Retrospect on the modelling activities 2005 - 2014 for the German-Indonesian Tsunami Early Warning System

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Mathematical Modelling for Tsunami Early Warning Systems
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Final Round-up Session
German - Indonesian Cooperation
on Tsunami Early Warning System
2005 - 2014
JAKARTA & BALI, 24-27 MARCH, 2014
PROTECTS
BHINNEKA TUNGGAL IKA

Outline

- GITEWS overview
- Evolution of TsunAWI and the scenario repository
- Focus: dataproducts
- Focus: scenario selection
- Focus: inundation simulation

GITEWS Timeline

German-Indonesian Tsunami Early Warning System

2005-2011	GITEWS project funded by BMBF
Nov. 2008	Inauguration of the tsunami early warning system in Jakarta
Sep. 2010	Evaluation by international experts
March 2011	Transfer of Ownership to Indonesia
2011-2014	PROTECTS – PROject for Training, Education and Consulting for Tsunami early warning Systems, BMBF

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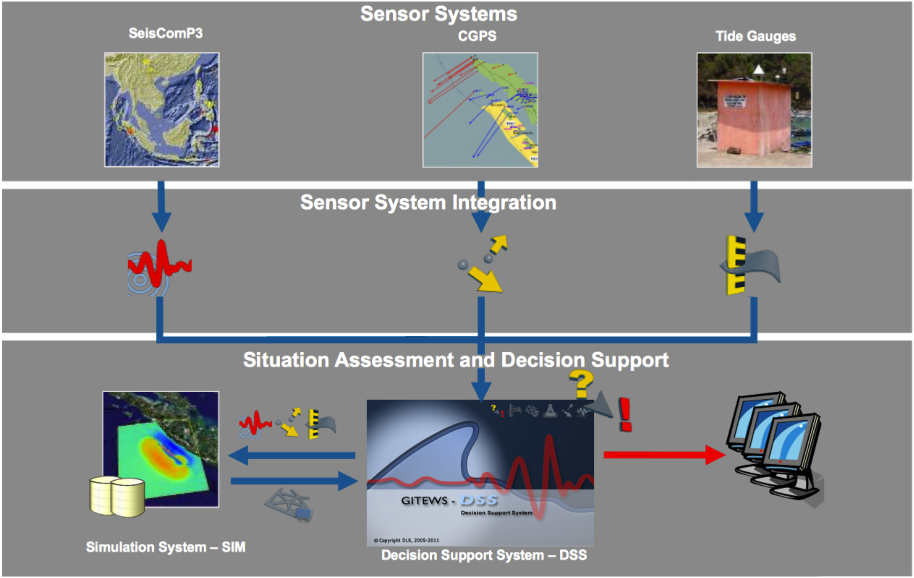
GITEWS System Overview



Sensor Systems

SeisComP3

CGPS

Tide Gauges

Sensor System Integration

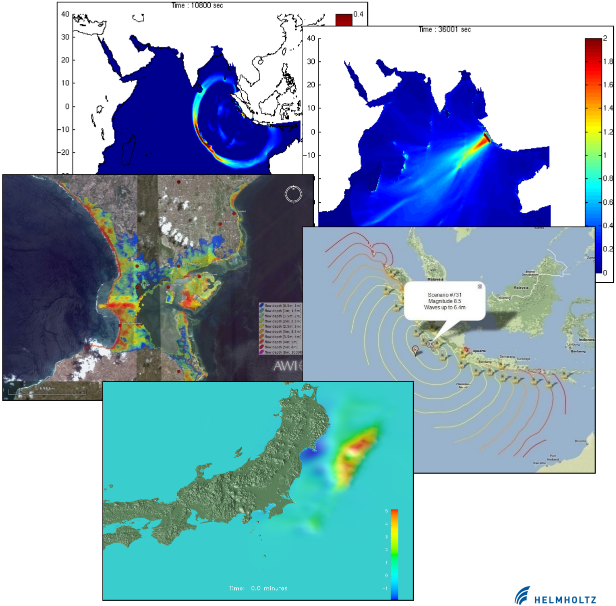
Situation Assessment and Decision Support

Simulation System – SIM

Decision Support System – DSS

GITEWS Simulation Products

- Regional
  - SSH time series
  - max. wave height
  - arrival times
  - inundation
- Indian Ocean
  - max. wave height
  - arrivaltimes
- Project regions
  - inundation
- verification with data from real events



TsunAWI

Non-linear Shallow Water Equations

$$\frac{\partial \mathbf{v}}{\partial t} + g\nabla\zeta + f\,\mathbf{k}\times\mathbf{v} + (\mathbf{v}\cdot\nabla)\mathbf{v} + \frac{r}{H}\,\mathbf{v}|\mathbf{v}| + \nabla(K_h\nabla\mathbf{v}) = 0,$$

$$\frac{\partial \zeta}{\partial t} + \nabla\cdot(H\,\mathbf{v}) = 0$$

Cartesian coordinates $(x, y) \in \Omega$,	horiz. velocity $\mathbf{v} = (u, v)$,
sea surface height ζ,	total waterdepth $H = h + \zeta$,
Coriolis parameter f,	Manning roughness coefficient r,

linear viscosity $K_h = c_1 \triangle x \triangle y$

Smagorinsky visc. $K_h = c_2 \triangle x \triangle y \triangle t \sqrt{(u_x)^2 + (v_y)^2 + \frac{1}{2}(u_y + v_x)^2}$

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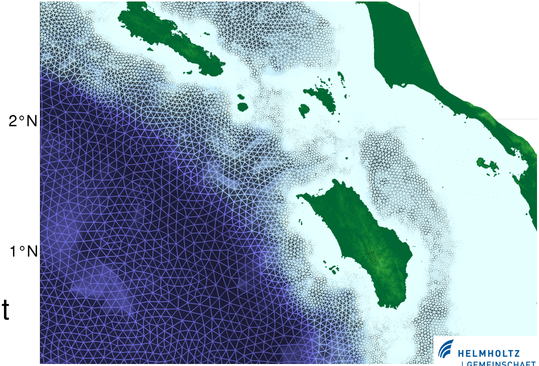
TsunAWI

In a nutshell

- Sibling of full ocean model FESOM
- Unstructured $P_1 - P_1^{NC}$ finite element grid, $\triangle x \leq \min\left(c_t\sqrt{gh},\ c_g\frac{h}{\nabla h}\right)$
- Initial conditions: Okada parameters, source model, land slide model
- Leap-frog time stepping
- Modules for tides, non-hydrostatic pressure
- Fortran90, OpenMP, netcdf
- Visualization with Matlab, OpenDX, GIS
- Scripts for batch and post processing, shapefile output



TsunAWI scenario repository

Scenarios 2007-2010

model physics linear shallow water

source model by GFZ: RuptGen 1.0, 1900 sources
336 epicenters, Mw=7.5, 7.7, **8.0**, 8.2, **8.5**, 8.7, **9.0**

bathymetry GEBCO 1’, accurate datasets for coastal regions

TsunAWI scenario repository

Scenarios 2007-2010 → since 2011

model physics linear shallow water

→ nonlin. advection added, Smagorinsky viscosity, improved inundation scheme

source model by GFZ: RuptGen 1.0, 1900 sources
336 epicenters, Mw=7.5, 7.7, **8.0**, 8.2, **8.5**, 8.7, **9.0**

→ RuptGen 2.1, 3470 sources
528 epicenters, Mw=7.2, 7.4, 7.6,. . . , 8.8, 9.0

bathymetry GEBCO 1', accurate datasets for coastal regions

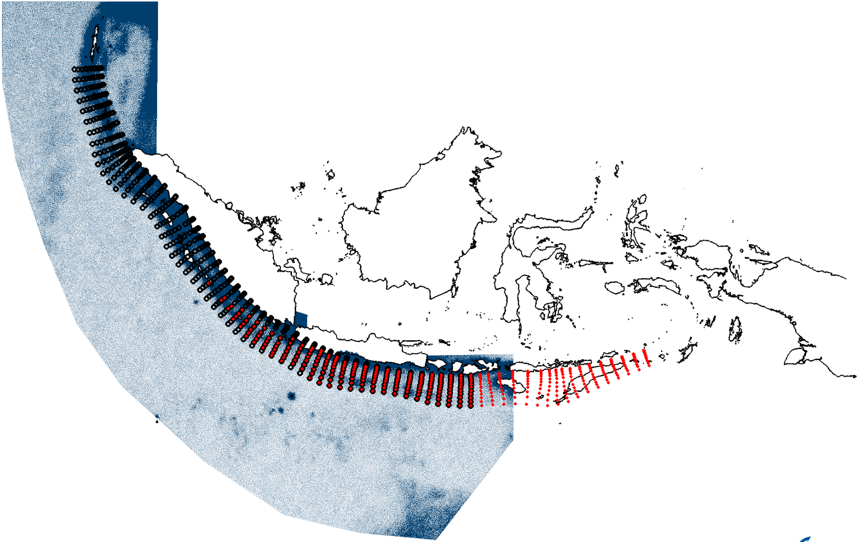
→ GEBCO 30" instead of GEBCO 1'

technical improvements

→ faster calculation, reduced scenario file size

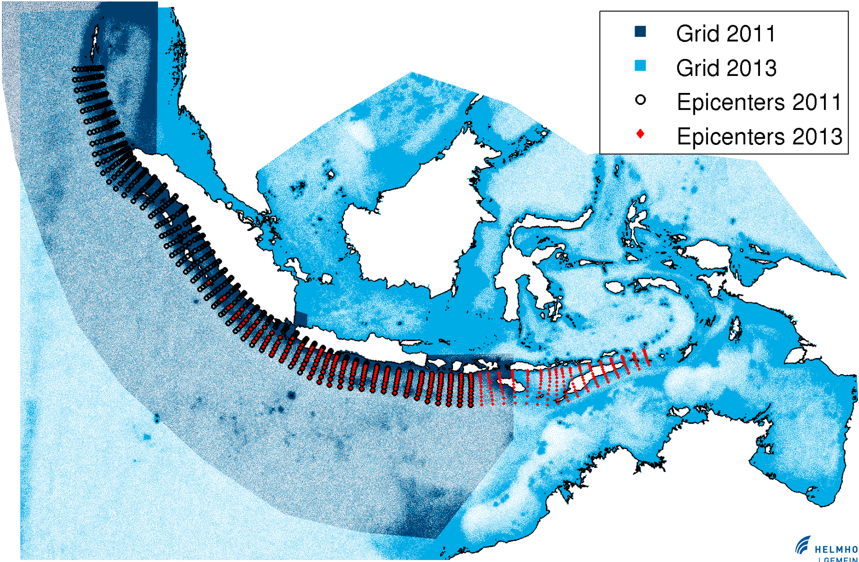
TsunAWI scenario repository

Model domain for scenarios 2011



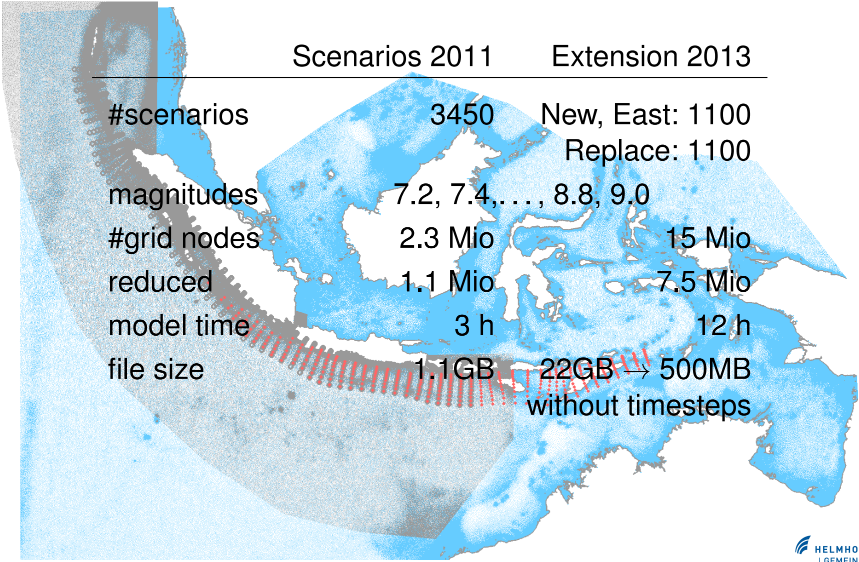
TsunAWI scenario repository

Model domain for scenarios 2011 and extension 2013



TsunAWI scenario repository

Extending the tsunami scenario repository

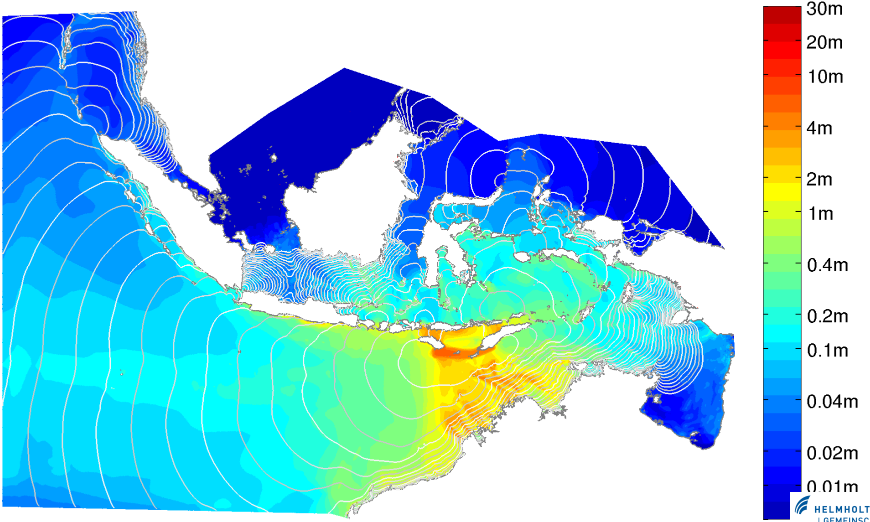


	Scenarios 2011	Extension 2013
#scenarios	3450	New, East: 1100 Replace: 1100
magnitudes	7.2, 7.4, . . . , 8.8, 9.0	
#grid nodes	2.3 Mio	15 Mio
reduced	1.1 Mio	7.5 Mio
model time	3 h	12 h
file size	1.1GB	22GB → 500MB without timesteps

Scenario data products

ETA isochrones and maximum amplitude

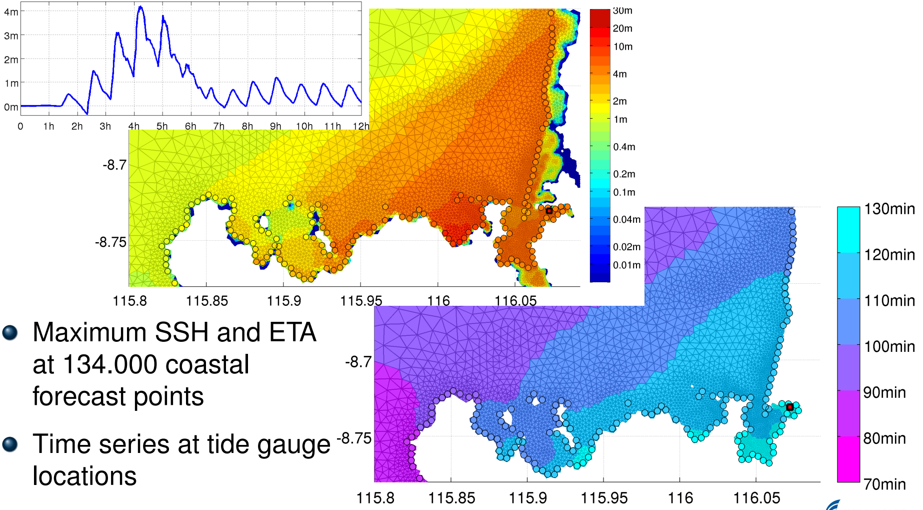
Example: Magnitude 9.0 in the Eastern Sunda Arc



Scenario data products

Coastal forecast points

Example: Magnitude 9.0 in the Eastern Sunda Arc, zoom to Lembar, Eastern Lombok



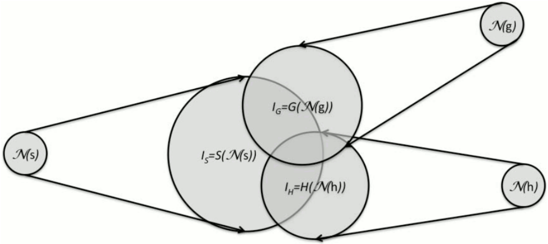
- Maximum SSH and ETA at 134.000 coastal forecast points
- Time series at tide gauge locations

Scenario selection algorithm

Theoretical background

Uncertainty reduction with multiple sensors

- Combine multiple sensors with corresponding uncertainties,



- For each scenario, define mismatch as weighted sum over comparison of the sensor measurements to scenario data,
- Choose scenarios with mismatch below a given threshold.

Scenario selection algorithm

GITEWS Implentation

Regard each sensor type with its characteristics in mind!

- Epicenter and magnitude are derived from multiple sensor data by approved SeisComP3.
- Reliable GPS data comes fast, too. But little experience so far, limited number of stations.
- Tide gauges hard to use for early warning in an automated algorithm.

Scenario selection algorithm

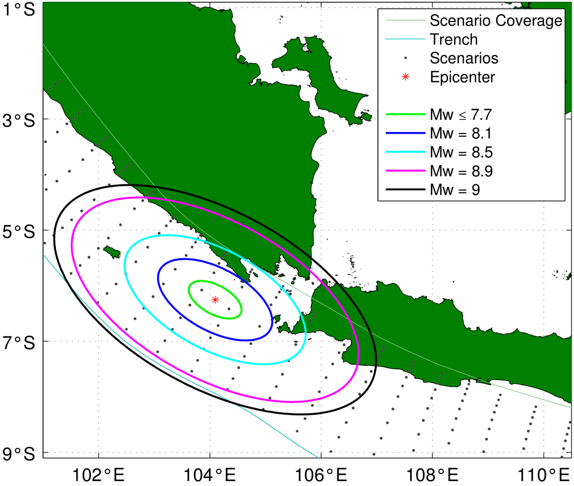
GITEWS Implentation

Regard each sensor type with its characteristics in mind!

- Epicenter and magnitude are derived from multiple sensor data by approved SeisComP3.
  → Use epicenter and magnitude to pre-select scenarios.
- Reliable GPS data comes fast, too. But little experience so far, limited number of stations.
  → Refine scenario selection by comparing GPS measurement and scenario data.
- Tide gauges hard to use for early warning in an automated algorithm.
  → Very valuable for all-clear and hind-casts.

Scenario selection algorithm

1. Step: Seismic pre-selection



Magnitude uncertainty:
$[M - 0.5; M + 0.3]$.

Epicenter uncertainty:
Ellipse parallel to the trench
$r_L = 10^{0.5[M+0.3]-1.8}$km,
$r_W = \frac{1}{2} r_L$.

Scenario selection algorithm

2. Step: Refine by GPS matching

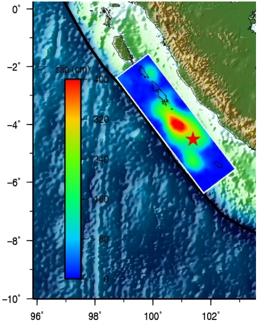
For all pre-selected scenarios, compare measured and scenario dislocation:

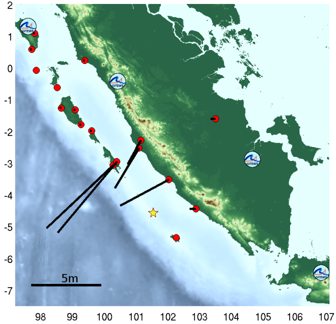
- Length of dislocation vectors (measurement with confidence interval),
- uncertainty factor of currently 3.5
    - Little experience with GPS measurements in Indonesia,
    - Limited set of scenarios: dip slip only, discrete epicentres, magnitudes,
    - Model uncertainty,
    - Strong earthquakes: saturation may take time, overshooting possible.
- If at least N measurements ($N = 2$, adjustable) do not fit for a scenario, the scenario is rejected.

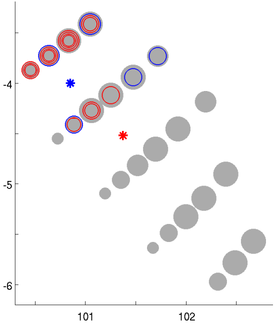
Scenario selection algorithm

2. Step CGPS e.g., Benkgulu Sept. 2007

USGS Finite Fault: Tsunami source NW of the epicenter.
Measured GPS-dislocations strong in the NW, but not SE.







GPS matching would reject all scenarios in the SE, and some very strong scenarios in the NW.

Inundation simulation

TsunAWI's inundation scheme

- Original plan: simulation tsunami propagation in deep water, only.
  But: Too strong reflections at the coast!

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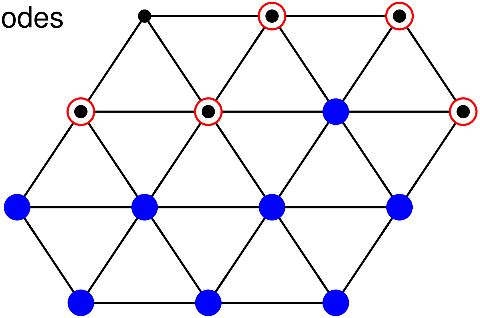

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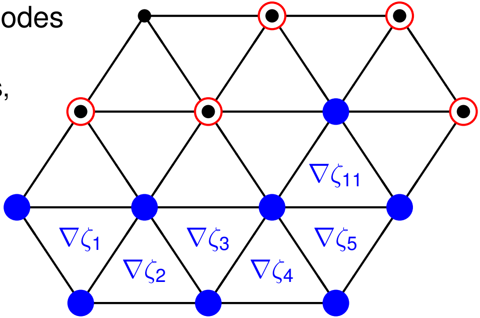

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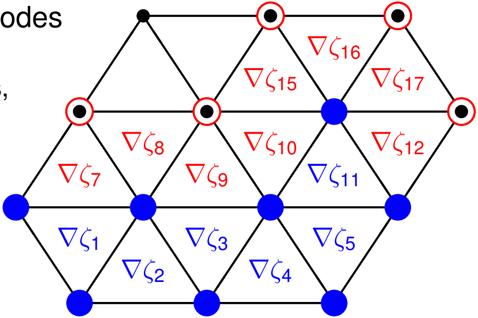
$$\nabla\zeta_j = \sum_{i \text{ wet}}^{i\cap j\neq\emptyset} a_i \nabla\zeta_i,$$



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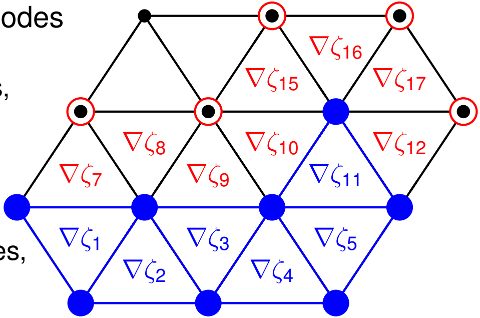

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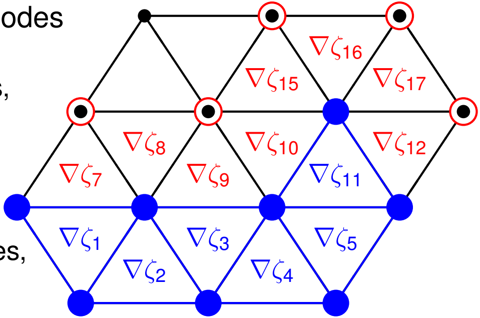
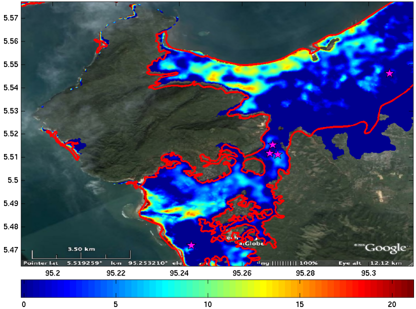


$$\zeta_n^{t+2\triangle t} = \sum_{m \text{ wet}}^{m\cap n\neq\emptyset} a_m \left(\zeta_m^t + (\nabla\zeta_m^{t+\triangle t}) \cdot (\mathbf{x}_n - \mathbf{x}_m)\right).$$

Inundation simulation

Example: Banda Aceh 2004

Simulation shows good agreement with measurements.



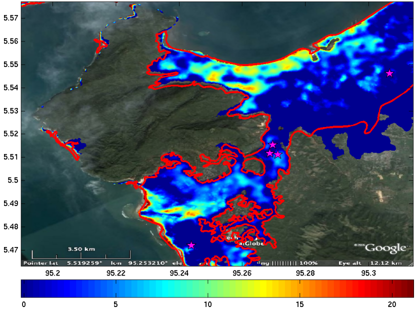
Inundation simulation

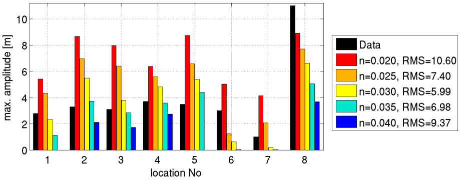
Example: Banda Aceh 2004

Simulation shows good agreement with measurements.

However, calibration remains difficult. The result is sensitive to

- source model,
- Manning coefficient,
- mesh resolution,
- topography data.





Inundation simulation

Sensitivity study on topography data

Three groups AIFDR, ITB, AWI,

Three models ANUGA, TUNAMI-N3, TsunAWI,

Three regions Padang (Sumatra), Maumere (Flores), Palu (Sulawesi)

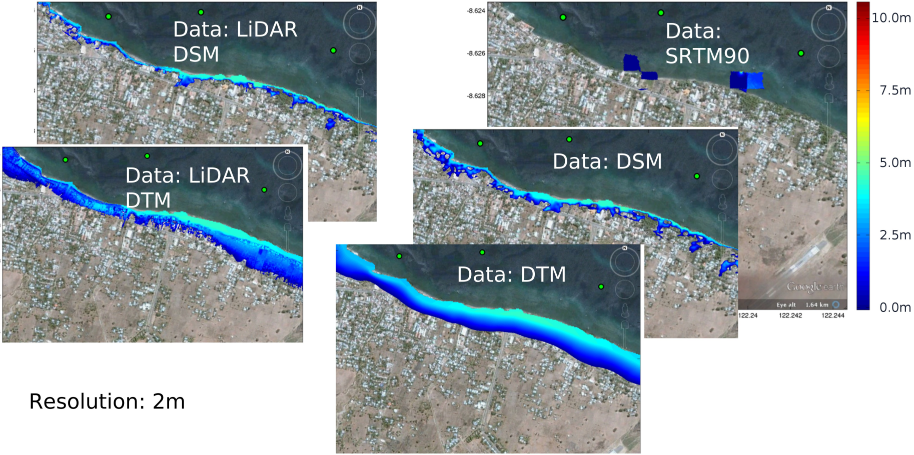
One conclusion **High quality topography data is crucial!**

- Free SRTM data (90m horizontal resolution, $\leq$16m vertical accuracy) only for rough estimates,
- Intermap (5m; 0.7m) and LiDar (1m; 0.15m) comparable for shallow water models,
- Results more sensitive to varying data sets than to varying resolution.

Inundation simulation

Sensitivity study on topography data

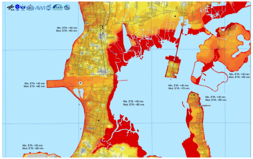
Example: synthetic scenario for Maumere, Flores

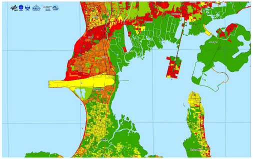


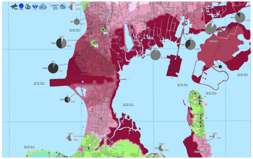
Resolution: 2m

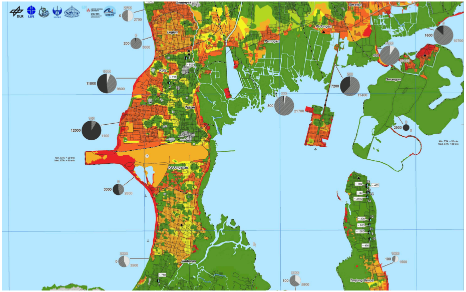
Inundation simulation

Deriving evacuation maps e.g., Kuta, Bali


tsunami risk


exposed people


evacuation time



risk map (with shelters)

Inundation simulation

Deriving evacuation maps e.g., Kuta, Bali

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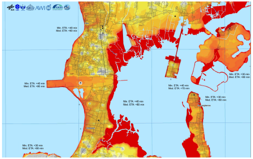
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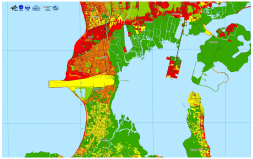
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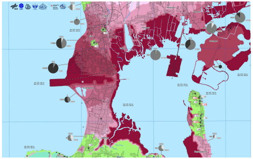
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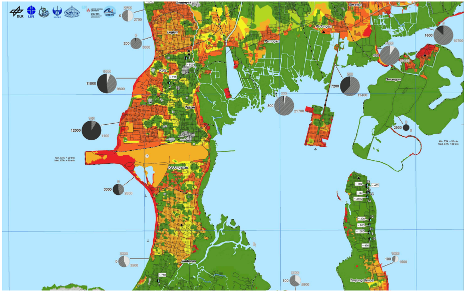
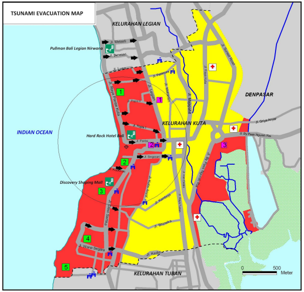

risk map (with shelters)

giz, local community



evacuation map

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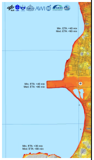
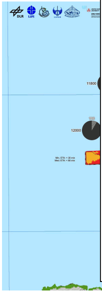


tsu



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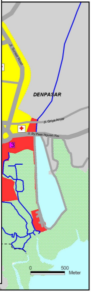

evacuation map

2014 — . . .

Outlook

- Further support for Indonesia
- Interface/GUI for TsunAWI for easy use by trained experts,
- Near real time modelling with TsunAWI,
- Cooperation with Chile.

- TsunAWI as testbed for numerical techniques for ocean modelling, in particular a coastal model.