Atmospheric River Reconnaissance Workshop

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Aircraft dropsonde observation of atmospheric rivers associated with tropical cyclones in the western North Pacific

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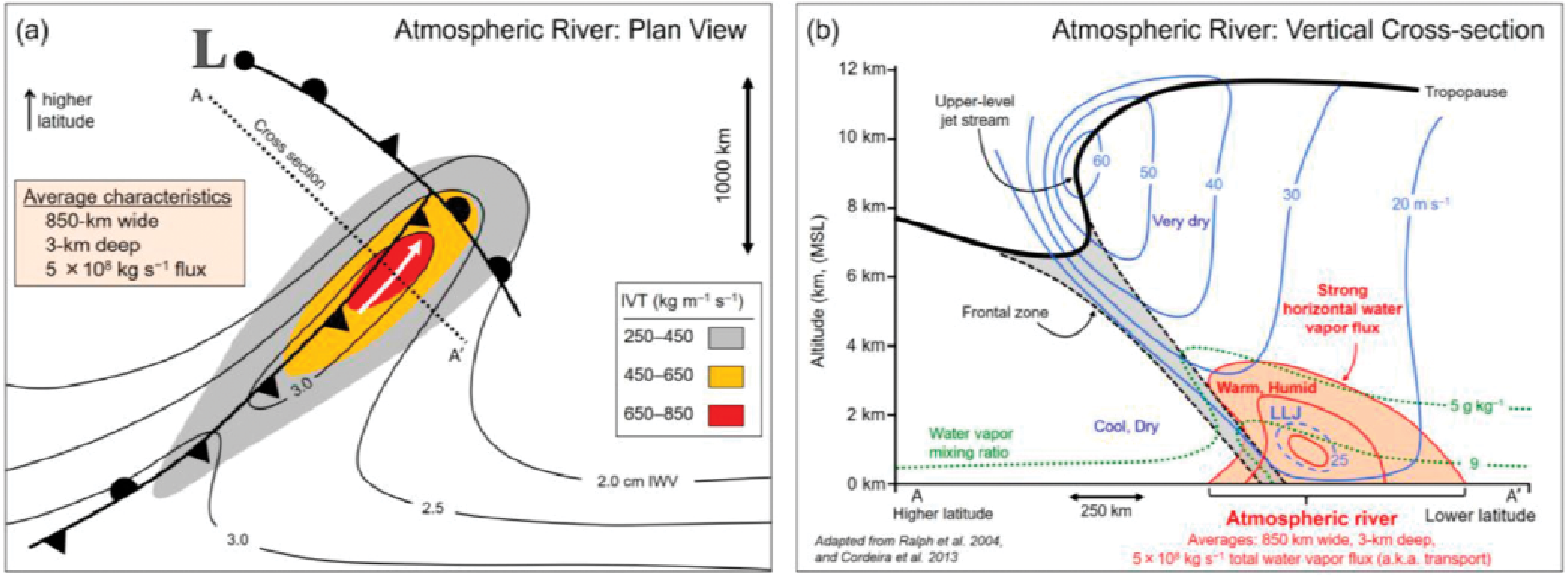
Flooding in Nagano on Oct. 13, 2019

Introduction

- In the western North Pacific, atmospheric rivers (ARs) occasionally form in association with tropical cyclones (typhoons) and cause a heavy rainfall in a distant region from the center of typhoons.
- ARs transport large amounts of water vapor and cause a heavy rainfall in landfall regions.
- ARs often cause quasi-stationary line-shaped mesoscale convective systems (QL-MCSs) and they bring heavy rainfalls in a local area. This results in severe disasters such as floods and landslides.
- Quantitatively accurate measurement of water vapor amount in ARs is difficult because most water vapor are present in the lower atmosphere over the sea. Moreover, ARs are very narrow and highly variable with time.
- An aircraft observation is promising to make accurate measurements of water vapor of ARs.
- Since 2017, T-PARCII (Tropical cyclone-Pacific Asian Research Campaign for Improvement of Intensity estimations/forecasts) project has been performing in situ aircraft observations of typhoons and ARs using a dropsonde system.
- The T-PARCII team performed dropsonde observations of an AR on 5 July 2022 using the Gulfstream IV (G-IV) jet.
- In this presentation, aircraft dropsonde observations of ARs will be introduced.

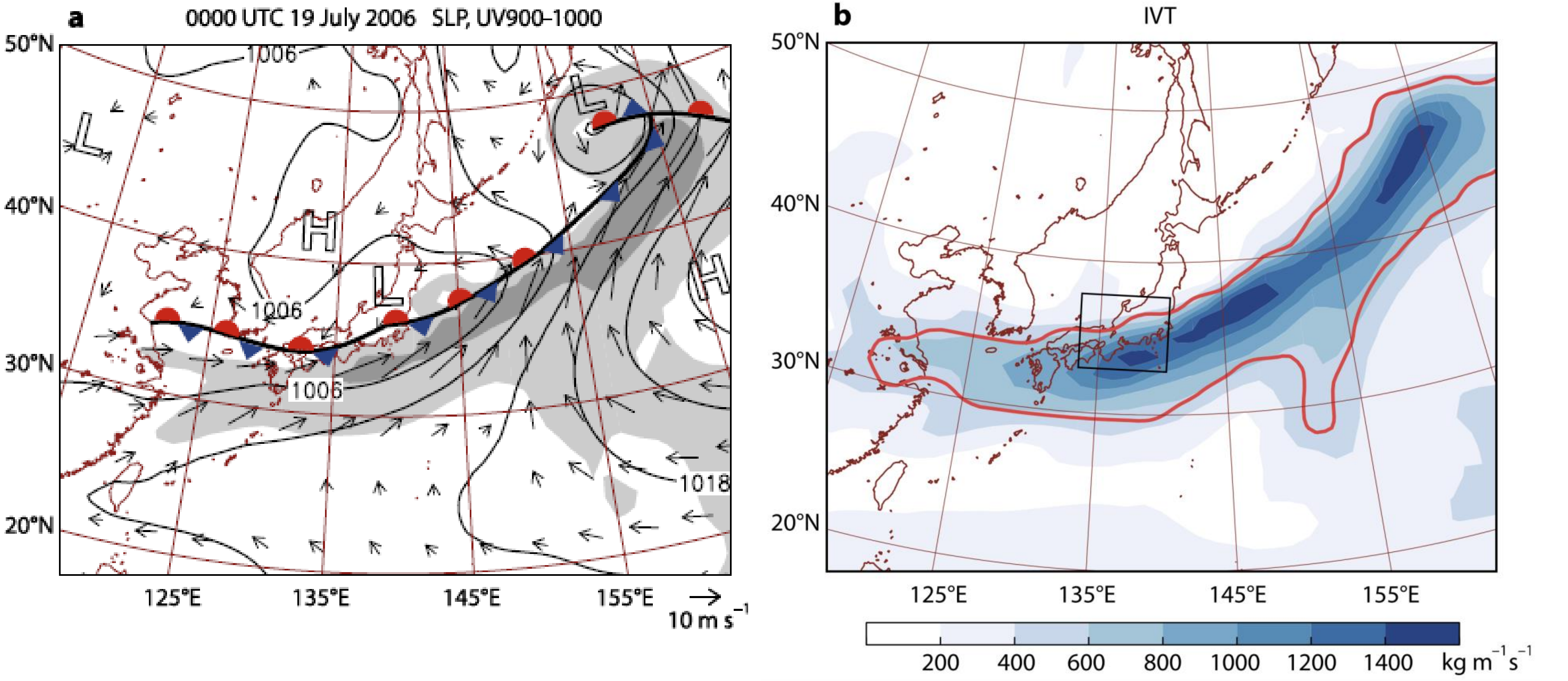
Schematic image of AR in the eastern North Pacific



Schematic summary of the structure and strength of an atmospheric river based on dropsonde measurements deployed from research aircraft across many atmospheric rivers and on corresponding reanalyses that provide the plan-view context. Magnitudes of variables represent an average midlatitude atmospheric river. Average width is based on atmospheric river boundaries defined by vertically integrated water vapor transport (IVT; from surface to 300 hPa) lateral boundary threshold of 250 kg m^{-1} s^{-1}. Depth corresponds to the altitude below which 75% of IVT occurs. The total water vapor transport (a.k.a. flux) corresponds to the transport along an atmospheric river, bounded laterally by the positions of IVT = 250 kg m^{-1} s^{-1} and vertically by the surface and 300 hPa. (a) Plan view including parent low pressure system and associated cold, warm, and warm-occluded surface fronts. IVT is shown by color fill (magnitude; kg m^{-1} s^{-1}) and direction in the core (white arrow). Vertically integrated water vapor (IWV; cm) is contoured. A representative length scale is shown. The position of the cross section shown in (b) is denoted by the dashed line A–A′. (b) Vertical cross-section perspective, including the core of the water vapor transport in the atmospheric river (orange contours and color fill) and the pre-cold-frontal low-level jet (LLJ), in the context of the jet–front system and tropopause. Water vapor mixing ratio (green dotted lines; g kg^{-1}) and cross-section-normal isotachs (blue contours; m s^{-1}) are shown. [Figure reproduced from Ralph et al. (2017b). Schematic prepared by F. M. Ralph, J. M. Cordeira, and P. J. Neiman and adapted from Ralph et al. (2004), Cordeira et al. (2013), and others.]

Ralph et al. (2018, *BAMS*)

AR in the western North Pacific (around Japan)

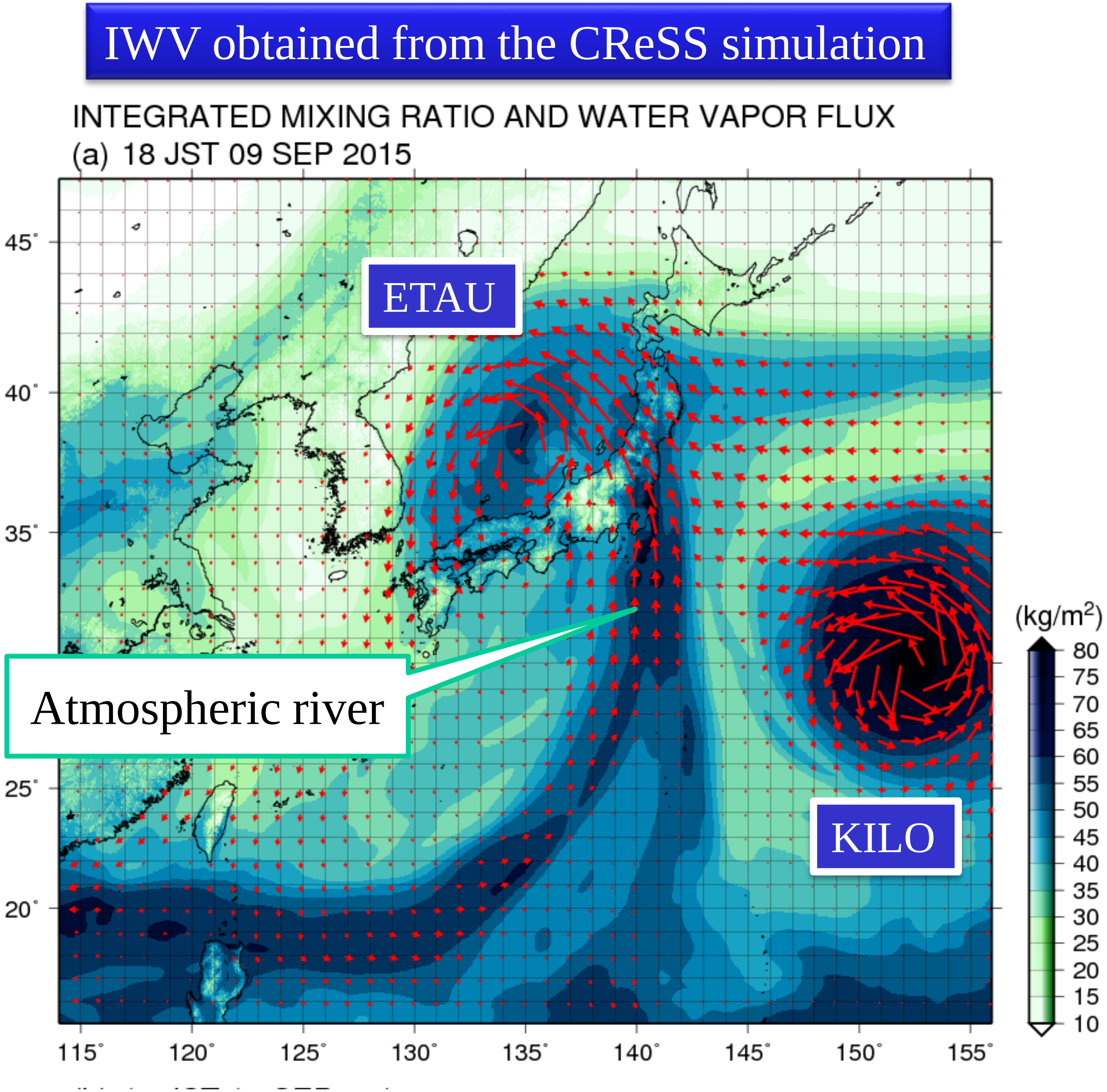


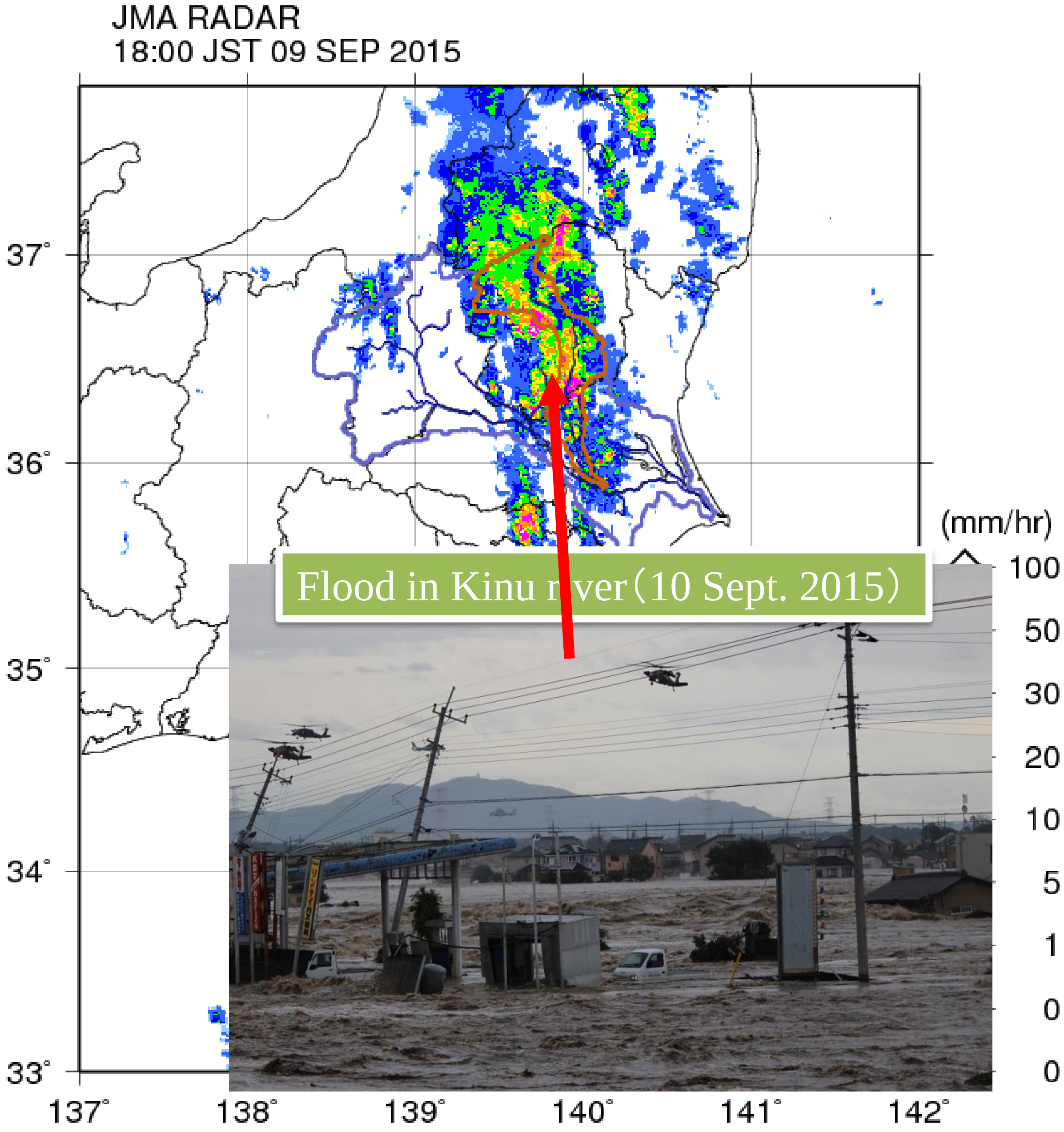
Kamae et al. (2017, *JC*)

FIG. 1. An example of an AR in the western North Pacific detected by IVT in JRA-55. (a) Surface weather chart at 0000 UTC 19 Jul 2006. Contours represent sea level pressure (hPa). Vectors indicate horizontal wind (m s^{-1}) averaged between 900- and 1000-hPa levels. Light and dark shading indicate regions where absolute wind speeds exceed 10 and 20 m s^{-1}, respectively. (b) IVT (kg m^{-1} s^{-1}) and outline of a detected AR (red line; 140 kg m^{-1} s^{-1} ?). Following texts are omitted.

- **The AR exists along the southern Baiu front and northern Pacific High.**
- **High IVT (also high IWV) ⇒ Cause of heavy precipitation events.**

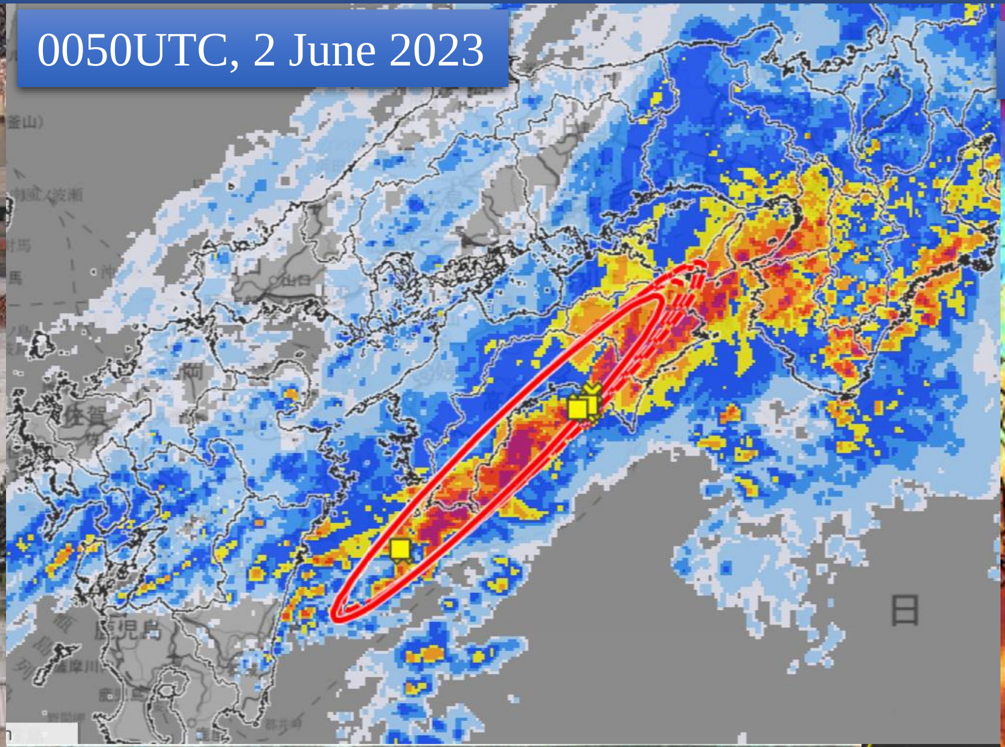
An atmospheric river associated with typhoons on 10 September 2015

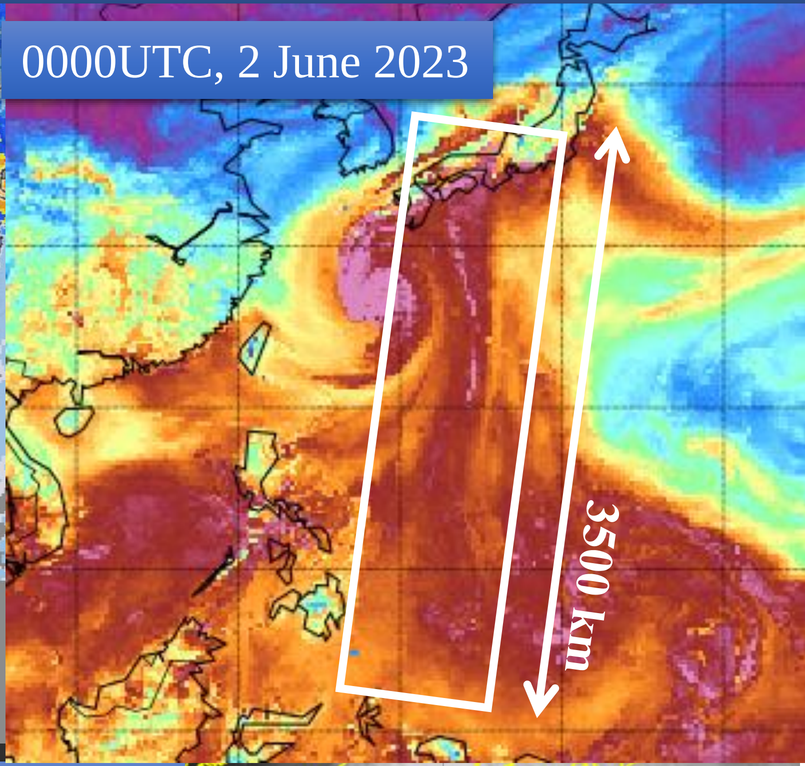


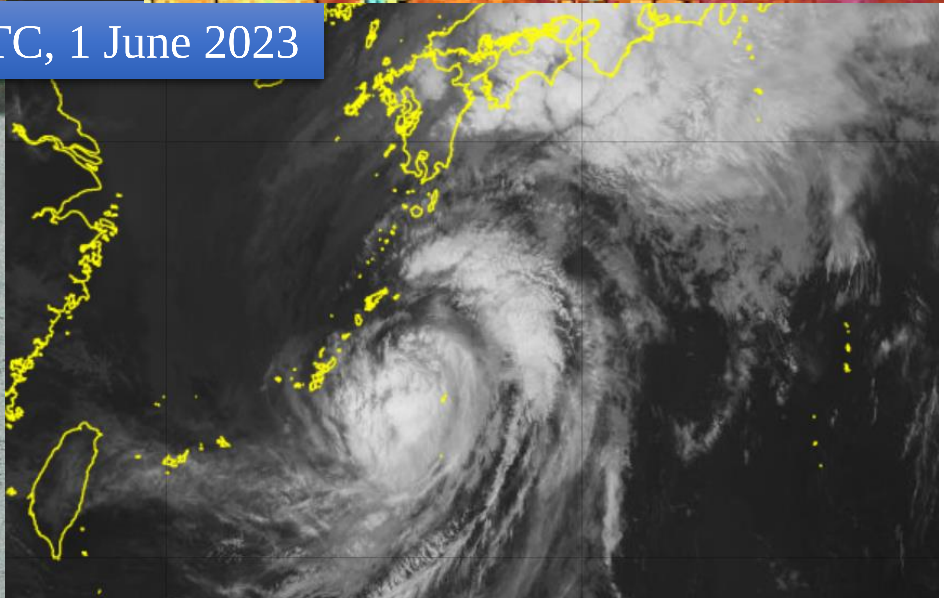


Heavy rainfall event caused by AR associated with tropical cyclone (Typhoon Warmer) on 2 June 2023


Chunichi newspaper

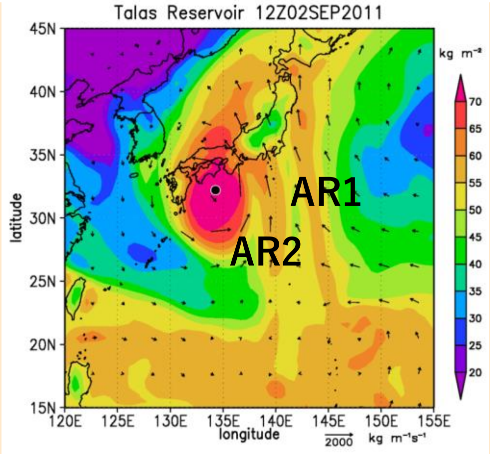


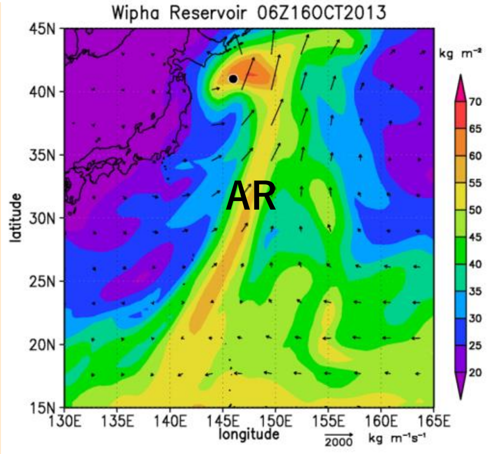


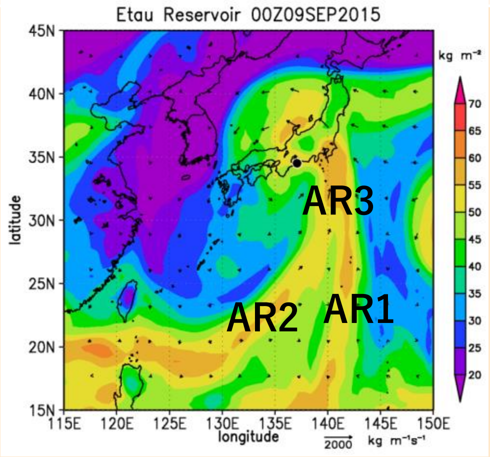


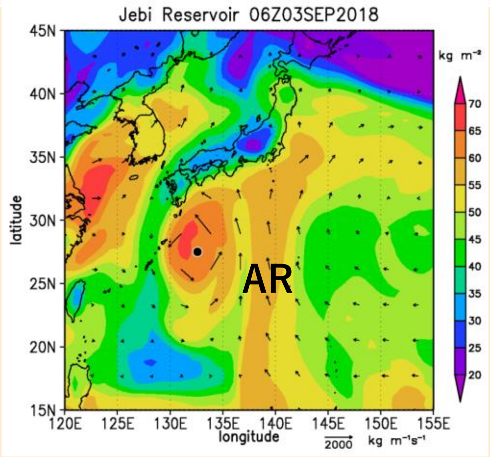
Atmospheric river events associated with typhoons

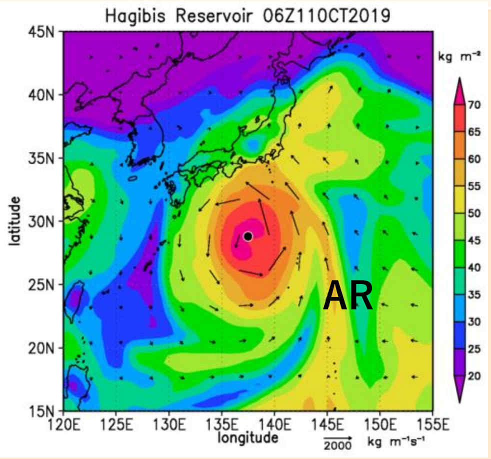
Talas (2011)	Wipha (2013)	Etau (2015)	Jebi (2018)	Hagibis (2019)
3 ARs	1 AR	3 ARs	1 AR	1 AR
12UTC, 2 Sept.	06UTC, 16 Oct.	00UTC, 9 Sept.	06UTC, 3 Sept.	06UTC, 11 Oct.







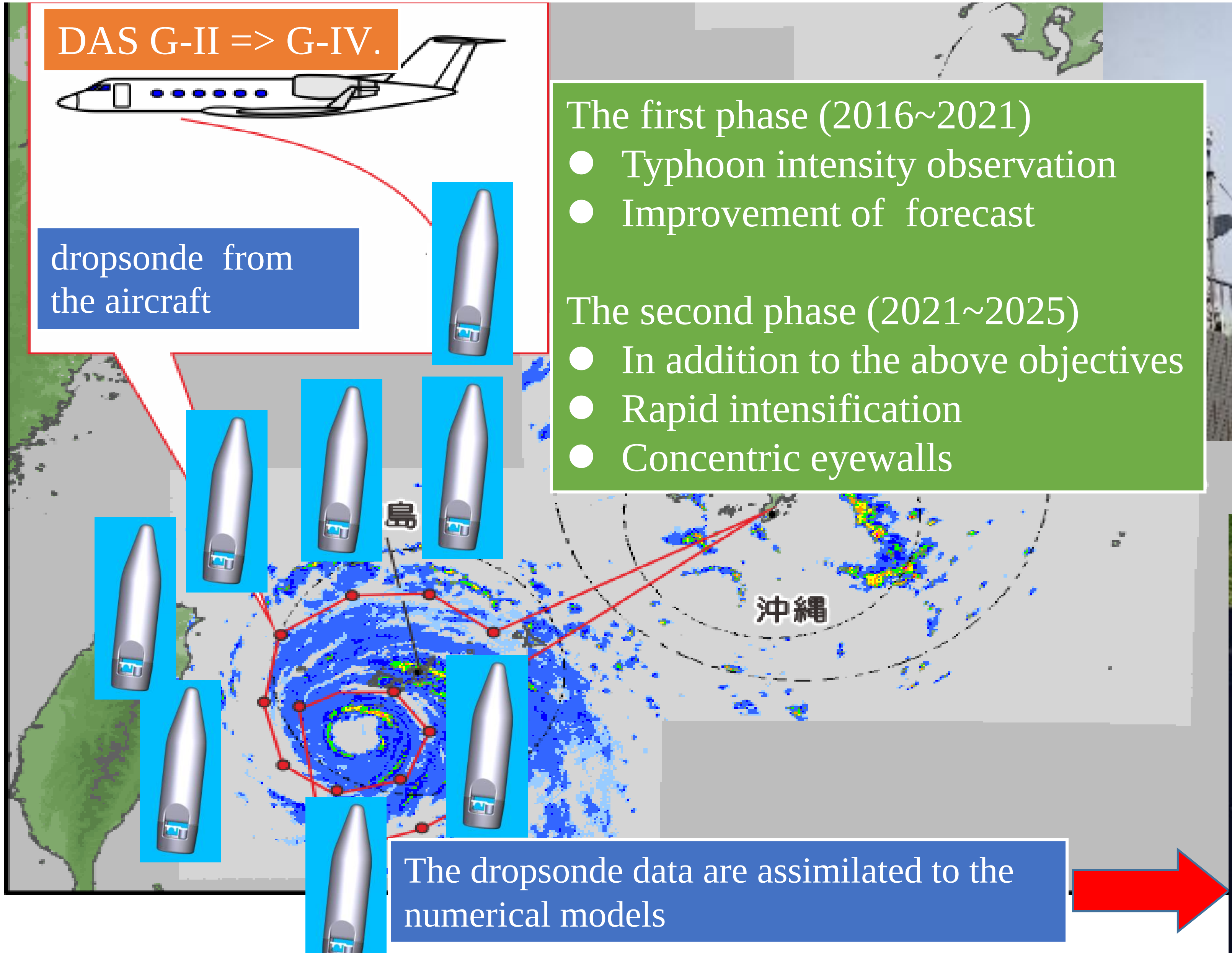




	Talas AR1	Talas AR2	Talas AR3	Wipha AR	Etau AR1	Etau AR2	Etau AR3	Jebi AR	Hagibis AR
Len (km)	1600	1100	2300	2300	1000	1300	(800)	1400	1000
W (km)	400	200	100	100	100	300	(200)	700	100
Dist. (km)	1200	800	1000	1000	1200	1200	(400)	1000	1000
Life time (hr)	32	12	12	36	30	36	(18)	60	30

【L】Max:2300 km, Min:800 km【W】Max:700 km, Min:100 km【Life time】Max:60 h, Min:12 h

T-PARCII (Tropical cyclone-Pacific Asian Research Campaign for Improvement of Intensity estimations/forecasts) is aiming to improve estimations and forecasts



The first phase (2016~2021)

- Typhoon intensity observation
- Improvement of forecast

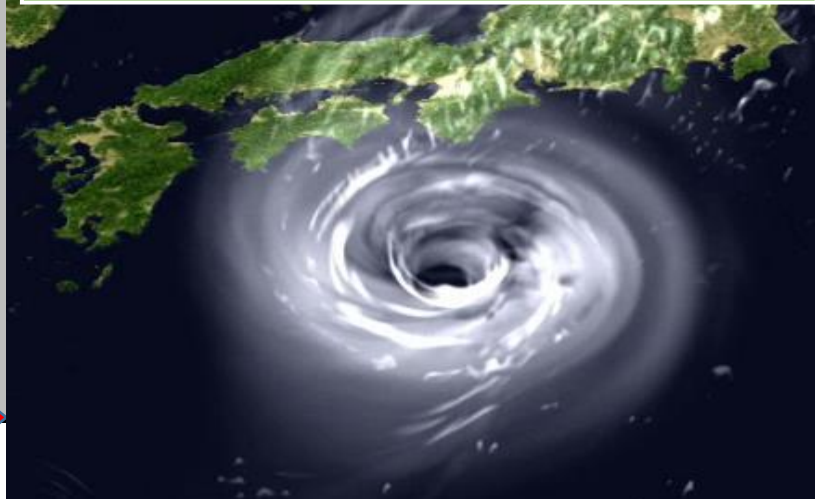
The second phase (2021~2025)

- In addition to the above objectives
- Rapid intensification
- Concentric eyewalls

X band radar

Ka radar

Typhoon prediction using numerical model



The dropsonde data are assimilated to the numerical models

Aircraft and dropsonde system for typhoon observation

Observation Jet (Gulfstream IV)
Capable of high-altitude observation and long-distance flight

Dropsonde shooter in the aircraft cabin

New dropsonde: biodegradable material used

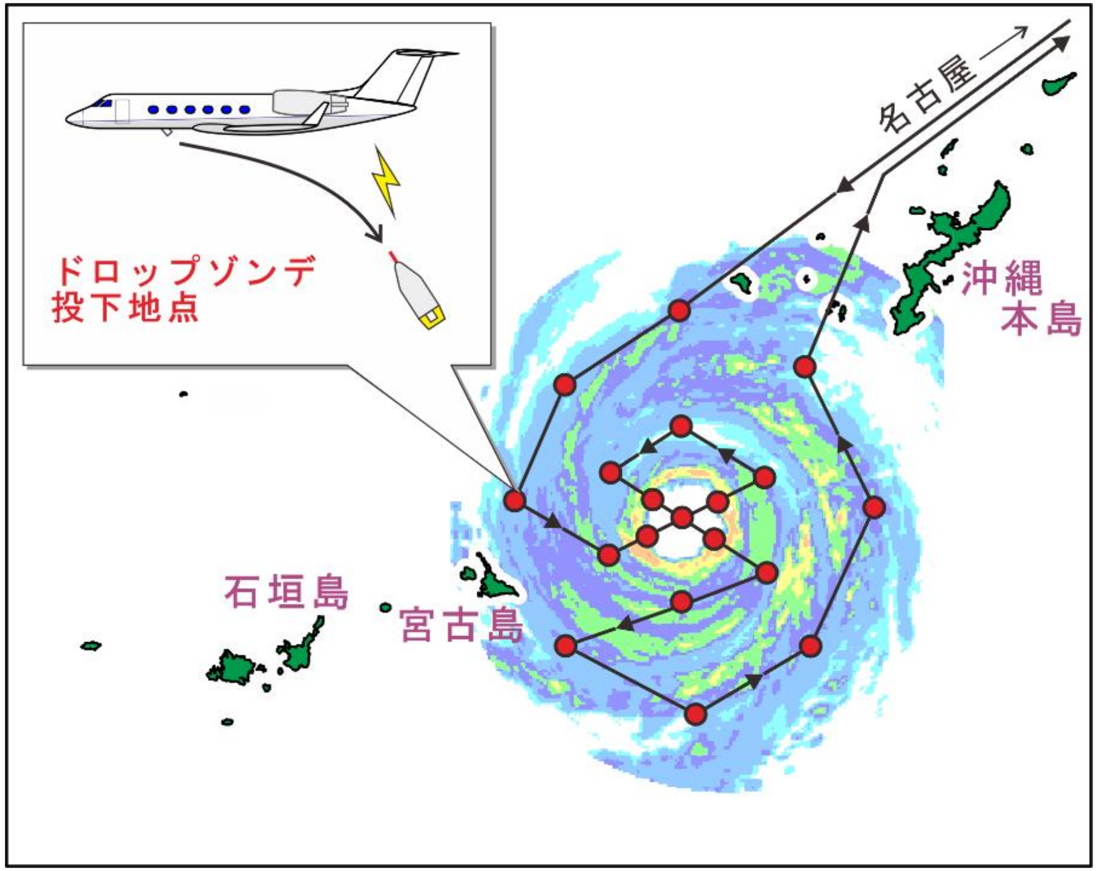
Dropsonde signal receivers installed inside the cabin

Dropsonde shooter outside of aircraft

Dropsonde launching taken at an altitude of 20,000 feet

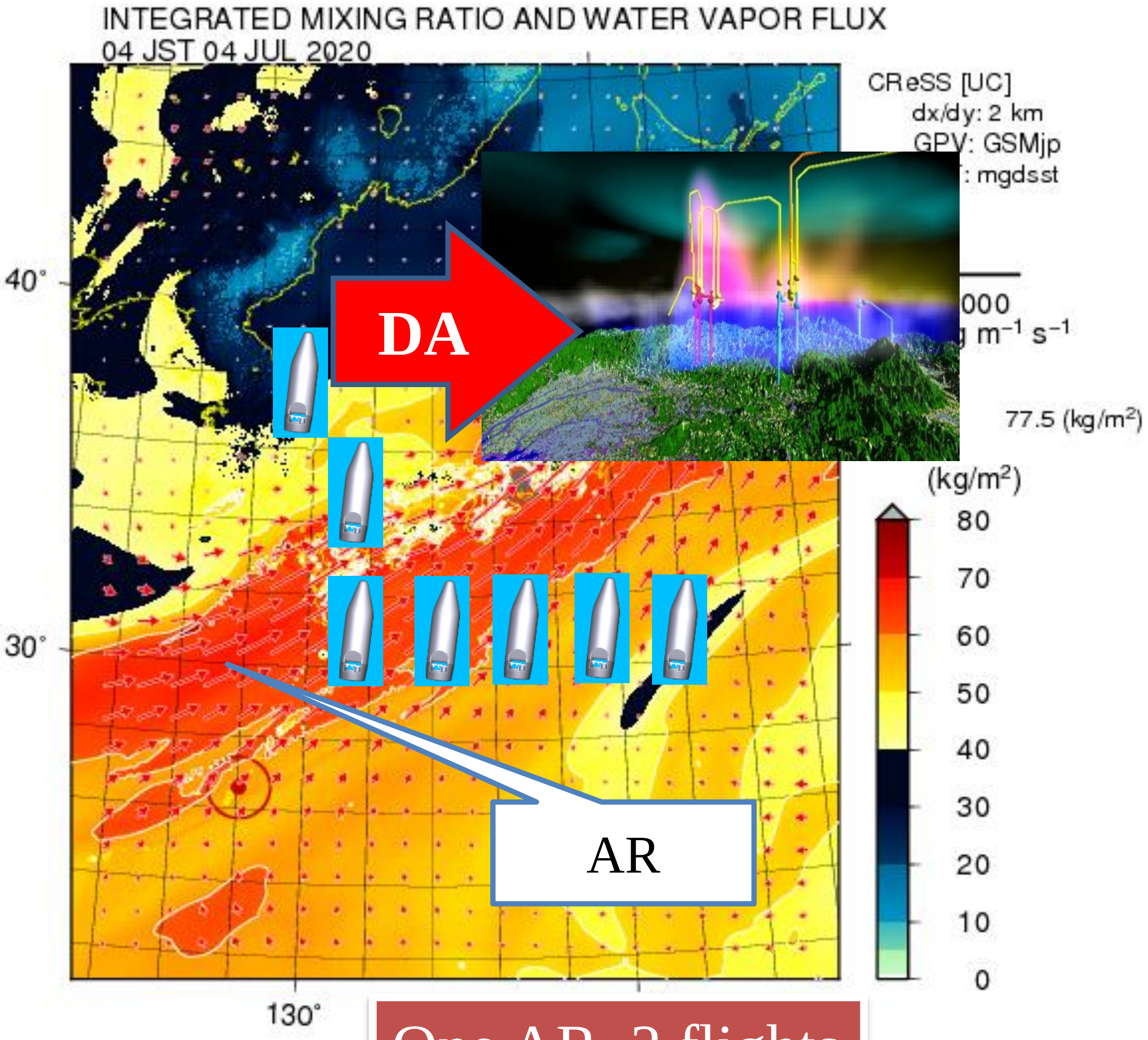
T-PARCII　Aircraft observations in 2022

Tropical cyclone (TC) mission



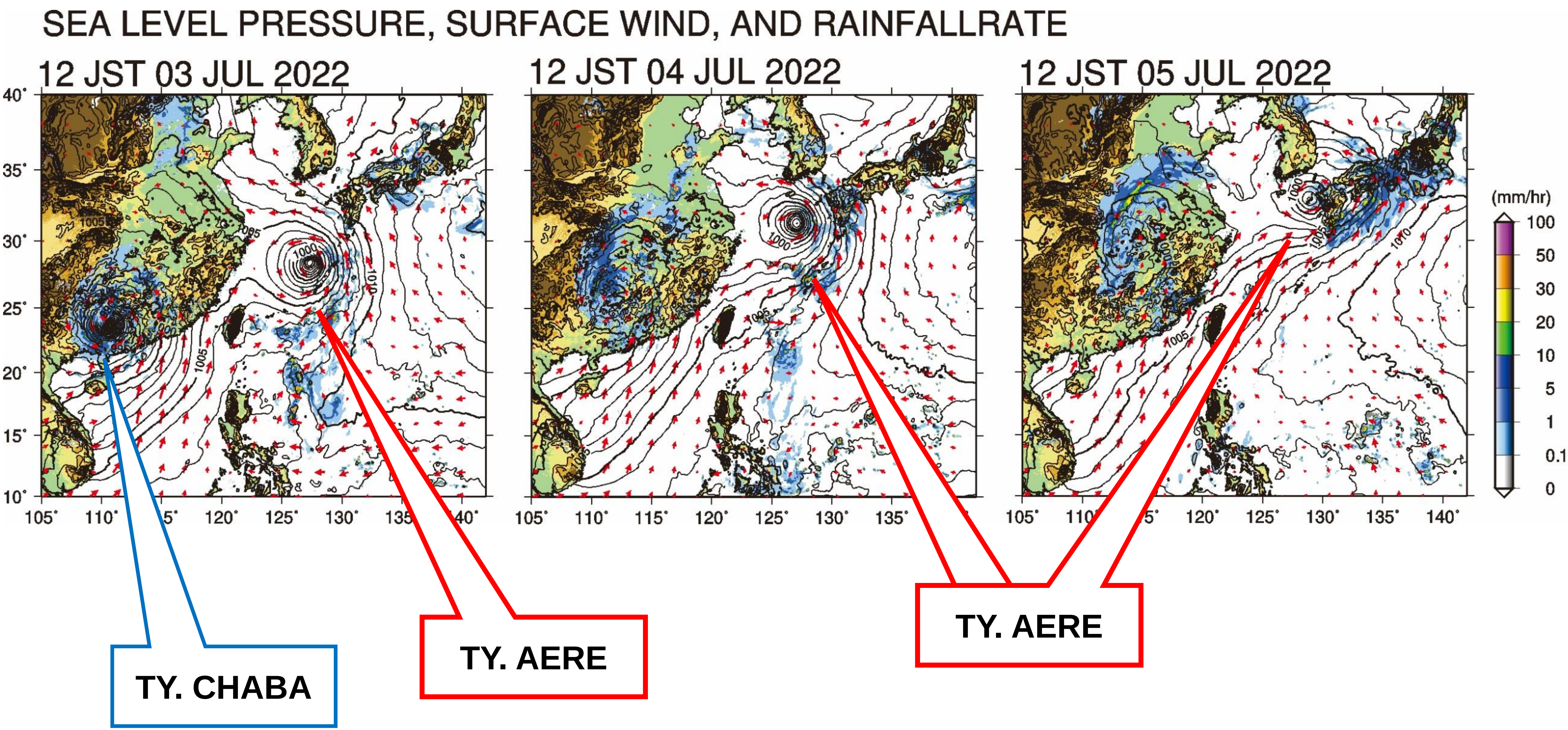
One typhoon, 2 flights

Atmospheric River (AR) mission



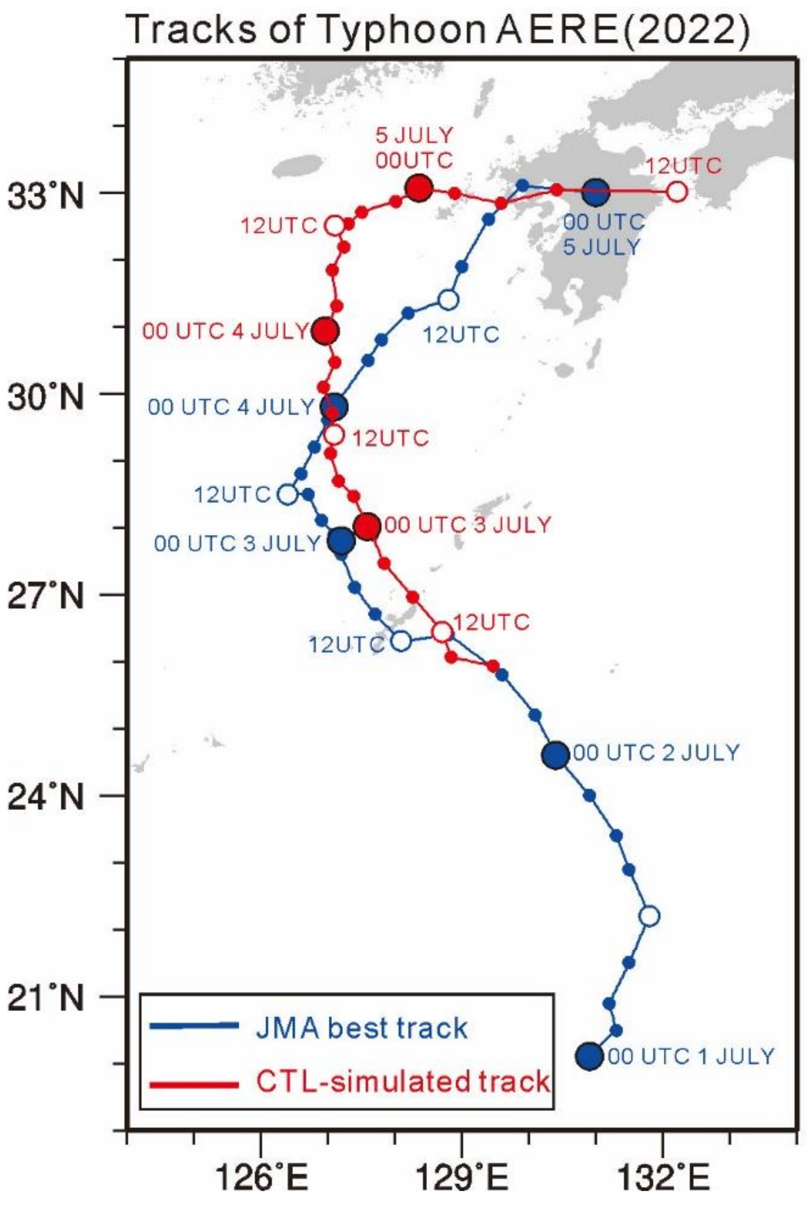
One AR, 2 flights

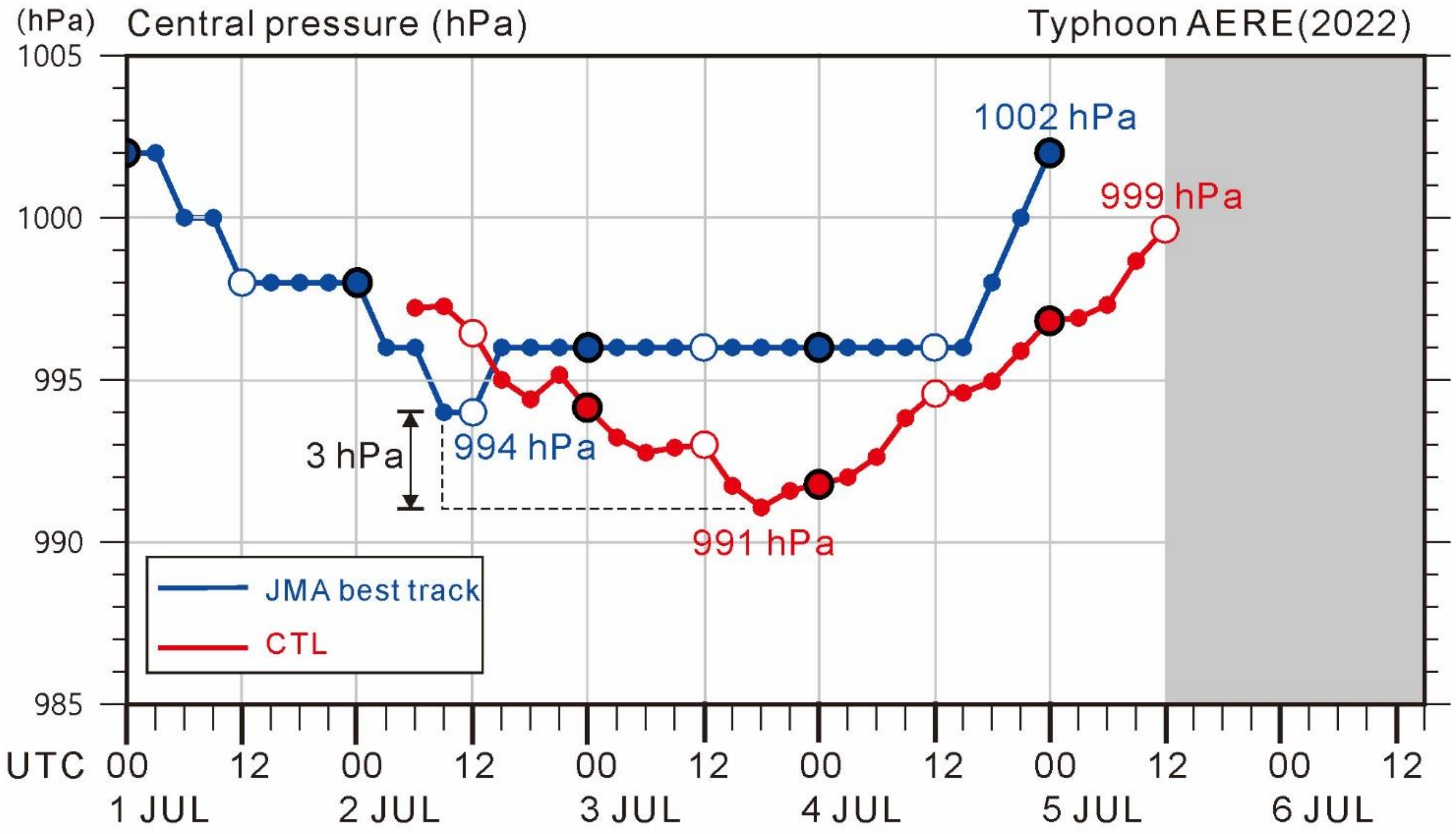
Sea level pressure, surface wind, and rainfall intensity



CReSS Simulation: Track and intensity of Typhoon AERE (2022)

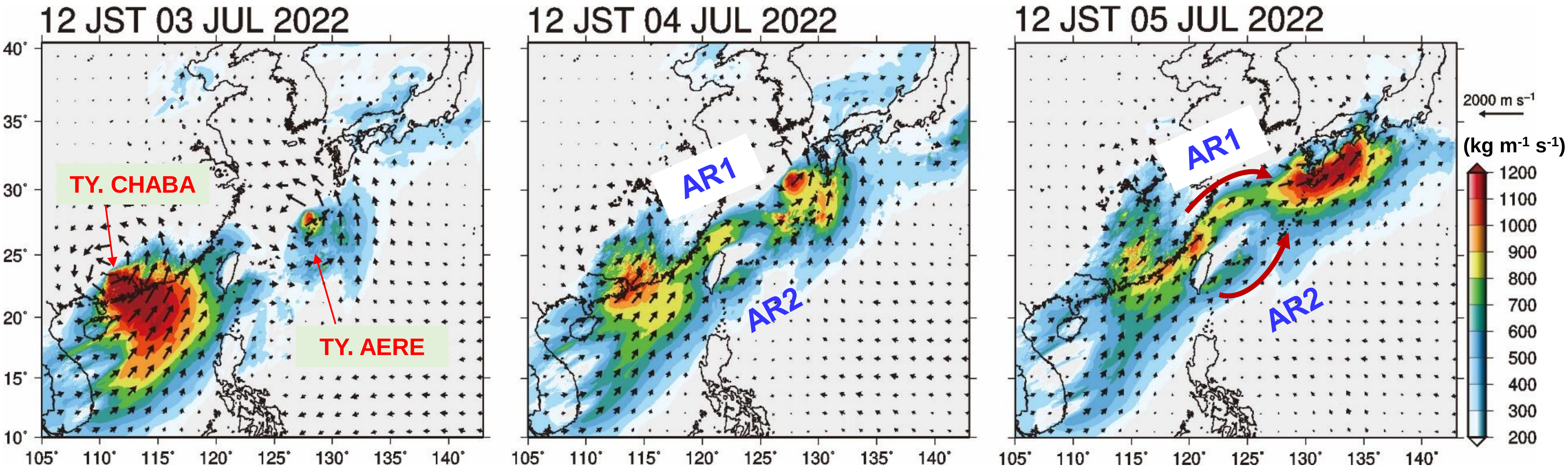
JMA VS. CTL





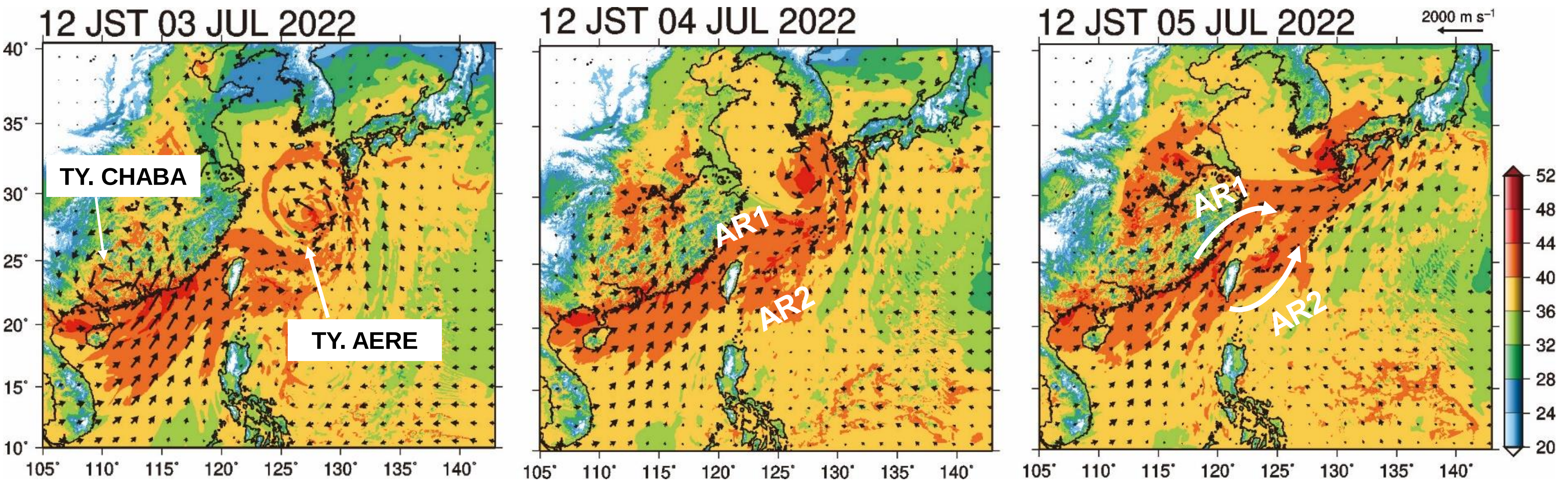
- Central pressure (lowest SLP: 991 hPa) in numerical simulation using the CReSS model agreed with the JMA best track data (lowest SLP: 994 hPa)
- The CTL shows the fairly accurate track and intensity evolutions.

IVT (integrated water vapor transport; shaded) and IVT Vector



- AR1: the water vapor transport passing to the west of Taiwan was an influence of Typhoon CHABA
- AR2: another water vapor transport is present to the east of Taiwan
- Both ARs eventually reached the western Japan to the east of Typhoon AERE (2022)

IWV (integrated water vapor; shaded) and IVT Vector



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- AR2: another water vapor transport is present to the east of Taiwan
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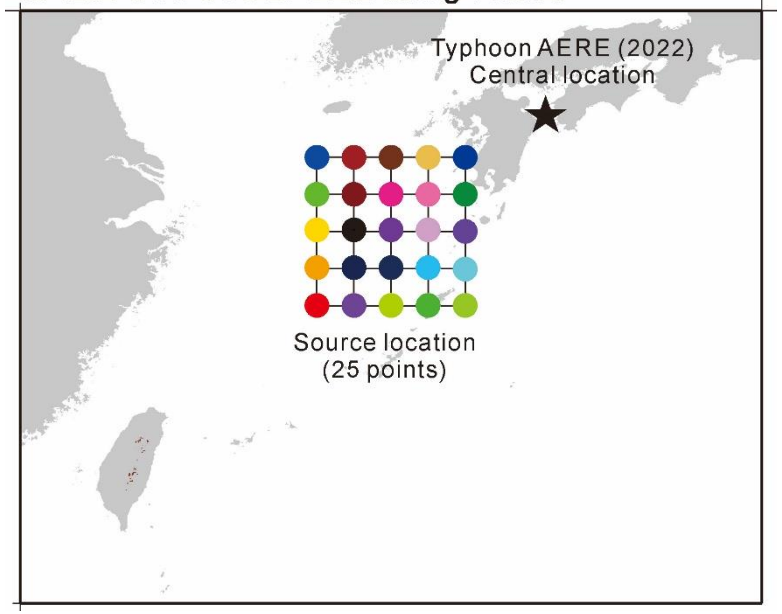
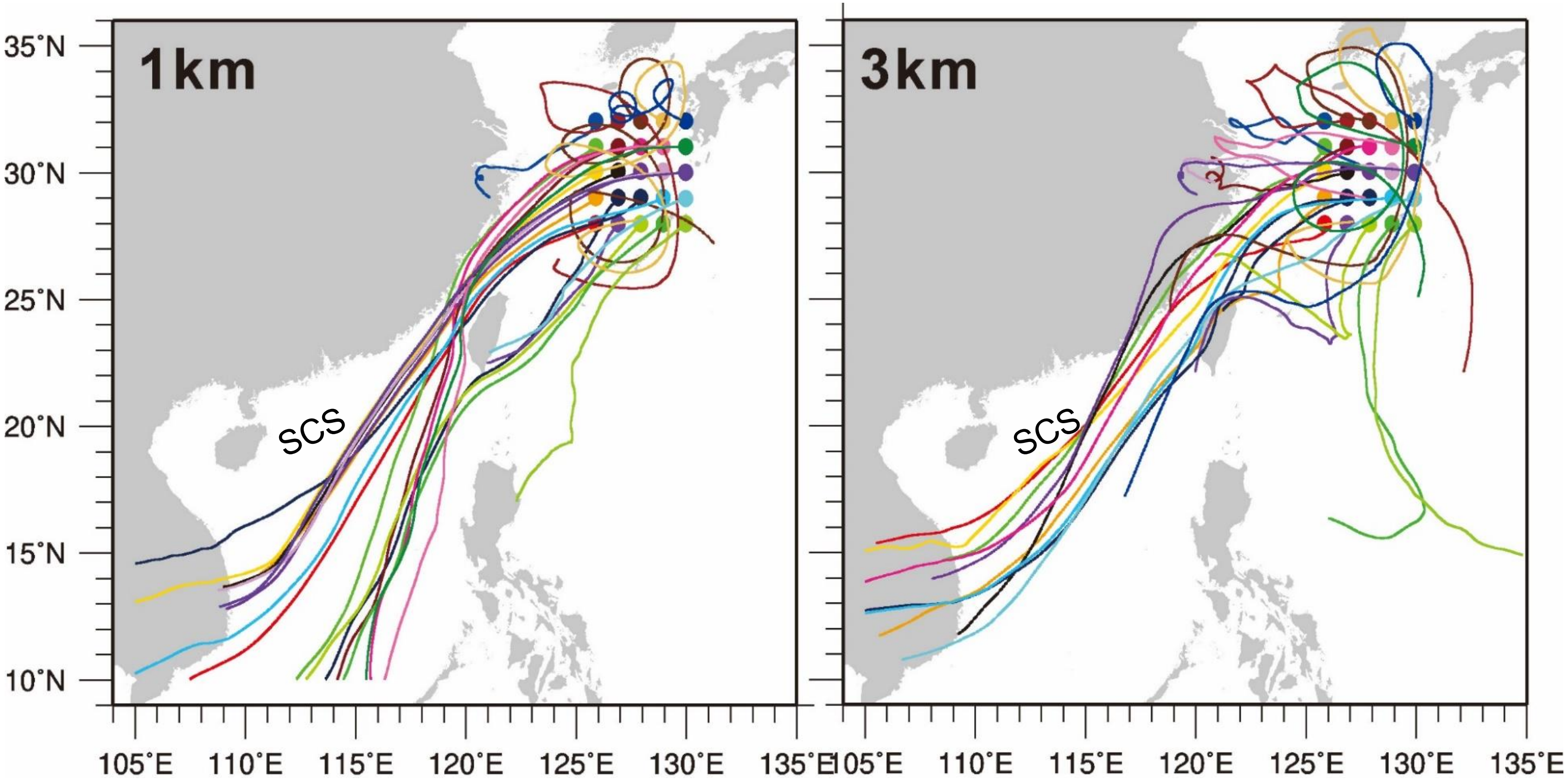
Backward air parcel trajectory analysis

78-h backward air parcel trajectories ending at 1200 UTC 5 JULY 2022 using CReSS

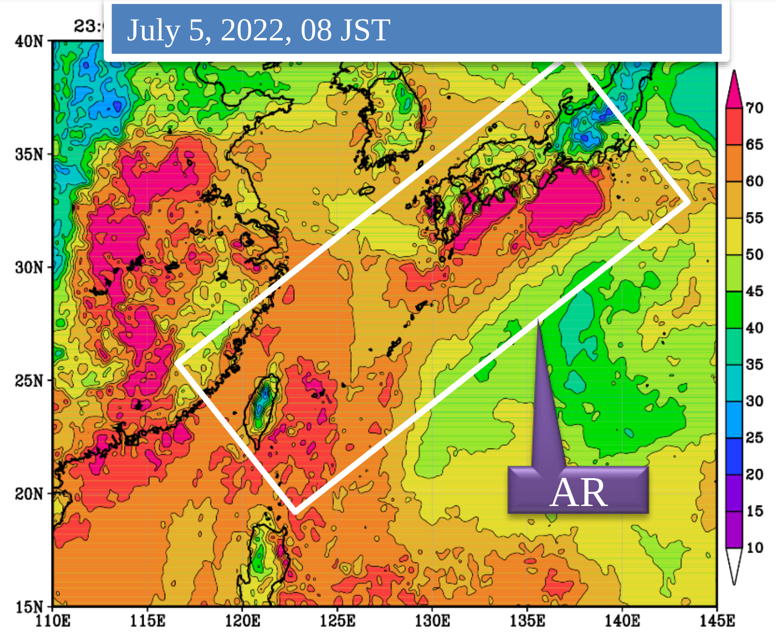


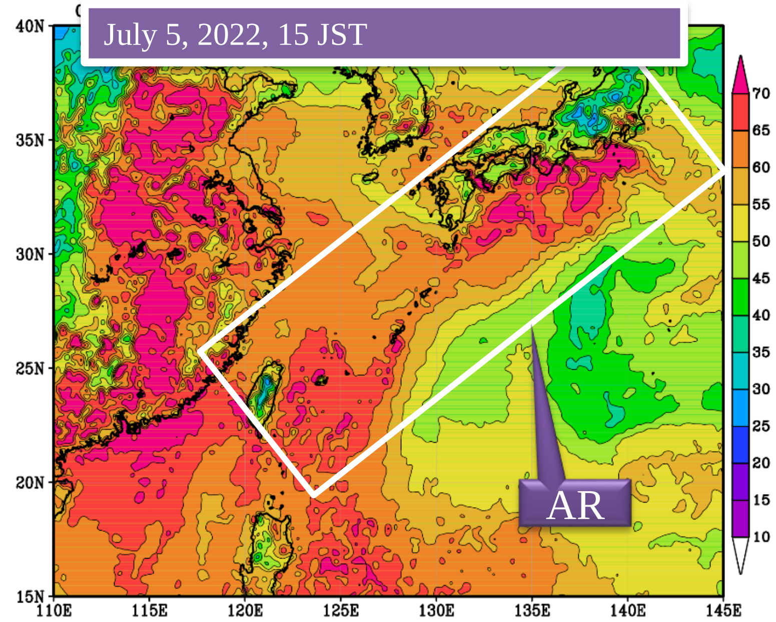
backward air parcel trajectory	
Input data	CReSS_output file (2.5 km resolution)
Start time	1200 UTC 05 July 2018
Total run time	Backward 78 hrs
Source location	Eight sets of 25 points → 0.5, 1, 2, 3, 4, 5, 6, 7 km → Upstream side of the Typhoon AERE (2022)



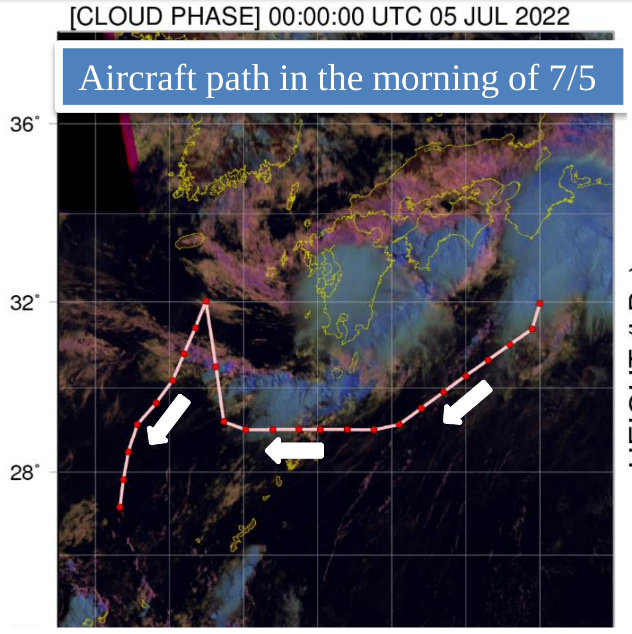
- The air parcels in the AR originated over the South China Sea (SCS).
- Taiwan topography has affected the air parcel trajectory.
  - air parcels ending at 1 km: passing to the west and east of Taiwan
  - air parcels ending at 3 km: passing to the west of Taiwan

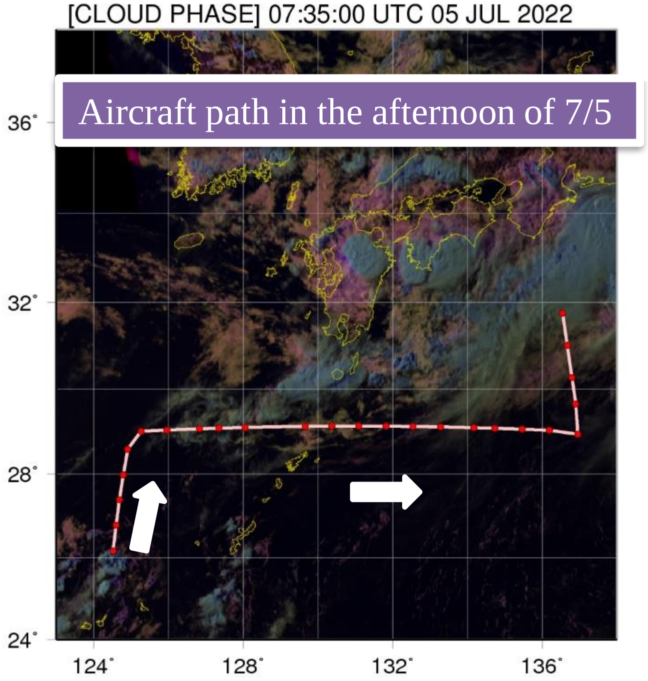
Aircraft observation of atmospheric river on July 5, 2022

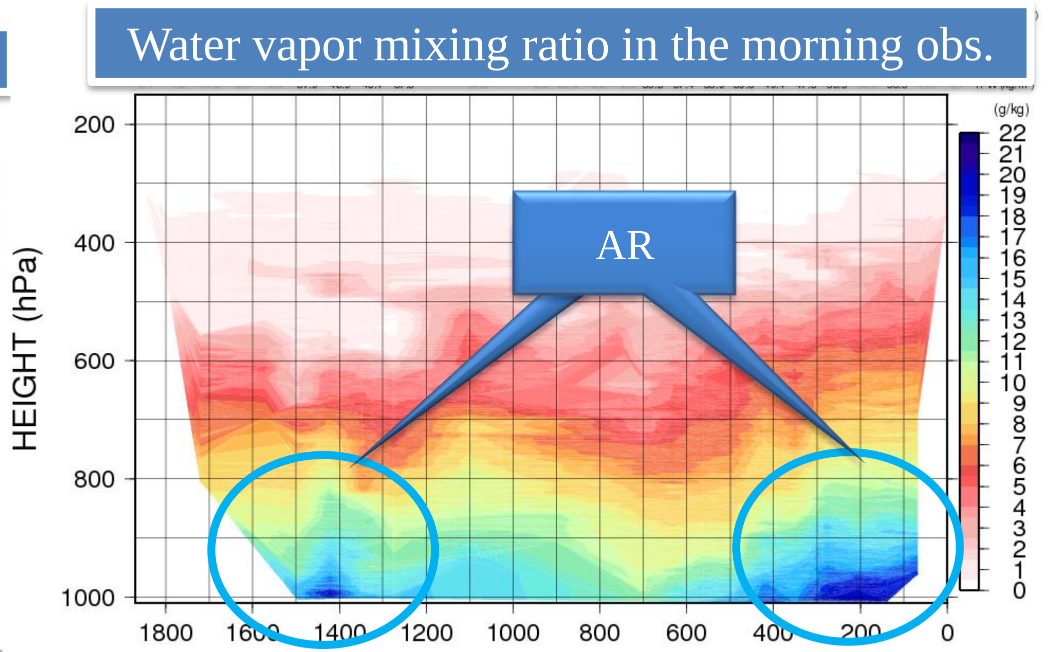


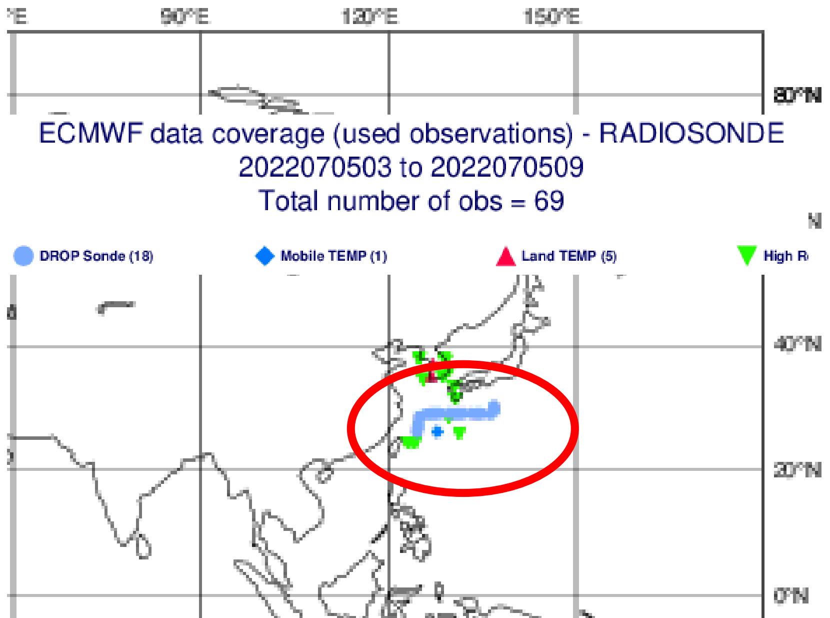


Vertically integrated water vapor（MIMIC2）

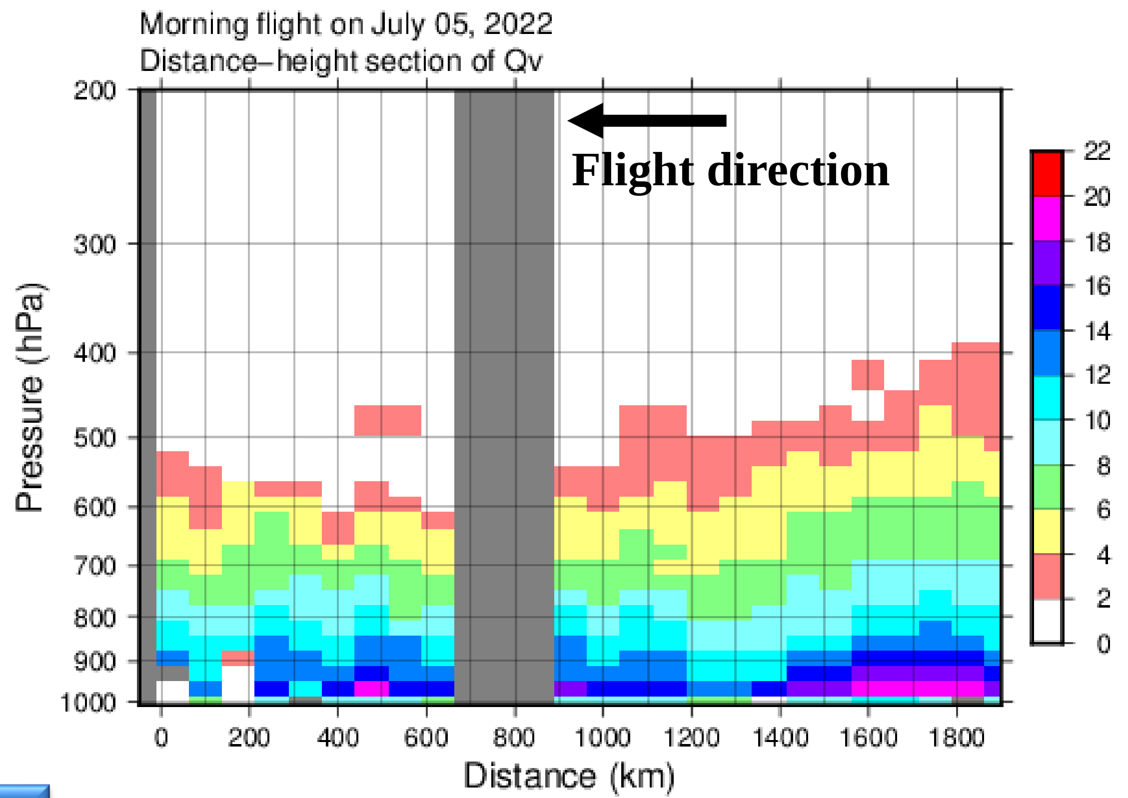




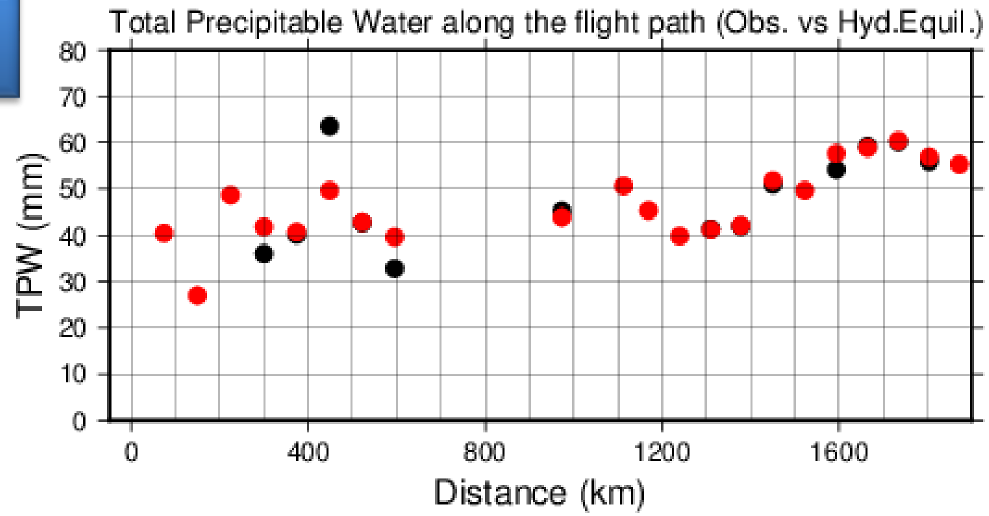




Vertical profiles of water vapor along the morning flight



IWV



- 23 of the 25 dropsoundings are observed the vertical profiles of water vapor.
- To estimate total precipitable water, height value obtained by the GPS data should be needed.
- If the height values are not obtained, they are retrieved from the pressure values using the hydrostatic equilibrium at a height of 300 hPa.

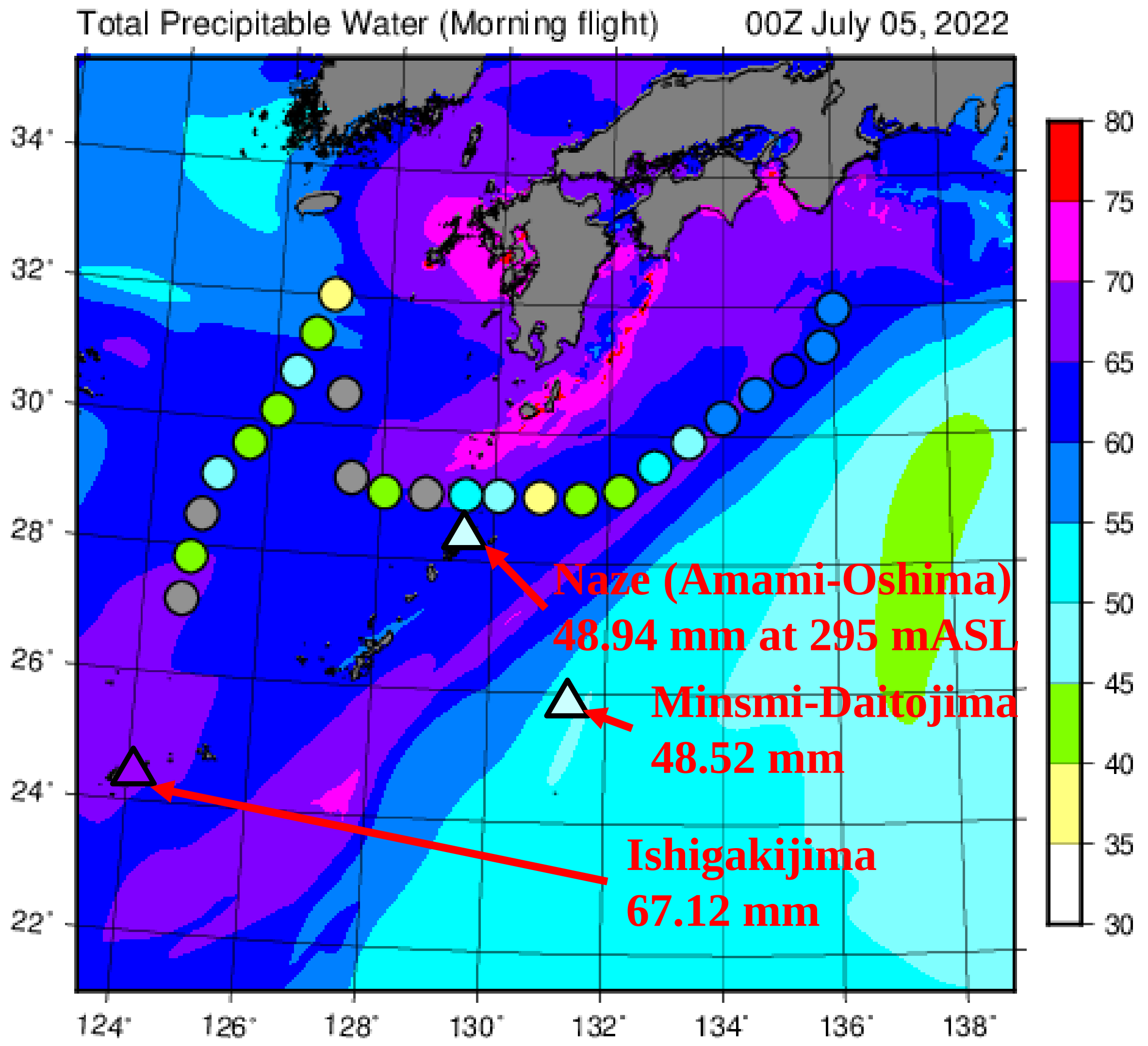
Total precipitable water

● Directly retrieved from observation

● Retrieved using the hydrostatic equilibrium at 300 hPa height

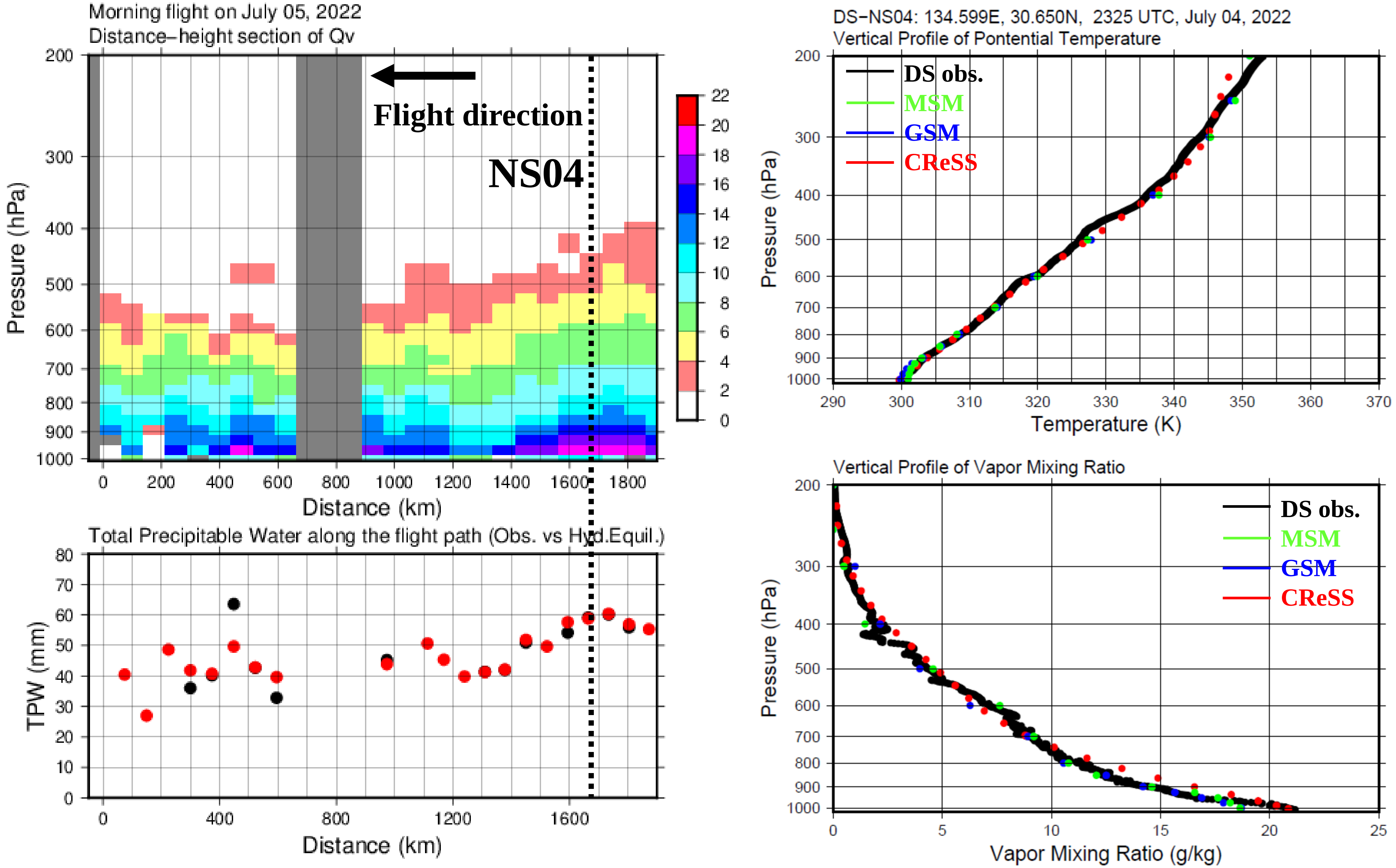
- East of 1450 km (south far from Kii Peninsula) is much water vapor (IWV > 50 mm)
- West of 1400 km is drier (East China Sea: IWV < 50 mm)

Comparison of IWV of the morning flight with the CReSS simulation

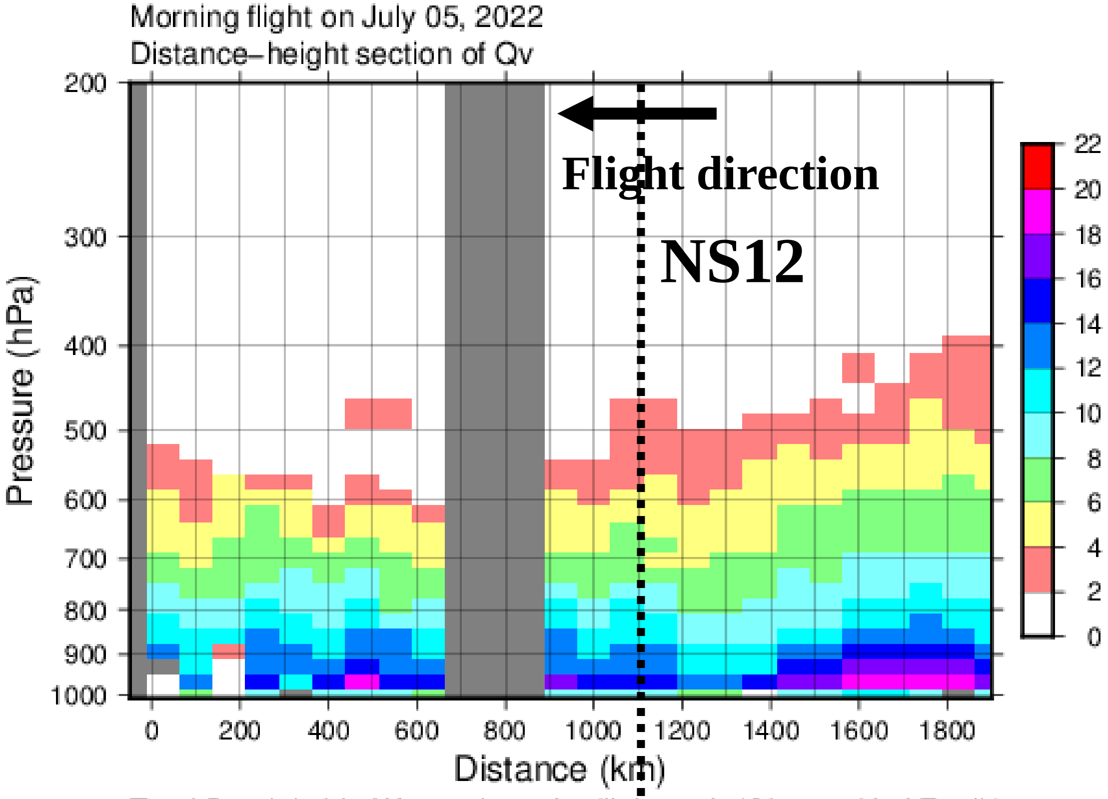


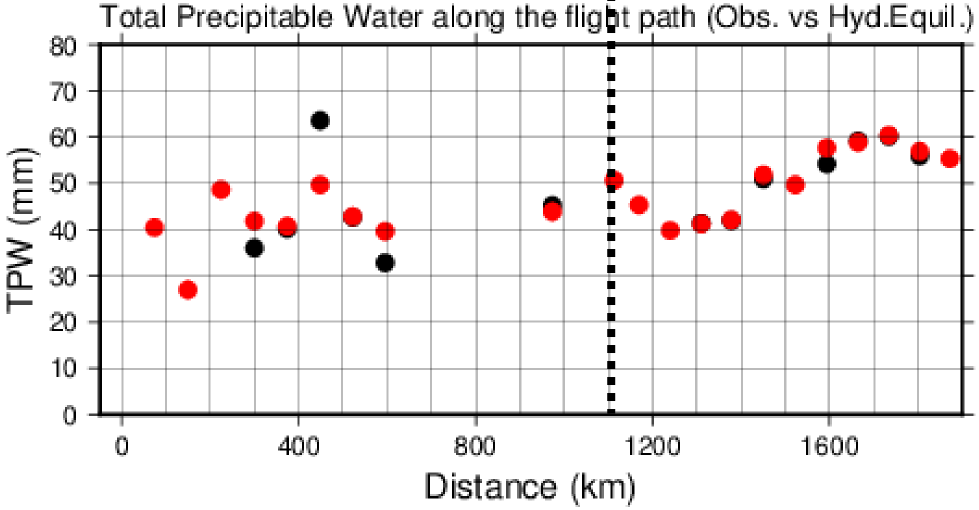
- Background color: Simulated IWV by CReSS at 00Z
- Colored circle: Retrieved IWV from the dropsounding observations
- Retrieved IWV points are drier than simulated one, except for the south of Kii Peninsula.

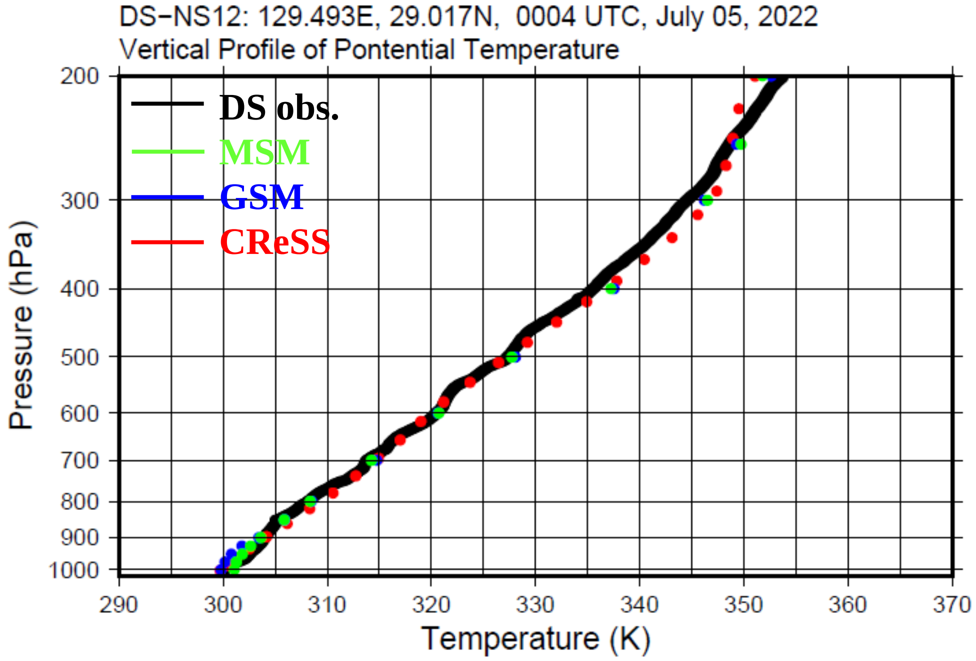
Potential temperature and water vapor profiles at NS04 sounding

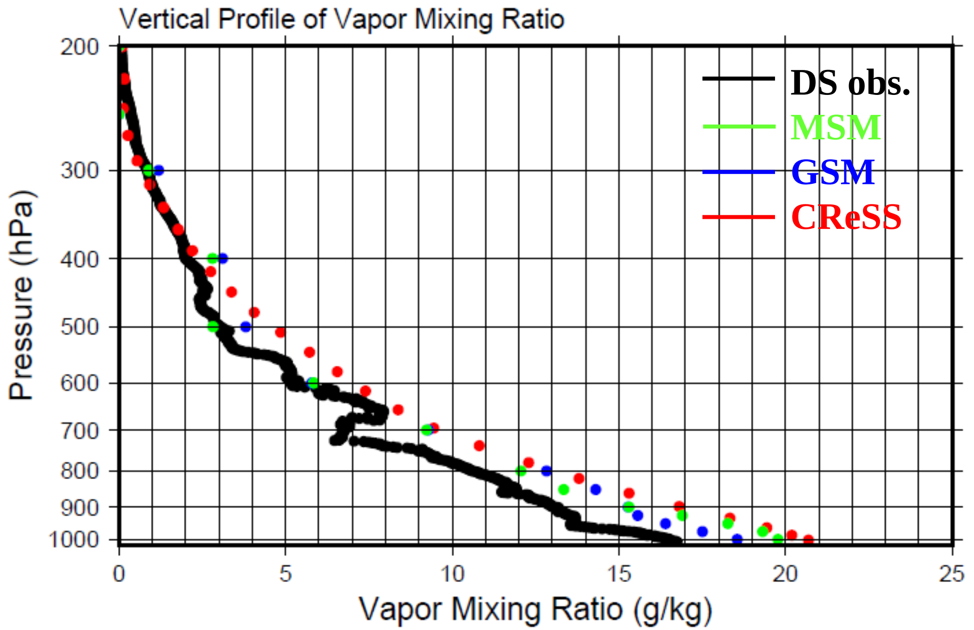


Potential temperature and water vapor profiles at NS12 sounding

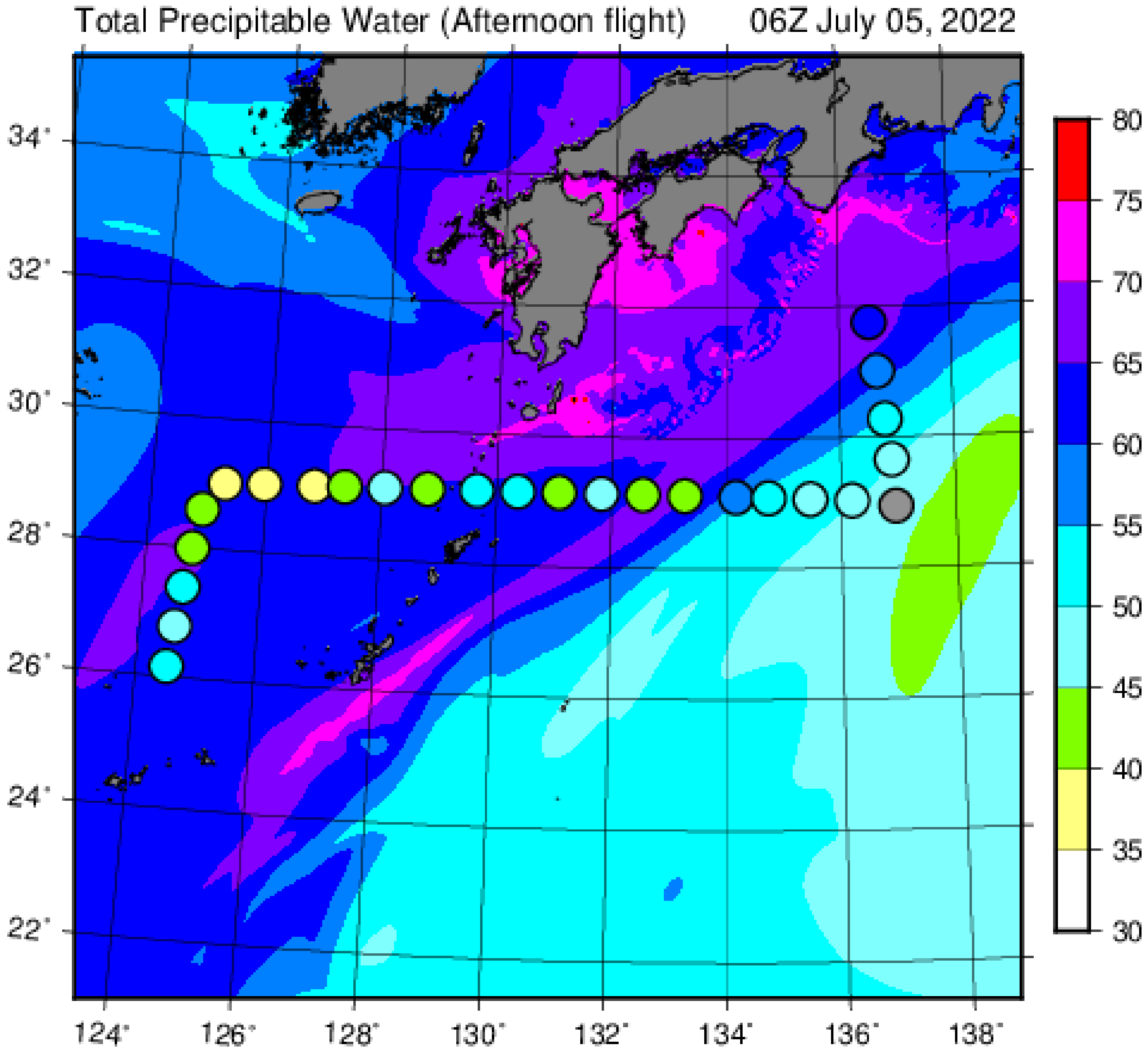








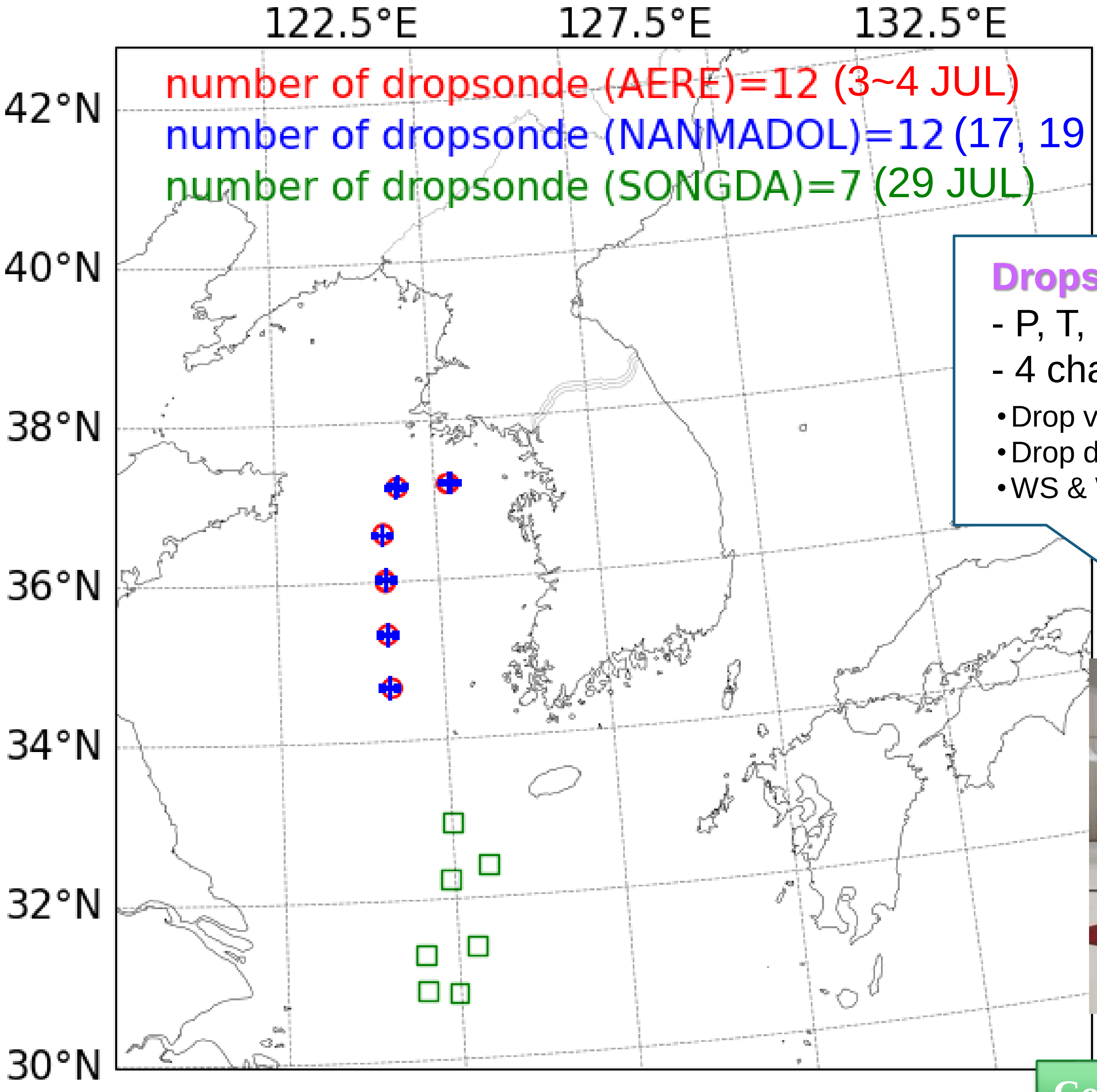
Comparison of IWV of the afternoon flight with the CReSS simulation



KMA/NIMS Atmospheric Research Aircraft

Identification	Type	King Air 350HW
	Manufacturer	Beechcraft
	Engine category	Turbo-prop
Flying Performance	Size (L/W/H) :	14.22/ 17.65/ 4.37 m
	Maximum take-off payload	7,425 kg
	Max altitude	9.6 km with maximum payload
	Range	2,871 km at maximum payload
	Mission flight	5.5 hrs with maximum payload

Courtesy of Dr. Goo Tae-Young of NIMS, KMA



Dropsonde (Vaisala, RD41)

- P, T, RH, WS & WD
- 4 channels
  - Drop velocity: ~11 m/s
  - Drop duration: ~8 min.(from 7.5km)
  - WS & WD estimated from GPS

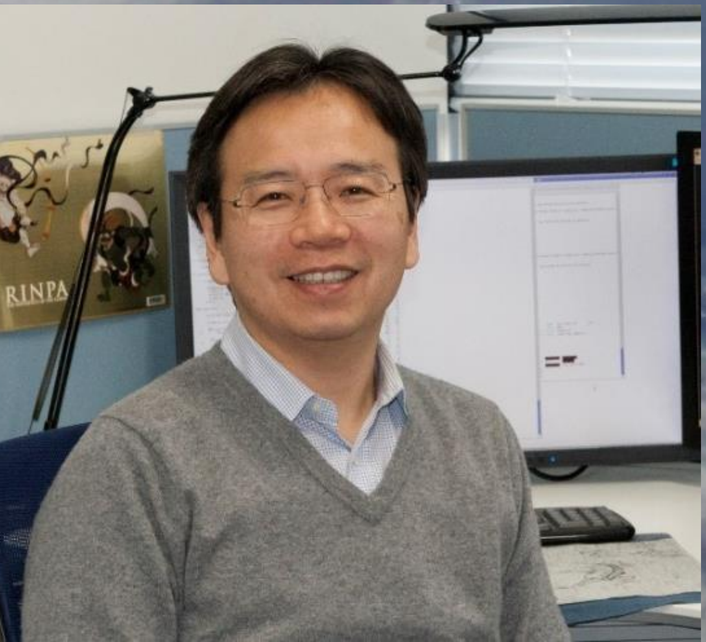
Courtesy of Dr. Goo Tae-Young of NIMS, KMA

Summary

- The T-PARCII team performed dropsonde observations of the AR on 5 July 2022 using the Gulfstream IV (G-IV) jet.
- A tropical depression changed from Typhoon Chaba was located over southern China and Typhoon Aere was present to the west of western Japan.
- Two major ARs extended from the South China Sea to western Japan. One is located in between China and Taiwan and the other to the east of Taiwan.
- A total of 53 dropsondes were launched from G-IV at a height of 43,000 ft during the round-trip flights over the Pacific and the East China Sea.
- The water vapor mixing ratio was more than 20 kg/kg below a height of 1 km to the south of western Japan.
- A southwesterly transported the low-level large water vapor toward Japan.
- Dropsonde data were transmitted in real time from G-IV to the Japan Meteorological Agency, and they were assimilated into a numerical model to perform weather forecasting.
- An aircraft observation is promising to make a highly-accurate measurement of water vapor of ARs.

Eye wall of typhoon Mindulle observed from inside of the eye at a height of 45000 ft on 29 September 2021

Thank you !!



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