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An assessment of the diversity in scenario-based tsunami forecasts for the Indian Ocean

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ABSTRACT

This work examines the extent to which tsunami forecasts from different numerical forecast systems might be expected to differ under real-time conditions. This is done through comparing tsunami amplitudes from a number of existing tsunami scenario databases for eight different hypothetical tsunami events within the Indian Ocean. Forecasts of maximum tsunami amplitude are examined at 10 output points distributed throughout the Indian Ocean at a range of depths. The results show that there is considerable variability in the forecasts and on average, the standard deviation of the maximum amplitudes is approximately 62% of the mean value. It is also shown that a significant portion of this diversity can be attributed to the different lengths of the scenario time series. These results have implications for the interoperability of Regional Tsunami Service Providers in the Indian Ocean.

1. Introduction

The Indian Ocean Tsunami Warning and mitigation System (IOTWS) has developed rapidly since its establishment after the Indian Ocean Tsunami of 2004. One of the major elements of the IOTWS is the concept of a Regional Tsunami Service Provider (RTSP). An RTSP is a centre that provides an advisory tsunami forecast service to one or more National Tsunami Warning Centres (NTWC). The RTSPs have a number of requirements that they need to meet (IOTWS, 2009), one of which is that they must have access to numerical model-based tsunami forecasts and the numerical model used should be appropriately benchmarked and validated (IOTWS, 2008; Synolakis et al., 2008). Another important aspect of the RTSP concept is that the service and products provided by each RTSP should be “inter-operable”. In this context, “inter-operable” means that the products to be exchanged are in the same format and relate to the same physical parameters.

The aim of the present work is to determine the extent to which event-specific tsunami amplitude forecasts from different numerical forecast systems differ, and therefore, how the relevant products from RTSPs might differ. This is done by comparing tsunami amplitudes for a number of different hypothetical tsunami events within the Indian Ocean, from a number of different tsunami scenario databases.

2. Model forecast databases

At time of writing there are three centres within the IOTWS exchanging numerical forecasts of tsunami amplitude in real-time during events. These centres are the Joint Australian Tsunami Warning Centre (JATWC), the German–Indonesian Tsunami Early Warning System (GITEWS) and the Indian Tsunami Early Warning

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Table 1
Details of the initial conditions used for the scenarios in the JATWC T2 scenario database.

Magnitude (M_w)	Width (W) (km)	Number of rupture elements	Length (approx.) (L) (km)	Slip (u_o) (m)
7.0	35	1	50	0.5
7.5	50	1	100	1
8.0	65	2	200	2.2
8.5	80	4	400	5
9.0	100	10	1000	8.8

Centre (ITEWC). Comparison between these three systems will be essential for an understanding of the implications of the IOTWS's RTSP concept. There are several other international systems that are able to provide tsunami amplitude estimates within the Indian Ocean and so in the present work, the study is extended to include a number of other existing data sets. This more comprehensive dataset will provide an improved assessment of the potential diversity in the forecasts.

Therefore, in the present work, forecasts from eight separate tsunami forecast systems are considered. It is emphasised that not all of these forecast systems are existing or proposed IOTWS RTSPs. Indeed, not all of them can truly be described as “forecast” systems as they are predominantly used for applications such as risk assessment and research. However, each of these systems is able to produce an estimate of tsunami amplitude at a specific location, when given details of a potentially tsunamigenic earthquake within the Indian Ocean. The eight forecast systems considered here are described in the remainder of this section, with the three existing RTSPs described first.

2.1. Joint Australian Tsunami Warning Centre (JATWC)

Tsunami forecasts for the JATWC are based on the T2 scenario database (Greenslade et al. 2009, 2011; Simanjuntak et al. 2011). The basis for the source locations within T2 is the set of subduction zones within the Indian, Pacific and South Atlantic Oceans as defined by Bird (2003). Earthquake epicentres are defined at 100 km intervals along these subduction zones, resulting in a total of 522 source locations.

The T2 scenario database includes five earthquake magnitudes of M_w=7.0, 7.5, 8.0, 8.5 and 9.0 at each source location. The ruptures for large earthquakes are represented as the sum of a number of smaller 100 km long rupture elements, each of which has their strike closely aligned with the local subduction zone. For example, for a M_w=8.0 scenario, two adjacent rupture elements are combined to create one rupture with length approximately 200 km, width of 65 km and slip of 2.2 m. Details of the rupture dimensions for each magnitude are shown in Table 1. When all five magnitude scenarios are included, this results in a total of 2069 individual scenarios in the T2 scenario database.

Sea-level for tsunamis generated by intermediate magnitude earthquakes, i.e. those with magnitudes other than 7.0, 7.5, 8.0, 8.5 and 9.0, is derived from the pre-computed scenarios by applying a scaling factor to them. This provides guidance for earthquakes with magnitudes ranging from 6.8 to 9.2 at 0.1 magnitude intervals. Details on the scaling factors can be found in Greenslade et al. (2009).

Dip values for the T2 scenarios range from a shallow 8° along the Makran fault, to almost 70° along the Hjort trench (southwest of New Zealand). In the locations where a dip rate has not been established a standard dip value of 25° is used. The underlying bathymetry dataset used in T2 is the Naval Research Laboratory Digital Bathymetry Data Base with 2′ resolution (NRL DBDB2[1]) with other bathymetries merged into it in particular regions (Mansbridge, unpublished document). All of the T2 scenarios have the same rake (90°) and depth (top of rupture=10 km) of the hypocentre.

The Okada (1985) solution is used to generate the seafloor displacement from the seismic source and the Method of Splitting Tsunamis (MOST) model (Titov and Synolakis, 1998) is used to generate the scenarios. The model simulation time for each scenario is 24 h to ensure that reflections off underwater features or distant coasts are captured. The horizontal grid spacing for T2 is 4′ and through the Courant–Friedrichs–Lewy (CFL) criterion, this imposes a limit of 12 s on the time step. The maximum tsunami amplitude for each scenario is calculated at each time step and only positive amplitudes are considered in the determination of maximum tsunami amplitude.

2.2. Indian Tsunami Early Warning Centre (ITEWC)

Tsunami forecasts from the Indian Tsunami Early Warning Centre (ITEWC) are based on an open ocean propagation scenario database of pre-run unit source scenarios covering the Makran and Sunda tsunamigenic source regions of the Indian Ocean (Nayak and Kumar, 2008a, 2008b, 2008c). Based on historical earthquake and tsunami data, about 1000 simulation points (i.e. synthetic epicentres) are selected along the two subduction zones with a separation of 100 km along the trench and 50 km across the trench. Fault geometry parameters have been carefully selected based on sensitivity studies. The strike angle is assigned according to historical earthquakes which actually occurred near the simulation point and triggered tsunamis in the past. In cases where the parameters of the historical earthquakes are uncertain, the strike angle is assigned in such a way that it will represent the worst case, i.e. parallel to the coast or the nearby trench. The dip angle and hypocentral depth are assigned so that the subducting zone is well represented by the simulation points and the rake angle is defined to be 90°. A fault length of 100 km, width of 50 km and displacement (slip) of 1 m define each unit source which is equivalent to a magnitude 7.5 earthquake.

During any earthquake event depending on earthquake's location and magnitude, a combination of basic unit source scenarios is selected from the scenario database and scaled up or down using a slip parameter derived from scaling relations for any depth. This eliminates the need for a large database of individual matching scenarios. Results for earthquakes with magnitudes ranging from 6.5 to 9.5 for any depth, at 0.1 magnitude intervals, can be obtained from the set of selected unit source scenarios by applying a scaling factor to the scenario results.

The unit source scenario database has been developed using the finite difference code TUNAMI-N2 (Imamura, 2006). Studies have been carried out to validate the model results with the December 26, 2004 Sumatra earthquake (Murthy et al. 2005; Usha et al. 2009). The model domain covers 30°N to 40°S latitude and 30°E to 130°E longitude with a grid spacing of 0.0450° (approximately 5 km). According to the CFL criterion, a model time step of 5 s is used, to ensure stability. Each scenario covers the entire Indian Ocean domain with 15 h of simulation time. Tsunami profiles are saved at Coastal Forecast Points (CFPs) for each scenario for the 15 h of computation at 15 s intervals. The CFPs are selected at 30 m depth assuming that until such depth, the computation is linear. About 1800 CFPs are selected for the tsunami domain separated by ~50 km covering all Indian Ocean rim countries (Nayak and Kumar, 2008a, 2008b, 2008c). Arrival times and wave heights at specific coastal locations for each scenario are stored in a database. Travel times to the coast are calculated by considering the speed of the wave at different depths (30 m, 20 m, 15 m and 10 m). The distance to the coast is divided

[1] http://www7320.nrlssc.navy.mil/DBDB2_WWW/NRLCOM_dbdb2.html