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Simulation of the minor tsunami generated by the September 30 2009 earthquake near Padang, Sumatra

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I. INTRODUCTION

The magnitude 7.6 earthquake on September 30 2009 at 10:16 UTC close to the city of Padang in West Sumatra generated a minor tsunami. Wave heights of 20cm were recorded at the tide gauge stations of Padang harbor.

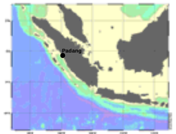

Fig.1: Earthquake Location.

The tsunami modeling group of Alfred Wegener Institute is part of the **GITEWS** project (German Indonesian Tsunami Early Warning System) and is responsible for creating a database of pre-calculated tsunami scenarios of various magnitudes and epicenter locations covering the Sunda Trench. In case of a tsunamigenic earthquake, the most probable scenario will be selected and serves as a forecast.

For modeling the wave propagation and inundation we use the unstructured finite element code **TsunAWI** (Harig et al. 2008). We show simulation results based on USGS fault parameters as well as scenarios from the **GITEWS** database closest to the event's epicenter.

II. METHOD

Governing Equations

Wave propagation is calculated by solving the nonlinear shallow water equations:

$$\frac{\partial h}{\partial t}+\nabla\cdot\left(\vec{v}(h+H)\right)=0$$

$$\frac{\partial \vec{v}}{\partial t}+(\vec{v}\cdot\nabla)\vec{v}+f\times\vec{v}+g\nabla h+\frac{C_d\vec{v}|\vec{v}|}{\rho(h+H)}-\nabla\cdot\left(A_h\nabla\vec{v}\right)=0$$

The finite element discretization of continuity and momentum equation is based on Hanert et al. (2005) and uses piecewise conforming linear basis functions for elevation and nonconforming linear basis functions for velocity.

Mesh Generation

We use an unstructured mesh covering the western part of the Indonesian coast. After creating a basic triangulation, the mesh is refined using the CFL-criterion and additional constraints on the bathymetry gradient:

$$\Delta x \le \min\left\{c_t\sqrt{gh},\, c_\nabla \frac{h}{\nabla h}\right\}$$


Fig.2: A detail of the mesh (Padang region).

The mesh comprises bathymetry and topography data from:

- GEBCO (1arc-min res.), Sonne Cruise SO186 (400m res.) and Scott Cruise (20m res.), sea maps
- SRTM (30m res.) and highly accurate HRSC data (50m res.) in Padang city

NUMBER OF NODES	2366319
NUMBER OF ELEMENTS	4721884
HIGHEST RESOLUTION	100m

Initial Conditions

Initial uplift functions for tsunami scenarios used for early warning are calculated using the software RuptGen by Babeyko (2007). RuptGen utilizes a number of micropatches covering the Sunda Trench (fig. 2).

Additionally TsunAWI can calculate initial water displacement using Okada's analytical formula (Okada, 1985).

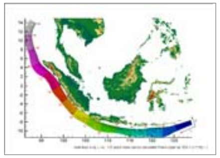
Fig.3: Sunda Trench, devided into patches (by A.Babeyko, GFZ).

III. SCENARIOS

Scenarios available in the database

In order to evaluate the selection process following the earthquake on September 30 we choose three of our pre-computed scenarios with following parameters:

- Epicenter location: 99.6157E, -0.9075N; Magnitudes: M_w 7.5, 7.6 and 7.7.

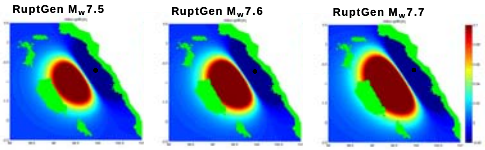

Fig.4: Initial uplift of scenarios calculated with RuptGen. Magnitudes from left to right: 7.5, 7.7 and 8.0.

Scenarios using USGS parameters

Initial uplift of Scenario 4 is based on USGS Centroid Moment Tensor Solution (nodal plane 1). Fault dimensions were calculated using formulas by Wells and Coppersmith (1994). The amount of slip results from Kanamori and Anderson's formula M_o=μLWD by assuming a rigidity of $\mu=3.5\times10^{10}\mathrm{Nm}^{-2}$. Okada parameters are given in the table below:

EPICENTER	99.917E /-0.714N
MAGNITUDE	7.6
AMOUNT OF SLIP	1.24m
DIM. OF FAULT	121km x 60km
STRIKE / DIP / RAKE	70°/ 52°/ 132°
FOCAL DEPTH	79km

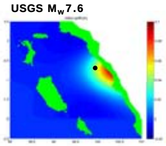

Fig.5: Initial uplift according to USGS CMT Solution.

Initial uplift distribution of Scenarios 5 and 6 is taken from the Finite Fault Model by G. Hayes, NEIC, based on 195 subfaults.

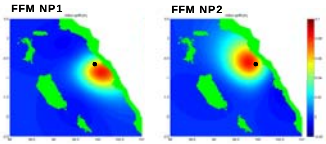

Fig.6: Initial uplift of finite fault model. Left: nodal plane1, right: nodal plane2.

IV. RESULTS

Maximum Wave heights

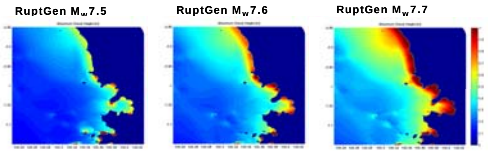

Fig.7: Maximum wave height [m] in Padang region of RuptGen scenarios.

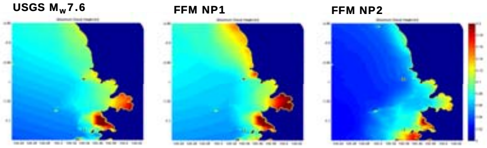

Fig.8: Maximum wave heights in Padang region of USGS scenarios.

Mareograms

We compare tide gauge data from Padang harbor gauge with simulation results. Mareograms are depicted in figure 7. Tides in gauge data were removed using Low-Pass filter (Walters and Heston, 1982).

The pre-computed scenarios show good agreement with respect to arrival time which is especially important in early warning, but overestimate wave heights of the leading crest. Scenarios with USGS parameters show better agreement with respect to wave heights, but the overall wave form is not reproduced very well.

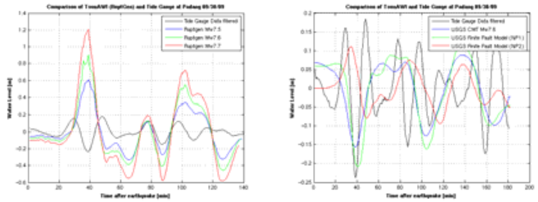
Fig.9: Comparison of tide gauge data with simulations. Left: pre-computed scenarios, right: USGS scenarios.

V. CONCLUSIONS

- The epicenter location of the pre-computed scenarios is located far to the west since the database does not yet contain scenarios with epicenters further east than 99.6°E, however arrival times are suitable for early warning purposes.
- For a more precise representation of the wave form a better implementation of the source mechanism and improved local bathymetry is needed.
- Comparison with Padang gauge data is problematic since the station is very close to the epicenter.

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