CRM simulations with parameterized large-scale dynamics using time-dependent forcings from observations

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In tropical studies it is common to run cloud-resolving models (or single-column models) with prescribed "large-scale forcing" – incl. domain-averaged vertical motion.

The specification of vertical motion tightly constrains the deep convection, almost independently of model physics, because the dominant balance in the heat equation is (all quantities being horizontal means)

$$wS \sim Q$$

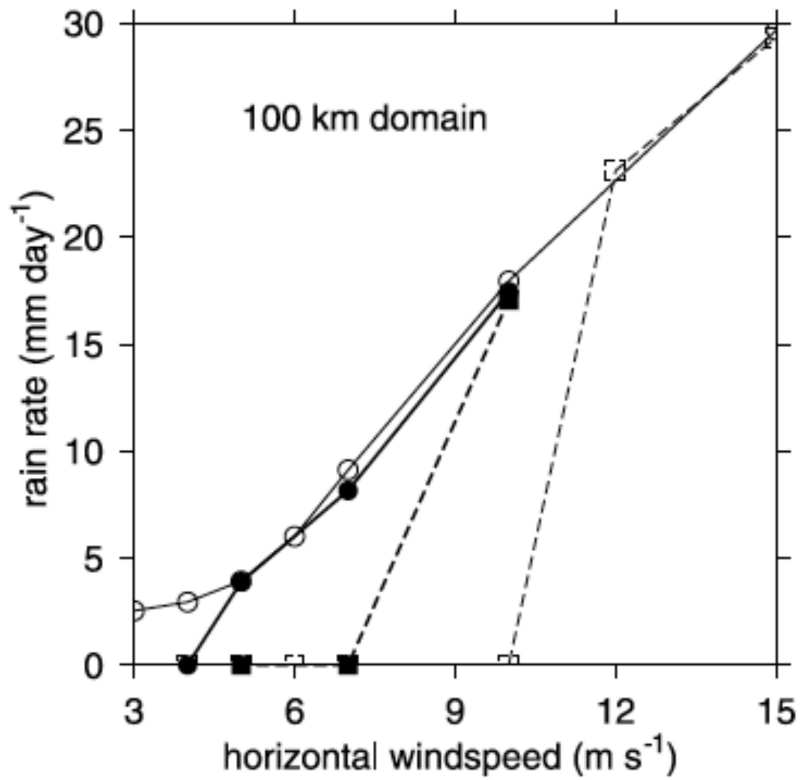
(with w large-scale vertical motion, S stratification of potential temperature/dry static energy, Q convective heating).

With this formulation, one cannot use the model to ask what controls the variability of deep convection, either in observations or in the model.

With “parameterizations of large-scale dynamics”, the model itself can determine the occurrence and intensity of deep convection.

The large-scale motion is determined interactively using feedbacks that we believe have some resemblance to those which a small tropical region experiences when interacting with a global atmosphere.

Parameterizations of large-scale dynamics have been used almost exclusively for idealized calculations



Steady precipitation as function of horizontal wind speed under WTG, Sessions et al. (2010)

Here we extend these approaches to the simulation of time-dependent cases from observations.

The reference temperature profile is taken from the obs, and allowed to be time-dependent. Other forcings are also from obs, esp. surface wind speed.

We use both WTG (e.g., Sobel and Bretherton 2000, Raymond and Zeng 2005)

$wS = T'/\tau$

and the damped wave method of Blossey et al. (2009) (low-freq. limit of Kuang (2008))

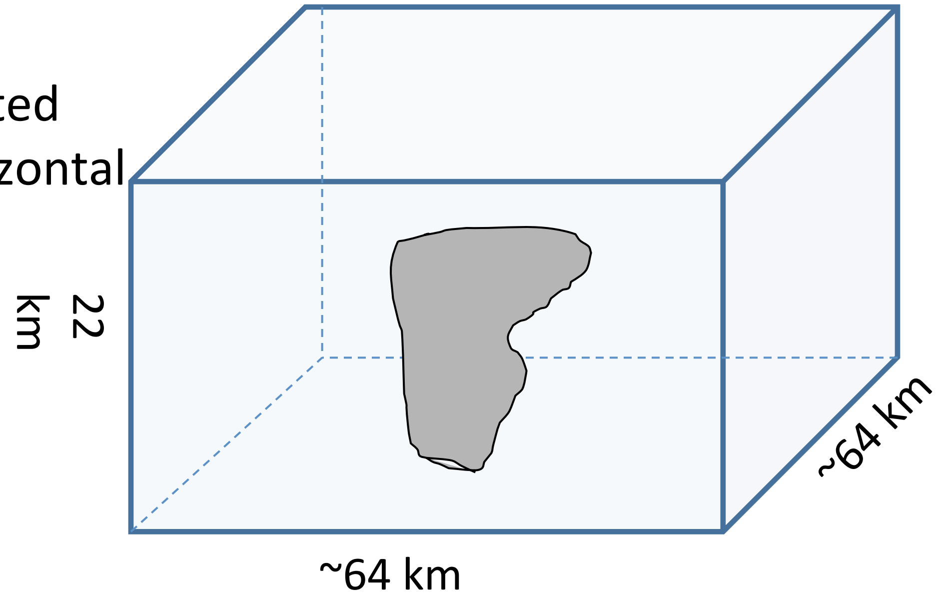
$$\frac{\partial}{\partial p}\left(\frac{f^2 + a_m^2}{a_m}\frac{\partial \omega'}{\partial p}\right) \approx \frac{k^2 R_d}{p} T_v'$$

Here f=0

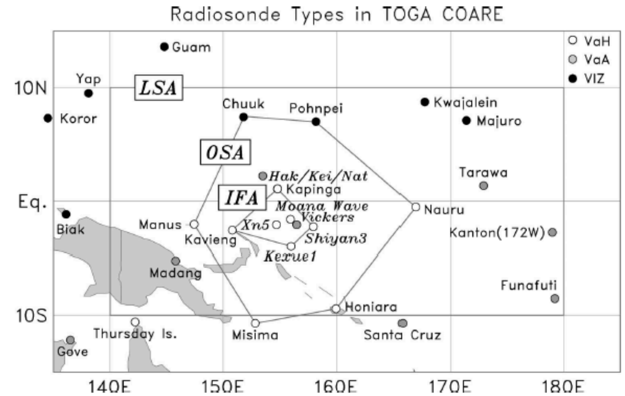
We choose TOGA COARE – it's well studied using traditional methods, and we are interested in the MJO…

CRM details

- WRF model V3.3
- Microphysics: Lin et al. (cloud water, cloud ice, rain, snow, graupel)
- First order closure for horizontal subgrid turbulence
- YSU PBL for vertical eddies
- Monin-Obukhov similarity theory for surface fluxes
- CAM radiation for imposed-w (and use resulting time series for wave-coupling integrations)
- Equatorial plane, f=0,
- Δx = 4 km, 64x64x22 km^2
- SST imposed
- Horizontal advection neglected
- Relax domain-averaged horizontal wind to obs at 1 hour



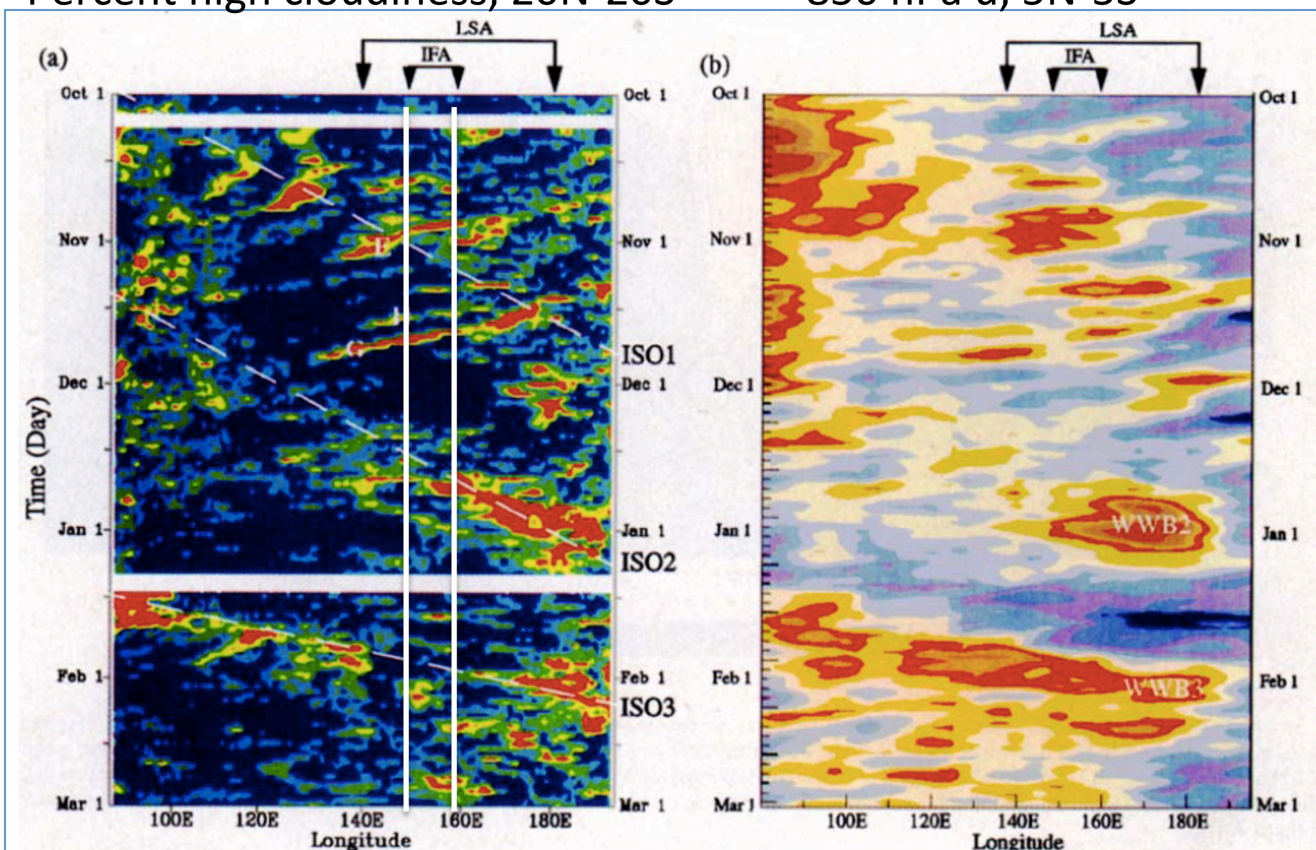
We carry out integrations for 4 month Period during TOGA COARE, in West Pac



Ciesielski et al. (2003)

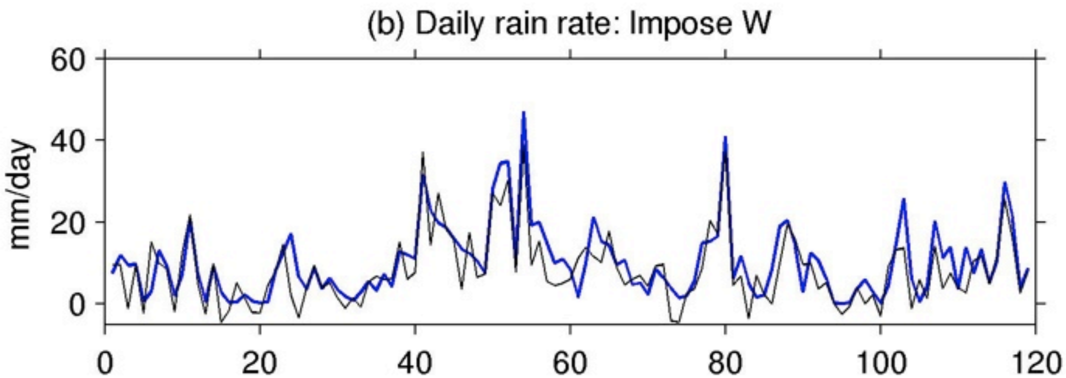
Percent high cloudiness, 20N-20S   850 hPa u, 5N-5S

Our integrations
Nov 1 – Feb 28



Chen, Houze and Mapes (1996)

Traditional method: "large-scale forcing" (imposed w)
From sounding array, Ciesielski et al. (2003)



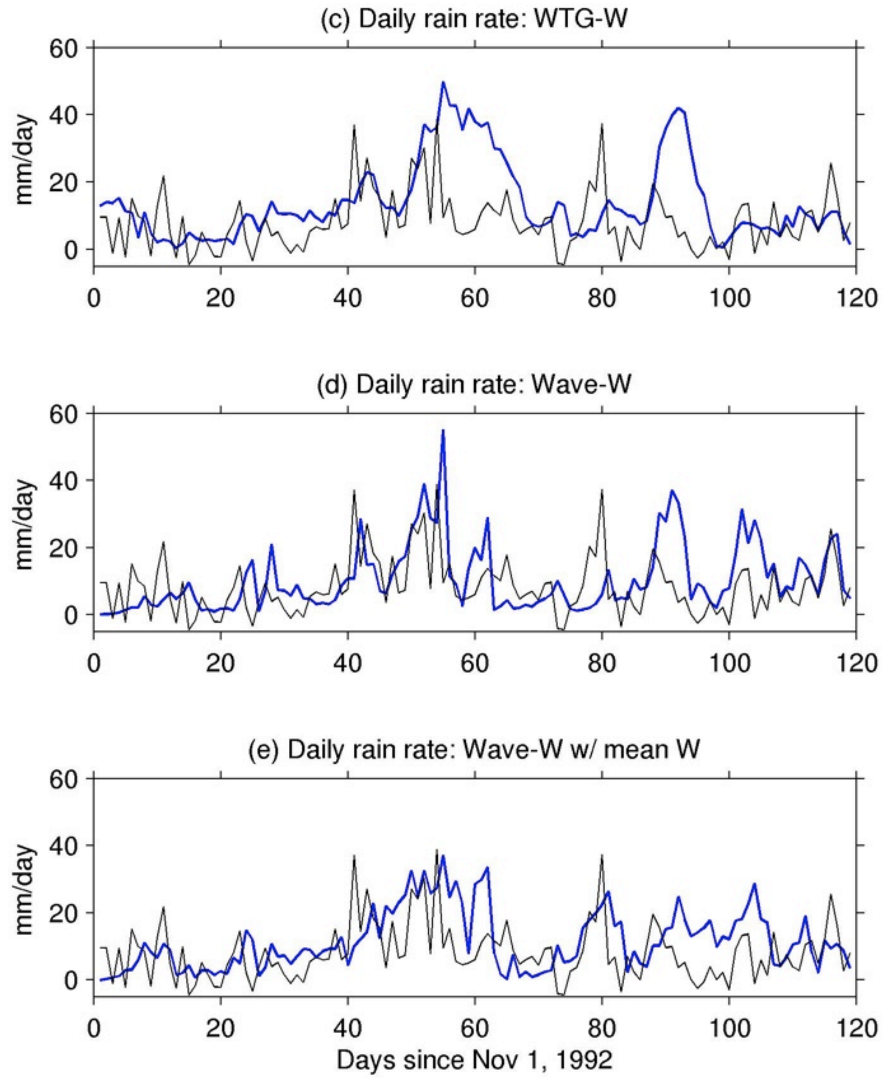
Black: "observed" IFA-mean rainfall (from budget, can be negative)
Blue: CRM simulation

Parameterized large-scale dynamics works! (at least somewhat)

WTG

Wave coupling
(λ = 6000 km)

Wave coupling
plus imposed time
mean *w* from obs
(wave coupling uses
time-mean T only)



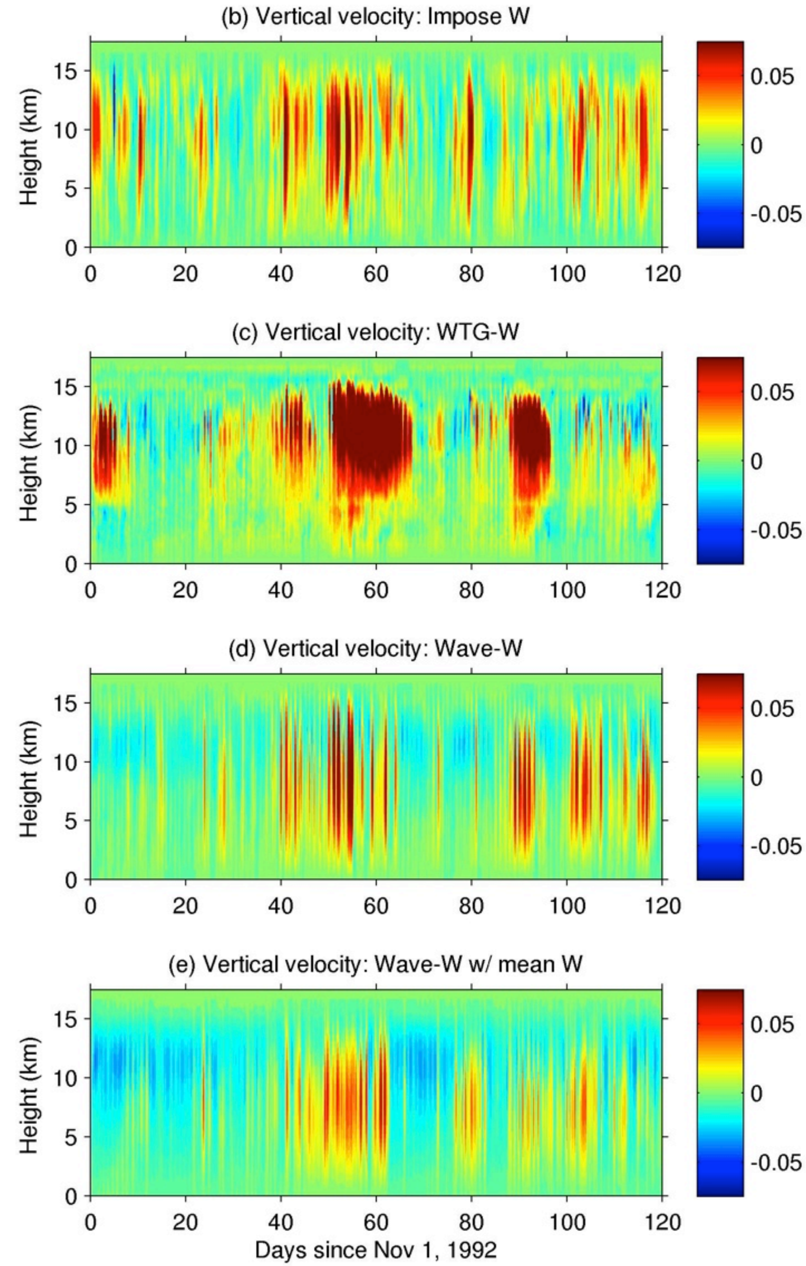
Vertical velocity vs. time and height

obs

WTG

wave

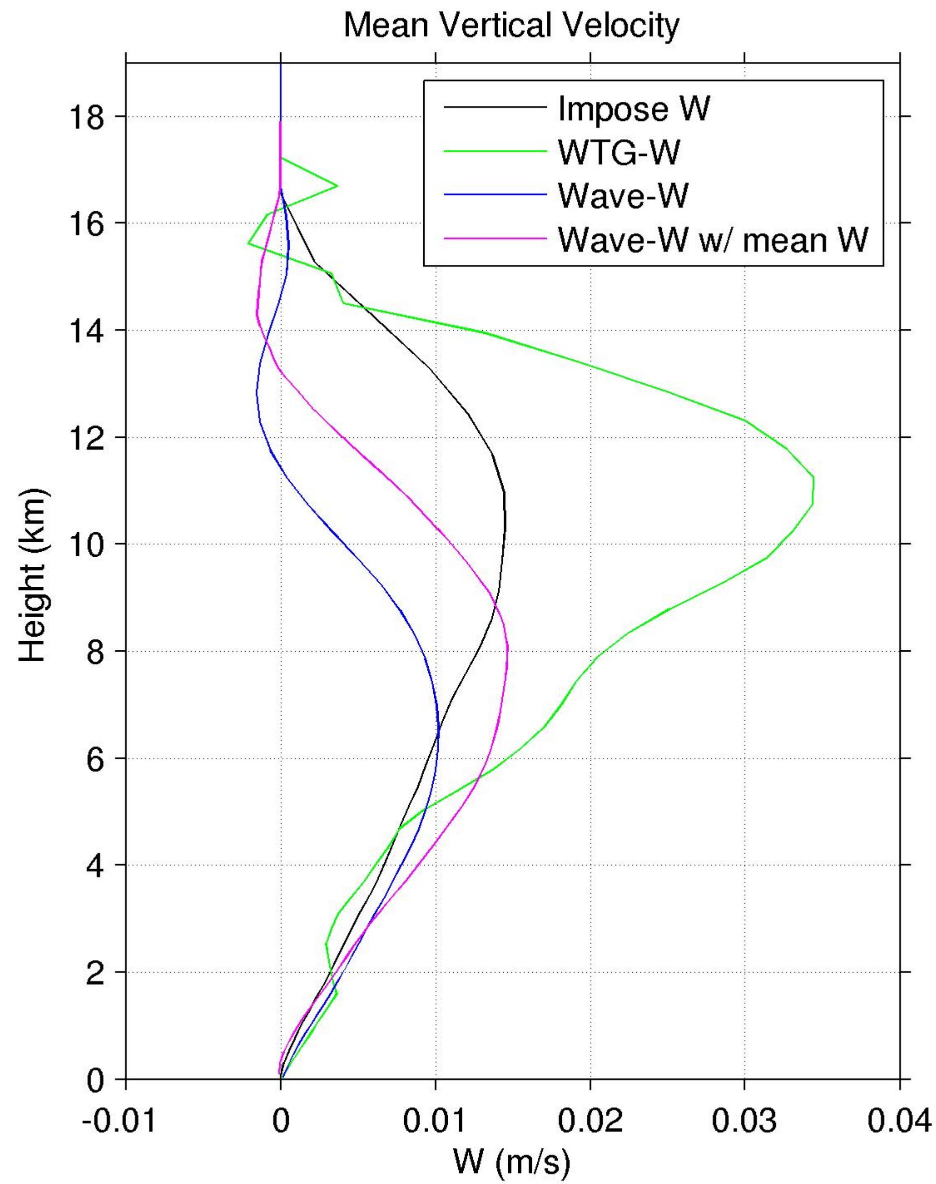
wave
+ mean



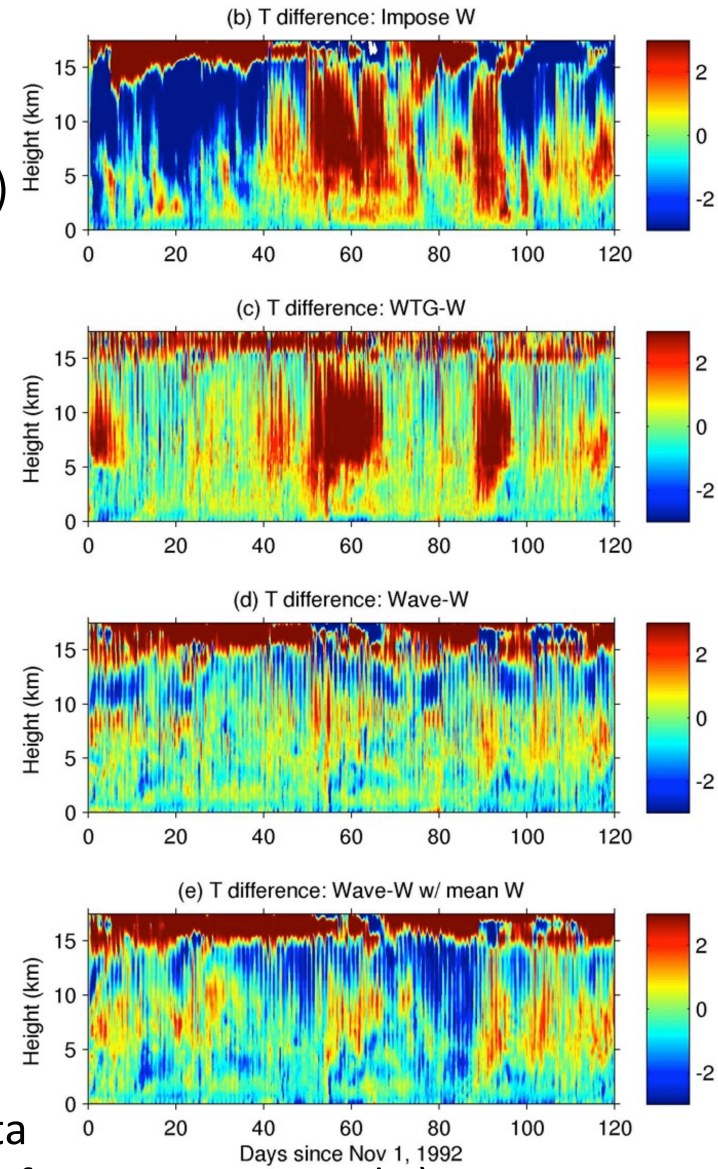
WTG is too top-heavy; this is a result of neglecting momentum entirely. Wave coupling on the other hand is not top-heavy enough.

WTG: $wS = T'/\tau$

Wave: $-w_{zz} \sim k^2 T'$



Theta differences from obs; with coupling these are not “errors”, but rather required to produce large-scale *w*



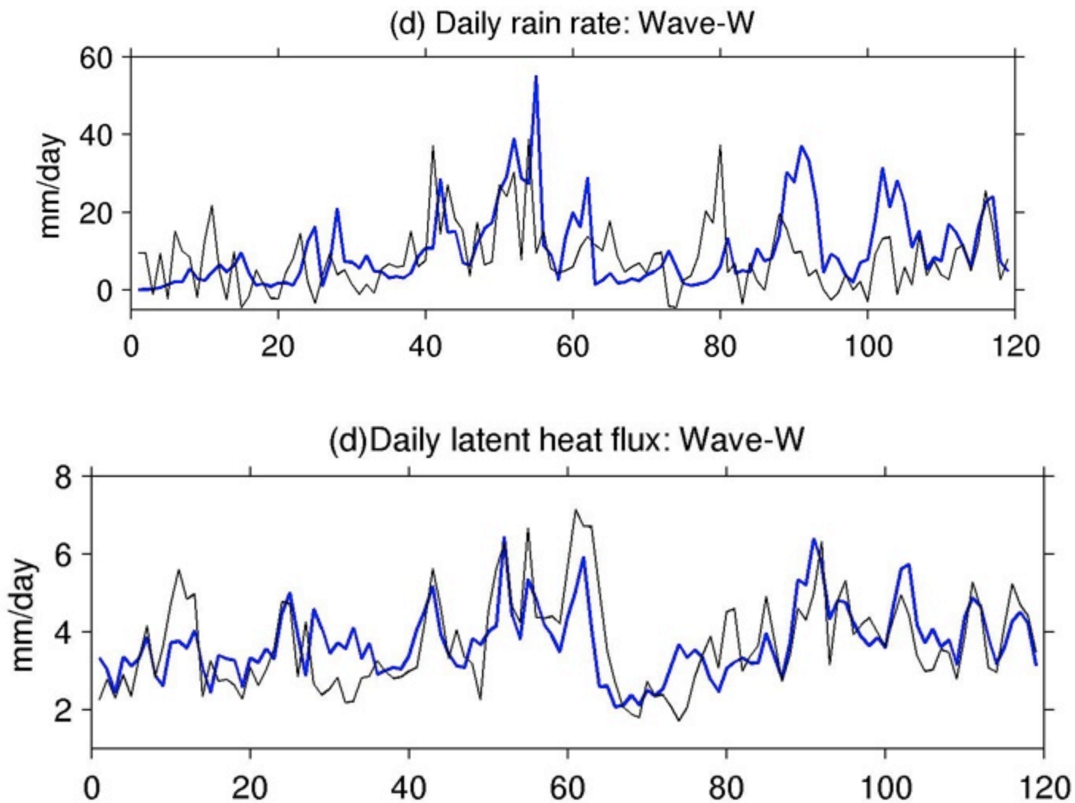
imposed w
(traditional)

WTG

wave

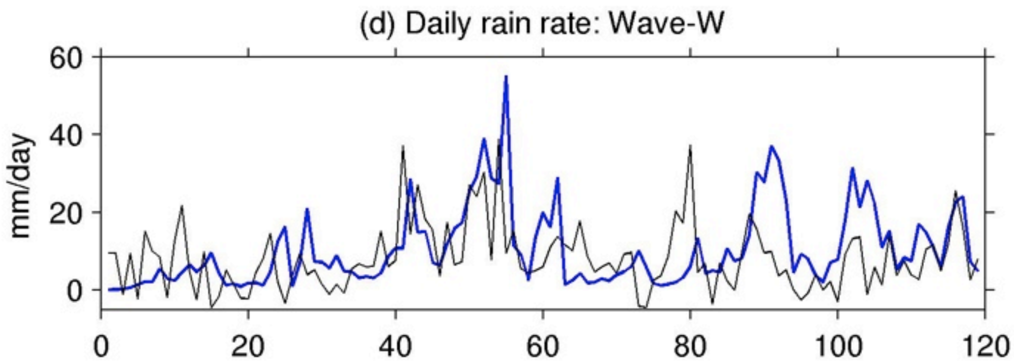
wave
+ mean *w*
(here theta difference from time-mean obs)

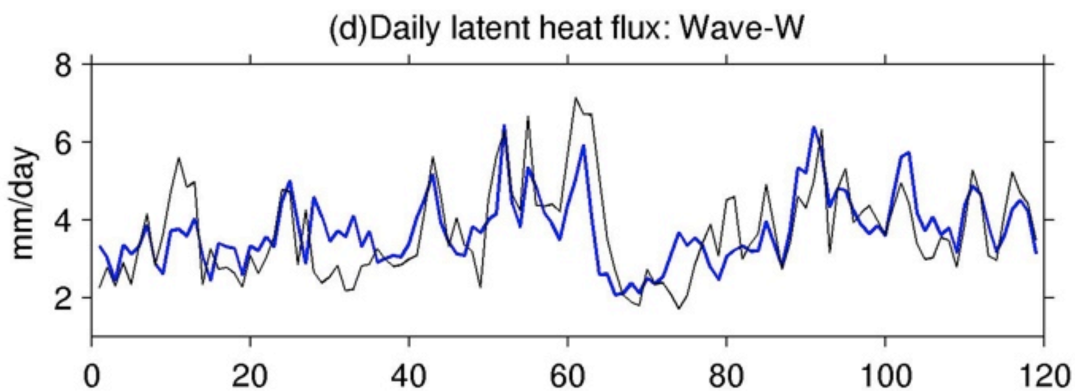
What success the method has appears largely attributable to control of deep convection by surface fluxes



What success the method has appears largely attributable to control of deep convection by surface fluxes

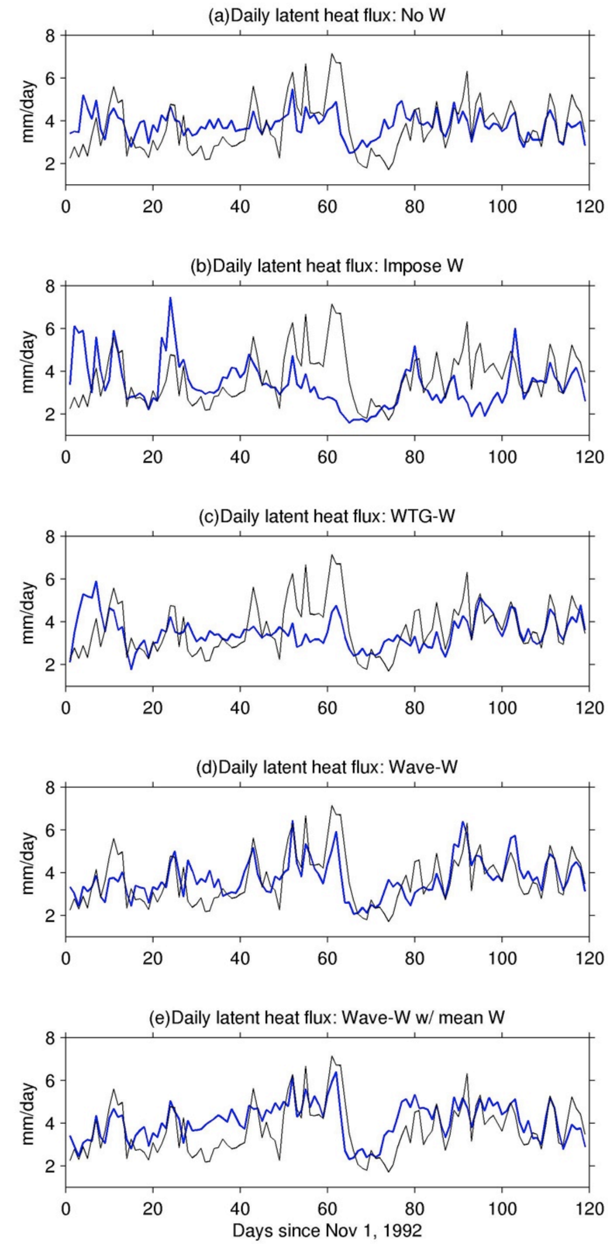
(If we use constant reference temperature profile, it doesn't matter much)





The surface fluxes themselves are largely controlled by the imposed surface wind, but there are also nontrivial feedbacks from the convection itself

(i.e., it's possible to get the fluxes wrong, even given the wind)



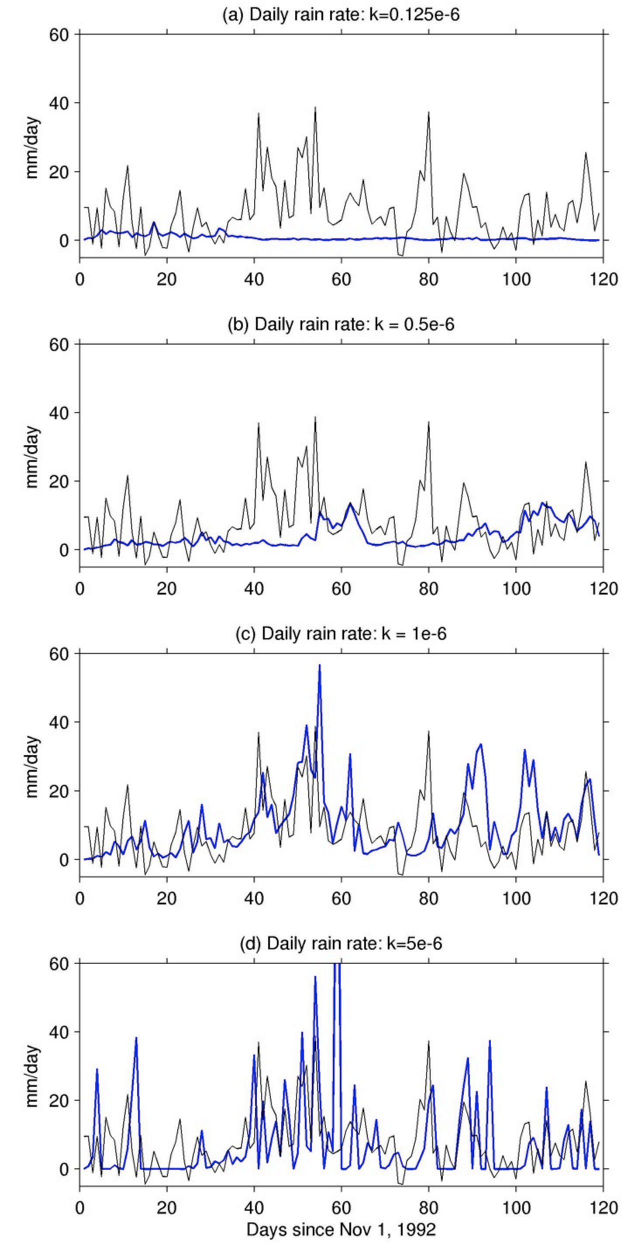
With wave method, substantial sensitivity to wavelength (in WTG, qualitatively similar sensitivity to τ)

50000 km

12500 km

6000 km

1250 km



Conclusions

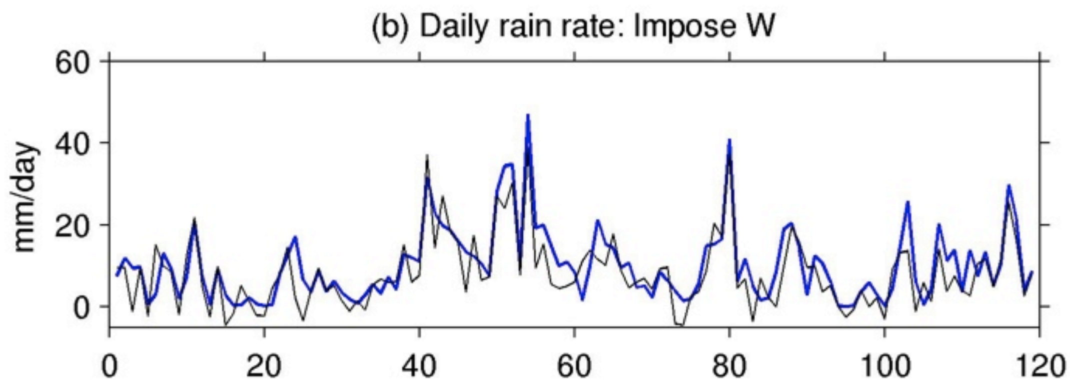
- With parameterized large-scale dynamics, we can simulate at least some part of the observed time-variability of deep convection – seem to get the MJO event.
- Both WTG and wave coupling work, the latter perhaps a little better.
- Surface wind speed seems the most important forcing for MJO convection over the TOGA IFA.
- WTG produces too top-heavy *w* because it assumes *T* adjustment is local in *z*, whereas *p* is nonlocally related to *T* by hydrostatic balance (and wave method knows this)

Issues and thoughts

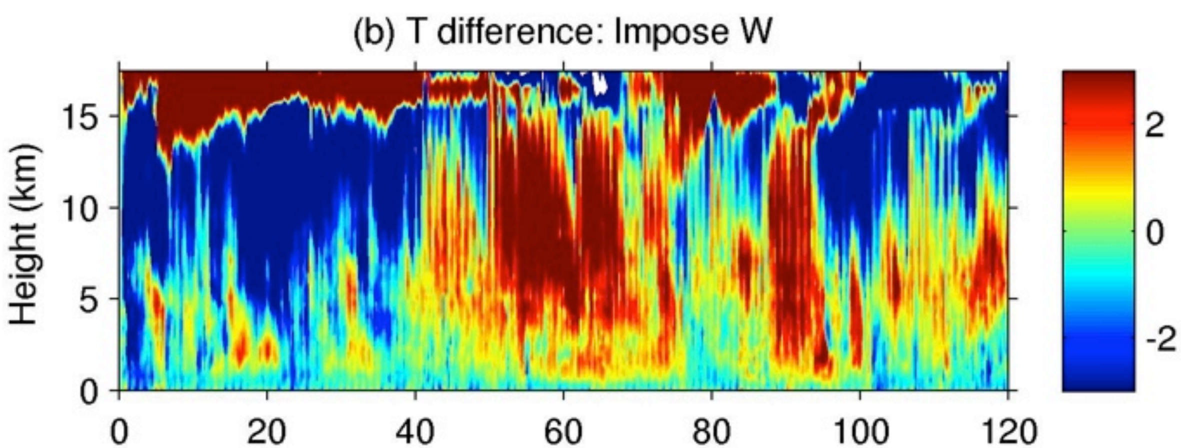
- All simulations shown here used specified radiation – interactive radiation kills the convection (Not true at all with traditional method)
- Can be long-lived sensitivity to initial conditions (multiple equilibria…)
- What do these results tell us about MJO dynamics? (We will do DYNAMO next…)
- If one does this with an SCM, one may get a more meaningful view into what controls the parameterized convection in a full 3D model.

The model error one can look at with traditional forcing is not in precip but in, e.g., the temperature field

precipitation



Potential Temperature Difference (model - obs)



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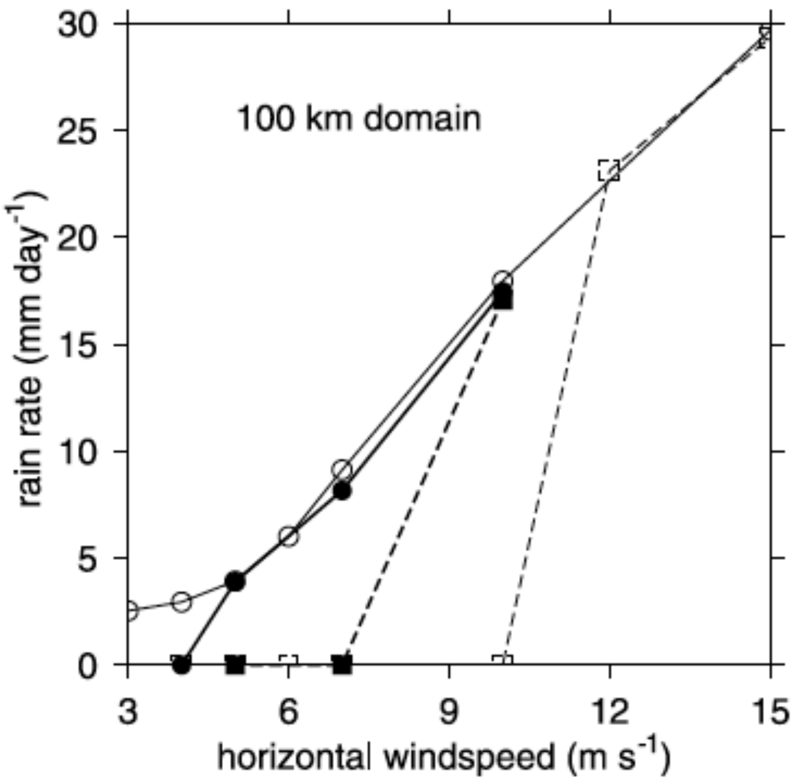

Steady precipitation as function of horizontal wind speed, Sessions et al. (2010)

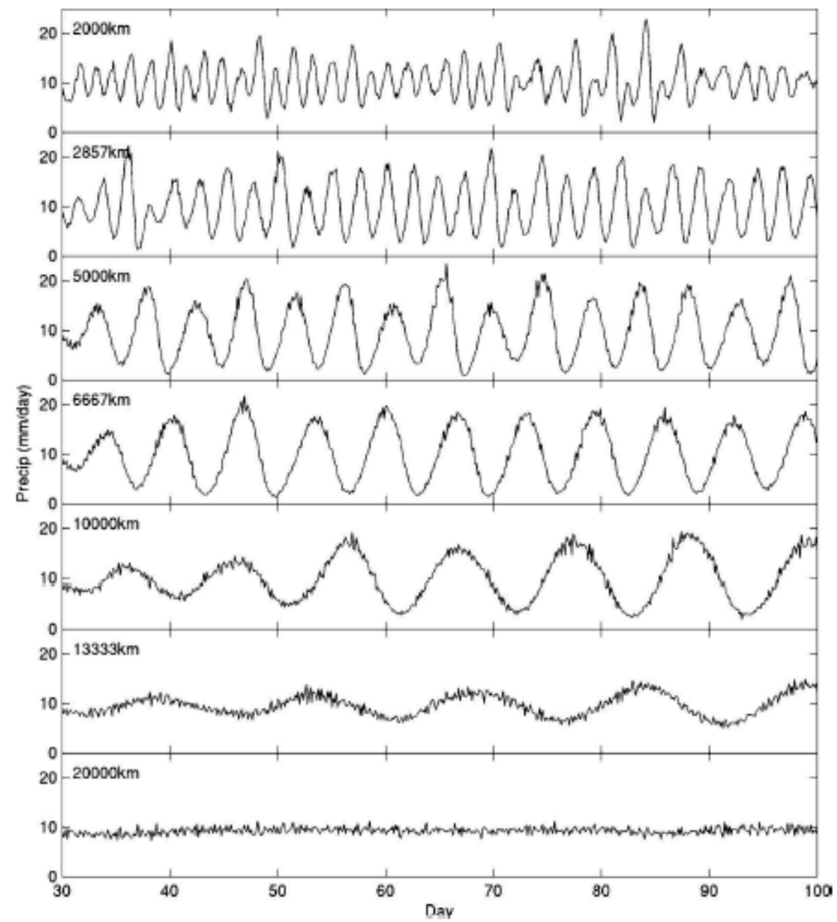

FIG. 2. Domain-averaged precipitation as a function of time after coupling to gravity wave is activated for wavelengths of (top to bottom) 2000, 2857, 5000, 6667, 10 000, 13 333, and 20 000 km.

Oscillating precipitation as function of time & horiz. wave number, Kuang (2008)