Some surprising effects of inhibiting convection coupling to divergent motions in a superparameterized version of the WRF model

CMMAP 2016 Winter Team Meeting

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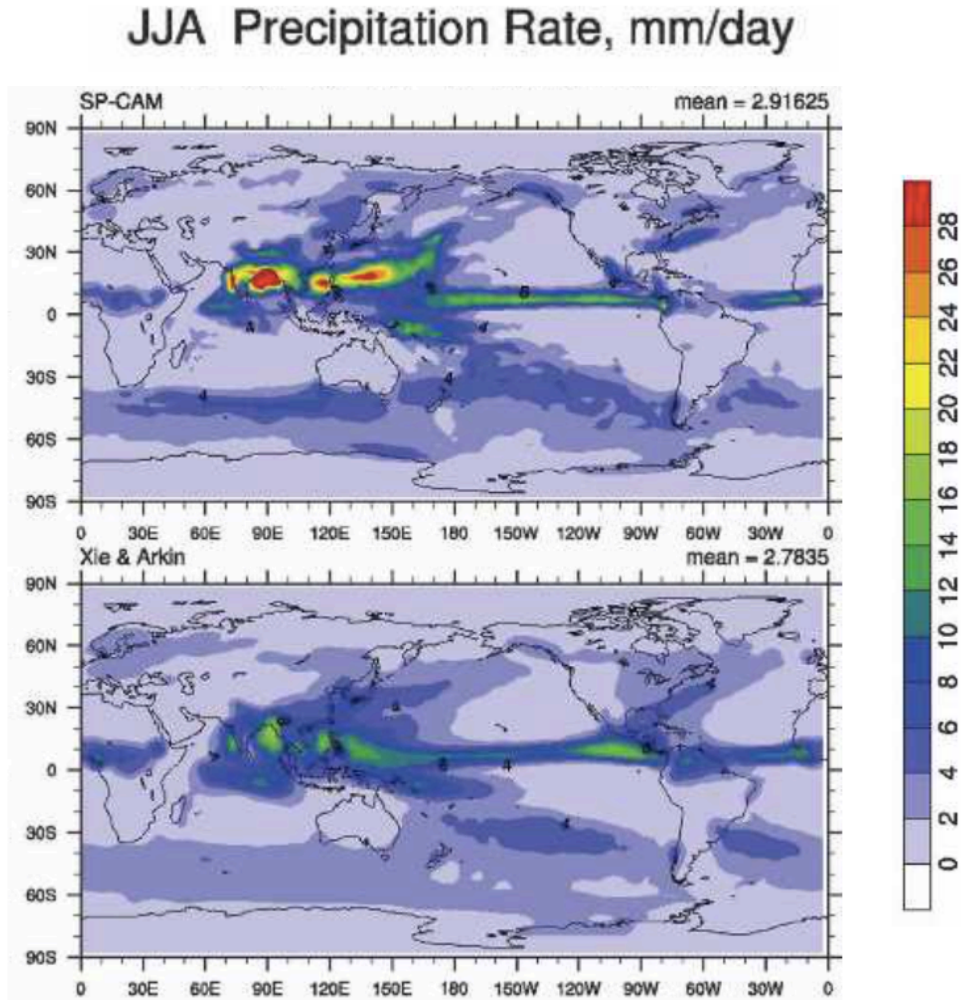
Overarching goal: Better understand the often puzzling behavior of global models in the tropics?

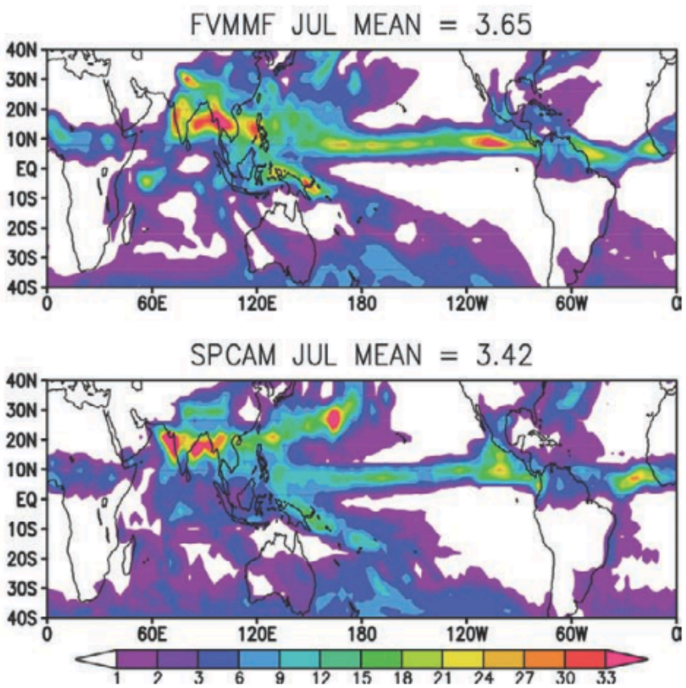
Relevant unsolved problem: The mystery of the so-called “Great Red Spot” (GRS), first seen in SP-CAM3



From: Khairoutdinov et al. (2005)

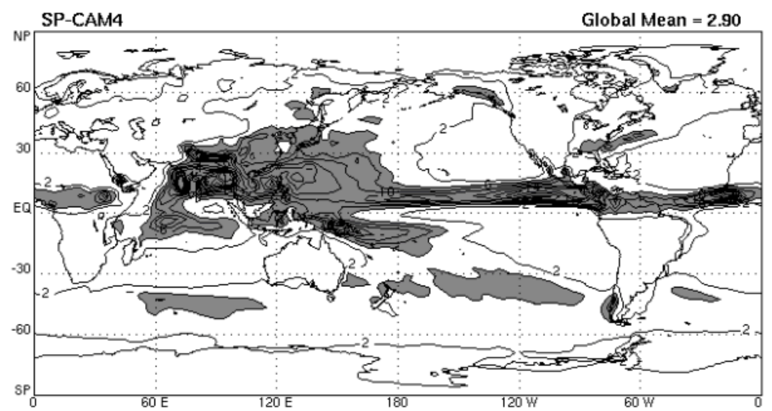
This same problem has since been documented in several other (atmosphere-only) SP models

NASA MMF

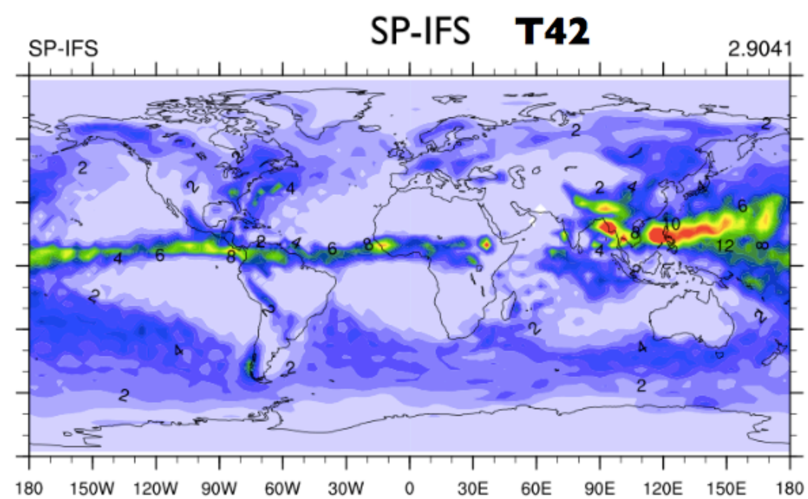


Tao et al. 2009

SP-CAM4

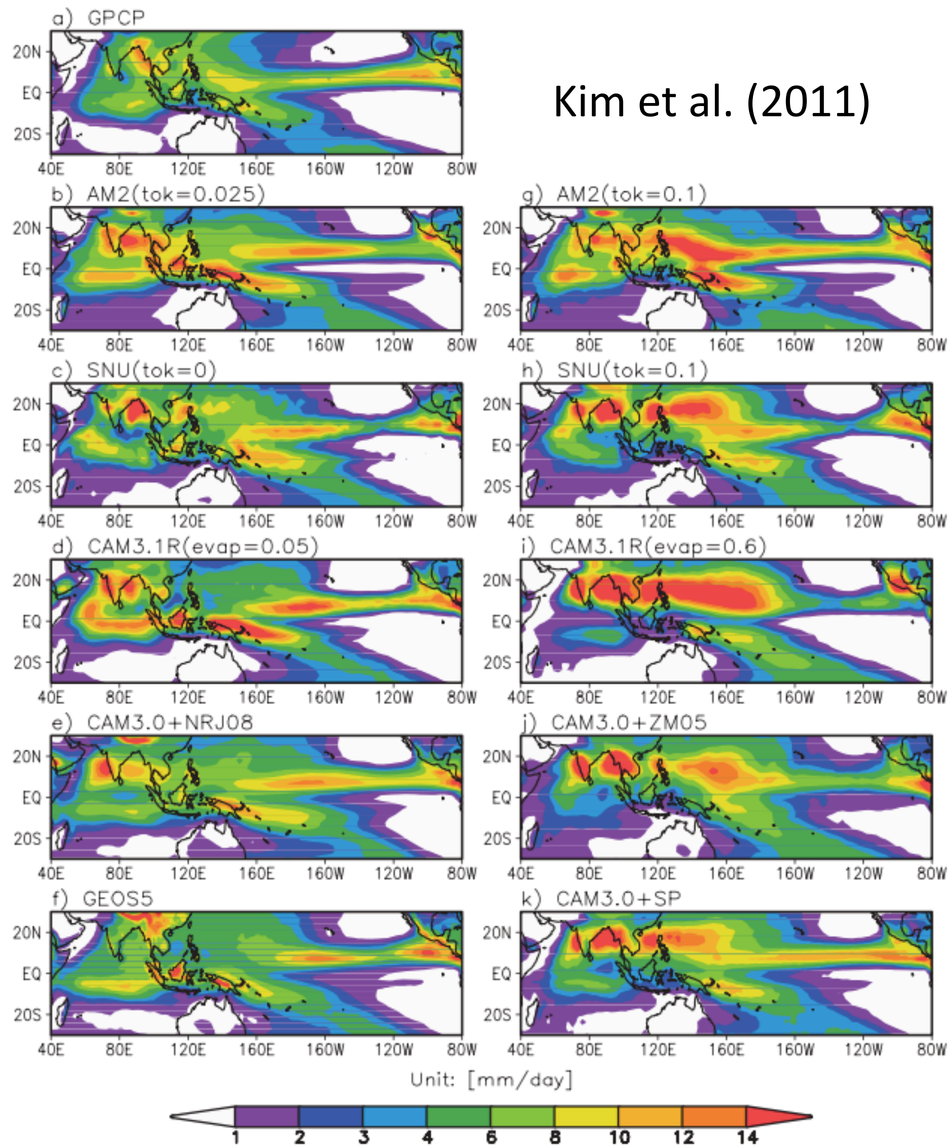


Randall et al. 2016



Khairoutdinov and Kim (2014 Winter CMMAP pres.)

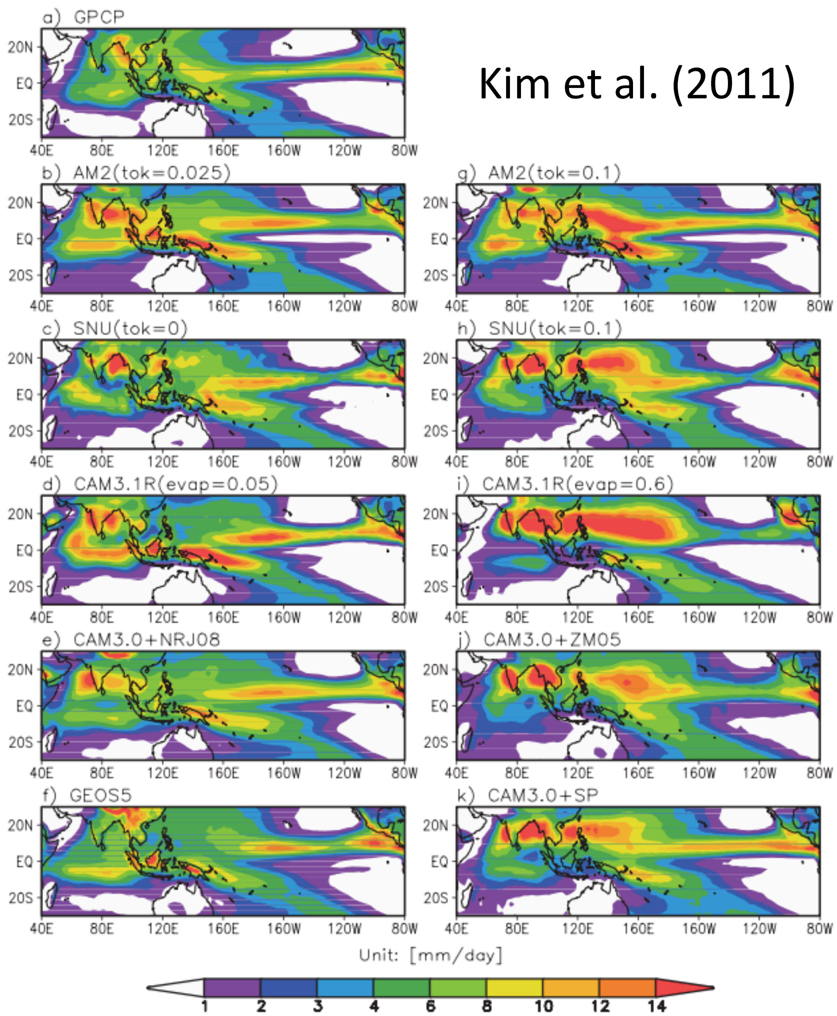
…as well as several conventional (atmosphere-only) models, under certain model modifications

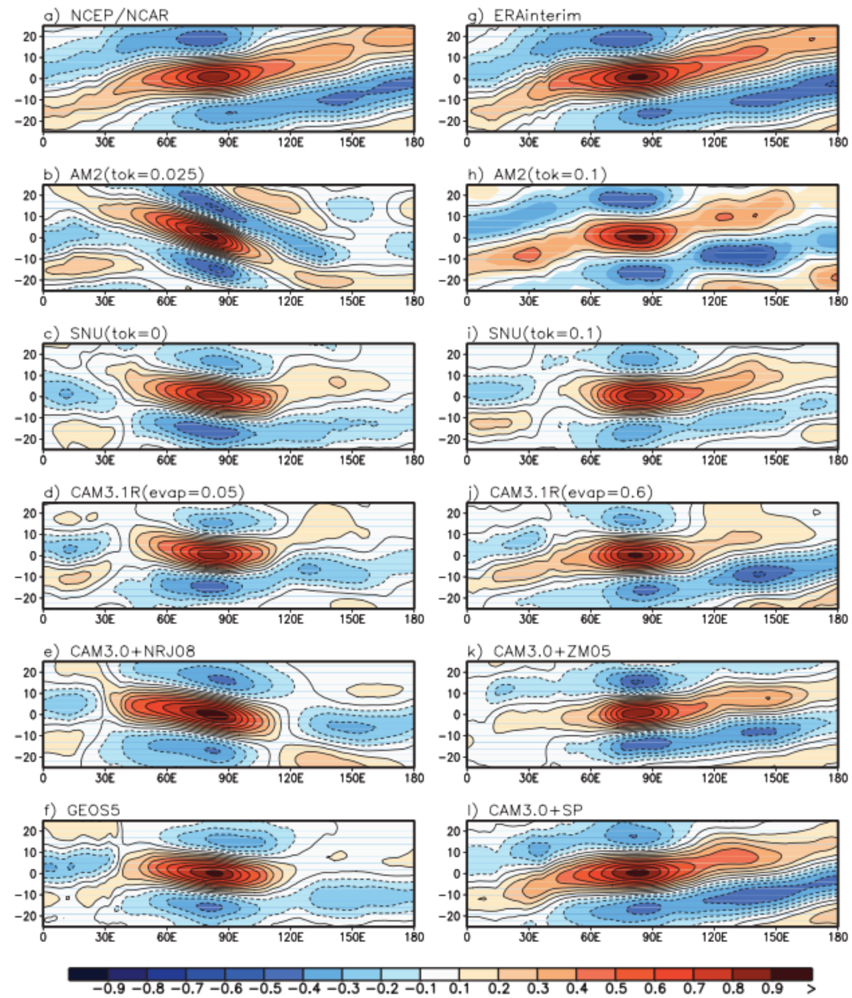


Kim et al. (2011)

The latter study further documented a link between the GRS and ISV activity during Boreal WINTER

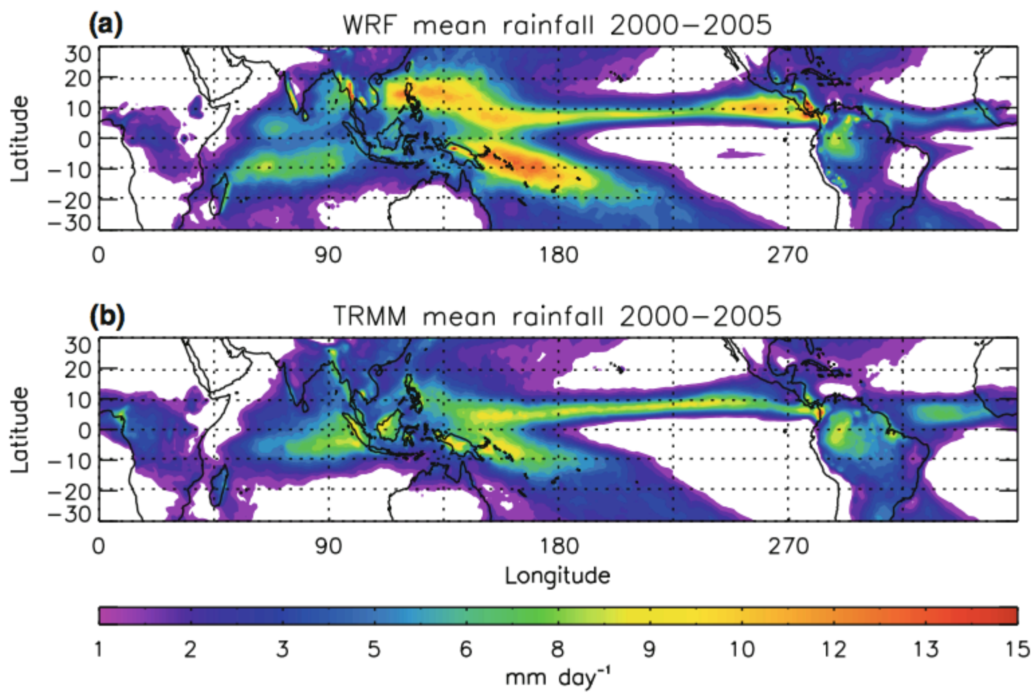
Kim et al. (2011)





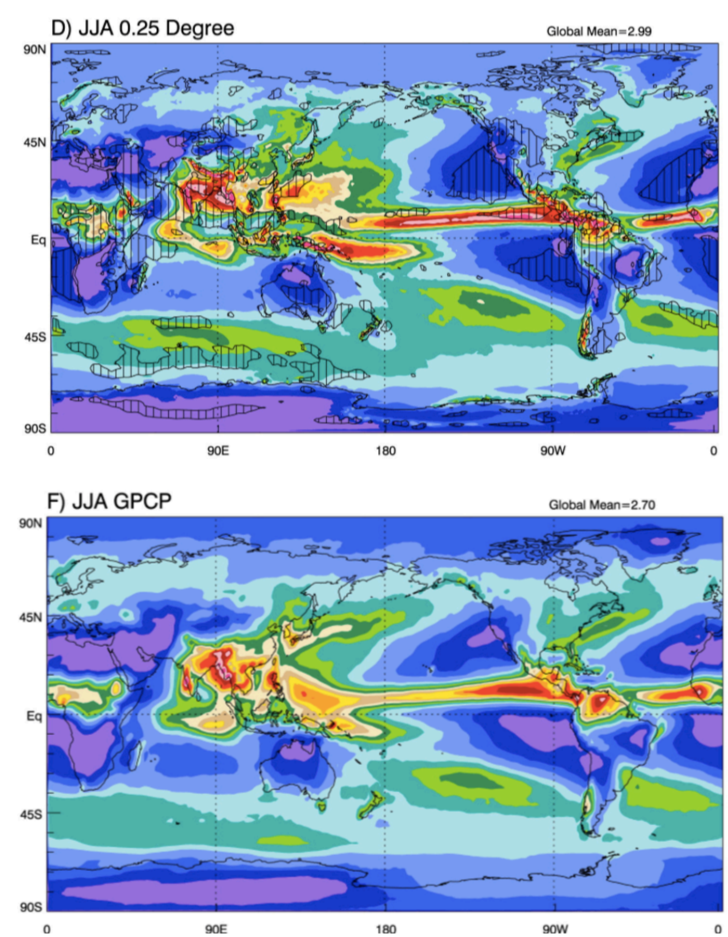
…however this relationship does not appear to hold for conventional models at higher horizontal resolution

36-km WRF channel model



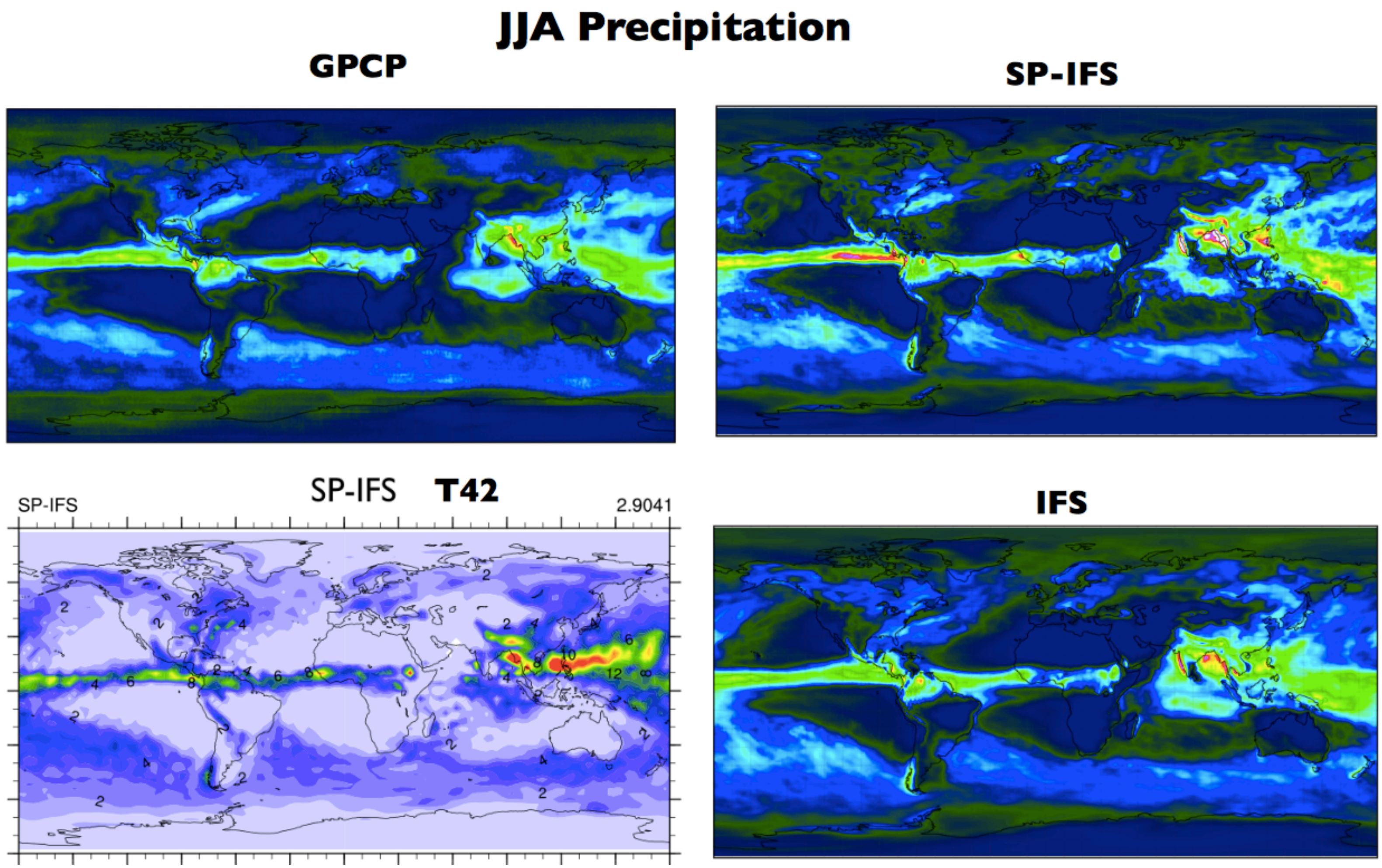
Tulich et al. (2009)

0.25-deg. CAM4



Bacmeister et al. (2014)

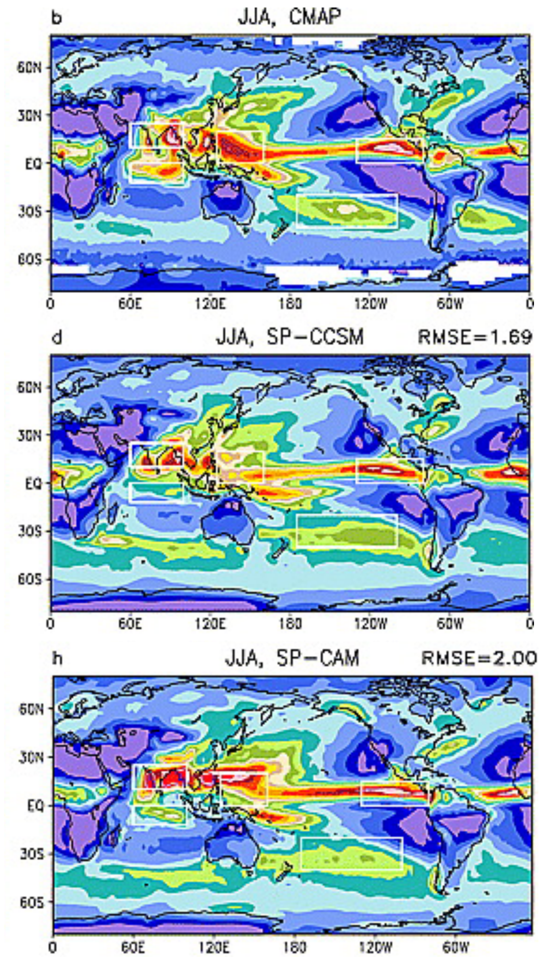
The GRS problem goes away in the SP-IFS as horizontal resolution is increased



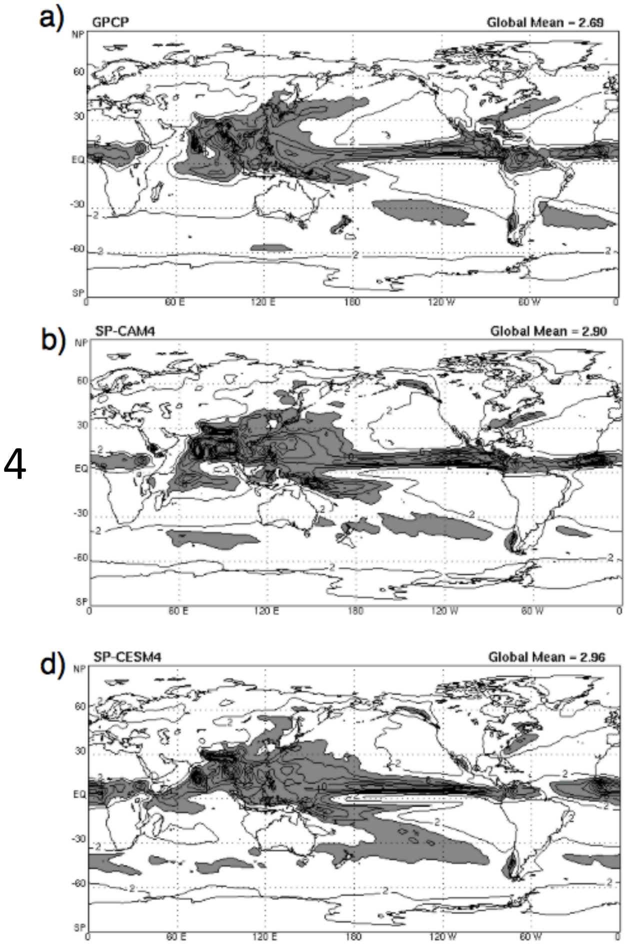
Taken from Marat's 2015 CMMAP presentation

The GRS problem is strongly mitigated in the SP-CAM when ocean coupling is included*

CAM3



CAM4



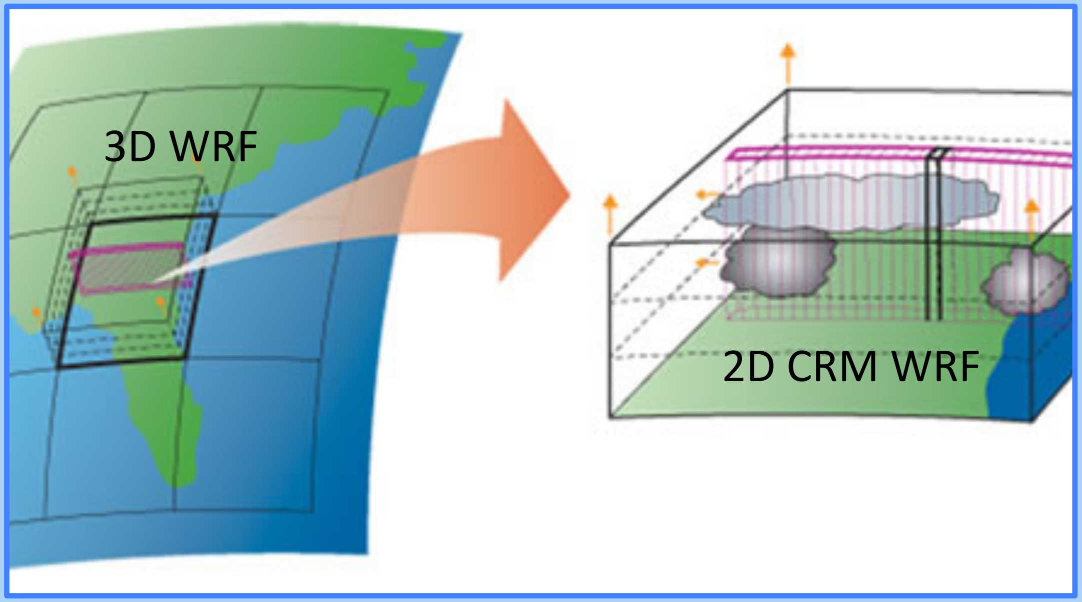
Stan et al. (2010)

Randall et al. (2016)

*at the expense of a negative SST bias in the tropics

So how does the SP-WRF perform in this regard?

First, a brief description of the model



Unique capabilities:

- Can be run either regionally or globally
- Wide variety of bulk physics options (all those in standard WRF)
- Land-atmosphere coupling handled at the CRM level
- Nudging to an analysis or observations (FDDA) available on the outer grid
- Novel treatment of convective momentum transport (CMT)

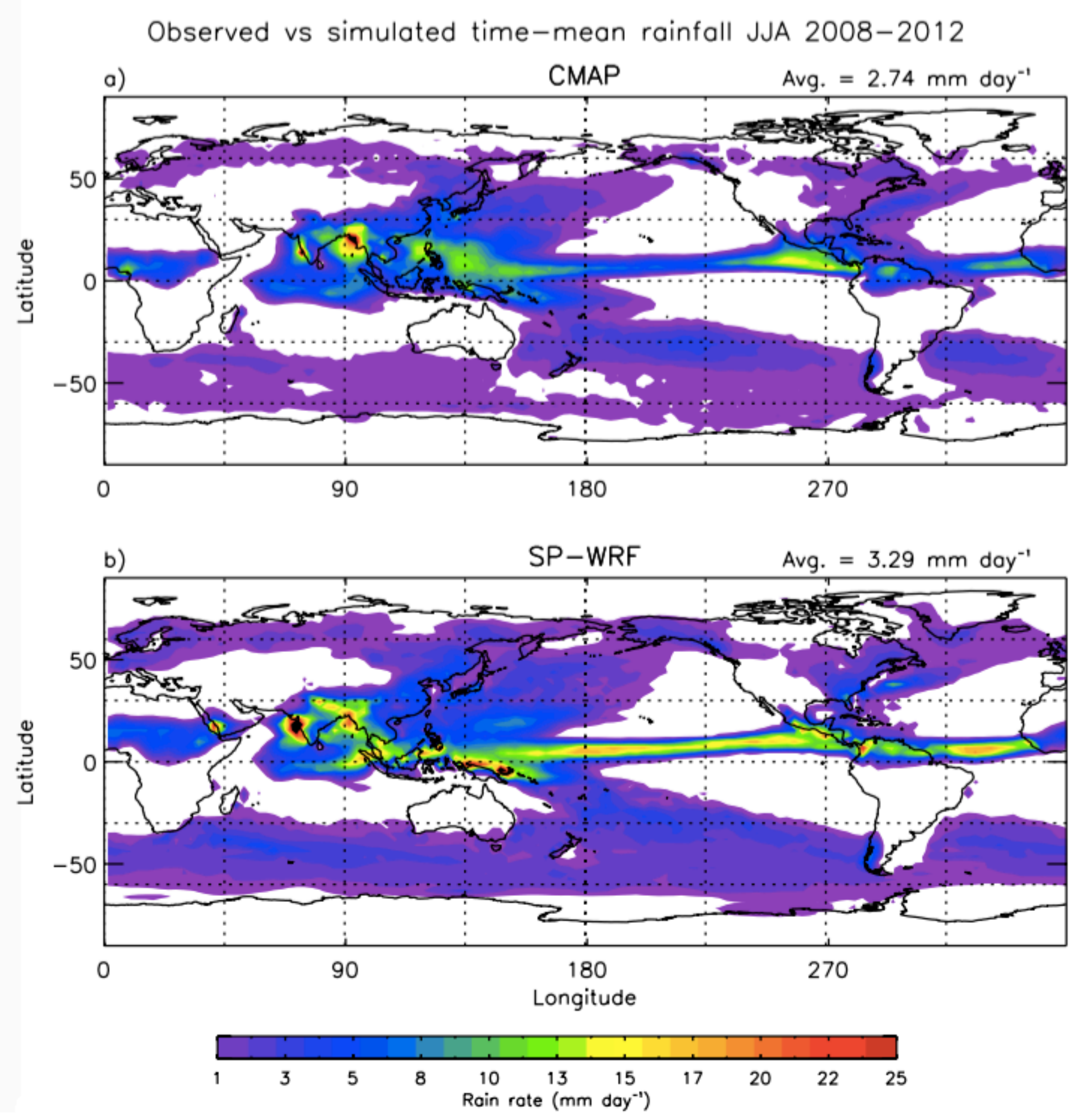
See Tulich (2015; JAMES) for further details

Some simulations of seasonal (JJA) climate

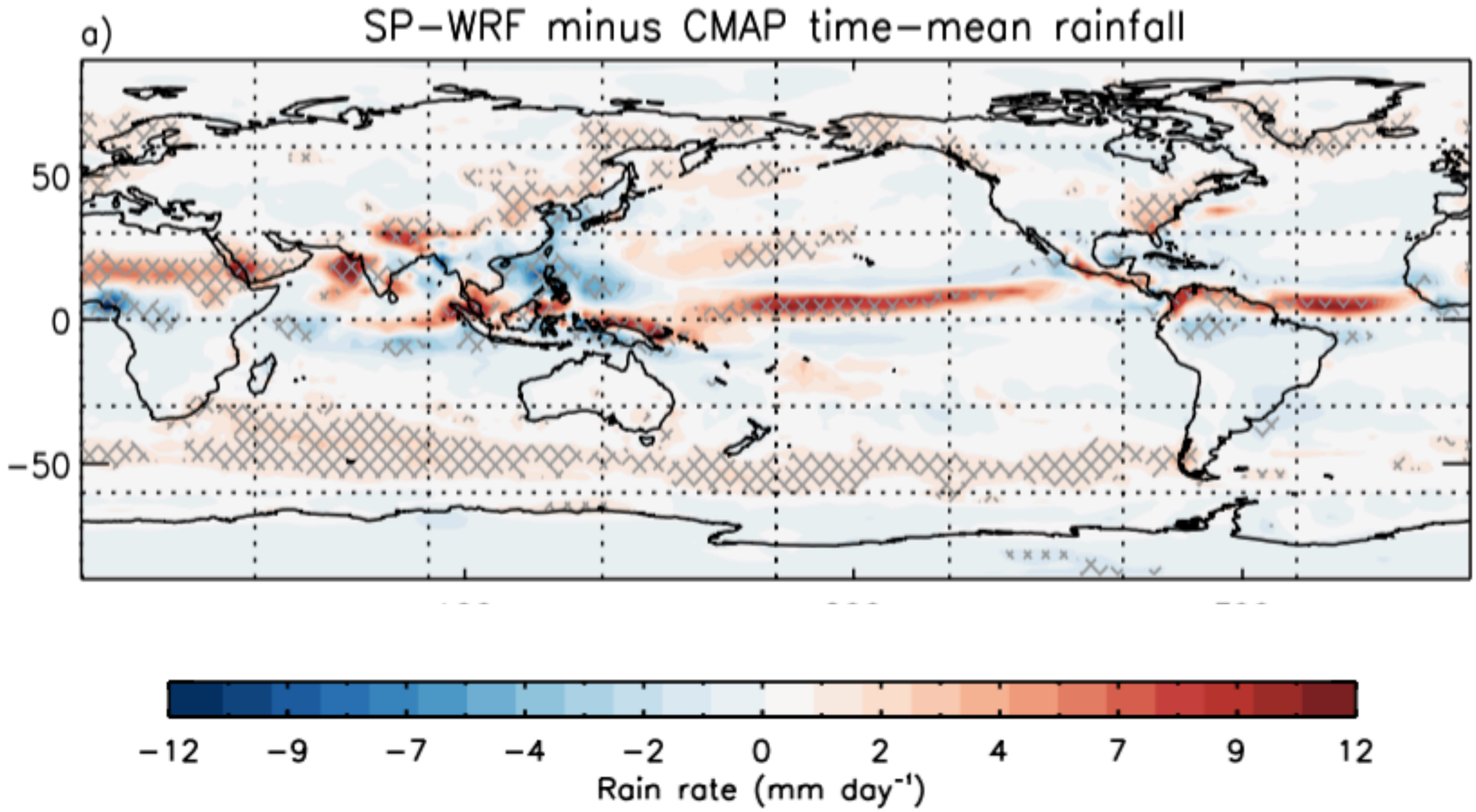
Model Setup:

- 2.8 x 2.8 deg. global; 32 x 4km CRMs (51 levels)
- CRMs oriented parallel to avg. low-level wind vector (as in Grabowski 2004)
- Goddard single-moment microphysics (Tao et al. 2002)
- Goddard SW and LW radiation (called every 20 mins at the CRM level)
- Turbulent mixing handled using 1.5 TKE scheme
- Surface fluxes handled using COARE3.0 (not available in standard WRF)
- Outer model nudged to ERA-Interim from May 29-31
- SSTs time-varying based on interim data
- Simulations performed for 5 JJA seasons (2008-2012)

Simulated rainfall looks quite different than all other existing SP atmosphere-only models

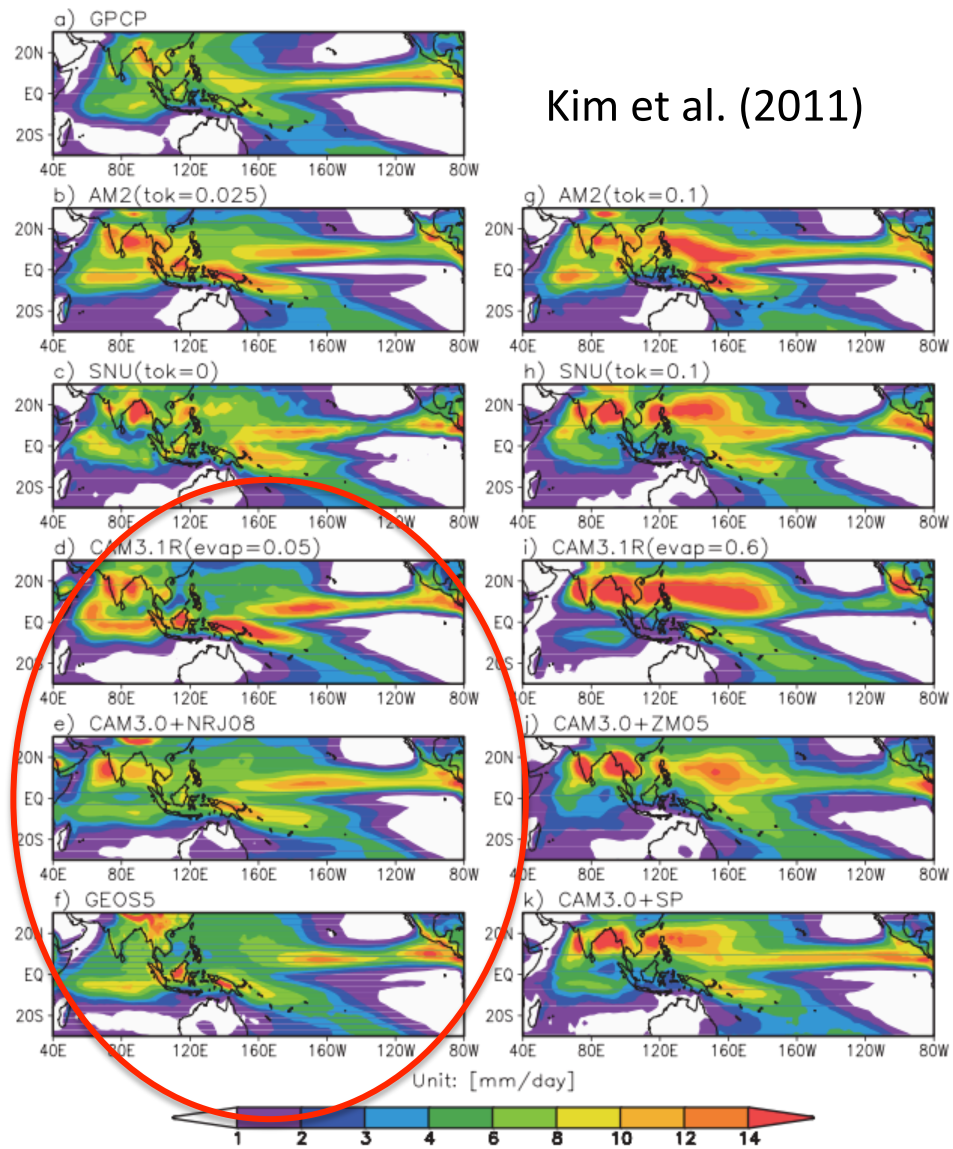


In terms of simulated-minus-observed differences: something like a "Great Blue Spot" (GBS)

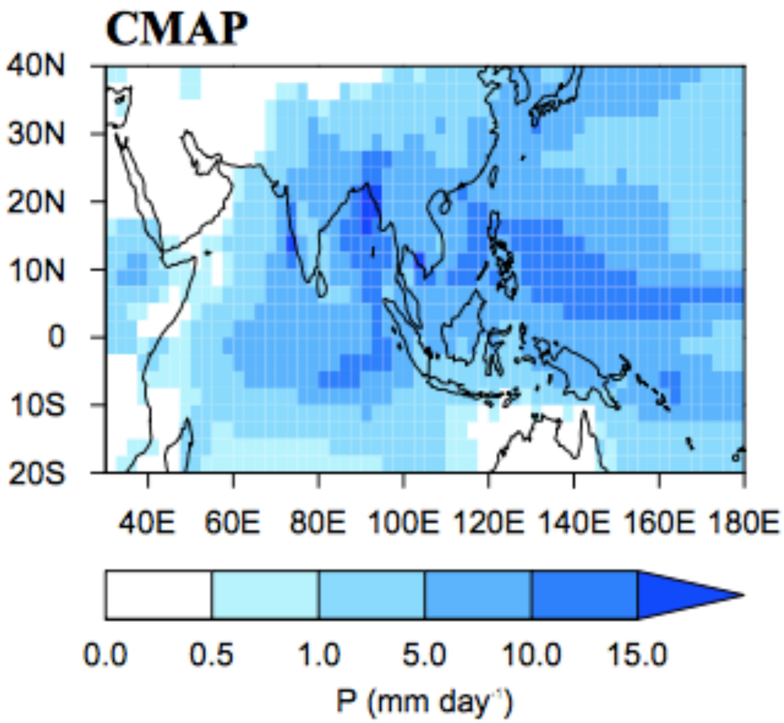


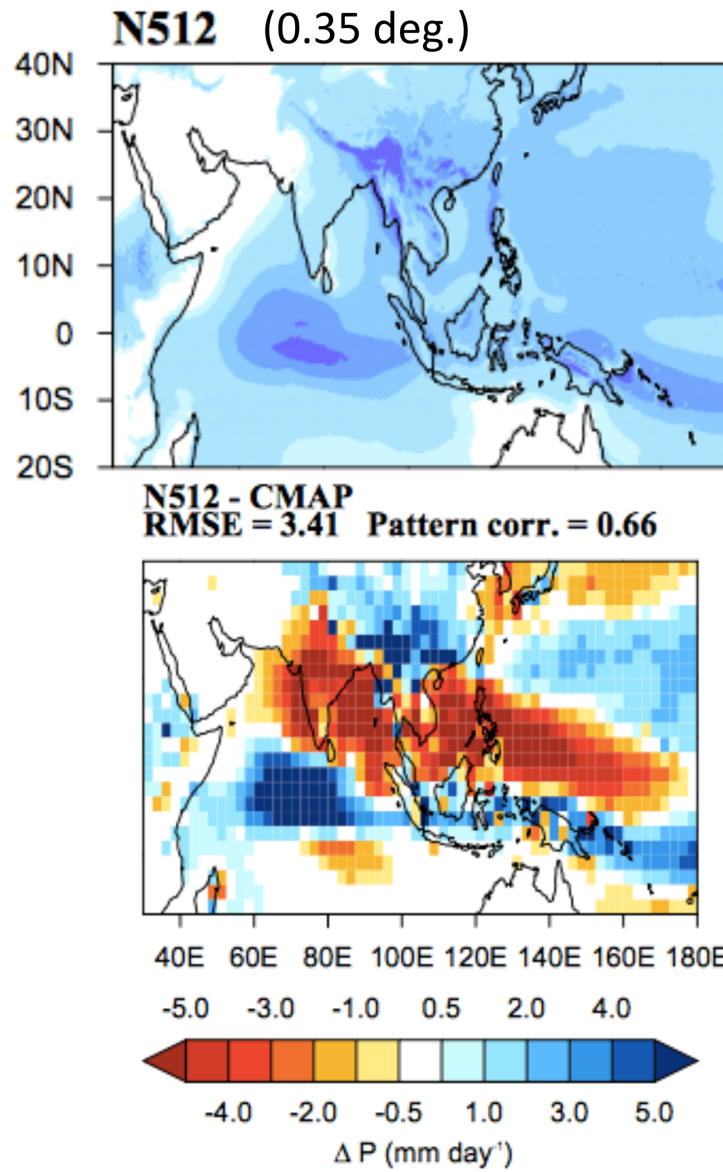
This alternate pattern of monsoon rain biases is not unprecedented

Kim et al. (2011)



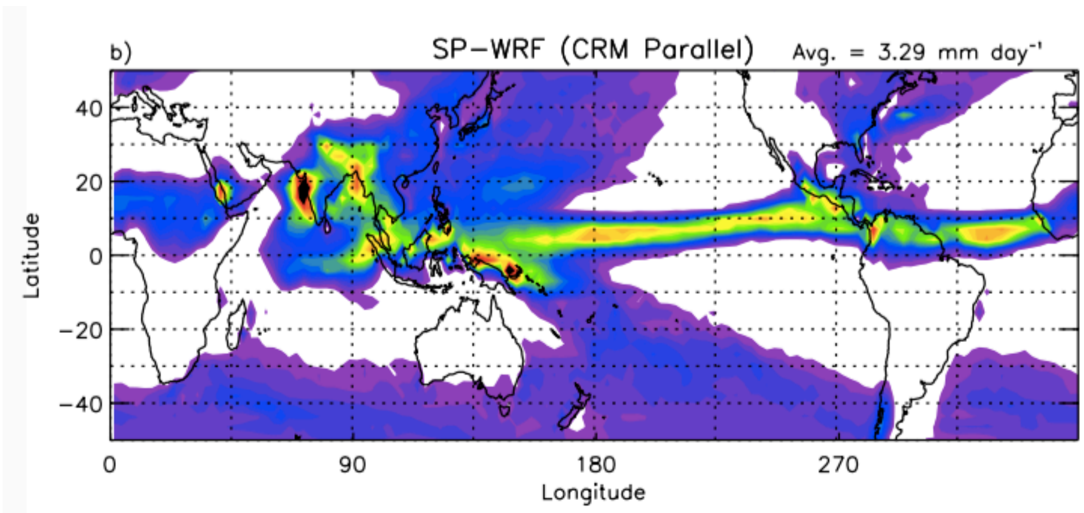
Similar bias pattern also seen at high resolution in the UK MetUM global atmosphere model



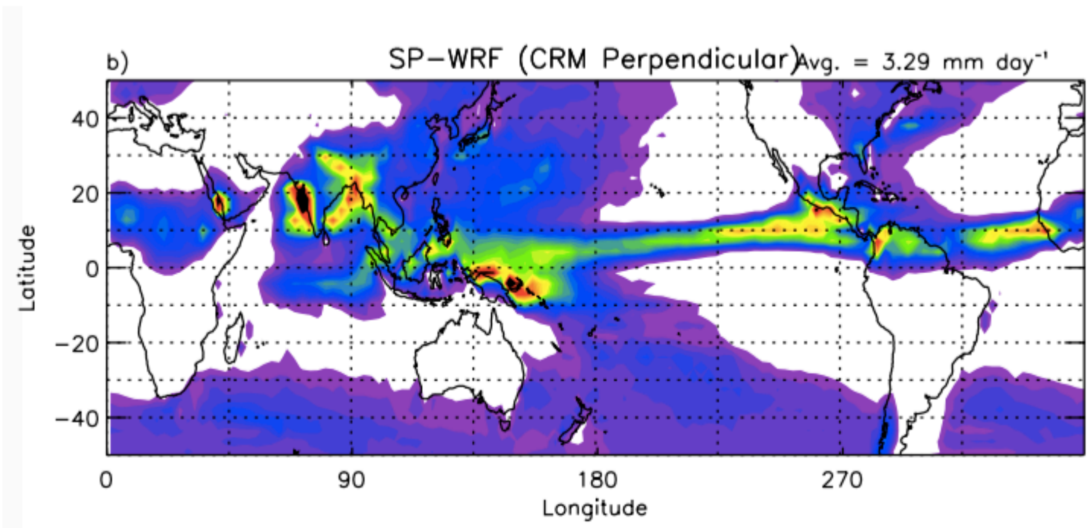


Johnson et al. (2015)

Additional SP-WRF runs show some improvement through a revised choice of CRM orientation

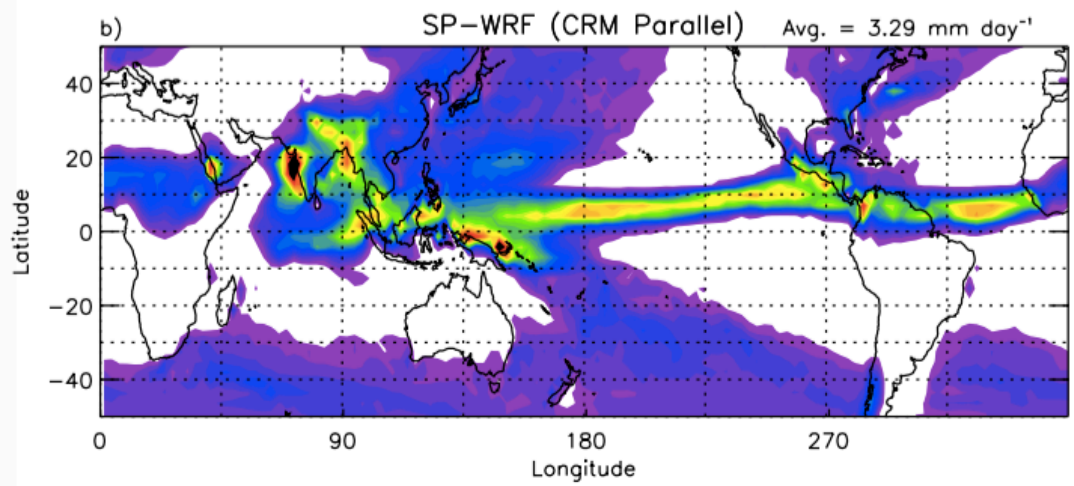


Control orientation:
CRM parallel to low-level wind vector

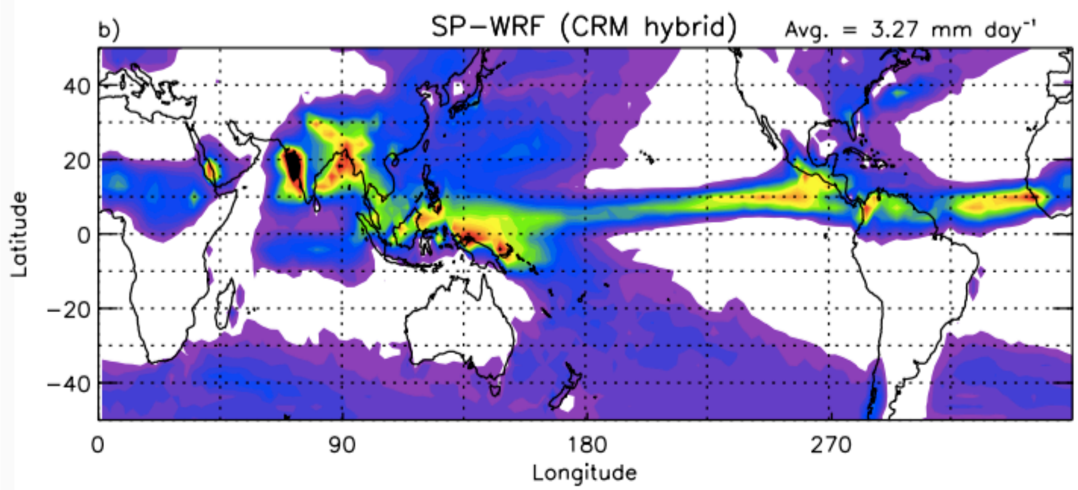


Revised orientation :
CRM perp. to low-level wind vector

Further improvement obtained using a hybrid CRM orientation strategy



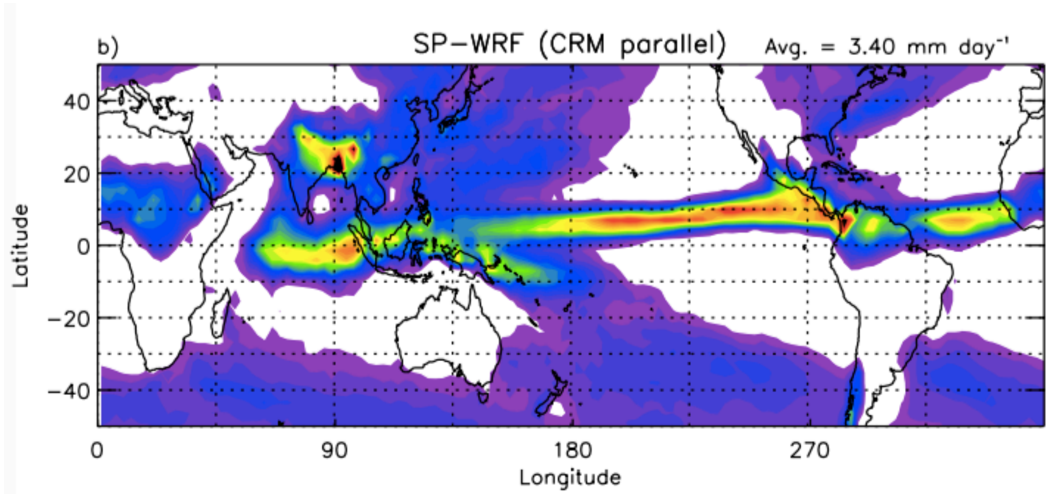
Control orientation:
CRM parallel to low-level wind vector



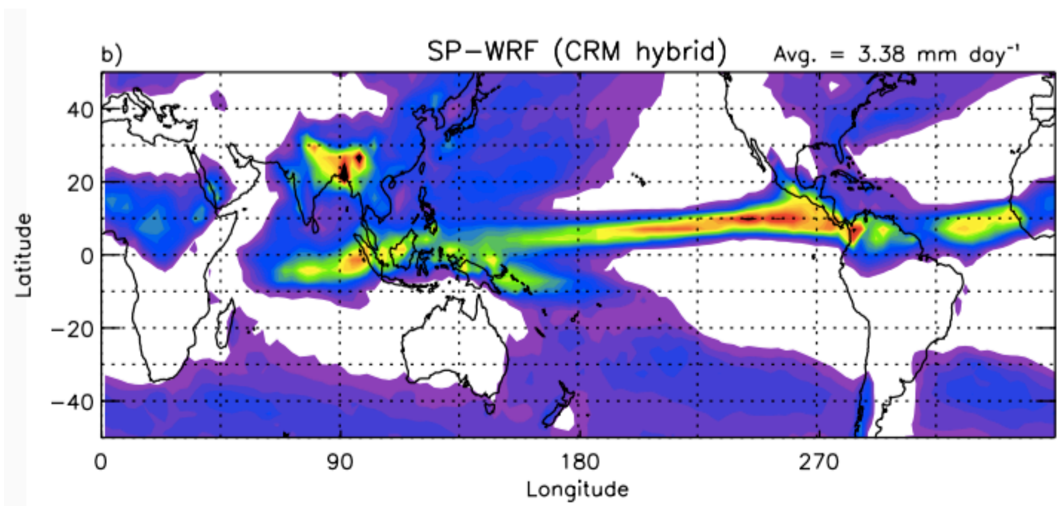
Hybrid strategy:
CRM parallel in regions of strong moist convection; perpendicular otherwise

However, substantial degradation is generally seen as global model resolution is increased!

1.4 x 1.4 deg. global; 16 x 4 km CRMs



Control:
CRM parallel to low-level wind vector



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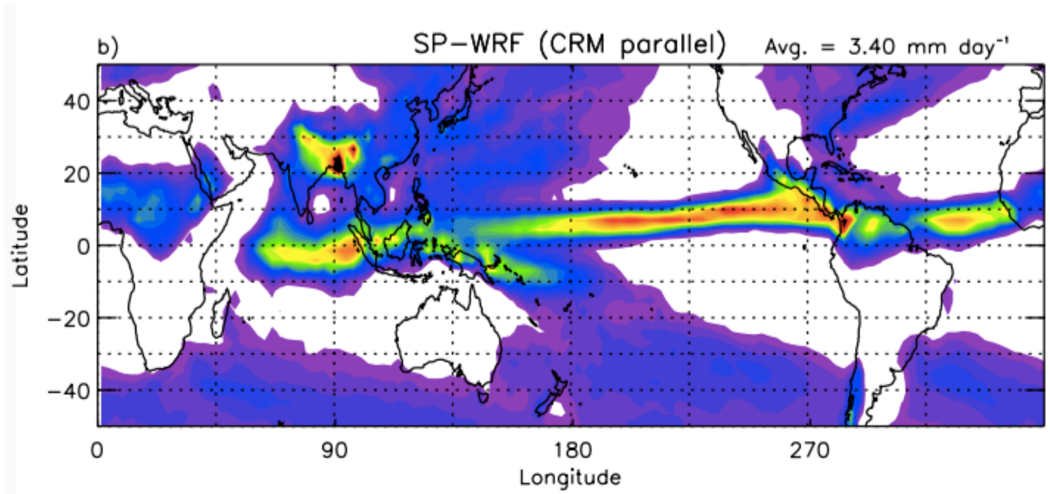

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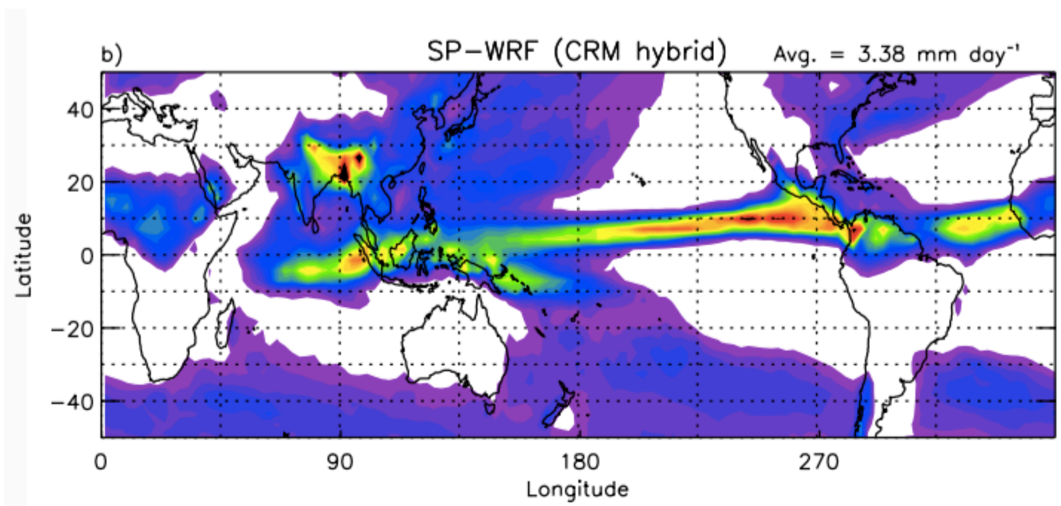

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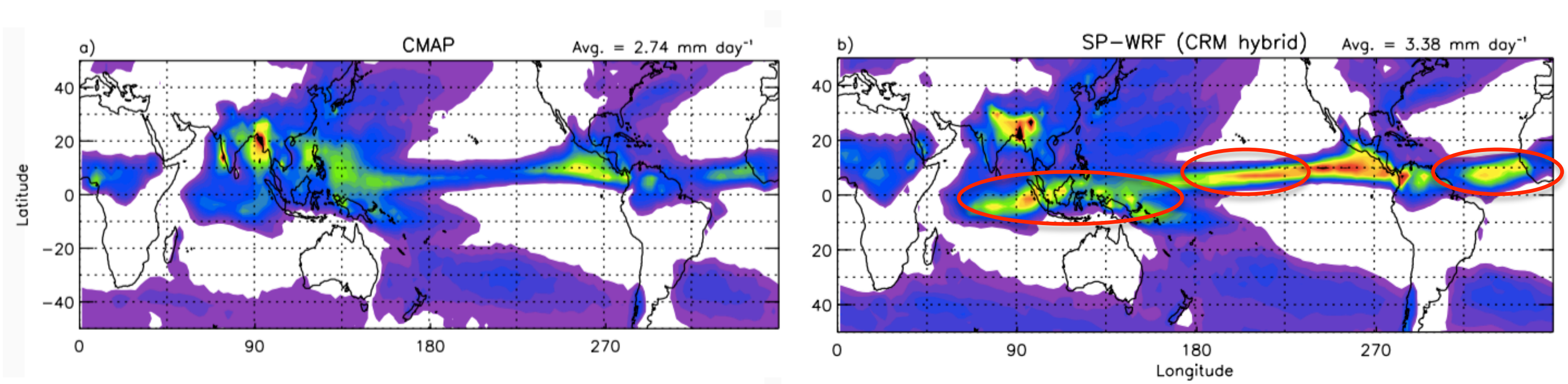
Divergence damping as a possible tonic?

Rationale:

Simulated convection appears to be too strongly coupled to divergent circulations forced by the lower boundary condition (e.g., diurnal gravity waves near Mar. Cont. etc., ITCZs near regions of strong SST gradients)



Divergence damping implementation

$$\frac{\partial u}{\partial t} = \cdots - \frac{1}{a\cos\phi}\frac{\partial}{\partial\lambda}\left(\nu_4 \nabla^2 D\right)$$

$$\frac{\partial v}{\partial t} = \cdots - \frac{1}{a}\frac{\partial}{\partial\phi}\left(\nu_4 \nabla^2 D\right)$$

$$\frac{\partial D}{\partial t} = \cdots - \nu_4 \nabla^4 D$$

$$\nu_4 = C_4 \frac{a^4 \cos^2\phi\, (\Delta\lambda)^2\, (\Delta\phi)^2}{\Delta t}$$

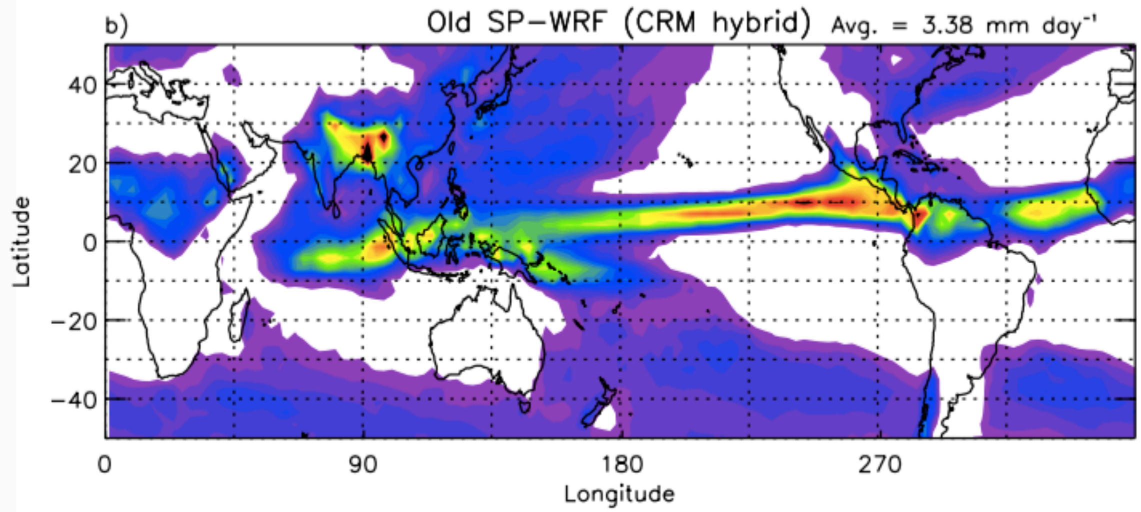
Here, choose $C_4 = 0.015$

Model setup for divergence damping sensitivity tests

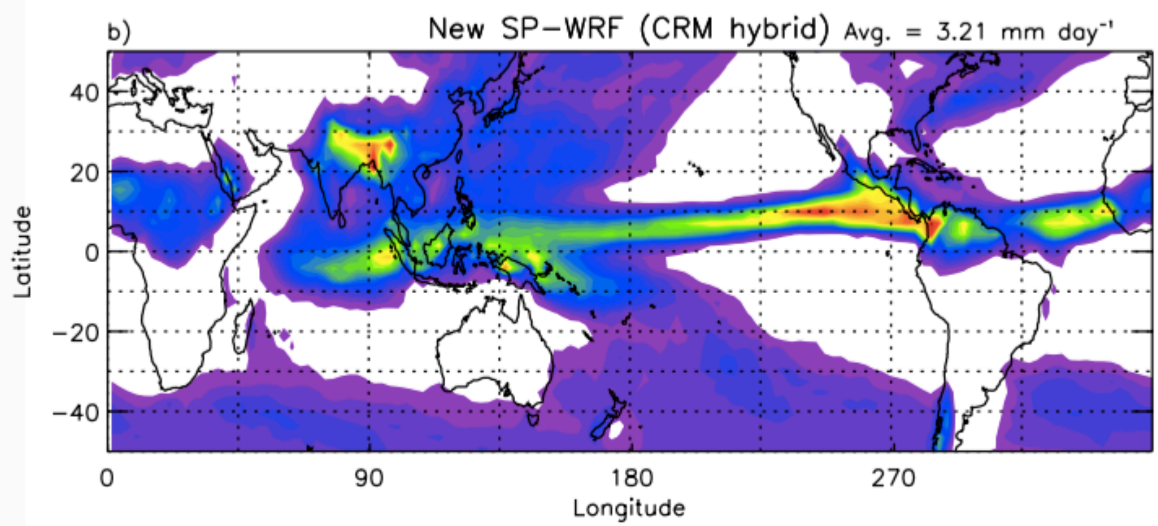
- 1.4 x 1.4 deg. global; 16 x 4km CRMs (51 levels)
- CRMs oriented using hybrid strategy
- Moist cond. is advected by the large-scale flow (as in SP-CAM)
- Revised treatment of surface wind gustiness in calculation of surface fluxes
- Same microphysics, radiation, etc.

Comparison of old vs new model runs without divergence damping

Old



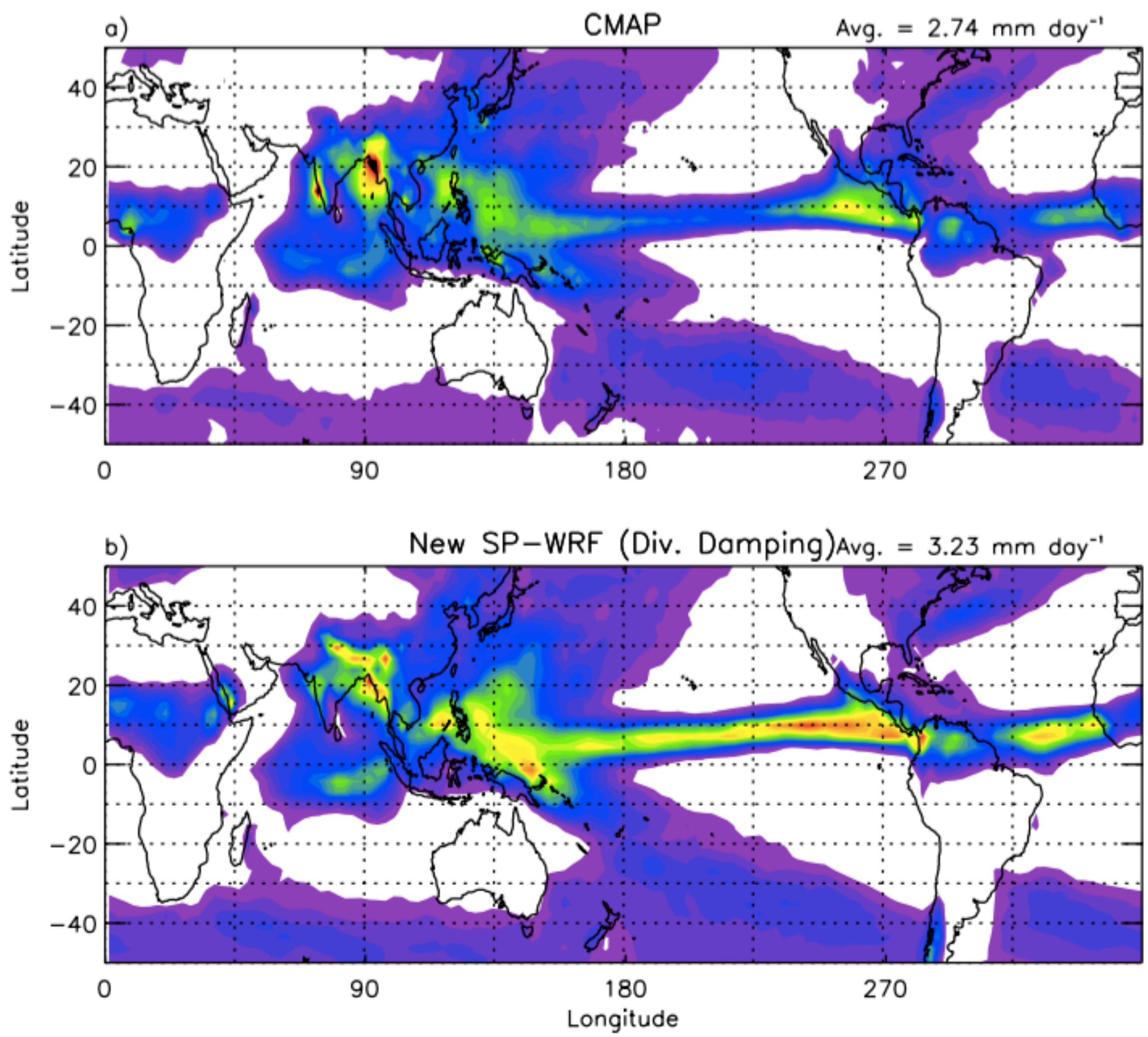
New



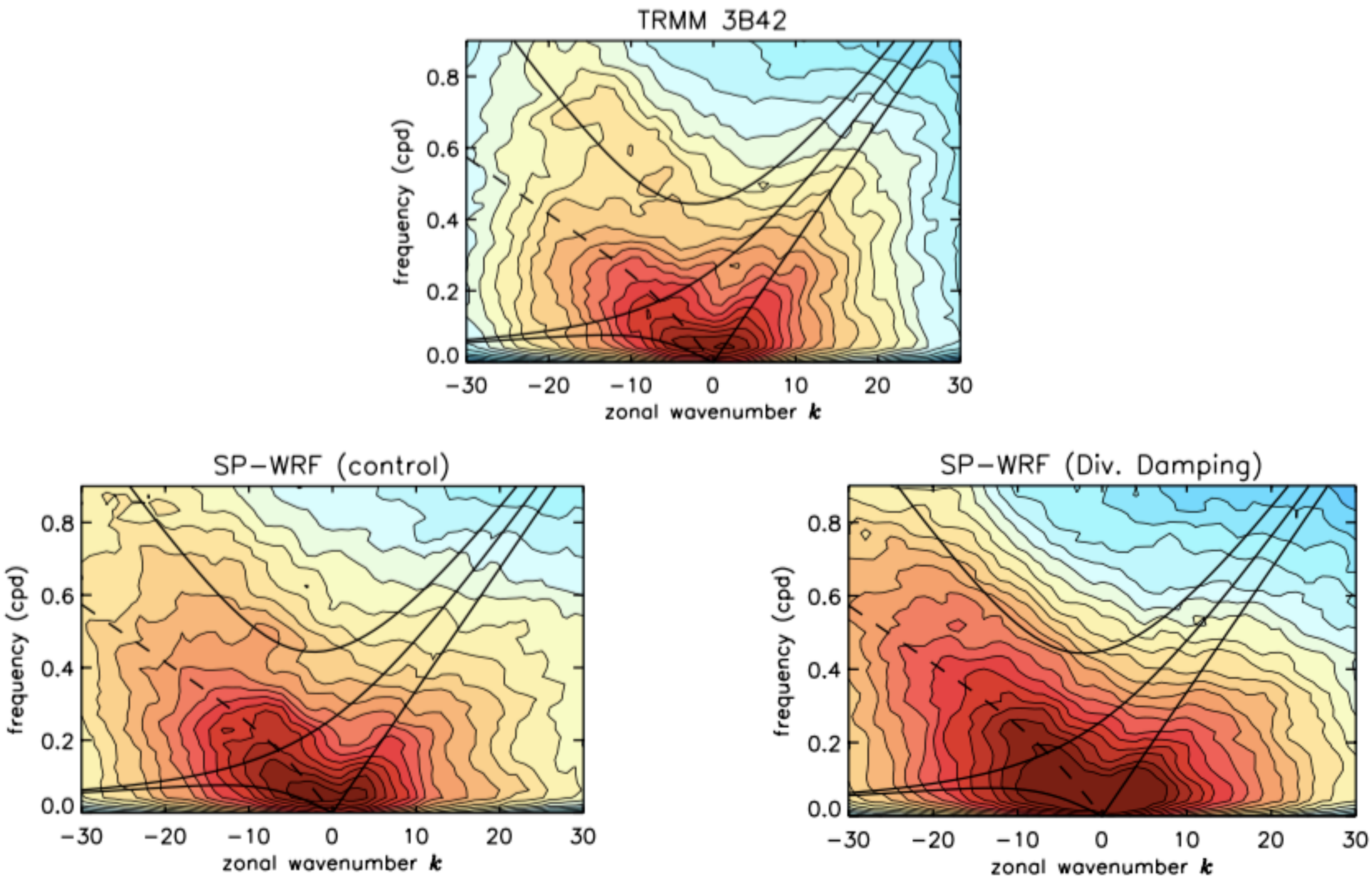
Inclusion of divergence damping leads to generally dramatic improvements!

Obs.

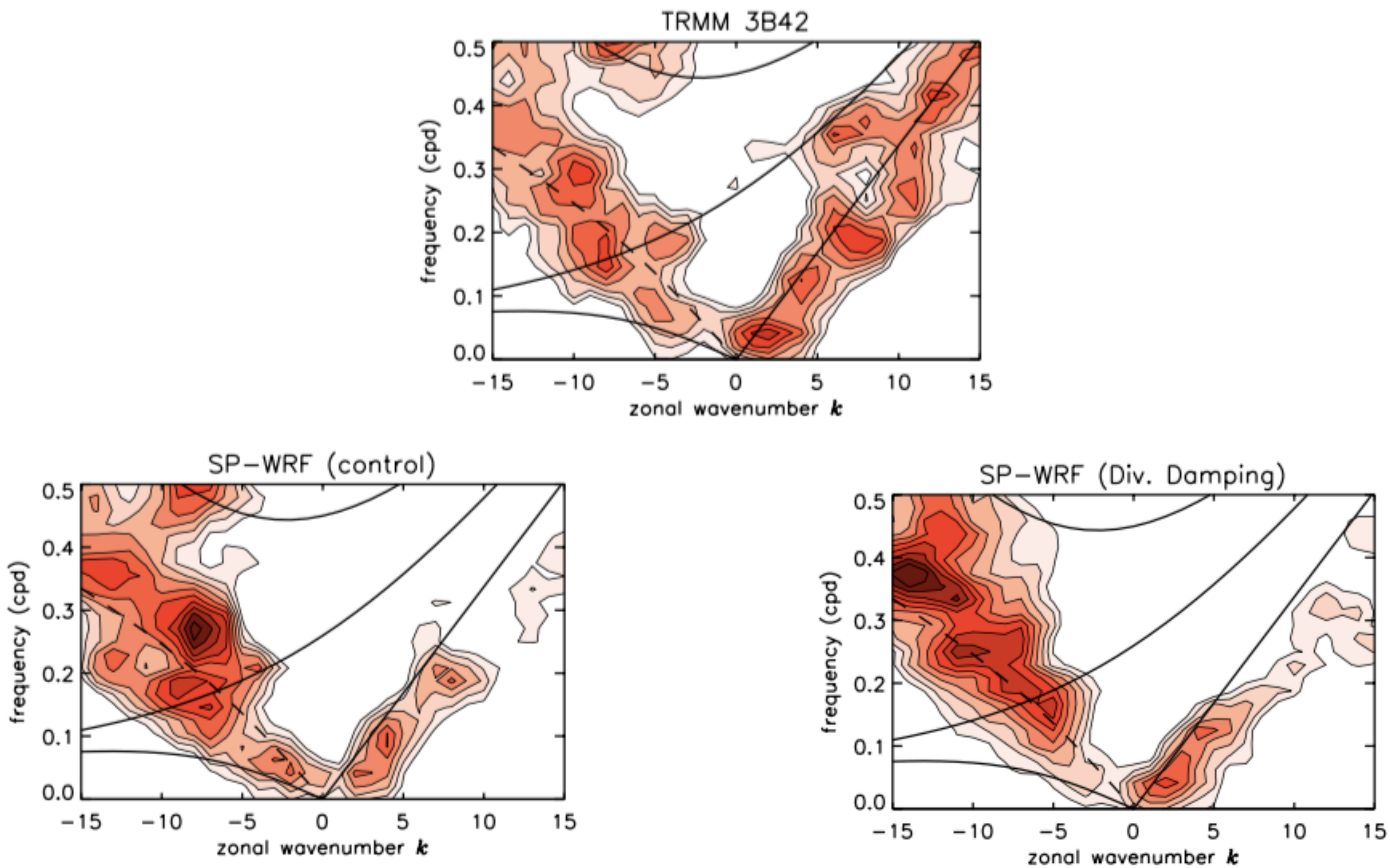
Model



The downside is that the simulated rain spectrum is generally degraded



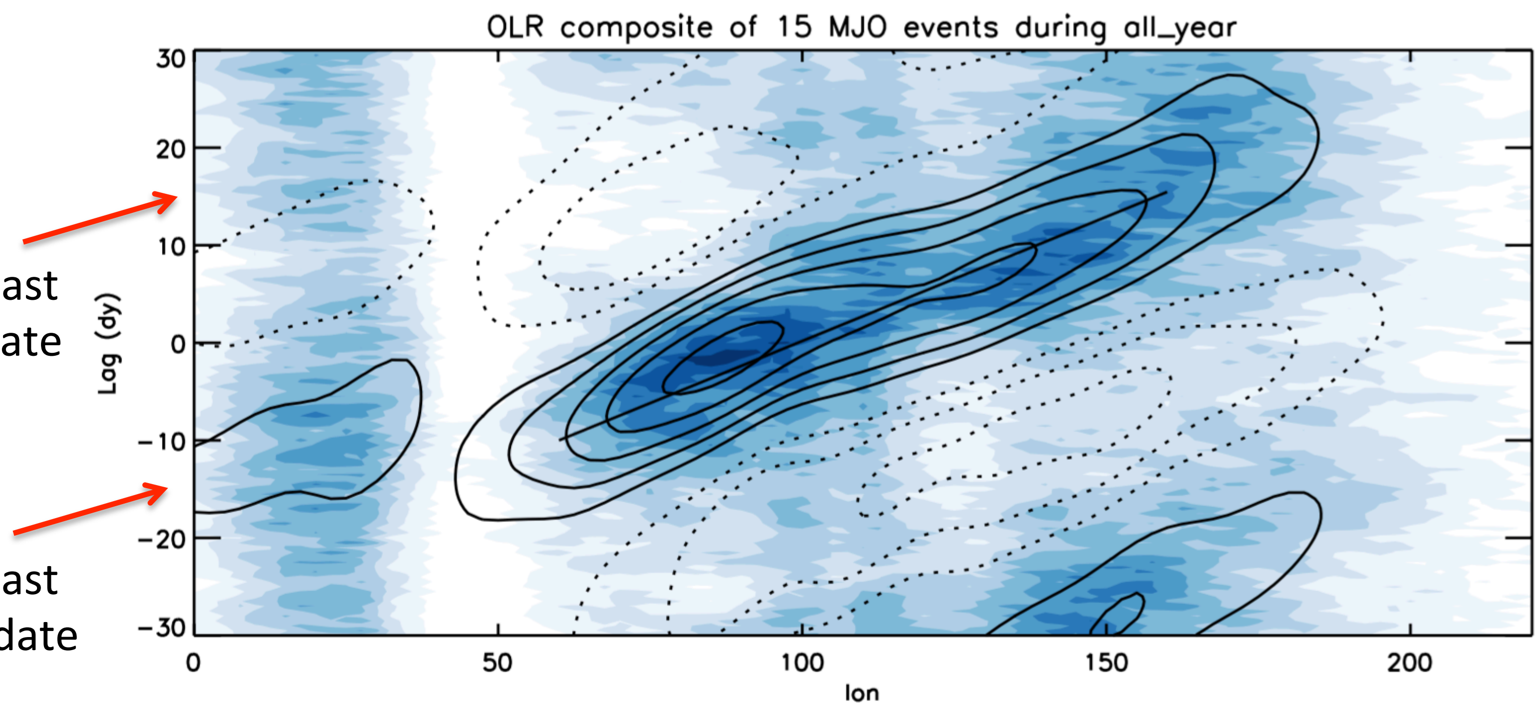
However, the signal to noise does show evidence of an improved MJO!



To further explore impacts on the MJO, performed an ensemble of MJO hindcasts

Hindcast end date

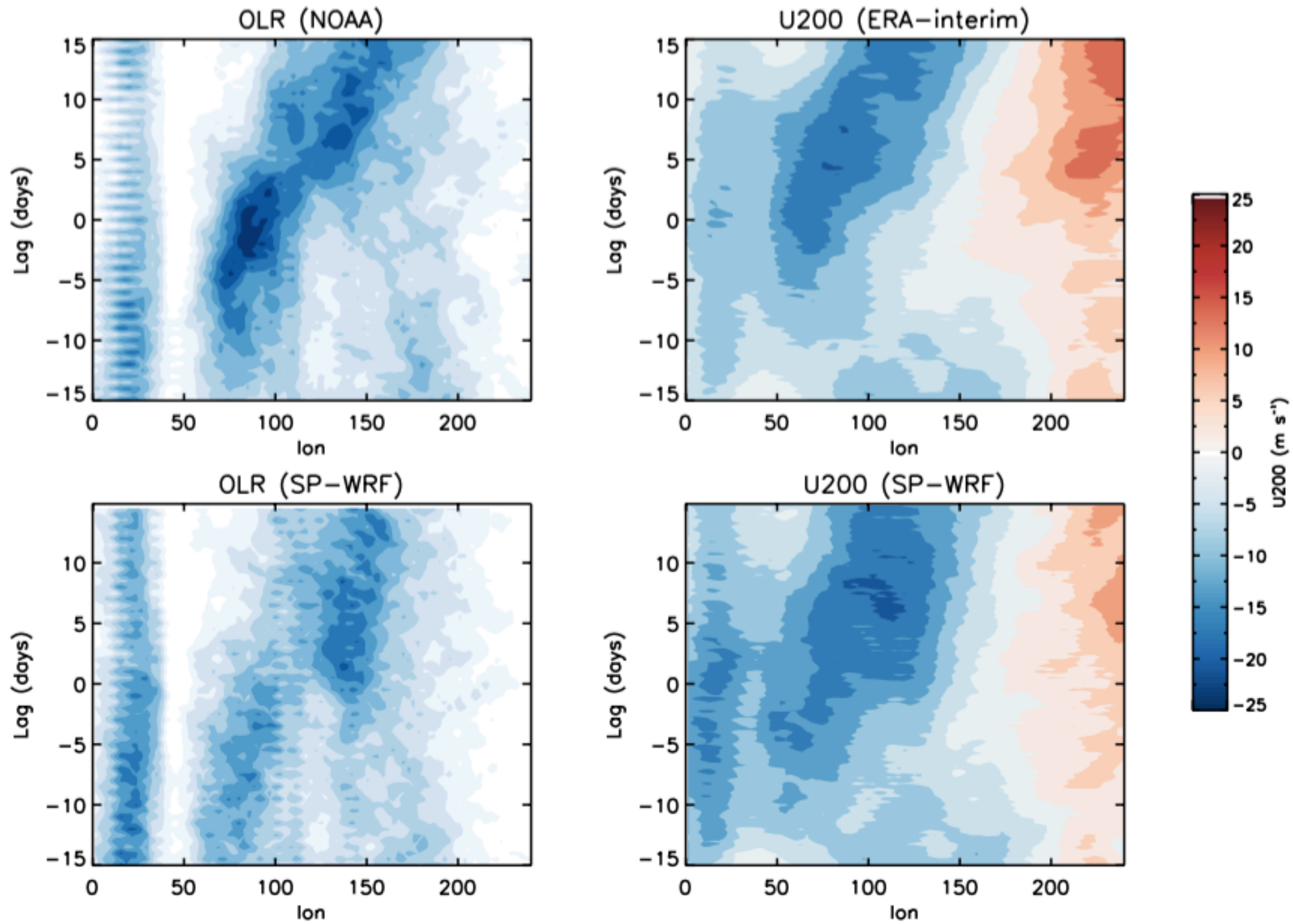
Hindcast start date



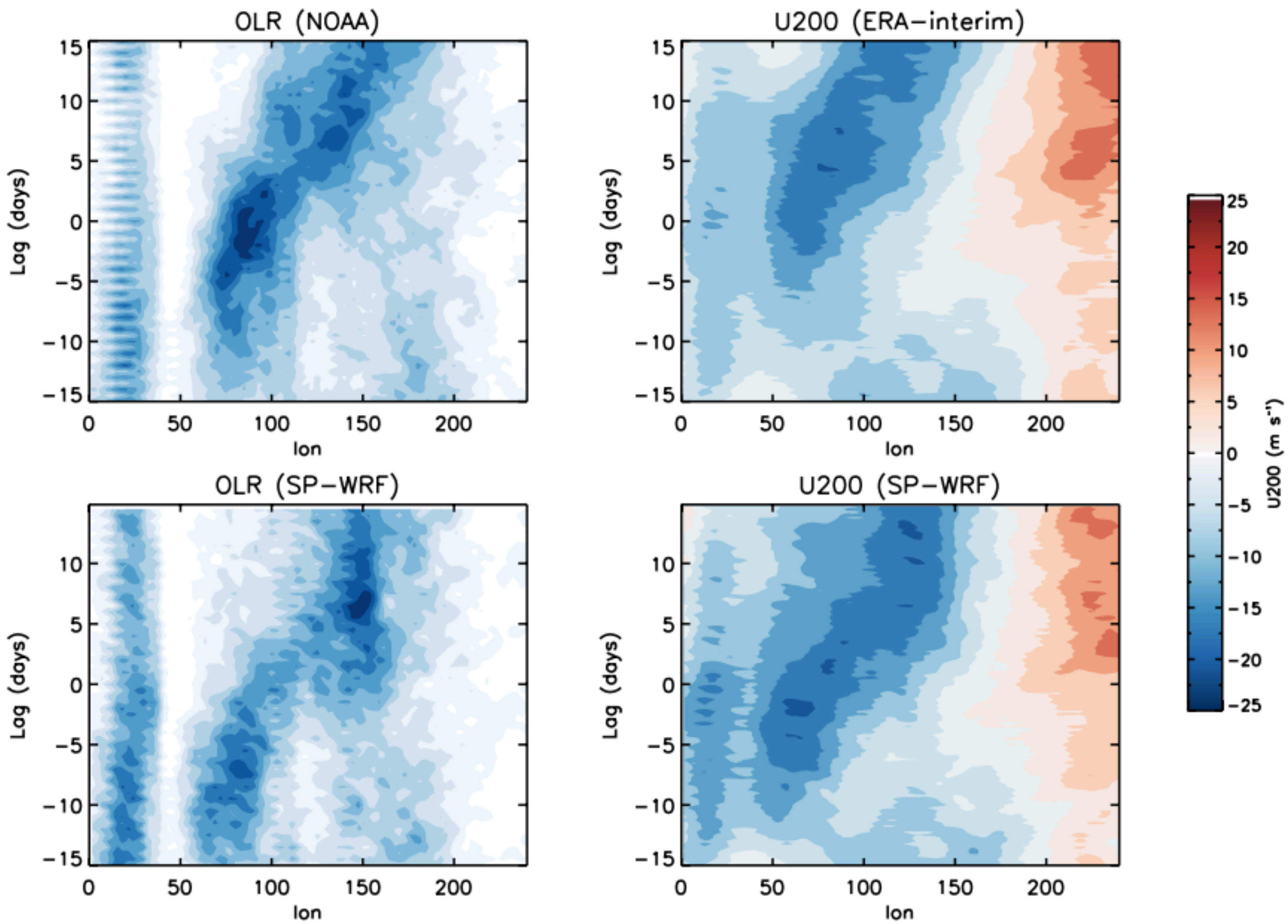
Experiment details:

- 1.4x1.4 deg. global (16 x 4 km CRMs)
- Initialized from ERAI (nudging for 5 days)
- Time-varying SSTs

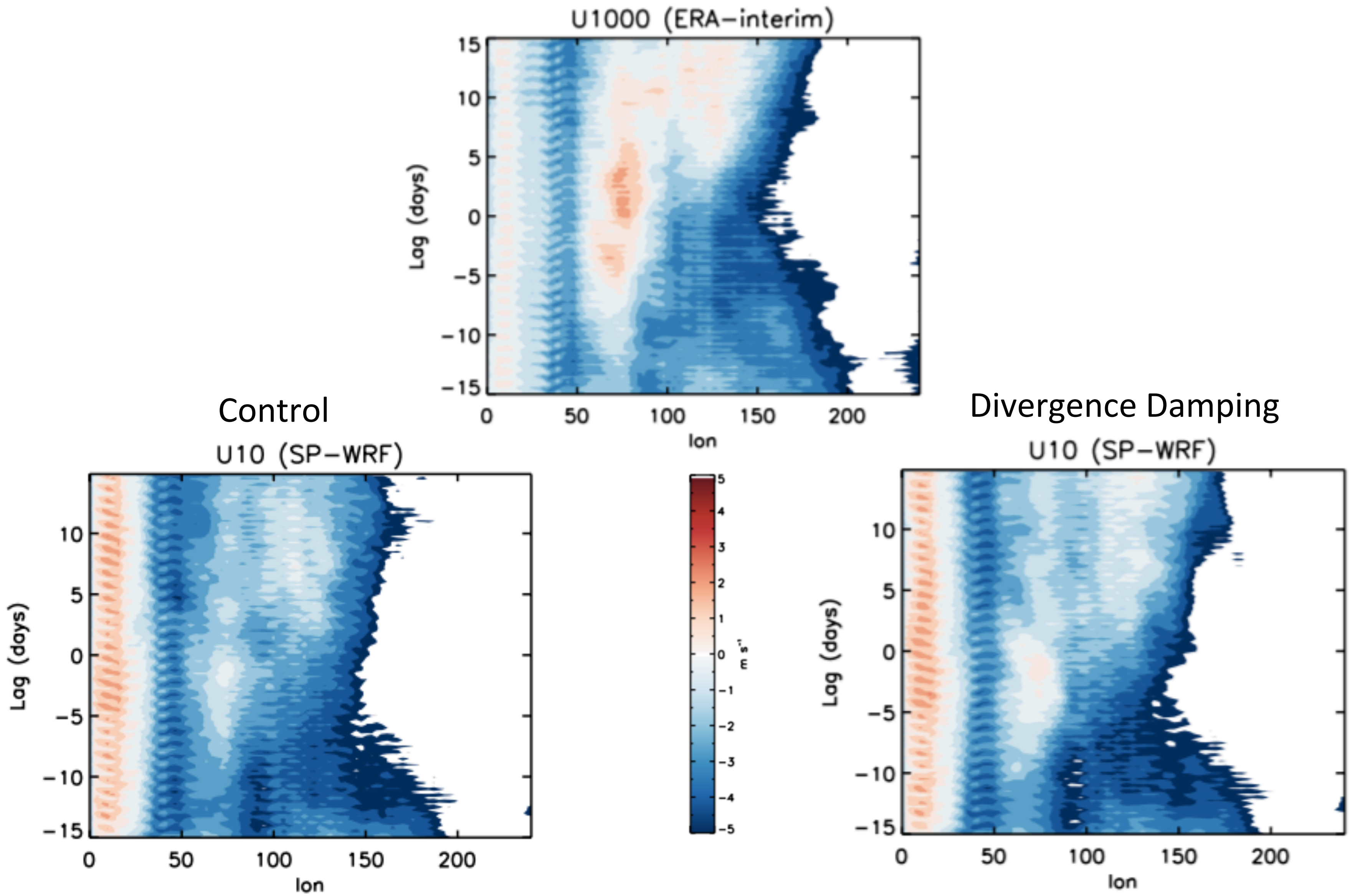
Ensemble averaged results without divergence damping



Addition of divergence damping increases the amplitude and coherence of the disturbance



Strengthening of near surface westerlies also apparent



Conclusions and implications

- Divergence damping provides an interesting "knob" in the SP-WRF
- Results of turning this knob indicate that:
  - Pattern of mean rain depends on time-varying behavior of convection
  - MJO "lives" more on the slow (rotational) manifold as opposed to the fast (divergent) manifold
- May need to reconsider previous MJO modeling work using conventional GCMS – does MJO simulation improve because of greater sensitivity to moisture or because convection is shifted more onto the slower (rotational) manifold?