The Centre for Australian Weather and Climate Research

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ABSTRACT

Tsunami warnings issued by the Joint Australian Tsunami Warning Centre (JATWC) are derived from a database (T2) consisting of more than two thousand pre-computed tsunami scenarios. Following any potentially tsunamigenic earthquake, warnings are issued for individual coastal zones with three different levels of threat: marine, land or no threat. The decision is based on wave amplitudes of the relevant T2 scenario within the coastal zones. Threshold amplitude values have been derived through analysis of observed impacts for recent events. Given that historical records are available for only a short time period and no observations for which a land threat would have been issued for Australia exist, it has been difficult to determine the appropriate threshold for a land threat and this is currently set at a relatively conservative value. A recent tsunami hazard assessment study for New South Wales investigated large (M_w > 8.0) earthquakes on known subduction zones and computed inundation distances using the Delft3D model nested within T2 scenarios. In this report, these modelling results are used to evaluate the threshold values for the JATWC tsunami warnings. A general conclusion is that the threshold values should not be modified on the basis of these results.

1. INTRODUCTION

After the Indian Ocean tsunami of December 26th 2004, the Australian Government committed AU$68.9M to the development of the Australian Tsunami Warning System (ATWS). The Joint Australian Tsunami Warning Centre (JATWC) was formally established as part of the ATWS in July 2007. Tsunami warnings issued by the Joint Australian Tsunami Warning Centre (JATWC) are derived from a database (T2) consisting of more than two thousand pre-computed tsunami scenarios (Greenslade et al. 2009; Greenslade et al. 2010; Simanjuntak et al. 2011). Following any potentially tsunamigenic earthquake, warnings are issued for individual coastal zones with three different levels of threat: land, marine or no threat. The decision to issue a warning for a given zone is based on comparing wave amplitudes of the relevant T2 scenario within the zone to pre-determined threshold values.

Threshold amplitude values have been derived through analysis of observed impacts for recent events (Allen and Greenslade, 2010). Given that historical records are available for only a short historical period and no observations for which a land threat would have been issued for Australia exist, it has been difficult to determine the appropriate threshold for a land threat and this is currently set at a relatively conservative value.

A recent tsunami hazard assessment study for New South Wales (NSW) investigated large (M_w > 8.0) earthquakes on known subduction zones and computed inundation distances using the Delft3D model nested within T2 scenarios (NSW State Emergency Service and Office of Environment and Heritage, 2012). Under the assumption that these inundation modelling predictions are accurate, the model results can be used to evaluate the land threat threshold values for the JATWC tsunami warnings.

2. BACKGROUND

2.1 T2 Scenario Database:

The T2 scenario database was developed to provide forecast guidance for the JATWC and contains pre-computed tsunami propagation results (amplitudes and currents) from tsunamis generated on subduction zones in the Pacific, south Atlantic and Indian Oceans. The scenarios are computed with the MOST (Method of Splitting Tsunami) model (Titov and Synolakis 1998) where the earthquake sources are modelled with the static displacement of the free water surface assumption from Okada (1985). The database currently consists of 2,069 scenarios and with appropriate scaling, can provide guidance for any earthquake along the major fault lines from Mw = 6.8 to Mw = 9.2 in the Indian Ocean and south-west Pacific, and Mw = 7.3 to 9.2 elsewhere. Figure 1 shows the T2 database earthquake sources with the New Hebrides, Tonga, Kermadec, Puysegur and South Chile subduction zones highlighted as the major source of tsunamis in this study.

2.2 Warning Thresholds

During a tsunami event, the JATWC issues one of three levels of threat for each Australian Marine Forecast Zone, i.e. coastal zone. The coastal zones used for tsunami warnings are the same as those used for the Bureau of Meteorology's coastal wind warnings and are reproduced on Fig. 3. Maximum amplitudes from the T2 scenario with the nearest epicentre and magnitude to the earthquake are used. If necessary, the wave amplitudes from that scenario are linearly scaled to the appropriate seismic magnitude (Greenslade et al., 2009). Maximum computed amplitudes at each grid point within each coastal zone are ranked and the 95th percentile is computed for each zone. If the 95th percentile is less than 20cm, "No Threat" is assigned to the zone. "Marine Threat" is assigned if the 95th percentile value is between 20cm and 55 cm, and "Land Threat" will be issued for anything larger. A "Marine Threat" means the tsunami may cause potentially dangerous waves and strong ocean currents in the marine environment, but does not require an evacuation, whereas a "Land Threat" anticipates possible land inundation and a major hazard for low lying coastal areas that will require evacuation.

The derivation of the warning thresholds (20cm, 55cm) is described in Allen and Greenslade (2010). In summary, observed coastal impacts for nine past events (see Table 1) led to retrospective or "ideal" warning schemes being designed.

The 95th percentile values of maximum amplitude from the relevant T2 scenario within the designated coastal zones were examined and thresholds that produced the best match for the ideal schemes were selected, leading to the 20cm and 55cm thresholds. These 95^{th} percentile values are plotted in Fig. 2.

Notably, no zones from any of the nine past events examined were deemed to have experienced significant or widespread inundation of land areas requiring the issuance of a Land Threat. This means that the method provided no specific guidance about where to set the threshold for a Land Threat, so a conservative approach was taken and the Land Threat threshold was set just above the highest Marine Threat value.

3. NSW TSUNAMI HAZARD STUDY

The NSW Tsunami Risk Assessment project was funded under the Attorney–General's Department; Natural Disaster Mitigation Program and managed by the NSW Office of Environment and Heritage (OEH) and the NSW State Emergency Service (NSW SES). It was undertaken in two stages, with the first stage being a broad risk assessment of the entire NSW coast (Somerville et al., 2009) and the second stage comprising detailed inundation modelling of a number of areas that stage one had identified as being amongst the more vulnerable, based on exposure. The environmental services company Cardno was engaged to undertake the inundation modelling and risk assessment (NSW SES and OEH, 2012). An important aspect of this study was that the T2 scenario database was used to provide boundary and initial conditions for the inundation modelling. This ensured that there were strong links between the hazard assessment study and the national warning system.

The five sites that were selected for the detailed inundation modelling were, from North to South, Swansea/Lake Macquarie, Manly, Botany Bay, Wollongong/Port Kembla and Merimbula. These are shown in Fig. 3, along with the boundaries of the NSW coastal zones. High-resolution Digital Elevation Models (DEMs) for each of the five sites were developed using data from a range of sources (NSW SES and OEH, 2012).

For each site, NSW SES and OEH (2012) identified specific earthquake events with average recurrence intervals (ARI) of 200, 500, 1000, 2000, 5000 and 10000 years using Geoscience Australia's Tsu-DAT software (Geoscience Australia, 2010). For each recurrence interval the most likely Tsu-DAT source event was determined and the corresponding T2 scenarios were selected. Since the rupture dimensions for Tsu-DAT and T2 are not identical, the corresponding T2 scenario was determined according to moment magnitude, rupture length, slip and wave amplitude at the 100m depth contour (see NSW SES and OEH, 2012 for details).

Each of the 5 sites was modelled with 19 different scenarios covering the specified recurrence intervals at Highest Astronomical Tide. The specific events modelled in this study are listed in Tables 2, 3, 4, 5 and 6. The study also included five scenarios for each site using Mean Sea Level, but those runs are not considered in this study.

The inundation for each of the 19 scenarios at each site was then computed using the Delft3D model. Delft3D is a robust three-dimensional finite-difference model. A specialised advection scheme denoted as the 'Flooding Scheme' was developed for tsunami modelling (Stelling and Deuinmeijer, 2003; Stelling, 1984) and inundation calculations are performed using a wetting and drying algorithm. Forcing was provided at a coarse outer grid from time series extracted from the T2 scenario database and the wave was passed through 3 to 5 progressively higher resolution nested grids until a 10m resolution grid, where the inundation calculations are performed. Extensive model calibration, verification and examination of various model sensitivities can be found in NSW SES and OEH (2012).

For the NSW risk assessment study, results for each ARI level at each site were combined to provide an overall threat assessment. These summary results are not relevant for the present work but can be found in NSW SES and OEH (2012).

4. METHOD

Since the NSW hazard assessment study uses the same underlying data as the national warning system, i.e. the T2 scenario database, the outcomes provide valuable information that can be applied to the warning system. In particular, as noted previously, there has been a lack of guidance on the value at which to set the Land Threat threshold, given that there have been no major inundation events in recent Australian history. Under the assumption that the inundation modelling results provide accurate predictions, they can be used to assess the validity of the Land and Marine Threat threshold values for the JATWC tsunami warnings.

In the present work, the maximum computed wave amplitudes from the inundation models for the studied regions were overlaid on Geographic Information System (GIS) maps. These maps show detailed land use of each site, indicating what type of infrastructure, if any, might be impacted in the event of a tsunami. The impact and inundation distances were then inspected and a threat level (i.e. No threat, Marine threat, Land threat) assigned for each event. These inundation extents have a one-to-one correspondence with a specific T2 scenario and a specific coastal zone (although note from Fig. 3 that Manly and Botany are located in the same coastal zone) so the threat levels assigned through inspection can be compared with the threat levels that the existing JATWC warning system would produce[1].

The assessment of threat level was undertaken subjectively, i.e. through inspection, rather than by assessing a quantitative threshold inundation level. The reason for this is that while the threat levels have quantitative thresholds that relate to offshore tsunami amplitudes (Allen and Greenslade, 2010) and wave amplitudes at a tide gauge (Australian Bureau of Meteorology, 2012) there are no quantitative overland thresholds relating to the threat levels. The assessment of Land, Marine or No Threat was straightforward for some cases (i.e. Land Threat for those cases where there was significant inundation) but in many cases it was borderline. This is discussed further in Section 6.

5. RESULTS

The main results are presented in Tables 2 to 6. In these tables, the threat levels determined through inspection are listed and briefly described alongside the corresponding warning messages that would be issued by the JATWC. Note that the descriptions of the inundation levels here do not relate to any formal flood levels such as those in the NSW State Flood Plan (NSW SES, 2008).

For Swansea (Table 2) it can be seen that there may be some issues with the less severe events. In cases where the JATWC would issue Marine Threats, the modelling results show some inundation that may require evacuations. For Manly (Table 3) the converse is the case, as there are five cases for which the JATWC would issue a threat level higher than that indicated from the inundation modelling results. One important point to note here is that Manly is only one part of the coastal zone, and a Marine Threat assessed here, for example, does not mean that inundation outside of this area, but still within the zone, will not be observed. This issue is discussed further in the next section.

For Botany (Table 4), again either the threat levels match or the JATWC warnings are conservative. This is the case for all scenarios, except for one (Mw 8.7 New Hebrides event) where the JATWC warning underestimates the threat compared to the inundation model. However, note that this is a borderline case where it is not obvious which threat level to assign from the inundation modelling. The results at Wollongong (Table 5) show very good correspondence except for two cases where the JATWC threat levels are conservative compared to the inundation modelling results. Finally, the results at Merimbula are mostly in correspondence, except for four cases for which the T2 warnings do not appear to be severe enough compared to the inundation model results (Mw 9.1 Tonga, Mw 8.9 New Hebrides, Mw 8.6 Puysegur and Mw 9.2 Tonga).

[1] Figures showing examples of the inundation modelling results at each site have been removed from this version of the report as requested by stakeholders.

Figure 4 presents a summary of the information shown in Tables 2 to 6. In this figure, the inundation scenarios assessed here are combined with the historical information from Allen and Greenslade (2010). In general, from this figure and the results summary above, it can be seen that the existing threshold levels for the Marine and Land Threat warnings are reasonable, and generally set conservatively. However there are some discrepancies and these discrepancies are not consistent across locations. For example, the results for Zone 5 and part of Zone 4 suggest that the Land Threat threshold could be lowered to, perhaps, 40 or 50 cm. However, this is likely to result in unnecessary evacuations in Zone 3.

6. DISCUSSION

There are a number of assumptions and issues involved in this work that need to be addressed. One of these assumptions is that the inundation modelling results are accurate - any interpretation of the results depends heavily on this assumption. The validity of this assumption can be demonstrated through the extensive validation of the DELFT3D implementation for these sites in NSW SES and OEH (2012). Preliminary investigation into the inundation results through comparison with an alternative tsunami inundation model (MOST) shows that the results are generally in agreement, however this is an area that requires further investigation.

As indicated in Tables 2 to 6, it has been difficult to assign the threat levels in some cases. Those cases with significant inundation, or with negligible wave activity are straightforward, but there are a number of borderline cases, which raise some questions. For example, should an event for which the only inundation that occurs is on an uninhabited island receive a Land Threat? There is clearly inundation in a case such as this but it is not threatening to life or property. If a Land Threat is issued, then the entire coastal zone is evacuated on this basis, which can be costly if done unnecessarily. On the other hand, if a Marine Threat is issued and inundation occurs, then it could be argued that the threat level was not severe enough. In this work, we have assigned the Threat level on a case-by-case basis after careful inspection of the potential impacts.

Another issue is that this study has assessed the threat thresholds for an entire coastal zone based on the inundation modelling results at just one (or two) location(s) within the zone. As noted above, even if a particular tsunami has not produced inundation at, for example, Swansea, there may be other areas within the zone that will experience some inundation from that event. However, these five sites were selected as being amongst the most at risk locations along the NSW coast based on NSW SES and OEH (2012), and we can be generally confident that these sites are therefore the “worst case” locations within each zone.

As a general conclusion, it appears that it would not be sensible to change either the Marine or Land thresholds on the basis of these results. One option that could be considered is to implement tailored thresholds, i.e. to have different Marine and Land Threat thresholds for each coastal zone. This could potentially be reasonable for the four zones considered here, but the required information to apply this to all zones does not exist, and considerable resources would be required to develop the information. Furthermore, there are advantages to having an operational system that is nationally consistent in its application.

Figure 4 shows that even tailored thresholds would not be ideal. It can be seen that while there is a general correlation between the 95^{th} percentile value and the amount of inundation, it is not clear-cut. Even within an individual zone, some events associated with higher offshore amplitudes do not produce inundation while some events associated with lower offshore values do. Ideally, real-time inundation forecasts would be available during a tsunami event. However, there are a number of issues associated with this. For example, one limitation of inundation modelling is that it applies to an individual location, and it may not be feasible to cover all coastal populations that are likely to be at risk during an event, due to computational limitations. If this were the case, then how should the locations be prioritised?

Another issue relevant to real-time inundation forecasting relates to the amount of information that is provided to the public. It may be that simple succinct warning messages (i.e. Marine Threat; Land Threat) are preferred as they are easier to communicate. However, in the current era of instant, rapidly updated and freely available digital information, it could be argued that the public is capable of dealing with large amounts of complex information, even when in contains a measure of uncertainty, and indeed, may even demand the same level of information that scientists and forecasters have access to (Hall, 2011). Clearly a balance needs to be found between the quantity of information and the ability to transmit the message efficiently.

7. CONCLUSION

Tsunami warnings issued by the Joint Australian Tsunami Warning Centre (JATWC) have been assessed using inundation modelling results for five sites in NSW. The results have indicated that the thresholds used by the JATWC warning scheme are in general set conservatively and they should not be modified on the basis of these results. The results have also discussed the potential for improving the JATWC warnings by developing “tailored” threshold levels for each coastal zone or by incorporating real-time inundation modelling in the forecast system.

ACKNOWLEDGMENTS

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APPENDIX

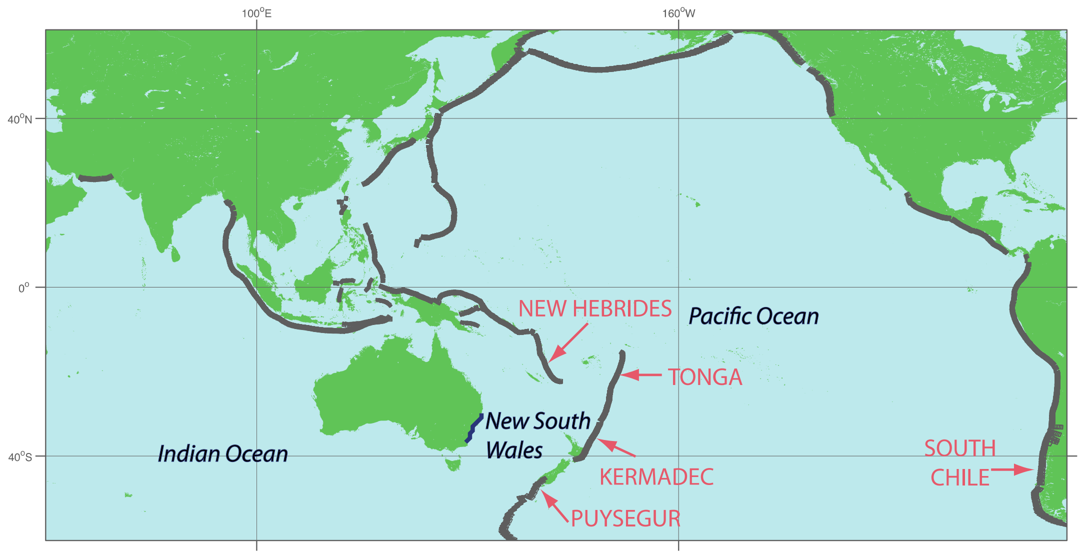

Fig. 1 T2 database scenario source locations (grey lines) are shown with respect to New South Wales. The subduction zones considered in this study are indicated.

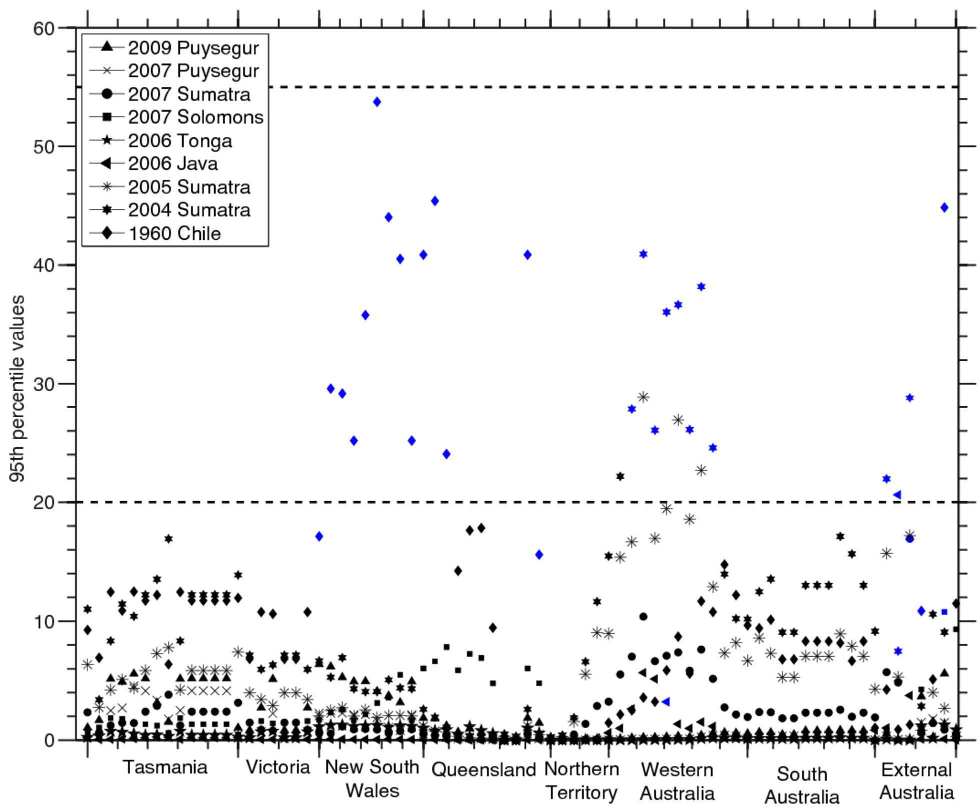

Fig. 2 The 95th percentile values for historical events (reproduced from Allen and Greenslade, 2010). The Marine and Land threat threshold values (20 cm and 55 cm respectively) are indicated by the horizontal dashed lines.

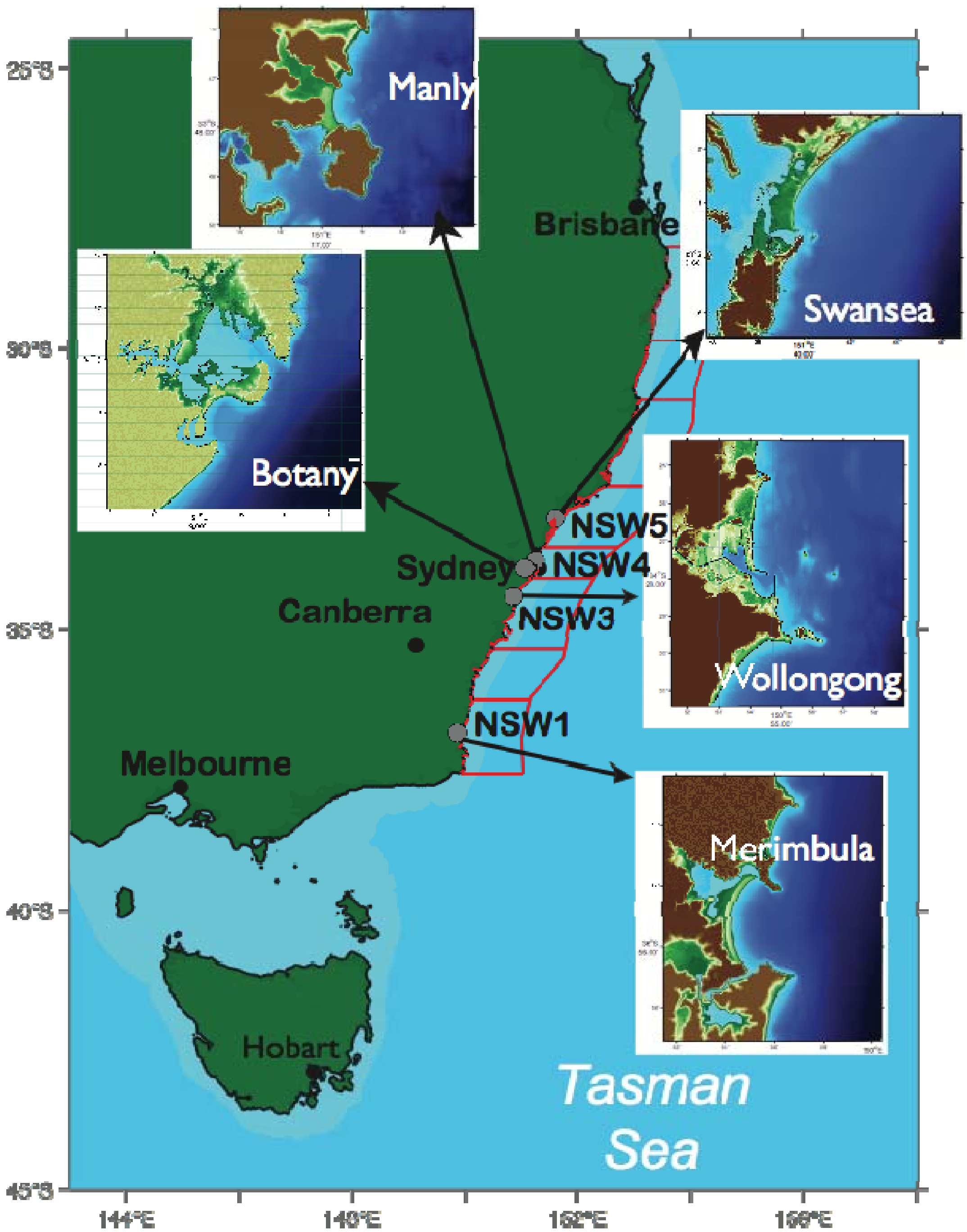

Fig. 3 The Australian Marine Forecast Zones are shown in red polygons in the map above. Swansea, Manly, Botany, Wollongong, and Merimbula are the five study sites investigated in the New South Wales study (NSW SES and OEH, 2012).

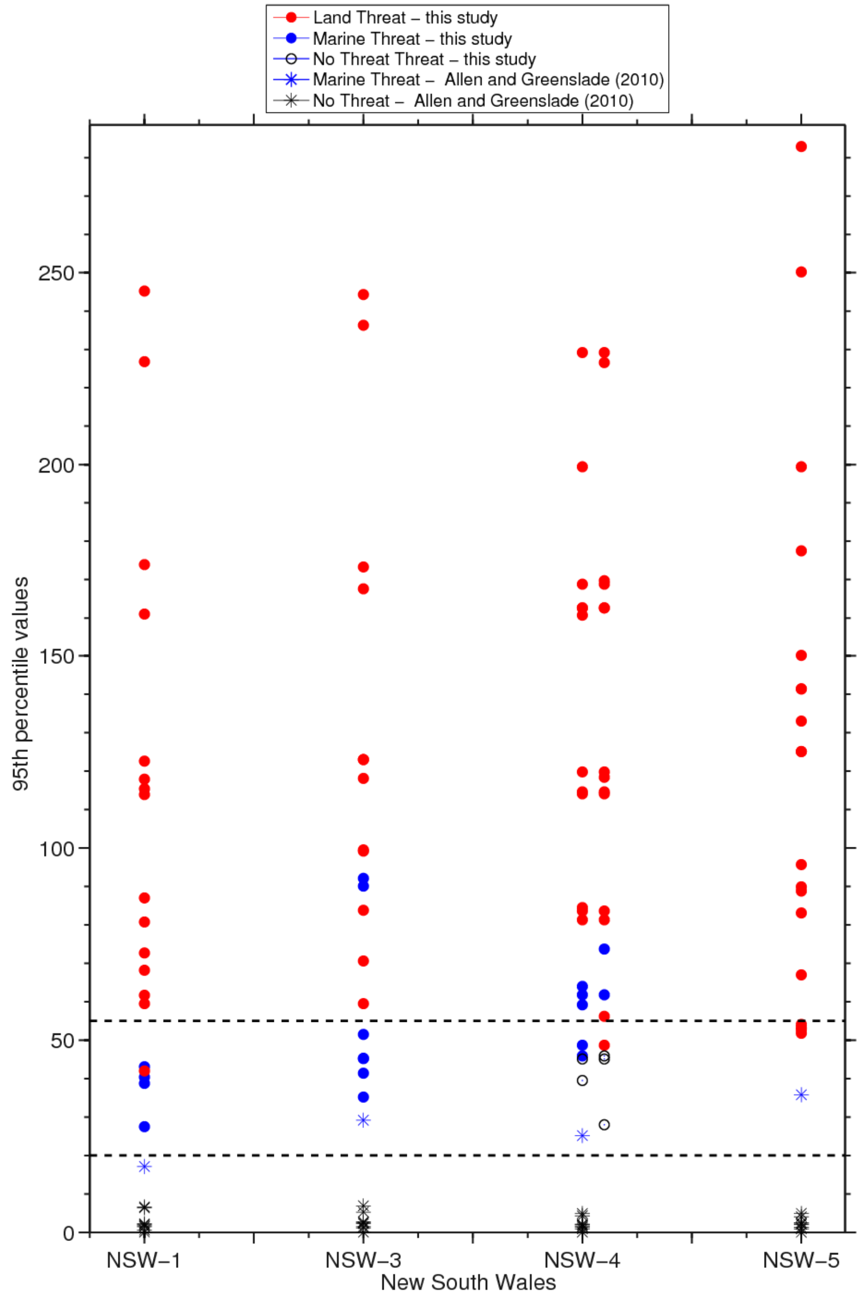

Fig. 4 The 95th percentile values for the T2 scenarios associated with each event listed in Tables 2 to 6, with the colour designating the assigned threat levels. Relevant values from Allen and Greenslade (2010) are also shown.

Table 1 Tsunami events used in deriving warning thresholds (from Allen and Greenslade, 2010).

Date	Source	Time	Longitude	Latitude	Magnitude
22 May 1960	Chile	19:11 UTC	74°30′ W	39°30′ S	9.5
26 Dec 2004	Sumatra	00:59 UTC	95°74′ E	3°18′ N	9.1
28 Mar 2005	Sumatra	16:10 UTC	97°01′ E	2°04′ N	8.6
3 May 2006	Tonga	16:10 UTC	174°13′ W	20°06′ S	7.9
17 Jul 2006	Java	08:19 UTC	107°18′ E	9°18′ S	7.7
1 Apr 2007	Solomons	20:40 UTC	156°59′ E	8°29′ S	8.1
12 Sep 2007	Sumatra	11:10 UTC	101°23′ E	4°31′ S	8.4
30 Sep 2007	Puysegur	05:23 UTC	163°52′ E	49°18′ S	7.4
15 Jul 2009	Puysegur	09:22 UTC	166°35′ E	45°45′ S	7.8

Table 2 Inundation model results compared to corresponding warnings for Swansea.

Scenario	Mw	Region	Return Period (years)	JATWC Threat	Inundation Model	Notes
233d	8.9	Kermadec	200	Marine	Land	Minor wave activity and flooding of low elevations
196c	8.7	New Hebrides	200	Marine	Land	Although the flow depths over land are low, there is substantial inundation along with minor wave activity.
215c	8.7	Puysegur	200	Marine	Land	Although the flow depths over land are low, there is substantial inundation along with minor wave activity.
402d	9.3	S. Chile	200	Marine	Land	Minor wave activity inside the bay and some minor flooding of uninhabited areas
245d	9.2	Tonga	200	Land	Land	Although the flow depths over land are very low, there is moderate inundation along with some minor wave activity inside the bay.
232d	9	Kermadec	500	Land	Land	Moderate inundation
194d	9	New Hebrides	500	Land	Land	Moderate inundation
217c	8.7	Puysegur	500	Land	Land	Significant inundation
245d	9.3	Tonga	500	Land	Land	Flow depths over land are very low, but inundation distances are extensive.
231d	9.1	Kermadec	1000	Land	Land	Significant inundation.
194d	9.1	New Hebrides	1000	Land	Land	Significant inundation
216d	9	Puysegur	1000	Land	Land	Significant inundation
233d	9.2	Kermadec	2000	Land	Land	Significant inundation
194d	9.1	New Hebrides	2000	Land	Land	Significant inundation
216d	9	Puysegur	2000	Land	Land	Significant inundation
194d	9.2	New Hebrides	5000	Land	Land	Extensive inundation
216d	9.1	Puysegur	5000	Land	Land	Extensive inundation
194d	9.3	New Hebrides	10000	Land	Land	Extensive inundation
216d	9.2	Puysegur	10000	Land	Land	Very high flow depths with major inundation of all low lying land near coast. This is the worst case scenario for this location.

Table 3 Inundation model results compared to corresponding JATWC warnings for Manly.

Scenario	Mw	Region	Return Period (years)	JATWC Threat	Inundation Model	Notes
232d	9	Kermadec	200	Land	Marine	No significant inundation, but strong wave activity
196c	8.7	New Hebrides	200	Marine	Marine	No significant inundation, but strong wave activity
215c	8.6	Puysegur	200	Marine	Marine	No significant inundation, but strong wave activity
402d	9.3	S. Chile	200	Marine	None	No significant wave activity
245d	9.1	Tonga	200	Marine	None	No significant wave activity
231d	9.1	Kermadec	500	Land	Land★	Minor flooding
194d	9	New Hebrides	500	Land	Land	Flooding and high flow depths
215c	8.7	Puysegur	500	Land	Marine◆	Minor flooding in uninhabited lands
245d	9.2	Tonga	500	Land	Marine◆	Minor flooding in uninhabited lands.
231d	9.2	Kermadec	1000	Land	Land	Flooding in low lying lands
194d	9.1	New Hebrides	1000	Land	Land	Flooding in low lying lands
216d	8.8	Puysegur	1000	Land	Land°	Minor flooding
228d	9.3	Kermadec	2000	Land	Land	Significant inundation
194d	9.2	New Hebrides	2000	Land	Land	Significant inundation
216d	8.9	Puysegur	2000	Land	Land	Inundation at various locations
194d	9.2	New Hebrides	5000	Land	Land	Inundation at various locations
216d	9	Puysegur	5000	Land	Land	Extensive tsunami hazard
194d	9.3	New Hebrides	10000	Land	Land	Extensive tsunami hazard. This is the worst case scenario considered at this location.
216d	9.1	Puysegur	10000	Land	Land	Extensive tsunami hazard

★ This study recommends Land Threat, although low flow depths and minor inundation suggest it is borderline with Marine Threat.
◆ The decision to deem this case a Marine Threat is borderline with making it No Threat.

° The decision to deem this case a Land Threat is borderline with making it Marine Threat.

Table 4 Inundation model results compared to corresponding JATWC warnings for Botany.

Scenario	Mw	Region	Return Period (years)	JATWC Threat	Inundation Model	Notes
233d	9.1	Kermadec	200	Land	Marine★	Minor wave activity
196c	8.7	New Hebrides	200	Marine	Land◆	Minor flooding
215c	8.6	Puysegur	200	Marine	None	No significant wave activity
402d	9.2	S. Chile	200	Marine	None	No significant wave activity
245d	9.1	Tonga	200	Marine	None	No significant wave activity
232d	9.2	Kermadec	500	Land	Land	High wave activity and minor flooding
194d	9	New Hebrides	500	Land	Land	High wave activity and minor flooding
215c	8.7	Puysegur	500	Land	Marine	High wave activity, but no significant flooding
244d	9.2	Tonga	500	Land	Land°	Minor wave activity with some flooding
231d	9.2	Kermadec	1000	Land	Land	Flooding observed in a number of areas
194d	9.1	New Hebrides	1000	Land	Land	Flooding observed in a number of areas
216d	8.8	Puysegur	1000	Land	Land	Flooding, but not as severe as above
228d	9.3	Kermadec	2000	Land	Land	Significant inundation
194d	9.2	New Hebrides	2000	Land	Land	Significant inundation
216d	8.9	Puysegur	2000	Land	Land	Significant inundation
194d	9.2	New Hebrides	5000	Land	Land	Significant inundation
216d	9	Puysegur	5000	Land	Land	Significant inundation
194d	9.3	New Hebrides	10000	Land	Land	Significant inundation (worst case scenario)
216d	9.1	Puysegur	10000	Land	Land	Significant inundation

★ The decision to deem this case a Marine Threat is borderline with making it No Threat.

◆ This study recommends Land Threat, although low flow depths and minor inundation making it a borderline with Marine Threat.

° The decision to deem this case a Land Threat is borderline with making it Marine Threat.

Table 5 Inundation model results compared to corresponding JATWC warning for Wollongong.

Scenario	Mw	Region	Return Period (years)	JATWC Threat	Inundation Model	Notes
232d	8.9	Kermadec	200	Marine	Marine	Wave activity
196c	8.6	New Hebrides	200	Marine	Marine	Wave activity
215c	8.6	Puysegur	200	Marine	Marine	Wave activity
402d	9.3	S. Chile	200	Marine	Marine	No potential hazard
247d	9.2	Tonga	200	Marine	Marine★	Minor wave activity.
233d	9.1	Kermadec	500	Land	Land	Minor flooding at the ports
194d	8.9	New Hebrides	500	Land	Land◆	Minor flooding near the ports
215c	8.8	Puysegur	500	Land	Marine	Minor wave activity
245d	9.3	Tonga	500	Land	Marine★	Minor wave activity
233d	9.2	Kermadec	1000	Land	Land	High wave activity with minor flooding
194d	9	New Hebrides	1000	Land	Land	High wave activity with minor flooding
216d	8.9	Puysegur	1000	Land	Land	Minor wave activity with minor flooding
231d	9.2	Kermadec	2000	Land	Land	Significant inundation
194d	9.1	New Hebrides	2000	Land	Land	Significant inundation
216d	8.9	Puysegur	2000	Land	Land	Minor wave activity and inundation
194d	9.2	New Hebrides	5000	Land	Land	Significant inundation
216d	9	Puysegur	5000	Land	Land	Significant inundation
194d	9.3	New Hebrides	10000	Land	Land	Extensive inundation (worst case scenario)
216d	9.1	Puysegur	10000	Land	Land	Extensive inundation

★ The decision to deem this case a Marine Threat is borderline with making it No Threat.

◆ The decision to deem this case a Land Threat is borderline with making it Marine Threat.

Table 6 Inundation model results compared to corresponding earthquake warnings for Merimbula.

Scenario	Mw	Region	Return Period (years)	JATWC Threat	Inundation Model	Notes
230d	9	Kermadec	200	Marine	Marine★	Minor wave activity and some inundation
195c	8.7	New Hebrides	200	Marine	Marine	Minor wave activity and some inundation
216c	8.4	Puysegur	200	Marine	Marine	Minor wave activity and some inundation
402d	9.3	S. Chile	200	Marine	Marine	Minor wave activity and some inundation
246d	9.1	Tonga	200	Marine	Land	Moderate inundation
231d	9.2	Kermadec	500	Land	Land	Extensive flooding
194d	8.9	New Hebrides	500	Marine	Land	Extensive flooding
215c	8.6	Puysegur	500	Marine	Land	Extensive flooding
246d	9.2	Tonga	500	Marine	Land	Extensive flooding
229d	9.2	Kermadec	1000	Land	Land	Extensive flooding
194d	9	New Hebrides	1000	Land	Land	Extensive flooding
216c	8.7	Puysegur	1000	Land	Land	Extensive flooding
229d	9.3	Kermadec	2000	Land	Land	Extensive flooding
194d	9.1	New Hebrides	2000	Land	Land	Extensive flooding
216d	8.8	Puysegur	2000	Land	Land	Extensive flooding
194d	9.2	New Hebrides	5000	Land	Land	Extensive flooding
216d	8.9	Puysegur	5000	Land	Land	Extensive flooding
194d	9.3	New Hebrides	10000	Land	Land	Extensive flooding (worst case scenario)
216d	9	Puysegur	10000	Land	Land	Extensive flooding

★ The decision to deem this case a Marine Threat is borderline with making it No Threat.

The Centre for Australian Weather and Climate Research is a partnership between CSIRO and the Bureau of Meteorology.