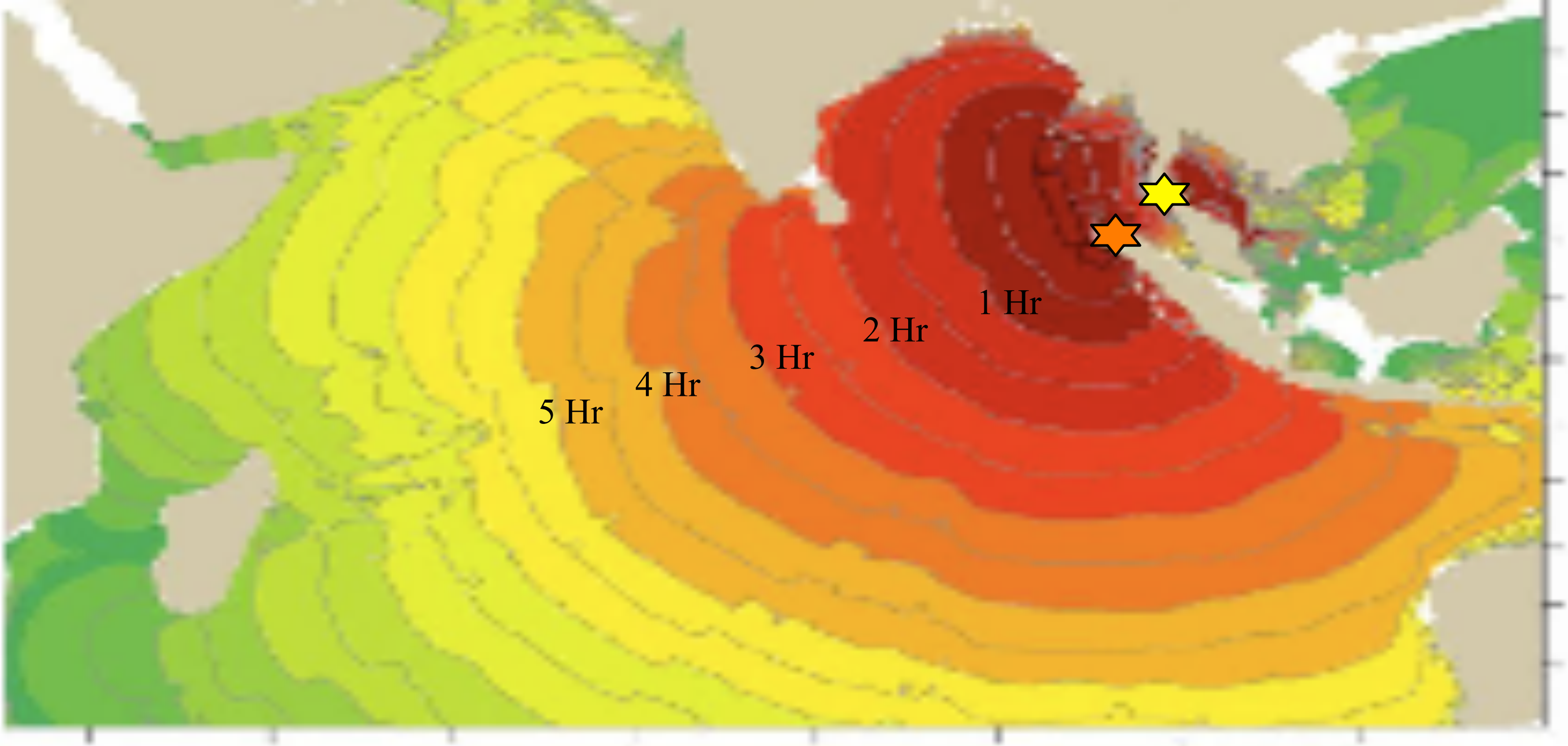
# GNSS Augmentation to the Tsunami Early Warning System (GTEWS)

**John LaBrecque**
**GGOS Geohazards Monitoring Focus Area**

Phuket Island, Thailand
December 26, 2004

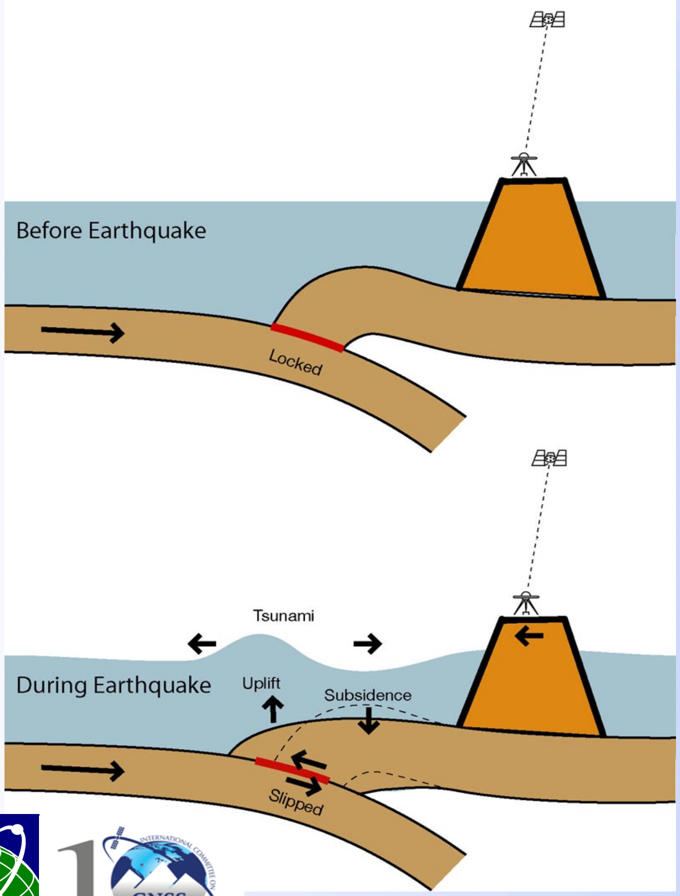



The 2004 Indian Ocean Tsunami claimed 250,000 lives with little warning.

# Three Studies of the 2004 Sumatra–Andaman Earthquake Recognized the Value of Regional GNSS Real Time Networks for Mega-Thrust Earthquakes

Analysis of IGS GPS network data in real time would have warned of the 2004 Indian Ocean Tsunami within 15 minutes- days before the long period seismic analysis provided an equally accurate assessment.

- Blewitt et al. 2006, Rapid determination of earthquake magnitude using GPS for tsunami warning systems
- Sobolev et al, 2007, Tsunami early warning using GPS Shield arrays
- Song et al, 2007, Detecting tsunami genesis and scales directly from coastal GPS stations





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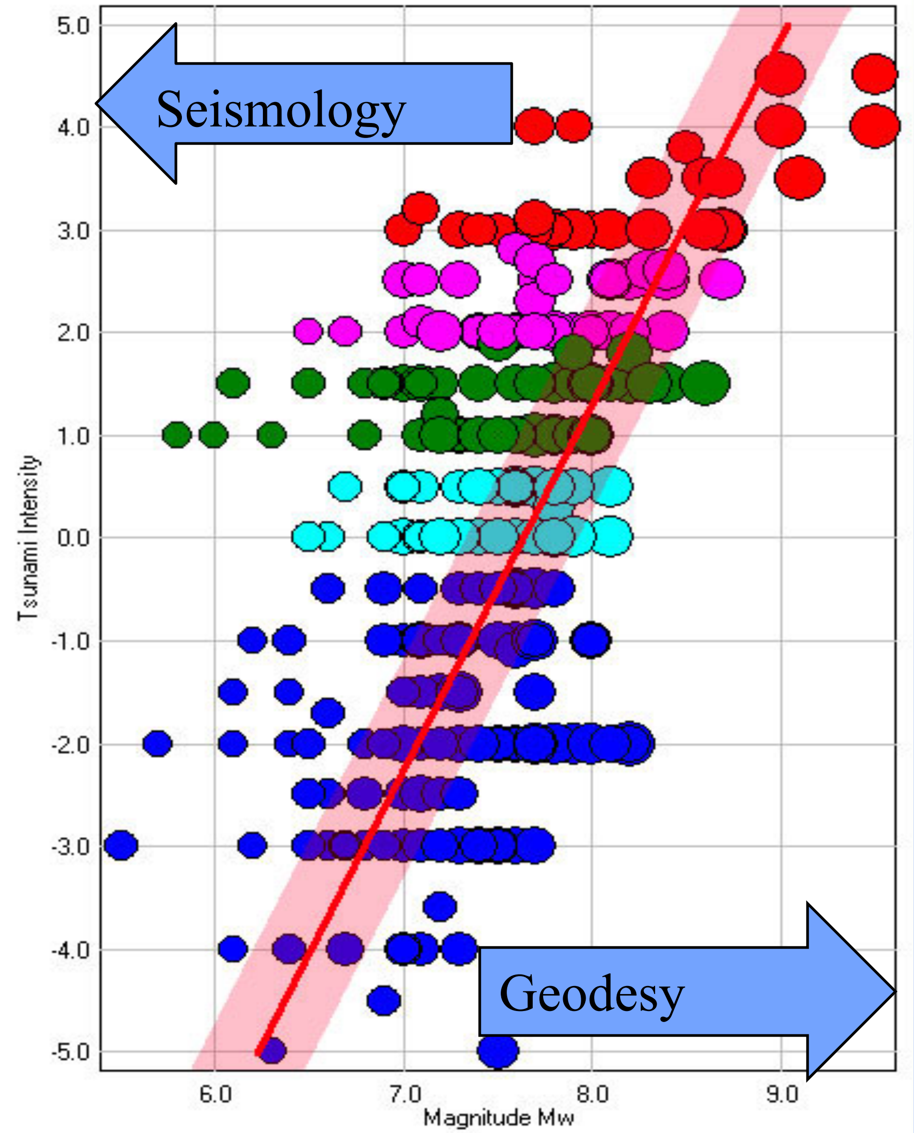


**Global Tsunami Magnitude (on Soloviev-Imamura scale) vs Earthquake Moment Magnitude since 1900 (from-Gusiakov, 2015)**

# Why GNSS Augmentation? Because Minutes Matter

**For mega-thrust earthquakes GNSS augmentation can provide accurate and timely input to tsunami warning models for both the epicenter near and far fields.**

- **GNSS provides accurate position and velocity of ground displacements**
- **GNSS accurately measures ionospheric dynamics (changes in Total Electron Content)**
- **Accurate inversions for earthquake moment magnitude take less than 3 minutes**
- **GNSS constellations and real time networks undergoing significant development**

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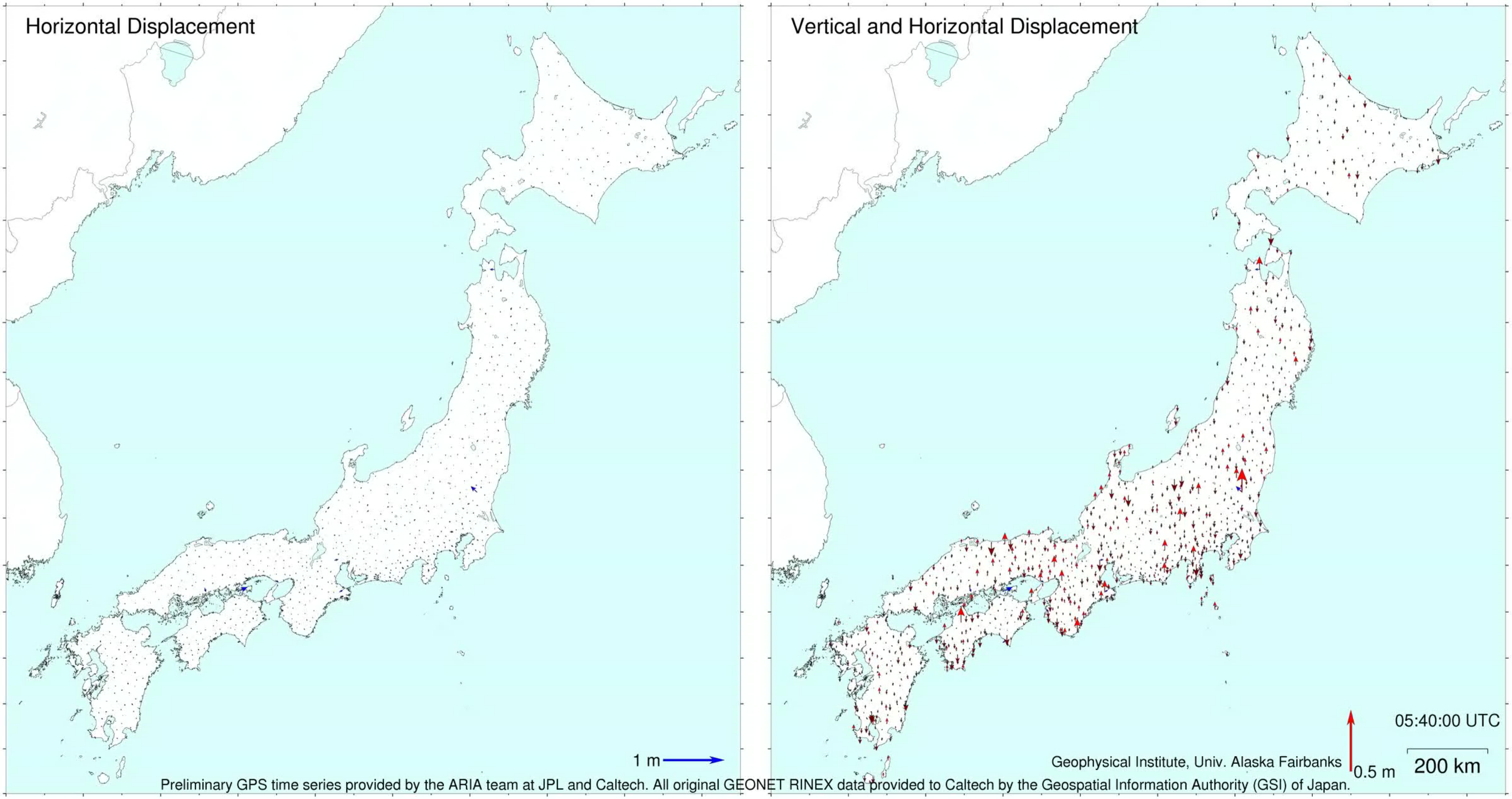
# The GTEWS Augmentation Will:

- Provide accurate tsunami warnings within minutes in the near field
- Provide tsunami tracking up to two hours prior to land fall in the far field.
- Build upon the General Assembly resolution***, A Global Geodetic Reference Frame for Sustainable Development*** and the UNGGIM
- Build upon **ICG/IGMA**, **IGS/RT** and **IGS/MGEX** initiatives

# The GTEWS Augmentation Endorsements:

- International GNSS Service, Pasadena, 2014
  http://kb.igs.org/hc/en-us/articles/204125433-2014-IGS-Workshop-Summary-Recommendations
- Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System -Honolulu, 2015
  http://www.ioc-tsunami.org/index.php?option=com_oe&task=viewDocumentRecord&docID=15449
- International Union for Geodesy and Geophysics-Prague, 2015
  http://www.iugg.org/resolutions/IUGGResolutions2015.pdf
- Asia-Pacific Space Geodynamics Project-Moscow, 2015
  *http://agora.guru.ru/display.php?conf=apsg-2015&page=item004&PHPSESSID=ulifq5u9fi4o8retibdl1fu3b3*

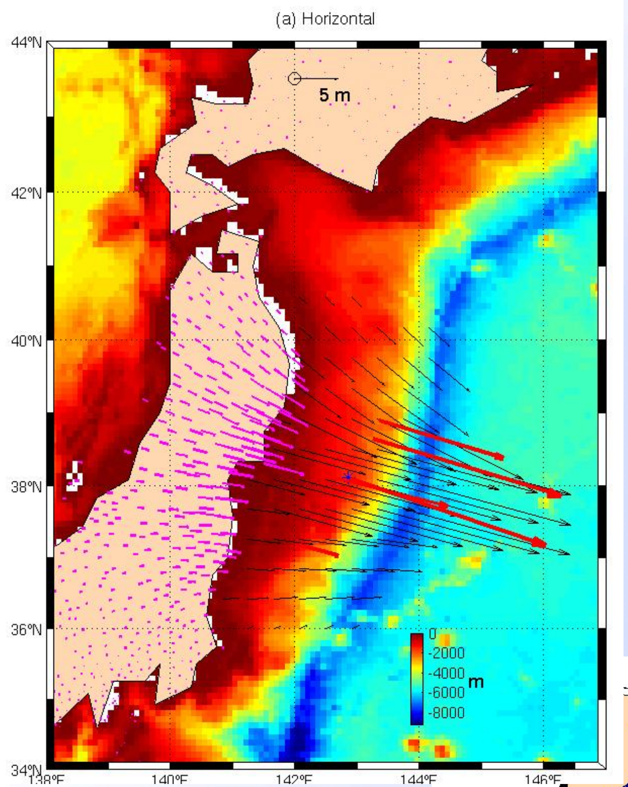
# Response of the Geospatial Information Authority of Japan (GSI) GEONET GPS Network to the March 11, 2011 Tohoku-Oki Earthquake

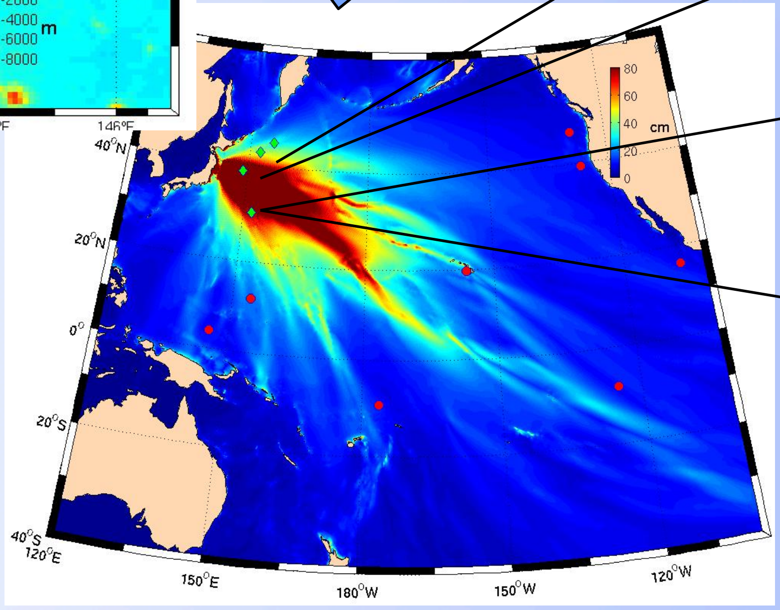


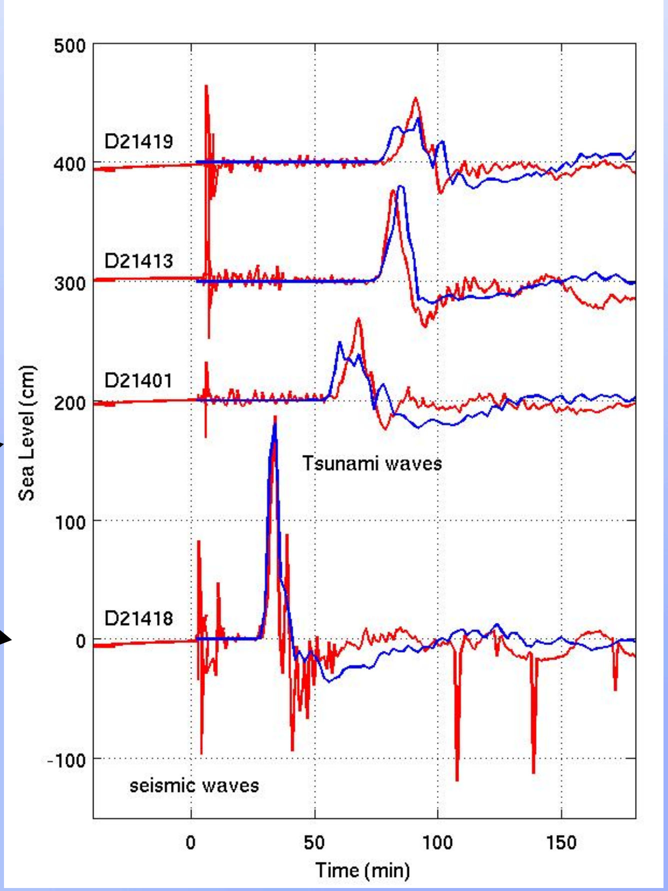

http://gps.alaska.edu/ronni/sendai2011.html: Ronni Grapenthin

# The 2011 Tohoku-Oki Tsunami: Prediction

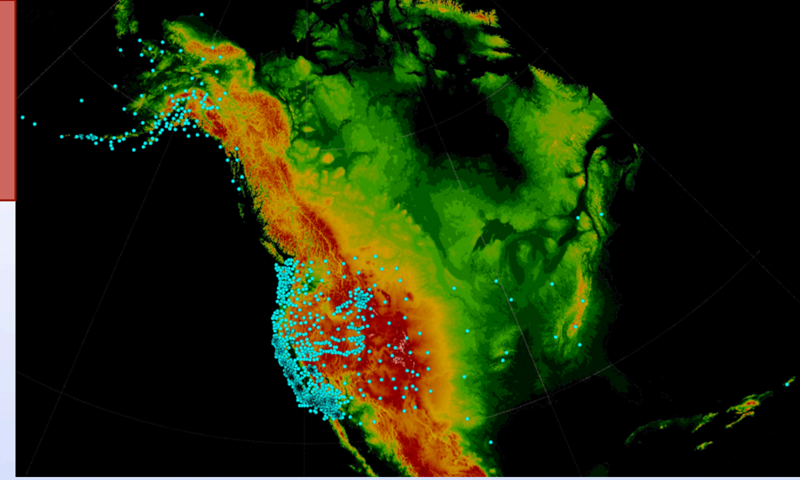
**Hindcast studies emplying a subset of the 1,300 receiver GeoNet data demonstrate that an accurate earthquake magnitude and tsunami predictions could be provided within 4 minutes (e.g. Song et al., 2012, Ohta et al., 2012, Melgar et al, 2012).**



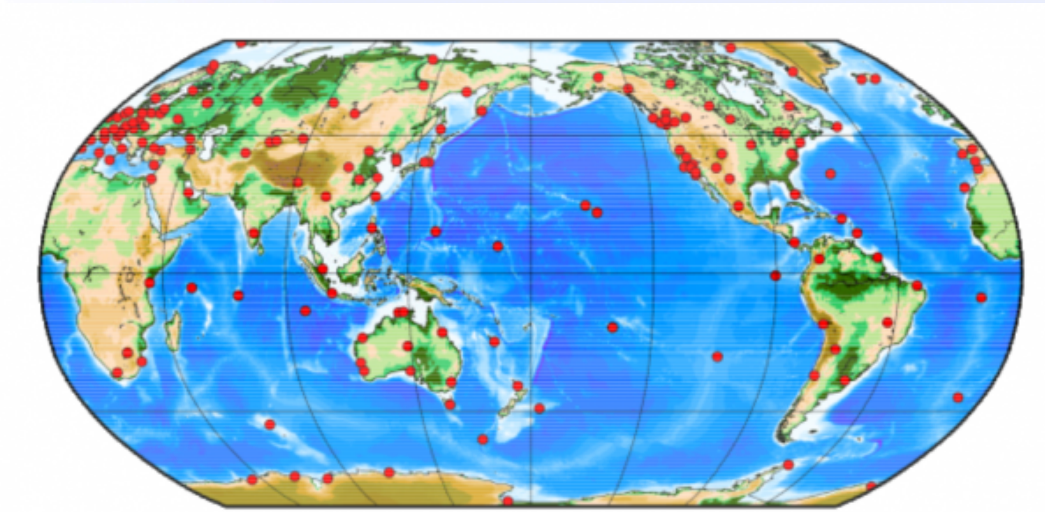



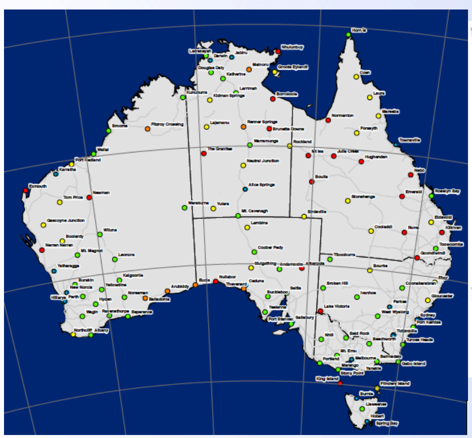
# Over 3,000 Real Time Indo-Pacific GNSS Stations



Earthscope Plate Boundary Observatory



GGOS/IGS  Real-Time Network



Australian Real-Time
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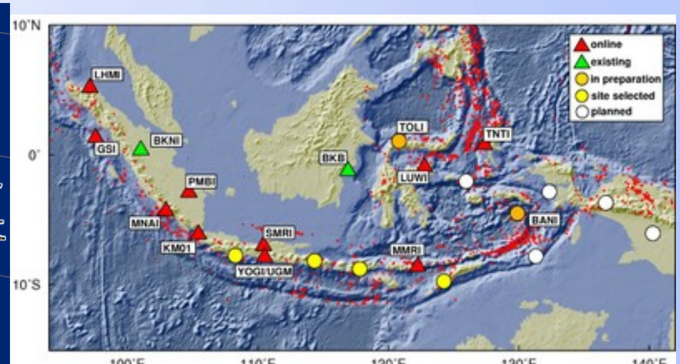
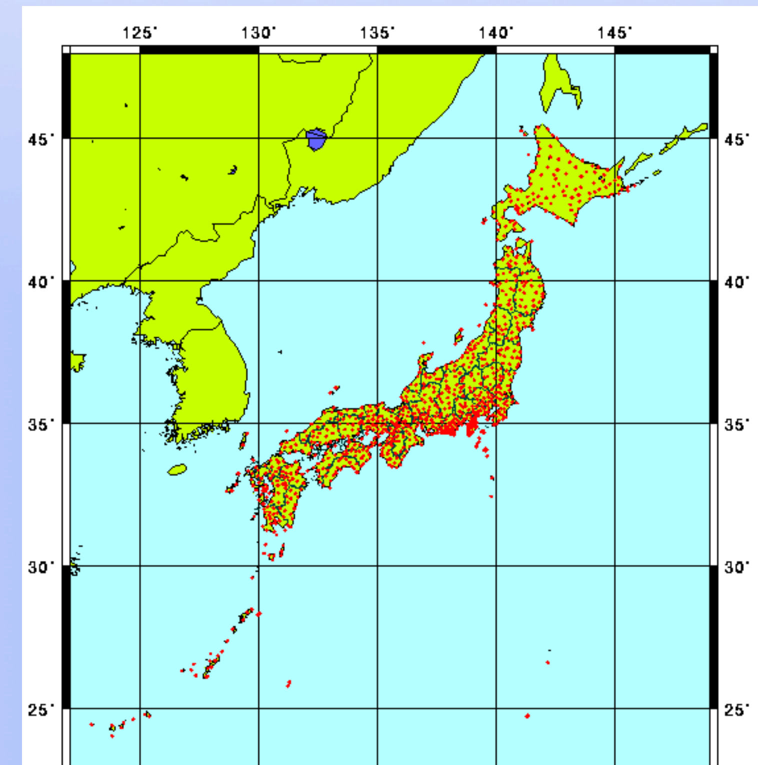
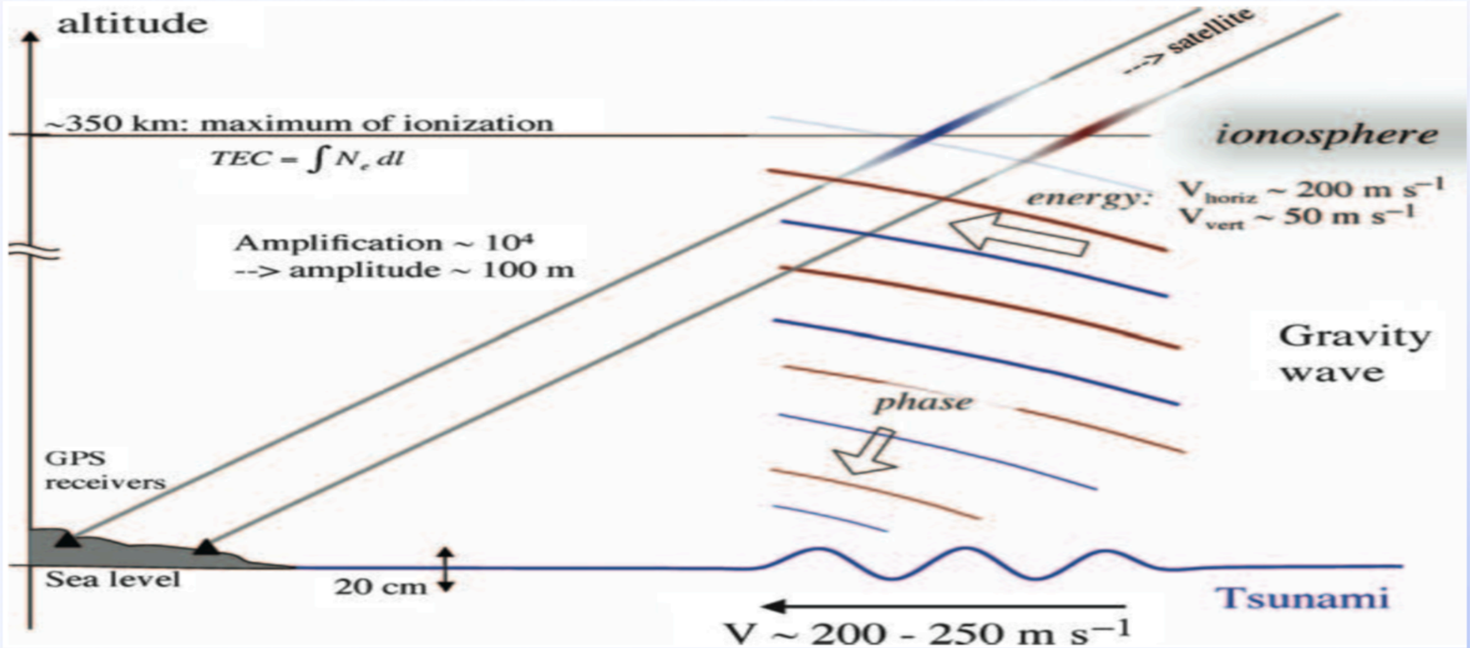



German-Indonesian Tsunami Early Warning (GITEWS)

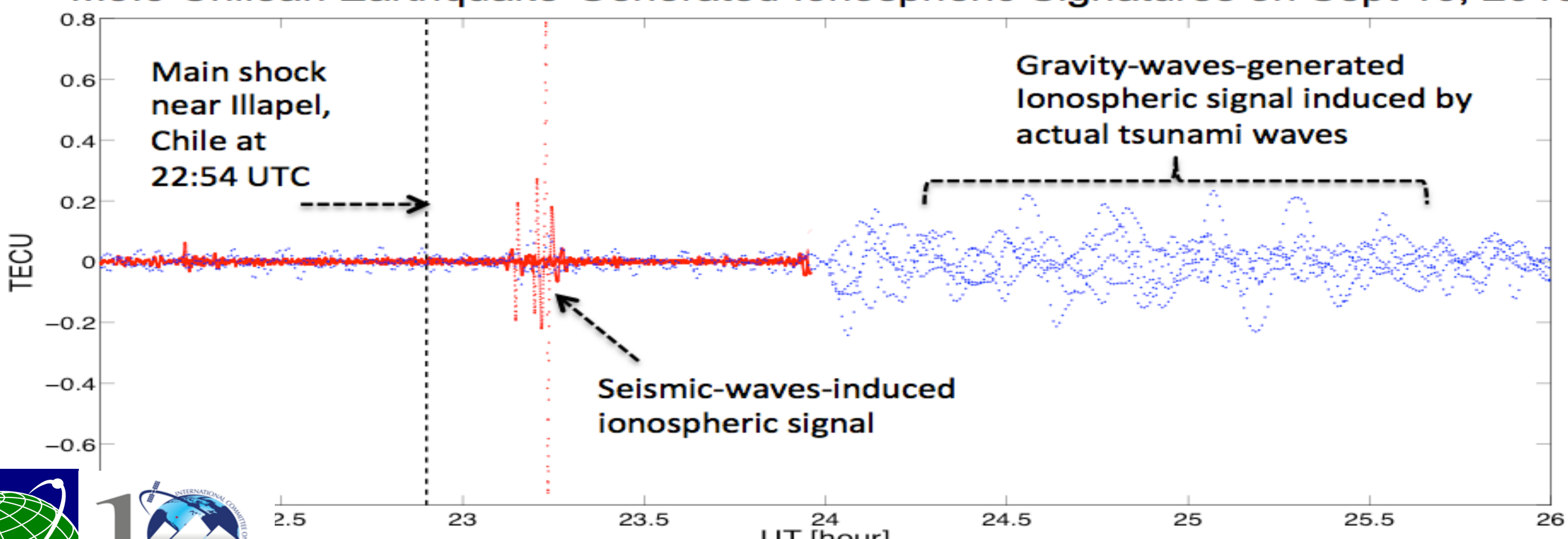



The GSI GEONET

# Tracking Tele-Tsunamis Using Coupled Ionospheric Waves

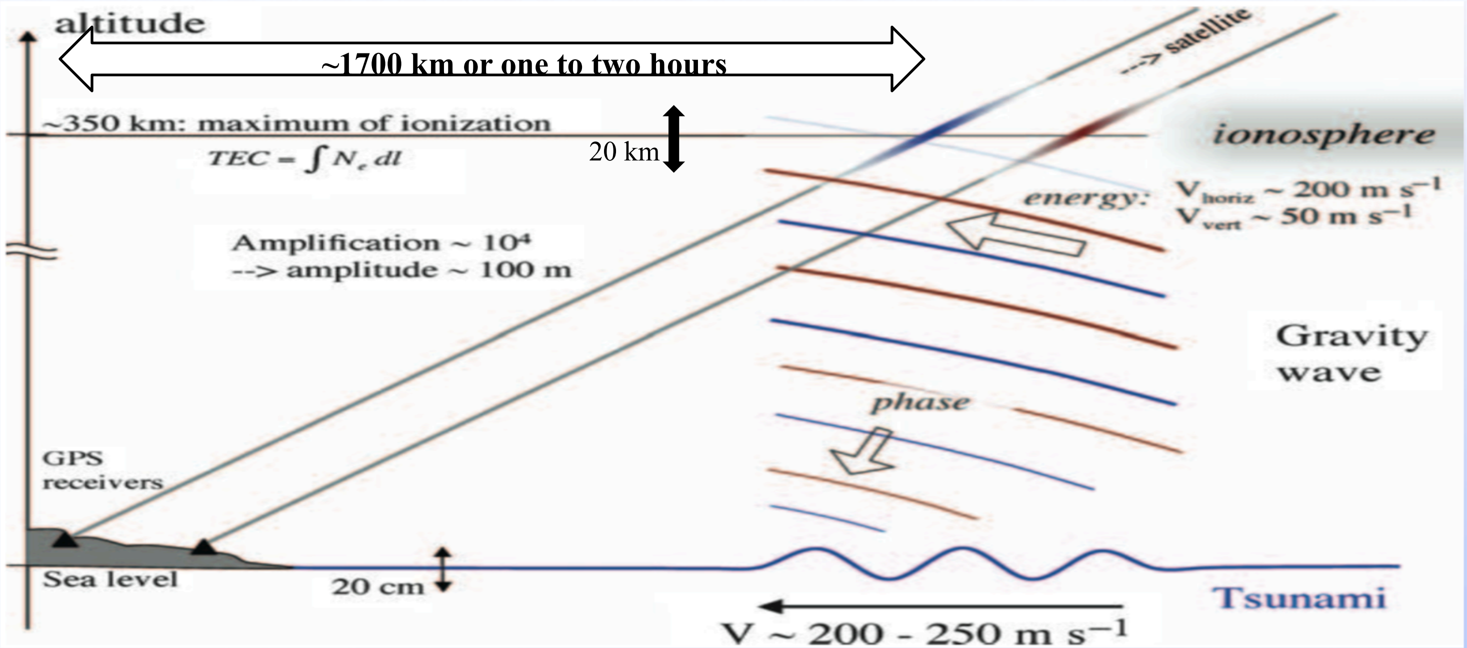


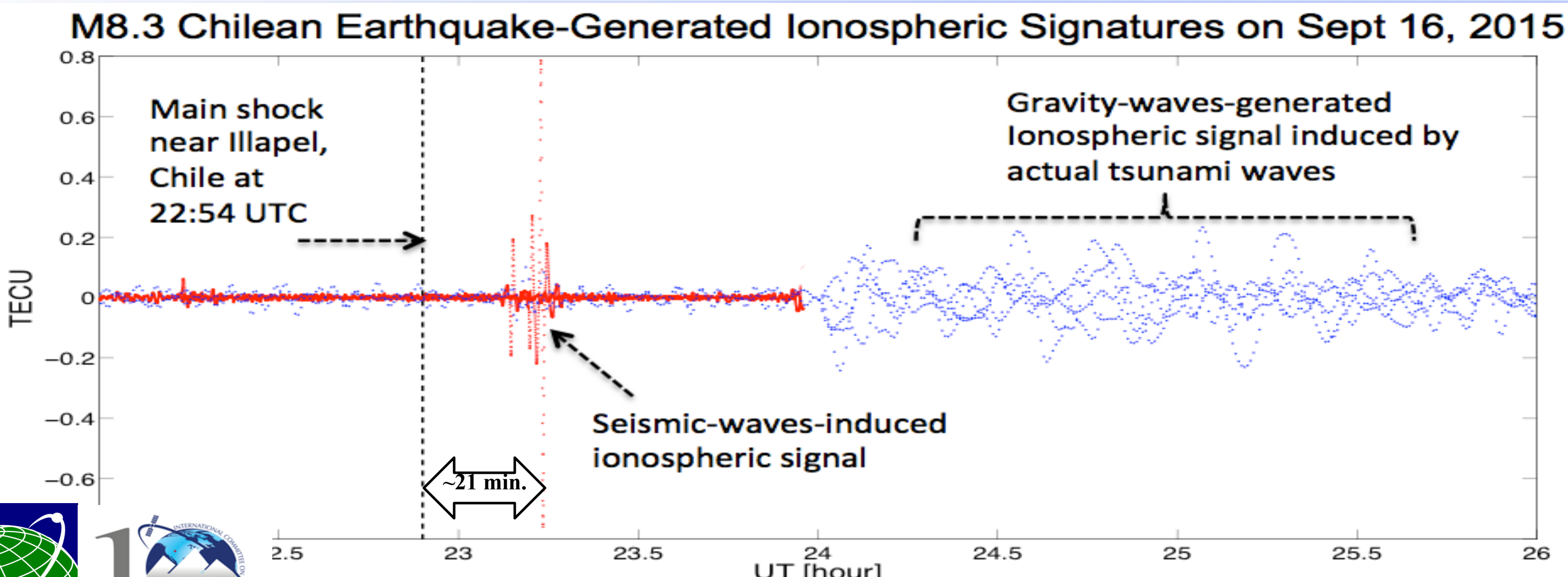

M8.3 Chilean Earthquake-Generated Ionospheric Signatures on Sept 16, 2015




Pers Com: Attila Komjathy, JPL

# Tracking Tele-Tsunamis Using Coupled Ionospheric Waves

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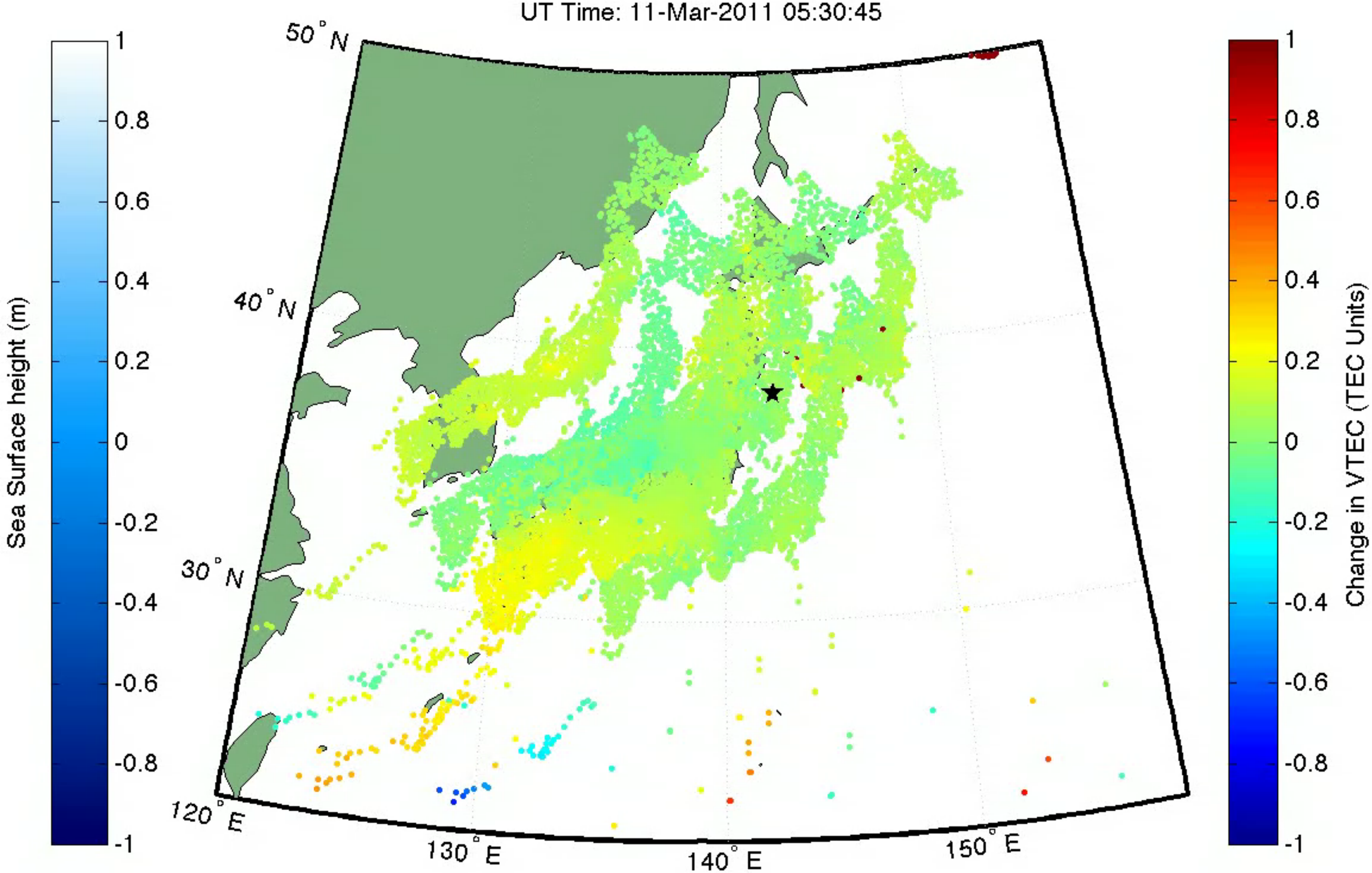
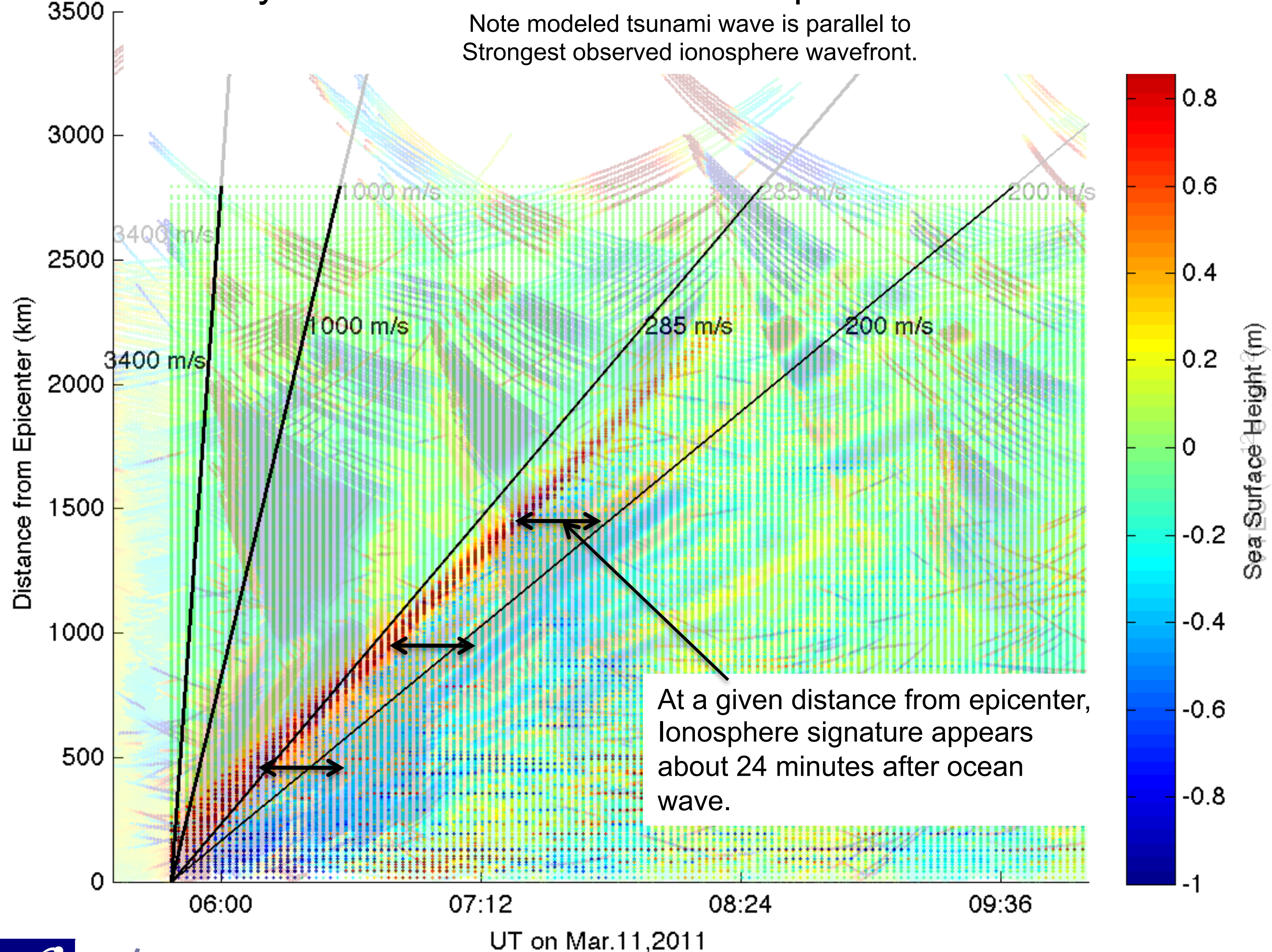
**Pers Com: Attila Komjathy, JPL**

# 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)

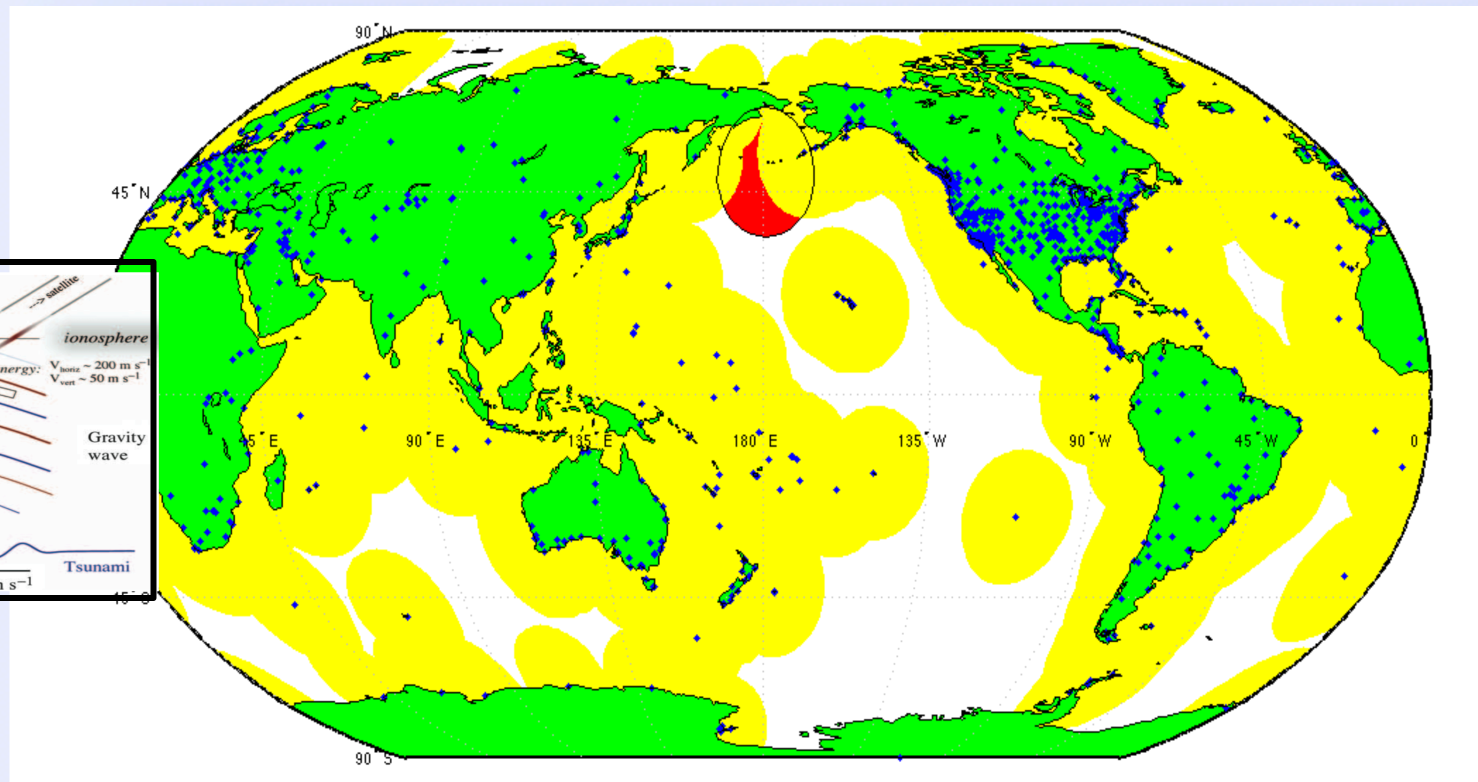
# Overlay of Tsunami Model and Ionospheric Observations

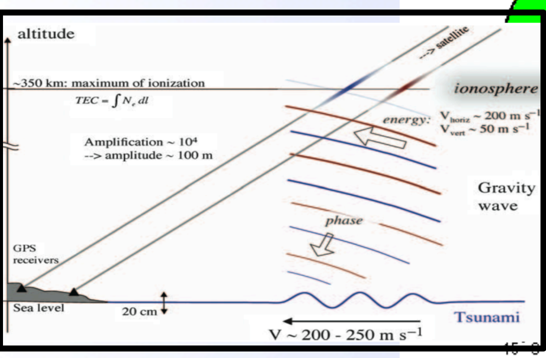



From the work of Song, Galvan, Komjathy, JPL

# Tsunami Tracking Capability of Current IGS Network

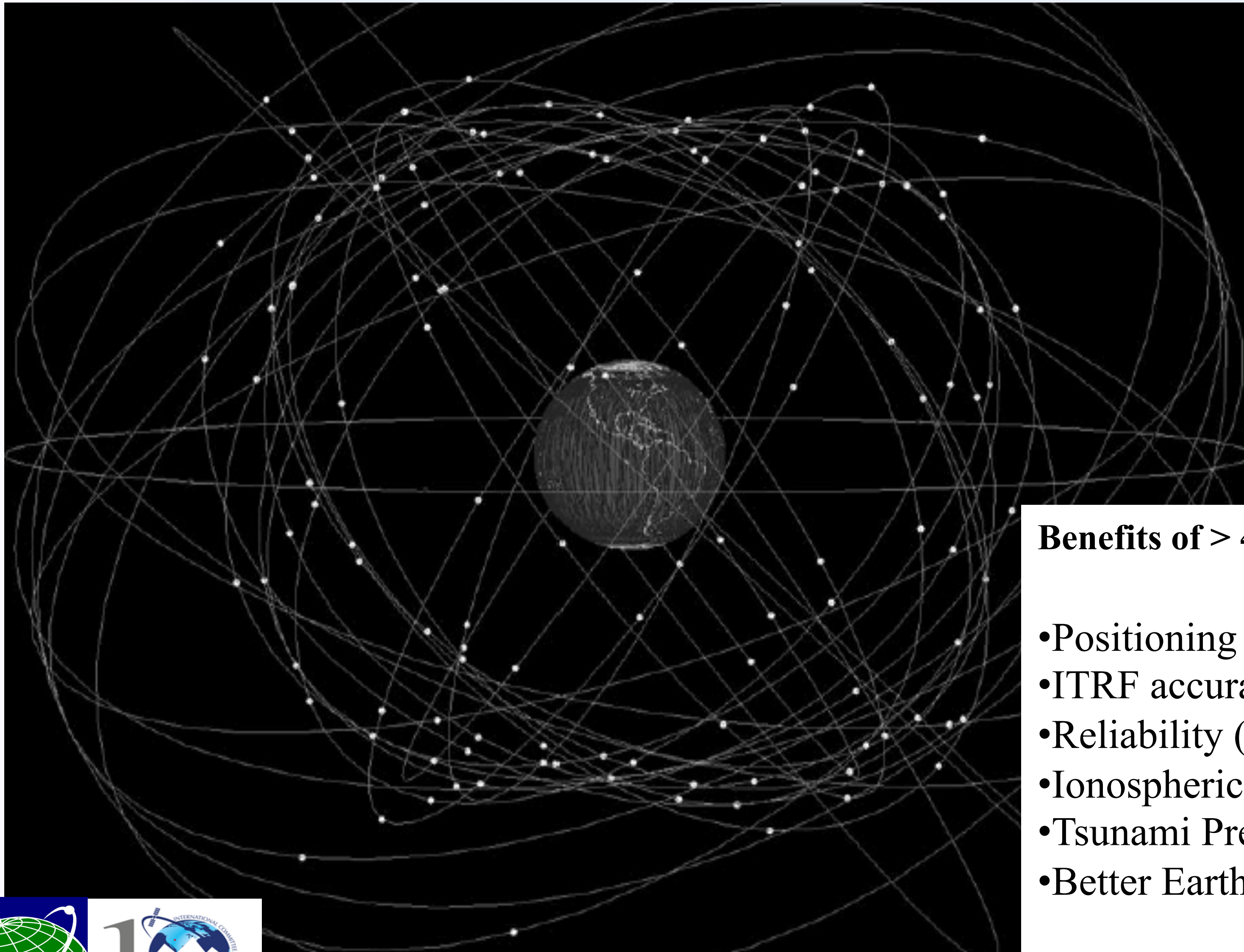
**Yellow zones indicate region of ionospheric piercing point detection from existing GNSS receiver network. Assumes 10 degree elevation and the Ionospheric shell at 450 km yields 1-2 hr advance tsunami detection**




Red zone is only circum-Pacific gap in coverage assuming all stations are upgraded to real time operation.

# GNSS Satellites and Signals will increase more than 400% in This Decade



Future (~2020)

| | |
|---|---|
| GPS | 30 |
| SBAS | 14 |
| GLO | 24 |
| BDS | 35 |
| GAL | 30 |
| QZS | 4 |
| IRNSS | 7 |
| | 144 |

**Benefits of > 4X GNSS Signals**

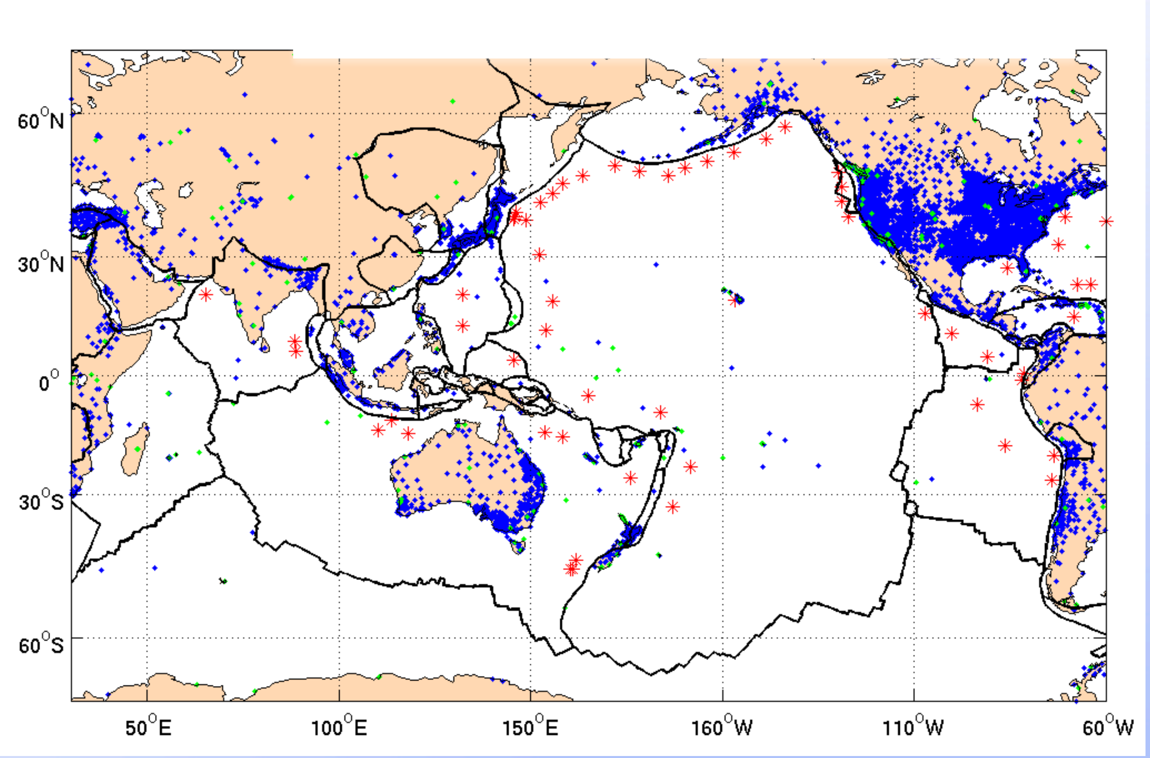
- Positioning Accuracy (~2X)
- ITRF accuracy (~2X)
- Reliability (~4X)
- Ionospheric Resolution (~4X)
- Tsunami Predicts (2X-4X)
- Better Earthquake Solutions (?)

# GNSS Tsunami Early Warning System (GTEWS) Augmentation Requires International Cooperation

- The Pacific Region is well populated with GNSS CORS Networks - many that stream data in real-time

- Several research groups have worked to advance GNSS-aided rapid earthquake magnitude assessment and tsunami wave tracking

- The UN General Assembly, IUGG, IOC, IGS, and APSG have issued resolutions for the sharing of geodetic data and for a GNSS-aided tsunami warning network.




Existing GNSS stations if streamed and analyzed in real-time will provide:

- Rapid and more accurate tsunami warnings

- Basin wide tracking of propagating tsunamis

# *International Union of Geodesy and Geophysics:*

**Resolution 4: July 2015**

**Considering:**

•That large populations may be impacted by tsunamis generated by megathrust earthquakes

• Among existing global real-time observational infrastructure, the Global Navigation Satellite Systems (GNSS) can enhance the existing tsunami early warning systems;

**Urges:**

•Operational agencies to exploit fully the real time GNSS capability to augment and improve the accuracy and timeliness of their early warning systems,

•That the GNSS real-time infrastructure be strengthened,

•That appropriate agreements be established for the sharing of real-time GNSS data within the tsunami early warning systems,

•Continued support for analysis and production of operational warning products,

**Resolves**:

•To engage with IUGG member states to promote a GNSS augmentation to the existing tsunami early warning systems.

•Initially to focus upon the Pacific region because the high frequency of tsunami events constitutes a large risk to the region's large populations and economies, by developing a prototype system, together with stakeholders, including scientific, operational, and emergency responders.

# GGOS: The GTEWS Augmentation Initiative

**In accord with the IUGG and other recommendations:**

**the Global Geodetic Observing System (GGOS) is drafting a <u>GTEWS Call for Participation as a catalyst for action.</u>**

**The participants will constitute a work group to**

- **develop a project charter;**
- **document a work plan;**
- **initiate cooperative activities for GTEWS development.**

**GGOS will also seek to engage operational agencies with a primary but non-exclusive focus upon the Indo-Pacific region.**

TENTH ANNUAL MEETING

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# Backup Material

Recommendation of the IGS 2014 Workshop, Pasadena, CA:

*"The IGS encourages and coordinates member organizations to establish protocols and develop a system for establishment of moderate density GNSS network (e.g. in Indo-Pacific), real-time data sharing, analysis centers, and advisory bulletins to the responsible government agencies in accord with the IAG's Global Geodetic Observing System (GGOS) Theme #2 for natural hazards applications."*

# The UN General Assembly

## *A Global Geodetic Reference Frame for Sustainable Development*

February *26, 2015*

**Recognizing** the importance of international cooperation, as no one country can do this alone, to realize the global geodetic reference frame and services to underpin Global Navigation Satellite Systems technology and provide the framework for all geospatial activity, as a key enabler of spatial data interoperability, disaster mitigation and sustainable development,

**Urges** Member States to implement open sharing of geodetic data, standards and conventions, on a voluntary basis, to contribute to the global reference frame and regional densifications through relevant national mechanisms and intergovernmental cooperation, and in coordination with the International Association of Geodesy

# *International Union of Geodesy and Geophysics:*

**Resolution 4: July 2015**

**Considering:**

•That large populations may be impacted by tsunamis generated by megathrust earthquakes

• Among existing global real-time observational infrastructure, the Global Navigation Satellite Systems (GNSS) can enhance the existing tsunami early warning systems;

**Urges:**

•Operational agencies to exploit fully the real time GNSS capability to augment and improve the accuracy and timeliness of their early warning systems,

•That the GNSS real-time infrastructure be strengthened,

•That appropriate agreements be established for the sharing of real-time GNSS data within the tsunami early warning systems,

•Continued support for analysis and production of operational warning products,

**Resolves**:

•To engage with IUGG member states to promote a GNSS augmentation to the existing tsunami early warning systems.

•Initially to focus upon the Pacific region because the high frequency of tsunami events constitutes a large risk to the region’s large populations and economies, by developing a prototype system, together with stakeholders, including scientific, operational, and emergency responders.

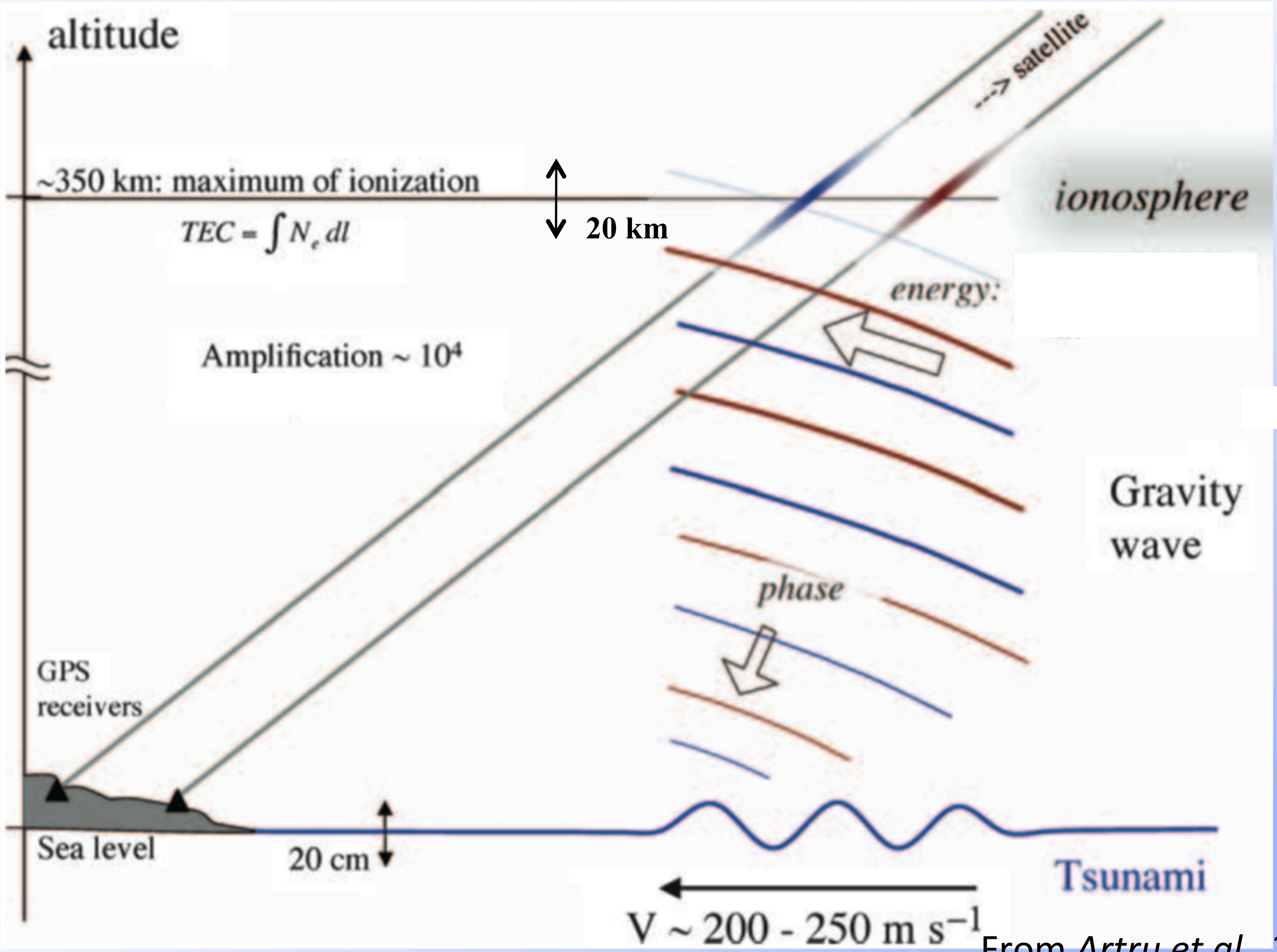
# Toward the Realization of a GNSS Augmentation to the Tsunami Early Warning System

We recommend that APSG in cooperation with the International Oceanographic Commission, Association of Pacific Rim Universities, the IUGG Commissions and Associations and the relevant Indo-Pacific governmental agencies work to advance a GNSS Augmentation to the Tsunami Early Warning Network via an

**Initial workshop in 2016 to define the requirements and next steps to establish a GNSS Augmentation to the Tsunami Early Warning System based upon the principles of shared resources and with the goal of establishing designs, agreements, and support to encourage cooperative improvements to infrastructure, algorithms, and data sharing.**

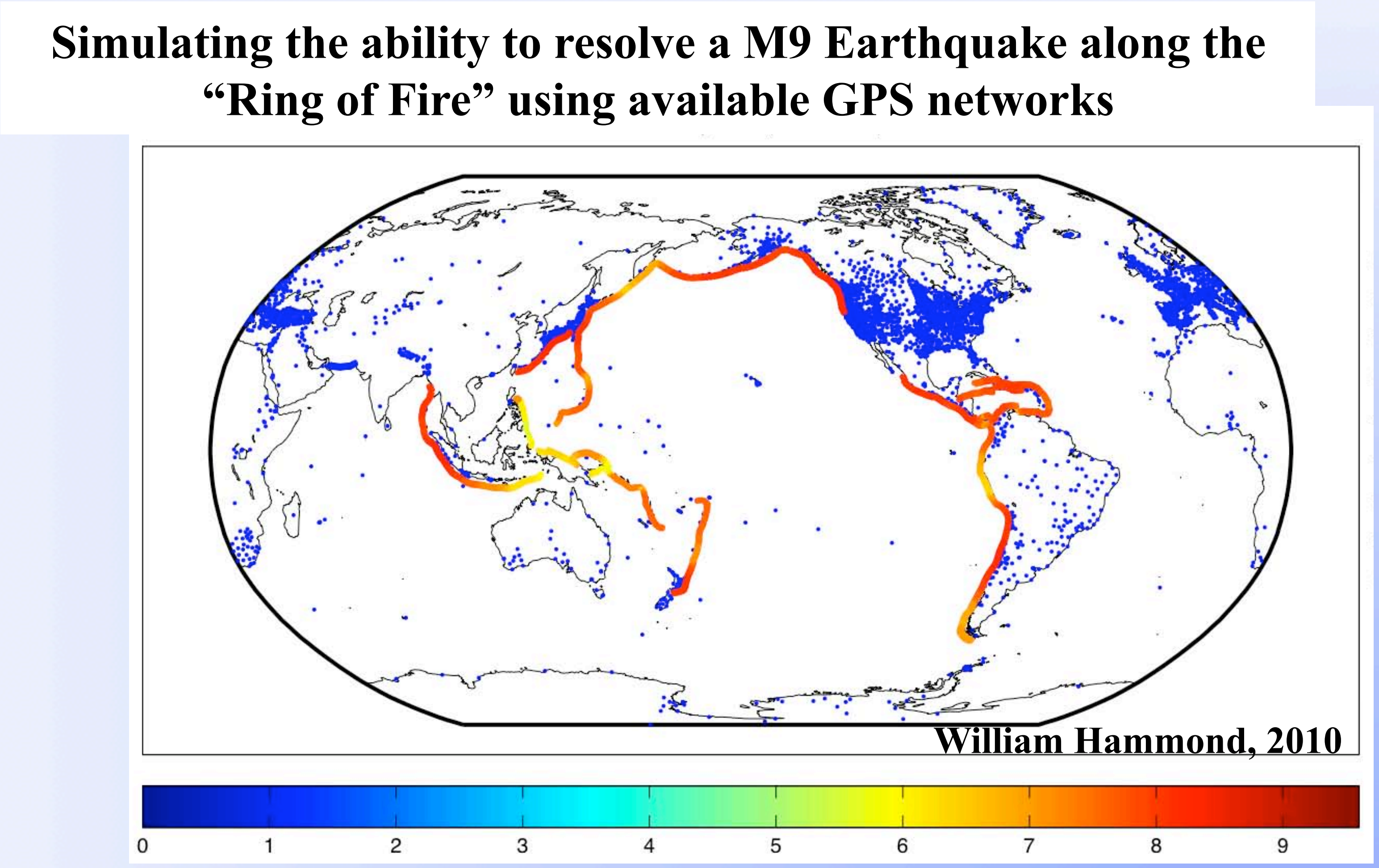
International Union of Geodesy and Geophysics (IUGG)

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




From *Artru et al.*, 2005

# Tsunami Prediction Capability of the Current Network




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

- GTEWS working group will seek a strengthened cooperation with:
  - The Asia-Pacific Economic Cooperation (APEC) and its sub-groups, the Policy Partnership for Science, Technology and Innovation (PPSTI) and its sub-committee the Emergency Preparedness Working Group (EPWG)
  - The IOC Tsunami Programme and the Intergovernmental Coordination Group
  - Association of Pacific Rim Universities (APRU) and its Multihazards Hub (APRU-MH) at Tohoku University
  - United Nations disaster agencies such as Office for Disaster Risk Reduction (UNISDR) and the International Committee on GNSS (ICG) and the GGIM.

- The GTEWS working group will seek sponsorship for one or more international working group meetings to develop the GTEWS Initiative and encourage interagency cooperative agreements.

- The GTEWS working group will seek to complete its work within 36 months.