Applications of TsunAWI: Operational Tsunami Database for Indonesia, Case Studies in Chile

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Abstract

The numerical simulation code TsunAWI was developed in the framework of the German-Indonesian Tsunami Early Warning System (GITEWS) and extended within the project PROTECTS. The simulation of prototypical tsunami scenarios plays a decisive role in the a priori risk assessment for coastal regions and in the early warning process itself. TsunAWI is suited for both tasks. It is based on a finite element discretization, employs unstructured meshes with high resolution along the coast, and includes inundation.

This contribution presents two fields of application:

Extension of the tsunami database for Indonesia

- Continuation of the GITEWS and PROTECTS developments in a collaboration with Geoscience Australia aiming at an extension of the scenario repository.
- Currently in the Indonesian tsunami early warning system the existing TsunAWI scenario database covers the Sunda subduction zone from the Andaman Islands to the Lesser Sunda Islands. There are 715 epicentres involved adding up to a scenario repository of about 4500 members.
- The ongoing extension covers additional fault zones in the North Eastern part of the Indonesian domain.

Scenarios for the Chilean coast

- Collaboration with the German Aerospace Agency (DLR) and the Hydrographic and Oceanographic Service of the Chilean Navy (SHOA).
- Prototypical calculation of a database with 558 scenarios.
- Case studies for the minor tsunamis after the earthquakes close to Iquique on 1 April 2014 and Illapel on 16 September 2015.
  - TsunAWI simulations with USGS finite fault source model.
  - Comparison of time series obtained from these specific simulations as well as database scenarios with tide gauge recordings.

The tsunami scenario repository and warning products

GITEWS and PROTECTS (2005-2014)

- Scenarios cover the coasts of Sumatra, Java and Bali.
- Calculations carried out in Grid 2011 and Grid 2013 (see in the figure to the right).
- 4570 scenarios for 715 epicenters from 92°E to 129°E
- Magnitudes 7.2, 7.4, ... 8.8, 9.0 (sources: RuptGen 2.1, GFZ, Andrey Babeyko).

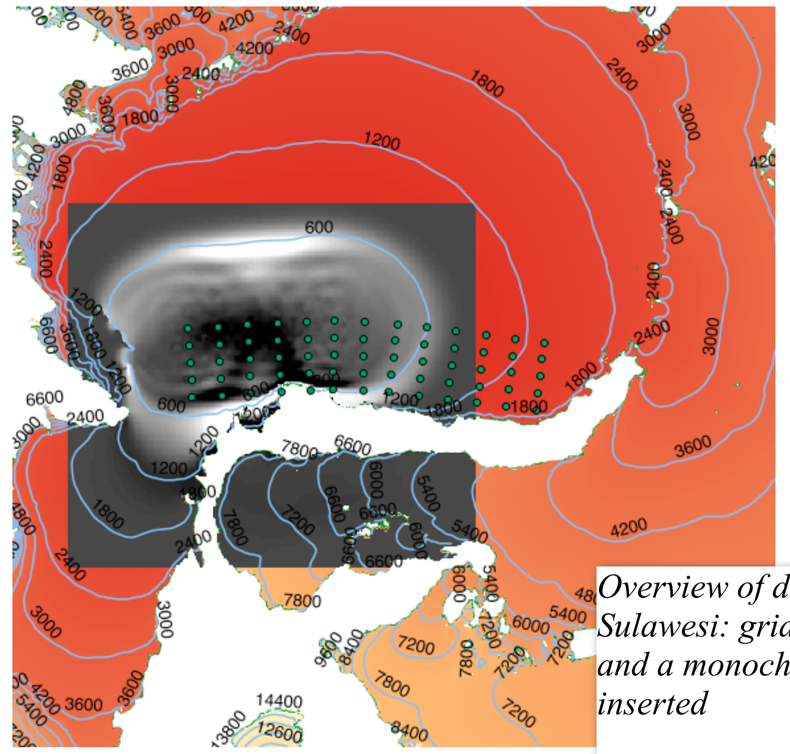
Ongoing extension (Collaboration BMKG - GA - AWI started in 2015)

- Fault zones in the North Eastern part of the Indonesian domain.
- The 12 fault zones to be completed in 2016 are displayed in the figure.
- Current operational mesh (Grid 2016):
  - 11.1 Mio nodes.
  - Resolution ranges from 20 km to 60 m.
  - 190,000 forecast points (POIs) POI density ranges from several km to 100 m.
  - Integration time 12h.

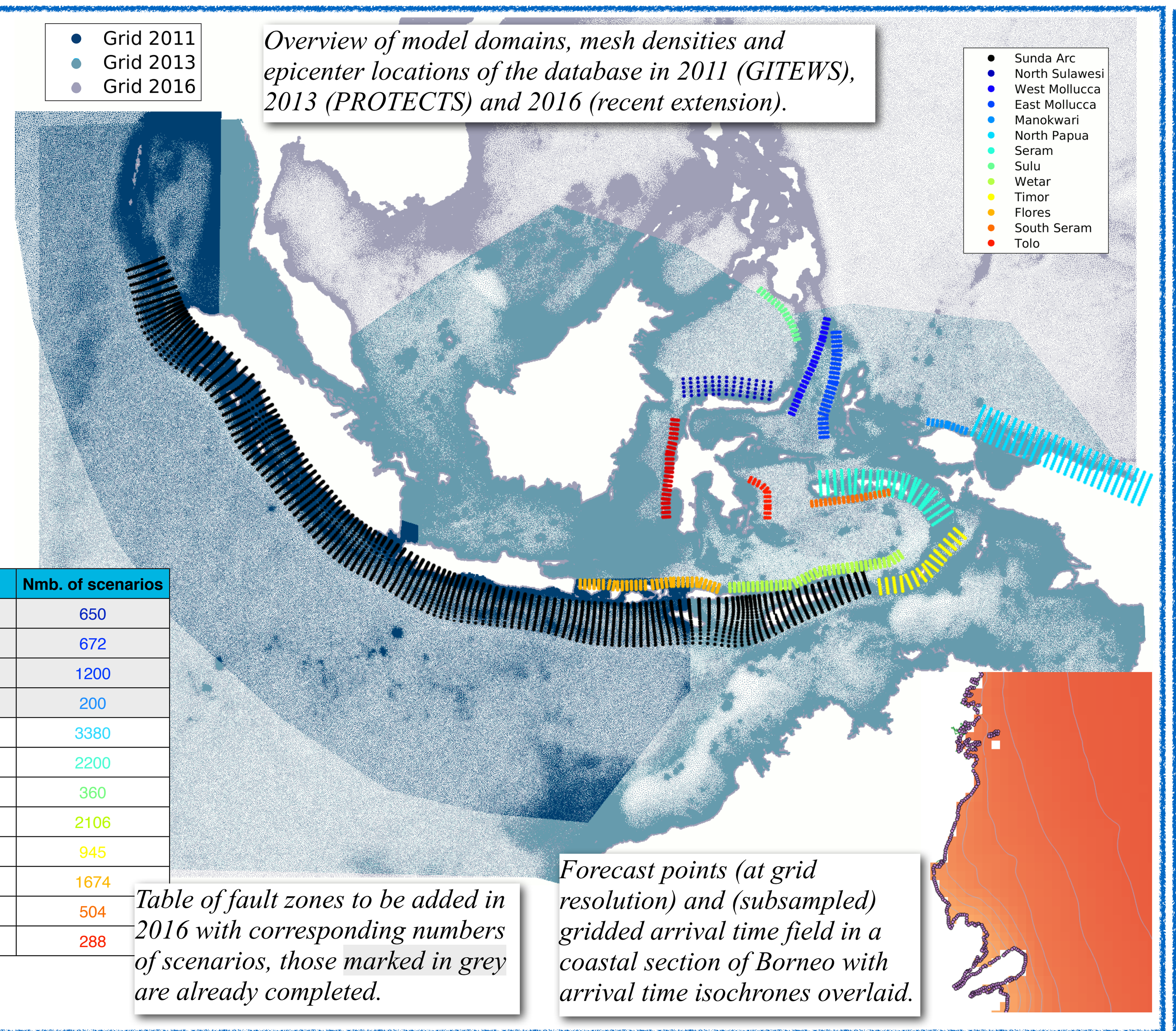
Data Products

The warning products are retrieved from model results in post processing stages. The data products consist of ascii files, gridded fields obtained by interpolation and metadata:

- SSH snapshots (73 files)
- gridded arrival time (1 file)
- max. wave height (MWH) (2 files)
- POI and tide gauge data (2 files)
- Metadata (1 file)



Overview of data products for a scenario in North Sulawesi: gridded arrival time with isochrone overlay and a monochrome SSH snapshot after 600 seconds inserted



Overview of model domains, mesh densities and epicenter locations of the database in 2011 (GITEWS), 2013 (PROTECTS) and 2016 (recent extension).

Fault zone	Nmb. of scenarios
North Sulawesi	650
West Mollucca	672
East Mollucca	1200
Manokwari	200
North Papua	3380
Seram	2200
Sulu	360
Wetar	2106
Timor	945
Flores	1674
South Seram	504
Tolo	288

Table of fault zones to be added in 2016 with corresponding numbers of scenarios, those marked in grey are already completed.

Forecast points (at grid resolution) and (subsampled) gridded arrival time field in a coastal section of Borneo with arrival time isochrones overlaid.

Scenarios for the Chilean coast

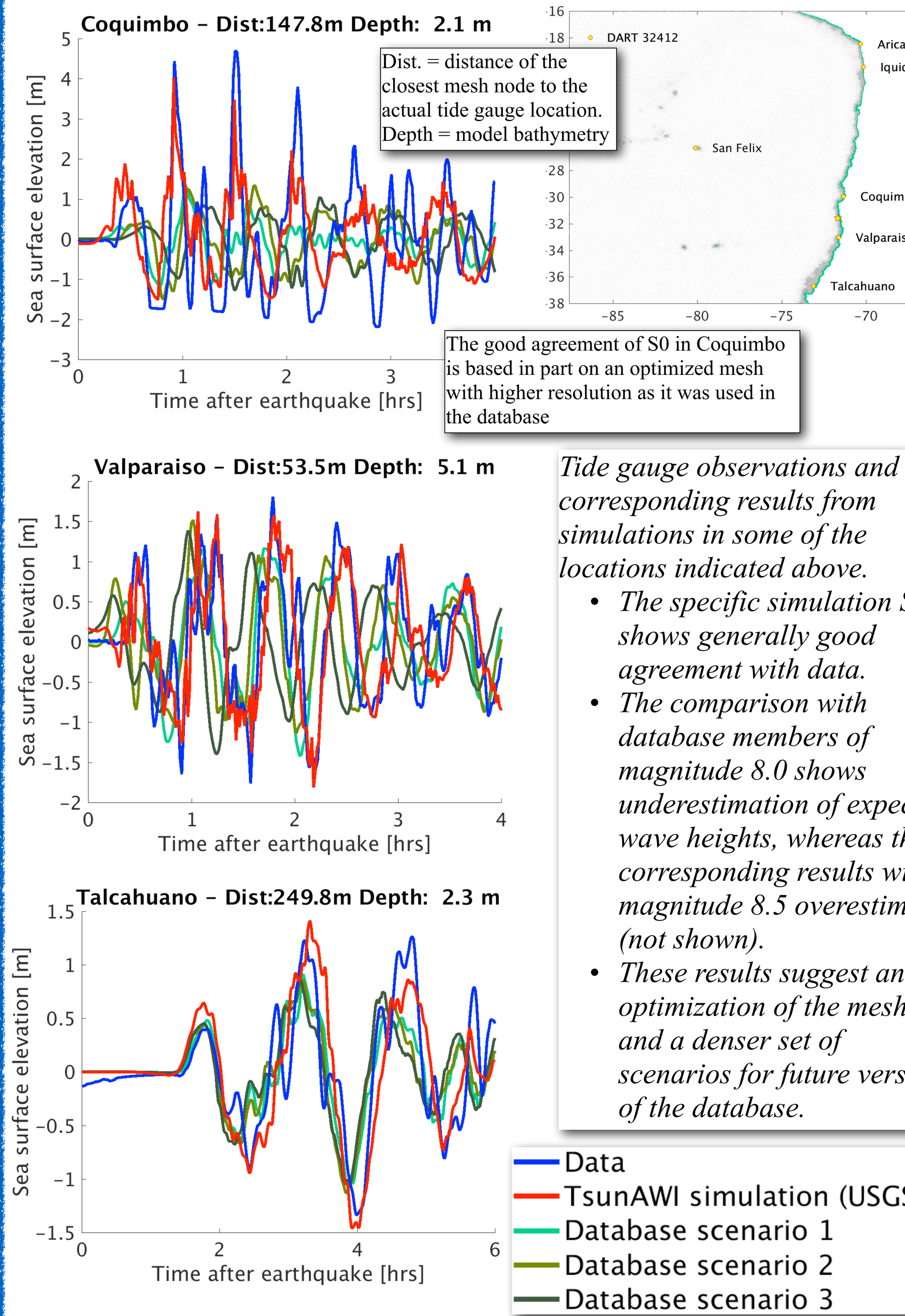
- In collaboration with DLR and SHOA prototypical scenario database for the chilean coast with 558 scenarios.
- Mesh covers part of the Pacific Ocean with resolution from 20 km to 50 m.
- Parameters provided by SHOA.
- Magnitudes:7.0, 7.5, 8.0, 8.5, 9.0.
- Depth 20 km and 30 km

In order to identify deficiencies in the database and modeling aproach comparisons of model results to measurements are crucial!

Earthquake on 16 September 2015

Observations after the Iquique earthquake are compared to simulation results

- Data:
  - Magnitude 8.3
  - Focal depth 22.4 km (USGS)
  - USGS Finite fault source
  - Tide gauge data from the IOC sea level station monitoring facility
  - DART Buoy data from the National Data Buoy Center
- TsunAWI Simulations:
  - S0 (using USGS source)
  - S1, S2 from the database (Mag 8.0, depth=20km)
  - S3 from the database (Mag 8.0, depth=30km)

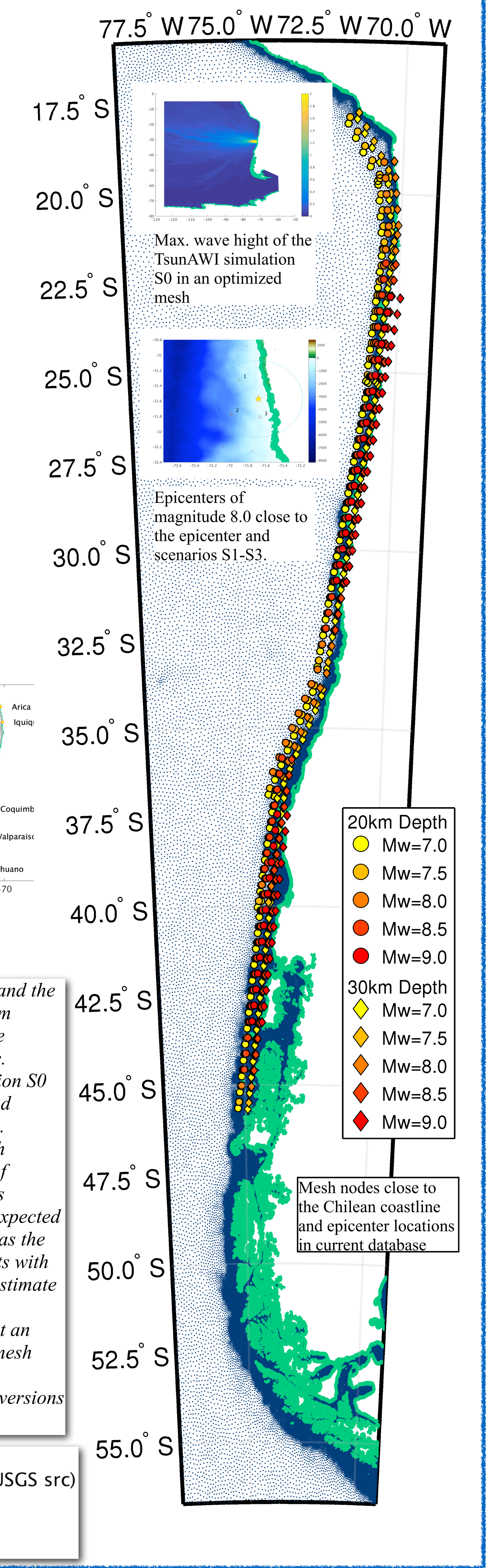


Dist. = distance of the closest mesh node to the actual tide gauge location. Depth = model bathymetry

The good agreement of S0 in Coquimbo is based in part on an optimized mesh with higher resolution as it was used in the database

Tide gauge observations and the corresponding results from simulations in some of the locations indicated above.

- *The specific simulation S0 shows generally good agreement with data.*
- *The comparison with database members of magnitude 8.0 shows underestimation of expected wave heights, whereas the corresponding results with magnitude 8.5 overestimate (not shown).*
- *These results suggest an optimization of the mesh and a denser set of scenarios for future versions of the database.*



Max. wave hight of the TsunAWI simulation S0 in an optimized mesh

Epicenters of magnitude 8.0 close to the epicenter and scenarios S1-S3.

Mesh nodes close to the Chilean coastline and epicenter locations in current database

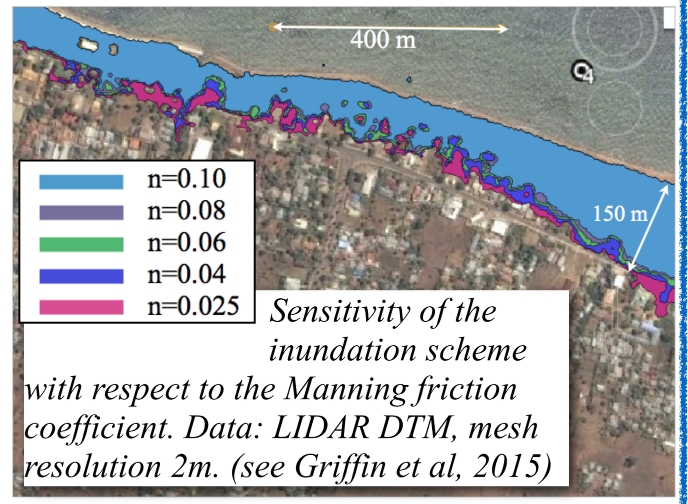
TsunAWI Model Description

The triangular discretization of the model domain allows for an excellent representation of complicated coastlines and bathymetry.

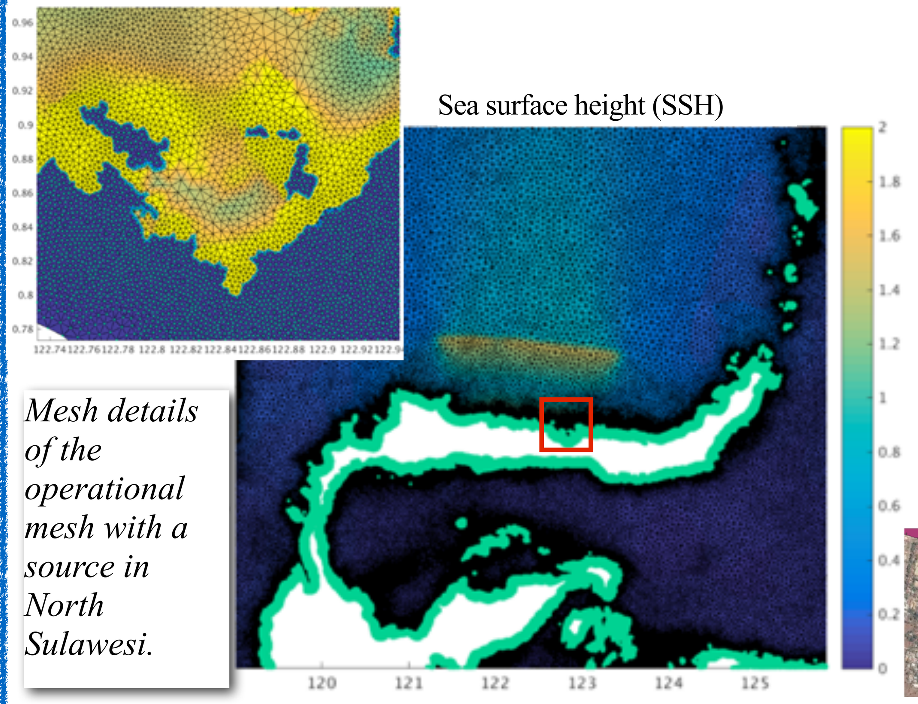
- Model for the nonlinear shallow water equations with radiation boudary conditions at open boundaries.
- Finite Elements with linear basis functions for the sea surface elevation and nonconforming basis functions for velocity.
- Surface triangulation with resolution depending on water depth and steepness of bathymetry:

$$\Delta x \leq \min\{c_t\sqrt{gh},\, c_g\frac{h}{\nabla h}\}\qquad h \text{ denotes water depth}$$

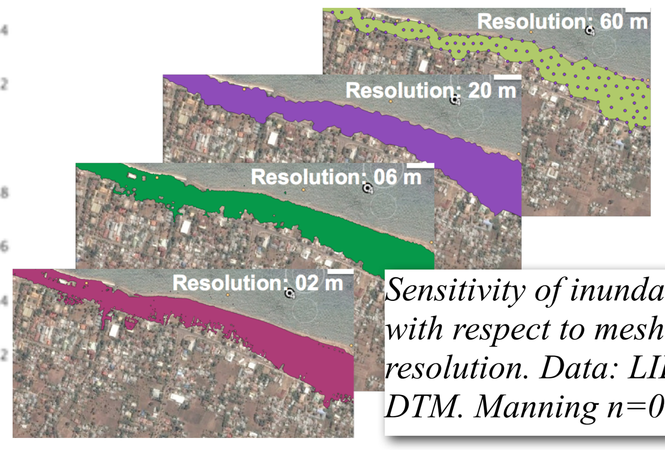
- Runup scheme based on extrapolation of model quantities to dry nodes in flooded areas. The corresponding Manning coefficient is currently constant and optimized using field measurements in Aceh after the tsunami in December 2004. Sensitivity studies highlight the role of friction and data quality (see figures)



Sensitivity of the inundation scheme with respect to the Manning friction coefficient. Data: LIDAR DTM, mesh resolution 2m. (see Griffin et al, 2015)



Mesh details of the operational mesh with a source in North Sulawesi.



Sensitivity of inundation with respect to mesh resolution. Data: LIDAR DTM. Manning n=0.025

Training

The database extension is accompanied by a series of training courses at BMKG, Jakarta. The topics include:

- Simulations with TsunAWI
  - Setting up the model, generating initial conditions.
  - Running computations on local clusters provided by DMInnovation.
  - Comparisons to alternative modeling approaches, especially to the model easyWave by GFZ.
- Post processing of simulations
  - Quality control of results
  - Generating warning products
- Import of warning products into TsunDaBI

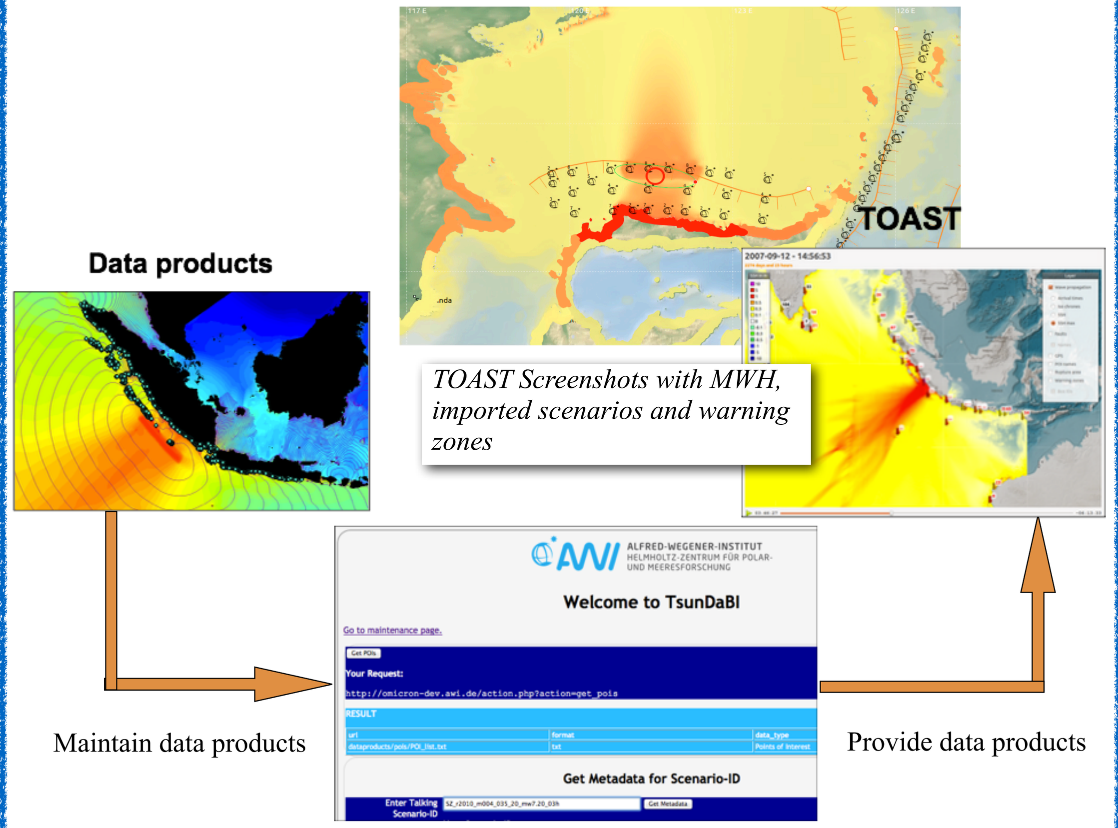
Opening the first workshop at BMKG Jakarta (BMKG - DMInnovation/GA - AWI) in May 2015.

Data product management

The newly developed interface TsunDaBI (Tsunami DataBase Interface) facilitates the transfer of warning products to the warning system. Tasks realized by the interface include:

- Import of data products described in the box above.
- Generation of an index database.
- Providing data products to other components (e.g. warning systems).

Current application: TsunDaBI as interface to the tsunami early warning system TOAST (developed by gempa GmbH)



TOAST Screenshots with MWH, imported scenarios and warning zones

Summary and Conclusions

- The finite element approach with triangular elements enables the generation of meshes representing all topographical features necessary for proper description of wave processes both in the deep ocean as well as in coastal areas.
- The scenario repository used in the operational tsunami early warning system of Indonesia (InaTEWS) is currently extended in collaboration with Geoscience Australia to include simulations in a larger part of the Indonesian domain.
- A new Tsunami database interface (TsunDaBI) for the transfer of warning products obtained from simulations was implemented.
- Comparisons to observations from the minor tsunami on 16 September 2015 shows good performance of the model in an optimized mesh with realistic source and suggests denser database and an obtimized mesh for precalculated scenarios.

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•Thanks to our project partners.

References:

•Griffin et al, An evaluation of onshore digital elevation models for modeling tsunami inundation zones. Front. Earth Science 3:32 (2015), doi: 10.3389/feart.2015.00032
•USGS Finite fault source obtained from: http://earthquake.usgs.gov
•Tide gauge data obtained from www.ioc-sealevelmonitoring.org

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