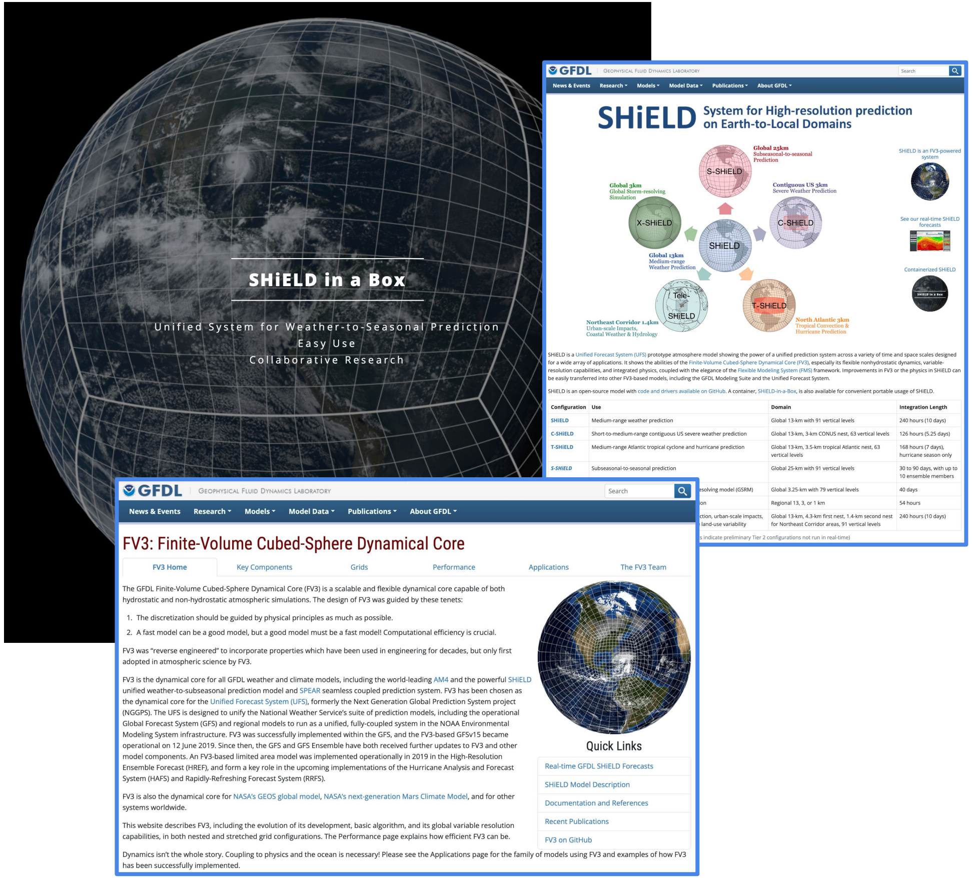
Advanced Weather Prediction Initiatives and Short-term Forecasts
- Mingjing Tong

Q3: How can GFDL research and modeling be further utilized to meet NOAA stakeholder needs and enhance research partnerships to ensure GFDL's success?

FV3 Team Public Resources

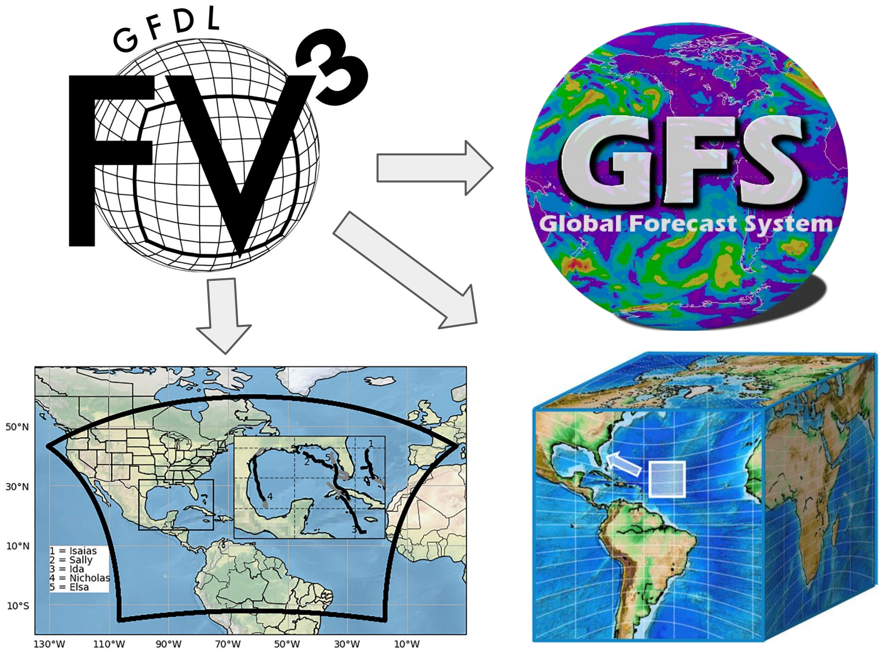
- FV3 & SHiELD portals
  Hubs for information, publications, and results
- Extensive Documentation for FV3 and the GFDL Vortex Tracker
- SHiELD-in-a-Box container
  Convenient end-to-end simulation anywhere including pre- and post-processing
- GitHub Public Releases
  Build environments, Issue Tracking, Continuous Integration, Examples, and more



Courtesy Lucas Harris

Continued NWS collaboration on FV3, GFDL Microphysics

- FV3 forms the dynamical core of the UFS and of a number of NCEP operational models: GFS, GEFS, HAFS (Harris et al. 2020, Zhou et al. 2022, Hamill et al. 2022, Guan et al. 2022, Ye et al. 2023, Hazelton et al. 2021, 2022)
- NCEP & GFDL collaborate on grid systems (Mouallem et al. 2022), whole & deep atmospheres, physics- dynamics coupling (Zhou and Harris 2022) and more. Shared GitHub repos facilitate knowledge and code transfer (Ramstrom et al. 2024, Kar et al. 2021)
- GFDL Microphysics has been used in several operational models and version 3 (Zhou et al. 2022) is being tested for HAFS v3



HAFS Domain (Alvey and Hazelton 2022)

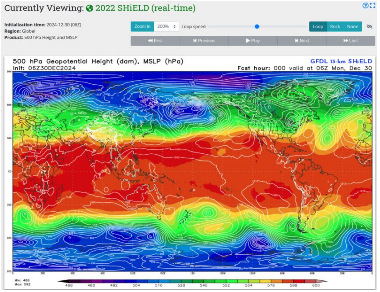
Moving Nest

Courtesy Linjiong Zhou

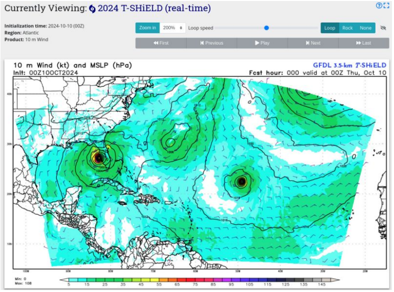
SHiELD real-time systems and public data

SHiELD real-time forecasts provide real-time forecast guidance, model performance evaluation and demonstrate model advances.

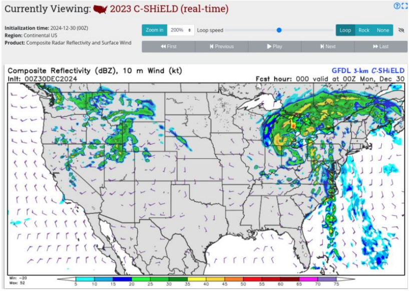
SHiELD:
Global medium-range weather prediction



T-SHiELD: Atlantic basin TC prediction.
Contributed to HFIP Real-time Experiment (HREx)



C-SHiELD: CONUS severe weather prediction
Contributed to HWT Testbed Spring Forecasting Experiment



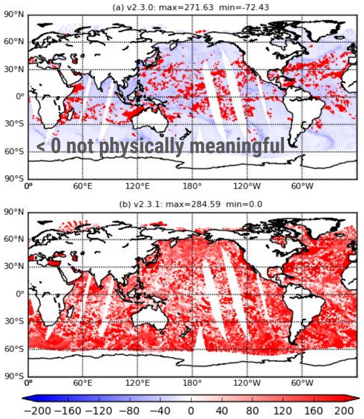
The SHiELD 4x-daily real-time forecast data have been archived on the GFDL PPAN since 2018 and are available for research purposes upon request.

Courtesy Linjiong Zhou

Cross-Line Office/Cross-agency Collaboration on All-sky Microwave Radiance Assimilation

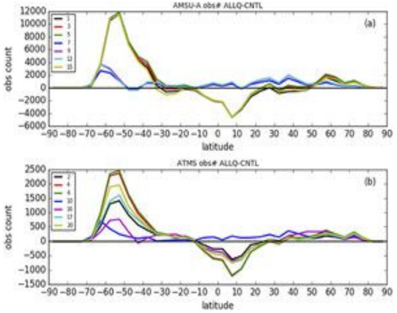
- The implementation of GFDL microphysics scheme in GFS (GFSv15) allows explicit prediction of precipitating hydrometeors (Zhou et al., 2019, Zhou et al., 2022)
- Developed new all-sky MW radiance assimilation framework that enable the assimilation of precipitation-affected radiance through collaboration with NCEP/EMC, NESDIS and JCSDA.
- The new all-sky framework has been implemented in GFS v16.3
- Research on non-gaussian observation error for all-sky MW assimilation (see poster by Chih-Chi Hu)
- Continue collaborating with JCSDA on CRTM new cloud table evaluation with the goal to improve the assimilation of MW radiances in deep convection regions.

Surface Emissivity Jacobian



~20% observation rejected due to negative emissivity jacobian can be assimilated with improved CRTM

One month AMSUA and ATMS data usage change relative to old framework



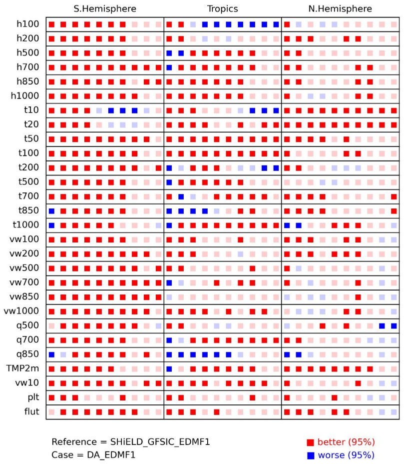
More observations assimilated, especially in extratropical cyclone regions

Tong et al., 2020

Development of Global Atmospheric DA system for SHiELD through Leveraging and Enhancing UFS DA Capabilities

- A global atmospheric DA system was developed for SHiELD by largely leveraging GFS DA capabilities
- The development involves consultation and discussion with NCEP/EMC, and our findings with the DA system were fed back to EMC.
- This development demonstrate the benefits of having a native DA cycling system for SHiELD - improving forecast, diagnosing forecast errors
- The insight gained from our system may have practical applications for GFS, as many of the software and scientific components utilized by both modeling systems are the same.

SHiELD 10-day forecast scorecard

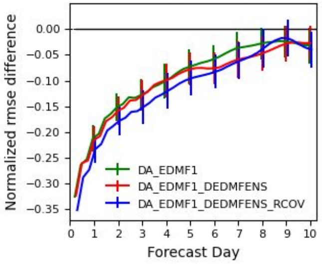


Significantly improved weather forecast using SHiELD native IC upon using GFS IC

Remarkable improvement in SH 500 hPa geopotential height forecast using SHiELD native IC

Tong et al., 2025

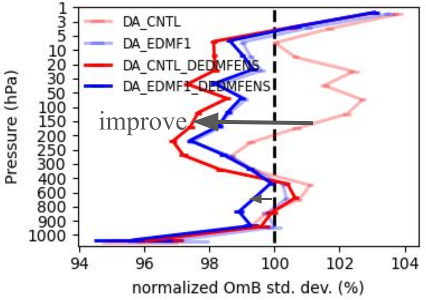
H500 RMSE S.Hemisphere



Development of Global Atmospheric DA system for SHiELD through Leveraging and Enhancing UFS DA Capabilities

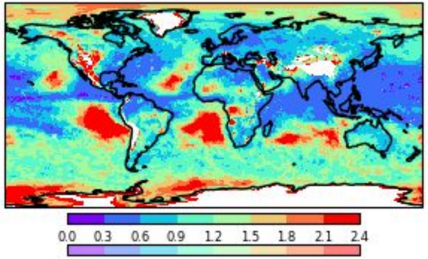
- The DA system is useful in identifying model errors
- Mitigate model errors through development in the ensemble and observation error

GPSRO bending angle OmB



Model error leads to insufficient ensemble spread manifested as largely degraded forecast fit to GPS RO bending angles, which can be improved with enhanced ensemble

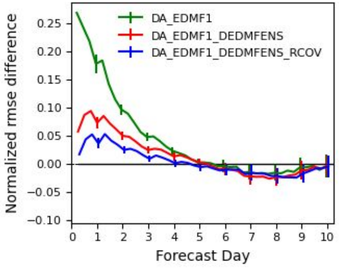
Temp 850 hPa mean forecast error



Model error leads to systematic forecast errors in marine stratocumulus regions

Tong et al., 2025

Normalized T850 RMSE (Tropics)

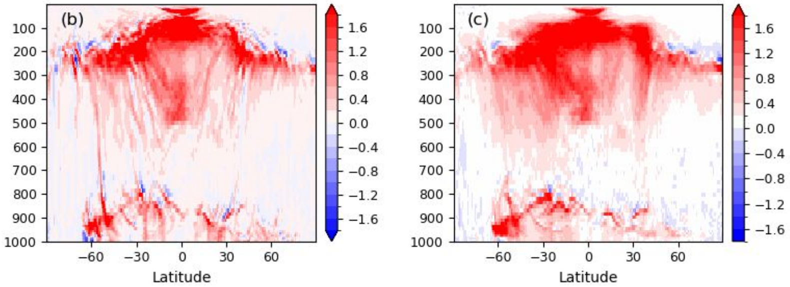


Systematic forecast error can be alleviated through improved ensemble and upgraded observation error covariances for IASI and CrIS

Development of Global Atmospheric DA system for SHiELD through Leveraging and Enhancing UFS DA Capabilities

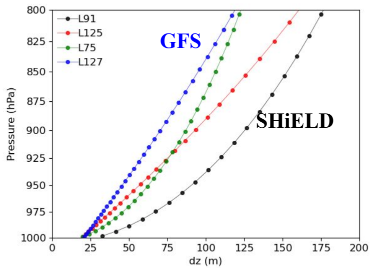
- In-depth understand root cause of analysis and forecast errors, better understand model strengths and weaknesses, set foundation for future model system improvement

Change in zonal mean temperature gradient norm (left) and temperature ensemble spread (right) due to reduction in eddy diffusion

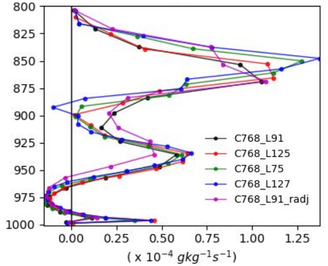


The strength of eddy diffusion impact ensemble spread through its impact on the gradient of the model state

Vertical grid size



6-hr mean total water tendency due to TKE-EDMF scheme

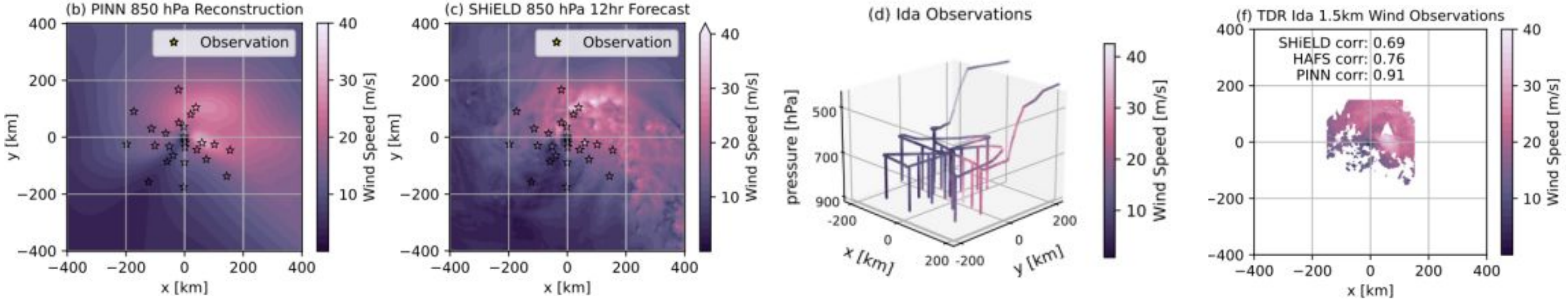


Impact of model vertical resolution on systematic error and the role of eddy diffusion in modulating stratocumulus cloud top and cloud amount

Tong et al., 2025

Physics-Informed Neural Network (PINN) for TCs

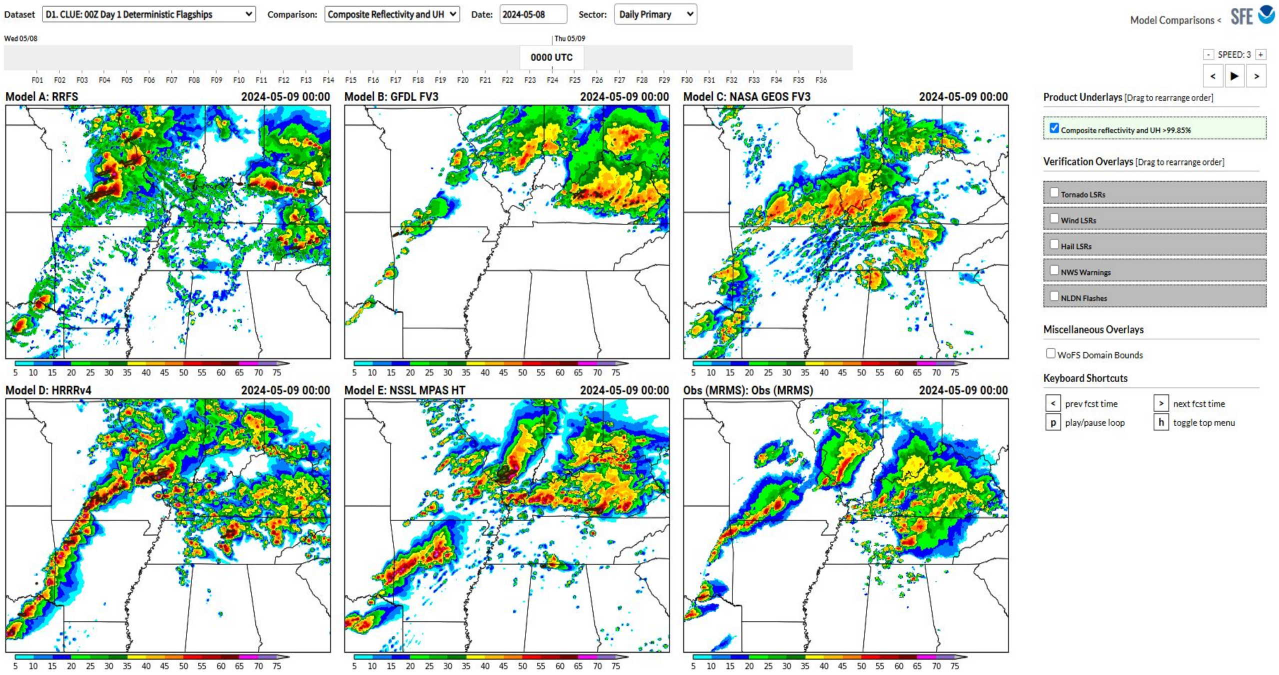
- Princeton University partnered with GFDL on a pioneer research using a physics-informed neural network (PINN) to reconstruct TC wind and pressure fields
- T-SHiELD forecast data together with real observations are used in the training of PINN
- This research demonstrates that PINN can be a computationally efficient alternative for tropical cyclone data assimilation.



Eusebi et al. (2024)

C-SHiELD in HWT Testbeds

- Participate in Spring Forecasting Experiment since 2017
- Contribute to development of severe weather forecast guidance
- Feedbacks benefit C-SHiELD development
- Experience gained from C-SHiELD development benefits RRFS
- Beyond short-term forecast: medium-range and subseasonal forecasts in development



Courtesy Kai-yuan Cheng

GFDL contributions to HAFS development

- The FV3-based regional high resolution Hurricane Analysis and Forecast System (HAFS) was implemented operationally in June 2023.
- GFDL has made other important contributions to HAFS implementation, including
  - Multiple same-level and telescoping nesting capacity in FV3 (Mouallem et al. 2022)
  - Positive-definite tracer advection scheme in FV3 that improves intensity forecasts (Harris et al. 2020)
  - Updated GFDL vortex tracker that is built in HAFS code for positioning the moveable inner nest (public code)
  - A flexible vortex initialization scheme that facilitate the work flow of basin-scale HAFS (Gao et al. 2023)
  - GFDL microphysics version 3 (Zhou et al. 2022) is being tested in HAFS v3

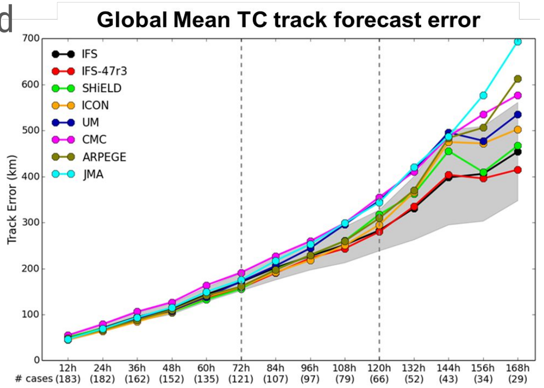
Courtesy Kun Gao

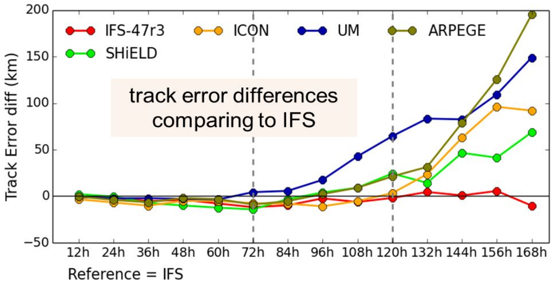
DIMOSIC– DIfferent MOdels - Same Initial Conditions

Phase I: 10-day forecasts initialized at 00Z every 3 days in the one-year period of **20180606-20190604**

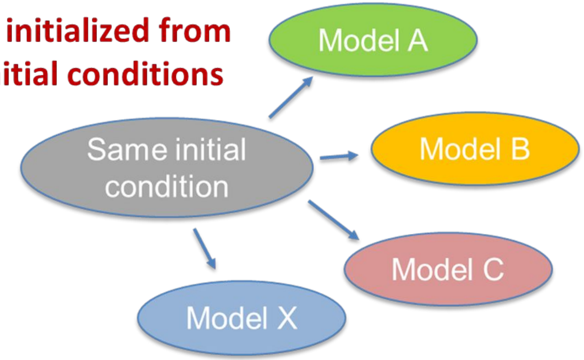
Model	Resolution
ARPEGE	5-25 km
GEM	15 km
GFS	13 km
GSM	20 km
ICON	13 km
IFS	9 km
SHiELD	13 km
UM	10 km

Courtesy Jan-Huey Chen





All models initialized from ECMWF initial conditions



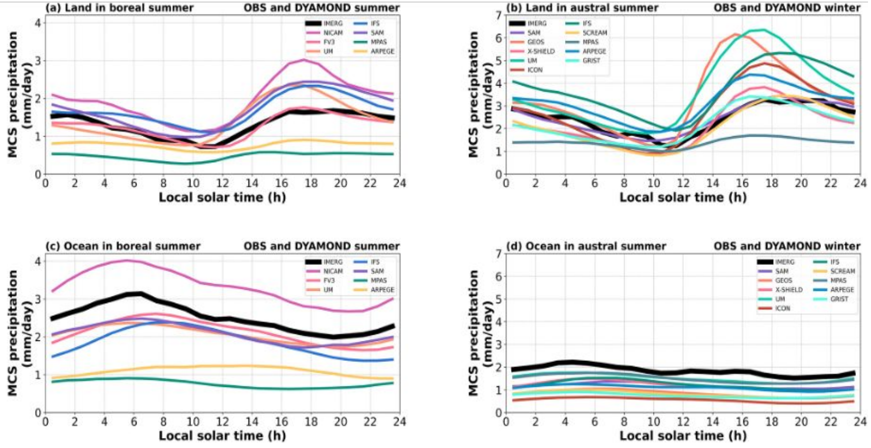
DIMOSIC phase II is on-going:

- Focus period: 20230829-20240829, every 3rd day.
- Updating current models with their new developed configurations.
- higher model output resolution for verification (0.5x0.5 → 0.25x0.25 degree)
- More models (GFS, MAPS, and KIM) will participate in phase II.
- Multi-model ensemble spread evaluation.

DYAMOND DYnamics of the Atmospheric general circulation Modeled On Nonhydrostatic Domains

- International intercomparison of kilometer-scale Global Storm-Resolving Models (Stevens et al., 2019, Stephan et al. 2022, Judt et al. 2021).
- GFDL has contributed X-SHiELD output to all three phases: **2017 Summer, 2021 Winter, upcoming 1-year**

Mesoscale Convective System (MCS) precipitation diurnal cycle of DYAMOND models



Song et al., 2024

Courtesy Linjiong Zhou and Lucas Harris

GSRMs — DYAMOND Summer 2016

Model	Resolution
ARPEGE-NH	2.5 km
FV3	3.25 km
GEOS	3 km
ICON	2.5 km
IFS	4 km
MPAS	3.75 km
NICAM	3.5 km
SAM	4 km
UM	5 km

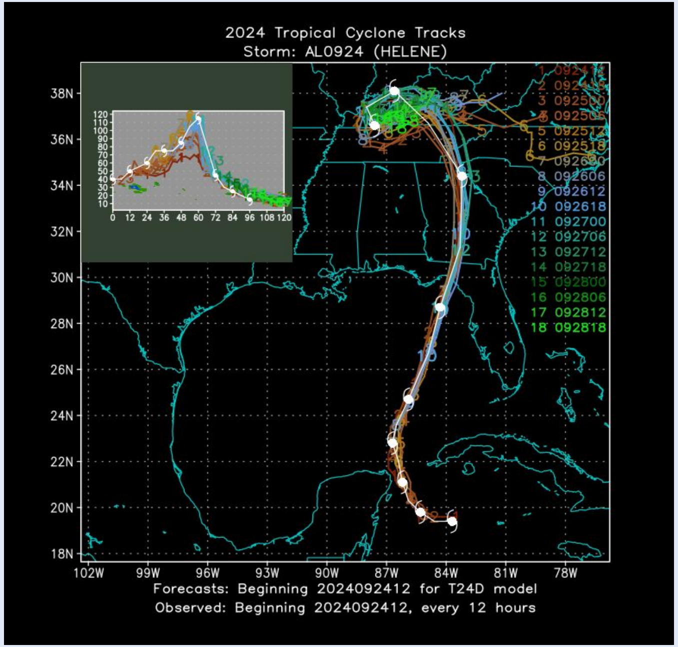
GSRMs — DYAMOND Winter 2020

Model	Resolution
ARPEGE-NH	2.5 km
GEM	4.5 km
GEOS	1.5 km
GRIST	5 km
ICON	2.5 km
IFS	4 km
MPAS	3.75 km
NICAM	3.5 km
gSAM	4 km
SCREAM	3 km
X-SHiELD	3.25 km
UM	4.8 km

GFDL Vortex Tracker

- The GFDL Vortex Tracker has provided real-time TC guidance from operational models to research models since 1998 (Marchok 2021).
- The tracker analyzes model data to diagnose metrics of storm position, intensity, wind structure and thermodynamic structure.
- Recent development highlights include:
  - Numerous upgrades to support implementation of the two new National Weather Service HAFS operational hurricane models.
  - New algorithms that more accurately diagnose critical TC near-surface wind-radii.
  - New algorithms for detection of tropical cyclogenesis that are better aligned with observational methods.
  - Establishment of GitHub repository to facilitate code management and community involvement.
  - Establishment of the GFDL Vortex Tracker as a component of the Unified Forecast System.

Courtesy Tim Marchok

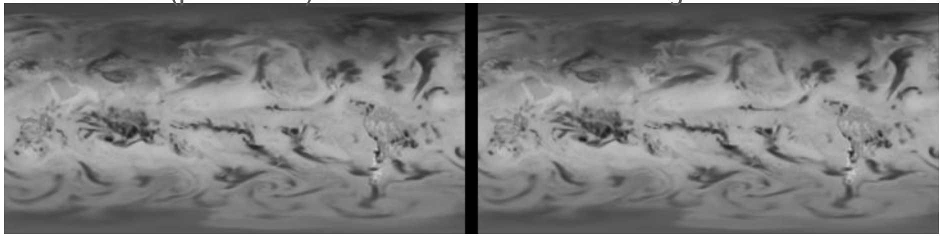


5-day T-SHiELD forecasts of track and maximum sustained winds (inset box) for all initialization times for Hurricane Helene (2024), as diagnosed by the GFDL Vortex Tracker.

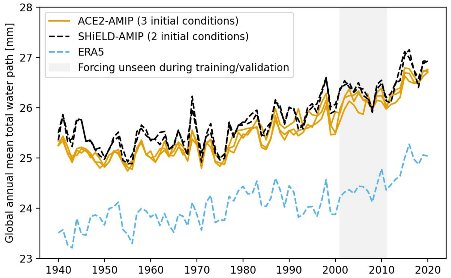
Ai2 ML collaboration

- Ai2's **corrective ML** and **ML parameterization** trained on SHiELD or X-SHiELD: help coarse-grid climate model behave like a more realistic high-res model (e.g. Sanford et al., 2023).
  - Transitioned onto GFDL HPC: preliminary work suggests it could improve Western US orographic precipitation (Hsieh et al., 2024).
- **Ai2 Climate Emulator (ACE)**: An autoregressive fully ML-based 1° atmosphere model with a 6 hour timestep:
  - Stable and maintains realistic weather variability for 100+ year rollouts with very high climate accuracy.
  - New v2 models trained on output from 100 km SHiELD exactly conserve dry air and water (Watt-Meyer et al., submitted), and can be coupled to a slab ocean to emulate the climate sensitivity to increased CO_2 (Clark et al., submitted).
- Ongoing work:
  - Coupling to an ML-based ocean emulator with M^2LInES.
- Future: Learn from coarsened output of X-SHiELD.

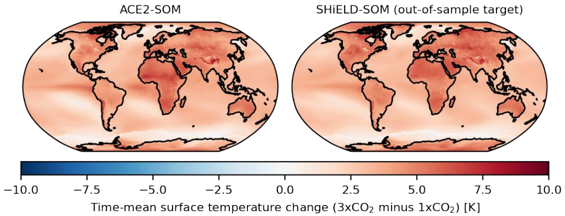
Courtesy Ai2 and Lucas Harris



Outgoing longwave radiation for first 100 days of simulation (Watt-Meyer et al., 2023)



81-year AMIP simulations with ACE2 (Watt-Meyer et al., submitted)



Mean surface temperature warming with $3xCO_2$ in ACE2-SOM and SHiELD-SOM (Clark et al., submitted)