generated by the TSPs. The goal is to assist NTWCS and DMOs to develop and test their national SOPS for use during real events, exercises and drills. In November 2015 the workshop was held in Hyderabad, India at TSP-India's facilities. In May 2016 the workshop will be held in Melbourne, Australia at TSP-Australia's facilities. The 2016 workshop will also help countries prepare for the next basin-wide tsunami exercise planned for September 2016.

3.3 Tsunami Exercises, Drills and Communication Tests

Every two years the ICG/IOTWMS coordinates the running of an Indian Ocean exercise and drill. The objectives of the exercises are to evaluate and improve the effectiveness of IOTWMS and its operational TSPs, NTWCs, and Disaster Management Organisations (DMOs), in responding to potentially destructive tsunamis. It also provides an opportunity for Indian Ocean countries to test their communication methods and review their SOPs, tsunami emergency response plans and tsunami emergency preparedness.

The next exercise (named IOWAVE16) is scheduled for 7-8 September 2016. The exercise will comprise two scenarios on successive days, one in the eastern Indian Ocean and the other in the north western Indian Ocean. The first scenario will simulate a magnitude 9.2 earthquake south of Sumatra, Indonesia and the second scenario will simulate a magnitude 9.0 earthquake in the Makran Trench south of Iran and Pakistan. Both scenarios will generate simulated tsunami waves travelling across the Indian Ocean basin. At the national level, port authorities, maritime safety and hydrographic agencies can also be involved in the exercise, particular those involved with relaying tsunami warning information to vessels at sea. The Australian Maritime Safety Authority (AMSA) is participating as NAVTEX Area Coordinator involved in disseminating tsunami warning information to vessels on the highs in the SE Indian Ocean.

Every six months communications tests are formally performed between each TSP and the 28 NTWCs across the Indian Ocean to ensure contact information is up-to-date and communications channels are fully operational.

3.4 Tsunami Warnings for Shipping and Safe Navigation

For vessels on the high seas it's important to receive tsunami warning information to avoid potentially damaged ports and waters not safe to navigate. Vessels in port should also receive tsunami warning information from local harbour and ports authorities, who will have been warned by their NTWC. Business Contingency Management plans for port operations may need to be enacted by ports and harbours under threat, affecting loading and unloading.

After the 2004 tsunami disaster the International Maritime Organization (IMO) decided that it needs to provide better dissemination of tsunami advices to shipping through official channels that are coordinated globally as part of the Global Maritime Distress & Safety System (GMDSS) including satellite broadcasts via INMARSAT and the coast radio NAVTEX service. That decision cut across existing coordination arrangements put in place under the auspices of IOC and WMO. Many maritime safety authorities are concerned they do not have the expertise to analyse and re-distribute tsunami warning information to vessels at sea, nor would the information be relayed in time.

The UNESCO/IOC Working Group on Tsunami and Other hazards related to sea level Warnings and mitigation Systems (TOWS-WG) has responsibility for establishing guidelines and standards for tsunami warnings globally. Its Task Team on Tsunami Watch Operations (TTTWO) is investigating the development of specialised tsunami warnings for ships on the high seas to be disseminated by designated 24/7 TSPs in the major ocean basins using existing maritime safety communication systems to address the concerns raised by some maritime safety authorities. The TTTWO recently met with Peter Doherty, Chair of the IHO/IMO/WMO Sub-Committee on the World-Wide Navigational Warning Service

(WWNWS-SC), which had also discussed the development of such products at its last meeting, which included a representative from the IOC. It was decided in the meeting with the TTTWO that samples of existing TSP bulletins will be shared with the WWNWS-SC, which will identify the type of information content most relevant to shipping on the high-seas. The TTTWO will then devise some sample tailored bulletins for the WWNWS-SC to review and provide feedback on at its next meeting in November 2016. Once agreed, designated TSPs from each tsunami warning system will provide tailored bulletins to the relevant NAVTEX Coordinators for forwarding to shipping in their Areas.

4 Contacts for Further Information on IOTWMS:

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