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Machine Learning-Based Global Ensemble Weather Prediction for Medium-Range Forecasting

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Background

Machine learning-based weather prediction (MLWP) models trained with operational reanalysis data or observations are demonstrating proficient forecasting abilities in the past couple of years. These models take significantly fewer computational resources than traditional numerical weather prediction (NWP) models and produce forecasts comparable to or better than the conventional NWP models.

In alignment with NOAA's AI strategic plan to dramatically expand the application of artificial intelligence (AI) in every NOAA mission area, we started MLWP development at NCEP EMC collaborating with NOAA research laboratories and the AI/ML communities. Here we present the results from global deterministic and ensemble forecasts.

ML development for global forecasts

❖ Build and train MLWP model GraphCast[1] with NCEP GFS data

- ➢ Build pre-trained ML-based weather prediction (MLWP) model GraphCast with Global Forecast System (GFS) data as input
- ➢ Establish near real time experimental global forecasts using GraphCast with GFS analysis as input, model weights are from GraphCast model trained with ERA5 by Google Deepmind
- ➢ Fine tune GraphCast with Global Data Assimilation System (GDAS) (a system to place observations onto grid space for GFS) as inputs for 20210321-20231231 with both ERA5 (GraphCastGFS13 or GGFS) and GDAS as truth dataset.
- ➢ Train GraphCast with GDAS as initial condition and truth dataset (GraphCastGFS13_test or TGFS)

❖ Develop ML Global Ensemble Forecast System

- ➢ Set up GraphCast based global ensemble model with pre-trained weights from Google Deepmind and GEFS v12 initial conditions generated from GDAS EnKF[2].
- ➢ Set up ML based global ensemble model (GCGEFS) with ensemble members created from fine tuned Graphcast weights, and inputs are still from GDAS EnKF.
- ➢ Build and set up GenCast[3] from Google Deepmind with GDAS EnKF initial conditions.

❖ Build a super ensemble with GCGEFS and operational GEFSv12[4]

- ➢ Build a super ensemble forecast system with 31 members of GCGEFS and 31 members of NWP operational GEFSv12.

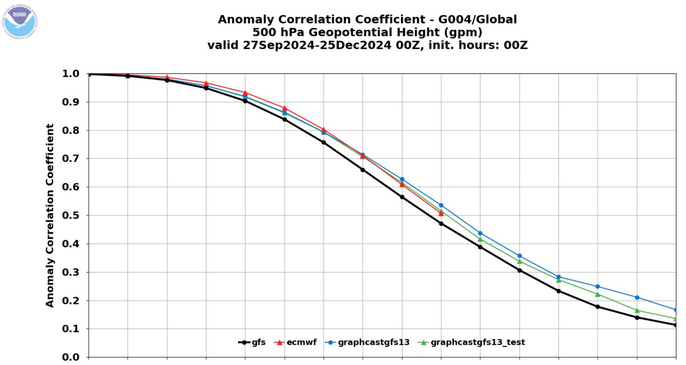
❖ Evaluate ML weather forecasts

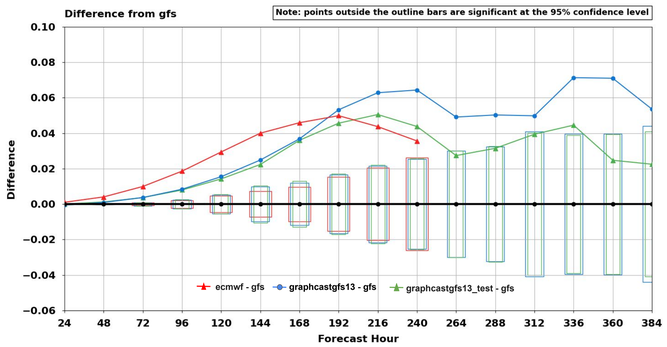
- ➢ Expanding the operational model evaluation package to ingest MLWP forecast results
- ➢ Evaluating ML global ensemble forecast results against model analysis and observations.

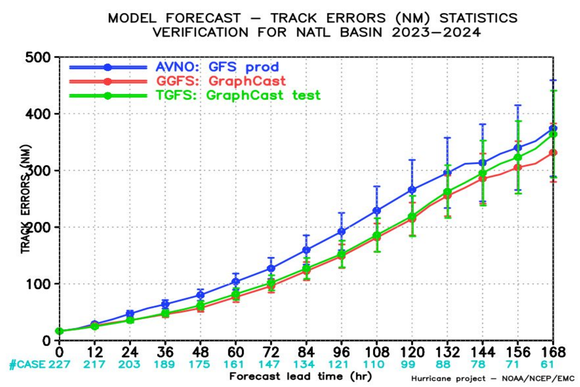
Reference:

1. Remi Lam et al. Learning skillful medium-range global weather forecasting. Science 382,1416-1421(2023). DOI:10.1126/science.adi2336
2. Zhou, Xiaqiong, et al. A Comparison of Perturbations from an Ensemble Transform and an Ensemble Kalman Filter for the NCEP Global Ensemble Forecast System. *Wea. Forecasting*, **31**, 2057–2074, (2016) https://doi.org/10.1175/WAF-D-16-0109.1.
3. Price, I., Sanchez-Gonzalez, A., Alet, F. et al. Probabilistic weather forecasting with machine learning. Nature 637, 90 (2025). https://doi.org/10.1038/s41586-024-08252-98
4. Zhou, Xiaqiong, et al. The Development of Next NCEP Global Ensemble Forecast System, STI Climate Bulletin, 159-163. (2019)

GraphCastGFS 16-day Forecasts



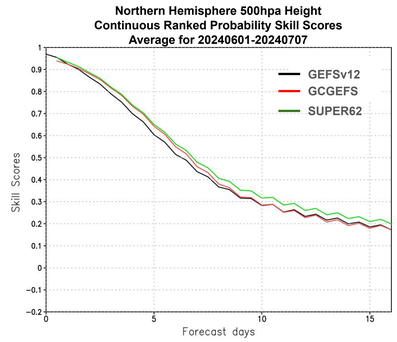


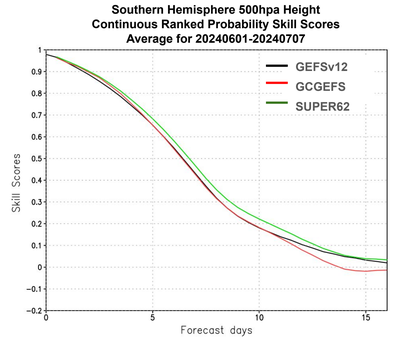


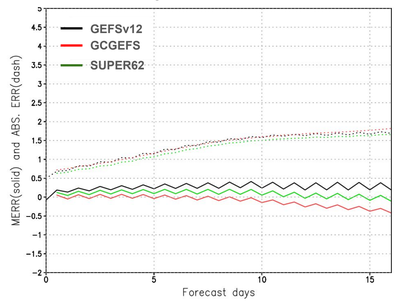
Results

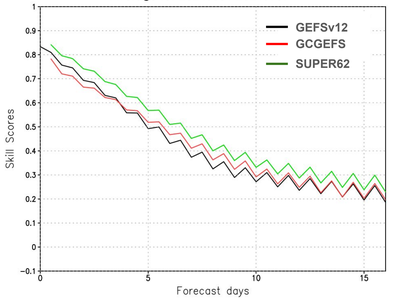
- ➢ Both GraphCastGFS13 (fine tuned with ERA5 using GDAS as initial condition) and GraphCastGFS13_test (trained with GDAS initialized with GDAS) performs significantly better than GFS. GraphCastGFS13 performs better than GraphCastGFS13_test.
- ➢ Both GGFS(GraphCastGFS13) and TGFS(GraphCastGFS13_test) showed reduction on hurricane track error on north Atlantic ocean for 2023-2024 hurricanes.
- ➢ GCGEFS shows performance comparable to GEFSv12 but requires significantly less resources to run, while the 62 member super ensemble with combined GCGEFS and GEFSv12 shows better skills than GCGEFS and GEFSv12.

Global Ensemble Forecasts









Resources for a Single 16 Day Global Ensemble Forecast

	Operational GEFSv12 31 members	GCGEFS 31 members
Number of cores	12288 CPU cores	8 GPU core2
Run time	160 mins	6 mins

Access MLWP models

- The MLWP Repository is managed on github for public access

https://github.com/NOAA-EMC/graphcast

https://github.com/NOAA-EMC/FourCastNet

https://github.com/NOAA-EMC/MLGEFS

https://github.com/NOAA-EMC/MLSFS

- The experimental global forecasts are available on NOAA AWS cloud

https://noaa-nws-graphcastgfs-pds.s3.amazonaws.com/index.html

https://noaa-nws-fourcastnetgfs-pds.s3.amazonaws.com/index.html

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