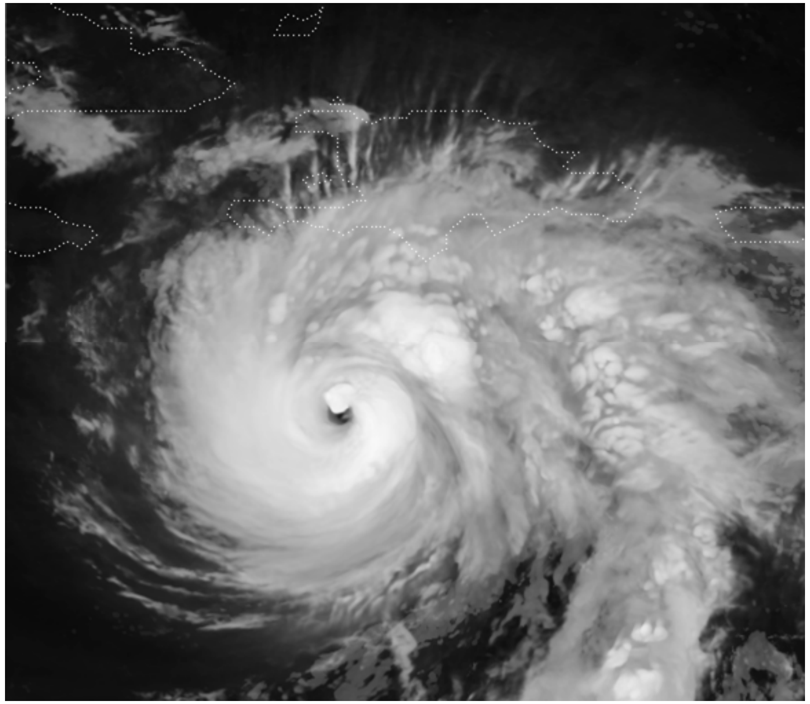
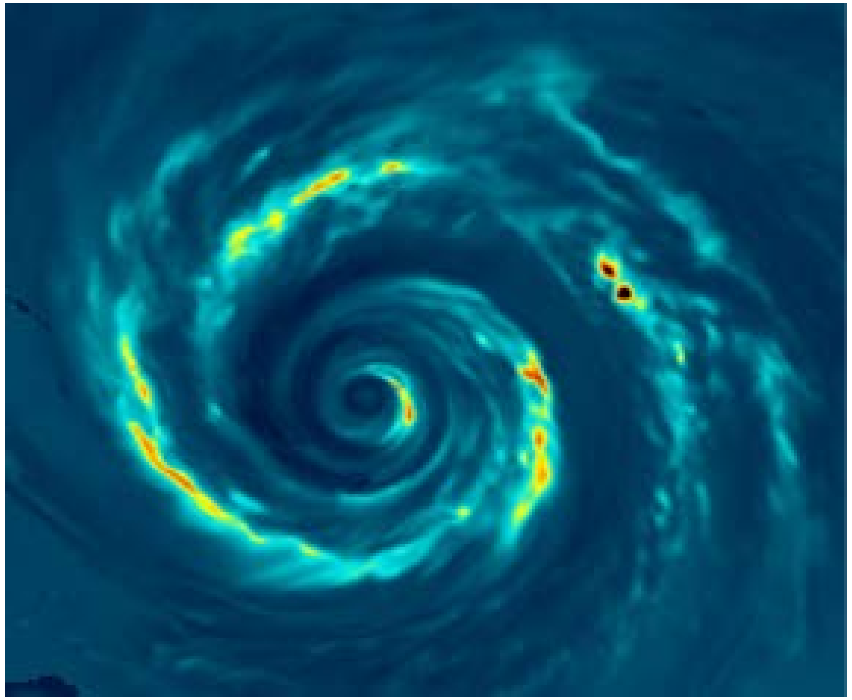
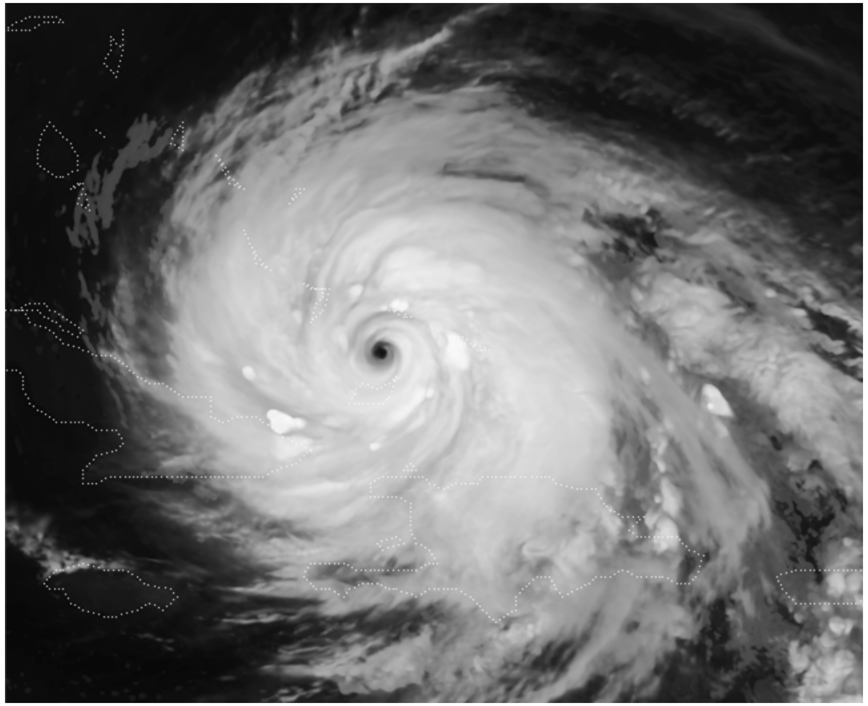




Unified FV3-based Weather and Climate Modeling at GFDL

Lucas Harris for S-J Lin and the GFDL FV3 Team

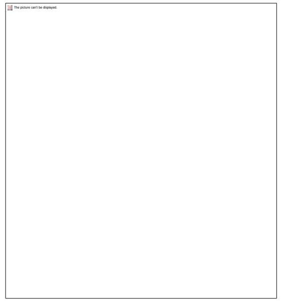
HFIP Annual Meeting

5 November 2018

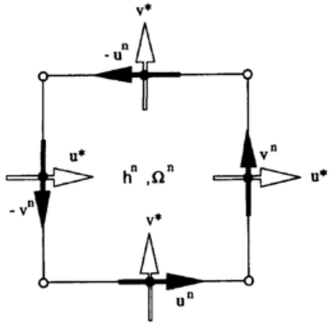
FV3: The GFDL Finite-Volume Cubed-Sphere Dynamical Core

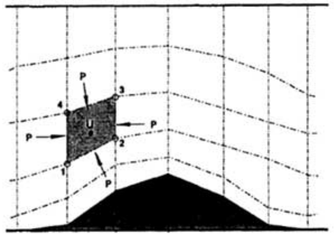
Goal: Physical consistency, fully-FV numerics, component coupling, and computational efficiency

Lin & Rood 1996
Efficient 2D high-order FV transport



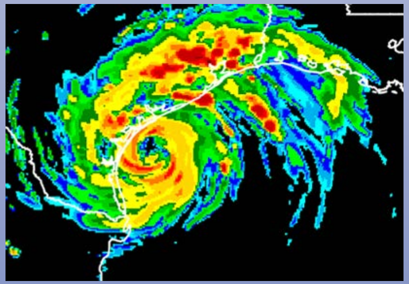
Lin & Rood 1997 FV horizontal solver focusing on nonlinear vorticity dynamics

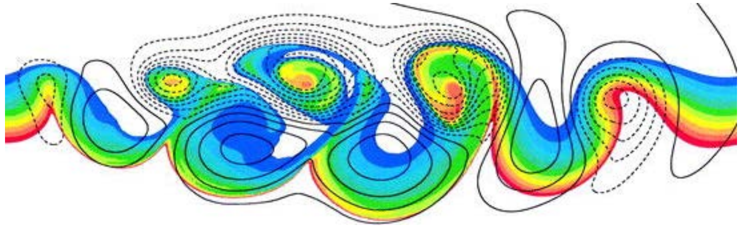




Lin 1997 Efficient, mimetic FV PGF

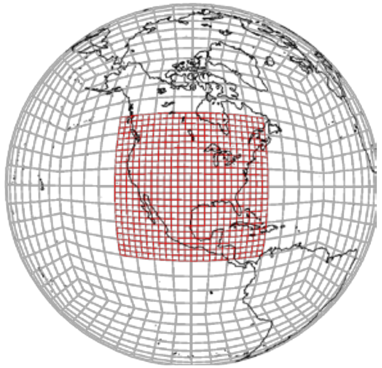
Next-generation FV3
Rigorous Thermodynamics
Flexible dynamics
Adaptable physics interface
Variable-resolution techniques
Regional & periodic domains

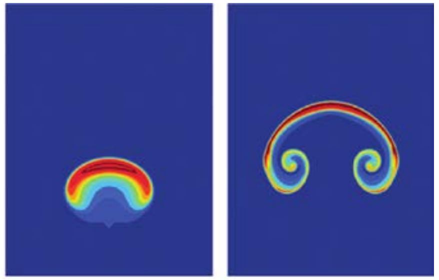




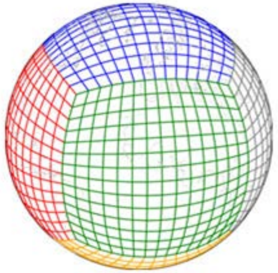
Lin 1998–2004 FV core with “floating” Lagrangian vertical coordinate: highly-accurate and stable vertical transport

Harris & Lin 2013, 2016
Variable resolution with two-way nesting and Schmidt grid stretching





Lin 2006, Chen & Lin et al 2013
Consistent Lagrangian nonhydrostatic dynamics



Putman & Lin 2007
Scalable cubed-sphere grid, doubly-periodic domain

The FV3 community

Many Models
Many Applications
One flexible dynamical core

CESM Framework
CAM-FV
CAM-FV3

NCAR

NEMS Framework
FV3-powered GFS, GEFS, CFS, WAM
HAFS, UFS, RRFS
FV3-based regional model
for HREF, Warn-on-Forecast

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

GEOS Chem
GEOS-Chem High-Performance

LASG FAMIL

Chinese Academy of Sciences

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

TaiESM; CWB prediction model

The GFDL Unified Modeling Suite

Models for prediction, projection, and research at all scales

- FV3: GFDL Finite-Volume Cubed-Sphere Dynamical Core
  - Not a model, a dynamical core…for now

- AM4: GFDL's CMIP6 Atmosphere Model
- CM4/ESM4: GFDL's CMIP6 Coupled-Climate Models
- HiRAM: High-Resolution Atmosphere Model for S2S prediction
- SPEAR: Coupled model for S2D prediction

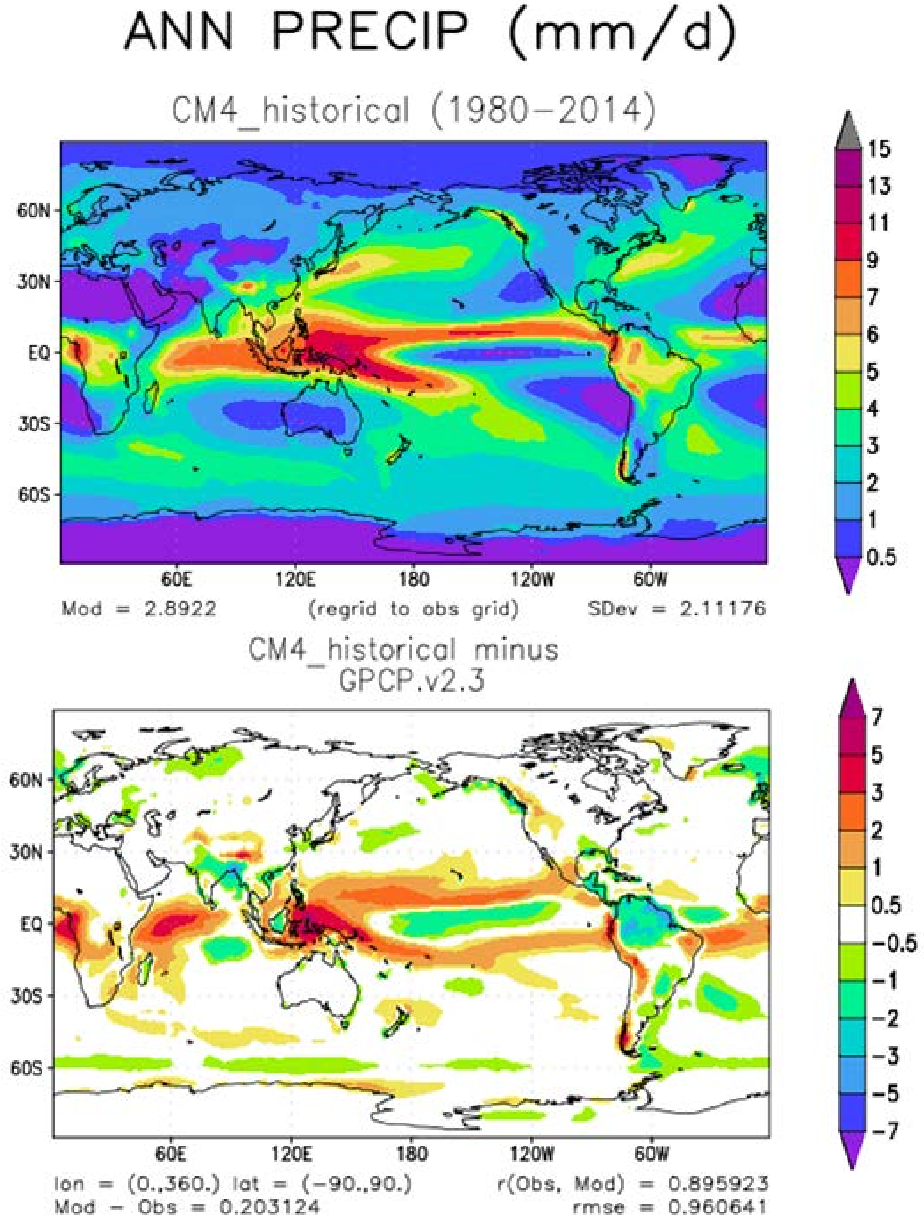
GFDL Physics Suite and LM4 Land Model

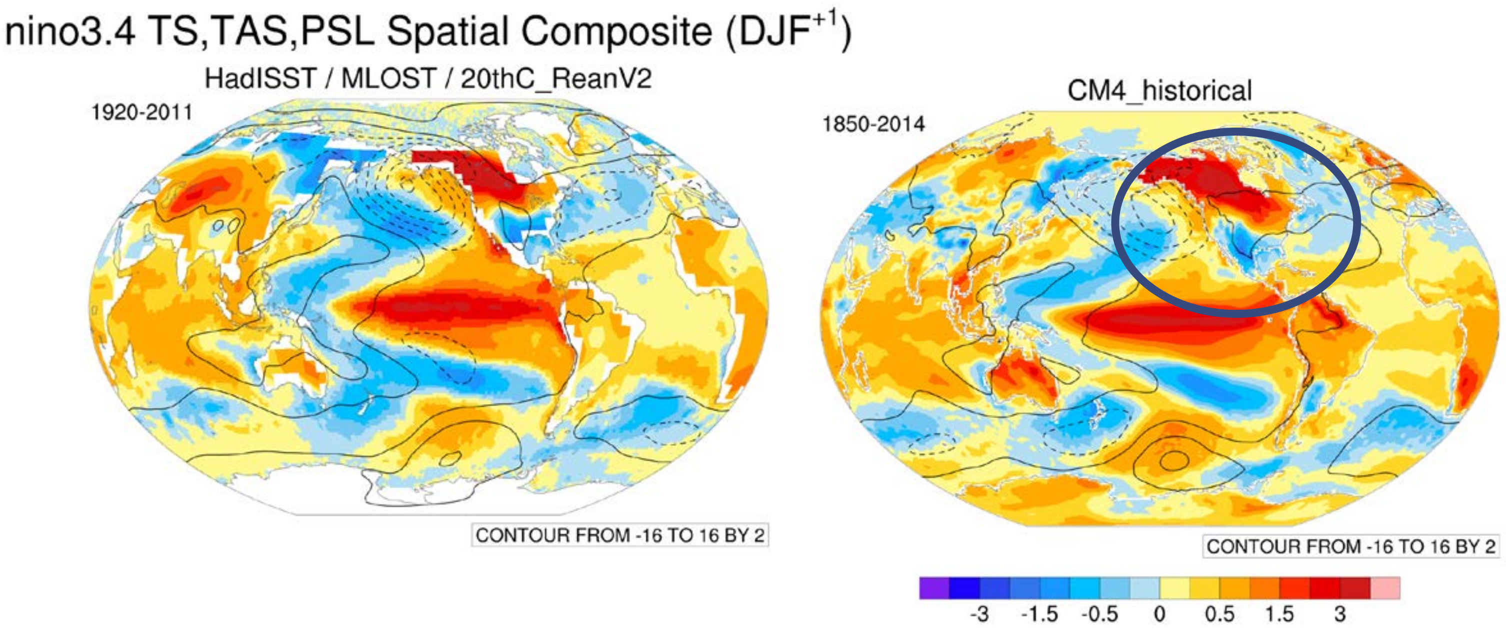
- fvGFS: Weather and S2S prediction model
  - Simple and focused; ideal for researchers and academics
  - Passes graduate student test!

Modified GFS Physics Suite and NOAH Land Model

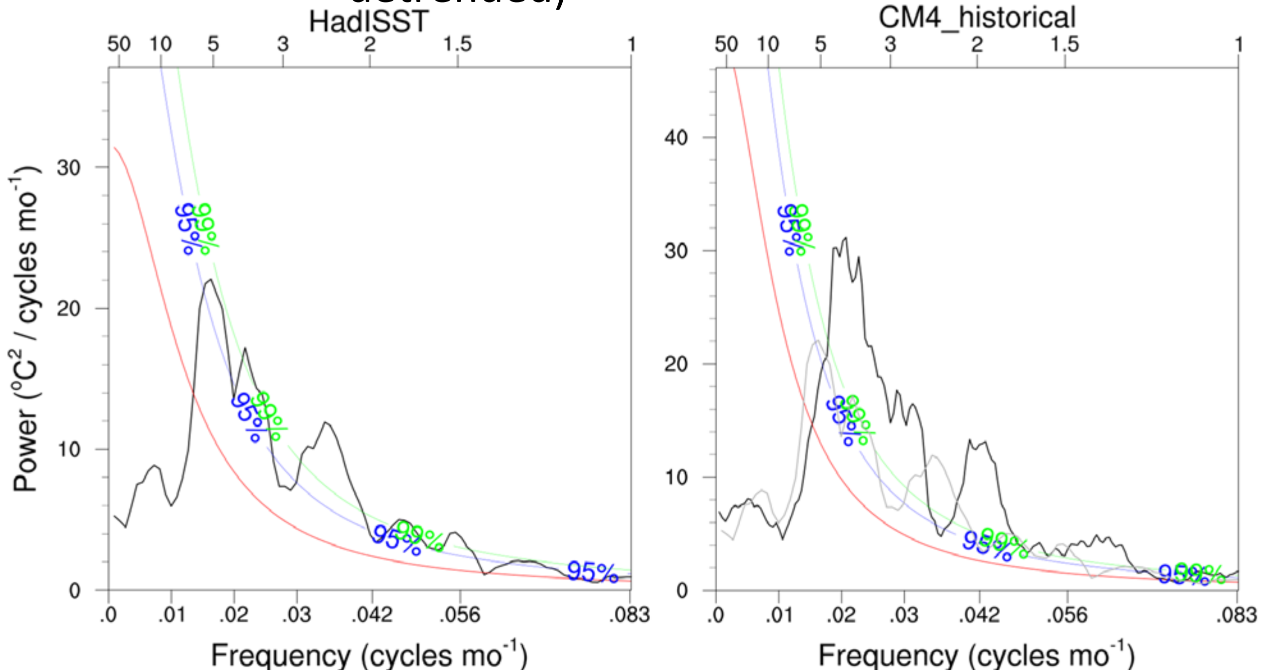
CM4

GFDL Coupled model v4
Courtesy GFDL MDT





Niño 3.4 (monthly, detrended)



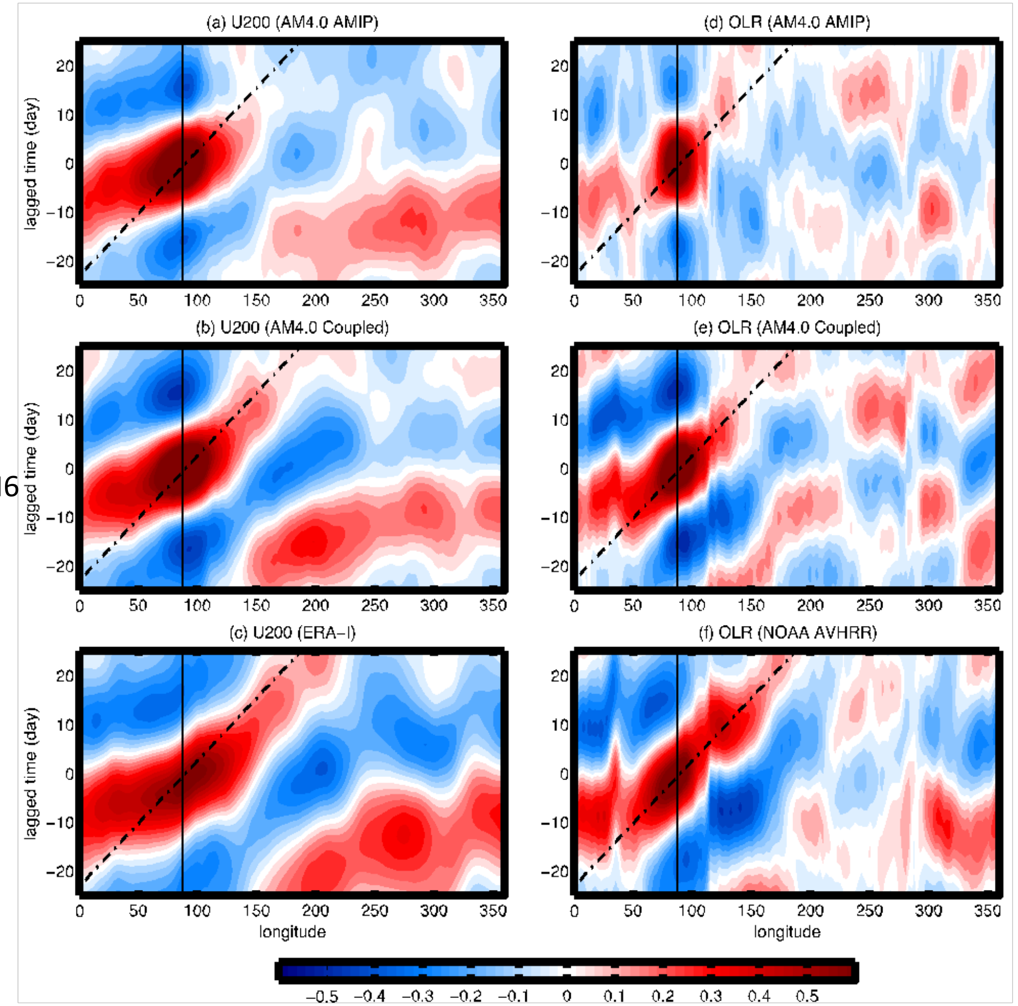
MJO: Variability and Impacts

U200 | OLR

AM4
Prescribed SST

AM4
Coupled to MOM6

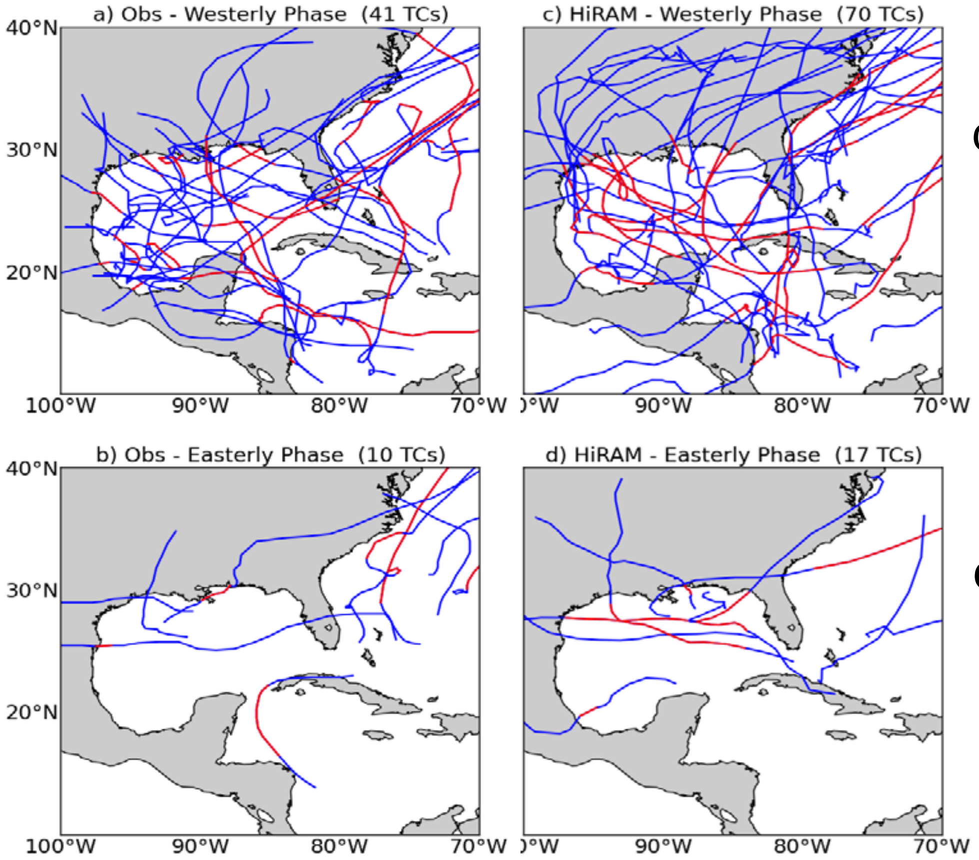
Observed



100-km AM4: Zhao et al 2018a,b (JAMES)

Observation | 25-km HiRAM

Tropical Storms
Hurricanes



Convectively **enhanced** MJO Phase

Convectively **suppressed** MJO Phase

25-km HiRAM (Simplified AM4 with GFDL MP)
Gao et al 2018 (JGR)
See highlight in *Eos*

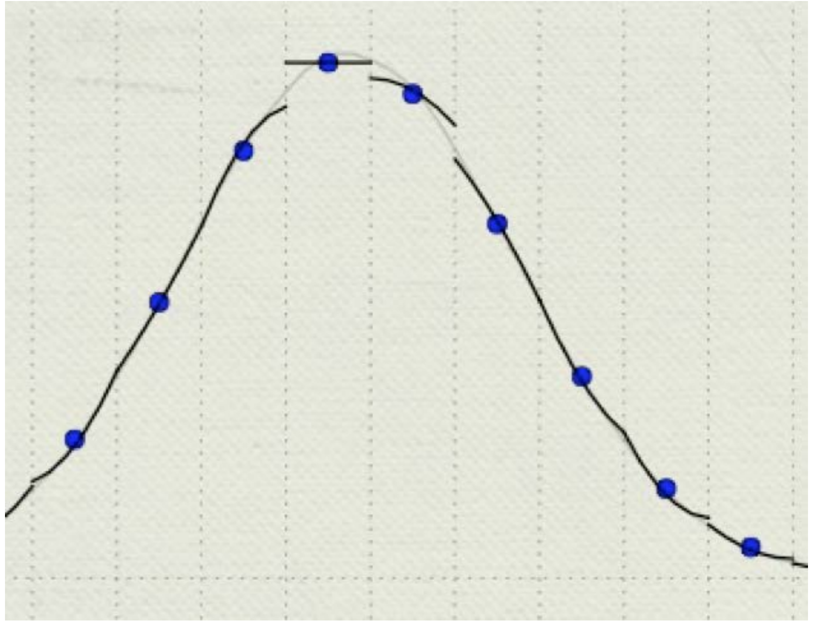
2018 fvGFS Upgrades

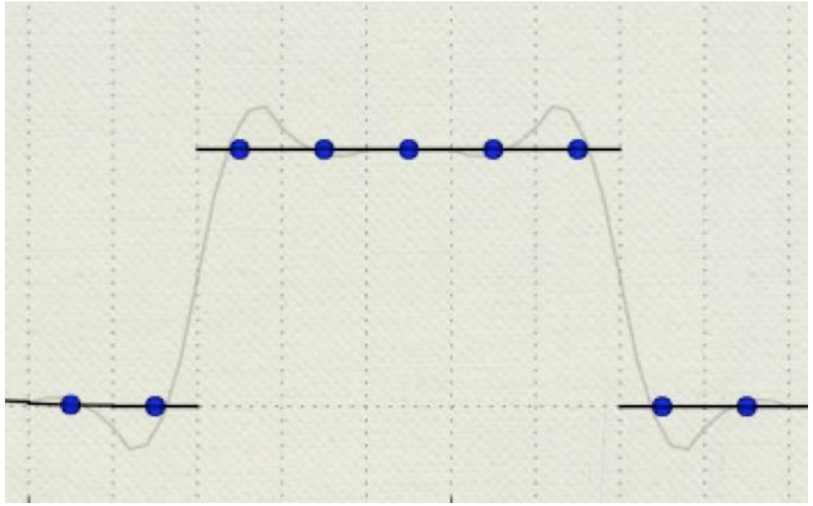
GFDL continues to develop *model* including dynamics and physics.

- 2018 FV3 Core
  - New positive-definite scalar advection
  - Revised nesting code to be more efficient and simpler
- 2018 GFDL MP
  - Inline microphysics (enabled in 13-km global and in continental 3-km nest)
- GFS PBL replaced by YSU (H. Shin, UCAR/GFDL)
- Mixed-layer ocean (B. Xiang, UCAR/GFDL)
- Operational Scale-Aware SAS
- Various GFS Physics Driver enhancements and re-tunings

Advection schemes in FV3

- A true finite-volume scheme computes fluxes by integrating the amount of subgrid mass flowing through a cell interface during a timestep.
- The subgrid distribution (black) is an *approximation* that gives a certain order of accuracy, given a set of cell mean values (blue), and that *limits* the reconstruction so that the creation of new extrema (noise) is prevented.
- FV3 always uses Piecewise-Parabolic advection (PPM), which is formally fourth-order before limiting





Advection Schemes in FV3: Dynamical Processes

- True FV schemes do as much as possible as a flux (just like real fluids). In FV3 all scalars (air mass, vorticity, vertical velocity, potential temperature) are advected by the same scheme, for best results.
- hord_{tm,mt,vt,dp} = 8: Strictly monotonic advection
  - No overshoots, but most diffusive
  - “hord” is just a selector for the reconstruction, and does not control “order of accuracy”
  - Monotonicity is “smart” diffusion, and can replace “physical” diffusion in some contexts (LES: Pressel and Schneider et al. 2017)

Advection Schemes in FV3: Dynamical Processes

- hord_xx = 6: Non-monotonic ("linear", "unlimited") with a **strong** filter: flatten reconstruction if curvature is too large
  - Best ACC but weakest TCs
- hord_xx = 5: Weak 2Δx filter: flatten reconstruction only if a 2Δx mode is present
  - Slightly degraded ACC, stronger TCs
  - **Warning:** hord_xx = 5 is only very weakly diffusive. Recommend increasing explicit damping to compensate, for best results.

Advection schemes in FV3: Tracer Advection

- Tracer advection must *always* be either monotonic or positive definite; negatives are bad for microphysics and chemistry
- hord_tr = 8: Strictly monotonic advection, same as hord_xx = 8
- hord_tr = -5: same as hord_xx = 5 but with a positive-definite limiter
  - *Not fully implemented in last FV3 delivery to EMC*

- Important: there is **no** explicit diffusion on tracers in FV3. hord_tr = -5 is effectively inviscid.

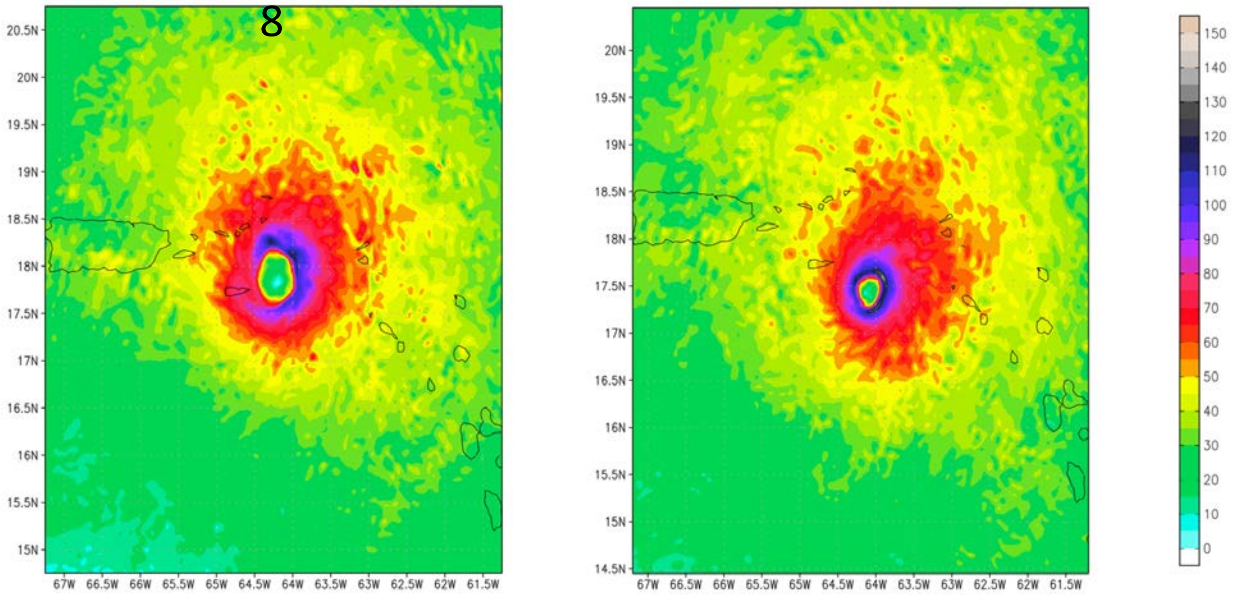
Hurricane Maria

2017 fvGFS
EDMF, hord_tr = 8

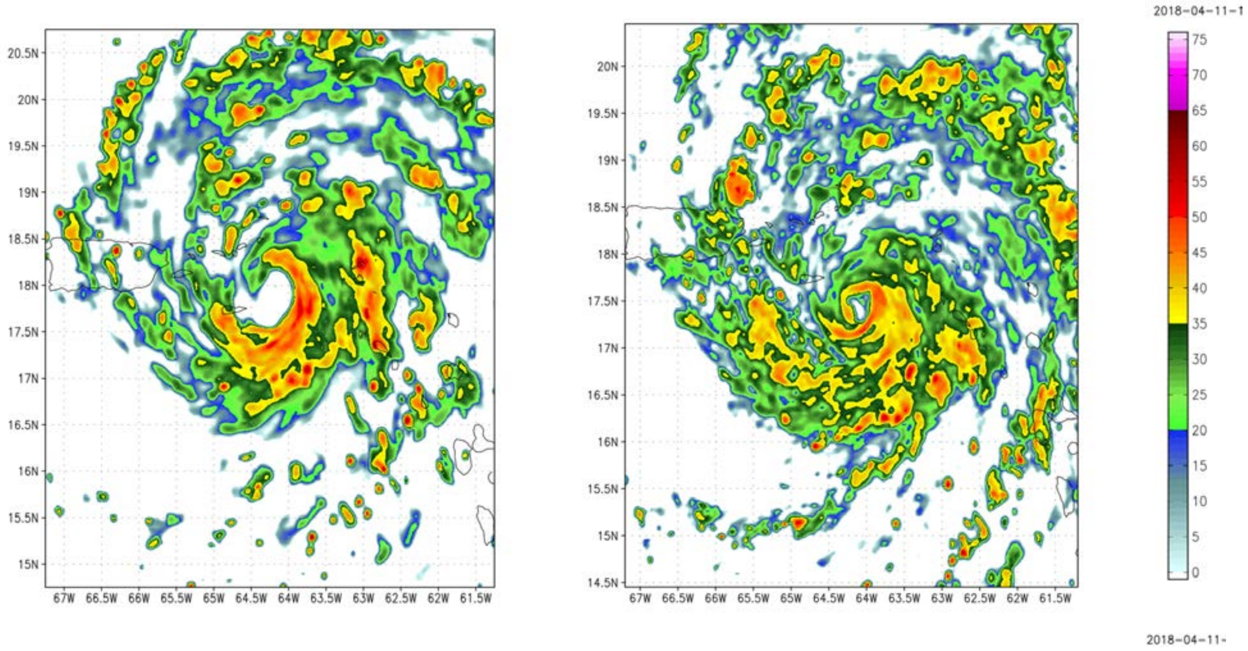
2018 fvGFS
YSU, hord_tr = -5

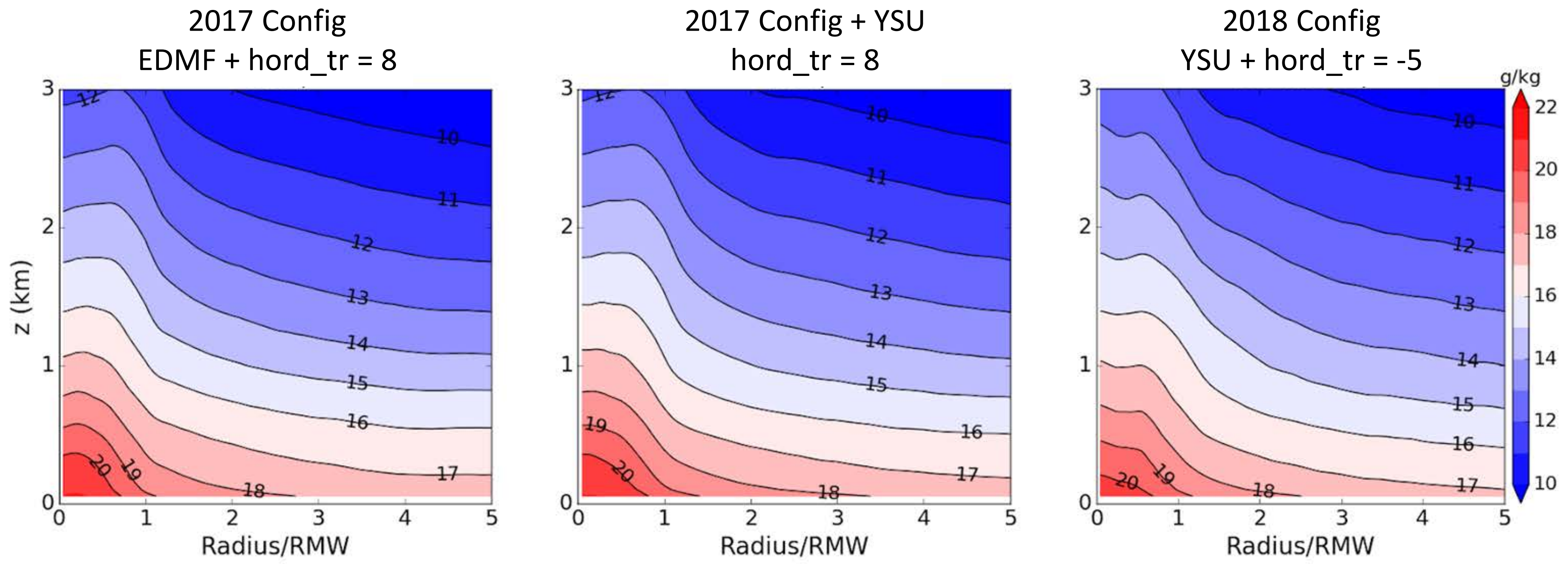
65-hour forecast
Init 12Z 17 Sep 18

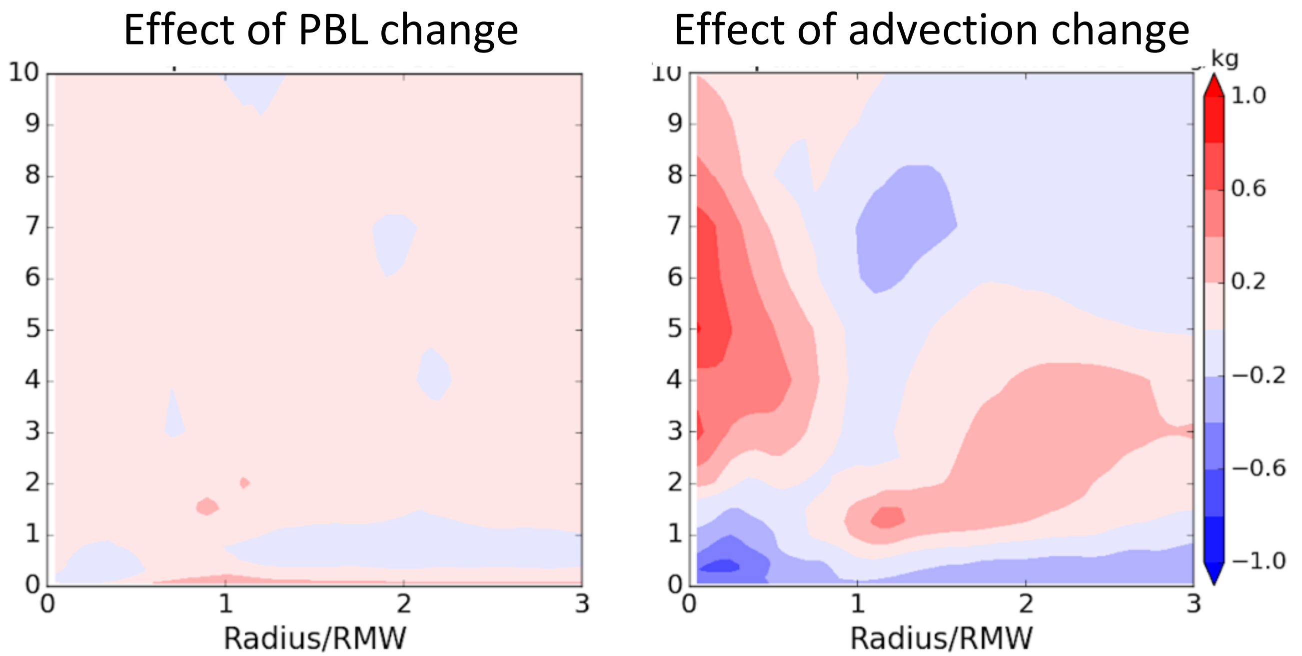
925-mb winds (kt)



4-km Radar
Reflectivity (dBZ)

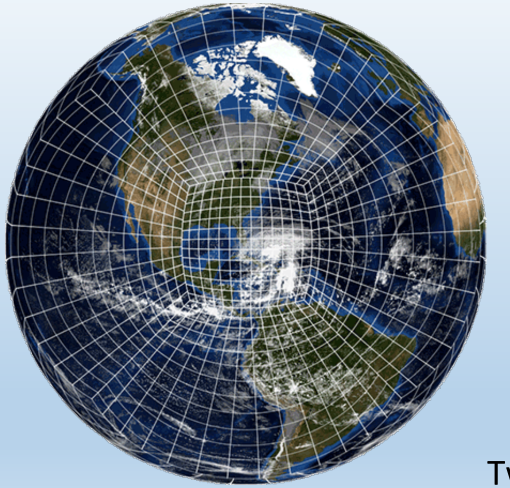


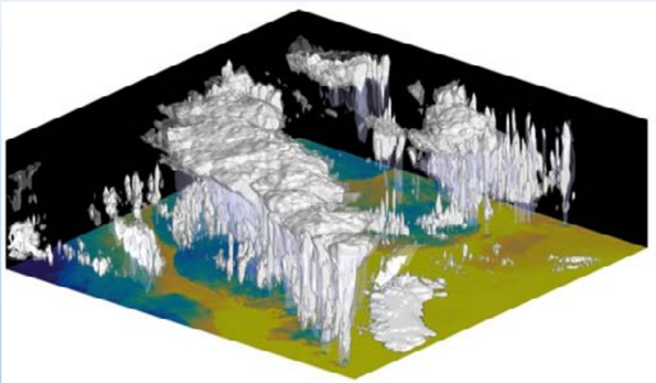




Radial composite
Water vapor specific humidity

The biggest difference is from the PD scheme!!



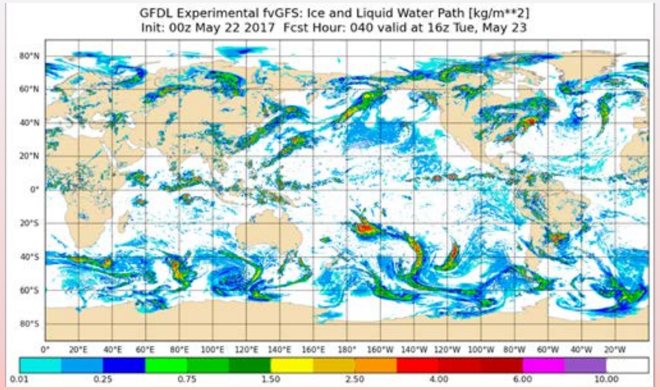


60–90 second
Two-way Interaction
Continual interaction on stretched grid

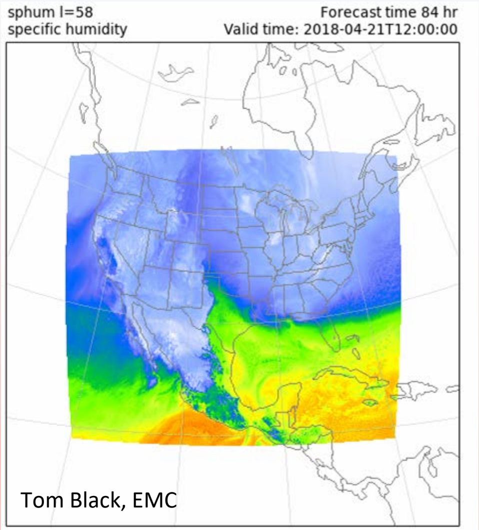
Global-to-regional Refinement
(two-way nesting, or stretching)

- Consistent, rapid interaction
- Improved BCs
- Large-scale interaction (great for TCs)
- Enables medium-range/S2S (decadal-centennial?) convective-scale prediction

An improvement upon existing models—
The key to next-generation CAMs?



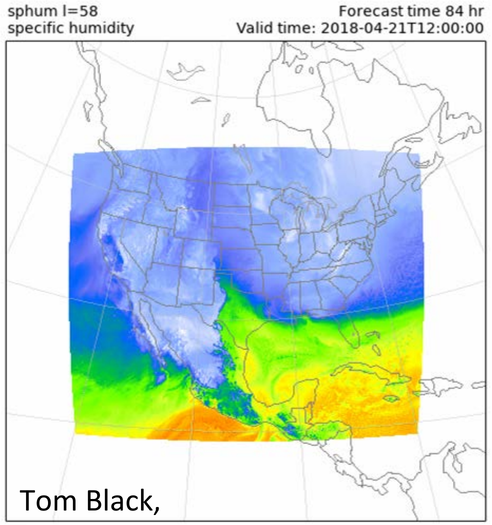
Three-hour
BC Update Frequency



Stand-alone Regional Model

- Low computational overhead
  Ideal for resource-limited users
- Simple and easy for short-term
- Good for extremely high resolutions
  LES, urban-scale, Warn-on-Forecast
  - 3-km is not the end!!

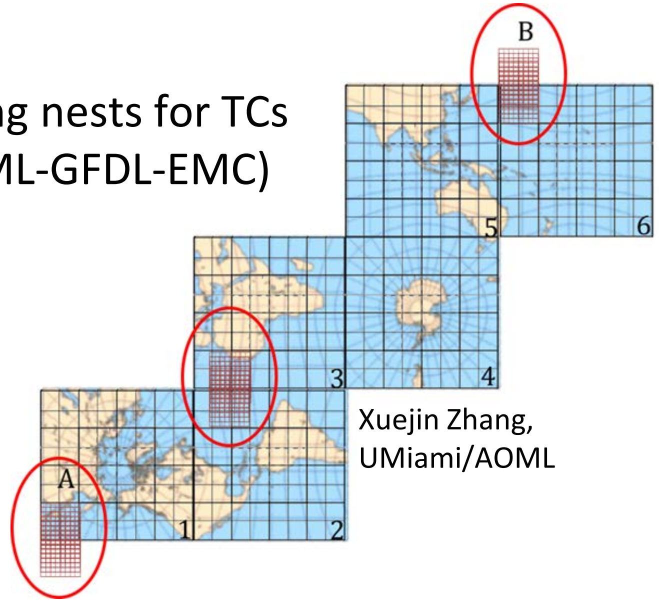
Under Construction



Tom Black,
EMC

Stand-alone regional
(EMC-GFDL)

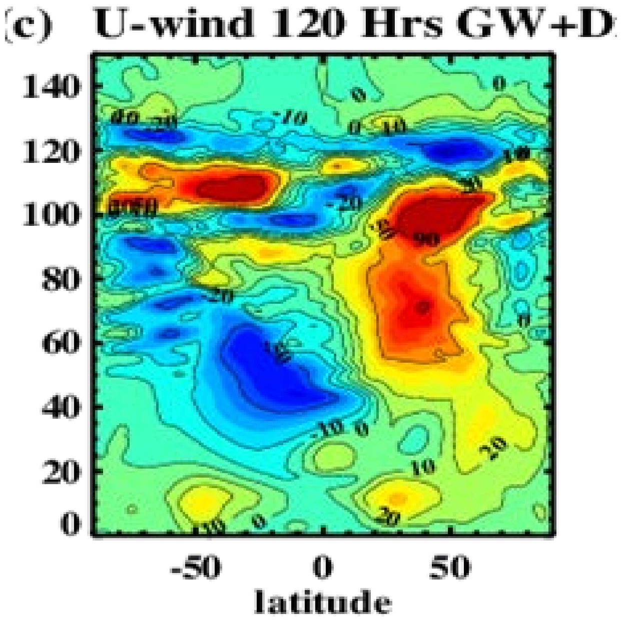
Moving nests for TCs
(AOML-GFDL-EMC)

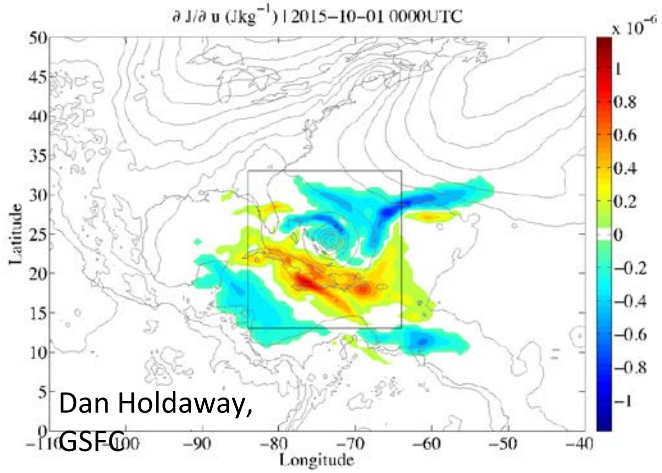


Xuejin Zhang,
UMiami/AOML

Deep atmosphere
and variable
composition for
WAM/ Geospace
(EMC-GFDL-SWPC)

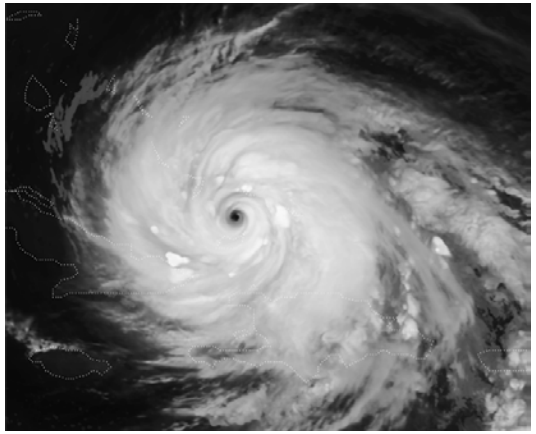
Valery Yudin,
CU/SWPC



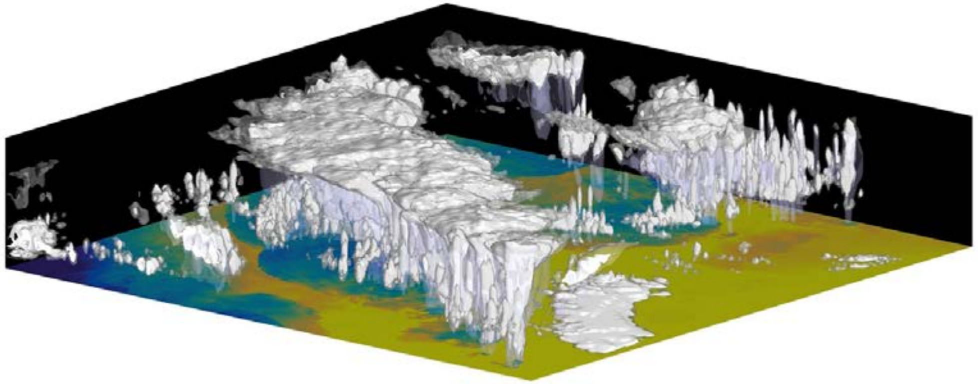


Dan Holdaway,
GSFC

FV3 Adjoint (NASA Goddard)



UWisc/SSEC Satellite
Simulator and Verification



Convective-scale prediction and DA
(GFDL, OU/CAPS, EMC, AOML, NSSL, PSU, ESRL, etc.)

GFDL "FV3-2020": Integrating Physics with Dynamics

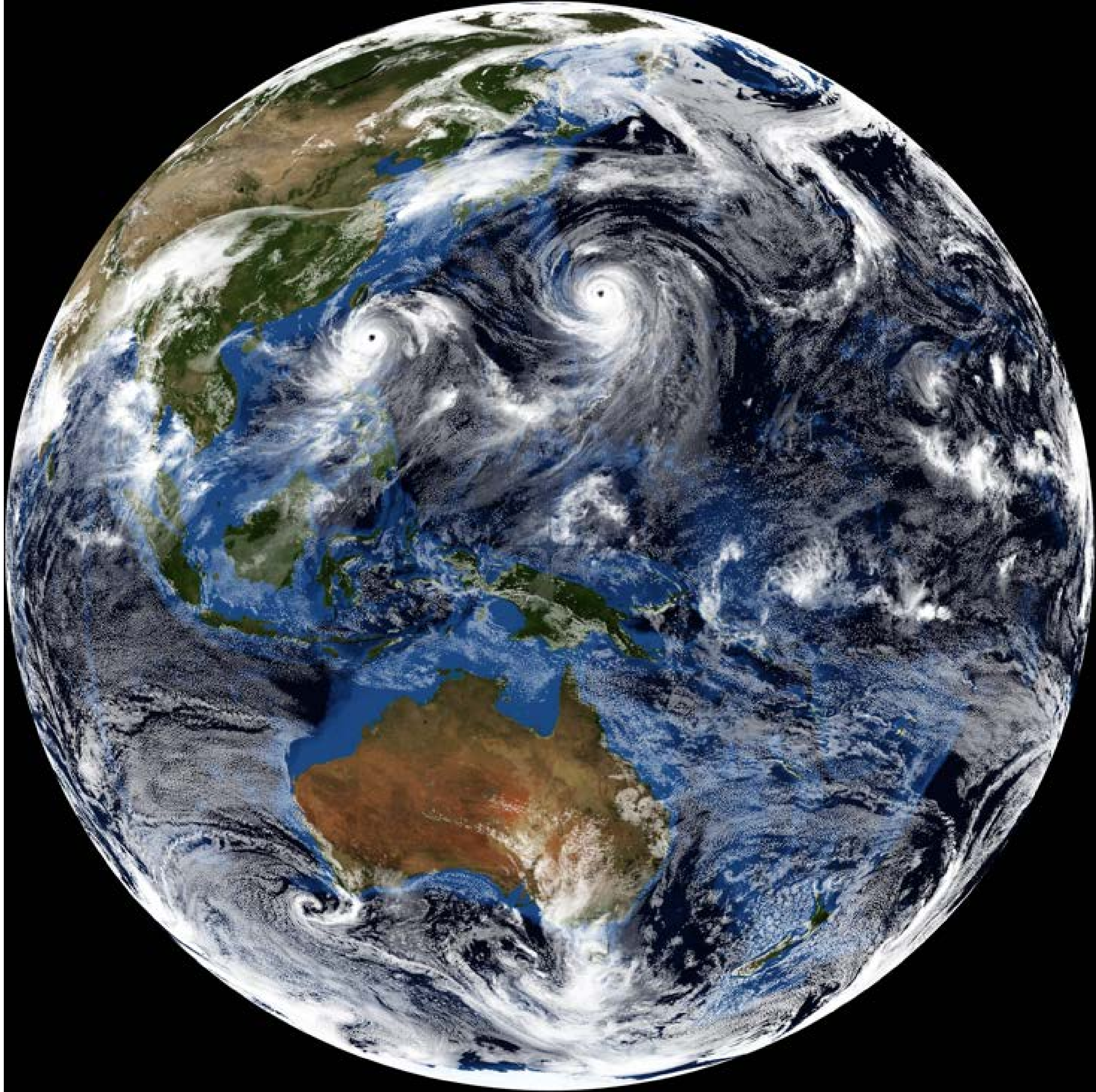
DYAMOND

Weather ❤□Climate

- International global cloud-resolving model inter-comparison
- 40-day fvGFS runs
  - 3-km c3072
    - Also 6.5-km c1536
  - GFDL MP, no convective parameterization, new SGO
- Evaluating climate (energy balance, circulation) as well as variability and weather events

Courtesy S-J Lin, Xi Chen, and Linjiong Zhou

www.gfdl.noaa.gov/visualizations-mesoscale-dynamics/



Concerns moving forward: Physics

- What is the Physics Development strategy for NGGPS?
  - Framework development is not physics development
  - Parameterization mix-and-match is not physics development

    Do we really believe parameter choices are already perfect for all purposes?
  - Successful models succeed by **holistic** model development, in tandem with other components, not assembling models like Legos
  - Successful physics suites succeed by **holistic** physics development
- Physics unification and/or differentiation: not just regional–global and weather–climate but also tropical–mid-latitude and marine–land–ice

Concerns moving forward: Longer-range Prediction

- Exploring 5–10 day hurricane prediction skill
  - Cannot move forward by moving back to 18 hour forecasts
- Will just any ocean coupling be good enough for S2S? Hurricane prediction? Hydrological and coastal modeling? (Maybe.)
- Seasonal/annual scales (0–2 years as per Weather Act): ????
  - Dominated by ENSO, stratospheric modes, land surface, cryosphere… Need to engage climate modeling community.

Concerns Moving Forward: Whither the regional models?

- Medium-range and S2S convective-scale prediction is the next frontier. How will we get there?
- What will the regional model be useful for? Even **higher** resolutions!
  - Urban scale, LES, Warn-on-Forecast, and other sub-km applications
- Need a better name.
  - "SAR" → "SARS"
  - FV3-CAM → NCAR CAM-FV3
  - ReginAM: **R**egional **A**tmosphere **M**odel
    - "Reginam" means "kingdom", "realm", or "domain"

Finite-Volume Advection

A Very Short Introduction