New Approach for Tsunami Detection Based on RTK-GNSS Using Network of Ships

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Background

- After the Indian Ocean Tsunami on 2004, there has been an increase in demand for Tsunami detection.
- Since we can't avoid an earthquake or Tsunami, early detection is critical for disaster prevention.
- To detect the Tsunami before it reaches the coast, Japan is using a GPS buoy system from 2008.
- The buoy sys successfully detected the Tsunami which occurred after the M9.0 earthquake in 2011.
- The system uses RTK-GNSS for position measurements and because of baseline restriction, deploying it 20km off the coast is the current limit.

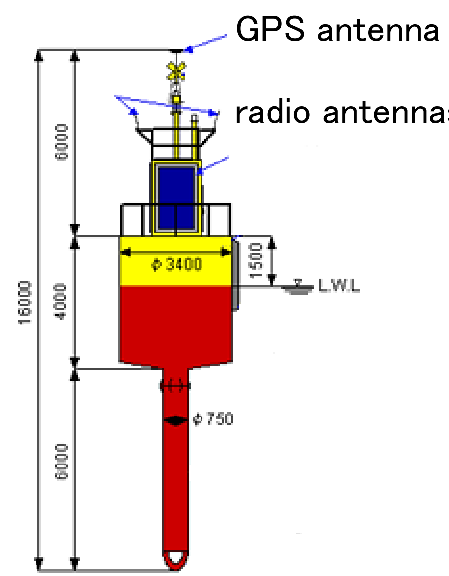
Outlines

- GPS Buoy
- Tsunami
- PPP
- Proposed method
- Test results
- Summary

GPS buoy

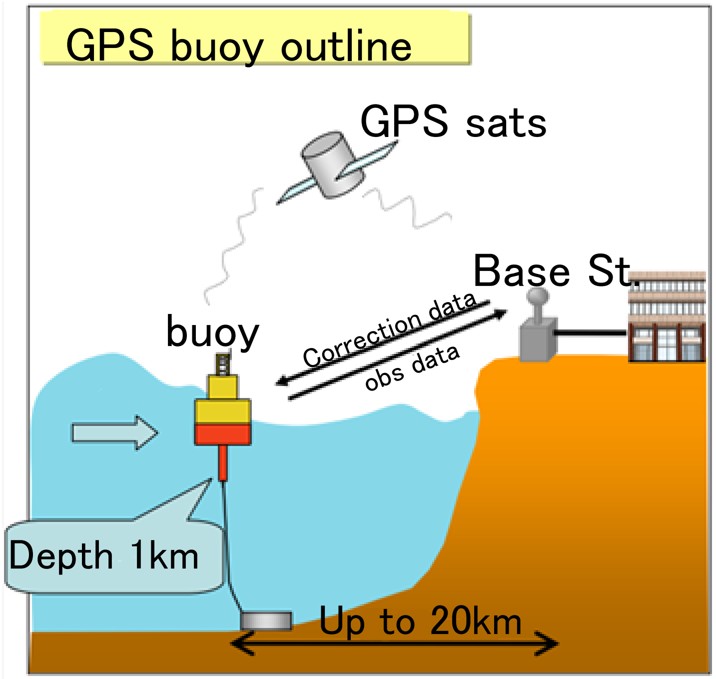
- Offshore wave-meter using RTK-GPS , daily offshore observations as well as Tsunami detection in case of emergency
- Buoy: length 16m diameter 3.5m 50t with solar panels and transmitters
- Moving from RTK-GPS to PPP-AR

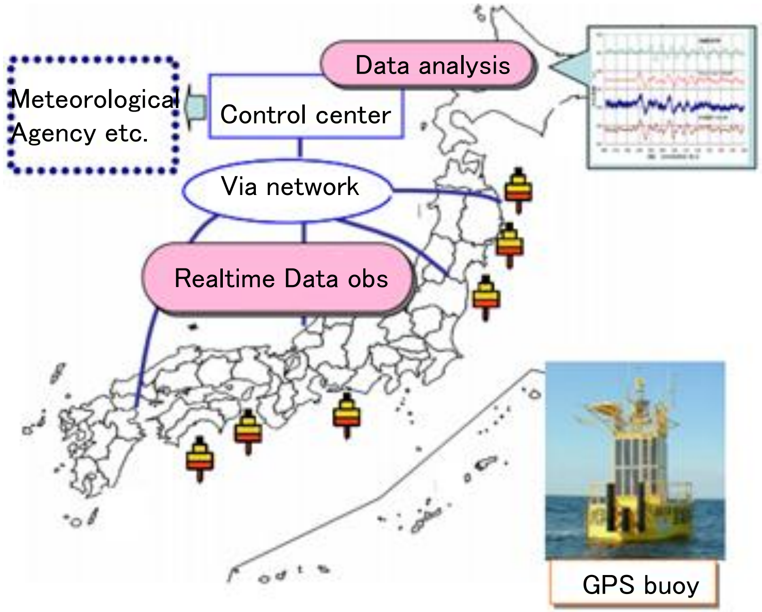
15 deployed and working



GPS buoy

- Real-time RTK position (1Hz)
- On Mar 11th 2011, *Tohoku* earthquake, it successfully detected Tsunami waves, 10mins before striking the coast

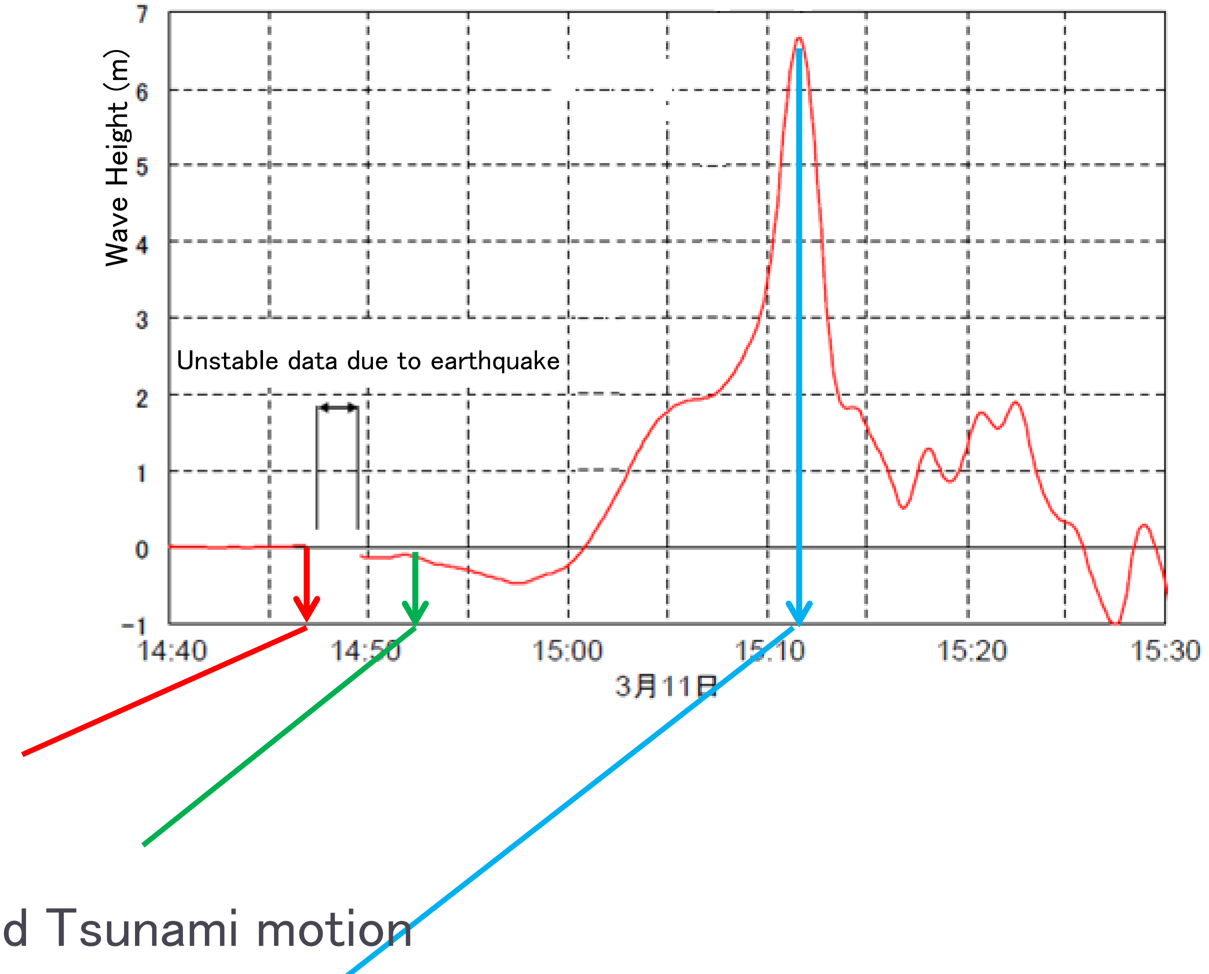




Tsunami detection (2011)

- *Tohoku earthquake*
- Epicenter

  130km east of *Sendai*



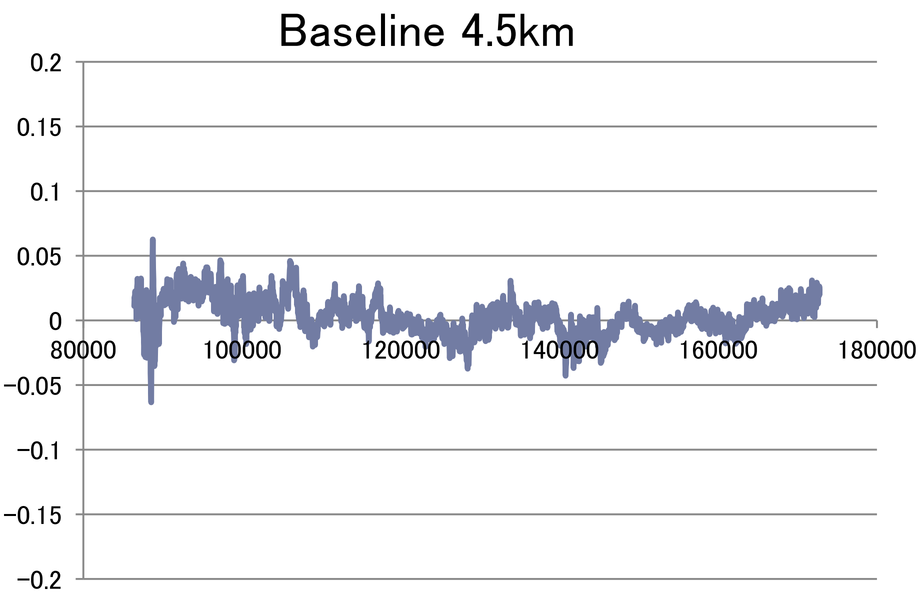
- South *Iwate* buoy
  - 10km offshore
  - Depth 200m

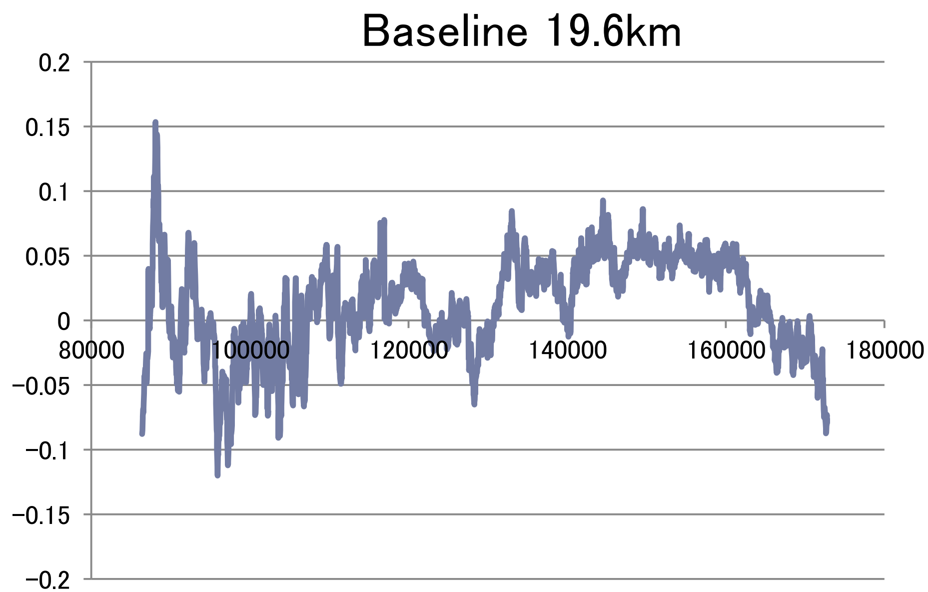
- 14:46 Earthquake
- 14:53 First detected Tsunami motion
- 15:12 Tip of Tsunami wave

Baseline restrictions

- Normal RTK-GNSS algorithm uses double-differential data made from two observation data, and makes up an observation equation to compute.

- Problem: some error terms have spatial correlation, which decrease as the baseline grows longer, thus the accuracy degrade.





Based on GSI reference raw data

PPP

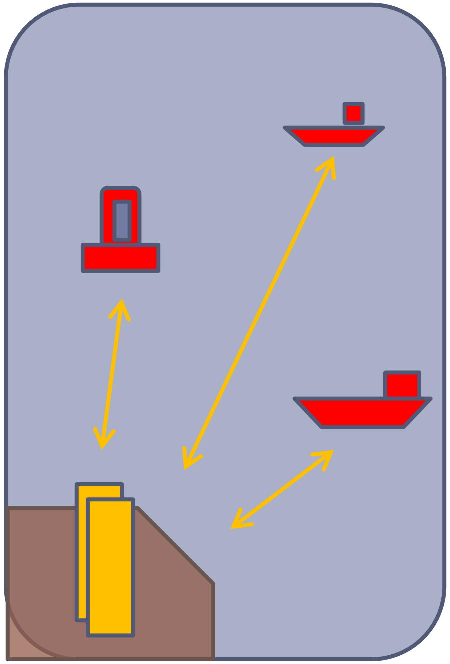
- PPP is very powerful method

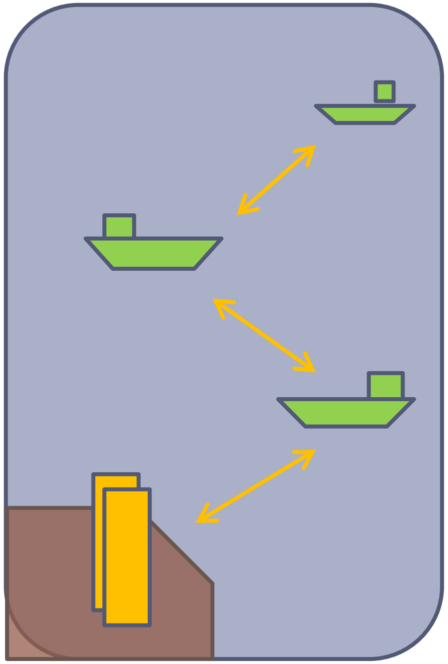
- Real-Time PPP
  - Sub decimeter horizontal accuracy
  - No exact base station needed
  - Needs precise ephemeris and accurate clock prediction

- PPP-AR
  - About 5cm horizontal accuracy
  - Needs base station, but baseline can grow to 1,000km

Long time to fix but it might be OK for Tsunami detection use.
Very desirable technique in the future.

Communication Network





- Current system uses buoys
  - $3million per buoy
- PPP certainly has the potential but cost of communication is high

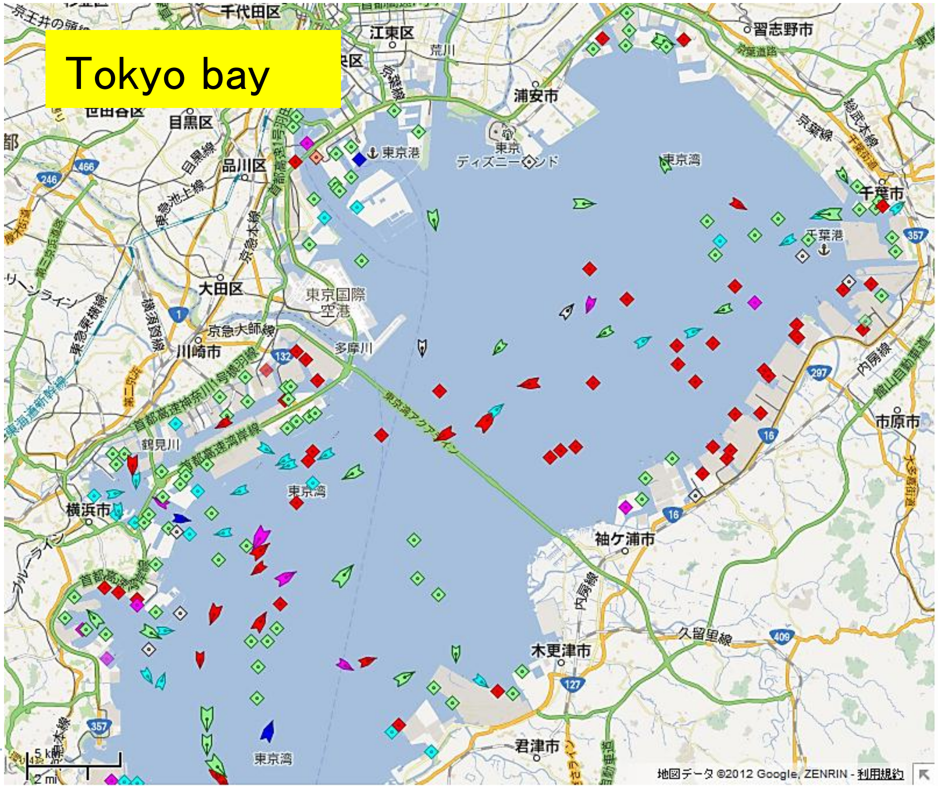
- Proposed method
- Use ships as basis
- VHF for communication

Ships and AIS

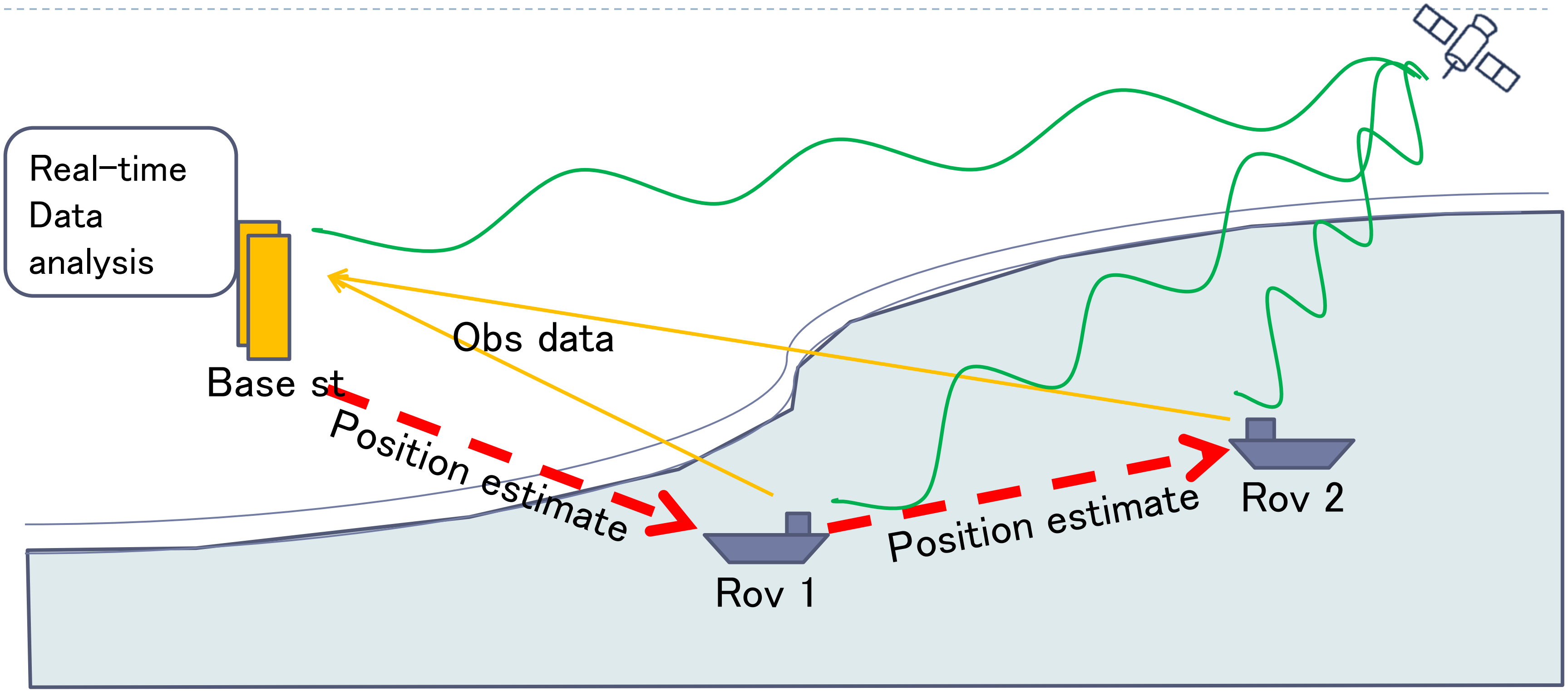
- AIS(Automatic Identification System)
- Ships equipped with AIS have GNSS receivers.
- A system that broadcast ship info automatic via VHF transmitter

- Used for SAR
- Can be displayed on ECDIS

- Uses two VHF channels
- Data rate 9.6Kbps
  - Horizontal range 70-80km



Proposed Method
RTK using dynamic base-station



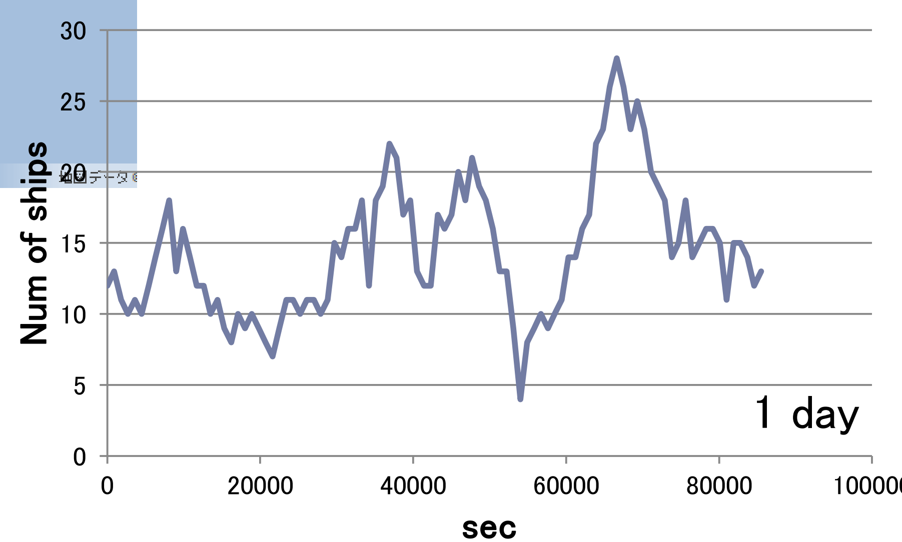
- Using RTK positioning from the base station to rov1, and then position rov2 in respect of rov1, we can achieve accuracy of few cm further offshore.

The question is "are there ships in suitable distance ?"

Examination of ships loaded with AIS

Survey area
(likely area for Tsunami)

South of *Nagoya*
North part of *Nankai* trough
50*50km



Ships in 20km radius of the coast
Ave 14.4 ships/15 min

Plus 8.5ships/hour 20km or more

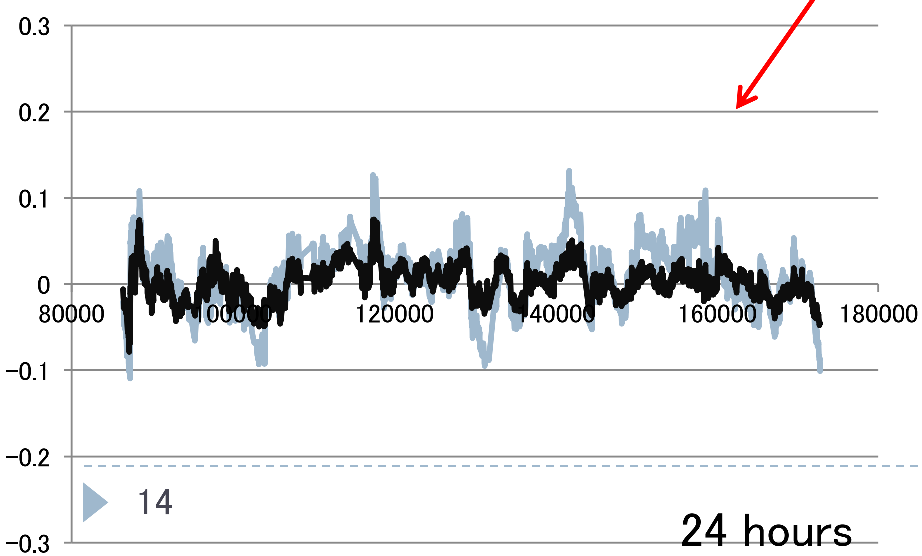
Stationary experiment

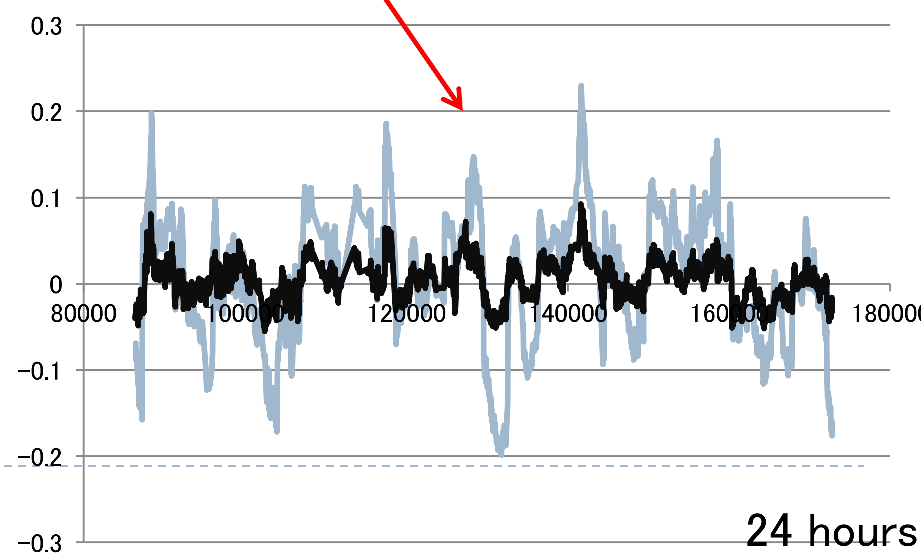
- 5 reference stations
  - Normal RTK positioning has an error scale of few cm. Proposed RTK uses the position with that error contained, so as we go down the line, the error will accumulate.

Vertical Error Investigation

- Upper: RTK results show position using each baseline
- Lower: Positioning results using Proposed RTK

RMS	rov1	rov2	rov3	rov4	
RTK	2.63	1.96	1.98	2.31	cm
Proposed RTK	–	3.76	5.42	7.44	cm
Baseline	11.3	19.9	29.1	39.5	km





Brief Summary

- The target area for Tsunami detection is probably within 30–50km for the emergency escape.
- Based on the stationary experimental results, the network of two ships will be practical and accuracy is OK.
- From the AIS information, the network of ships are sufficient.

Experiment using Real Ship

- Experiment using a ground station and 2 anchored ships

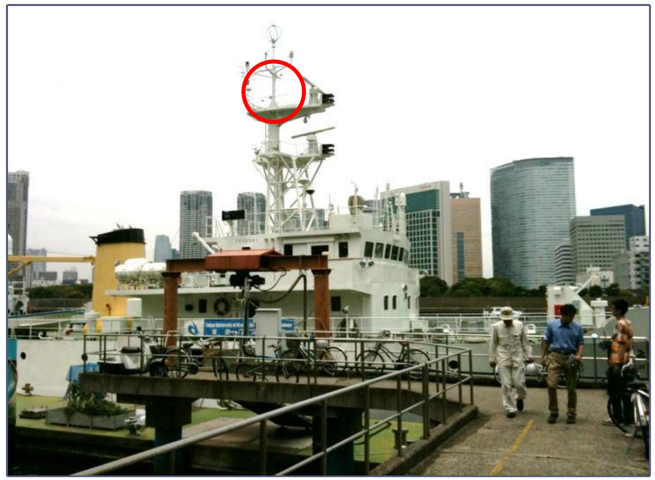
- Aug 7th 2012 3h(2Hz)
  - Base station *Setagaya* NovAtel OEM5
  - Ship 1 *University Dock* NovAtel OEM6
  - Ship 2 *Urayasu Dock* NovAtel OEM6

Another reference stations was installed near Rover 1 (our university).

Experiment using Real Ship

- Positioning using proposed RTK method

Rooftop
Base Station



Ship 1

Ship 2

Evaluation of the Ship Test

- Prior RTK analysis

  From University to Ship1 (−100m)

  From University to Ship2 (13km) ➡ #1

  Reference positions in all epochs in two ships were prepared.

- Actual RTK analysis using our proposed method

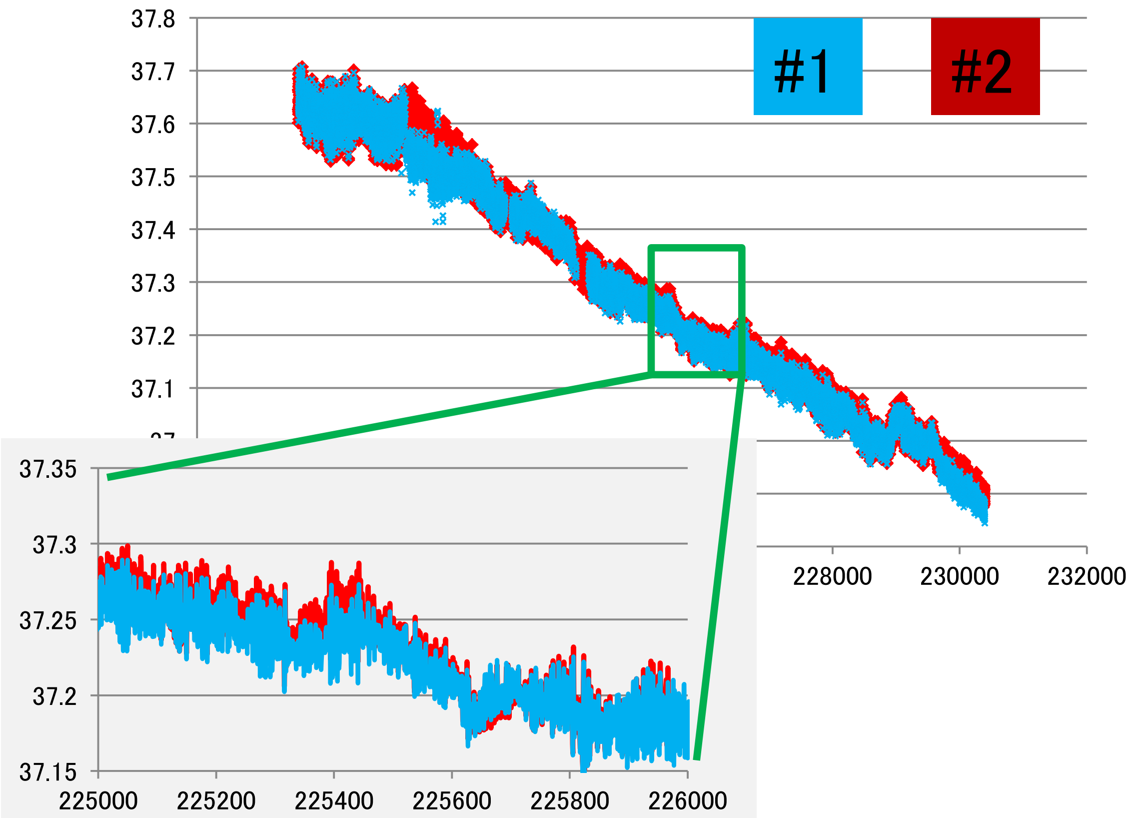
  From Setagaya base station to Ship1 (16km)

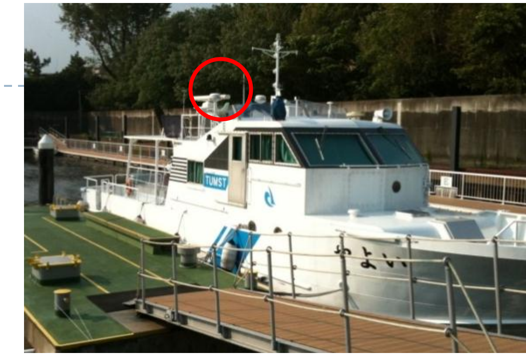
  From Ship1 to Ship2 (13km) ➡ #2

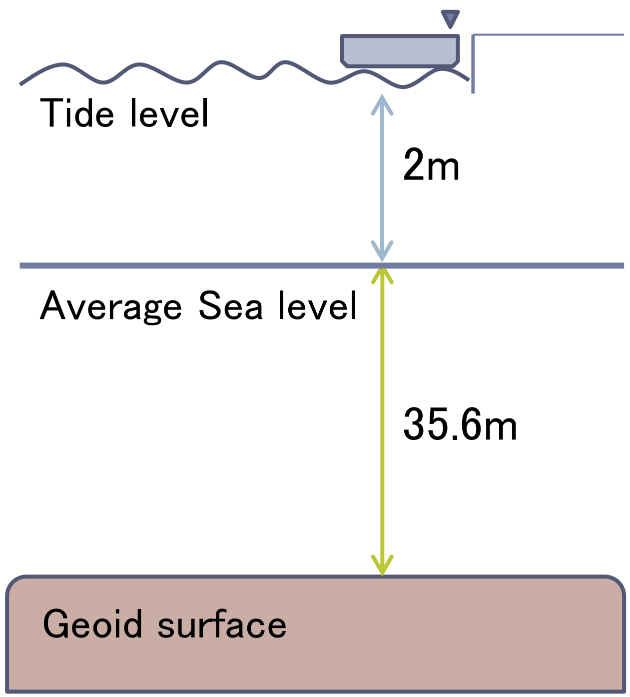
- Finally, the altitude variations of Ship2 were compared between #1 and #2.

Experiment using Ship

- Base station to rov2 (via rov1)
  - Overall baseline 28.4km







Summary

- For Tsunami detection, the use of ship network were verified in both stationary case and real ship case. Accuracy was what we expected.

- Other candidates for precise positioning, PPP or medium distance RTK should be evaluated.

- The data link between ships and base stations on land is still a challenge. VHF is used in GPS buoy.

- If the data size of correction data can be small, we may able to use QZS as a data transfer for PPP or RTK near Japan.

End of presentation

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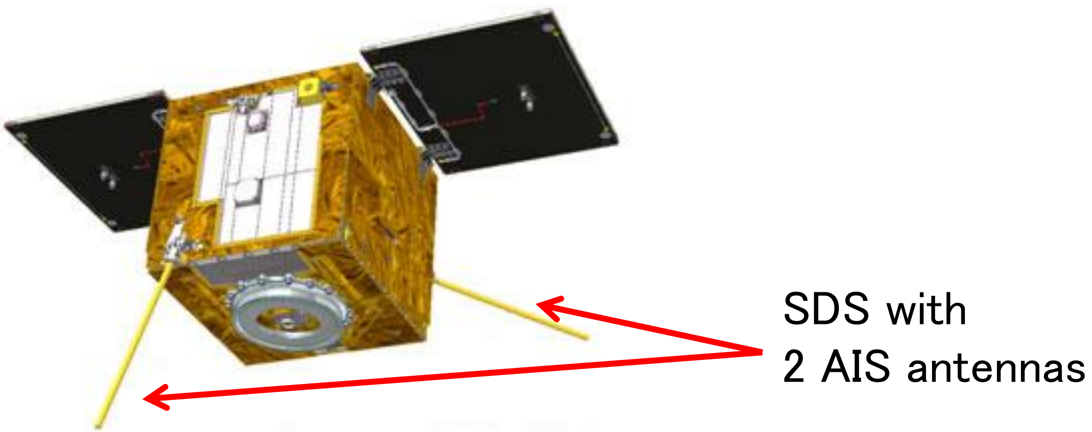
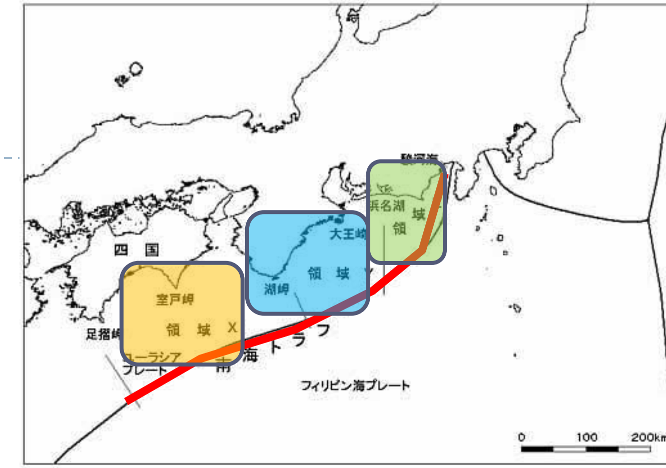
Thank you for listening

SPace based AIS Experiment (SPAISE)

- AIS transmitted signals only reach 80km horizontally, but vertical range is over 400km and can be monitored in space. American co. "ORBCOMM" launched 5 communication satellites equipped with AIS receivers in 2008.
- Japan also launched a SDS(Small Demonstration Satellite) loaded with SPAISE on May 5th 2012.



Nankai trough



- Steep trough south of Japan.

  Philippine-sea plate sinks under the Eurasian plate.

- Seismic activity is very high and earthquakes of M8 class tend to occur every 100 to 200 years or so.
- Most of the time they occur simultaneously, devastating the region
  - Last *Tokai* earthquake was 150 years ago

水深と観測値

- Tsunami waves are lower at deeper ocean and tend to get higher as they reach the shallow coast

- Estimation of measurements for a meter high tsunami at coastline (relation between depth and height at see)

depth	Estimated measurements
10m	65cm
50m	45cm
100m	35cm
200m	30cm
1,000m	15cm

- *Tohoku* depth 1km = 60–80km offshore
- *Nankai* depth 1km = 30–50km offshore

Ships and A.I.S

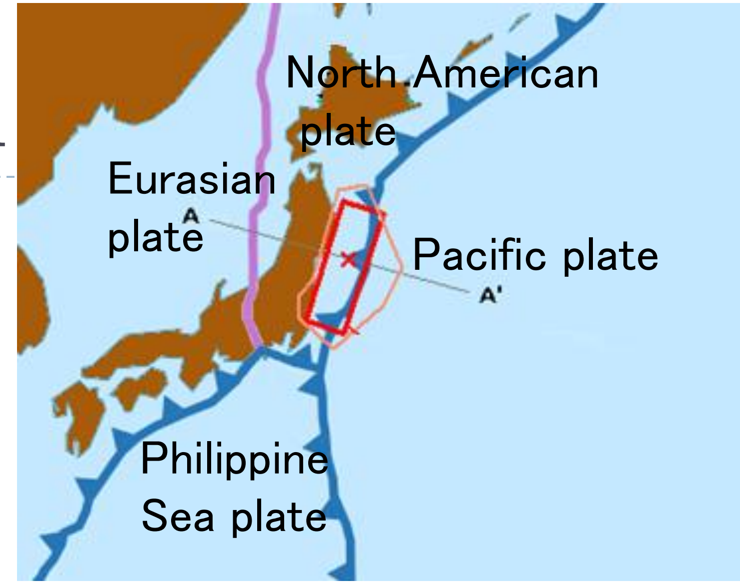
- Ships which go abroad have the same equipment (GNSS receiver) as the GPS buoy

- But the problem is that they don’t have a network to send the information.

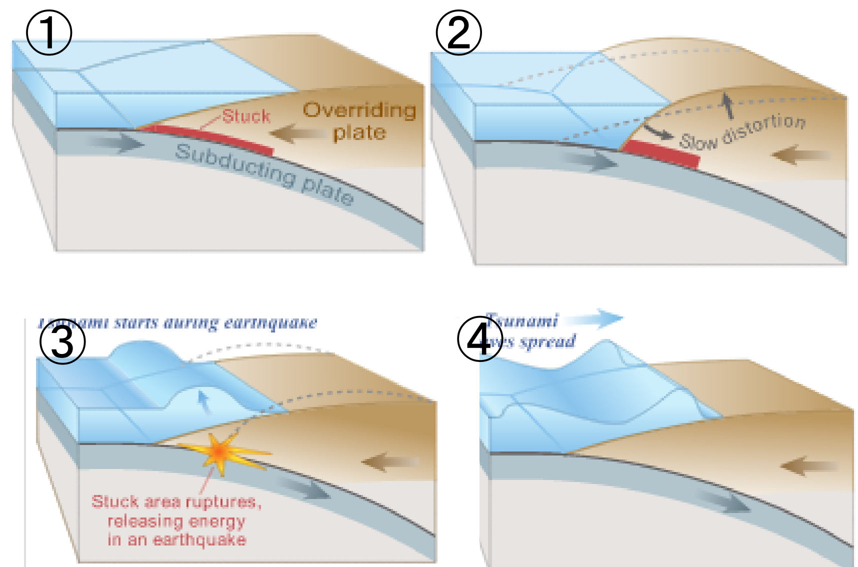
- Communication: satellite com and VHF radio
  - INMAR-B 9600bps
  - INMAR-F 64Kbps

Earthquake and Tsunami

- "1 out of 10" and the plates

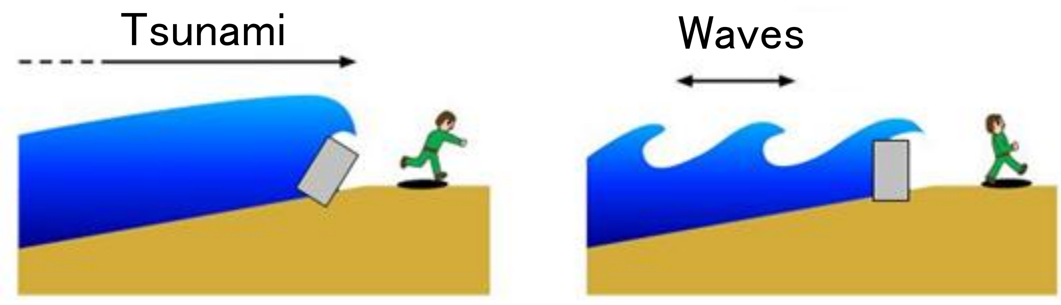


- Mechanism (2011 *Tohoku*)
  - ① Each year Pacific plate sinks under N.A plate by few cm
  - ② The upper plate get compressed
  - ③ Compression reaches the limit and upper plate springs (earthquake)
  - ④ Sea water above gets wedged (Tsunami)



Tsunami

- Difference between a meter high wave and a Tsunam



- 1m Tsunami offshore becoming 10m at the coastline
  - Wave speed V=$\sqrt{g * h}$→ speed drops as the depth gets shallow →the following waves catch up→the waves have no ware but up
- Wave height prediction
  - After a earthquake occur the agency immediately calculates the position and scale and matches the pre-calculated Tsunami prediction height from the database.