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

Baoqiang Xiang, Jan-Huey Chen, Lucas Harris, Shian-Jiann Lin, Linjiong Zhou, Kun Gao, Yongqiang Sun, Xi Chen, Thomas L. Delworth

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S2S prediction is a frontier but remains very challenging.

**S2S: 2 Weeks to 2 months**

- **WEATHER FORECASTS**: Predictability comes from initial atmospheric conditions.
- **S2S PREDICTIONS**: Predictability comes from initial atmospheric conditions, monitoring the land/sea/ice conditions, the stratosphere and other sources.
- **SEASONAL OUTLOOKS**: Predictability comes primarily from sea-surface temperature conditions; accuracy is dependent on ENSO state.

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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

**Surface air temperature**

- **Week 3**
  - Surface air temperature map for Week 3.

- **Week 4**
  - Surface air temperature map for Week 4.

**Extreme cold days**

- **Week 3**
  - Extreme cold days map for Week 3.

- **Week 4**
  - Extreme cold days map for Week 4.

Xiang et al. 2019

Xiang et al. in preparation
S2S results #3: 27 days of MJO prediction skill

GFDL

Vitart (2017)

operational

Kim et al. 2014

Xiang et al. 2015

Kim et al. 2014
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

\[ \text{UFS} = \text{FV3} + \text{MOM6} + \ldots \]

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 Hi*gh*-resolution modeling for Earth-to-Local Domain)

- **FV3**
- **GFS**

**fvGFS**

**SHiELD**

GF ofL 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

**T-SHIELD**
- Tropical/Hurricane Nest

**C-SHIELD**
- Continental Nest

**R-SHIELD**
- Regional

**S-SHIELD**
- Global Cloud-Resolving

**X-SHIELD**

*S2S Applications*

(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)

- AM4/LM4
- MOM6/SIS2
- CM4
- SPEAR

- SPEAR_LO (100km)
- SPEAR_MED (50km)
- SPEAR_HI (25km)

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

SHiELD (3km/13km/25km)  SPEAR (100km/50km/25km)

Daily Weather Forecasts  S2S  Seasonal to decadal and century Predictions

- Thunderstorms, Tornadoes, Hurricanes...
- Hurricanes, MJO, Heat waves, Droughts...
- ENSO, Hurricanes, Precipitation/ Temperature anomalies

One codebase, one compile script, one executable, one runtime, one post-processing
FV3 is flexible, adaptable, robust, and fast
Nested configuration of SHiELD improves MJO prediction

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
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
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

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Thank You!
Backup slides
Toward to Sub-seasonal prediction

- Impact of MJO on Gulf of Mexico TCs

Observation

Convectively enhanced MJO Phase

Convectively suppressed MJO Phase

HiRAM

Blue – TSs
Red - Hurricanes

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

For the super-active 2017 hurricane season:
- fvGFS outperforms GFS when using GFS IC
- fvGFS outperforms IFS when using IFS IC

TC track errors in the North Atlantic basin

North Hemisphere H500 ACC

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

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

• Medium-range derecho prediction

3-km cfvGFS
Harris et al
In revision at JAMES
T-SHiELD: 2011-2 Hindcasts

At boundary of nested grid; a grid artifact?
The GFDL FV3 Dynamical Core

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

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

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

  - **Lin 1997**
    - Efficient, mimetic FV PGF

  - **Lin 1998–2004**
    - FV core with “floating” Lagrangian vertical coordinate

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

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

  - **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

<table>
<thead>
<tr>
<th>Year Range</th>
<th>HY</th>
<th>NH</th>
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<tbody>
<tr>
<td>1990-2010</td>
<td>0.88</td>
<td>0.86</td>
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<tr>
<td>2000-2010</td>
<td>0.94</td>
<td>0.96</td>
</tr>
<tr>
<td>1990-2014</td>
<td>0.72</td>
<td>0.76</td>
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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

13 km fvGFS

4 km fvGFS
CONUS stretched