Water Vapor Analysis Over the Ocean using Shipborne GNSS Measurements for the Mitigation of Weather Disaster

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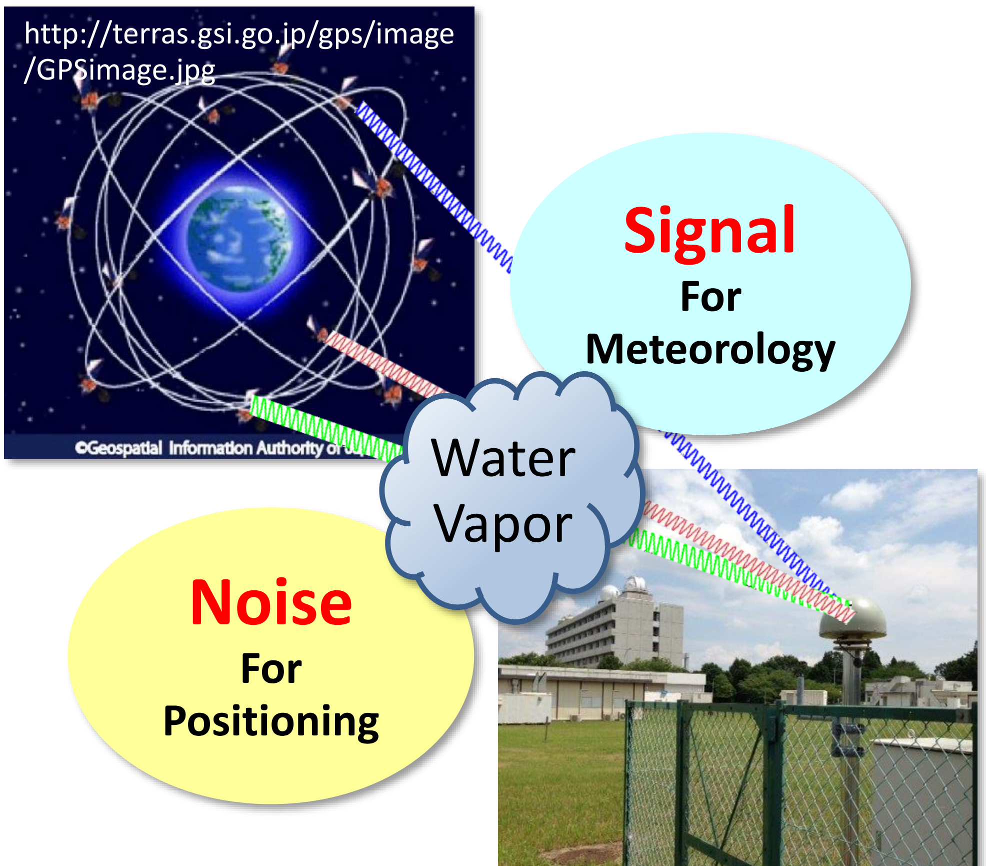
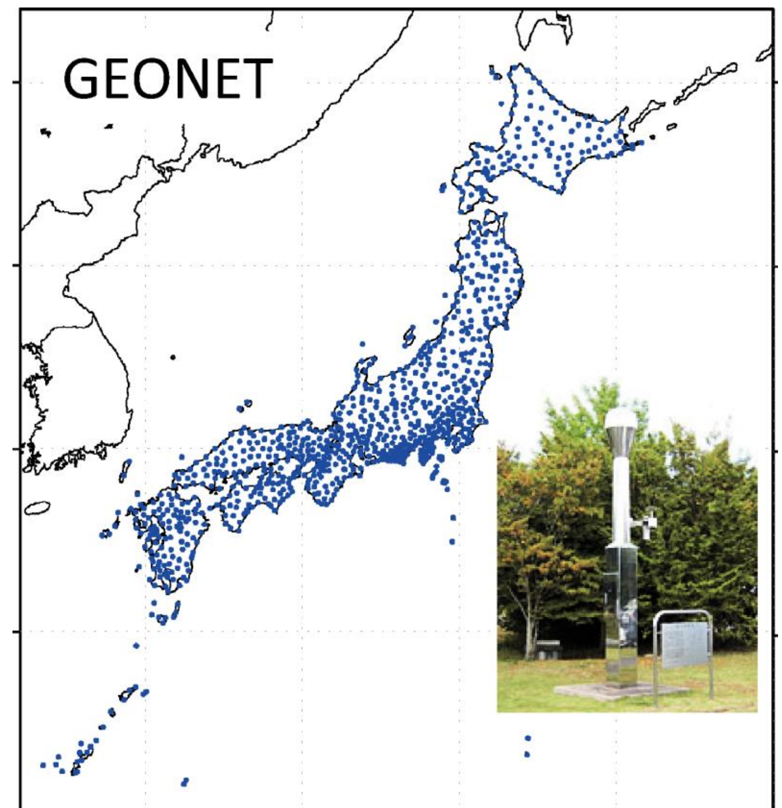
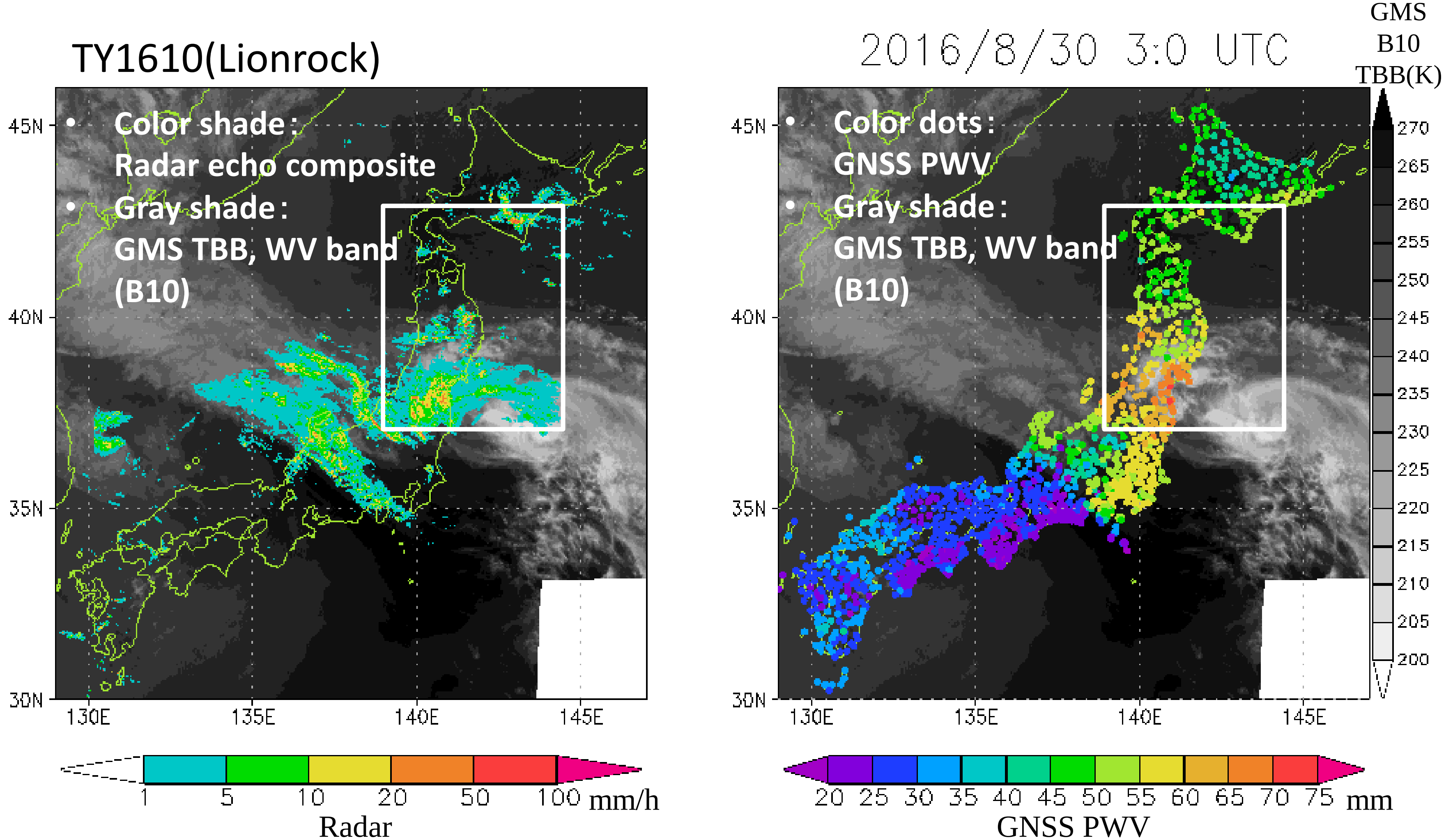




GNSS : Practical water vapor sensor

High accuracy, continuously, under all weather

TY1610(Lionrock)



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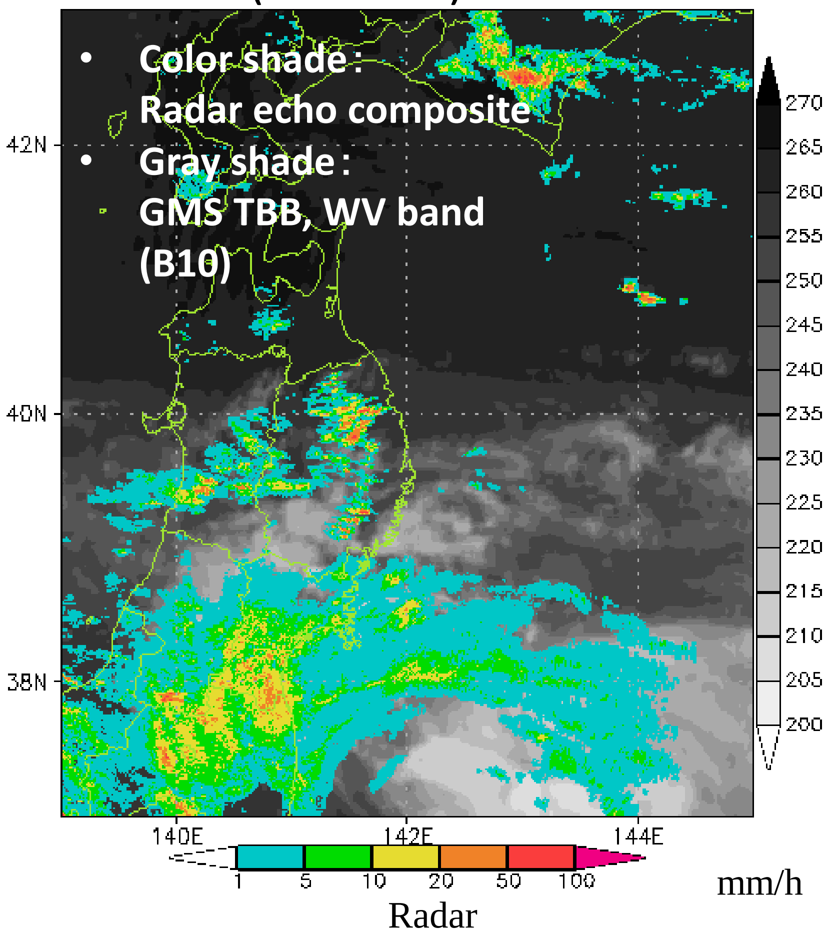
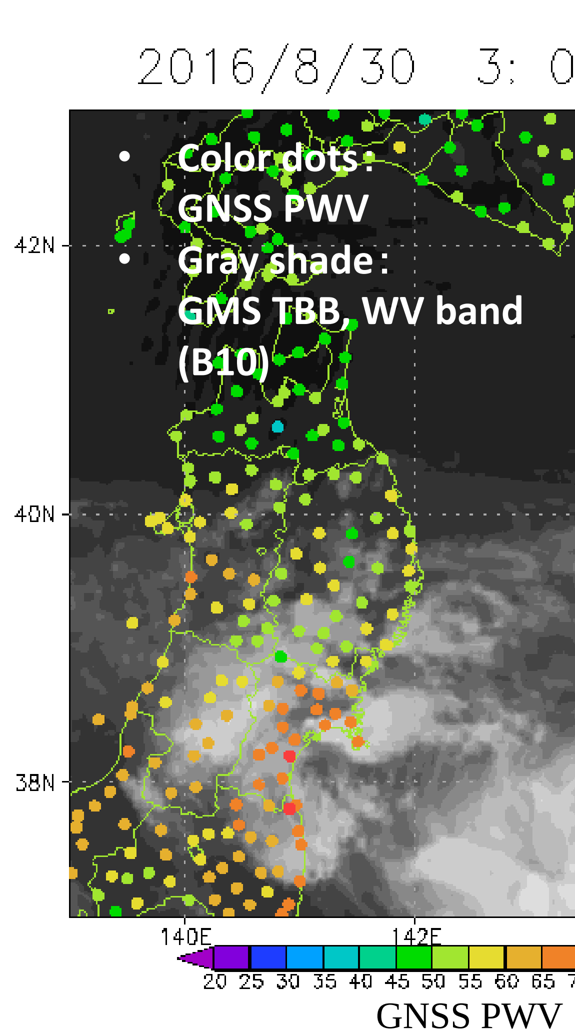
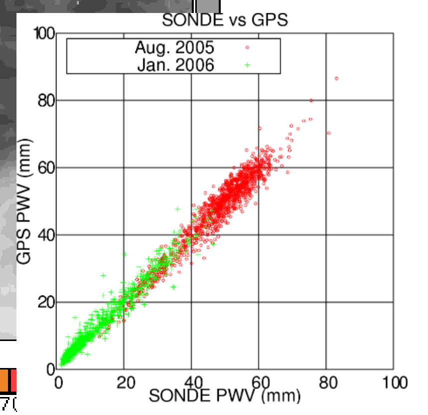


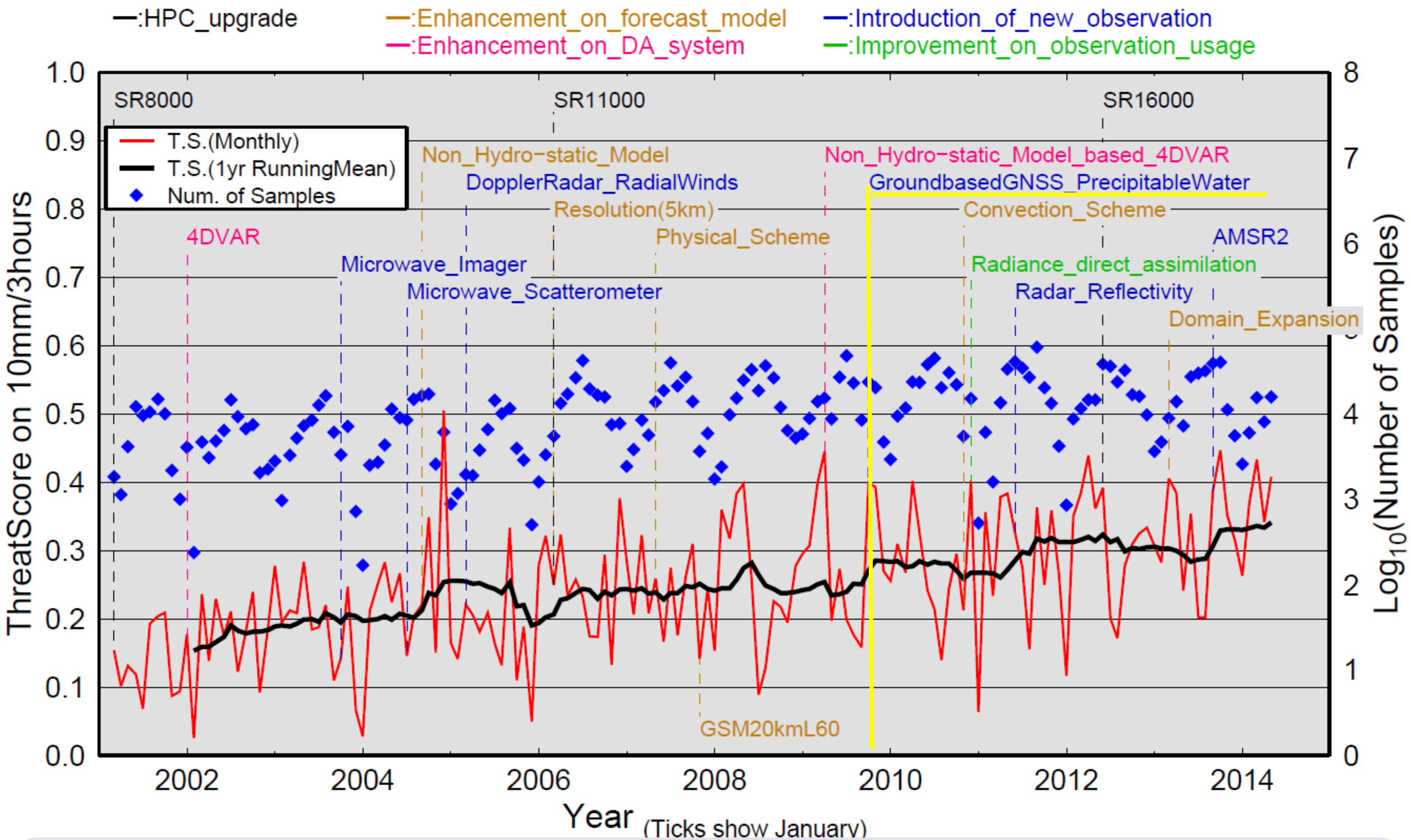




Sonde vs GNSS (Near Real-time)
Shoji (2009)

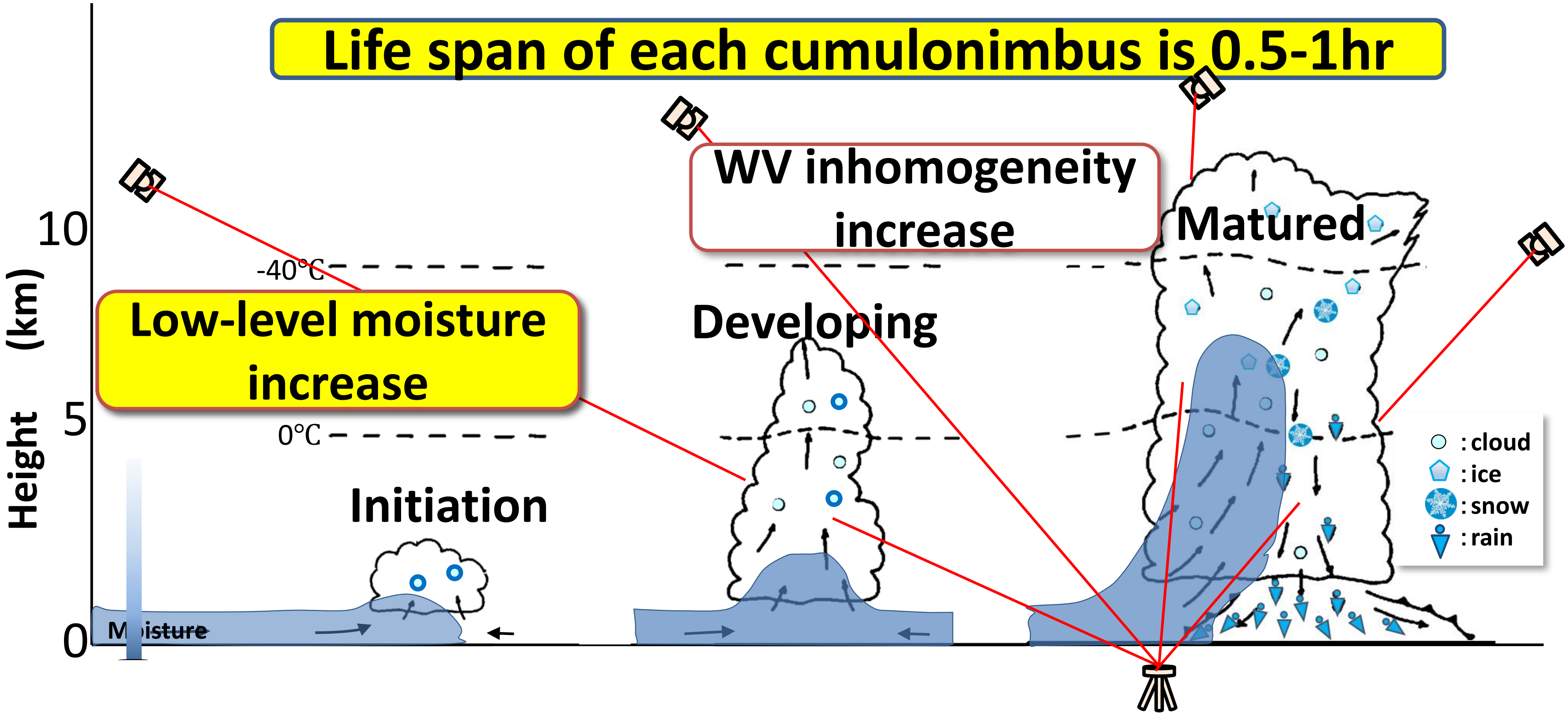
- GNSS PWV has been used as one of WV data in JMA's operational NWP system since Oct. 2009.

Improvement of forecast score



GPS R & D Groups in JMA and MRI were awarded by the director general of JMA in 2010.

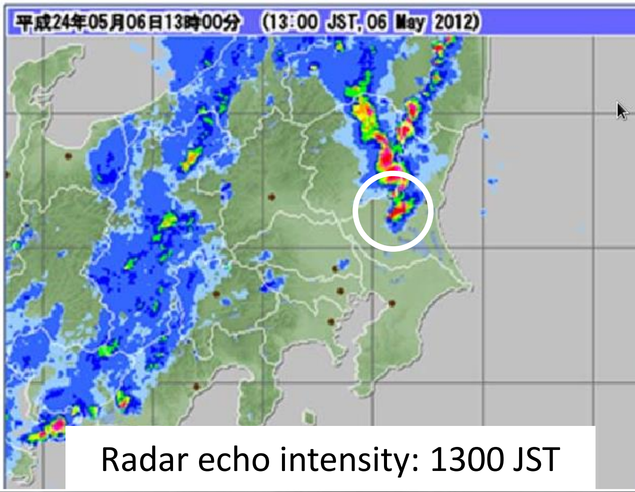
Water Vapor:
Energy source of hazardous weather



GNSS can monitor WV variation over a lifetime of cumulus convection

H.R. Byers and R. R. Braham. Jr., (1949) (Modified)

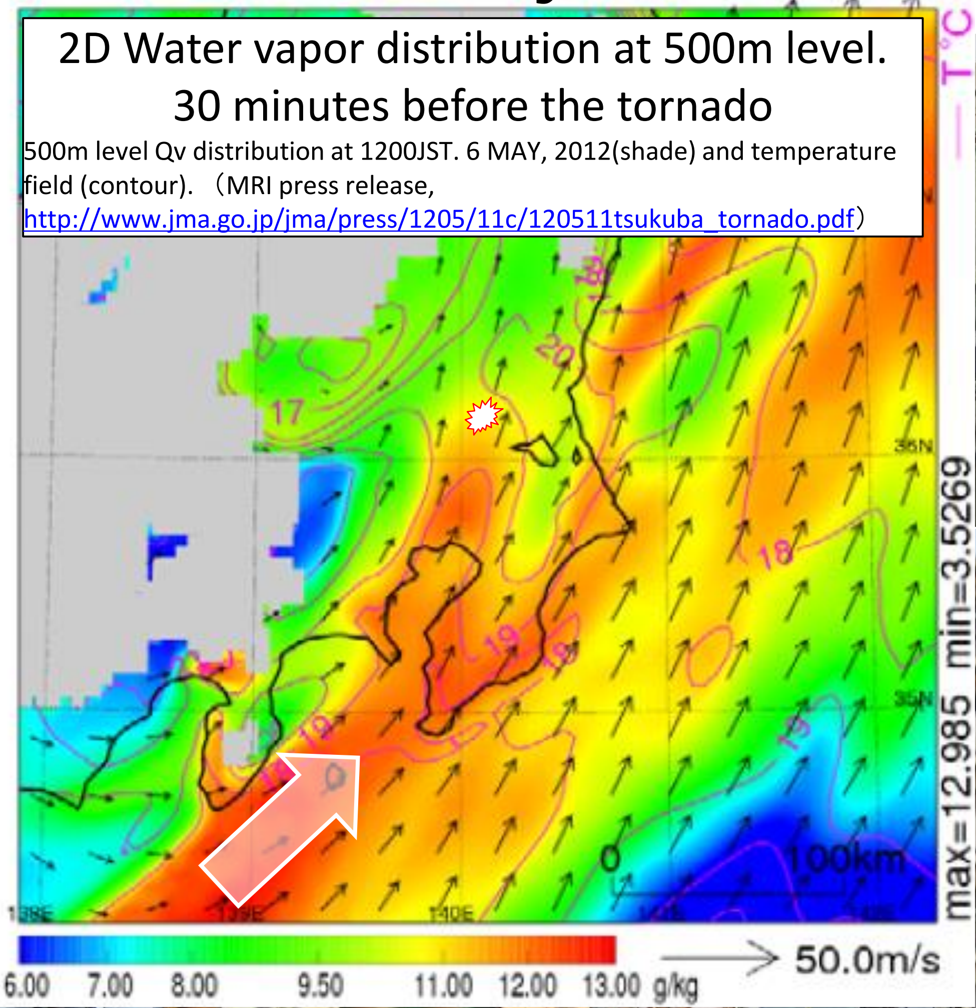
Low-level WV from the Ocean triggered a Strong (F3) Tornado on 6 May 2012

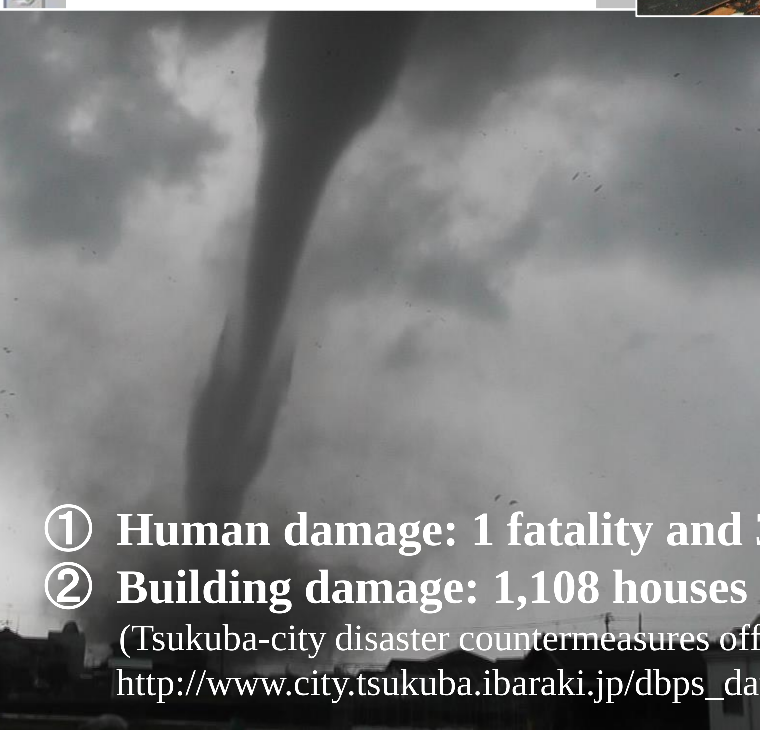


Radar echo intensity: 1300 JST

2D Water vapor distribution at 500m level.
30 minutes before the tornado

500m level Qv distribution at 1200JST. 6 MAY, 2012(shade) and temperature field (contour). （MRI press release, http://www.jma.go.jp/jma/press/1205/11c/120511tsukuba_tornado.pdf）



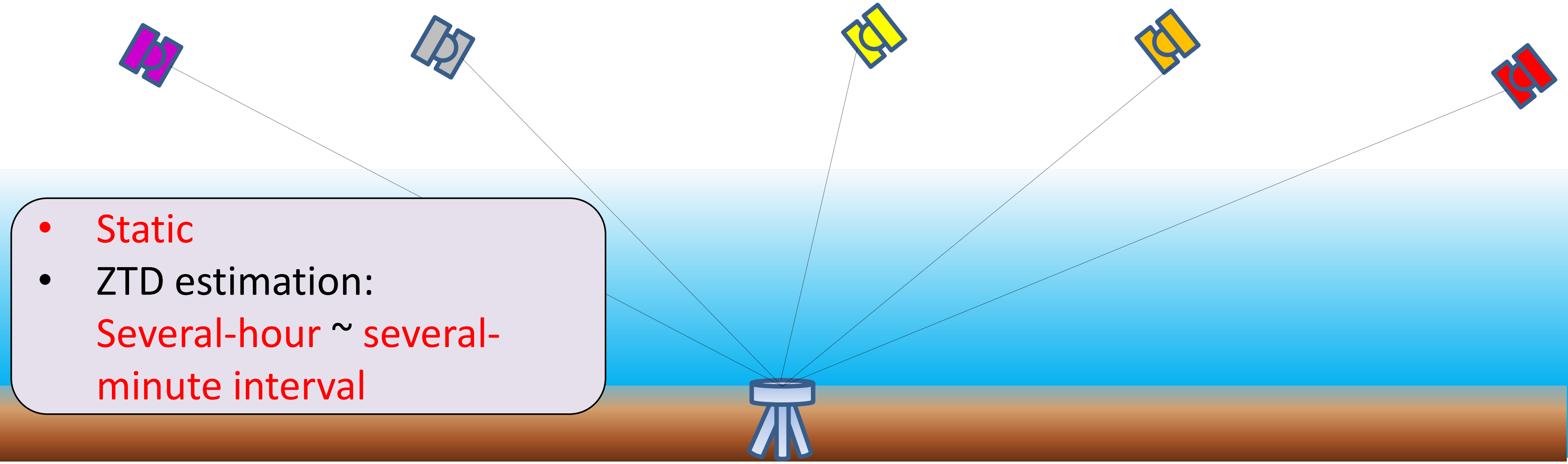


① **Human damage: 1 fatality and 37 injuries**

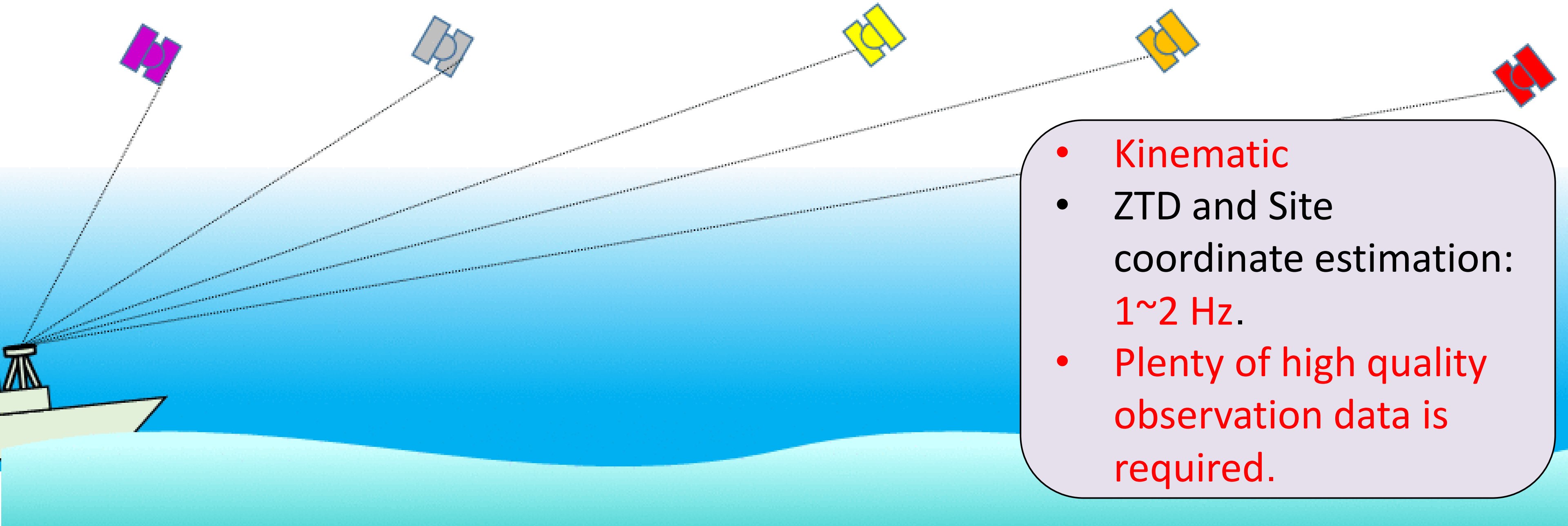
② **Building damage: 1,108 houses and 41 industrial plants**

(Tsukuba-city disaster countermeasures office http://www.city.tsukuba.ibaraki.jp/dbps_data/_material_/localhost/kou002/tatsumaki/No231.pdf)

Precise Point Positioning: Static and Kinematic



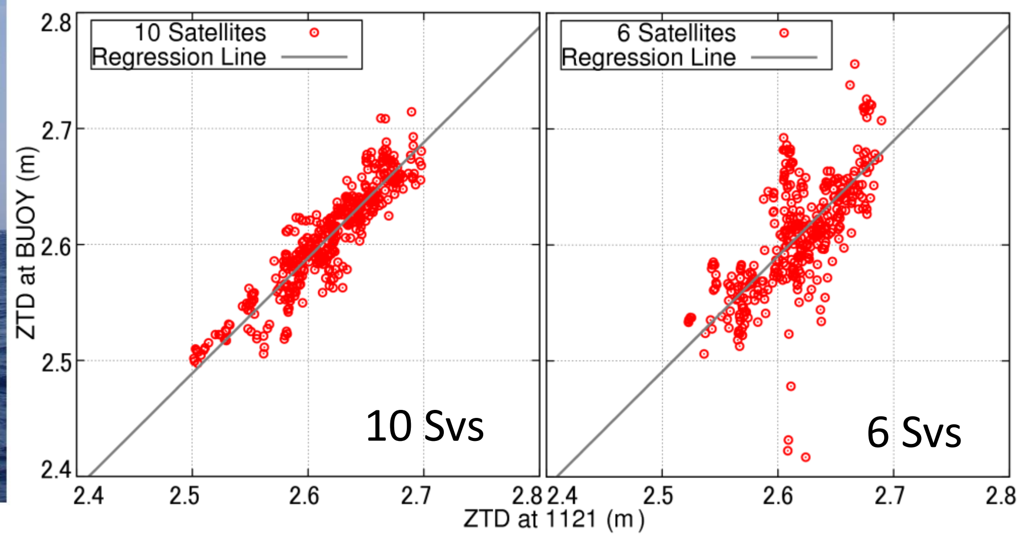
- Static
- ZTD estimation: Several-hour ~ several-minute interval

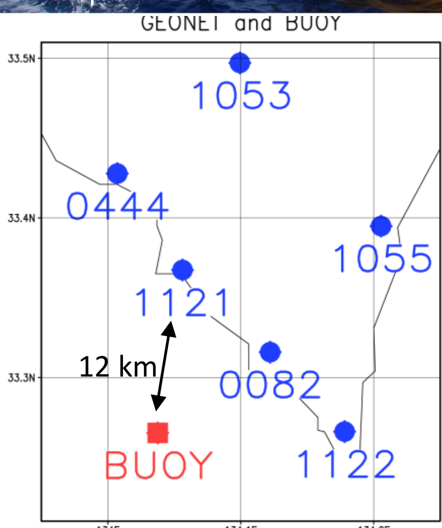


- Kinematic
- ZTD and Site coordinate estimation: 1~2 Hz.
- Plenty of high quality observation data is required.

Kinematic PPP needs more than 10 GNSS satellites for practical PWV analysis

Teruyuki Kato, 2012/2/3:http://ictfss.nict.go.jp/yokohama2012/DL/03_Kato_20120203.pdf





■ : GPS buoy Tsunami gauge

● : GEONET

Shoji et al. 2010

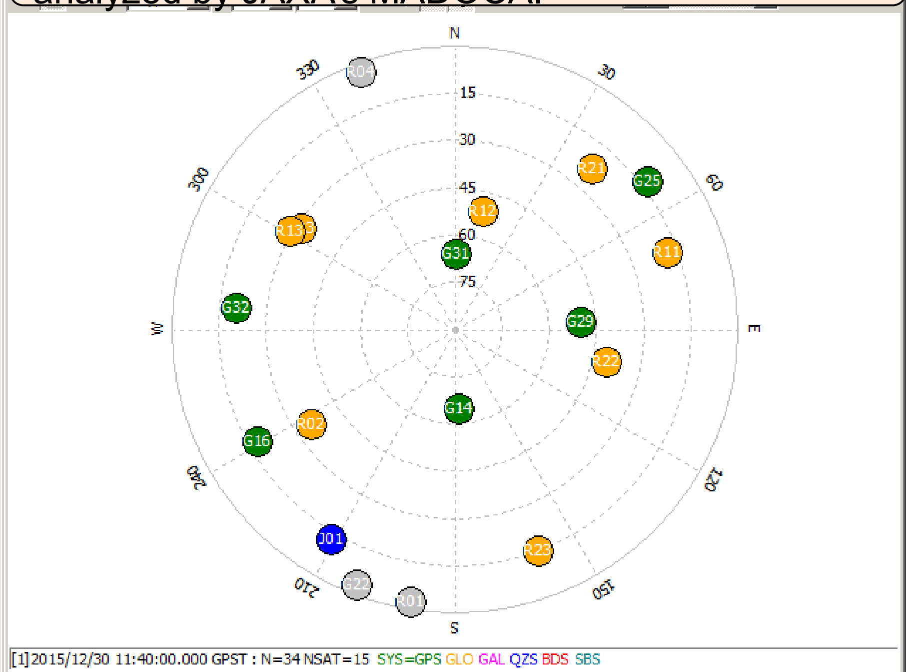
1. Retrieved PWV accuracy depends on the number of SVs which are used in PPP analysis.

Multi-GNSS provides visibility of more than 10 satellites at all times

31 satellites → ≒60 satellites

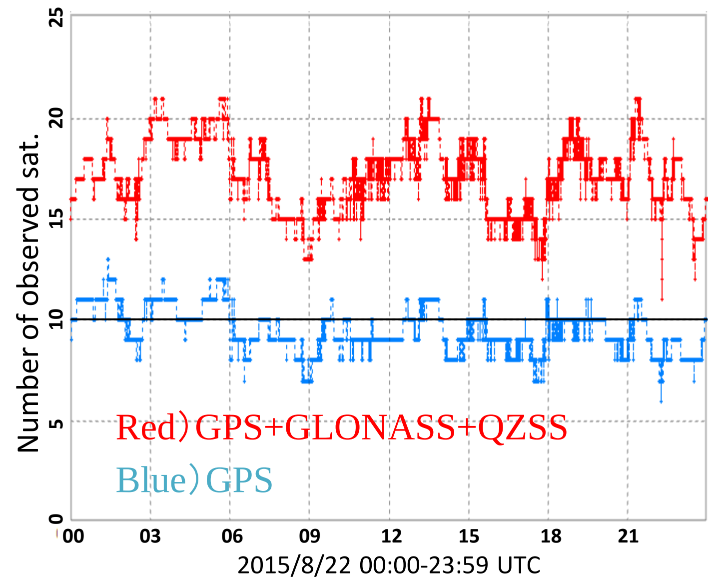
Skyplot of GNSS satellites observed at MRI GNSS station
2015/12/30 11:40-14:40 (UTC)

Orbit and clock of GPS, GLONASS, and QZSS are analyzed by JAXA's MADOCA.



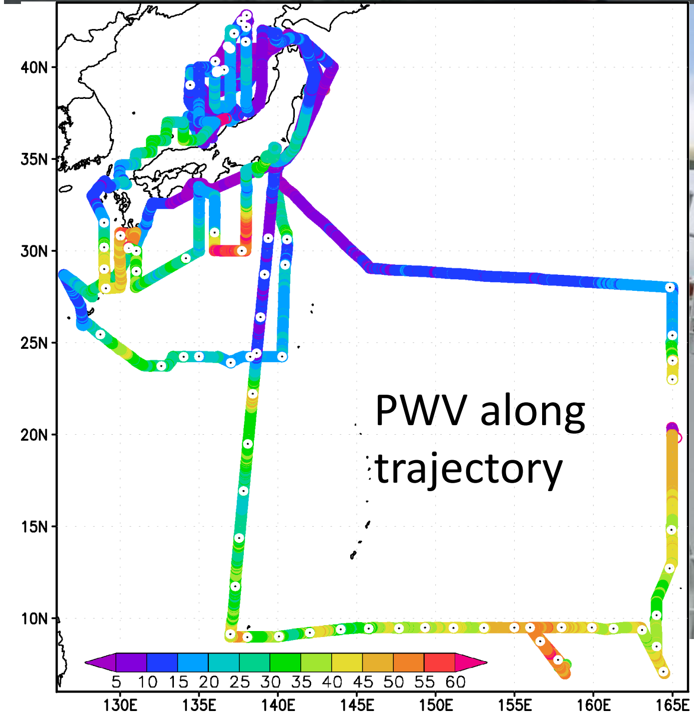
● : GPS, ● : GLONASS, ● : QZSS
● : < 5 degree elevation

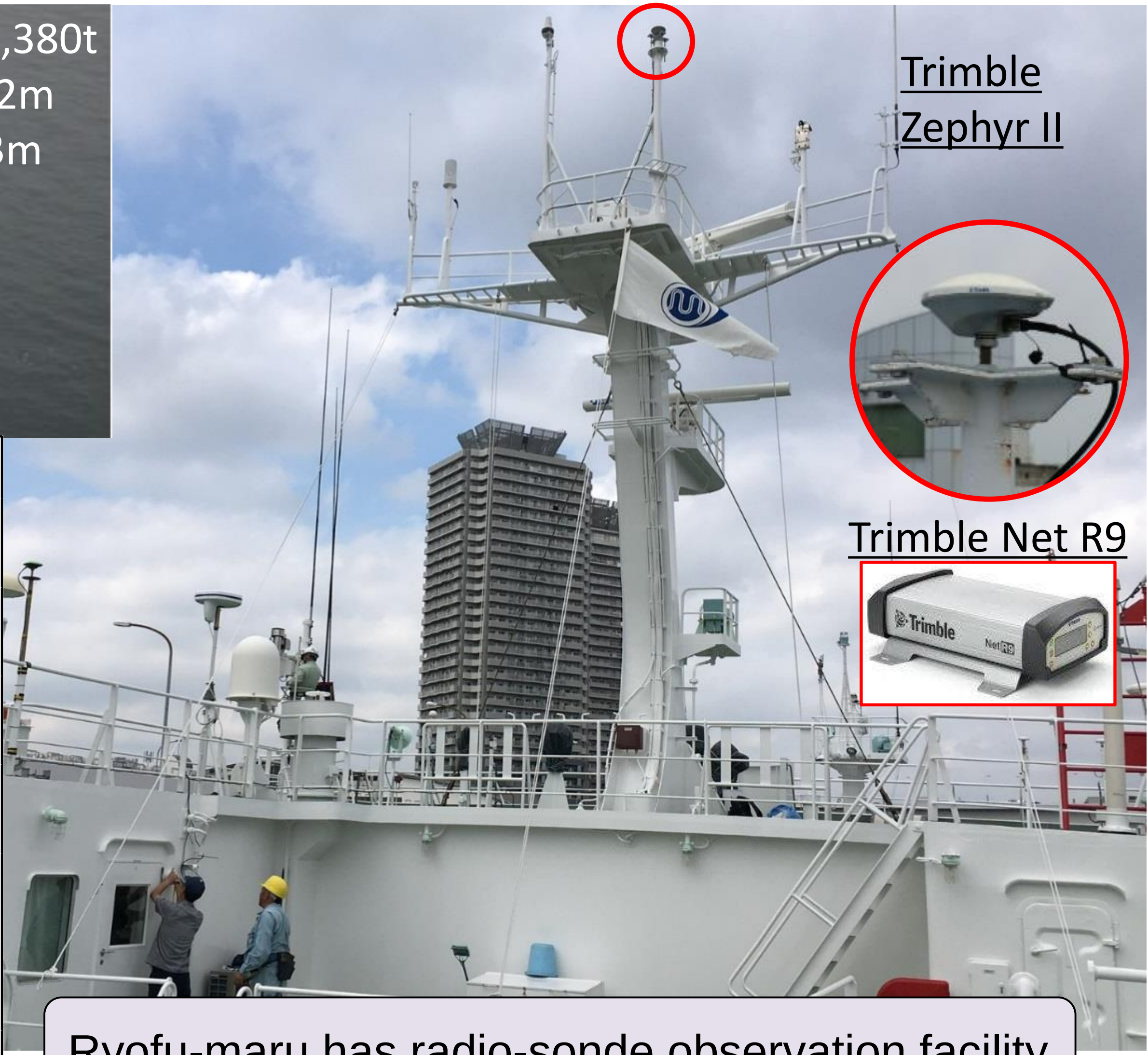
24-hour sequence of number of observed GNSS satellites



More than 10 GNSS satellites can be observed anytime.

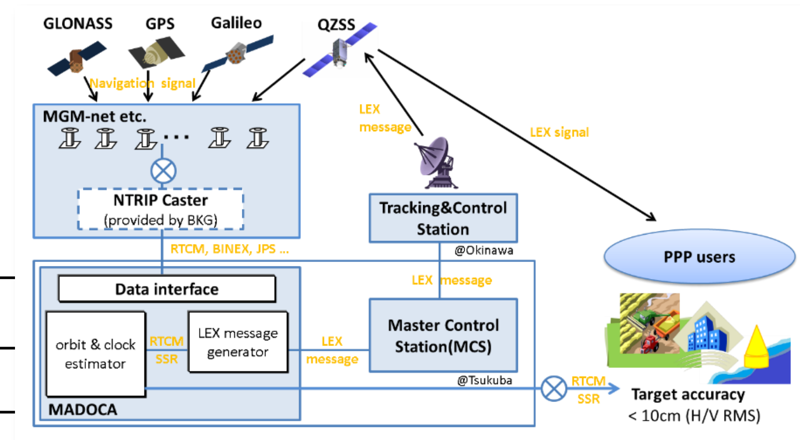
WV retrieval experiment over the OCEAN Oct. 2016 – Jun. 2017





Ryofu-maru has radio-sonde observation facility.

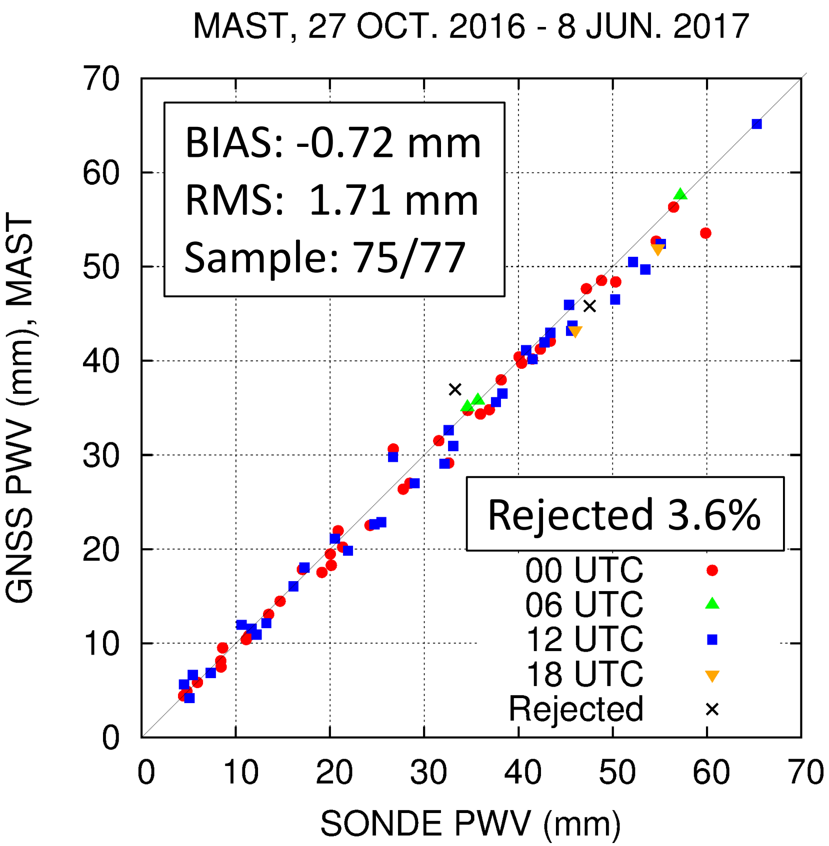
Specification of GNSS Analysis

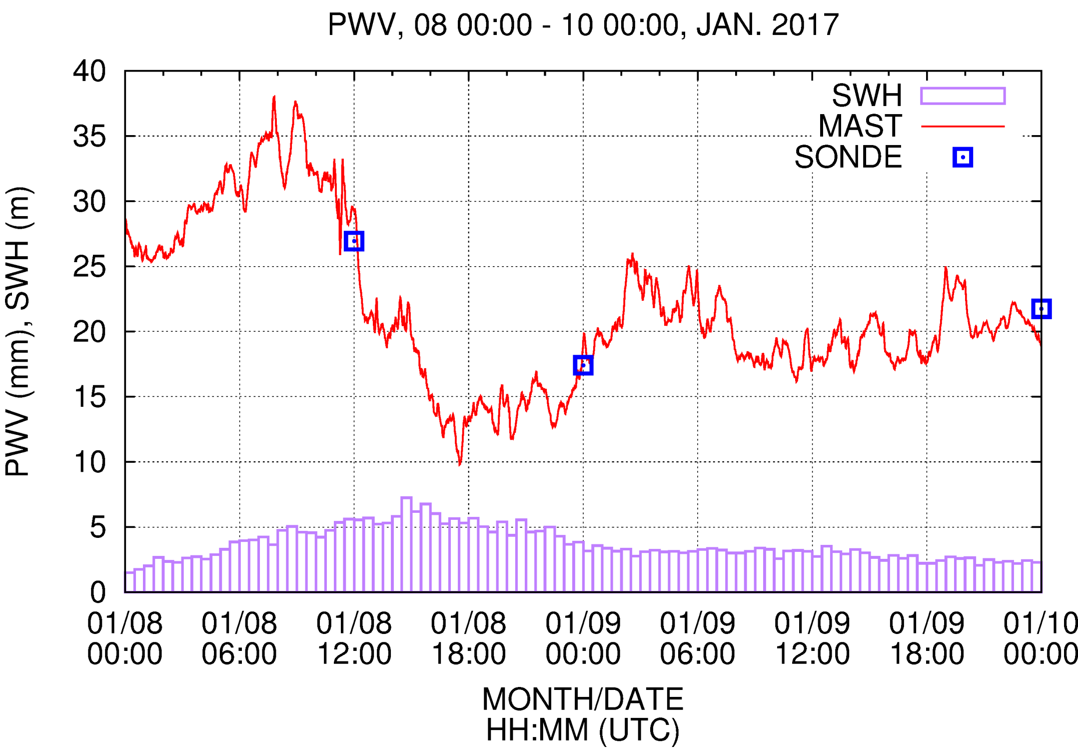


Classification	Specification	
Software	RNX2RTKP (RTKLIB ver. 2.4.2, p12)	
Analysis procedure	Precise Point Positioning - Kinematic (Shipborne GNSS)	
Integer ambiguity	Not fixed (no PPP-AR applied)	
Ephemeris	MADOCA realtime product (MDC2)	https://ssl.tksc.jaxa.jp/madoca/public/public_index_en.html
Mapping function	GMF (no gradient estimation)	Boehm et al. 2006
Elevation cut-off angle	3 degree	
Antenna phase center variation	IGS08_1915.atx	ftp://ftp.igs.org/pub/station/general/igs08.atx
Ionosphere correction	Ionosphere-free linear combination	
ZHD	$ZHD = 0.002277 \cdot P$ $P = 1013.25 \times (1 - 2.2557 \times 10^{-5} h)^{5.2568}$	Elgered et al. 1991
Time dependent parameters	• Antenna coordinate • Receiver clock • ZWD random-walk variable with process noise of $0.1 mm/s^{1/2}$	Updated every 1 sec

Retrieved PWV using RTKLIB with MADOCA real-time product

Shoji *et al. Earth, Planets and Space* (2017) 69:153,DOI 10.1186/s40623-017-0740-1

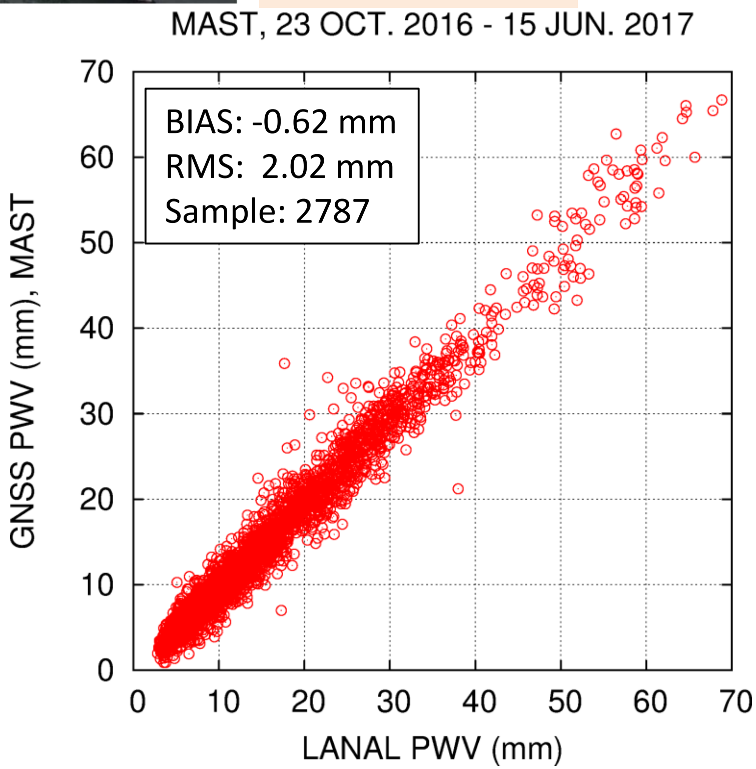




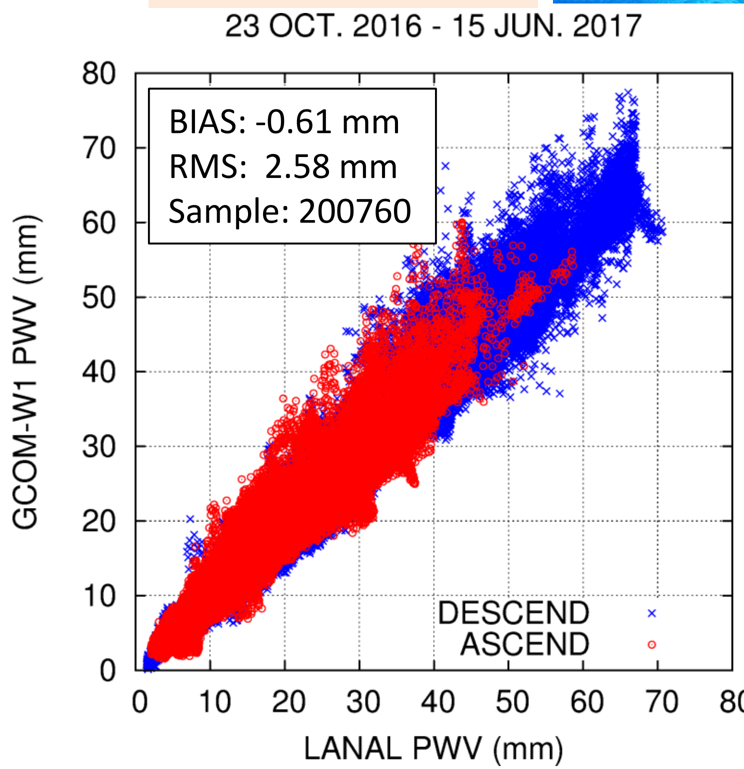
PWV measurement by Ocean platform GNSS is promising.

Comparison with JMA's hourly NWP analysis

Ship-borne GNSS

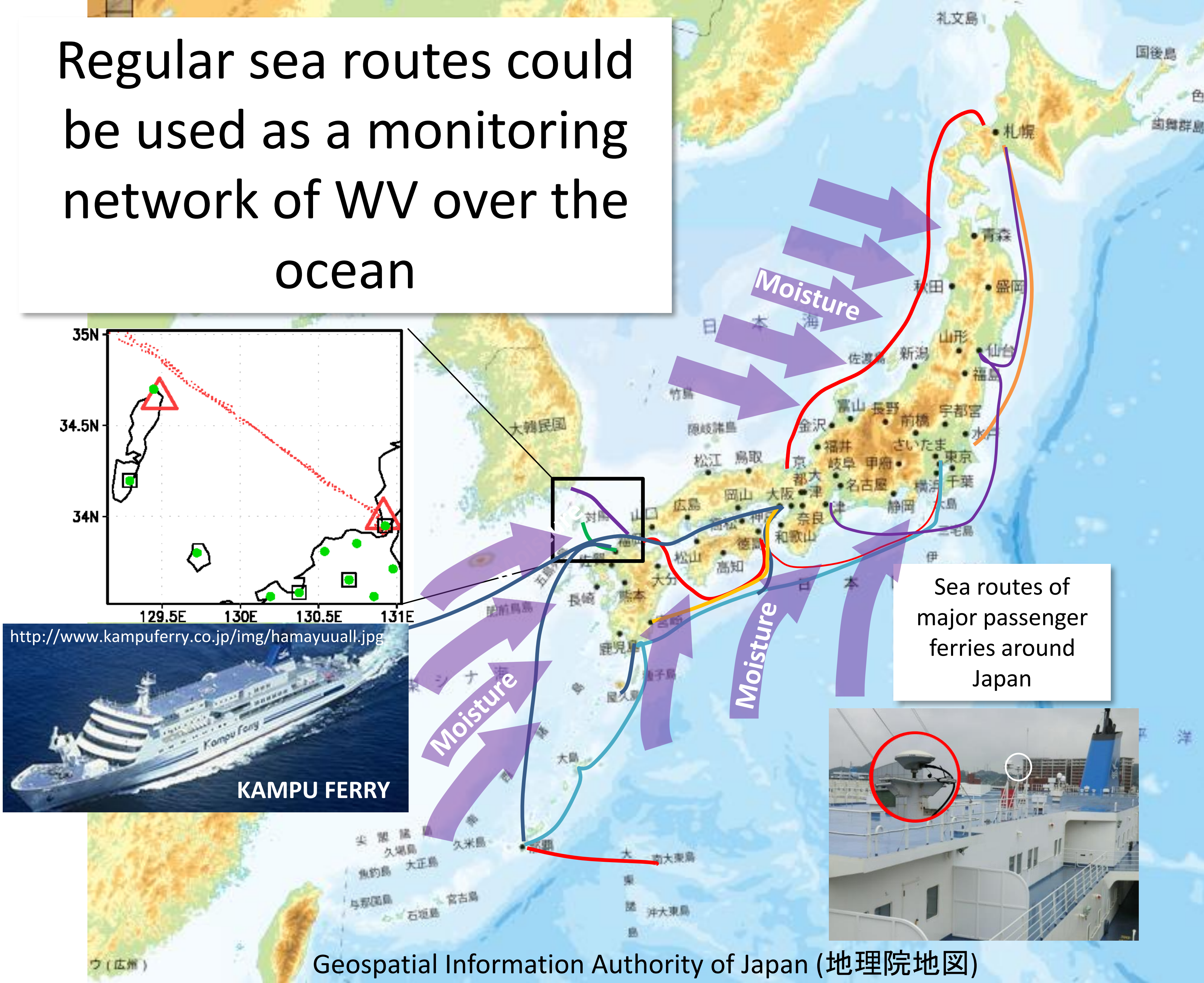


Satellite-borne MWR



Ship-borne GNSS shows better agreement with JMA's NWP analysis (LA) than satellite-borne MWR.

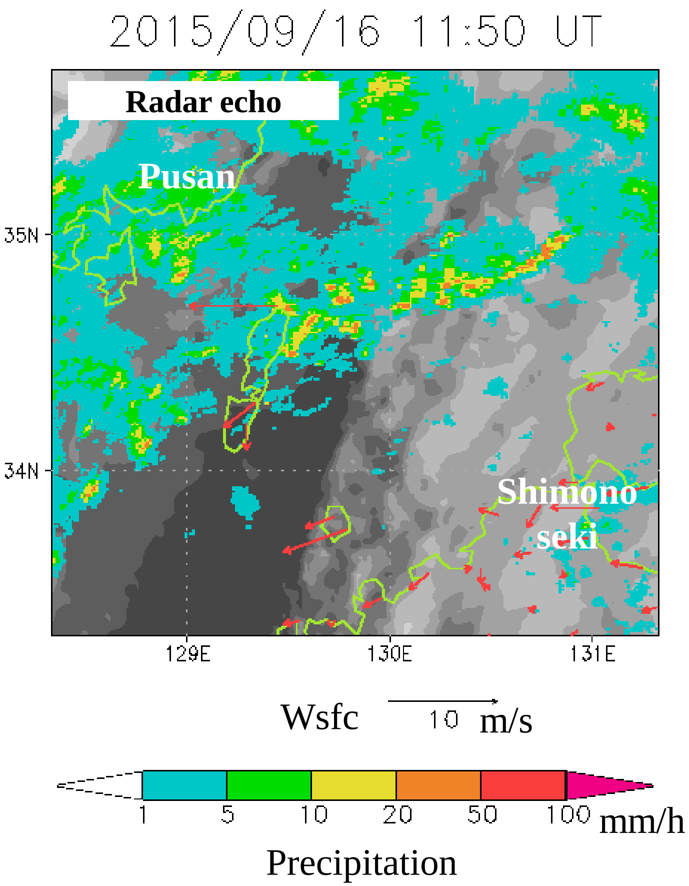
Regular sea routes could be used as a monitoring network of WV over the ocean

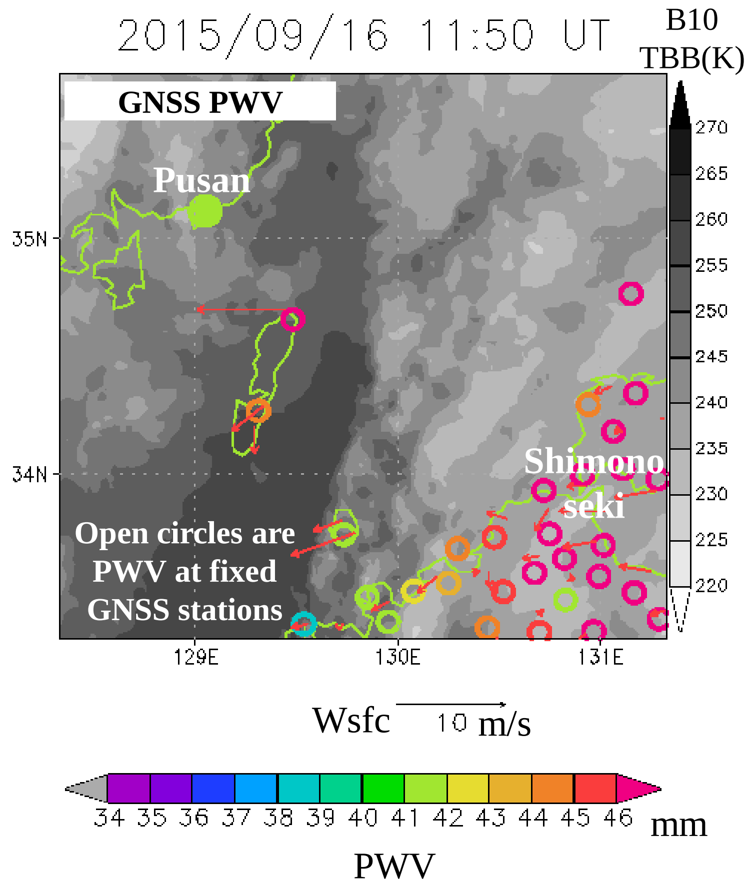


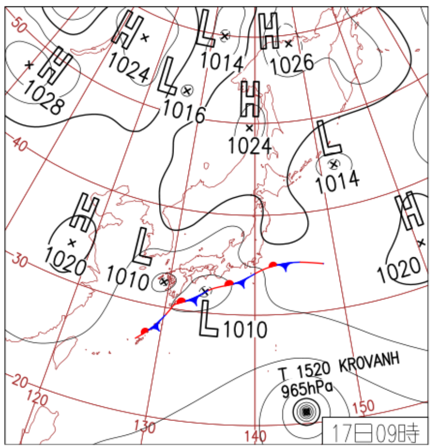
Sea routes of major passenger ferries around Japan

Geospatial Information Authority of Japan (地理院地図)

17 Sep. 2015





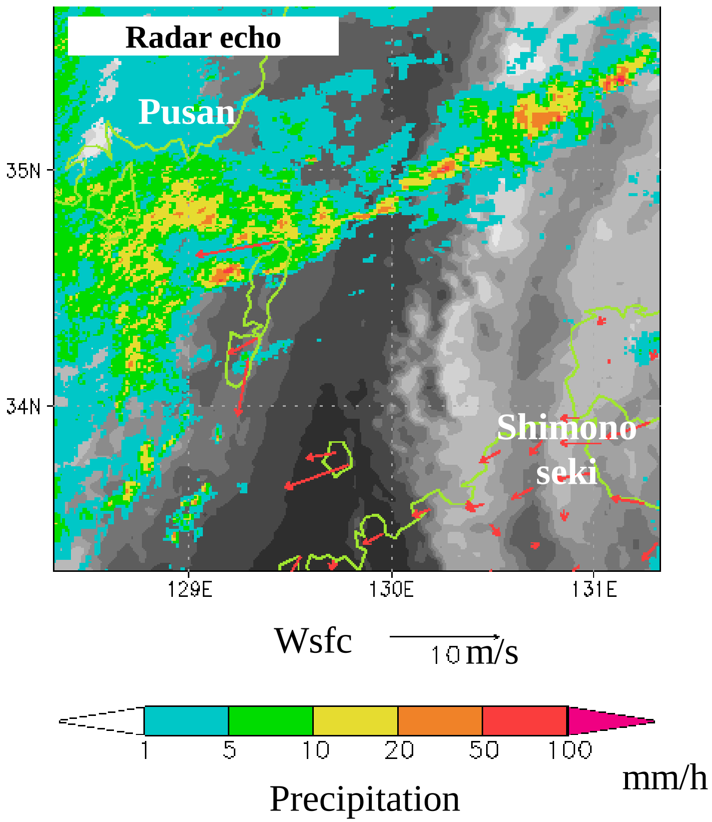


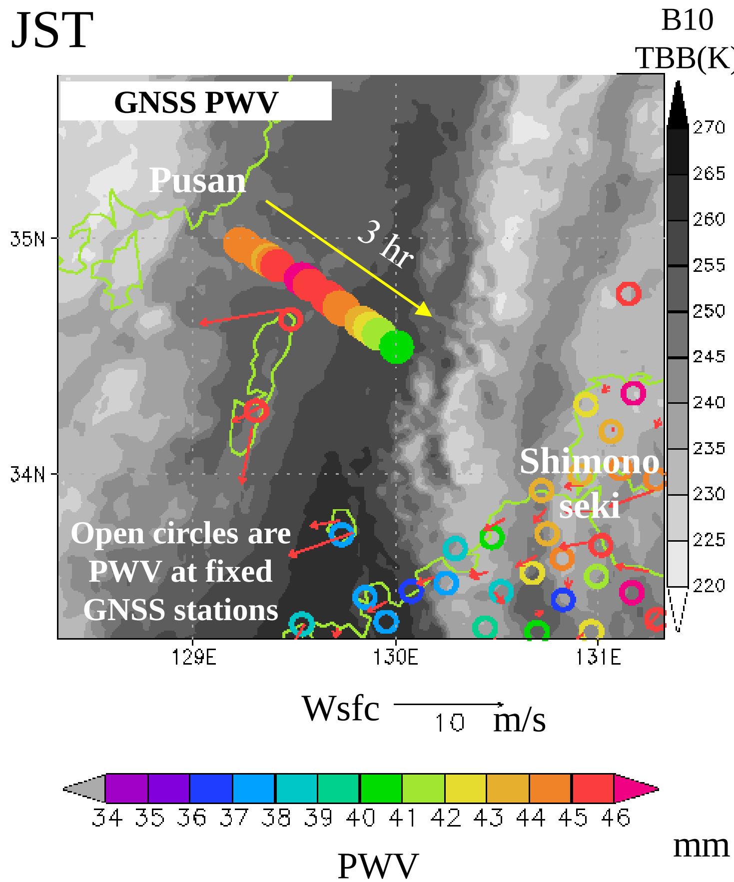
17日(木)チリ沿岸でMw8.3の地震

南岸に前線が停滞し、沖縄・奄美や西～東日本と東北南部で曇りや雨。上空の寒気の影響もあって長崎県上大津で83mm/1hの猛烈な雨。東北北部や北海道は高気圧に覆われて晴れ。

17 Sep. 2015

0110 JST





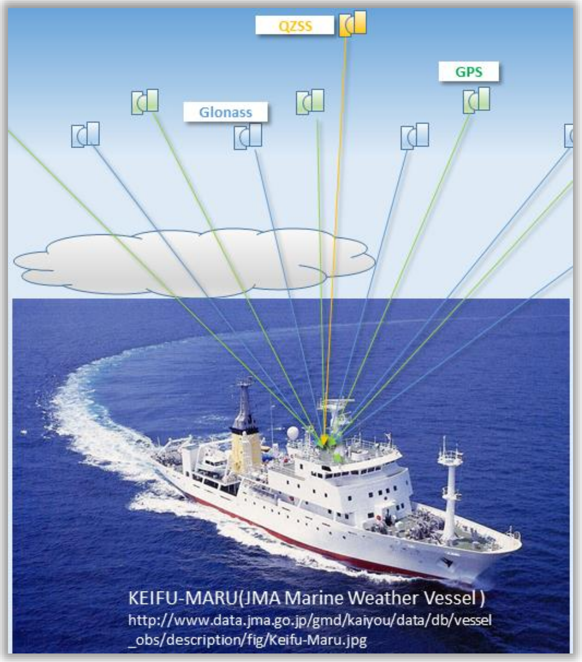
- PWV gradient associated with precipitation system is well expressed

Thank you for your attention

Summary

1. For monitoring of hazardous cumulus convection
   - ➢ Continuous WV monitoring is indispensable
2. JMA's operational GNSS PWV assimilation resulted stepwise improvement in precipitation forecast
3. Innovations in GNSS remote sensing technology enable us to monitor WV variation over a lifetime of convection
   - ➢ Initiation stage
     - Moisture increase in low-level
     - WV measurement over the ocean using GNSS on floating buoys and/or vessels
   - ➢ Development ~ matured stage
     - WV inhomogeneity
     - Slant path delay analysis
4. The results obtained by experimental WV observation using shipborne GNSS are promising.
   - ➢ Agree with radiosonde observation with 2mm RMS (Shoji et al. 2017).
   - ➢ Continuous observation could capture strong WV gradient associated with strong precipitation system.

Acknowledgements



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- We would like to express our deepest appreciation for the support and help given by the Kampu Ferry Company.
- A part of the study was also supported by JSPS KAKENHI Grants 16H06310.
- RTKLIB ver.2.4.2 (patch 12) was downloaded from the following link; https://github.com/tomojitakasu/RTKLIB/archive/master.zip.
- We would like to express our sincere appreciation for Mr. Tomoji Takasu for his valuable comments and supports for the GNSS analysis.
- The GEONET observation data were acquired from the ftp server of the Geospatial Information Authority of Japan (GSI) in RINEX format.
- MADOCA real-time product was provided by JAXA via the internet (https://ssl.tksc.jaxa.jp/madoca/public/public_index_en.html).