The Development of the Unified Forecast System for S2S Prediction at GFDL

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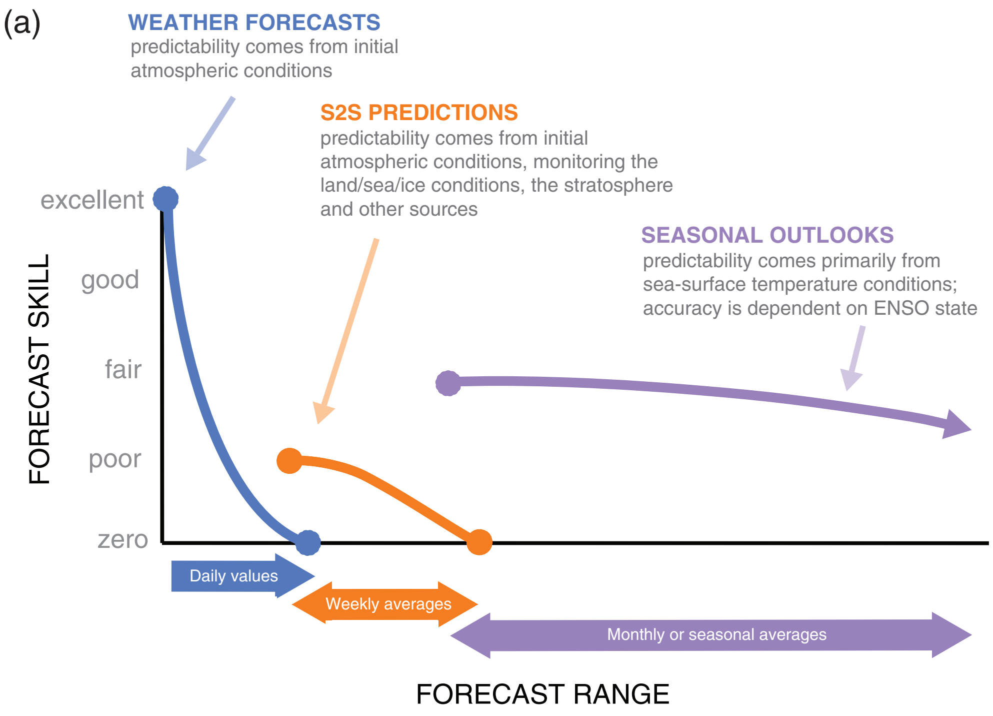
2019 US CLIVAR Summit

S2S prediction is a frontier but remains very challenging

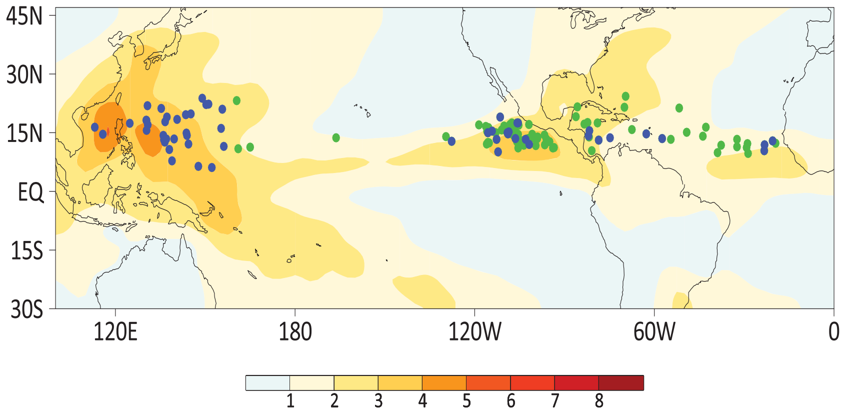
S2S: 2 Weeks to 2 months



White et al. 2017

S2S results #1: TC genesis

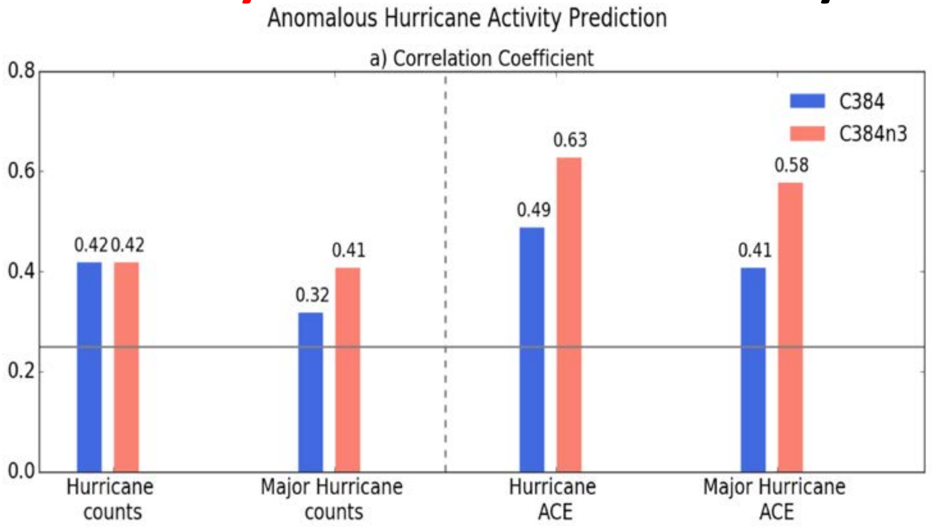
Two-week TC genesis prediction



174 TC genesis out of 597 observations
30% of TCs can be skillfully predicted
with 1-2 week lead time

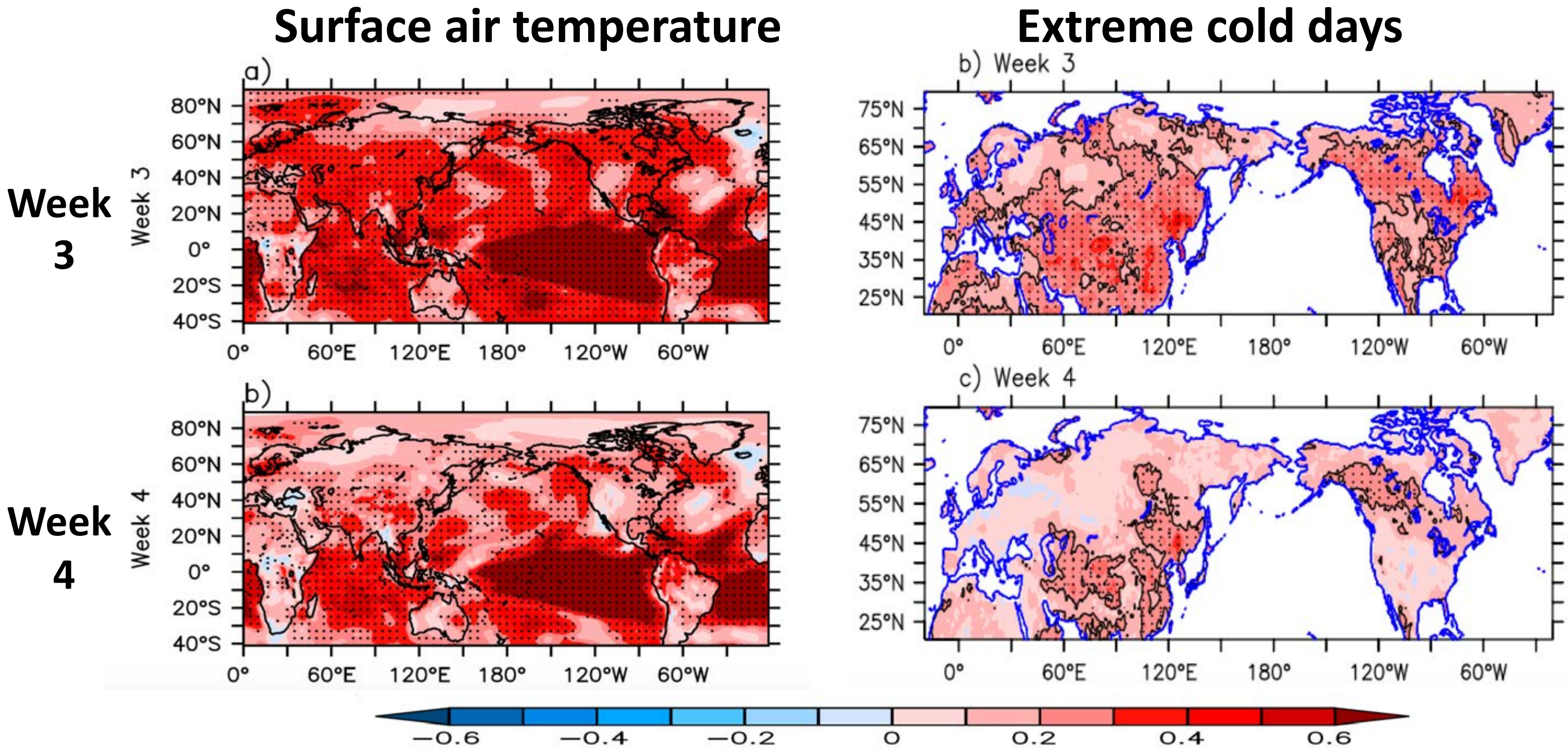
Jiang et al. 2018; Xiang et al. 2015

Monthly total Hurricane Activity



Gao et al. 2019

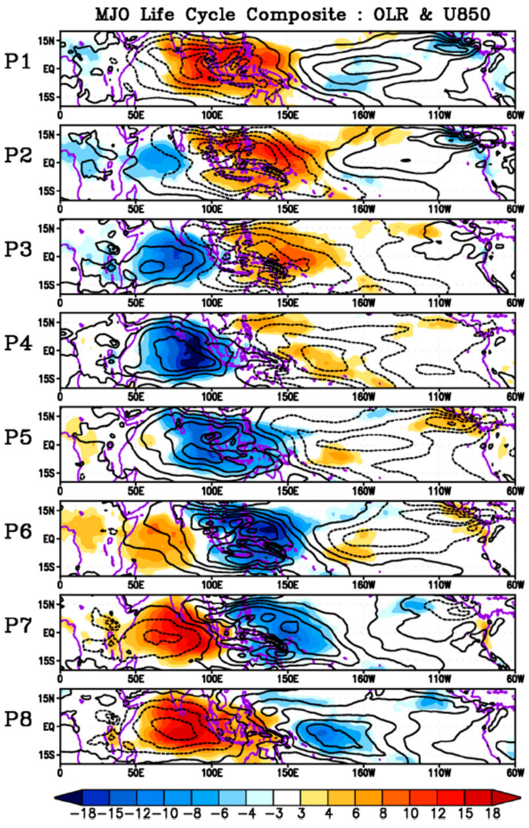
S2S results #2: week 3-4 prediction of temp and extremes



Xiang et al. 2019

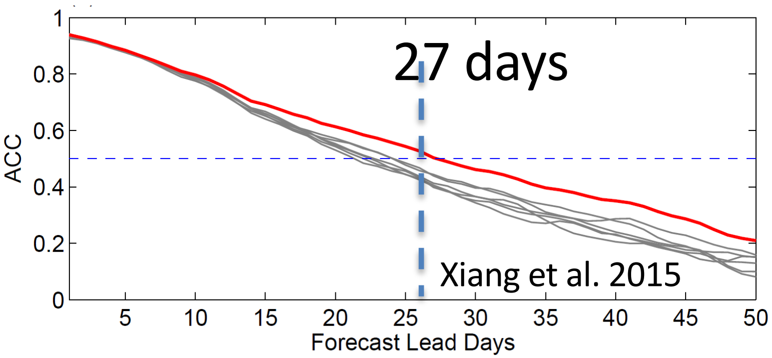
Xiang et al. in preparation

S2S results #3: 27 days of MJO prediction skill

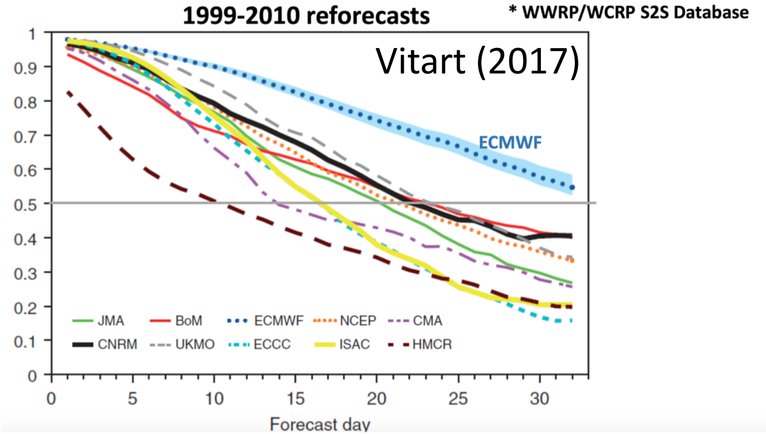


Kim et al. 2014

GFDL



operational



UFS provides an opportunity to accelerate improvements in S2S prediction

The **Unified** Forecast System (UFS) is a **community-based, coupled, comprehensive** Earth modeling system. The UFS numerical applications span local to global domains and predictive time scales from sub-hourly analyses to seasonal predictions.

GFDL contributes to the UFS development:

1) FV3 (Finite-Volume Cubed-Sphere Dynamical Core) + GFDL Microphysics
2) MOM6 ocean model

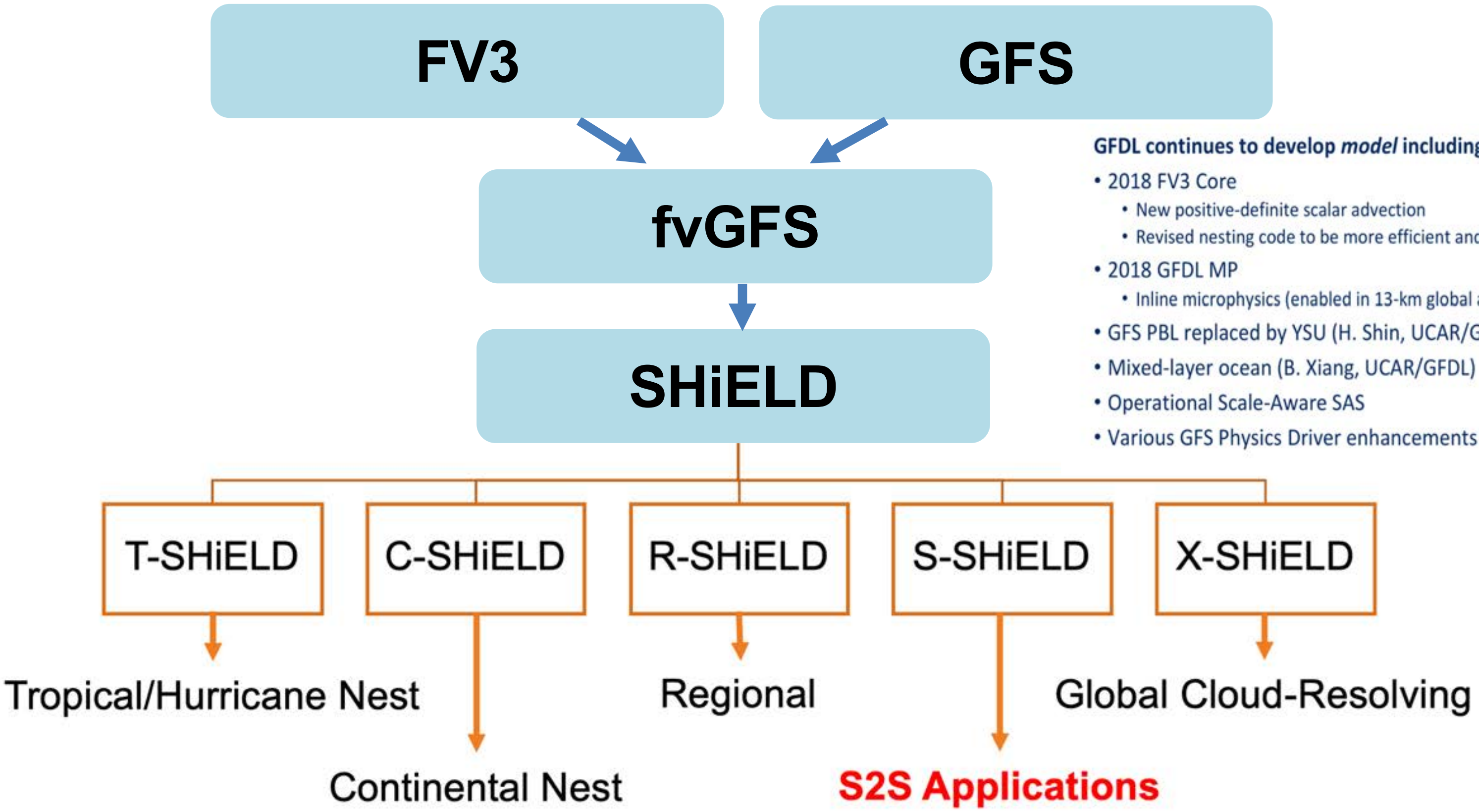
UFS = FV3 + MOM6 + ……

https://ufscommunity.org

GEFSv12 (uncoupled) will be the first NWS modeling system for sub-seasonal predictions, planned for implementation in 2020 (target for operational in 2022).

The newly developed GFDL models (SHiELD and SPEAR) are UFS implementations at GFDL

SHiELD (System for High-resolution modeling for Earth-to-Local Domain)

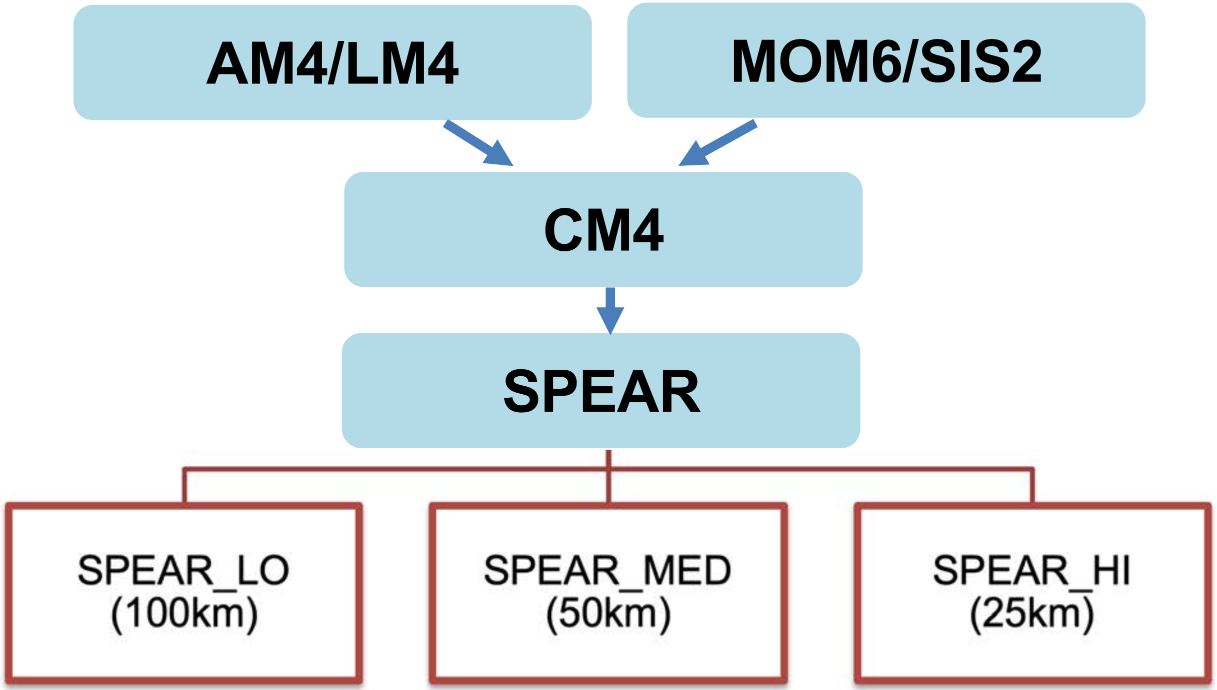


GFDL continues to develop *model* including dynamics and physics.

- 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

(Chen et al. 2019a,b; Harris et al. 2019; Zhou et al. 2019; Hazelton et al. 2018 ……)

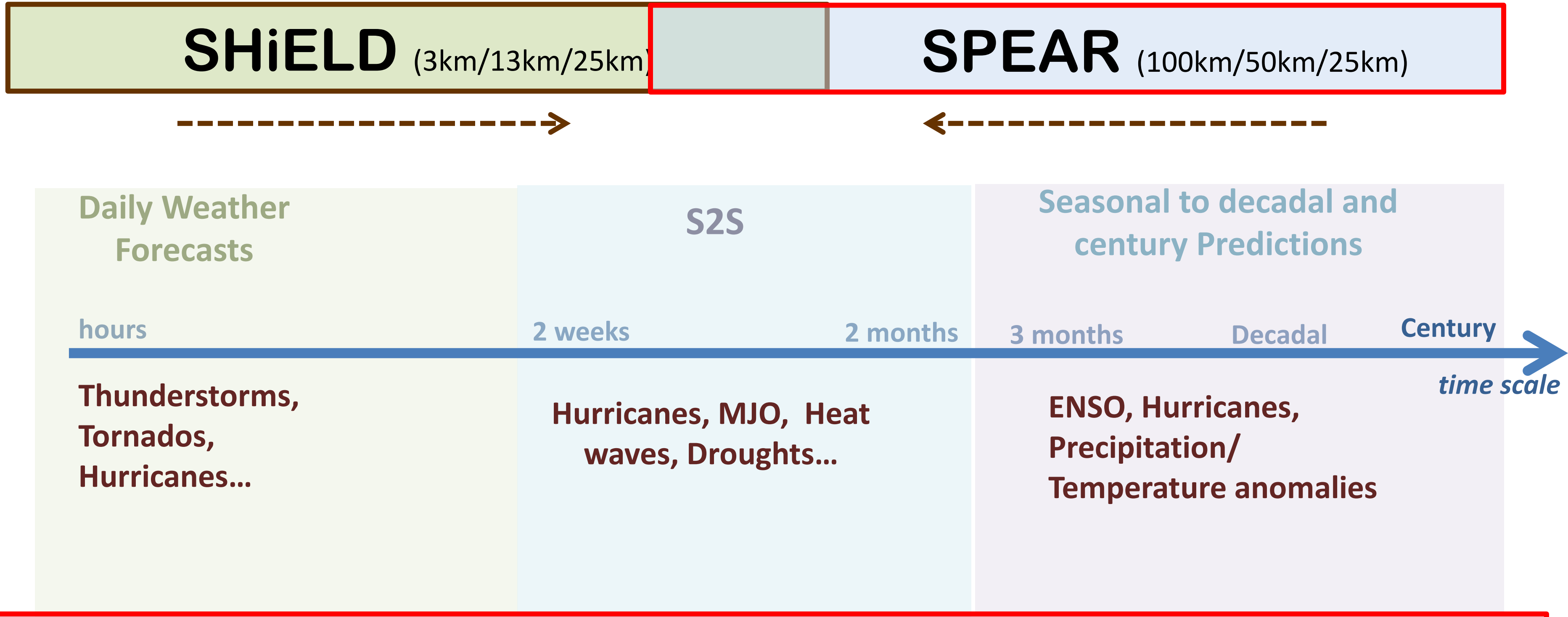
SPEAR (Seamless System for Prediction and EArth System Research)



Ocean/Ice (MOM6/SIS2): 1° ocean

(Delworth et al. 2019; Zhao et al. 2018a,b; Adcroft et al. 2019; Held et al. 2019 ……)

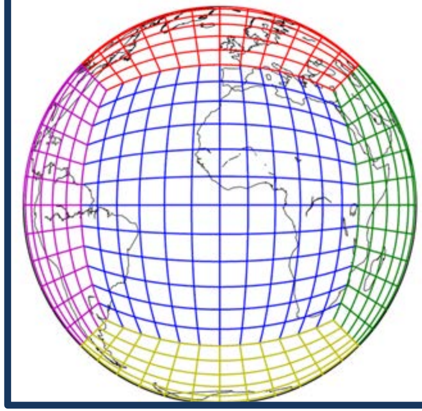
SHiELD & SPEAR



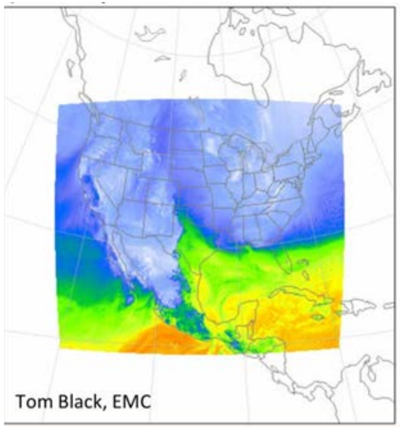
One codebase, one compile script, one executable, one runtime, one post-processing

FV3 is flexible, adaptable, robust, and fast

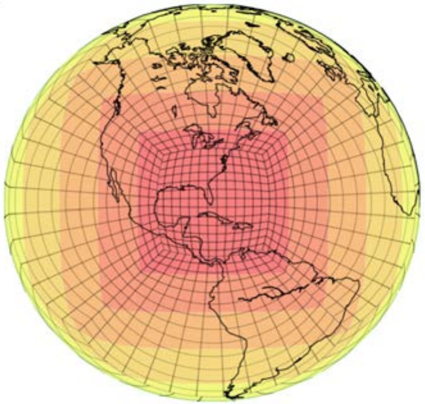
uniform



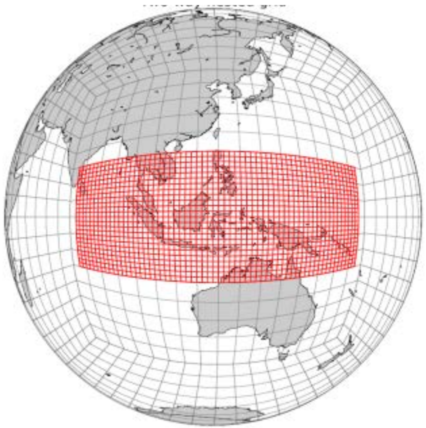
regional



stretched

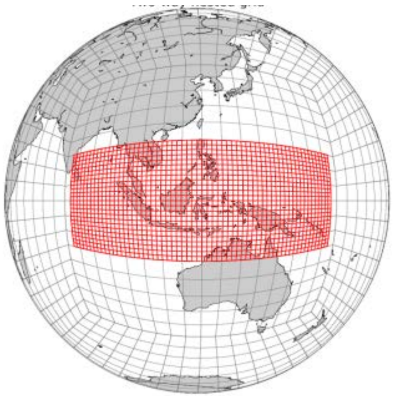


nested

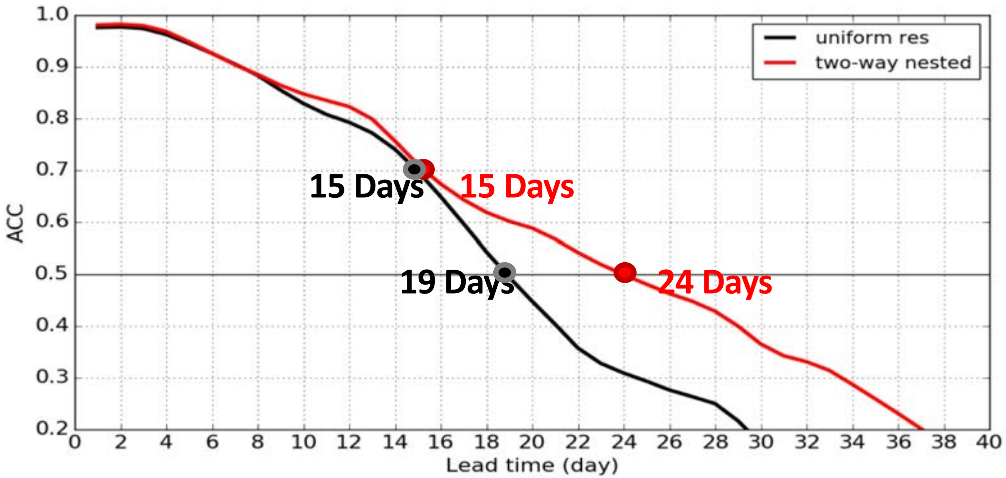


Nested configuration of SHiELD improves MJO prediction

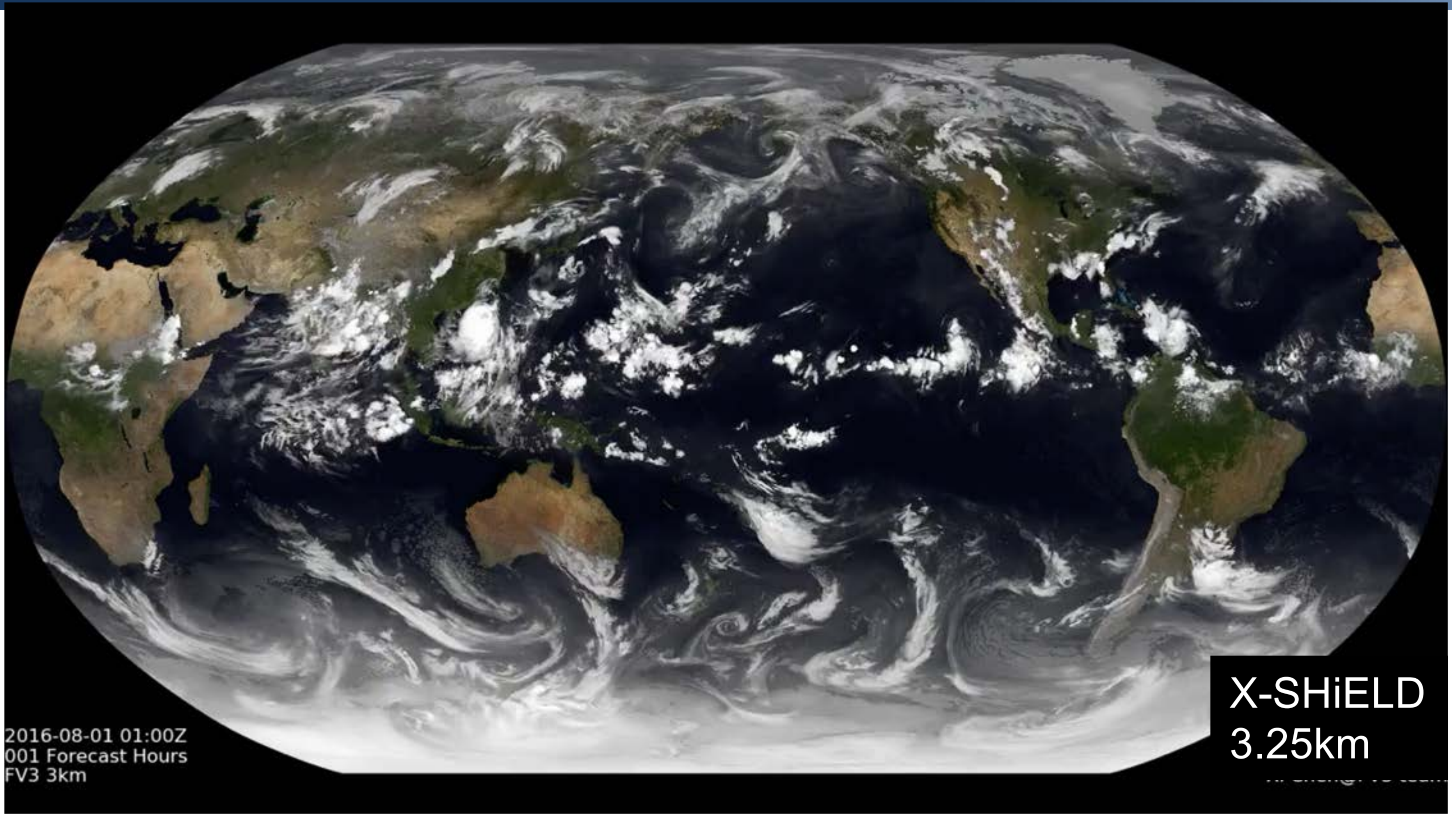
VS



Correlation skill



Experimental global cloud-resolving subseasonal hindcast (X-SHiELD)



Thunderstorms → Convective Systems → Fronts and Hurricanes → Baroclinic Waves → Long Waves

Source: https://www.gfdl.noaa.gov/video/FV3.C3072.robin.olr.mp4

Ongoing S2S efforts

1) Developing and evaluating SHiELD/SPEAR's S2S prediction skill

Case studies before long reforecasts

2) Improving our understanding on S2S prediction

--- sources of predictability, window of opportunity for prediction, key factors influencing S2S prediction skill (initialization, model resolution, model biases …)

3) Exchanging innovations and updates with other UFS models, contributing to operational S2S predictions

Gaps for S2S prediction

S2S prediction is still at its infancy and developing stage!

- **Intrinsic model errors**
- **Imperfect initial conditions (land, sea ice …)**
- **No standard metrics**
- **High computational costs**
  - long hindcasts (at least 10 years?)
  - it takes a long time to get reforecasts after model upgrades

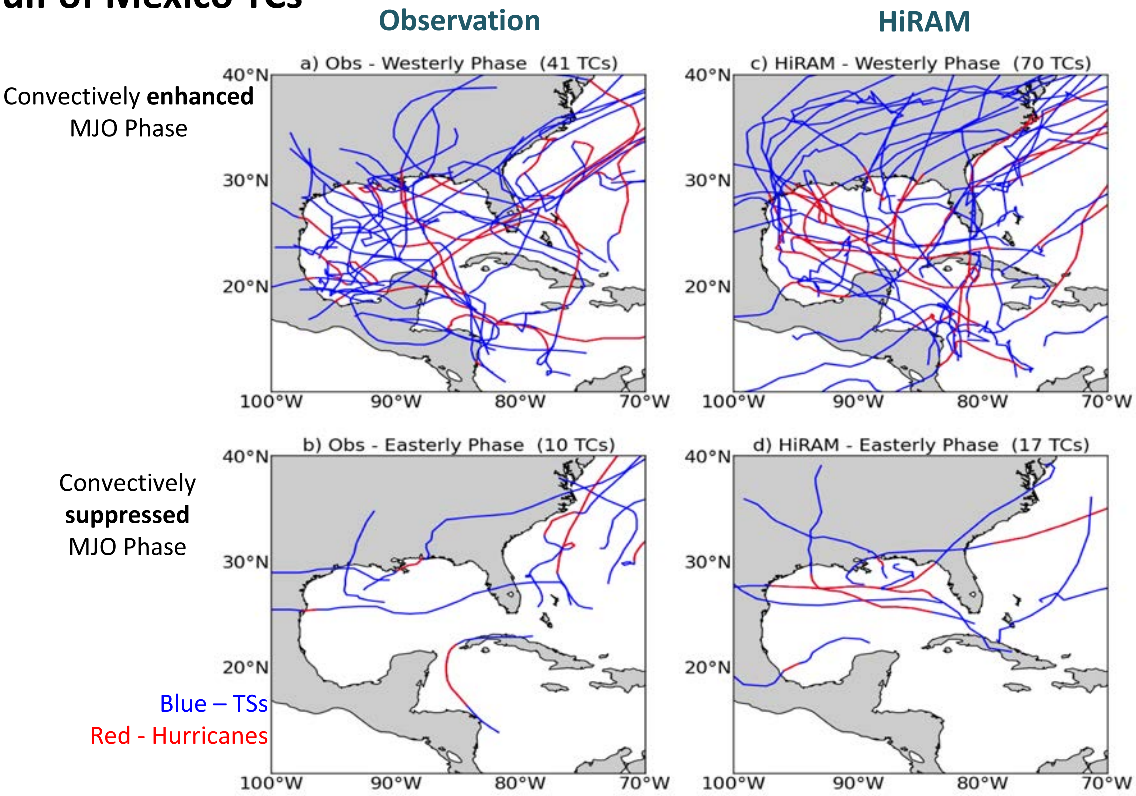
……

Visualization
Xi Chen @ FV3 Team

Backup slides

Toward to Sub-seasonal prediction

- **Impact of MJO on Gulf of Mexico TCs**



counts/day x 100

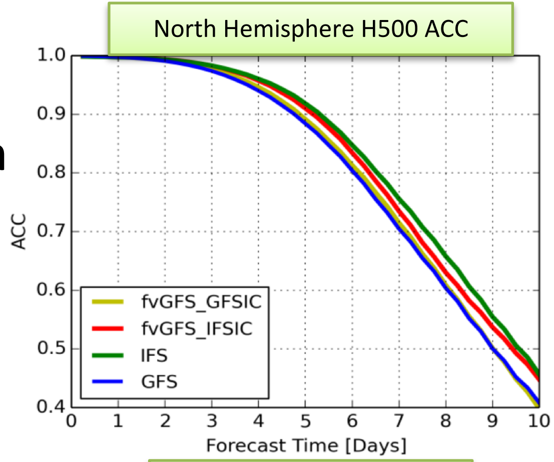
From Weather Forecasts to S2S Prediction

- # GFDL fvGFS:

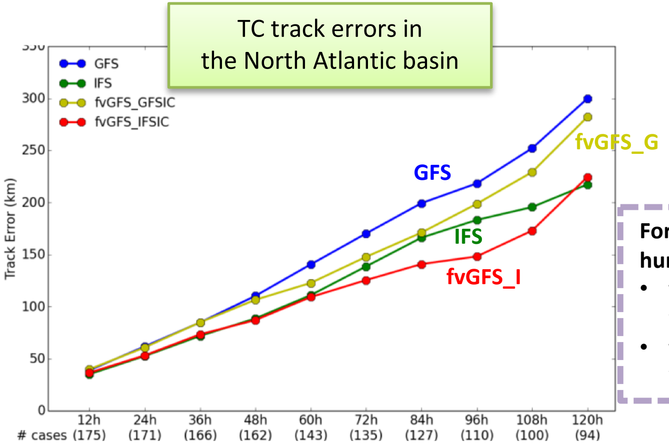
The finite-volume Global Forecast System

FV3 coupled to a heavily modified GFS Physics suite and the NOAH land model:

- EDMF PBL → **YSU PBL**
  (courtesy Hailey Shin, UCAR/GFDL)
- Z-C Microphysics → **GFDL six-category MP**
  (Zhou et al. 2019; BAMS)
- Specified SST → **Mixed-layer ocean**
  (courtesy Baoqiang Xiang, UCAR/GFDL)
- **Scale-Aware SAS shallow/deep convection**
  (Hong et al, 2017)
- **Initialized from GFS/ECMWF analyses**



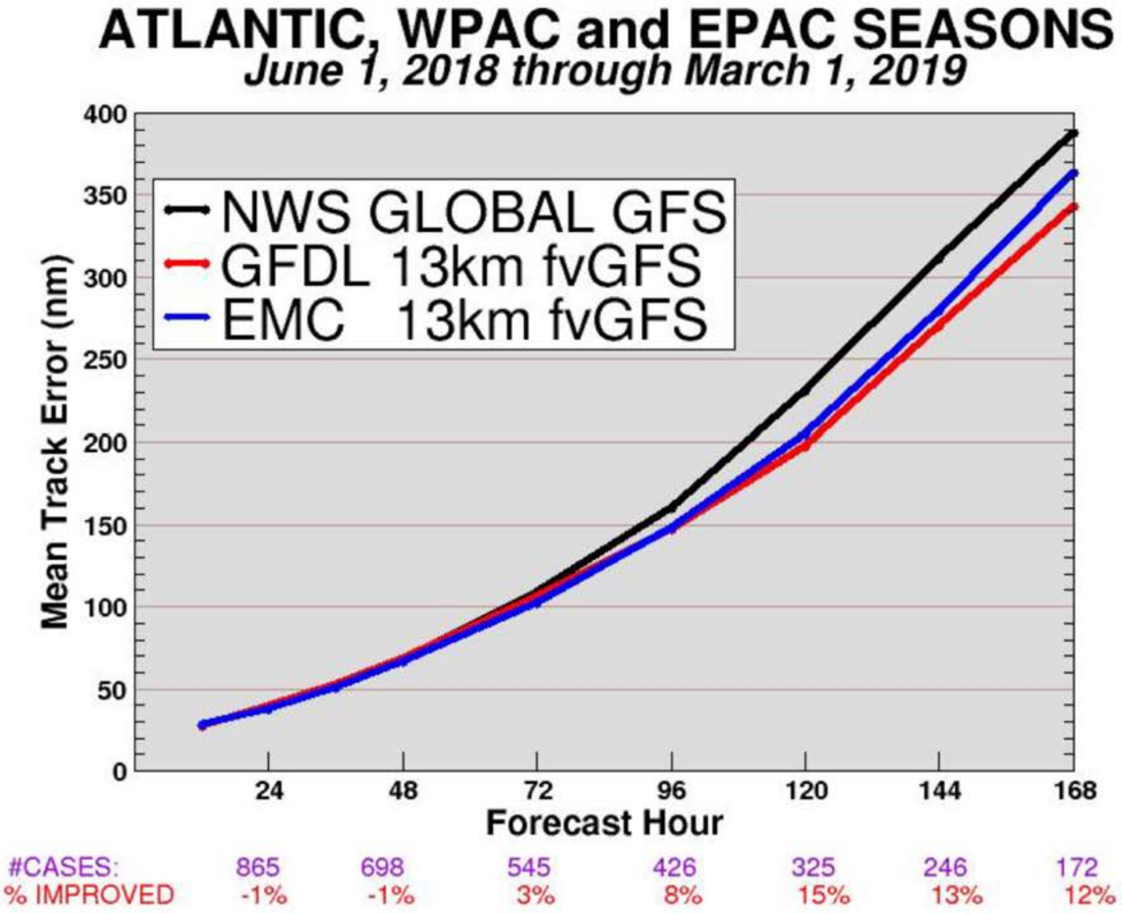
13-km fvGFS
Chen et al. 2017
(GRL, minor revision)



For the super-active 2017 hurricane season:

- fvGFS outperforms GFS when using GFS IC
- fvGFS outperforms IFS when using IFS IC

Hurricane Prediction

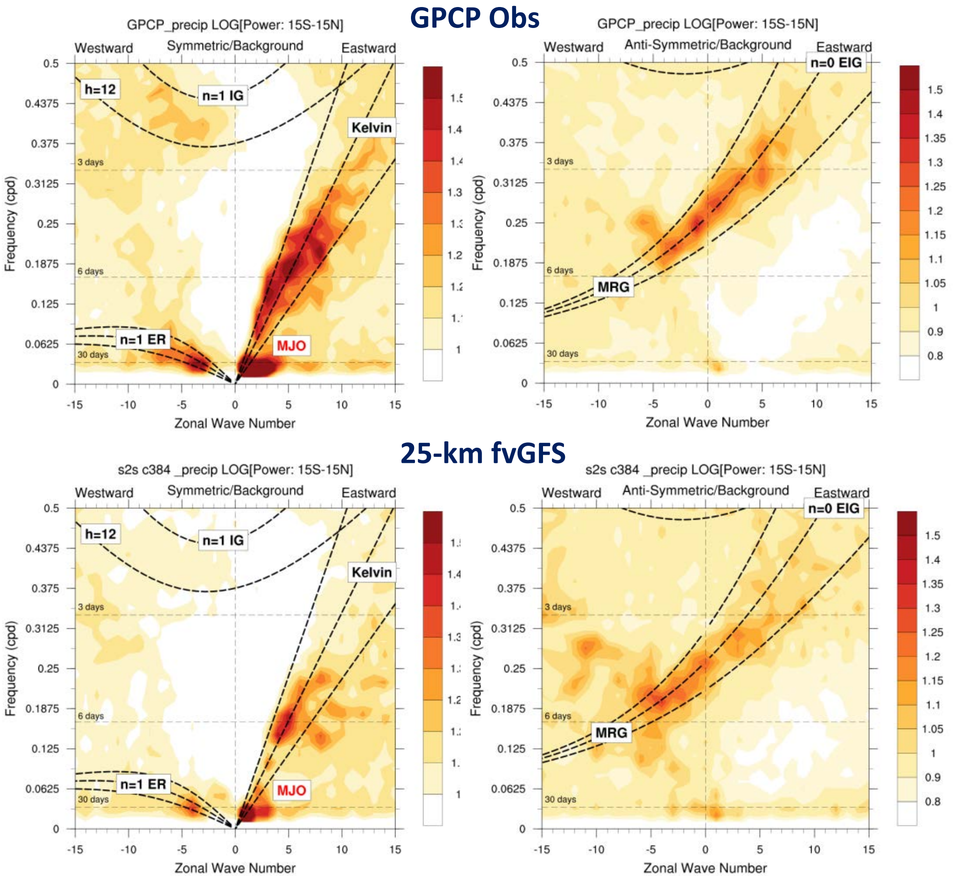


Courtesy of Morris Bender

GFDL fvGFS for S2S Prediction

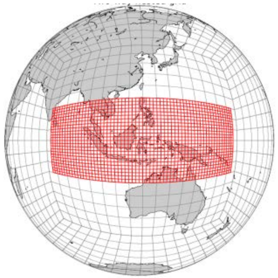
- Targeted model resolution: **25 km**
- Preliminary results based on the 10-year climatology run:
  - Convectively coupled equatorial waves (CCEWs):
    - MJO
    - Mixed Rossby–gravity waves (MRG)
    - Equatorial Rossby waves (ER)
    - Kelvin waves

25-km fvGFS
Jan-Huey Chen & Yongqiang Sun

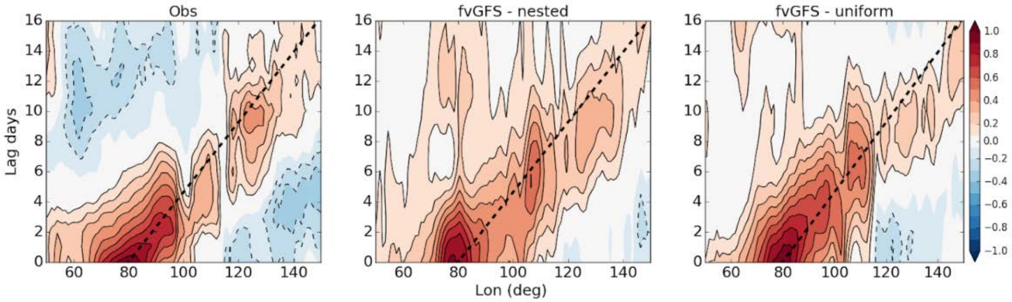


In the Two-way Nested fvGFS

- MJO prediction
  - 4-km nested within 16-km global model
  - YSU; Scale-aware SAS; Mixed-layer Ocean



Lagged-correlation analysis
based on tropical-averaged precipitation

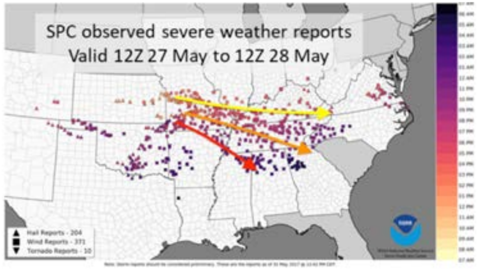


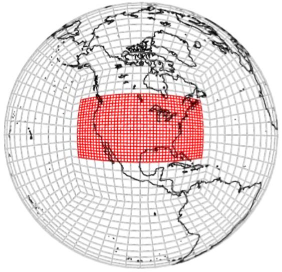
Obs **Nested** **Uniform**

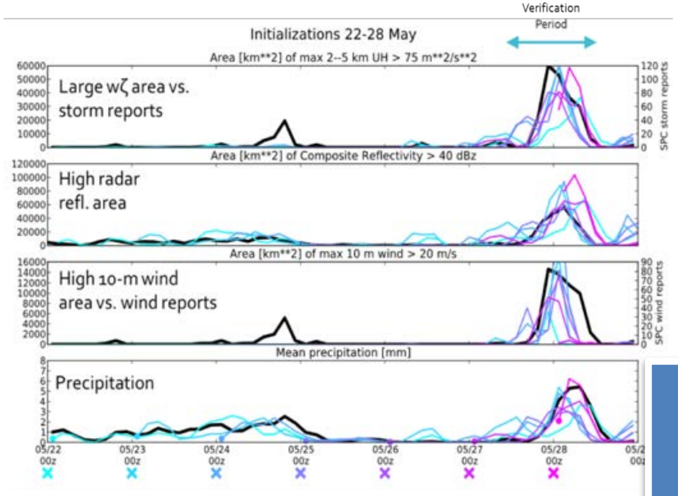
The two-way nested configuration better captures the propagation of MJO convection across Maritime Continent (100-150E).

Lucas Harris & Kun Gao

- Medium-range derecho prediction

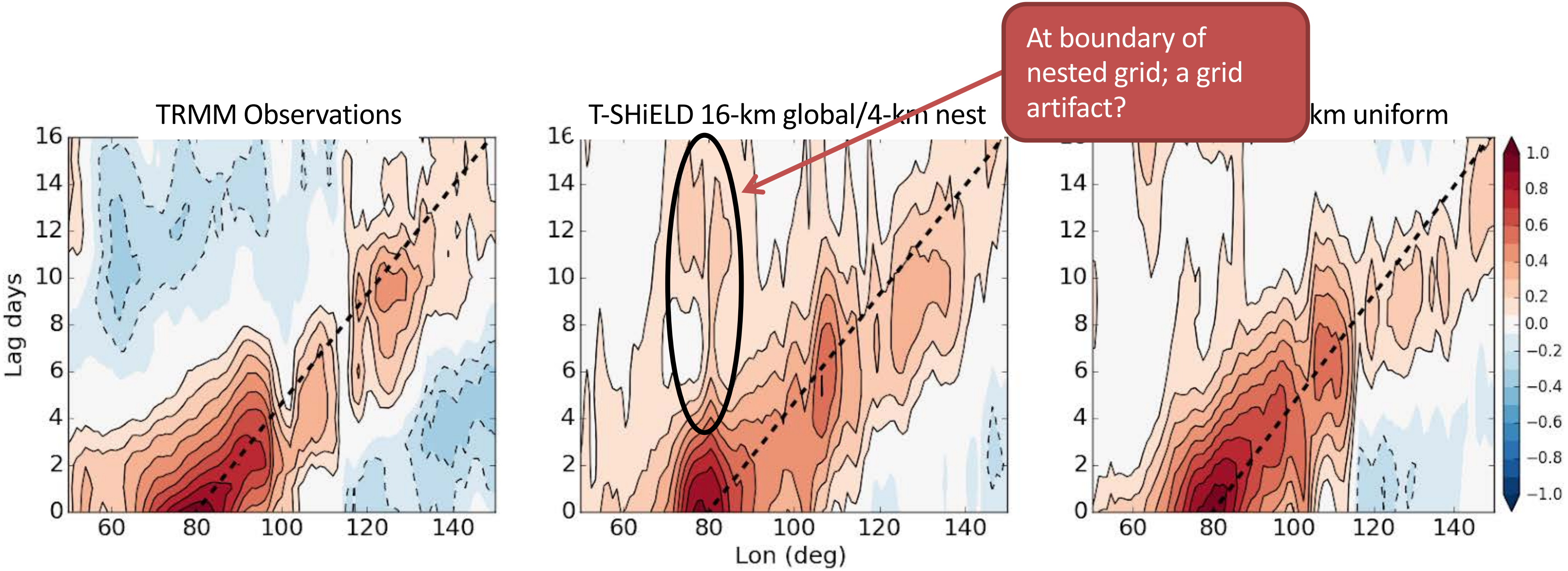






3-km cfvGFS
Harris et al
In revision at JAMES

T-SHiELD: 2011-2 Hindcasts

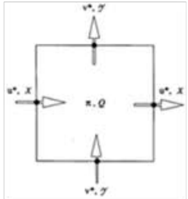


The GFDL FV3 Dynamical Core

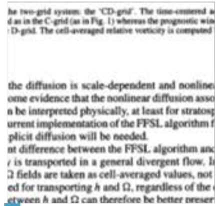
- **Key element of the seamless cross-scale predictions**

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

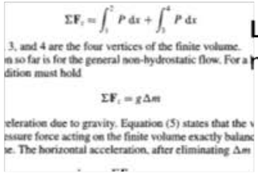
Lin & Rood 1996
Efficient 2D high-order conservative FV transport



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


he two-grid system: the 'CD-grid'. The time-centered a
d as in the C-grid (as in Fig. 1) whereas the prognostic win
D-grid. The cell-averaged relative vorticity is computed

the diffusion is scale-dependent and nonline
ome evidence that the nonlinear diffusion asso
n be interpreted physically, at least for stratosp
urrent implementation of the FFSL algorithm f
plicit diffusion will be needed.
nt difference between the FFSL algorithm and
is transported in a general divergent flow. I
Ω fields are taken as cell-averaged values, not
ed for transporting h and Ω, regardless of the
etween h and Ω can therefore be better preser

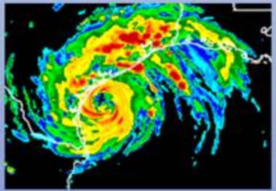

$$\Sigma \mathbf{F}_x = \int_1^2 P\,dx + \int_3^4 P\,dx$$
3, and 4 are the four vertices of the finite volume.
n so far is for the general non-hydrostatic flow. For a
dition must hold

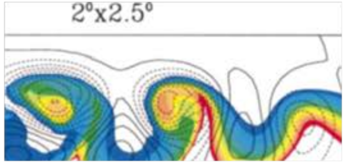
$$\Sigma \mathbf{F}_z = g\,\Delta m$$

eleration due to gravity. Equation (5) states that the
essure force acting on the finite volume exactly balanc
e. The horizontal acceleration, after eliminating Δm

Lin 1997 Efficient, mimetic FV PGF

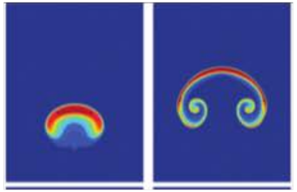
Next-generation FV3
Rigorous Thermodynamics
Flexible dynamics
Adaptable physics interface
Variable-resolution techniques
Regional & periodic domains

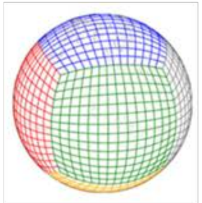




Lin 1998–2004 FV core with "floating" Lagrangian vertical coordinate

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

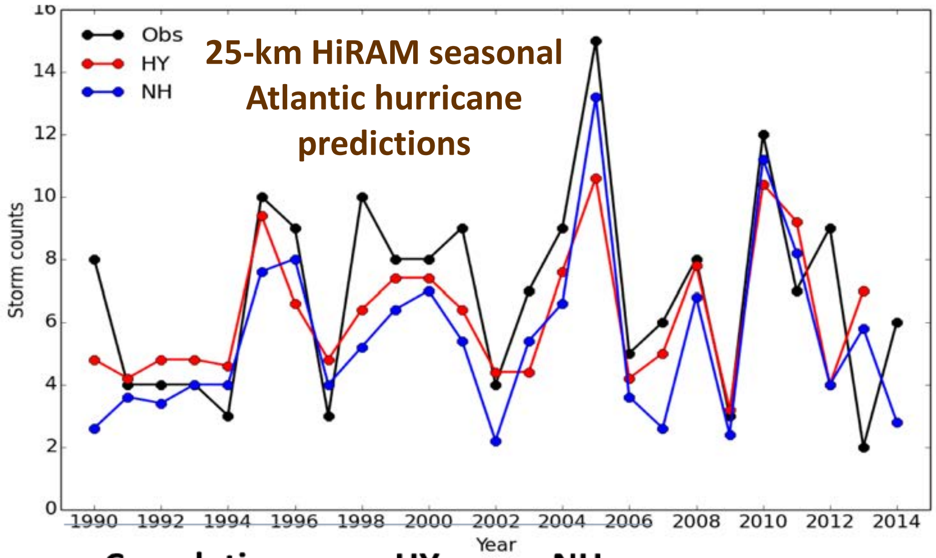




Putman & Lin 2007
Scalable cubed-sphere grid, doubly-periodic domain

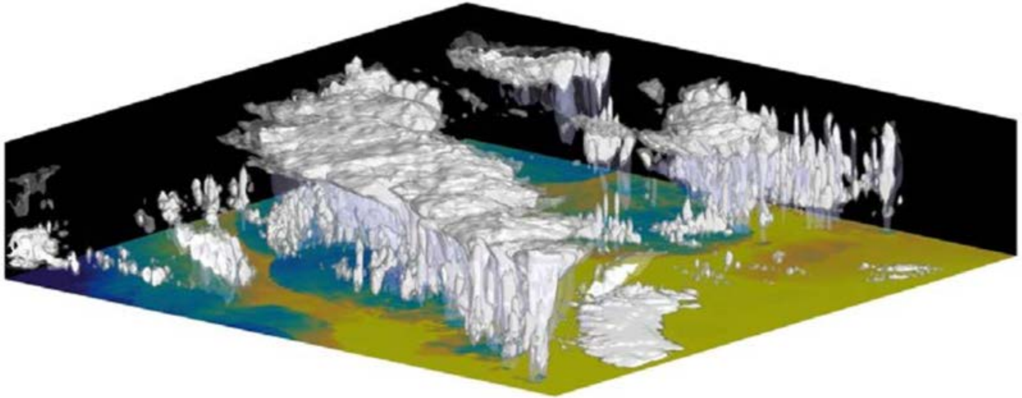
S2S Hurricane Predictability in HiRAM

- HiRAM: “fast AM4-like” S2S Atmosphere model with prescribed aerosols and six-category GFDL microphysics
  - 2012 Hydrostatic version: 32 levels, single-plume conv.
  - 2015 Nonhydrostatic version: 63 levels, double-plume conv.
- 25-km HiRAM shows *remarkable* predictability of Atlantic hurricanes during 2000s

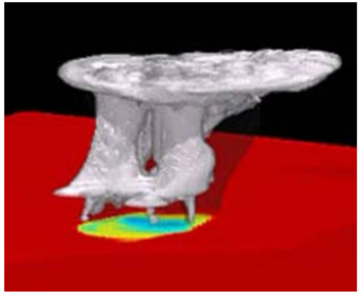


Correlation	HY	NH
1990-2010	0.88	0.86
2000-2010	0.94	0.96
1990-2014	0.72	0.76

J.-H. Chen and S-J Lin (2013; 2016)



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

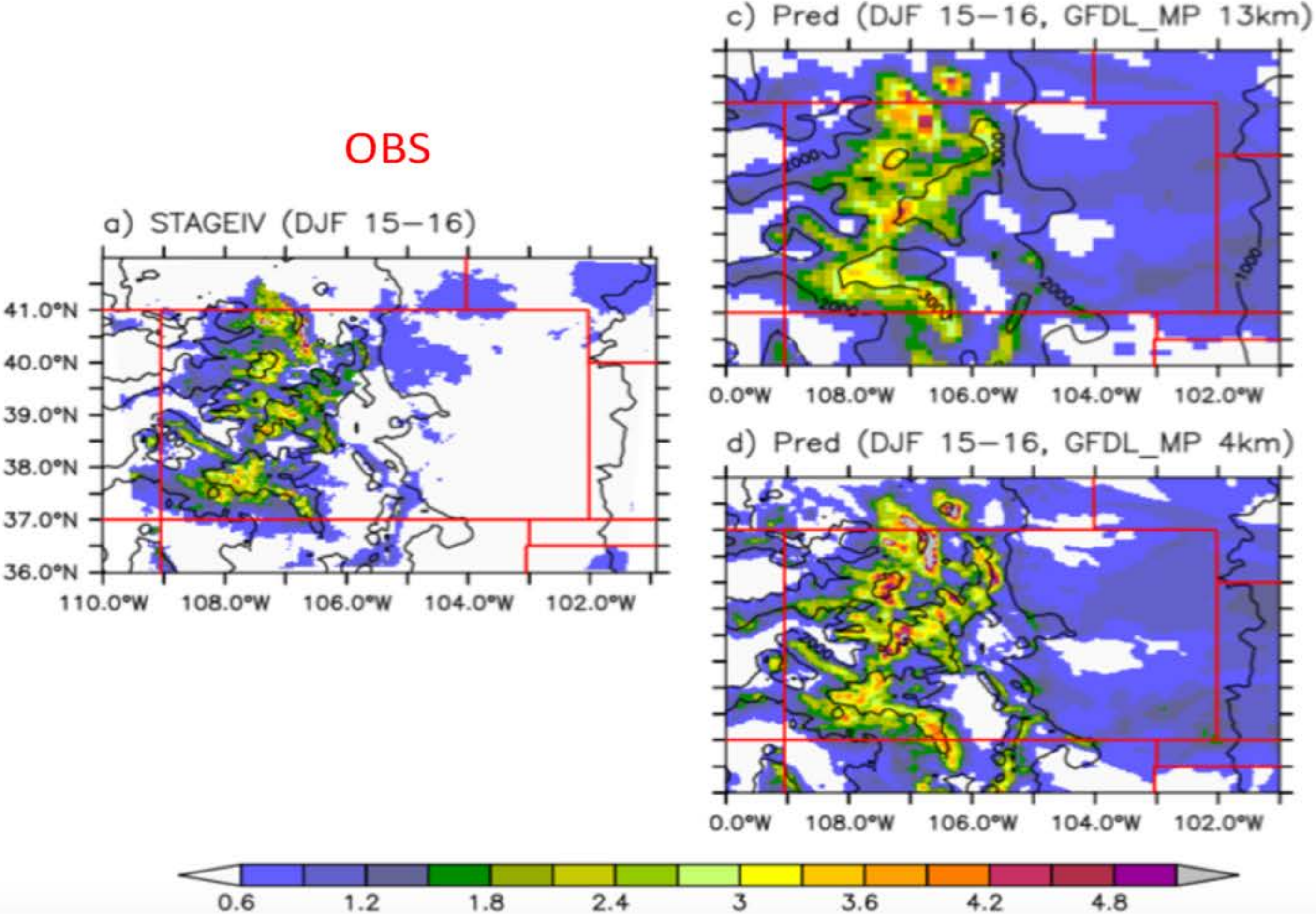


we are experimenting global convection permitting/resolving subseasonal hindcasts;
ii) the regional refined methods make the explicit representation of extreme weather events (tornado-like features; major hurricanes)

5-day forecasts
DJF 15–16
With GFDL MP

OBS

fvGFS



13 km fvGFS

4km fvGFS
CONUS stretched