GNSS buoy array in the ocean for natural hazard mitigation

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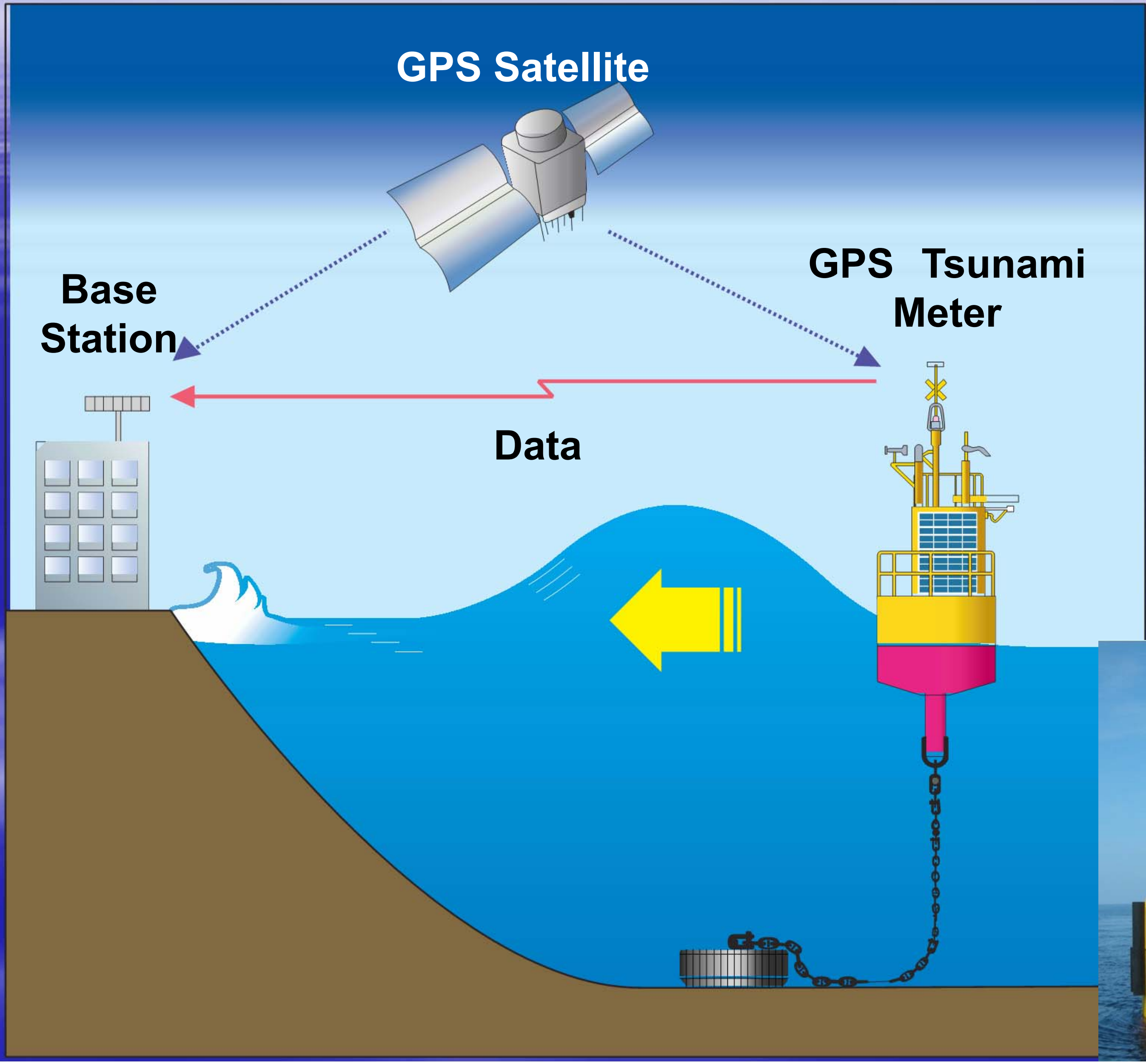
GNSS applications in Earth science
From static to high-rate observations

- Applications by “static” observations (30 sec)
  - Crustal deformations, plate motions
  - Earthquake mechanisms, volcanic eruptions,
    - Discovery of slow slip events along subduction zones
  - GPS meteorology, Ionospheric monitoring
- Applications by “high-rate” observations (1 Hz)
  - GPS seismometer
  - GPS-acoustic system for ocean bottom crustal movements monitoring
  - GPS buoy for, first, tsunami monitoring, then, application to meteorology and ionosphere in the ocean

Basic concept



Contents

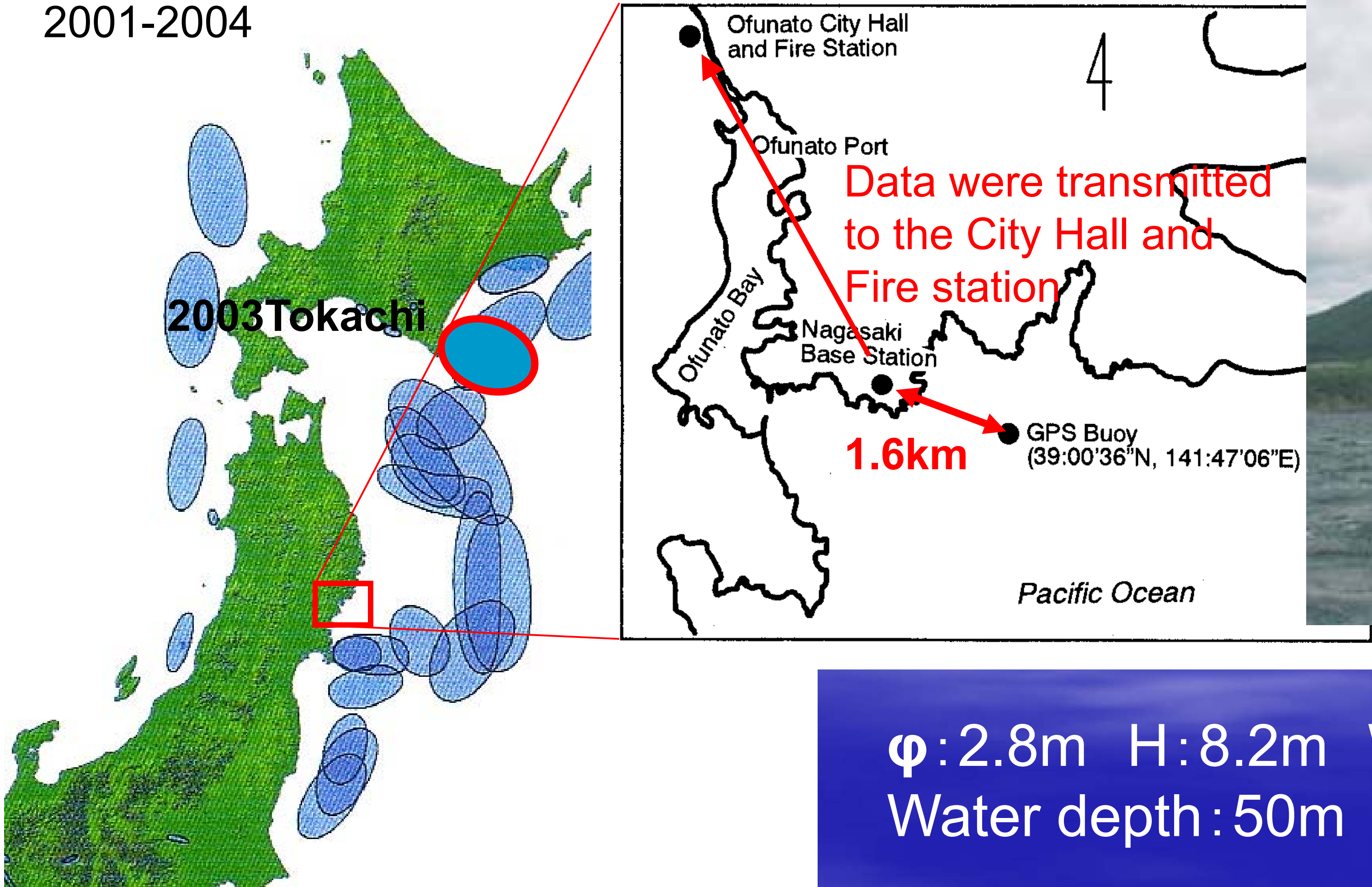
- Review of developments of GPS buoy
- Lessons from the 11 March 2011 Tohoku-oki tsunami
- Recent developments for solving the problems
- Further developments for applying to the ocean bottom crustal deformation monitoring, meteorology and ionospheric monitoring
- Summary and outlook

Proto-type GPS buoy – first experiment -

January 1997

GPS buoy for operational test off Ofunato, northeastern Japan

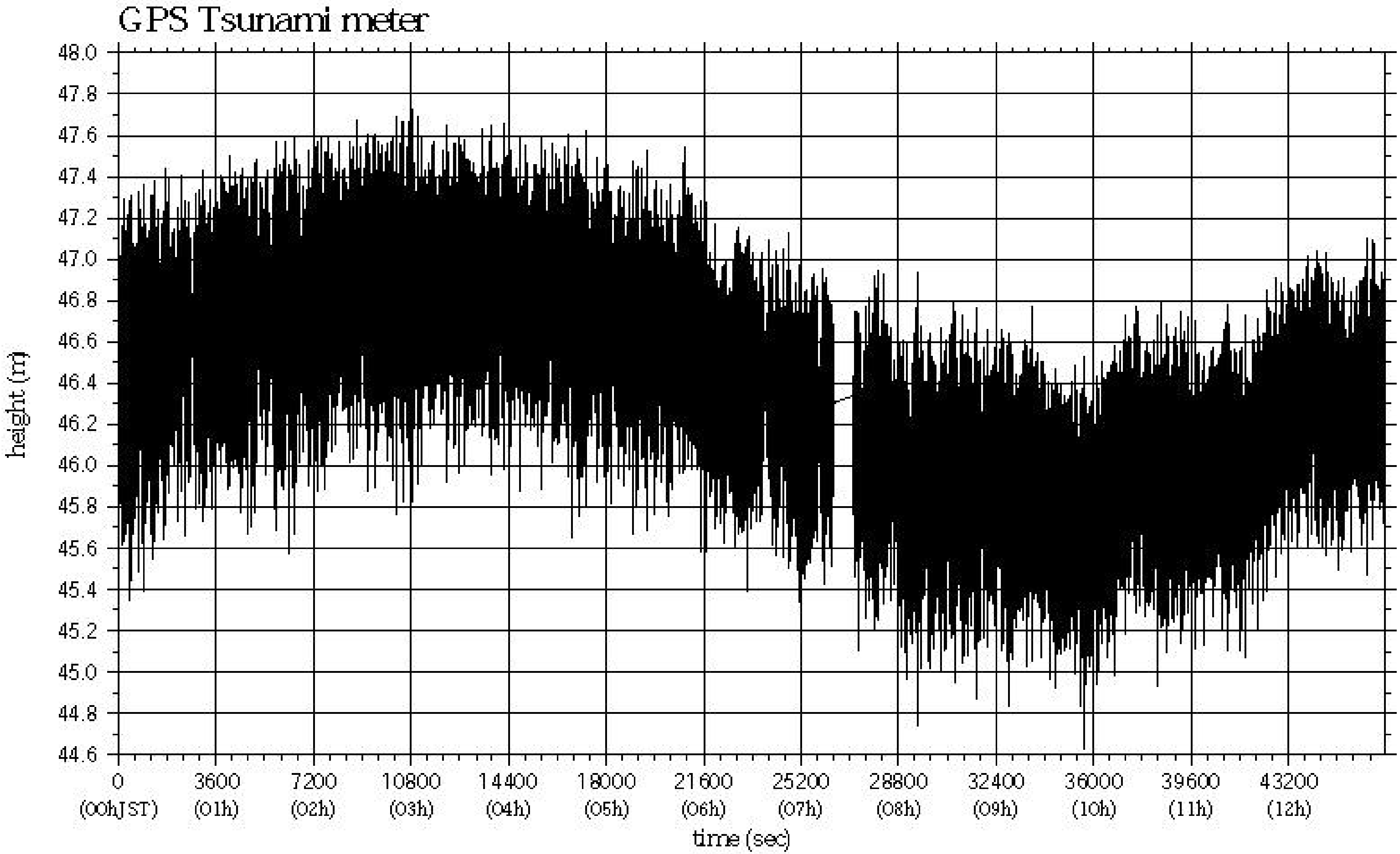
2001-2004



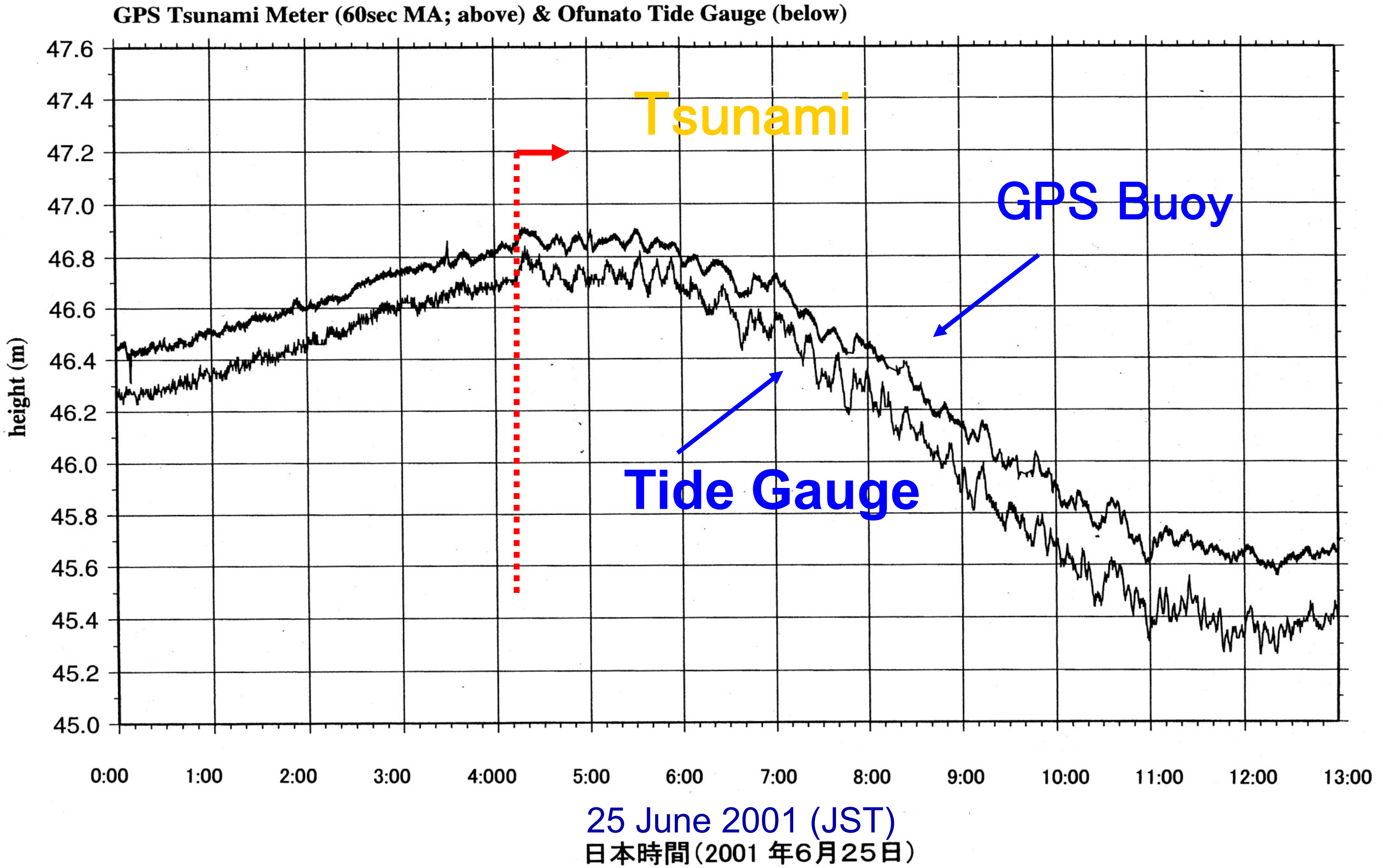
φ : 2.8m H : 8.2m Weight : 12ton
Water depth : 50m

Peru Earthquake JST25/06/2001

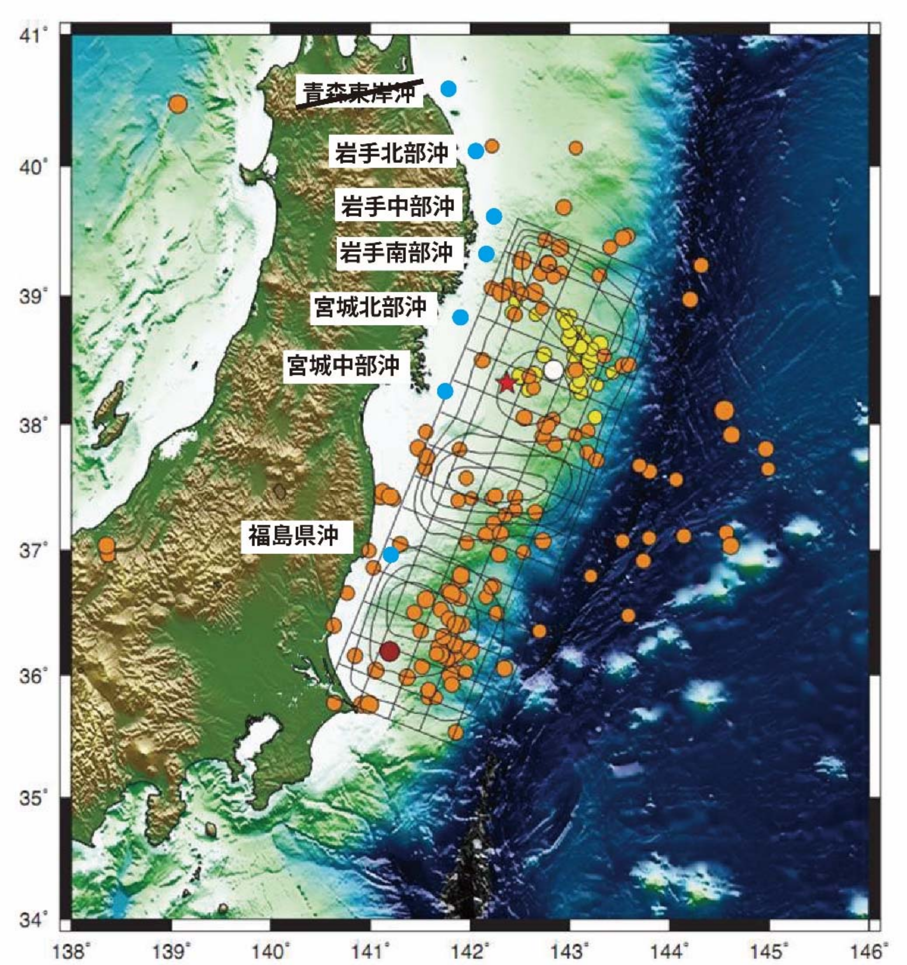
Original 1Hz data



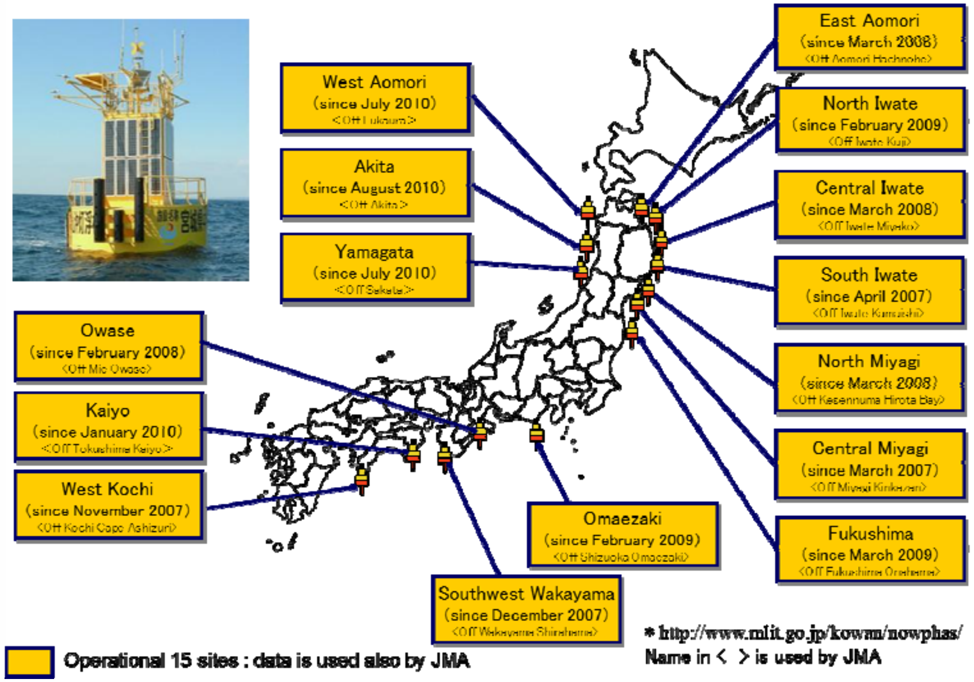
Peru Earthquake JST25/06/2001
Filtered buoy data and tide gauge data



GPS buoys implemented as "wave meter" operated as a national wave monitor system NOWPHAS

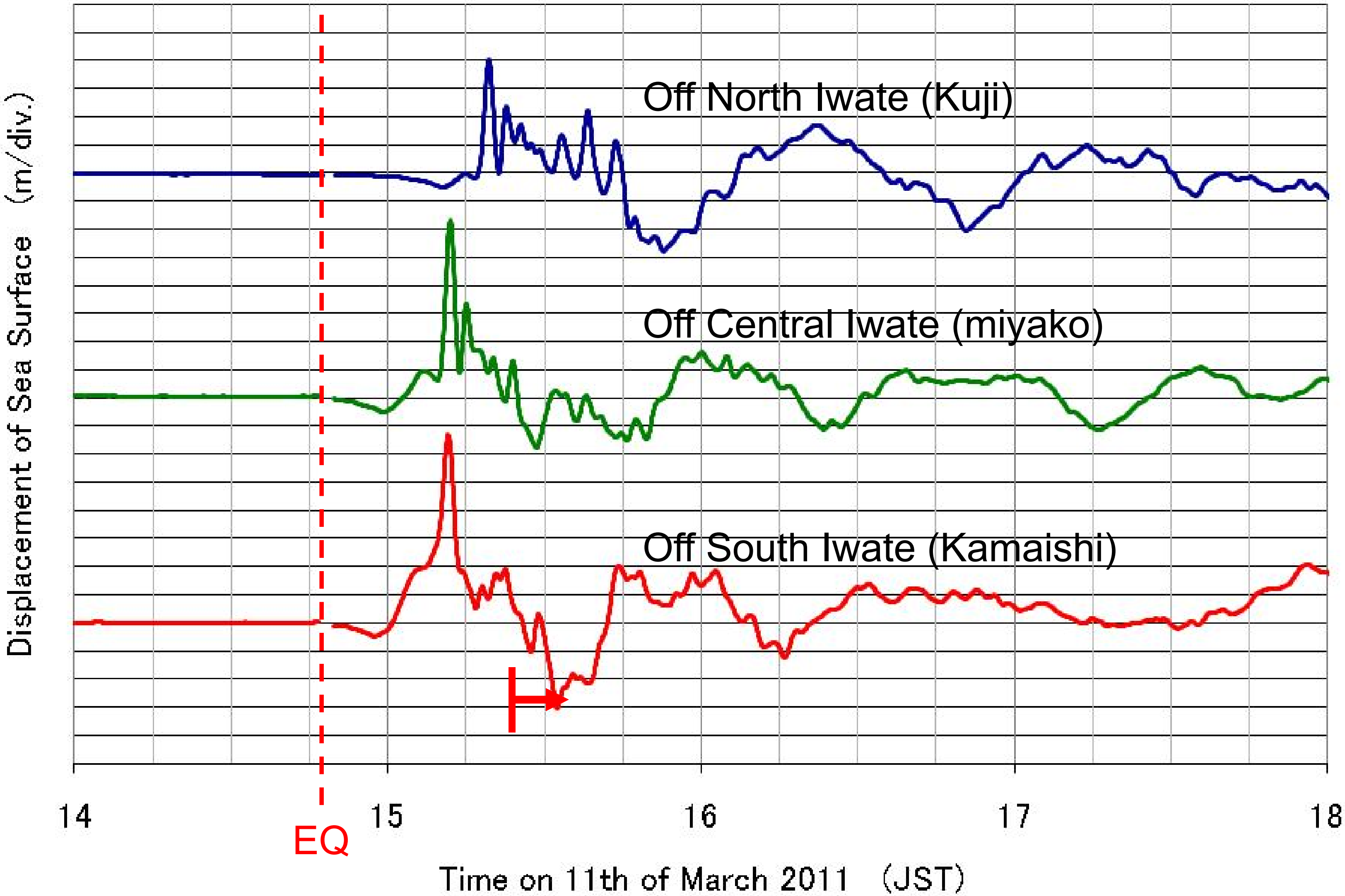


(From ERI HP)



- System uses RTK-GPS and data transmission by radio.
- Placed within 20km from the coast.
- Established at 15 sites as of 2012.
- Real time monitor on the Web is available.

Observed tsunamis due to the Tohoku-Oki earthquake on 11th March 2011 by GPS buoys



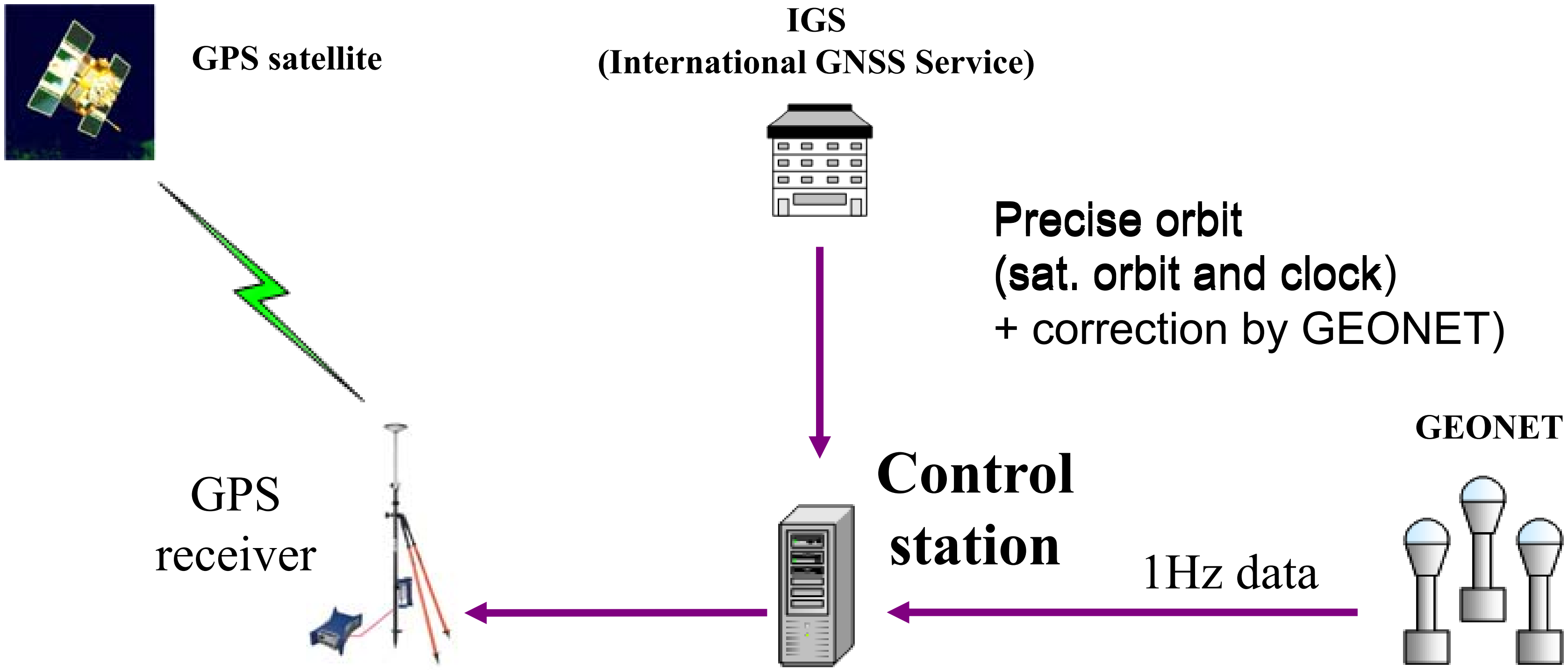
(Courtesy of Port and Airport Research Institute)

Lessons from the 11 March Tohoku-oki tsunami and their countermeasures

- GPS buoy should be placed much farther offshore for effective early warning (>100km)
- Problems to be solved for far-offshore buoy deployments

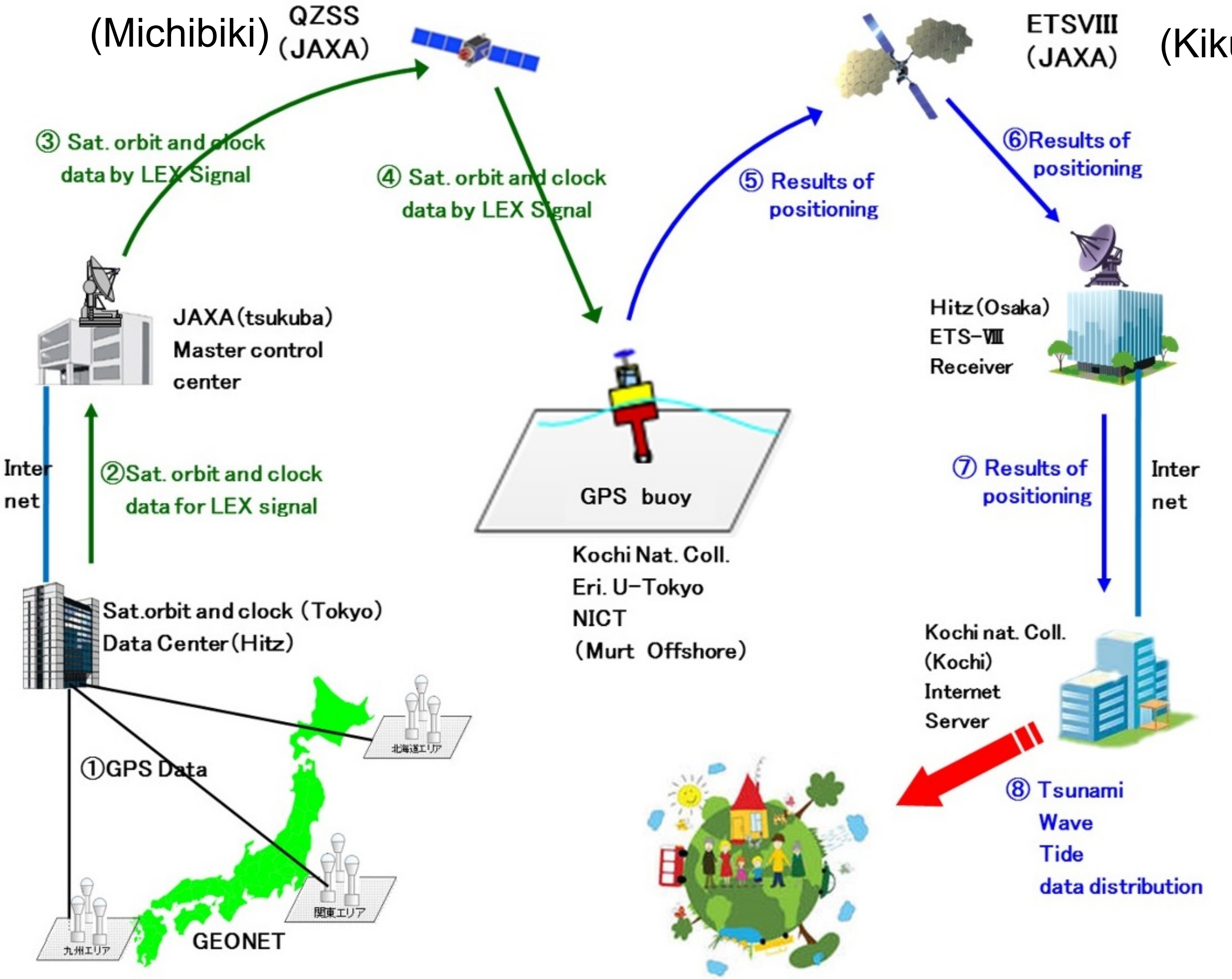
1. Baseline mode kinematic observation has distance limit for accurate measurements (<20km).
   - New algorithm of Precise Point Positioning should be introduced
2. Surface radio system is not adequate for long distance data transmission
   - Data transmission via satellite is needed

New algorithm: PPP-AR
(Precise Point Positioning with Ambiguity Resolution)



Conventional PPP uses only IGS orbits/clock.
New PPP-AR uses corrections by GEONET data

Experiments with QZSS & ETS-VIII



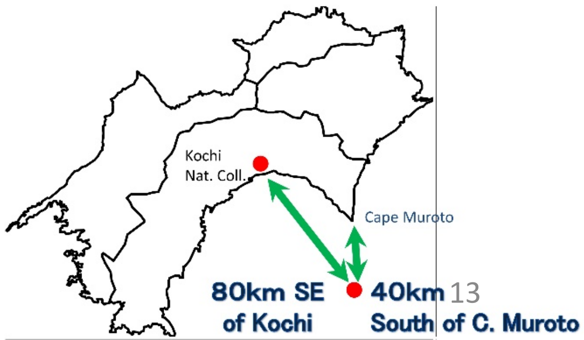
➢Period of experiments

16 Dec. 2013 – 5 Jan., 2014

1 - 15 Jun., 2014

➢Purpose

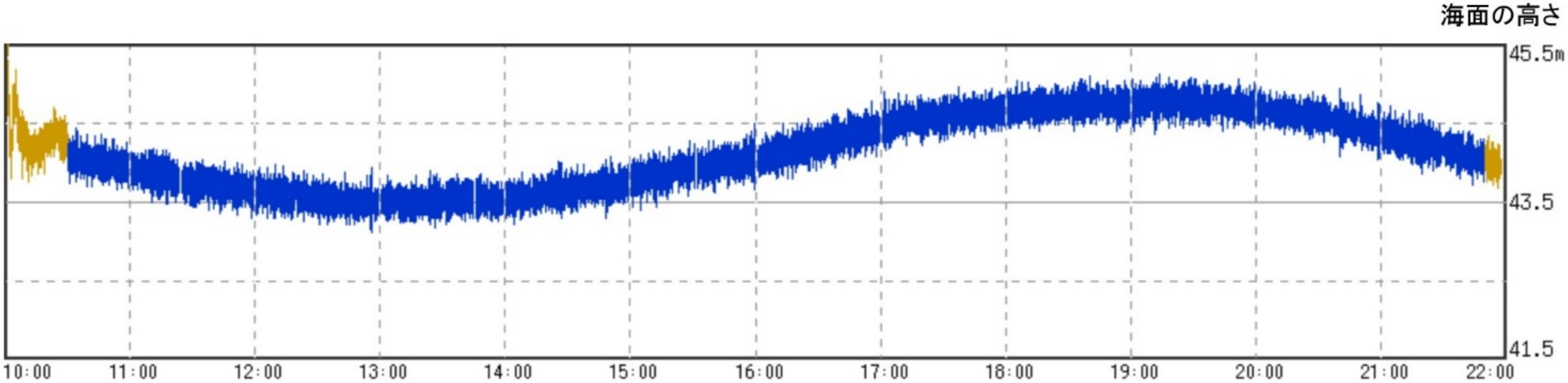
- Correction data transmission using LEX/QZSS
- Positioning data transmission via ETS-VIII.
- Real-time data dissemination through internet

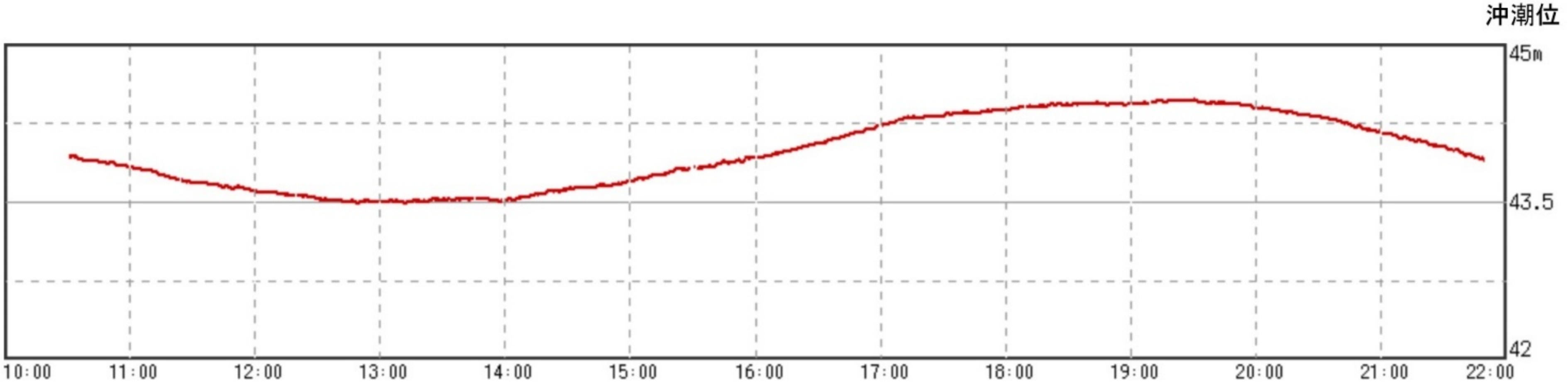


Experiments with QZSS & ETS-VIII

実験期間：2013年12月16日～2014年1月5日（1/3 10:00～22:00, 1/4 8:00～18:00, 1/5 8:00～18:00）

表示開始日時：2014 年 1 月 3 日 10 時 (JST)　表示期間：12 時間　データ表示



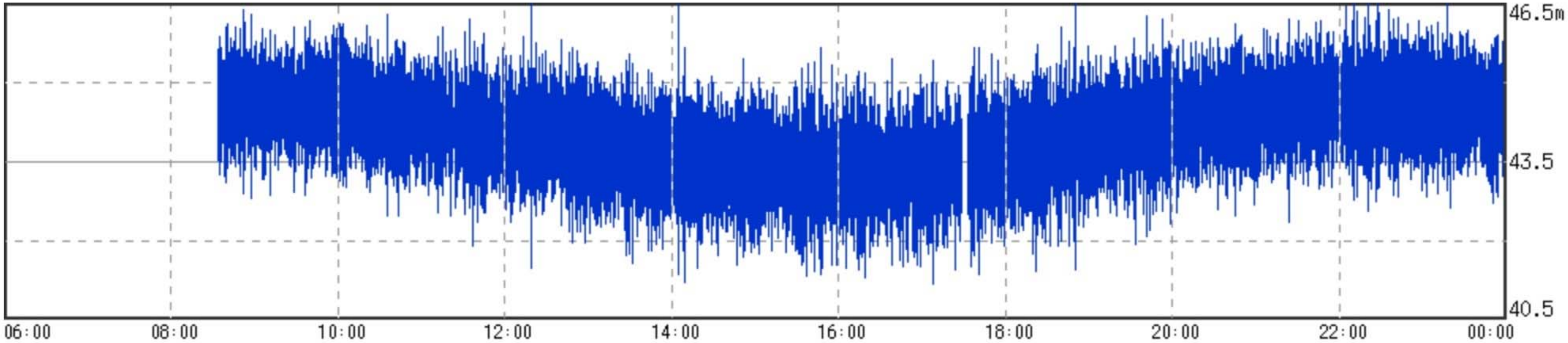


※—Fix解、—Float解、—沖潮位
※【横軸】時刻、【縦軸】（上）海面の変位、（下）沖潮位
※表示期間を長くした場合、表示までに時間を要することがあります。
※周波数偏移に対するコマンド実行のため、20秒程度の欠損が発生する場合があります。

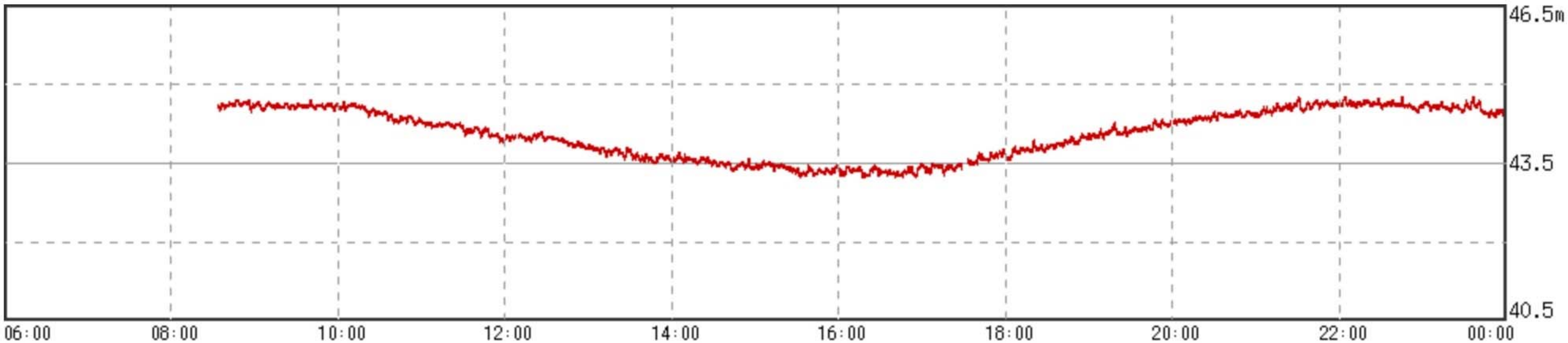
Experiments with QZSS & ETS-VIII

表示開始日時: 2014 年 6 月 18 日 6 時 (JST)　表示期間: 18 時間　データ表示

海面の高さ ±3m



沖潮位 ±3m



※—Fix解、—Float解、—沖潮位
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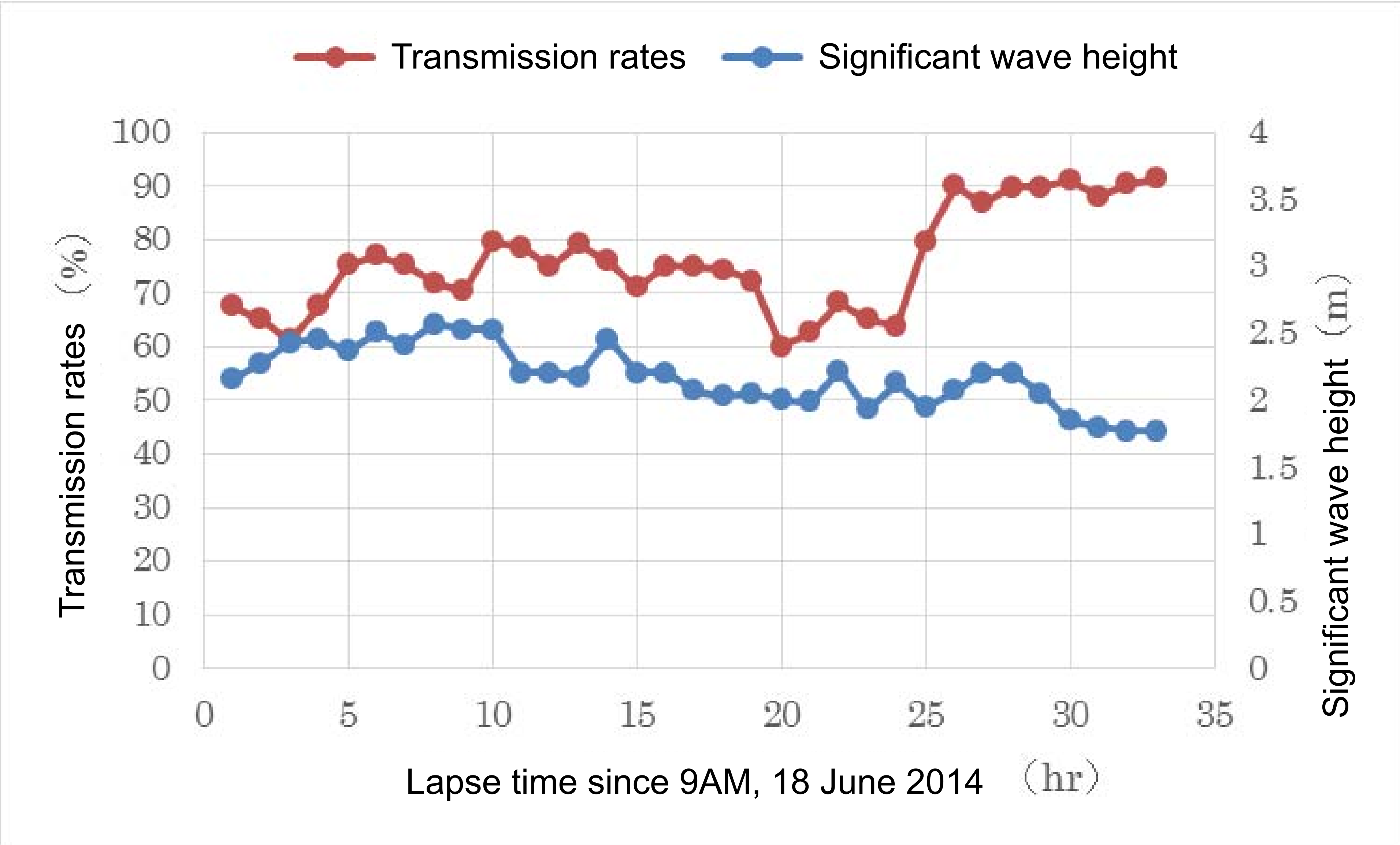
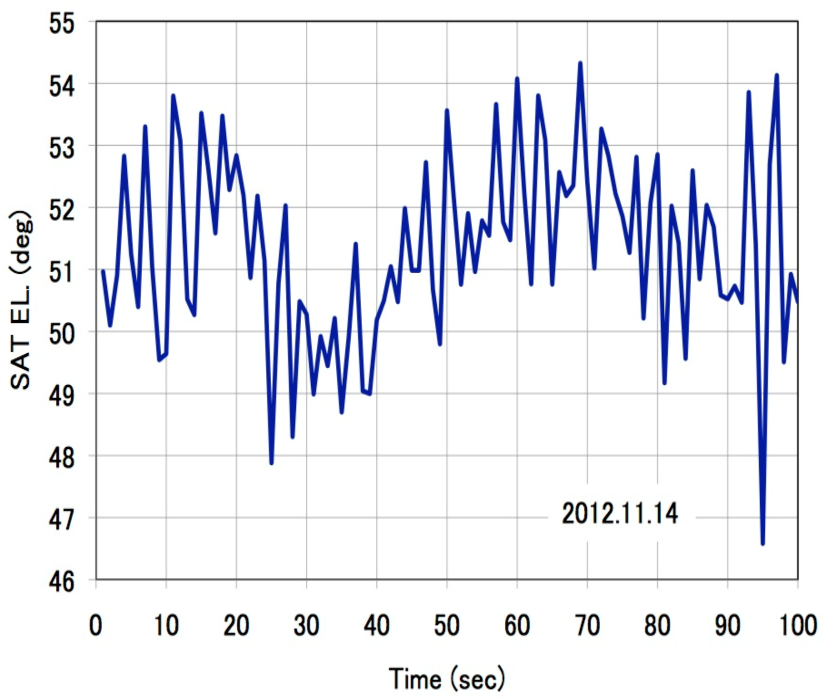
Experiment with QZSS & ETS-VIII

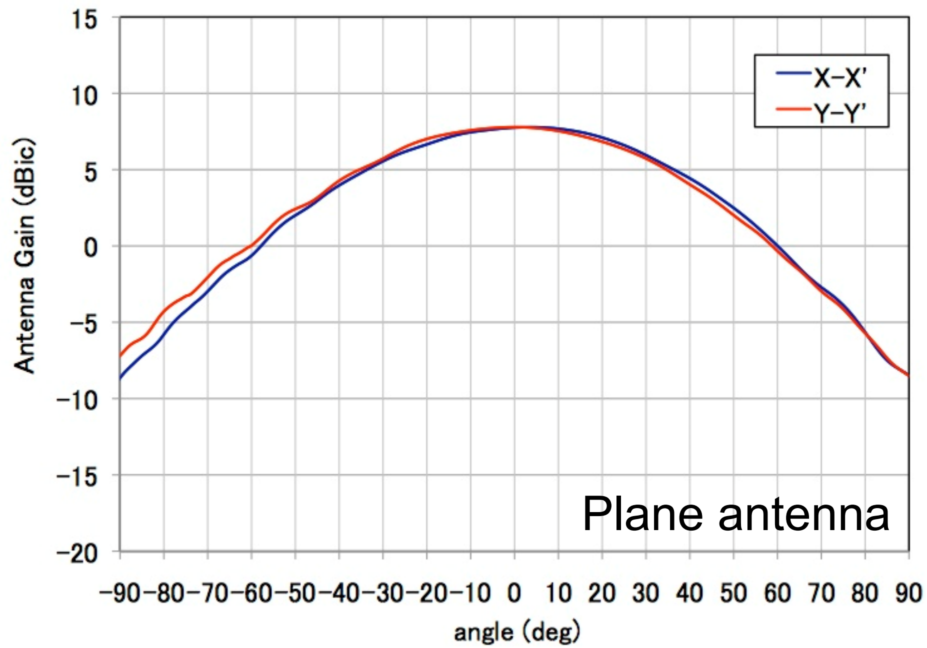


Experiment with QZSS & ETS-VIII

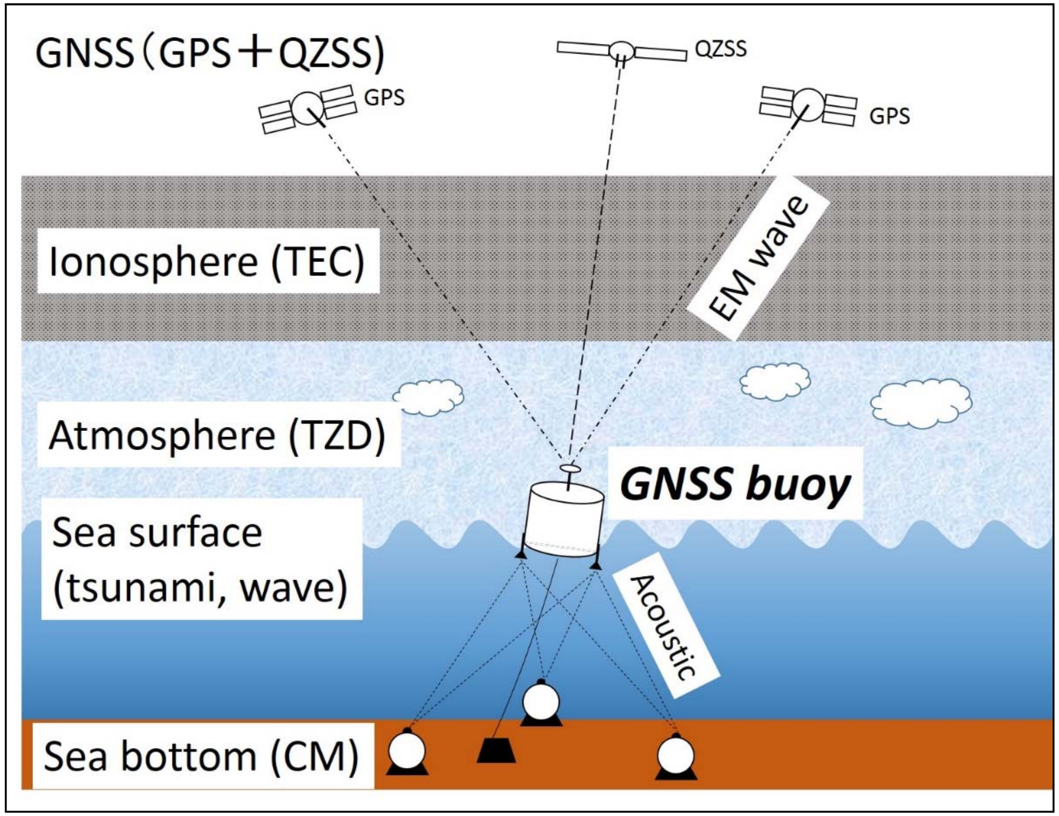
Temporal change of elevation angle



Antenna gain w.r.t. zenith angle



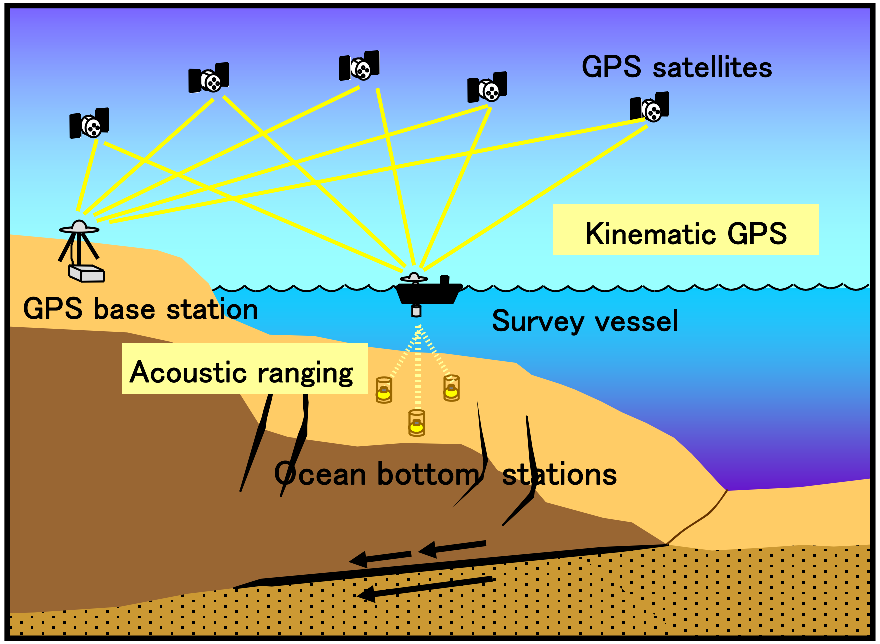
Multi-purpose GNSS buoy for disaster mitigation

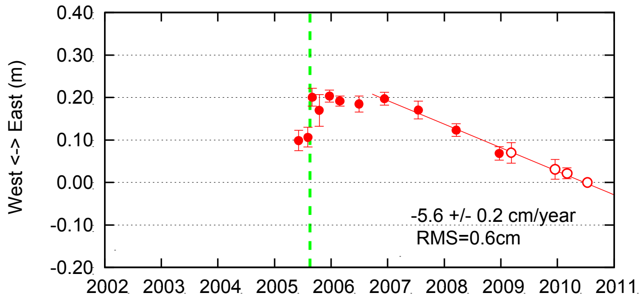


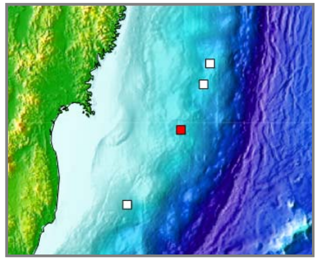
- Tsunami early warning as well as wave monitoring is already operation
- Ocean bottom crustal movements
  - Continuous monitoring by GPS/Acoustic system
- Atmospheric research (GPS meteorology)
  - Contribution to weather forecast
- Ionospheric research
  - Contribution to space weather forecast
- Ocean surface monitoring with ancillary equips

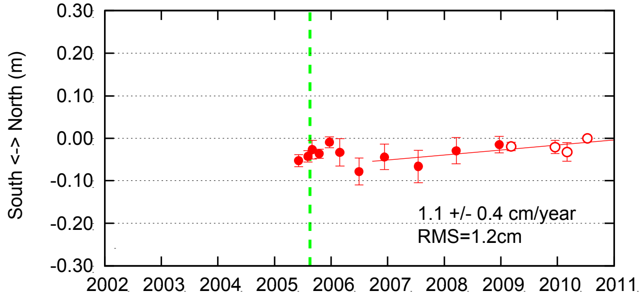
- High speed satellite communication is required

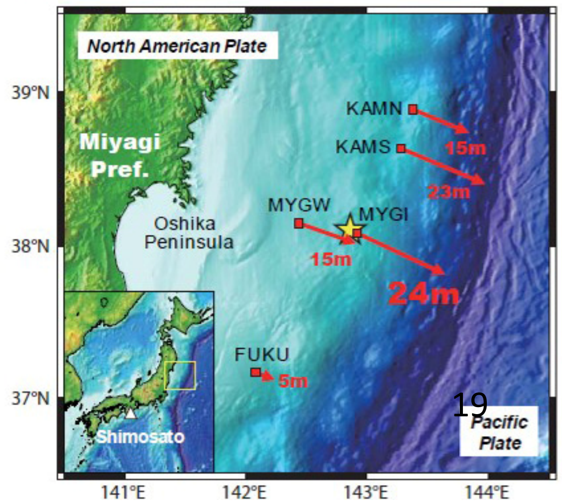
Ocean bottom crustal movement observation using GPS/Acoustic system





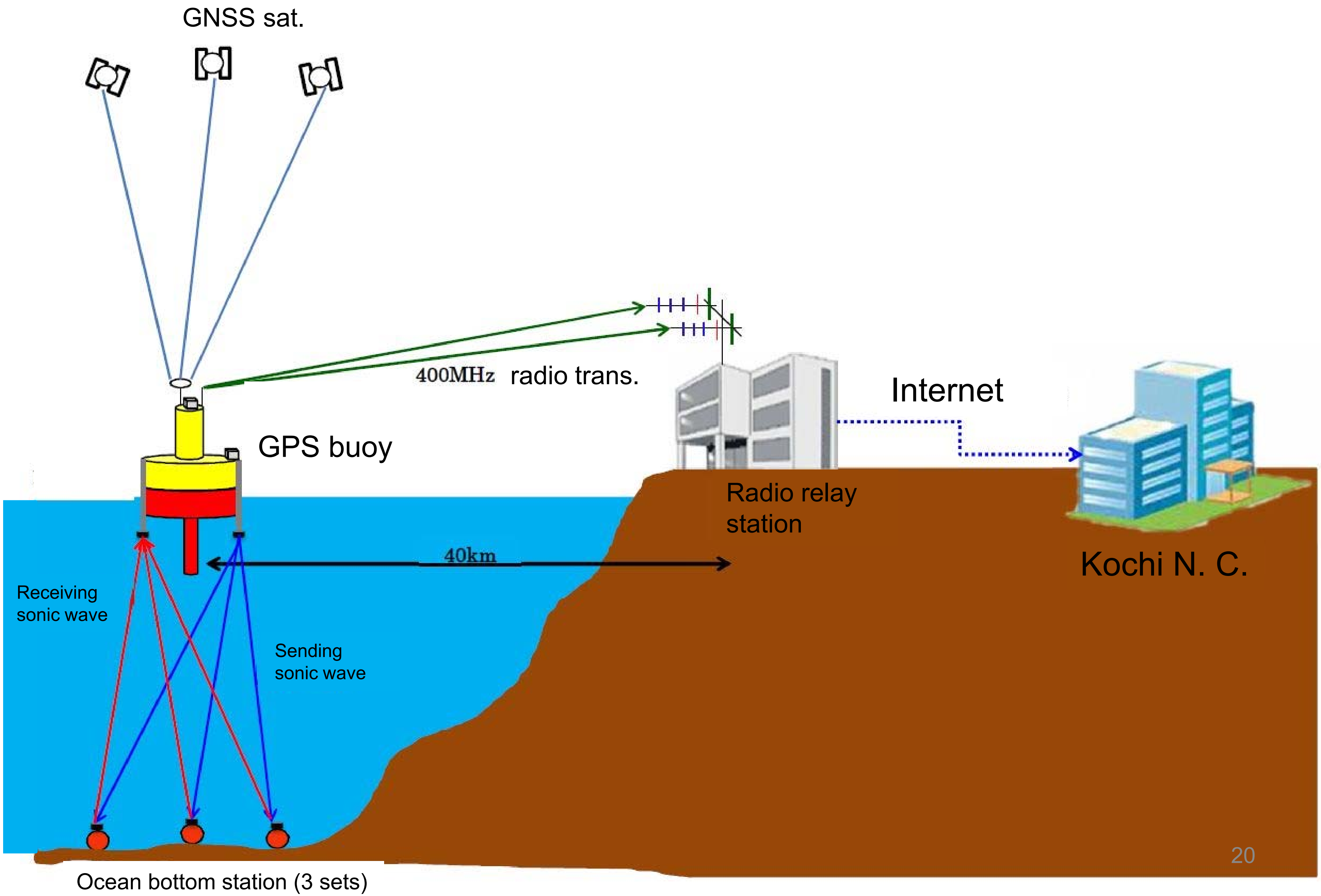




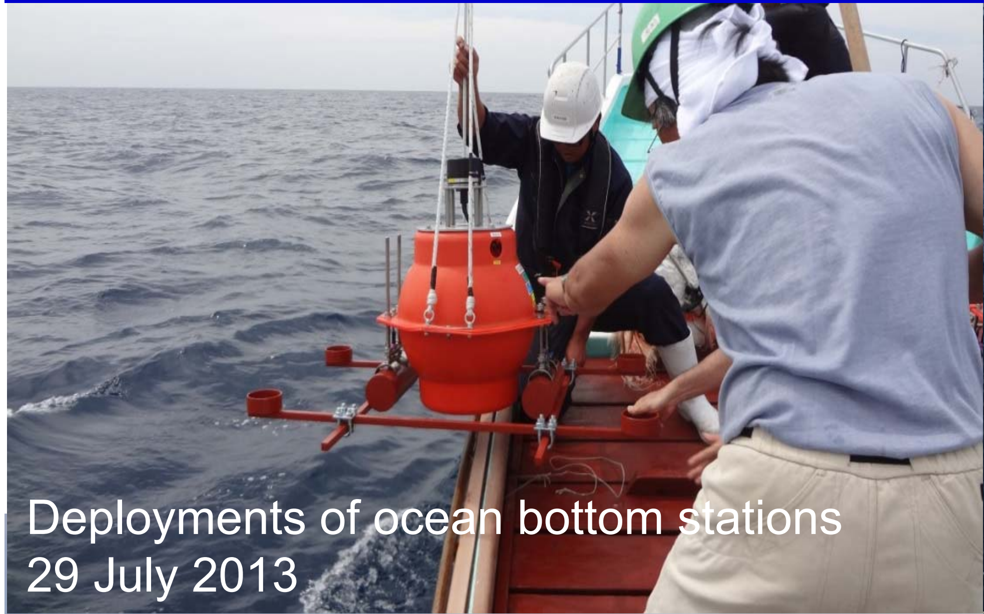


Slides provided by Mariko Sato
(Japan Coast Guard)

Application to ocean bottom crustal movements monitoring using GNSS buoy



Experiment in 2013



Deployments of ocean bottom stations
29 July 2013

CTD observation: 31 July 2013

GPS/Acoustic ranging using buoy:
2 August – 2 October, 2013

GPS/acoustic ranging using a boat:
31 July 2013

Comparison of received acoustic waves

Acoustic waves using a boat

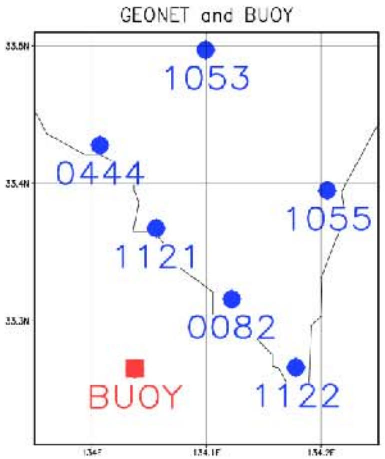
Correlation coefficient: 0.2

Acoustic waves using a buoy

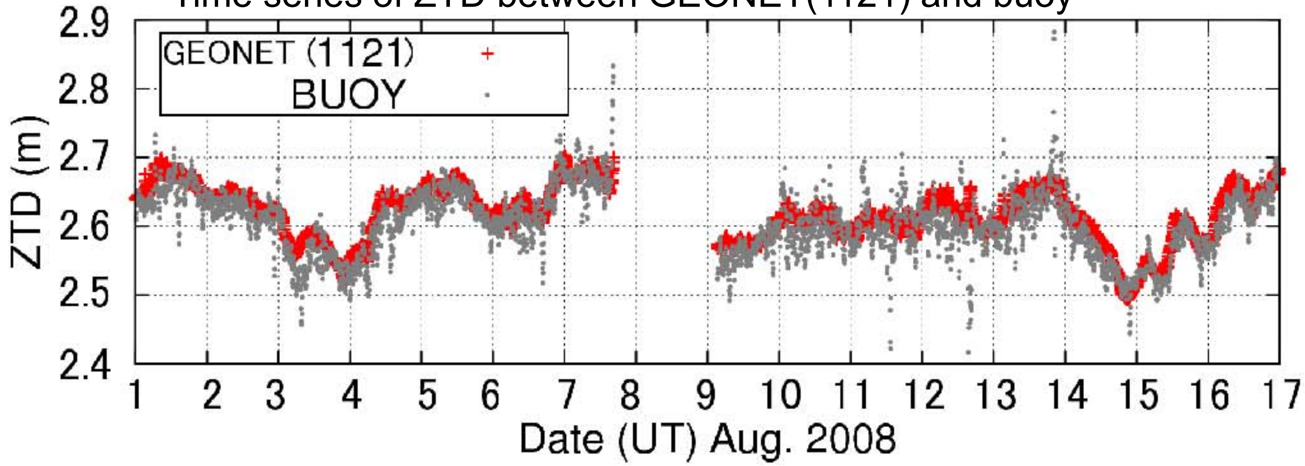
Correlation coefficient: 0.8

Application of GNSS buoy for weather forecast

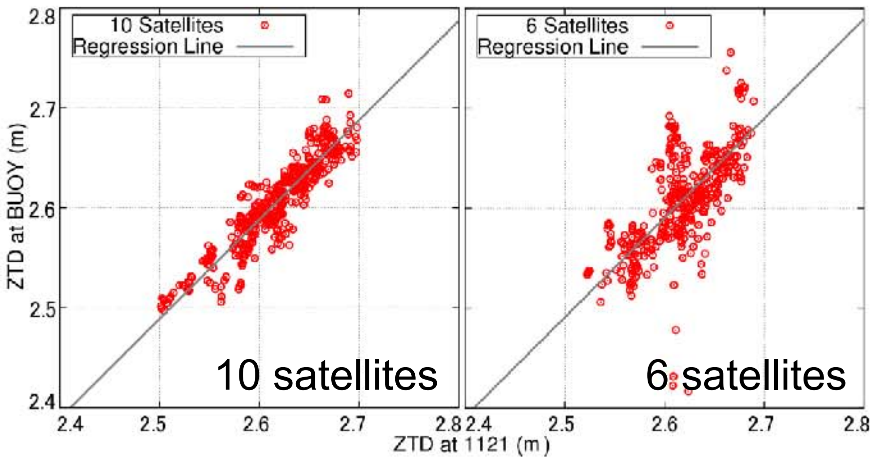
GPS buoy and GEONET sites



Time series of ZTD between GEONET(1121) and buoy



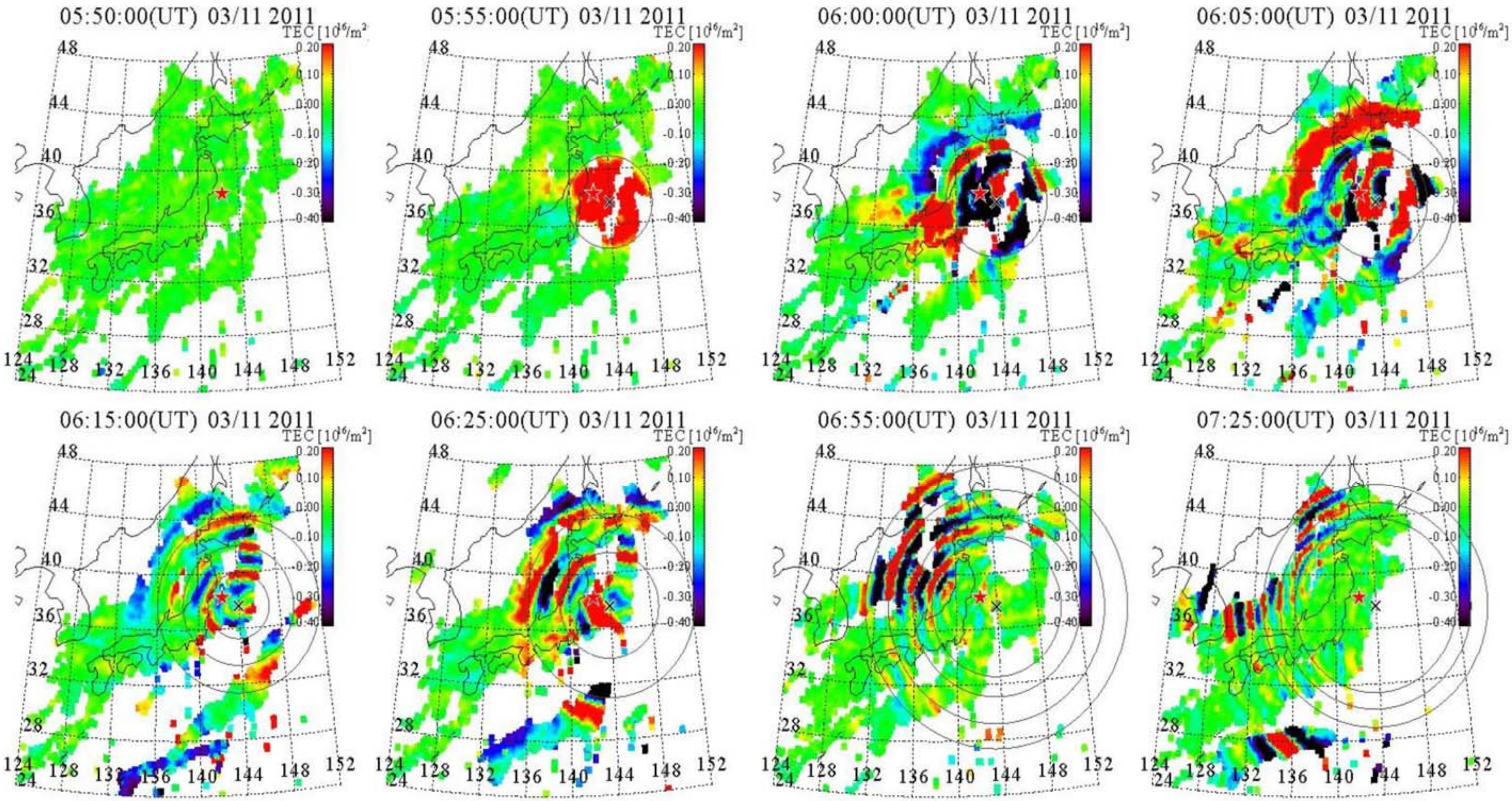
- ➢ Comparison is made between buoy and the GEONET site of the lowest height nearby the buoy.
- ➢ Data period: 1-16 August 2008
- ➢ Time series at the buoy (●) is generally consistent with that on the ground (●), yet the former differs from the latter at some time periods.



- ➢ More satellite number provides better agreement between the two, implying adding satellites other than GPS, such as GLONASS, may improve the results.

（Y. Shoji：Spring Meeting of MSJ 2010）

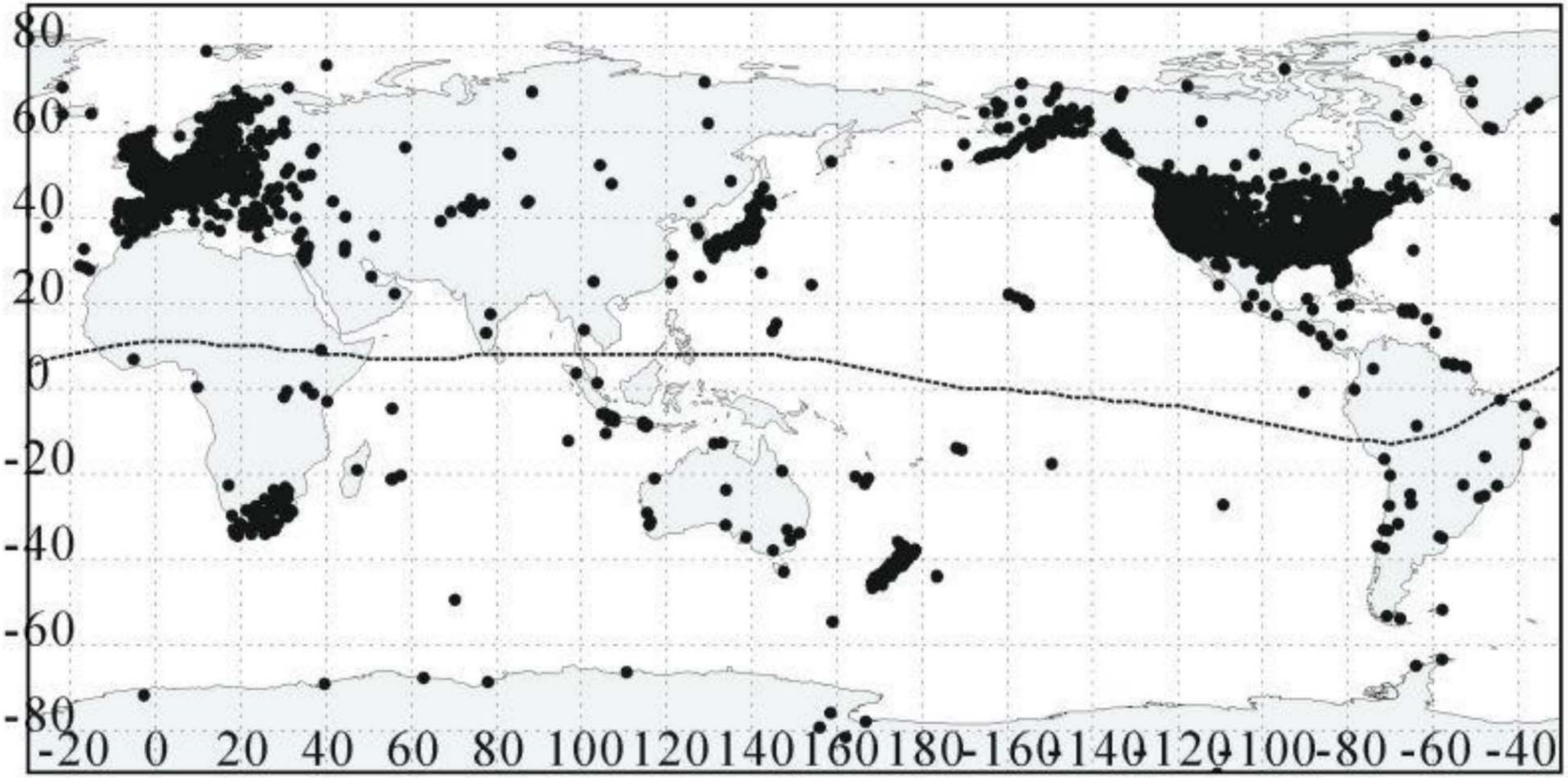
TEC variation observed at the 2011 Tohoku earthquake by NICT



- TEC variation observed using GEONET data. Short period variations with less than 10 minutes of periods are shown. X indicates ionospheric epicenter. Concentric circle is centered at the ionospheric epicenter. Cut-off elevation angle is 15deg.

（translated from the slide by Tsugawa）

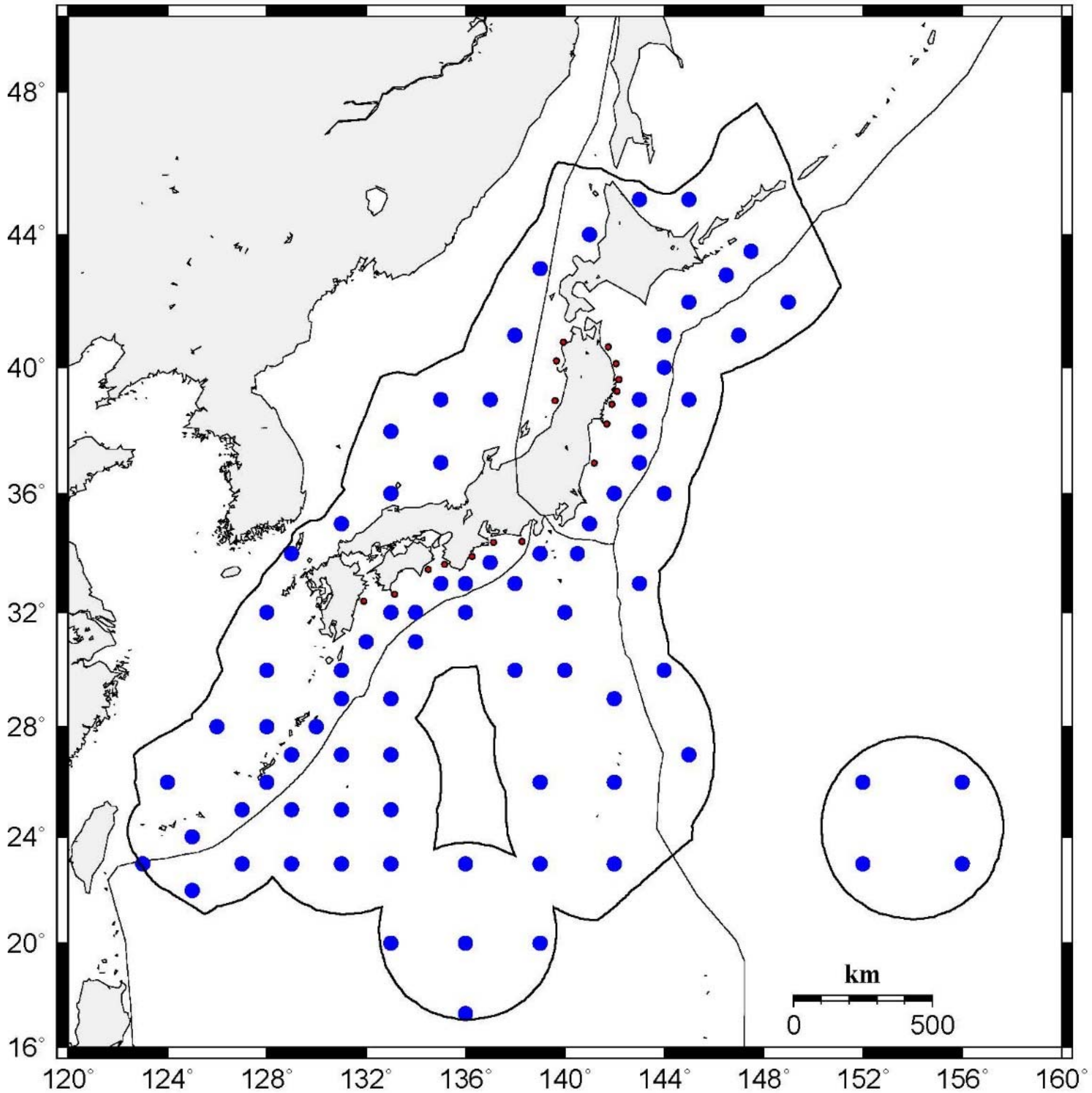
Global ground-based GNSS network
- Next step to the oceanic region -



- More than 5,000 ground-based GNSS sites data are available online as of Jan. 2012, over the world.
- More distributed GNSS sites in the ocean, together with more GNSS satellites, improves spatial resolution and decreases blank area.

（translated from the slide by Tsugawa）

Proposal of GNSS buoy array in the western Pacific



(81 sites in the Japanese EEZ; Modified from Tsugawa et al., 2012)

Expected cost for 81 sites:

(Very coarse!)
Construction 300million$
Operation 10million$/yr

Feasible? or Not?

Summary

- Current GNSS buoy system uses baseline mode and has limits of distance up to 20km.
- We are testing a system that would be deployed at far offshore of 100km or more.
  - A new algorithm of PPP-AR is successfully applied to the system.
  - Test of satellite data transmission has been successful.
- If it is capable of deploying GNSS buoy at far offshore, a GNSS buoy array in the western Pacific or elsewhere would be a next challenge for multi-purpose disaster mitigation infrastructure in the region.

Thank you very much for your kind attention !