The GFDL FV3 Dynamical Core
Configuration and Applications

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for the GFDL FV3 Team

UFS MRW Application Training
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Outline:

• Who is using FV3?
  – The global FV3 community
• FV3 at GFDL
  – History of climate modeling
  – The unified modeling suite
• Modern NWP
  – Seamless weather-climate prediction/projection
• Special focuses:
  – Hurricanes, severe weather, MJO, diurnal cycle...
• Global cloud-resolving modeling
Who is using FV3?
– The Global FV3 Community

- Ames Mars GCM
- AM4 CM4 ESM4
- SHIELD SPEAR
- GEOS, DAS, MERRA(2)
- GEOS-chem High-Performance
- CAM-FV
- NCAR
- GFSv15 v16 GEFSv12
- MRW SRW HAFS ...
- Taiwan Central Weather Bureau
- CWBGFS
- GFDL-atmos_cubed_sphere
- GFDL
- NASA
- NOAA
- LASG FAMIL
- UCLA
- Harvard
- Ames
- NCAR
- CWBGFS
- GitHub

Fork FV3 on GitHub
From Ming Zhou
2019 GFDL Review
From CM2.0 to CM2.1 -- The importance of vorticity

Zonal-mean wind stress: CM2.0 vs. CM2.1

Global-mean Ocean Temp diff. (K) in control-climate integrations

Delworth et al. 2006 J Clim
**FV3 at GFDL**

The GFDL Fourth-Generation Unified Modeling Suite

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<th>Weather; Subseasonal to Seasonal (S2S)</th>
<th>Seasonal to Decadal (S2D)</th>
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- **Weather Scale Physics**
  - FV3
  - AM4.0
  - AM4.1

- **Climate Scale Physics**
  - FV3
  - AM4.0
  - AM4.1

- **Atmos. DA**
  - Global uniform/Nested/Stretched Grids
  - 3-25 km horizontal resolutions
  - 63-91 vertical levels

- **Mixed-Layer Ocean**
  - MOM6
  - SIS2
  - Ocean DA (ECDA)

- **NOAH Land model**
  - NOAH
  - LM4.0

- **Ocean DA**
  - SIS2
  - 1 degree horizontal resolution
  - 75 vertical layers

- **Simplified Aerosol Chemistry**
  - FV3
  - AM4.0
  - AM4.1

- **AM4.0**
  - 100/50/25 km horizontal resolutions
  - 33-63 vertical levels

- **AM4.1**
  - 100/50/25 km horizontal resolutions
  - 33 vertical levels

- **Fully Interactive Atmos. Chemistry**
  - COBALT
  - 1/2 degree horizontal resolution
  - 75 vertical layers

All models use the Flexible Modeling System (FMS) framework and are part of the Unified Forecast System.
Modern NWP

GFDL seamless prediction/projection modeling system

**Daily Weather Forecasts**
- hours
- 2 weeks
- 1 month
- 3 months to 2 years

**Sub-seasonal to Seasonal Predictions**
- HiRAM (50km/25km)
- FLOR/HI-FLOR (50km/25km; 1deg Ocean)

**Decadal Predictions**
- ENSO, Hurricanes, Precipitation/ Temperature anomalies

**Climate Projections**
- Century

- Thunderstorms, Tornados, Hurricanes...
- Hurricanes, MJO, Heat waves, Droughts...
- ENOS, Hurricanes, Precipitation/ Temperature anomalies

**CURRENT/PREVIOUS GENERATION**

**CURRENT/NEXT GENERATION**

SHiELD (formally called fvGFS) (3km/13km/25km)

SPEAR (100km/50km/25km atm/land; 1° Ocean)
SHiELD System for High-Resolution Prediction on Earth-to-Local Domains

Weather- to-Seasonal Application

- **C384**: 25km Subseasonal-to-seasonal Prediction
- **C768r15n3**: 20-3km Severe Weather Prediction
- **C768**: 13km Global Weather Prediction
- **C768n4**: 13-3km Tropical Cyclone/MJO Prediction
- **X-SHiELD**: 3km Global Cloud-resolving Simulation
- **R-SHiELD**: 3km Regional Storm Prediction Idealized Test
- **S-SHiELD**: 3km Regional Storm Prediction

Harris et al. (2020) Courtesy of Linjiong Zhou, Kun Gao, Kai-Yuan Cheng
The GFDL SHiELD Real-Time Model Website
https://shield.gfdl.noaa.gov/new
Operator: Matt Morin
13-km SHiELD Evolution

Incremental improvements in FV3 and Physics

- 2016: Tuned NGGPS, GFS Physics
- 2017: GFDL Microphysics, EMC SA-SAS
- 2018: Inline GFDL MP, Pos-Def Advection, YSU Turbulence, Mixed-layer Ocean
- 2019: Updated FV3, Revised GFDL MP, URI-GFDL Sea State
- 2020: Overhauled GFDL MP, New cloud-radiation, UW/EMC TKE-EDMF

Global H500 ACC Diff. to GFS

Global H500 RMSE Diff. to GFS

Courtesy Linjiong Zhou Harris et al, 2020, JAMES
13-km SHiELD Evolution

Tropical Precipitation vs. TRMM 25-km data

CONUS Precipitation vs. Stage4

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Year-over-year reduction in precipitation forecast error
The importance of initial conditions

SHiIELD C768 (13km)

NH h500 ACC

Ongoing Collaborations with ECMWF: **DIMOSIC** Project (Different MODELS - Same Initial Conditions) based on
- Chen et al. 2019, GRL
- Magnusson et al. 2019, QJ

2017 Season TC Track Error
North Atlantic Basin

Chen et al. 2019, GRL
Locations of AMSU-A observations that meet the precipitation screening criterion in deep-convection (high-impact) areas are rejected in the original all sky framework but are kept in the new all-sky framework.

Benefited form the use of the GFDL microphysics scheme, the all-sky radiance assimilation framework was expanded to include precipitating hydrometeors.
SHiELD v2020
Push our flagship to **8.5 km** resolution (C1152)

Major changes:
- 2020 version of FV3
- 2020 version of GFDL MP
- YSU PBL -> TKE-EDMF PBL
- GFSv14 ICs -> GFSv15 ICs

Other changes:
- Horizontal resolution: 13km -> 8.5km
- Latest version of fix_am
- Mountain block intensity
- 2020 version of FMS
Hurricane forecasts

SHiELD C768 (13km) and T-SHiELD (3-km two-way nest)

Results as of 26 October 2020.

Courtesy Kun Gao & Morris Bender
Severe Storm Forecasts

C-SHiELD (3 km)

- 3-km CONUS nest for severe weather prediction out to 5 days
- Leverages advances from other SHiELD configurations
  - Revised diffusion and shallow convection, updated GFDL microphysics and PBL
- Submitted to 2020 Spring Forecasting Experiment at the NOAA Hazardous Weather Testbed in Norman, OK
  - Received high marks for pre-storm environment and cold pools
  - FV3-NSSL (diff. MP, PBL, LSM) does very well with storm structure every year

From NOAA Hazardous weather testbed: https://hwt.nssl.noaa.gov/
Madden-Julian Oscillation

Seamlessness in the GFDL Modeling Suite

CMIP Earth-System Models

100-km AM4 Atmosphere (C96 FV3 + GFDL Climate Physics) + 25-km MOM6 + LM4

CM4 Coupled Climate Model

Even at 100-km good MJO propagation is found...if coupled to an ocean

Zhao et al. 2018a,b

S2S & S2D Prediction Models

Observations

25-km S-SHiELD Atmos. w/ MLO

50-km SPEAR MOM6-Coupled S2D

Courtesy Baoqiang Xiang and Yongqiang Sun
Madden-Julian Oscillation

S-SHiELD (25km) and T-SHiELD (4-km two-way nest)

**25-km S-SHiELD**

Mixed-layer ocean adds 8 days of useful skill

**4-km nested T-SHiELD**

4-km Maritime Continent Two-Way Nest efficiently improves predictability and propagation of MJO compared to 16-km uniform parent
Diurnal Cycle

S-SHiELD (25km) and T-SHiELD (5-km two-way nest)

JJA Diurnal Cycle for 25-km S-SHiELD climate sim and 13-km SHiELD forecasts vs. TRMM

➤ Superior to all CMIP5 Models

Harris et al. 2020, JAMES

US MAMJ Diurnal Cycle for 5-km C-SHiELD S2S forecasts vs. StageIV

Courtesy Kai-Yuan Cheng
Global cloud-resolving modeling

X-SHiELD C3072 (3.25km)

3.25-km GCRM seamlessly integrated with other GFDL models

Partnering with Vulcan, Inc and the University of Washington to build a hybrid ML model to emulate X-SHiELD in a cheap low-resolution model

Courtesy S-J Lin, Xi Chen, and Linjiong Zhou
From below the conference table comes the thrum of incoming phone alerts. The new weather forecast has rolled in, and the climate scientists, even though it's not typically their business, dig out their phones to look: snow tomorrow—hardly unusual for early February in Princeton, New Jersey. But the weather models have the storm breaking severe, dumping a foot or more. A snow day seems likely.

Across the table at the Geophysical Fluid Dynamics Laboratory (GFDL), Shian-Jiann "S. J." Lin is not convinced. He is the master of 20,000 lines of computer code that divide the atmosphere into boxes and, with canny accuracy, solve the equations that describe how air swirls around the globe. For decades, Lin's program has powered the long-term simulations of many climate models, including GFDL's—one of the crown jewels of the U.S. National Oceanic and Atmospheric Administration (NOAA).

Now, Lin's domain is expanding to a different side of NOAA: the short-term weather forecasts of the National Weather Service (NWS). By 2018, Lin's program will be powering a unified system for both climate and weather forecasting, one that could predict conditions tomorrow, or a century from now—and do it faster and better than current models. His work will soon be guiding mayors planning not just for snow plows, but also rising seas.

But Lin has started early. His small team is already running a prototype forecast on their supercomputer. And in his typically confident and brash style, he offers a minority report about the next day's storm. "If our forecast is correct, it's only 3 to 6 inches," Lin announces. His peers at the