Evaluations of the PanGu Weather Ensembles in Tropical Cyclone Forecasting

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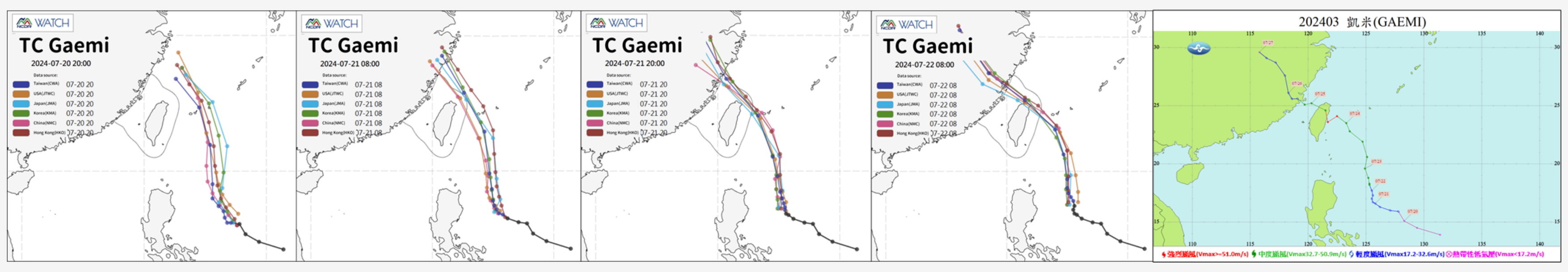
Introduction

In Taiwan, Tropical Cyclones(TC) are the most common extreme weather events. Their strong winds and heavy rainfall frequently cause damage. Enhancing the ability to forecast TC intensity and track is the primary direction we want to improve.

Pangu Weather(PGW) has demonstrated strong performance in TC track forecasts but often exhibits weaker intensity forecasts compared to observations.



Gaemi was the first TC landfall in Taiwan in 2024. It was characterized by rapid intensification as it approached Taiwan, with forecast tracks from various countries differing from the observation track. Its strong winds and heavy rainfall caused significant impacts in Taiwan.

We focuses on Gaemi to understand whether integrating the PGW with ensemble simulations can improve the forecasting.

Data and Method

Data sources

1. European Centre for Medium-Range Weather Forecasts(ECMWF) ERA5 reanalysis data.
2. Central Weather Administration(CWA) typhoon database.

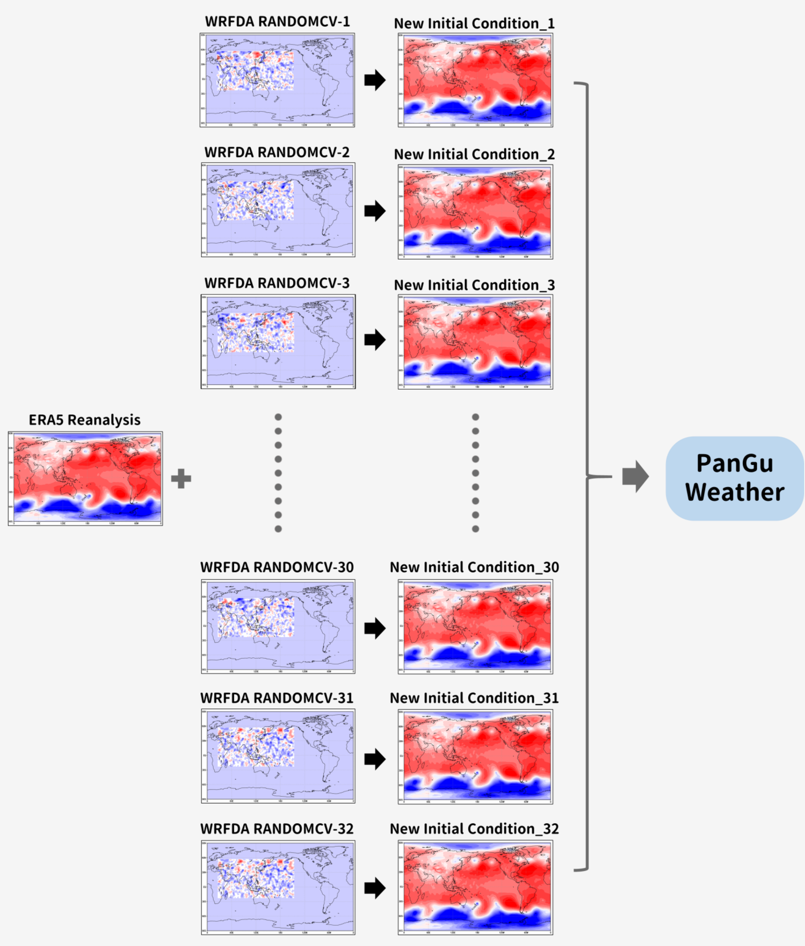
Data processing

1. Pangu Weather(PGW)

   It is a machine learning weather prediction (MLWP) model, trained on 39 years of ERA5 reanalysis data. We perform 120-hour forecast for each initial time.

2. WRFDA RANDOMCV

   We use WRFDA RANDOMCV to add random perturbation, covering approximately one-quarter of the Earth's surface, to ERA5 reanalysis data to create 32 initial conditions. Then, we extract only the noise components and integrate them with the original reanalysis data to form new initial conditions.



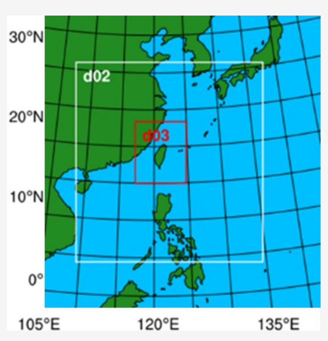
Methods

1. Ensemble:

   The first initial time is set to five days before the TC landfall, resulting in a total of five initial times. For each initial time, 32 random perturbation ensemble members are generated.

2. Forecast verification:

   We use a 2500 km*2500 km area centered on Taiwan to validate the mean variable errors.



3. TC case study:

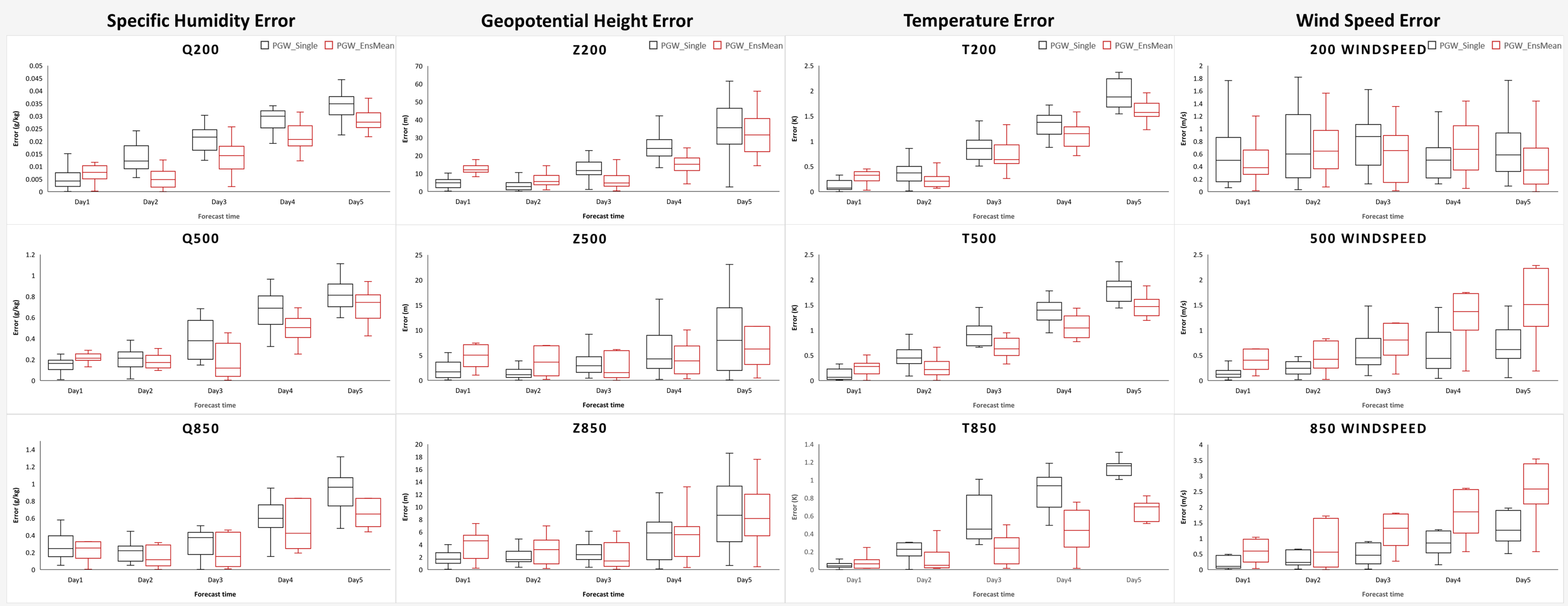
   Mean track errors and minimum sea level pressure(MSLP) errors are used to assess the performance in forecasting TC tracks and intensities.

References

1. Bi, K., Xie, L. et al. (2023). Accurate Medium-Range Global Weather Forecasting with 3D Neural Networks. Nature, 619, 533–538. Doi: 10.1038/s41586-023-06185-3
2. Bozzznavita, M. (2024). On Some Limitations of Current Machine Learning Weather Prediction Models. Geophysical Research Letters, 51(12). Doi: 10.1029/2023GL107377
3. Bouallègue, Z. B. et al. (2024). The Rise of Data-Driven Weather Forecasting: A First Statistical Assessment of Machine Learning–Based Weather Forecasts in an Operational-Like Context. Bulletin of the American Meteorological Society, 105(6), 864–883. Doi: 10.1175/BAMS-D-23-0162.1

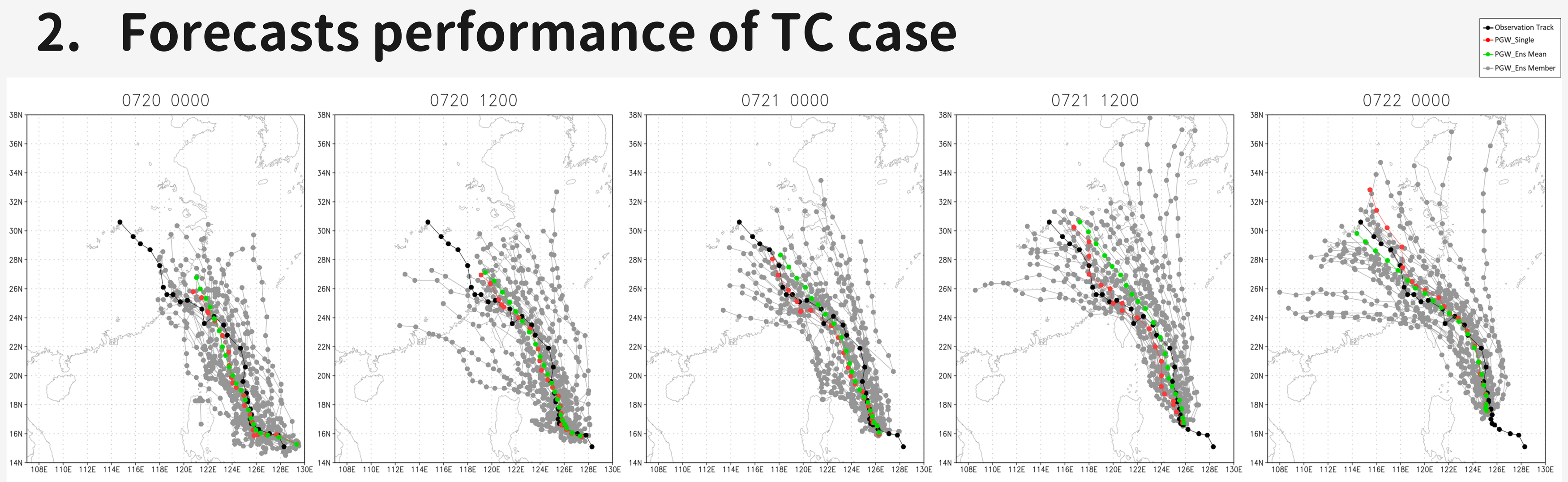
Results

1. Variable errors at different pressure levels

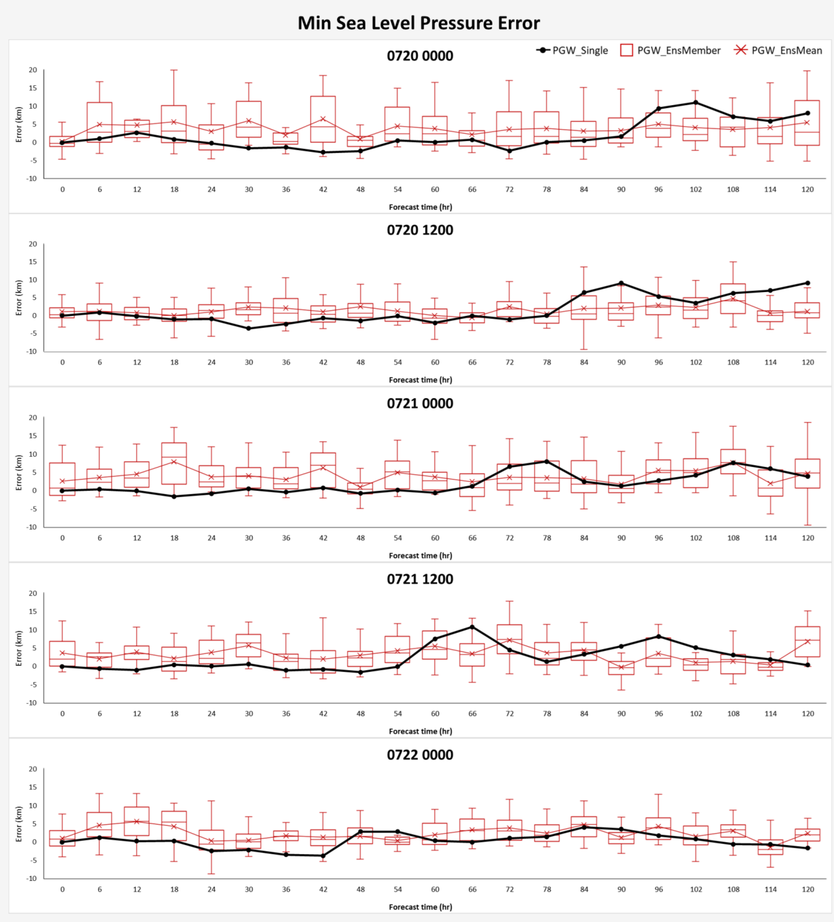


Specific humidity, geopotential height, and temperatures across the lower, middle, and upper levels indicate that the Pangu ensemble (PGWEns) consistently outperforms the Pangu single member (PGWSingle) beyond the third day of the forecast period. This improvement effectively addresses the issue of growing forecast errors in the original PGWSingle over extended durations.

2. Forecasts performance of TC case



From the TC track error chart, both PGWEns and PGWSingle show excellent track forecast capabilities. As the TC approaches landfall in Taiwan, their forecast tracks tend to be more closely with observations. However, the insufficient spread of PGWEns (around 0.5) may explain why its track errors are occasionally larger than those of PGWSingle. This situation also occurred in MSLP, accompanied by weaker intensity predictions. Yet, certain members were able to produce intensity forecasts close to observations across five initial times.



Conclusions

PGWEns generating environments closer to observations in a simplified and efficient way, addresses declining accuracy beyond longer forecast time. For TC case, its forecast performance is comparable to PGWSingle, but some members achieve significantly smaller errors, showcasing the potential of PGWEns. Enhancing spread and prediction capabilities could refine forecasts and aid disaster prevention efforts in Taiwan.

Future Works

1. Enhance Perturbation: Test higher perturbations to improve forecast accuracy for longer durations.
2. Expand Perturbation area: Extend the area beyond one-fourth of earth to enhance prediction performance.
3. Analyze TC-Related Systems: Examine key systems affecting tracks and intensities, like monsoon trough and subtropical high.
4. Add Diverse Cases: Include TCs from various months and strengths for broader evaluations.

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