Tsunami-Simulation
für das indonesische Fühwarnsystem

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Wissen um 11
Haus der Wissenschaft, Bremen
3. Mai 2014


Final Round-up Session
German - Indonesian Cooperation
on Tsunami Early Warning System
2005 - 2014
JAKARTA & BALI, 24-27 MARCH, 2014

Überblick

- Aufbau des indonesischen Frühwarnsystems
- Das Tsunami-Simulationsprogramm TsunAWI
- Szenarien-Datenbank
- Szenarien-Auswahl im Warnfall
- Überflutungssimulation

GITEWS

Deutsch-Indonesisches Tsunami-Frühwarnsystem

2005-2011	GITEWS-Projekt, vom BMBF gefördert
Nov. 2008	Einweihung des Warnsystems in Jakarta
Sep. 2010	Begutachtung durch internationale Experten
März 2011	Übergabe an Indonesia
2011-2014	PROTECTS – PROject for Training, Education and Consulting for Tsunami early warning Systems, BMBF

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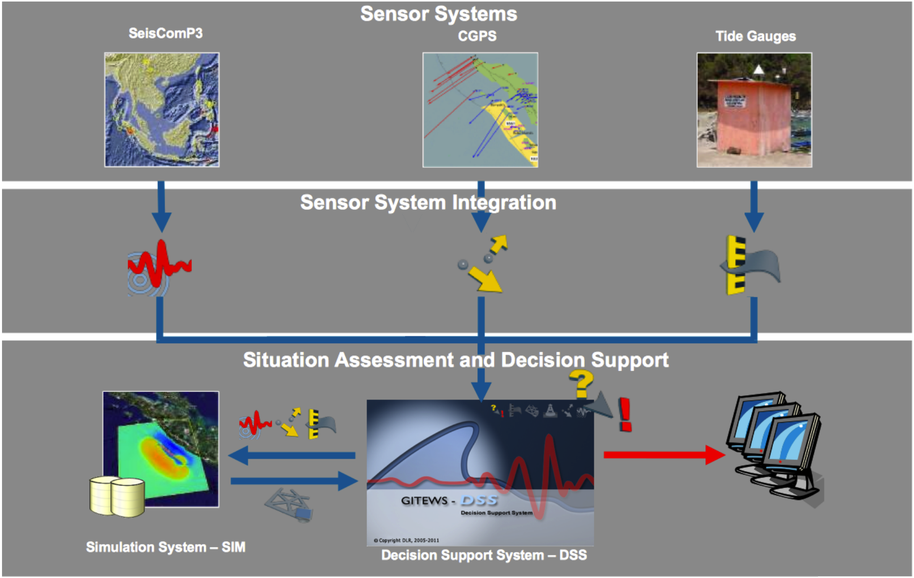
Frühwarnsystem Überblick

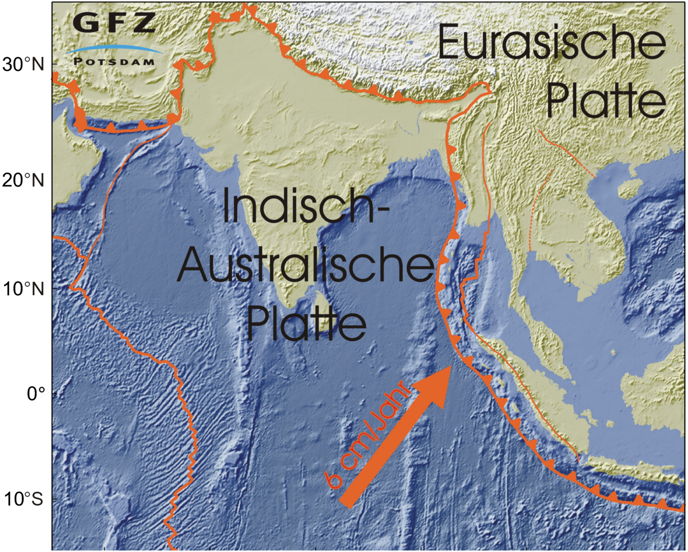
Warnraum am Badan Meteorologi, Klimatologi dan Geofisika, Jakarta

Frühwarnsystem Überblick



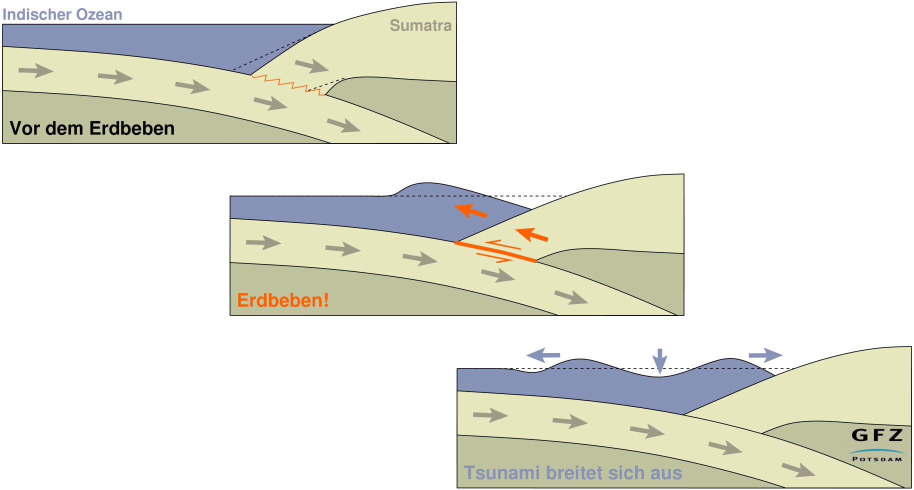
Frühwarnsystem Überblick

Plattentektonik



Tsunami-Modellierung

Erdbeben als Tsunami-Auslöser



Tsunami-Modellierung

Die nicht-linearen Flachwassergleichungen

Impulsgleichung

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

Kontinuitätsgleichung

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

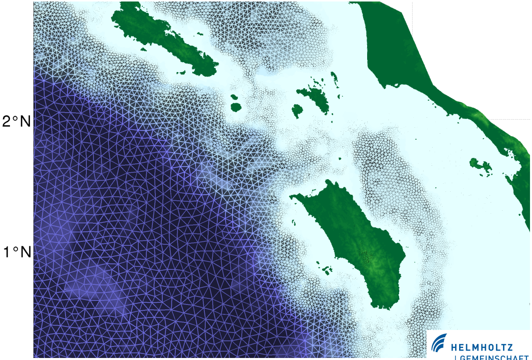
Kart. Koordinaten $(x, y) \in \Omega$,
Meeresspiegelauslenkung ζ,
Coriolis Parameter f,
Viskosität K_h.

horiz. Geschw. $\mathbf{v} = (u, v)$,
totale Wassertiefe $H = h + \zeta$,
Manning Bodenreibung r,

Tsunami-Modellierung

In Stichpunkten

- Abgeleitet vom Ozeanmodel FESOM
- Unstrukturierte $P_1 - P_1^{NC}$ finite Elemente, $\triangle x \leq \min\left(c_t\sqrt{gh},\ c_g\frac{h}{\nabla h}\right)$
- Anfangsbedingungen aus Erdbeben (Okada Parameter, Quellmodell) oder Landrutsch-Modell
- Leap-frog Zeitschritt
- Module for Gezeiten, nicht-hydrostatisch
- Fortran90, OpenMP, netcdf
- Visualisierung mit Matlab, OpenDX, GIS
- Skripte for Batch und Post-prozessierung, GIS output



TsunAWI Szenarien-Datenbank

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 Szenarien-Datenbank

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

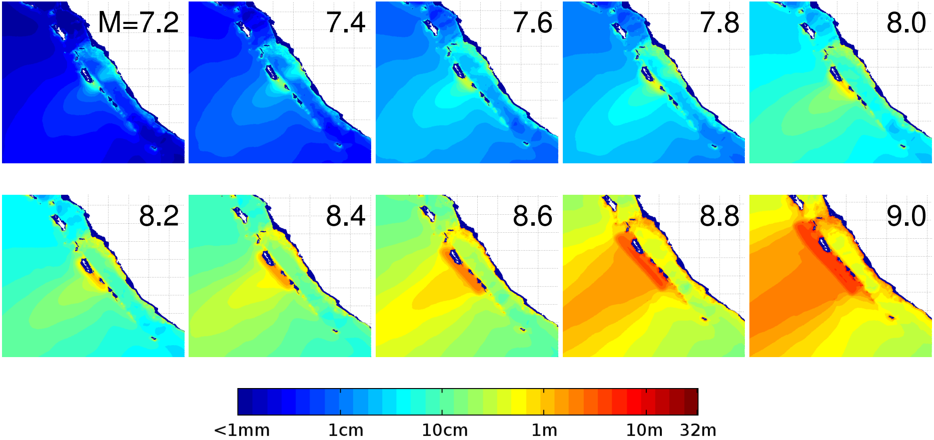
→ GEBCO 30" instead of GEBCO 1'

technical improvements

→ faster calculation, reduced scenario file size

TsunAWI Szenarien-Datenbank

Einfluss der Magnitude auf die maximale Wellenhöhe



Logarithmische Skala: Magnitude +1 $\Longrightarrow$ Energie $\times$31,6

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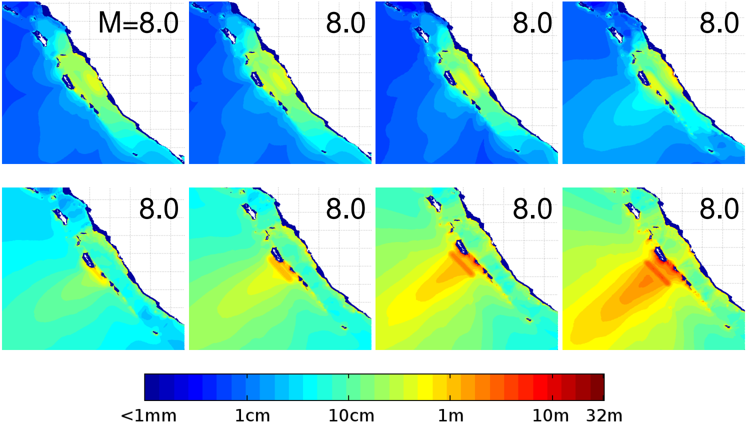
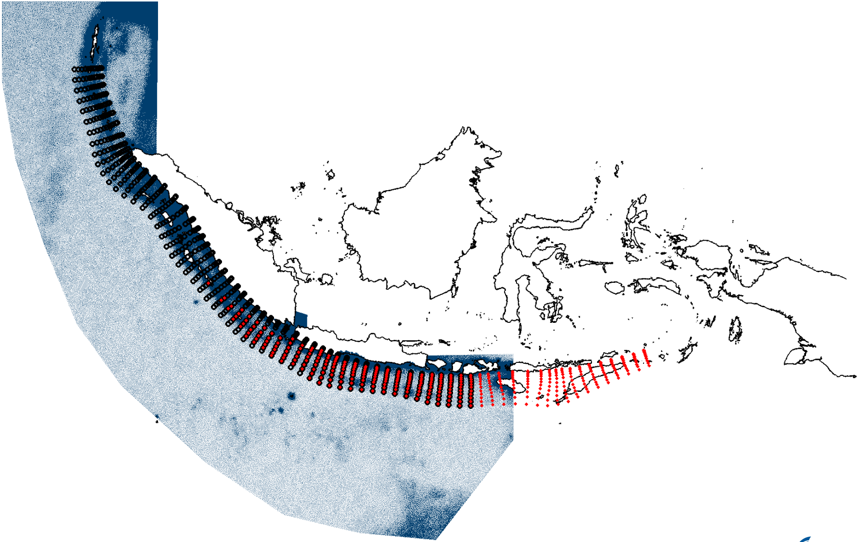
Einfluss der Lokation auf die maximale Wellenhöhe



An der Küste tiefes Epizentrum in festem Gestein,
am Trench Epizentrum dicht unter der Oberfläche in weichem Gestein.

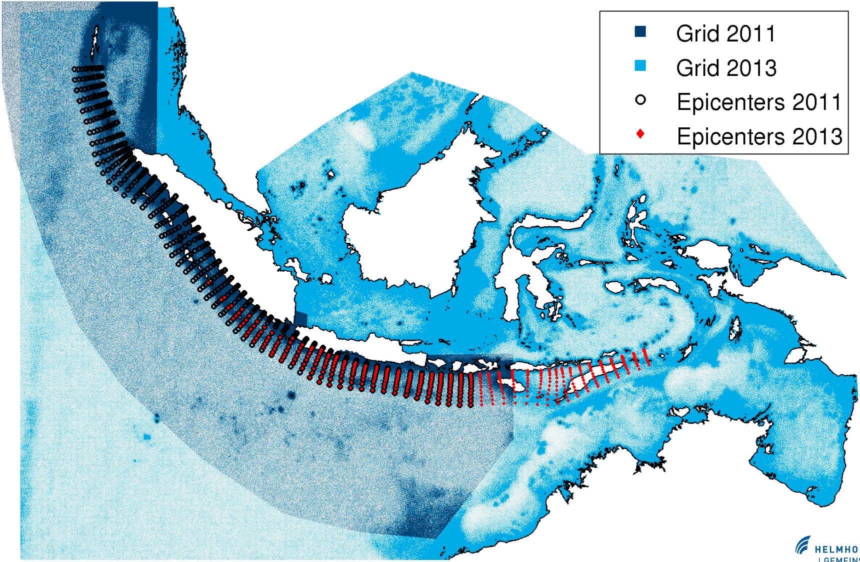
TsunAWI Szenarien-Datenbank

Model domain for scenarios 2011



TsunAWI Szenarien-Datenbank

Model domain for scenarios 2011 and extension 2013



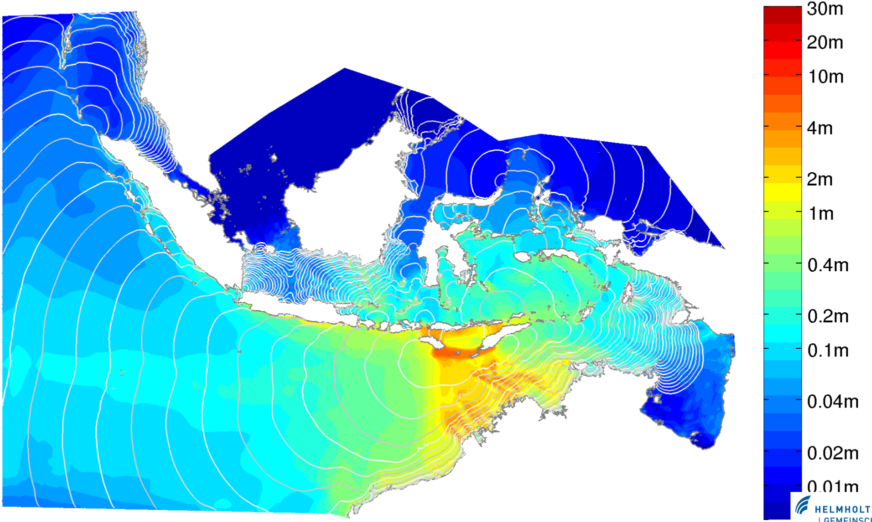
TsunAWI Szenarien-Datenbank

	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
resolution	50m - 150m - 15km	
model time	3 h	12 h
compute time	0:45 h 2× 8 Core Xeon Nehalem	15 h 1× 8 Core Xeon Westmere
file size	1.1GB	22GB → 500MB without timesteps

Scenario data products

ETA isochrones and maximum amplitude

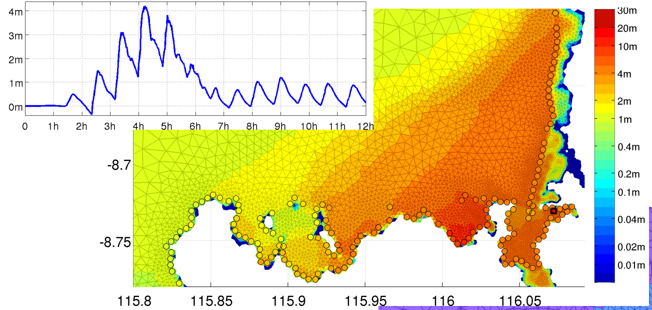
Example: Magnitude 9.0 in the Eastern Sunda Arc



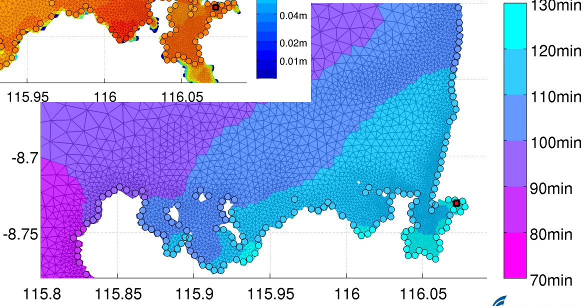
Scenario data products

Coastal forecast points

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

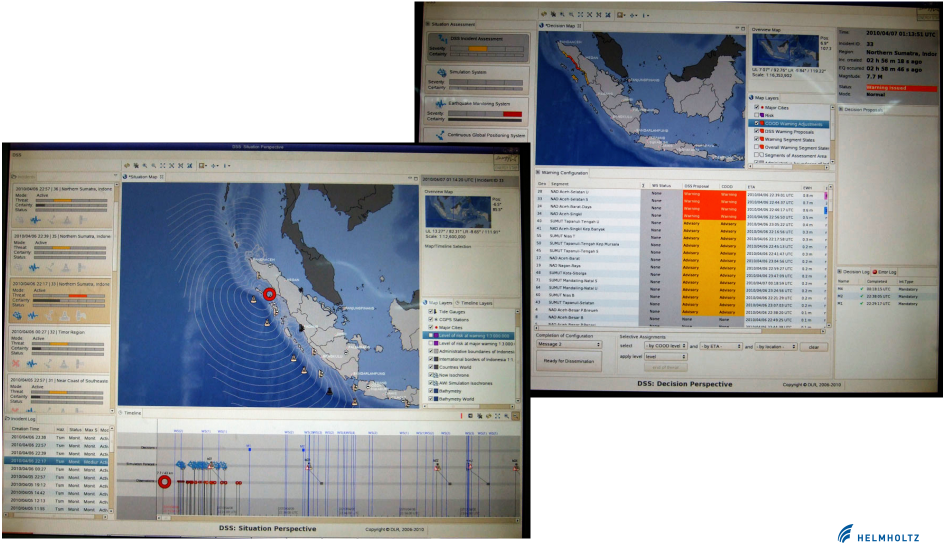


- Maximum SSH and ETA at 134.000 coastal forecast points
- Time series at tide gauge locations



Scenario data products

Mini-Tsunami am 7. April 2010



Szenarien Auswahl-Algorithmus

Unsicherheit reduzieren mit Multi-Sensordaten

- Epizentrum und Magnitude sind Ergebnis von ausgeklügelter Verarbeitung vieler seismischer Messstationen (SeisComP3, GFZ).
- Verlässliche GPS-Verschiebungsdaten kommen auch schnell. Aber bisher wenig Erfahrung, begrenzte Zahl von Stationen.
- Küstenpegel in den ersten Minuten nur nicht für automatisierte Szenarienauswahl geeignet.

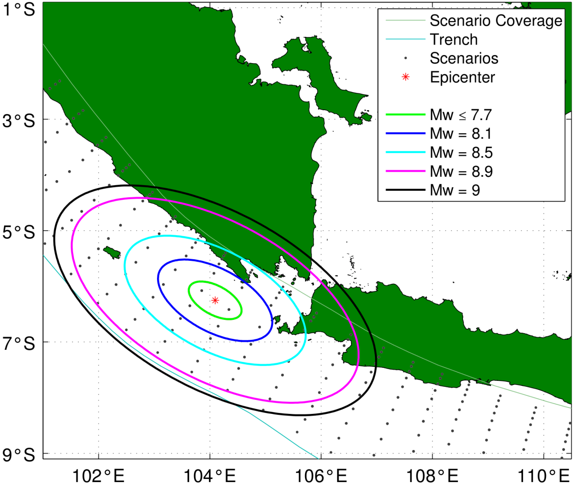
Szenarien Auswahl-Algorithmus

Unsicherheit reduzieren mit Multi-Sensordaten

- Epizentrum und Magnitude sind Ergebnis von ausgeklügelter Verarbeitung vieler seismischer Messstationen (SeisComP3, GFZ).
  $\rightarrow$ Epizentrum und Magnitude zur Vorauswahl von Szenarien.
- Verlässliche GPS-Verschiebungsdaten kommen auch schnell. Aber bisher wenig Erfahrung, begrenzte Zahl von Stationen.
  $\rightarrow$ Szenarien-Vorauswahl mit GPS eingrenzen.
- Küstenpegel in den ersten Minuten nur nicht für automatisierte Szenarienauswahl geeignet.
  $\rightarrow$ Sehr wertvoll für Entwarnung und Verifikation.

Szenarien Auswahl-Algorithmus

1. Step: Seismic pre-selection



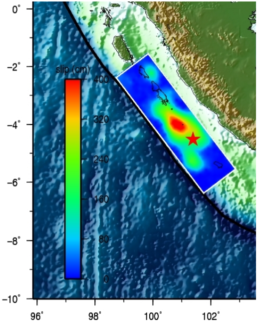
Magnitude uncertainty:
$[M - 0.5; M + 0.3]$.

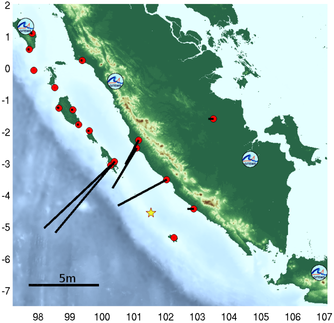
Epicenter uncertainty:
Ellipse parallel to the trench
$r_L = 10^{0.5[M+0.3]-1.8}$km,
$r_W = \frac{1}{2} r_L$.

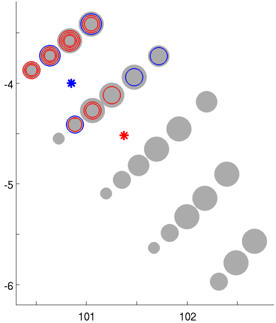
Szenarien Auswahl-Algorithmus

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.





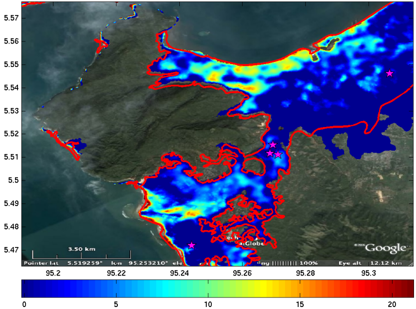


GPS matching would reject all scenarios in the SE, and some very strong scenarios in the NW.

Überflutungssimulation

Example: Banda Aceh 2004

Simulation shows good agreement with measurements.



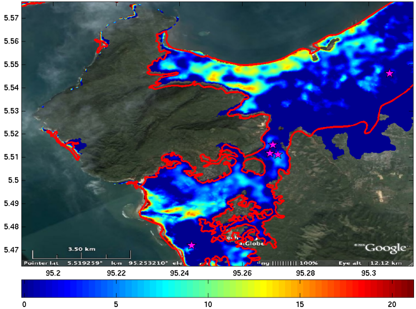
Überflutungssimulation

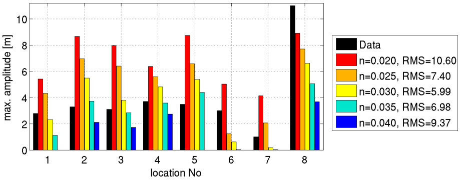
Example: Banda Aceh 2004

Simulation shows good agreement with measurements.

However, calibration remains difficult. The result is sensitive to

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





Überflutungssimulation

Sensitivity study on topography data

Three groups AIFDR, ITB, AWI,

Three models ANUGA, TUNAMI-N3, TsunAWI,

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

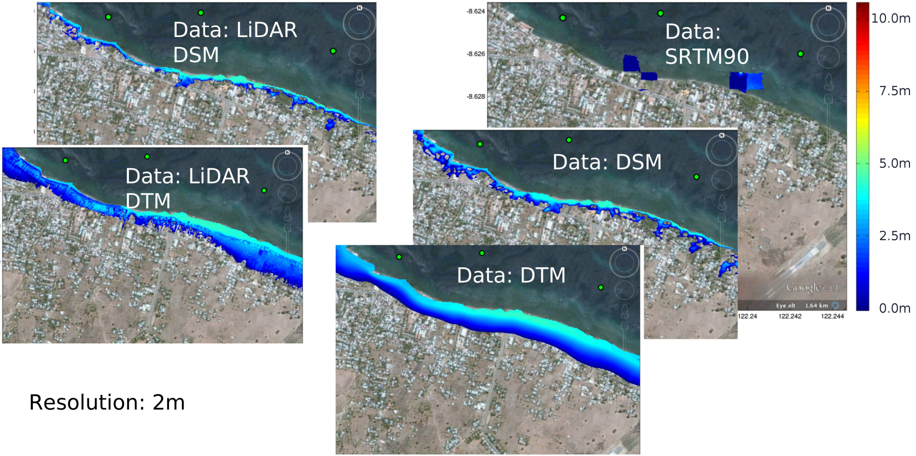
One conclusion **High quality topography data is crucial!**

- 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.

Überflutungssimulation

Sensitivity study on topography data

Example: synthetic scenario for Maumere, Flores



Resolution: 2m

Überflutungssimulation

Deriving evacuation maps e.g., Kuta, Bali

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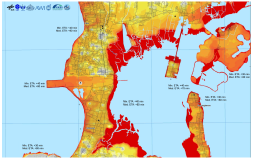
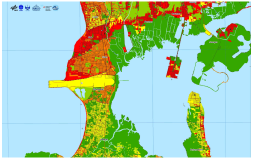
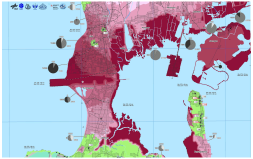


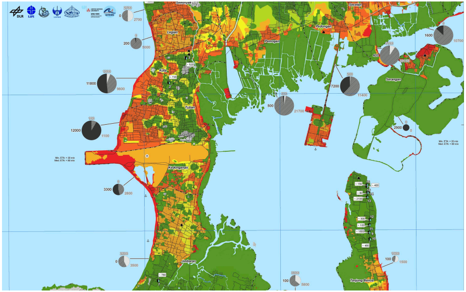
tsunami risk



exposed people



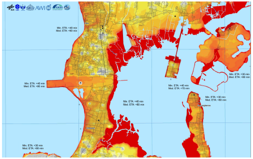
evacuation time



risk map (with shelters)

Überflutungssimulation

Deriving evacuation maps e.g., Kuta, Bali



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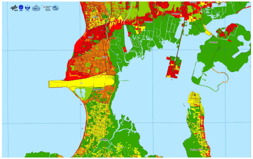

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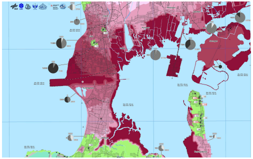

evacuation time

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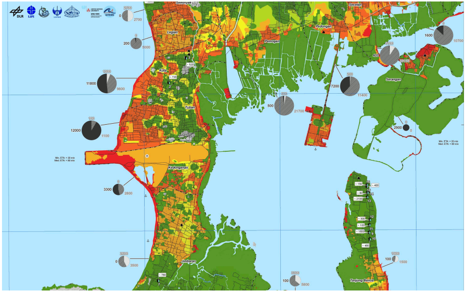
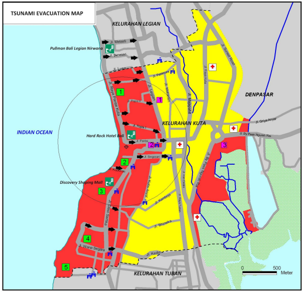
DLR



risk map (with shelters)

giz, local community



evacuation map

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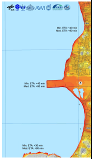
Überflutungssimulation

Deriving evacuation maps e.g. Kuta, Bali



tsu

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DLR

risk map (with shelters)

evacuation map

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