Developments of GNSS Buoy for a Synthetic Geohazards Monitoring System

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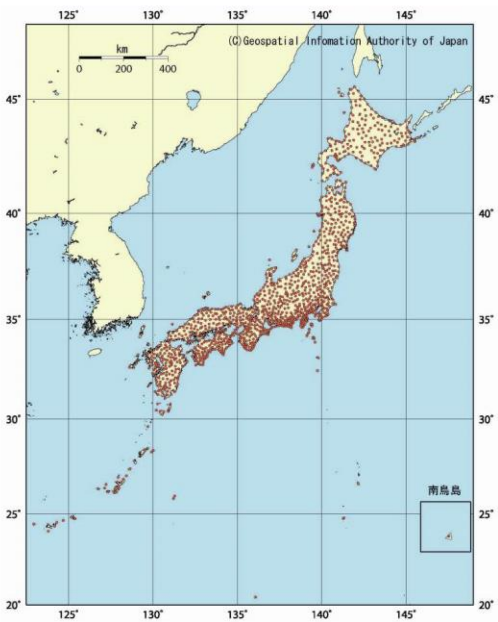
Global cGNSS network – dense onshore network and very sparse oceanic region -

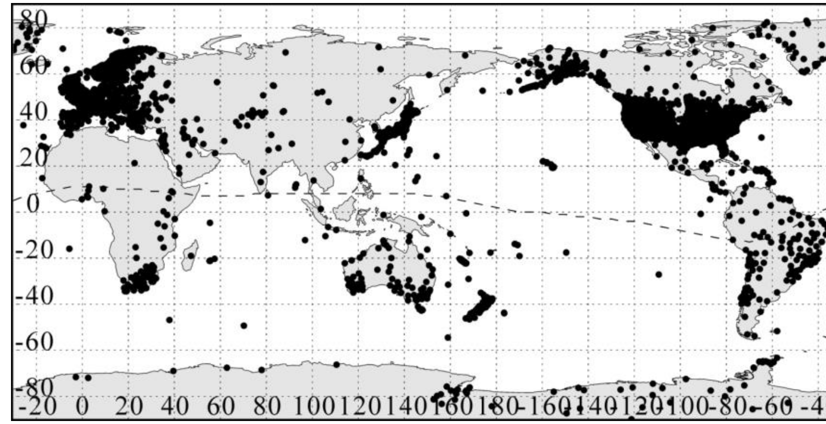
More than 1200 sites with about 20km spacing in Japan (GEONET) has been used extensively to study crustal movements, earthquakes as well as atmosphere and ionosphere.



（from *GSI webpage）

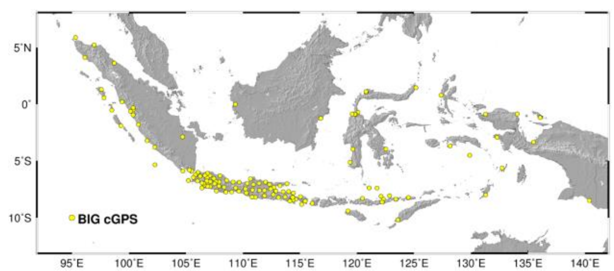
(GSI: Geospatial Information Authority of Japan)

More than 6000 continuous GNSS (cGNSS) sites over the globe but only onshore



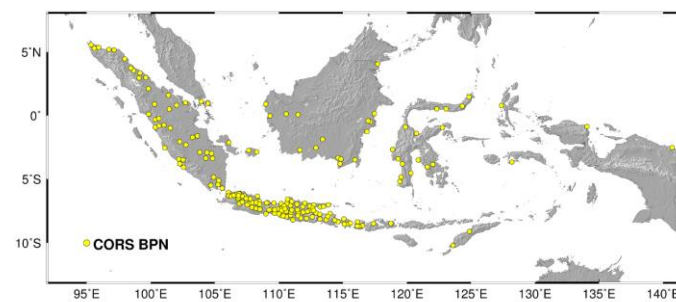
（courtesy by T. Tsugawa）

GNSS buoy array in the ocean will fulfill vacant areas of cGNSS network



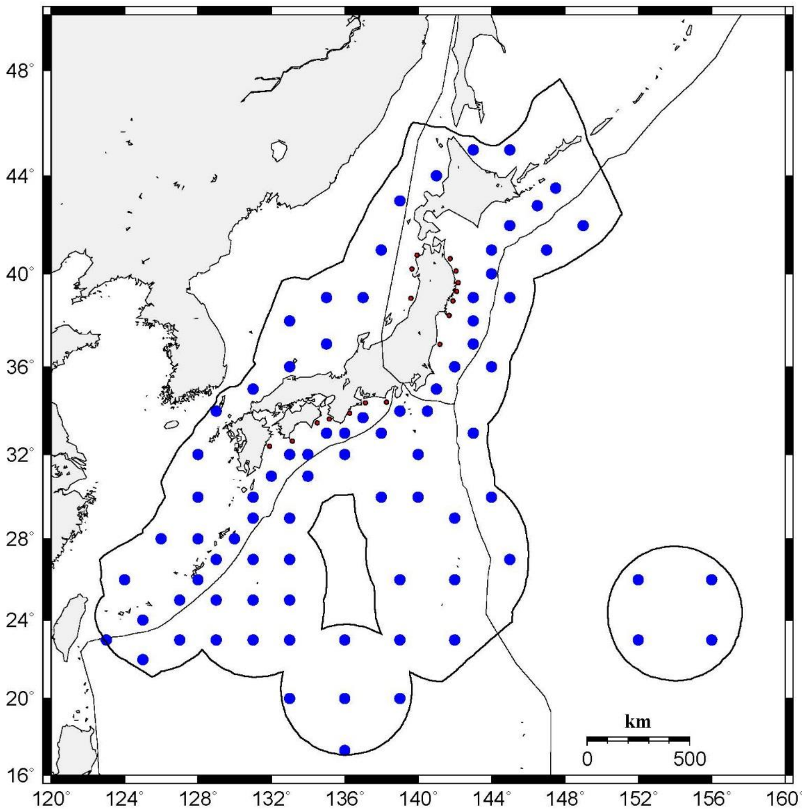
GPS CORS managed by BIG (Geospatial Agency of Indonesia)
(**118 stations** in 2014)

(courtesy by H. Z. Abidin)



GPS CORS managed by BPN (National Land Agency) (**183 stations** in 2014)

Our goal: GNSS buoy array in the ocean

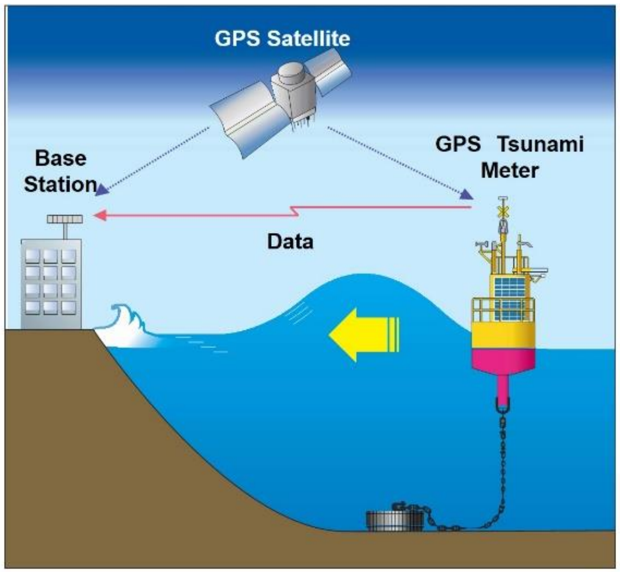


(81 sites in the Japanese Exclusive Economic Zone (EEZ); Modified from Tsugawa et al., 2012)

Contents

- History of developing GNSS buoy for tsunami early warning
- A problem found and its solution, and improvements
- Further possible applications of GNSS buoy
- Significance of GNSS buoy array

Development of GNSS buoy for early tsunami detection



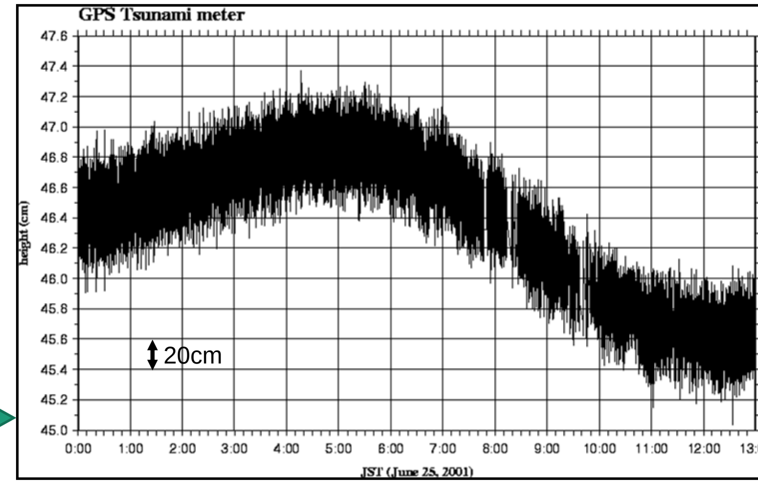
- We have developed GNSS buoy for early tsunami detection for about 20 years.
- Conventional baseline mode RTK-GPS has been used.
- Higher than a few centimeter of tsunamis have been successfully detected.

Prototype buoy in 1997

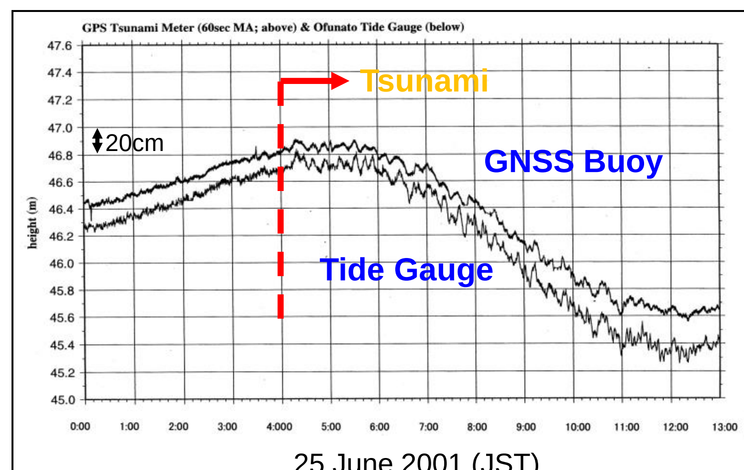
Off Ofunato (2001-2004)

First detection of tsunami due to the 2001 Peru earthquake

Original record

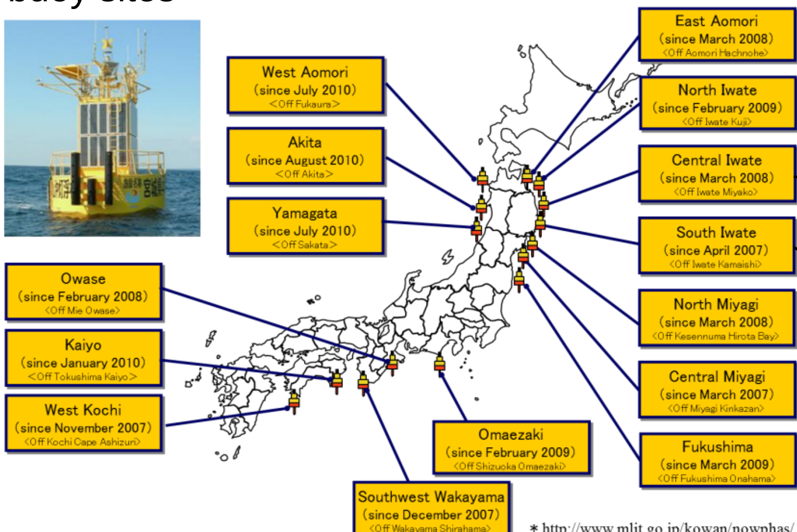


LPF record



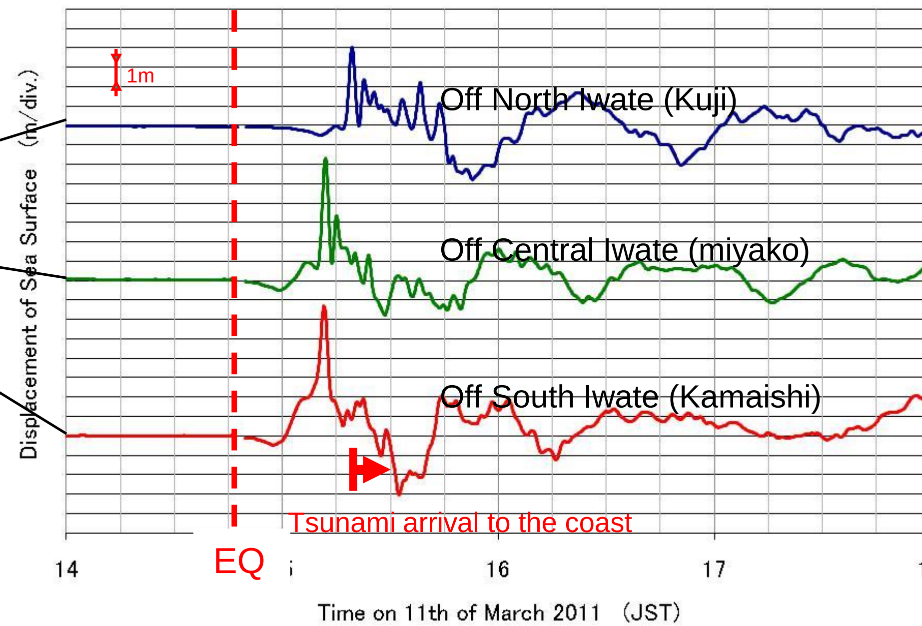
National GNSS buoy array implemented as "wave meter" (NOWPHAS) detected 11 March 2011 Tohoku-oki tsunami

NOWPHAS (The Nationwide Ocean Wave information network for Ports and HArvourS) buoy sites



Operational 15 sites : data is used also by JMA

* http://www.mlit.go.jp/kowan/nowphas/
Name in < > is used by JMA



- System uses RTK-GPS and data transmission by maritime radio.
- Placed within 20km from the coast.
- Established at 15 sites as of 2011.
- Real time monitor on the Web is available.

- Tsunami was detected before its arrival to the coast.
- The information was used to update the tsunami alert.
- Updated alert was not effectively used by people, resulting in lots of tsunami victims.
- Buoys need to be placed much farther from the coast.

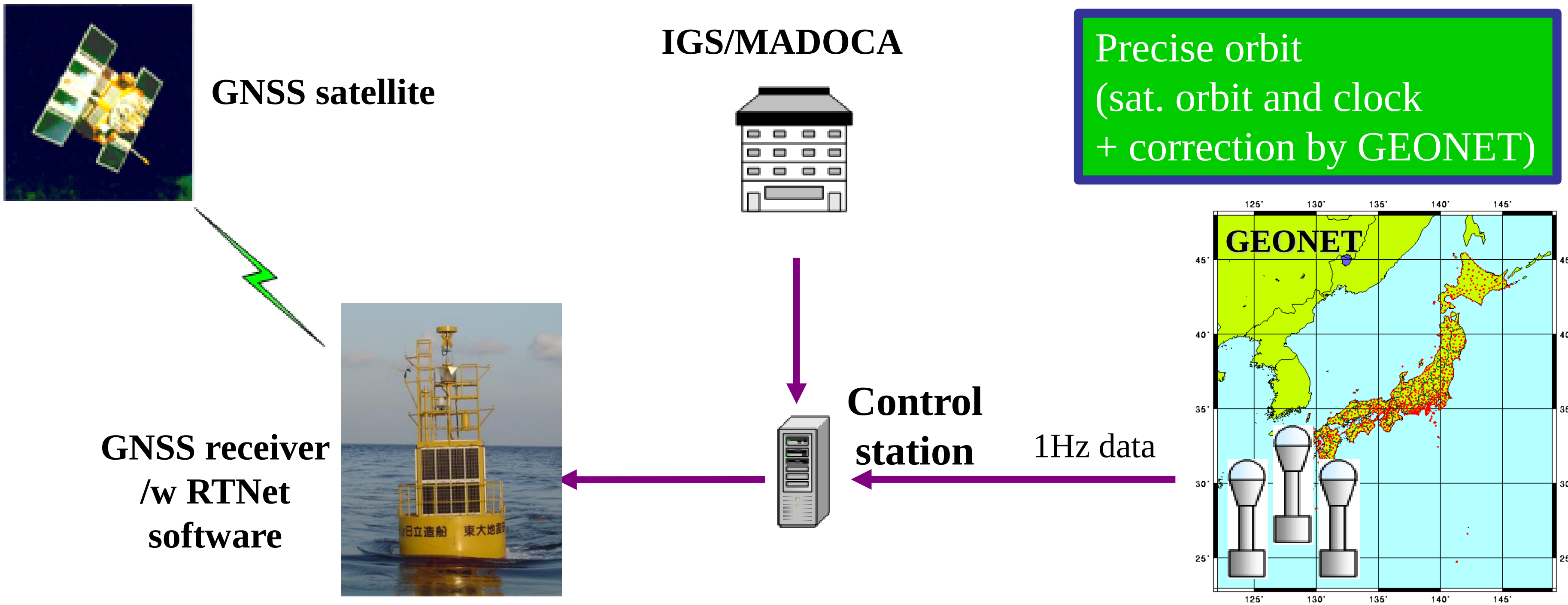
How can we deploy GNSS buoys at far offshore?

- New algorithm of Precise Point Positioning with Ambiguity Resolution (PPP-AR)
- Satellite data transmission

These technologies may resolve the problem of deploying GNSS buoys at far offshore

New algorithm: PPP-AR

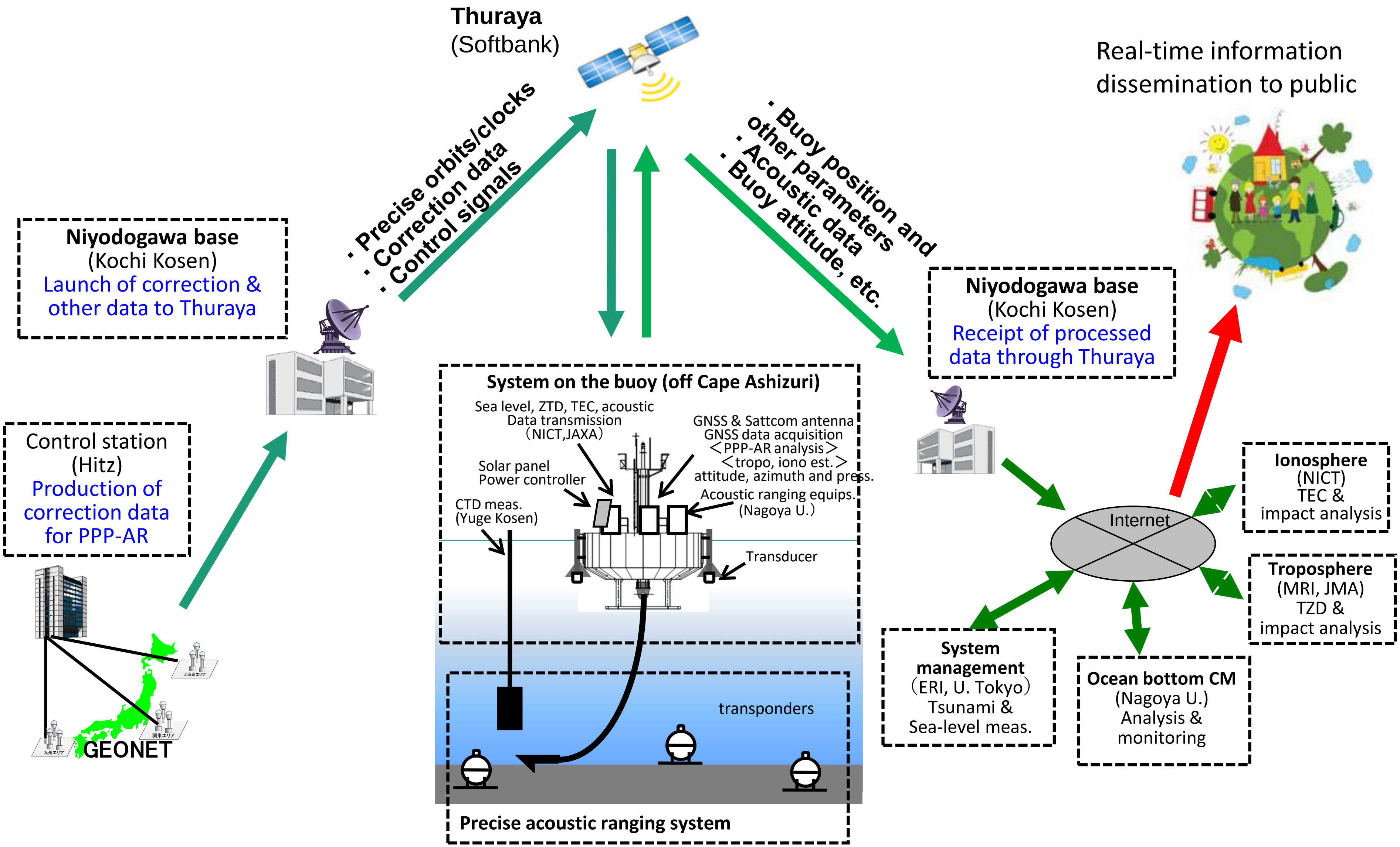
（Precise Point Positioning with Ambiguity Resolution）



Conventional PPP uses only IGS orbits/clock, New PPP-AR uses corrections by GEONET regional data.
Algorithm proposed by Mervart et al. (2008) was employed.
Test results suggest that a few centimeters accuracy (vertical) is possible for distance farther than 1,500km away from GEONET.

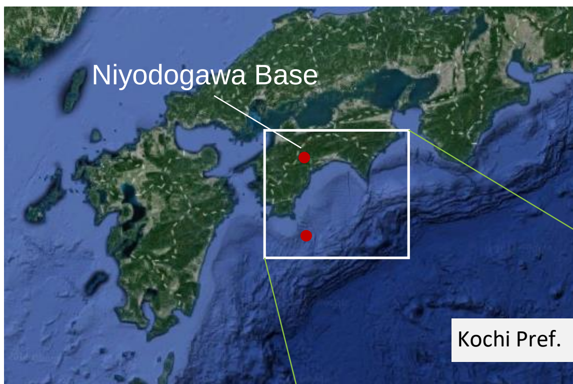
(※PPP-AR: L. Mervart, et al. ; Precise Point Positioning with Ambiguity Resolution in Real-Time, presented at ION GNSS 2008)

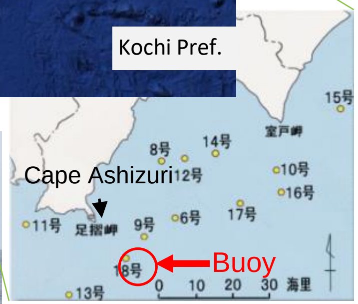
Data flow using satellites



Sea-level monitoring by GNSS buoy

Location of Niyodogawa base & GNSS buoy





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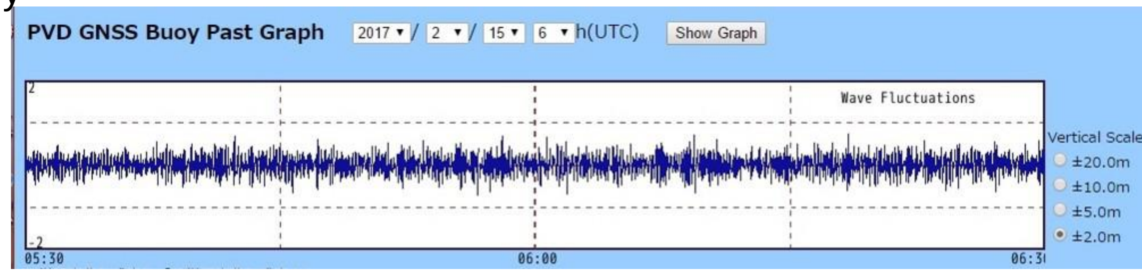
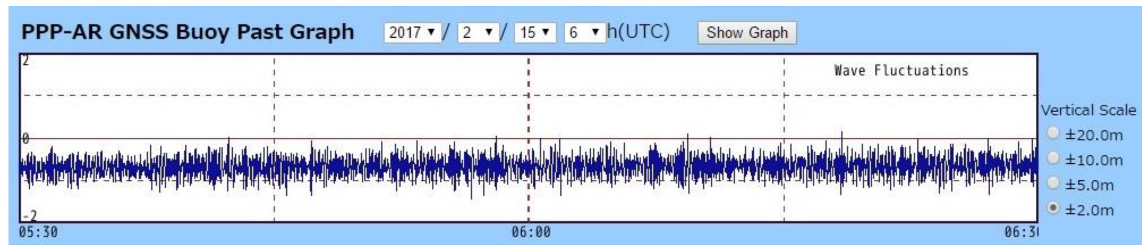




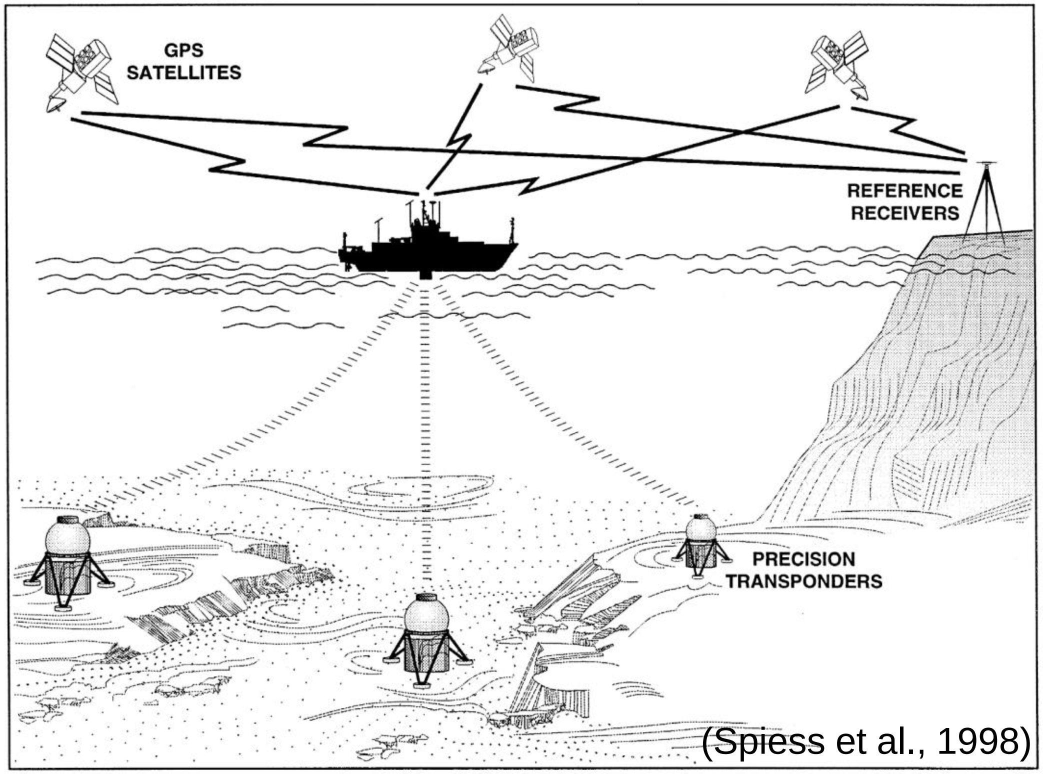
Sample output of sea-level change of 1-hour
Up：PVD, Down：PPP-AR
Passive antenna was used for satellite communication

- We rented one of fishery buoys (#18) operated by Kochi Prefecture.
- Buoy is located about 40km south of Cape Ashizuri.

※PVD: H. Ishiki, et al. ; Precise Variance Detection by a Single GPS Receiver --- PVD (Point precise Variance Detection) Method ---, The Geodetic Society of Japan, Vol. 46, No.4, pp.253-267, 2000.

Multi-GNSS environment is indispensable for a stable continuous operation.

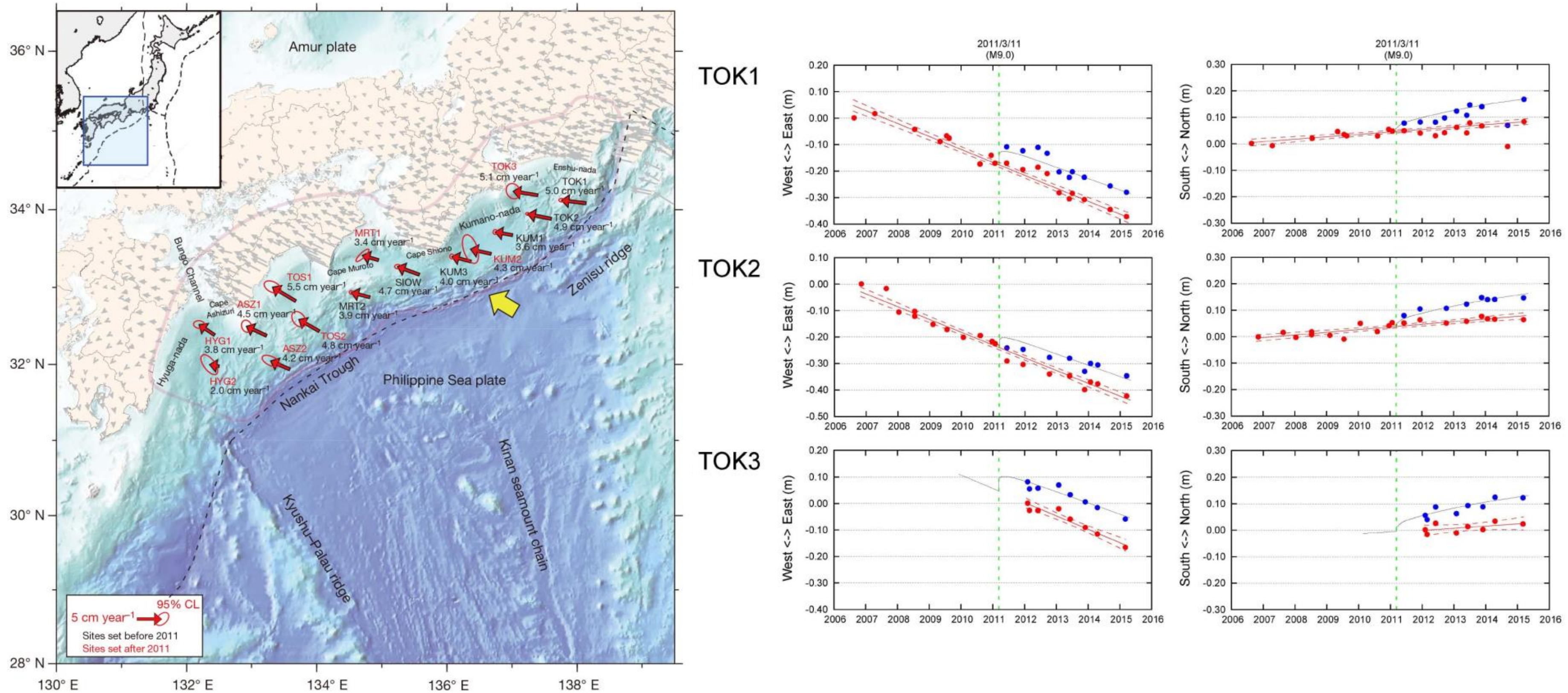
GNSS-Acoustic system for observing ocean bottom crustal movements



- The idea was introduced by Spiess and his colleagues in early 1980’s. Japan Coast Guard and university groups has developed the system and attained a few centimeters’ accuracy of positioning.
- Position of vessel is precisely determined by GPS.
- Distances between the vessel and the ocean bottom transpoders are measured by sound.
- Position of the center of geometry of the ocean bottom transponders can be estimated in a few centimeters.

Deployments of transponders in June 2017 (photos courtesy by Mr. M. Kita)

Ocean bottom crustal movement observation using GNSS-Acoustic system



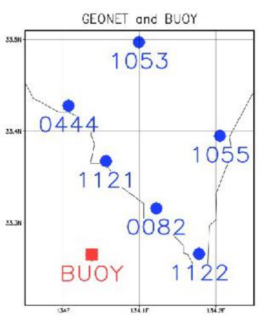
Observed ocean bottom crustal movement (left) and sample plot of temporal change of site position (right) (after Yokota et al., 2016)

- GNSS-Acoustic system has been used to measure the ocean bottom crustal movements.
- As ships has been used for GNSS-Acoustic system, measurements has been done only several to ten times a year, at most.
- Our GNSS buoy can be used for <u>CONTINUOUS</u> observation of the ocean bottom crustal movements.

Application of GNSS buoy for weather and space weather forecast

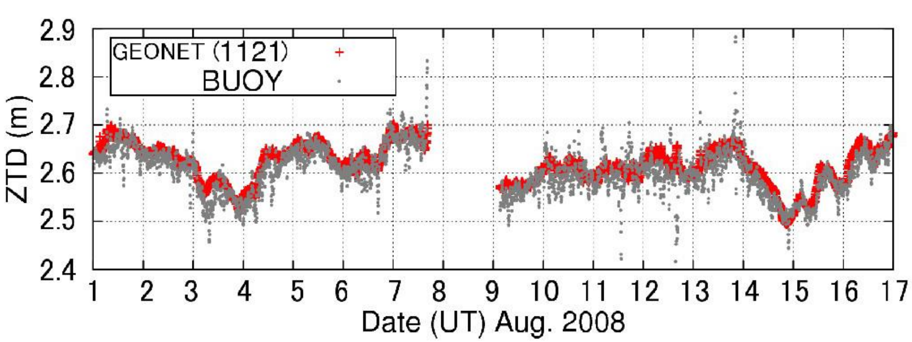
Tropospheric Zenith Delay is derived from GNSS and is converted to water vapor to implement in numerical weather prediction

GPS buoy and GEONET sites



- 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.

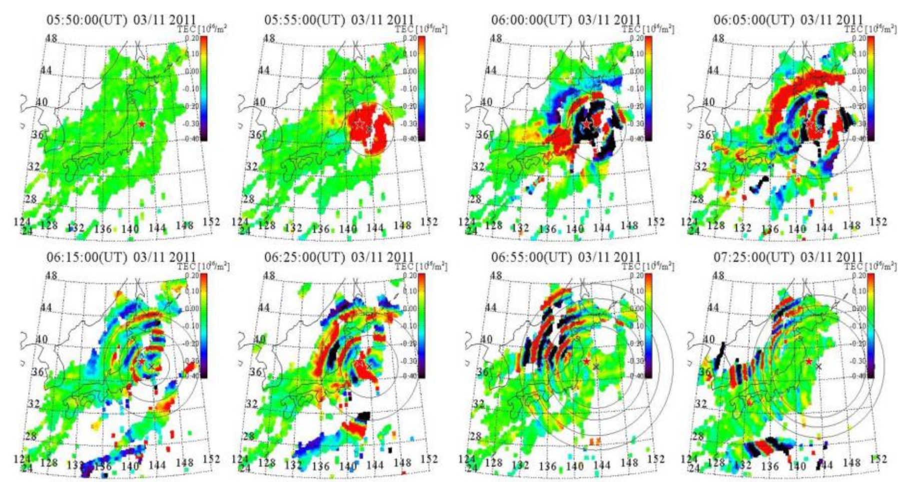
Time series of ZTD by GEONET(1121) and GNSS buoy



（Y. Shoji, 2010）

Total electron content (TEC) in the ionosphere along the slant path is derived from GNSS and is used for space weather monitoring

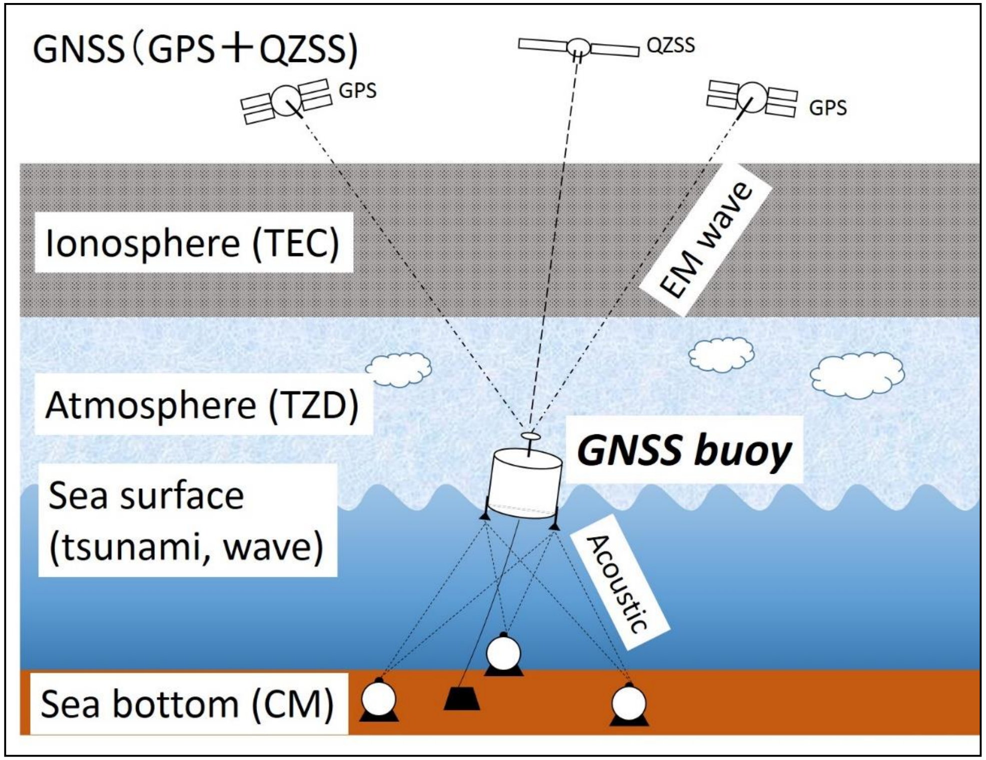
TEC variation observed at the 2011 Tohoku earthquake



- TEC variation observed using GEONET GNSS 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.

（Tsugawa, 2012）

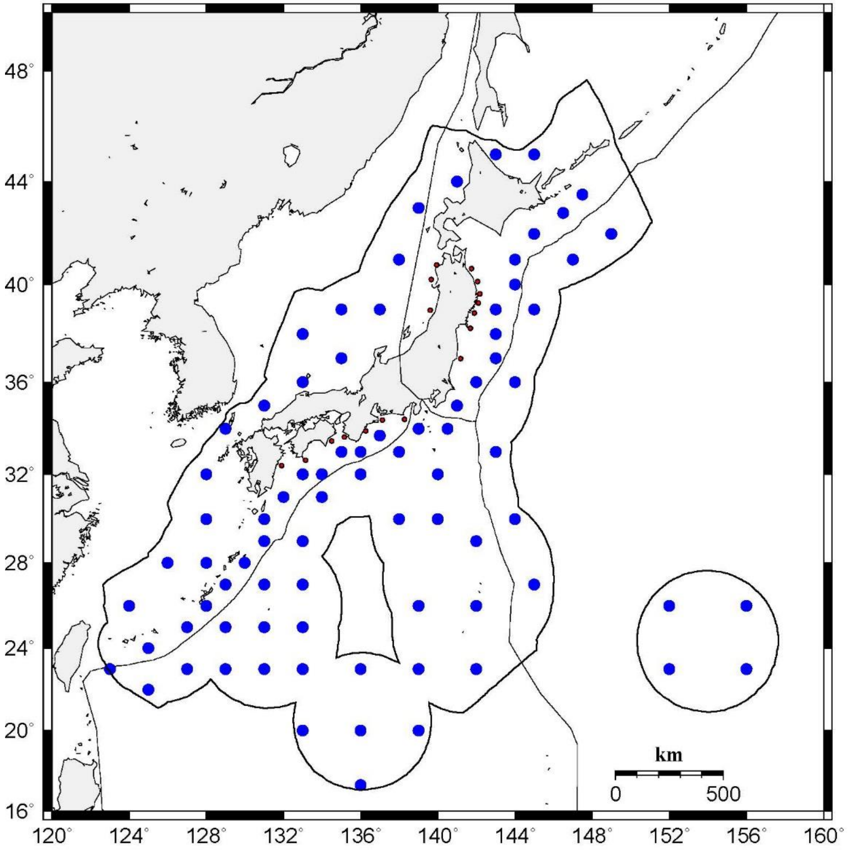
Multi-purpose GNSS buoy for geohazards monitoring



- Sea level change (1hz to long-term)
  - Tsunami early warning and wave monitoring, environmental change
- Ocean bottom crustal movements
  - Slow slip events, asperity monitoring, source studies, tsunami early warning through real-time source determination
- Atmospheric water vapor
  - Torrential rain forecast, storm monitoring and weather forecast
- Ionospheric total electron content
  - Nowcast and forecast of ionospheric space weather
- Ocean surface monitoring with ancillary equips
  - Atmosphere-ocean interaction, ocean current modeling, current monitoring, etc.

Proposal of GNSS buoy array in the northwestern Pacific

OCEAN GEONET !?



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

- Onshore dense GNSS array such as GEONET in Japan has much contributed to develop new insights in earth sciences and geohazards monitoring such as crustal deformation, earthquake studies, slow slip events as well as meteorology and ionospheric studies.
- Introduction of offshore GNSS buoy array will further contribute to various fields in earth sciences through providing new data in the currently vacant oceanic areas.
- Buoys can be used to put other ancillary sensors for ocean sciences as well.
- Further application of data are for geohazards monitoring in the ocean, such as tsunami, ocean bottom crustal movements, heavy rain and storm forecasts, high tides, ionospheric disturbances, etc.