Tackling Model Biases in GFDL Climate and Forecast Models

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S2S Community Workshop: Toward Minimizing Early Model Biases
Session: Lessons learned: Reduction of Model Biases
June 5, 2024

Two GFDL Forecast Systems

1. SHiELD (from weather):

--- Forecast-oriented physics development

2. SPEAR (from climate): AM4/LM4+MOM6/SIS2

--- Process-level development with emphasis on model physics and mean climates

Assumption:
A realistic representation of mean climate and variabilities is essential for S2S prediction

Overall AM5 Development Plans

Code Incorporated Likely Possibly

Physics	AM4	AM5
Radiation	Sea/ESF (1999)	RTE-RRTMG (2019)
Convection	Double Plume Convection (DPC)	Improved DPC (non-equilibrium convection)
Cloud Microphysics	Rotstayn-Klein	Morrison-Gettleman-2
Boundary Layer	Lock et al (2000)	Eddy Diffusivity Mass Flux (EDMF)
Land	LM4	LM4.2++/HTiles
Orographic gravity wave drag	Garner et al (2005)	Updated Garner et al (2005)/GFS
Non-orographic gravity wave drag	Alexander and Dunkerton (1999)	A new CG-drag
Stratospheric ozone	Prescribed	Linear ozone
Aerosol indirect effect	Liquid only (Ming et al. 2006)	Dust and temperature-dependent ice nucleation + updated liquid (Nenes)
Aerosol/chemistry	Simplified	Updated aerosol processes (emissions, deposition) consistent with ESM but chemistry is still simplified

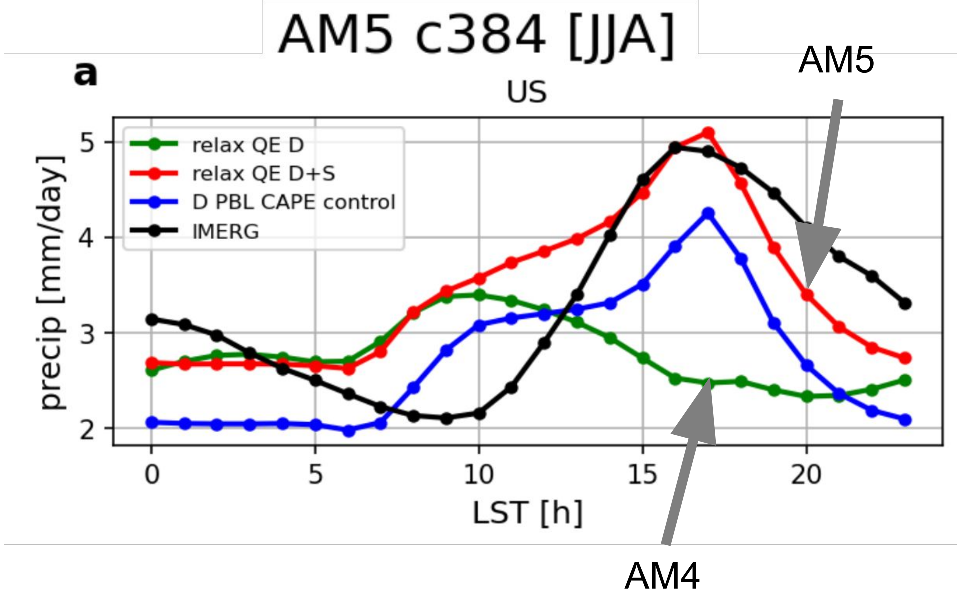
Long-standing model biases with examples from AM5 development

1) Diurnal cycle of land precipitation
2) Tropical Cyclones
3) MJO
4) QBO
5) Coastal Stratocumulus
6) Double ITCZ

1) Diurnal Cycle of Land Precipitation

AM4:

$$\left(\frac{\partial CAPE}{\partial t}\right)_{deep} = -\frac{CAPE - CAPE_0}{\tau}$$



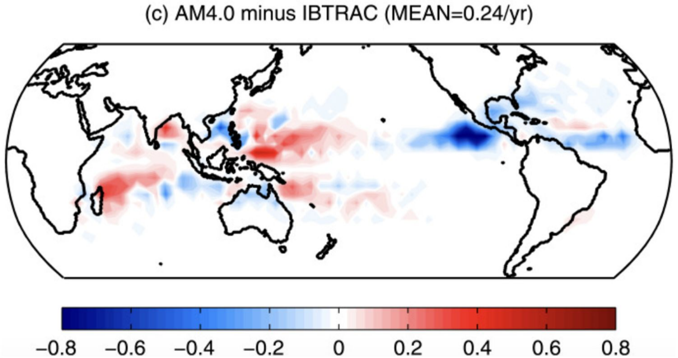
AM5 with non-equilibrium convection (NEC):

$$\left(\frac{\partial CAPE}{\partial t}\right)_{deep} = -\frac{CAPE - CAPE_0}{\tau} - \left(\frac{\partial CAPE}{\partial t}\right)_{shal}$$

Zhang et al. 2024, under review

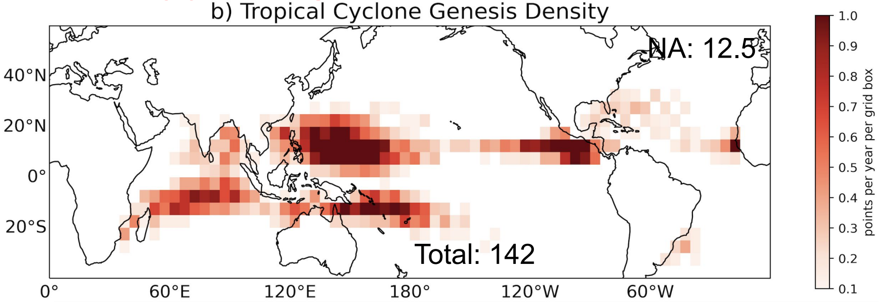
2) Tropical Cyclones

TC Genesis

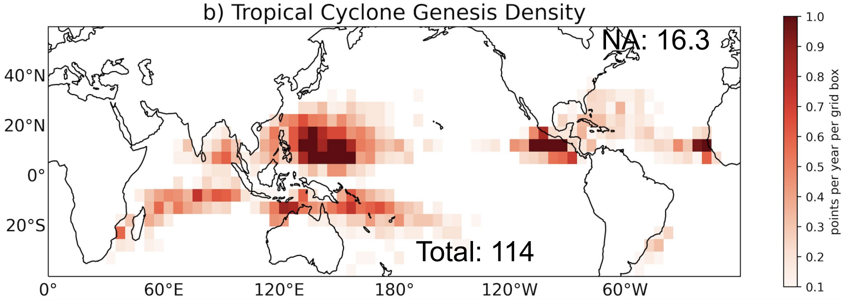


AM4 biases

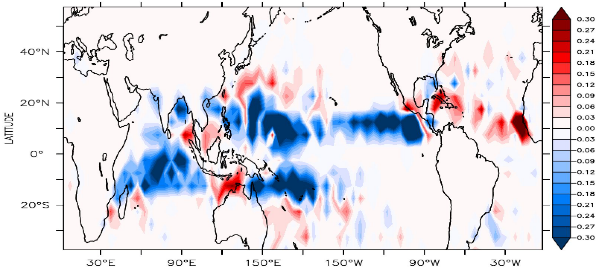
Without NEC



with NEC

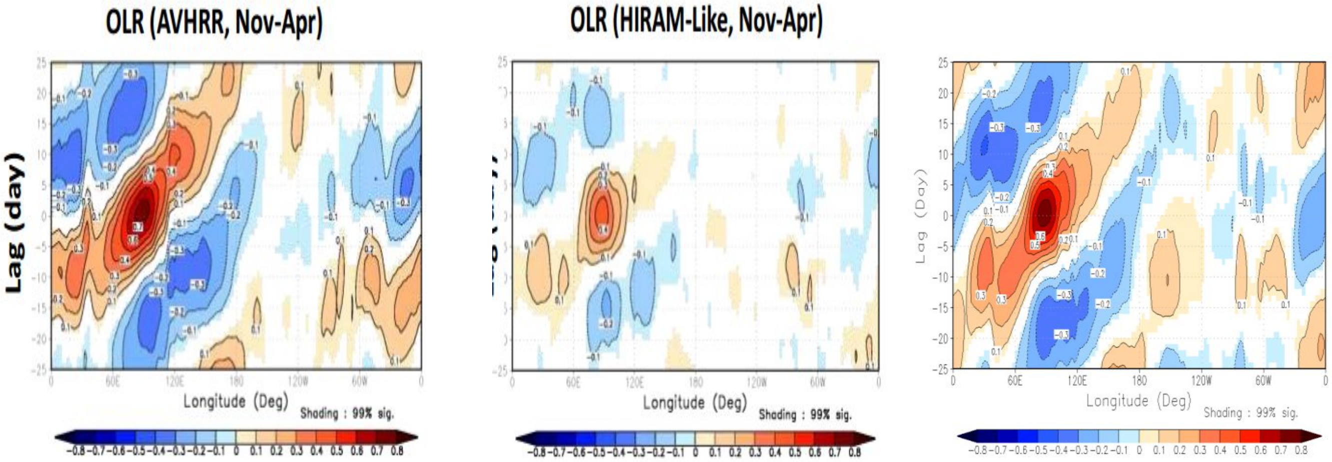


NEC - Control



Global: 21% reduction
NA: 30% increase

3) MJO



Single plume

Double plume

- An additional plume is introduced to represent deep/organized convection with entrainment rate dependent on ambient RH
- Shallow cumulus moistening ahead of deep/organized convection
- Enhance LW and SW cloud radiative effect via convective microphysics
- Enhance the effect of cold pools through precipitation re-evaporation

4) QBO

Non-orographic gravity wave scheme in GFDL models

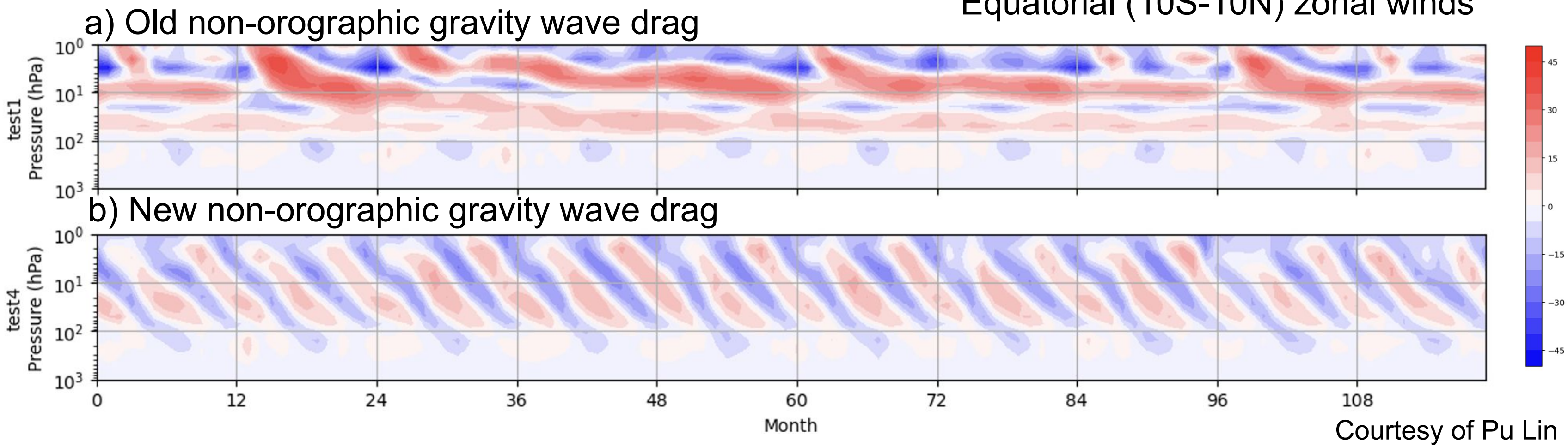
Default: AD99

- Alexander and Dunkerton 1999
- Wave source is an arbitrary constant over SH, NH and tropics.
- Simple treatment for wave propagation.

New: Beres

- Beres et al. 2004
- Wave source is determined by convective heating profile
- More sophisticated treatment for wave propagation.
- Current implementation is intended for tropical waves only. Additional scheme for extratropical waves is not activated.

Equatorial (10S-10N) zonal winds

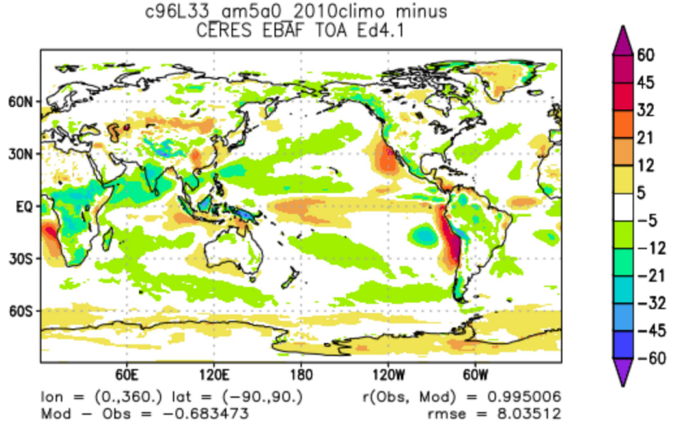


Courtesy of Pu Lin

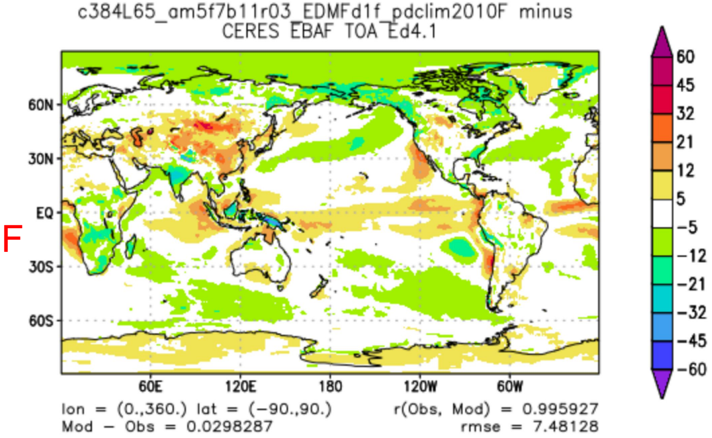
5) Costal Stratocumulus

TOA shortwave absorption bias

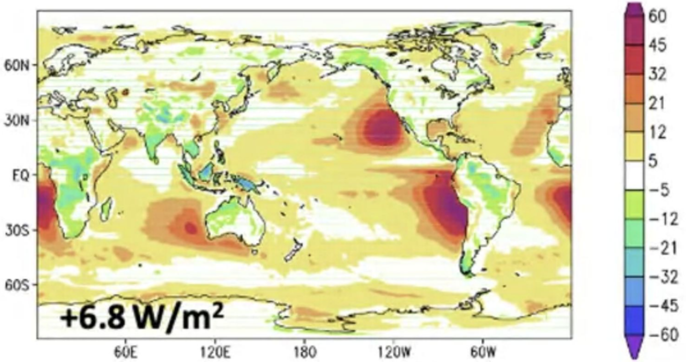
AM4
(100 km)
Using LOCK PBL



A prototype
AM5 (25 km)
using TKE-EDMF



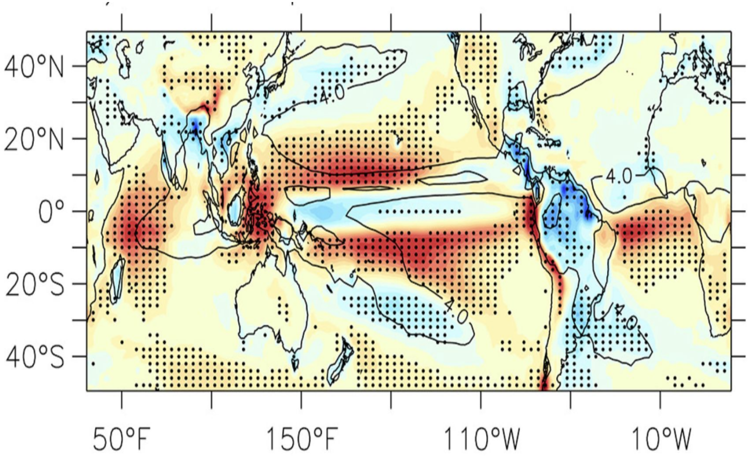
Initial version of AM5 with TKE-EDMF

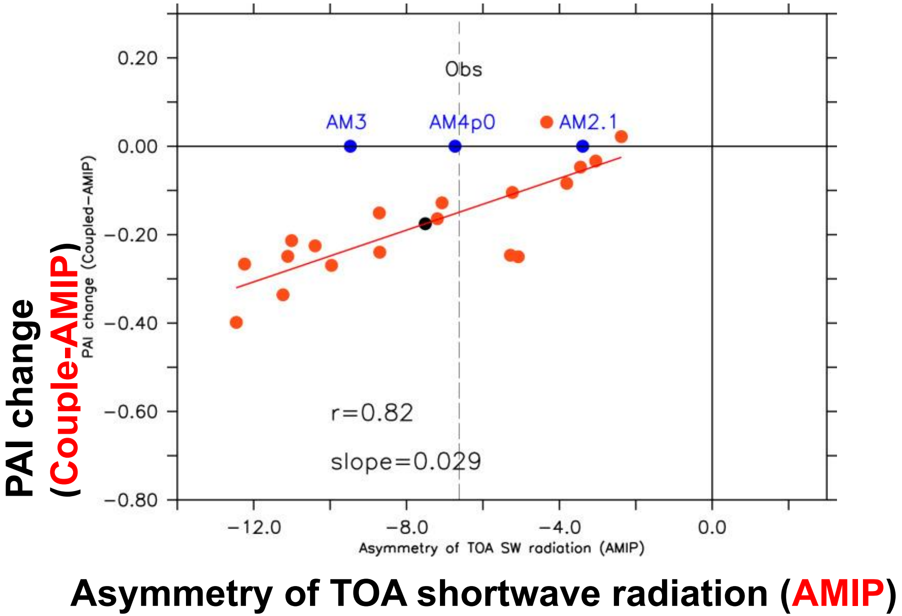


Courtesy of Zhihong Tan

6) Double ITCZ

CMIP5 model precipitation bias





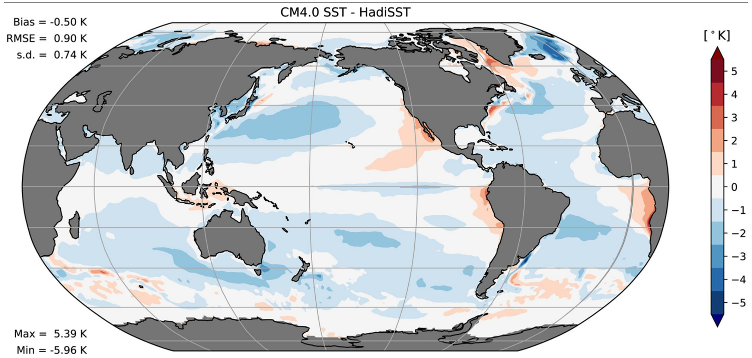
Prediction of the severity of double ITCZ problem in coupled model from AMIP simulation:

$$PAI_{coupled} - PAI_{AMIP} = 0.021 \times F_{AMIP} - 0.05,$$

Xiang et al. 2017; Zhao et al. 2018

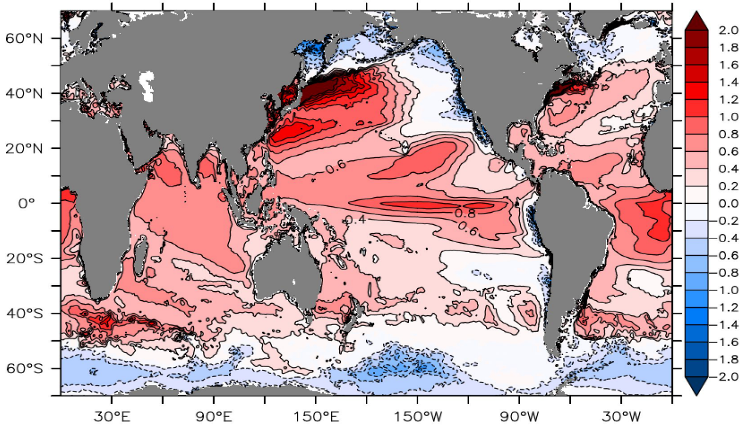
Mean SST in coupled model simulations

Mean SST bias from the **historical** simulation of CM4 (2005-14)



Held et al. 2019

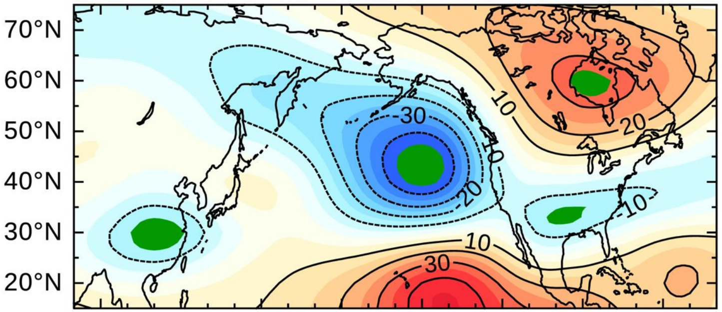
A prototype CM5 (25km) – CM4 (100km)

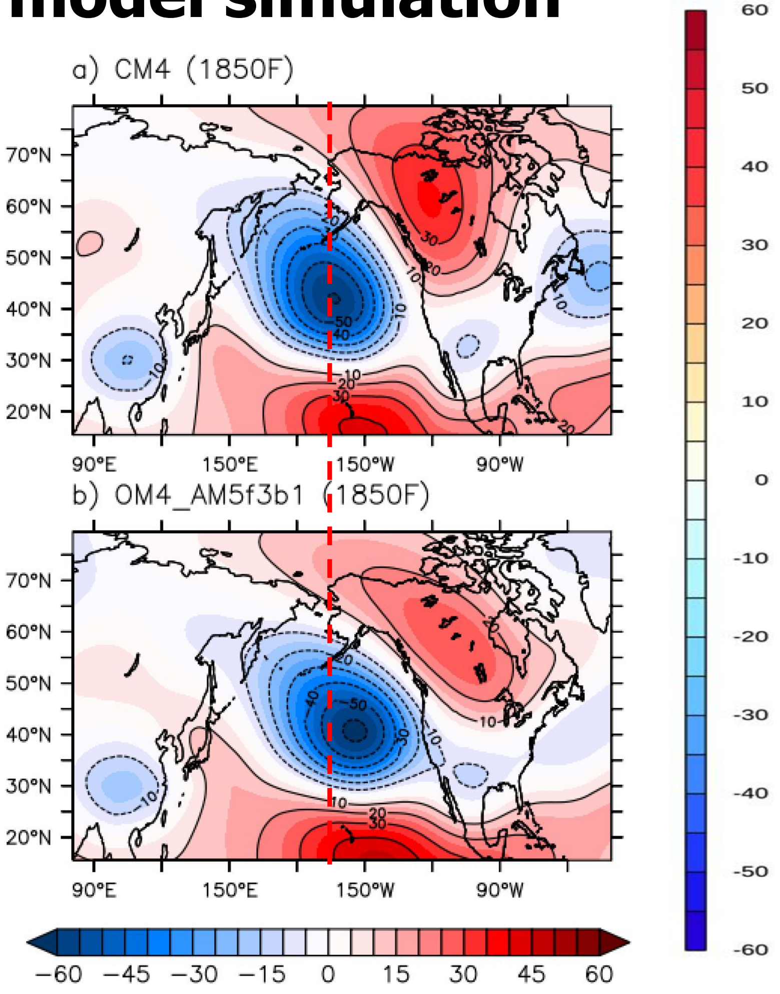


Monitoring the coupled model simulation

Regression of DJF 200 hPa geopotential height onto Nino3 index

(a) NCEP/NCAR Reanalysis (1958-2009)



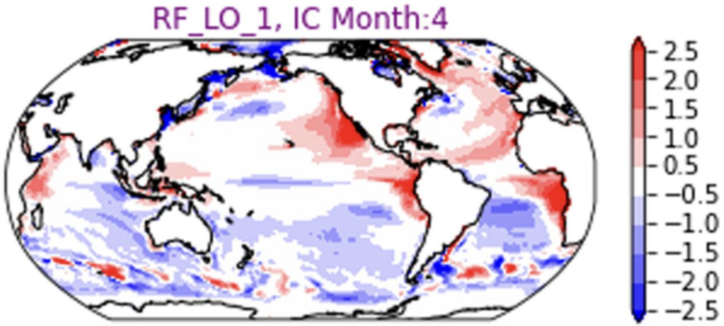


In addition to improving simulations of mean states and variabilities,

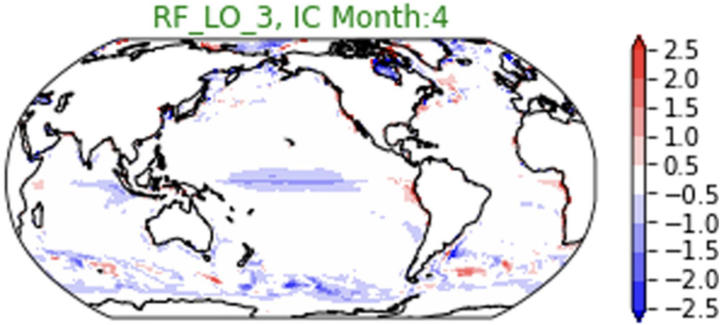
what else can we do to reduce model biases and improve forecast skills?

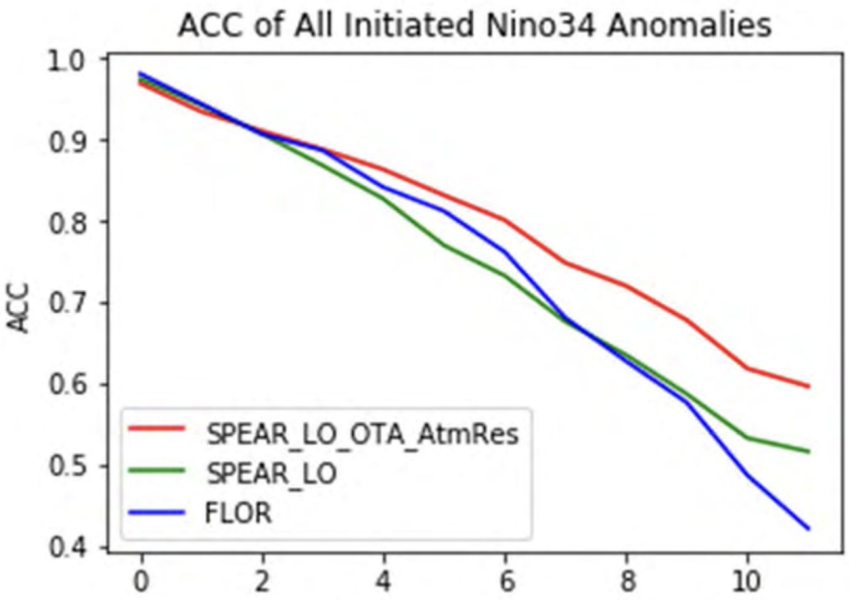
Reduced SST bias with Ocean Tendency Adjustment (OTA)

SPEAR_LO



SPEAR_LO_OTA



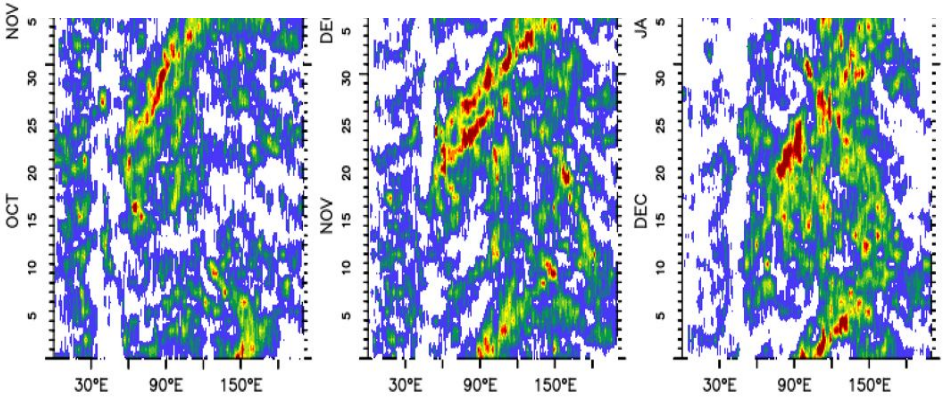


SST bias on August with initialization on April

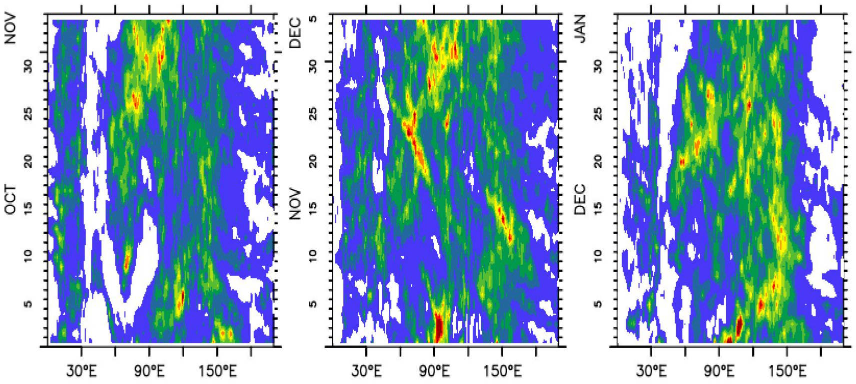
Lu et al. 2020

Sensitivity of MJO prediction to initialization strategy

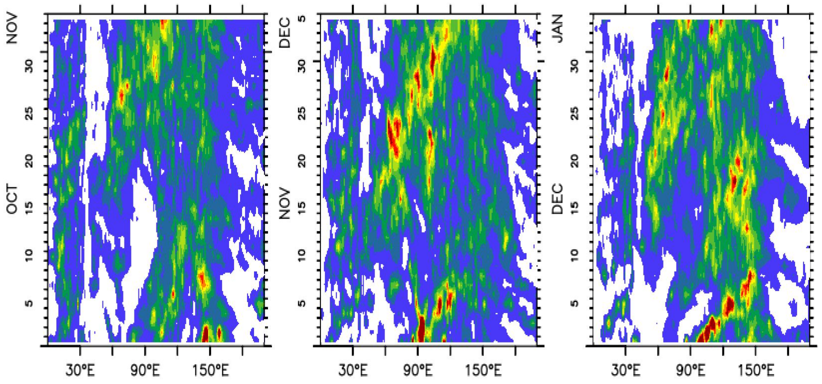
Observed 3 MJO events in 2011



Initialization by nudging wind & temperature

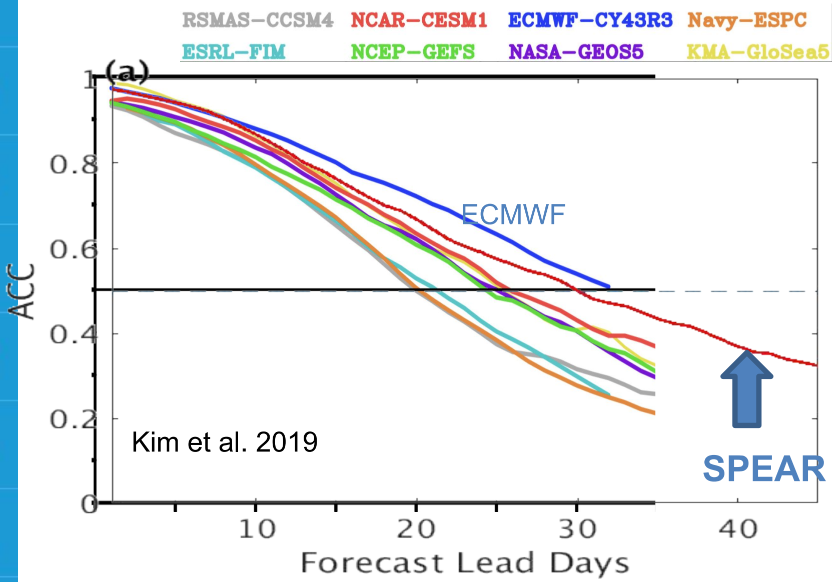


Initialization by nudging wind, temperature, humidity

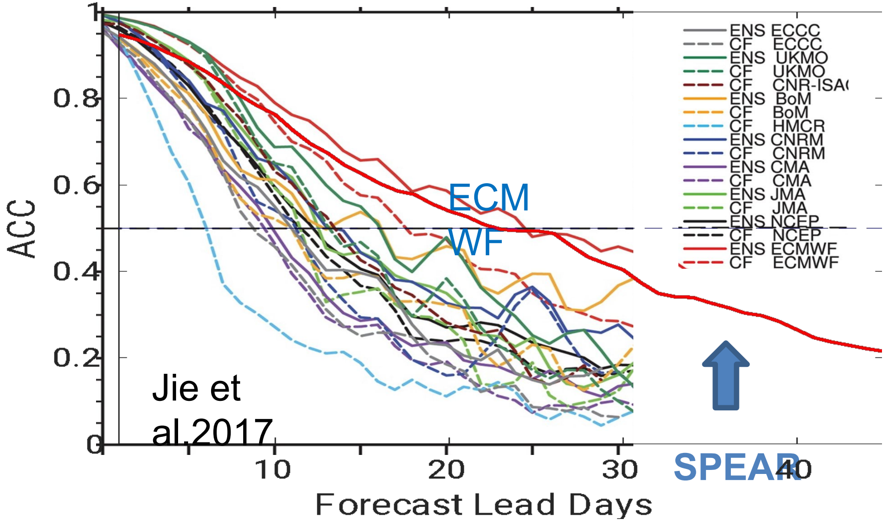


MJO/BSISO Predictions in SPEAR

Wintertime MJO prediction (30 days)
(using Wheeler Hendon index)



Summertime BSISO prediction (22 days)
(using Lee et al. index)



Xiang et al. 2021, BAMS; Xiang et al. 2024, J. Clim

Summary

A model with better representations of mean climate and variabilities is essential for S2S prediction.

- Physics-based development is fundamental, but tuning is always important
- Single-column and doubly periodic simulations help understand model behaviors/biases
- Thorough validation with observations
- Regularly run coupled simulations

…

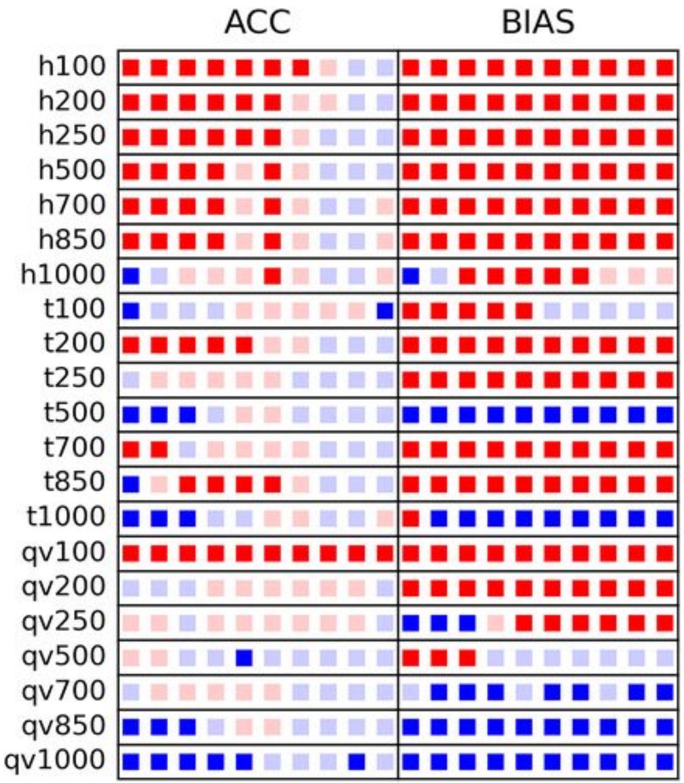
Thanks

SHiELD model

Impacts of GFDL Microphysics Update on the forecast skill in the first 10 days

Update from GFDL MP2 to MP3:

1) Particle size distribution
2) Microphysics processes
3) Aerosol-based CDNC
4) Code reorganization



Scorecard

Red: improvement
Blue: degradation