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Development of Japanese Disaster Mitigation System Using Real-time PPP with Ambiguity Resolution for Tsunami Buoys and Ground Network

Masayuki Kanzaki, Yasuhiro Matsushita, Hitoyoshi Nishimura
Akira Wada, Hideshi Kakimoto, Minoru Hayashi
Hitachi Zosen Corporation, Tokyo, Japan

Christian Rocken, Tetsuya Iwabuchi, Leos Mervart, James Johnson, Zdenek Lukes
GPS Solutions Inc., Boulder CO, USA

Outline

- The Great Eastern Japan Earthquake

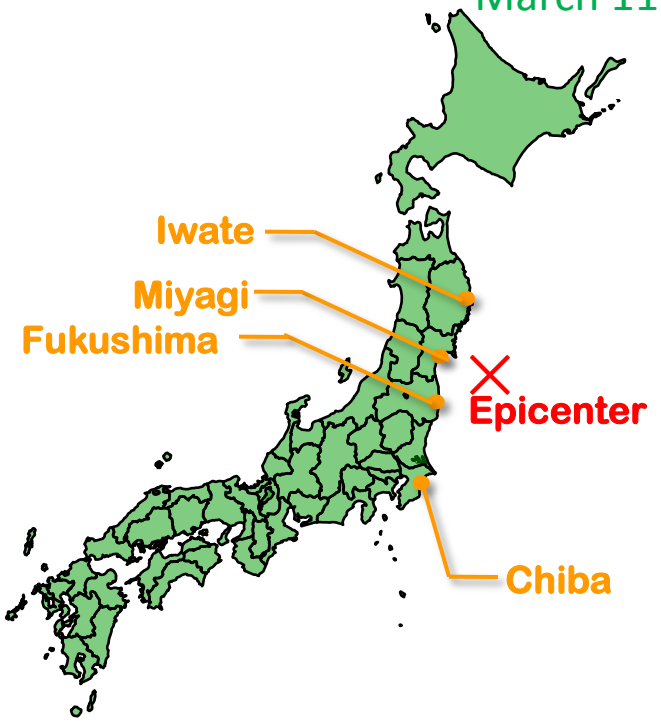
- Achievements of GPS Buoys
- Limitation of Current Tsunami Monitoring System
- New GPS Buoy Monitoring System with PPP-AR

- GPS and Seismometer
- Improve Tsunami Warning System by Ground PPP-AR Network
- Ionospheric Disturbances after Great Eastern Japan Earthquake

- Proposal of Deployment of Multi-purpose GNSS Buoy Network

The Great Eastern Japan Earthquake

Process of Tsunami warning



Referred to
Japan Meteorological Agency website;
http://www.mlit.go.jp/kowan/nowphas/

March 11 14:46 **Earthquake occurrence**

14:49 **Tsunami warning**

14:50 **Tsunami forecast – 3m in Iwate, 6m in Miyagi, 3m in Fukushima**

Tsunami was observed by GPS buoys

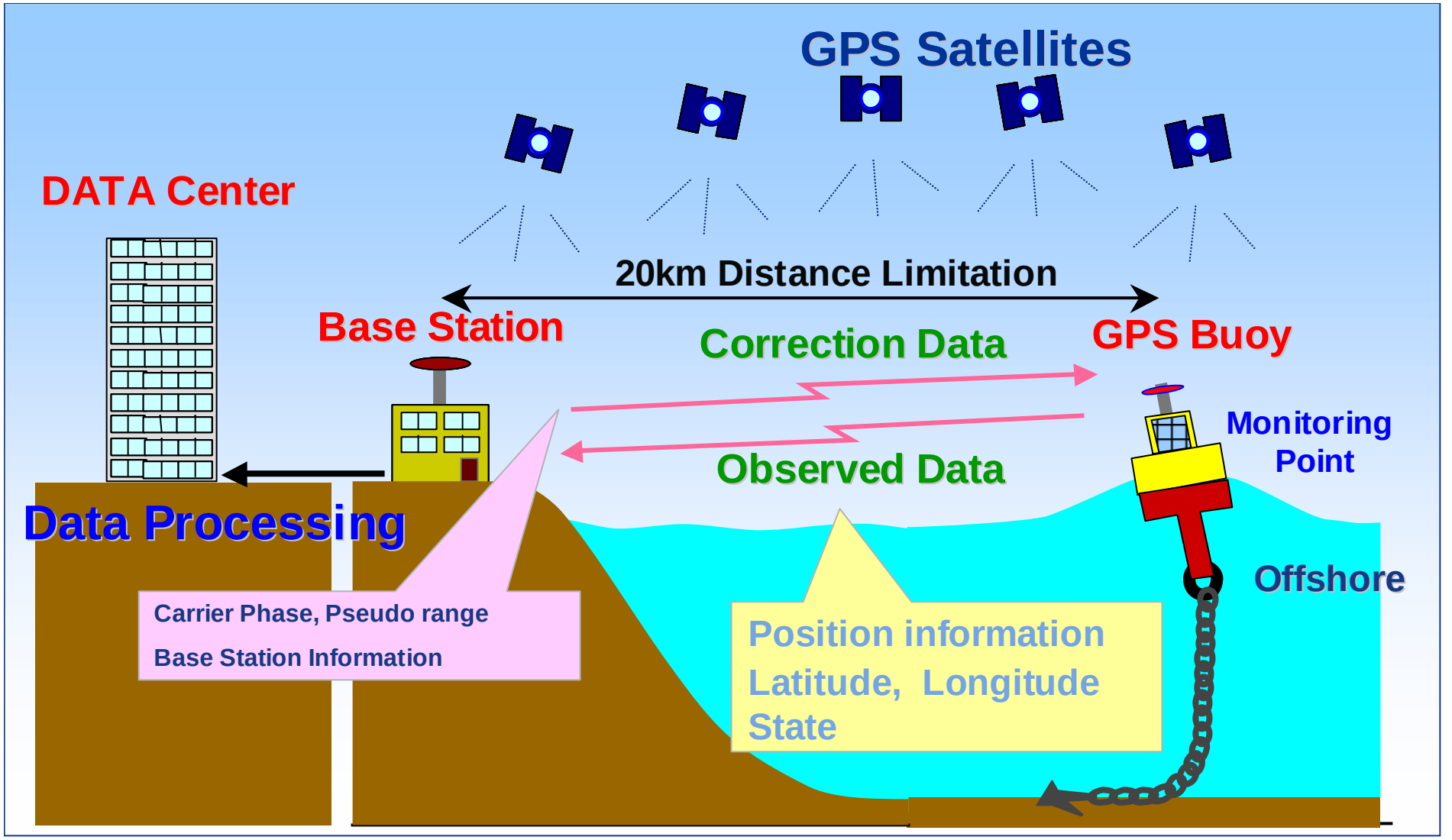
Tsunami warning level was raised.

15:14 **Tsunami warning**
Tsunami forecast – 6m in Iwate, over 10m in Miyagi, 6m in Fukushima

15:30 **Tsunami warning**

15:31 **Tsunami forecast – over 10m in Iwate to Chiba**

Overview of GPS Buoy System



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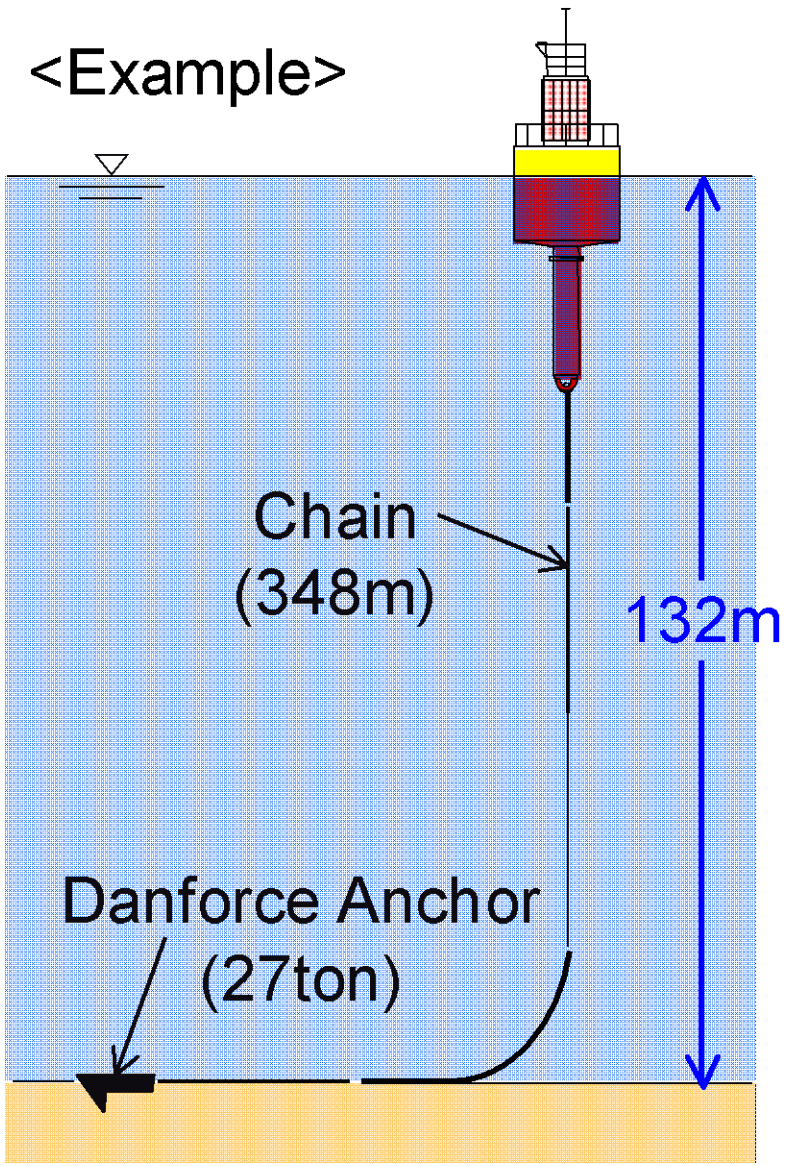
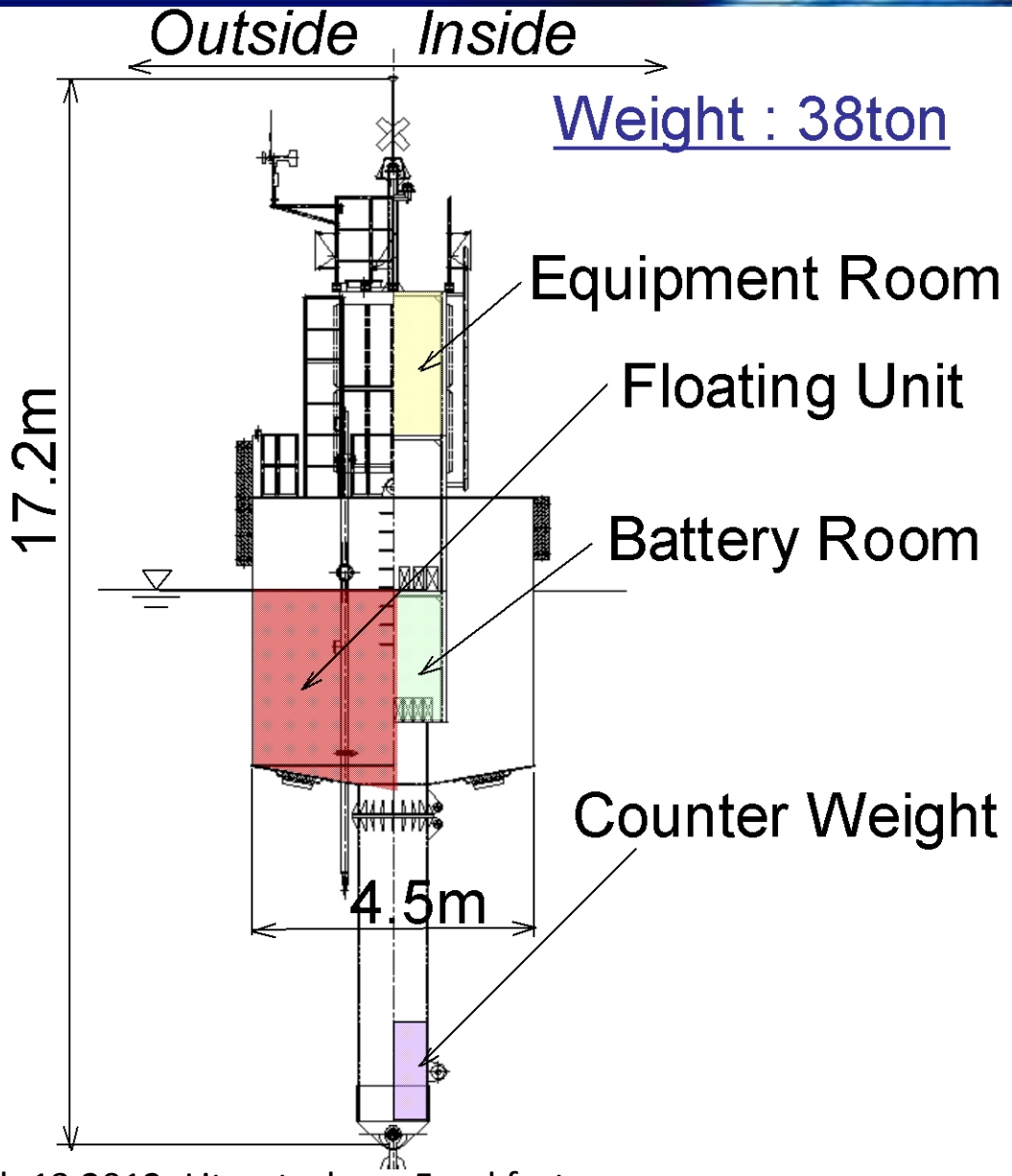
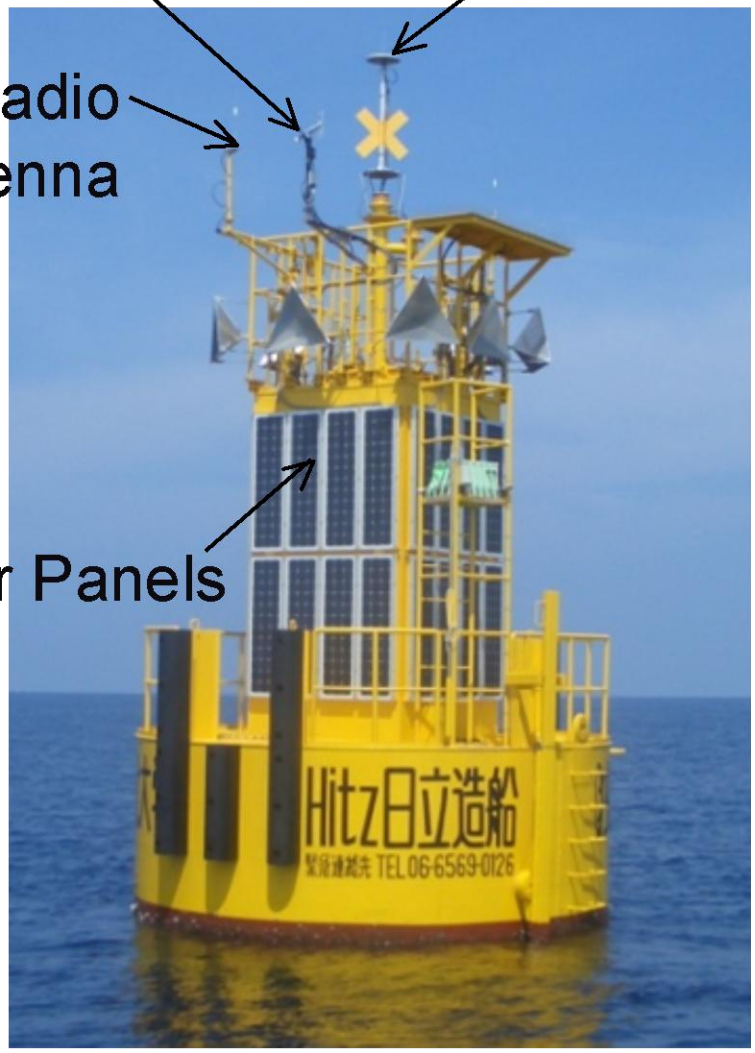
Specification of GPS Buoy (Example)





Instruments



Observation Item

Wave, Tide-level, Tsunami

Wind Speed & Direction,

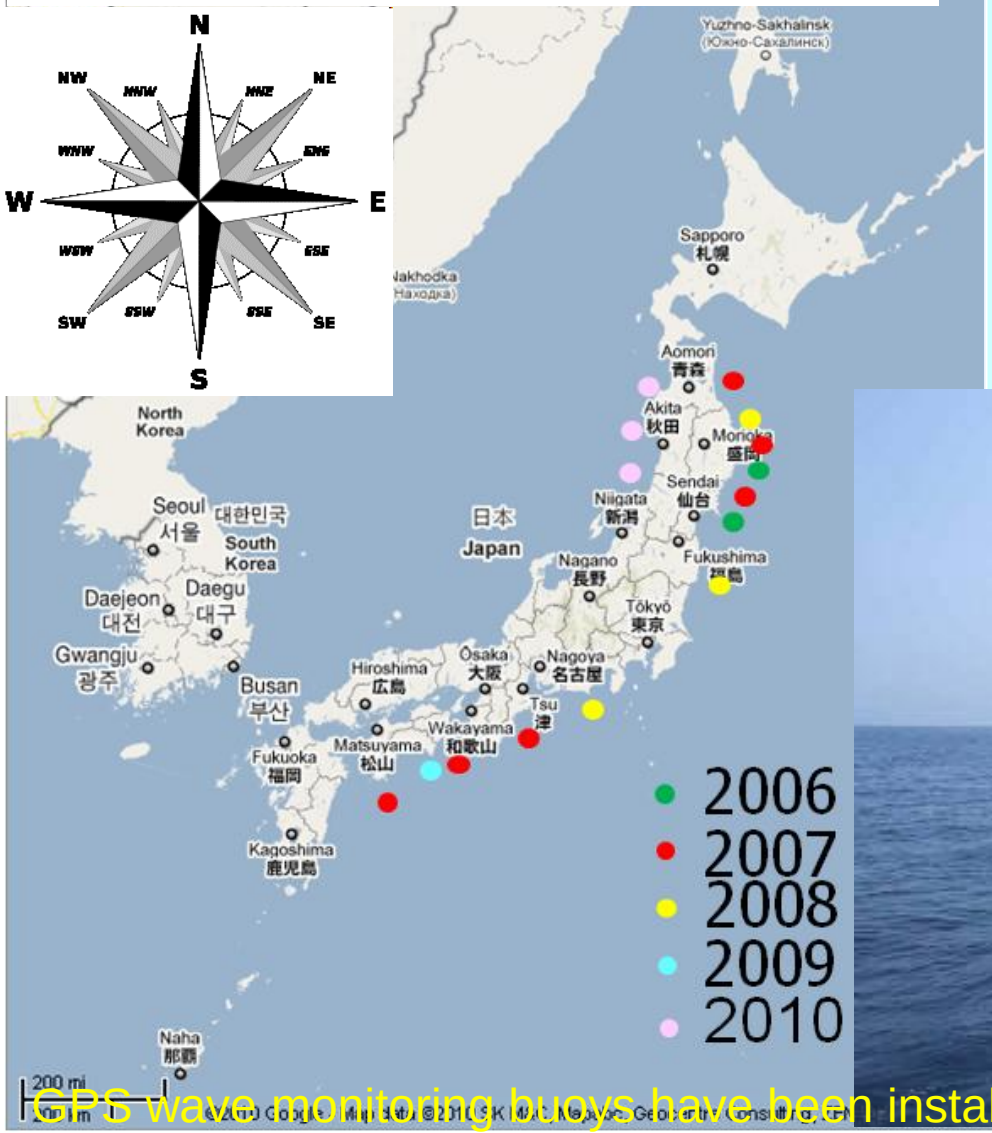
Water Temperature

Current Speed & Direction

Atmosphere Temperature & Pressure

Deployment of GPS Buoys

Distribution Map of GPS Buoy in Japan



1) GPS WAVE GAUGE

Now, 15 sites are operated in Japan.

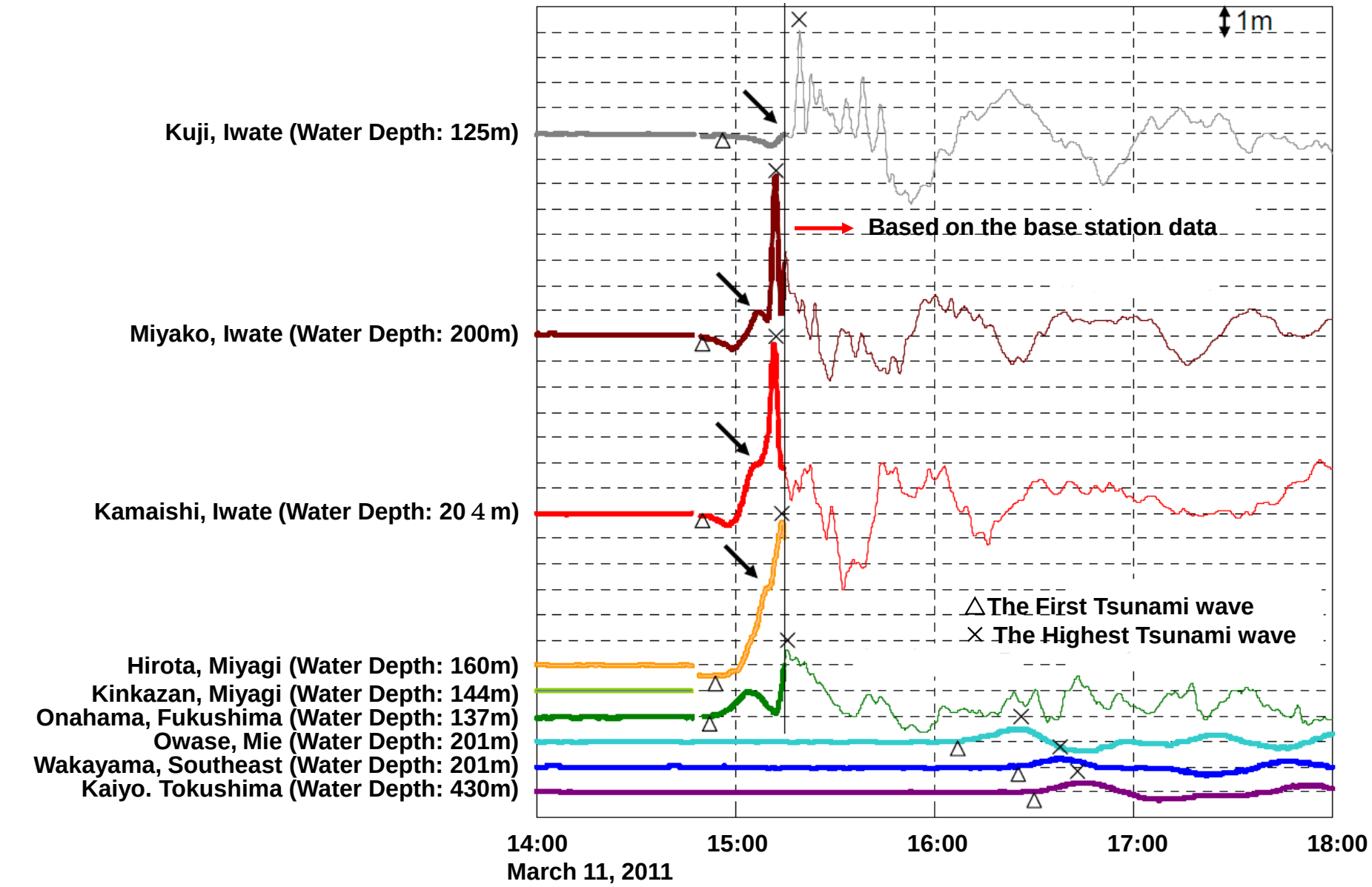
2) INSTALLATION CONDITION

20km offshore.

100m ~ 400m sea depth.

GPS wave monitoring buoys have been installed by Ports and Harbors Bureau, MLIT

The Great Eastern Japan Earthquake Detected Tsunami at GPS Bouys



The Great Eastern Japan Earthquake Newspaper Article

Tsunami More Than 10m High

1.On11ofMarch,atabout15:10, the shocking data was sent to JMA. The GPS buoy 20km from Kamaishi city, Iwate observed Tsunami more than 3m high.

2. At15:14, JMA predicted Tsunami again more than 10m high in Miyagi, more than 6m in Iwate and Fukushima.

Authority: The Daily Yomiuri

津波「10メートル超す」

警報 25分後に変更

気象庁 緊迫の決断

3.11の記録 大地が海が

15

Limitation of Current Tsunami Monitoring System

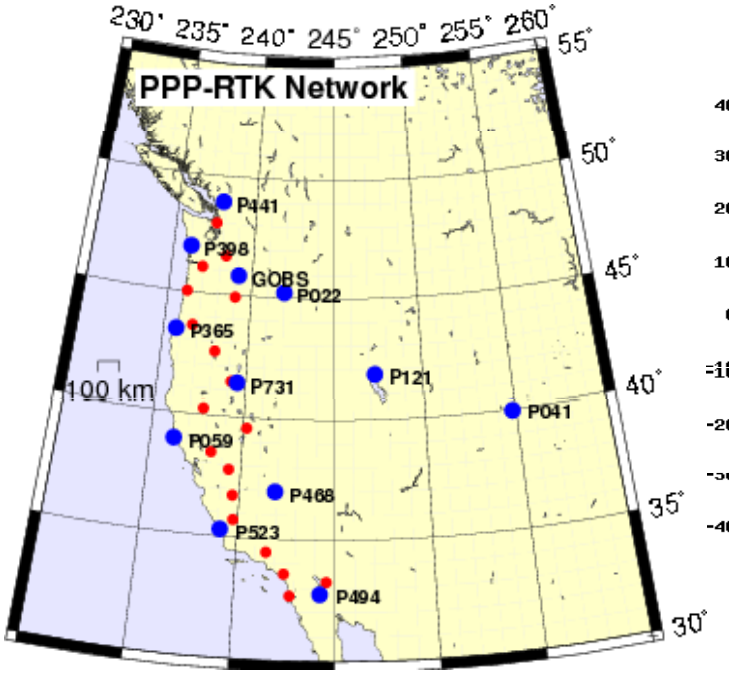
- **Current GPS buoy system using RTK technique**
  - **Based on base-line processing using dual frequency receivers**
  - **Base-line processing has limitation for distance**
    - **20km is limitation for ordinary RTK**
    - **No VRS (Virtual Reference Station) technique in the ocean**

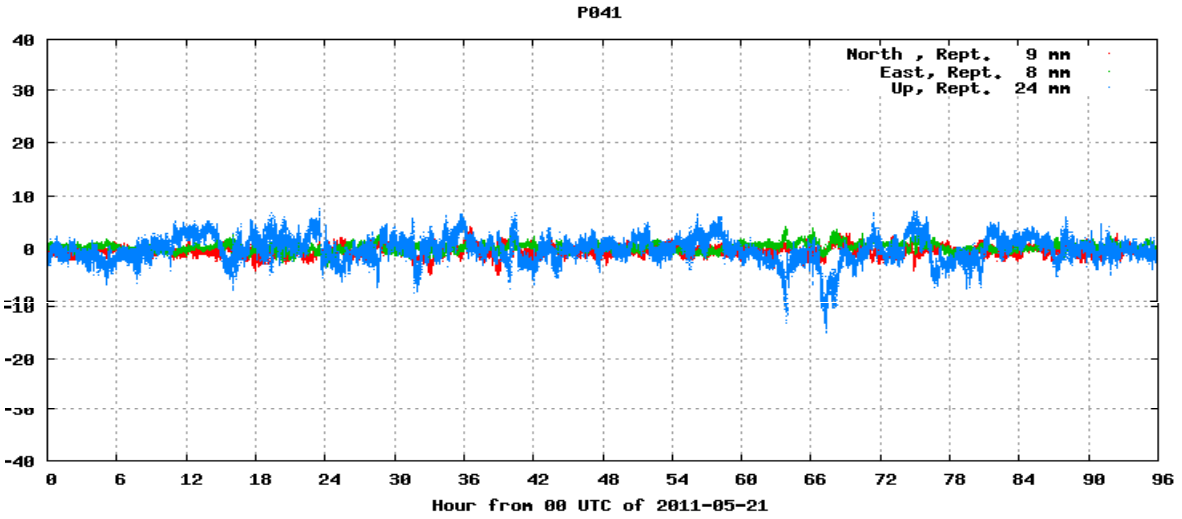
- **PPP (Precise Point Positioning)**
  - **No limitation for distance**
  - **Accuracy does not meet to detect Tsunami at offshore**
    - **~20cm accuracy in height by ordinary PPP**

- **New processing scheme need**
  - **No limitation in distance with ~3-5cm accuracy**
  - **PPP+RTK**

New Monitoring System with PPP-AR

- **PPP-AR – Precise Point Positioning with Ambiguity Resolution**
  - **RTNet (Real Time Network software) can be estimate precise Satellite clocks and correction data for ambiguity resolution**
  - **Ground GPS Network are required**
  - **Validated PPP-AR processing 1,300km far from Network**
  - **Evaluating PPP-AR with experimental Buoy in Japan**





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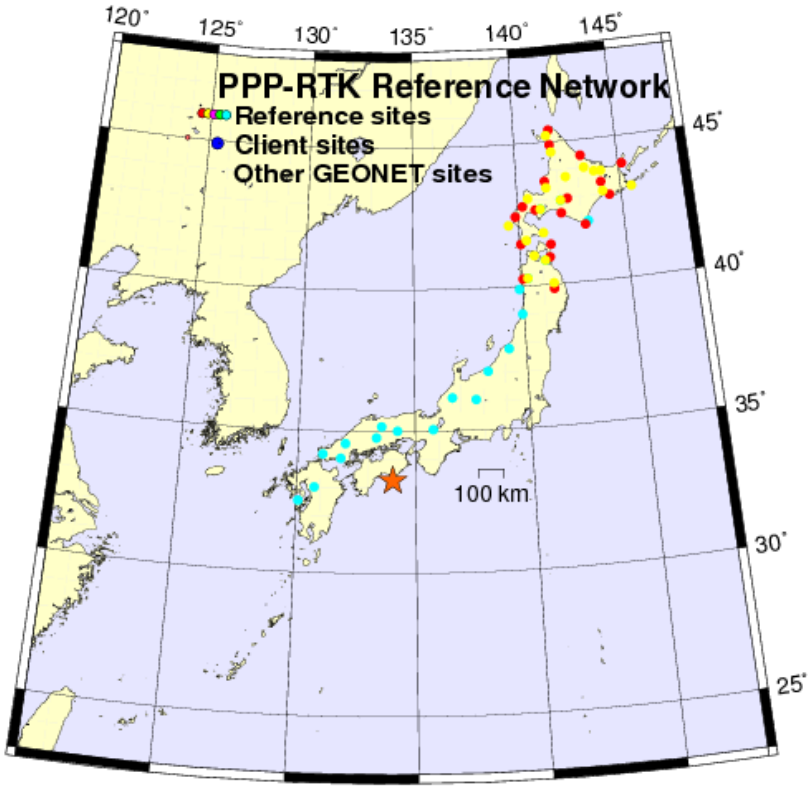
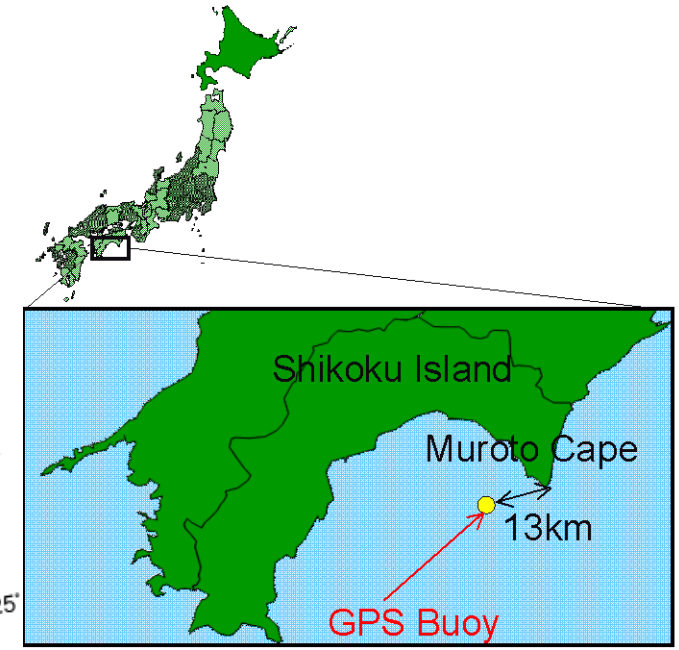
PPP-AR for Buoy Processing in Japan with Muroto Experimental Buoy





Apr.2008 ~ now

- Reference network is set at Northern Japan (red circles) a part of GEONET (GPS Earth Observation Network) operated by GSI
  - GSI: The Geospatial Information Authority of Japan, MLIT
- Buoy station is more than 1,000 km far from the reference network
- Compare with ordinary RTK processing (13km distance)

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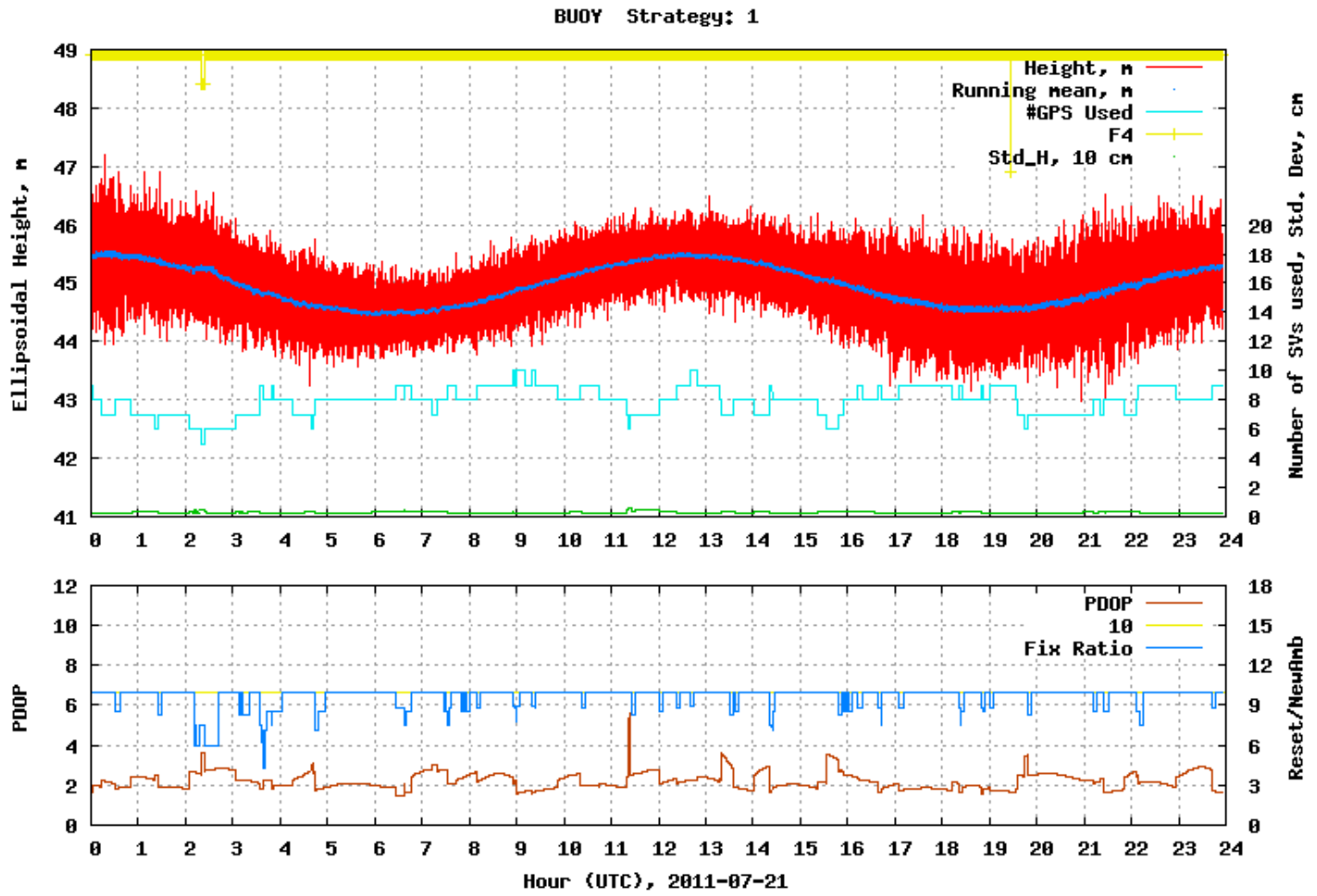
PPP-AR for Buoy Processing in Japan
RTK Results (Reference)



- **100m/s constrain**

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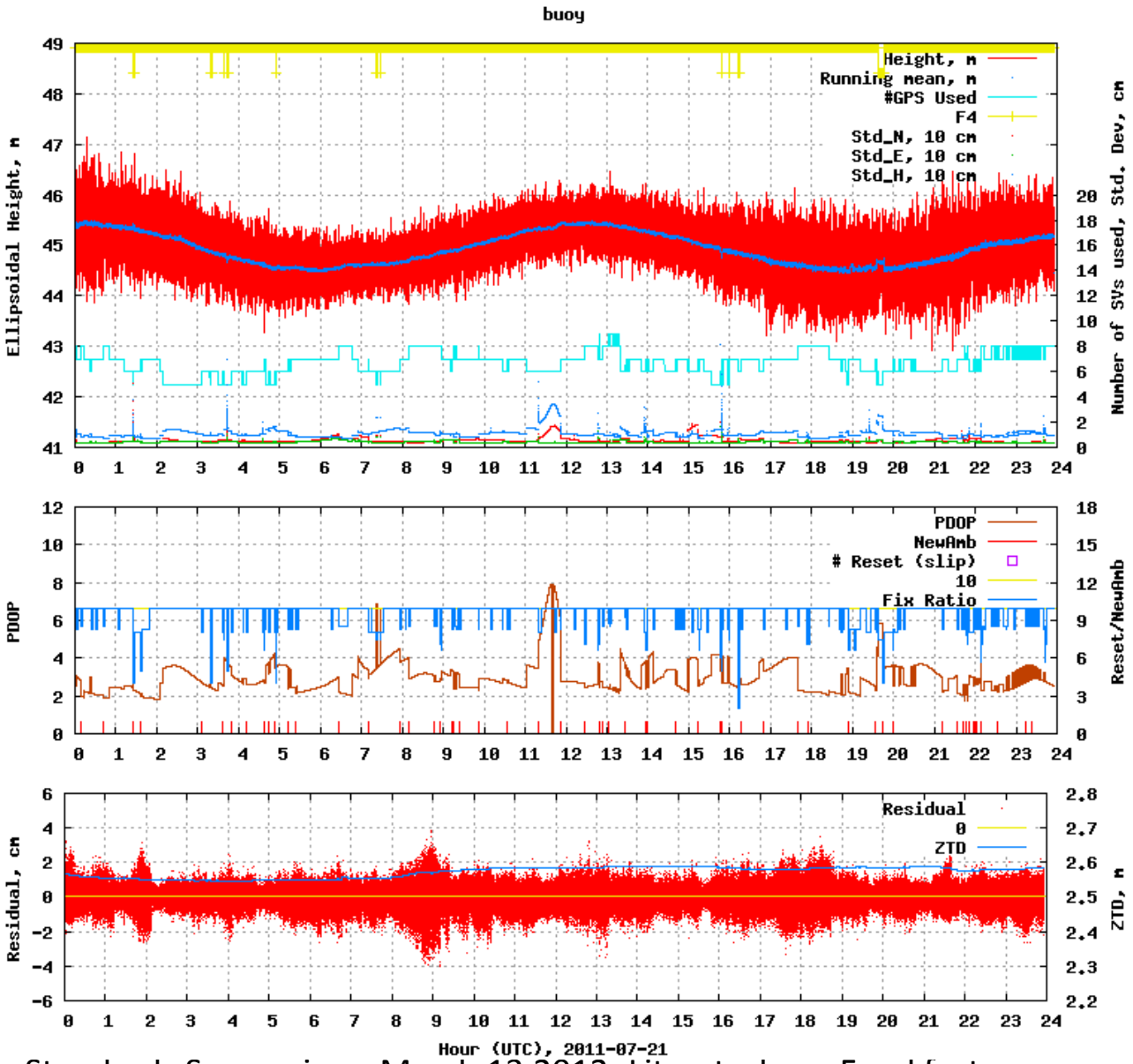
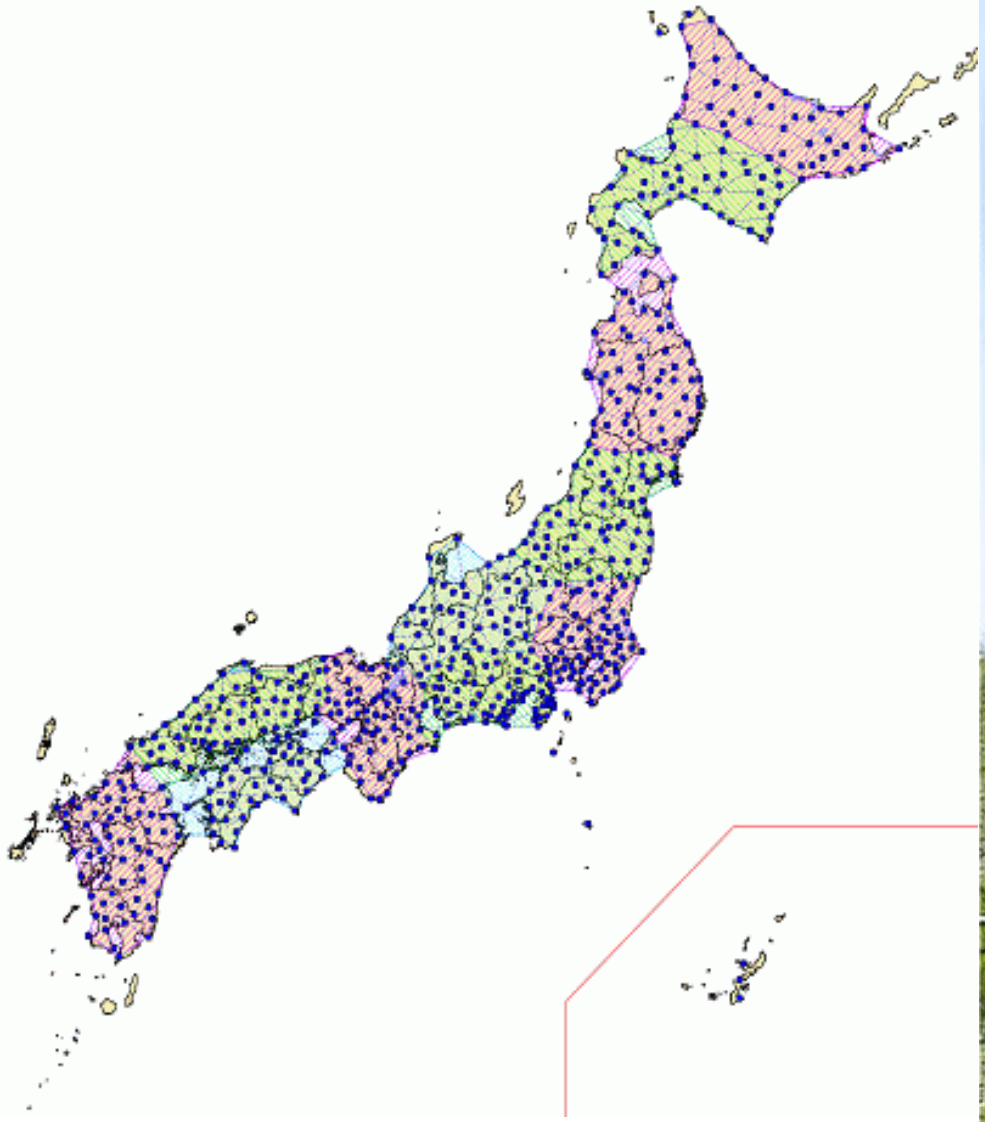
PPP-AR for Buoy Processing in Japan
PPP-AR Results

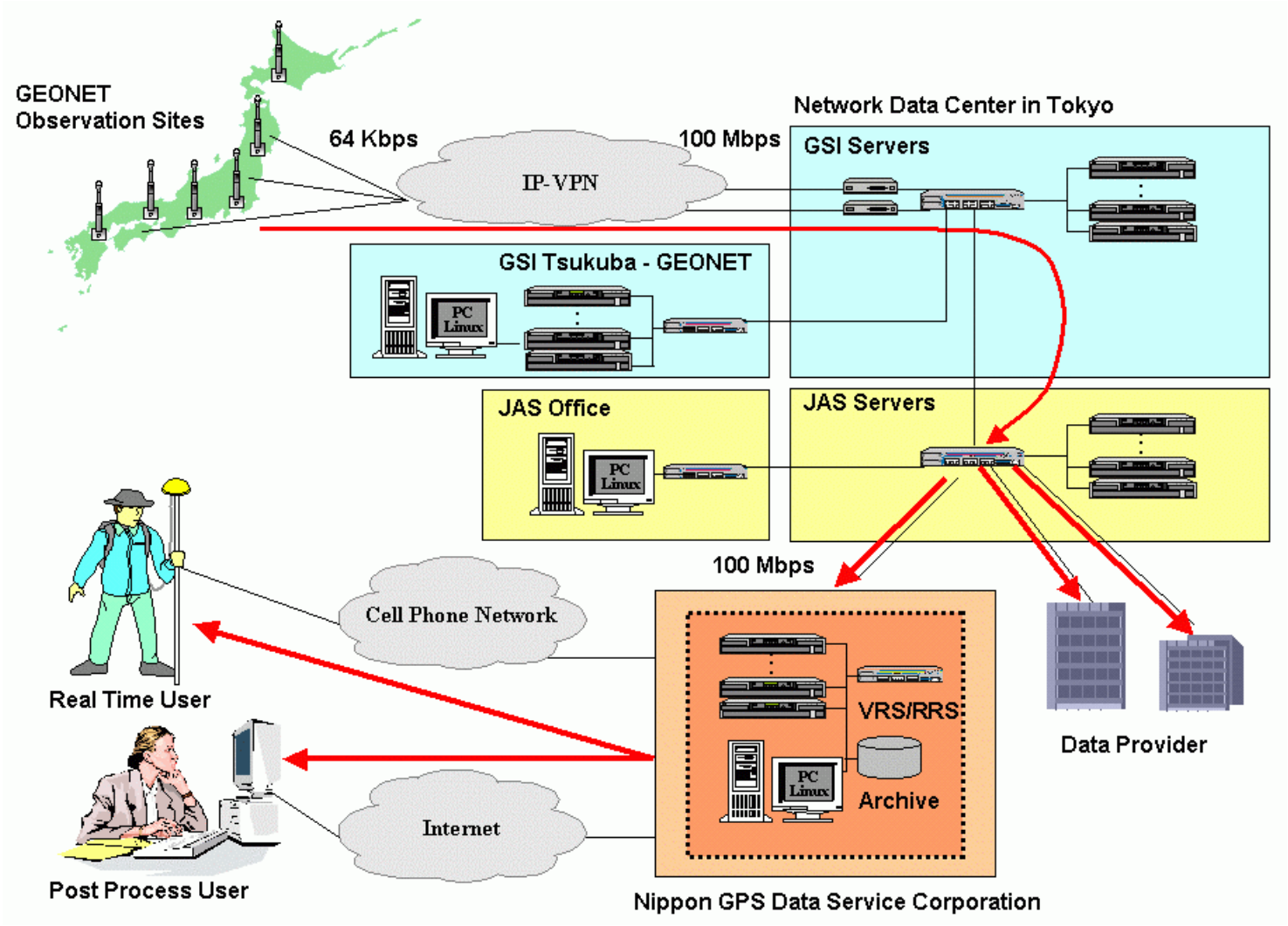


Ground Network - GEONET

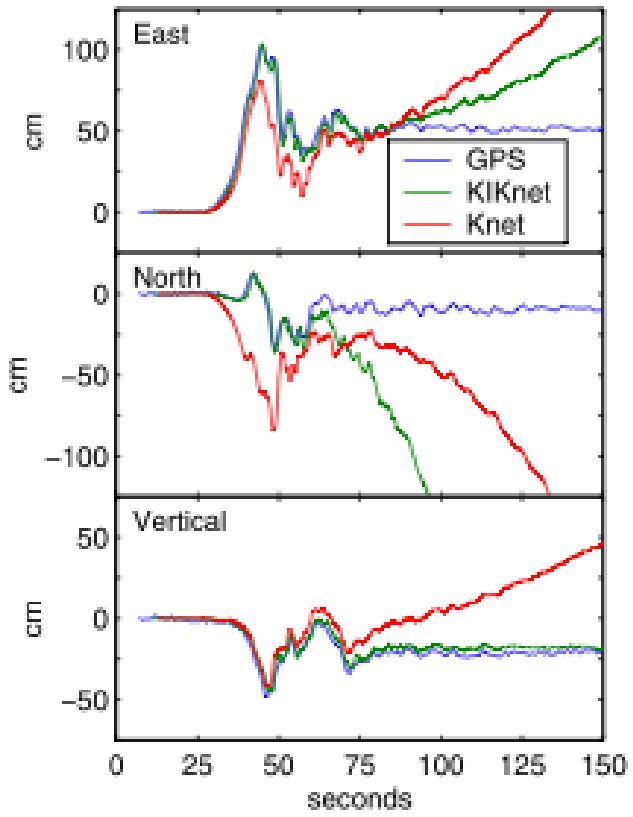


World Largest
Nation-wide GPS Infrastructure

Real Time Observation Data



GPS and Seismometer (Accelerator)

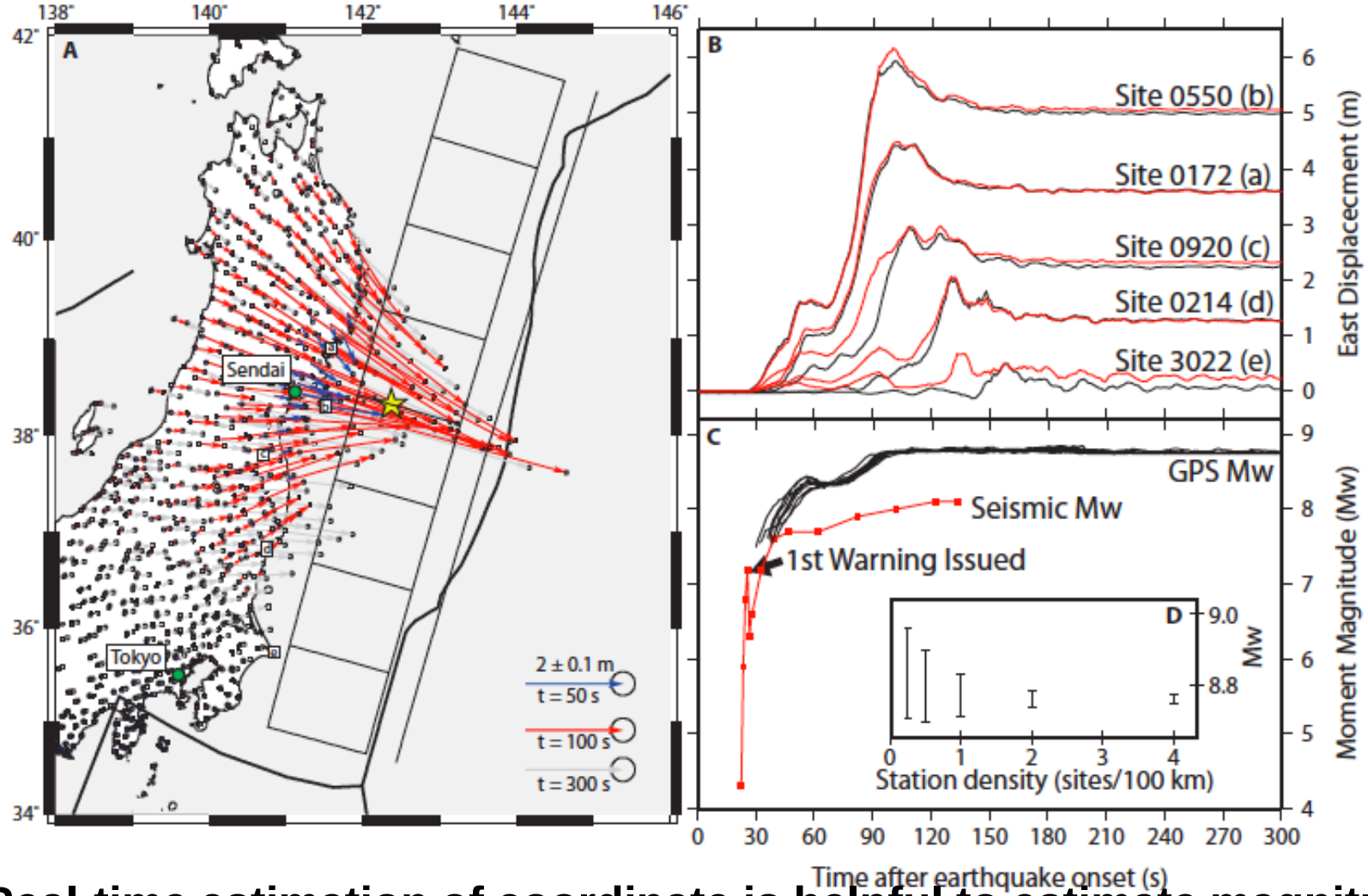


Miyazaki et al., 2004

Figure 2. Comparison of 1-Hz GPS (blue-0144) and integrated acceleration records for KiKnet (green-HDKH07) and Knet (red-HKD110).

- **Increased noise of accelerometer due to integration for two times**
- **GPS can detect coordinate variations with few cm accuracy in the period of strong motion**

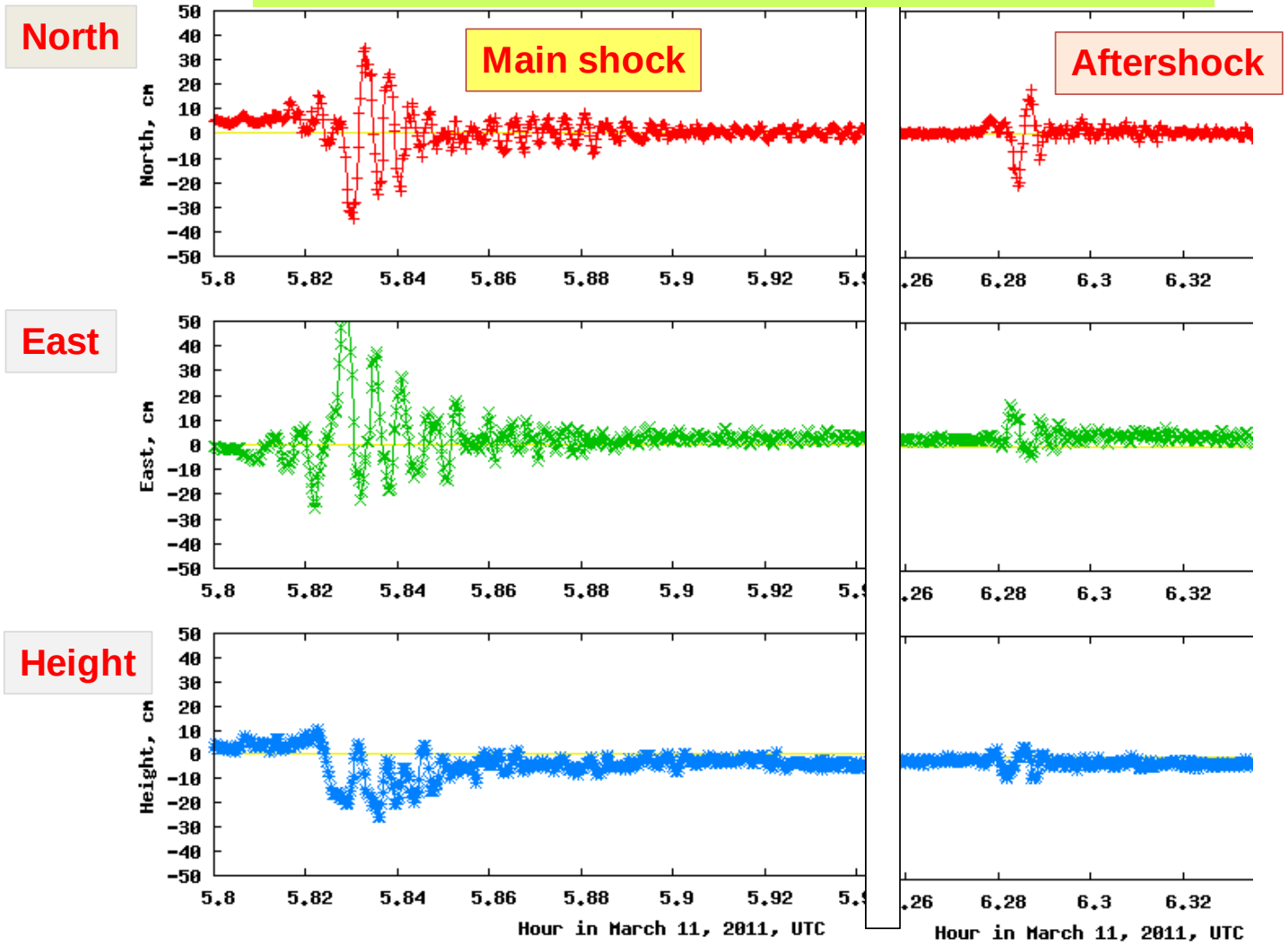
GPS Positioning and Seismometer Acceleration Data



- **Real-time estimation of coordinate is helpful to estimate magnitude of the earthquake: GPS Mw=8.8 in 3 minutes, Seismometer Mw=7.9**

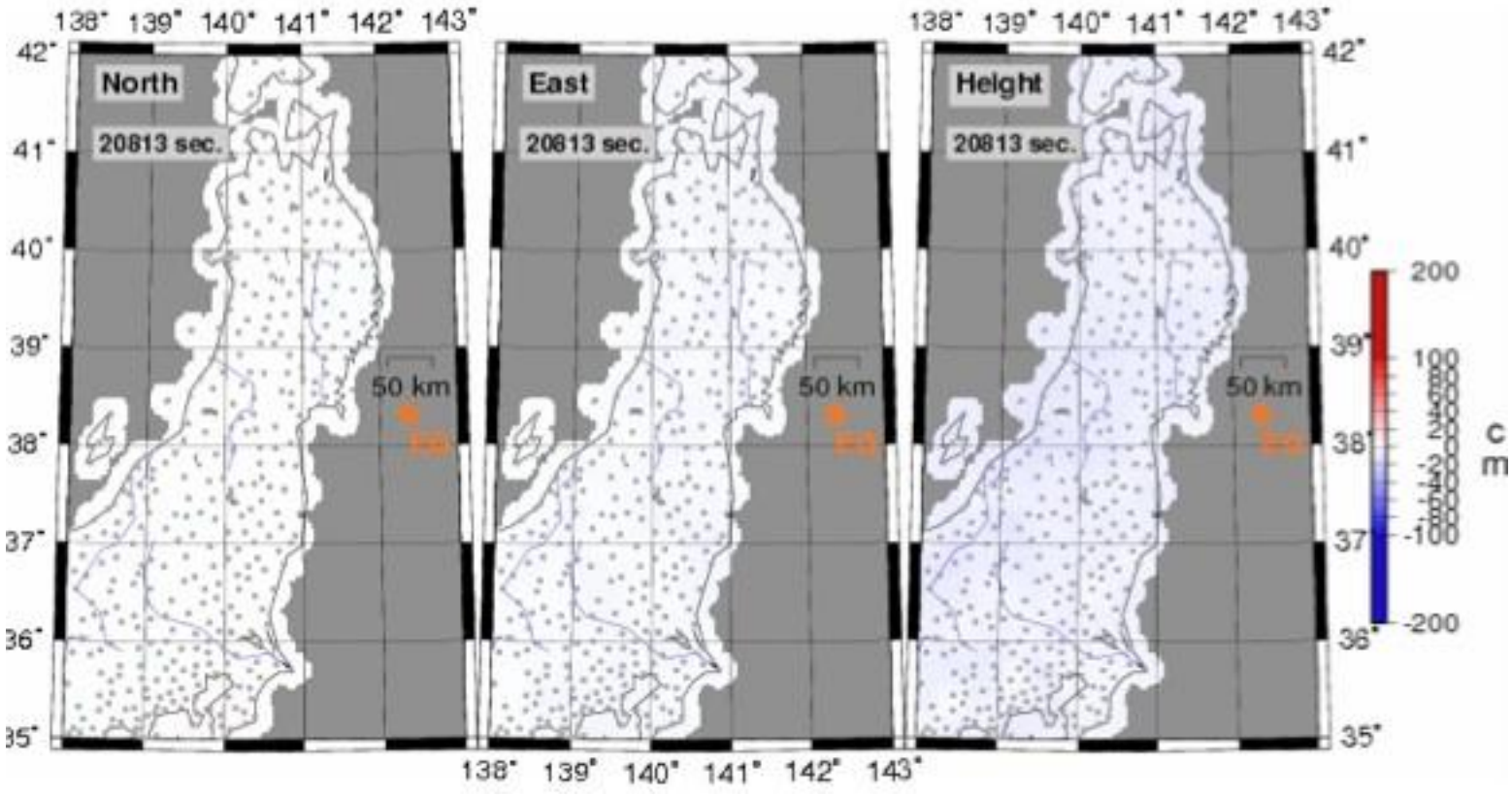
Solution from Real-Time Monitoring System

The Great Eastern Japan Earthquake March 11, 2011



- **True real-time monitoring of seismic wave at GEONET 0227 (Chiba)**

The Great Eastern Japan Earthquake (M 9.0)



- **Rapid and precise inversion of fault model for better estimate of magnitude of the earthquake with GNSS, Early warning for Tsunami**
- **Propagation of seismic wave based on observation could be provided to mobile devices such as cell phone**

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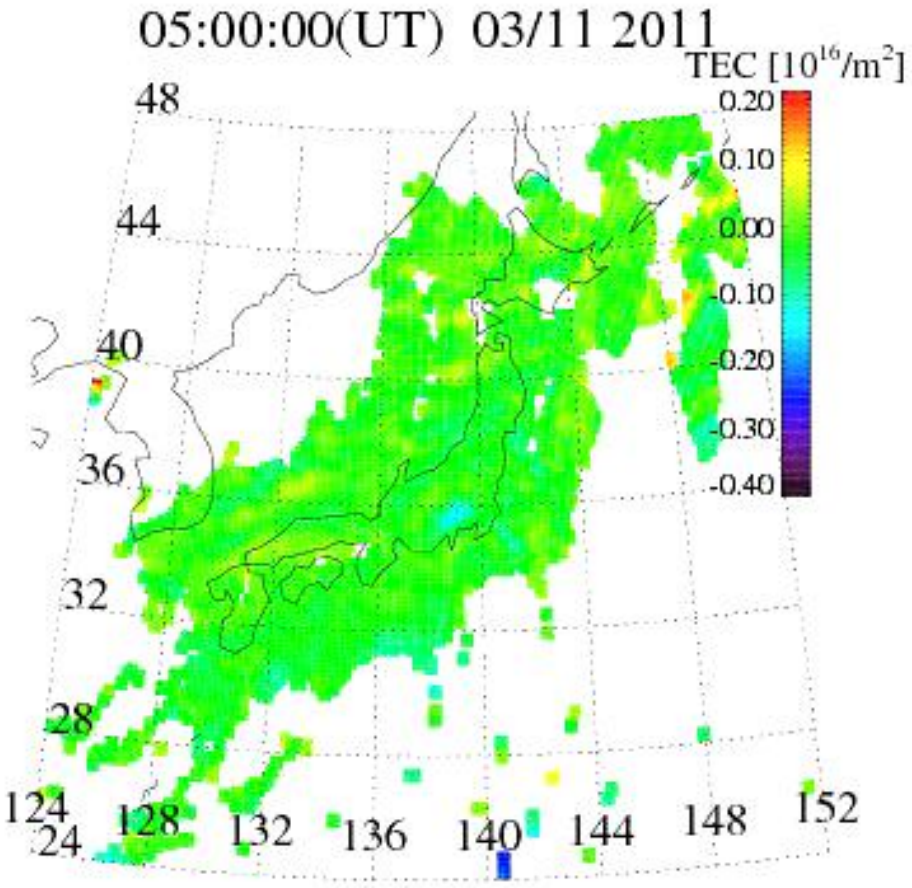
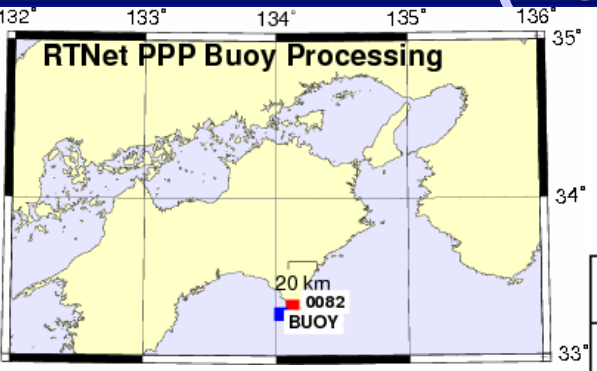
Ionospheric Disturbances after The Great Eastern Japan Earthquake

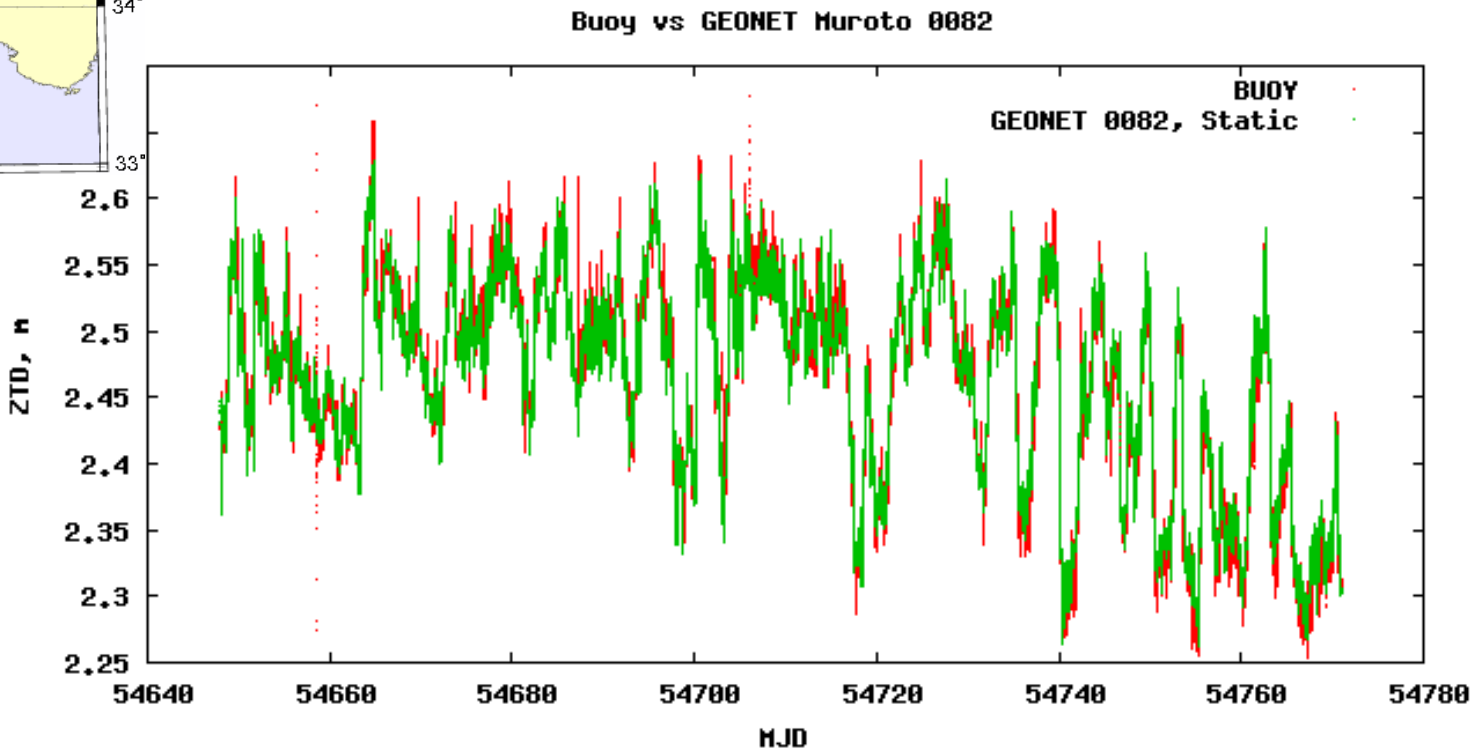
- **Ionospheric disturbances were observed by GPS total electron content (TEC) and ionosonde observations after the 2011 off the Pacific coast of Tohoku Earthquake at 05:46 on March 11, 2011.**



Processed by
Dr. Takuya Tsugawa
Space Weather and Environment Laboratory
Applied Electromagnetic Research Institute,
National Institute of Information and Communications Technology (NICT) JAPAN

Multipurpose Use of GPS Buoy
ZTD (Zenith Total Delay) Monitoring





- Comparison for 122 days in 2008 (GEONET 0082 30 sec, Muroto buoy 1Hz)
- Number of samples: 344,886, RMS in ZTD: 20mm (PWV 3 mm)
- The result suggest that monitoring of PWV in open ocean is possible
  - PWV: Precipitable Water Vapor

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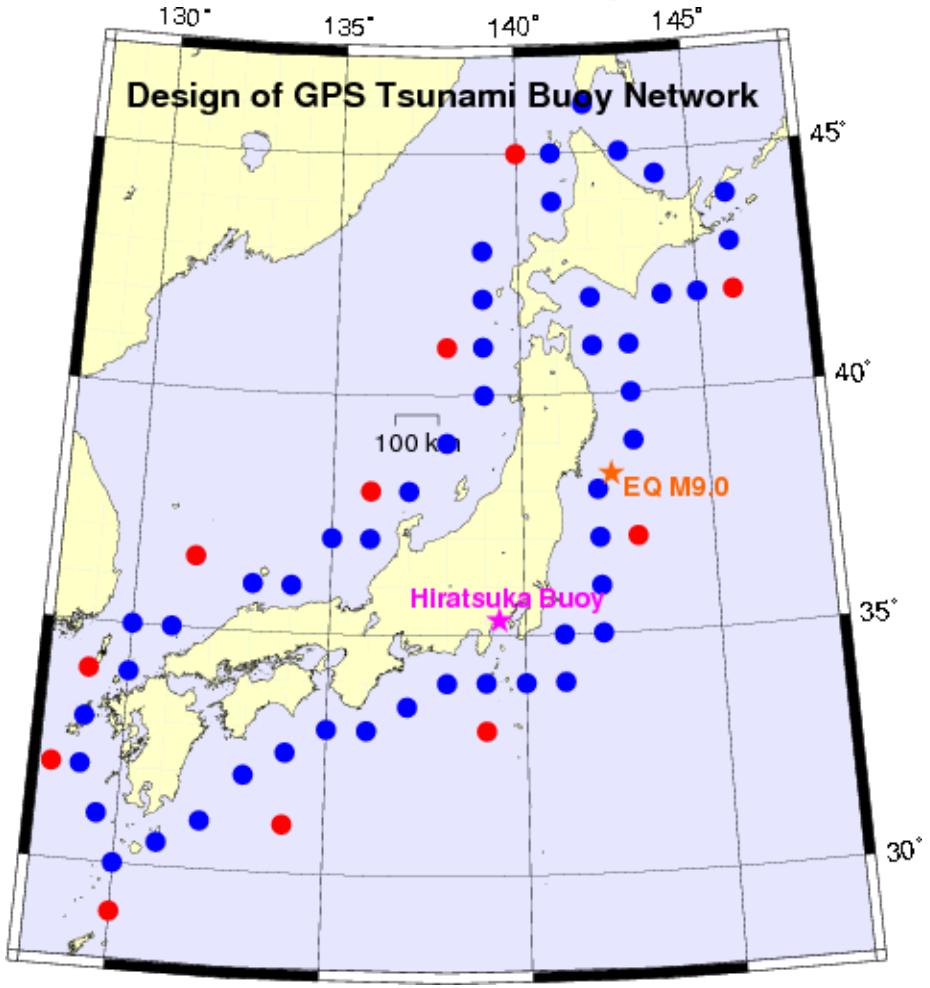
Proposal of Deployment of Multi-purpose GNSS Ocean Buoy Network



- **Tsunami, Wave and Atmospheric (ION and TRP-PWV) monitoring**
- **PPP-AR is better than RTK because of no requirement of reference station**
- **Deploy similar system globally for moisture database**

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Summary and Implication

- **Current GNSS buoy and RTK processing is not enough for quick warning of Tsunami**
  - **Ports and Harbors Bureau, MLIT deployed GPS Buoy for port management, main purpose is not a Tsunami detection**
- **Real-time monitoring of Tsunami at buoys far offshore and rapid warning of Tsunami based on real observation would be great help to mitigate natural disasters due to Tsunami**
- **PPP-AR for more accurate real-time monitoring of Tsunami is under experiment based on real-time GEONET data streaming**
- **Real-time monitoring of seismic wave would be helpful to mitigate natural disasters caused by earthquake**
- **Meteorology and multi-purpose maritime observation possible by loading various observation unit.**

Demonstration of processing http;//rtgps.com

The authors would like to thank Ports and Harbors Bureau, MLIT and Port and Airport Research Institute to provide monitoring data and pictures data, Dr.Tsugawa of NICT to use his results on this presentation.

Backup

Upper Left and Middle: Installation Buoy, Right: Danforce Anchor

Bottom Left: Buoy and Chain on the Vessel

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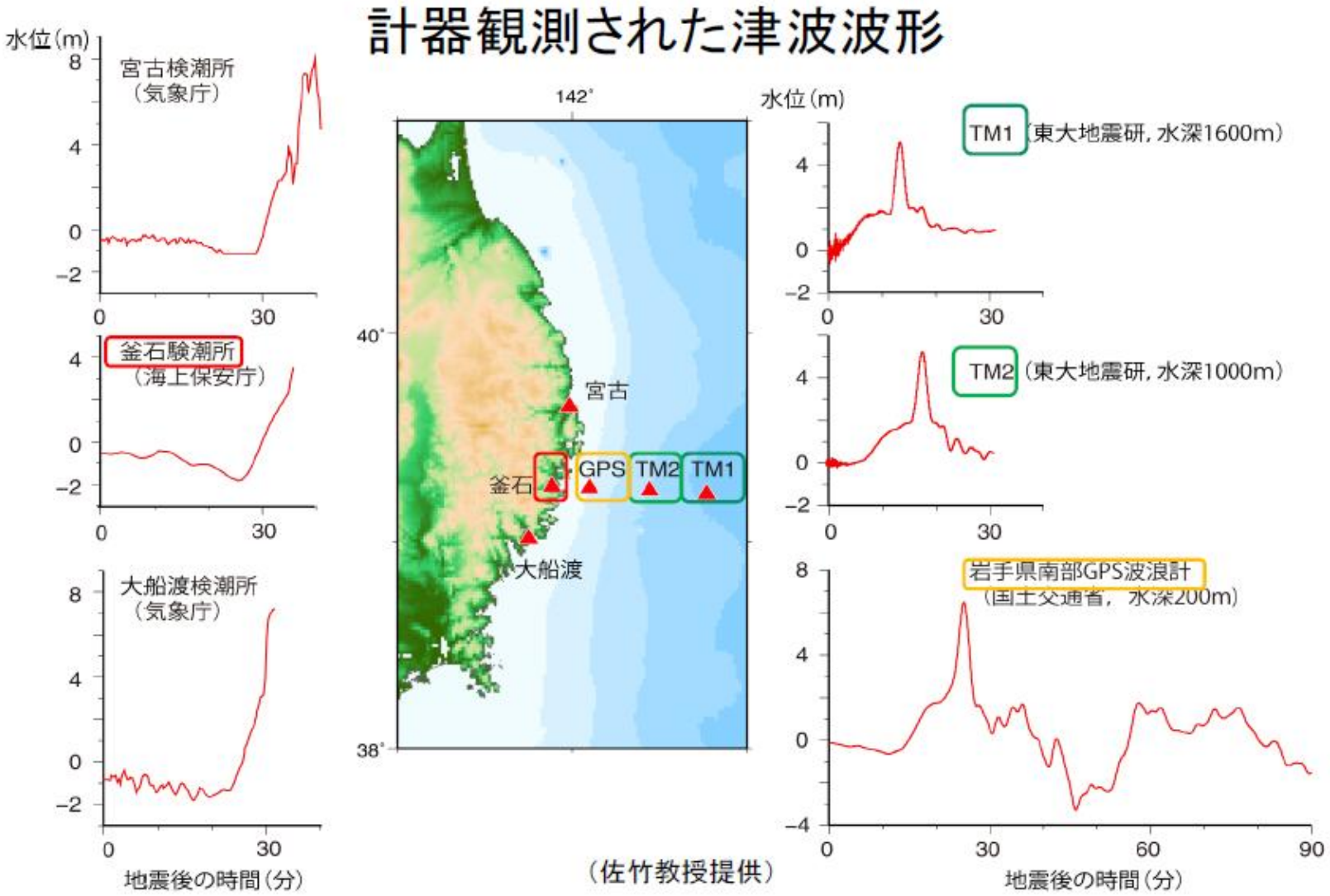
Backup



Backup