Real-time Earthquake and Tsunami Early Warning System

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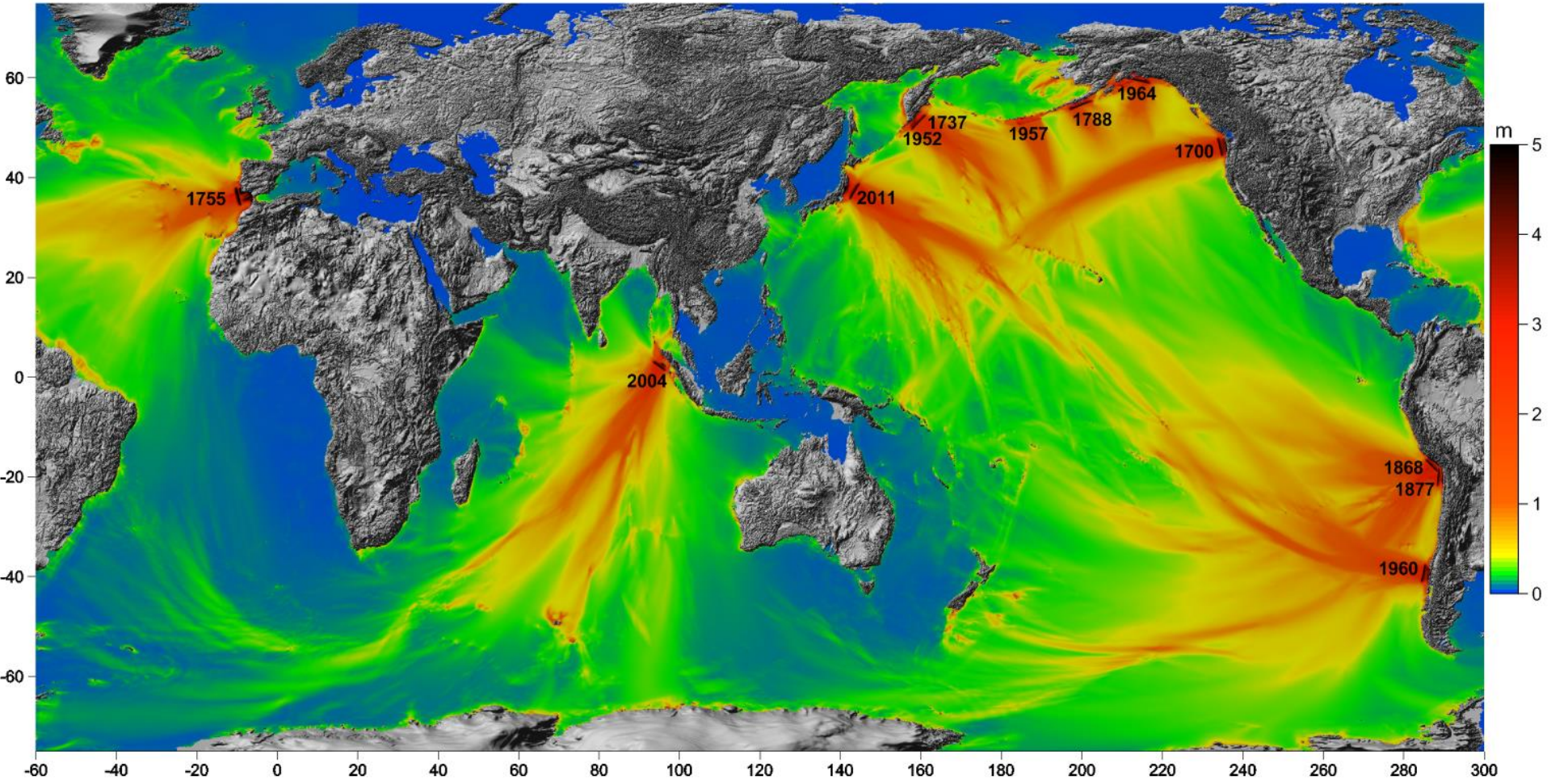
Plus many many more.

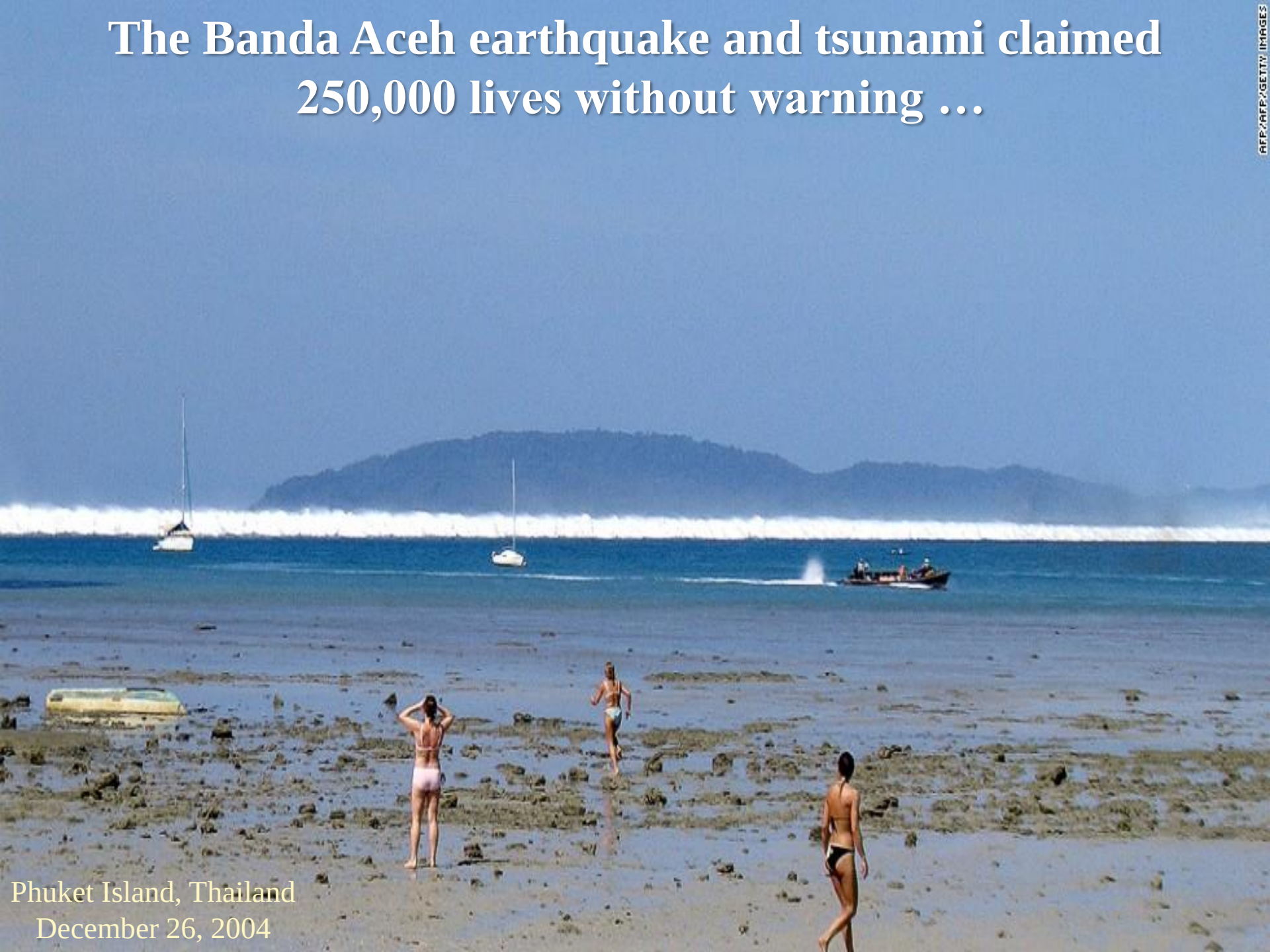
The Significant Earthquakes Triggered Tsunamis

(https://www.ngdc.noaa.gov/nndc/struts/form?t=101650&s=1&d=1)



Energy flux for trans-oceanic mega-tsunamis historically known. Insert figure – distribution of fatalities over the tsunami propagation time (up to 85% fatalities occur during the first hour). Calculations are made in ICT SB RAS by means of MGC numerical package for tsunami modeling (Chubarov, Babailov, Beisel, 2011). Ref: Gusiakov et al, 2015

The Banda Aceh earthquake and tsunami claimed 250,000 lives without warning …



Phuket Island, Thailand
December 26, 2004

What questions are asked when there is an earthquake in tsunami prone regions?

Where was the earthquake? **Lat/Lon/Depth**

How large was it? **Accurate Magnitude**

Could the earthquake generate a tsunami?
Nature of earthquake – thrust, normal, strike-slip, oblique

Was there a tsunami? **DART buoys, other**

How much time do communities have before the tsunami makes landfall? **Tsunami energy modeling**

How far will the tsunami come onshore?

How deep will the water be?
Subsidence measurements and inundation modeling

Real-time GNSS can help address many of these questions for most earthquakes

Where was the earthquake? **Lat/Lon/Depth** ✓

How large was it? **Accurate Magnitude** ✓

Could the earthquake generate a tsunami?
Nature of earthquake – thrust, normal, strike-slip, oblique ✓

Was there a tsunami? **DART buoys, other** ✓

How much time do communities have before the tsunami makes landfall? **Tsunami energy modeling**

How far will the tsunami come onshore? ✓

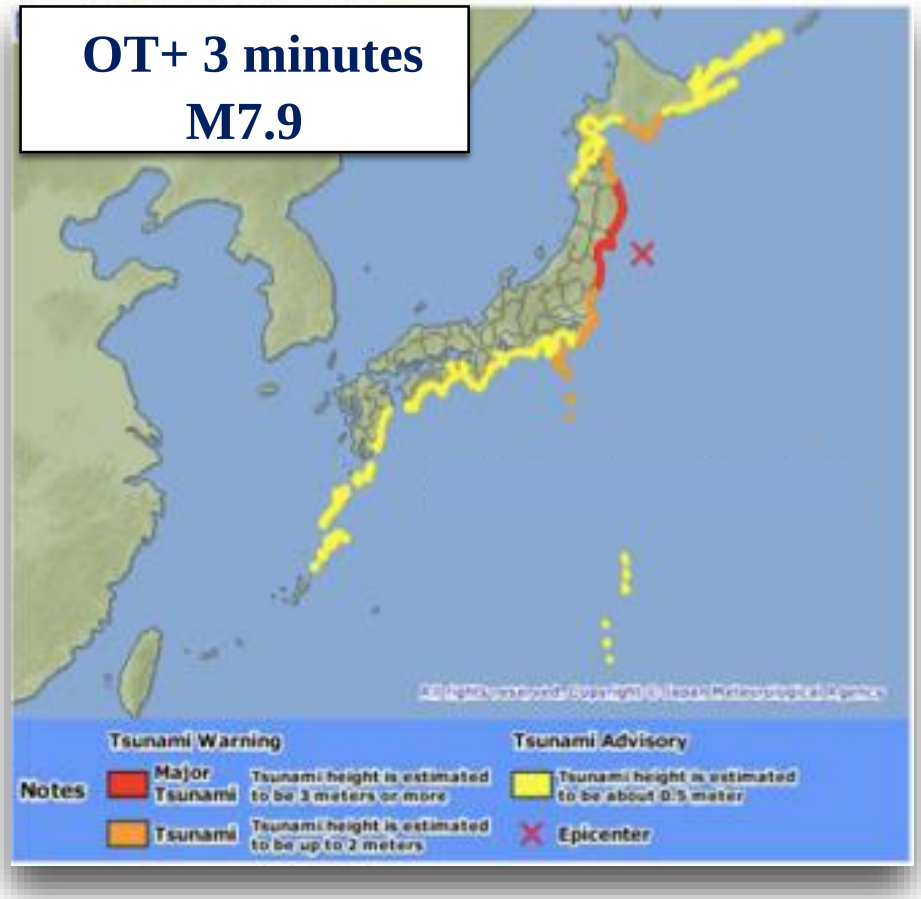
How deep will the water be? ✓
Subsidence measurements and inundation modeling

Measurement of the land surface deformation
Measurement perturbations in the ionosphere
Improves latency and accuracy of models
Next generation models include coastal subsidence

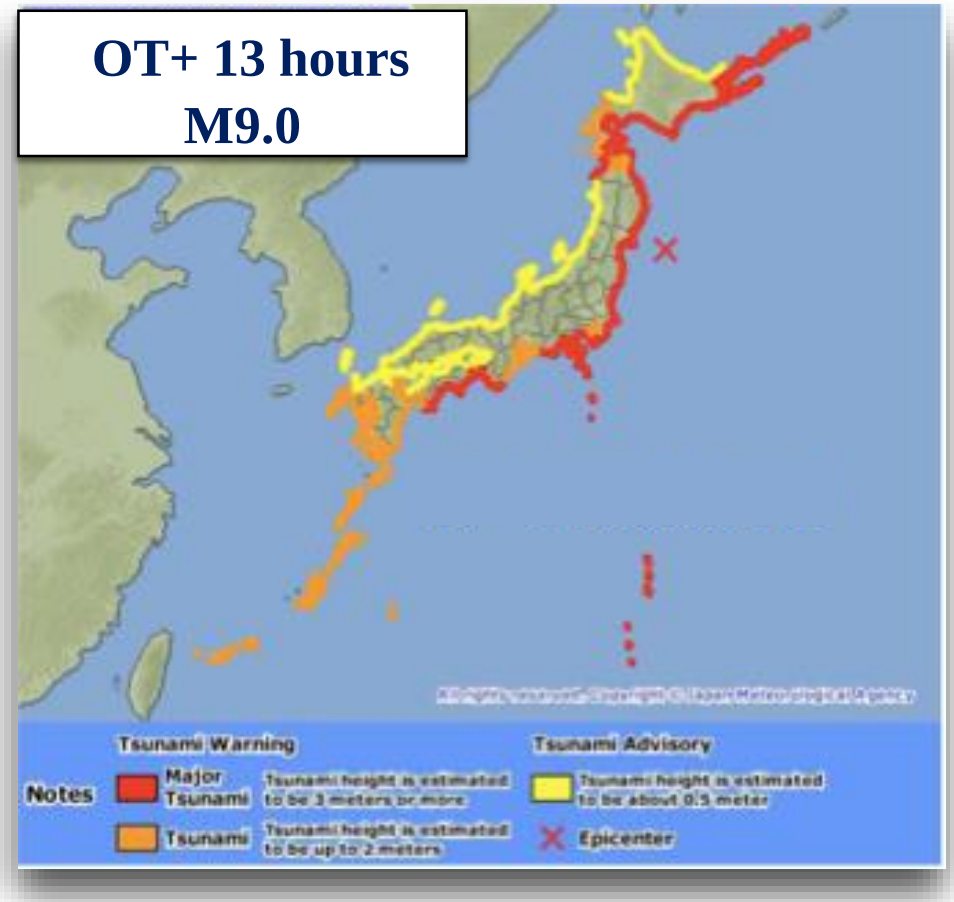
Real-Time GNSS

Seismic Data Alone Underestimated Earthquake Size

Fast and Accurate Magnitude Determination Is Essential



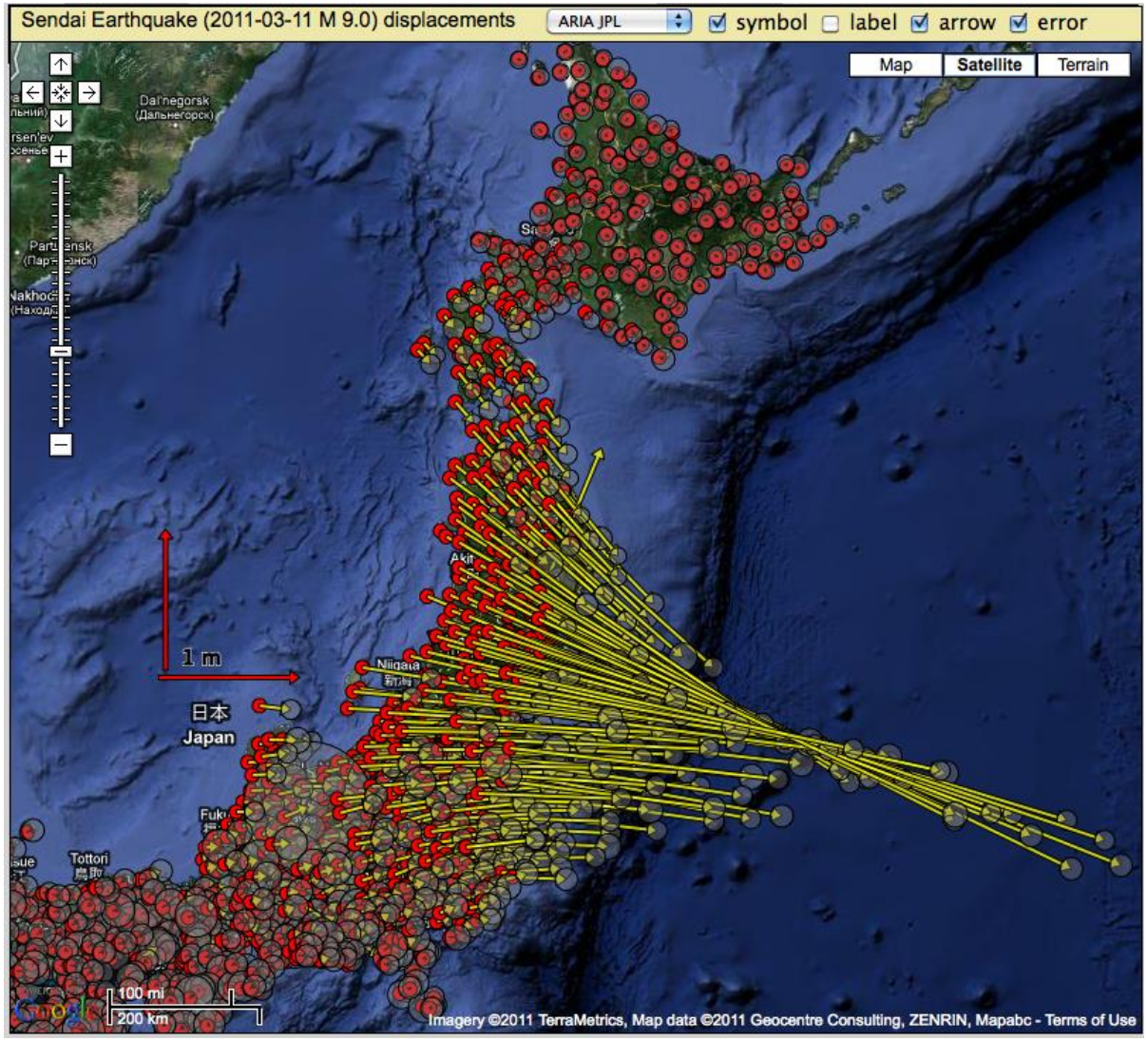
Japan seismic data =>
magnitude => tsunami impact based on precomputed database
Japanese Meteorological Agency



Japan seismic data & teleseismic data =>
magnitude => tsunami impact based on precomputed database
Japanese Meteorological Agency

Source - Ozaki et al, 2011, EPS

GNSS Earthquake and Tsunami Early Warning



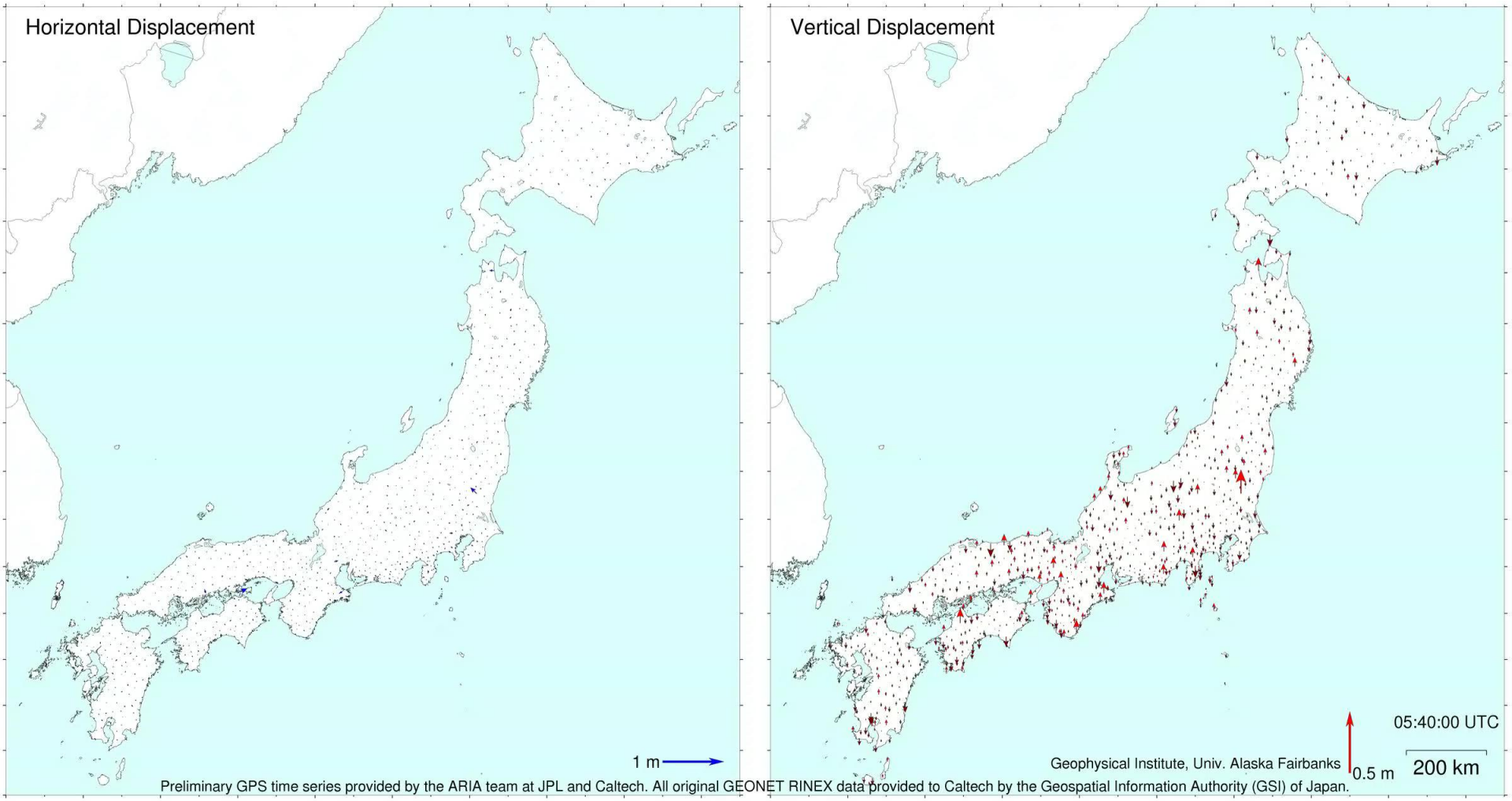
Data courtesy of the Geospatial Information Authority of Japan GSI

GEONET GPS Array

Great East Japan Earthquake and Tsunami

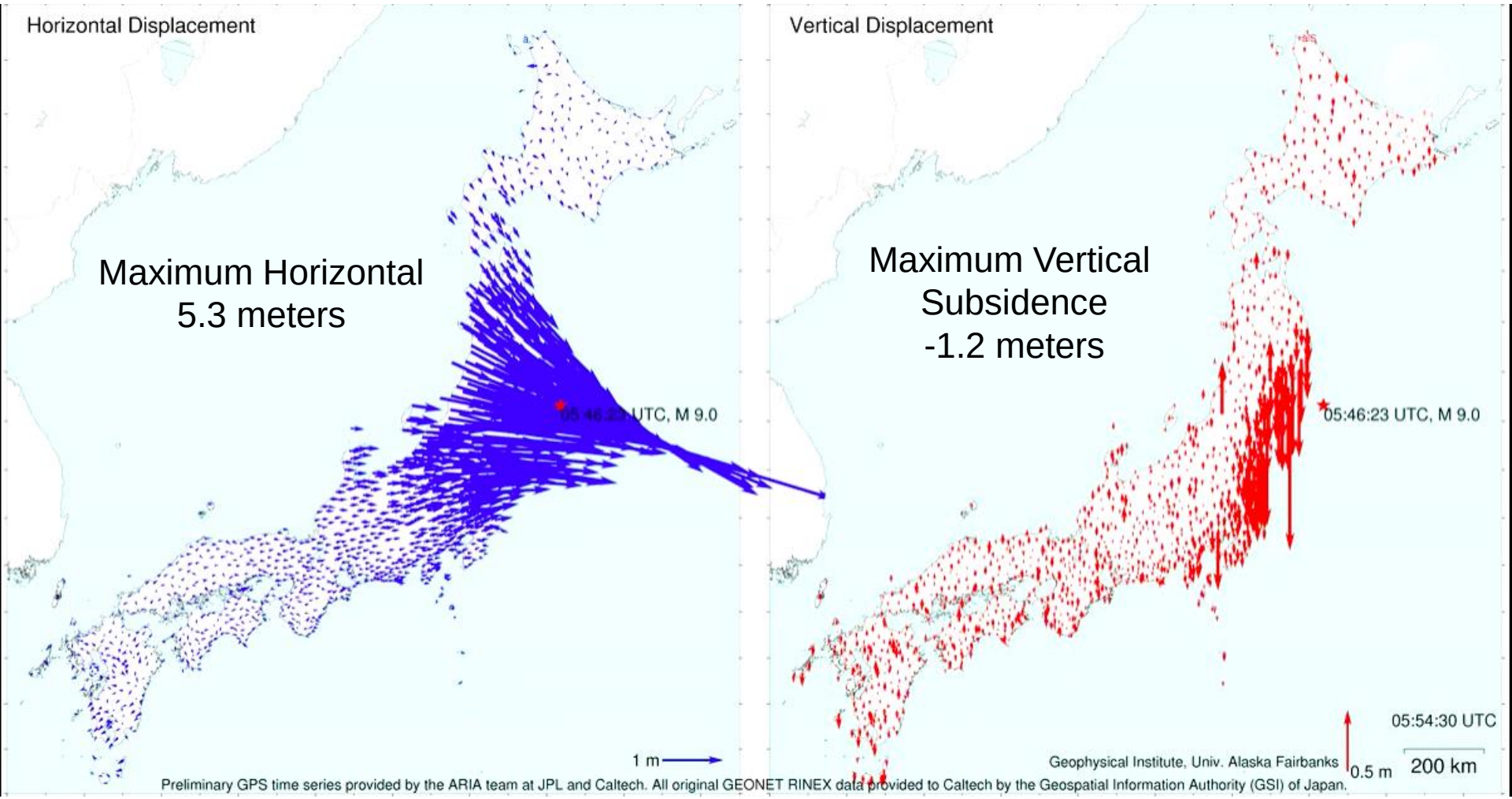
Maximum GPS displacement ~5 meters

GSI GEONET GPS Array Earthquake Displacement Pattern



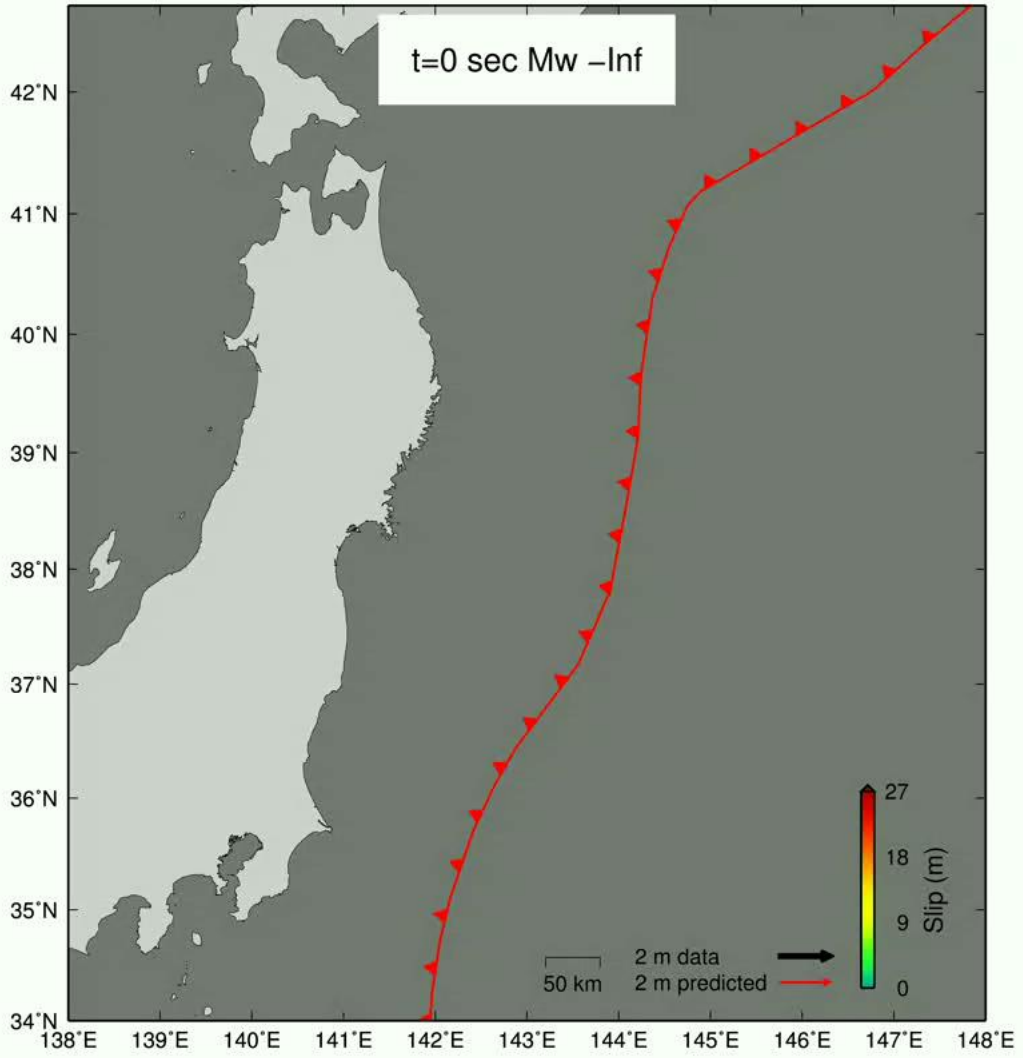
http://gps.alaska.edu/ronni/sendai2011.html: Ronni Grapenthin

GSI GEONET GPS Array Earthquake Displacement Pattern



http://gps.alaska.edu/ronni/sendai2011.html: Ronni Grapenthin

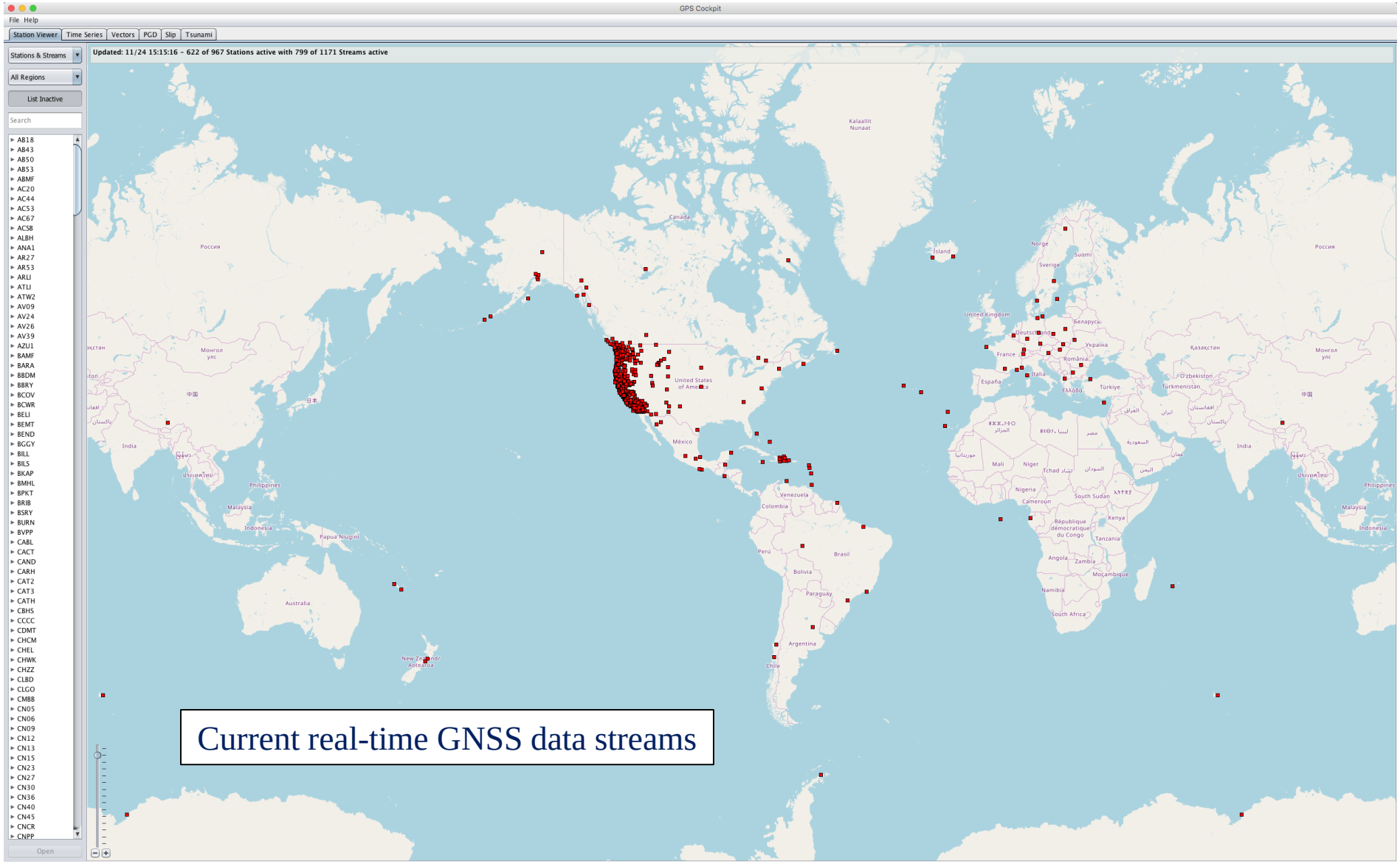
Real-Time GNSS for Rapid Earthquake Magnitude Determination and Fault Slip Distribution



S. E. Minson et al, 2013
JGR

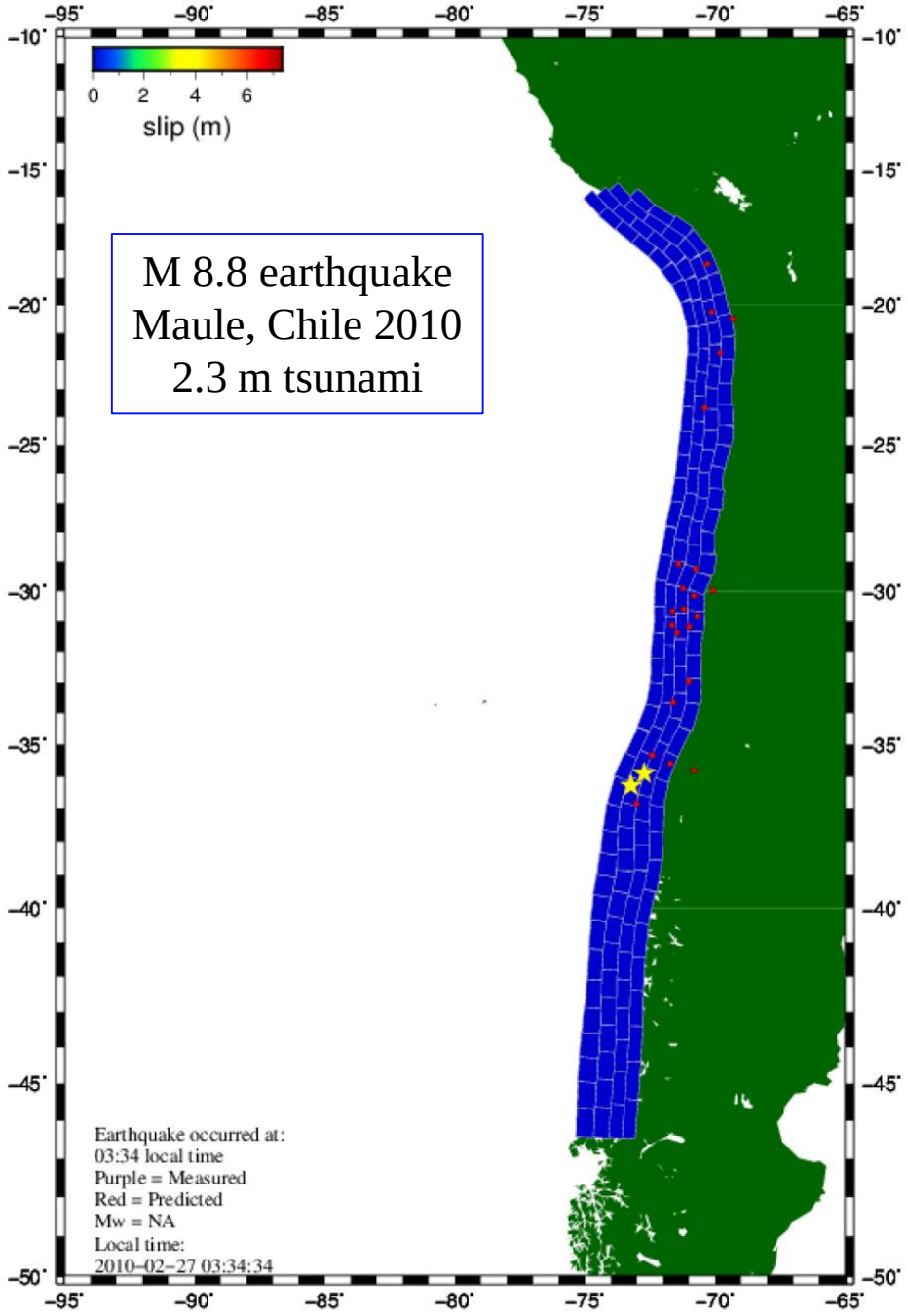
Current real-time GNSS data streams to NASA partners

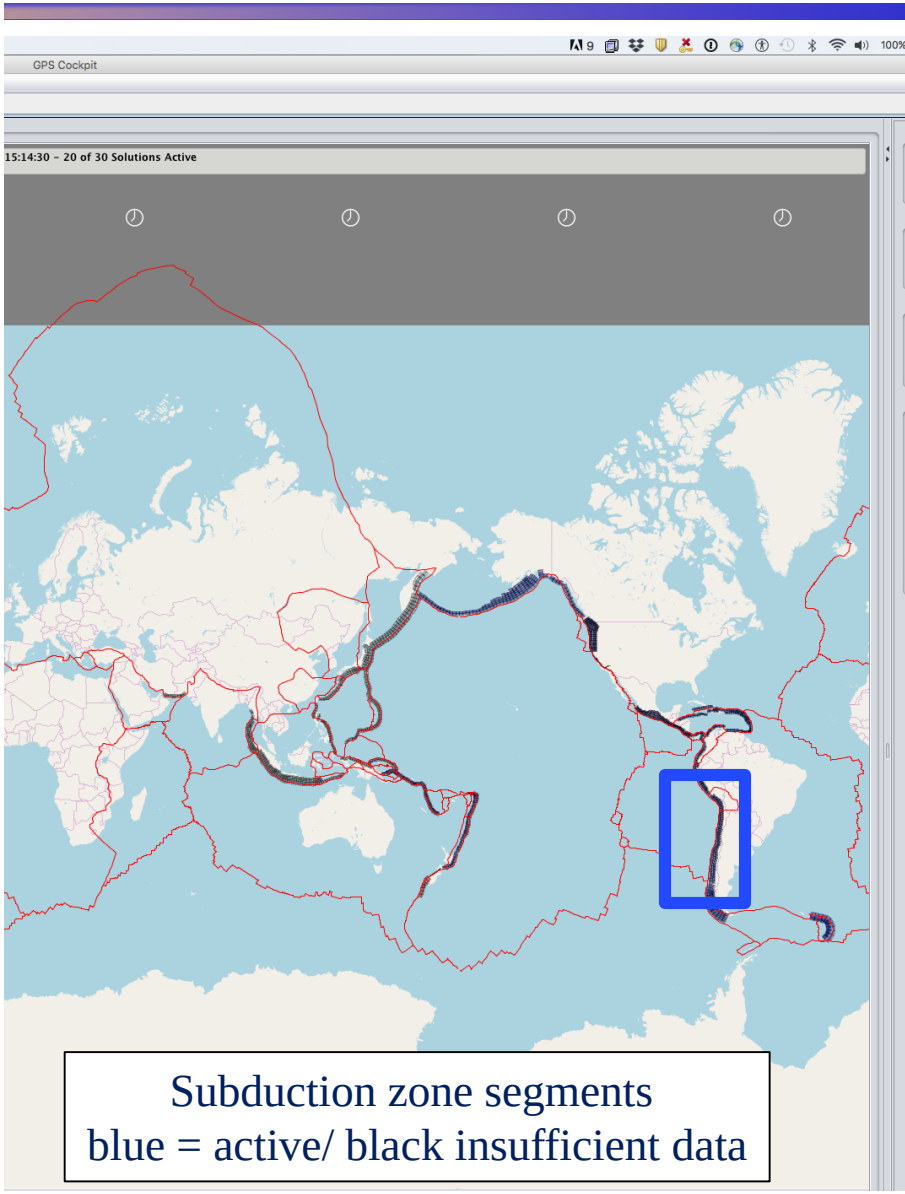
Prototype capability will be operational at NOAA's Tsunami Warning Centers –Early 2018



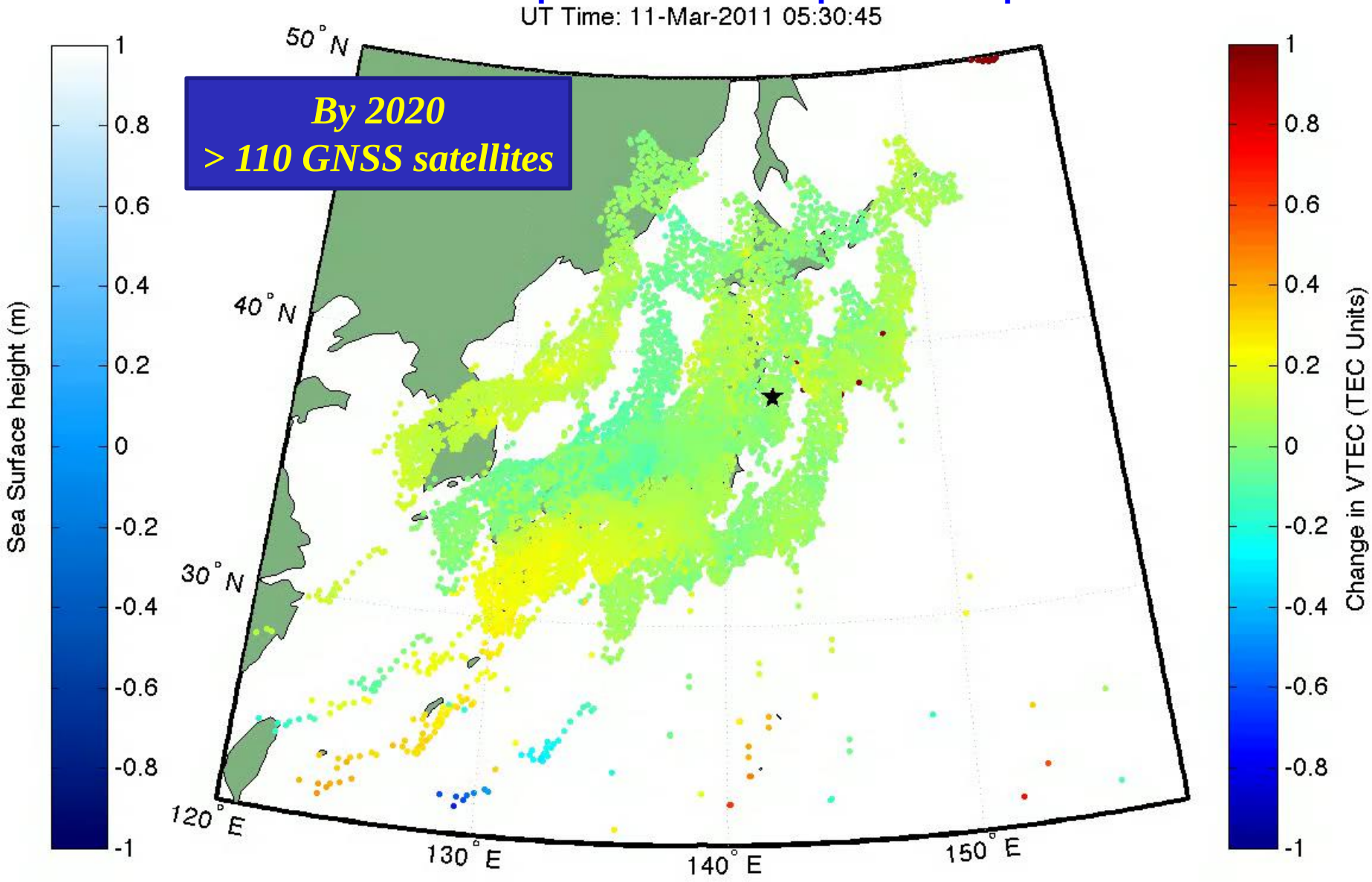
lel for a Predefined Fault

on 20 of 30 subduction zone segments

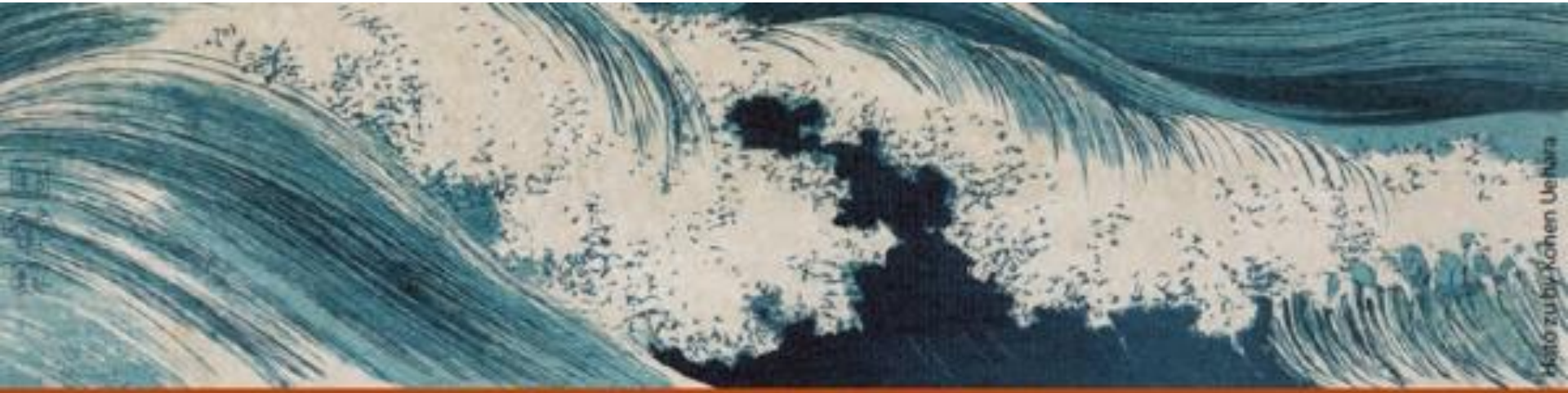




Emerging new technology for detection and tracking tsunamis:
GSI's GEONET Captured the Ionospheric Coupled Waves



Ionospheric Response to Mw 9.0 Tohoku Earthquake and Tsunami in Japan on March 11, 2011, A.Komjathy, D.A.Galvan, M.P Hickey, P.Stephens, Mark Butala, and A.Mannucci, (http://visibleearth.nasa.gov/view.php?id=77377)

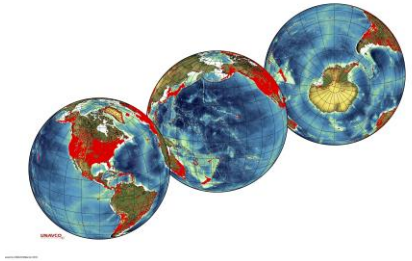


GNSS TSUNAMI EARLY WARNING SYSTEM WORKSHOP

July 25-27, 2017 • Westin Hotel, Sendai, Japan

Sendai rtGNSS Workshop Findings
1: Data / Networks

- **We need to promote the open sharing of rtGNSS data** for ***early warning and hazard assessment***. Goal is to save lives.
- **Where are the holes in real-time GNSS coverage?**
  - Earthquake detection
  - Earthquake/tsunami modeling
  - Tsunami wave propagation detection and tracking.

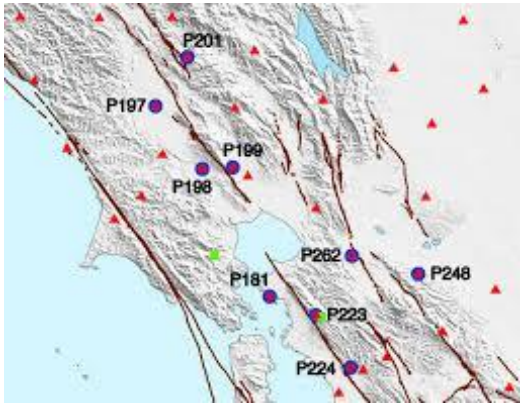


- **We need to develop a strategy to establish rtGNSS capability at existing continuous sites.**
  - *Upgrade existing sites to real-time.*
  - *Increase bandwidth*

- **We need to develop a strategy to fill in data gaps such that there is global coverage?**
  - I.e. World Bank.

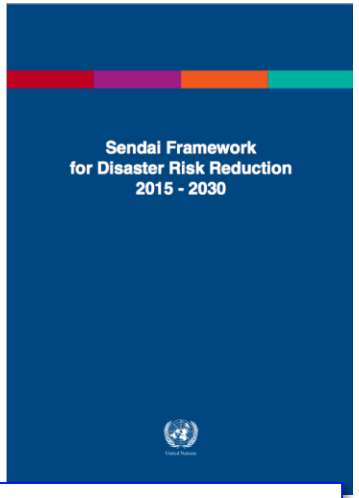
Sendai rtGNSS Workshop Findings 2: Data streaming for early warning

- We need to develop a plan for data streaming/ restreaming that is optimized for each region.
  - I.e. is there sufficient bandwidth and acceptable data latency
- We need to develop a strategy for data streaming redundancy. If one area is impacted by an event, then there should be sufficient data mirroring to provide rtGNSS early warning capabilities.
- Who is responsible for data archiving?



Sendai rtGNSS Workshop Findings

SENDAI FRAMEWORK FOR DISASTER RISK REDUCTION



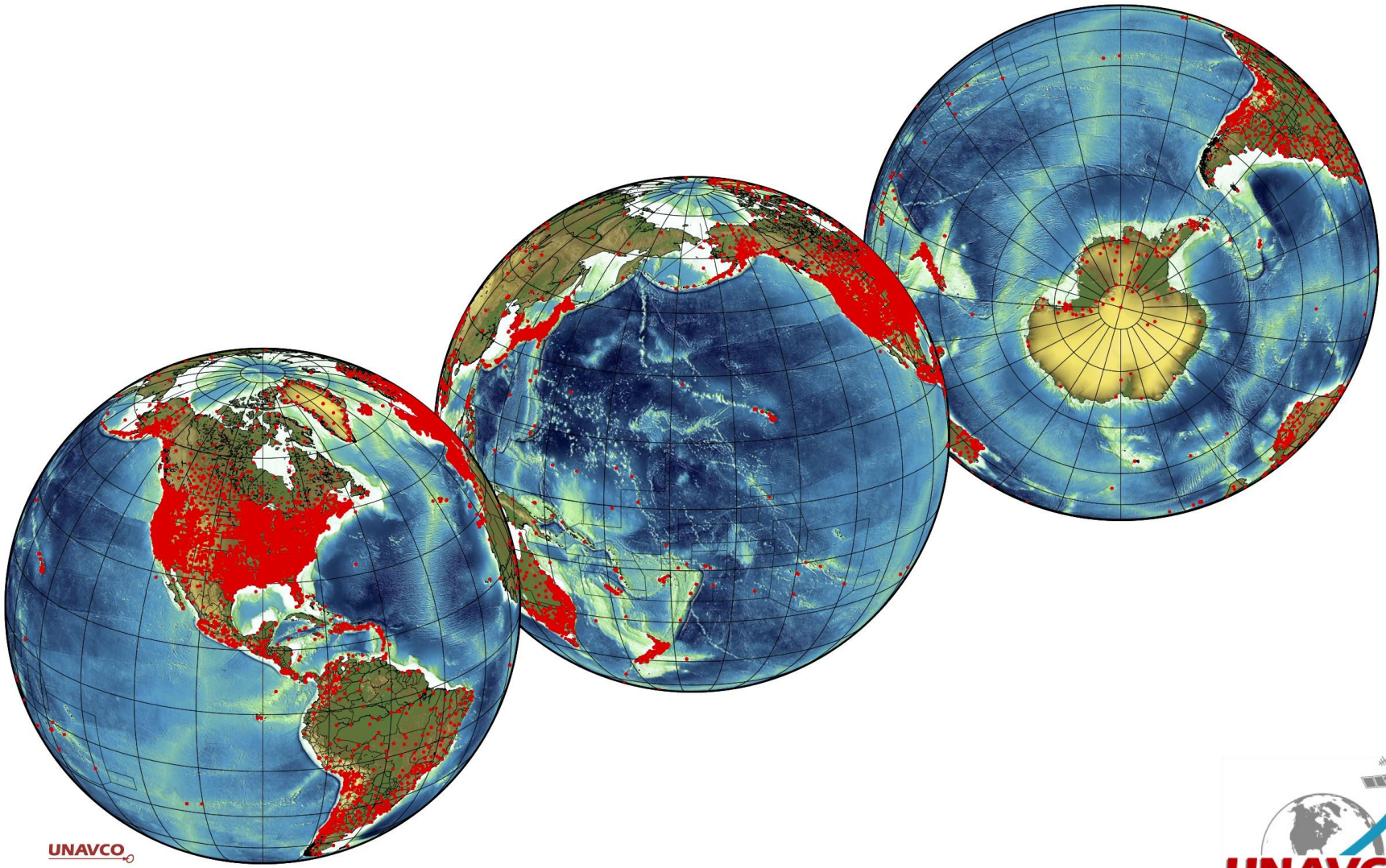
A real-time GNSS network would support a number of goals described the Sendai Framework

Data sharing supports the UN's Sendai Framework for Disaster Risk Reduction 2015-2030. ***50 specific items***

- Item 14: …here is a need to enhance **international cooperation**….
- Item 18 (g): Substantially increase the availability of and a **warning systems** and disaster risk information and assess
- Item 20: Priorities for actions: **Priority #1 Understanding disaster risk**.
- Item 22: concerted international cooperation, an enabling international environment and means of implementation are needed to **stimulate and contribute to developing** the knowledge, capacities and motivation for disaster risk reduction at all levels, in particular for **developing countries**.
- Item 23 Policies and practices for disaster risk management should be based on an **understanding of disaster risk**
- Item 24a: To promote the **collection, analysis, management and use of relevant data** and practical information and ensure its ***dissemination***

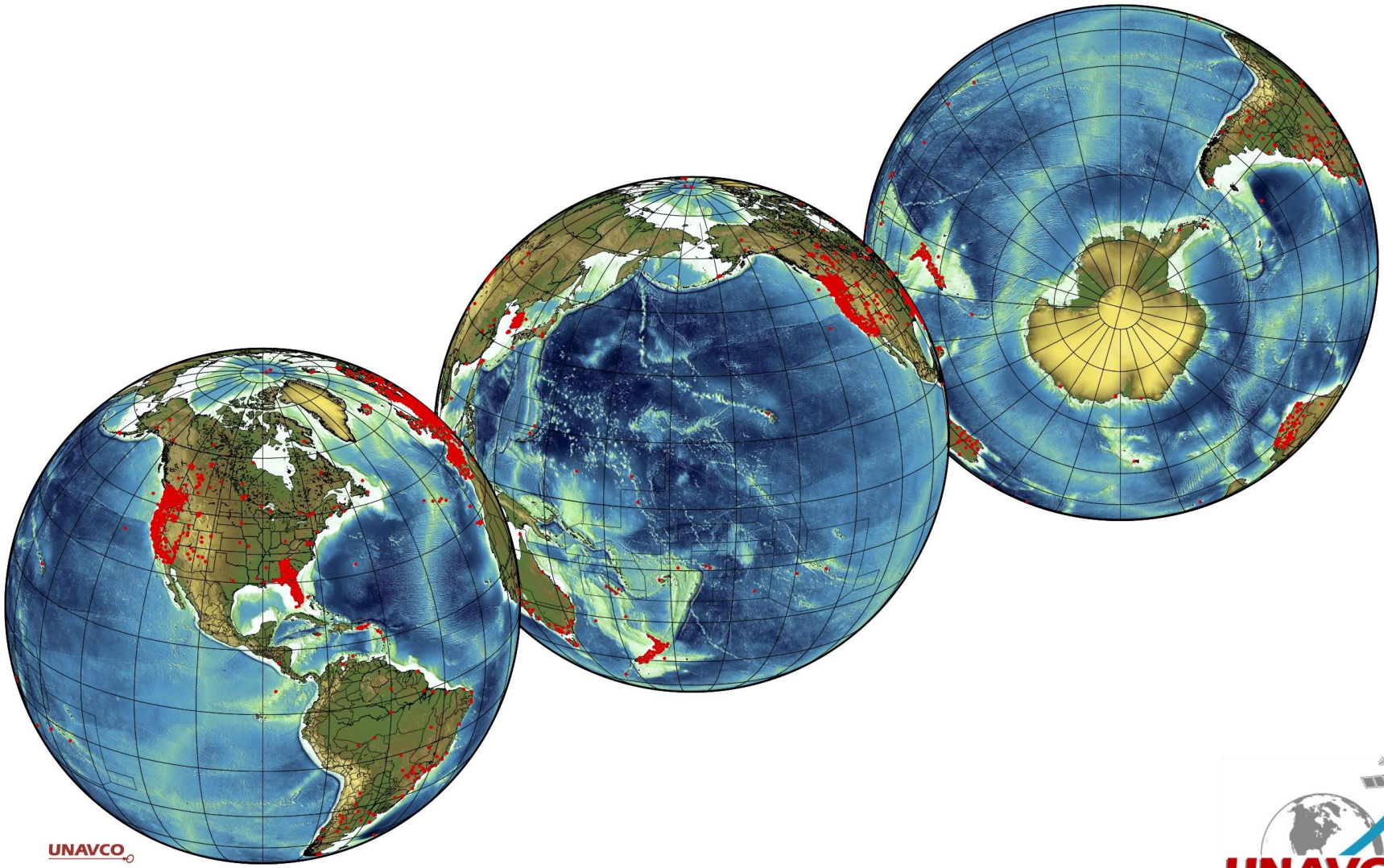
GNSS 99.99% of the time Scientific Research

Known and Publically Accessible Continuous GNSS sites – 14,667



UNAVCO

Known and Publically Accessible Real-Time GNSS sites – 2,287



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GNSS Earthquake and Tsunami Early Warning

Expanding the earthquake and tsunami early warning globally requires access to **shared *real-time*** GNSS data in areas that are:

- Seismically active
- Coastal communities that may be impacted by a tsunami

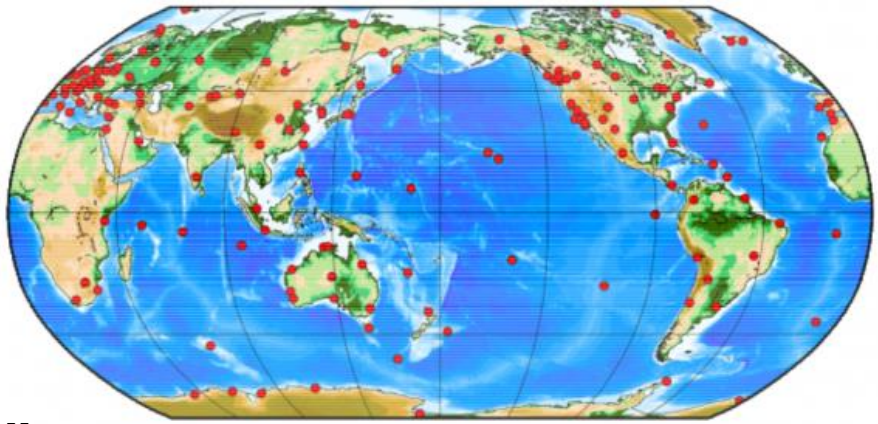
Partnership with regional/national tsunami and earthquake early warning Centers.

- The GNSS Early Warning approach ***enhances*** current capabilities

Partnerships with the International GNSS and Earth Observation's communities

- ICG – UN International Committee on Global Navigation Satellite Systems + UNOOSA
- IGS – International GNSS Service
- GGOS – Global Geodetic Observing System
- GEO – Group on Earth Observations
- CEOS – Committee on Earth Observation Satellites

GGOS/IGS Real-TimeNetwork



Gerald Bawden

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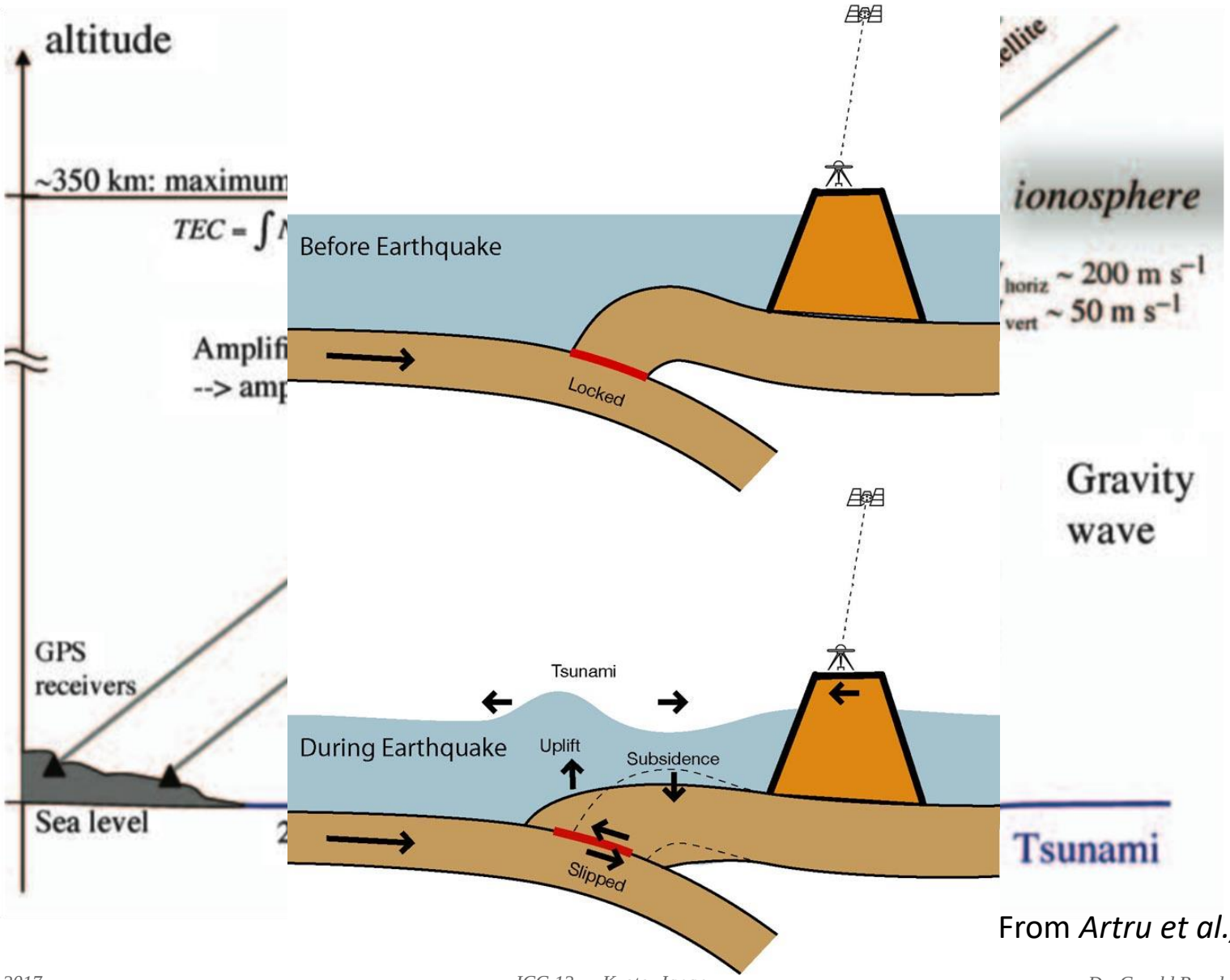
The Tsunami Generated Displacement of the Ocean Surface Couples to the Ionosphere



From *Artru et al.,* 2005