S2S Prediction of Tropical Cyclones and the MJO at GFDL

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IP4, IITM PUNE, 27 NOVEMBER 2019

THANKS ALSO TO S-J LIN, HAILEY SHIN, XIANAN JIANG, AND TIM PALMER
# The GFDL Prediction Modeling System

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>Daily Weather Forecasts</th>
<th>Sub-seasonal to Seasonal Predictions</th>
<th>Decadal Predictions</th>
<th>Climate Projections</th>
</tr>
</thead>
<tbody>
<tr>
<td>hours</td>
<td>hours</td>
<td>1 month</td>
<td>Decadal</td>
<td>Century</td>
</tr>
<tr>
<td>2 weeks</td>
<td>2 weeks</td>
<td>3 months to 2 years</td>
<td>ENSO, Hurricanes, Precipitation/Temperature anomalies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thunderstorms, Tornadoes, Hurricanes...</td>
<td>Hurricanes, MJO, Heat waves, Droughts...</td>
<td></td>
<td>time scale</td>
</tr>
</tbody>
</table>

- **HiRAM** (50km/25km)
- **SHiELD** (3km/13km/25km)
- **FLOR/Hi-FLOR** (50km/25km; 1deg Ocean)
- **SPEAR/SPEAR-HI** (50km/25km; 1deg Ocean)

**CMIP5 Generation**

**CMIP6 Generation**
Seasonal Hurricane Predictability in HiRAM

- HiRAM: S2S Atmosphere model with prescribed aerosols and six-category GFDL microphysics
  - v2012: Hydrostatic, 32 levels, single-plume conv.
  - v2015: Nonhydro, 63 levels, double-plume conv.

- 25-km HiRAM shows *remarkable* predictability of Atlantic hurricanes during 2000s

<table>
<thead>
<tr>
<th>Year Interval</th>
<th>HY</th>
<th>NH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-2010</td>
<td>0.88</td>
<td>0.86</td>
</tr>
<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>
</tr>
</tbody>
</table>
Beyond-weather genesis: Sandy & Haiyan

Observation

HiRAM

Predictions vs. obs of wave modes and genesis ★
Sandy and Haiyan genesis predictable to 11 days

50-km HiRAM ensemble coupled with 1deg ocean
Beyond-weather TC Genesis Prediction

Global & Basin Genesis Skill

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

50-km HiRAM ensemble coupled with 1deg ocean

Jiang et al. 2018 (JClim)
HiRAM and the Madden-Julian Oscillation

- MJO prediction skill

Operational models

Vitart (2017)

50-km HiRAM coupled with 1deg ocean

Xiang et al. 2015 (JClim)

Potential predictability better for initially strong events than weak ones
The MJO in GFDL Climate Models

GFDL AM4—the atmosphere of CM4 and SPEAR—has a good MJO but only if coupled to the ocean. The UW Double-Plume convection allows AM4 and HiRAM to have a much better MJO than does CM2.1 and FLOR, which used RAS.

**Uncoupled AM4**

**AM4 coupled to 1-deg Ocean**

**Observations**
S2S MJO-Tropical Cyclone Linkage

- Impact of MJO on TC Genesis
  - Phases 8+1
    - Obs
    - HiRAM
  - Phases 4+5
    - Obs
    - HiRAM
  - Genesis density: number of TCs formed in each 10° × 10° box per day

- Impact of MJO on Gulf of Mexico TCs
  - Observation
    - a) Obs - Westerly Phase (41 TCs)
    - b) Obs - Easterly Phase (10 TCs)
  - HiRAM
    - c) HiRAM - Westerly Phase (70 TCs)
    - d) HiRAM - Easterly Phase (17 TCs)
  - Convectively enhanced MJO Phase
  - Convectively suppressed MJO Phase
  - Blue – TSs
  - Red - Hurricanes

Gao et al. 2017 (JGR)
S2S Nested Prediction of Atlantic TCs

25-km Uniform Domain

25-km Global & 8-km Two-way Nest

Nonhydrostatic HiRAM
15 years of 30-day simulations
5 Members init 1st of July–Nov
Gao et al. 2019 (GRL)

MDR Shear Anomalies: Model vs. Obs

25-km HiRAM
8-km Nest

5% Significance Level

Nested Grid maintains large-scale skill
Hurricane Structure and Rapid Intensification

Nonhydrostatic HiRAM
15 years of 30-day simulations
5 Members init 1st of July–Nov

Gao et al. 2019 (JAMES)

25-km simulates TCs which are too large and seldom undergo Rapid Intensification (RI)

8-km matches observed RI rates; tied to better representation of small, intense cyclones?

→ S2S Prediction of Rapid Intensification??

Gao et al, JAMES 2019
GFDT SHiELD
System for High-resolution prediction on Earth to Local Domains

GFDT’s Weather-Timescale UFS Implementation (formerly fvGFS)
FV3 Dynamical Core coupled to a heavily modified GFS Physics and NOAH LSM

• Implemented alongside CM4, ESM4, and SPEAR within GFDT’s Flexible Modeling System (FMS)—a unified Earth Modeling System

• Demonstrates basic capability of components as well as demonstrating new science and capabilities in FV3 and physics

• Informs further development of components and framework

• Advances in SHiELD can be seamlessly transitioned into other UFS implementations (GFS, HAFS) and FV3-based models (GFDT AM4 and SPEAR, NASA GEOS, CESM-FV3, TaiESM, F-GOALS, etc.)

FV3 Philosophy: Many applications, many models, one adaptable dynamical core
GFHDL SHiELD
System for High-resolution prediction on Earth to Local Domains

- 2018 In-line GFDL Microphysics
  - L. Zhou and S-J Lin, in prep

- Modified YSU PBL
  - Stability improvements for small Δz and long physics ΔT
  - Courtesy Hailey Shin and S-J Lin

- NCEP Scale-Aware SAS convection
  - J. Han et al 2017

- Mixed layer ocean (courtesy Baoqiang Xiang)
  - 15-day timescale restoring SST to climatology; prognostic mixed-layer depth; rain cooling
S-SHiELD
S2S prediction model

25-km (c384) global domain

10-year climatological SST integration

MJO Composite using Wheeler & Henden method

Daily Precip
CI = 0.2 mm/d

5 m/s propagation
S-SHIELD Diurnal Cycle

Comey et al (2017) metric and CMIP6 results

Adapted by Yongqiang Sun
T-SHiELD
Maritime Continent Configuration

Global 16 km domain with a 4x two-way nest centered on equator and covering maritime continent

Simulations initialized from GFS Analyses and integrated for 40 days

Focusing on DYNAMO (2011–2012) but also looking at active 2015–2016 period

63 vertical levels; first mid-level at 15 m AGL
T-SHiELD DYNAMO Hindcasts

• 34 cases initialized each day MJO is in phase 2 or 3
  3 Oct 2011 to 27 March 2012
• Nest improves MJO skill even **beyond** the boundaries of the nest!!
• Initialization at other phases show less skill, but nesting still gives better skill
25 February 2012

Observations 16-km Uniform 16- & 4-km nest
Late Feb 2012: Sensitivity to ICs

Observations:
- 16-km Uniform
- 16- & 4-km Nested
24 Nov 2011
A challenging forecast

Observations  16-km Uniform  16- & 4-km nest

MJO Phase: 5S-5N init 2011124

Phase 7 Western Pacific Phase 6
Phase 8
Phase 4 Maritime Continent
Phase 5

Observations 16-km Uniform 16- & 4-km Nested
Initiation: How predictable?

Observations

16-km Uniform

16- & 4-km Nested
T-SHiELD Diurnal Cycle

Weather prediction models are designed to get good diurnal cycles (otherwise skill would be bad)

“SAS Doesn’t Suck”
S2S Global Cloud-Resolving Modeling

NASA Goddard and GFDL have collaborated on FV3-based GCRMs for over a decade.

We now have enough computing power to run GCRMs on S2S Timescales, as in the DYAMOND project’s 40-day simulations.

GFDL is developing X-SHiELD (eXperimental SHiELD) to explore the capabilities of GCRMs for model development, process understanding, and as a future prediction model.
## Computational Performance

<table>
<thead>
<tr>
<th>Model</th>
<th>Cores</th>
<th>Time to 1 day</th>
<th>Core-hours per day</th>
<th>Cost relative to 25-km</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>25-km uniform (c384)</strong></td>
<td>3264</td>
<td>1.65 min</td>
<td>62.1</td>
<td>1.0</td>
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<tr>
<td>Scaled from 91 levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>16-km uniform (c640)</strong></td>
<td>1151</td>
<td>9.0 min</td>
<td>172.7</td>
<td>2.8</td>
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<tr>
<td><strong>16-km / 4-km MC Nest</strong></td>
<td>3503</td>
<td>12.1 min</td>
<td>706.4</td>
<td>11.4</td>
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<tr>
<td><strong>3.25-km uniform (c3072)</strong></td>
<td>13482</td>
<td>57 min</td>
<td>12808</td>
<td>206</td>
</tr>
<tr>
<td>Scaled from 79 levels</td>
<td></td>
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</tbody>
</table>

Performance on Gaea-C4 partition (Cray XC40)
The GFDL Experience on MJO Propagation

Are convective scales necessary for a good MJO? **No,** but we do see improved skill with the nest, propagating beyond the nest’s boundaries.

Any sort of interactive ocean—whether mixed-layer or fully dynamic—greatly improves propagation.

The excellent diurnal cycle in SHiELD—partially the gift of the SAS convective scheme—also greatly improves propagation through the maritime continent.

MJO skill or propagation *not* particularly sensitive to choice of PBL scheme (not shown).