Impacts of GNSS RO Data Assimilation on Tropical Cyclogenesis Predictions Using WRF Hybrid 3DEnVar

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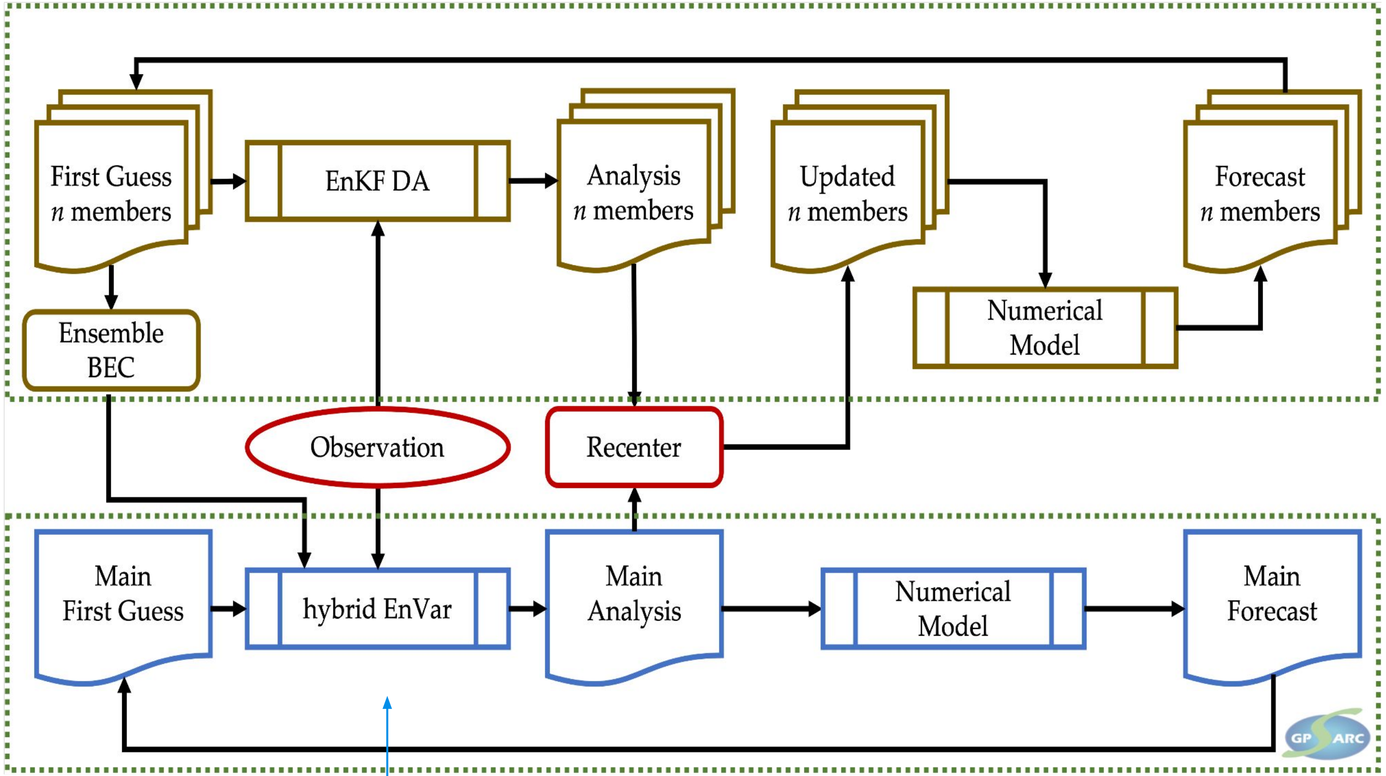
Introduction

- Typhoons, frequently accompanied by intense winds and heavy rainfall, can cause significant damage; therefore, accurate and precise predictions of tropical cyclogenesis are essential.
- GNSS RO data, particularly from the FORMOSAT-7/COSMIC-2 mission, covers the tropical region with better penetration close to the surface, offering valuable insights for predicting tropical cyclogenesis.
- Chen et al. (2020), Teng et al. (2022) have investigate the RO data impact with the WRF 3DVAR method.
- In this study, we use the WRF hybrid 3DEnVar assimilation system, which considering the flow-dependent error covariance.

WRF-WRFDA: hybrid 3DEnVar

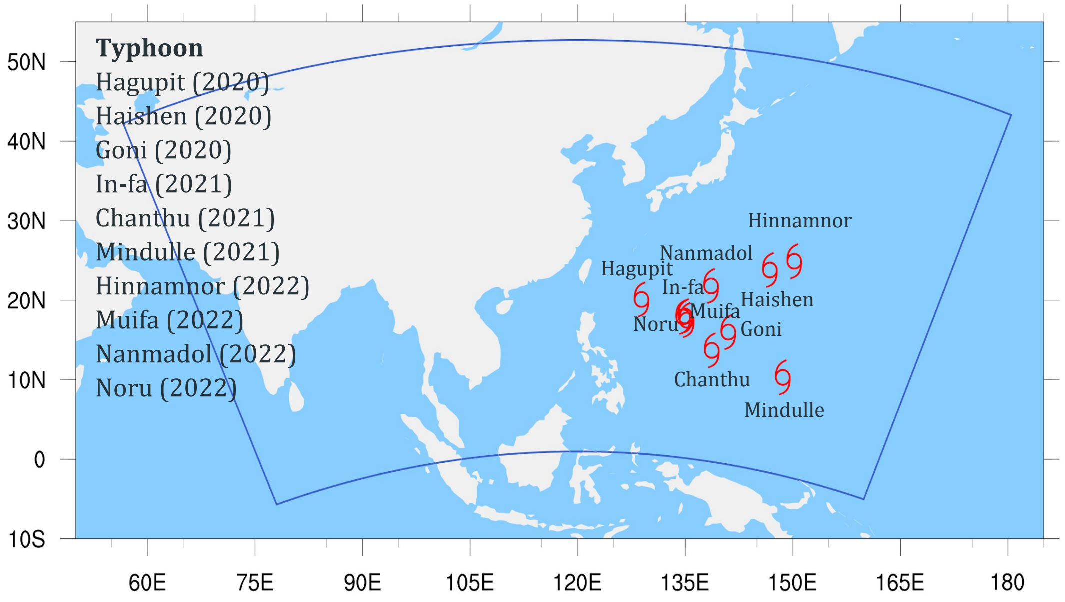
WRF 3DEnVar system



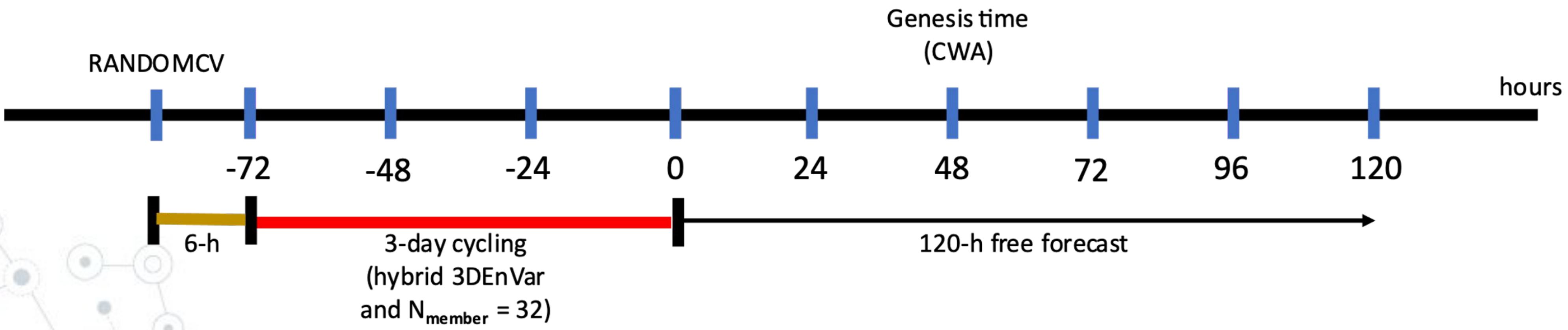
Background error covariance (**B**) is weighted sum of static $\mathbf{B}_s$ and ensemble $\mathbf{B}_e$

- **Model: WRF v4.2**
- **Data Assimilation: hybrid 3DEnVar**
- **Horizontal resolution: 15-km**
- Model top: 20-hPa
- Model configuration: The same as CWA's operation (Goddard 4-ice microphysics, Kain-Fritsch cumulus parameterization, YSU PBL, RRTMG for the radiation effects, etc.)
- Initial condition: NCEP FNL 0.25° horizontal resolution

Ten Typhoon Cases (2020-2022)



EXP	Description
GTS	conventional data
EPH	conventional data, and GNSS RO data with the **nonlocal refractivity operator** (FORMOSAT-7/COSMIC-2, MetOp, GRACE, KOMPSAT-5, PAZ)

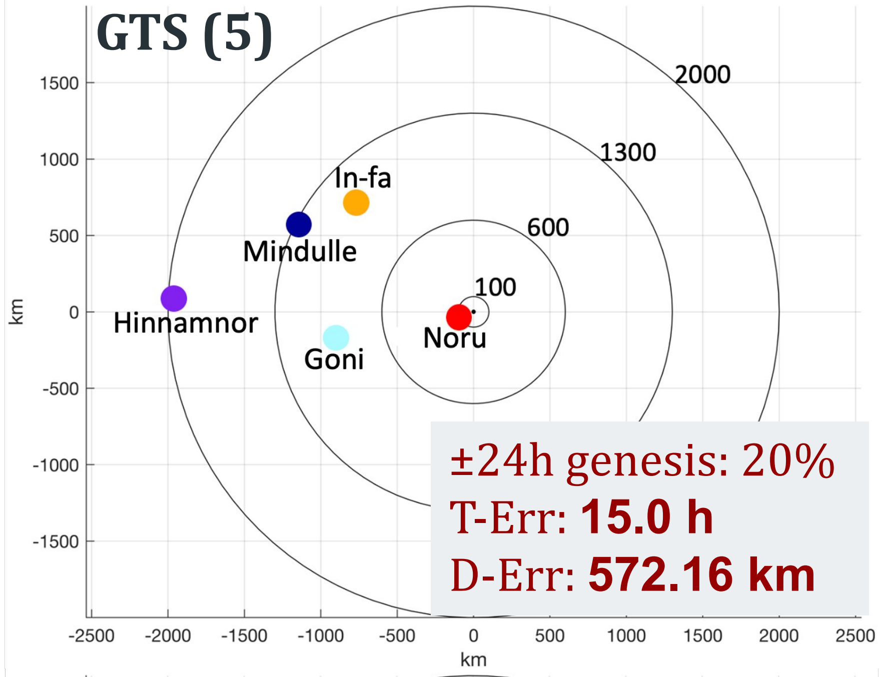


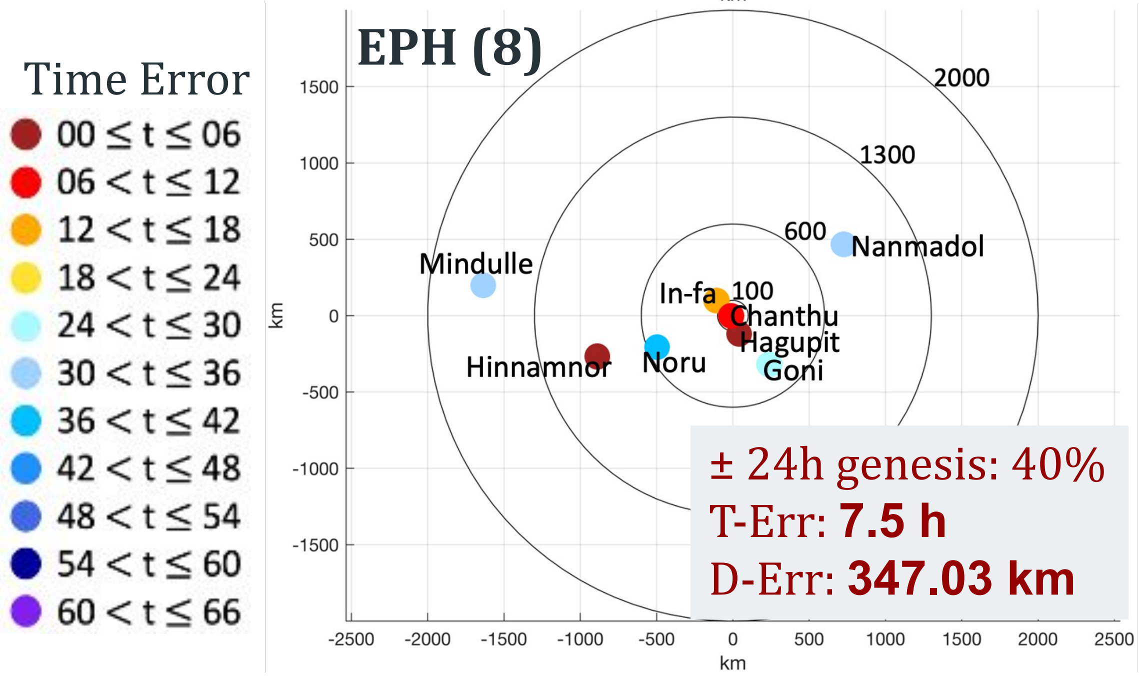
Three are 2000-3000 RO soundings assimilated for each case, and >75% from FS7/C2.

Simulated Results

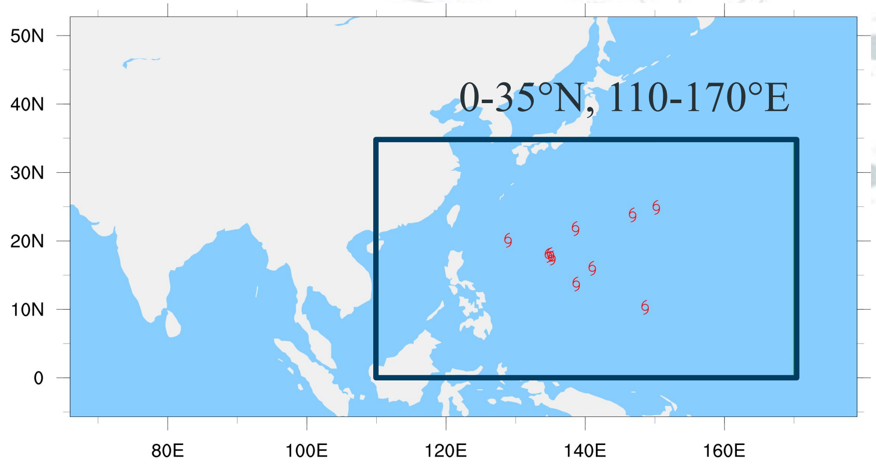
Typhoon	GTS	EPH
Hagupit (2020)	x	-03
Haishen (2020)	x	x
Goni (2020)	+30	-30
In-fa (2021)	+18	-15
Chanthu (2021)	x	-09
Mindulle (2021)	+57	+36
Hinnamnor (2022)	+66	-03
Muifa (2022)	x	x
Nanmadol (2022)	x	-36
Noru (2022)	+12	-39
Genesis case	**5**	**8**

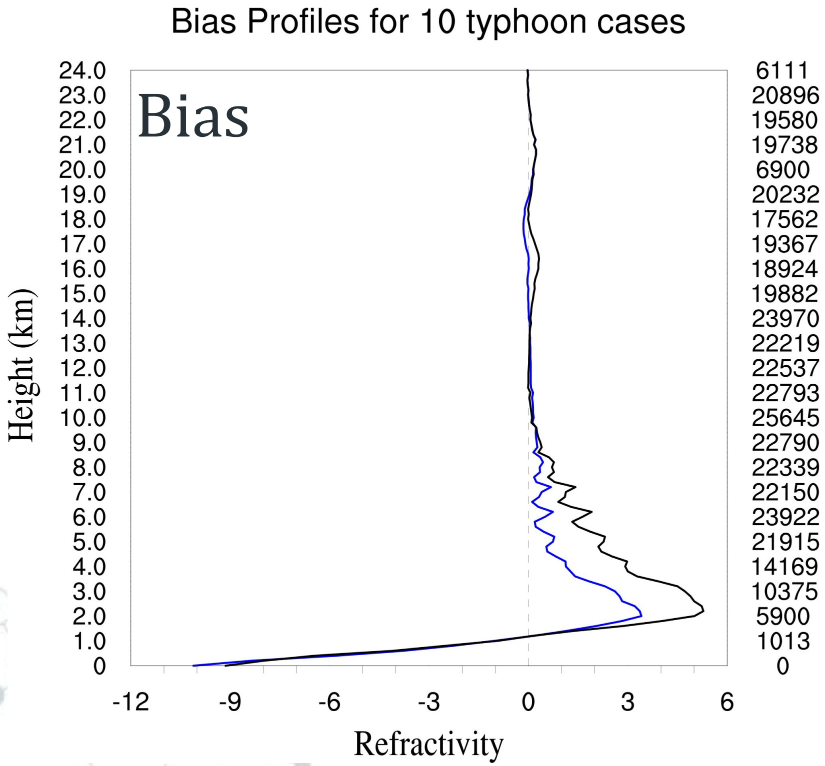
+ late genesis
– early genesis
x no genesis

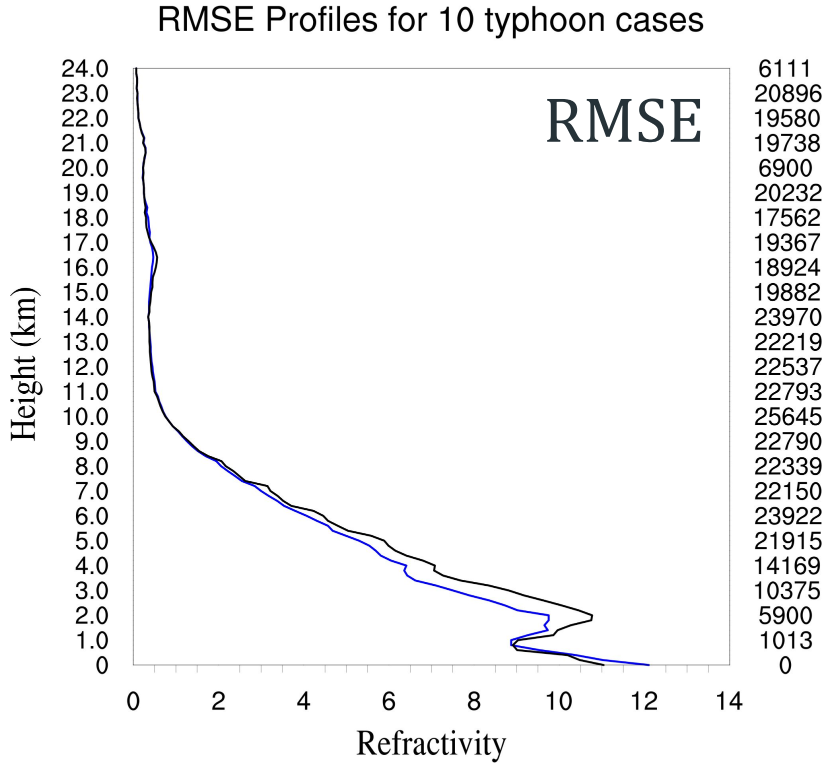




Verification against GNSS RO refractivity





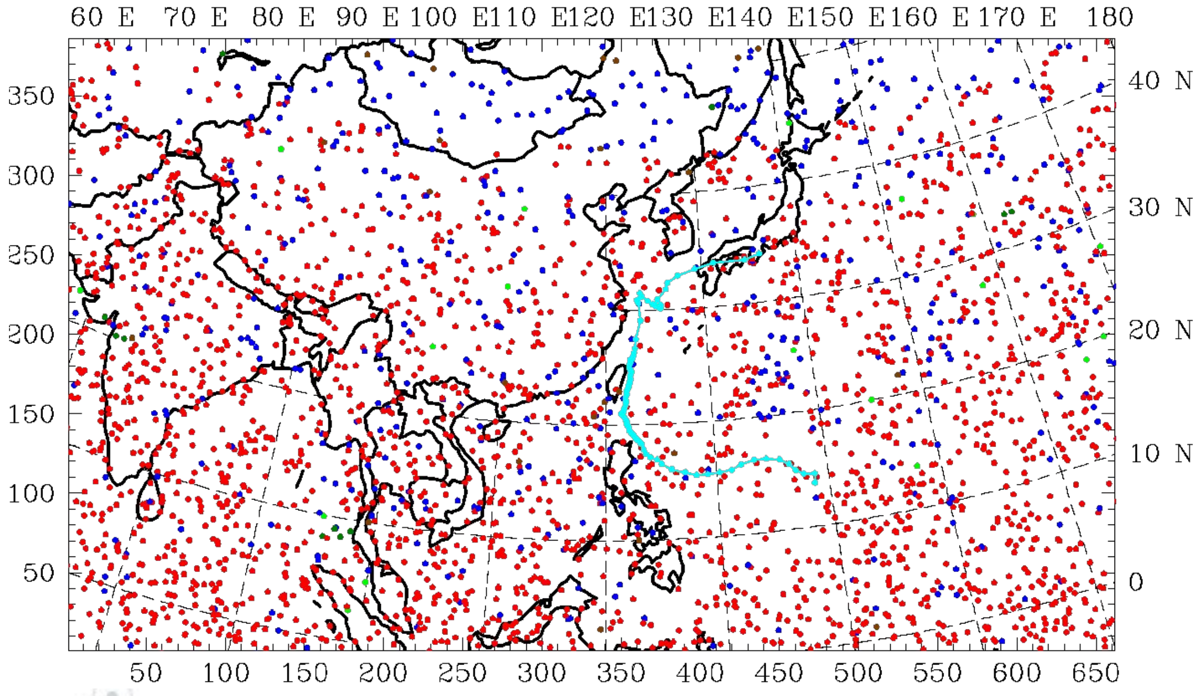


Typhoon Chanthu (2021)

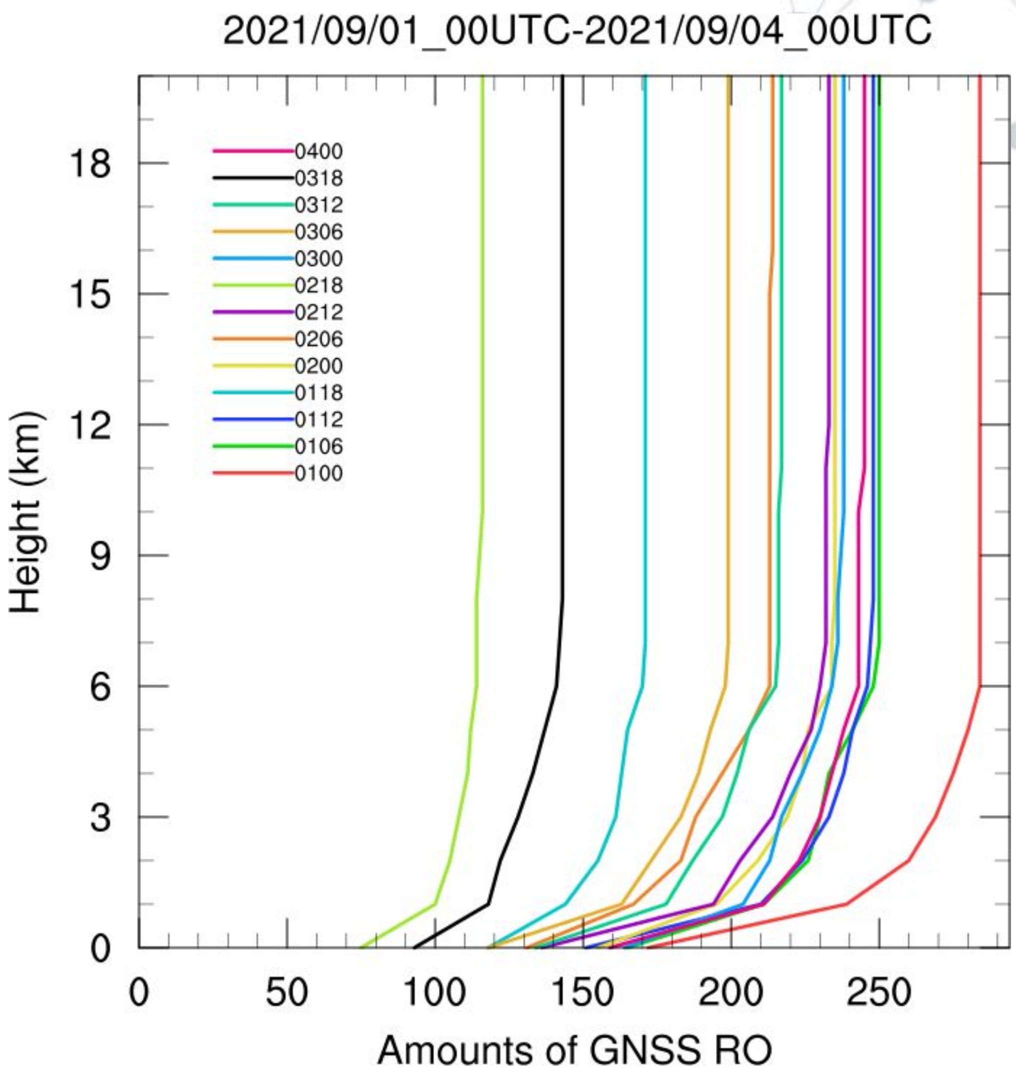
	Chanthu (2021)	
	Time	Location
GTS	x	x
EPH	9-h earlier	23.87-km

GNSS RO data for Chanthu case

2793 RO soundings in the 3-day period

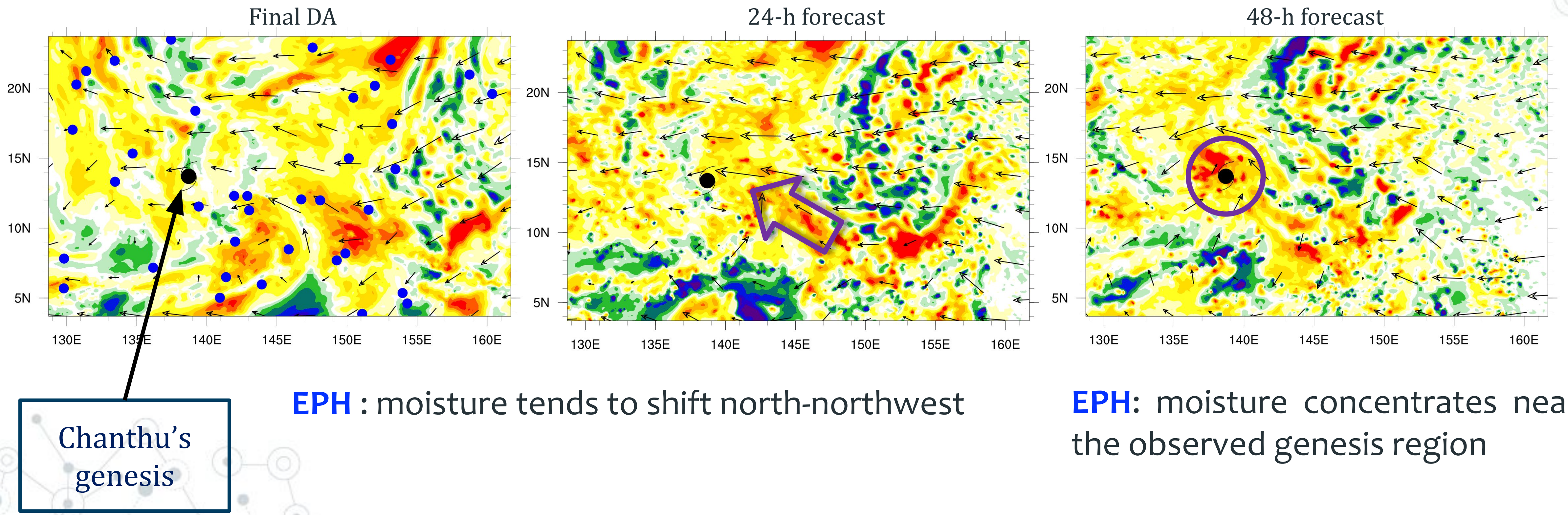


FS7/C2(~80%), Metop, PAZ, Grace, KOMPSAT5



Typhoon Chanthu

Differences (EPH-GTS) at the 700-hPa QVAPOR

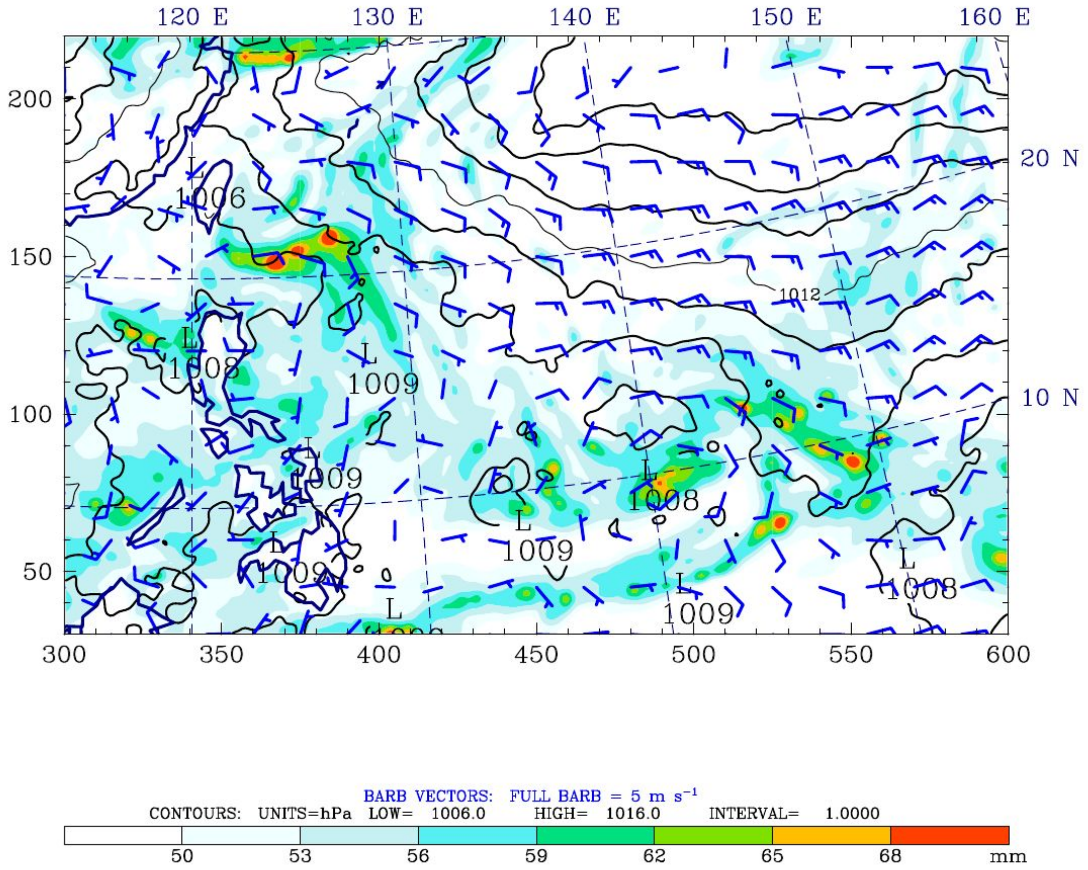


EPH : moisture tends to shift north-northwest

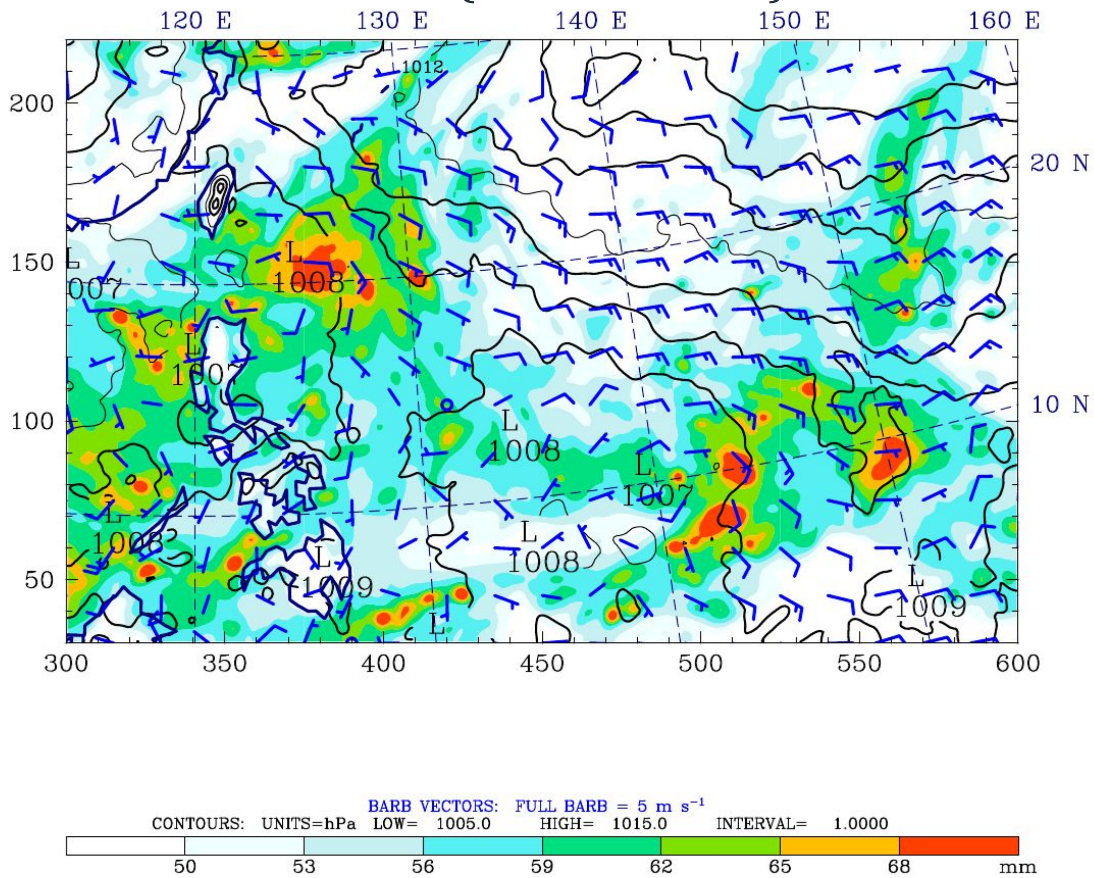
EPH: moisture concentrates near the observed genesis region

TPW, SLP, 10m Wind (0h forecast)

GTS (without RO data)

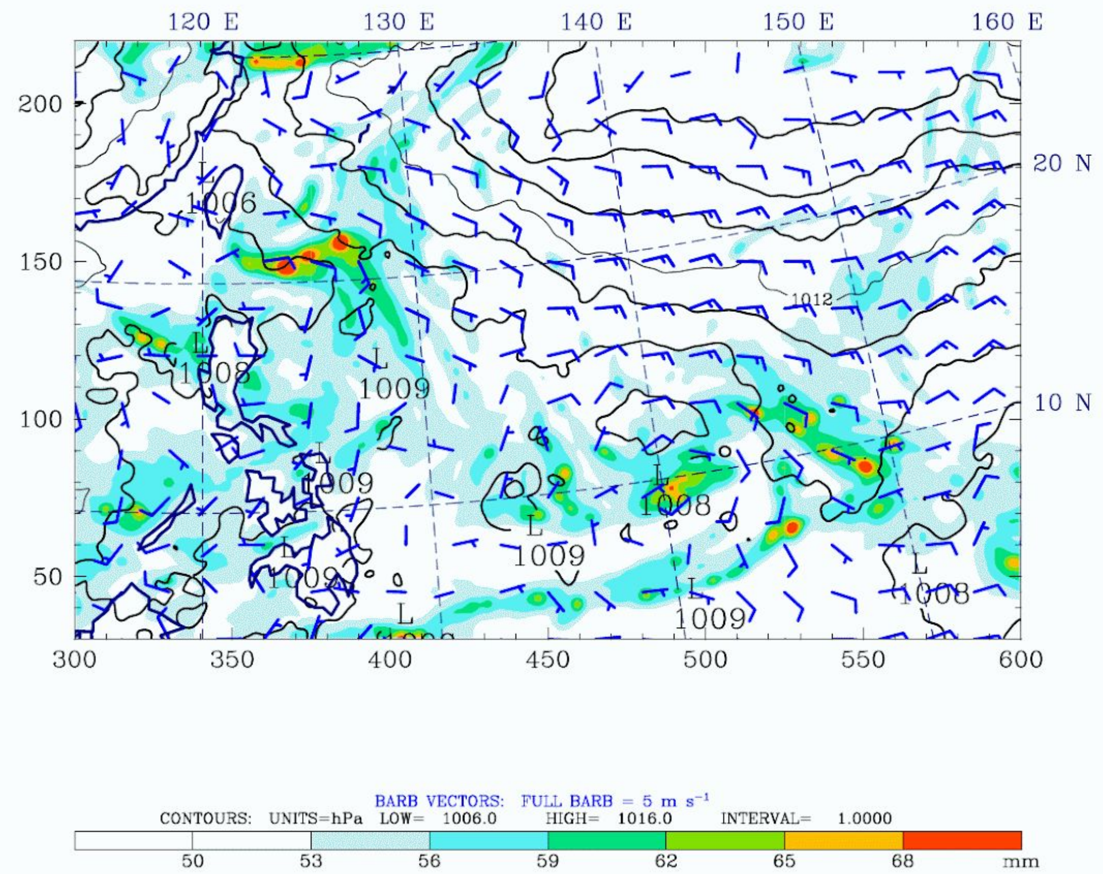


EPH (with RO data)

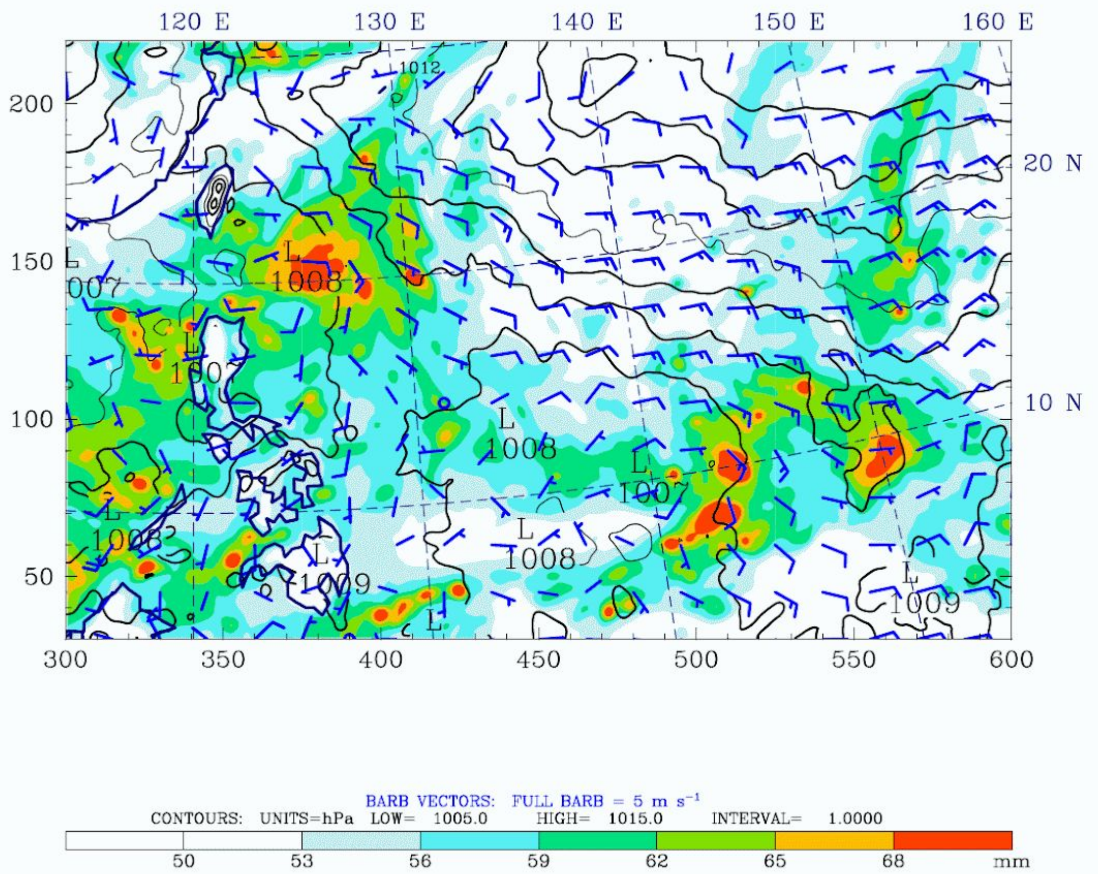


TPW, SLP, 10m Wind (5-day forecasts)

GTS (without RO data)

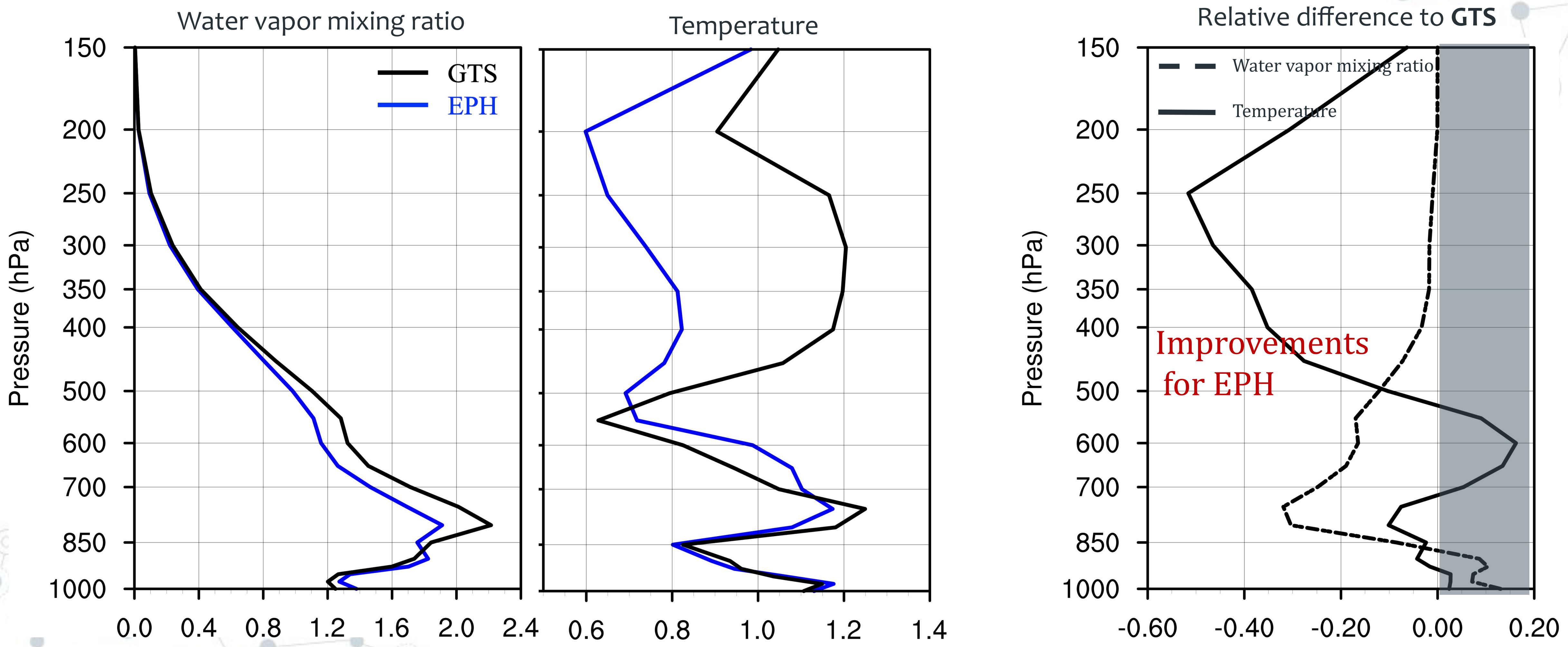


EPH (with RO data)



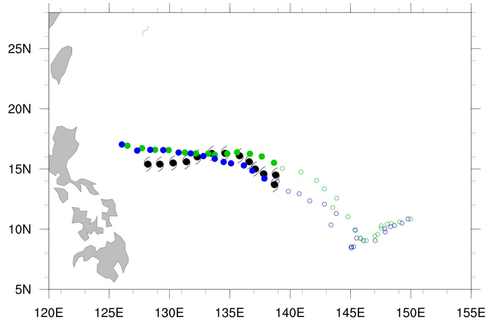
Verification against ERA5 at Chanthu's genesis time

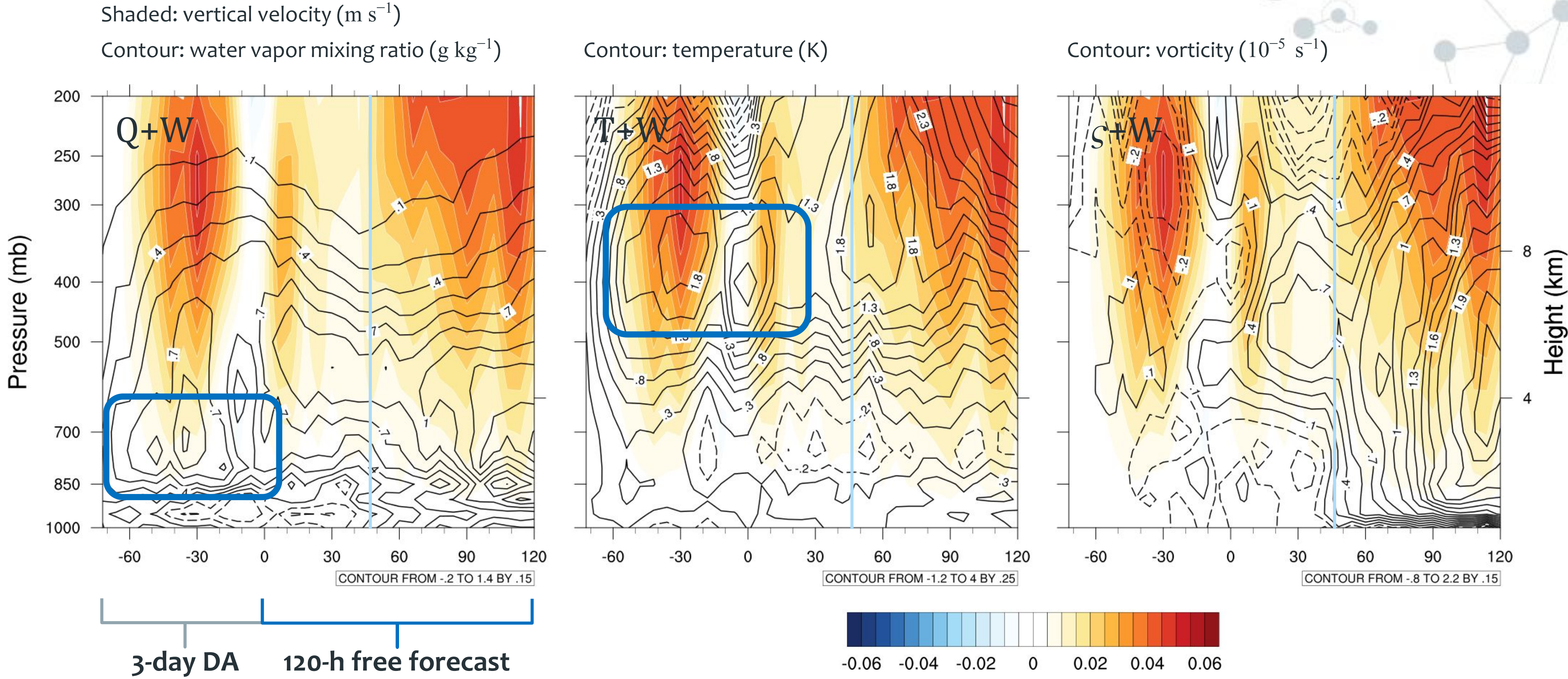
WRF 48-h forecast (RMSE)



Time-height section difference (EPH – GTS)

Averaged over 6° x 6° box following the 500-mb vorticity center.



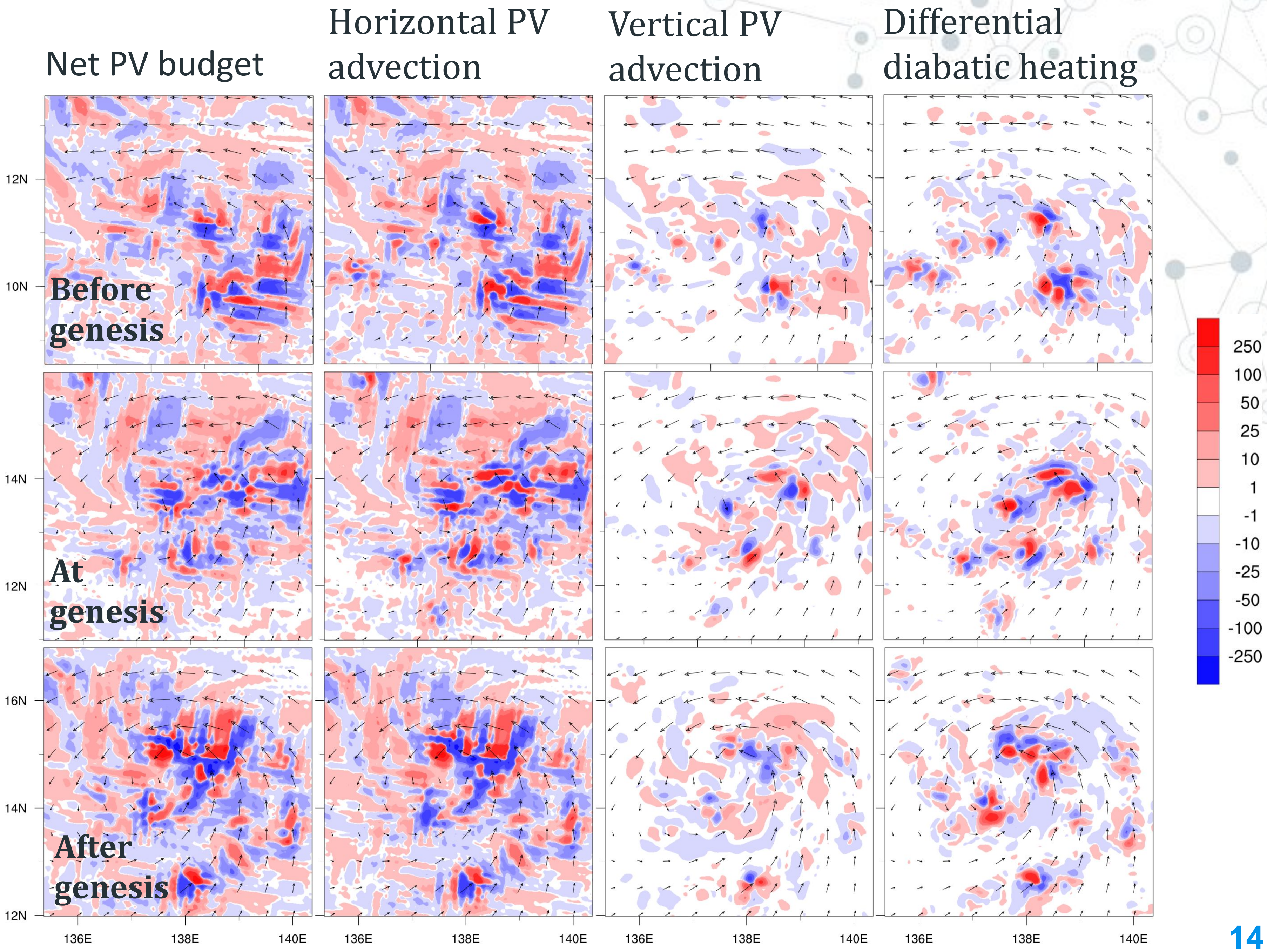


The increasing moisture in the mid-troposphere facilitates convection, driving strong vertical motions and eventually developing midlevel vorticity.

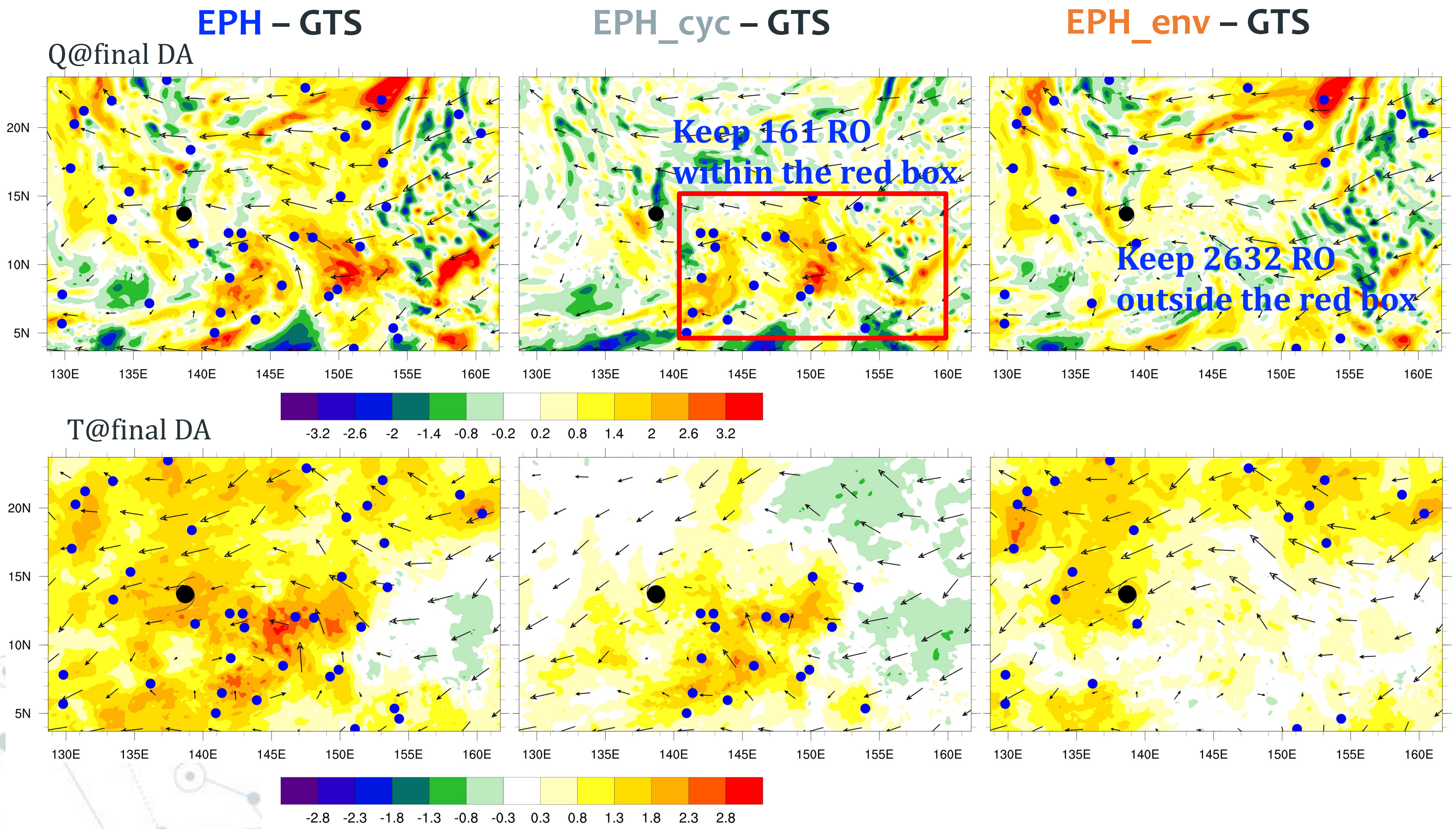
PV Tendency Budget for EPH

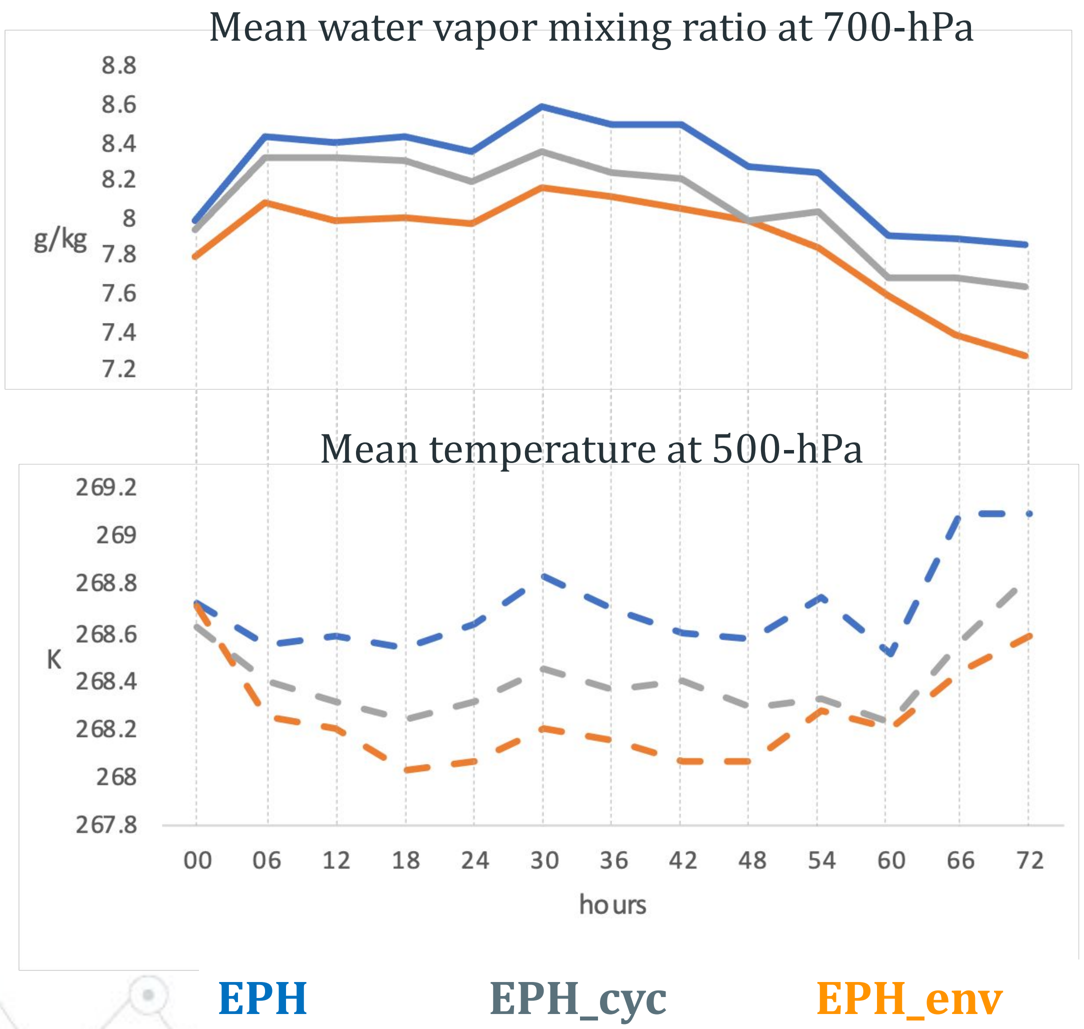
Average from 1-5 km

Unit: 10^{-5} PVU s^{-1}



Sensitivity Experiments – RO data near precursor region





Chanthu (2021)

	Time_Error	Location_Error
EPH	9-h earlier	23.87-km
EPH_cyc	18-h earlier	264.65-km
EPH_env	x	x

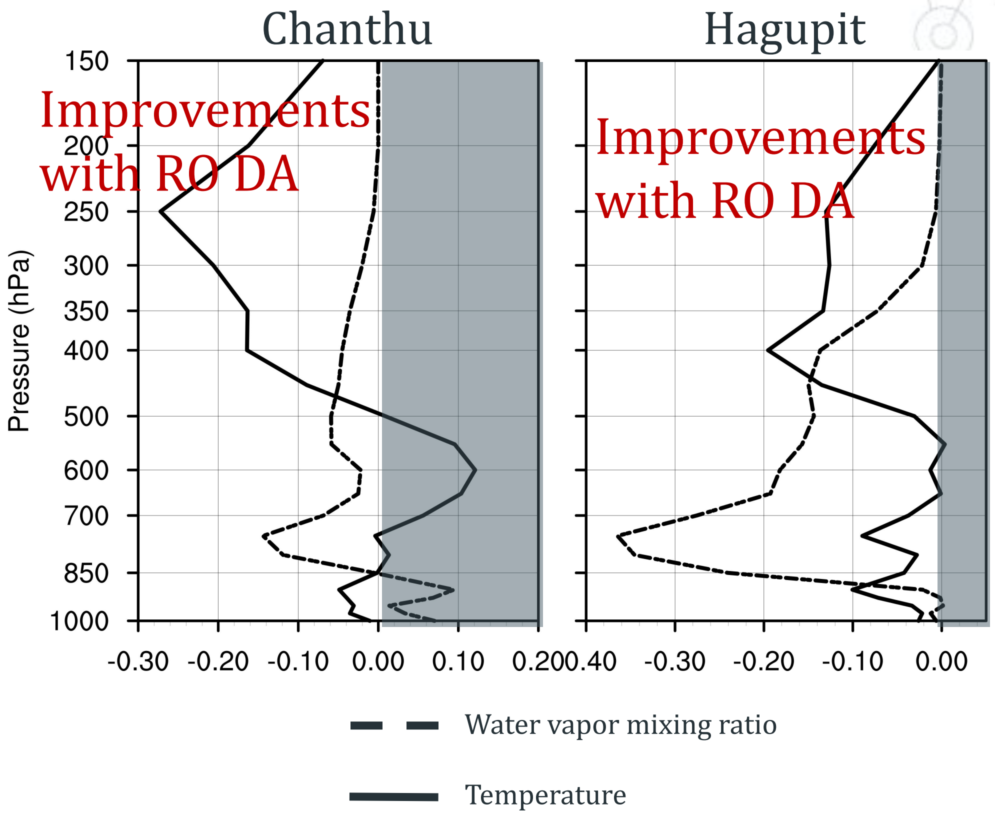
The RO soundings near the precursor region play an important role for the simulation of TC formation.

Including Satellite Radiance DA (Two Typhoon Cases)

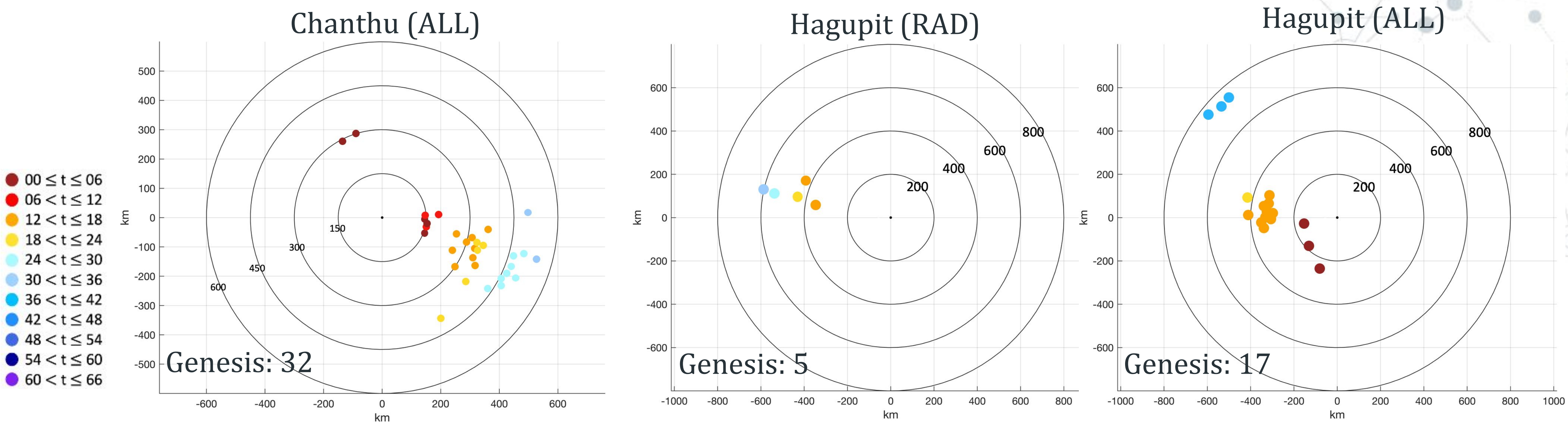
EXP	Description
GTS ⇨ RAD	conventional data, and satellite radiance data (AMSU-A, HMS, HIRS-4)
EPH ⇨ ALL	conventional data, GNSS RO data, and satellite radiance data

	Chanthu (2021)		**Hagupit (2020)**	
	Time Error	Loc. Error	Time Error	Loc. Error
RAD	x	x	6-h later	221.43 km
ALL	18-h earlier	298.98 km	3-h later	89.41 km

Verification against ERA5 (RMSE at 48-h forecast, the genesis time)



32 Ensemble Forecasts



	TY Chanthu		TY Hagupit	
	RAD	ALL	RAD	ALL
Predictability (±24h genesis err.)	0	68.8%	9.4%	43.8%
AVE. Loc. Err. (km)	x	287.98	411.31	314.26
Abs. AVE. Time Err (hr)	x	14.9	19	15

Summary

- This study investigates the impact of GNSS RO DA on the cyclogenesis of ten tropical cyclones in the northwestern Pacific region from 2020 to 2022.
- Statistical analyses reveal significant improvements on time and location predictions of tropical cyclogenesis.
- Case studies on two specific typhoons, Chanthu (2021) and Hagupit (2020), further underscore the efficacy of GNSS RO DA in improving moisture and temperature predictions, which are crucial for cyclogenesis forecasts.
- The GNSS RO data assimilation improves the prediction of tropical cyclogenesis, which is also evidenced by the ensemble forecasts.