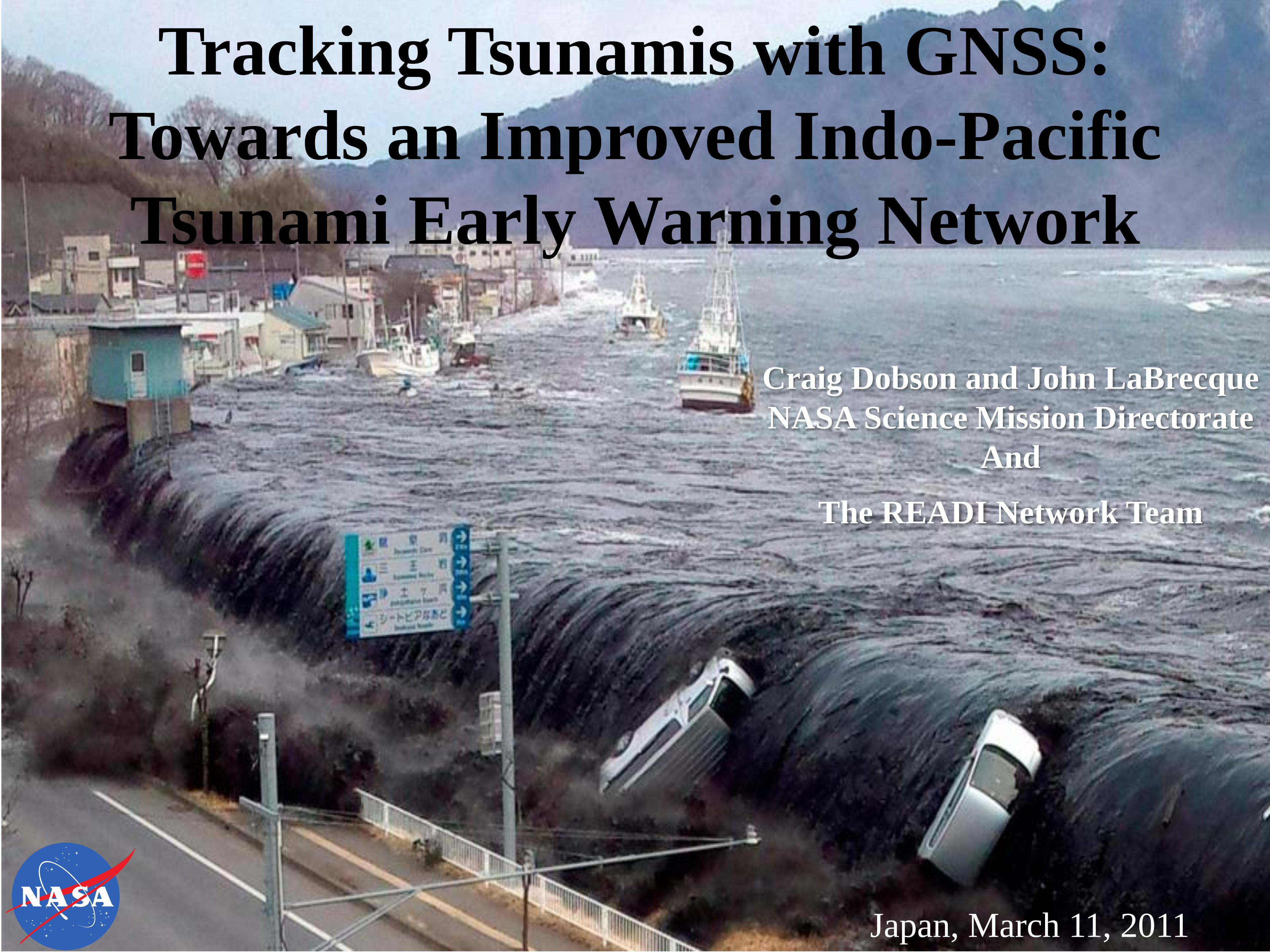

Banda Aceh, December 26, 2004



Tracking Tsunamis with GNSS: Towards an Improved Indo-Pacific Tsunami Early Warning Network

Craig Dobson and John LaBrecque
NASA Science Mission Directorate
And

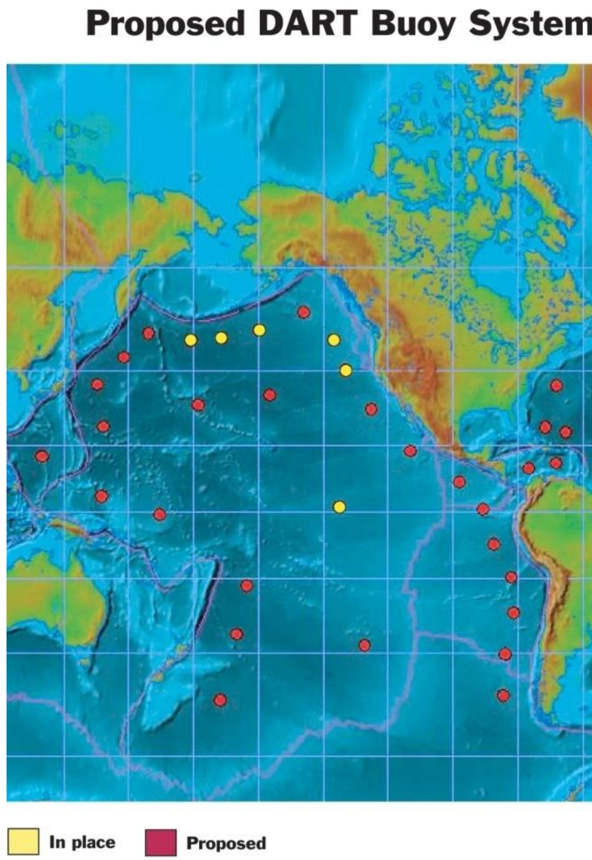
The READI Network Team

Japan, March 11, 2011

Current Tsunami Warning System

Earthquake-Magnitude-Based Tsunami Warnings (NOAA's PTWC)

Mw less than 6.5 (Mw: Moment Magnitude)	Earthquake Message Only
Mw 6.5 to 7.5	Tsunami Information Bulletin
Mw 7.6 to 7.8	Regional Tsunami Warning
Mw > 7.8	Expanding Warning / Watch
Confirmed Teletsunami	Pacific-Wide Warning



Unfortunately,

1. Seismic Mw estimates require 20 minutes or more for an accurate solution;
2. Earthquake magnitude is not a reliable indicator of a resulting tsunami;
3. DART system requires considerable maintenance and provides point source data.

Proposed: Indo-Pacific GNSS Disaster Early Warning Network

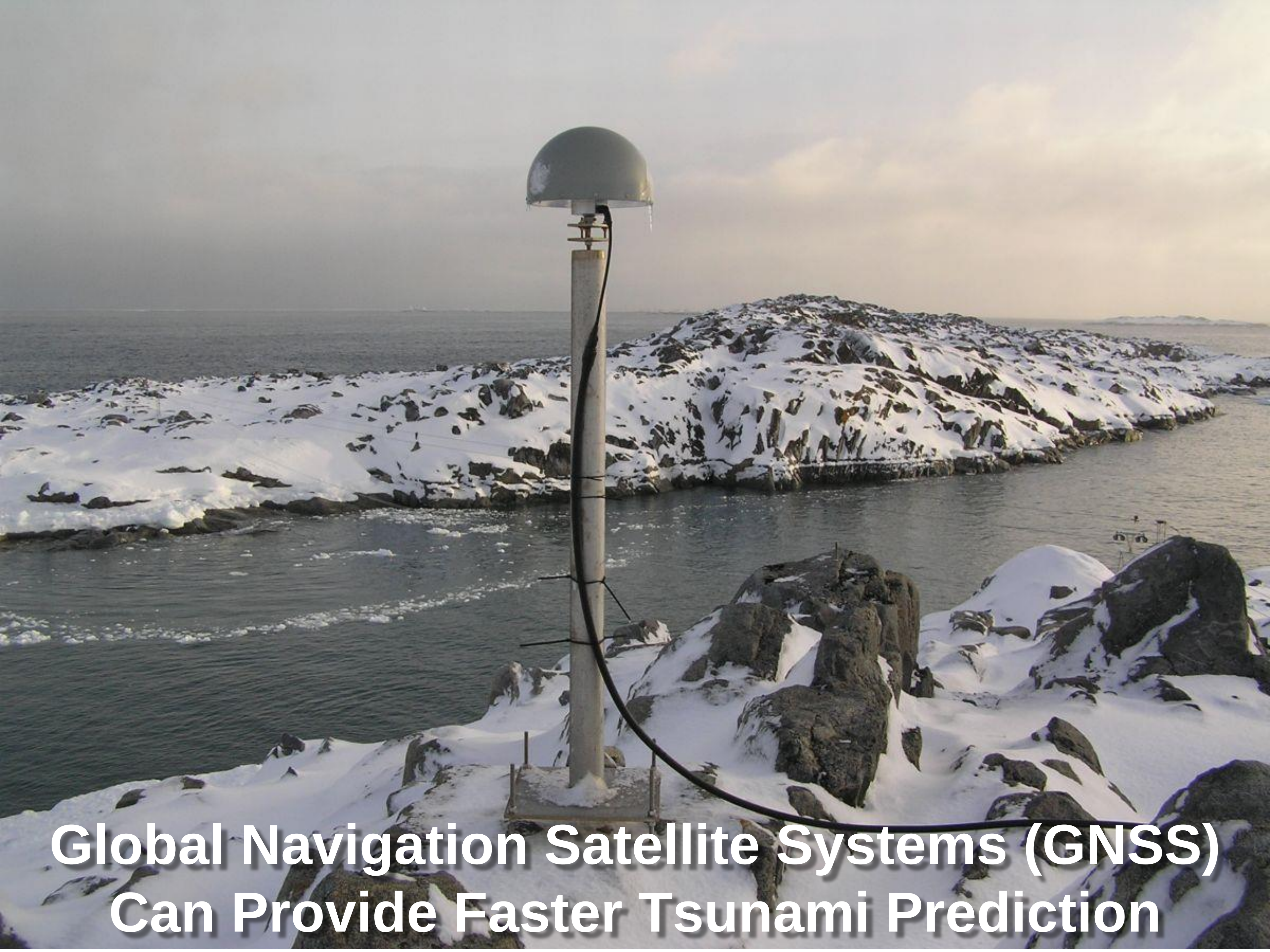
Pacific Basin Earthquakes and Volcanic Eruptions pose <u>regional hazards</u> that do not obey national boundaries.

The Pacific Basin is ringed by subduction zones and violent volcanoes with demonstrated ability to generate large earthquakes and devastating tsunamis that propagate basin wide.

A moderately sufficient GNSS network has been deployed within the circum-Pacific and on Pacific Islands.

Communication infrastructure is available for near real time GNSS data distribution either continuous or event responsive.

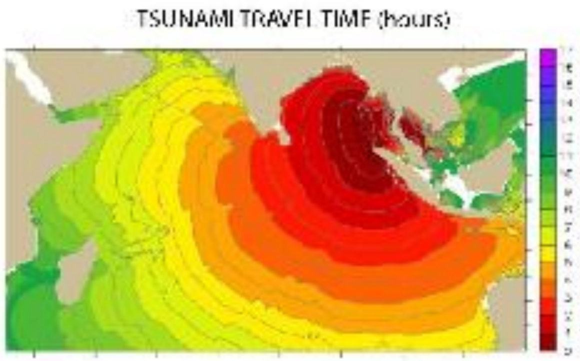
It is proposed that this network begin real time distribution.

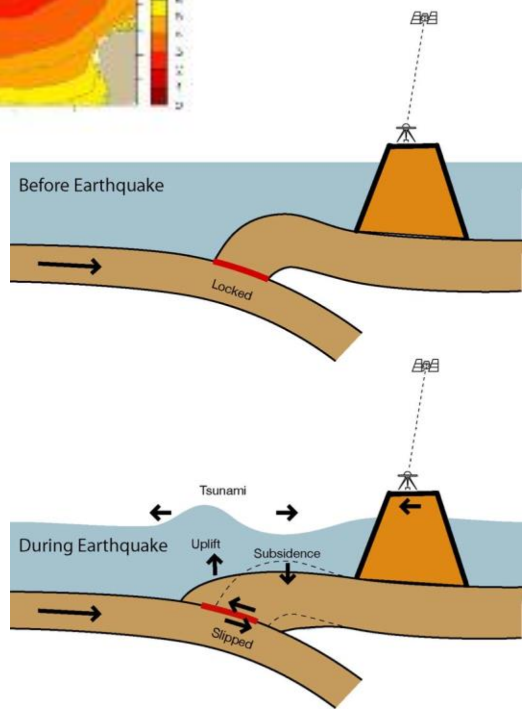


Global Navigation Satellite Systems (GNSS) Can Provide Faster Tsunami Prediction

Post Processing of regional geodetic data taken on December 26,2004 Demonstrated the Value of a Global Regional GNSS Real Time Network

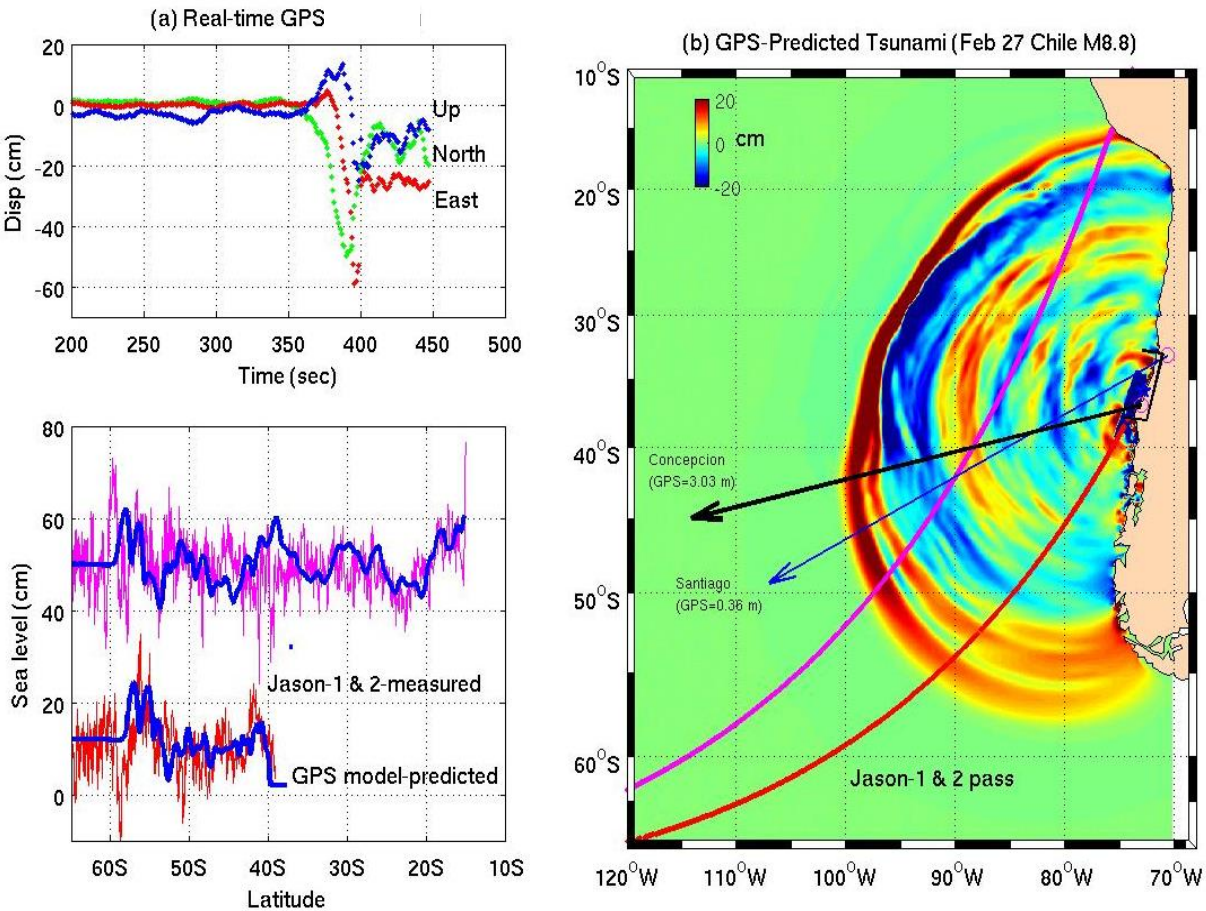
A Dense Global Real Time GPS Network would have warned of the Indian Ocean Tsunami within minutes- hours to days before the seismic analysis-





GPS station displacements on 26 December, 2004 observed by the International GNSS Service Network (IGS/GGOS). The largest arrow (SAMP) has been scaled down by a factor of two for clarity. Ref: Blewitt, Hammond, Kreemer, Plag, Stein, Okal, 2009,J. Geodesy.

February 27, 2010: Chile M8.8 Earthquake Demonstrated First Real Time GPS based Tsunami Prediction using GDGPS with NASA Applied Sciences funding to The GREAT Alert Project



(a): NASA's Global Differential GPS (GDGPS) measures the Chile M8.8 earthquake displacement in real time at Santiago.

(b): JPL GREAT alert team predicts a moderate sized tsunami using the real-time GPS and the Song tsunami generation model.

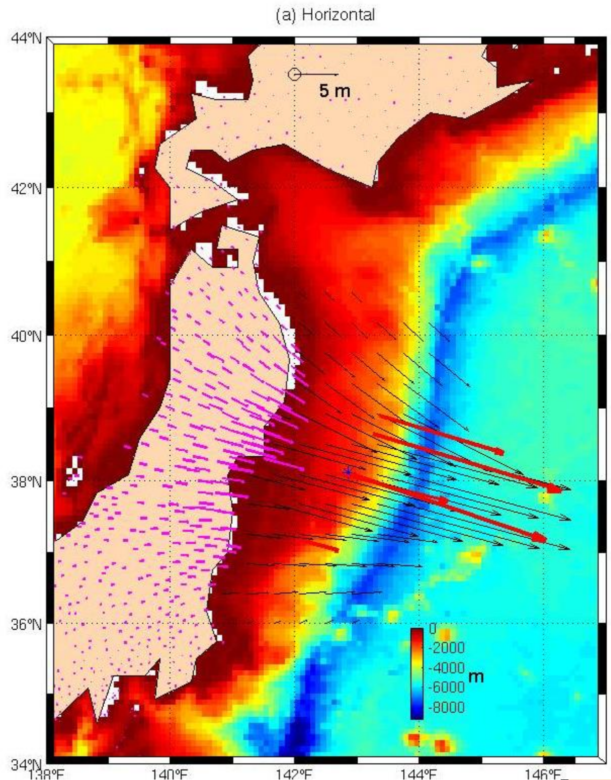
(c): NASA/CNES satellites Jason-1 and Jason-2 confirm the tsunami amplitude prediction of the GPS-based model prediction.

(d): Next steps: Strengthen real time GDPS network, automate models.

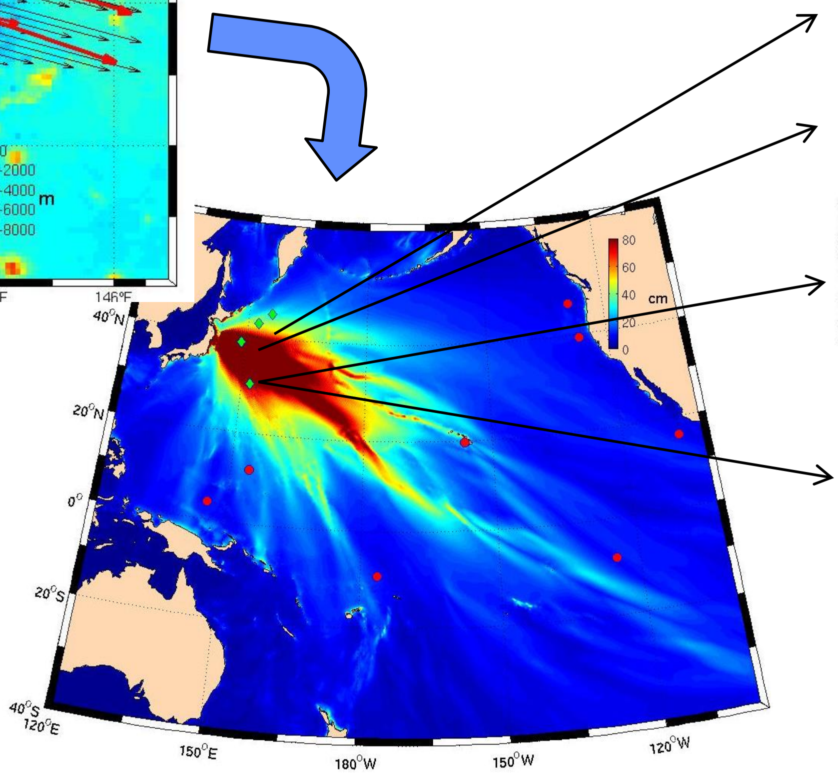
Tony Song , Yoaz Bar-Sever, et al. /JPL

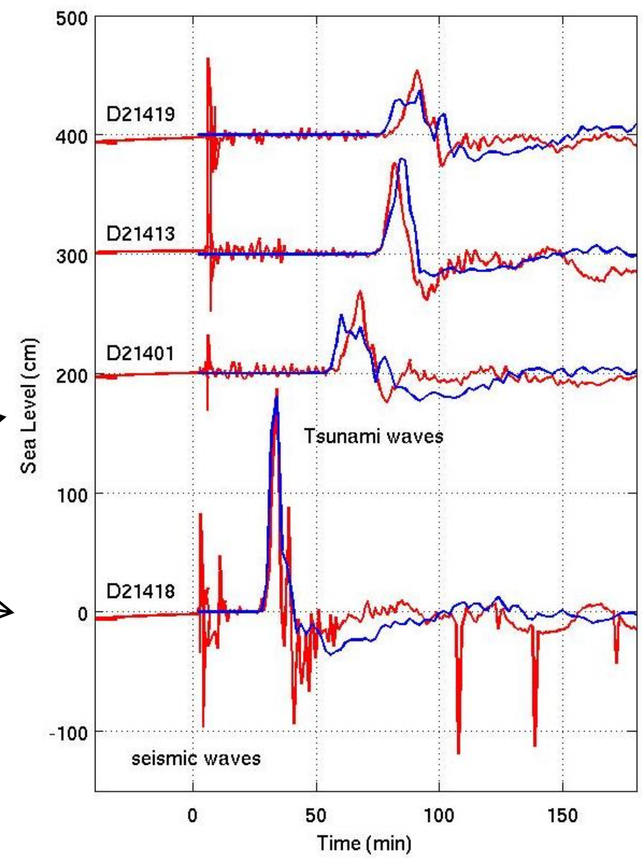
Song Y.T., 2007, Detecting tsunami genesis and scales directly from coastal GPS Stations, Geophys Res. Ltts.

The 2011 Tohoku-Oki Tsunami



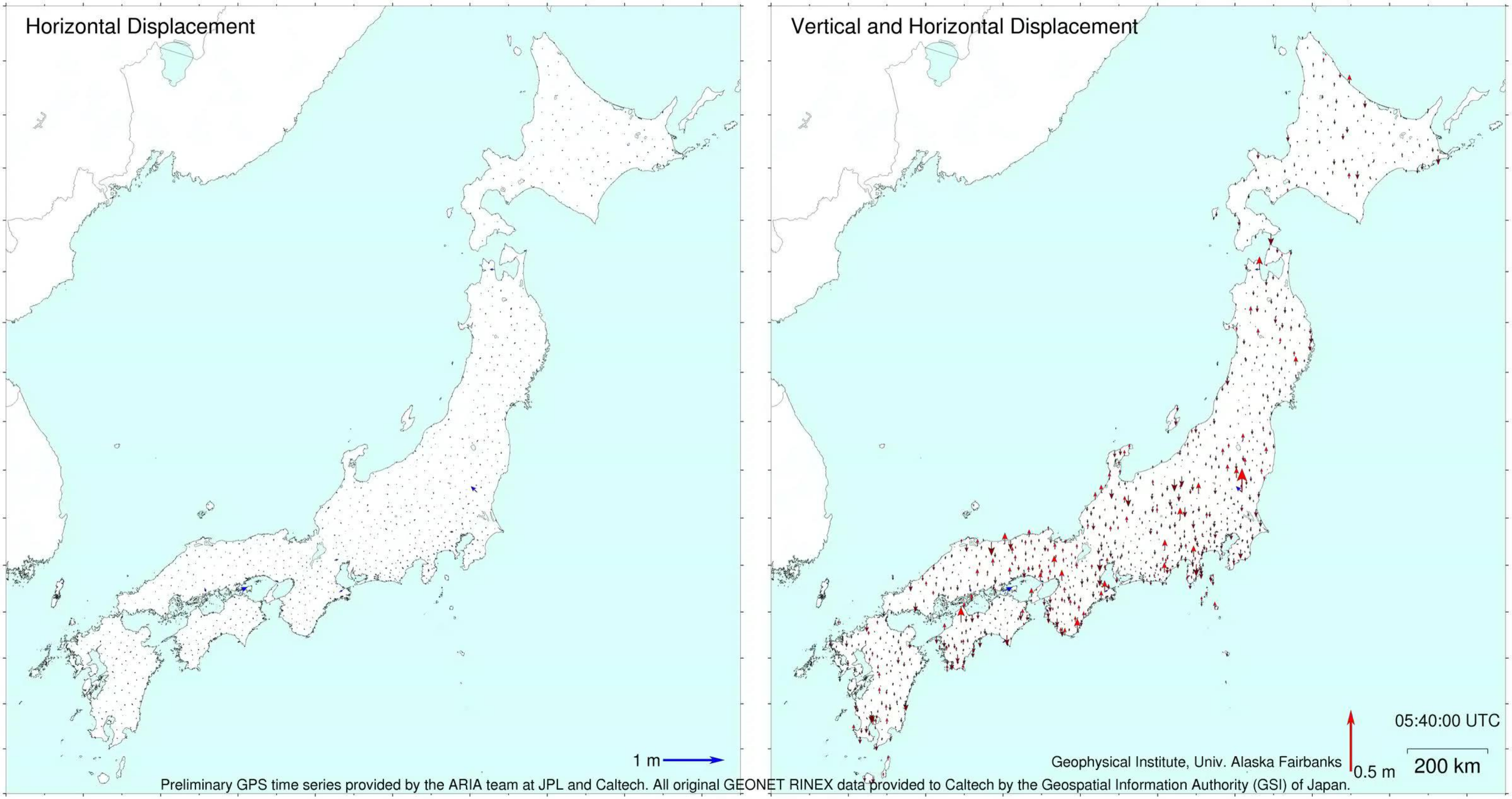
There are about 1,200 GPS stations (GeoNet) on Japanese Islands. Study shows that they were capable of predicting the tsunami and could have saved more lives if were used (Song et al., GRL, 2012).



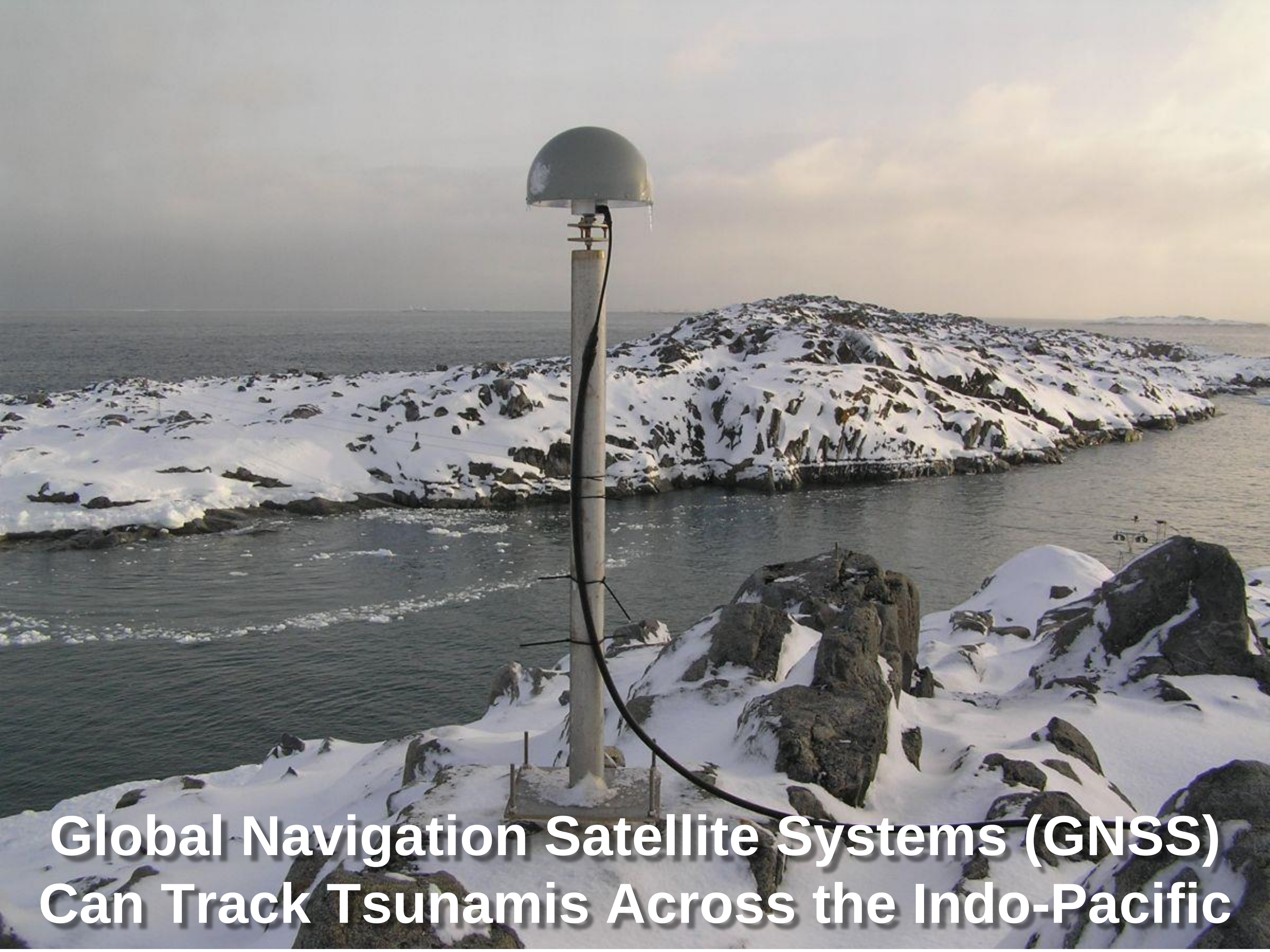


March 11, 2011:The GSI GEONET GPS Array

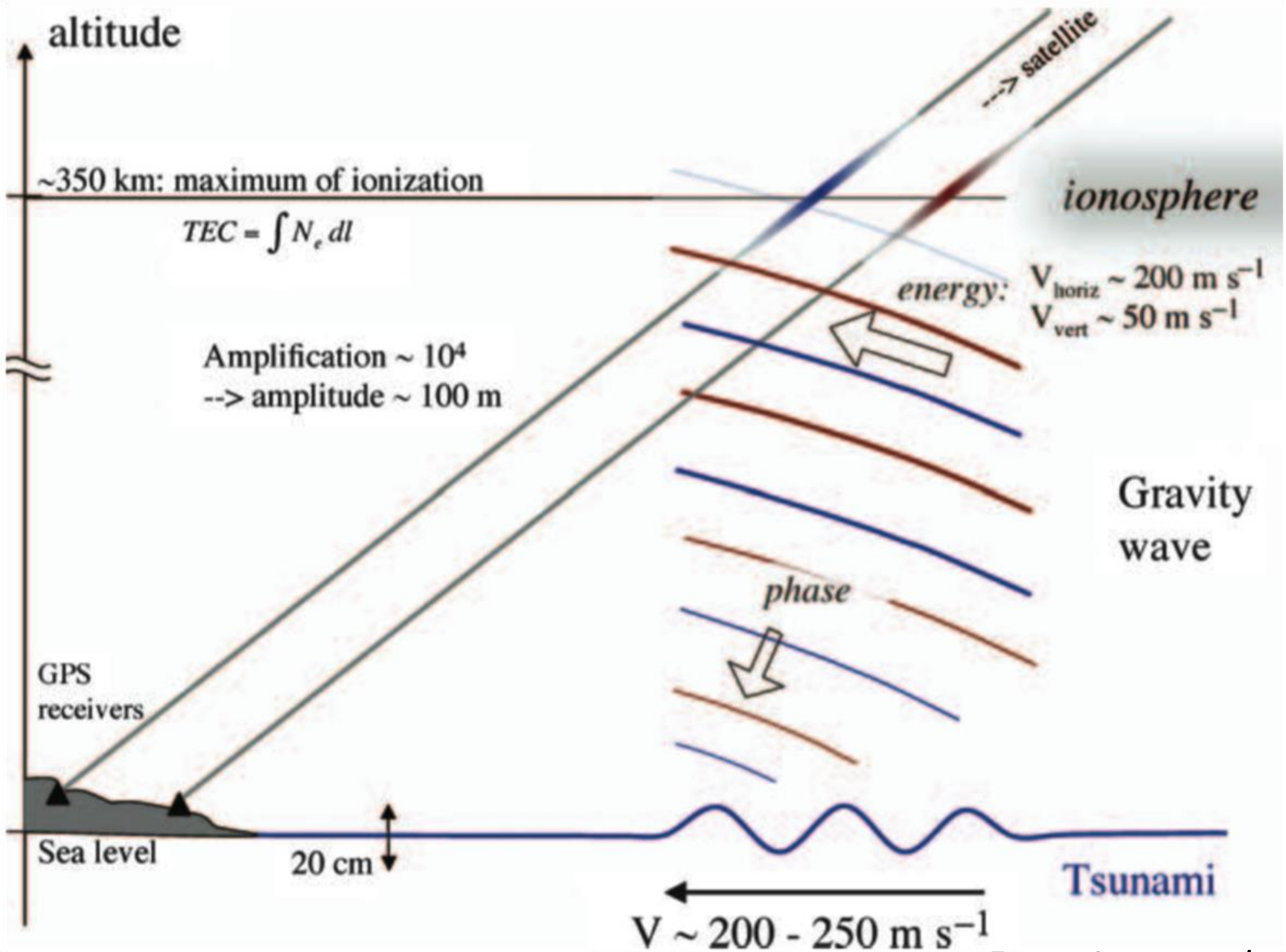
- **Demonstrated Capability to Predict a Tsunami**
- **First use of GPS to Predict**
- **First Observe the Resulting Tsunami**



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

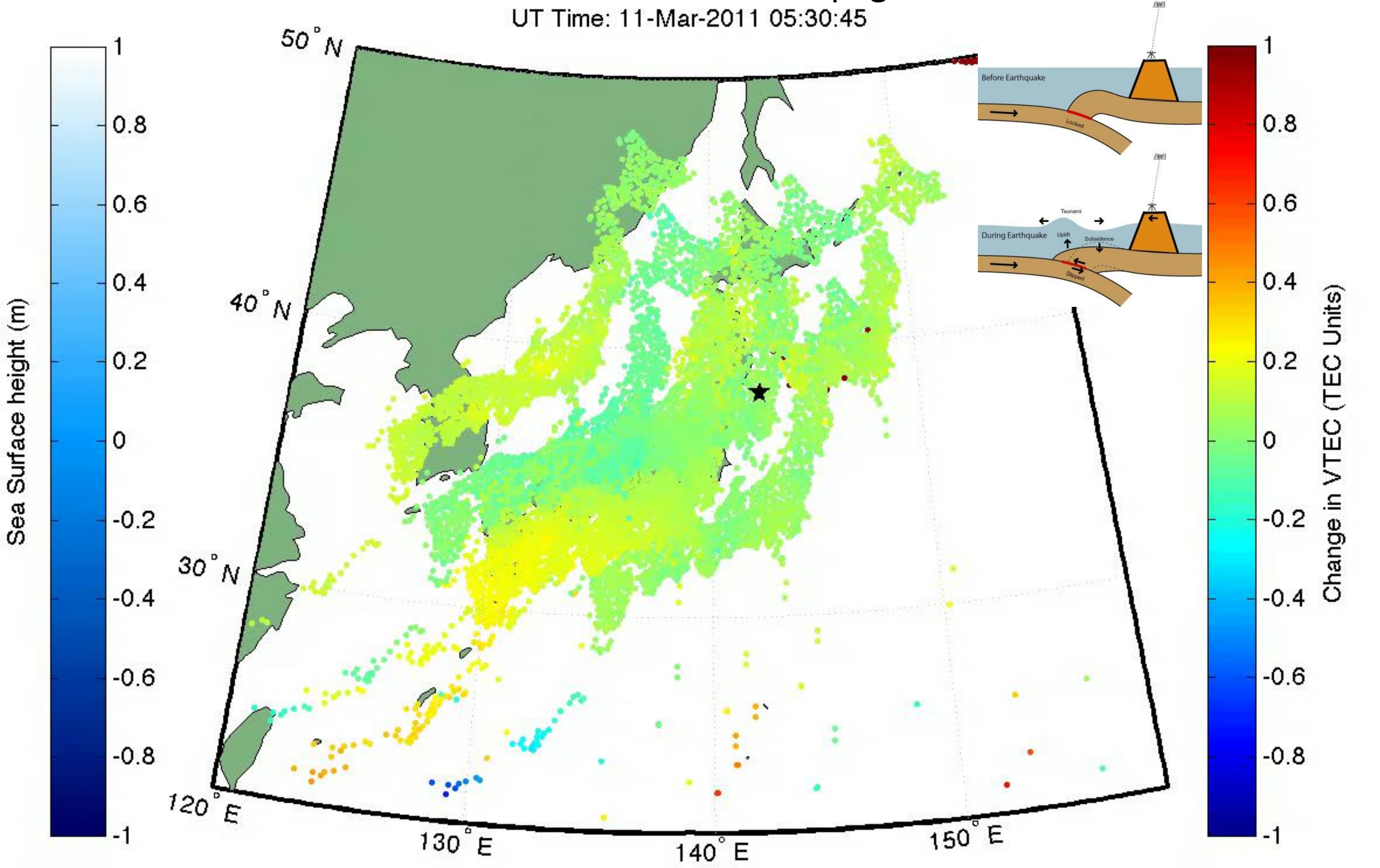

Global Navigation Satellite Systems (GNSS)
Can Track Tsunamis Across the Indo-Pacific

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



From *Artru et al.,* 2005

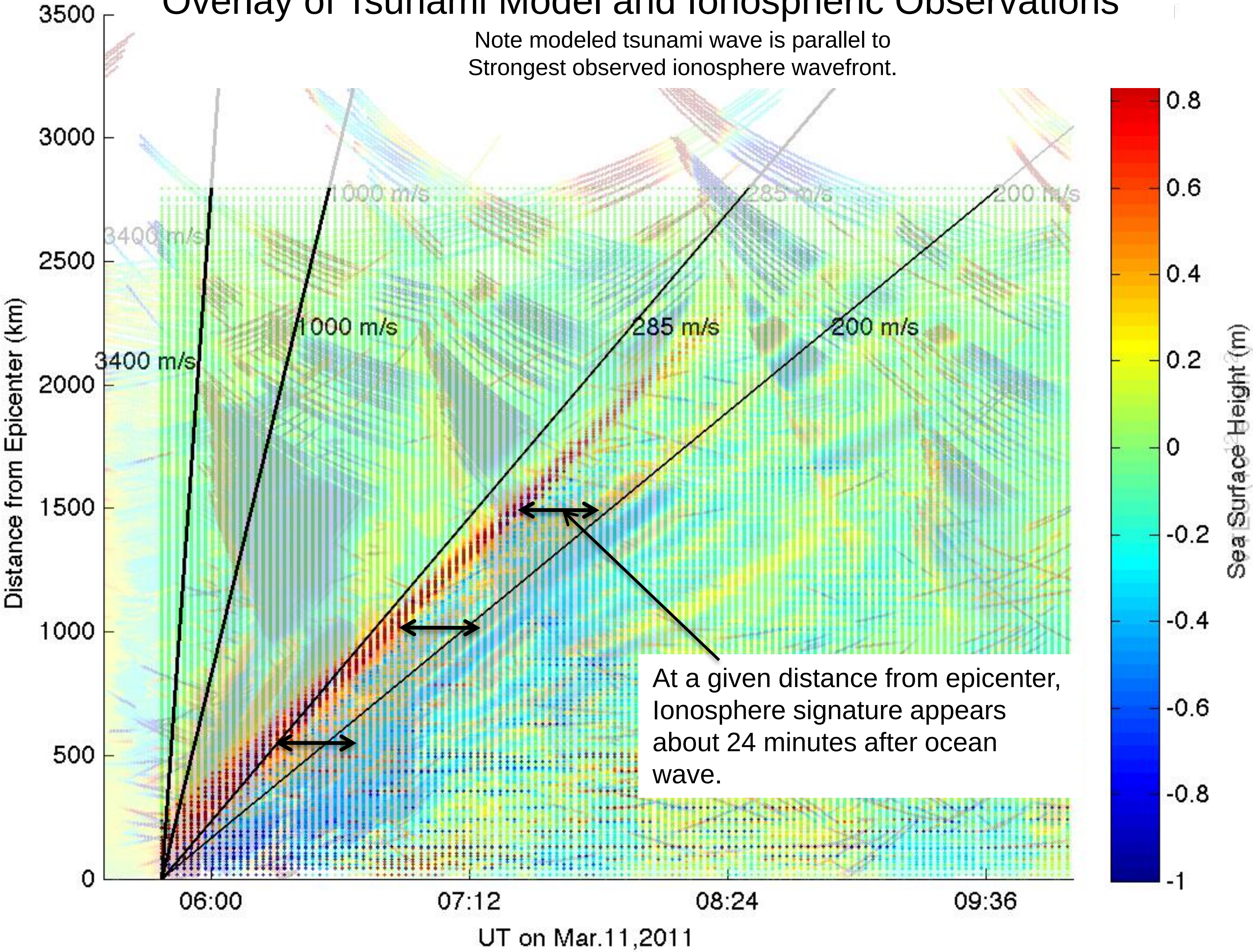
GSI's GEONET Also Captured the Ionospheric Coupled Waves and Imaged the Tsunami Generation and Propagation-For the First Time



Ionospheric Response to Mw9.0 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)

Overlay of Tsunami Model and Ionospheric Observations

Note modeled tsunami wave is parallel to
Strongest observed ionosphere wavefront.

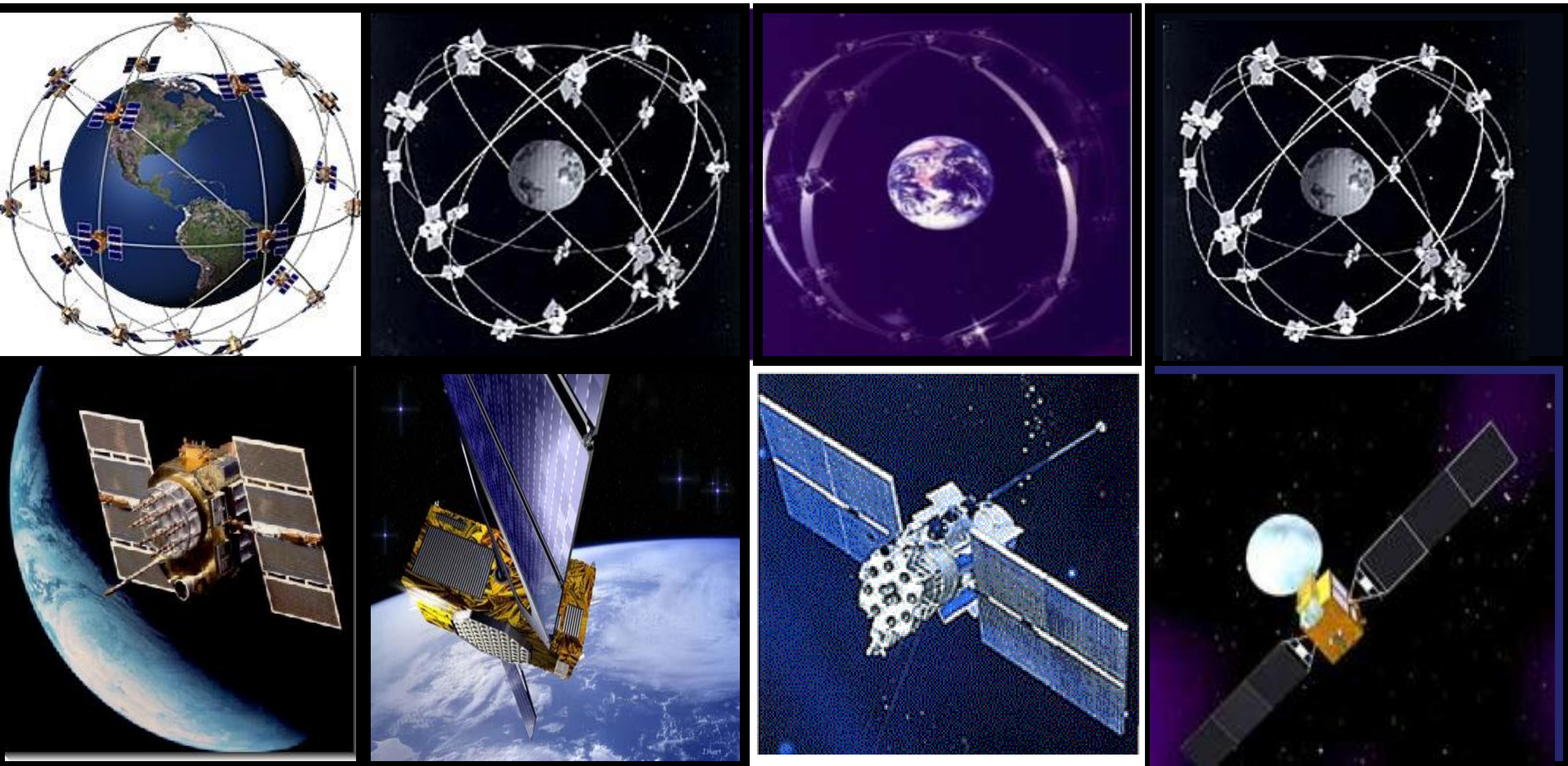


From D.A. Galvan et al., 2012


Global Navigation Satellite System (GNSS)
Size Will Increase By More Than 400%
In This Decade

The Global Navigation Satellite System (GNSS) constellations will increase to over 110 satellites by 2020

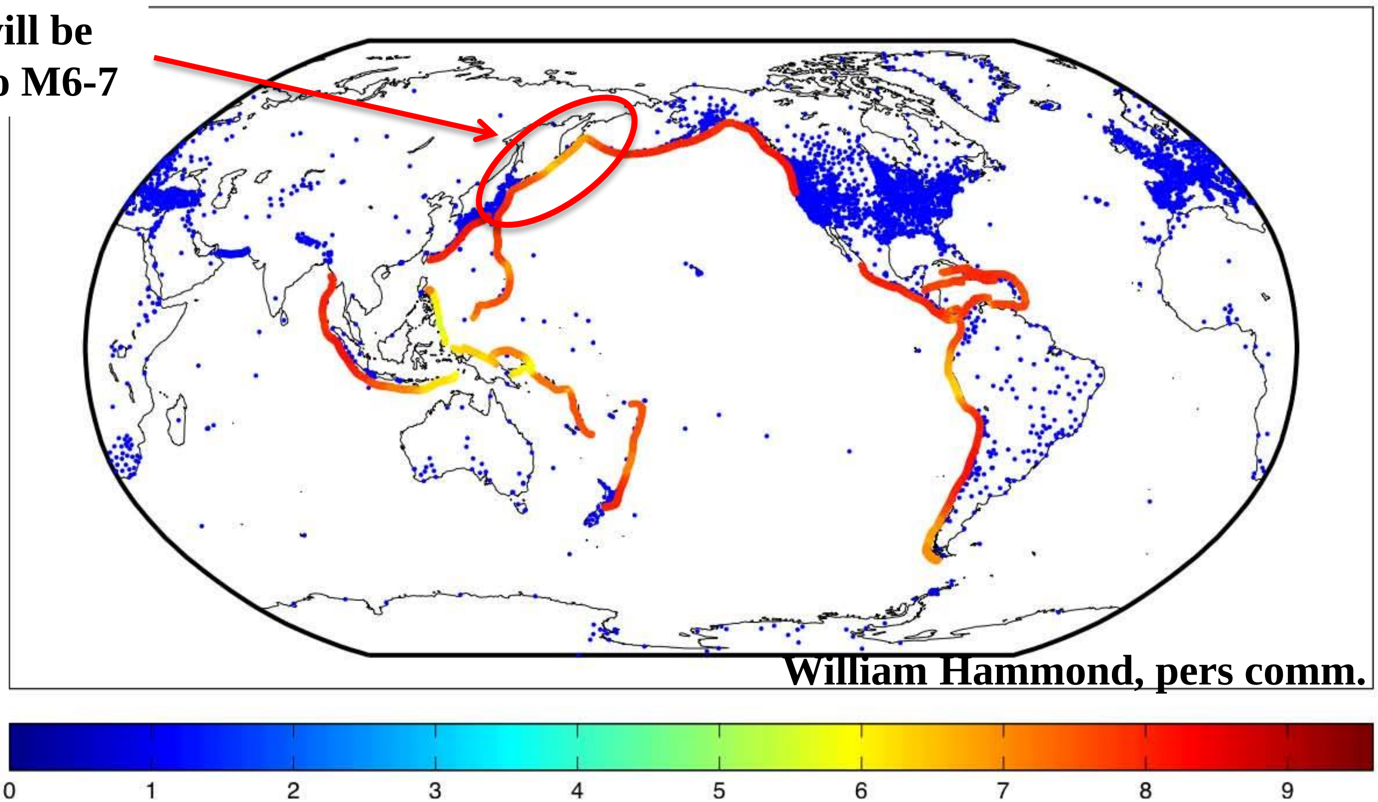
GPS Galileo GLONASS Beidou



Tsunami Prediction Capability of the Current Network

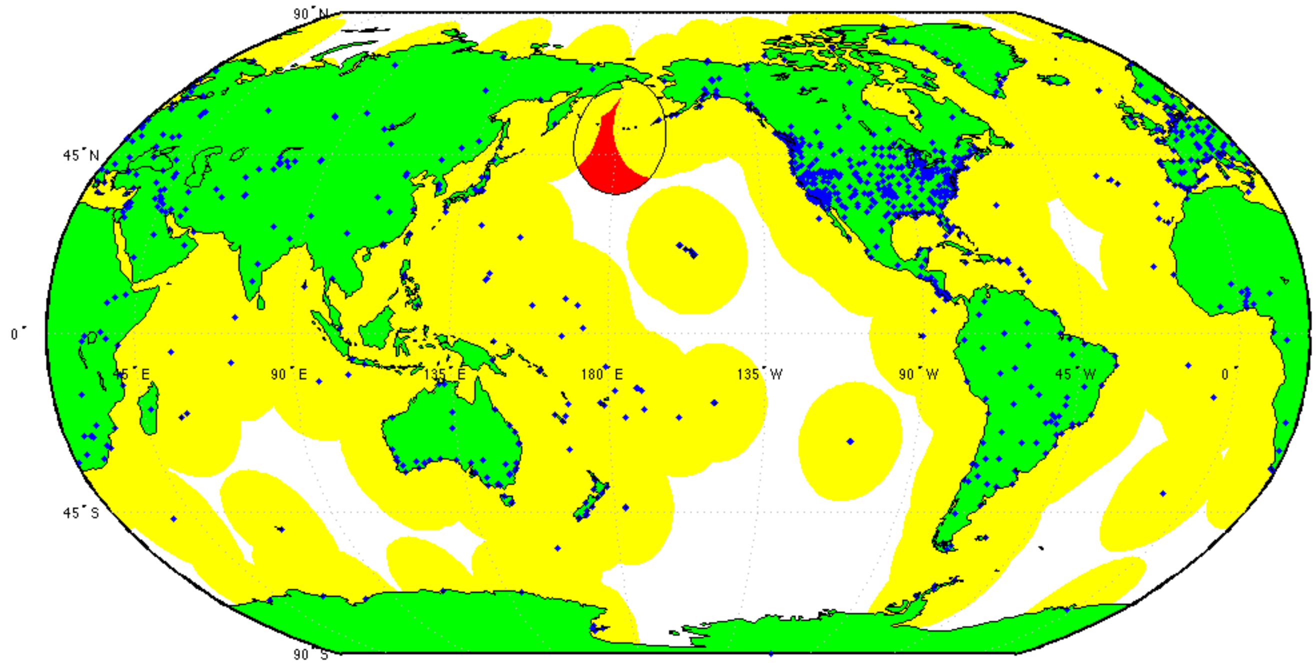
Simulating the ability to resolve a M9 Earthquake along the "Ring of Fire" using available GPS networks

M9 earthquake will be under-resolved into M6-7



Simulations indicate that the Kamchatka-Kuril region (as well as many other regions along the "ring of fire") is not equipped with sufficient density of GNSS receivers to enable GNSS-based resolution of large earthquakes

Tsunami Tracking Capability of Current Network

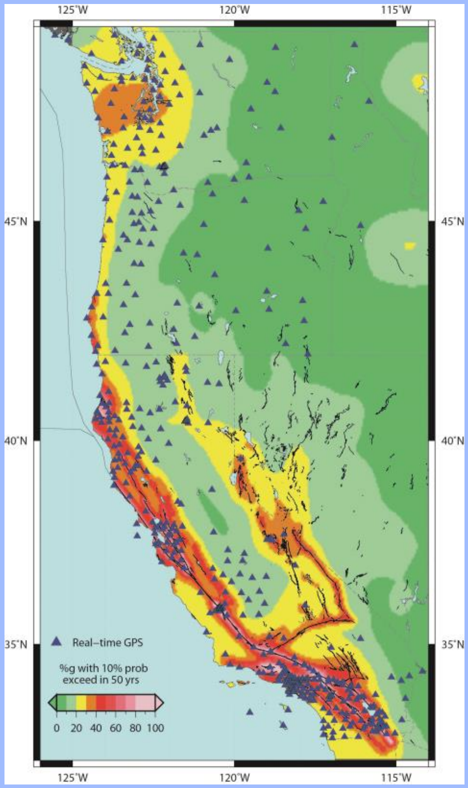


Prepared by A. Komjathy et al, JPL. Assumes > 10 degree elevation angle

Red zone is the only circum-Pacific gap in coverage for mapping ionospheric dynamics. The coverage gaps in the central could be filled by strategicly positioned GNSS equipped mid-ocean DART buoys

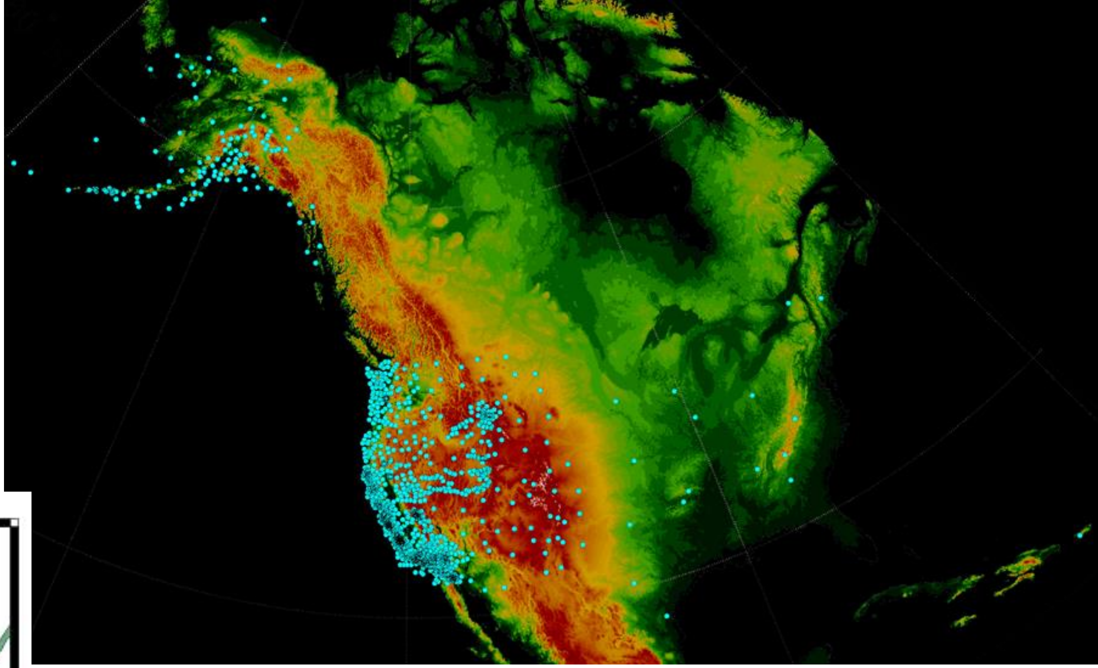
The READI Working Group

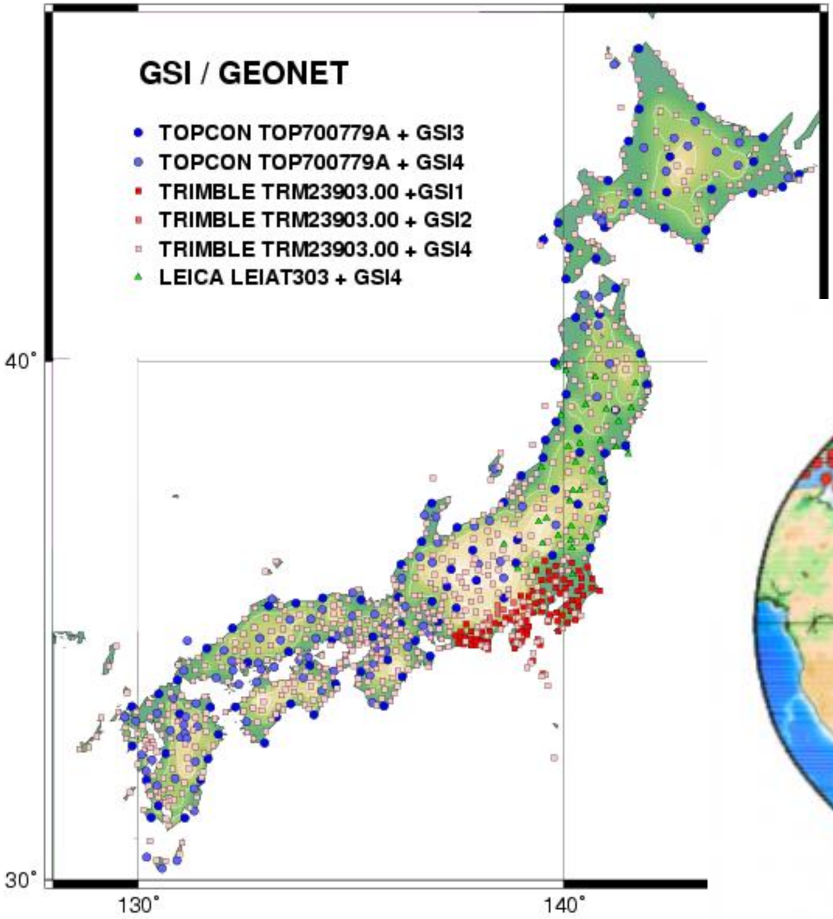
- **R**eal-Time **E**arthquake **A**nalysis for **D**isaster m**I**tigation network (READI): ~550 GPS stations
- Super set of GPS networks maintained by (sorted according to largest to smallest number of stations):
  - UNAVCO/PBO
  - USGS (Pasadena and Menlo Park)
  - UC Berkeley
  - Scripps Institution of Oceanography
  - California Department of Transportation



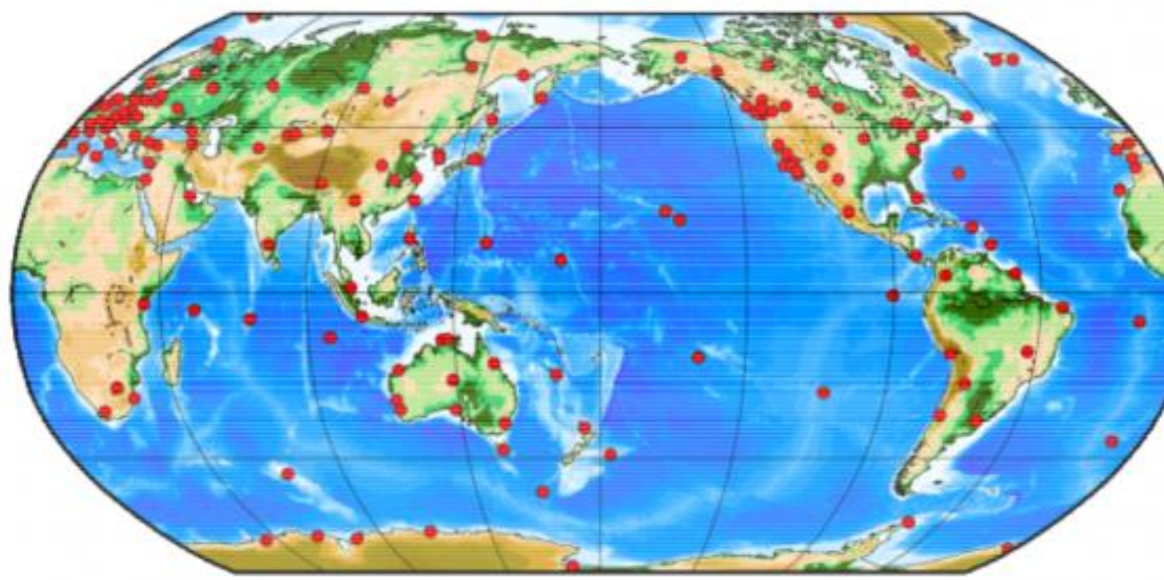
Over 3,000 Pacific Basin GNSS Stations

Earthscope Plate Boundary Observatory





GGOS/IGS Real-TimeNetwork



What's Needed to Move This Forward

1. Lead by example.
   - Continue demonstration/prototyping efforts by READI group and NOAA Pacific Tsunami Warning Center
   - Provide for open access to US real-time GNSS data
   - Evaluate existing US GNSS networks (i.e., the EarthScope PBO network) and how they might evolve to better support such a capability. Use simulations to study optimum network density, location and communications.

2. Engage the international community.
   - Use international organizations and fora, such as APEC and GGOS, as well as bilateral discussions to encourage the nations of the Indo-Pacific in the creation of an Indo-Pacific GNSS Disaster Early Warning Network:
     - ✓ Through the sharing of real time GNSS data;
     - ✓ Analyzed by multiple regional analysis centers;
     - ✓ Under the scientific leadership of the Global Geodetic Observing System.