S2S Prediction of Tropical Cyclones and the MJO at GFDL

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THANKS ALSO TO S-J LIN, HAILEY SHIN, XIANAN JIANG, AND TIM PALMER

The GFDL Prediction Modeling System

Daily Weather Forecasts	Sub-seasonal to Seasonal Predictions	Decadal Predictions	Climate Projections
hours – 2 weeks	1 month – 3 months to 2 years	Decadal	Century
Thunderstorms, Tornados, Hurricanes…	Hurricanes, MJO, Heat waves, Droughts…	ENSO, Hurricanes, Precipitation/ Temperature anomalies	*time scale*

CMIP5 Generation

HiRAM (50km/25km)

FLOR/HI-FLOR (50km/25km; 1deg Ocean)

SHiELD (3km/13km/25km)

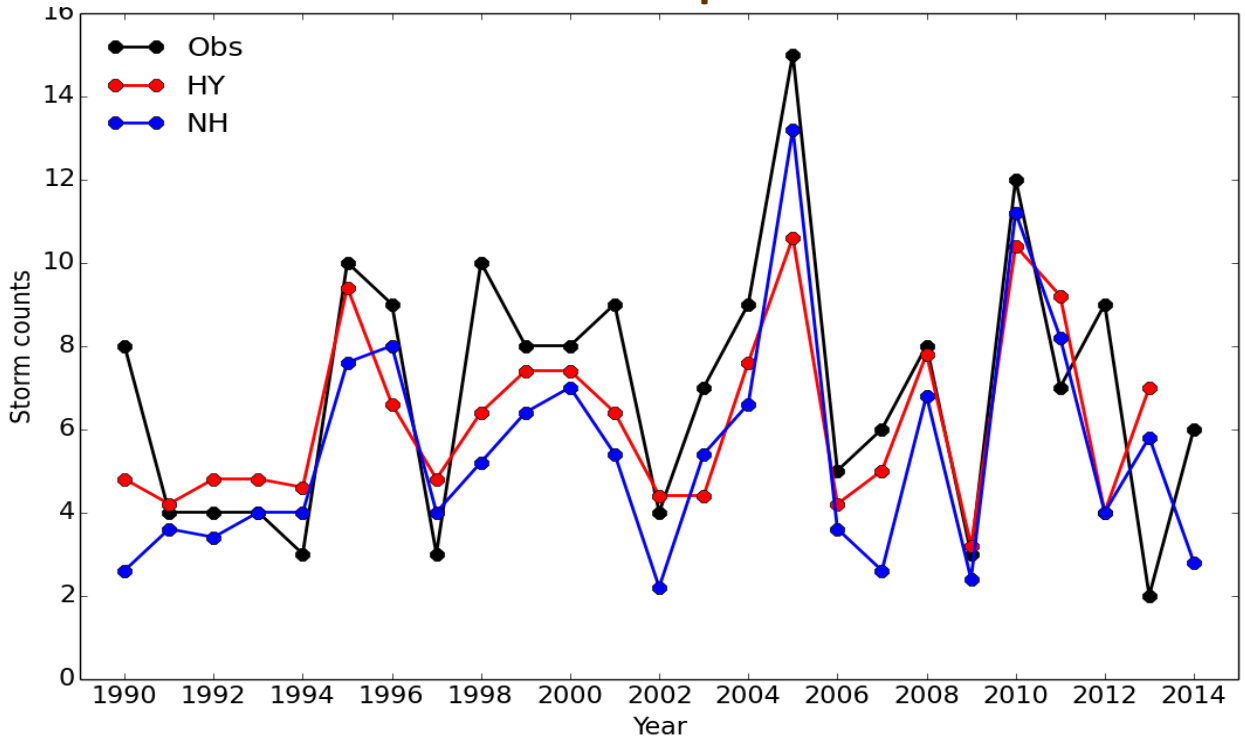
CMIP6 Generation

SPEAR/SPEAR-HI (50km/25km; 1deg Ocean)

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

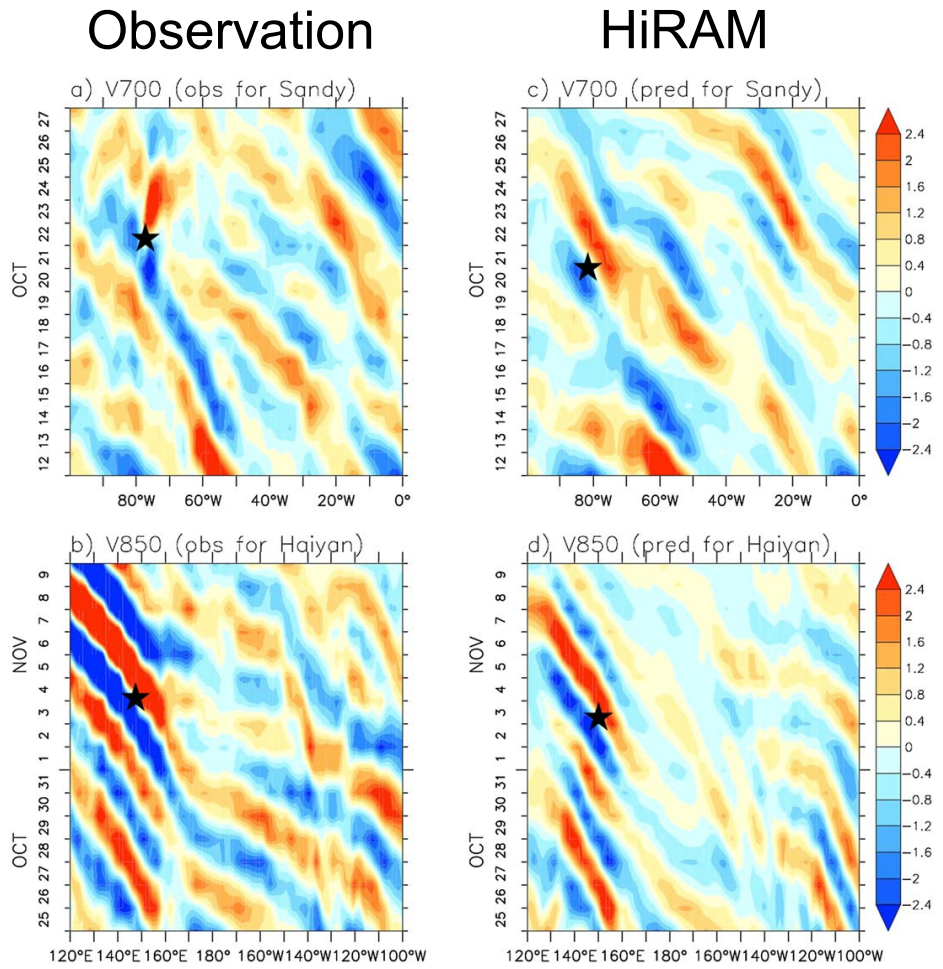
25-km HiRAM ensemble seasonal Atlantic hurricane predictions

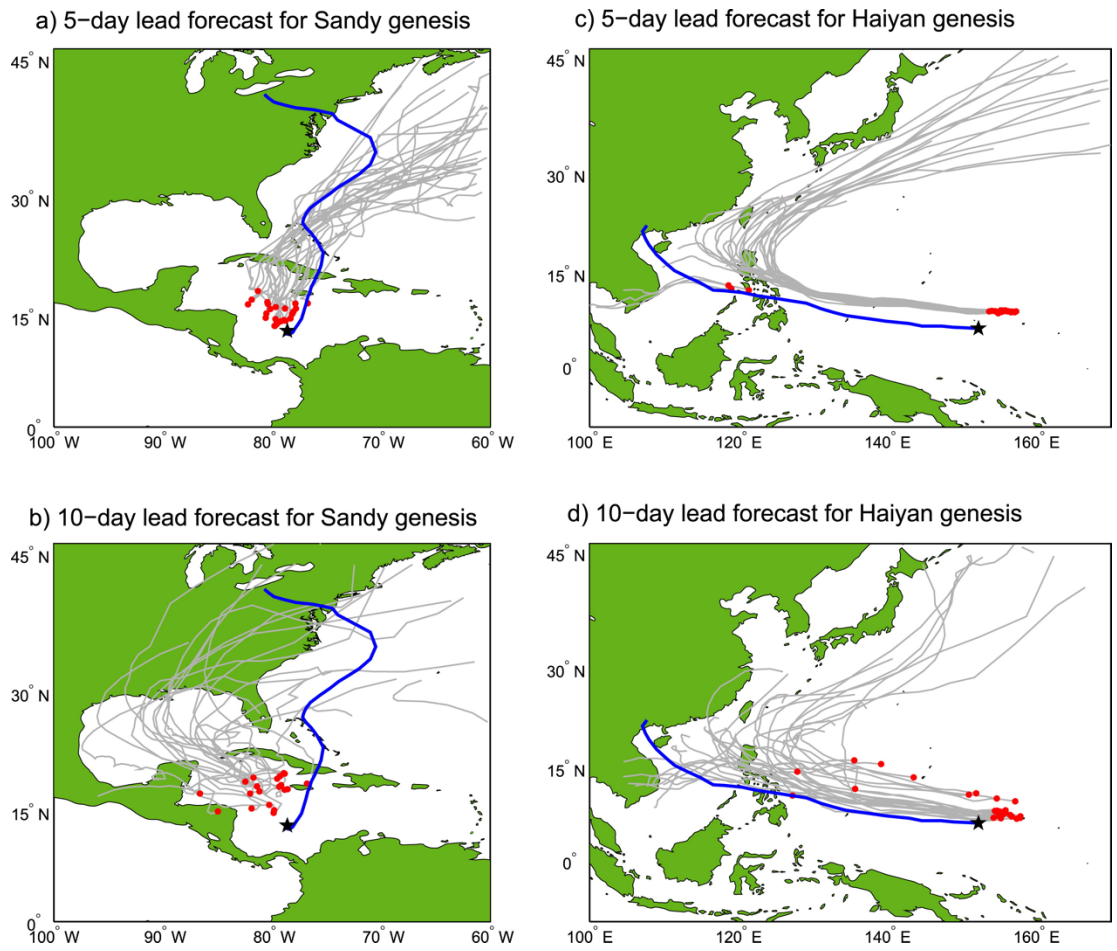


Correlation	HY	NH
1990-2010	0.88	0.86
2000-2010	0.94	0.96
1990-2014	0.72	0.76

J.-H. Chen and S-J Lin (2013 JClim and 2016 Hurricane

Beyond-weather genesis: Sandy & Haiyan





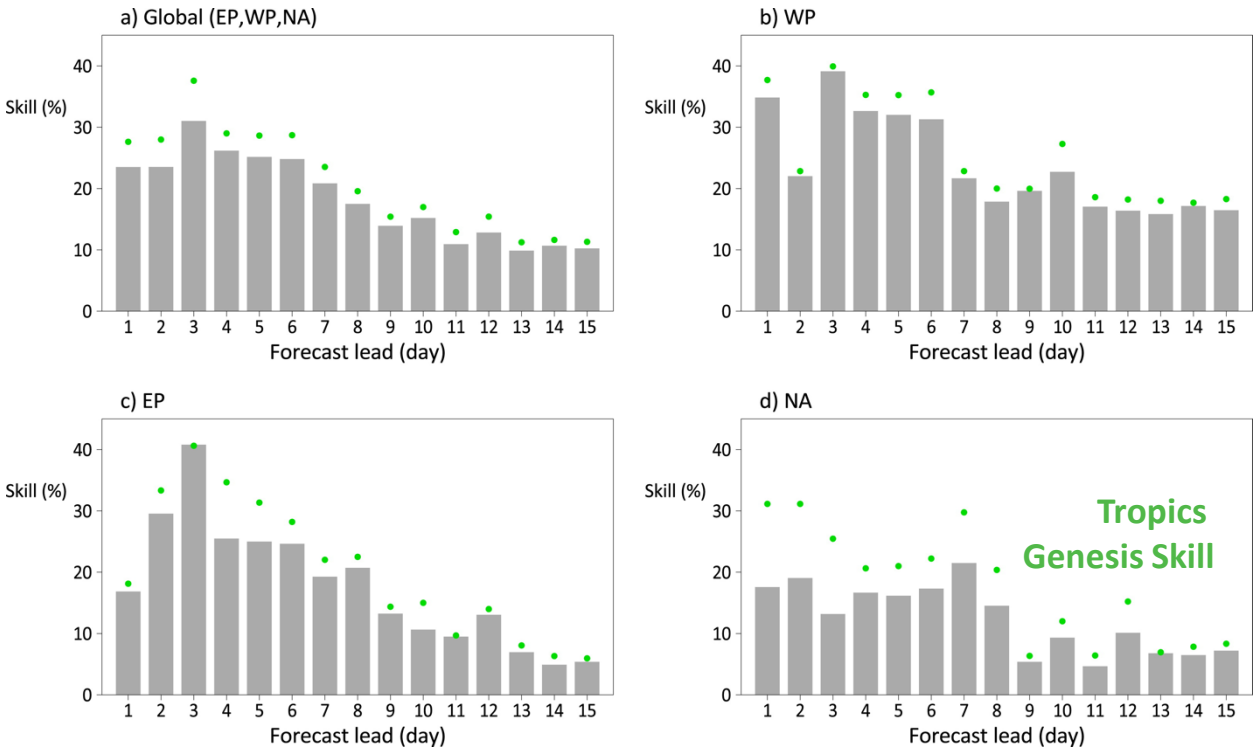
Predictions vs. obs of wave modes and genesis ★

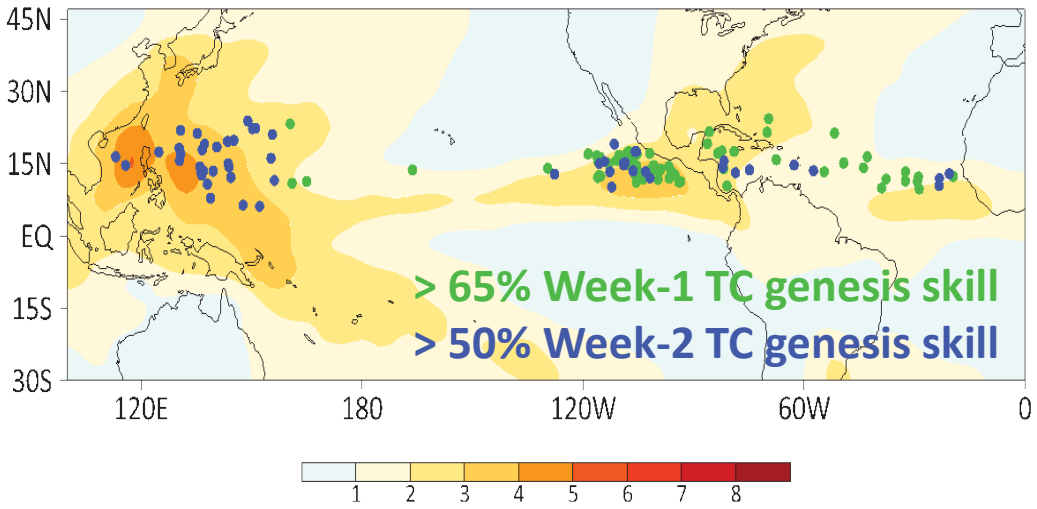
Sandy and Haiyan genesis predictable to 11 days

50-km HiRAM ensemble coupled with 1deg ocean

Beyond-weather TC Genesis Prediction

Global & Basin Genesis Skill





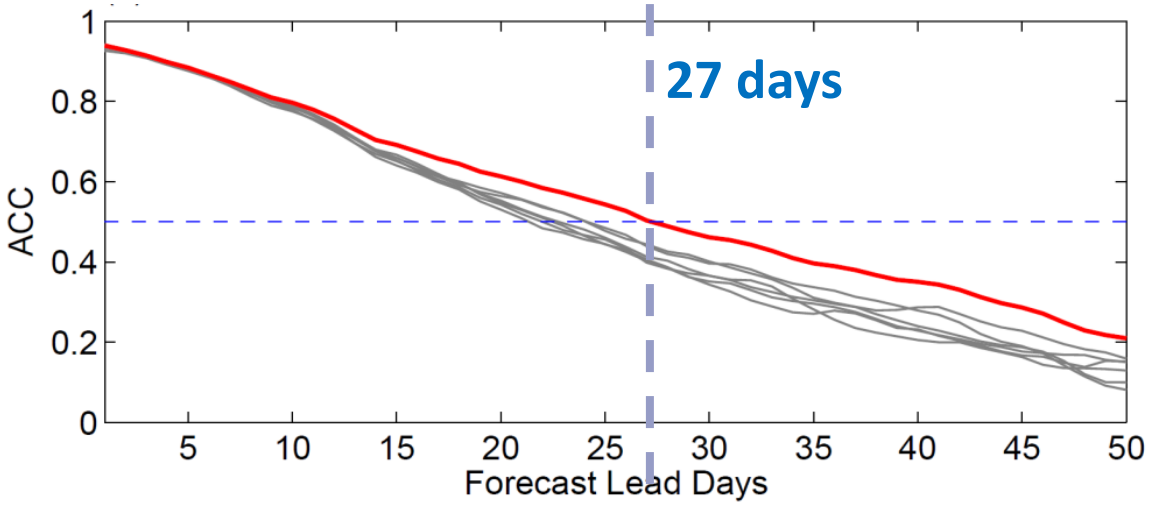
174 TC genesis out of 597 observations

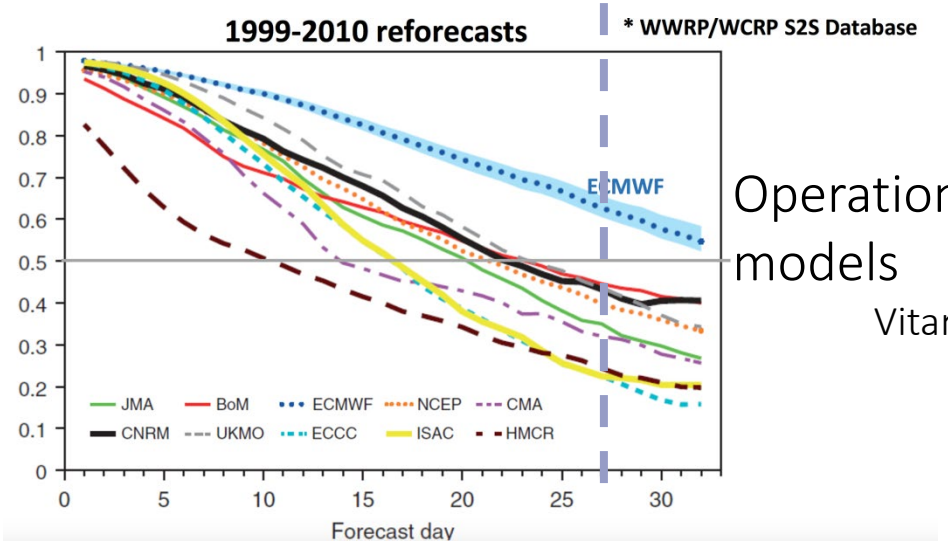
30% of TCs can be skillfully predicted with **1-2** week lead time

50-km HiRAM ensemble coupled with 1deg ocean

HiRAM and the Madden-Julian Oscillation

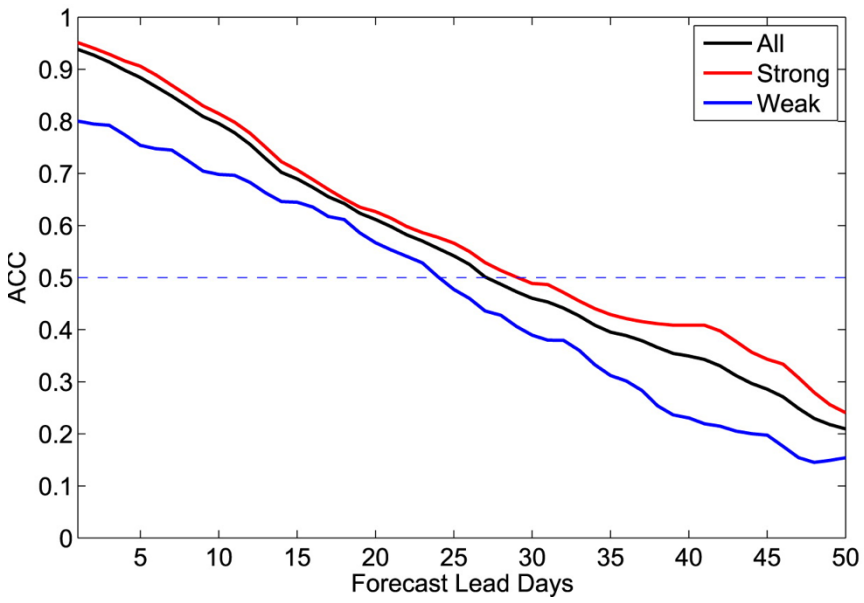
- **MJO prediction skill**





Operational models

Vitart (2017)



Potential predictability better for initially strong events than weak ones

50-km HiRAM coupled with 1deg ocean
Xiang et al. 2015 (JClim)

The MJO in GFDL Climate Models

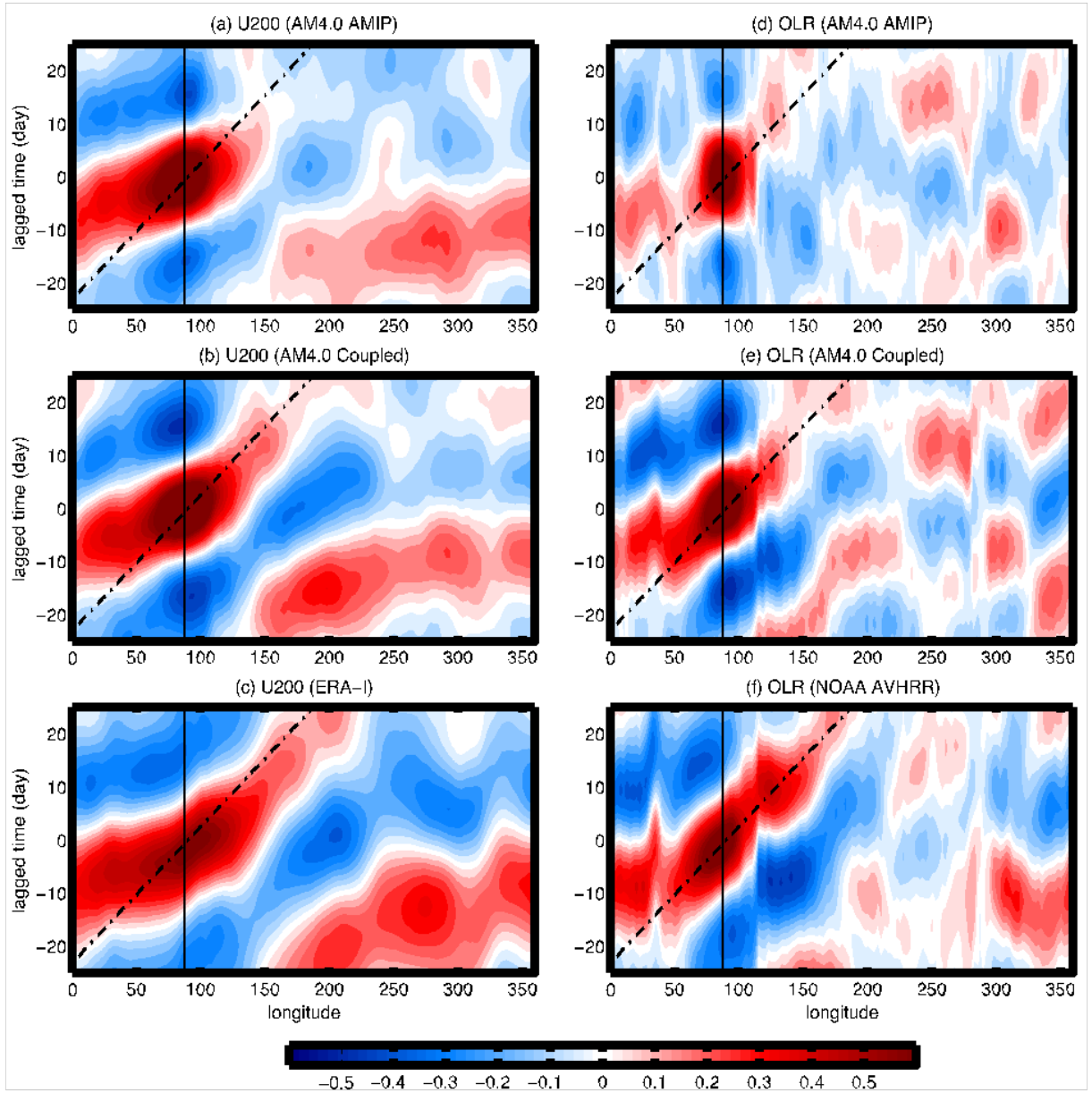
- GFDL AM4—the atmosphere of CM4 and SPEAR—has a good MJO but only if coupled to the ocean
- The UW Double-Plume convection allows AM4 and HiRAM to have a much better MJO than does CM2.1 and FLOR, which used RAS

U200 | OLR

Uncoupled AM4

AM4 coupled to 1-deg Ocean

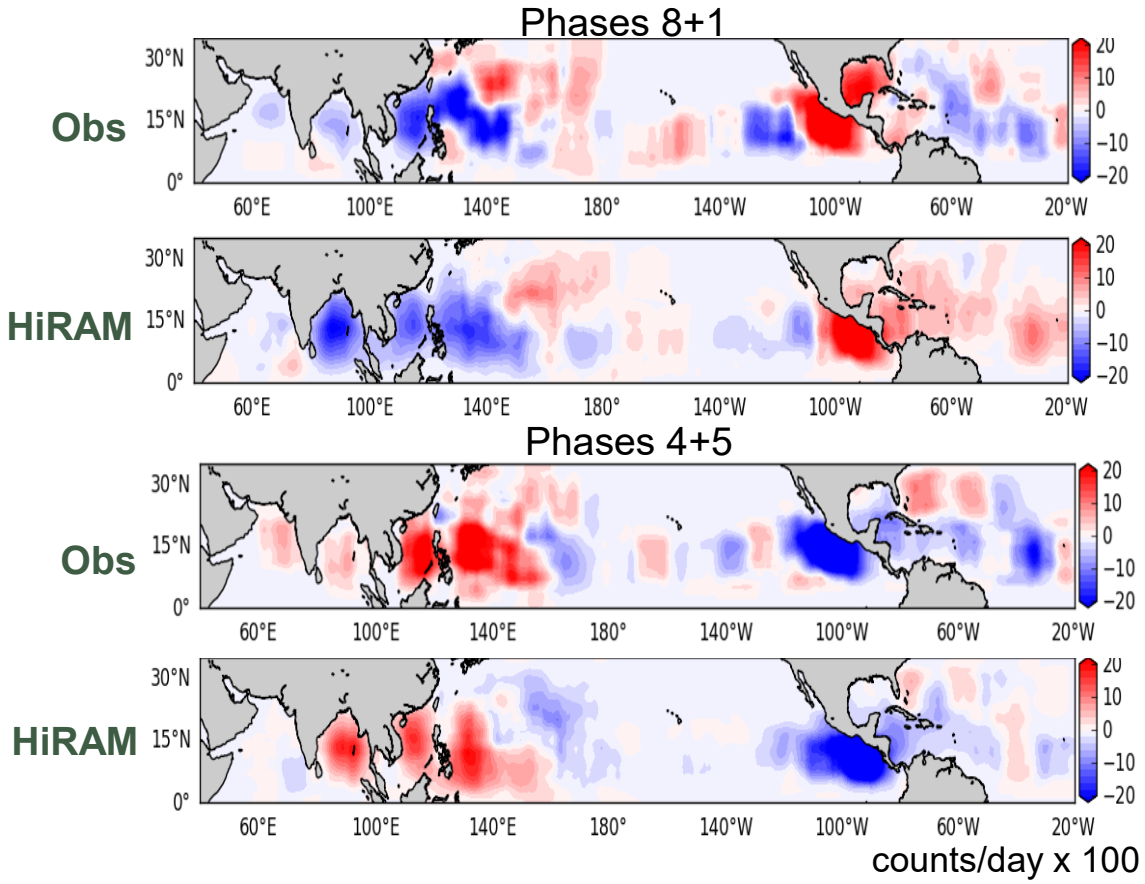
Observations



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

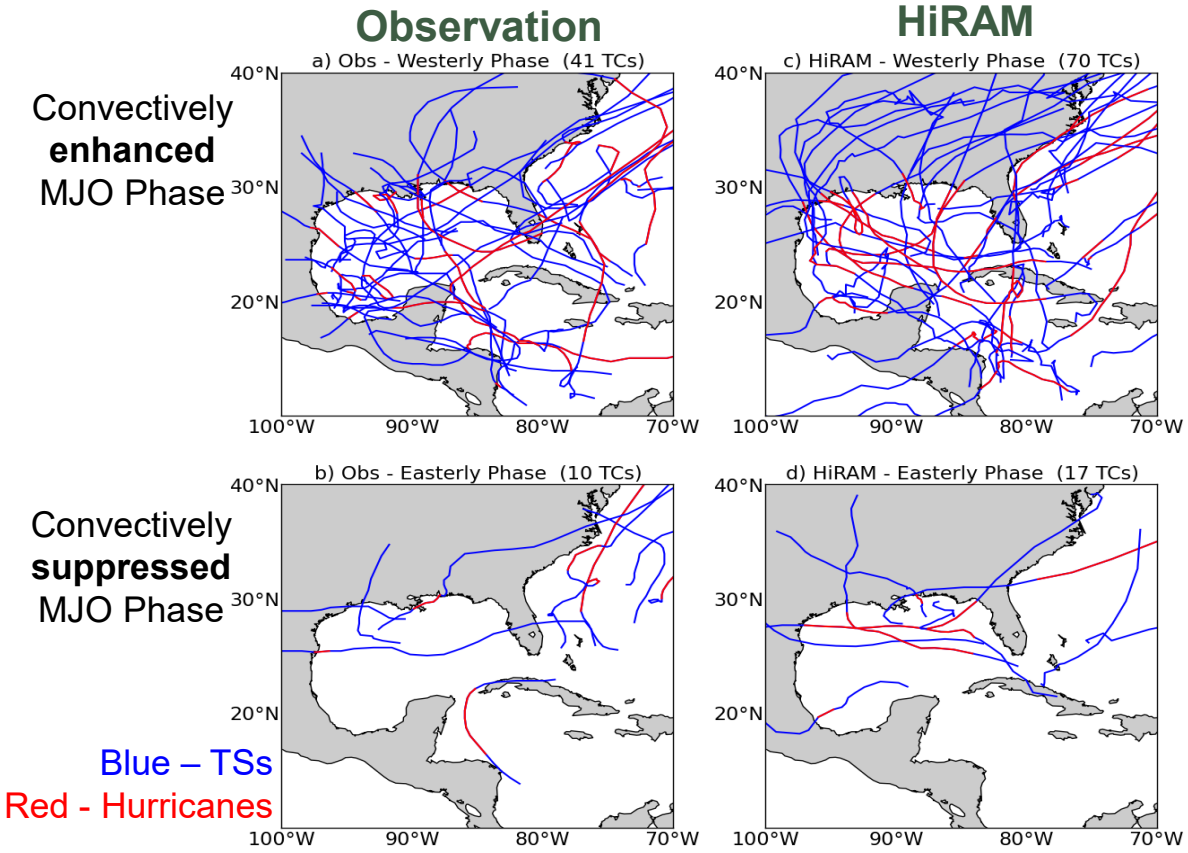
S2S MJO-Tropical Cyclone Linkage

- **Impact of MJO on TC Genesis**



Genesis density: number of TCs formed in each 10° × 10° box per day

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

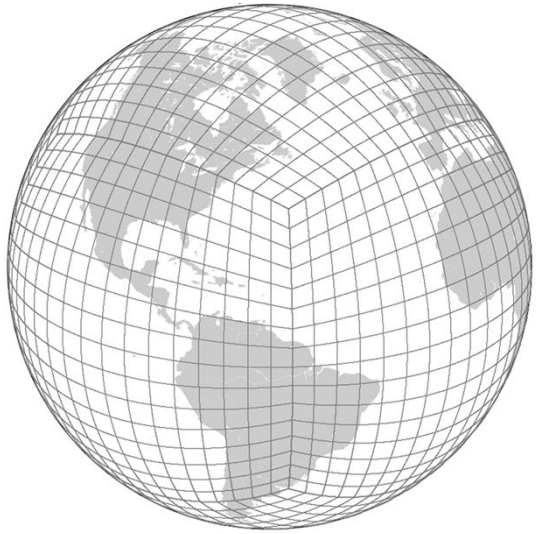


25-km Nonhydrostatic HiRAM

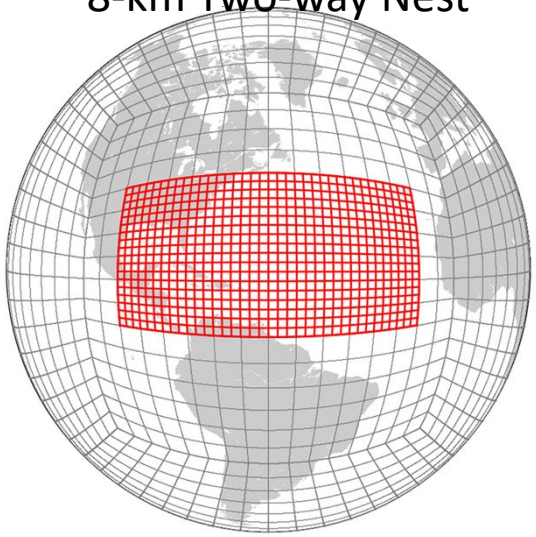
Gao et al. 2017 (JGR)

S2S *Nested* Prediction of Atlantic TCs

25-km Uniform Domain



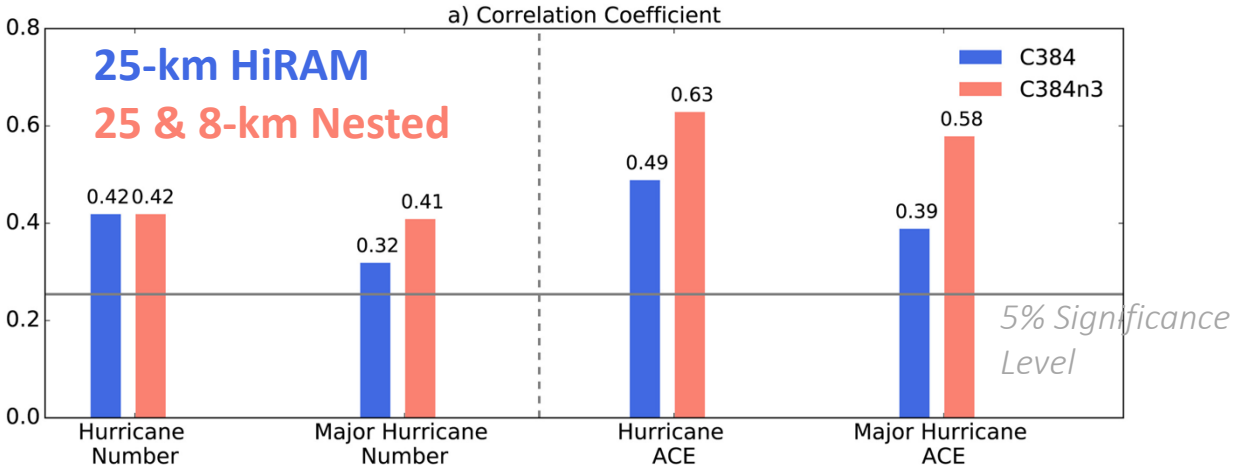
25-km Global &
8-km Two-way Nest



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

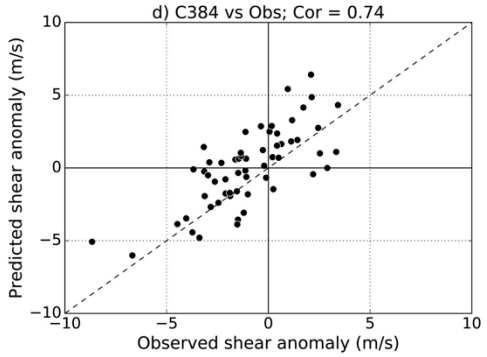
Gao et al. 2019 (GRL)

Anomalous Hurricane Activity Prediction

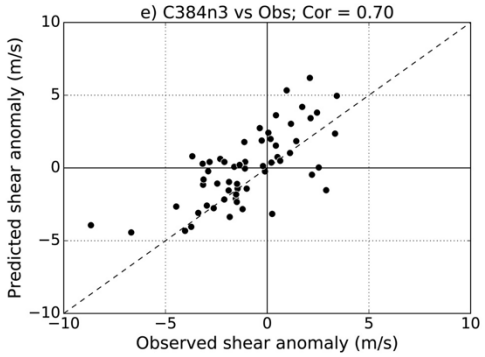


MDR Shear Anomalies: Model vs. Obs

25-km HiRAM



8-km Nest



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

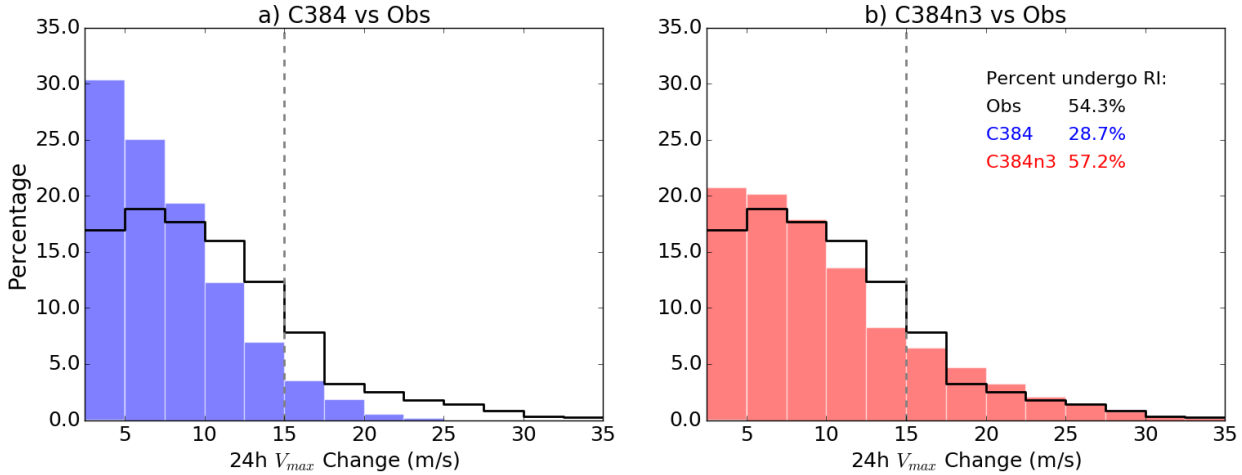
Gao et al. 2019 (JAMES)

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

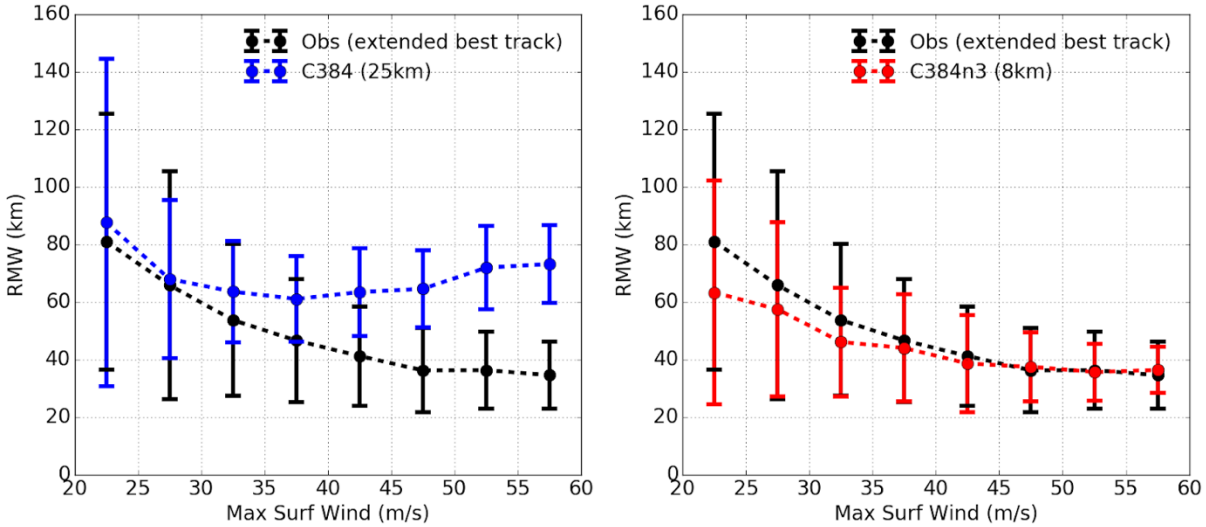
8-km matches observed RI rates; tied to better representation of small, intense cyclones?
➜ S2S Prediction of Rapid Intensification??

24 hour intensification rates

25km HiRAM vs 8km nest vs Obs



Radius of Mean Winds (RMW)



Gao et al, JAMES 2019

GFDL SHiELD

System for High-resolution prediction on Earth to Local Domains

GFDL'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 GFDL'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 (GFDL AM4 and SPEAR, NASA GEOS, CESM-FV3, TaiESM, F-GOALS, etc.)

FV3 Philosophy: **Many applications, many models, *one* adaptable dynamical core**

GFDL 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

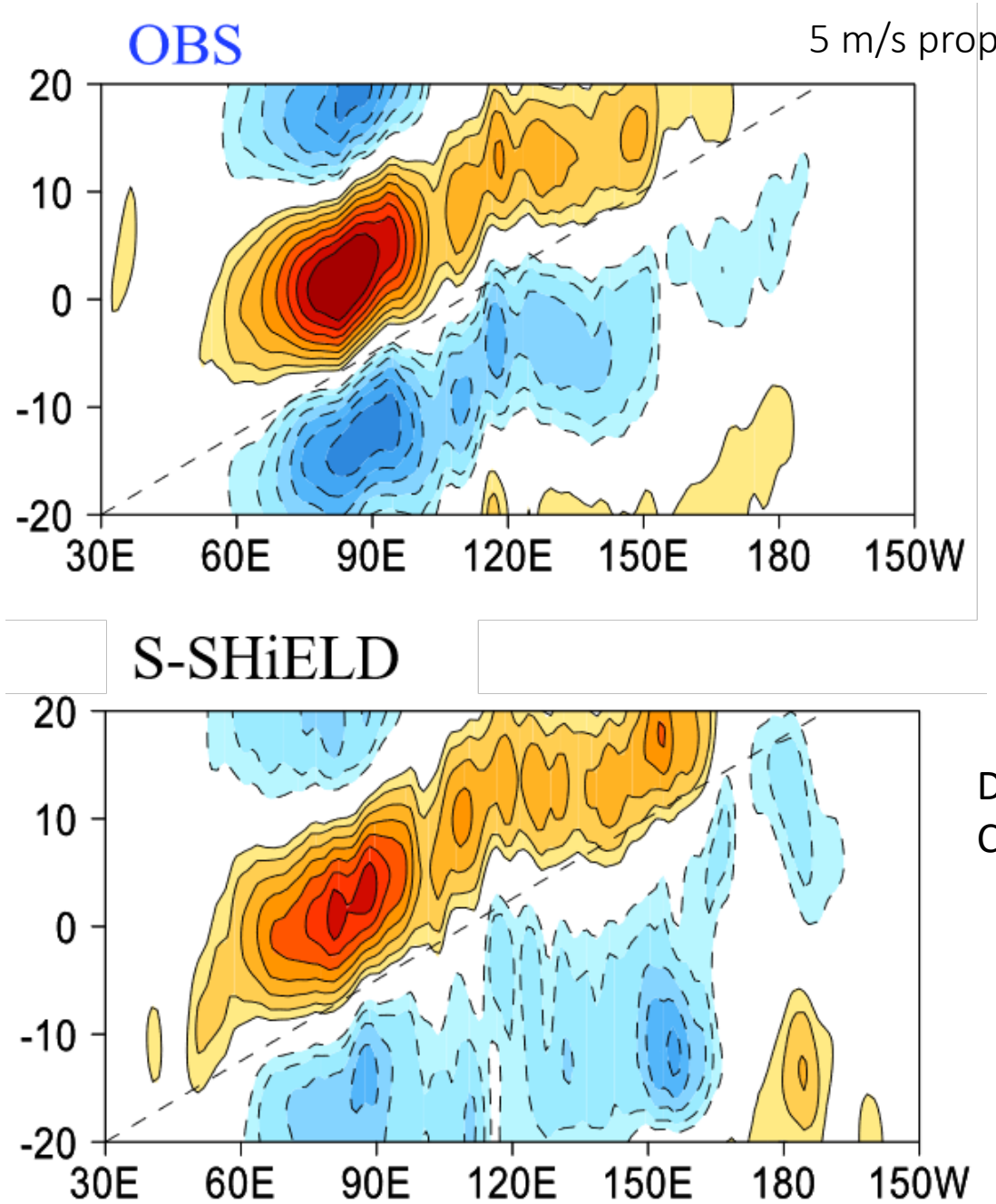
S-SHiELD

S2S prediction model

25-km (c384) global domain

10-year climatological SST integration

MJO Composite using Wheeler & Henden method



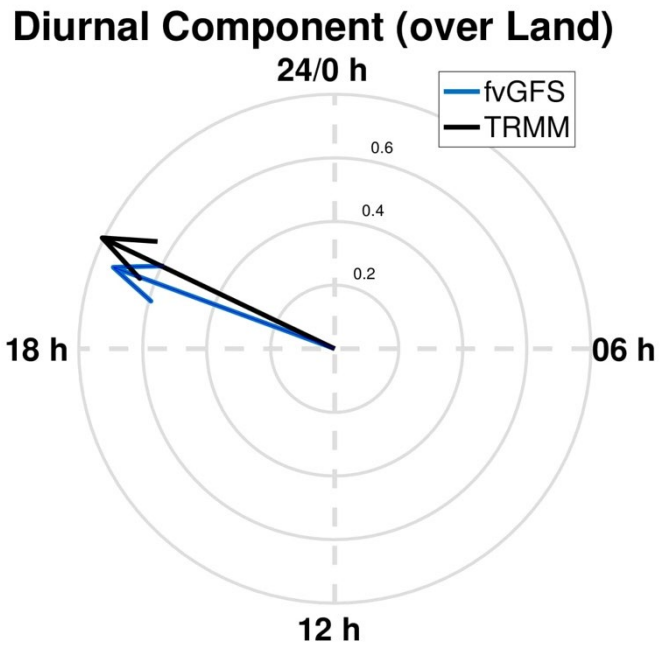
Daily Precip
CI = 0.2 mm/d

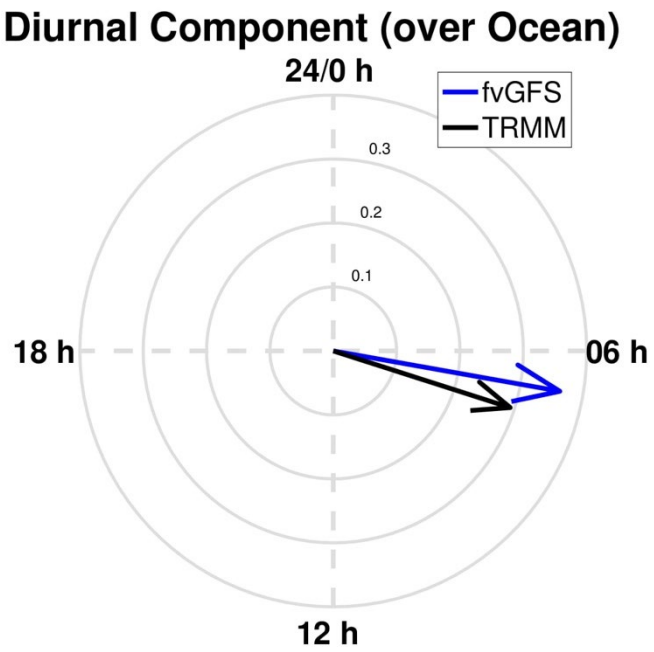
Courtesy Yongqiang Sun

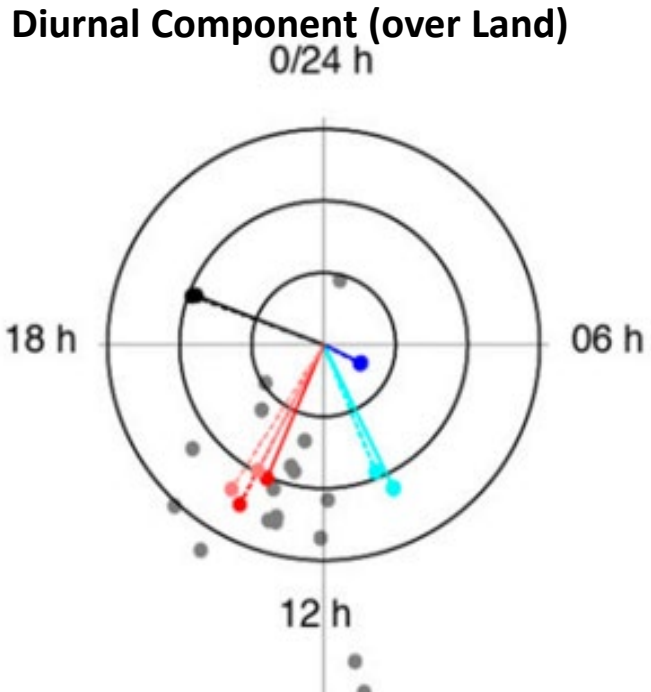
S-SHiELD Diurnal Cycle

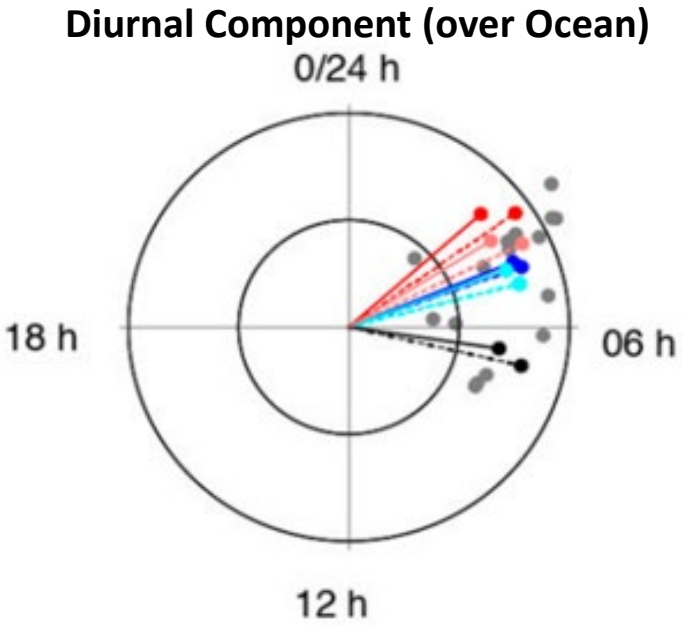
Comey et al (2017) metric and CMIP6 results

Adapted by Yongqiang Sun









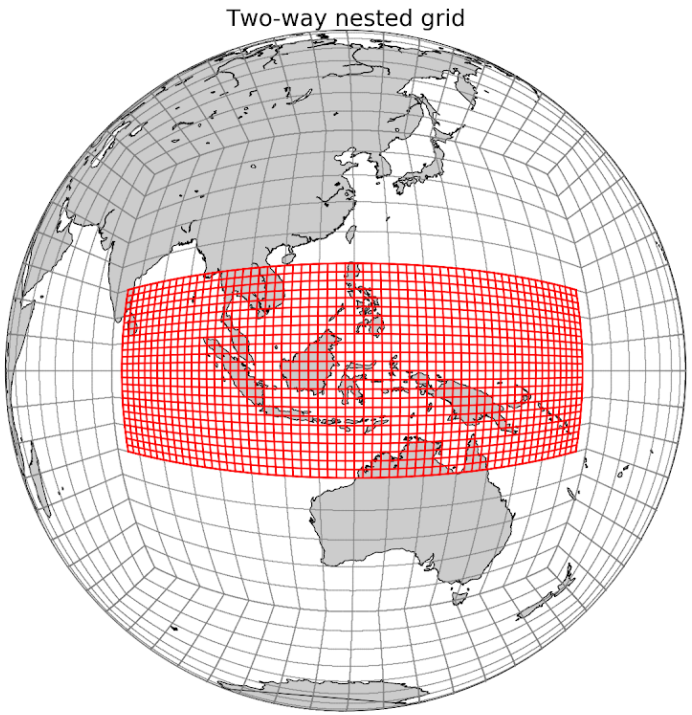
T-SHiELD
Maritime Continent Configuration

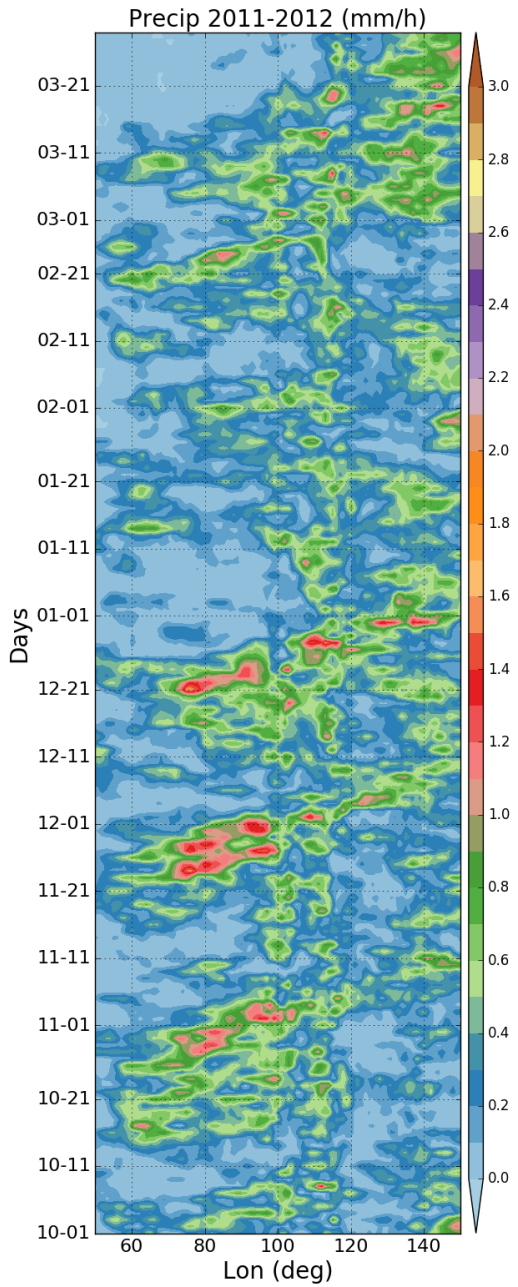
Global 16 km domain with a 4x *two-way* nest centered on equator and covering maritime continent

Simulations initialized from GFS Analyses and integrated for 40 days

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

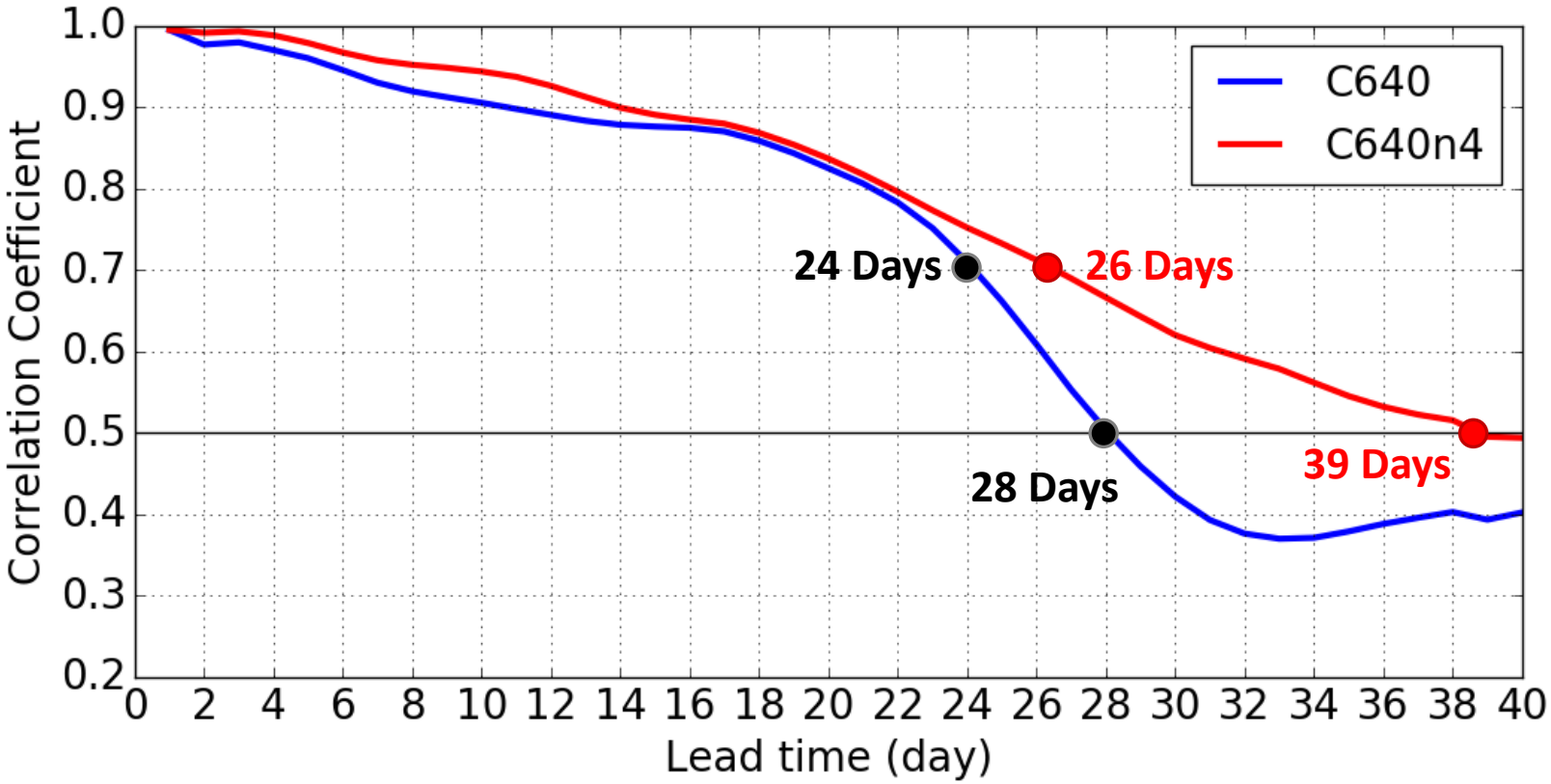
63 vertical levels; first mid-level at 15 m AGL





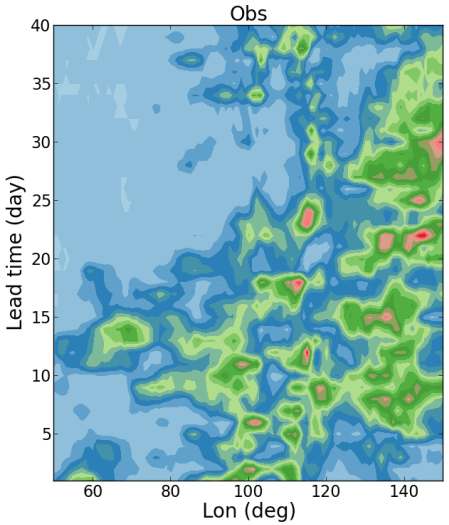
T-SHiELD DYNAMO Hindcasts

- 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

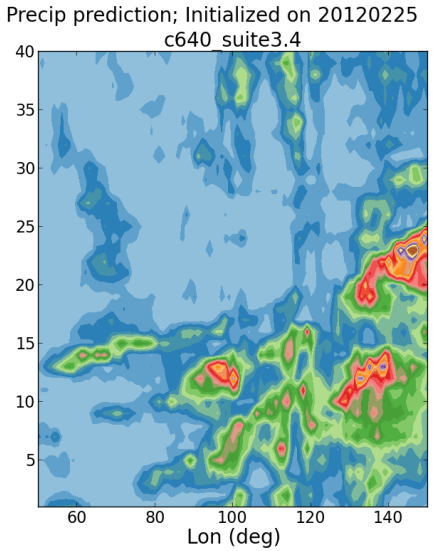


25 February 2012

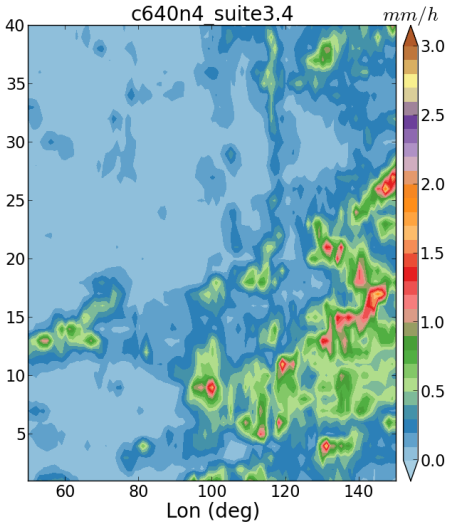
Observations

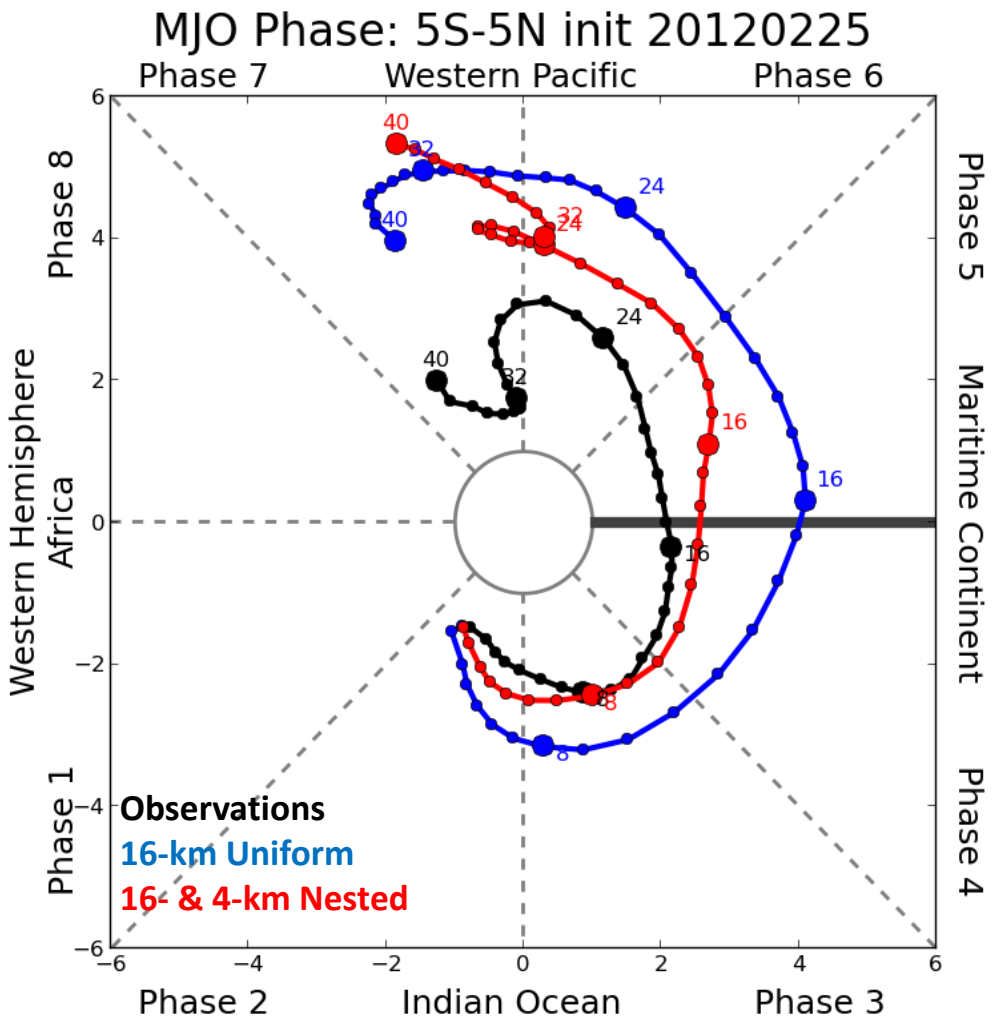


16-km Uniform

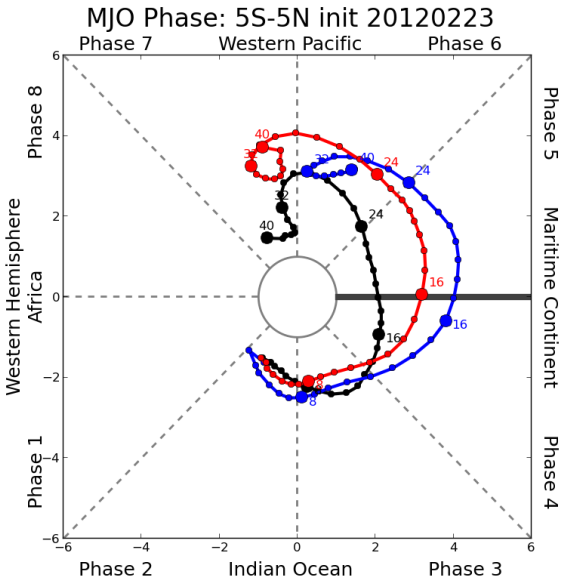


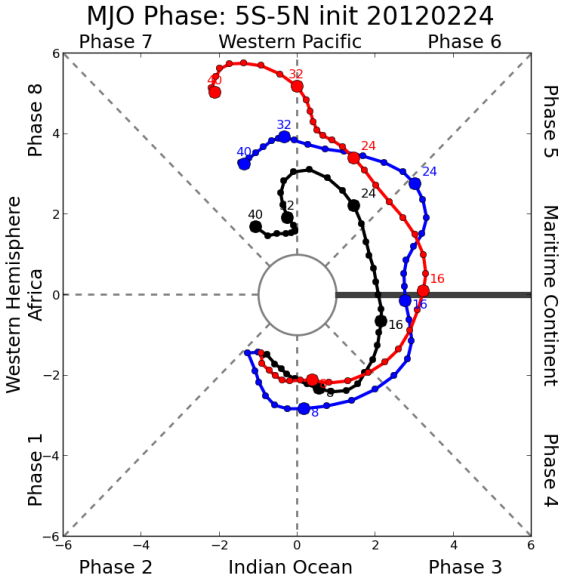
16- & 4-km nest

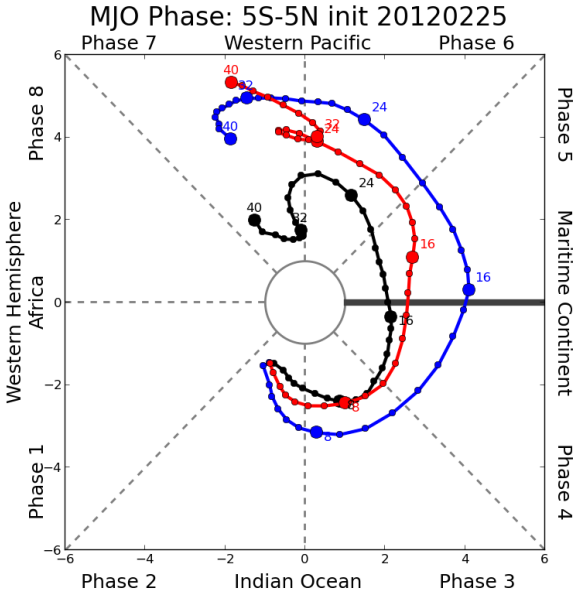


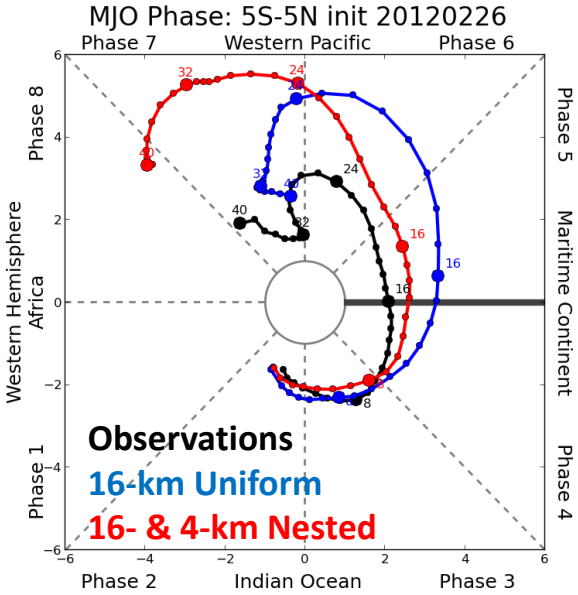


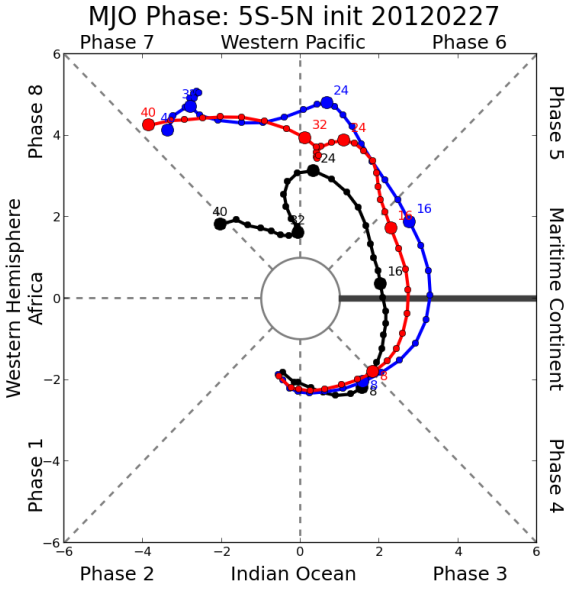
Late Feb 2012: Sensitivity to ICs







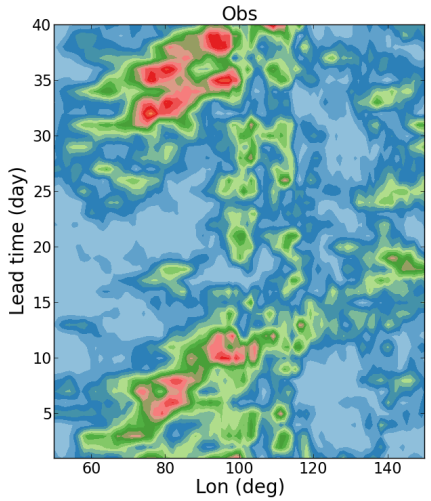




24 Nov 2011

A challenging forecast

Observations



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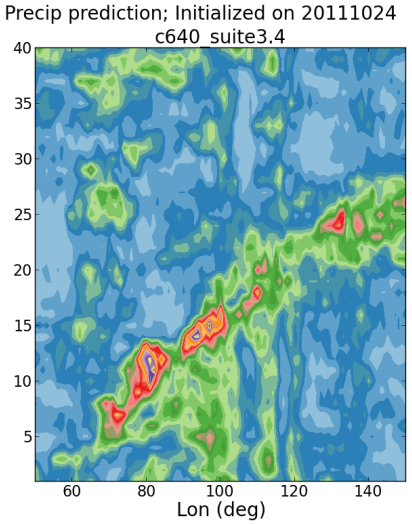
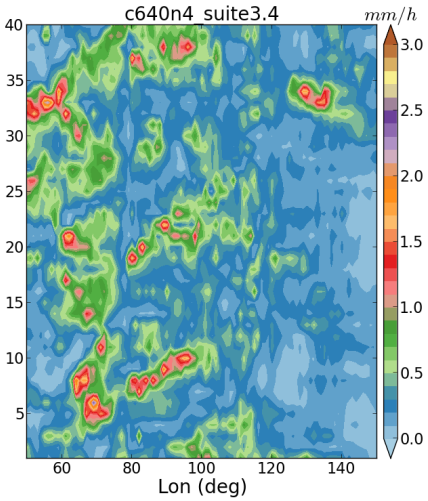
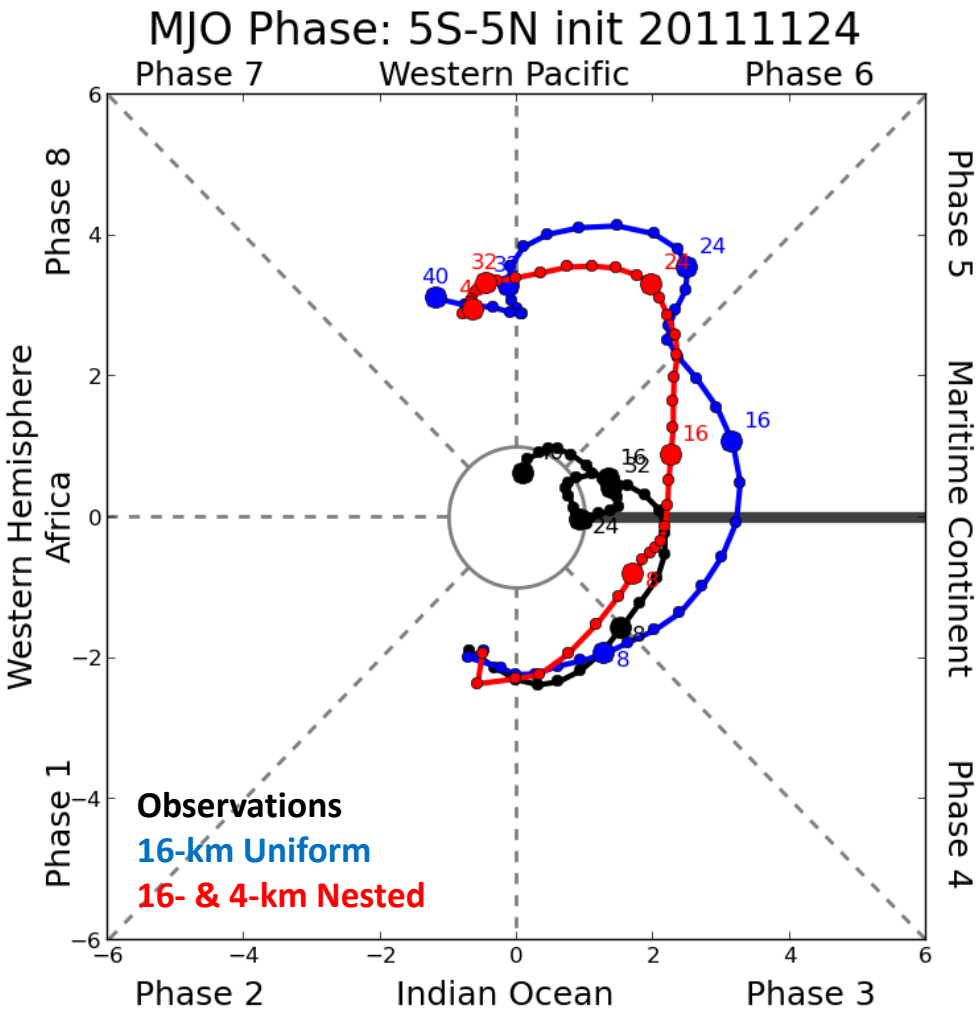
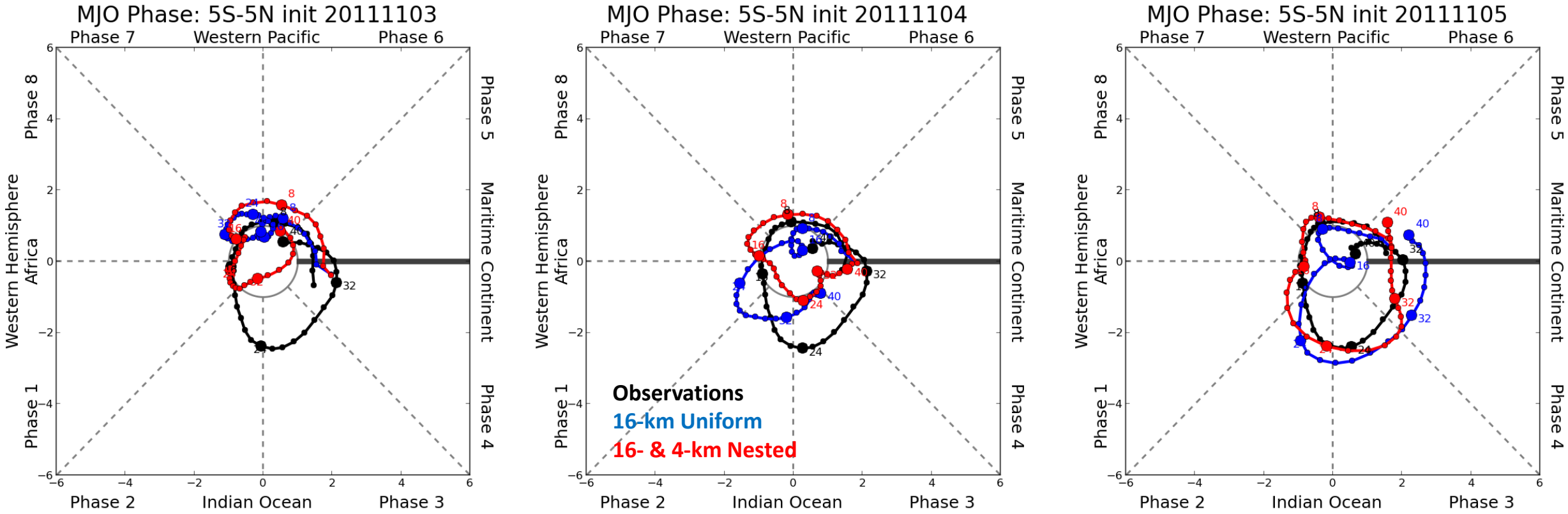


16- & 4-km nest





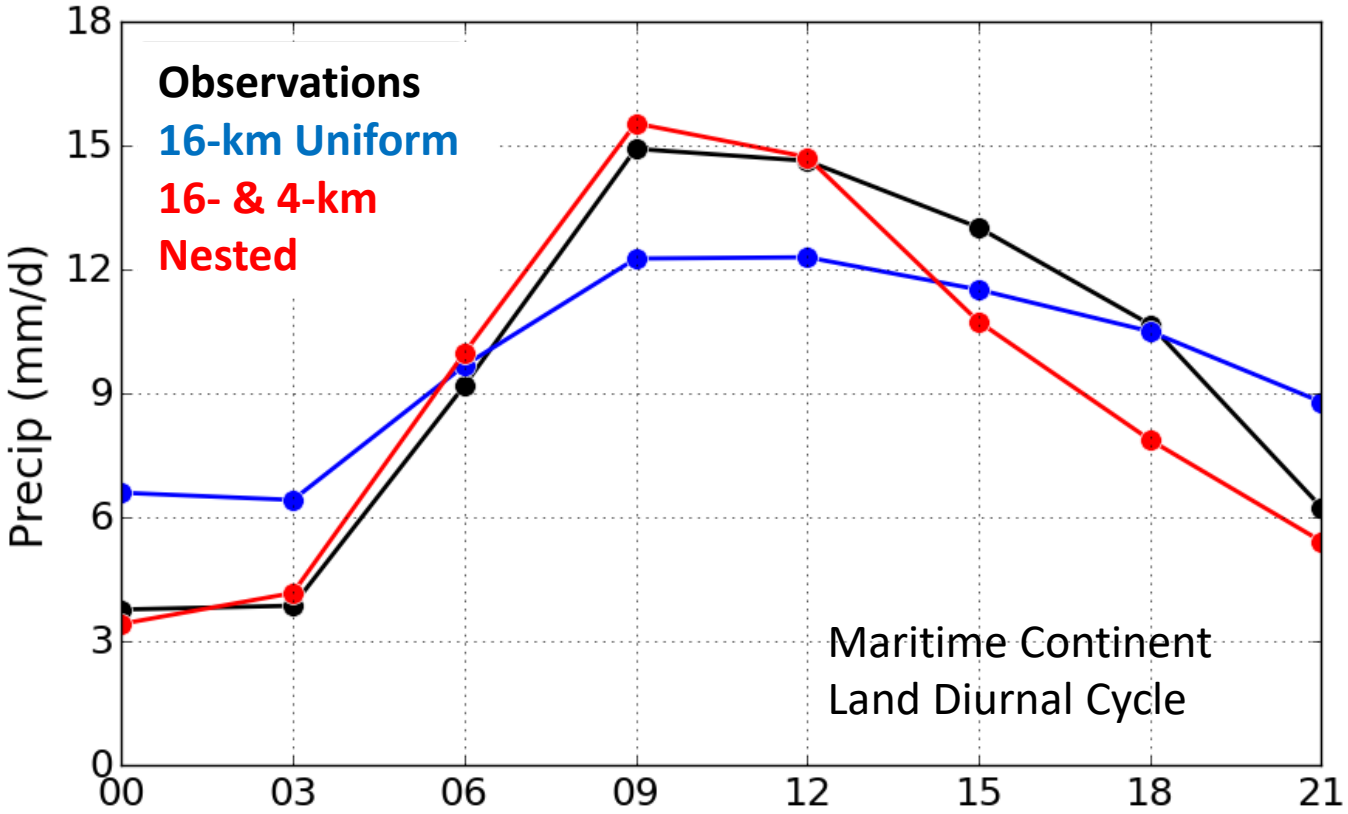
Initiation:
How predictable?



T-SHiELD Diurnal Cycle

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

"SAS Doesn't Suck"

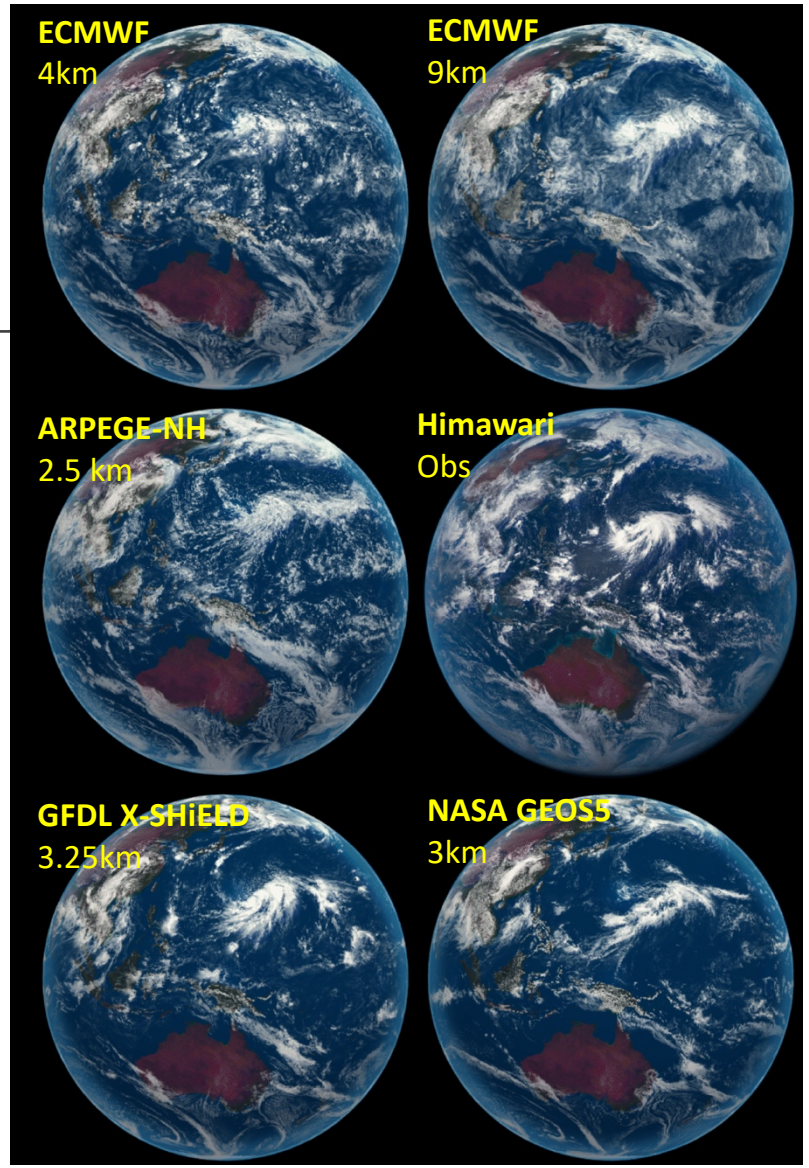


S2S Global Cloud-Resolving Modeling

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



DYAMOND vs. Satellite: Stevens et al 2019, PEPS

Computational Performance

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

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)