Geohazards

GNSS Augmentation to Tsunami Early Warning Systems

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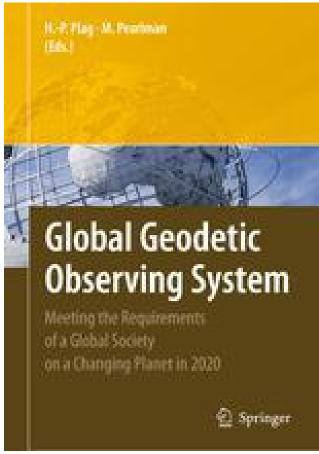
The Vision: GGOS2020



The ***Global Geodetic Observing System (2009)*** set a path to develop and apply geodetic science, technology, and infrastructure to mitigate our vulnerability to natural hazards.

Example: Tsunami Warning

The GGOS Geohazards Initiative **GNSS Augmentation for Tsunami Early Warning** (GATEW) builds upon the **IGS Real Time Service (GPS-RT)** and **IGS Multi-GNSS Experiment (M-GEX)**.

The GATEW Working Group will be a catalyst and motivating force to define requirements, identify resources, and encourage international cooperation.

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GATEW Initiative Highlights:

- The GGOS laid the foundation for the GATEW Initiative through formal recommendations by the IGS, IUGG, IOC, and the APSG.

- On April 1,2016 GGOS released a Call for Participation (CfP) in a Working Group for GNSS Augmentation to the Tsunami Early Warning Systems (GATEW). http://kb.igs.org/hc/en-us/articles/218259648-Call-for-Participation-GNSS-Augmentation-to-the-Tsunami-Early-Warning-System

- **One year later, GATEW working group membership includes 16 members from 11 nations.**

- **The CfP for the GATEW working group remains open and membership is growing.**

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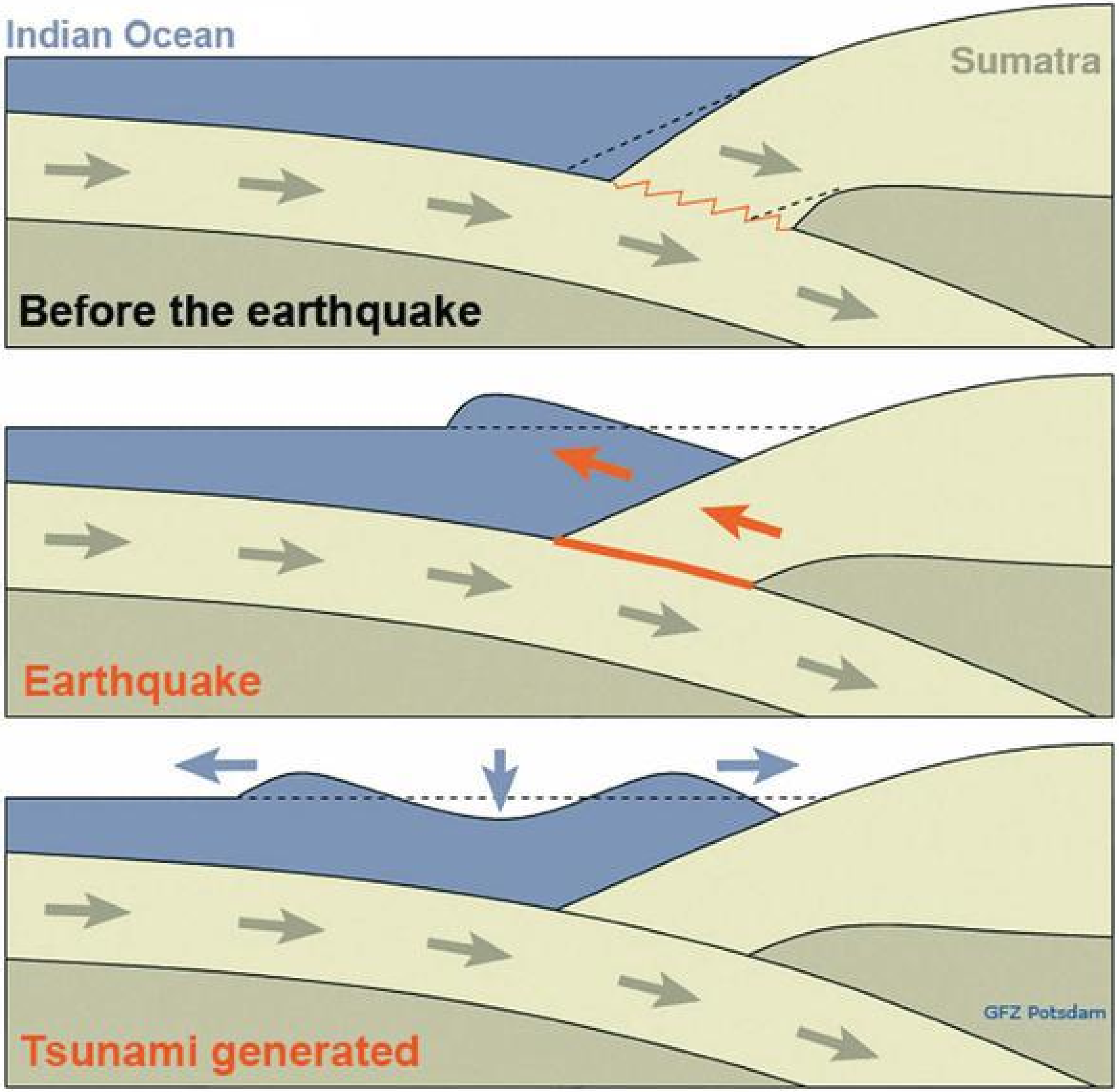
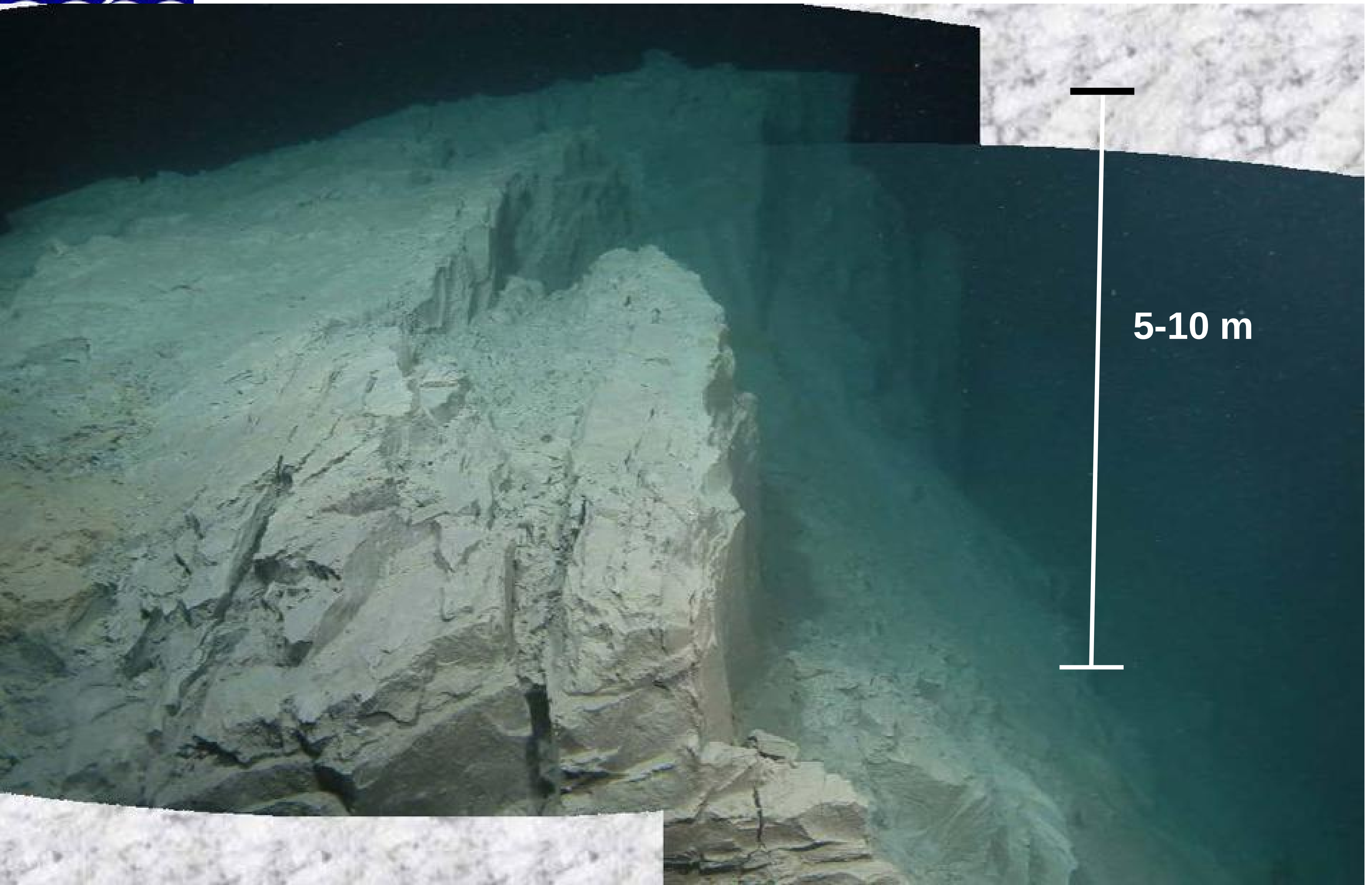
Tsunami Generation

Tsunami Formation



Vertical Displacement after the 2004 Sumatra Quake



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Tsunami Source Characterisation
for
Tsunami Modelling

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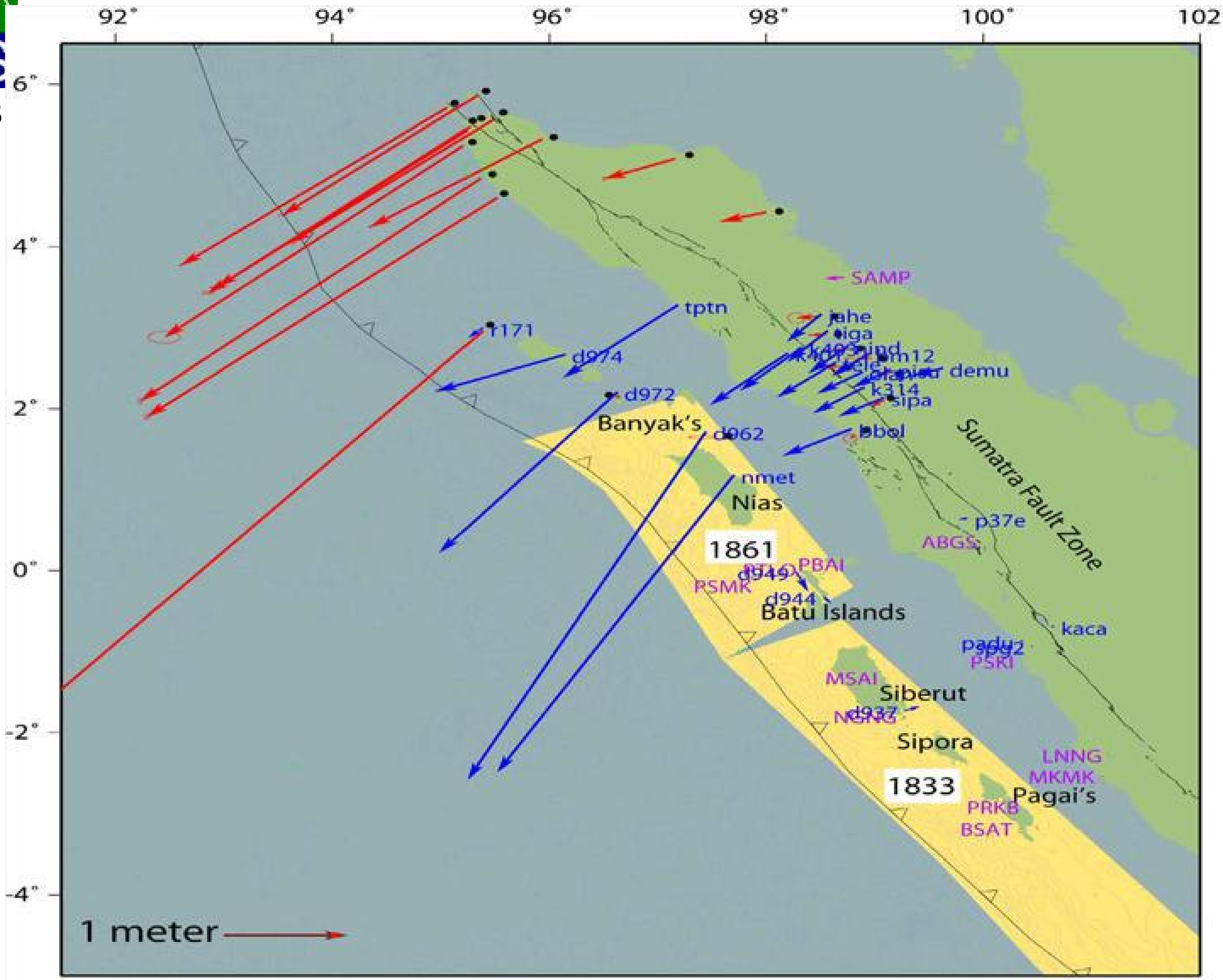
Coseismic Displacement Sumatra 2004



Vigny et al., 2005

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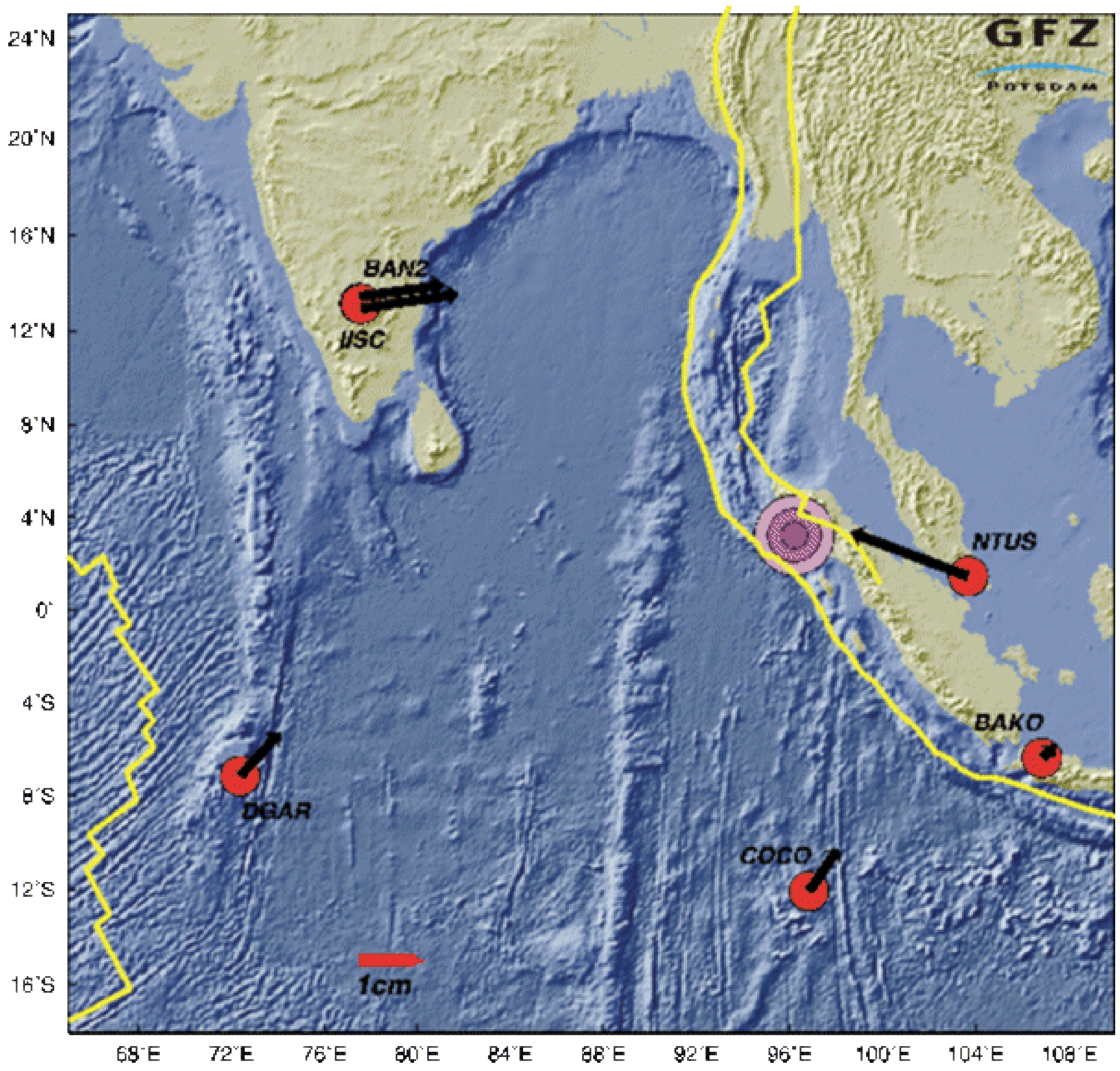
Displacements after the Sumatra Quake



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The Problem of Near Field Tsunami Forecasting

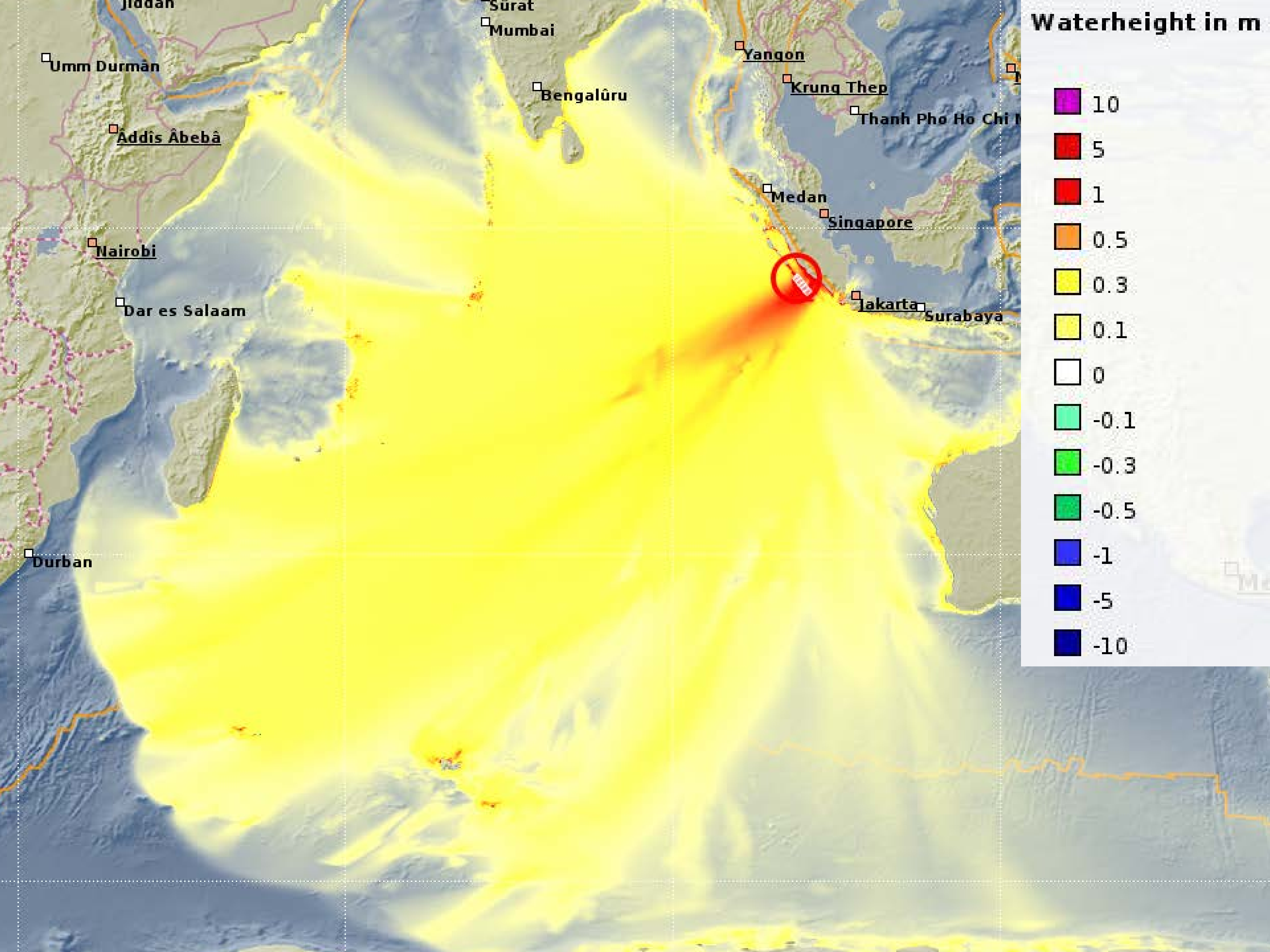
Definitions

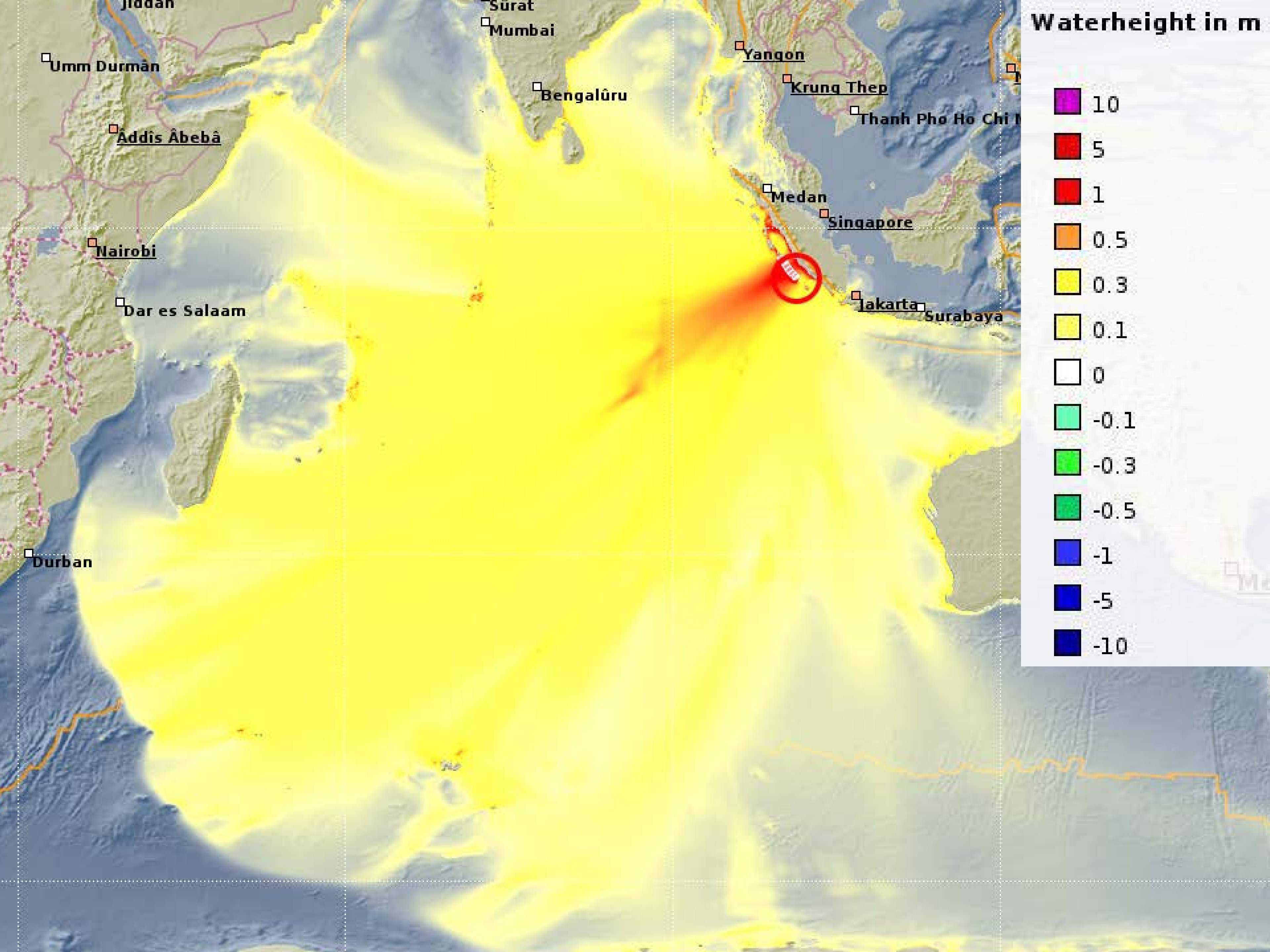
Far-field tsunami

Long tsunami travel distance compared to earthquake rupture length. In this case the rupture orientation (given by the fault orientation) is essential but details like the exact position of the rupture or slip distribution are not critical for tsunami forecast at a given coastal point.

Near-field tsunami

Tsunami travel distance in a similar order (of magnitude) of the earthquake rupture length. Exact position and parameters of the rupture plane as well as the slip distribution are essential for tsunami forecast at a given coastal point.


Jiddah
Surat
Mumbai
Umm Durmân
Yangon
Krung Thep
Bengalûru
Thanh Pho Ho Chi
Addis Âbebâ
Medan
Singapore
Nairobi
Dar es Salaam
Jakarta
Surabaya
Durban
Waterheight in m
10
5
1
0.5
0.3
0.1
0
-0.1
-0.3
-0.5
-1
-5
-10



Waterheight in m
10
5
1
0.5
0.3
0.1
0
-0.1
-0.3
-0.5
-1
-5
-10
Jiddah
Surat
Mumbai
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Yangon
Krung Thep
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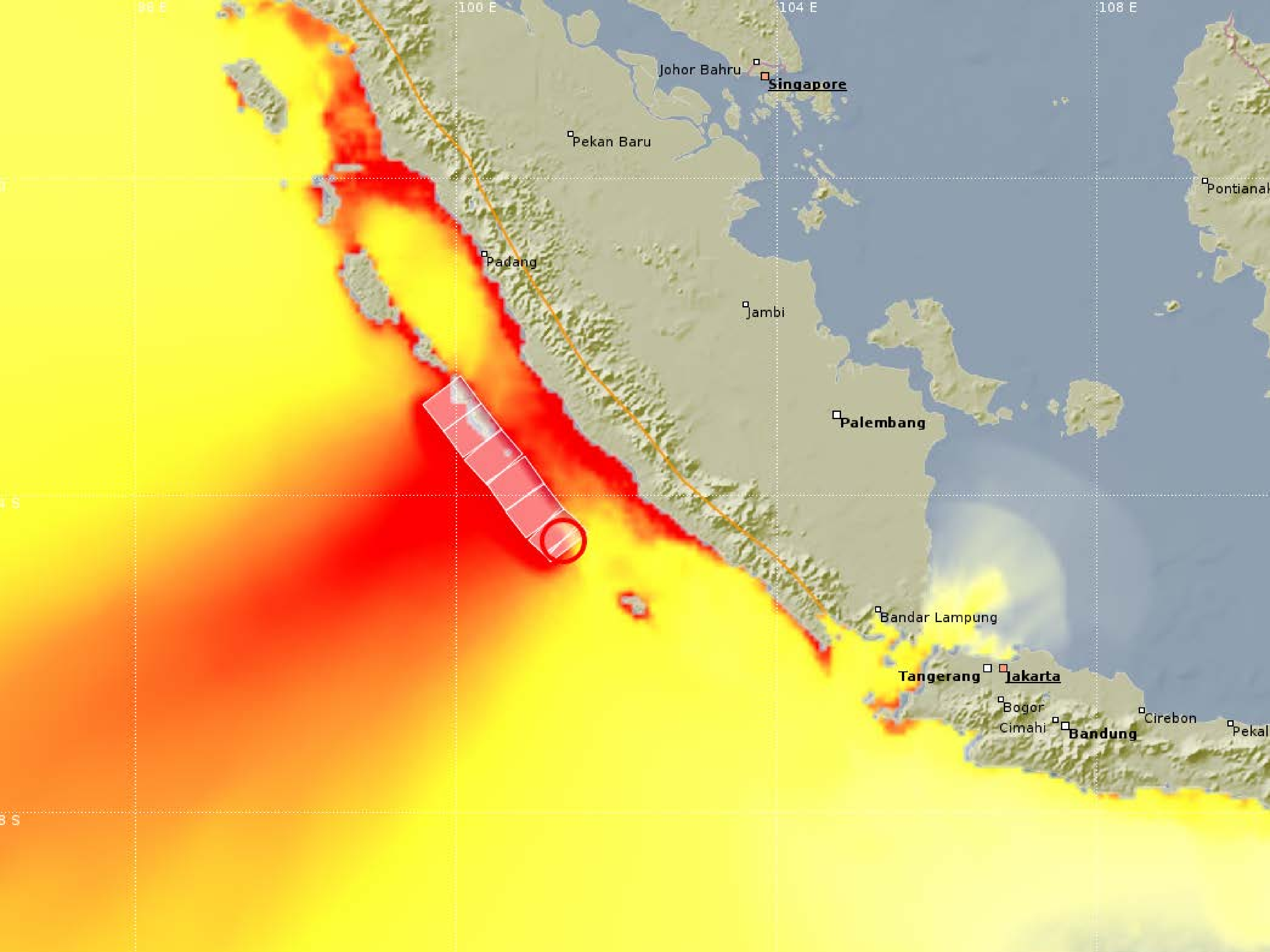
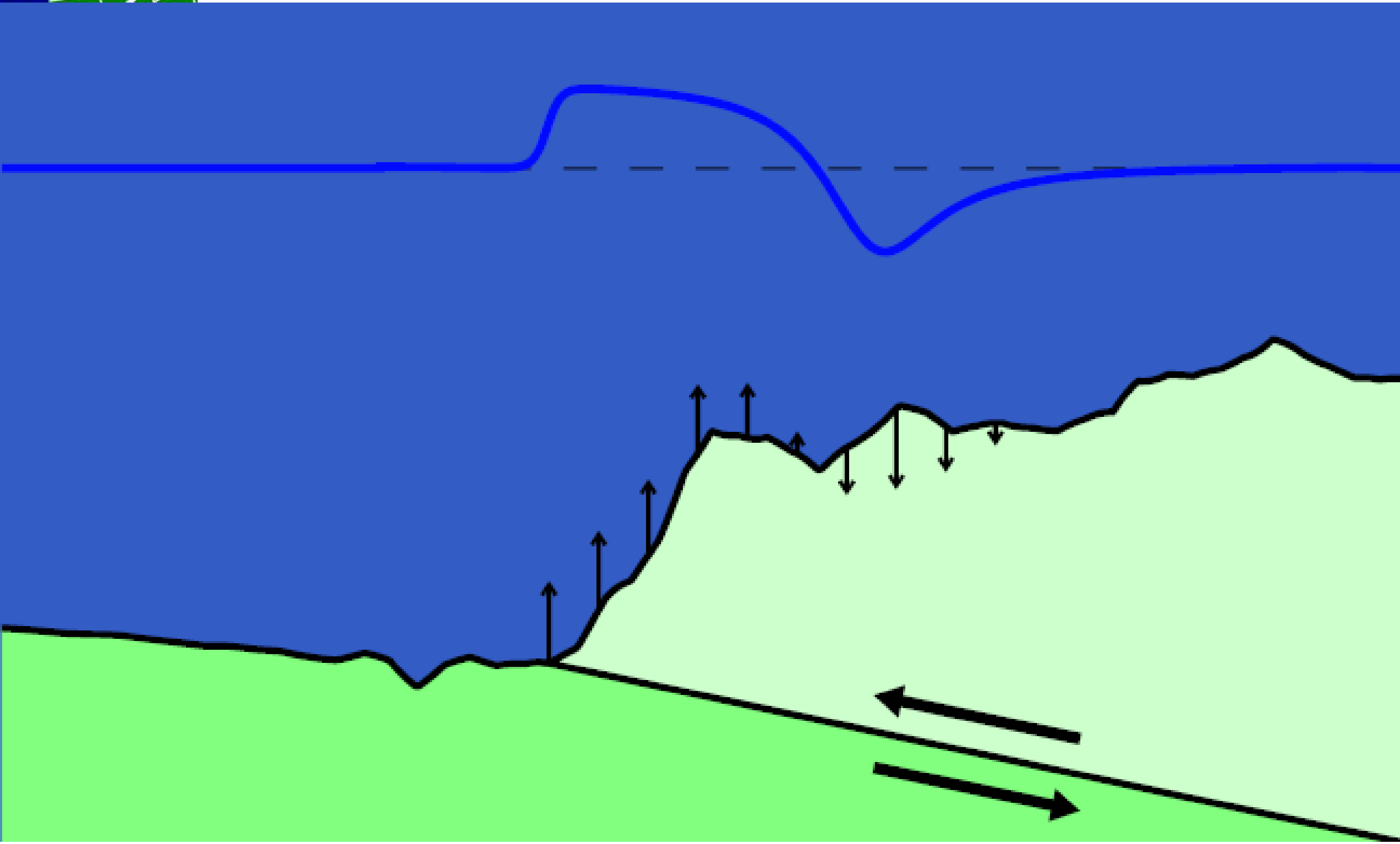
Thanh Pho Ho Chi
Addis Âbebâ
Medan
Singapore
Nairobi
Dar es Salaam
Jakarta
Surabaya
Durban



98 E
100 E
104 E
108 E
4 S
8 S
Johor Bahru
Singapore
Pekan Baru
Pontianak
Padang
Jambi
Palembang
Bandar Lampung
Tangerang
Jakarta
Bogor
Cimahi
Bandung
Cirebon
Pekal

Vertical Dislocations



“GPS Shield” for Sumatra

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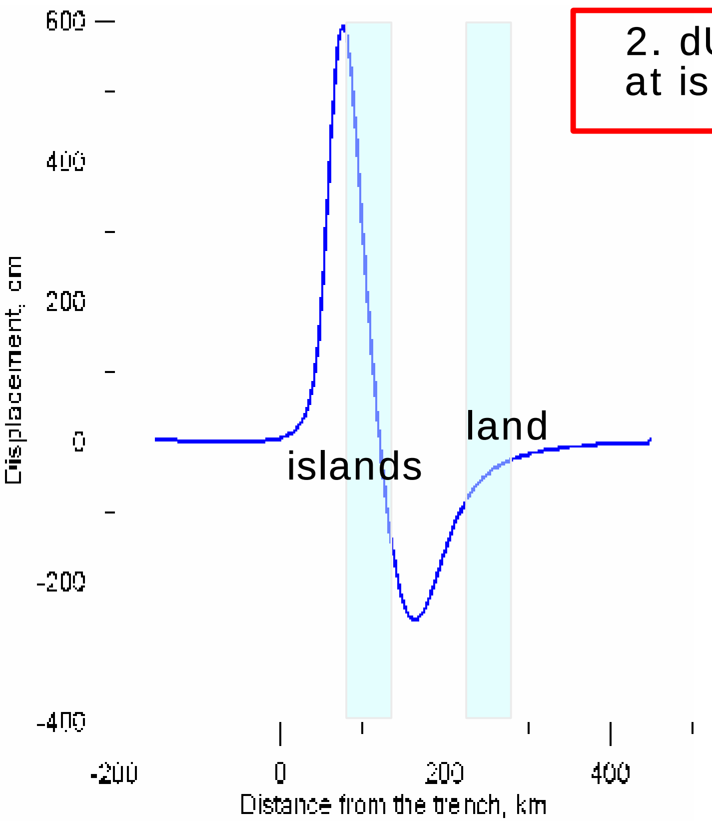
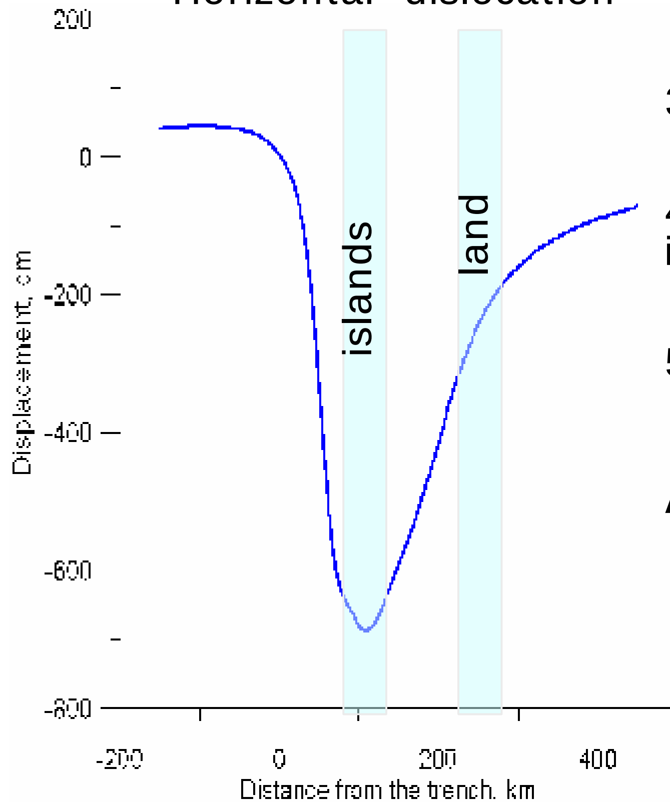
1. Uz at islands

2. dUz/dx at islands



Vertical dislocation

Horizontal dislocation



3. Ux at islands

4. dUx/dx at islands

5. Uy at islands

Additionally

Ux,Uy and Uz at land

“GPS Shield” for Sumatra

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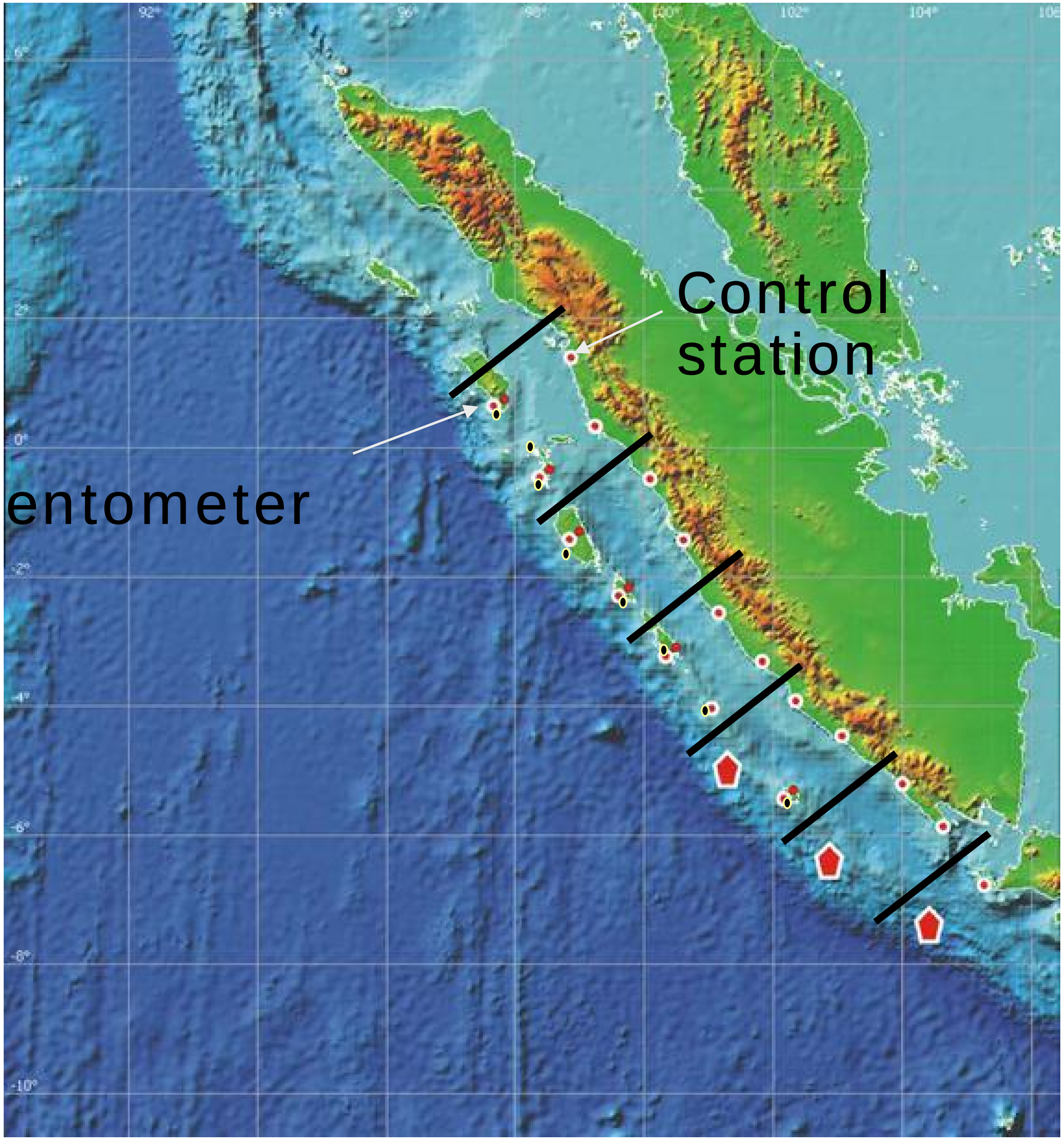


10 s: P-wave at the closest island station–trigerring high GPS sampling rate (1Hz=>10Hz)

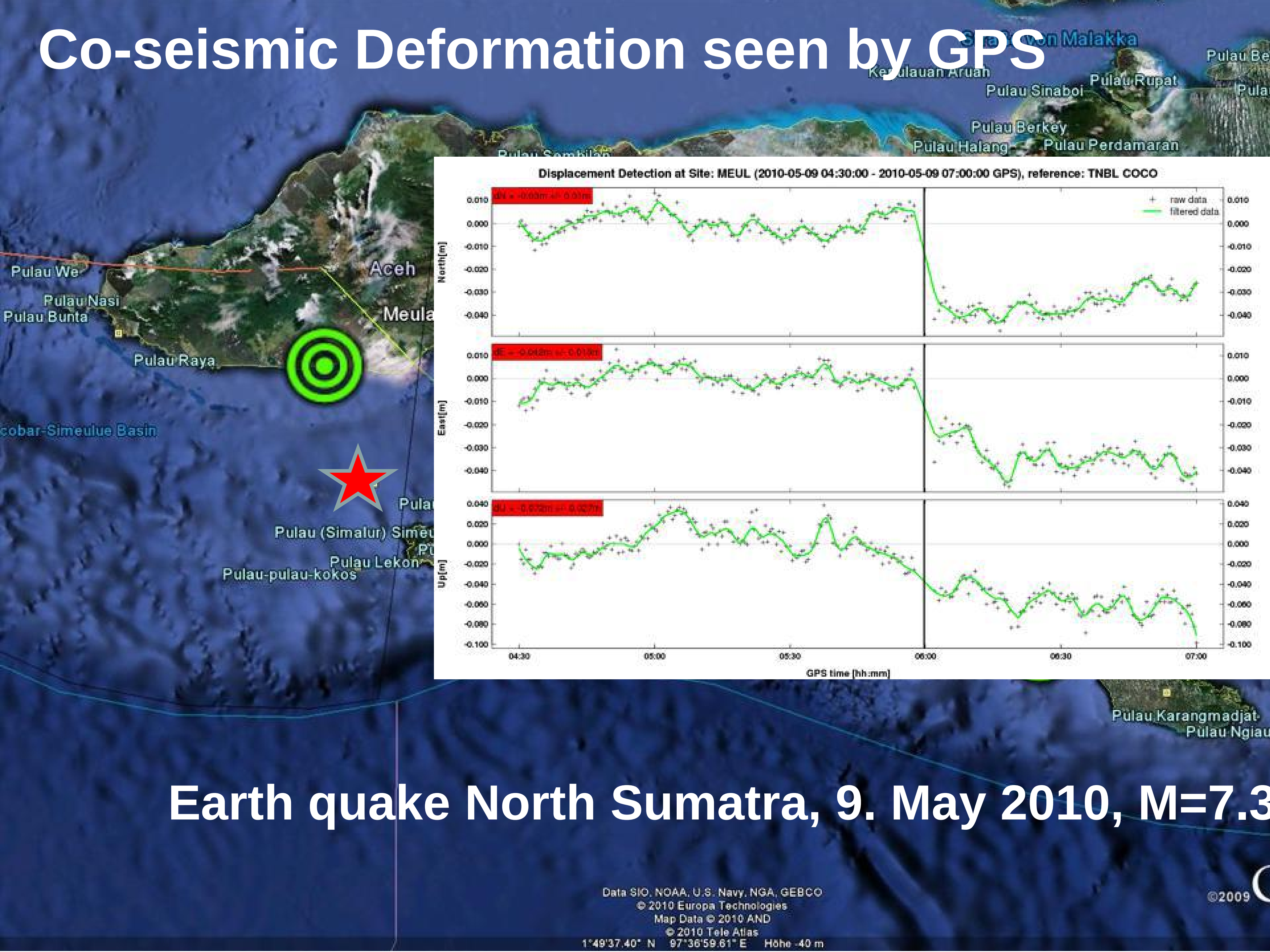
1 min: initial tsunami wave formed; strong GPS signal at island station

2 min: GPS signal at island station established—first estimation of fault parameters

3 min: GPS signal at control (land) station established—first verification of fault parameters

4-5 min: Tsunami at island tide-gage—second verification of fault parameters

Co-seismic Deformation seen by GPS



Earth quake North Sumatra, 9. May 2010, M=7.3

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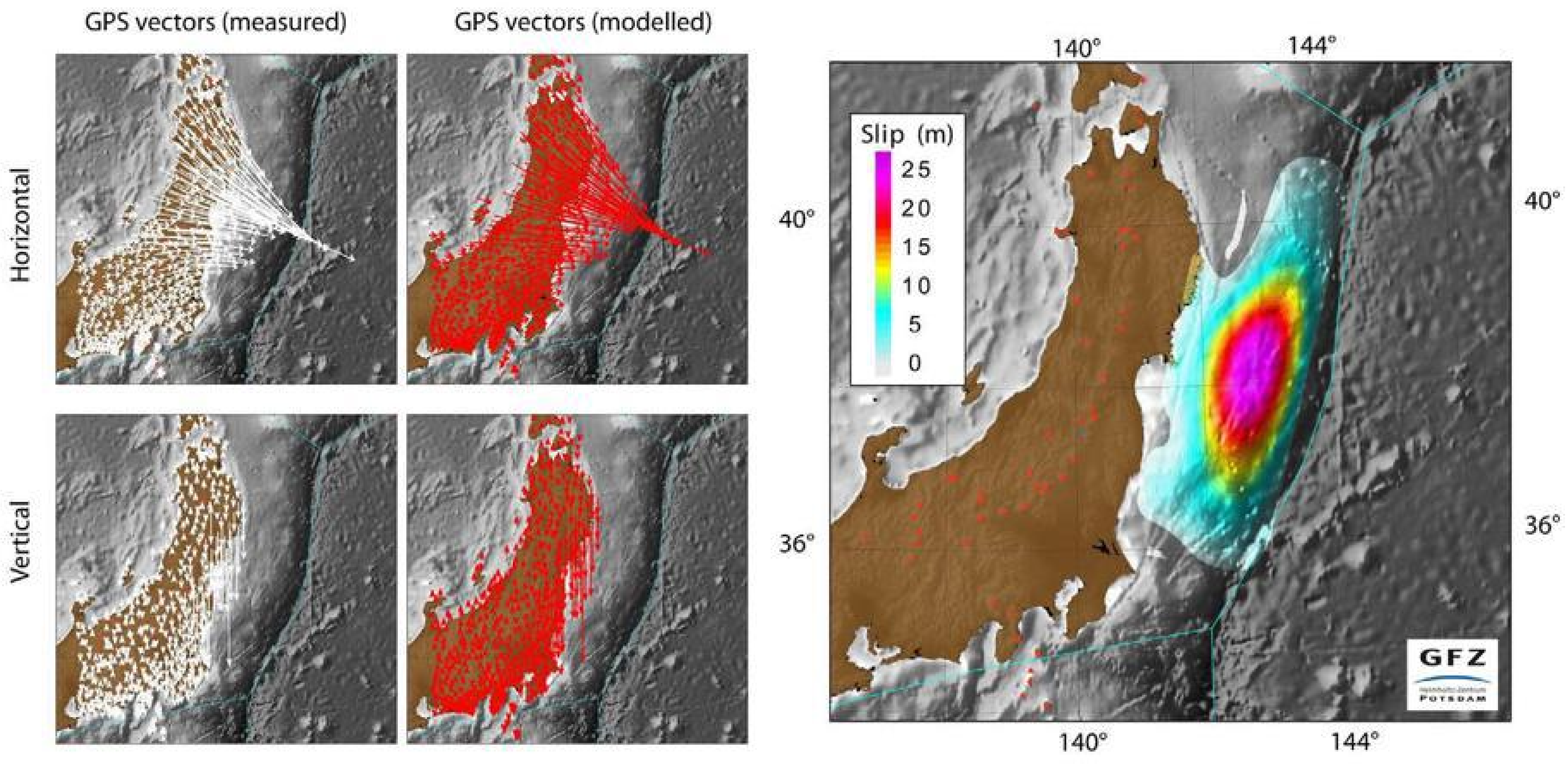
Honshu Earthquake (11. 3. 2011)



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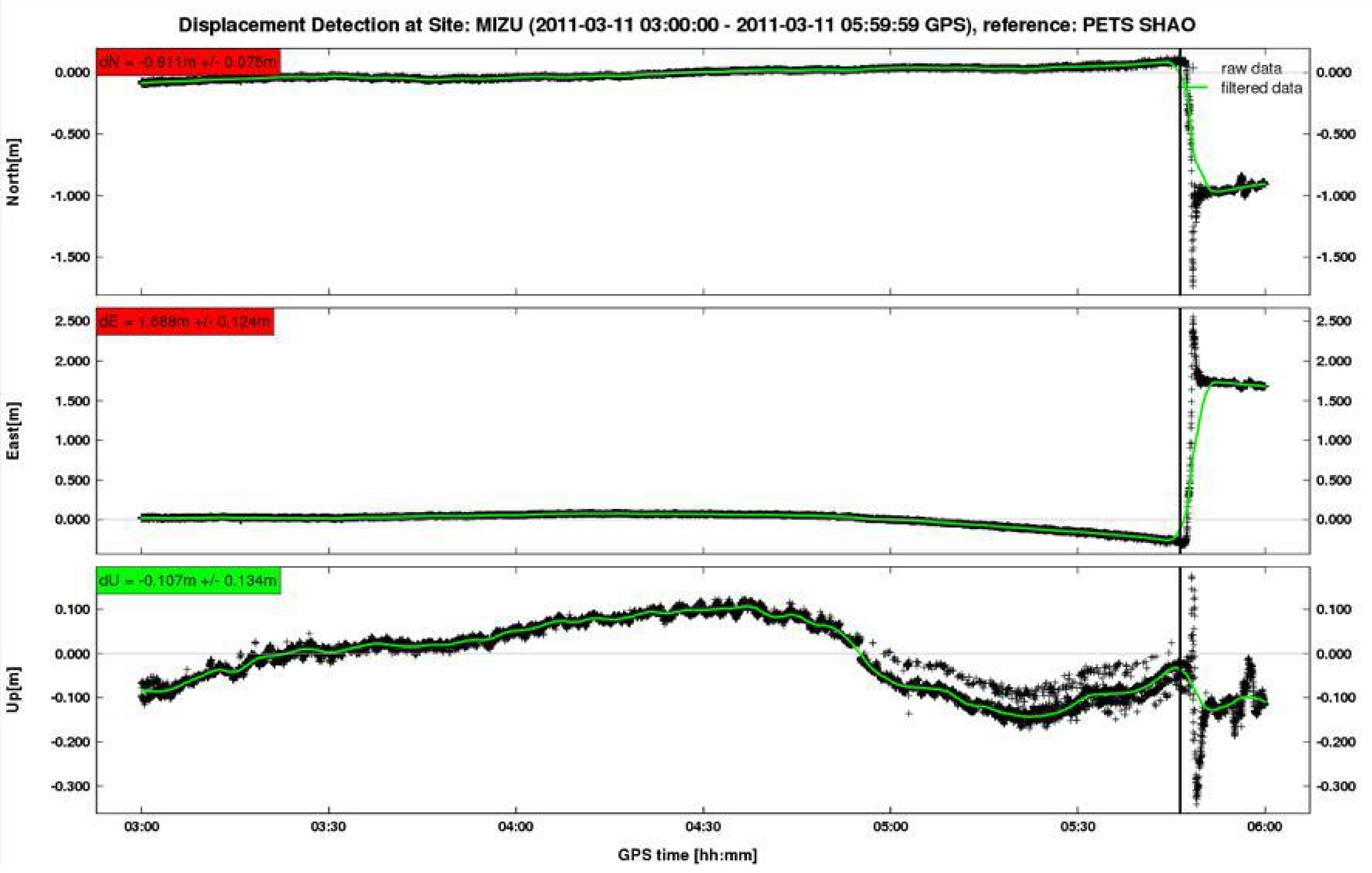
Coseismic Displacement GPS Station MIZU after the Honshu Earthquake (11. 3. 2011)



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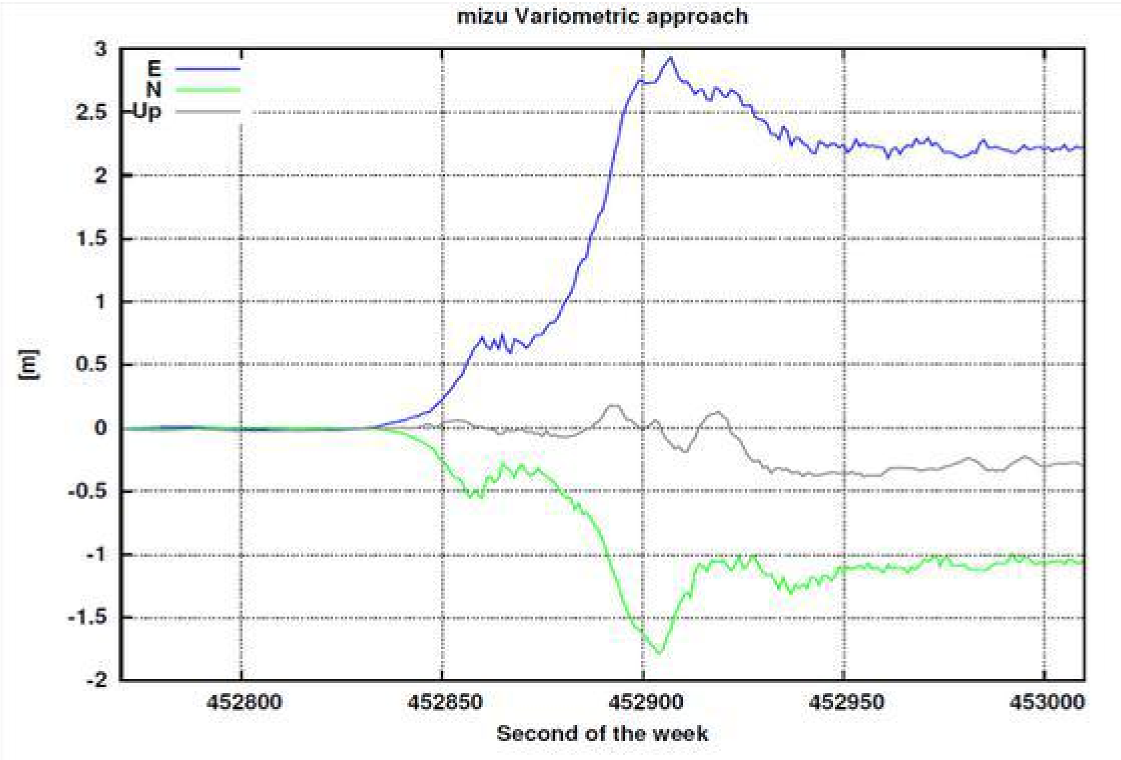
VADASE (Variometric Approach for Displacements Analysis Stand-alone Engine)

Algorithm embedded into receiver firmware permitting to estimate the receiver displacements, in realtime and without any need for corrections from other sources



http://www.vadase.eu/

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GPS-based tsunami early warning: Replaying the Tohoku 2011 event

'Replaying' means: simulate the situation as it might have taken place in a Warning Center connected to the GEONET GPS-array.

Procedure:

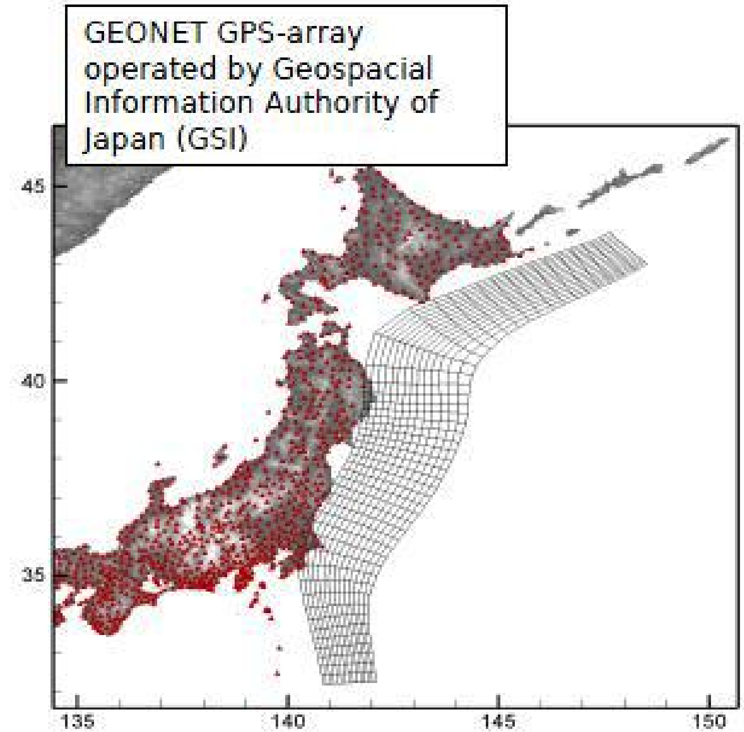
On input: a stream of raw GPS-observations for about 500 GEONET stations

1.GPS-processing: convert GPS-obseravtions into displacements.
$\Delta t < 15$ sec.

2.Restore tsunami source: invert displacements into co-seismic slip; determine magnitude
$1 < \Delta t < 60$ sec.

3.Estimate tsunami impact: compute wave propagation and coastal impact using the inverted source.
$\Delta t < 15$ sec.

Constanty keep repeating pp. 1-to-3 ...



Höchner & Babeyko, EGU 2012

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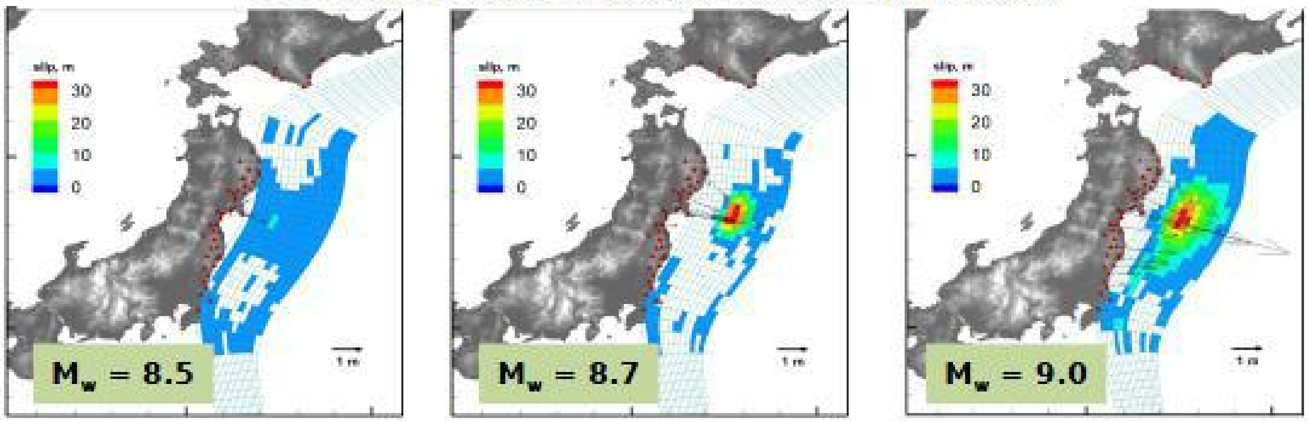
GPS-based tsunami warning within 3-5 minutes

60 sec (+Δt_p) **90 sec (+Δt_p)** **180 sec (+Δt_p)**

GPS displacements and source inversion

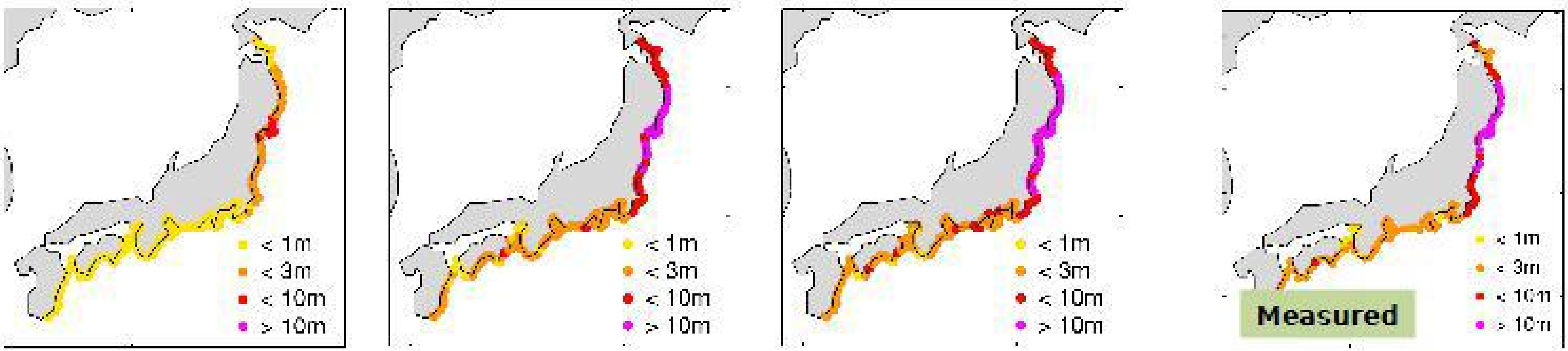


GPS-data: by courtesy of Geospacial Information Authority of Japan (GSI)

Processing time Δt_p currently 30 to 90 sec

Resulting instant tsunami forecast

Compare to field observations



Höchner & Babeyko, EGU 2012

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Continuous Tsunami Observation in Real-Time

Tsunami of 26. 12. 2004

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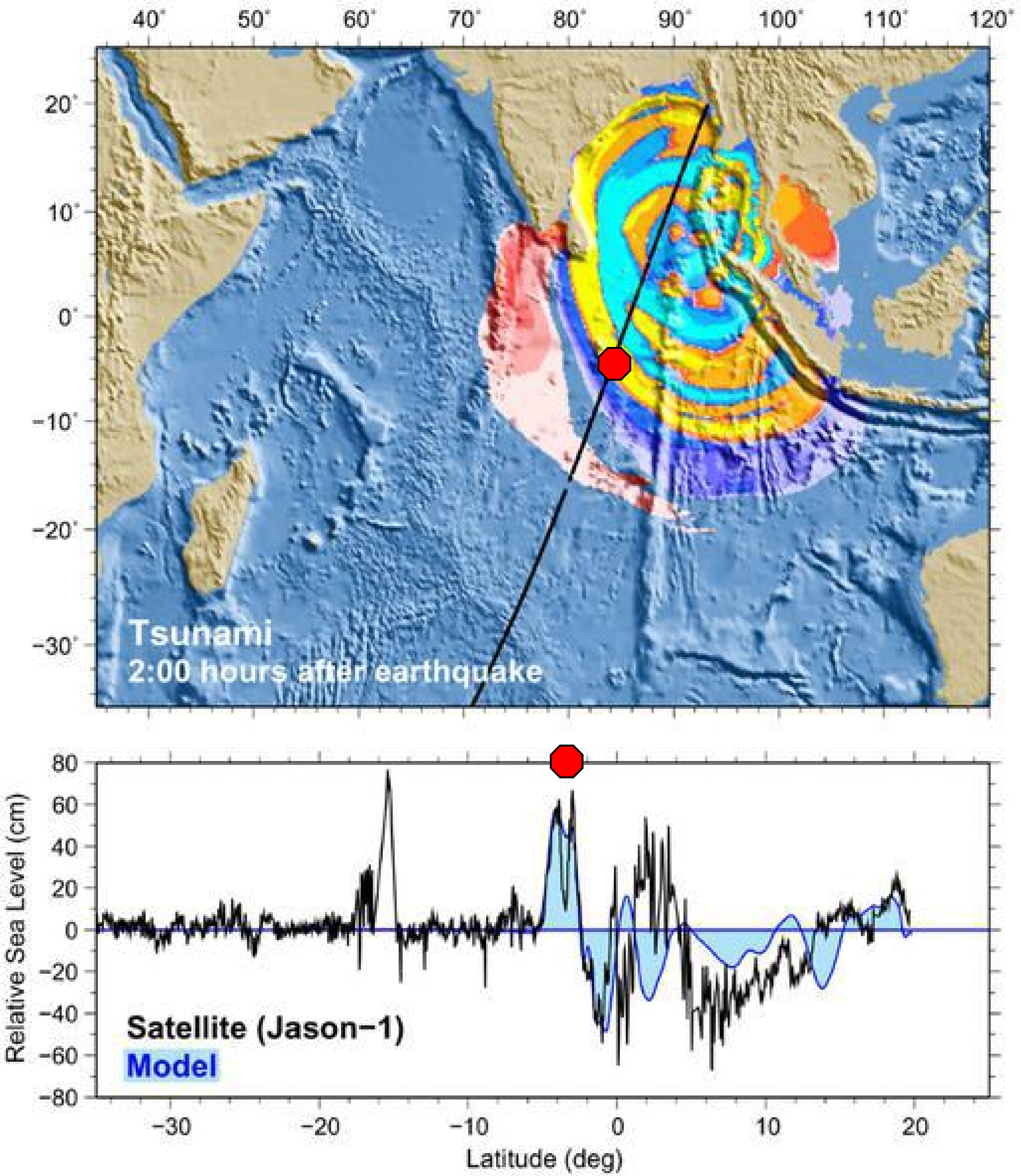
Tsunami of 26. 12. 2004, 2 hours after the quake, observed by Satellite Altimetrie



Real-Time Sea Level Monitoring

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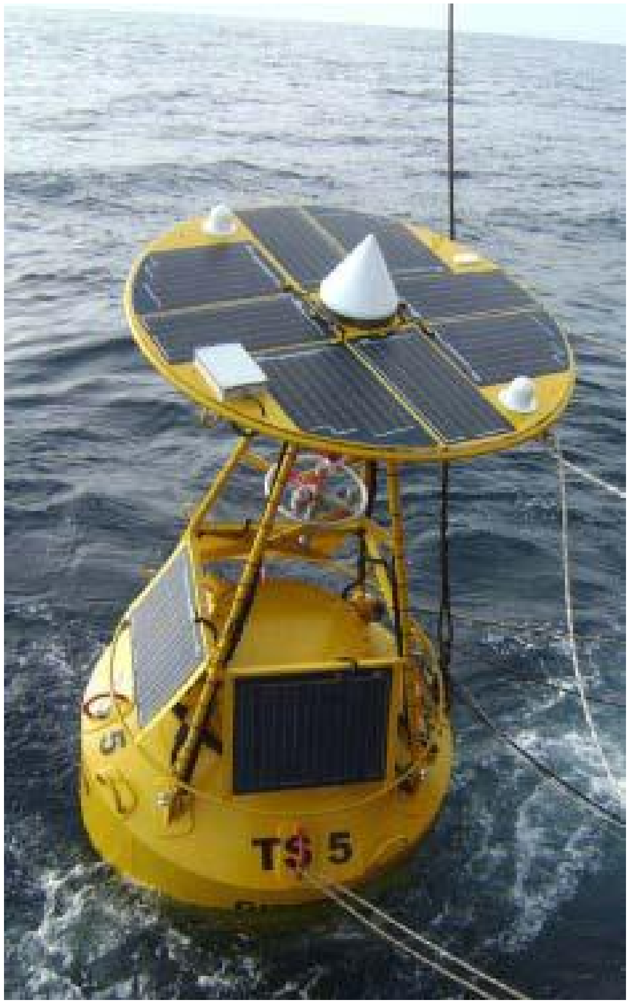
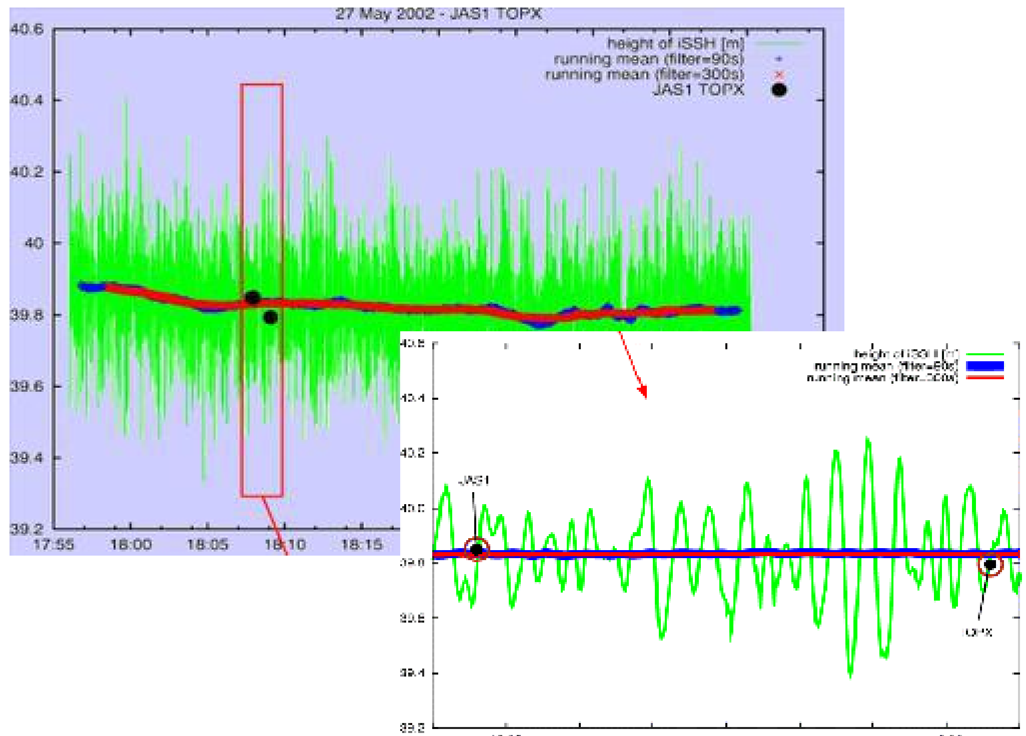
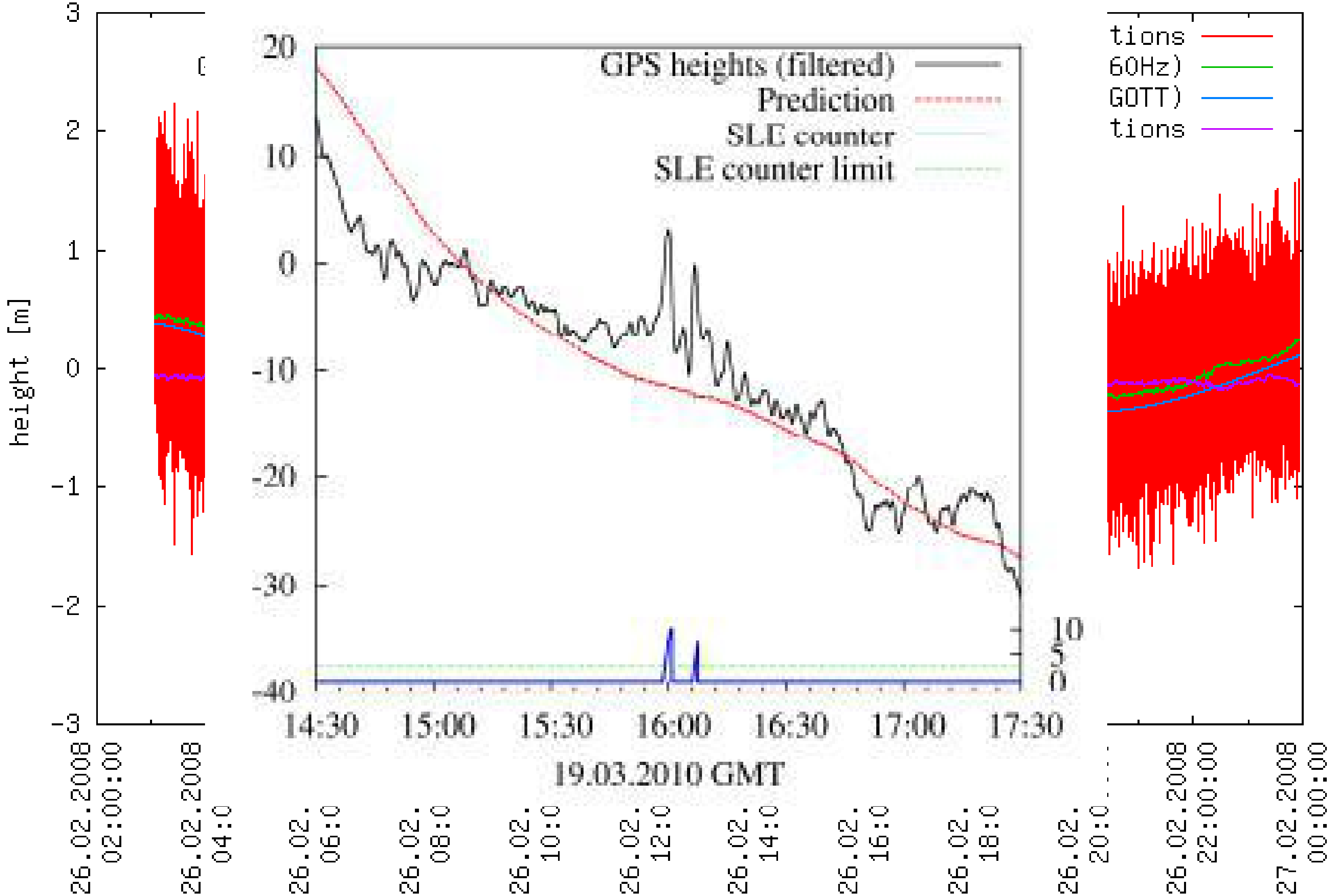


Time series (1 hour) of local sea level changes by GPS



GPS Buoy


GPS heights (filtered)
Prediction
SLE counter
SLE counter limit
20
10
0
-10
-20
-30
-40
10
5
0
14:30
15:00
15:30
16:00
16:30
17:00
17:30
19.03.2010 GMT
height [m]
3
2
1
0
-1
-2
-3
tions
60Hz)
GOTT)
tions

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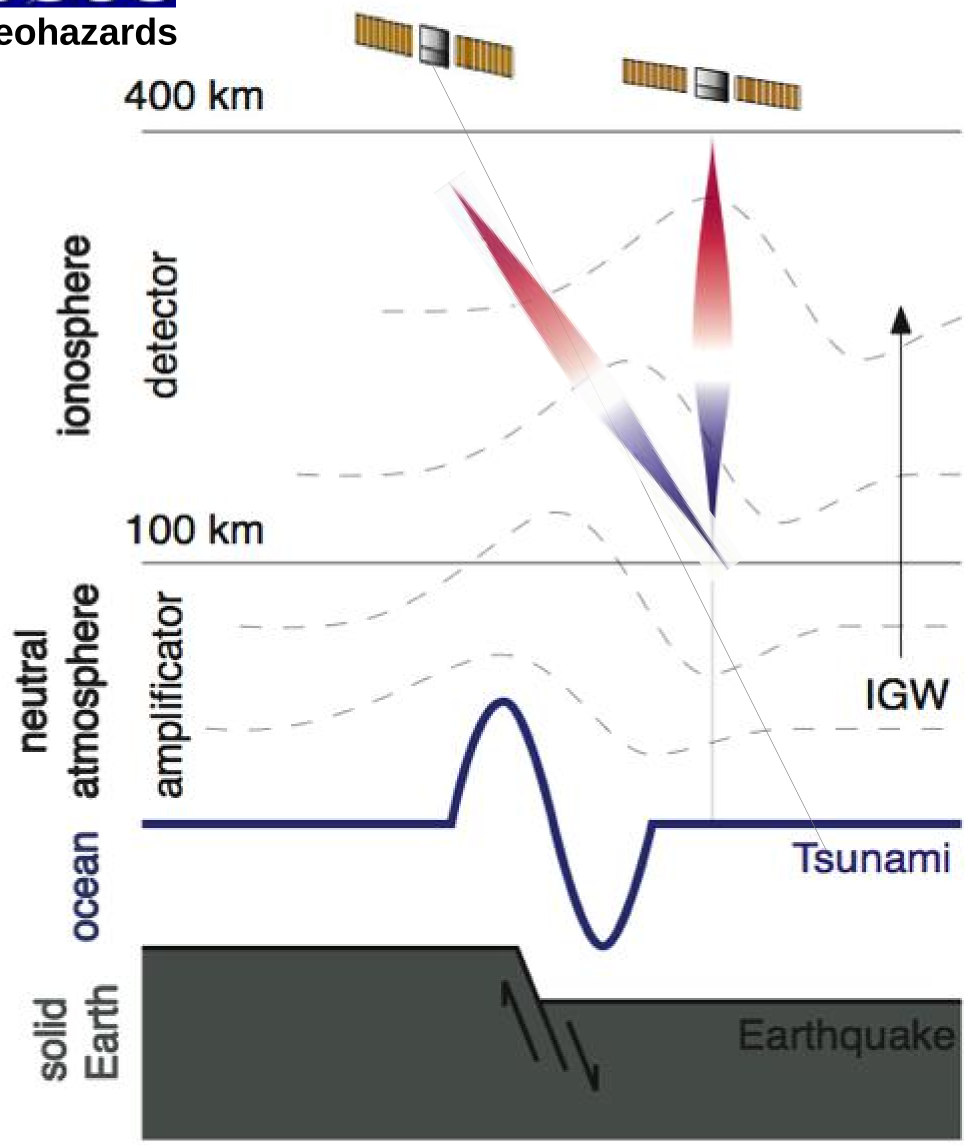
Principles of monitoring ionospheric disturbances by GNSS



4

$$TEC = \int_{surf}^{sat} N_e \, ds$$

3

N_e

2

$V_X \, V_Y \, V_Z$

1

V_Z

[Occhipinti et al., GRL, 2006]

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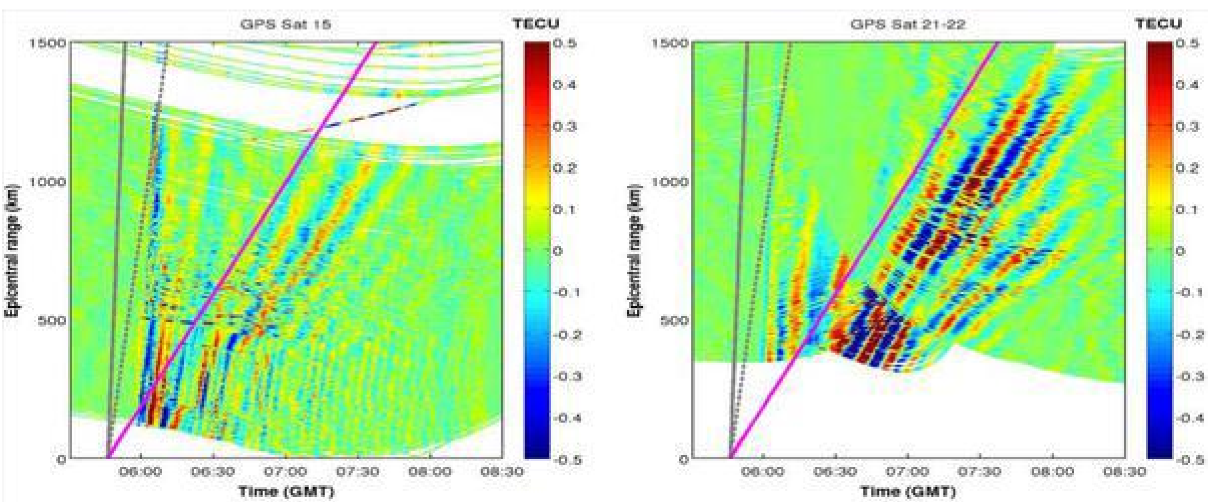
GEONET

Tohoku 2011, M 9.0

[Rolland et al., EPS, 2011]



[Occhipinti et al., JGR, 2013]

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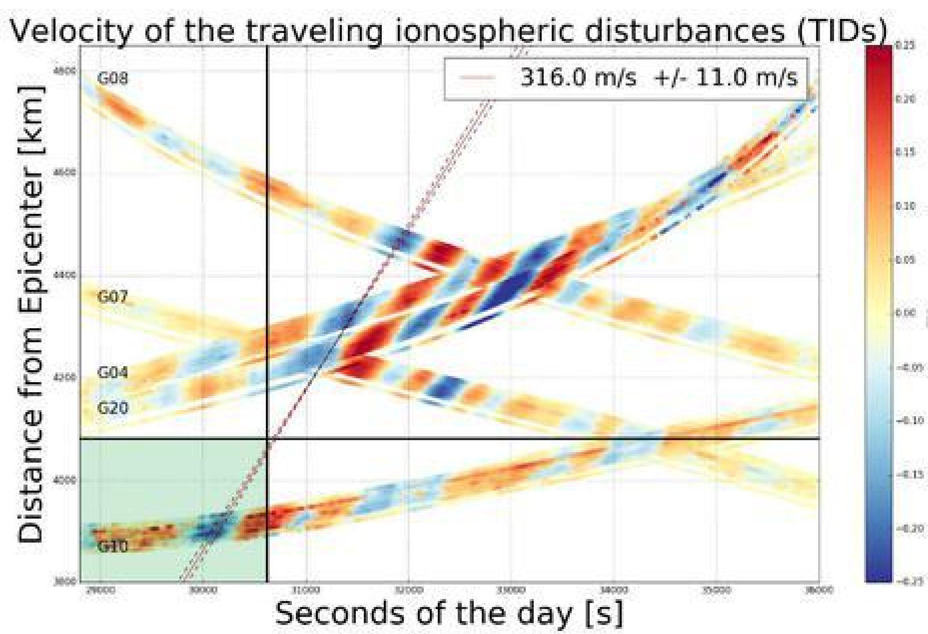
Real-Time Detection of Tsunami Ionospheric Disturbances with a Stand-Alone GNSS Receiver: the VARION Approach

- Focus on real-time accurate sTEC variation
- direct sTEC variation estimation from the observations of a stand-alone GNSS receiver (single station approach)
- advantages: no infrastructure, no post-processing, no initialization needed

- designed in 2015 at University of Rome “La Sapienza”
- developed and validated in 2016 by Giorgio Savastano in close collaboration with Attila Komjathy, Jet Propulsion Laboratory.

sTEC variations for two hours (08:00 to 10:00 UT – 28 October 2012) for the 7 satellites observed from the 56 Hawaii GPS permanent stations for the Tsunami generated by the Haida Gwaii earthquake.

- Tsunami induced Disturbances (TID) clearly visible in significant sTEC variations.
- The vertical and horizontal black lines represent the Tsunami arrival time at the Hawaiian Islands and the distance to the epicenter.
- The straight line fitted to sTEC minima for different satellites, represents the TIDs mean propagation velocity.



Caption and figure from: Savastano, G. *et al.* Real-Time Detection of Tsunami Ionospheric Disturbances with a Stand-Alone GNSS Receiver: A Preliminary Feasibility Demonstration. *Sci. Rep.* **7**, 46607; doi: 10.1038/ srep46607 (2017)

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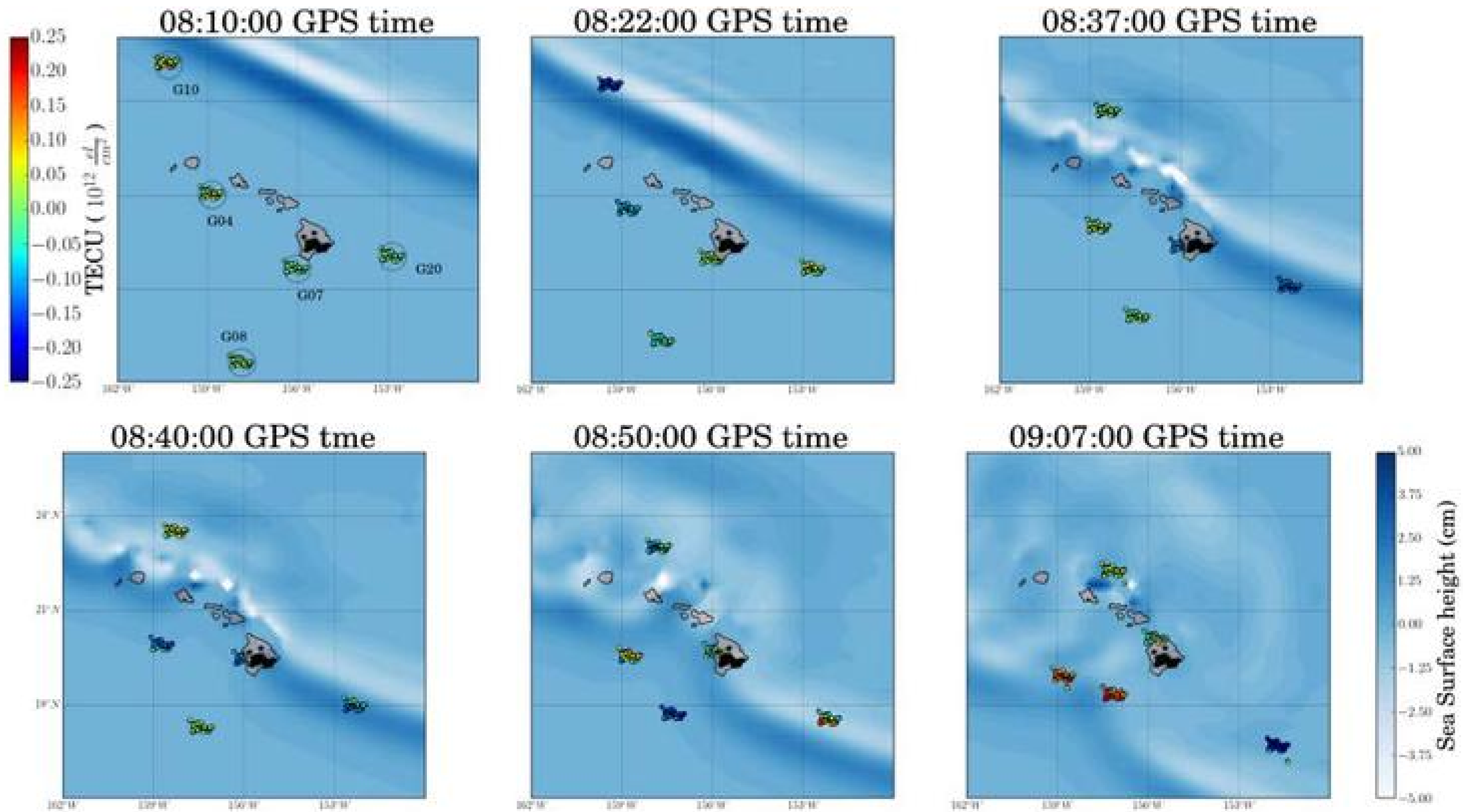
Space-time sTEC variations at 6 epochs within 08:00 to 10:00 UT – 28 October 2012 for the 5 satellites showing TIDs, plotted with the tsunami MOST model

TIDs are consistent in time and space with the tsunami waves



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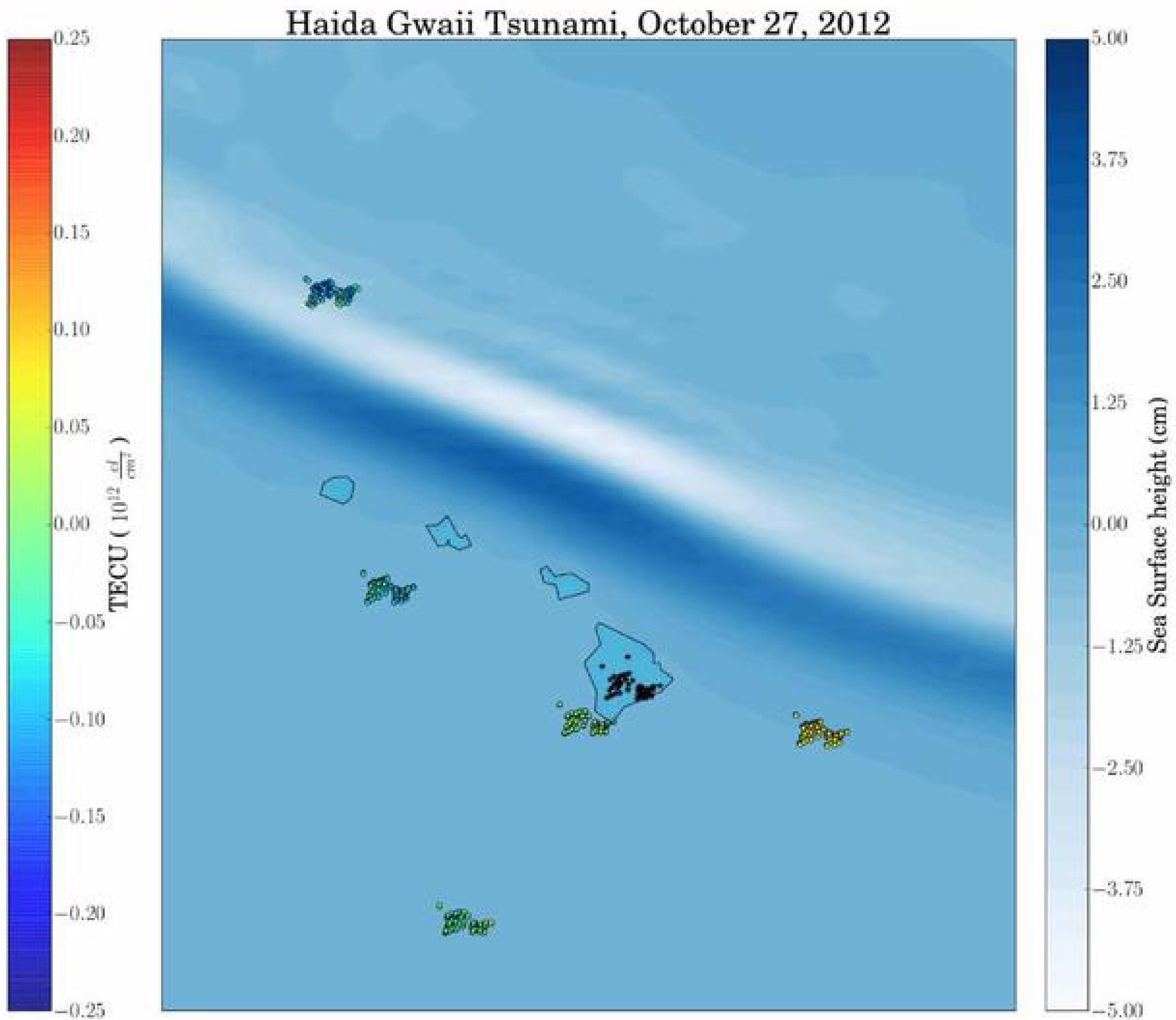
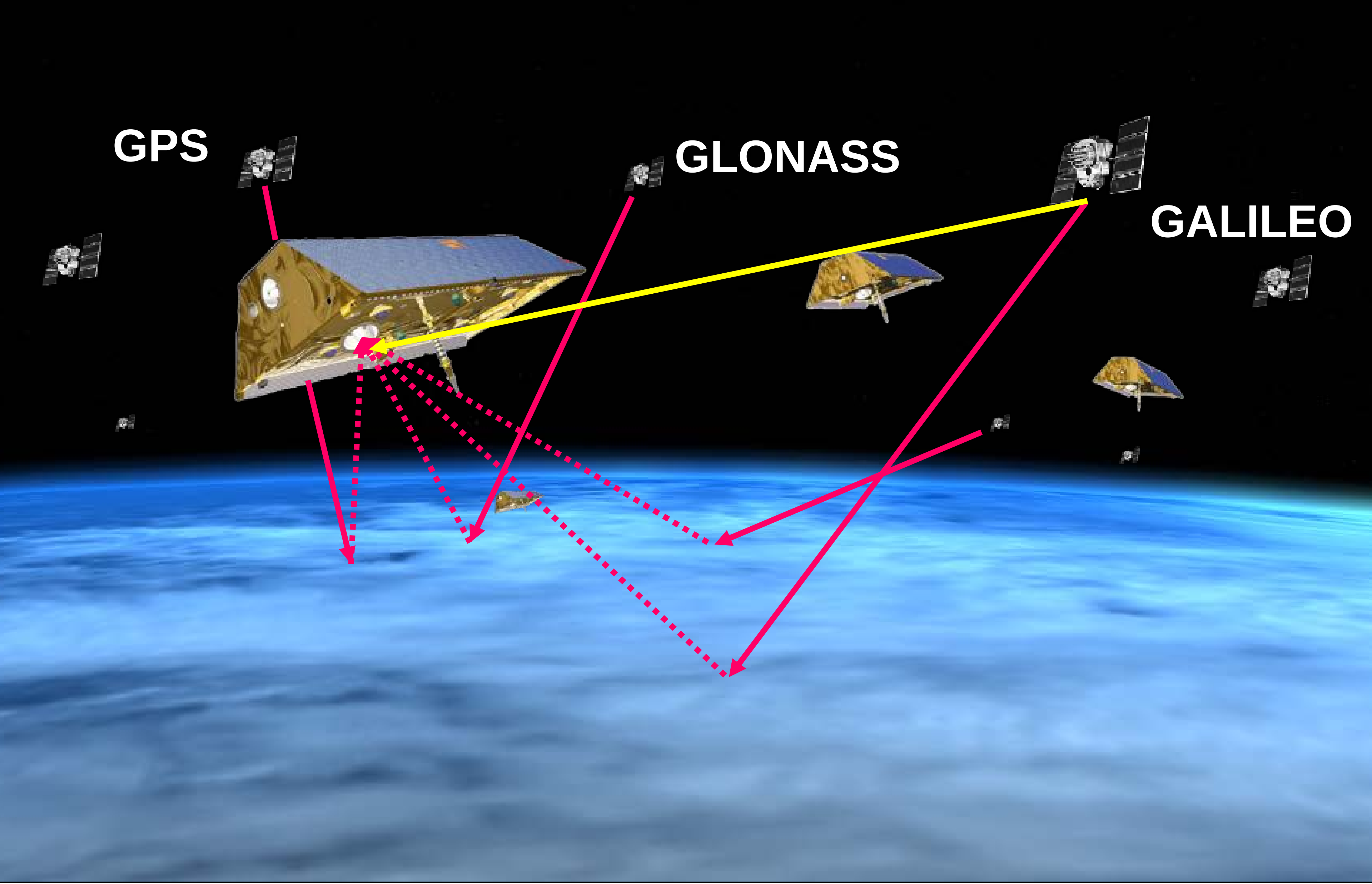


Satellite Constellation as Component o
future Multi-Hazard Early Waring Syste



GNSS-Altimetry

IAG GGOS
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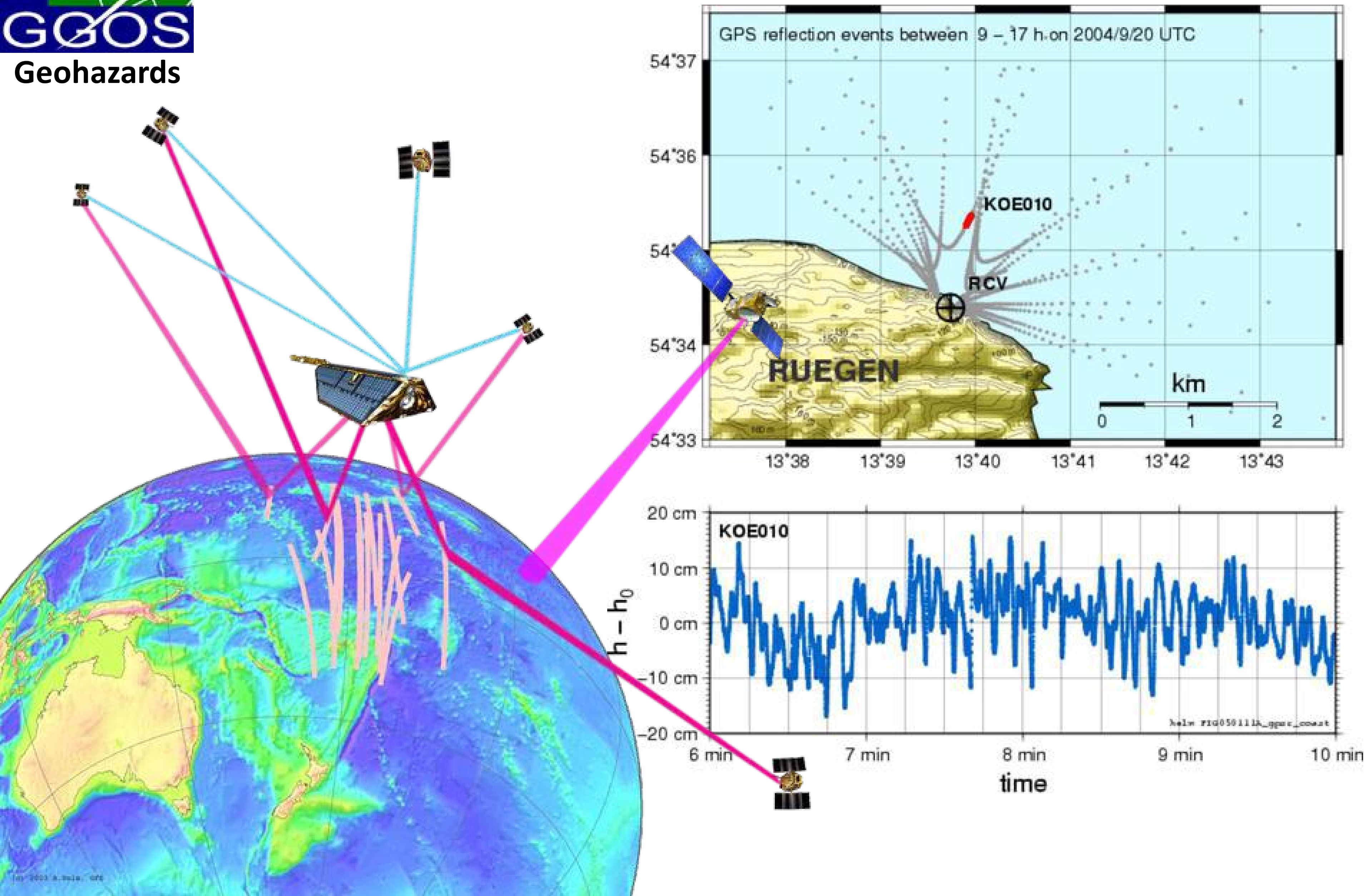

GTEWS 2017 Workshop on GNSS Tsunami Early Warning Systems

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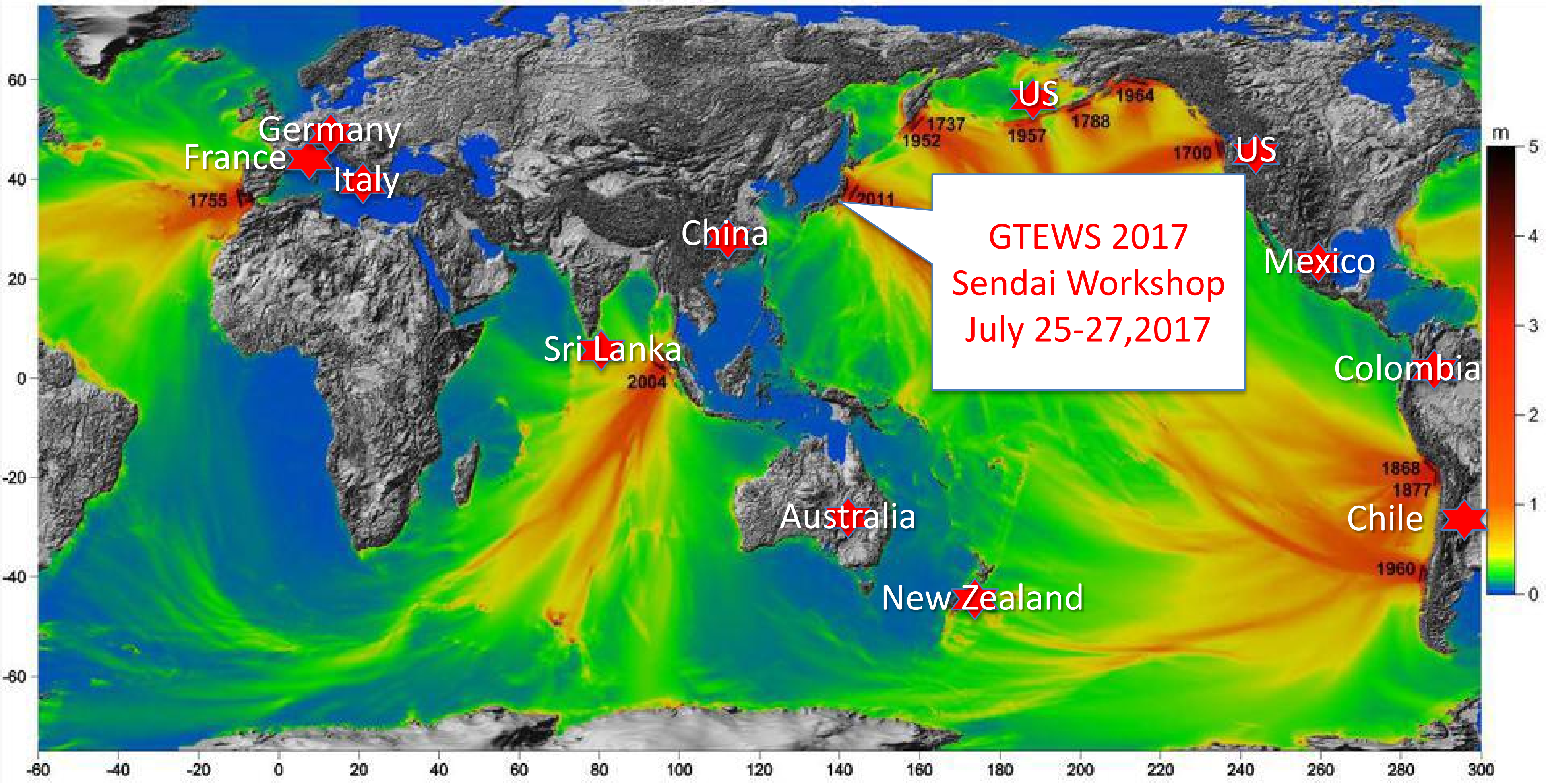

11 Nations

16 member Agencies and Institutions