Prediction and Scientific Insights Using the SHiELD Model Family

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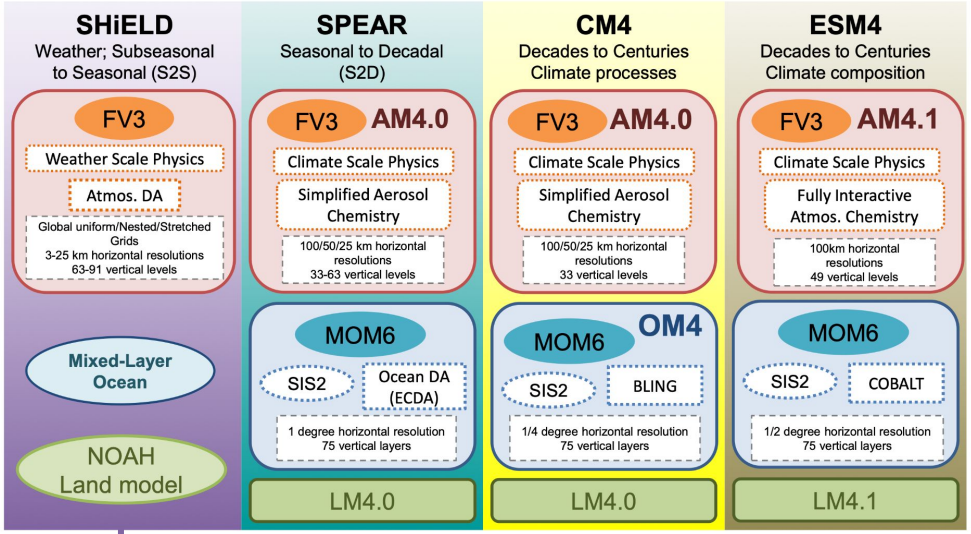
Q2: Concerning NOAA's key mission element of understanding, predicting, and projecting changes in the Earth System, how can GFDL drive further advances in these areas, including extremes and environmental hazards, through scientific innovation based on observations, theory, and modeling? Where are the strengths, gaps, and new frontiers?

NOAA GEOPHYSICAL FLUID DYNAMICS LABORATORY

5-Year Review
January 28-30, 2025

GFDL Model Configurations in 2019

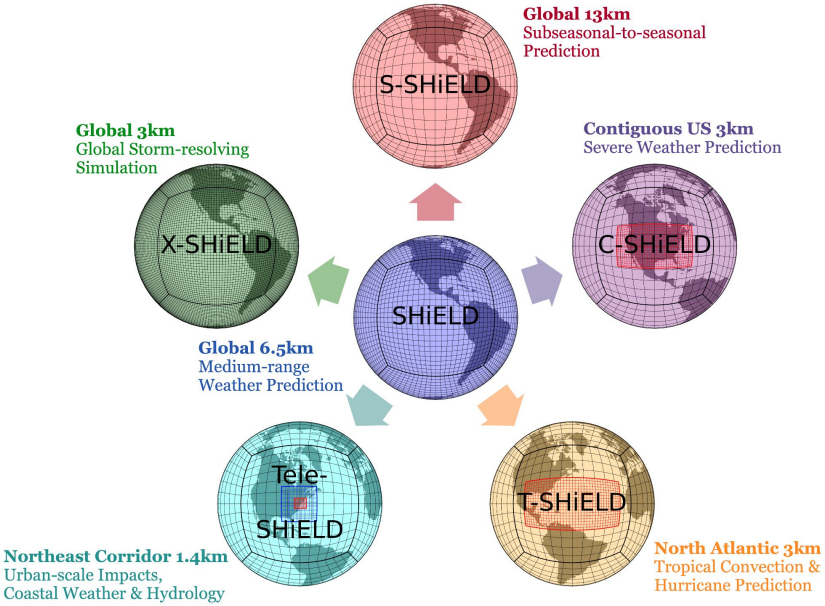


Source: GFDL 5-Year Lab Review 2019

(Left) SHiELD is the weather-to-seasonal component of the GFDL Seamless Modeling System.

(Right) SHiELD is a research-focused prototype of the Unified Forecast System (UFS), demonstrating the capabilities of a unified prediction system for a broad range of applications.

SHiELD System for High-resolution prediction on Earth-to-Local Domains



Homepage: https://www.gfdl.noaa.gov/shield/

Harris et al. (2020) with updates in 2024

GFDL Research with SHiELD Models

Key Innovations

- **Advanced numerics, turbulence, grid/nesting** (Harris et al. 2020/2021, Chen 2021, Gao et al. 2021/2023, Mouallem et al. 2022/2023; **Harris Q1**, **Gao Q2**)
- **Modernized modeling language and infrastructure** (Cheng et al. 2022, Dahm et al. 2023; **Elbert Q1**)
- **Advanced dynamics-physics coupling and physical parameterization** (Zhou et al. 2022, Zhou and Harris 2022)
- **Enhanced data assimilation** (Tong et al. 2020/2025; **Tong Q3**)

Blue: in-person presentation
Magenta: prerequisite slides

Weather Prediction Applications

- **Global medium-range weather predictions** (Zhou et al. 2022/2024, Zhou and Harris 2022)
- **Thunderstorms and winter storms predictions over the U.S.** (Zhou et al 2019, Kaltenbaugh et al. 2022)
- **Tropical cyclones: track, intensity, structure, and landfall** (Marchok 2020, Gao et al. 2021/2023/2024, Chen et al. 2023, Chen et al. 2023; **Gao Q2**)

Climate and Extreme Events

- **Global storm-resolving simulations and global warming responses** (Cheng et al. 2022, Harris et al. 2023, Bolot et al. 2023, Merlis et al. 2024, Guendelman et al. 2024, Dong et al. 2024, Gentile et al. 2025; **Harris Q1**)
- **Drought and heat waves** (Yoon et al. 2024; **Xiang Q1**)

Experimental Studies

- **Idealized TCs, radiative convective equilibrium, and supercells** (Jeevanjee and Zhou 2022, Gao et al. 2024, Cheng et al. 2024; **Gao Q2**)

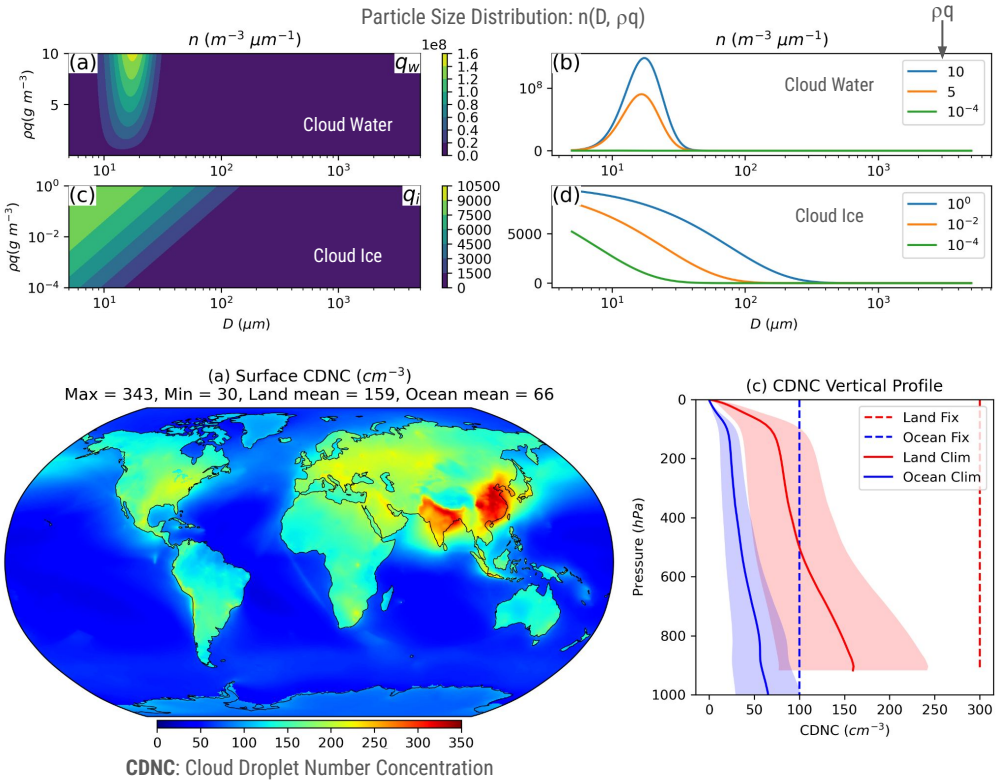
Advances in SHiELD's Coupling and Parameterization

Dynamics-Physics Coupling

- FV3 conserves moist total energy (Harris et al., 2020), while physics conserves dry enthalpy.
- Integrated dynamics-physics coupling enhances thermodynamics consistency and interaction.
- Improved prediction of high-impact events like hurricanes (Zhou and Harris, 2022).

Microphysics Parameterization

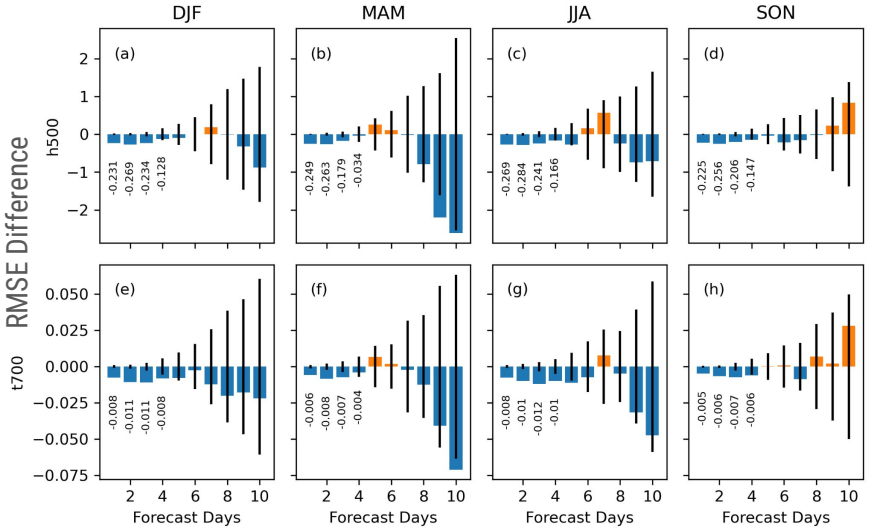
- Cloud microphysics is critical for cross-scale weather prediction (Zhou et al., 2019).
- GFDL scheme uses observed particle size distribution (***top***) and prescribed aerosol (***bottom***).
- Reduced cloud fraction errors, better prediction accuracy (Zhou et al., 2022).



Zhou et al. (2022)

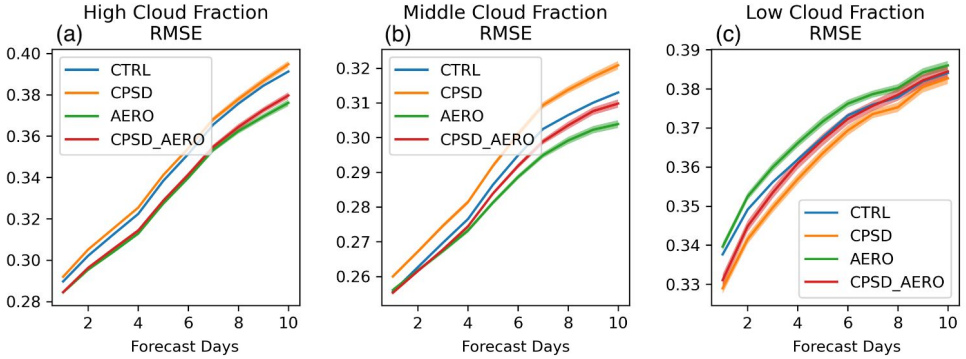
Improvements in Global Medium-Range Weather Prediction

Forecast Improvements with GFDL Microphysics Upgrade



Enhanced global large-scale circulation predictions with prescribed aerosol included

CTRL: default GFDL microphysics version 3; **CPSD**: PSD included
AERO: aerosol included; **CPSD_AERO**: combined CPSD and AERO



Reduced root mean square error (RMSE) in global cloud fraction prediction with observed particle size distribution (PSD) and prescribed aerosol included

Zhou et al. (2022)

Toward Global Kilometer-scale Extreme Weather Predictions

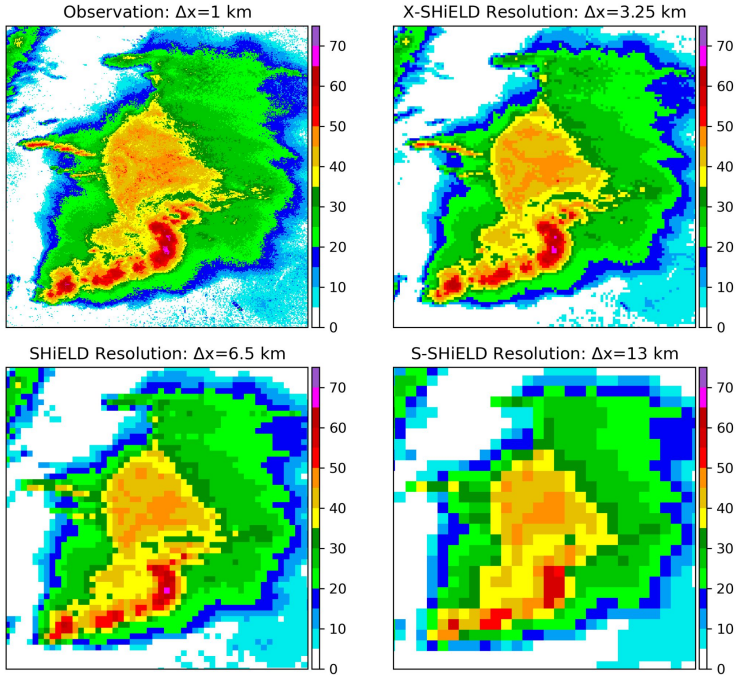
6.5-km SHiELD: A Digital Twin of Earth for Global Convective-Scale Medium-Range Prediction

SHiELD	13km	6.5km
Grid Configuration	C768	C1536
Remapping Timestep	150 s	75 s
Acoustic Timestep	18.75 s	9.375 s
Convection Scheme	v2017	v2021
Shallow Convection Vertical Constraint (cthk/top)	-	200 hPa / 0.7
Shallow Convection Detrainment Rate (c1)	0.0005 m^{-1}	0.002 m^{-1}
Mountain Block Strength Factor (cdmb)	3.5	5.0
PBL Background Diffusion over the Ocean (xkzm)	1.5 m^2/s	0.5 m^2/s
Mixed-Layer Ocean Lapse Rate (gam)	0.2 K/m	0.1 K/m

GFDL near-real-time forecast: https://shield.gfdl.noaa.gov Zhou et al. (2024)

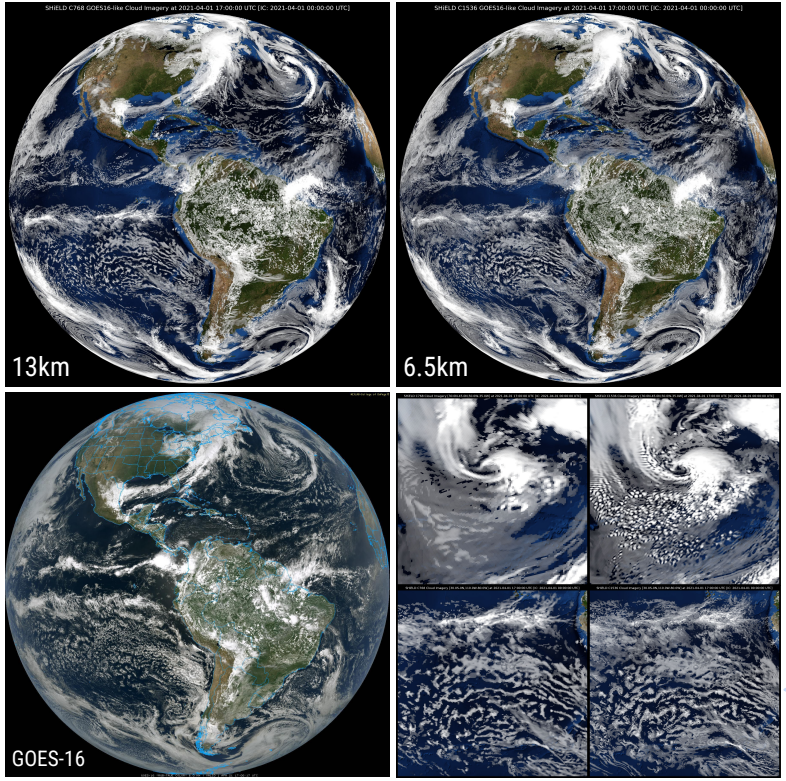
The 6.5-km SHiELD leverages FV3's superior scalability.
Physics are optimized for peak model performance across scales.

Strategic Goals:
— Deliver outstanding predictions of global large-scale circulation.
— Achieve robust synoptic-scale weather forecasting.
— Enhance meso-scale convection simulation for greater accuracy.



Observed Radar Reflectivity at 18Z, May 9, 2023

Toward Global Kilometer-scale Extreme Weather Predictions



Zhou et al. (2024)

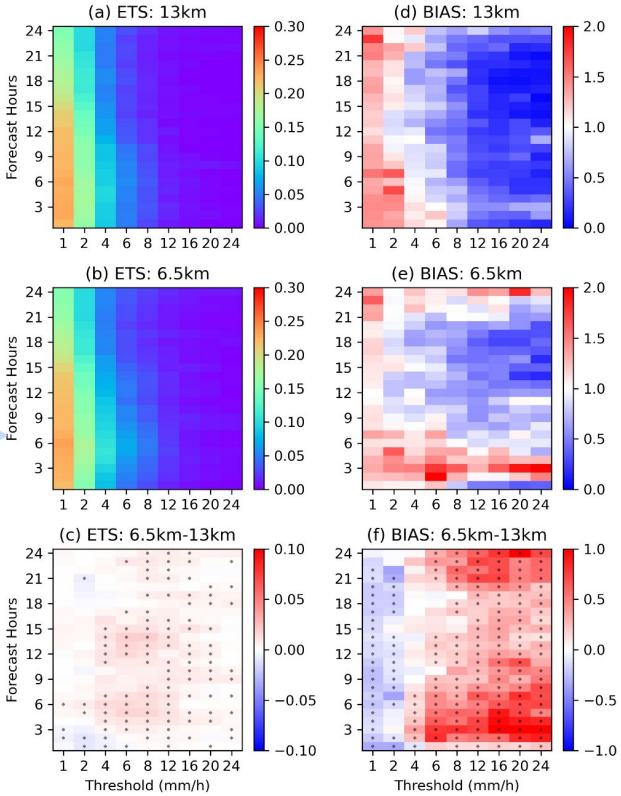
13km (left) vs. 6.5km (right)

6.5-km vs. 13-km SHiELD

- Improved medium-range global prediction.
- Reduced global precipitation bias.
- Reduced tropical cyclone intensity errors and biases

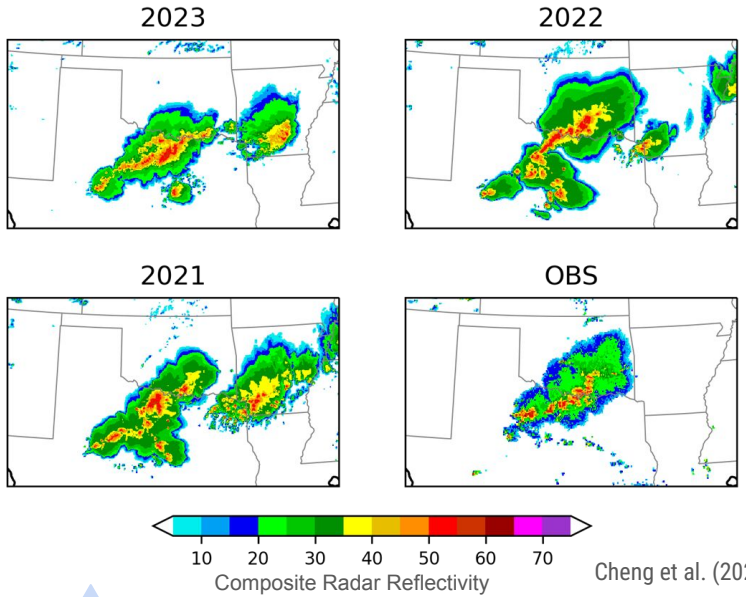
Improved forecast accuracy and reduced forecast frequency biases for heavy precipitation over the U.S.

Predicted similar cloud patterns to GOES-16, captures mesoscale cumulus convections, generates more marine stratiform clouds



Continental Thunderstorm and Winter Storm Predictions in C-SHiELD

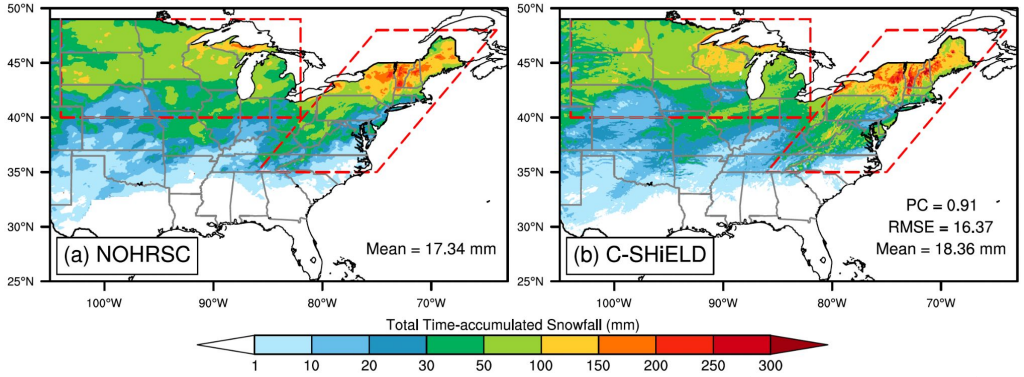
2019050123Z (Fcst hour: 23)



Cheng et al. (2023)

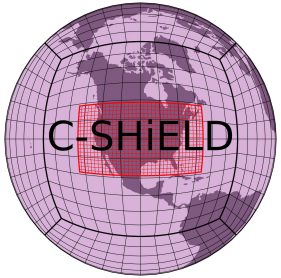
Least-diffusive advection scheme and upgraded GFDL microphysics enhance storm structure

Total Accumulated Snowfall (mm) During 2021–2023 Winter Seasons



Han et al. (2024; submitted to WaF)

Contiguous US 3km
Severe Weather Prediction



C-SHiELD accurately predicts winter storm snowfall patterns and magnitudes, capturing more terrain-following details

Observation: National Operational Hydrologic Remote Sensing Center (**NOHRSC**) snow water equivalent

Vision for Future SHiELD Models

- **Model development goals**
  - Enhance global kilometer-scale medium-range forecasting capabilities up to 15 days.
  - Target mesoscale convective systems and severe weather prediction through focused C-SHiELD development.
  - Complete full coupling of SHiELD with MOM6, SIS2, WW3, and LM4 components.

- **Science goals**
  - Investigate continental convection, winter weather, hydrological extremes, and tropical cyclones across the U.S. on weekly to subseasonal timescales.
  - Examine cloud-convection-radiation interactions with large-scale circulations, focusing on their influence on predictability and sensible weather events.
  - Study atmosphere-surface interactions, emphasizing hydrological extremes, convective storms, tropical cyclones, and coastal storm events