GNSS Augmentation to the Tsunami Early Warning System (GTEWS)

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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
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
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
• Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System -Honolulu, 2015
• International Union for Geodesy and Geophysics-Prague, 2015
• Asia-Pacific Space Geodynamics Project-Moscow, 2015
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
Hindcast studies employing 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

GGOS/IGS Real-Time Network

Australian Real-Time Network

German-Indonesian Tsunami Early Warning (GITEWS)

Earthscope Plate Boundary Observatory

The GSI GEONET
Tracking Tele-Tsunamis Using Coupled Ionospheric Waves

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

Main shock near Illapel, Chile at 22:54 UTC

Gravity-waves-generated Ionospheric signal induced by actual tsunami waves

Seismic-waves-induced ionospheric signal

Pers Com: Attila Komjathy, JPL
Tracking Tele-Tsunamis Using Coupled Ionospheric Waves

- 1700 km or one to two hours
- ~350 km: maximum of ionization
- $T E C = \int N_e \, dl$
- Amplification $\sim 10^4$
- $\rightarrow$ amplitude $\sim 100$ m
- Gravity wave
- $V \sim 200 - 250$ m s$^{-1}$
- $V_{\text{horiz}} \sim 200$ m s$^{-1}$
- $V_{\text{vert}} \sim 50$ m s$^{-1}$

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Seismic-waves-induced ionospheric signal

Gravity-waves-generated ionospheric signal induced by actual tsunami waves

~21 min.
GSI’s GEONET Also Captured the Ionospheric Coupled Waves and Imaged the Tsunami Generation and Propagation—For the First Time

UT Time: 11-Mar-2011 05:30:45

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

At a given distance from epicenter,
Ionosphere signature appears
about 24 minutes after ocean
wave.

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.
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.
In accord with the IUGG and other recommendations: the Global Geodetic Observing System (GGOS) is drafting a GTEWS Call for Participation as a catalyst for action.

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.
References

• Xu, Z. and **Y. T. Song**, Combining the all-source Green’s functions and the GPS-derived source for fast tsunami prediction – illustrated by the March 2011 Japan tsunami, *J. Atmos. Oceanic Tech.*, [http://dx.doi.org/10.1175/JTECH-D-12-00201.1](http://dx.doi.org/10.1175/JTECH-D-12-00201.1), 2013.
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
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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.
The Tsunami Generated Displacement of the Ocean Surface Couples to the Ionosphere

From Artru et al., 2005
Simulating the ability to resolve a M9 Earthquake along the “Ring of Fire” using available GPS networks

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.