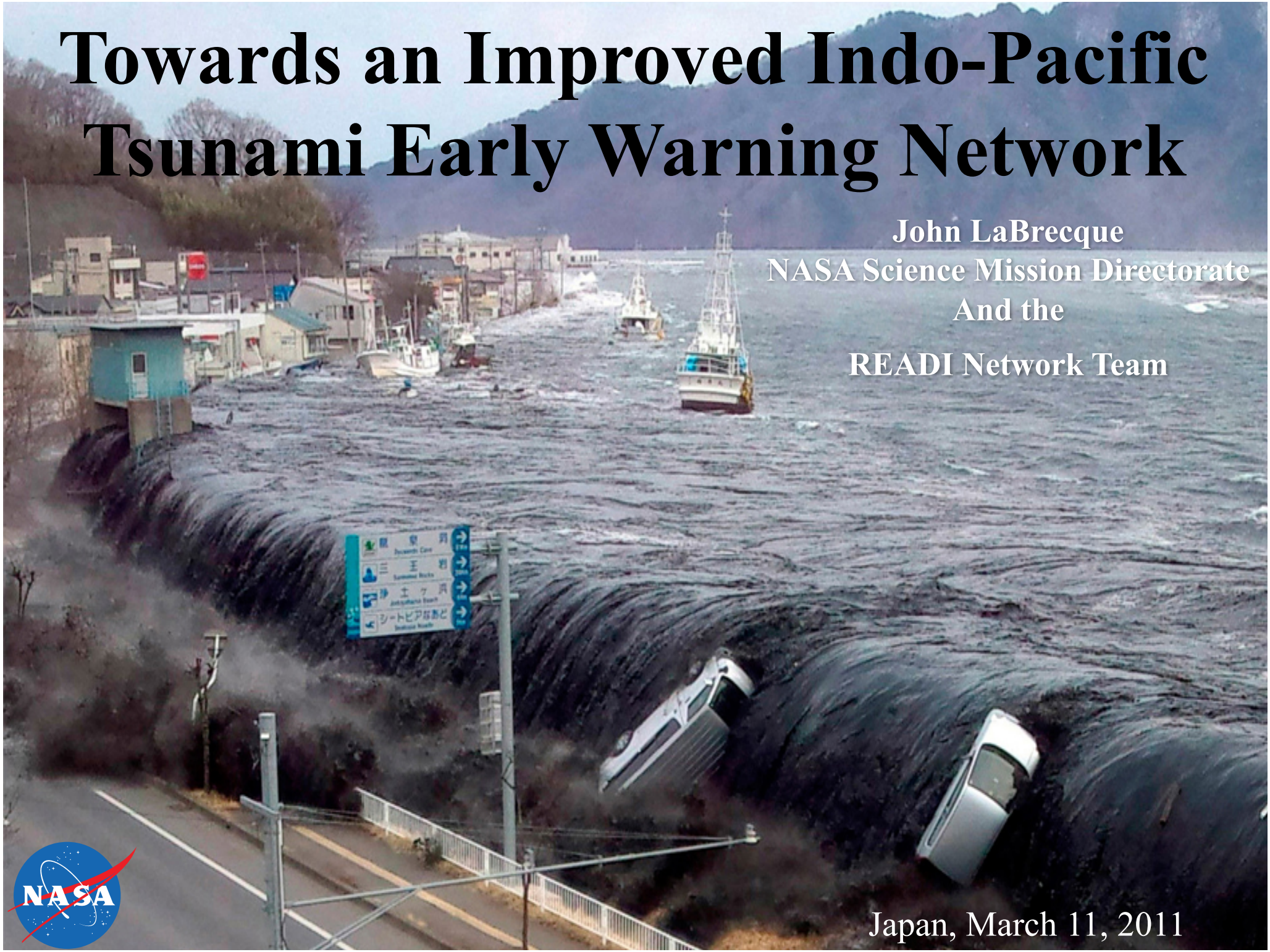

Banda Aceh, December 26, 2004

# Towards an Improved Indo-Pacific Tsunami Early Warning Network

John LaBrecque
NASA Science Mission Directorate
And the
READI Network Team

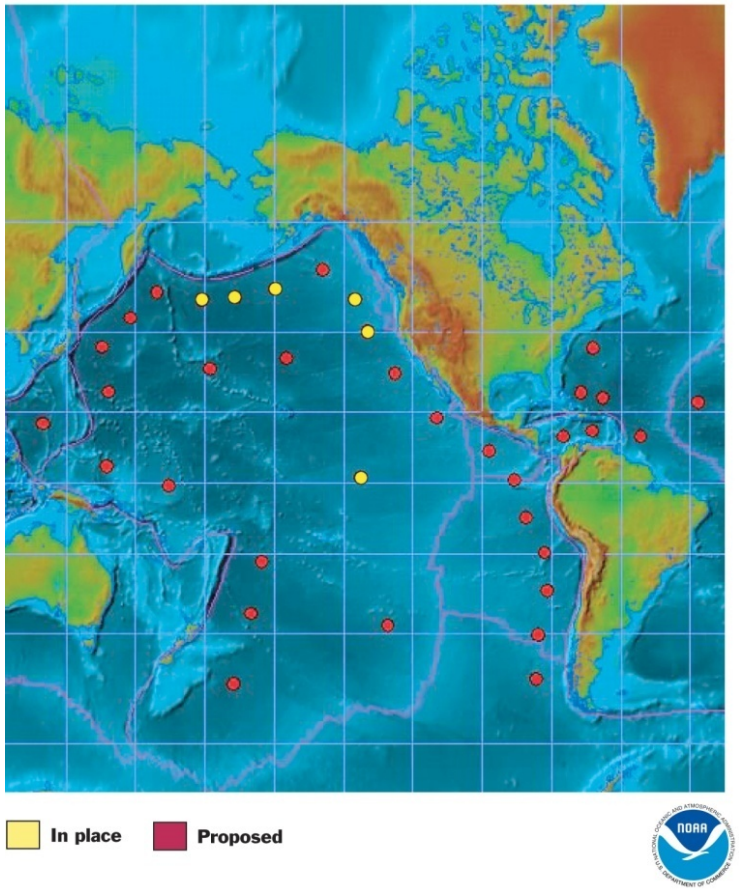


# Current Tsunami Warning System

**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 |

**Proposed DART Buoy System**




Unfortunately,

1. Earthquake magnitude is not a good indicator of a resulting tsunami;
2. DART system has inherent delays.
3. Seismic Mw estimates require at 20 minutes or more

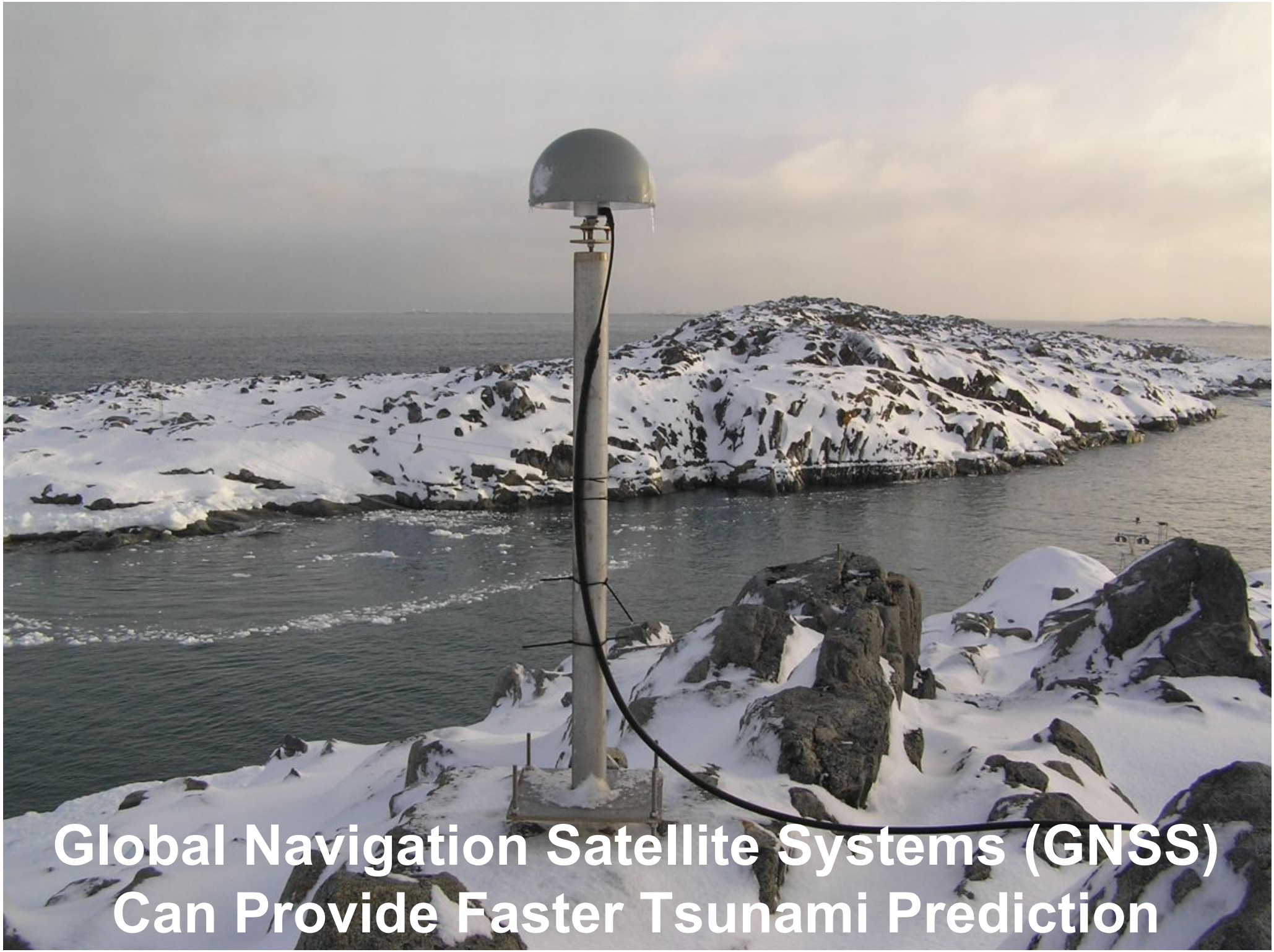
# Proposed: Indo-Pacific GNSS Disaster Early Warning Network

**Pacific Basin Earthquakes and Volcanic Eruptions pose regional hazards 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.**

**Dense GNSS regional networks are being deployed within the circum-Pacific and on Pacific Islands.**

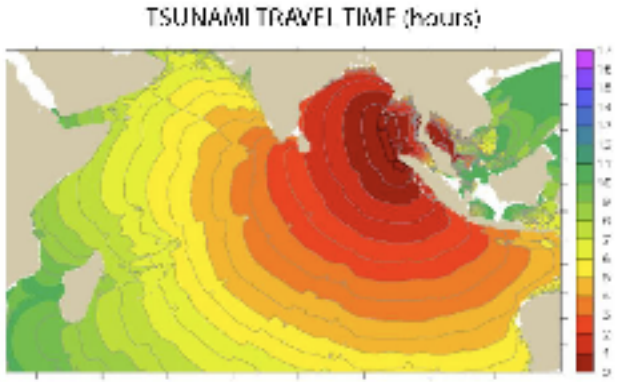
**Communication infrastructure is available for near real time GNSS data distribution either continuous or event responsive.**

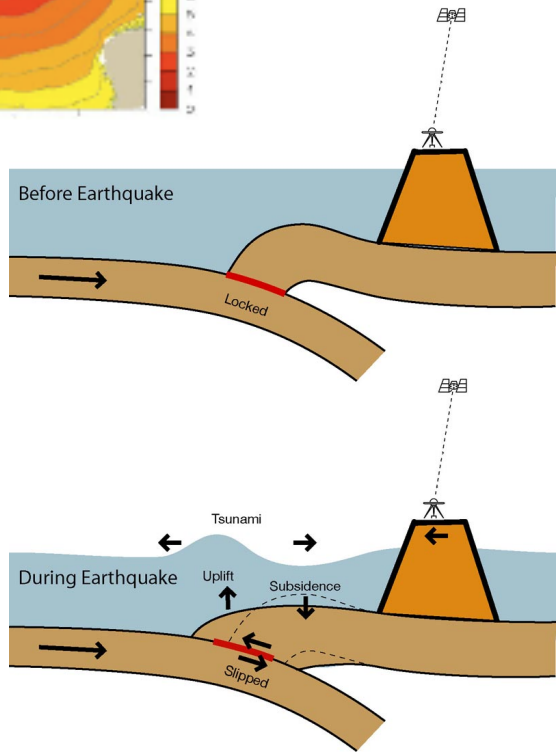


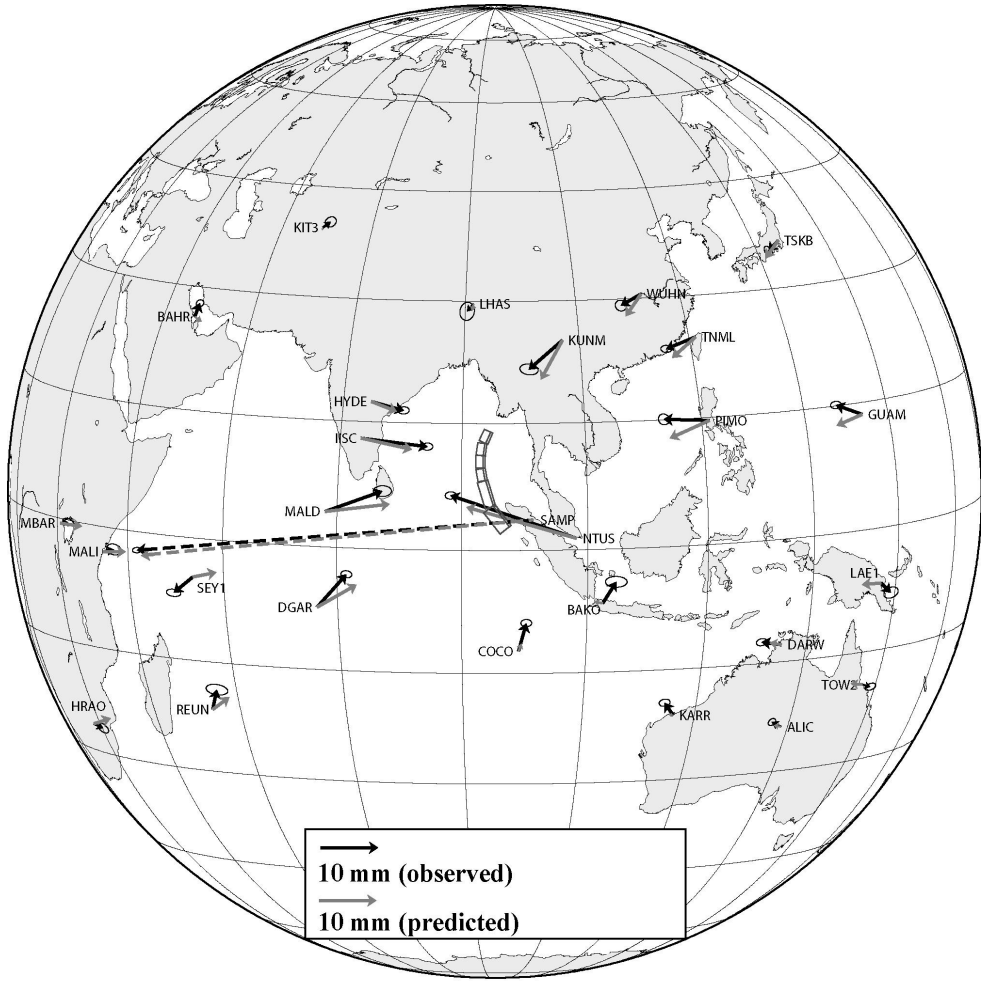
# Global Navigation Satellite Systems (GNSS) Can Provide Faster Tsunami Prediction

# 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 before the seismic analysis-

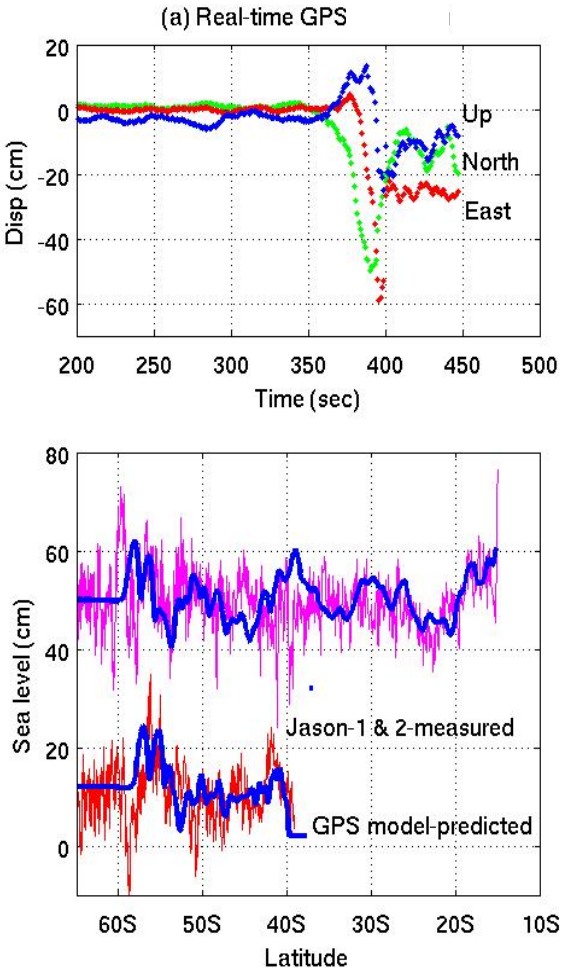


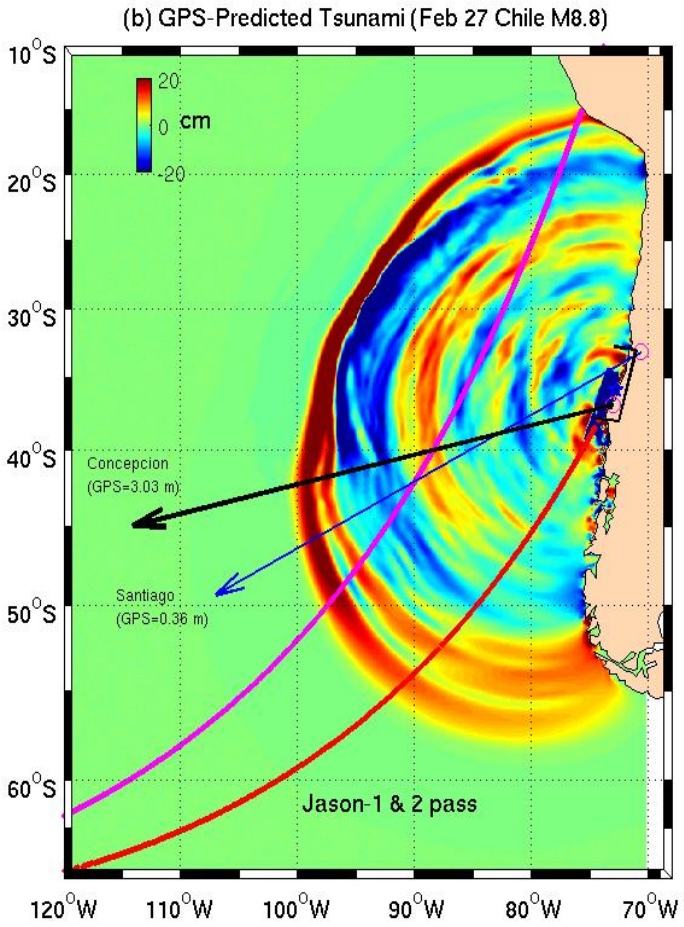




GPS station displacements on 26 December, 2004 observed by the International GNSS Service Network (IGS/GGOS). The largest arrow (SAMP) has been scaled down by a factor of two for clarity. Ref: Blewitt, Hammond, Kreemer, Plag, Stein, Okal, 2009,J. Geodesy.

# 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.**

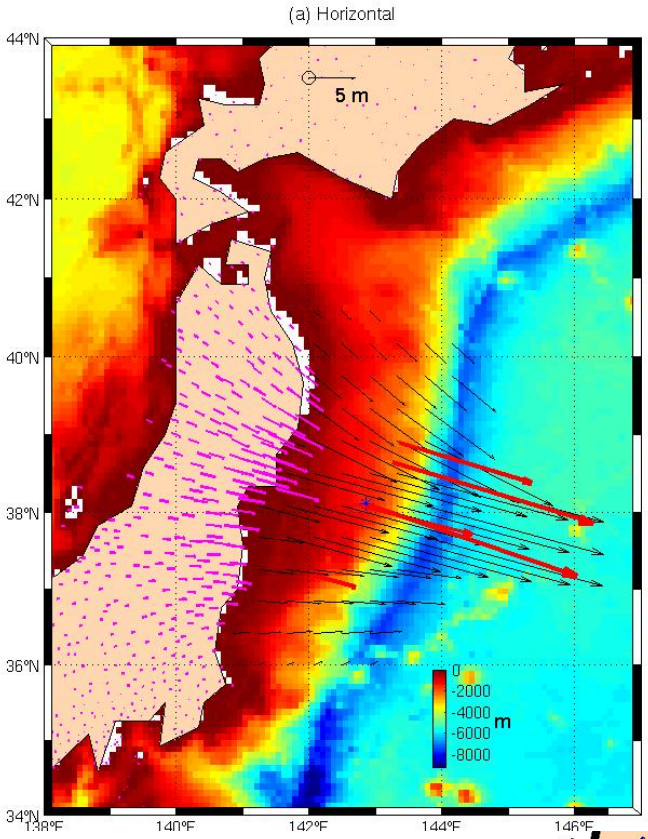
**(c): NASA/CNES satellites Jason-1 and Jason-2 confirm the tsunami amplitude prediction of the GPS-based model prediction.**

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

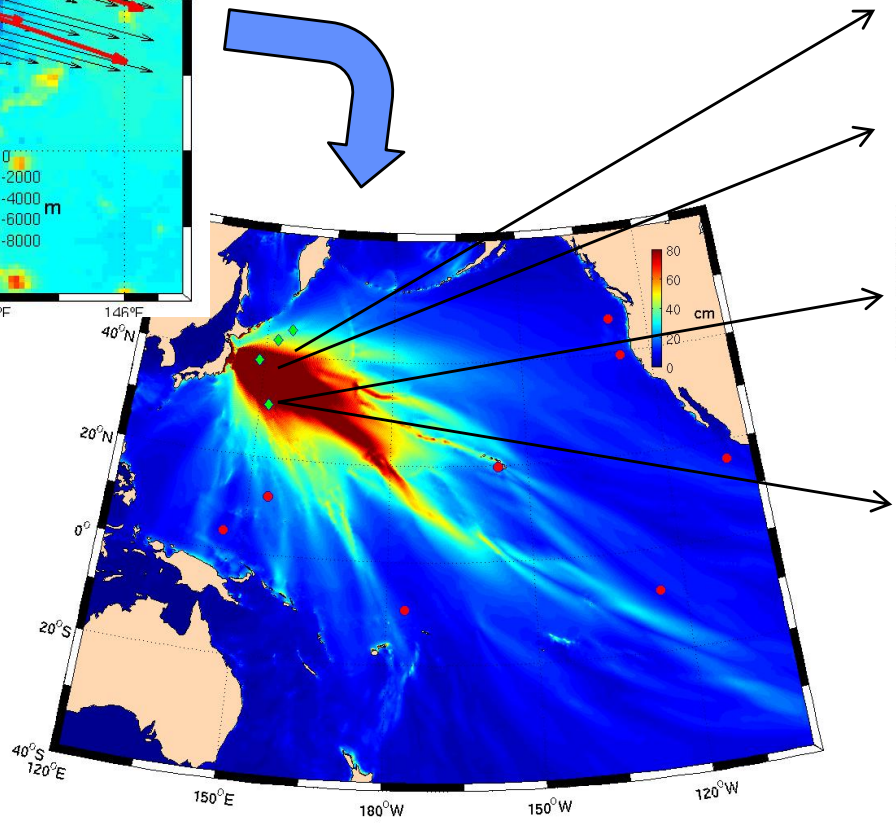
**Tony Song , Yoaz Bar-Sever, et al. /JPL**

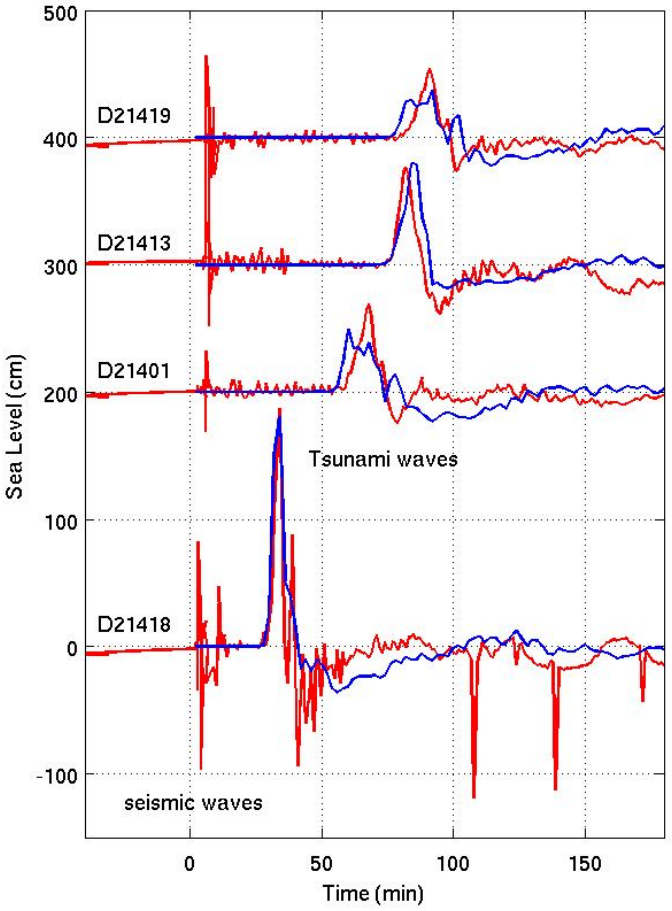
**Song Y.T., 2007, Detecting tsunami genesis and scales directly from coastal GPS Stations, Geophys Res. Ltts.**

# The 2011 Tohoku-Oki Tsunami



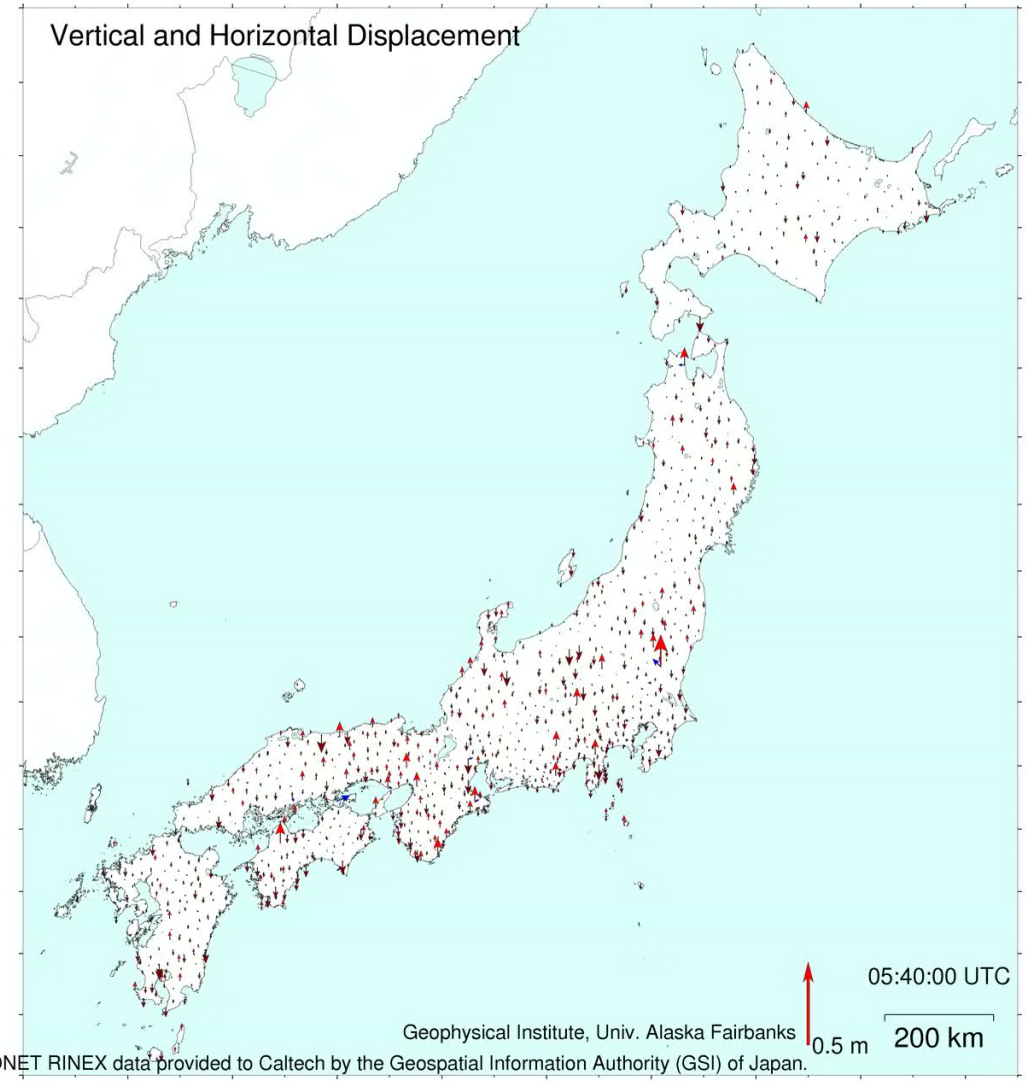

There are about 1,200 GPS stations (GeoNet) on Japanese Islands. Study shows that they were capable of predicting the tsunami and could have saved more lives if were used (Song et al., GRL, 2012).



# 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**

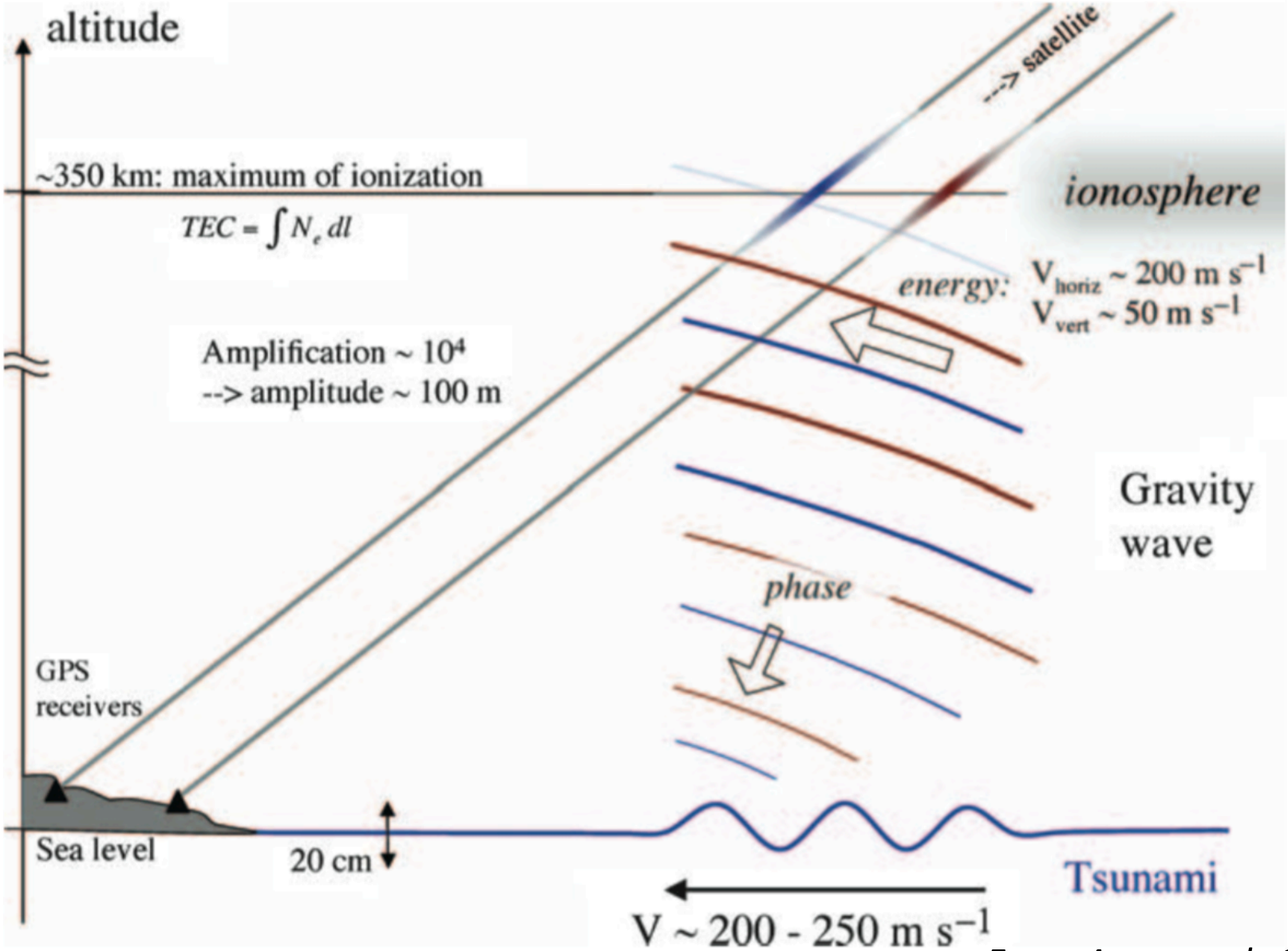




Preliminary GPS time series provided by the ARIA team at JPL and Caltech. All original GEONET RINEX data provided to Caltech by the Geospatial Information Authority (GSI) of Japan.

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

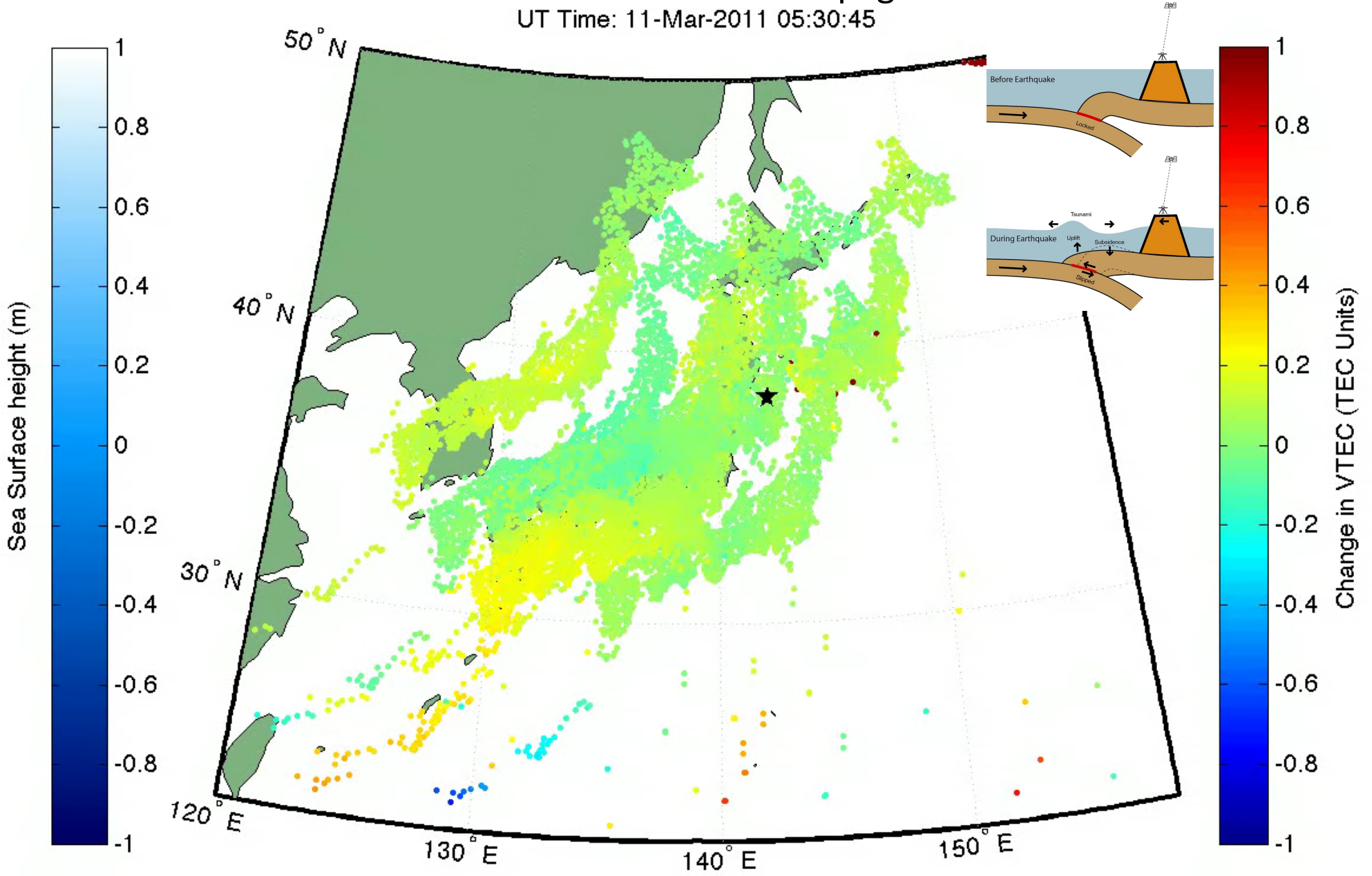

Global Navigation Satellite Systems (GNSS)
Can Track Tsunamis Across the Indo-Pacific

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




From *Artru et al.,* 2005

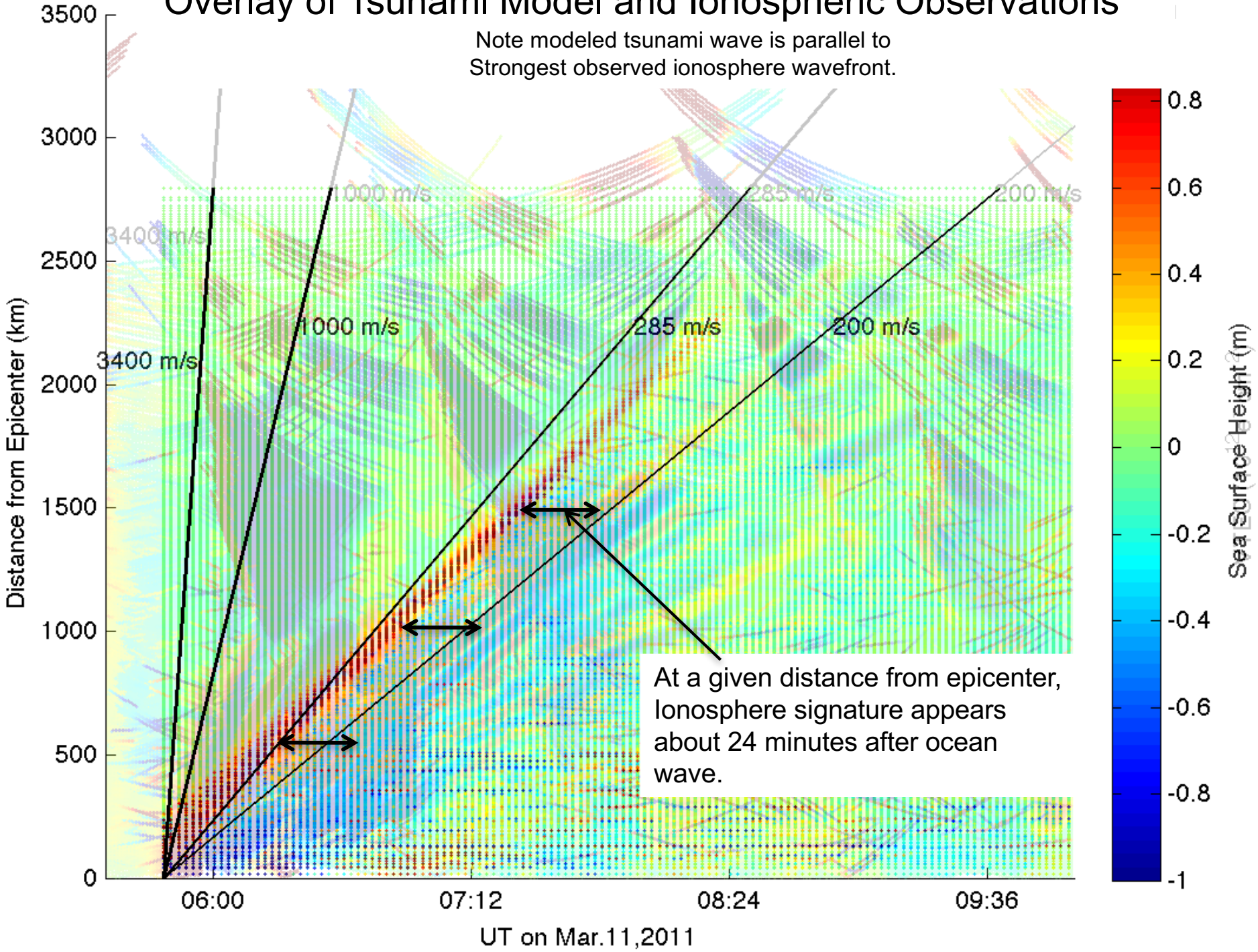
# GSI's GEONET Also Captured the Ionospheric Coupled Waves and Imaged the Tsunami Generation and Propagation-For the First Time




**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

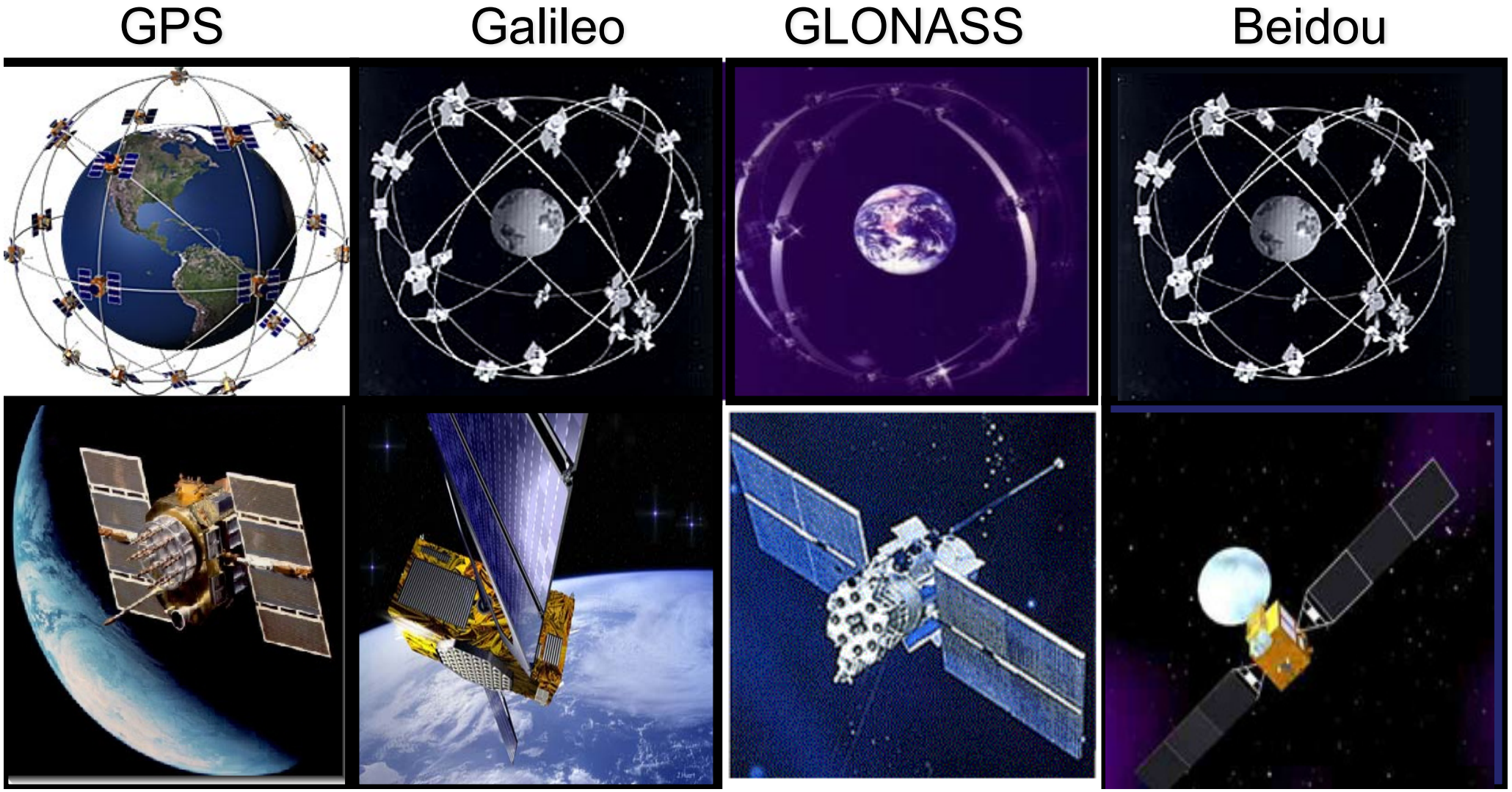
Note modeled tsunami wave is parallel to
Strongest observed ionosphere wavefront.




From the work of Song, Galvan, Komjathy, JPL


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

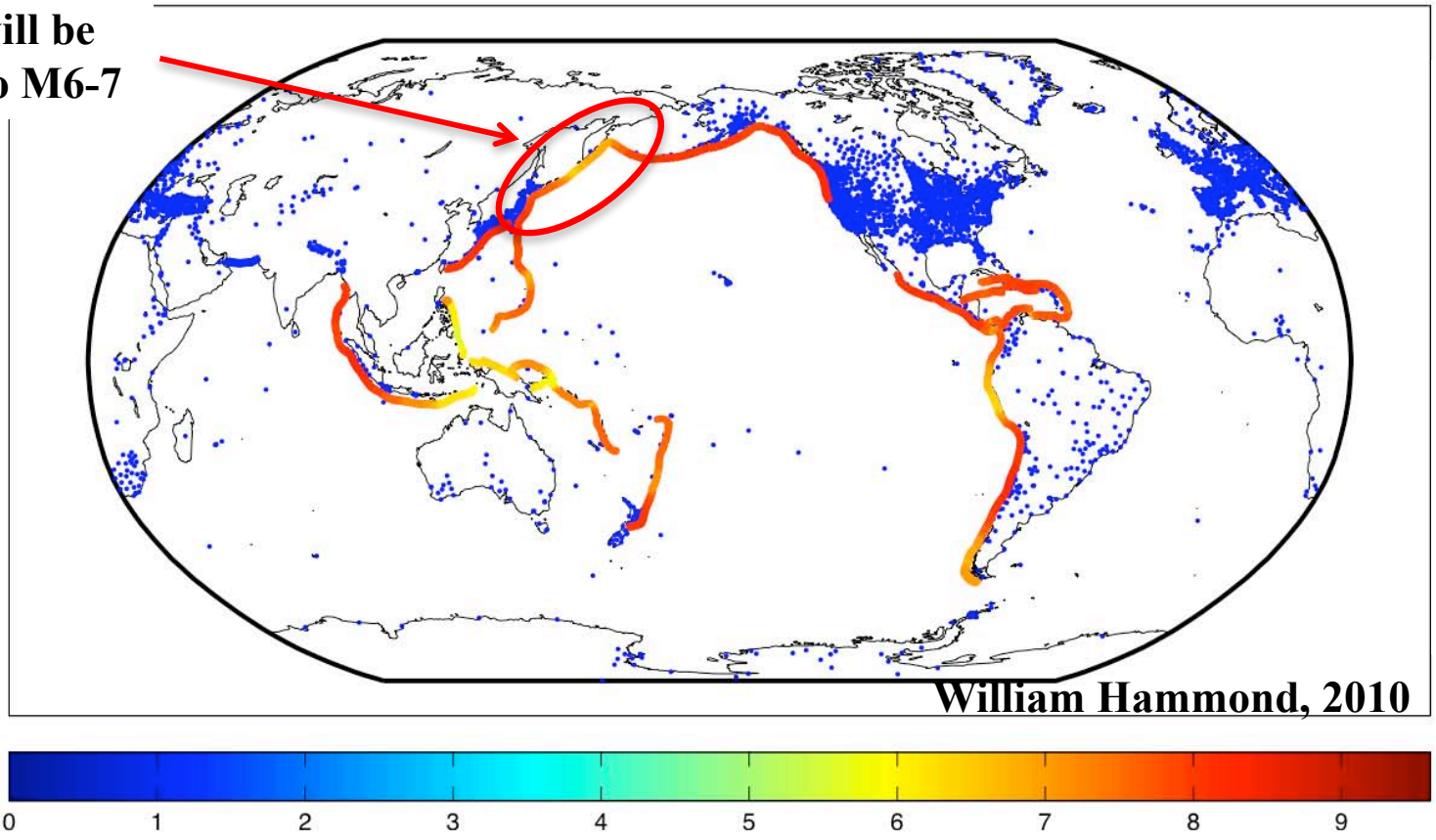
# The Global Navigation Satellite System (GNSS) constellations will increase to over 110 satellites by 2020



# Tsunami Prediction Capability of the Current Network

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

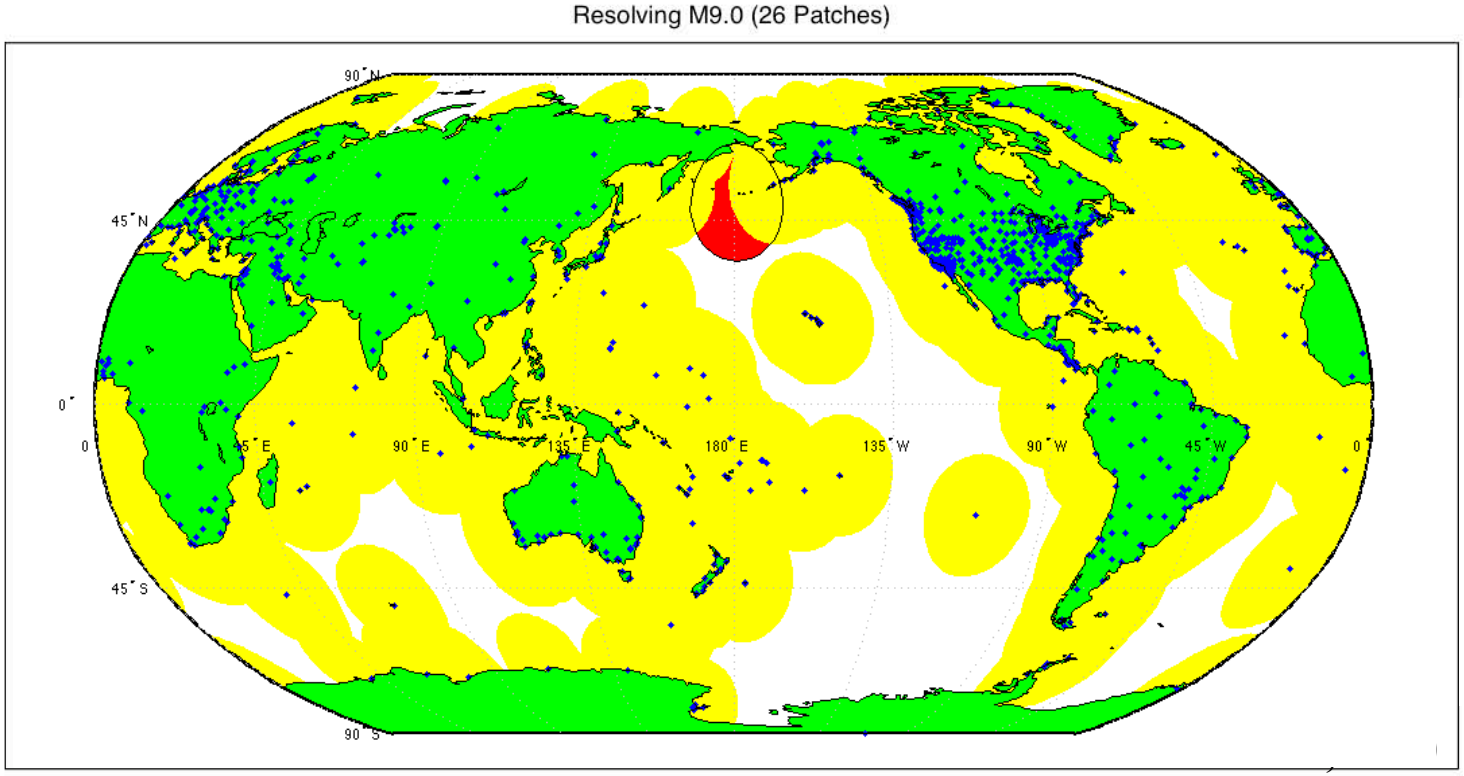
**M9 earthquake will be under-resolved into M6-7**




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

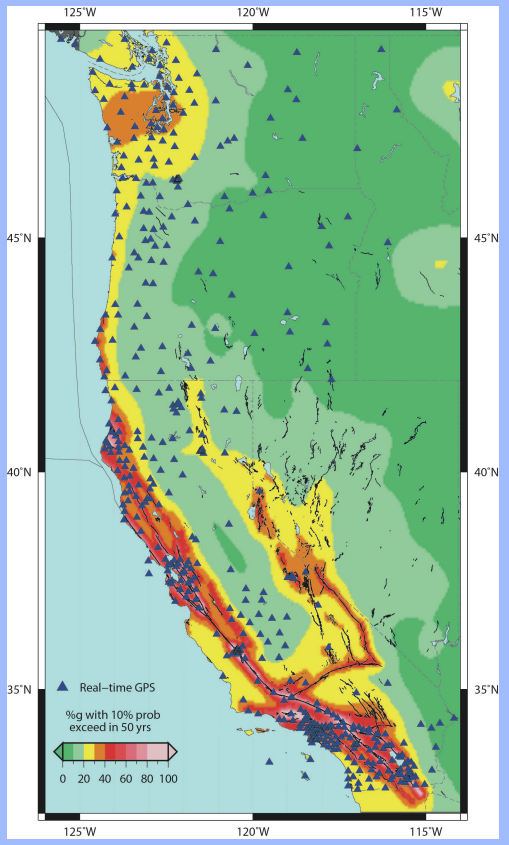
## Assumes 10 degree elevation and the Ionospheric shell at 450 km




Red zone is only circum-Pacific gap in coverage.

# The READI Working Group

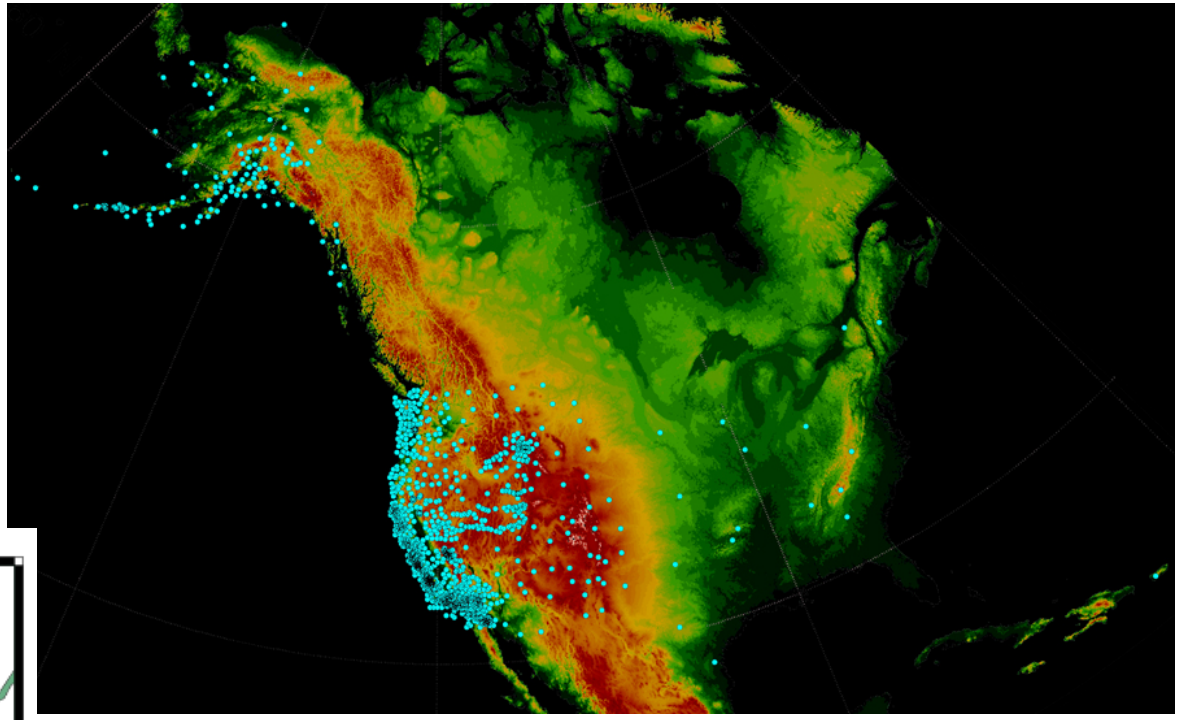
- **R**eal-Time **E**arthquake **A**nalysis for **D**isaster m**I**tigation network (READI): ~550 GPS stations
- Super set of GPS networks maintained by (sorted according to largest to smallest number of stations):
  - UNAVCO/PBO
  - USGS (Pasadena and Menlo Park)
  - UC Berkeley
  - Scripps Institution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

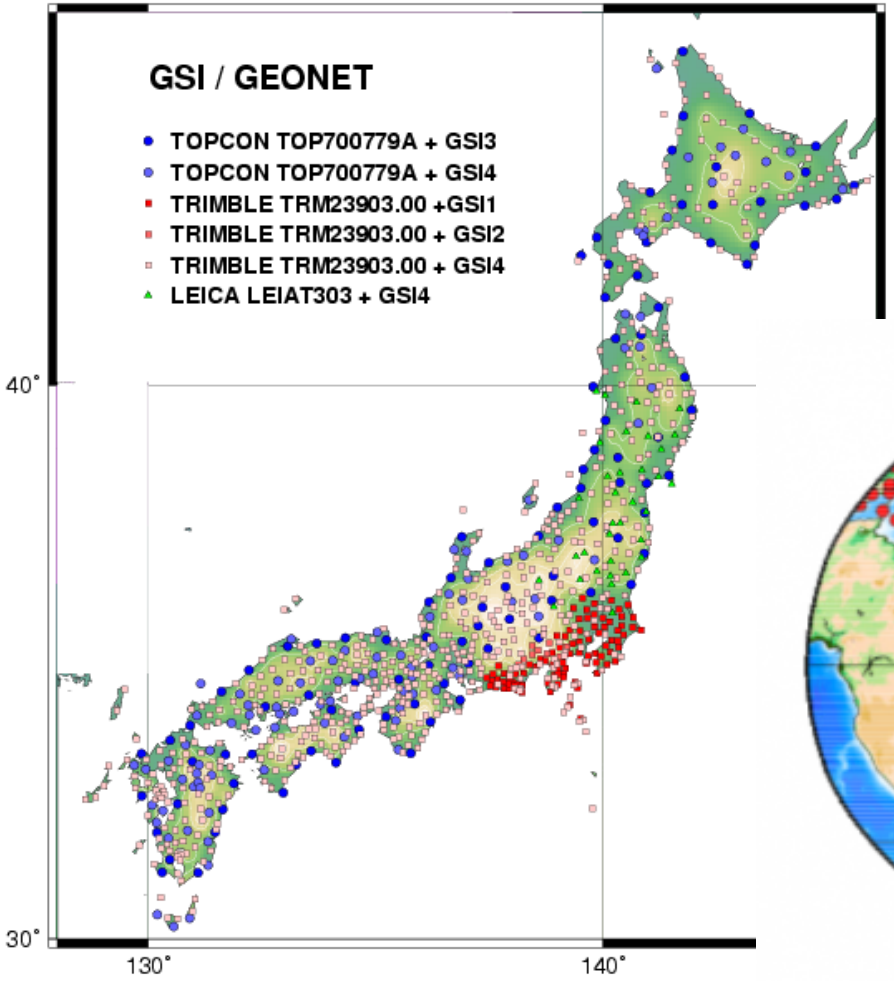



Jet Propulsion Laboratory
California Institute of Technology

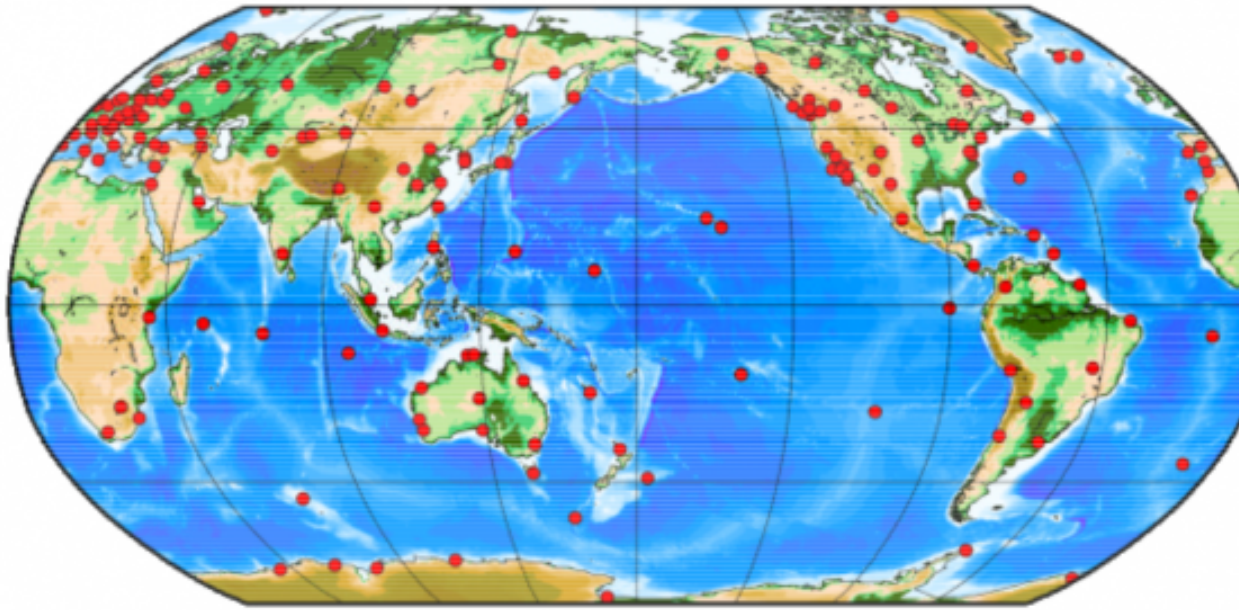
# Over 3,000 Pacific Basin GNSS Stations

Earthscope Plate Boundary Observatory






GGOS/IGS Real-TimeNetwork



# Towards and Indo-Pacific Disaster Early Warning Network

Recognizing: During the past decade large earthquakes and resulting tsunamis have claimed hundreds of thousands of lives and billions in national treasures of the Indo-Pacific region.

Recognizing: These large earthquakes and resulting tsunamis are regional and international in the extent of their impacts.

Recognizing: Significant new developments in real time GNSS technology and infrastructure have demonstrated rapid characterization of earthquakes, the prediction of tsunami potential and observation and tracking of tsunamis.

Recognizing: Significant ground network GNSS infrastructure is in place within the Indo-Pacific region.

We recommend that the APEC 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;
- Analysed by multiple regional analysis centers;
- Under the scientific leadership of the Global Geodetic Observing System.