結合機器學習與傳統物理模式之混合架構在TWRF颱風預報中的應用與成效探討

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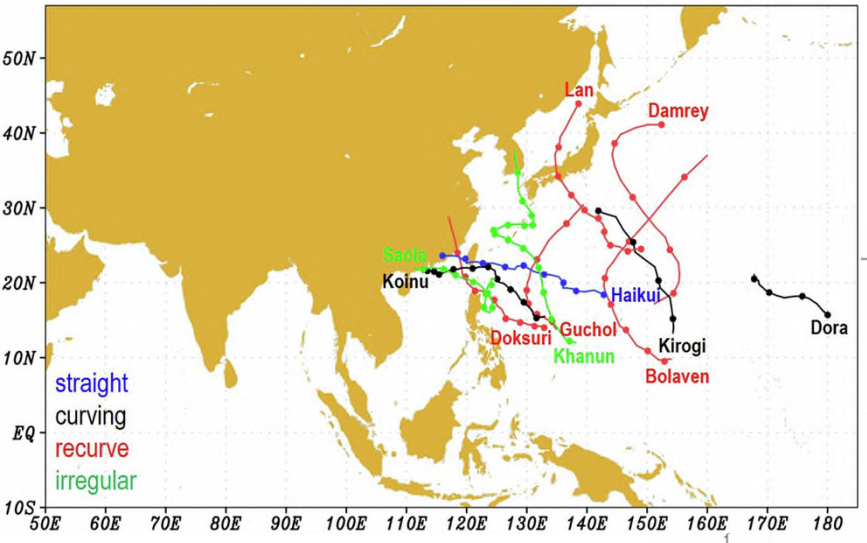
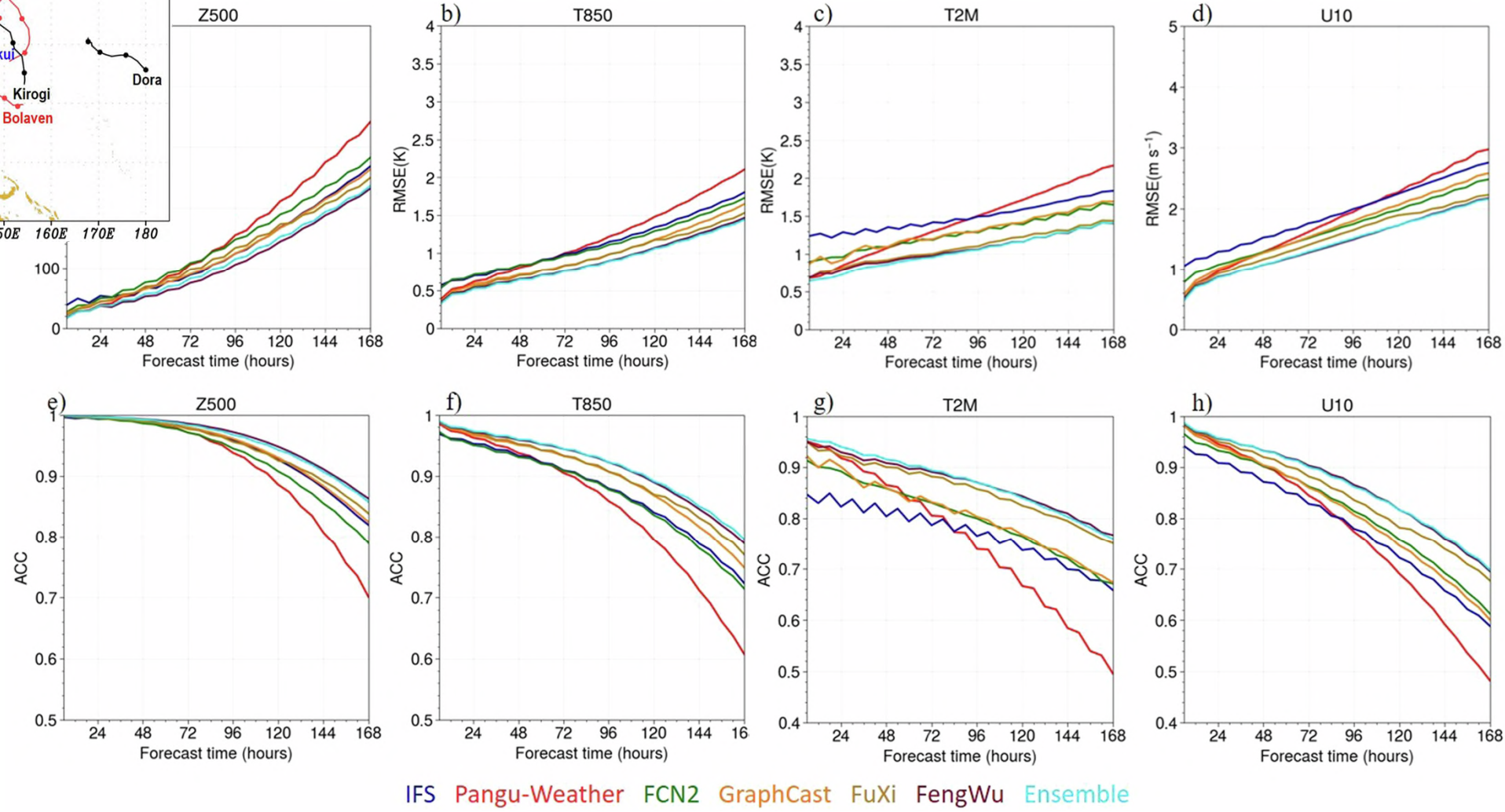
Verification



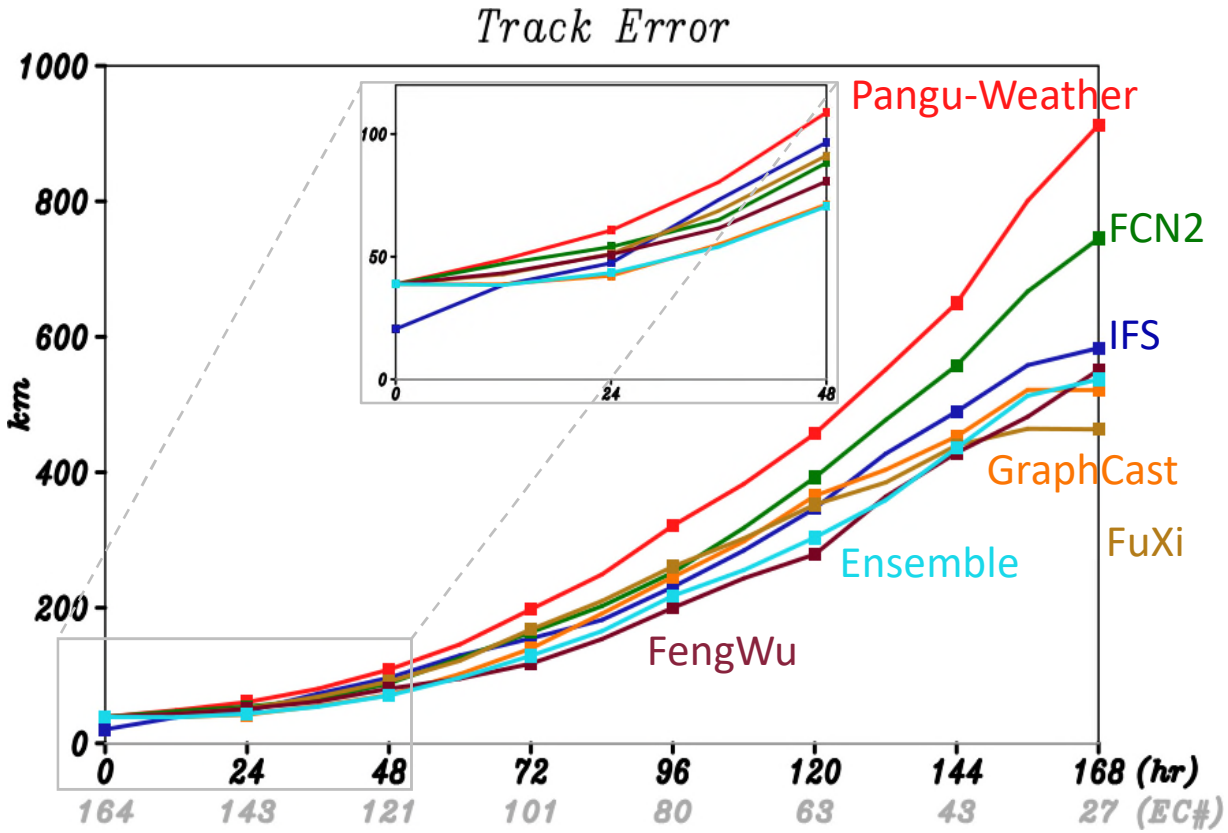
The performing order of the models are
FengWu
FuXi
GraphCast
FCN2
Pangu-Weather

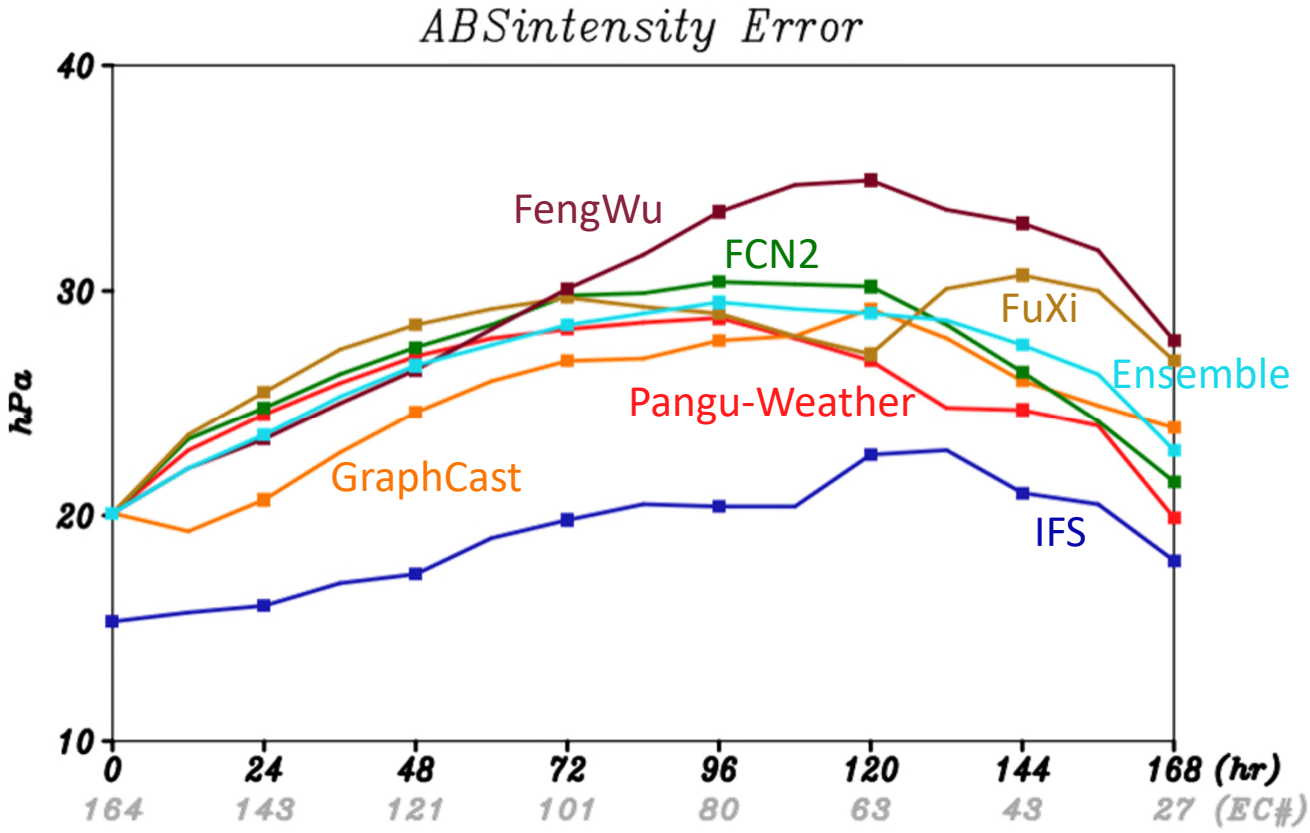
The IFS places in the middle of the group.



(Liu et al., 2024)

Averaged Track and Absolute Intensity Errors



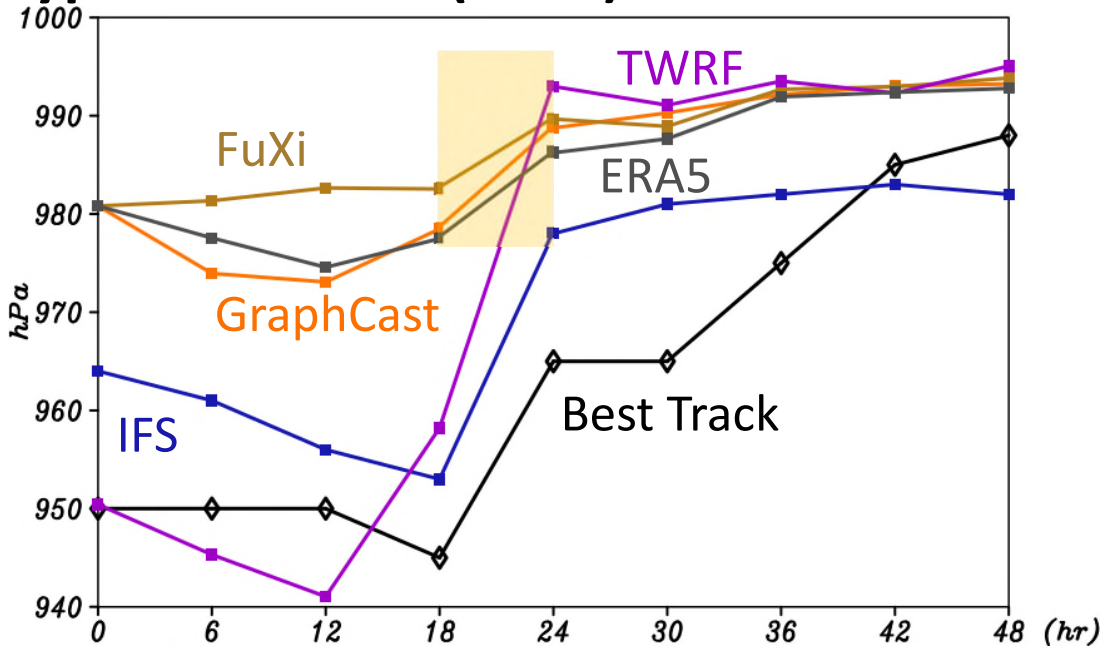


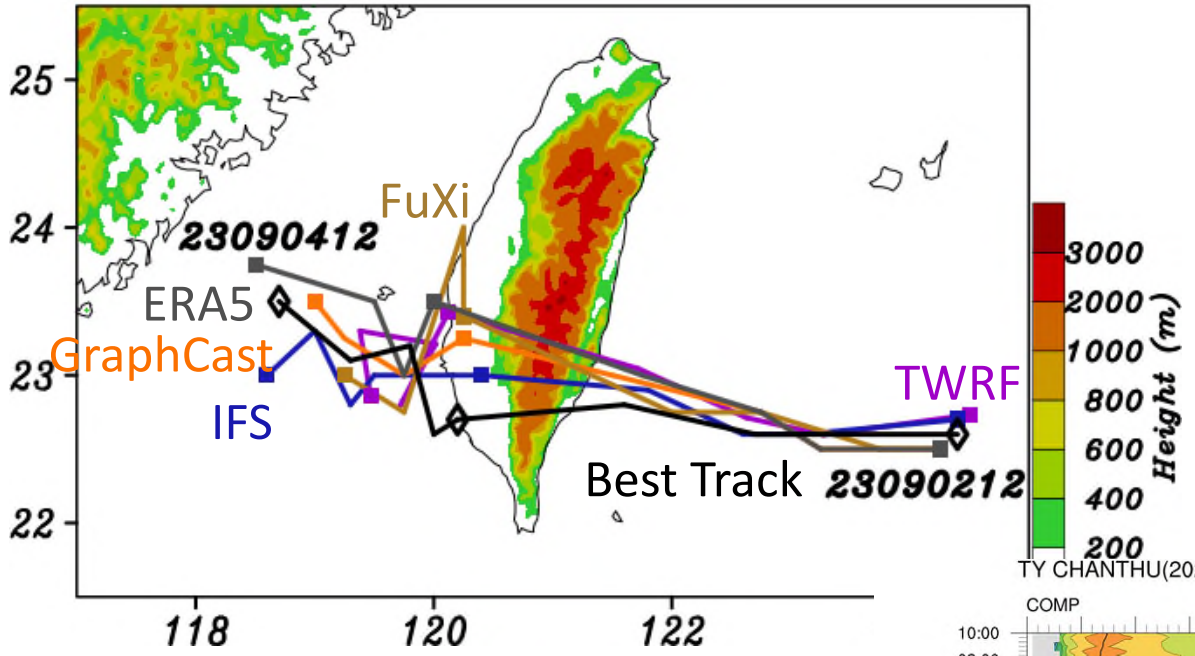
Machine learning-based weather prediction (MLWP) models have achieved good skill in typhoon track forecasting.

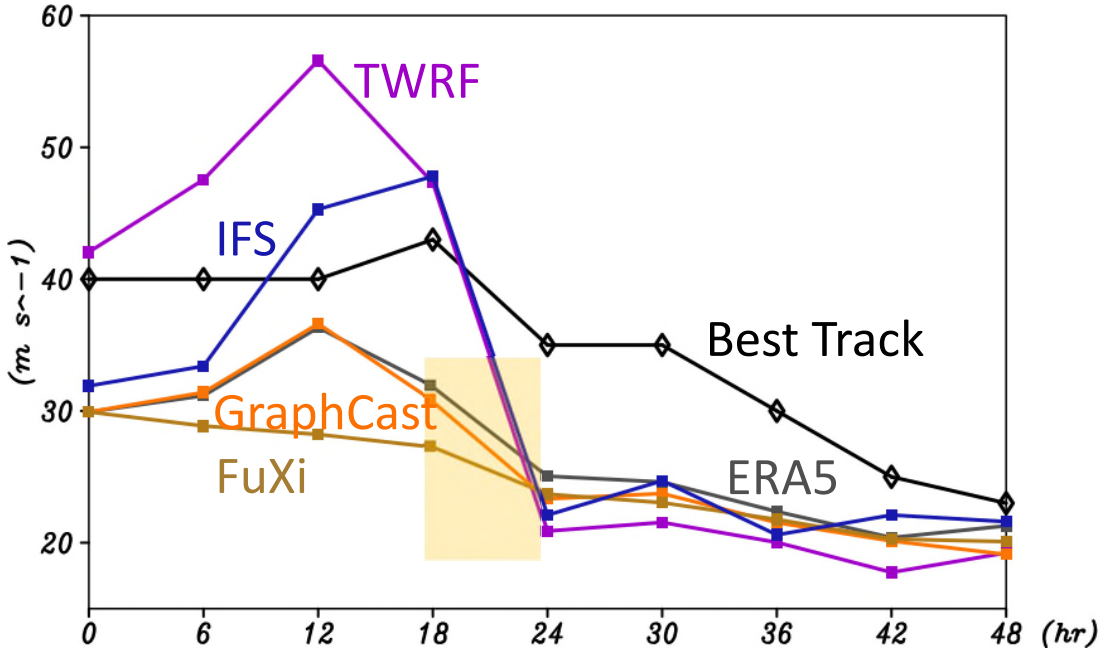
However, their coarse resolution and lack of detailed structure limit their ability to predict typhoon intensity, strong winds, and heavy rainfall at the regional scale.

(Liu et al., 2024)

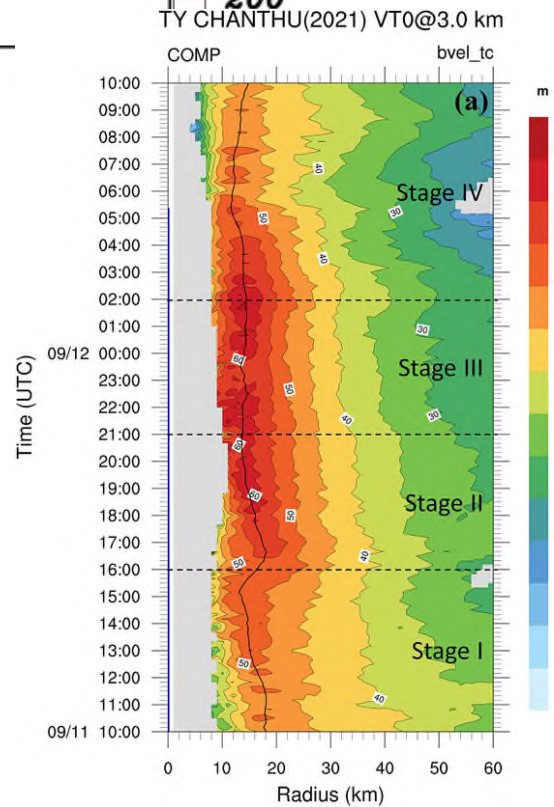
Typhoon Haikui (2023) 48-h Forecasts Track & Intensity







Typhoon Chanthu (2021)
tangential wind at 3-km altitude



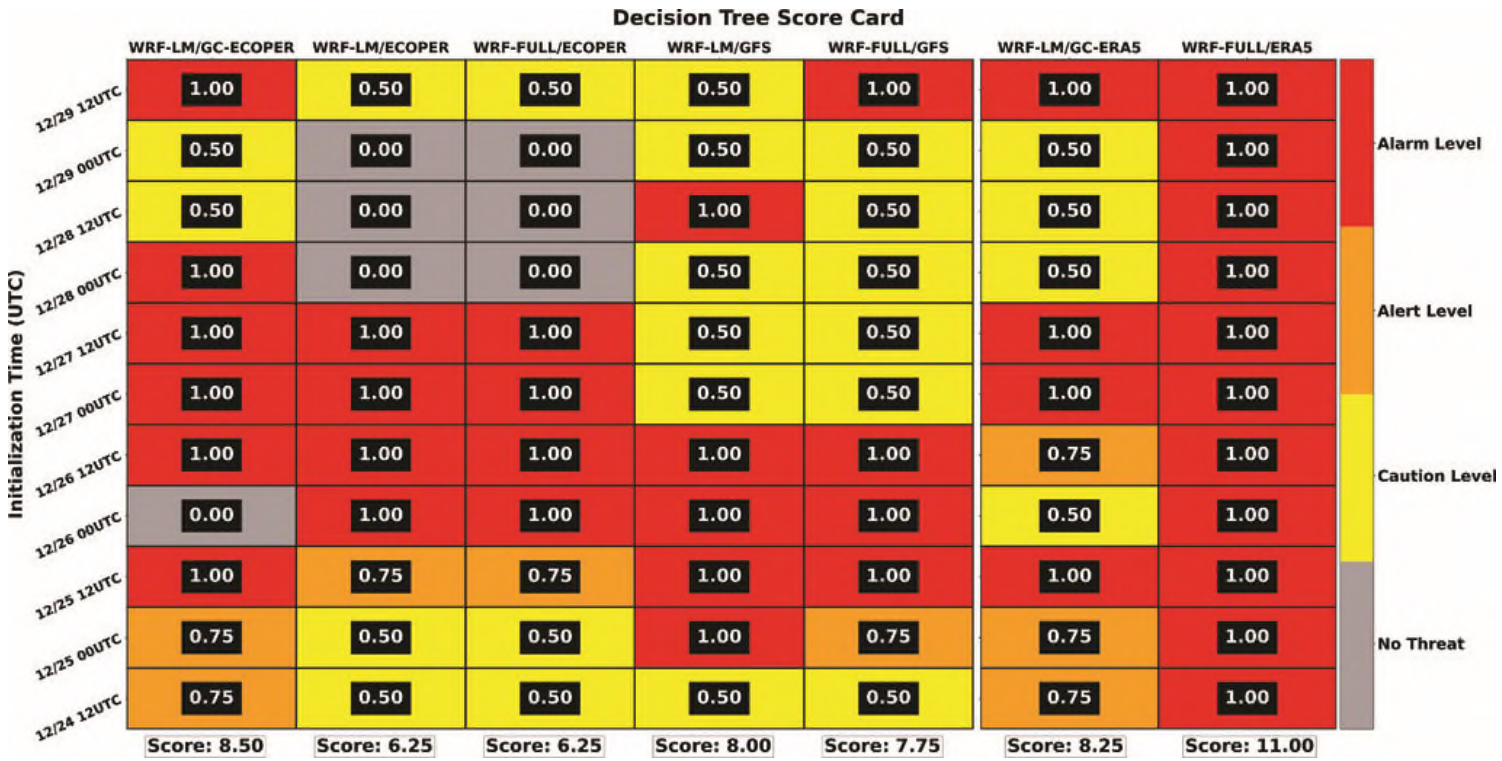
(Fang et al., 2024)

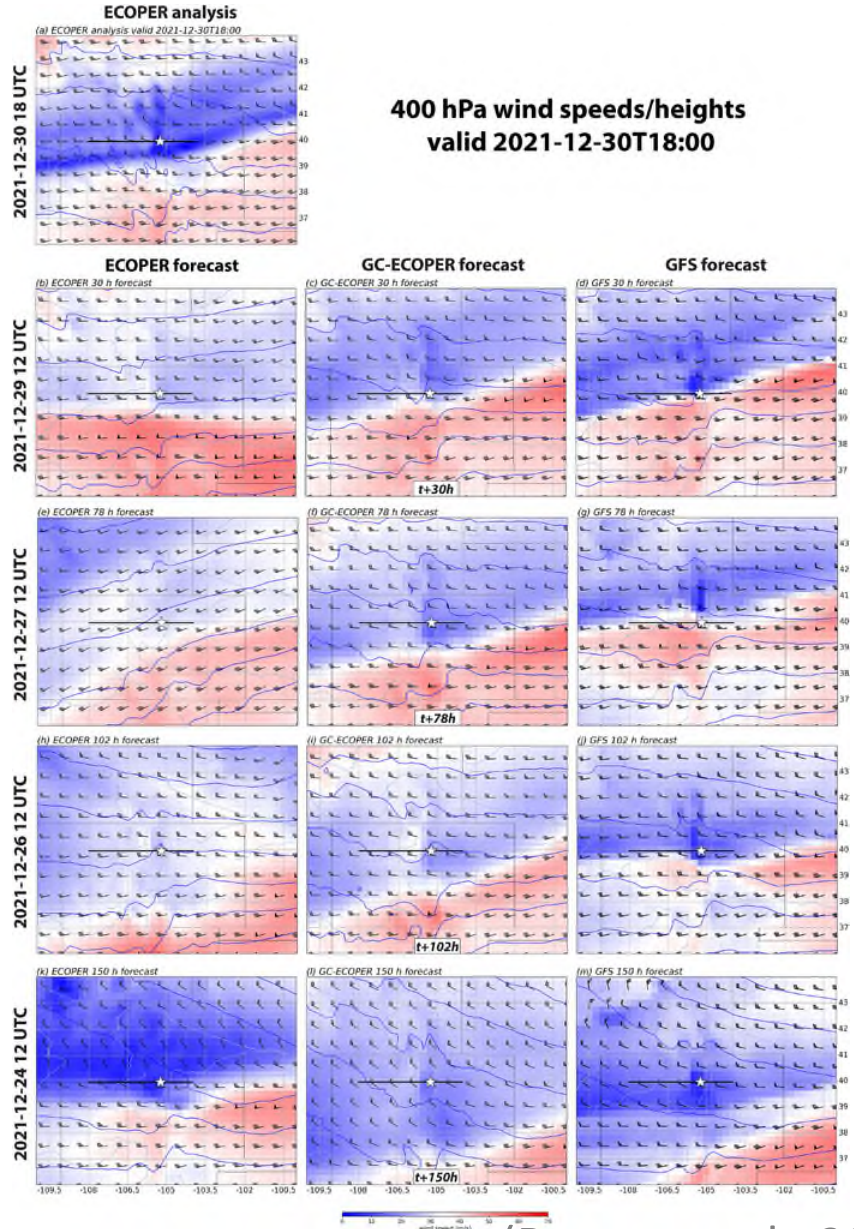
Motivation

1. Machine learning-based weather prediction (MLWP) models have achieved good skill in typhoon track forecasting.
2. However, their coarse resolution and lack of detailed structure limit their ability to predict typhoon intensity, strong winds, and heavy rainfall at the regional scale.
3. To address these limitations, an effective approach is to use MLWP models for synoptic-scale forecasts, which are then refined by high-resolution regional models to better capture detailed structures and local impacts.

Hybrid Weather Forecasting

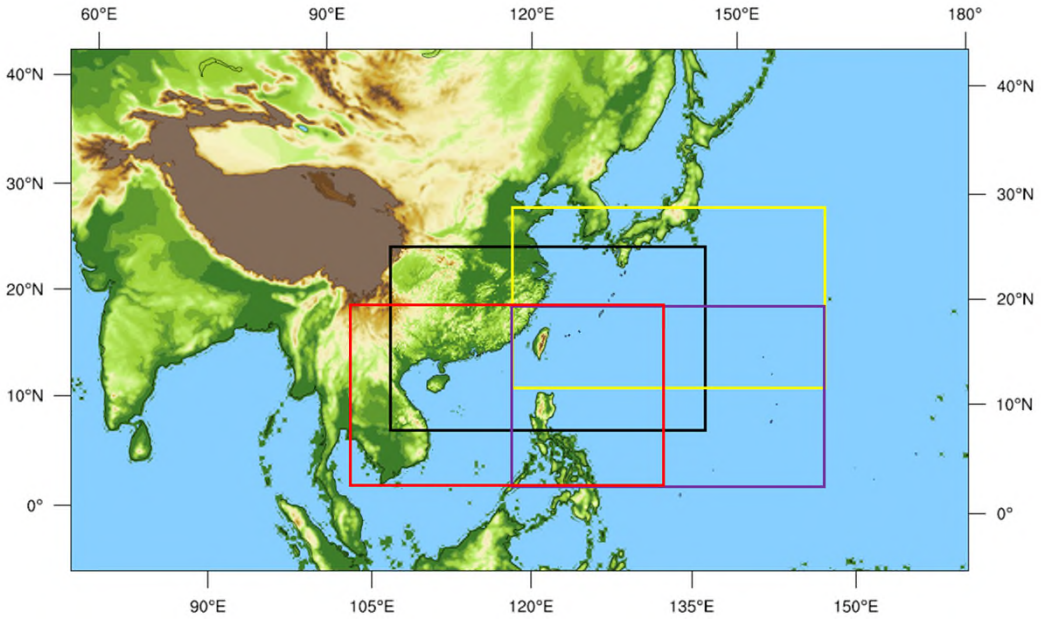
GC-initialized WRF forecasts are competitive with those guided by NCEP and ECMWF operational products, offering a promising hybrid approach for utility weather forecasting.





(Brewer et al., 2025)

Configuration of TWRF & Experiment Design



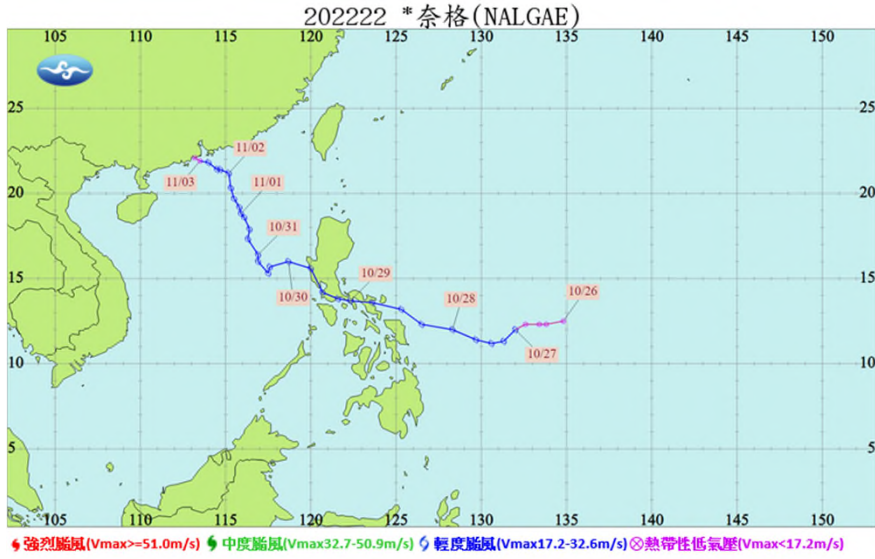
Domain	D01	D02
Grid points	662*386	1161*676
Resolution (km)	15	3
Vertical level	52	
Physical scheme	Goddard	
Cumulus parameterization scheme	Kain-Fritsch	-----
Planetary boundary layer scheme	YSU	
Land surface process scheme	Noah land surface model	
Radiation process scheme	RRTMG	

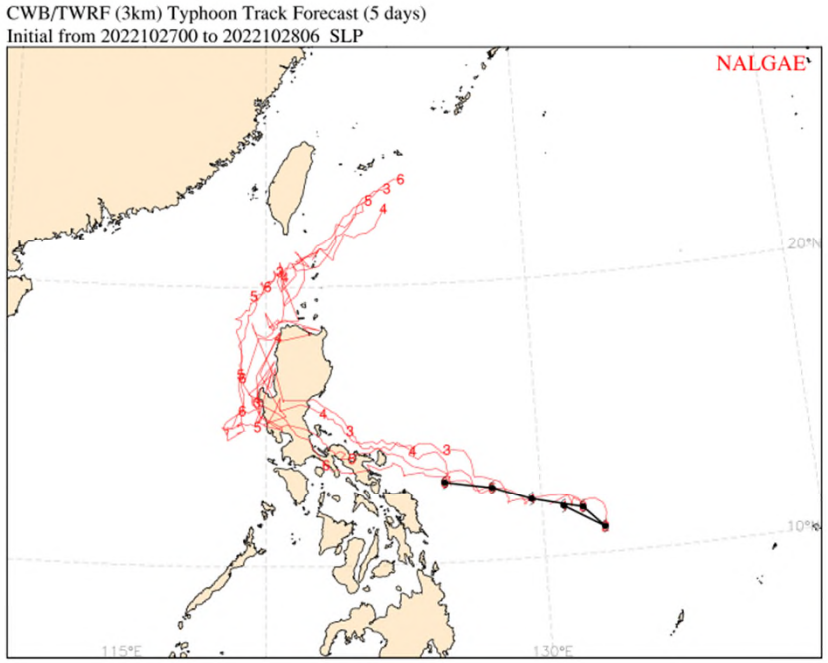
	GraphCast
	37 levels
1 hPa	u (Zonal Wind)
.	v (Meridional Wind)
.	w (Vertical Wind)
.	z (Geopotential)
.	q (Specific humidity)
1000 hPa	T (Temperature)
Surface	NCEP GFS

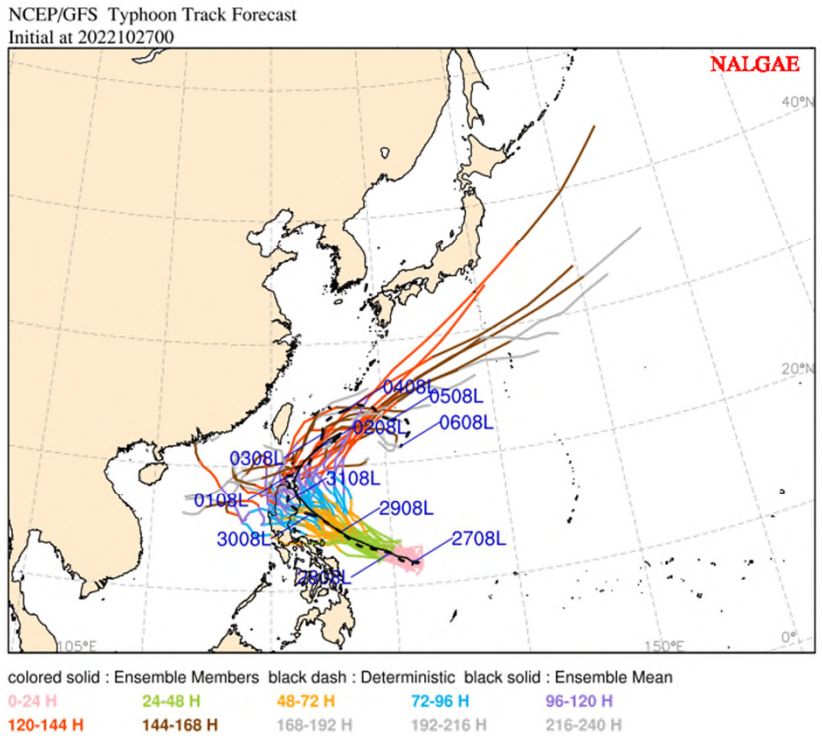
Experiment	TWRF	TWRF_GCera5
IC		ERA5
BC	EC+NCEP	GraphCast
Surface		NCEP

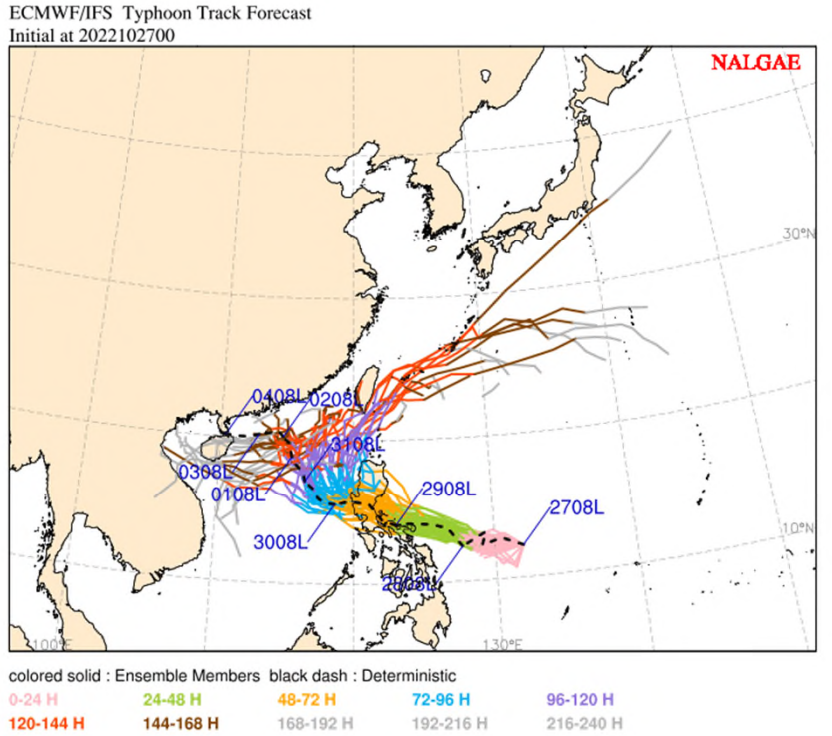
Case Study: Typhoon Nalgae (2022)

1. Early forecasts showed large divergence in track after Nalgae crossed the Philippines.
2. In particular, TWRF predicted an early northward turn, incorrectly suggesting that Taiwan would be significantly affected.



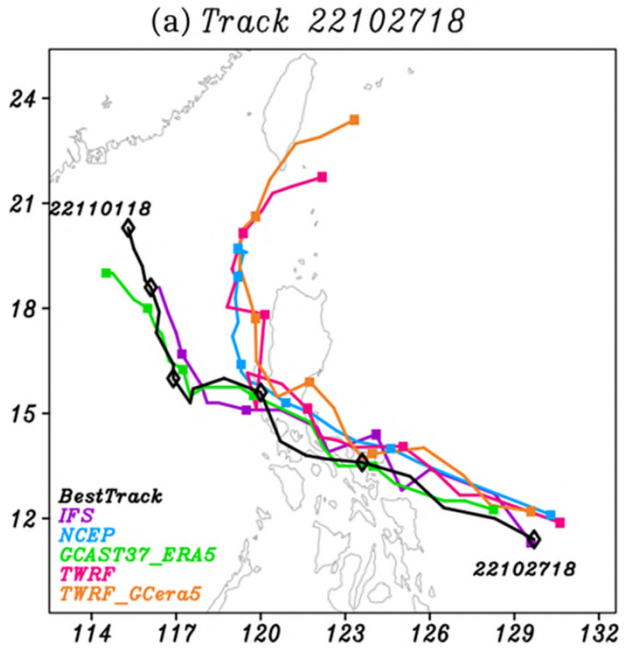


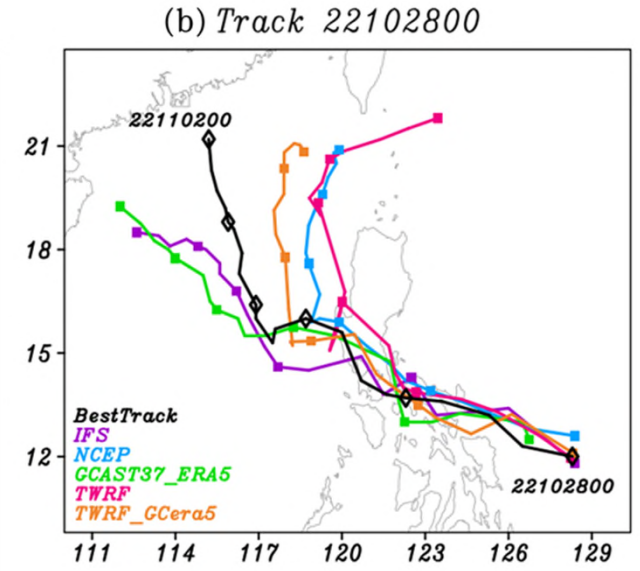


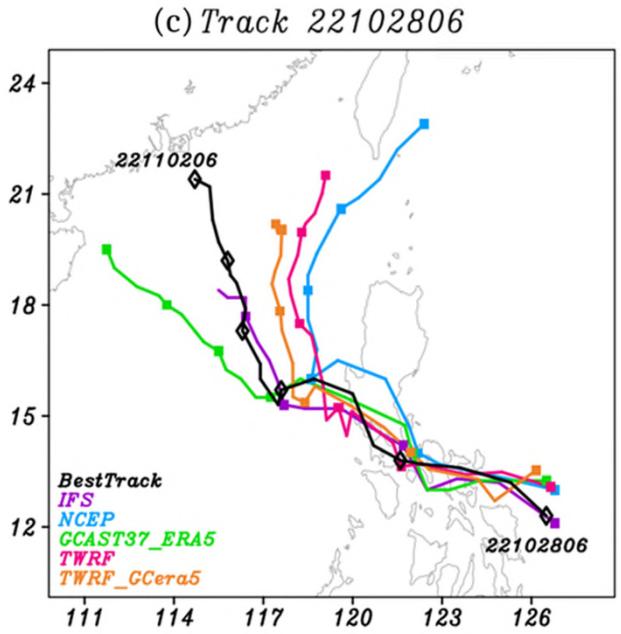


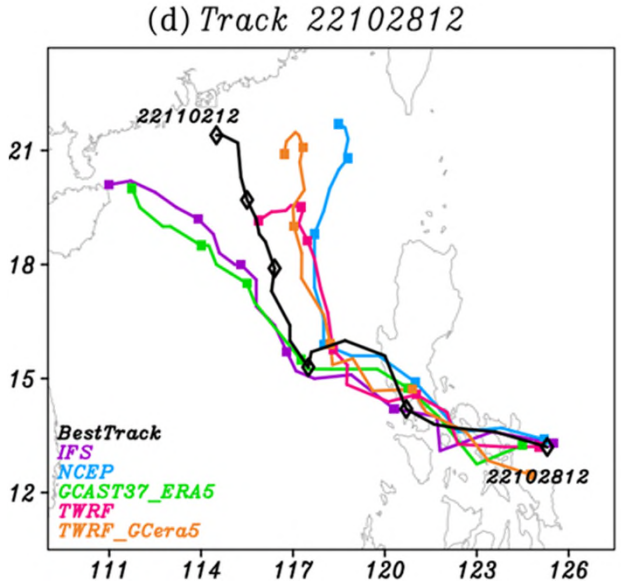
Track Forecast

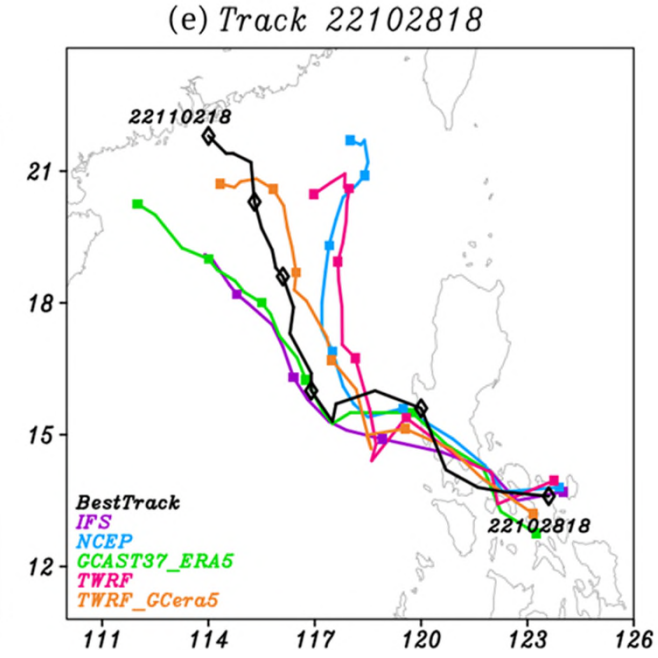
1. IFS and GraphCast provide comparably good track predictions.
2. NCEP and TWRF tend to predict and earlier northward turn, a consistant eastward bias after crossing the Philippines.
3. The hybrid–TWRF (TWRF_GCera5) shows clear improvements in reducing this eastward bias.



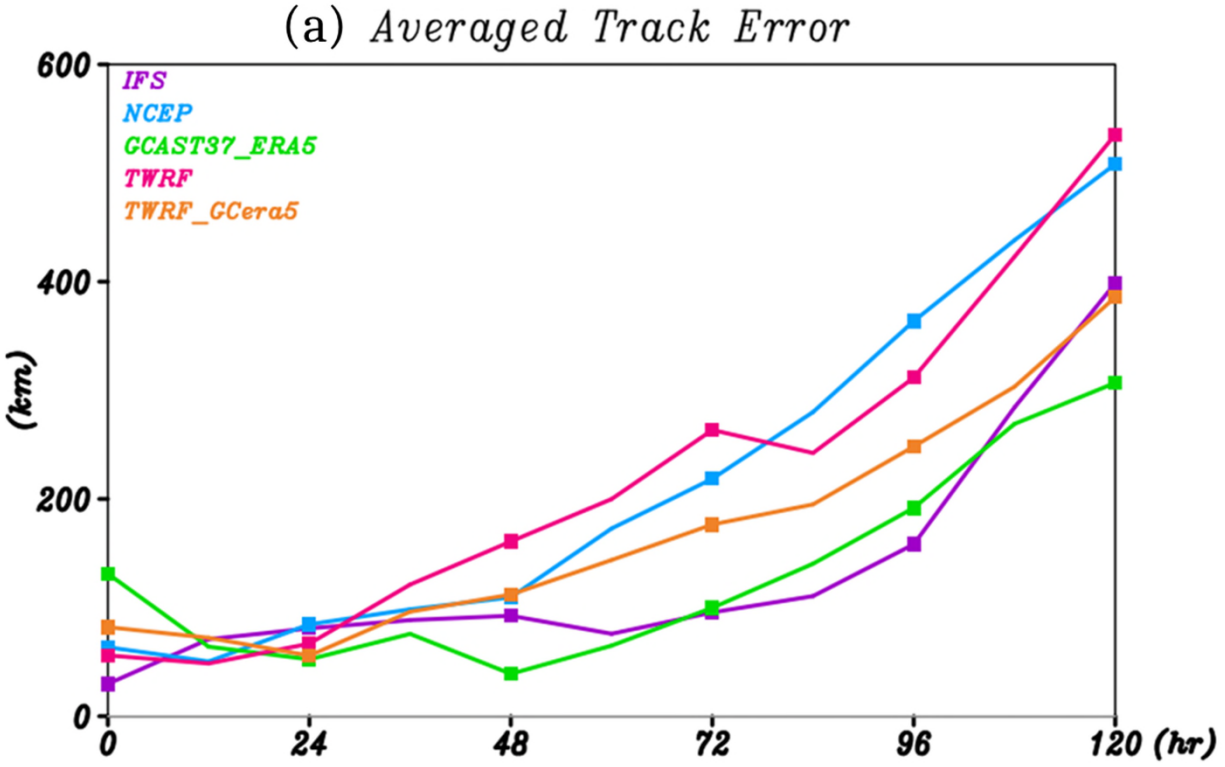


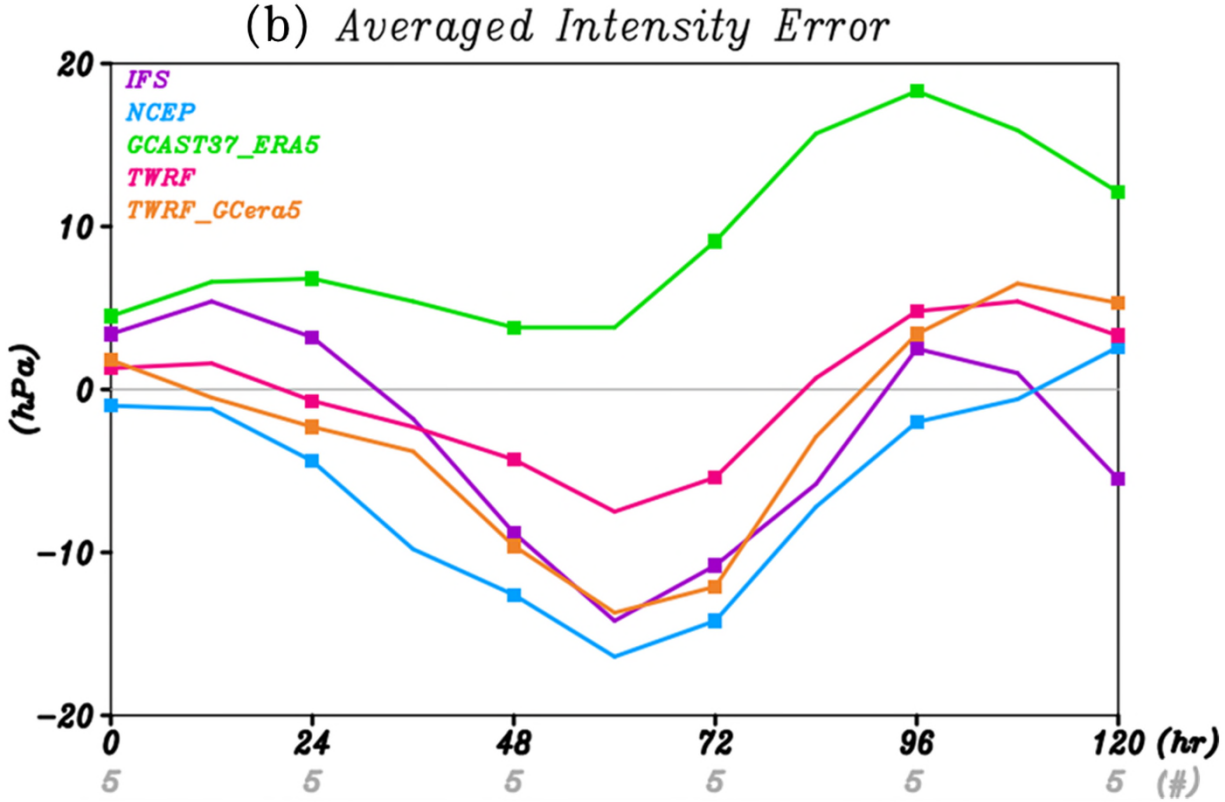






Averaged Track & Intensity Errors





The hybrid-TWRF demonstrated improved track prediction compared to the original TWRF and produced comparable intensity forecasts. These results highlight the potential of this hybrid method for enhancing typhoon forecasts within regional dynamical models

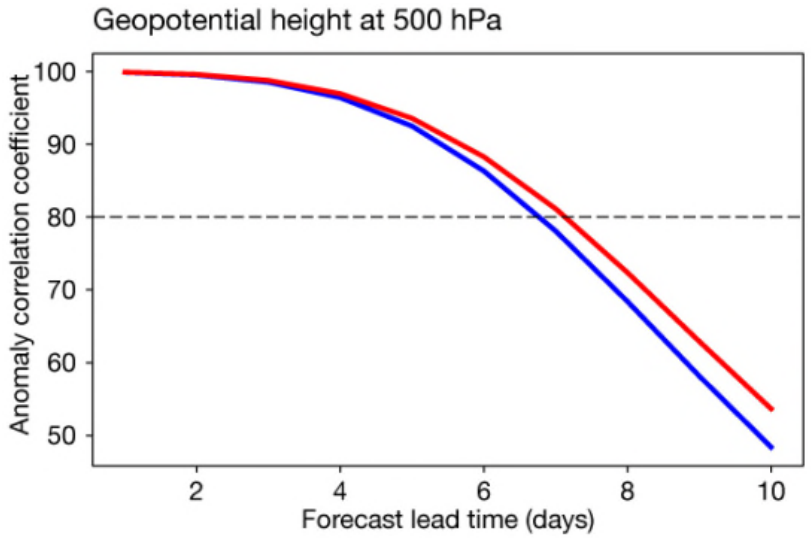
Future Work

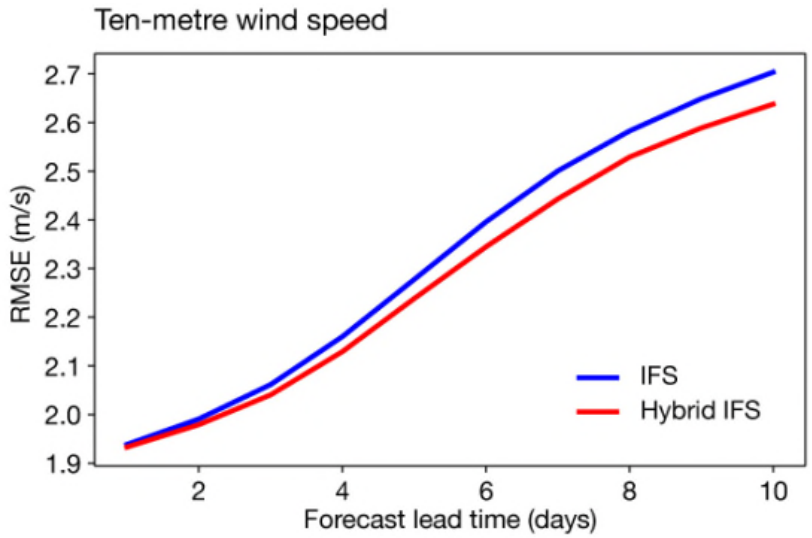
1. More typhoon cases will be tested to assess the robustness and general applicability of this hybrid method across different storm types.
2. Further investigation is needed to understand the dynamical response of TWRF to MLWP-derived boundary conditions.
3. The impact of using different MLWP models or ensemble members as boundary conditions will also be explored.
4. Explore the application of spectral nudging to better constrain large-scale circulation in the hybrid modeling framework, thereby improving typhoon track and intensity forecasts.

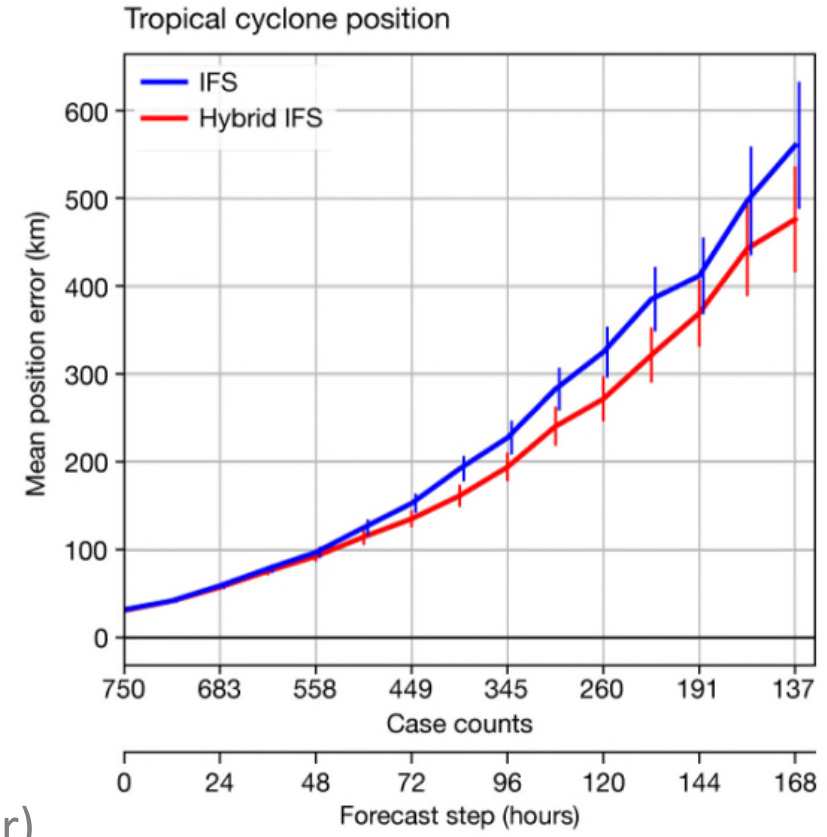
Application of Spectral Nudging

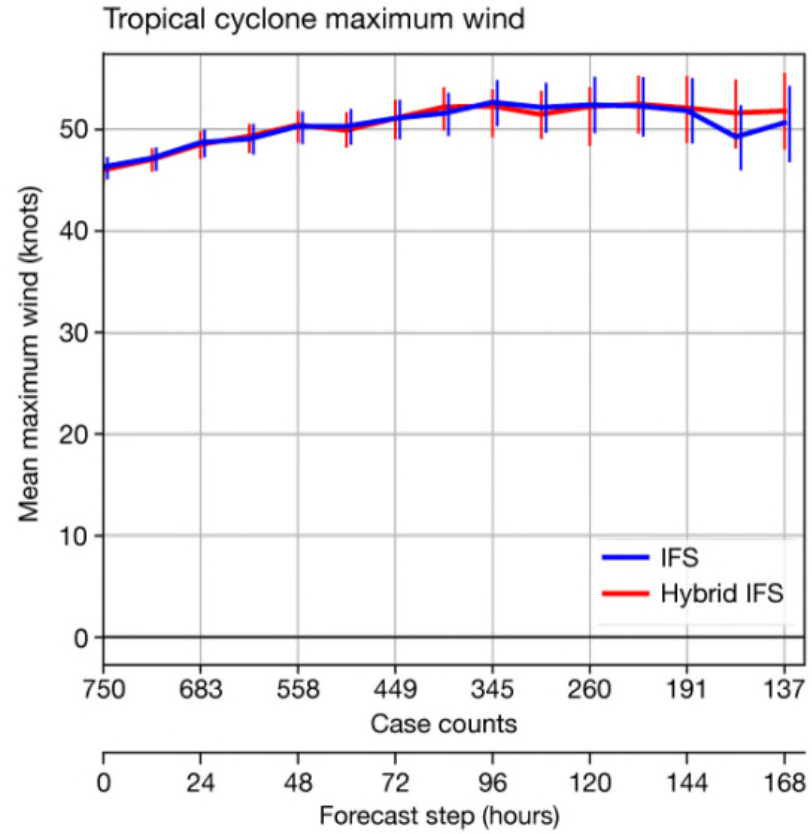
1. A hybrid system applying spectral nudging to constrain the large-scale temperature and vorticity of IFS to AIFS forecasts, while allowing small-scale features to evolve under IFS physics.
2. The hybrid model improves northern hemisphere skill scores by 15–20% for upper-air and surface fields.
3. At day 5, the hybrid model reduces track errors by ~50 km.

(ECMWF Newsletter)







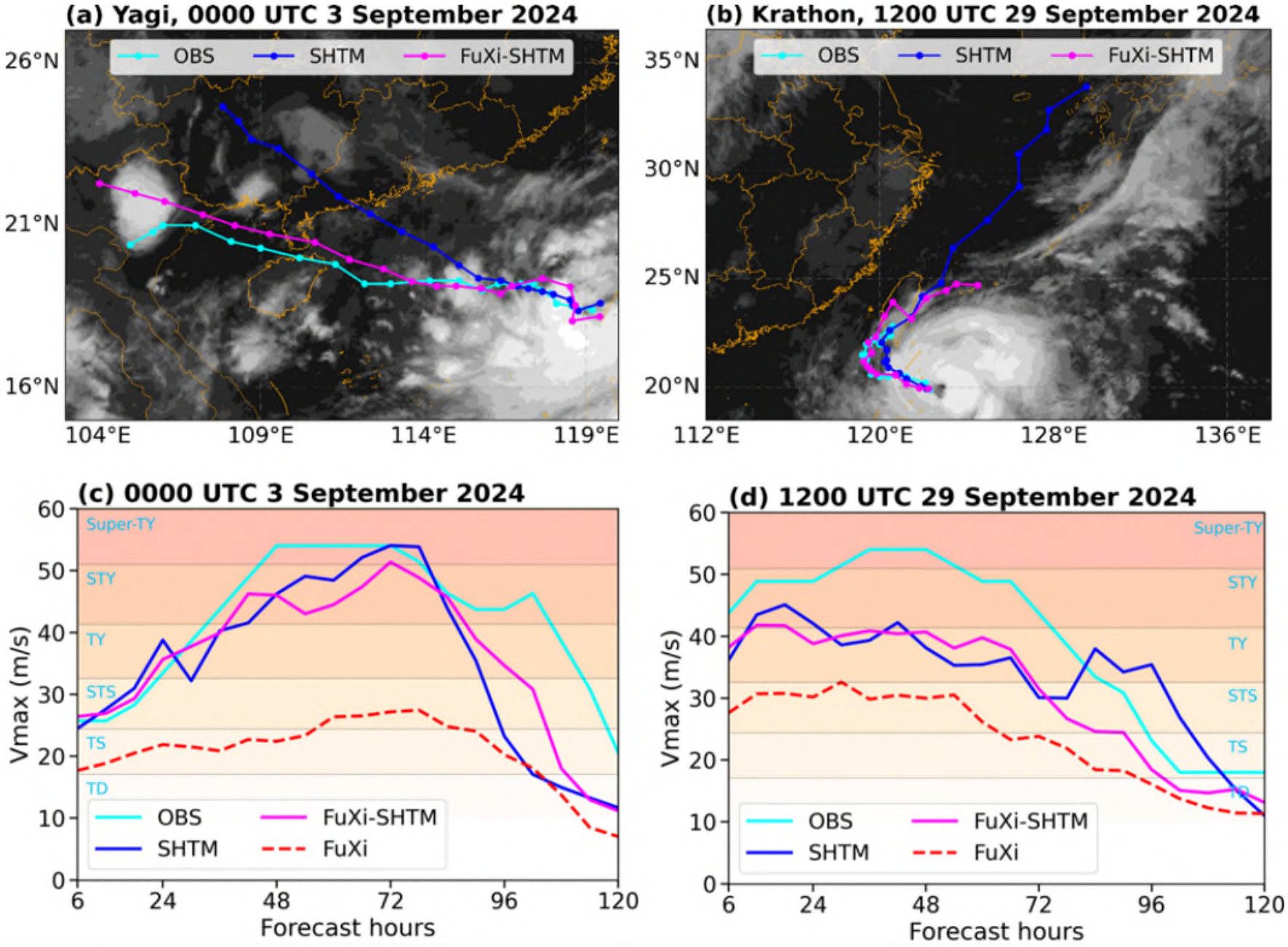


Application of Spectral Nudging

1. FuXi-SHTM:

   Uses spectral nudging to combine ML-based FuXi (large-scale forecasts) with physics-based SHTM (Shanghai Typhoon Model) (mesoscale processes).

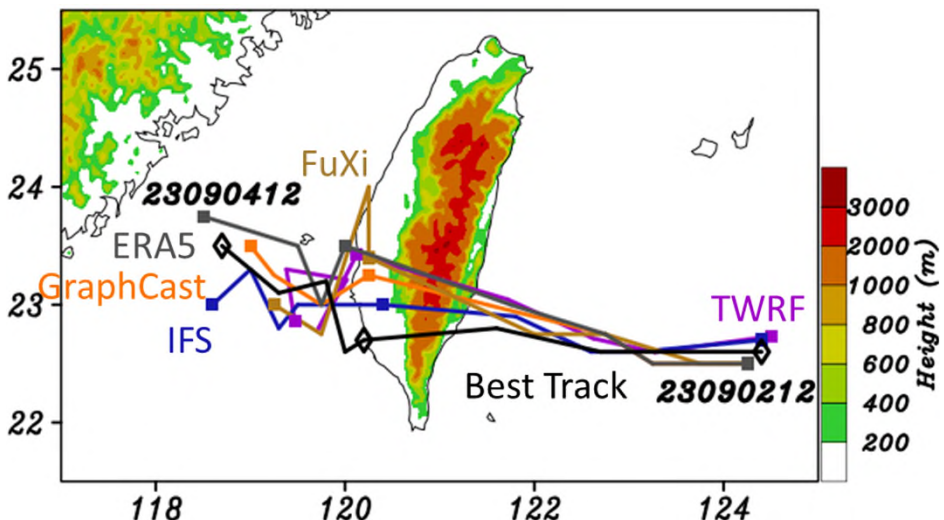
2. Improves track & intensity forecast of Typhoon Yagi (2024) and Krathon (2024).

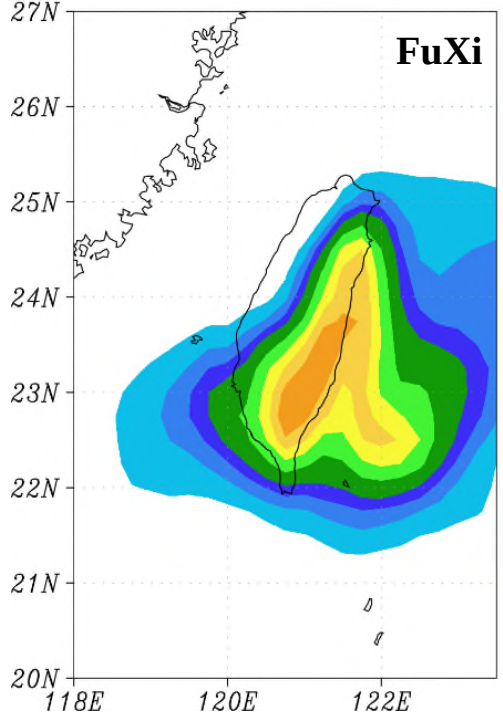


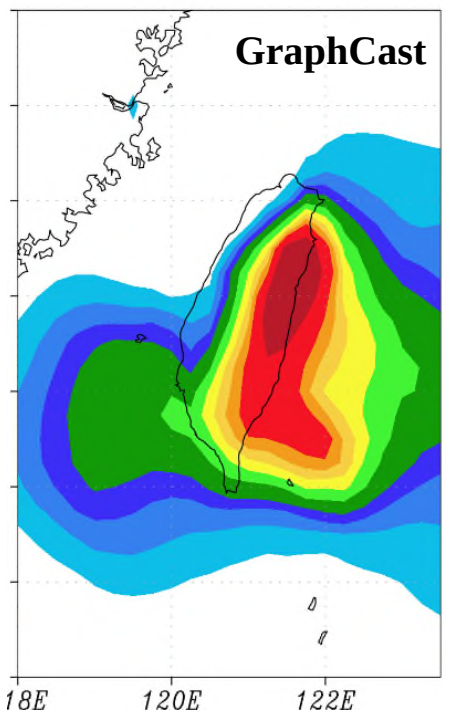
(Niu et al., 2025)

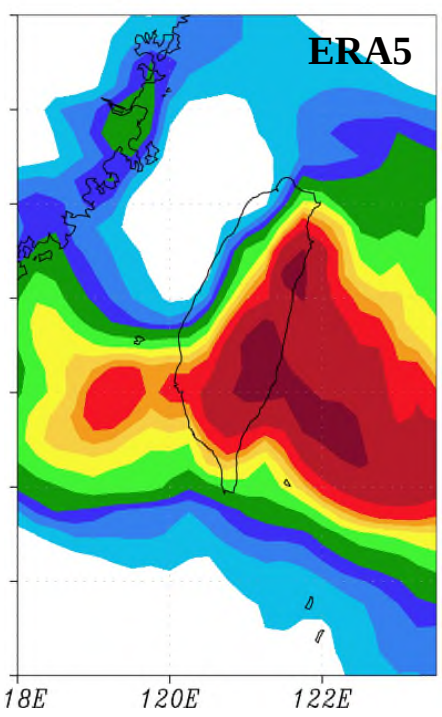
Typhoon Haikui
48-h Accumulated Rainfall

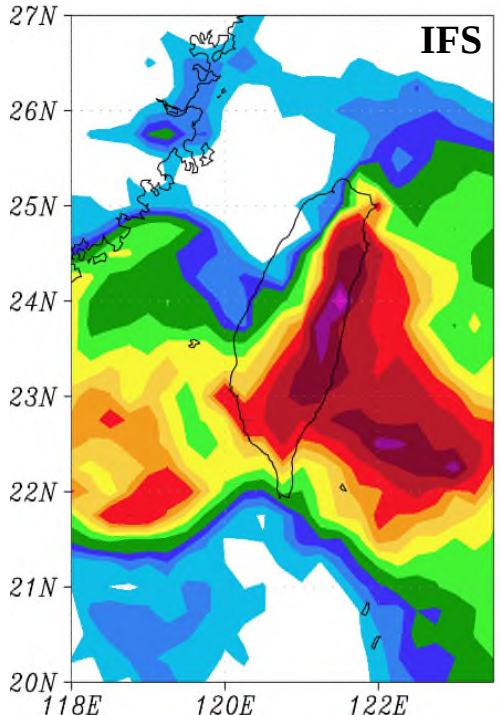
1. Only **TWRF (3 km) reaches** rainfall over **700 mm**
2. **ERA5 and IFS shows** good rainfall **pattern with less detail**
3. **FuXi and GraphCast** show **smaller** amount.
4. Despite a small TC track difference, **FuXi's weaker rainfall** may **be from weaker TC intensity** during the first 24 hours

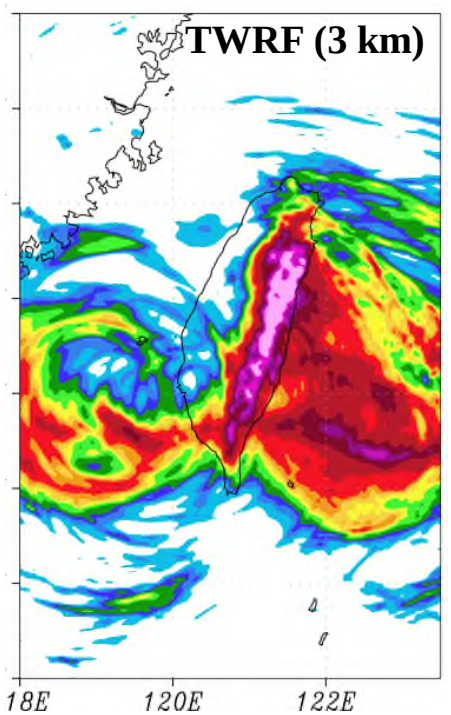


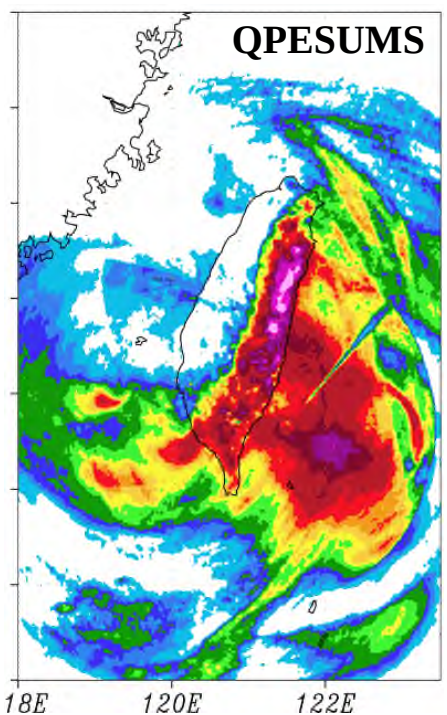












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