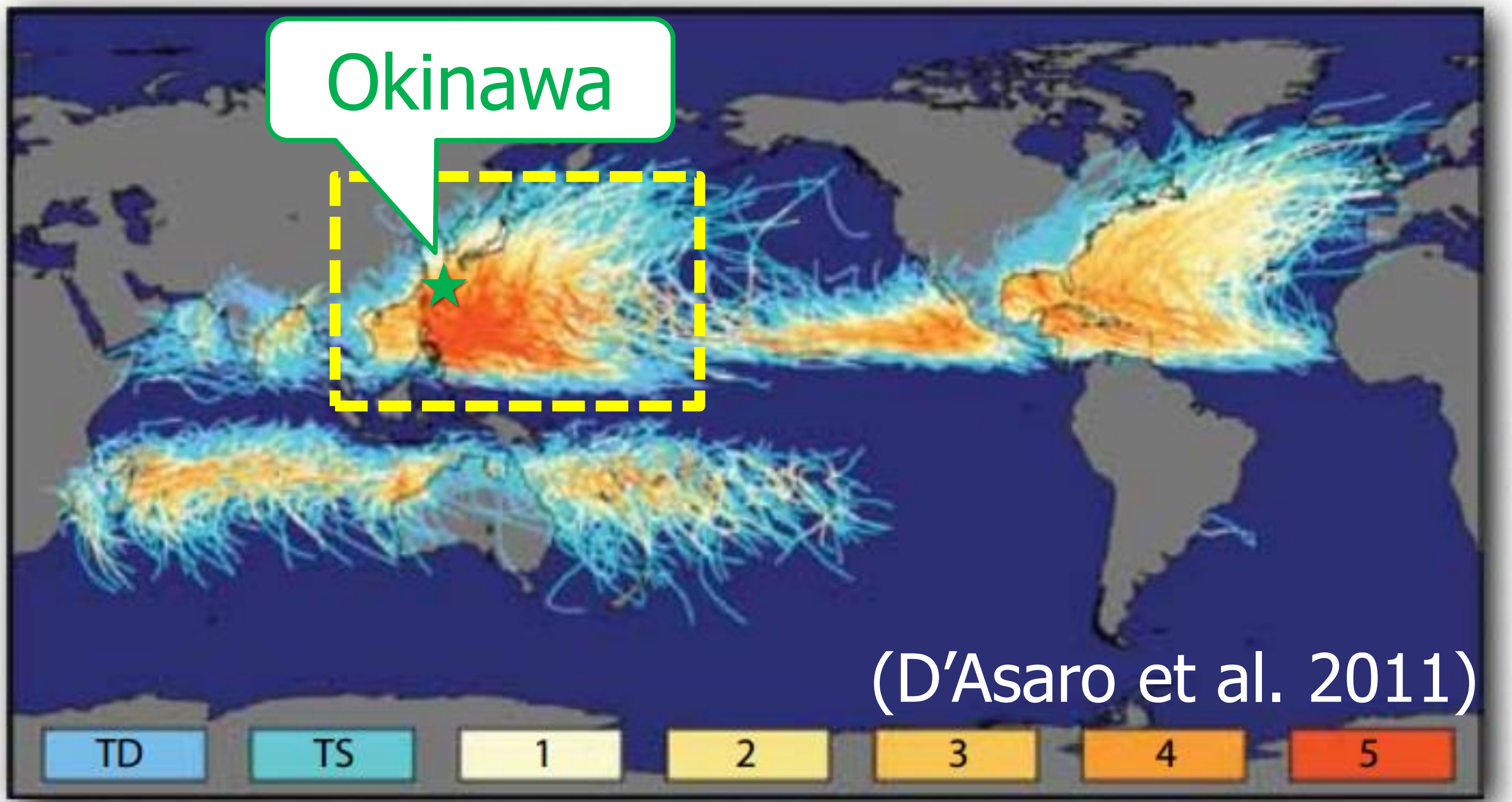
Observational campaigns for better weather forecasts
ECMWF, Reading, UK
11 June 2019

Analysis and forecast using dropsonde data from inner-core region of tropical cyclones obtained during the aircraft missions of T-PARCII

Kosuke Ito[1,2]*, Hiroyuki Yamada[1], Munehiko Yamaguchi[2],
Tetsuo Nakazawa[2], Norio Nagahama[3], Kensaku Shimizu[3],
Tadayasu Ohigashi[4], Taro Shinoda[5], and Kazuhisa Tsuboki[5]
(1: U. Ryukyus, 2: JMA/MRI, 3: Meisei Electric, 4: NIED, 5: Nagoya U.)

Acknowledgment: This work is supported by MEXT KAKENHI Grant 16H06311, 18H01283 and "Advancement of Meteorological and Global Environmental Predictions Utilizing Observational 'Big Data' of the MEXT "Social and Scientific Priority Issues (Theme 4) to be Tackled by Using Post 'K' Computer". This research was conducted using the K computer at the RIKEN Advanced Institute for Computational Science (hp170246).

Tropical cyclones (TCs)



(D'Asaro et al. 2011)

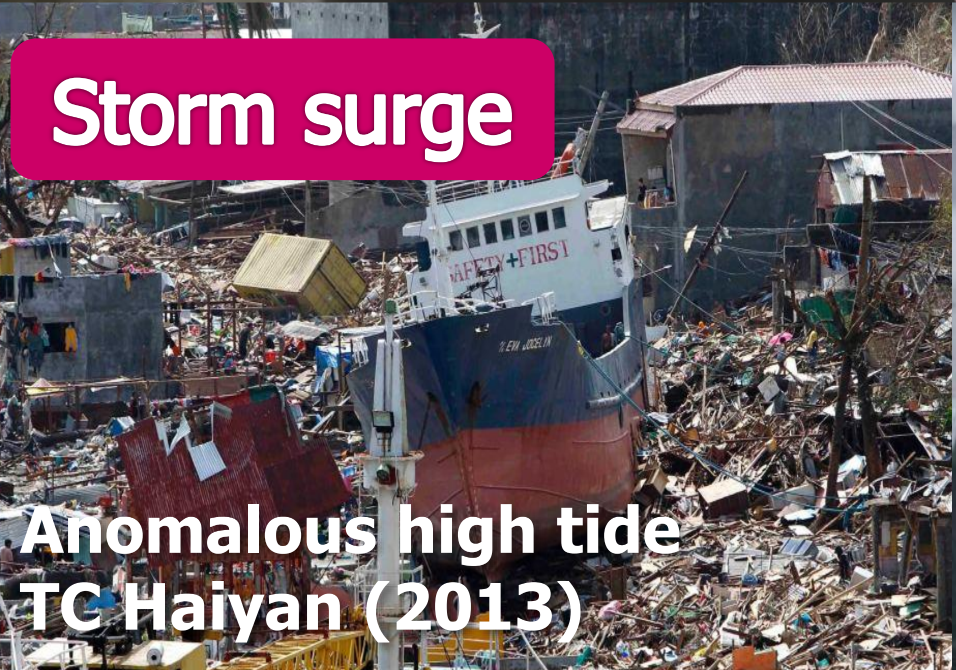
The Western North Pacific (WNP) is the region where violent TCs occur most frequently.

Wind

Maximum Gust 81.1m/s
TC Dujuan (2015)

Rain

Max. total rainfall 3000 mm
TC Morakot (2009)



Storm surge

Anomalous high tide
TC Haiyan (2013)

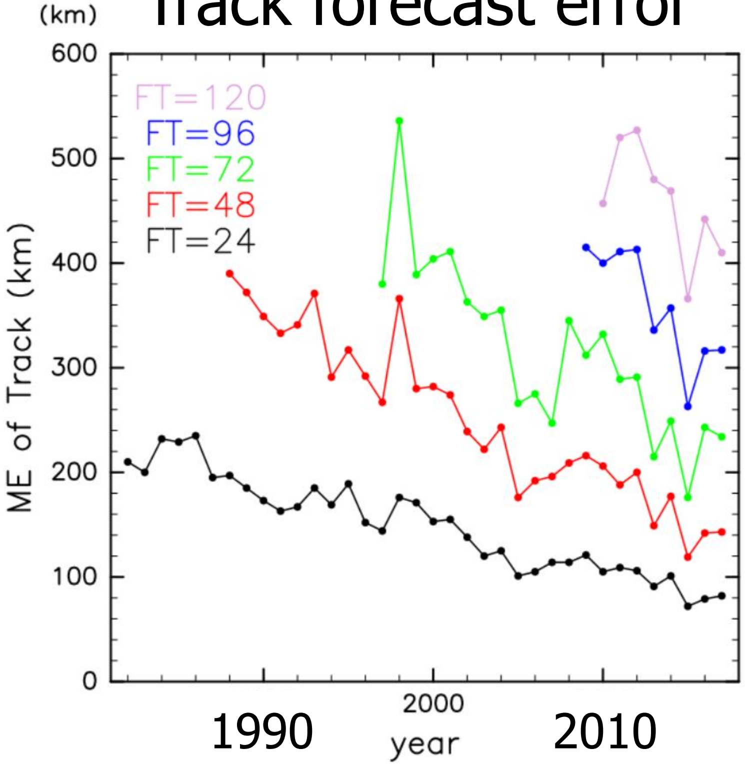
Wave

High wave
TC Lionrock (2016)

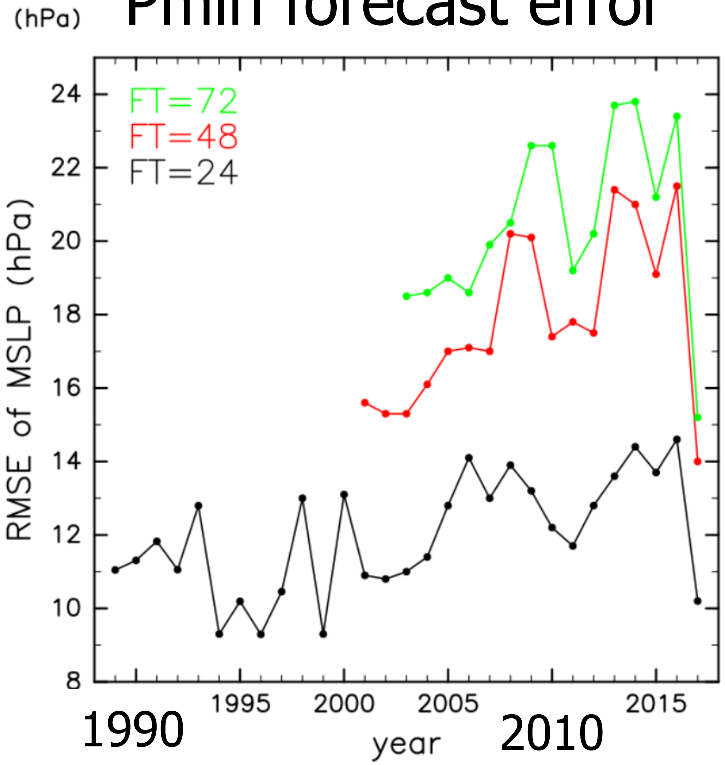
Forecast skill of TCs in WNP by RSMC Tokyo

- Track forecasts have been improved in the last three decades.
- Intensity forecasts also have been improved since 2017
- Further improvements are important for disaster prevention.

Track forecast error



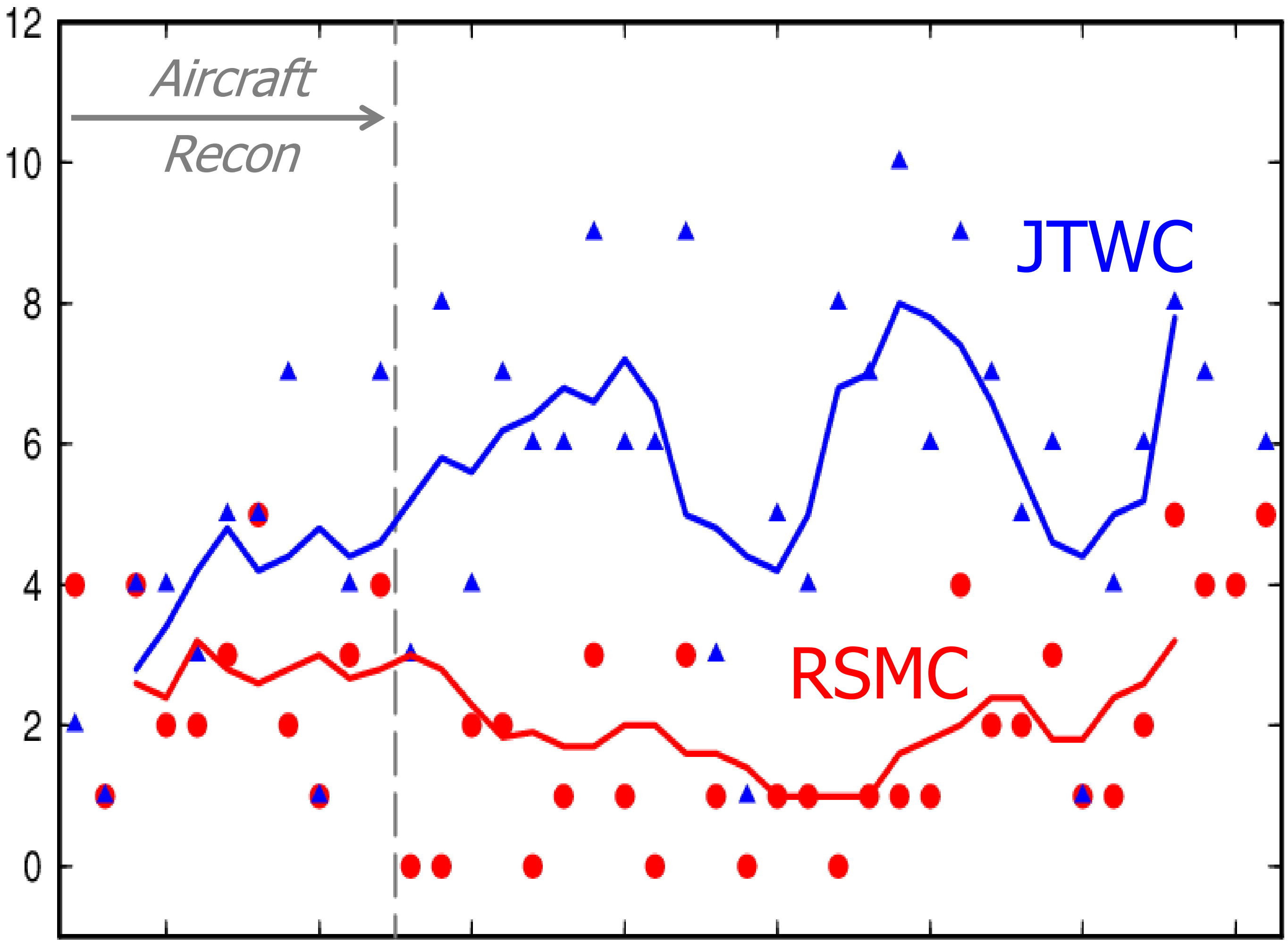
Pmin forecast error



(Ito, 2016, SOLA; values updated)

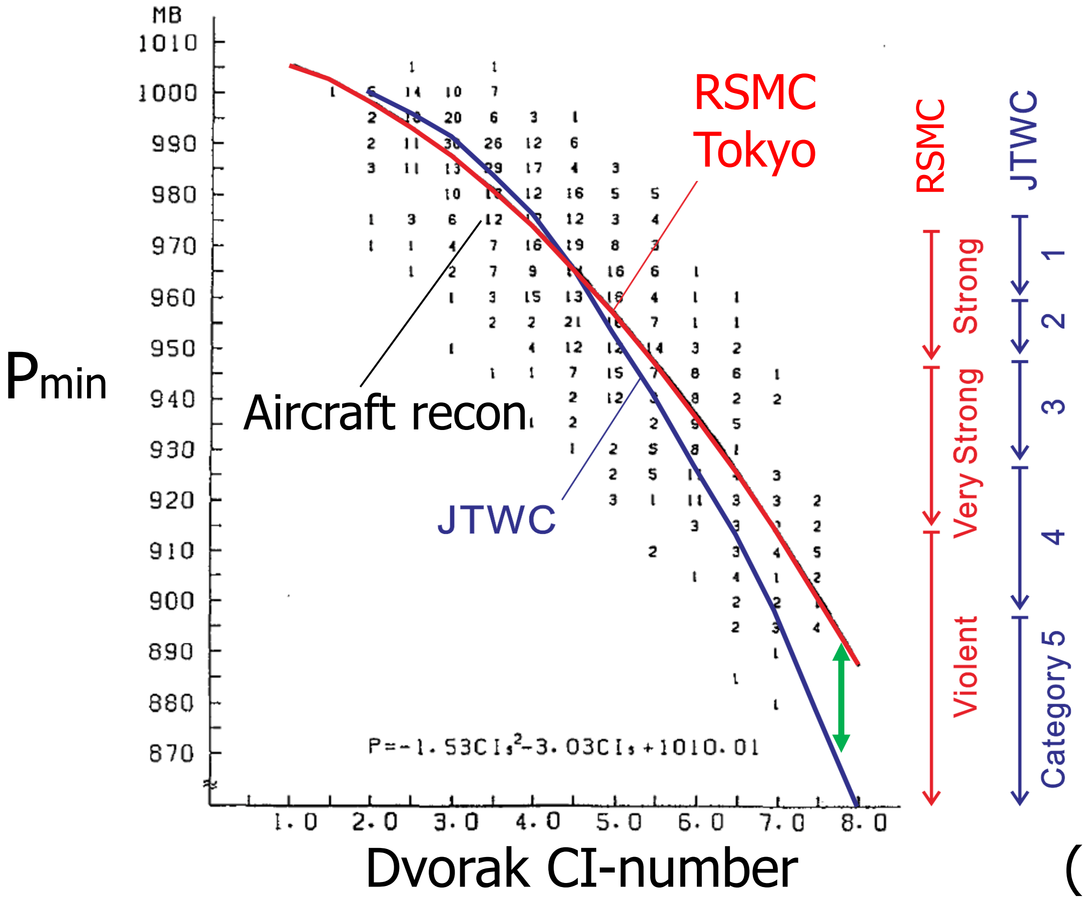
Number of Violent TCs (>54 m/s of 10-min winds)

- Large discrepancy between JTWC and RSMC Tokyo best track after the US aircraft reconnaissance was terminated in 1987.



The need for a ground truth of TC intensity

- Dvorak technique: satellite-based cloud image recognition
  Satellite-based CI-number → (regression line) → TC intensity
- Residual of each aircraft data from a regression line is 13 hPa.
  → We cannot verify the TC intensity forecast skill less than this.
- The discrepancy between JTWC and RSMC is large for CI > 6.0.

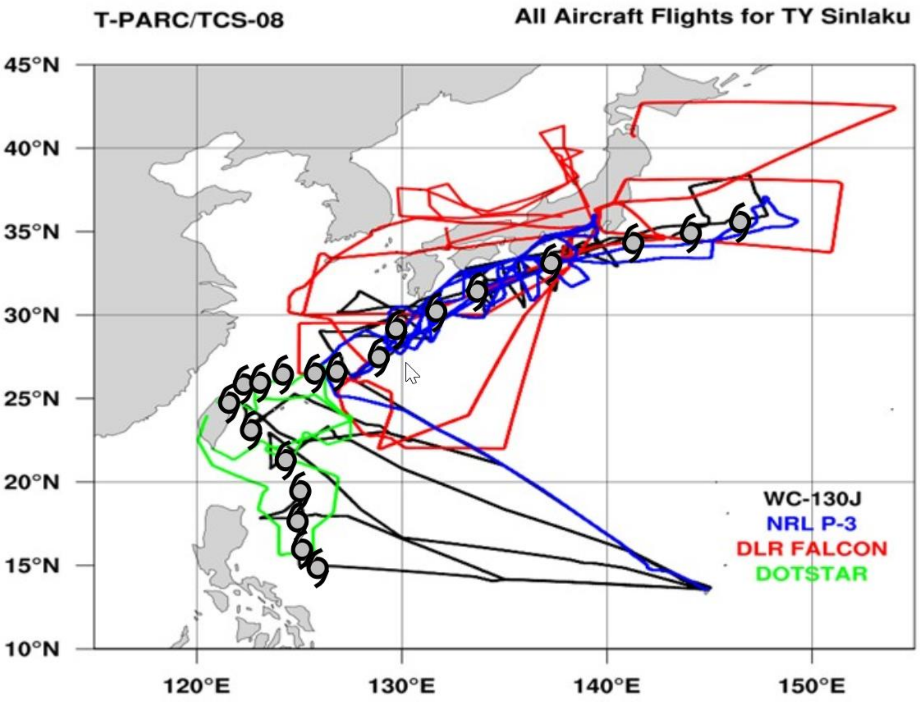


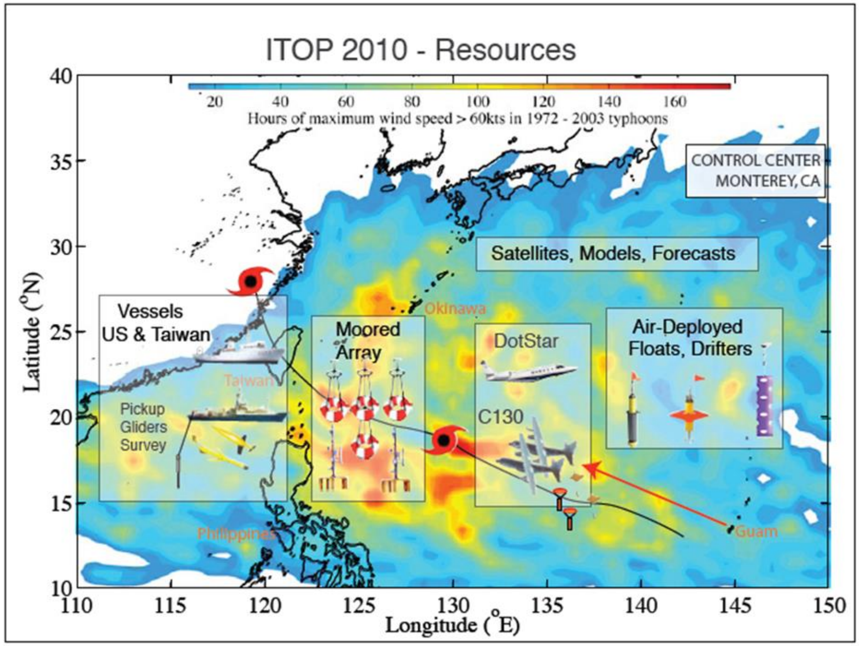
(Koba et al., 1990)

Direct measurements with aircrafts in WNP after 1987

T-PARC / TCS08 (2008)

ITOP (2010)

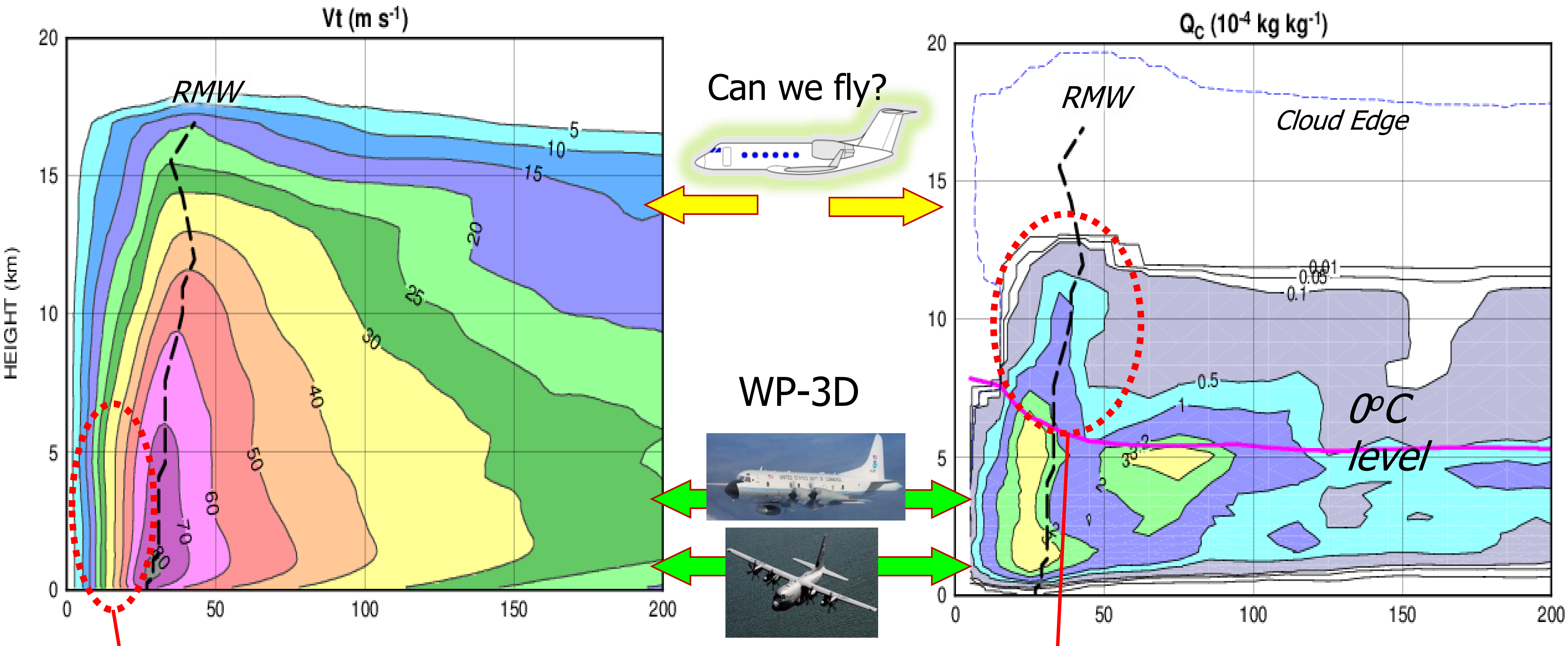




Eye penetration were only made by military-purpose planes.
Is it possible to safely observe a TC inner-core with a jet aircraft?

At what altitude can we penetrate safely?

Radial-height sections of a simulated TC (P_{min}=911.2hPa)
→ Shear and icing do not seem severe in the upper level (>13km)



Can we fly?

WP-3D

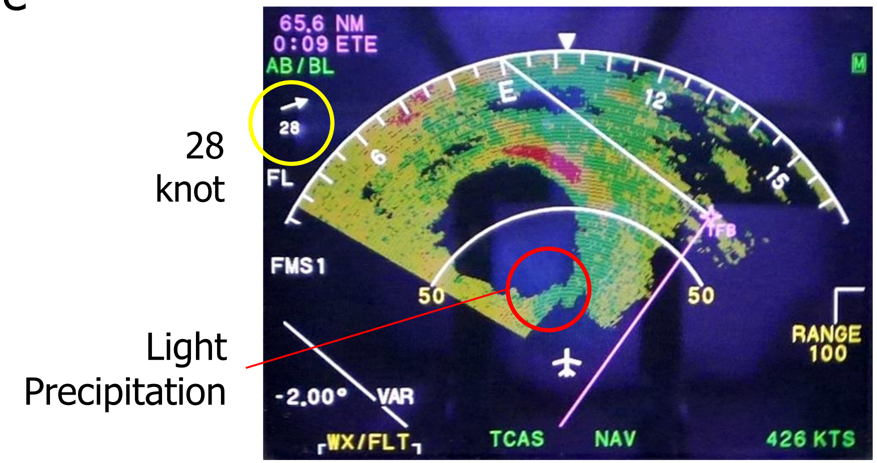
WC-130

Strong Horizontal shear
(up to 4.7 m/s/km)

Heavy icing of supercooled droplets

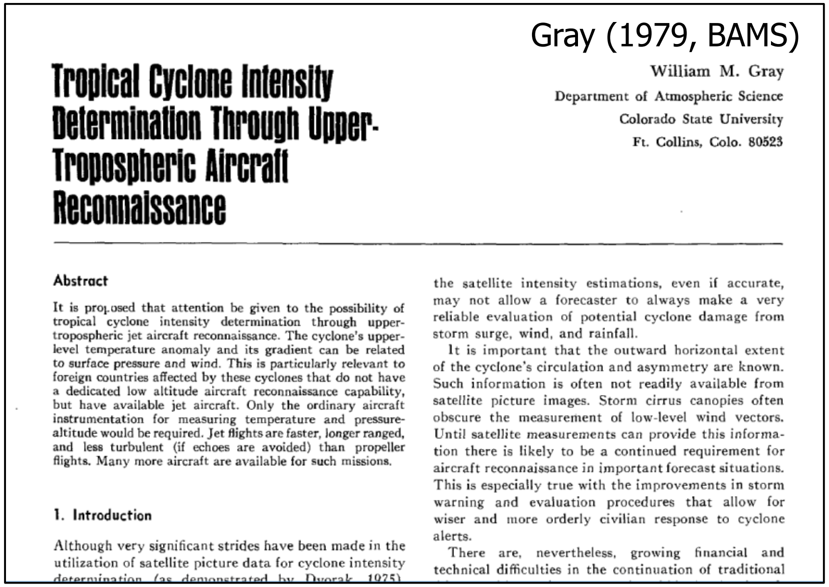
Upper-Tropospheric Recon (Gray, 1979, BAMS)

- In the upper tropopshere, winds become significantly weak and turbulence is generally less intense (if we avoid the region with strong echoes).
- No special crew training would be required.
- Measurement of the upper warm core may contribute to typhoon intensity estimation.
- This idea had never come true in WNP.



28 knot

Light Precipitation



Gray (1979, BAMS)

Tropical Cyclone Intensity Determination Through Upper-Tropospheric Aircraft Reconnaissance

William M. Gray
Department of Atmospheric Science
Colorado State University
Ft. Collins, Colo. 80523

Abstract

It is proposed that attention be given to the possibility of tropical cyclone intensity determination through upper-tropospheric jet aircraft reconnaissance. The cyclone's upper-level temperature anomaly and its gradient can be related to surface pressure and wind. This is particularly relevant to foreign countries affected by these cyclones that do not have a dedicated low altitude aircraft reconnaissance capability, but have available jet aircraft. Only the ordinary aircraft instrumentation for measuring temperature and pressure-altitude would be required. Jet flights are faster, longer ranged, and less turbulent (if echoes are avoided) than propeller flights. Many more aircraft are available for such missions.

1. Introduction

Although very significant strides have been made in the utilization of satellite picture data for cyclone intensity determination (as demonstrated by Dvorak, 1975), the satellite intensity estimations, even if accurate, may not allow a forecaster to always make a very reliable evaluation of potential cyclone damage from storm surge, wind, and rainfall.

It is important that the outward horizontal extent of the cyclone's circulation and asymmetry are known. Such information is often not readily available from satellite picture images. Storm cirrus canopies often obscure the measurement of low-level wind vectors. Until satellite measurements can provide this information there is likely to be a continued requirement for aircraft reconnaissance in important forecast situations. This is especially true with the improvements in storm warning and evaluation procedures that allow for wiser and more orderly civilian response to cyclone alerts.

There are, nevertheless, growing financial and technical difficulties in the continuation of traditional

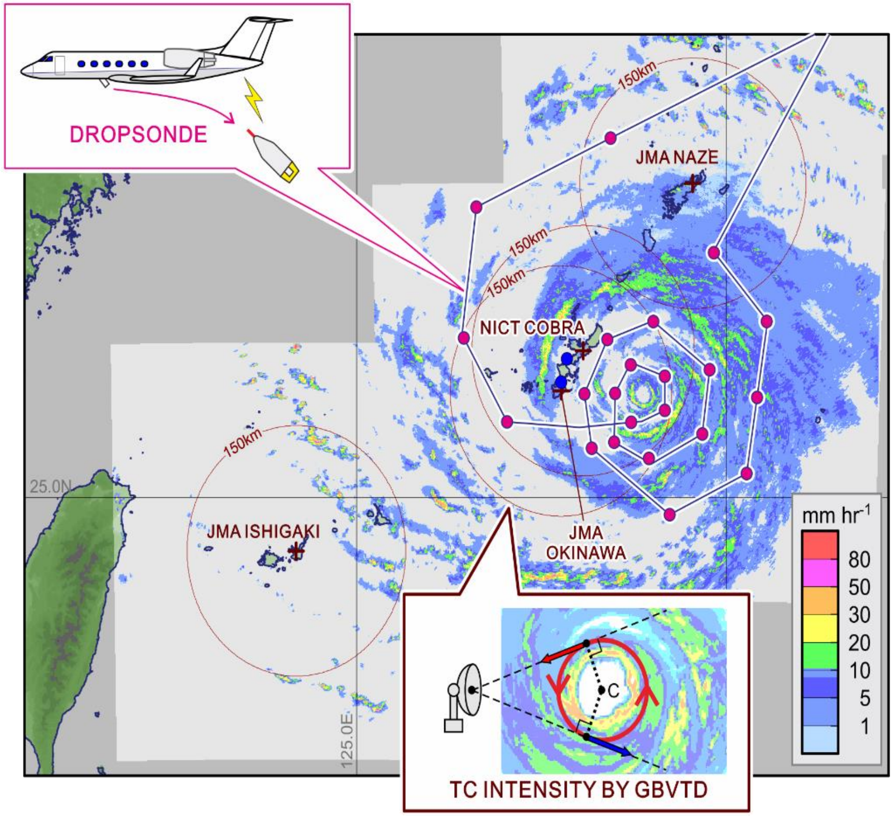
In the recon of Typhoon Lan (2017):

- Weak eyewall echoes and weak winds at 43,000 ft enabled us to enter the eye without suffering severe turbulence.
- Dropsounding from this level enabled us to examine the thermodynamic features of the eye up to 13 km of altitude.
- This was the first attempt of Gray (1979)'s proposal in WNP.

T-PARCII

Tropical Cyclones-Pacific Asian Research Campaign for the Improvement of Intensity Estimations/Forecasts

PI: Prof. Kazuhisa Tsuboki (Nagoya Univ.), FY2016-2020

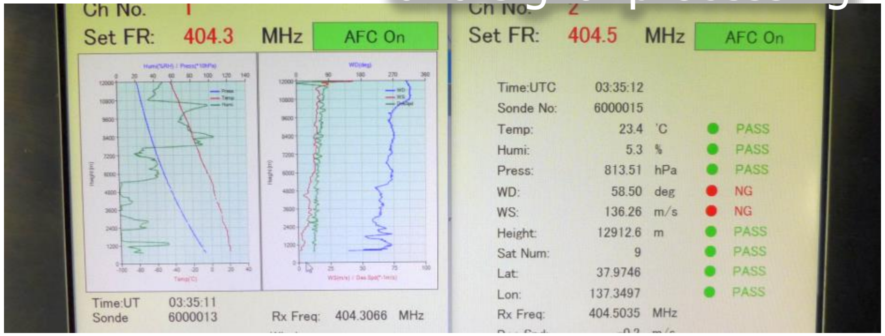


A dropsounding system was newly developed by Meisei Electric.

Flight level is 43,000 ft (~13.8 km) during penetration of a typhoon.

In-Flight Works

Dropsonde deployment and signal processing



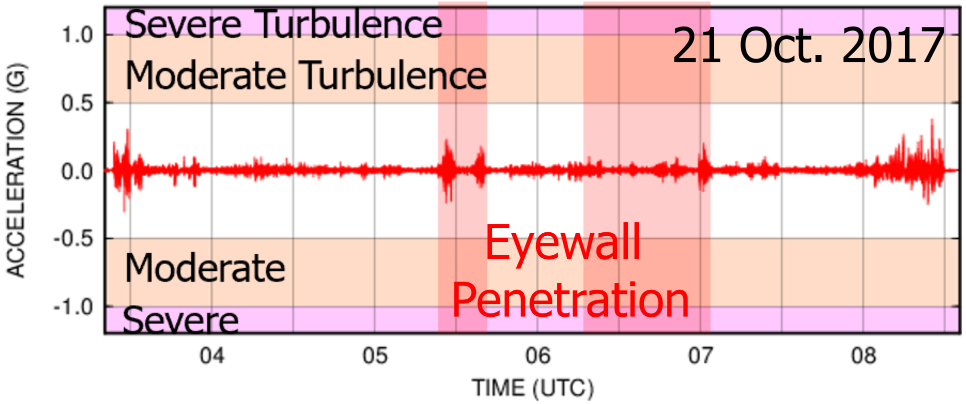
Ch No. 1
Set FR: 404.3 MHz AFC On

Time:UT 03:35:11
Sonde 6000013
Rx Freq: 404.3066 MHz

Ch No. 2
Set FR: 404.5 MHz AFC On

Time:UTC	03:35:12		
Sonde No:	6000015		
Temp:	23.4	'C	● PASS
Humi:	5.3	%	● PASS
Press:	813.51	hPa	● PASS
WD:	58.50	deg	● NG
WS:	136.26	m/s	● NG
Height:	12912.6	m	● PASS
Sat Num:	9		● PASS
Lat:	37.9746		● PASS
Lon:	137.3497		● PASS
Rx Freq:	404.5035	MHz	

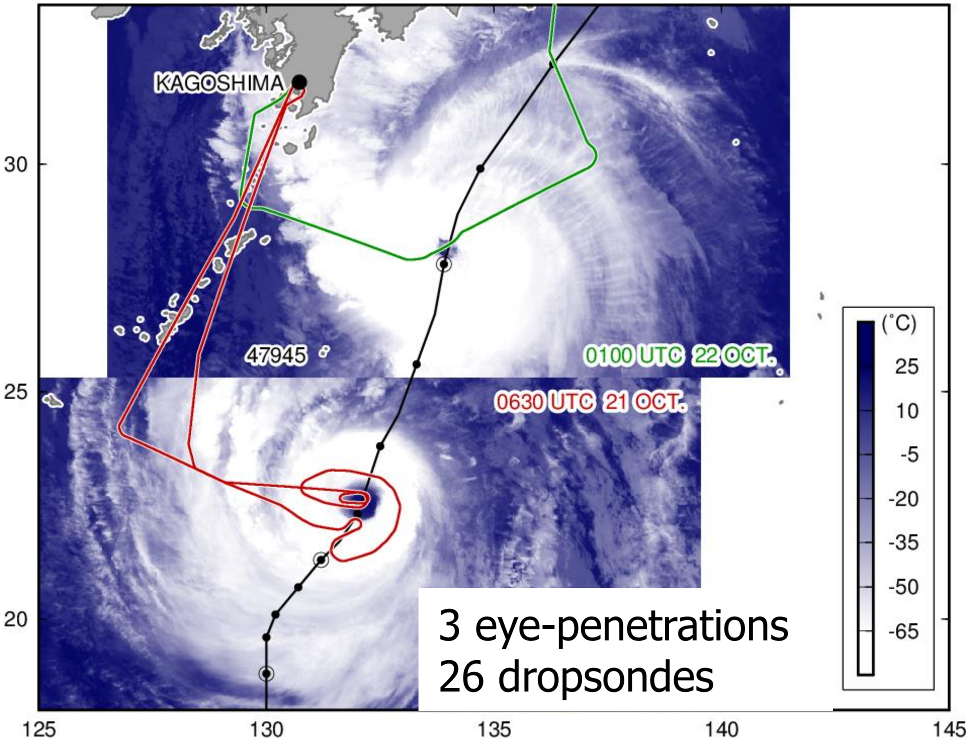
Navigation using the weather radar



Penetration Flights into the Eye of strong TCs

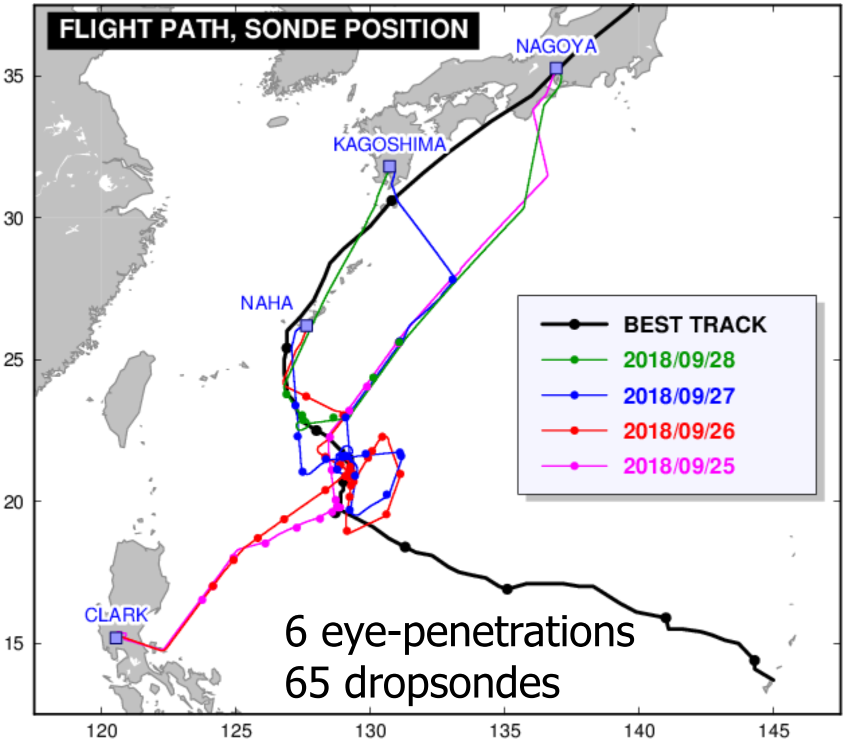
- TC Lan (2017) and TC Trami (2018) were successfully observed by 26 and 65 dropsondes dropped from 13.8 km.
- We collaborated with DOTSTAR in both cases, and we collaborated with SATREPS project for the Trami case.

TC Lan (2017), ~925 hPa



3 eye-penetrations
26 dropsondes

TC Trami (2018), 915~955 hPa

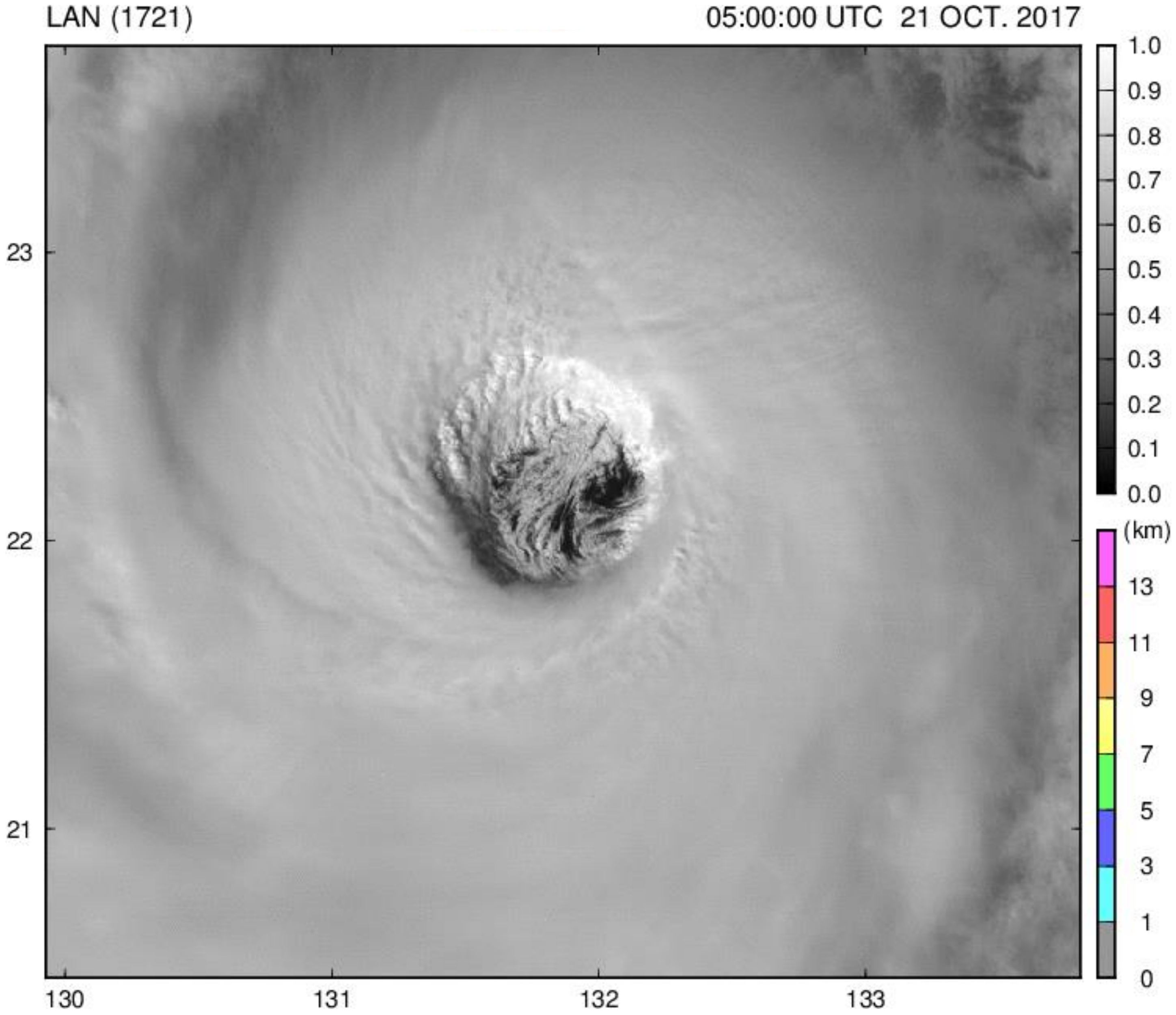


6 eye-penetrations
65 dropsondes

The eye of TC Lan (2018) on 21 Oct. 2017

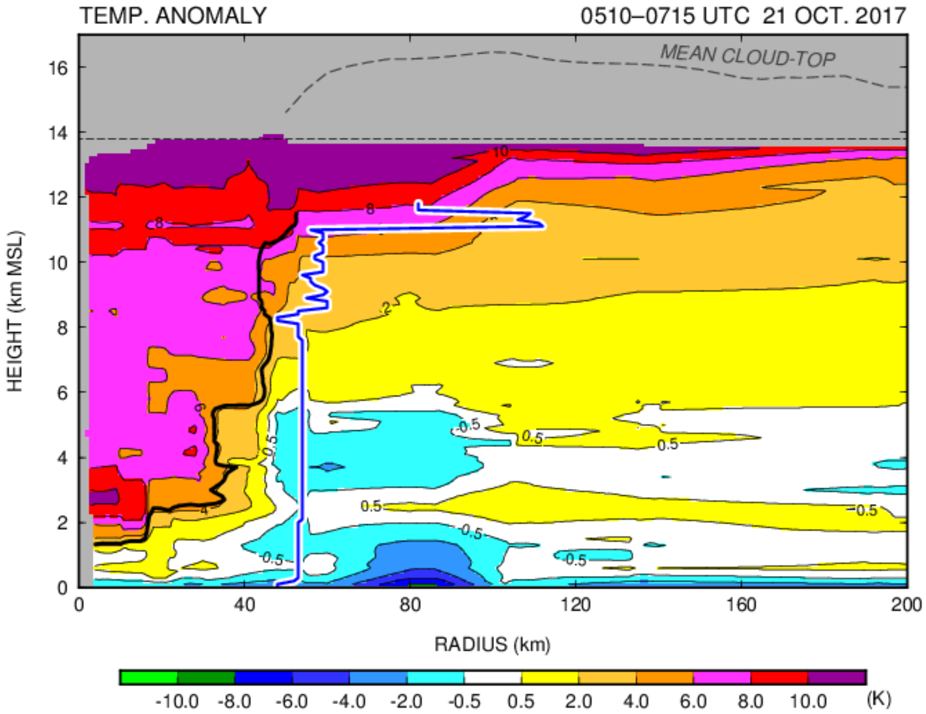
(Univ. Ryukyus / T-PARCII)

Dropsonde Locations (on 21 Oct. 2017)

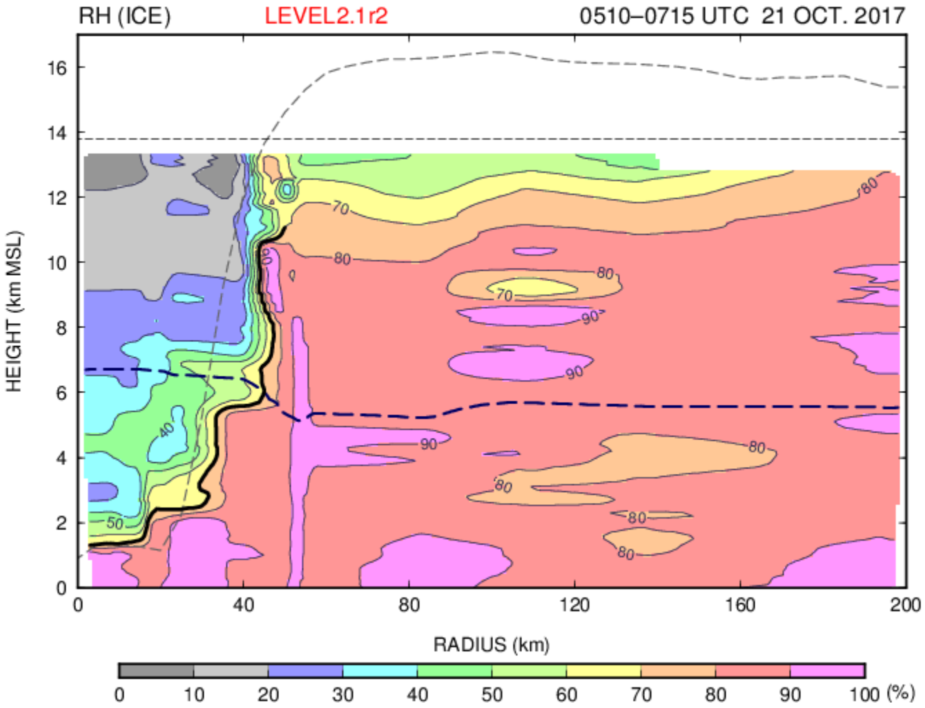


Radius-Height Plots of TC Lan
(on 21 Oct. 2017)

Temperature Anomaly



Relative Humidity

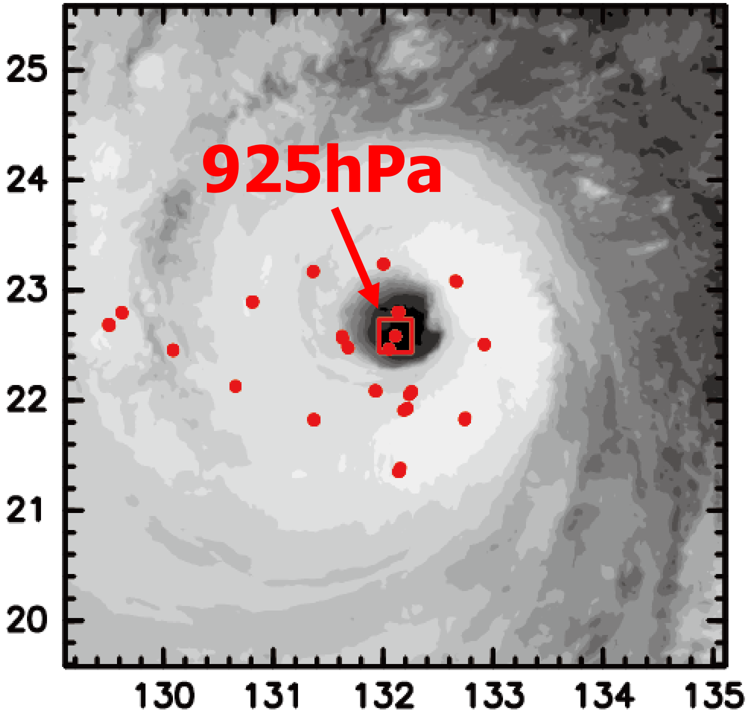


Double warm-core structure in a deep, dry layer of the eye could be captured by dropsondes. A possible physical explanation for the lower one is given in Yamada et al. (submitted to JMSJ).

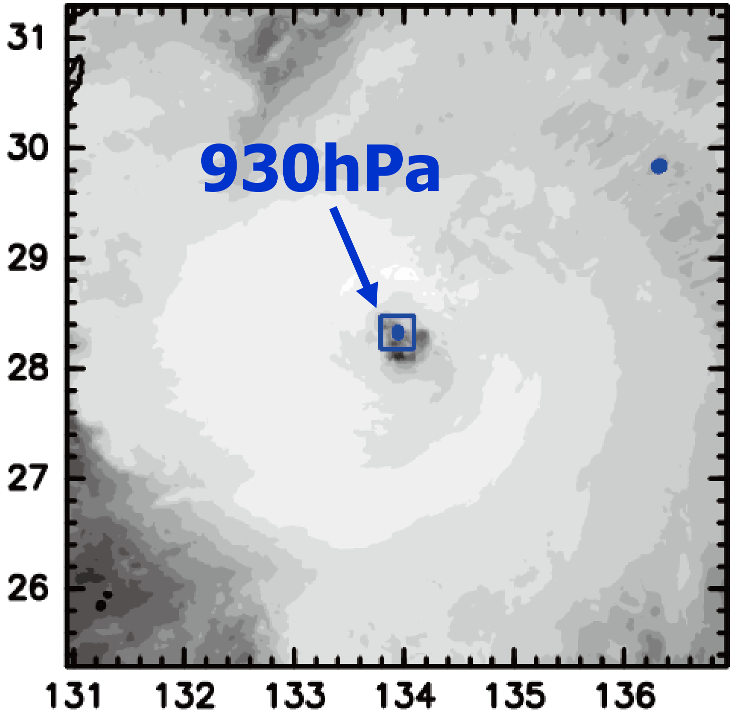
Analysis and forecast with dropsondes

- The inner core of TC Lan was observed on 21–22 October during the first missions of T-PARCII.
- We evaluated the impact of dropsondes on the intensity analysis and forecast skill.

06:52:30 UTC 21 October 2017

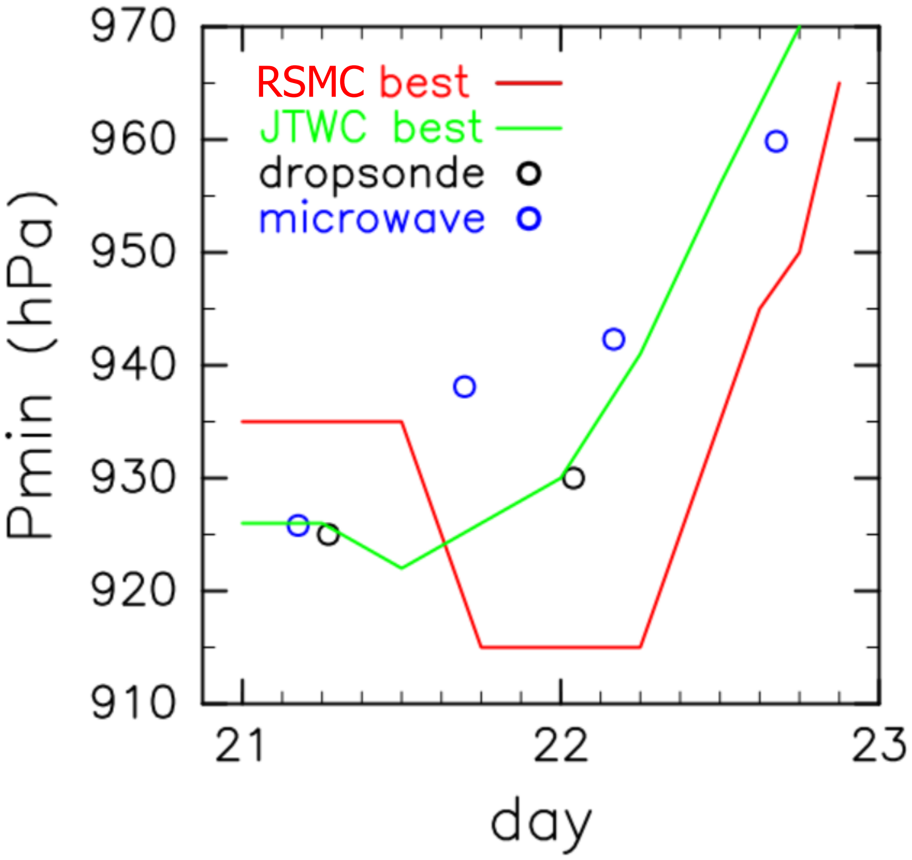


01:15:00 UTC 22 October 2017



Comparison of Pmin

- Large discrepancies among the datasets
  - RSMC Tokyo*: Intensifying (935 hPa → 915 hPa)
  - The others: Neutral or weakening
- We can verify recently proposed methods such as microwave-based one.

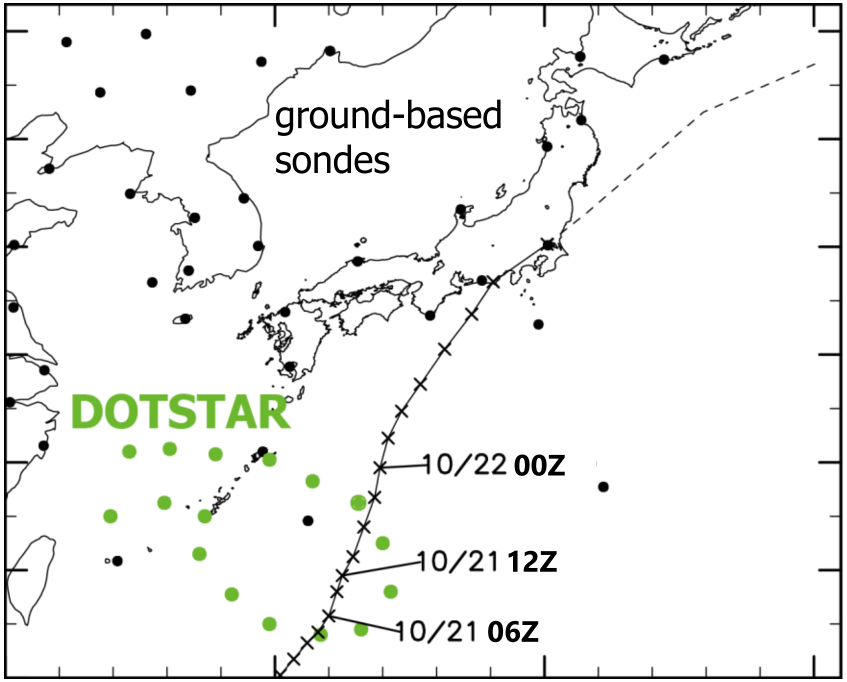


(Ito et al., 2018, SOLA)

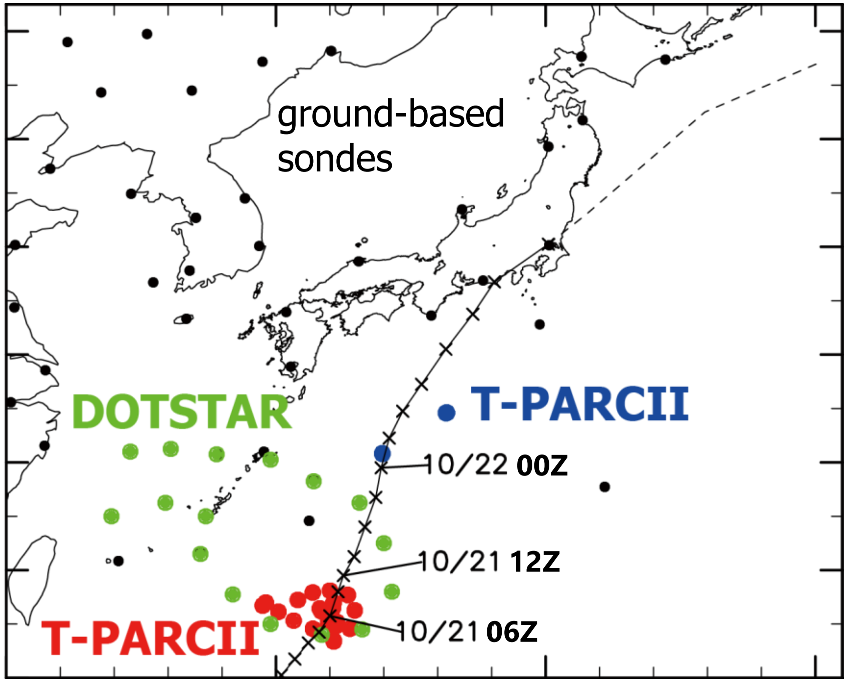
DA experiments: CTRL & TPARCII

- DA and forecast experiments to evaluate the impacts of T-PARCII observations
    - ➢ NoTPARCII: Fcst following DA without T-PARCII dropsondes
    - ➢ TPARCII: Fcst following DA with T-PARCII dropsondes

NoTPARCII



TPARCII



(Ito et al., 2018, SOLA)

Common setting

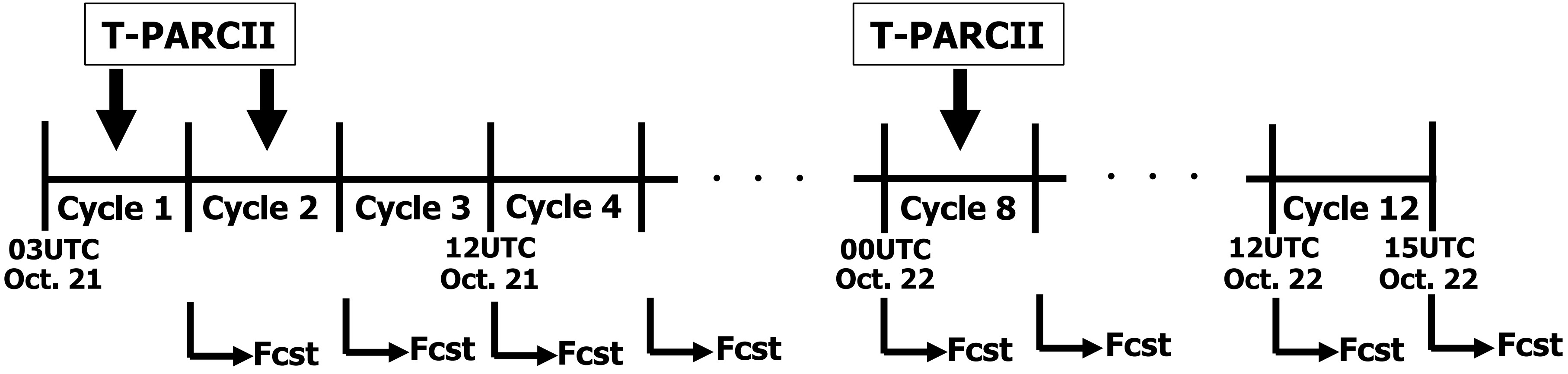
DA system	JMA-NHM-based 4D-Var (JNoVA) (Sawada and Honda, 2009)
DA window	3 hours
Observations	Conventional sonde, ship, wind profiler, bogus, TPW, aircraft (including DOTSTAR)
Grid spacing	DA: 15 km & 5 km; Forecast: 5 km
Microphysics	DA: Large-scale cond.; Forecast: KF, MYNN3

Dropsonde data treatment in the TPARCII experiment

Variable	U, V, T, RH, Psfc (QCed by Meisei Electric)
Thinning	U, V, T, RH to the designated levels and classified into hourly time slots
Obs. error	Same as conventional sondes obs. error in JMA MA
Outer QC	$\lvert \text{fist guess} - \text{obs.} \rvert < \text{obs. error} \times 10$
Location	Considering horizontal drift during the fall

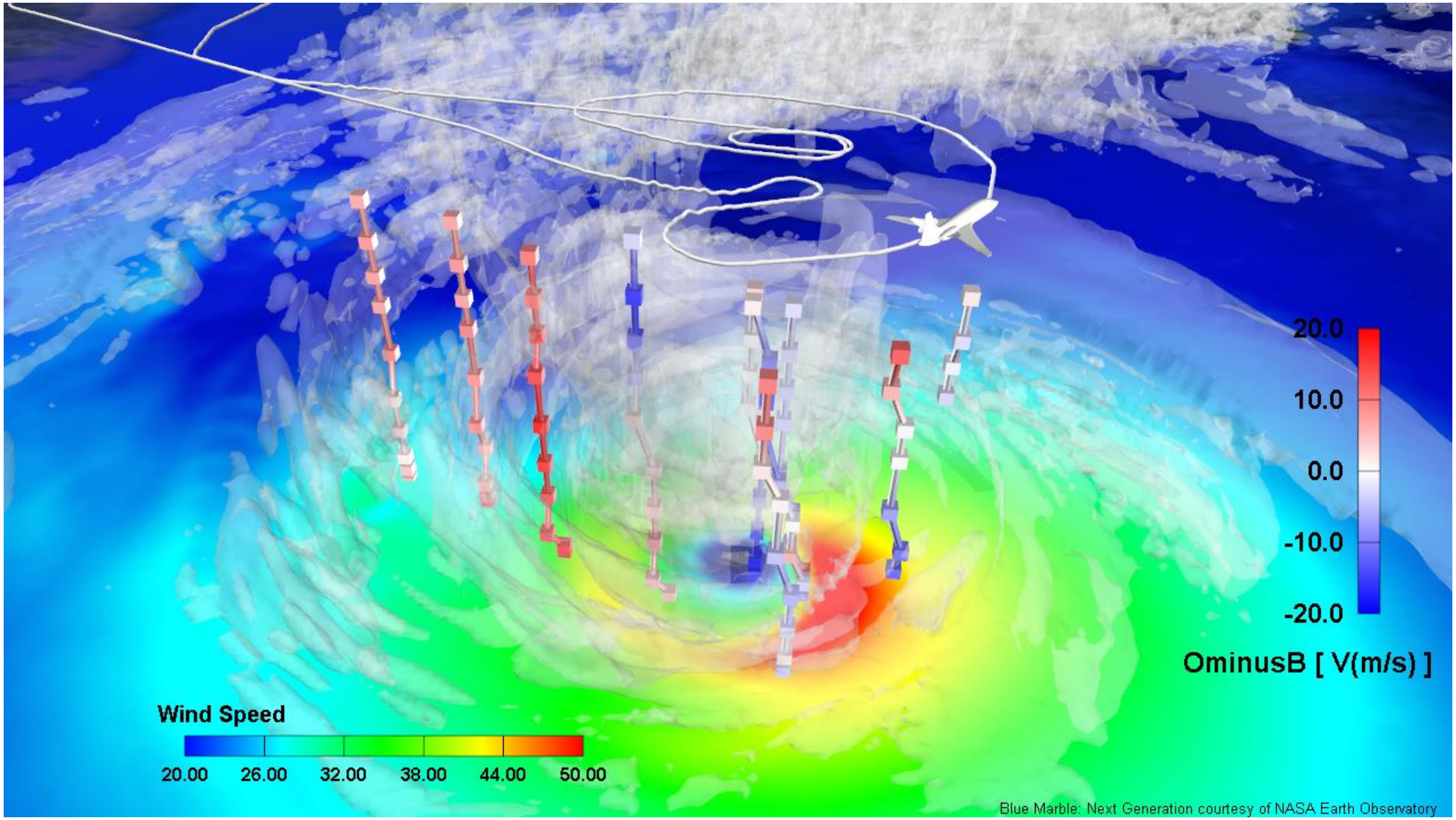
Time schedule

- Twelve DA cycles:
  - ➢1st cycle: 03-06UTC 21Oct (First dropsondes)
  - ➢12th cycle: 12-15UTC 22Oct (Just before landfall)
- At the end of each DA cycle, the forecast experiment was conducted (12 forecasts).
- NoTPARCII and TPARCII differ only for assimilation of dropsondes in the cycles 1, 2, and 8.



Innovation (obs – first_guess) of V

- $|V_{obs} - V_{first\_guess}| \sim 10\text{-}20$ m/s
- Large deviation detected in the west of TC center
  →Improvements expected

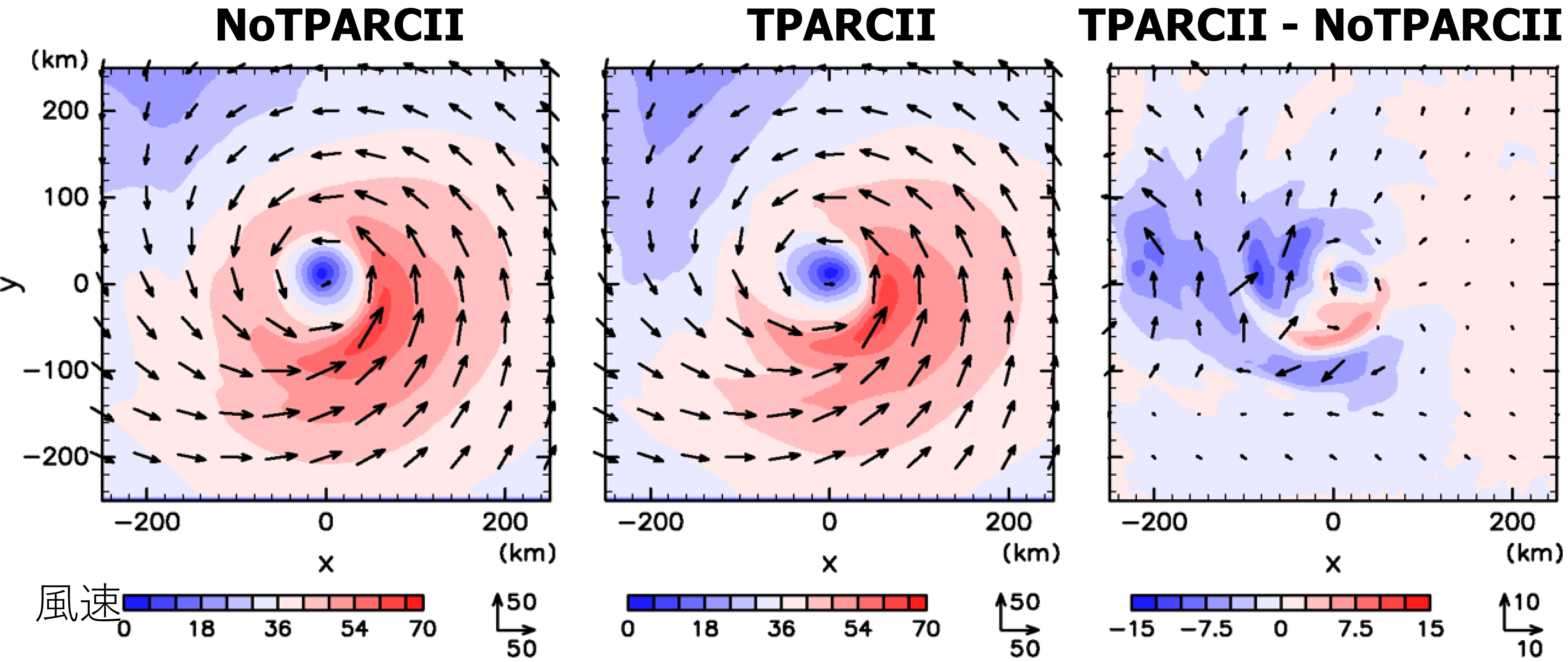


Blue Marble: Next Generation courtesy of NASA Earth Observatory

（Courtesy of Cybernet Inc. Co. Ltd.）

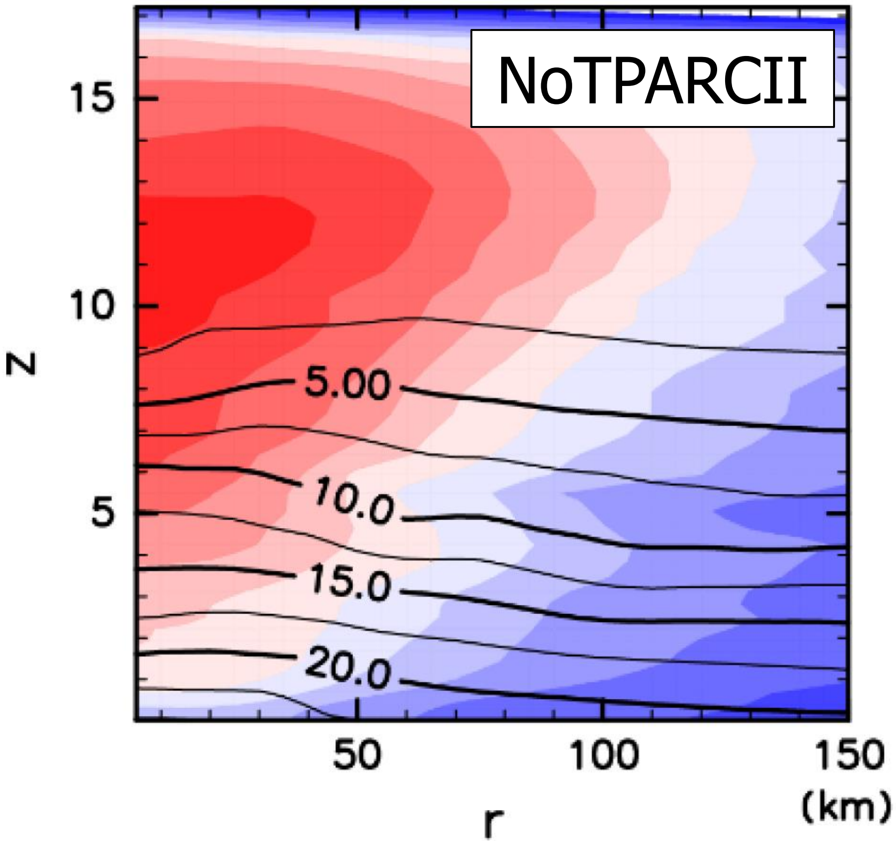
Wind at 850hPa in the analysis (Cycle 1)

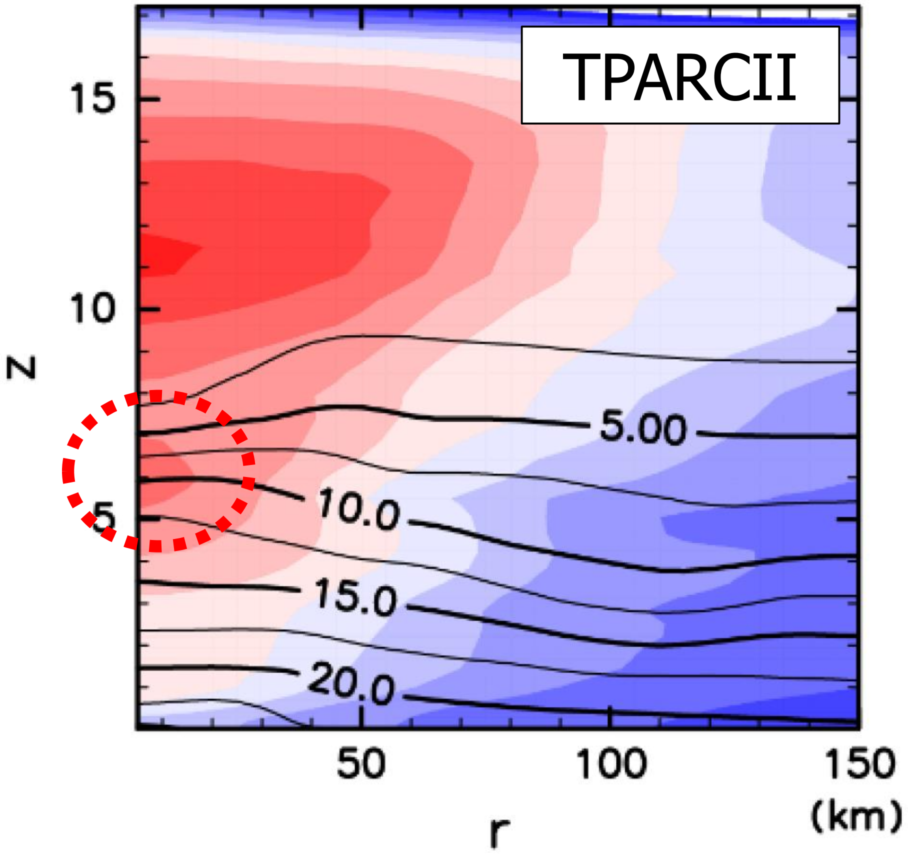
- Adding T-PARCII dropsondes yielded
  - Weaker southward wind
    →TC Lan moves faster to the north in TPARCII
  - The structure becomes more asymmetric with additional dropsondes.



Double warm cores

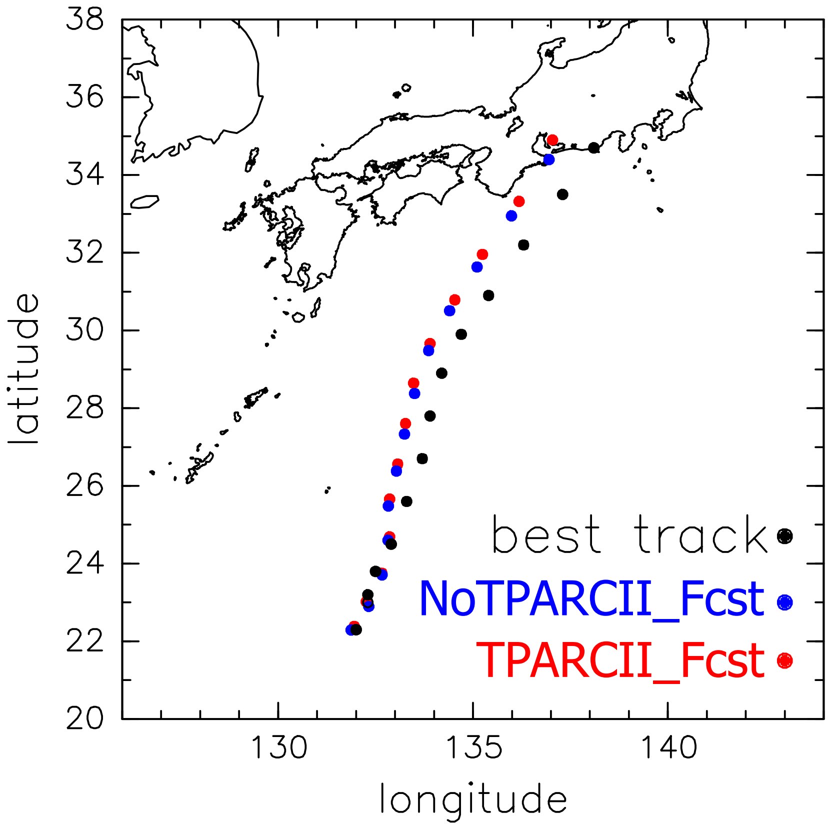
- The lower warm core was reproduced by assimilating dropsondes in the inner core region.

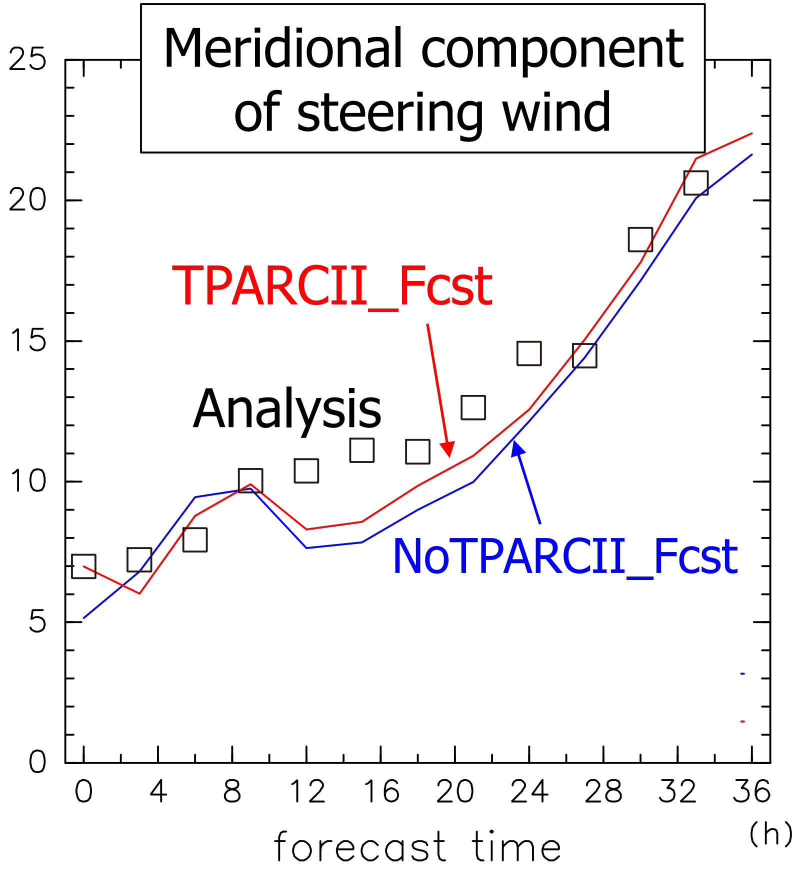




TC position change (Fcst from cycle 1)

- TPARCII
  - ➢ TC Lan displaces to the north by 60km
  - ➢ Northward wind stronger by ∼0.5m/s on average
- Consistent with the best track and DA result

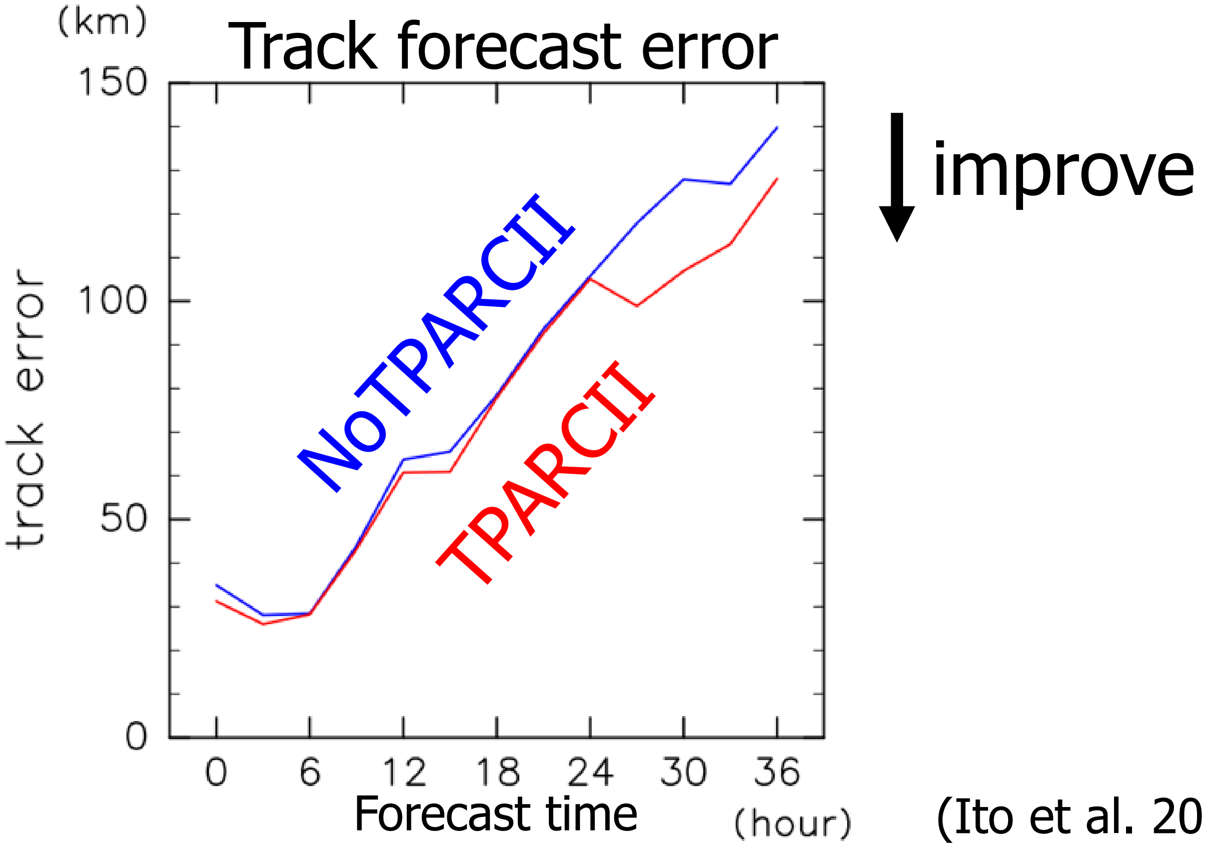



Meridional component of steering wind

(Ito et al., 2018, SOLA)

Track forecast (averaged over 12 cycles)

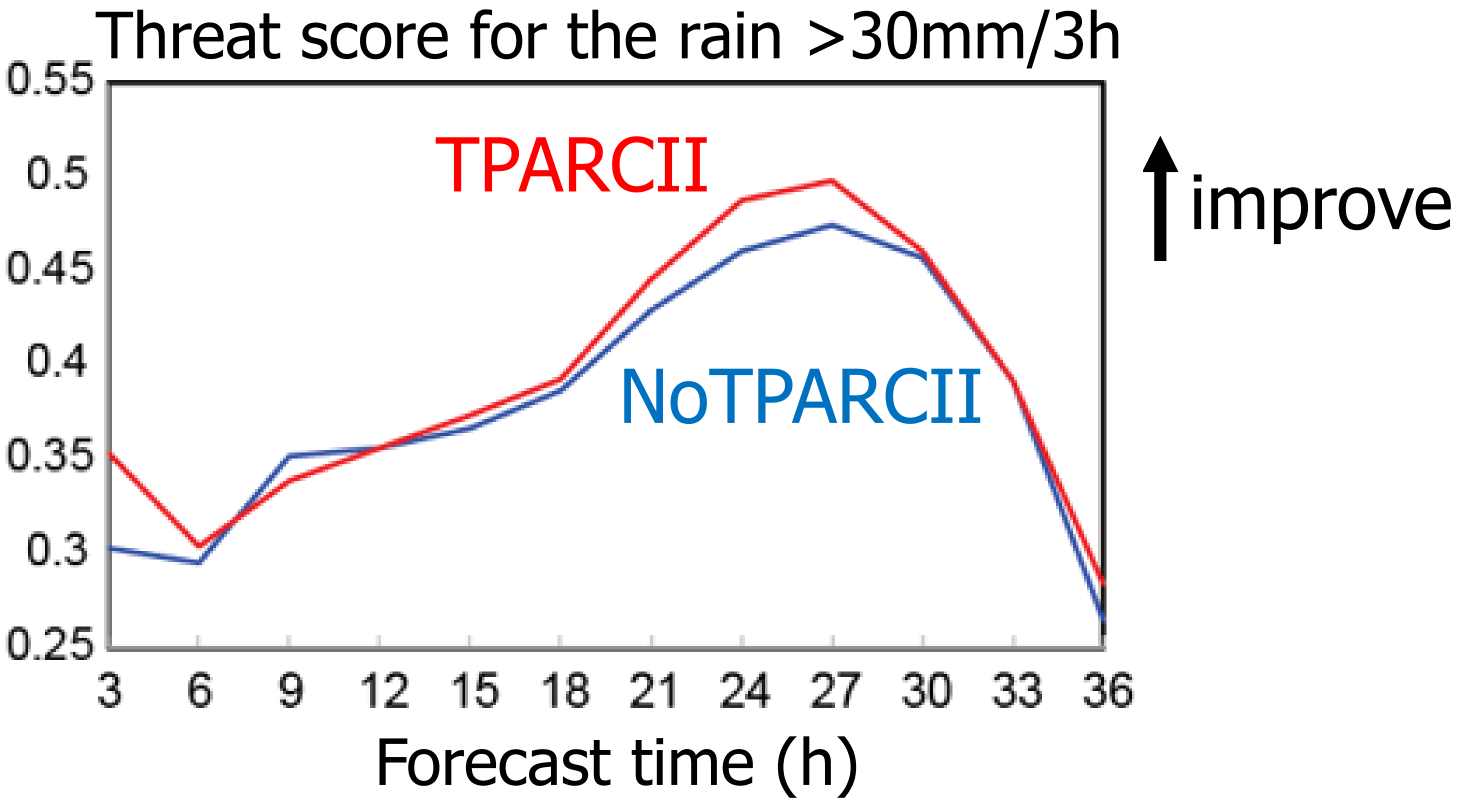
- Track forecast error decreases up to 16% in TPARCII.
- Very encouraging result!
  - The assimilation of the inner-core observations with a high-resolution mesoscale DA system may enhance the track forecast skill.



(Ito et al. 2018, SOLA)

Rainfall forecast (averaged over 12 cycles)

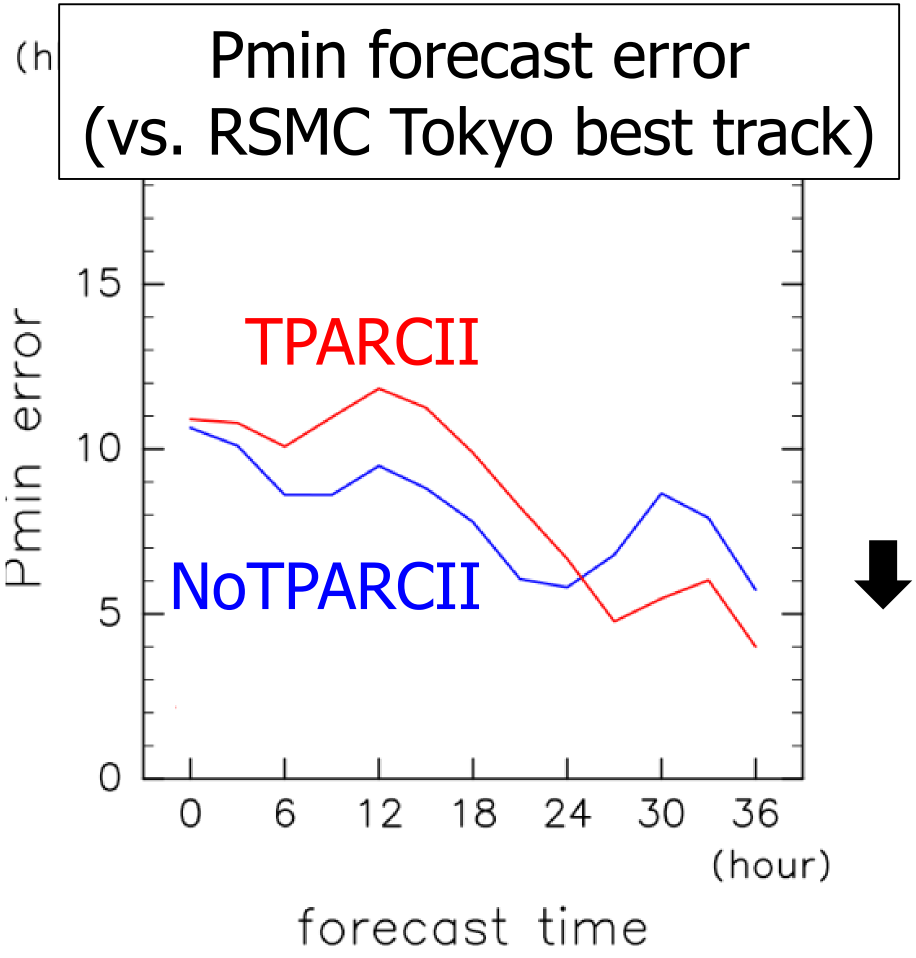
- Threat score = hit / (hit + false alarm + miss)
- Threat score becomes higher for the strong rainfall by adding T-PARCII observations.
- It is consistent with the improvement in track forecast


Threat score for the rain >30mm/3h

(Ito et al., 2018, SOLA)

Pmin forecast (averaged over 12 cycles)

- Pmin forecast “error”:
  Difference from the RSMC Tokyo best track
- Pmin forecast “error” is generally larger in TPARCII.



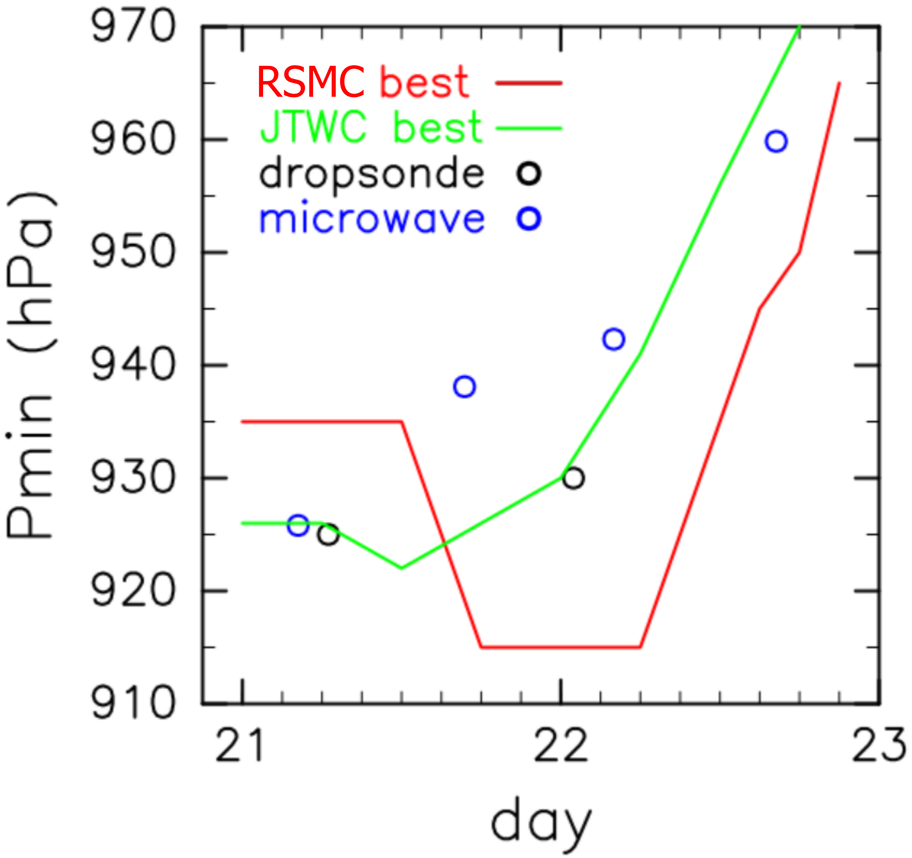
Pmin forecast error
(vs. RSMC Tokyo best track)

⬇**improve**

(Ito et al., 2018, SOLA)

Comparison of Pmin

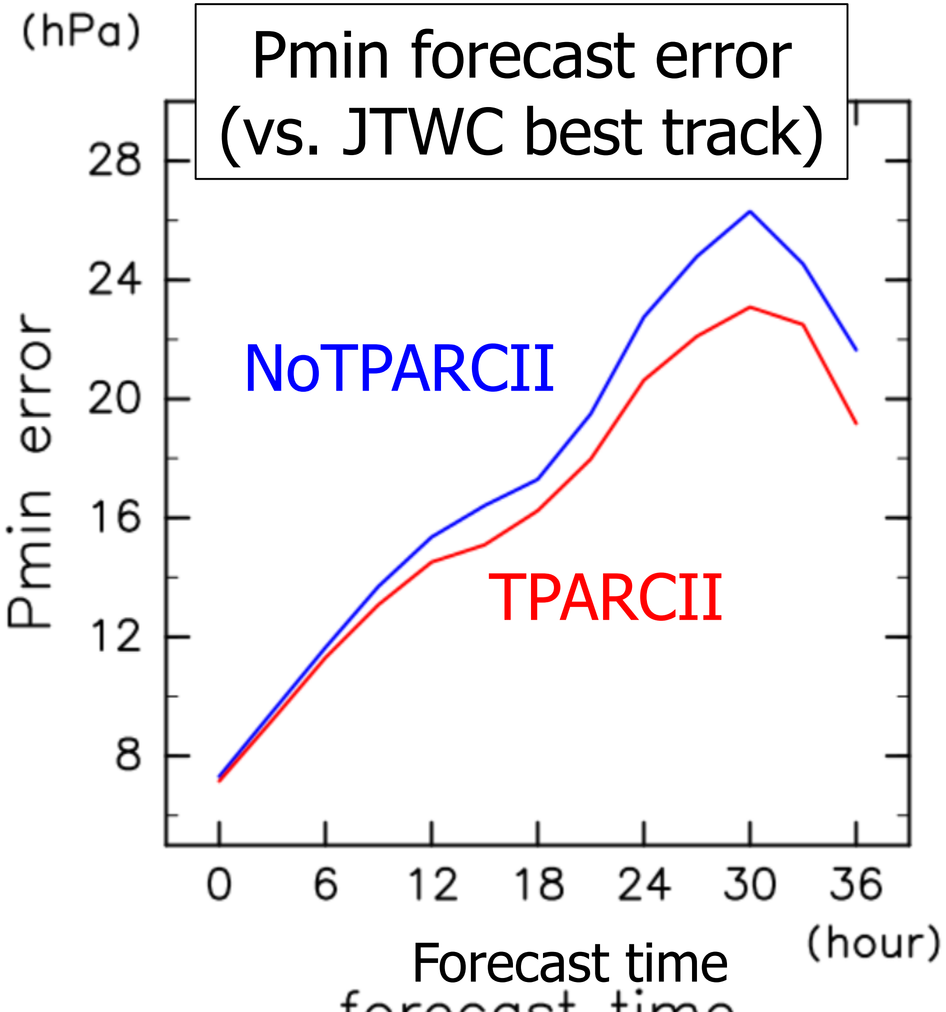
- Large discrepancies among the datasets
  - RSMC Tokyo*: Intensifying (935 hPa → 915 hPa)
    *published before T-PARCII level-2 data became available
  - The others: Neutral or weakening
- We can verify recently proposed methods such as microwave.



(Ito et al., 2018, SOLA)

If we employ JTWC Pmin as a reference…

- Pmin forecast “error” (re-defined):
  Difference from the JTWC best track
- Pmin forecast “error” decreases in TPARCII (!)



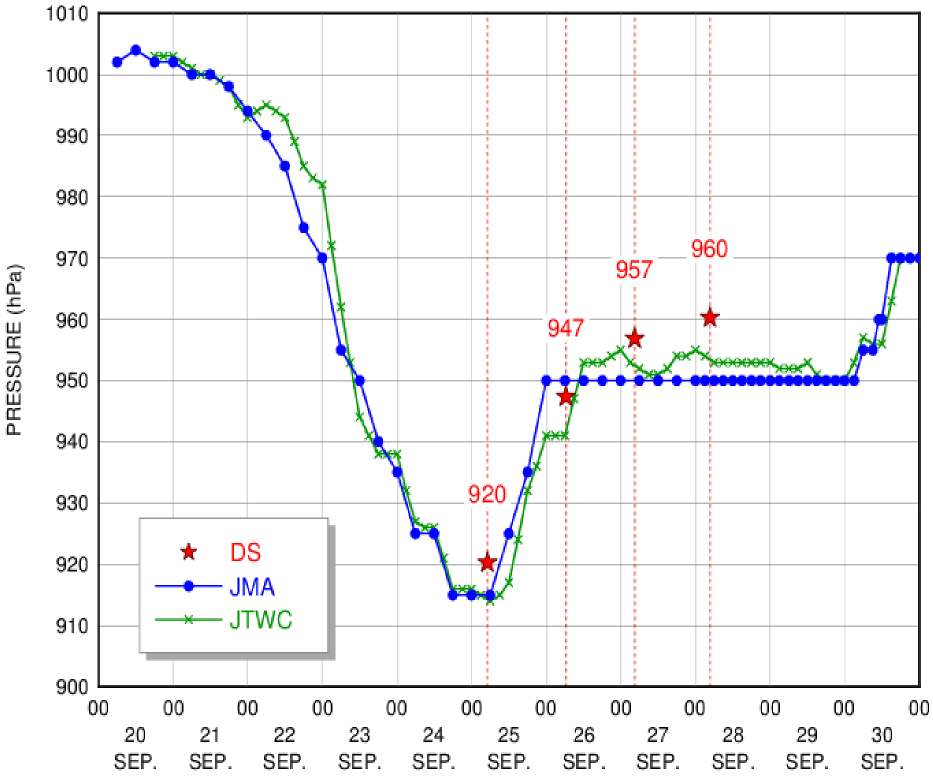
Pmin forecast error
(vs. JTWC best track)

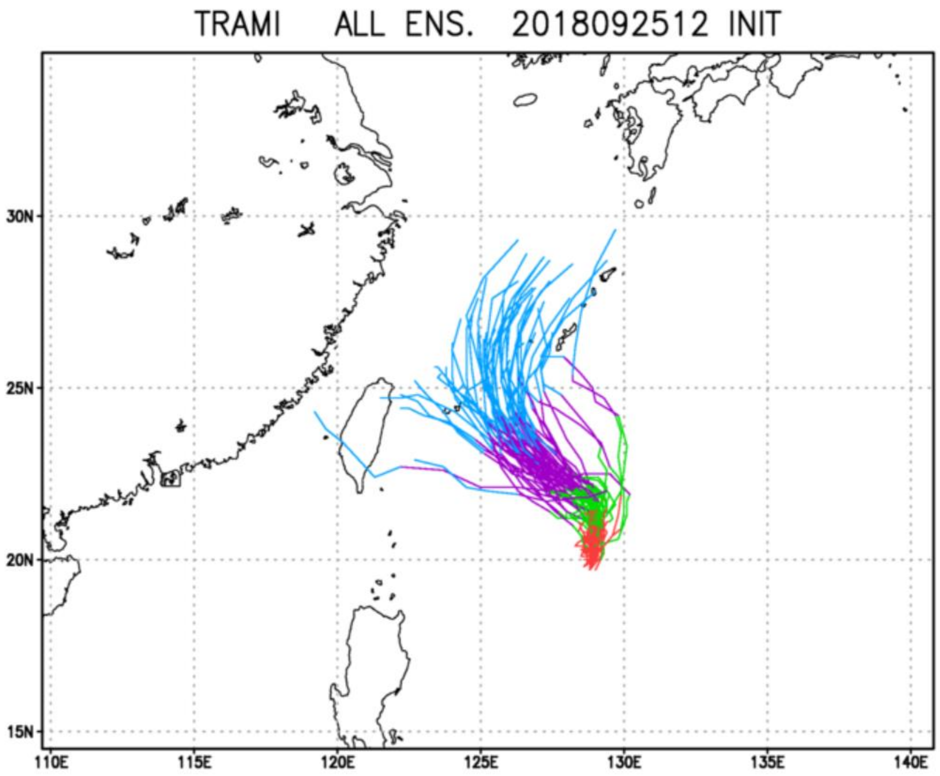
Forecast time

⬇**Improve**

TC Trami (2018)

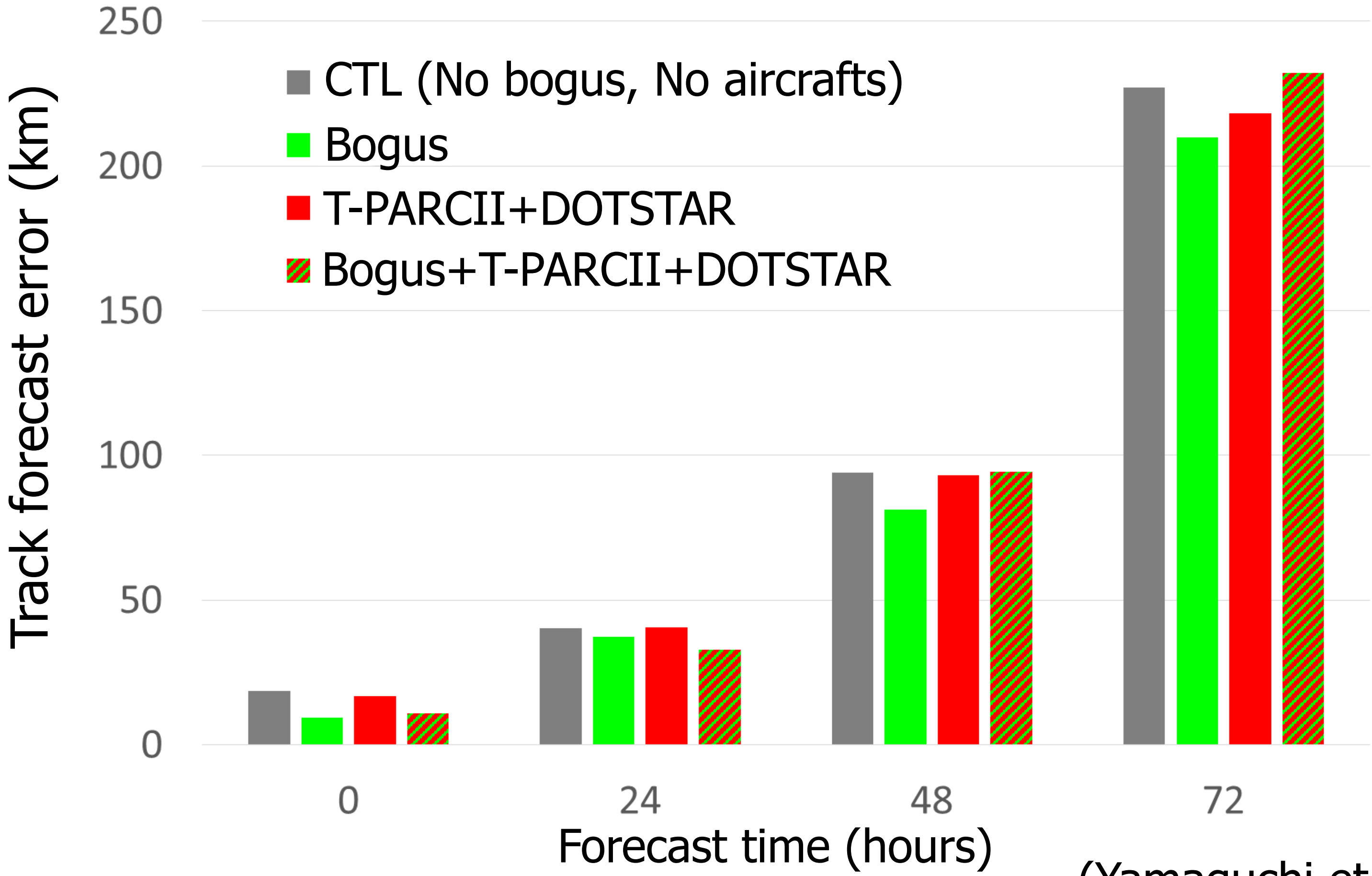
- Discrepancies of Pmin were less than 10 hPa.
- Large uncertainty in the track forecast





Forecast with a global DA system for Trami

- Assimilation of dropsondes and following forecasts were tested for Trami with a JMA-operational global DA system.
- Assimilation of T-PARCII and DOTSTAR data yielded the better results than CTL, and further investigation is needed.

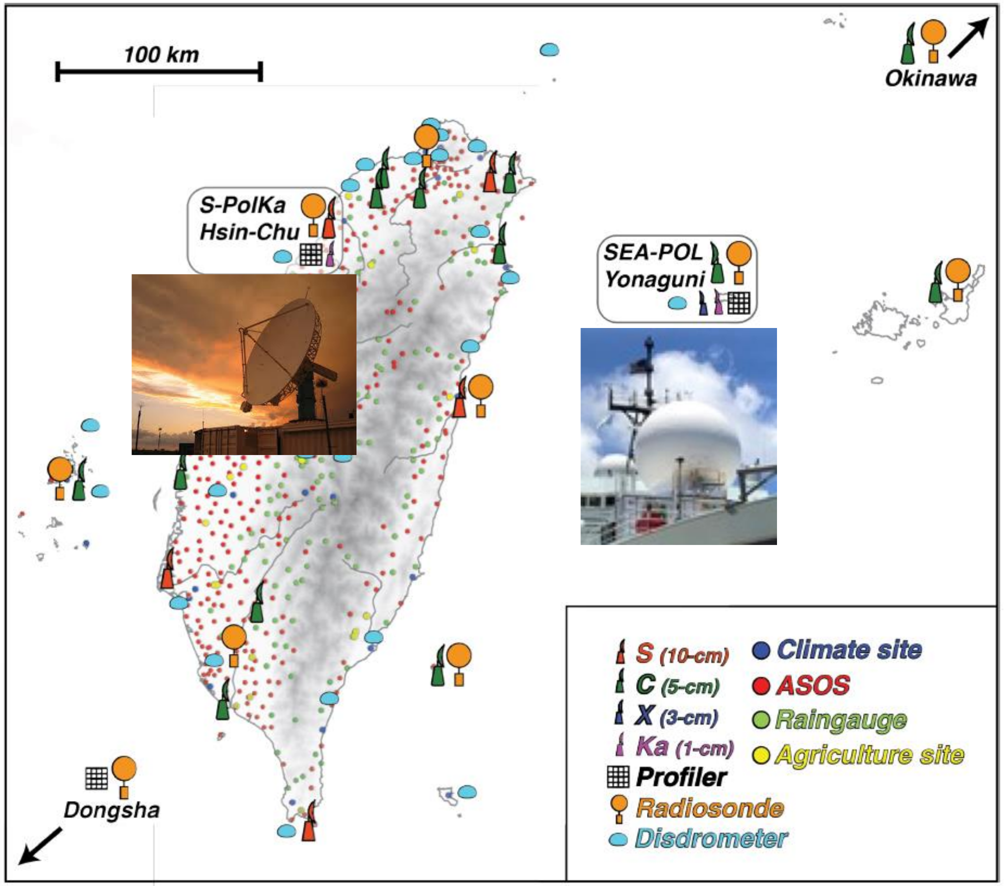


(Yamaguchi et al., in prep.)

TAHOPE – PRECIP - TPARCII

Taiwan USA Japan

- Joint international field campaign for baiu/meiyu and TCs in Taiwan and Okinawa during May-August 2020.
- NCAR S-Polka, CSU SEA-POL, aircrafts (US, Japan, Taiwan)



Concluding remarks

- The best track is not a ground truth.
  →TC intensity forecast skill cannot be evaluated beyond the level of their uncertainties.
- In the WNP, the number of ground truths is limited.
- T-PARCII: New strategy for deeply observing the inner core of a TC with a jet-engine aircraft
  → Important for the forecast skill evaluation, validating new intensity estimation techniques and investigating a deep structure.
- These data also contribute to the accurate track and rainfall forecast through a high-resolution DA system.
- We have not tested a developing TC.
- The dropsonde data with a rapid QC is transferred to GTS since 2018. The full T-PARCII data is available upon request one year after an aircraft mission.

Thank you