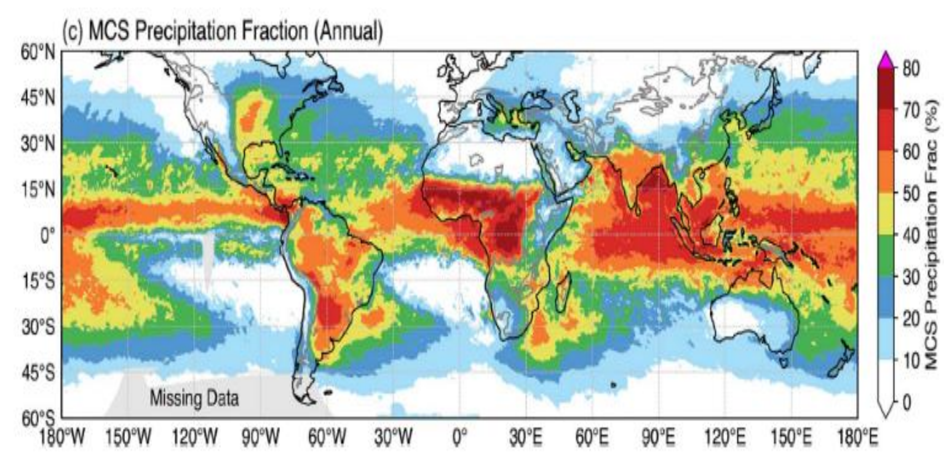
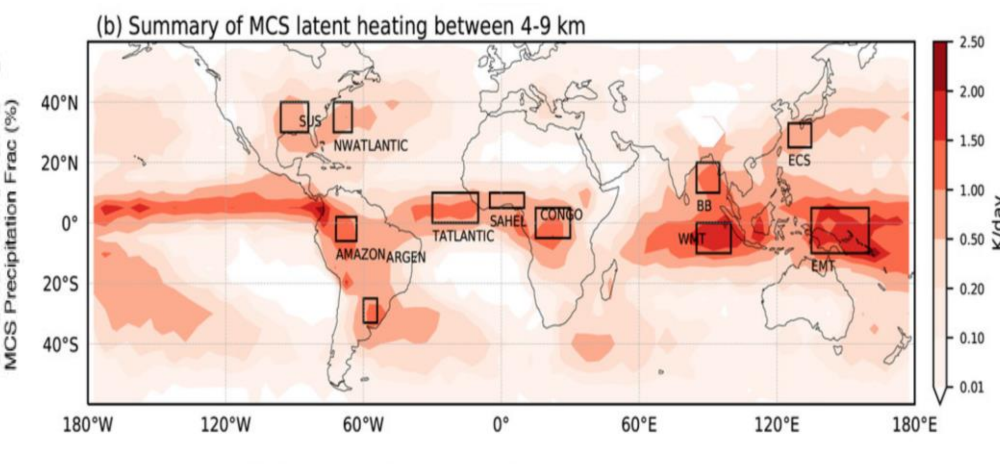
Towards a stochastic parameterization of unresolved MCS impacts on large scales





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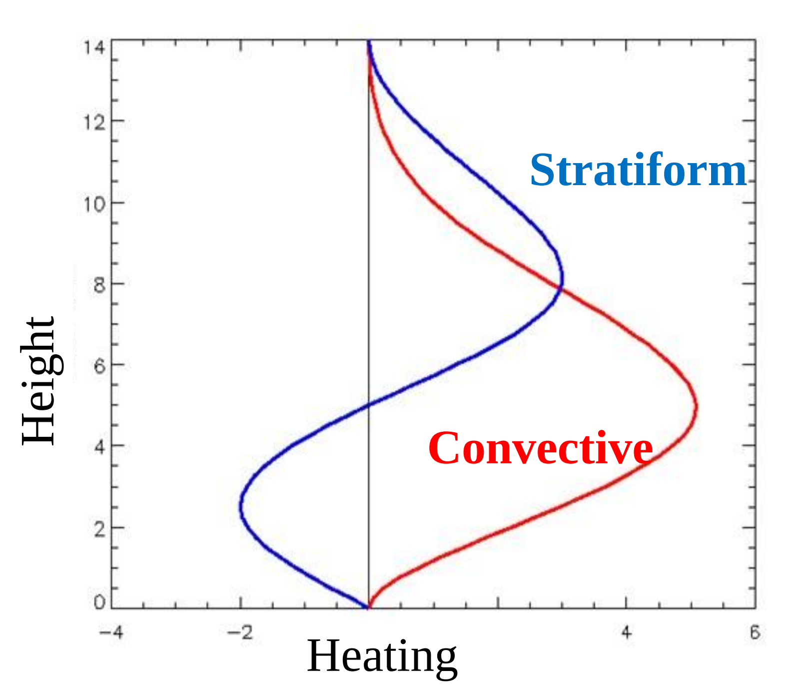
Introduction

- Mesoscale Convective Systems responsible for >50% of rainfall in large areas of tropics
- MCSs alter convective heating profile. Can couple to dynamics and reshape large-scale circulations

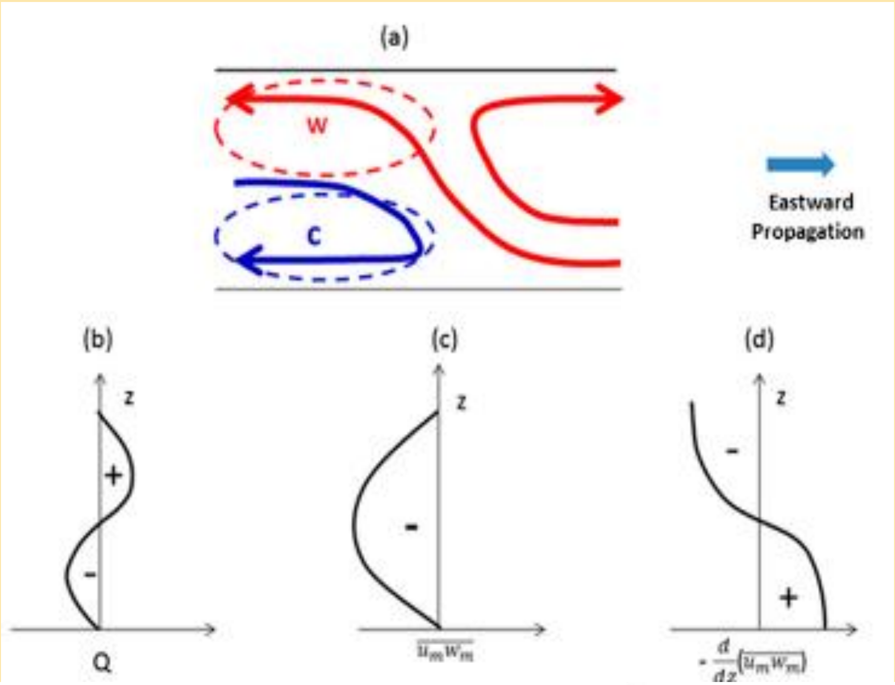


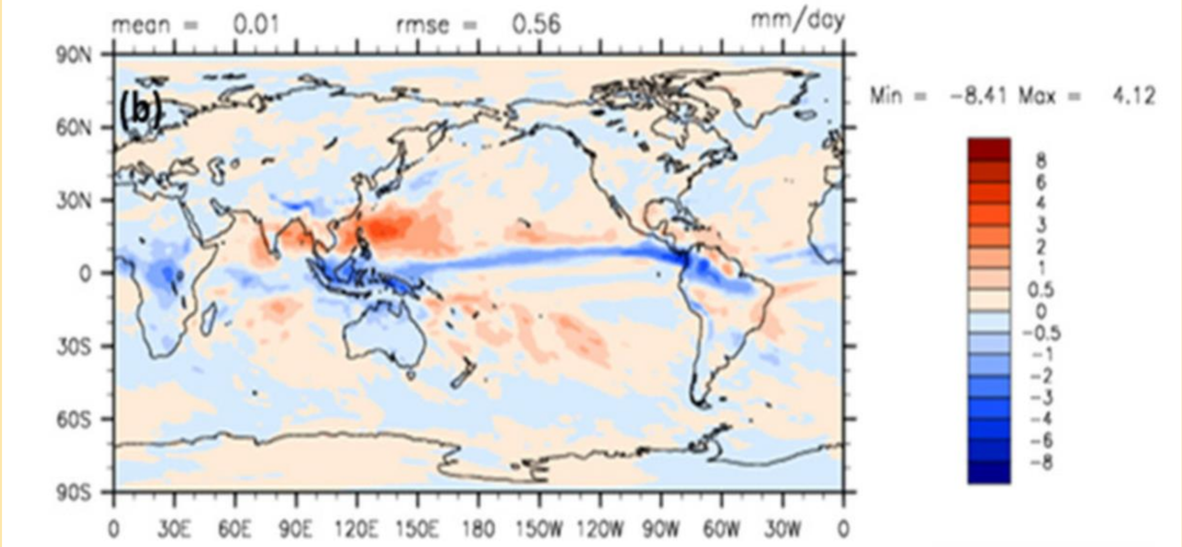
Houze (2004)

- Heating aloft, but cooling in lower troposphere, where melting and evaporation occur
- Global models parameterize convection
- And struggle to represent the stratiform part

Parameterizing MCS effects?

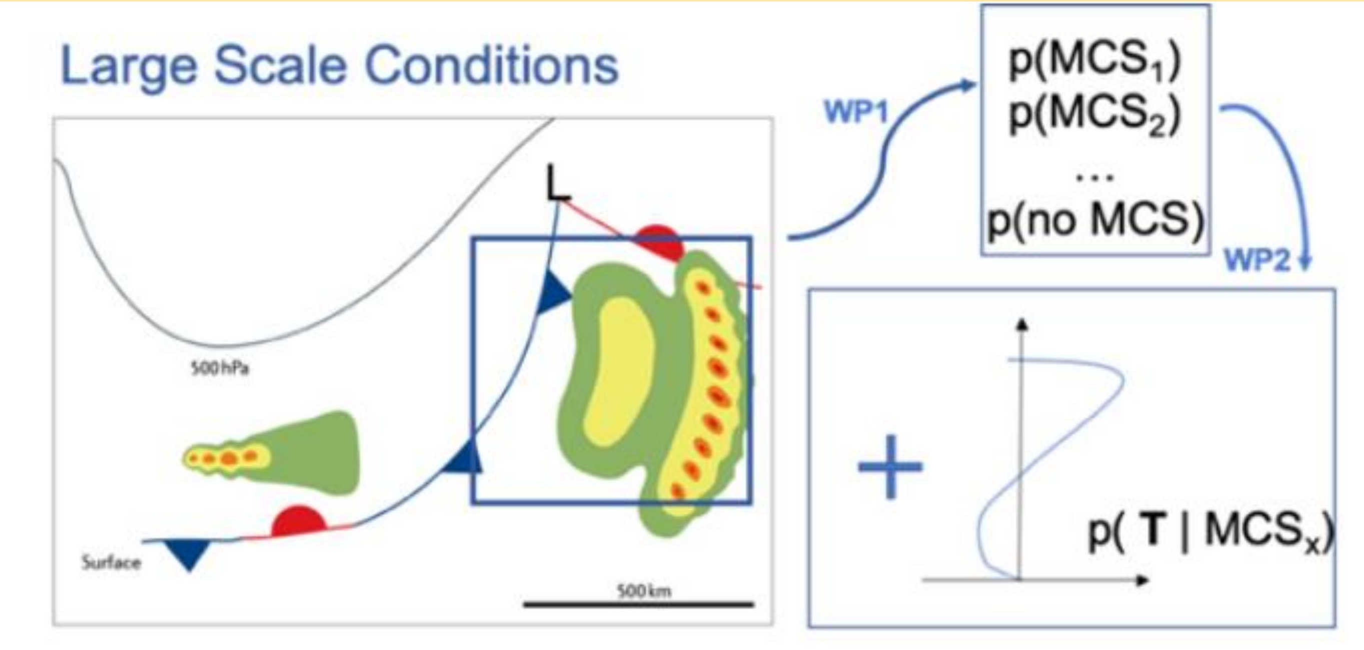
- Multiscale Coherent Structure Parameterization (Moncrieff et al 2017) makes heating profile more top-heavy and provides additional momentum transports
- Improved precipitation across the ITCZ and Maritime Continent in CAM and E3SM



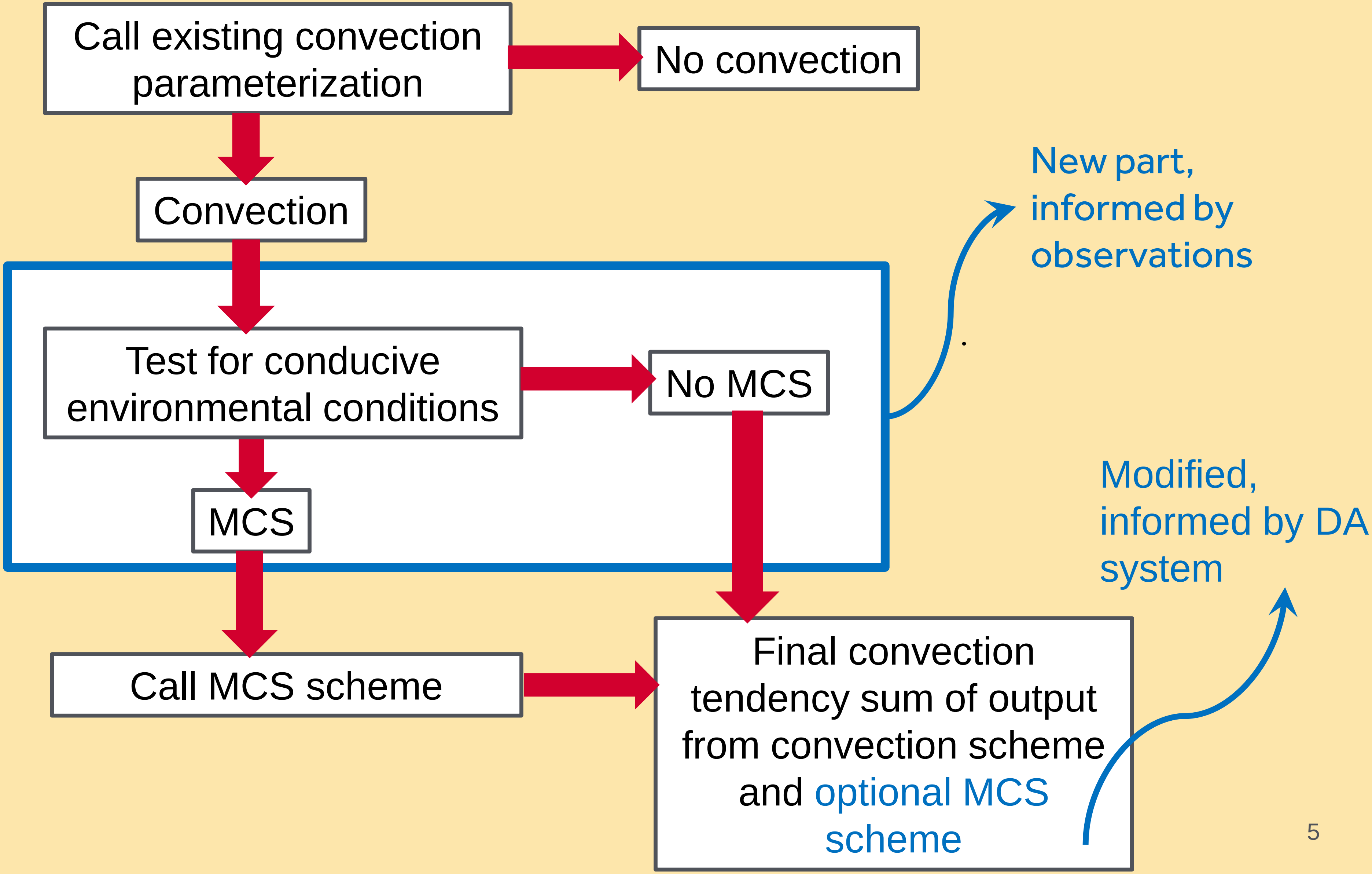


MCS:PRIME

- We target global ensemble NWP
- Develop the ideas by:
  - including dependence of occurrence on environmental state
  - reformulating missing tendencies based on analysis of DA increments
- Both parts with a stochastic formulation



MCS scheme envisaged



CoMorph-A Convection Scheme

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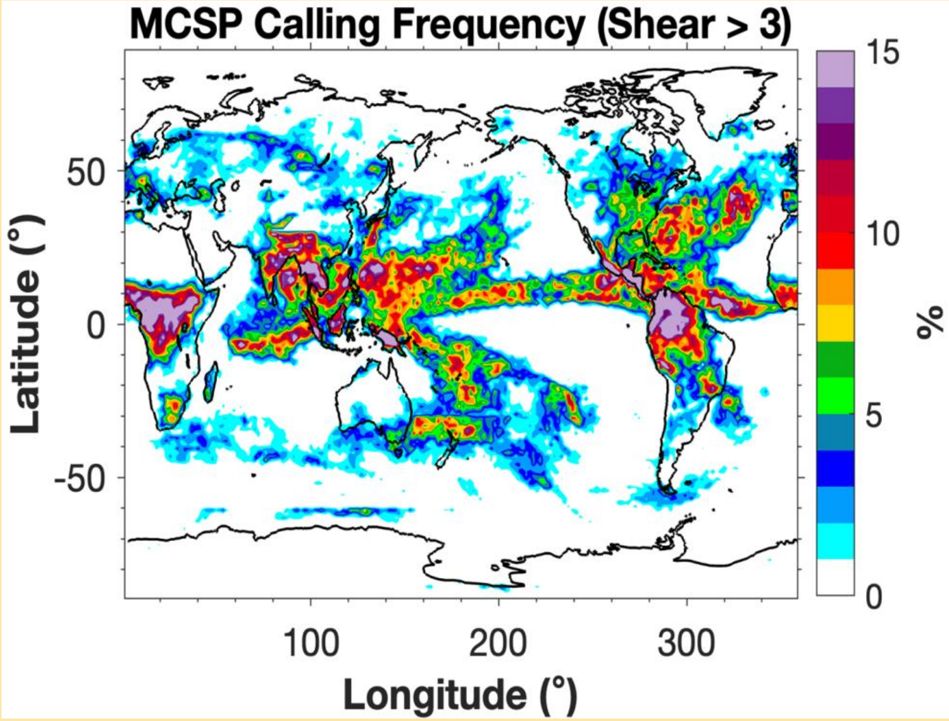
- New mass flux scheme for the Unified Model
- Competitive but not yet operational

- Initiated at any level, proportional to buoyant instability
- No distinction between shallow, deep and mid-level
- Entrainment rate depends on the turbulent mixing-length in the parcel's source layer, and on precipitation in the previous timestep (i.e., simple memory effect)
- Separate consideration of cloud-mean and cloud-core properties in detrainment calculations
- Implicit numerics prevent artificial on/off noise

- Developed through large Met Office / university partnership, ParaCon, but especially by Mike Whitall

A minimal implementation

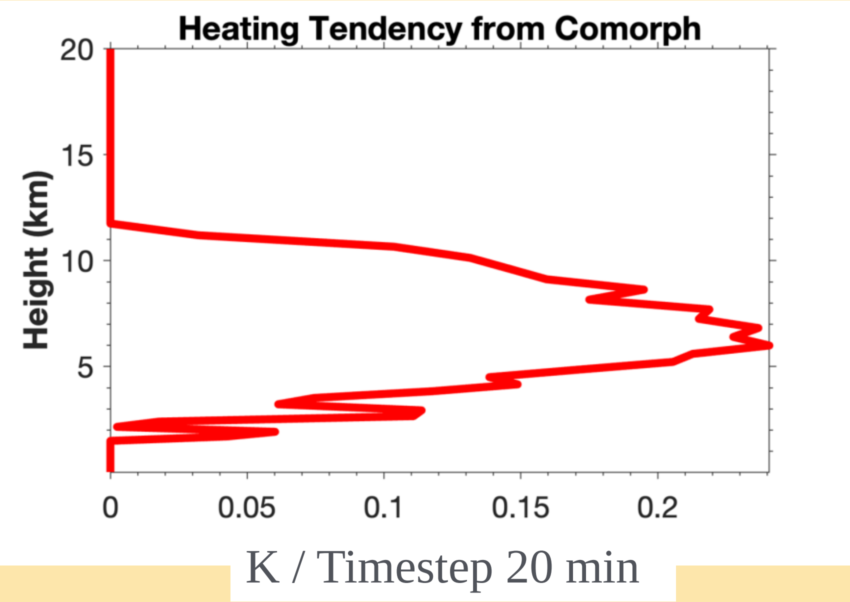
- MCS requires deep convection
  - Cloud top temperature < 0°C
  - Cloud base pressure > 600 mb
  - Cloud base and top pressure difference > 300 mb
- And requires some wind shear
  - Speed difference (600mb – lowest level) > 3 ms^{-1}

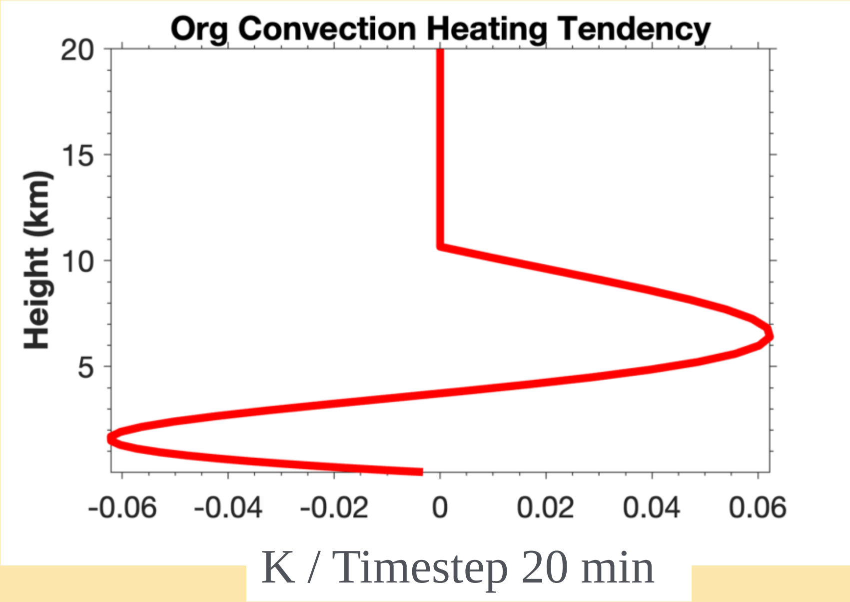


Fraction of timesteps where MCS scheme active

A minimal implementation

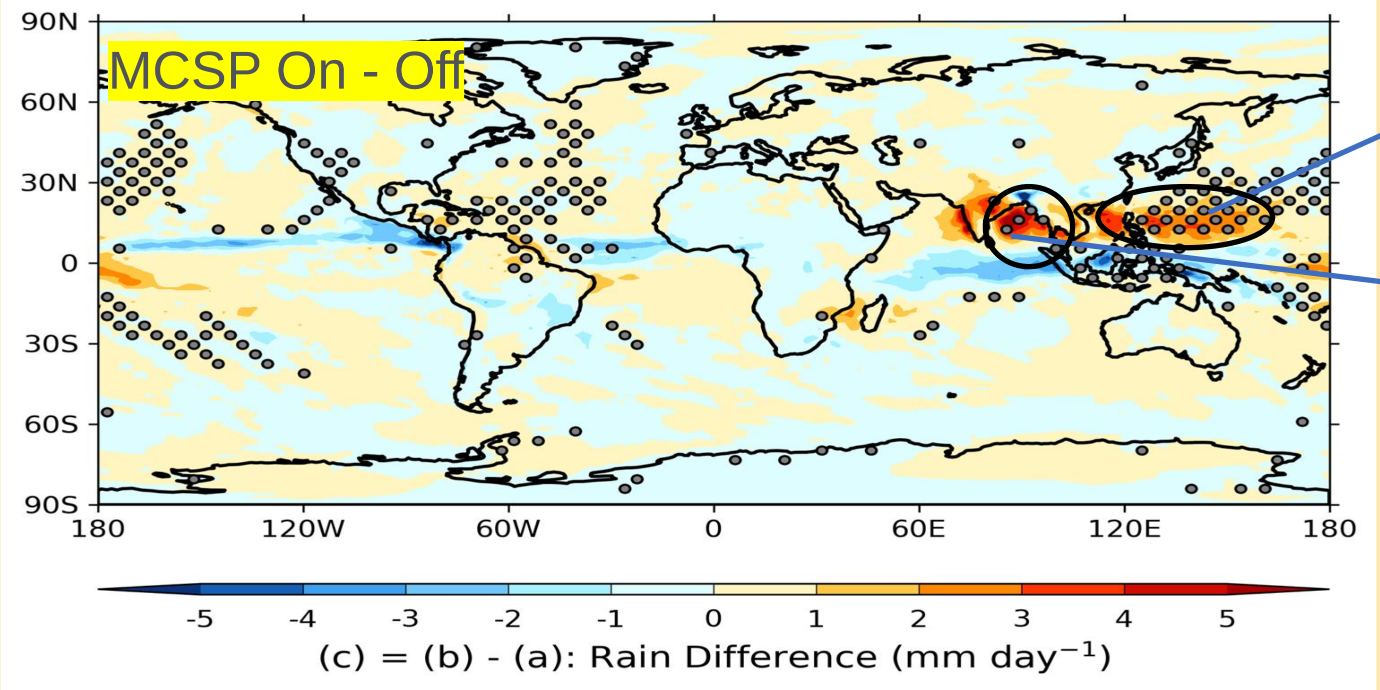
- An example
- Peak value is ~25% of CoMorph peak





A 5 year climate test run

- Following AMIP-UM setup in CMIP6
- N96 (192x144 points, 85 vertical levels, Δt=20min)



Increase of wet bias

Decrease of dry bias

Dots where this UM run significantly disagrees with CMIP6 (outside 5-95 percentile range)

- Broadly similar to CAM and E3SM
- Emphasizes changes with CoMorph compared to old UM scheme

Precipitation seasonal cycle

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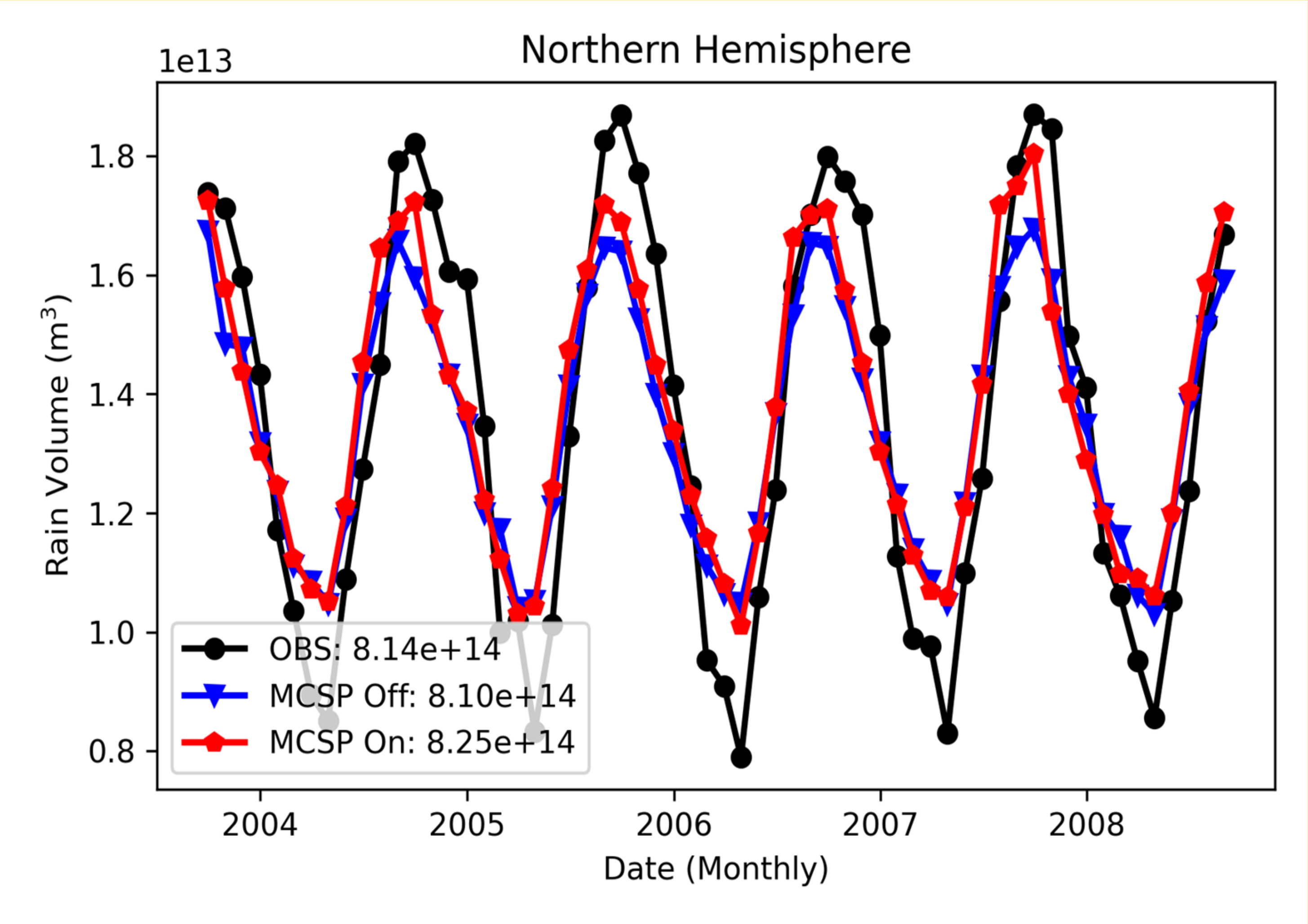
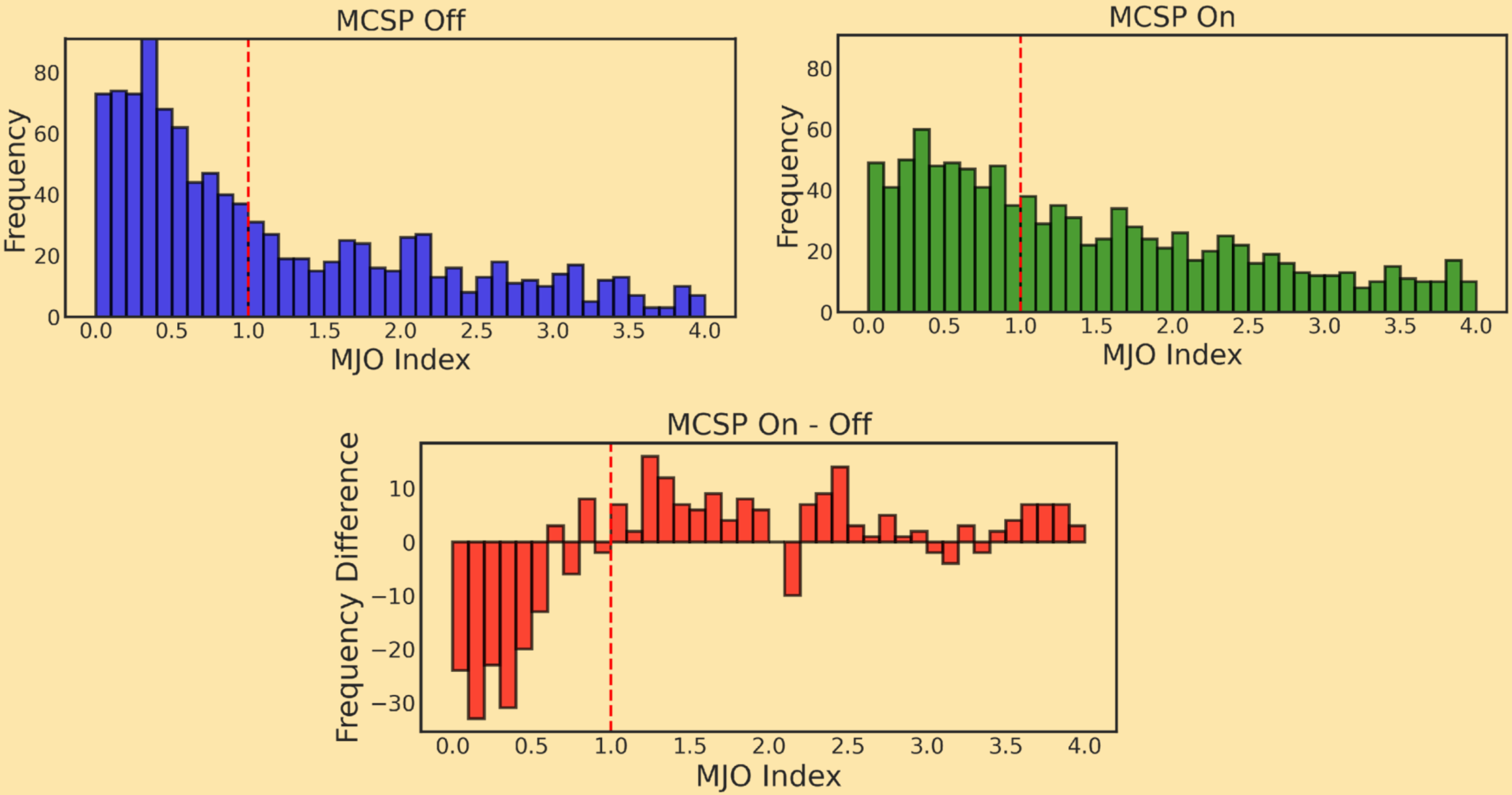


Stronger N hemisphere cycle due to stronger Asian monsoon

Enhanced MJO



Relative stabilization at low levels discourages stationarity / encourages eastward progression of convection

Observational tracking data

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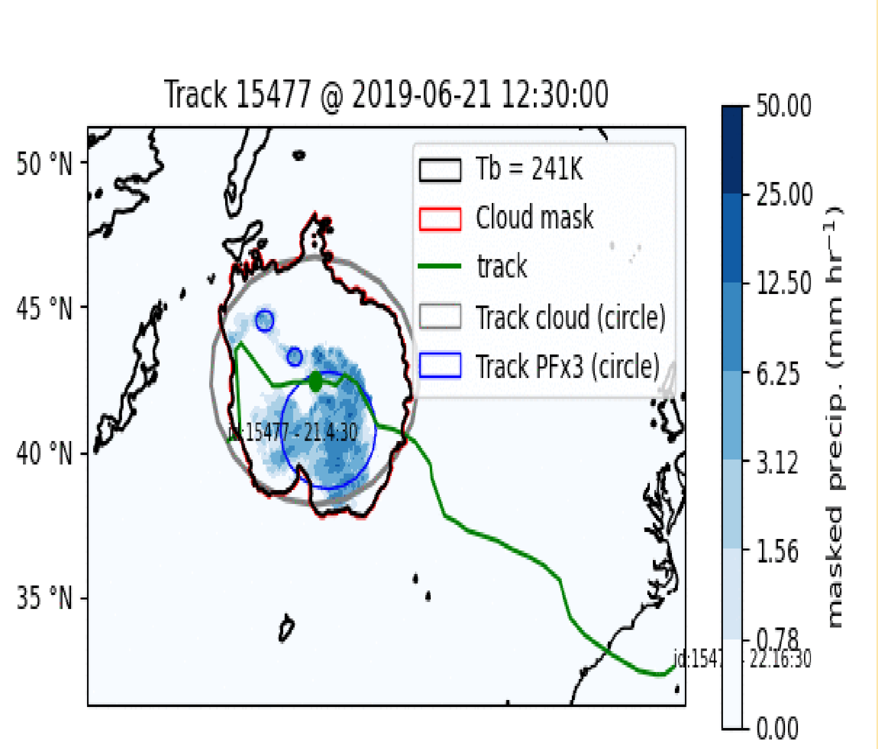
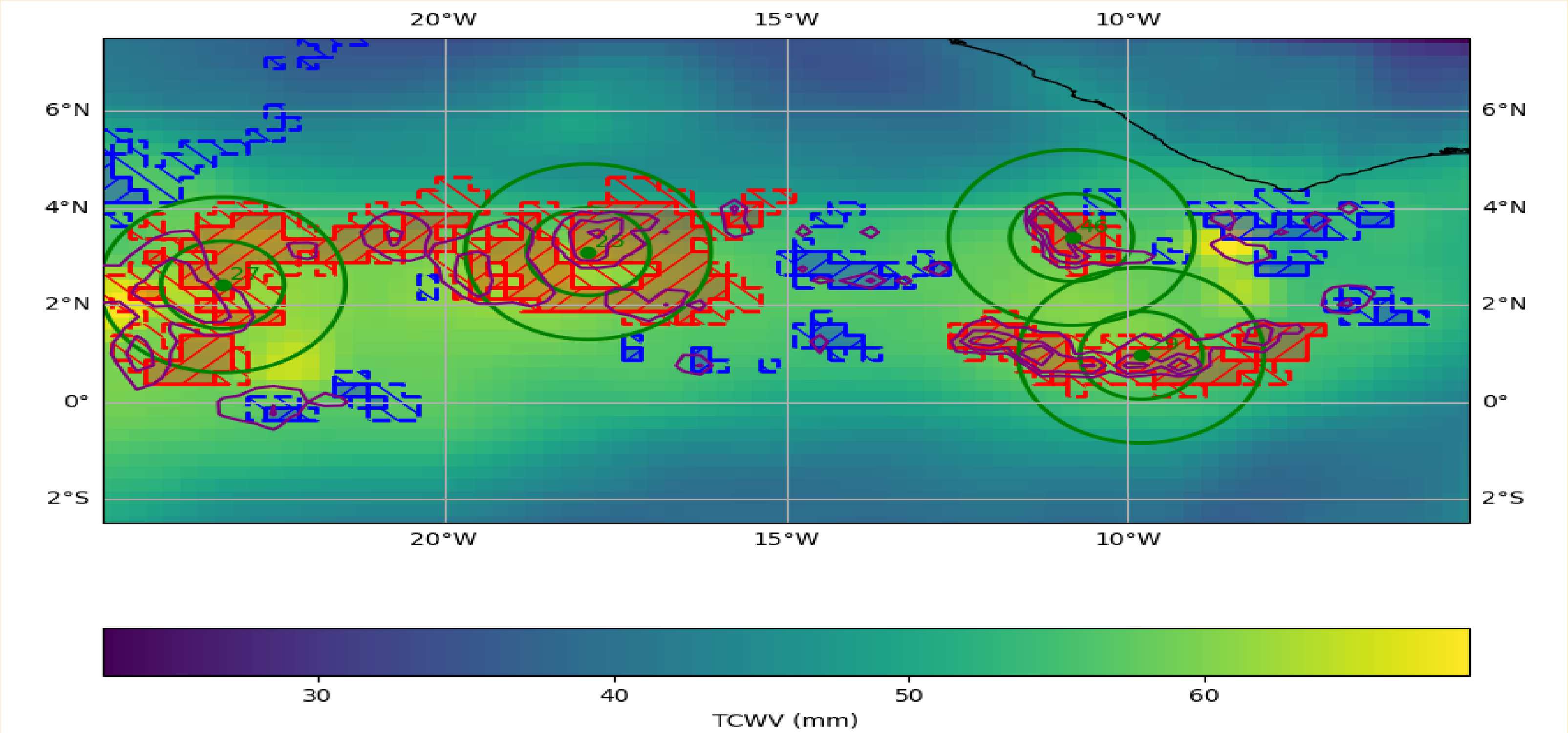
- Feng et al. (2021) data from 2000-2020
- Based on NASA Global Merged IR V1 infrared brightness temperature, T_b< 225 K for cloud core, T_b< 241 K for cloud shield, as well as IMERG precipitation
- MCS area > 4 x 10^4km^2, duration > 4 h, as well as other lifetime-dependent thresholds



Match to ERA5 conditions for CAPE, Total Column Water Vapour (TCWV), vertically integrated Moisture Flux Convergence (MFC), and various measures of shear

Analysis regions overlayed on TCWV



- Shield < 241K (dashed)
- Core < 225K (solid)
- Red=MCS
- Blue=convective, non-MCS
- Green circles: 100, 200km

Evolution of MCS environment

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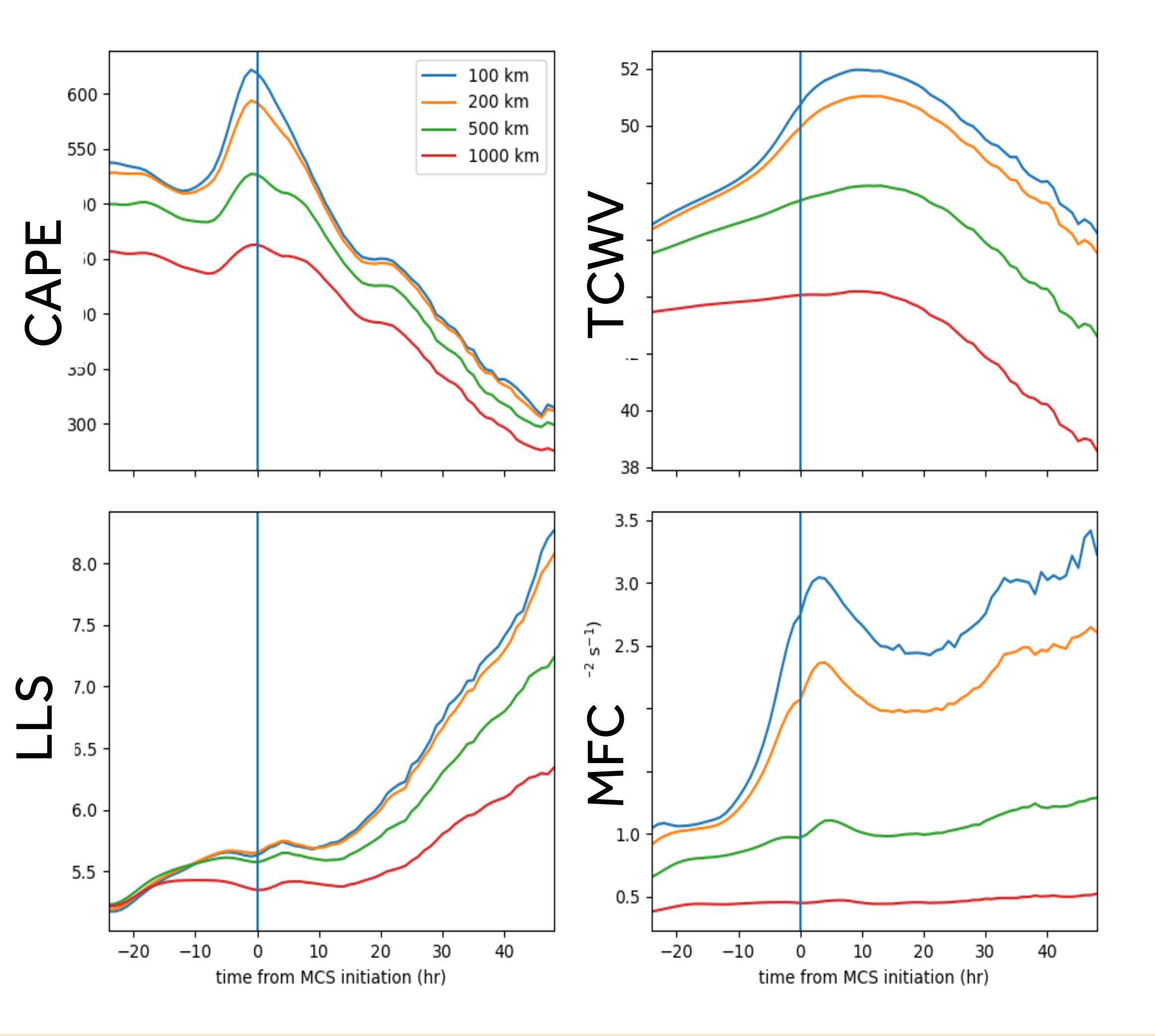
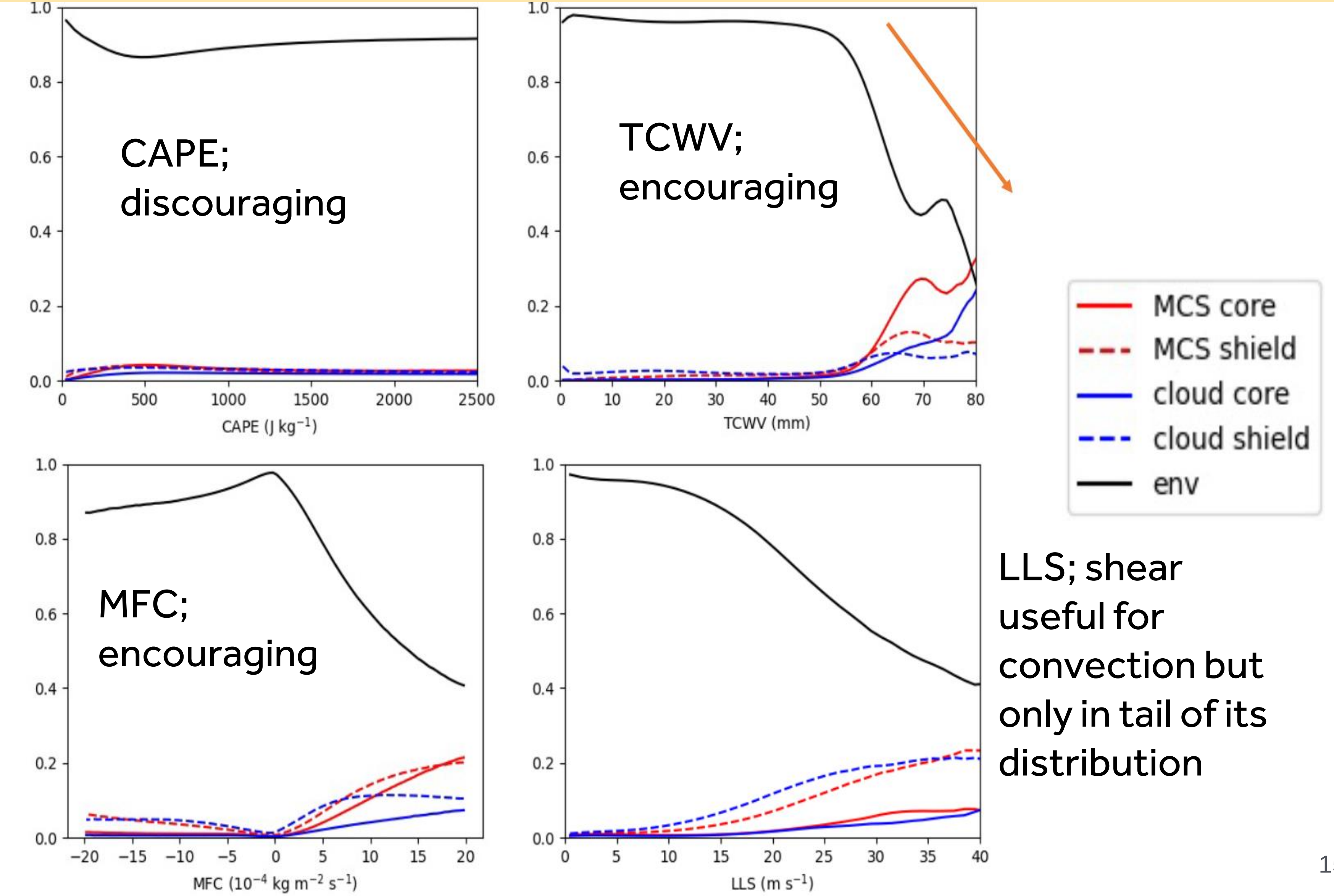
- Before MCS initiation, use initation centroid
- After MCS initiation, use track centroid

- Increases in CAPE, TCWV and MFC 5-10 hr beforehand. Smallest spatial scale has the largest change.
- Low-level shear shows a weak increase, but stronger increase over the next 15h

- P(environment | MCS) is interesting but….



Want to know P (MCS | variable)



LLS; shear useful for convection but only in tail of its distribution

Scheme needs P (MCS | conv, variable)

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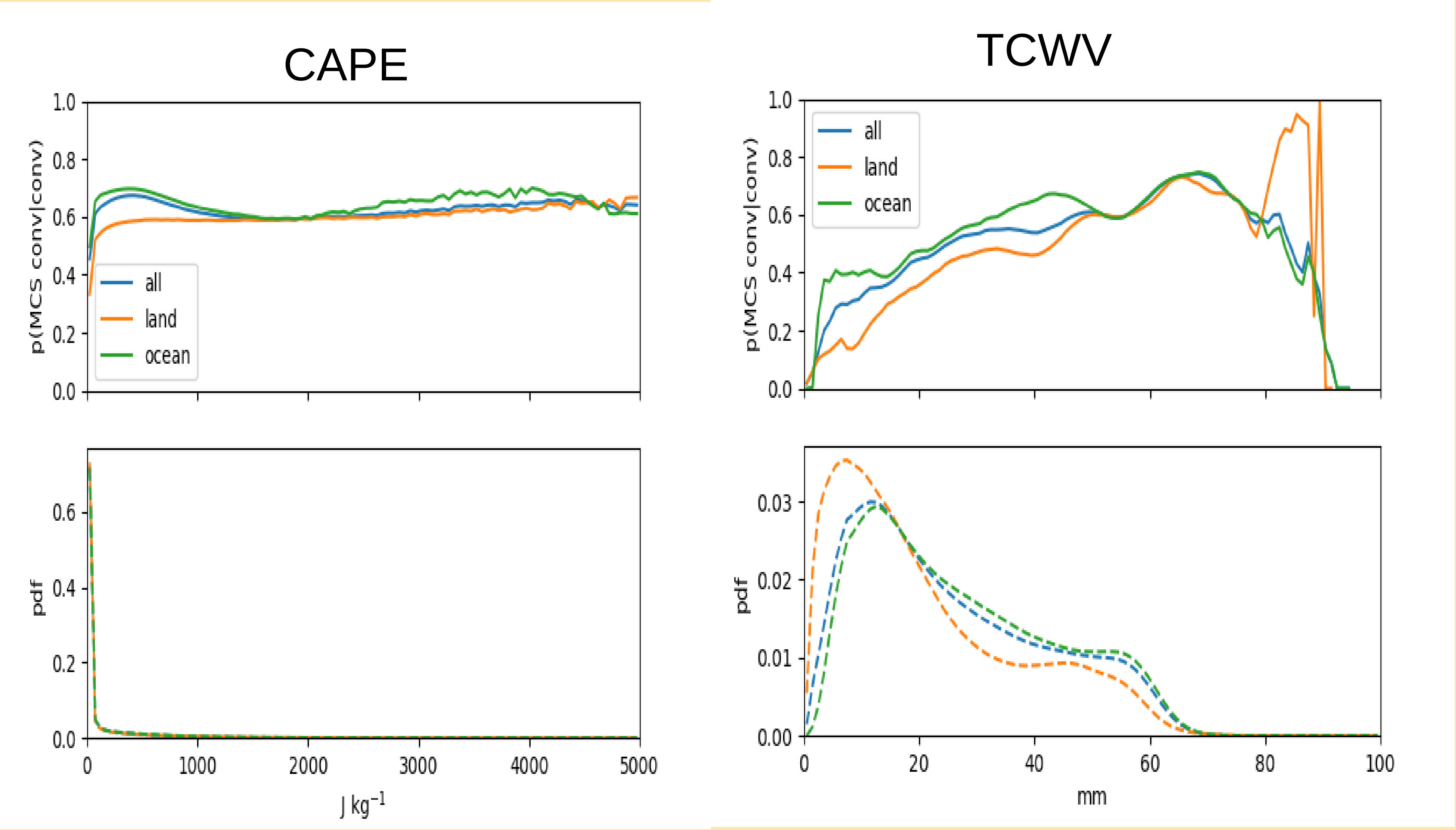

Conditional probs

prob of variable

- Clear dependence on TCWV, indicating route for including environmental conditions in a stochastic call of the MCS parametrization

Conclusions

- A parameterization of MCS effects has substantial potential to improve global NWP and climate models
  - Improved seasonal cycle in N hemisphere and the MJO
  - Reduced bias over Bay of Bengal
  - But amplifies a bias over the western Pacific
- Clear increases in different environmental variables 5-10 hours before MCS initiation
  - There is precursor information in the environment
- Decision to activate the MCS is based on observed P(MCS | convection, env state)
  - Shear has little predictive power from this perspective
  - TCWV has the clearest signal for distinguishing MCS
- Next steps
  - Implement MCS predictors
  - Revise MCS tendencies with guidance from DA increments associated with MCS

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- Moncrieff, M. W., C. Liu, and P. Bogenschutz, 2017: Simulation, Modeling, and Dynamically Based Parameterization of Organized Tropical Convection for Global Climate Models. *J. Atmos. Sci*., **74**, 1363–1380.

Extras

- CoMorph formulation
- Intermittency in CoMorph
- Rain rate plots
- Precipitation seasonal cycle in S hemisphere
- MJO related plots
- Conditional probabilities for MFC

CoMorph

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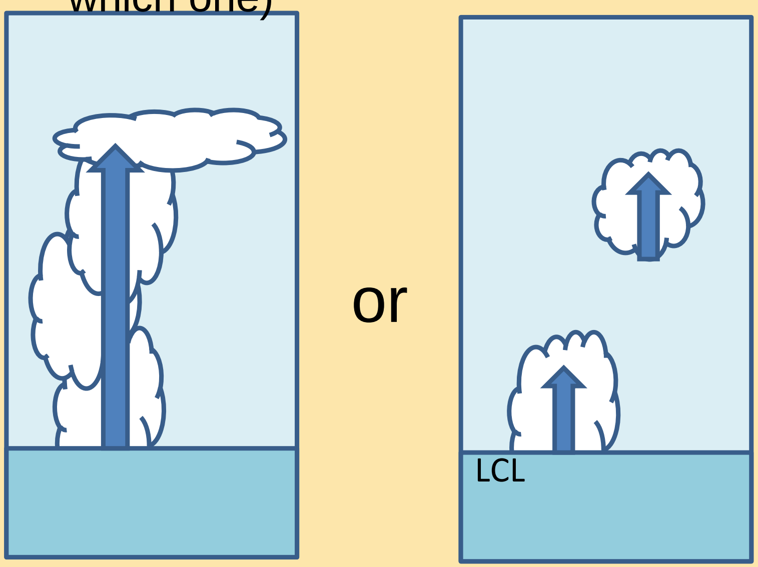
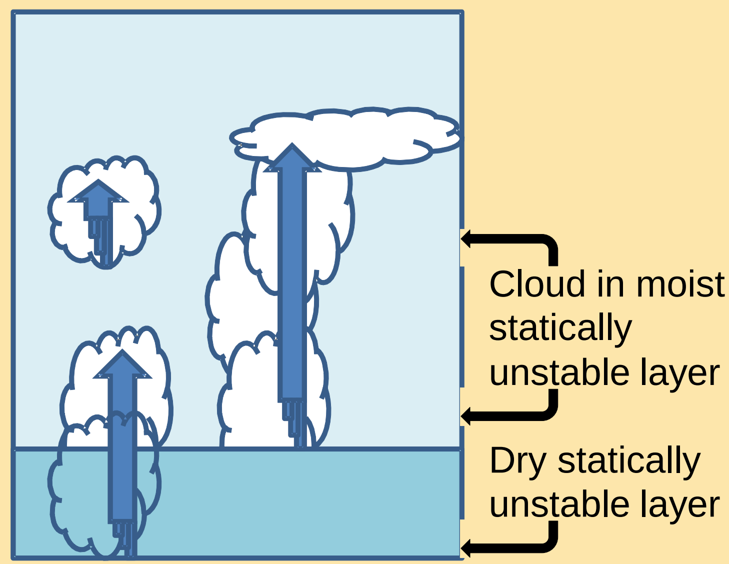
“Traditional” approach:

- Complex empirical trigger functions
- A-priori diagnosis of a unique “cloud-base” height
- Plume can only start from surface or other prescribed height
- Separate schemes for “deep”, “shallow” and “mid-level” convection (must pre-diagnosed which one)



- Convecting parcels launch from any height where there is local vertical instability
- Plumes from different unstable layers integrated independently
- Same parcel ascent / descent code for all plumes
- Updraft radius depends on the turbulent mixing-length in the parcel’s source-layer.



CoMorph Mass Flux Budget

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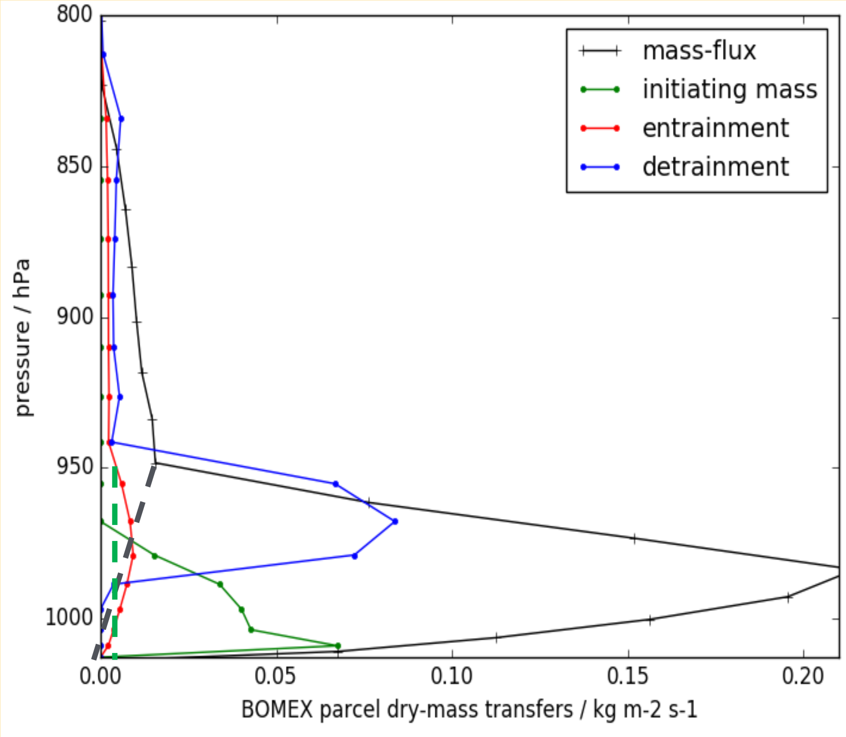
Diagnostic bulk vertical mass transport budget

$$\frac{\partial M}{\partial z} = g + e - d$$



Initiating mass-source depends on local instability: (dry-static instability in clear-air, moist-static instability in large-scale cloud)

$$g = \frac{1}{4}\rho\sqrt{-N^2}$$

Entrainment rate inversely proportional to radius. Radius is proportional to turbulence length-scale from the boundary-layer scheme, with enhancement by the previous precip

$$e = M\frac{0.2}{R}$$

$$R_{init} = \alpha h_{BL}$$

$$\alpha = \alpha_0 + \frac{pr/q}{pr_{max}/q_{ref}}(\alpha_{max} - \alpha_0)$$

Detrainment rate based on sorting an assumed-PDF of buoyancy within the bulk plume, with implicit numerical method

$$d = \frac{M}{dz}\int_{T_{v\,edge}}^{T_{v\,env}} PDF(T_v)\, dT_v$$

Mike Whitall

CoMorph Detrainment

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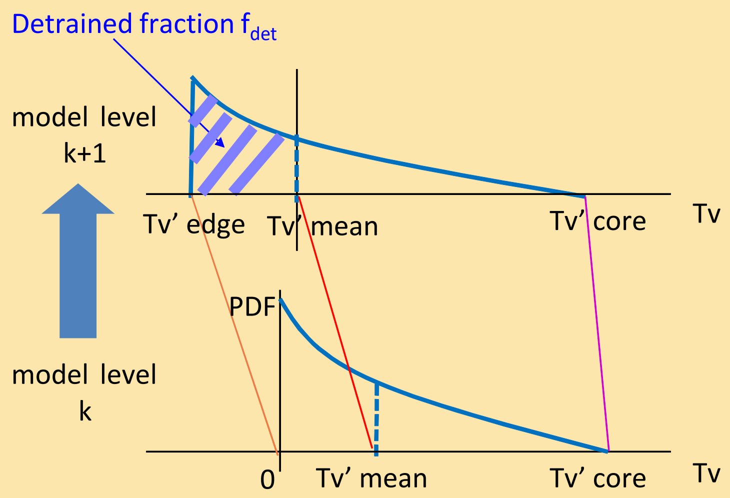
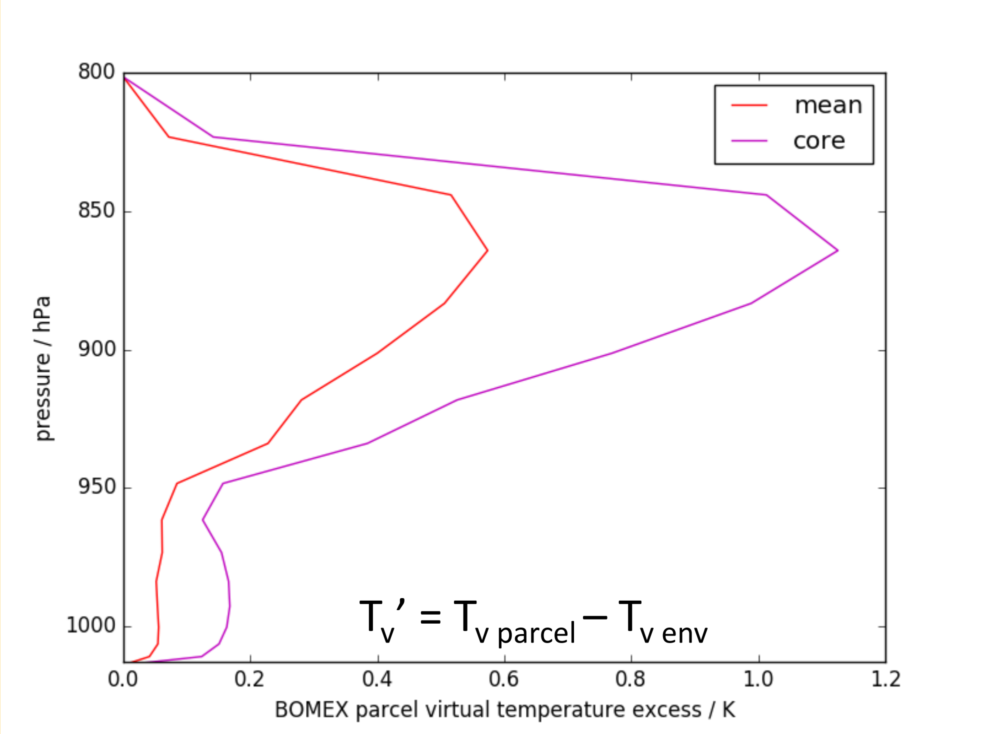
Implicit Assumed-PDF-based detrainment

- Buoyancy, T, q, u, v, etc assumed to have a power-law PDF *within the bulk plume*.
- Separate ascent calculations for in-plume mean properties, and a less dilute parcel "core"
- At each level, detrain the fraction of the PDF which becomes non-buoyant (due to entrainment, changes in environment Tv, etc)





$T_v' = T_{v\,parcel} - T_{v\,env}$

But how to define $T_{v\,env}$ when it is changing due to the convective increment?

For smooth behaviour. need implicit-in-time discretization, accounting for the convective heating.

Mike Whitall

A snapshot of rain rates

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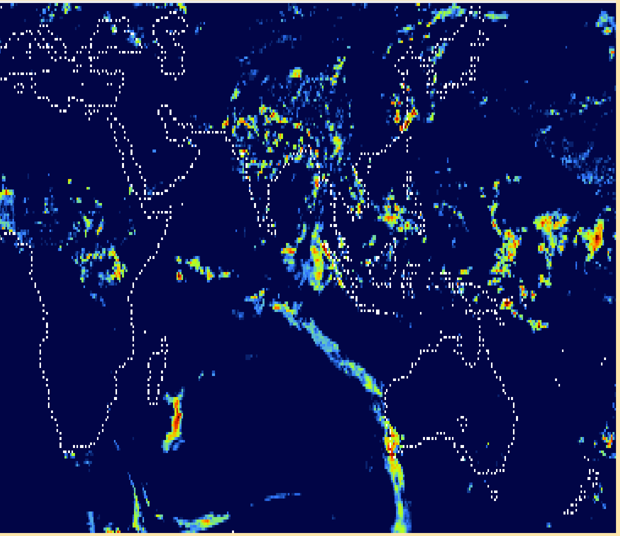
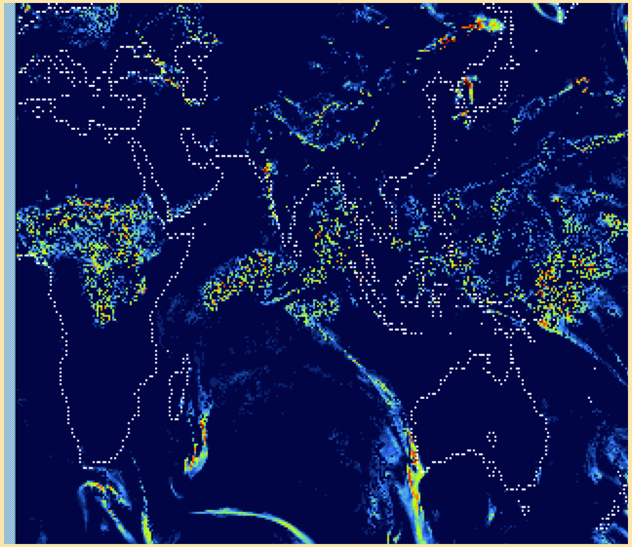
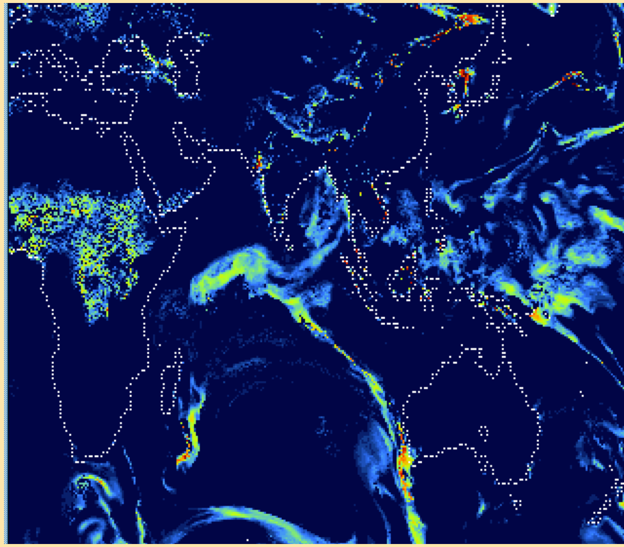


TRMM data



Old scheme, CAPE-based closure



A CoMorph test

Equatorial waves with CoMorph

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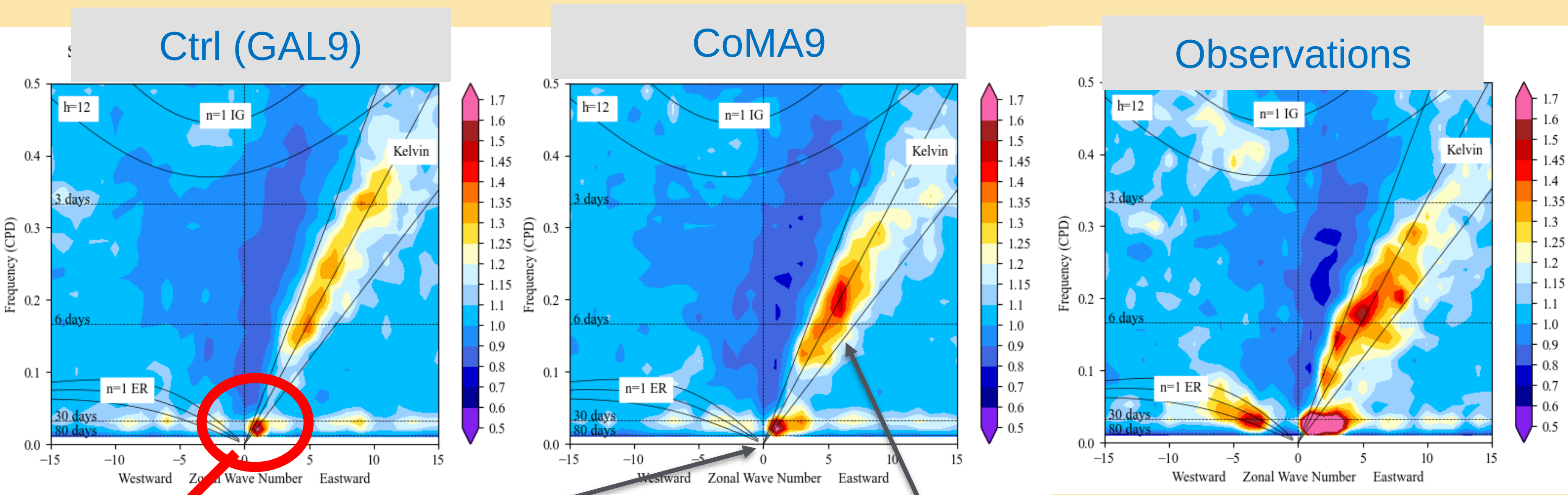
- N96, atmosphere only.
- Tropical wavenumber-frequency spectrum for precipitation



Slightly stronger MJO

Improved Kelvin wave strength

MJO

Adrian Lock

Rain rate bias

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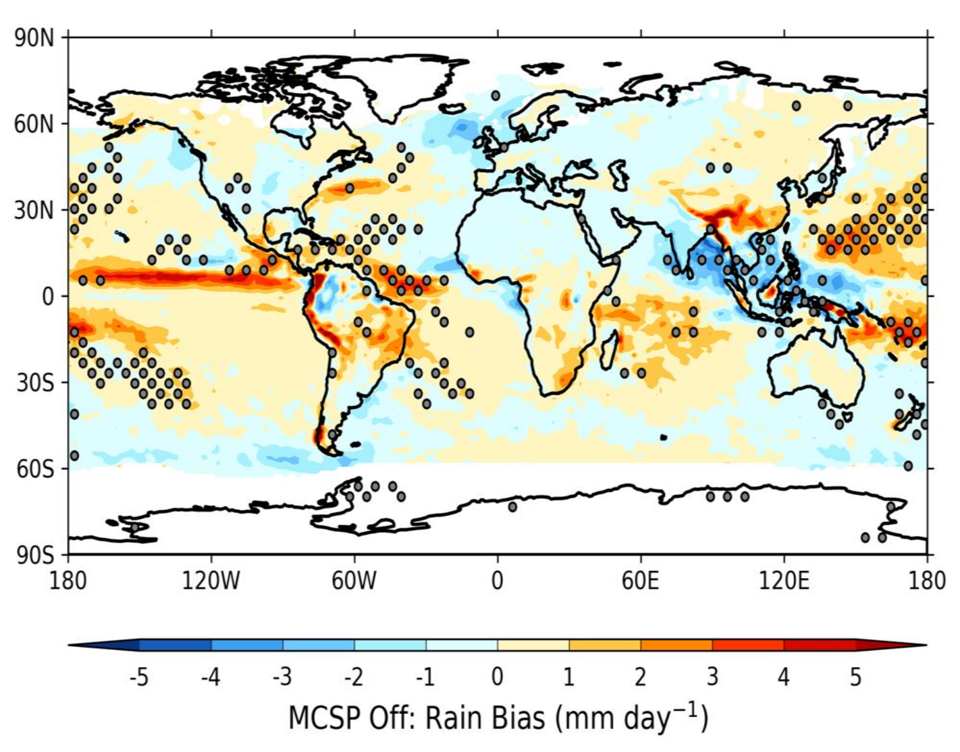
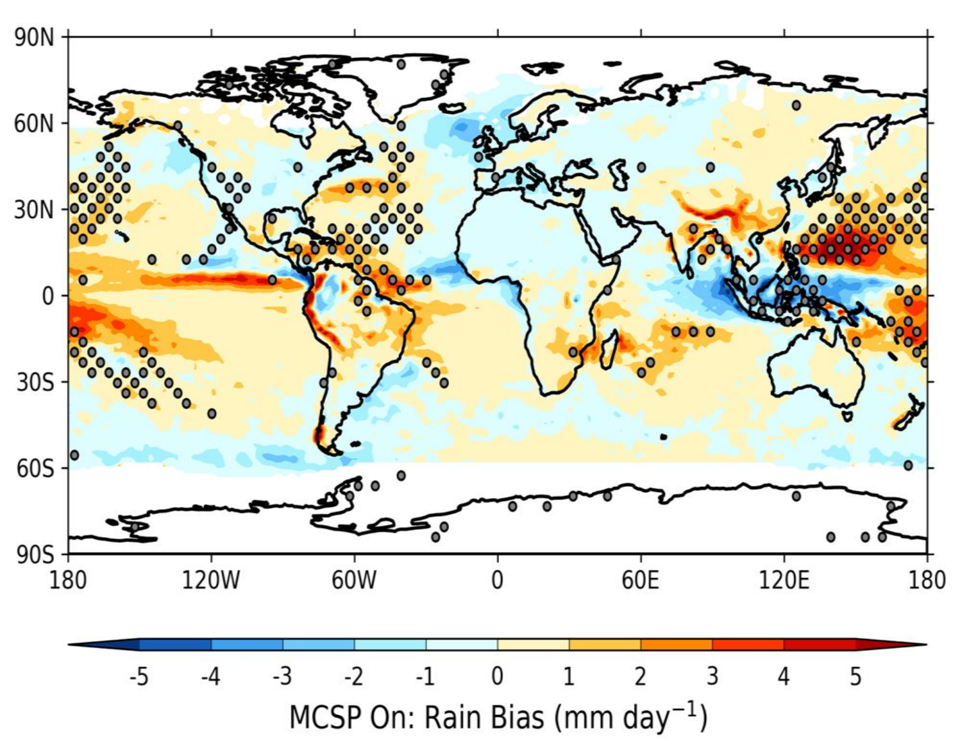
MCSP Off- OBS
correlation: 0.886



MCSP On - OBS
correlation: 0.886



Change in absolute bias

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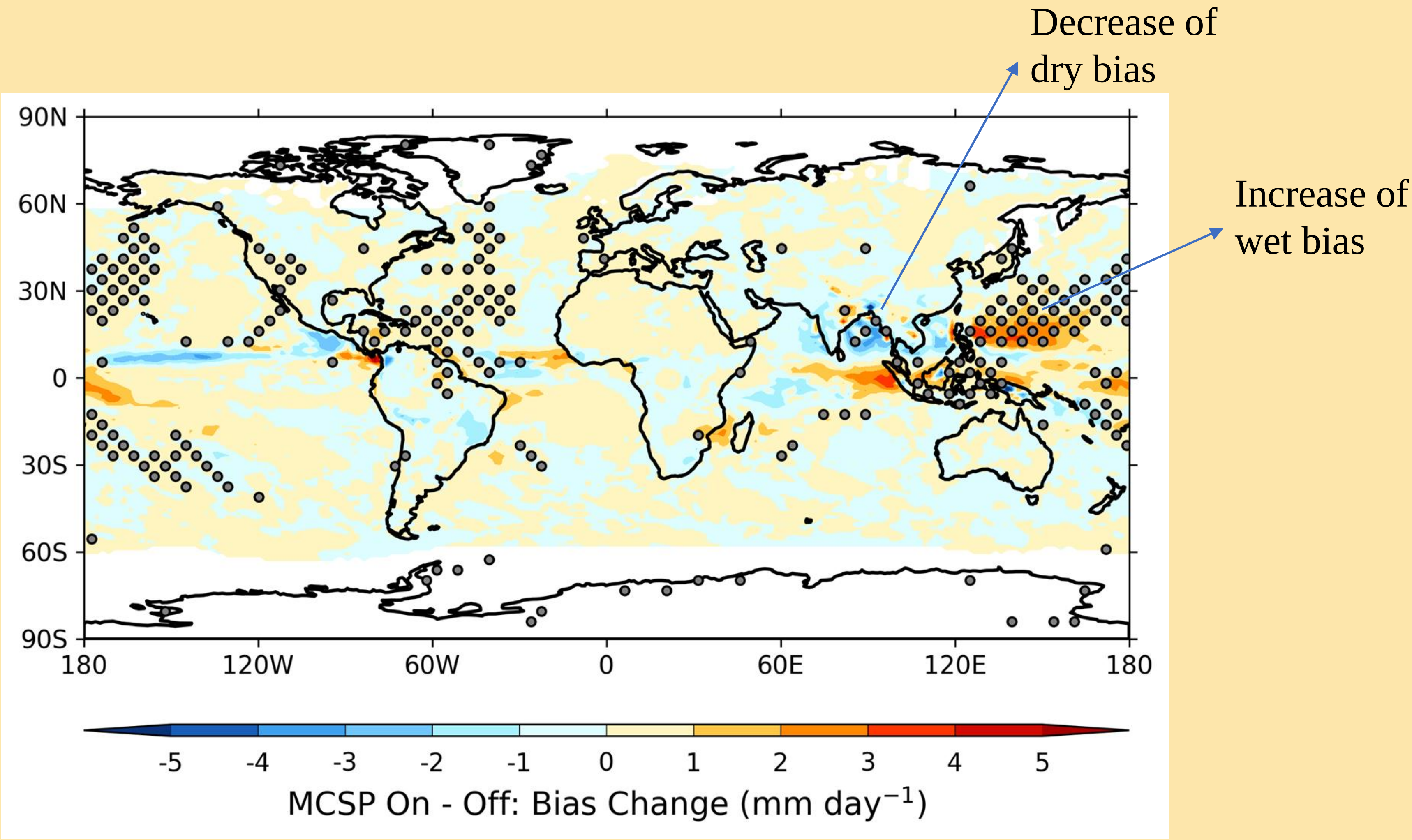

Precipitation seasonal cycle

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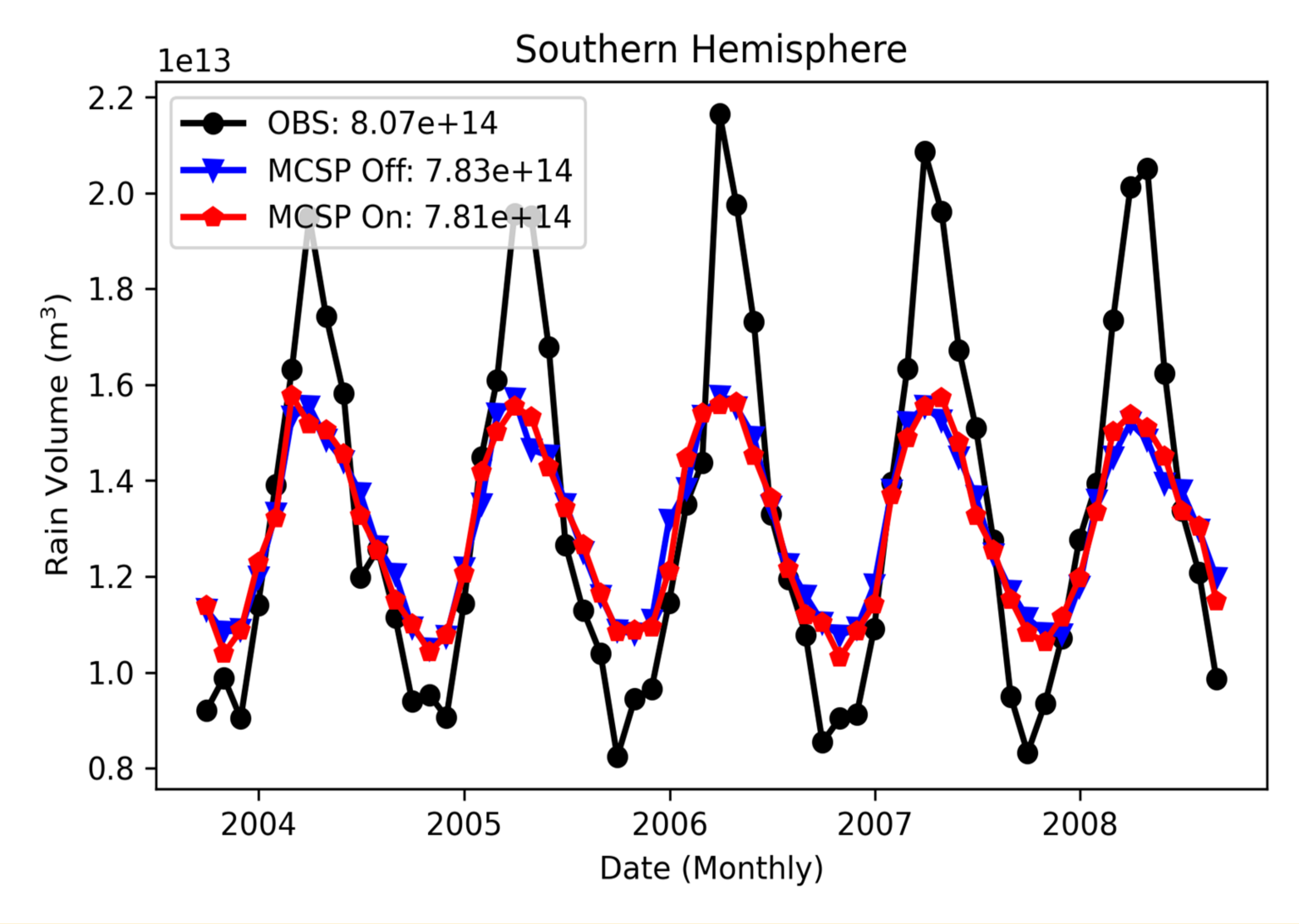

No change in S hemisphere

Tropical wave frequency

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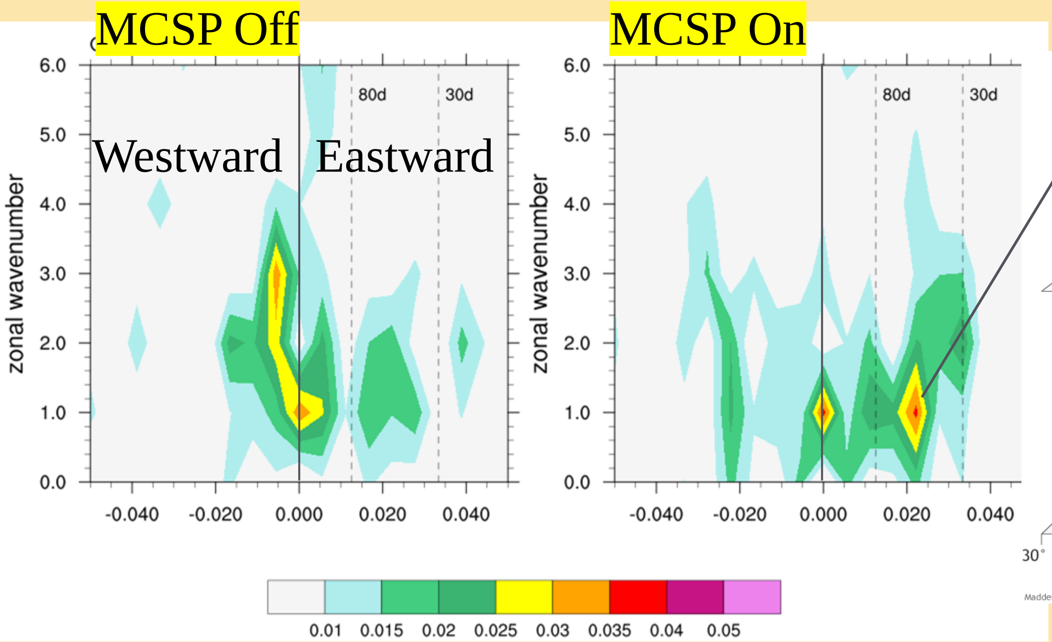
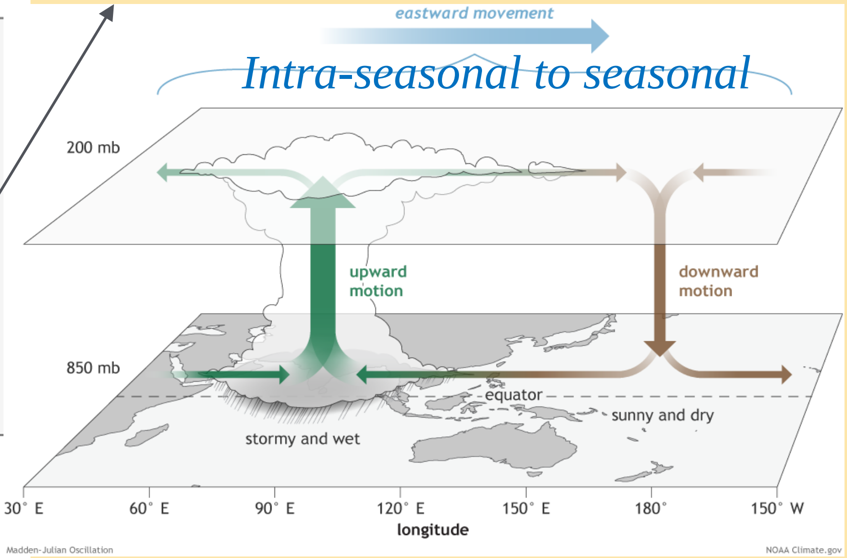


Madden–Julian Oscillation (MJO)



MCSP scheme enhances the plausible eastward-propagating waves and suppresses the unrealistic westward-propagating waves (May-Oct spectra)

MJO life cycle, OLR and U850 anomalies

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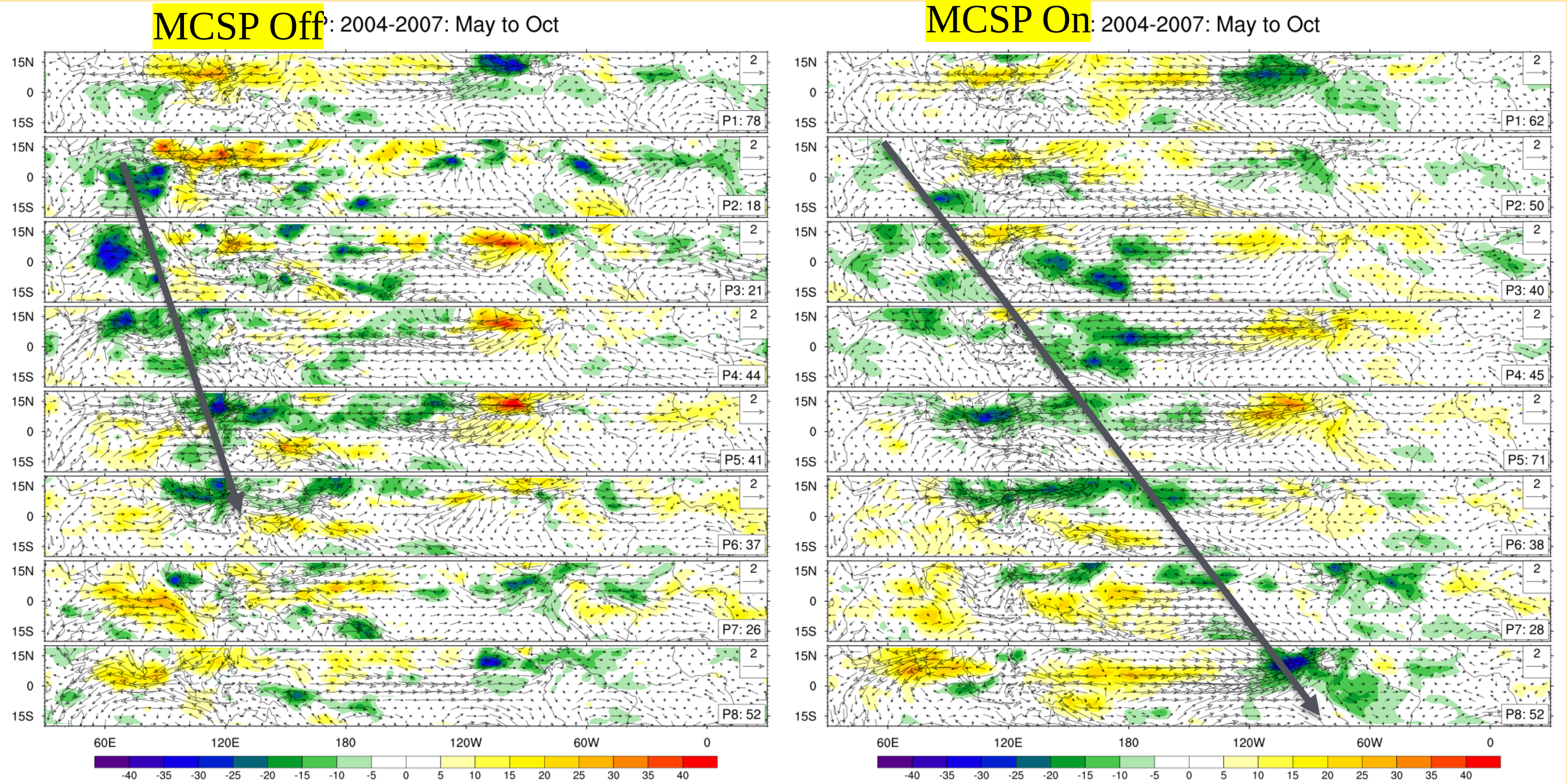

Scheme needs P (MCS | conv, variable)

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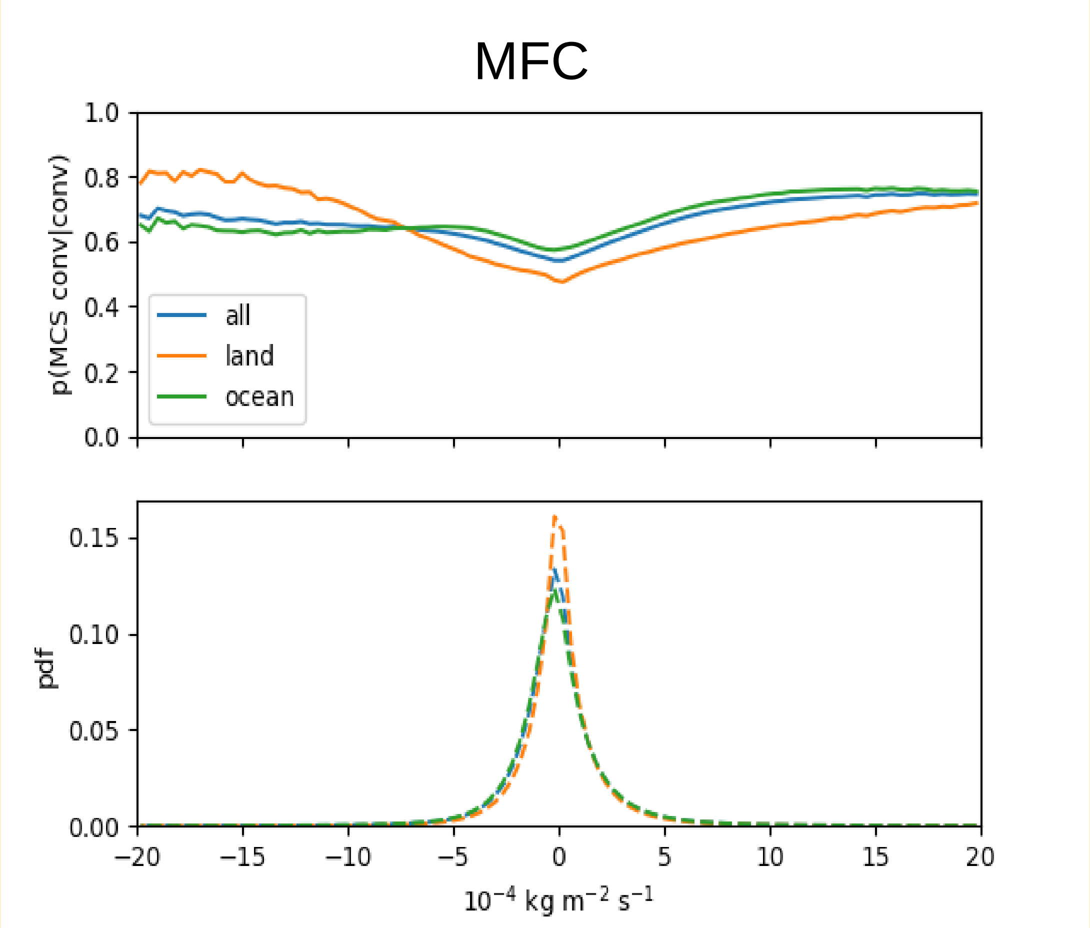

Conditional probs

prob of variable

- Some change with MFC but TCWV is more marked