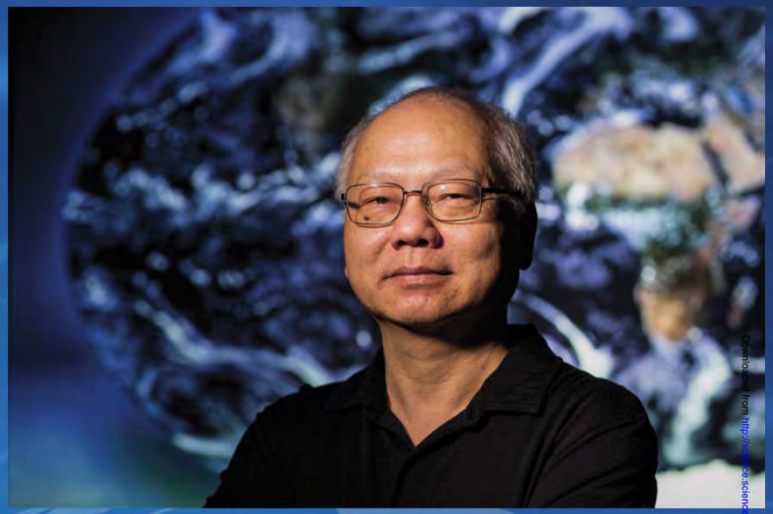
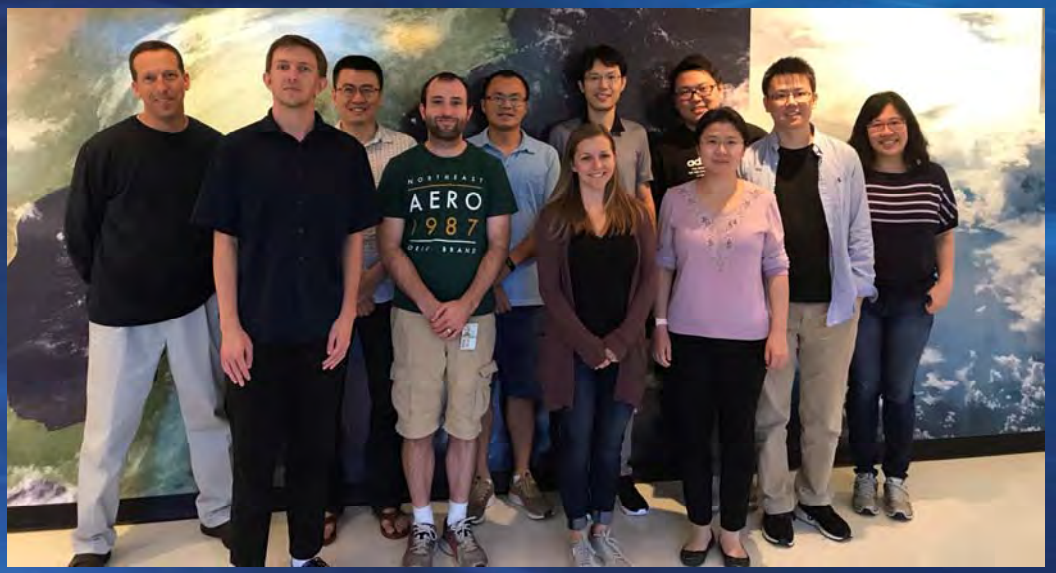
FV3 at GFDL and Beyond





THE WEATHER MASTER

How Shian-Jiann Lin's atmospheric grids could unify weather forecasts and climate models

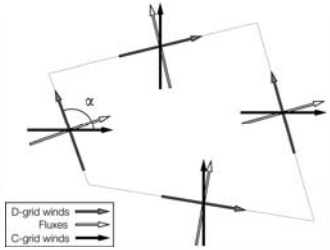
By **Paul Voosen**

Presented by Lucas Harris

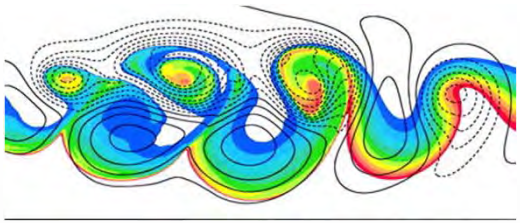
Geophysical Fluid Dynamics Laboratory Review

October 29-31, 2019

FV3: The GFDL Finite-Volume Cubed-Sphere Dynamical Core



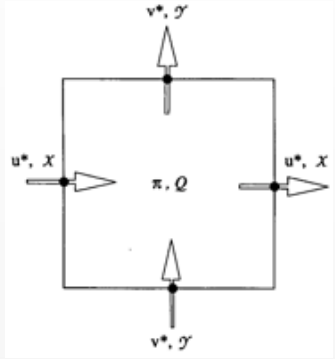
1997 FV Shallow-water Solver: Vorticity-First Dynamics



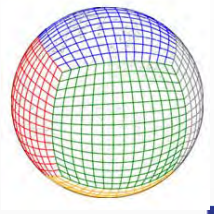
1998–2004 FV Core: Mimetic FV Pressure force and novel Lagrangian Vertical Coordinate

The FV3 Way

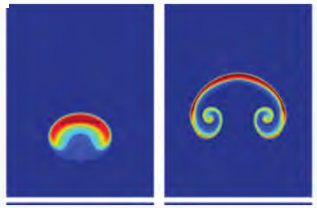
- Physical consistency
- Fully-FV numerics
- Component coupling
- Computational efficiency



1994–1996 FV Advection ("Lin & Rood"): Revolutionary Transport



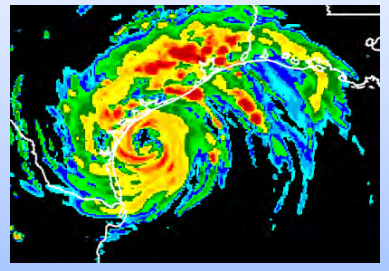
2007 FV → FV^3: The Cubed-sphere Grid

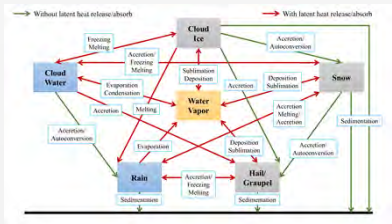


2006–2013: Nonhydrostatic Lagrangian Dynamics

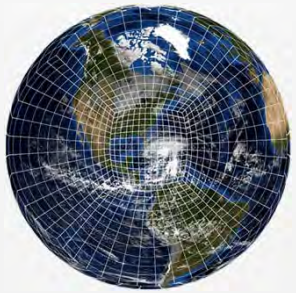
Next-Generation FV3

Rigorous Thermodynamics
Flexible dynamics
Adaptable physics interface
Variable-resolution techniques
Regional & periodic domains
Powerful initialization, DA, and nudging functions





2013–2019 Physics-Dynamics Interactions: Integration and rigorous moist thermodynamics



2013–2016 Variable resolution: nesting and stretching

The Global FV3 Community

Many Models
Many Applications
<u>One</u> flexible dynamical core

CESM Framework
CAM-FV
CAM-FV3

NCAR

FMS Framework
AM/CM/ESM 2/3/4
HiRAM, FLOR, HiFLOR, SPEAR
fvGFS/SHiELD

NEMS Framework
GFSv15, GEFSv12
UFS, HAFS

GEOS Chem
GCHP

GMAO Framework
GEOS, DAS, MMF, MERRA(2)
GISS Model E
Ames Mars model

TaiESM

Taiwan Central Weather Bureau

CWBGFS

Chinese Academy of Sciences

LASG FAMIL

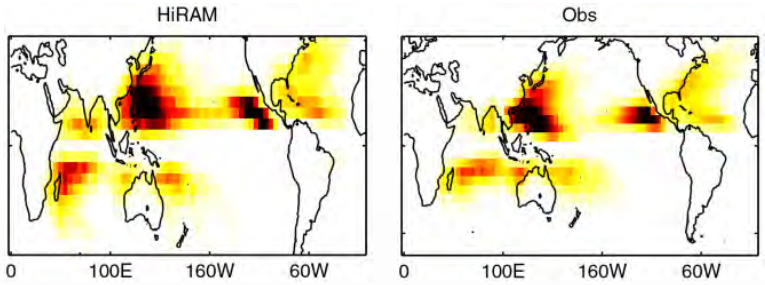
FV3 At GFDL: Climate Modeling

FV3 supports GFDL's strengths in variability, coupling, and extremes

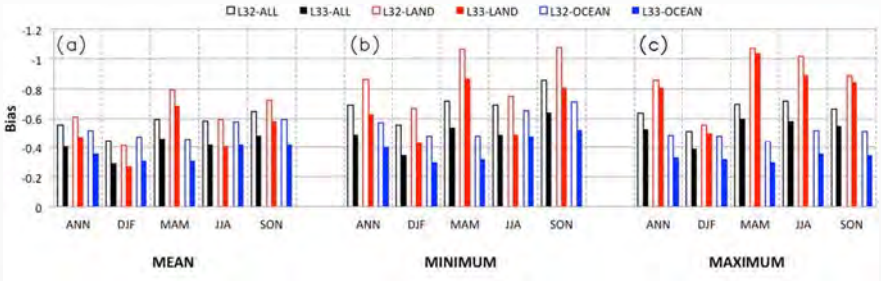
AM4's new surface-layer level → better surface climatology

Nesting and stretching → RCM in a global model

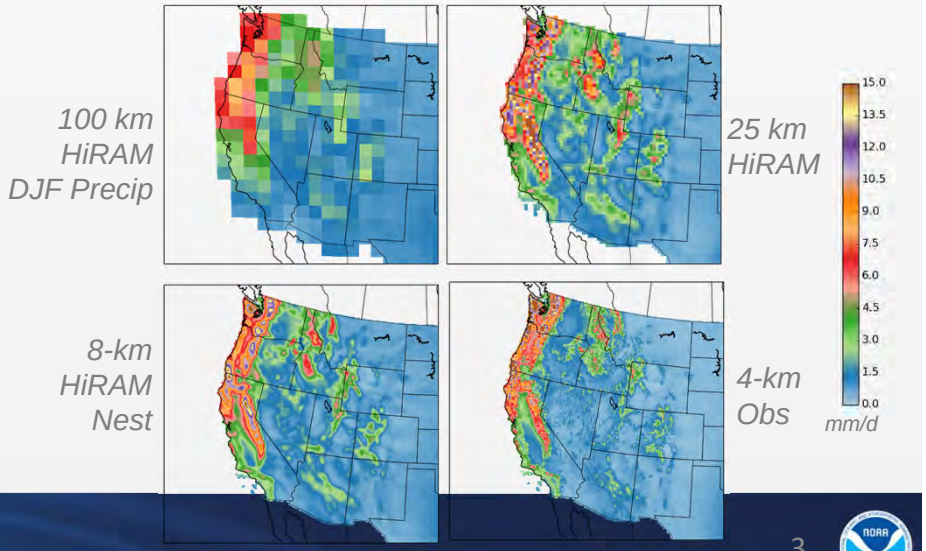
Improvements at other scales also benefit climate models



TC Track Density: Shaevitz et al (2014, JAMES)



T2M Biases in AM4 with (solid) and without (unfilled) 10-m surface layer: Shin et al (2019, JAMES)

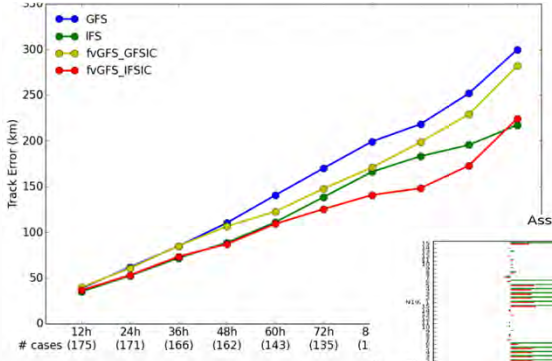


FV3 At GFDL: Prediction Modeling

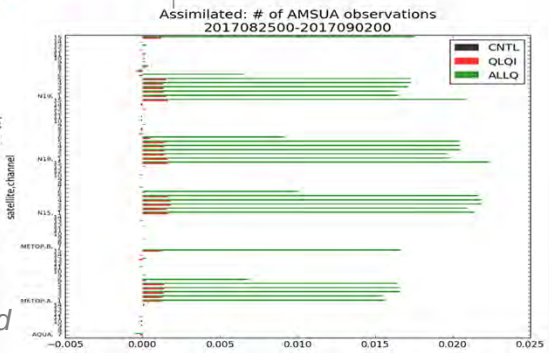
FV3 is a powerful foundation for unified prediction. Advances in GFDL systems can be seamlessly transitioned into other FV3-based models

Initialization from NCEP or EC analyses, or with native data assimilation to leverage new model features

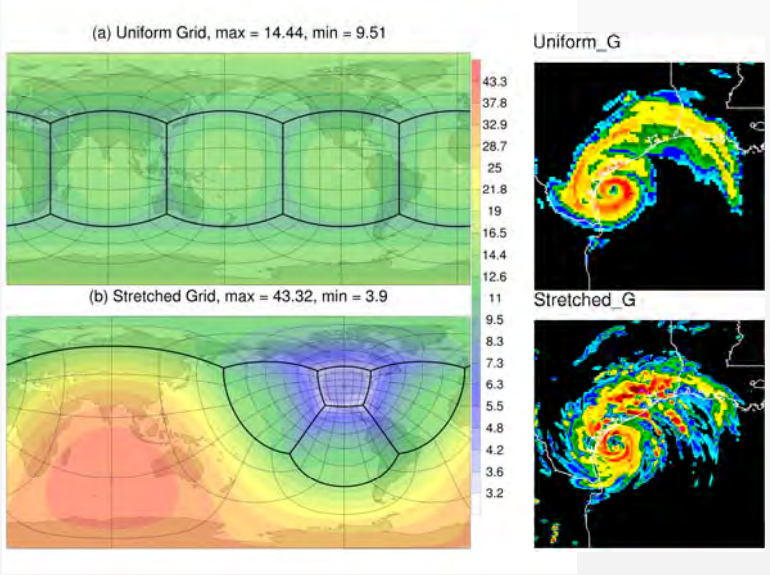
Variable-resolution grids allow enhanced resolution for longer-range forecasting



J-H Chen et al 2019, GRL



M-J Tong et al, submitted



L. Zhou et al 2019, BAMS

See Jan-Huey Chen and Baoqiang Xiang's talks for more SHiELD prediction results and Mingjing Tong's Poster for SHiELD-DA development

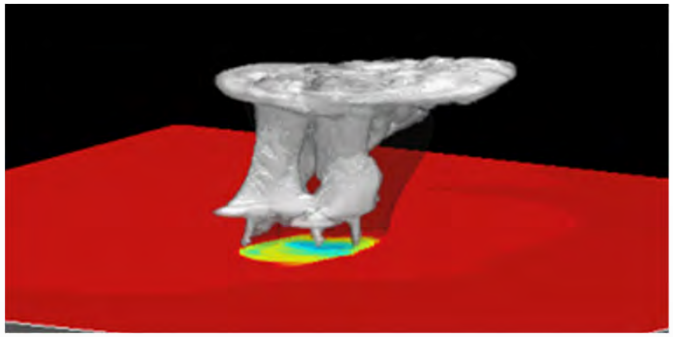
FV3 At GFDL: Convective Scale

Switchable nonhydrostatic dynamics: one core, all resolutions

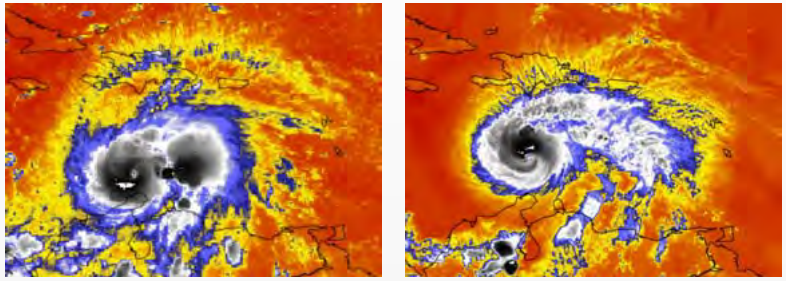
Nonlinear vorticity dynamics and mimetic PGF allow better representations of small-scale severe weather and hurricane processes

Doubly-periodic and regional domains open doors to new applications and seamless high-resolution process studies

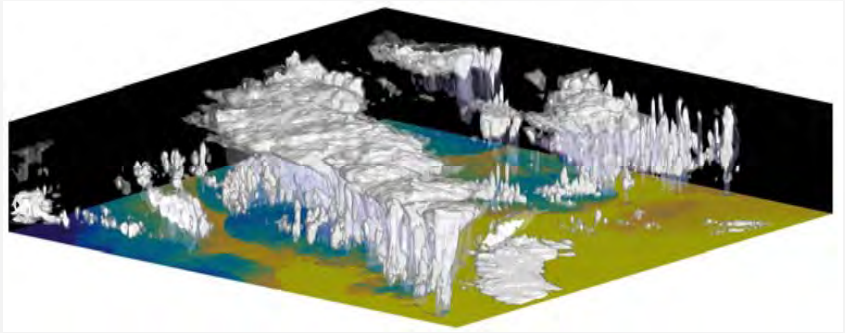
See Kun Gao's poster for convective-scale S2S



1-km super-stretched global FV3



Hurricane Matthew (2016): GOES-13 (left) vs. 2-km T-SHiELD (right)
Courtesy S. Nebuda and J. Otkin, SSEC/UWisc



Squall Lines in 3-km C-SHiELD

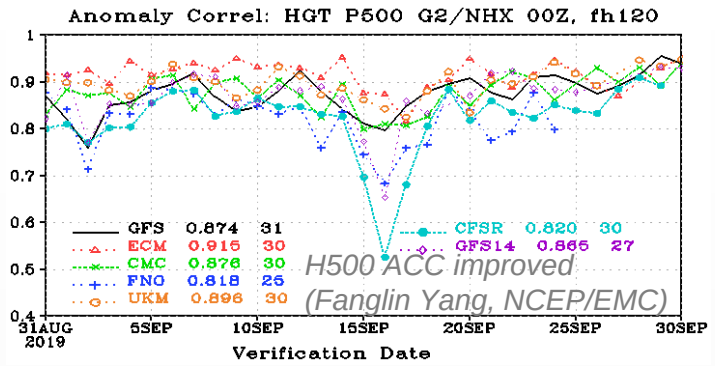
NGGPS and GFSv15

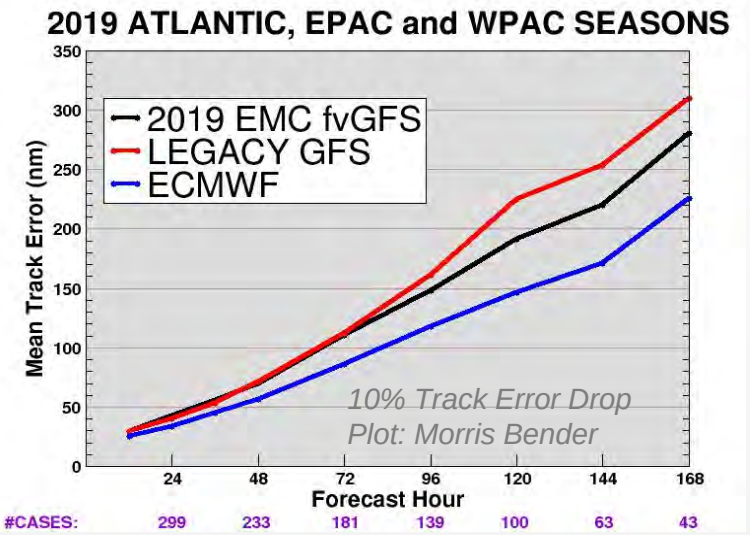
FV3 was selected in 2016 as the core for NOAA's **Next-Generation Global Prediction System** (NGGPS)

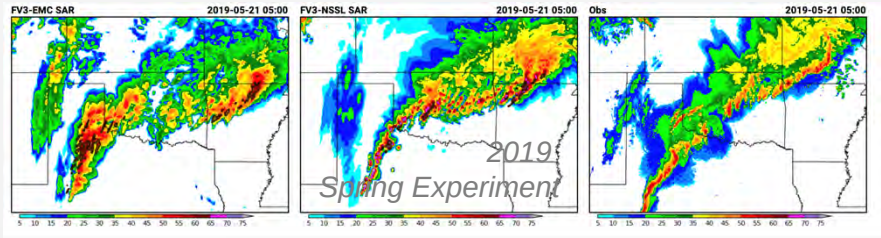
FV3-based GFSv15 with GFDL microphysics **operational** 12 June 2019. Improvements to large-scale skill, tropical cyclone track and structure, and US precipitation vs. Legacy spectral GFS

<u>FV3 opens the path to NWS model unification.</u> FV3-based prototypes of CONUS, hurricane, and S2S prediction models show great promise.

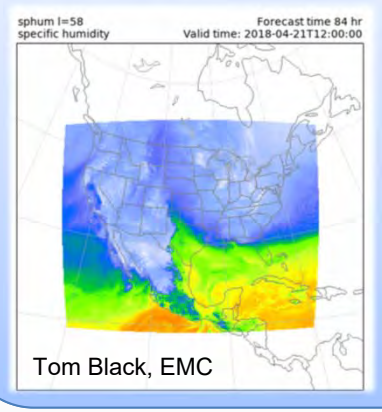
→ 2020: FV3-based GEFS and an FV3 member in HREF





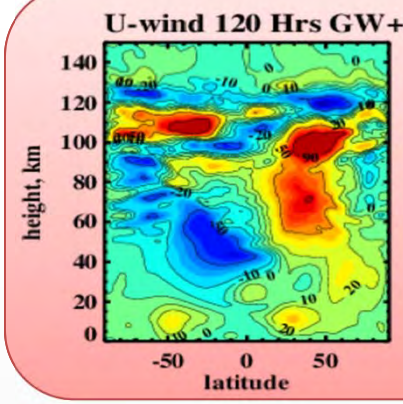


FV3 Coming Attractions



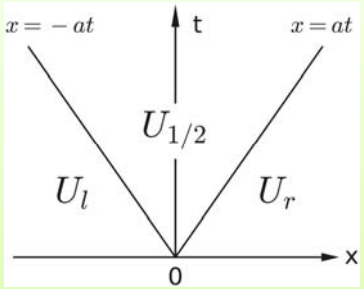
Tom Black, EMC

Stand-alone regional weather and climate model (EMC-GFDL)

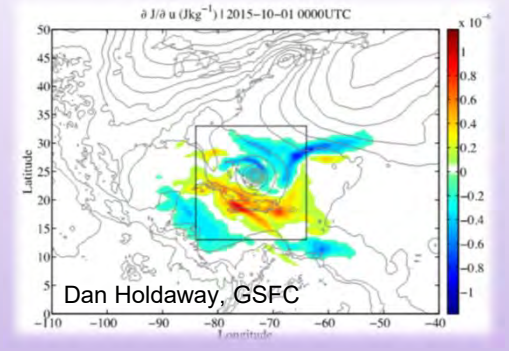


Deep atmosphere variable-composition atmospheres (EMC-GFDL-SWPC)

Valery Yudin
CU/SWPC



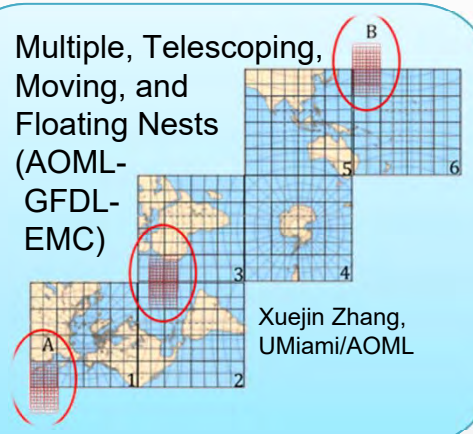
LMARS Fast Riemann Solver (Chen et al 2013, 2018)



Dan Holdaway, GSFC

FV3 Adjoint (NASA Goddard)

Multiple, Telescoping, Moving, and Floating Nests (AOML-GFDL-EMC)



Xuejin Zhang, UMiami/AOML

CLASP
Coupling of Land and Atmospheric Subgrid Parameterizations

Process-study framework for Physics-Dynamics Interactions

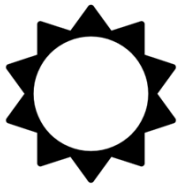
GPUs and Domain-Specific Languages (GFDL-NASA Goddard-Vulcan-CHCH)

Rethinking Physics-Dynamics Coupling

Moving modeling forward requires breaking the strict separation of physics and dynamics.

Partially-resolved and fast processes can be integrated directly into FV3 for better dynamical consistency, energy conservation, and efficiency

Super FV3



Slow Processes

Intermediate Processes

Fast Processes

PHYSICS

Para. Update

- Radiation
- Cloud MP
- Pollutant Source/Sink
- Sub-Grid-Orog. effects
- PBL, etc.

DYNAMICS

Tracers Update | Prog. Vars. Update

In-line GFDL MP
See Linjiong Zhou's poster

Integrated dust prediction and improved FV3 Energetics
See Xi Chen's Poster

Graphics courtesy Xi Chen and Yuan Ma

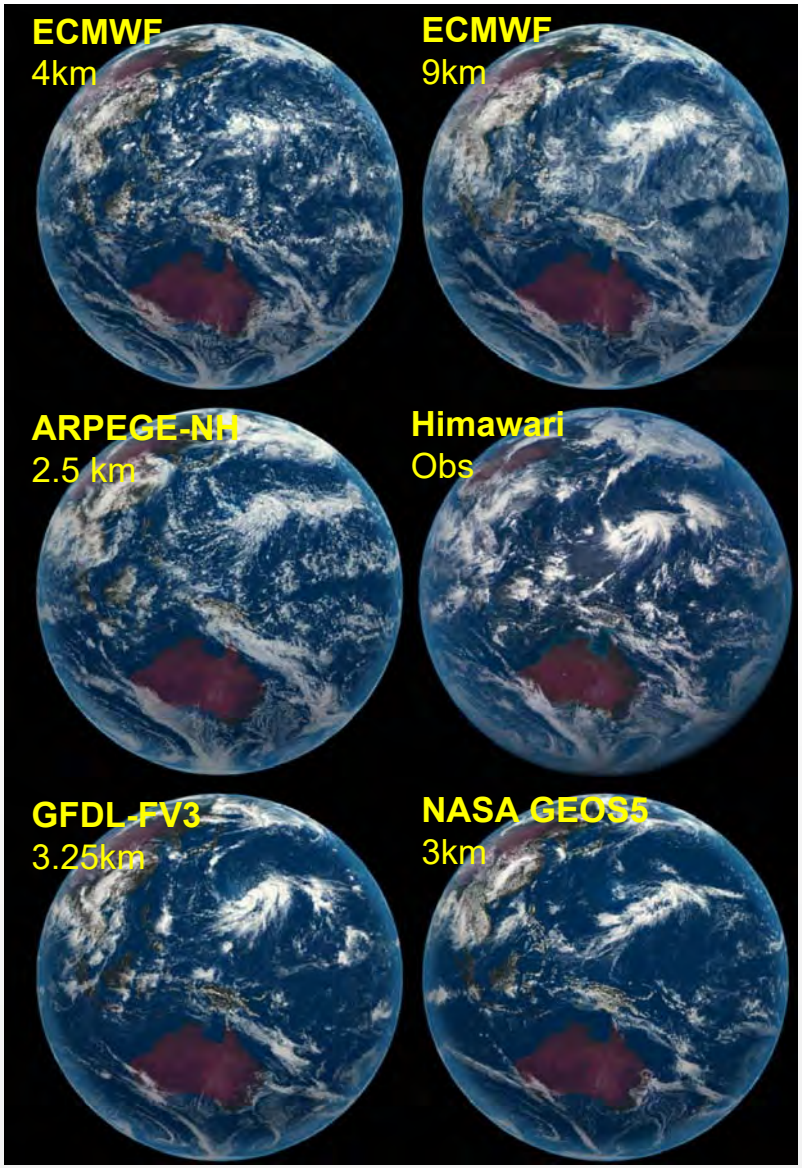
Global Cloud-Resolving Modeling

2009: FV3-based GCRMs at NASA and GFDL

2019: DYAMOND
First international inter-comparison of GCRMs to study convection-general circulation interactions.

FV3-based X-SHiELD and GEOS5 lead US submissions.

Vulcan Inc and GFDL are developing a Hybrid Model-Machine Learning system: GCRM input in, new moist physics out



DYAMOND vs. Satellite: Stevens et al 2019, PEPS