Towards a probabilistic parametrisation of Mesoscale Convective Systems

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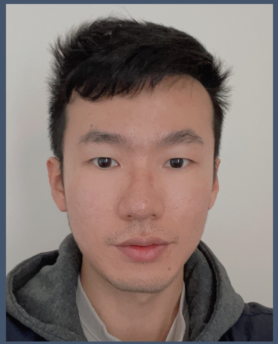
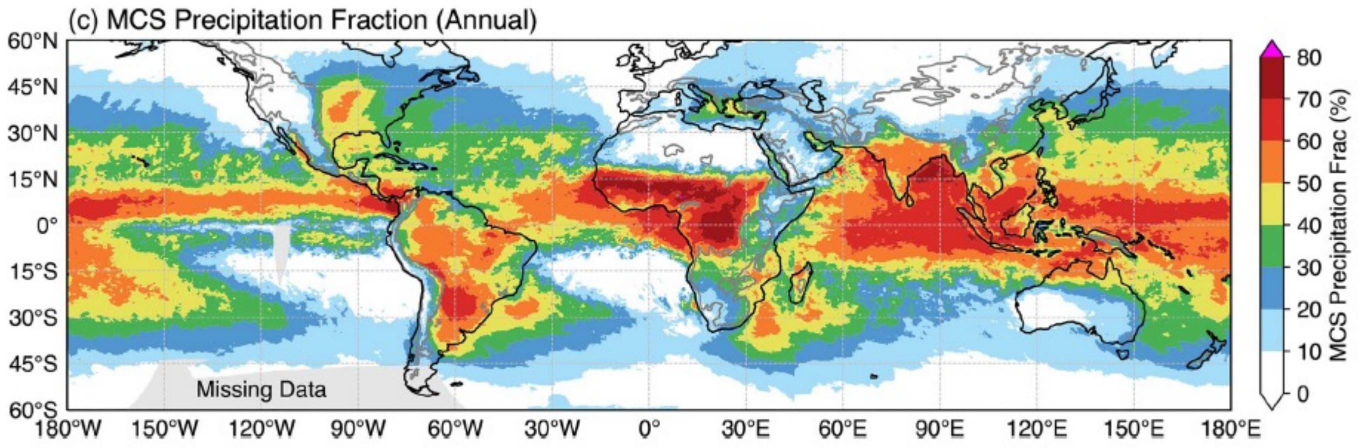


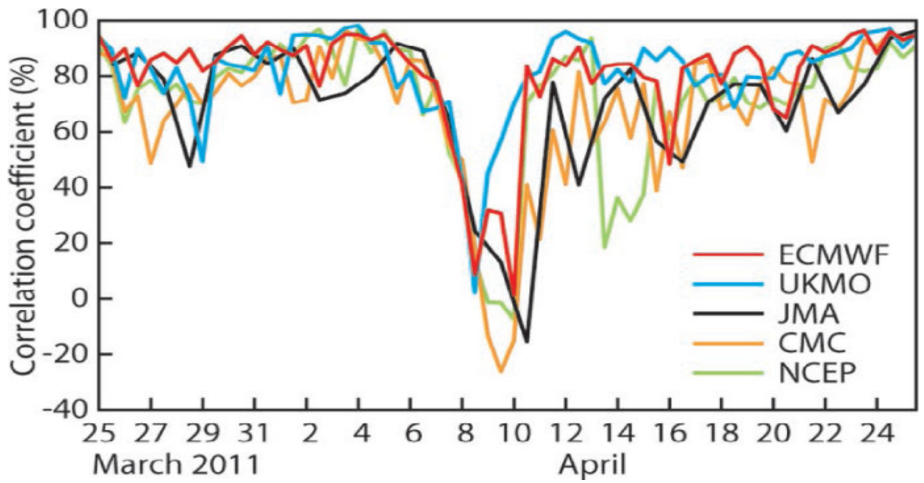
IAMAS, IUGG, Thursday 13 July 2023

Mesoscale Convective Systems (MCSs)

- MCS: long lived, spatially organised group of convective elements
  - Coherent mesoscale overturning circulation
  - Large upper-level stratiform component
- MCSs responsible for >50% of rainfall in large areas of tropics, >80% in some regions.
- MCS feedback onto large-scales. Can couple to dynamics in interesting ways.
- Poorly represented in weather and climate models



M. Moncrieff

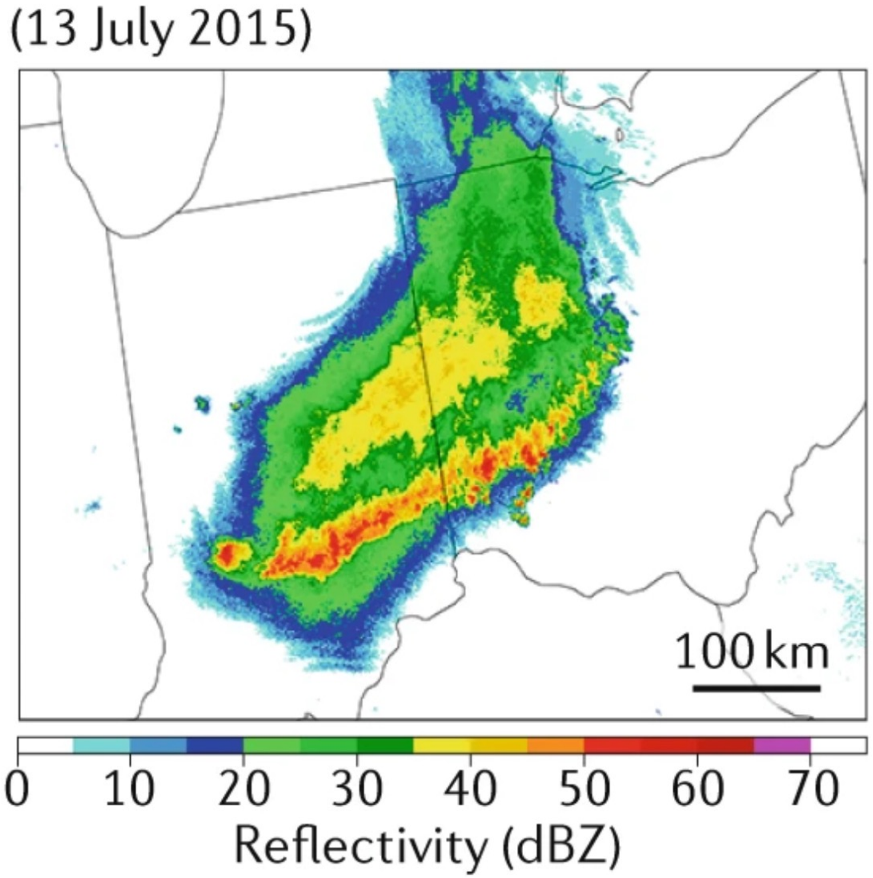


Rodwell et al, 2013

The MCS:PRIME project

Natural Environment Research Council

- *PRobabilistic forecasting and upscale IMpacts in the **grey zone***



The MCS:PRIME project

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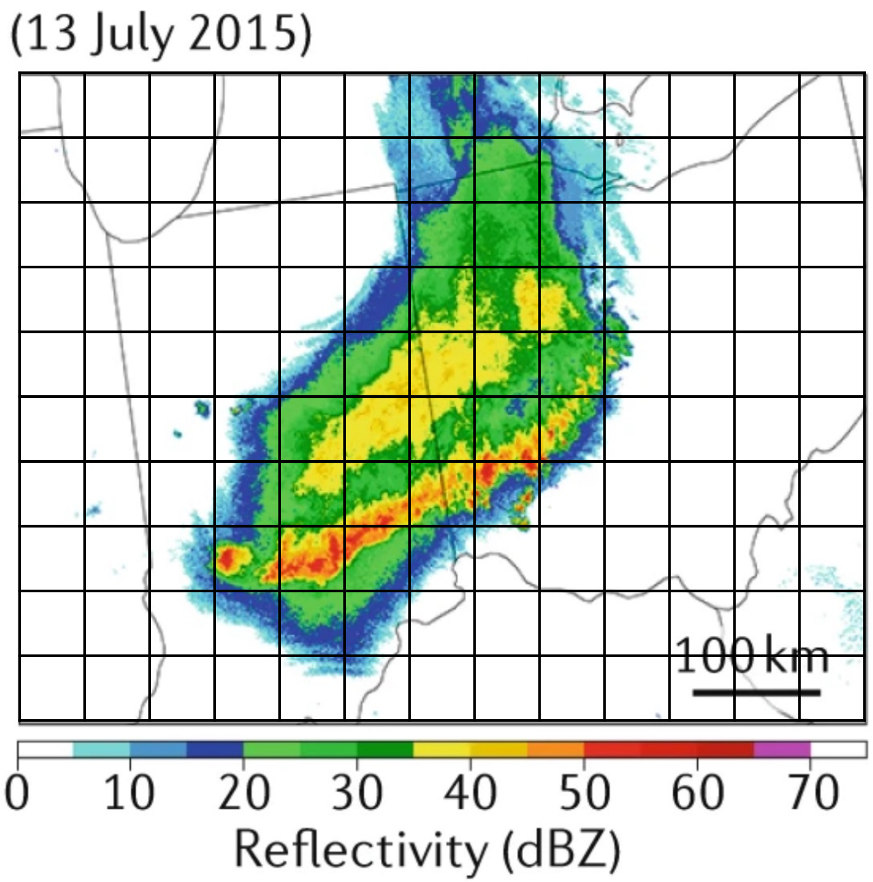
➢ *PRobabilistic forecasting and upscale IMpacts in the* ***grey zone***



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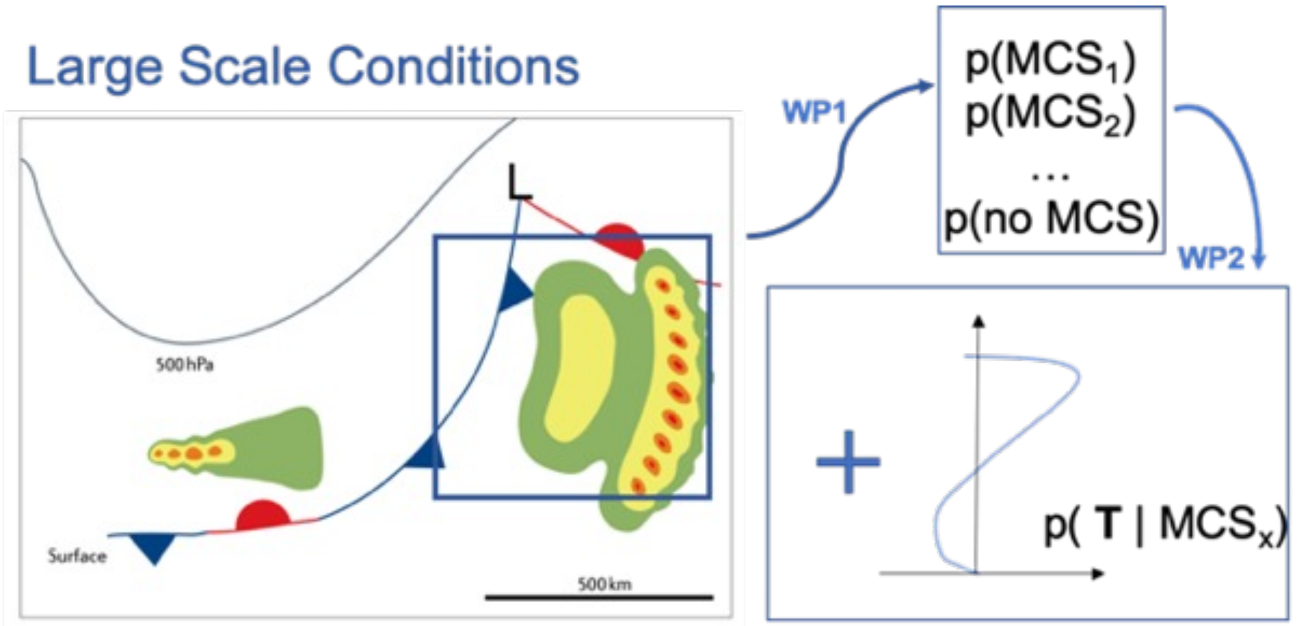


E.g. An existing MCS scheme

➢ The **MCSP** scheme of Moncrieff et al., 2017

- Second baroclinic normal mode with amplitude proportional to vertically averaged convective heating (via tunable parameter α)

- Scheme triggered if column exceeds wind shear threshold of 3 m^{-2}

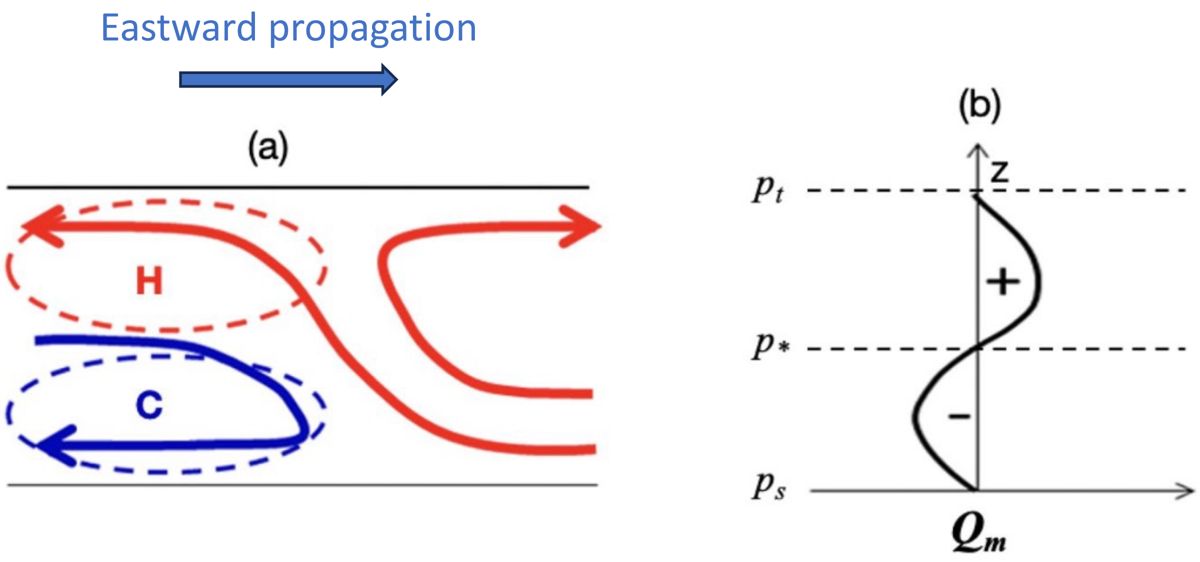
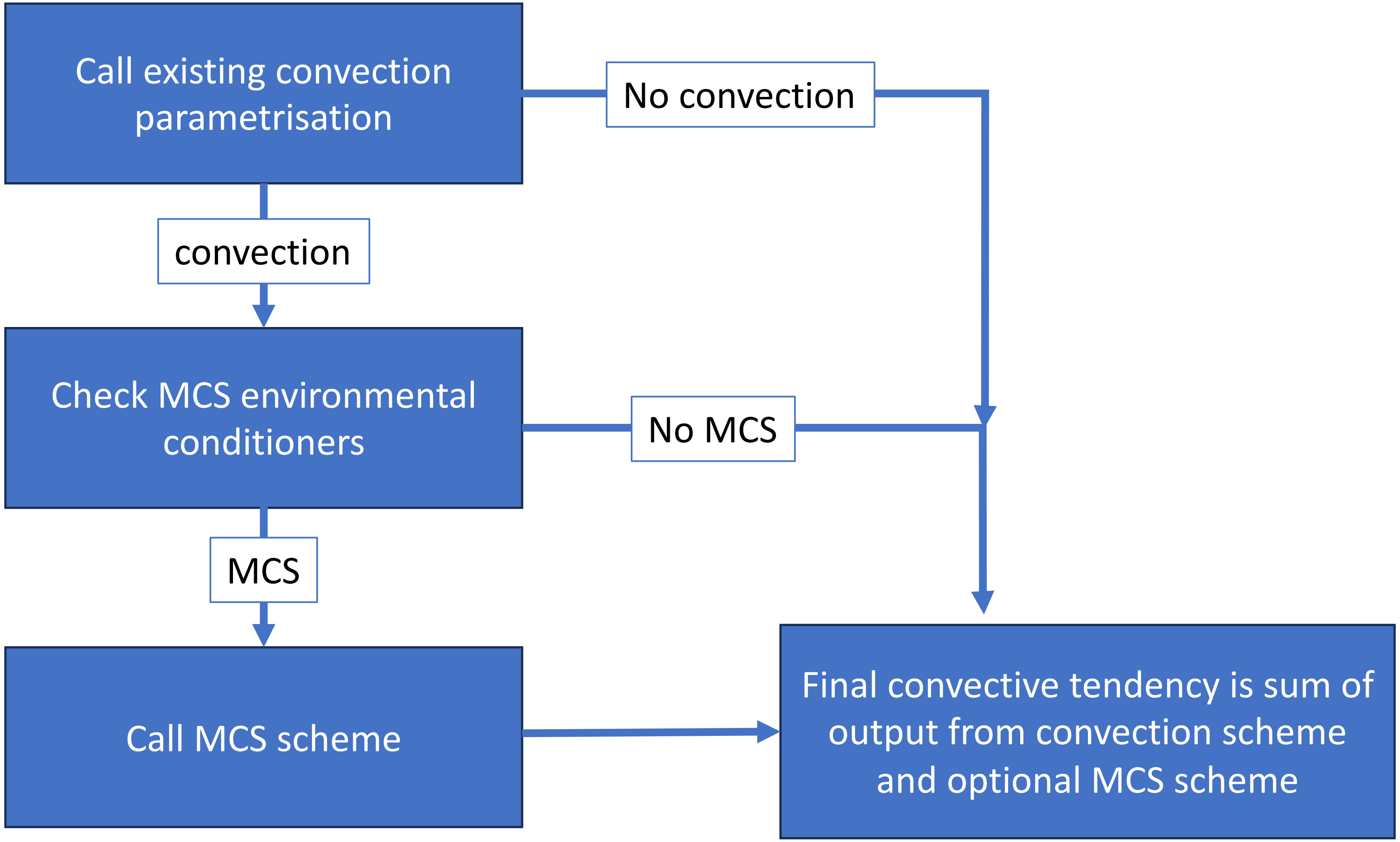
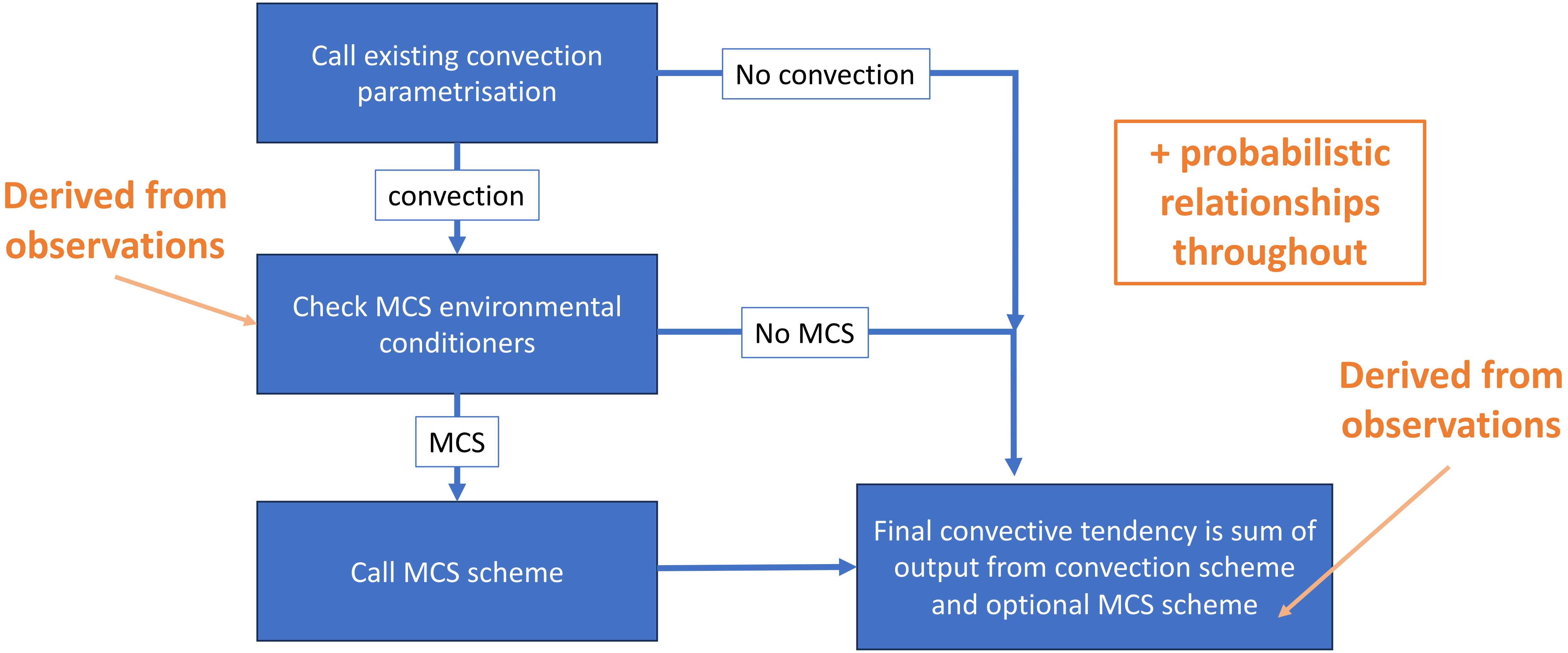


Fig from Chen et al, 2021, JAMES

MCS:PRIME follows same basic structure …



… but with physically motivated improvements

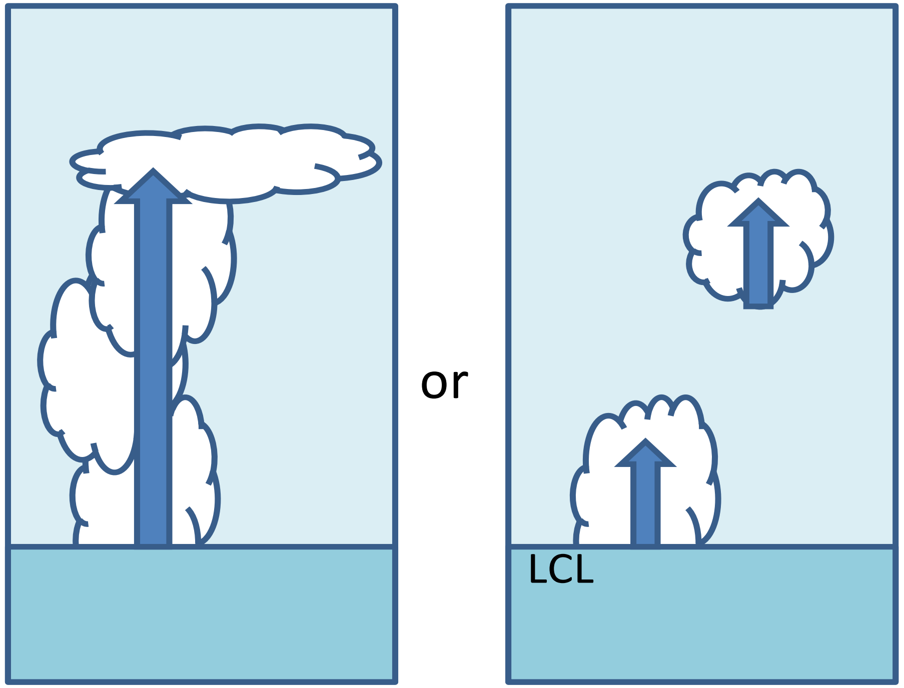


1. Implement Moncrieff scheme in Met Office model

- First challenge: couple with the new CoMorph convection scheme
  - New mass flux scheme for the UM, currently in trials
  - Large MO / university partnership, ParaCon, but especially by Mike Whitall

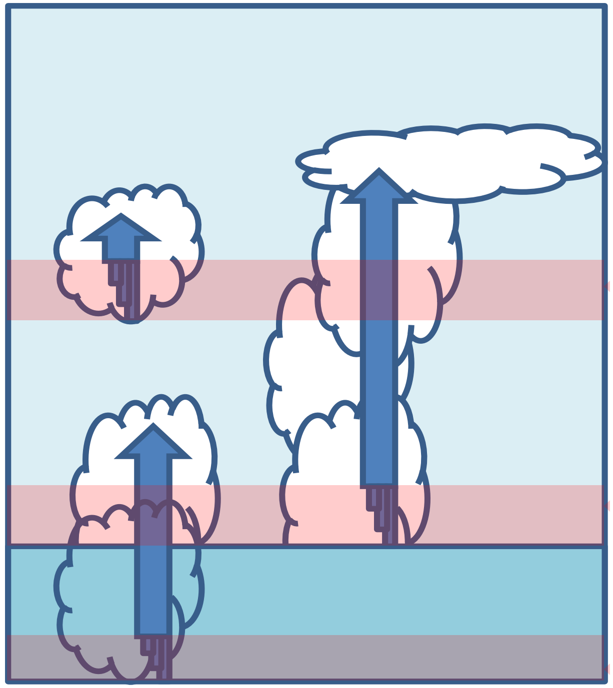
"Traditional" approach:

- Complex empirical trigger functions.
- Plume can only start from surface or diagnosed cloud base.
- Separate schemes for "deep", "shallow" and "mid-level" convection (must be pre-diagnosed which one to trigger).



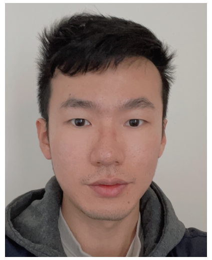
CoMorph – Back to Basics:

- Convecting parcels launch from any height where there is local vertical instability.
- Plumes from different unstable layers integrated independently.
- Single parcel ascent / descent code for all plumes.



Slide from Mike Whitall

Work by Zhixiao Zhang

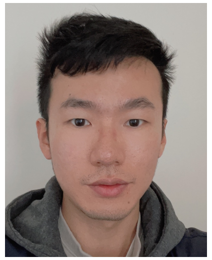


1. Implement Moncrieff scheme in Met Office model

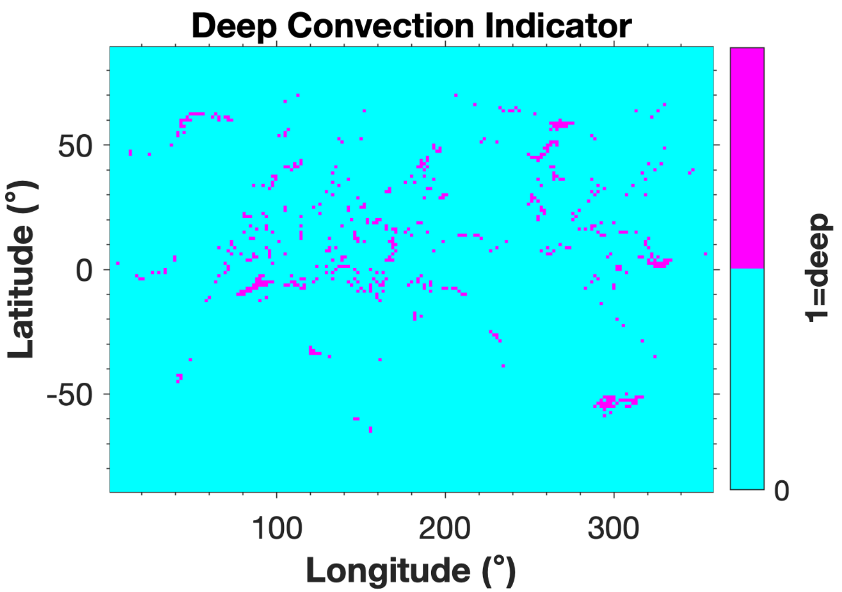
Triggering organized convection parametrisation requires:

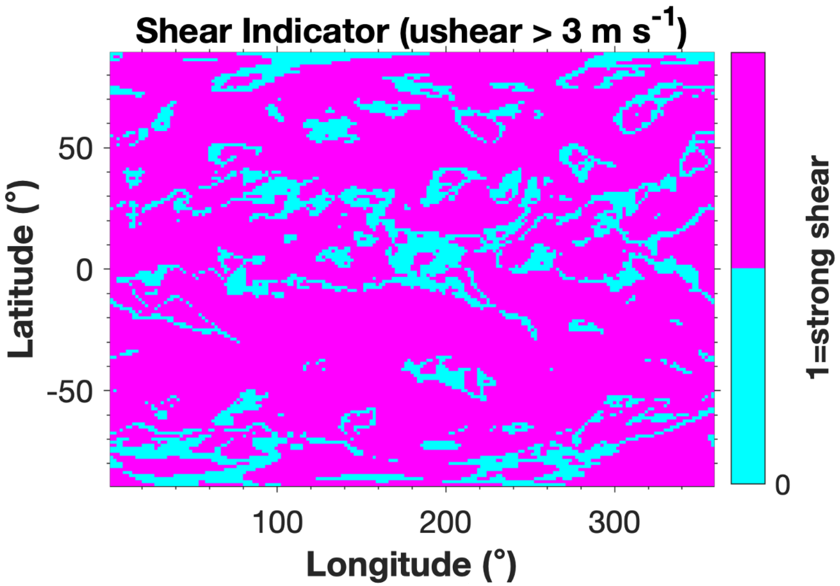
- NEW Deep convection indicator: org_deep_ind = 1
  - Cloud top temperature < 0 ^{o}C
  - Cloud base pressure > 600 mb
  - Cloud base and top pressure difference > 300 mb
- Wind shear indicator (set by namelist parameter): org_shear_ind = 1
  - Vertical wind shear | (600mb – lowest level) | > 3 m/s

Work by Zhixiao Zhang

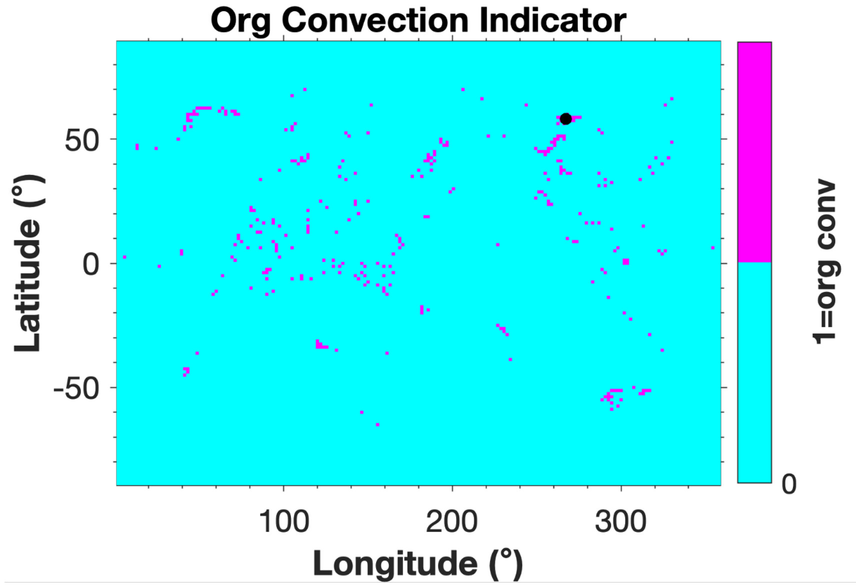


Triggering conditions

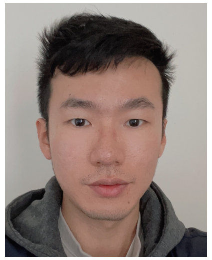




Meet both deep and shear indicator >

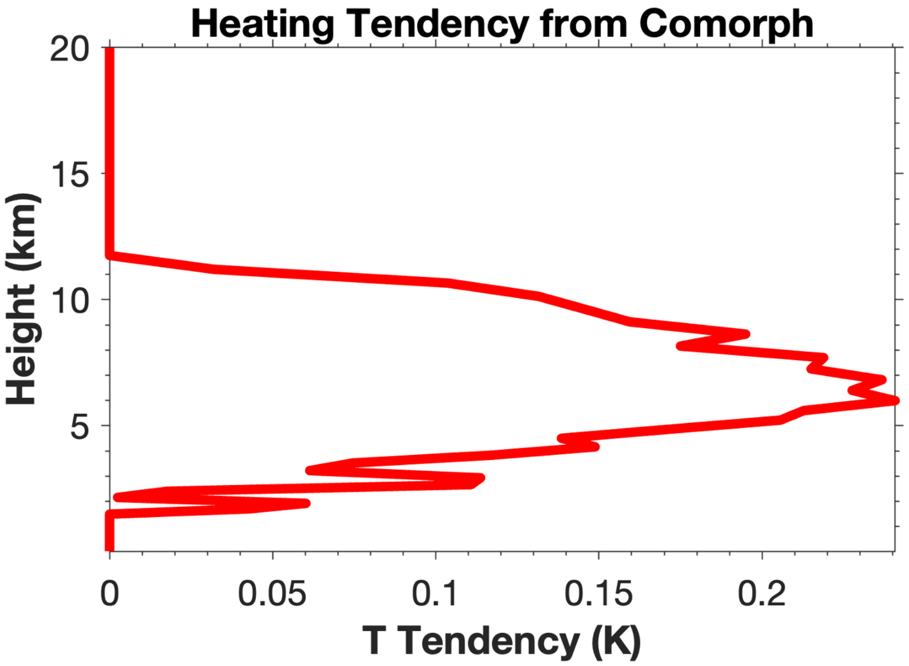


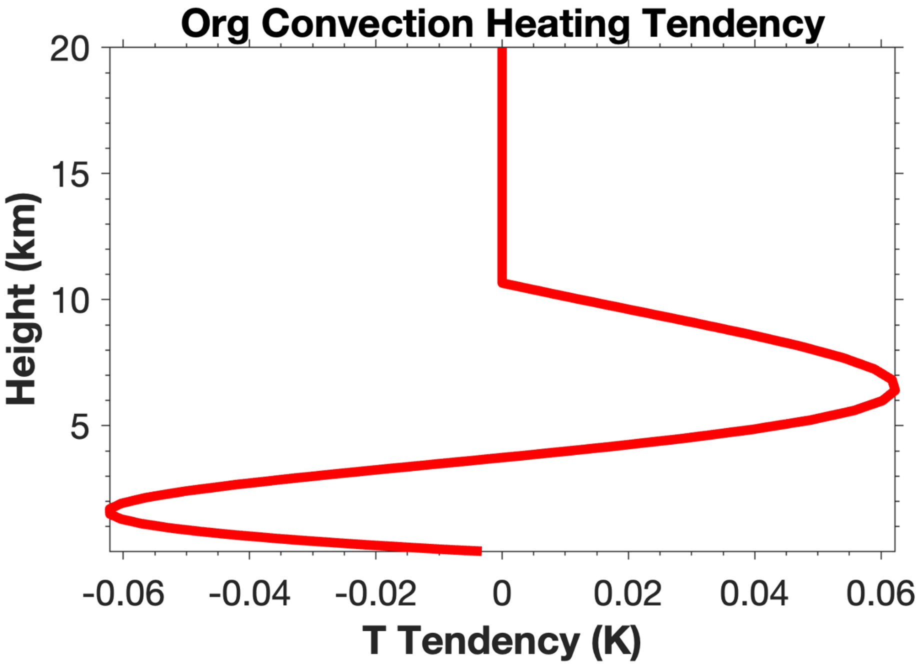
Work by Zhixiao Zhang



Preliminary tests of “vanilla” scheme

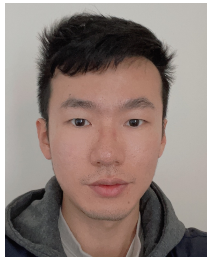
- Following AMIP-UM setup in CMIP6
- From Sept 2003 to Sept 2008
- Global N96 (192*144 pixels, 1 to 2 degrees), 85 vertical levels, 20 min timestep

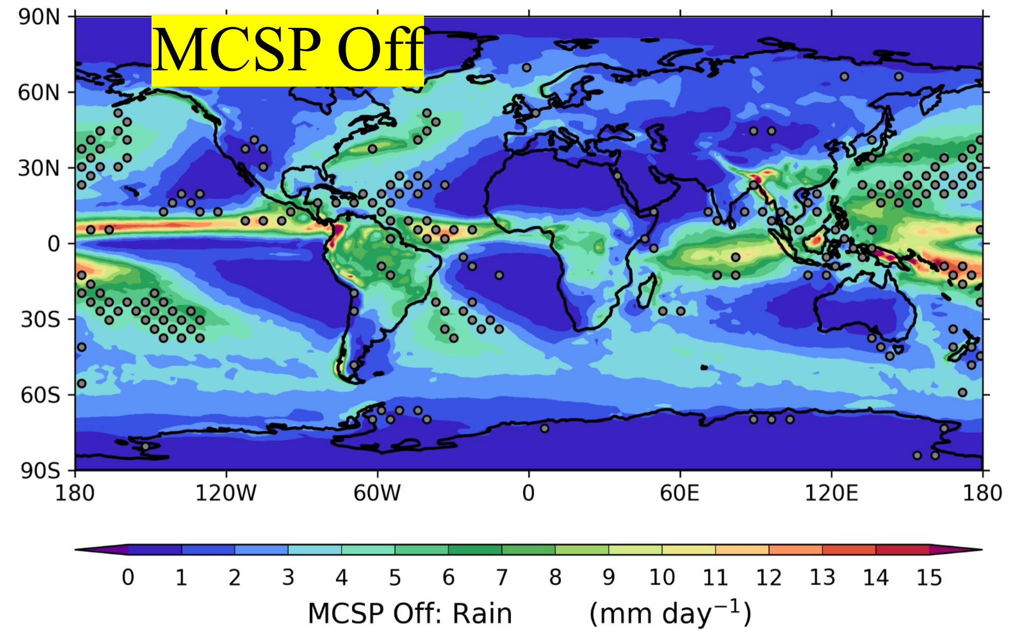


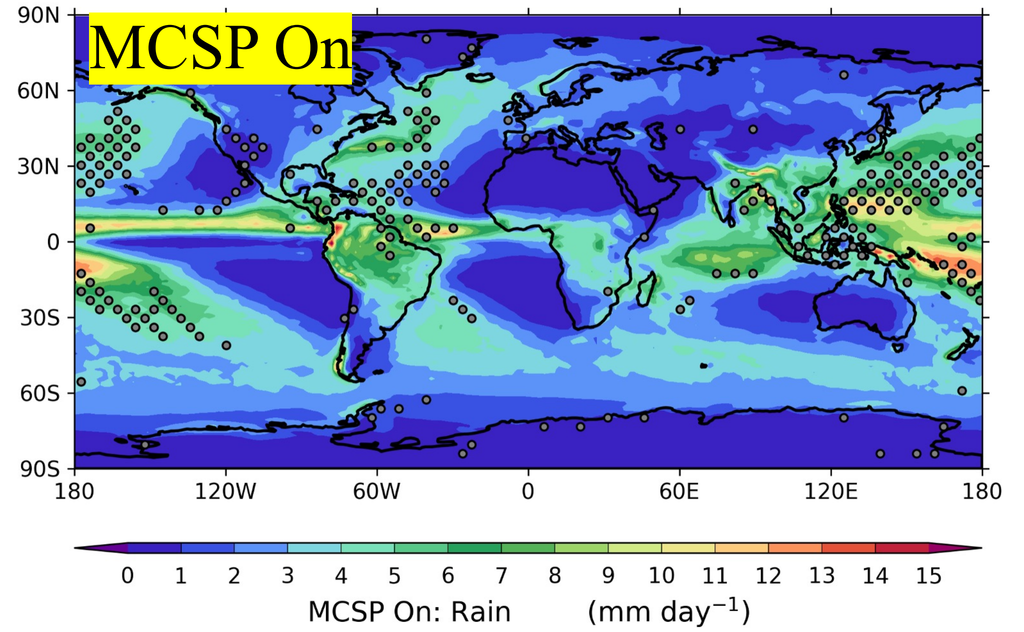


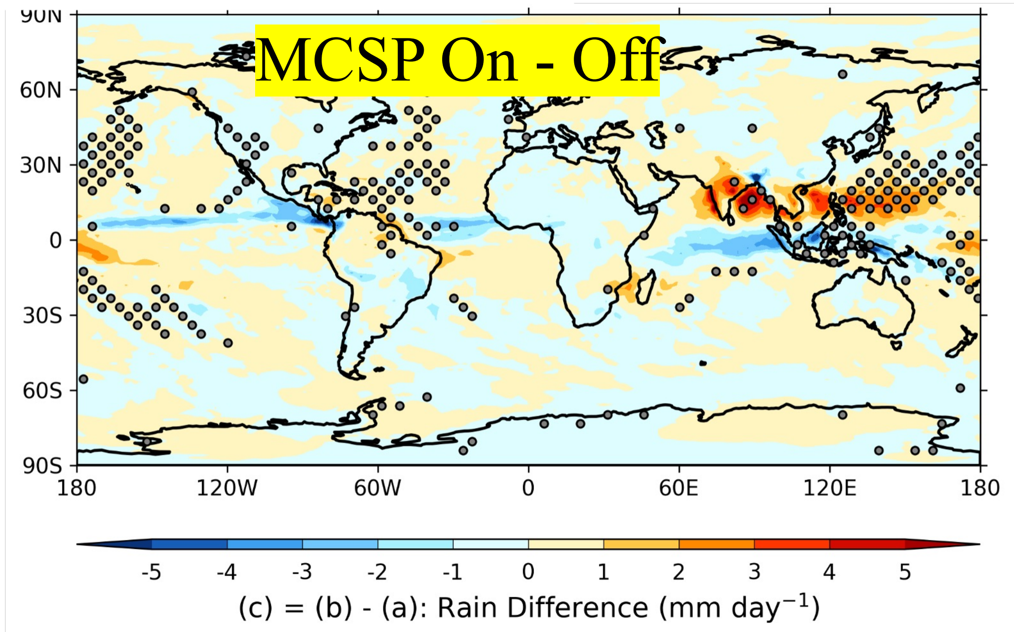
Rain Rate & Significance Test

Work by Zhixiao Zhang





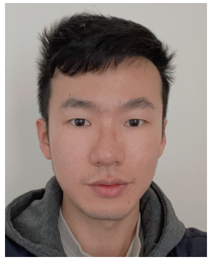


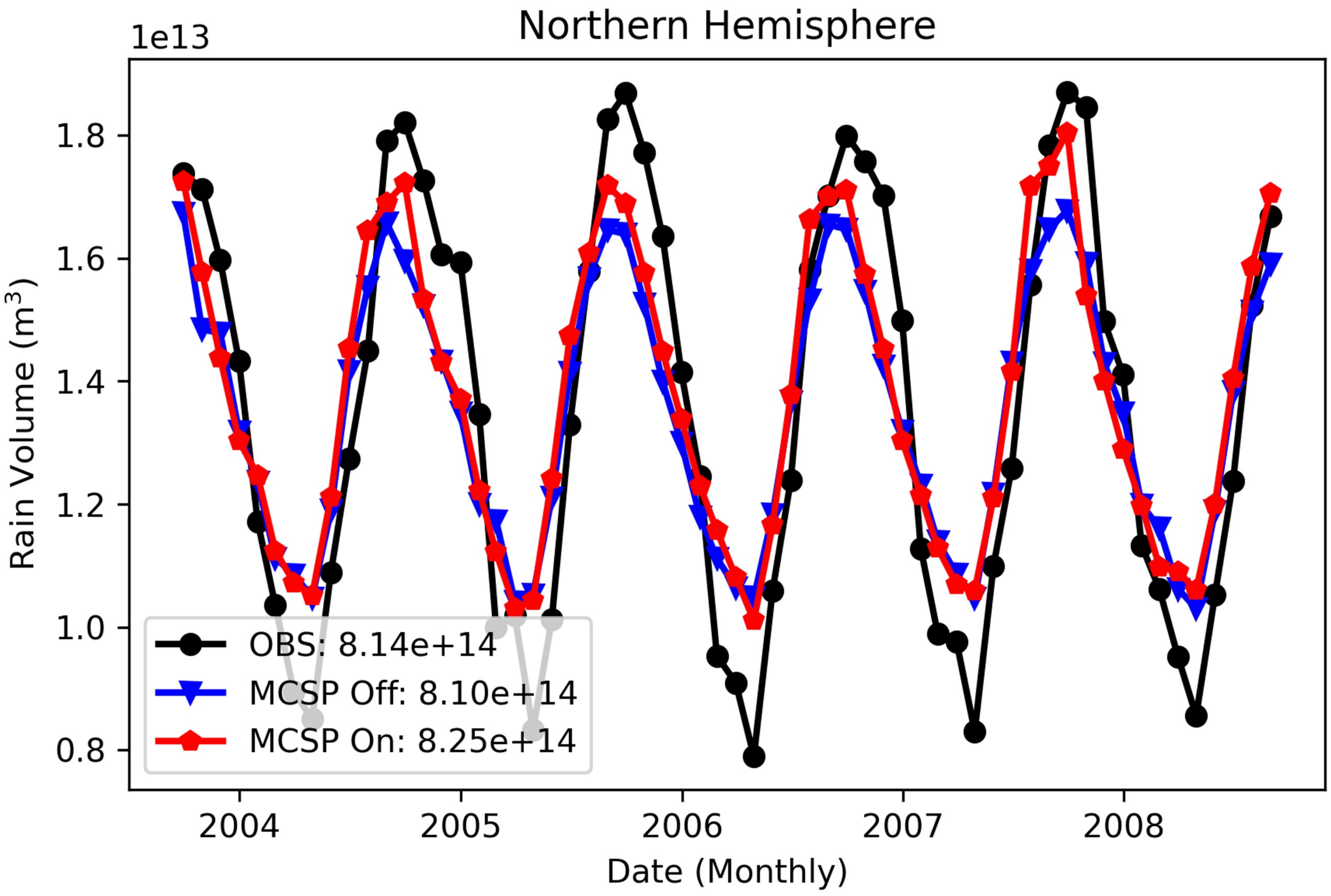


Dots indicate that the UM run significantly disagrees with CMIP6 (out of 5th-95th percentile range)

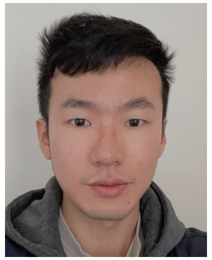
Precipitation Seasonal Cycle

Work by Zhixiao Zhang

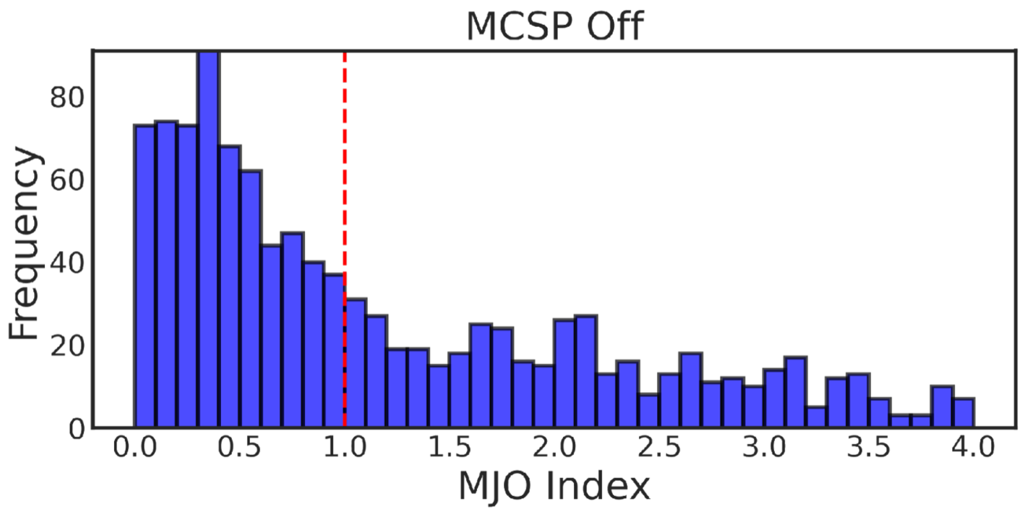


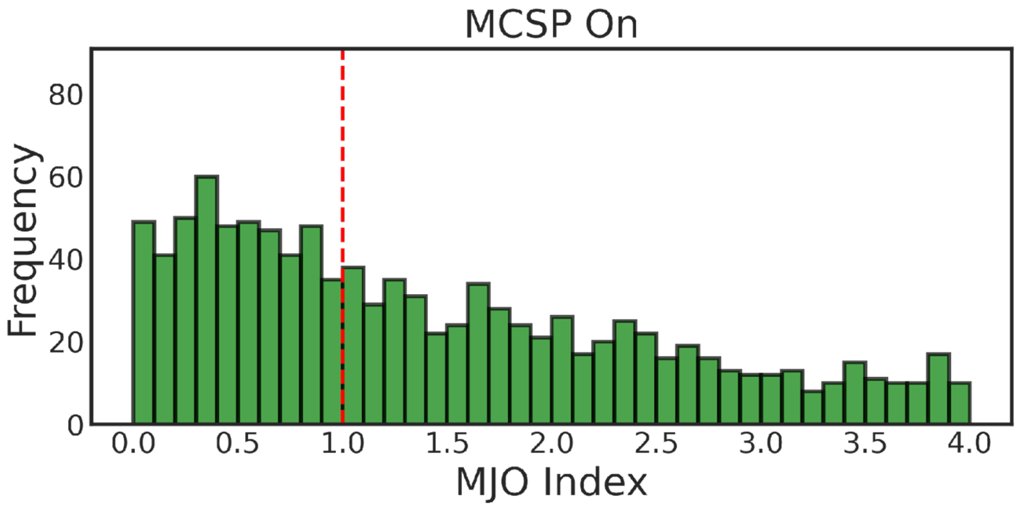


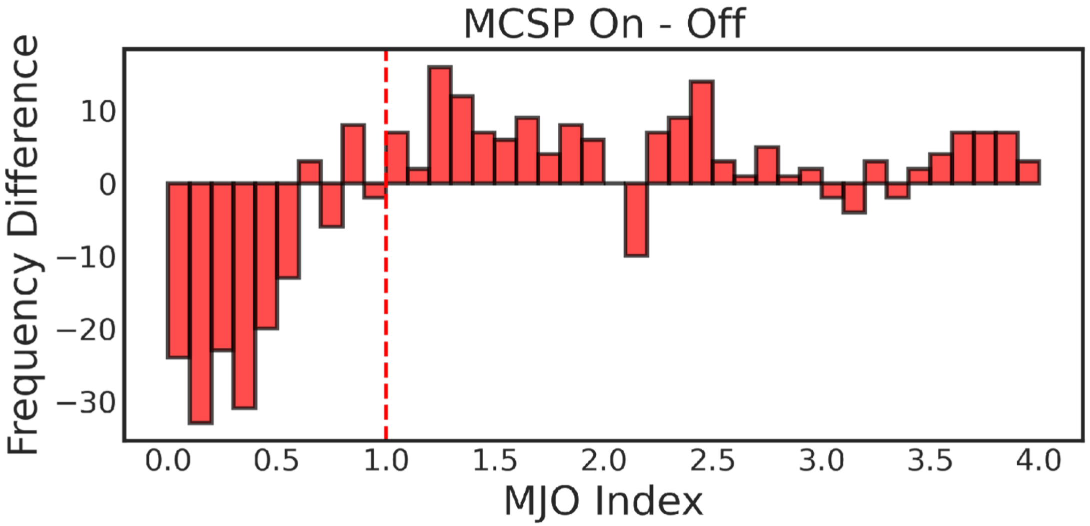
Work by Zhixiao Zhang



Significant increase in MJO activity



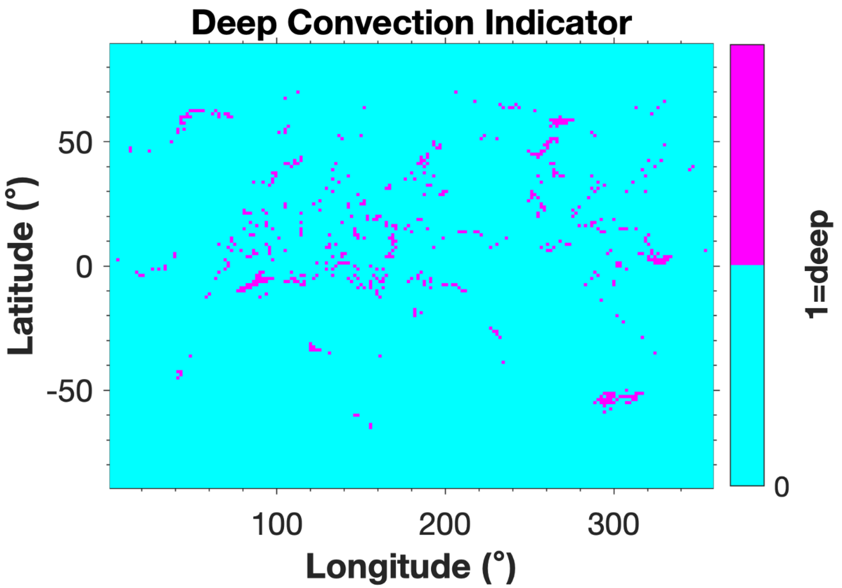


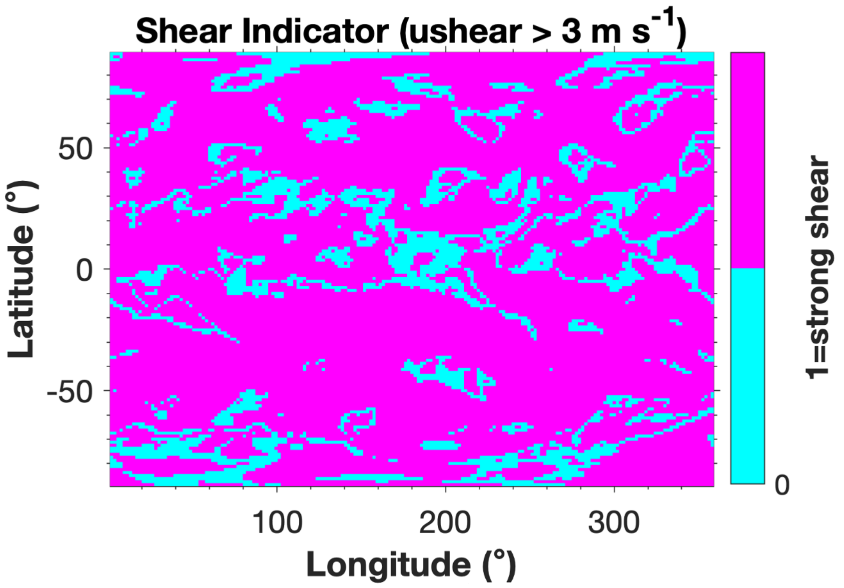


Consistent with earlier results in NCAR's CAM and DoE's E3SVv1

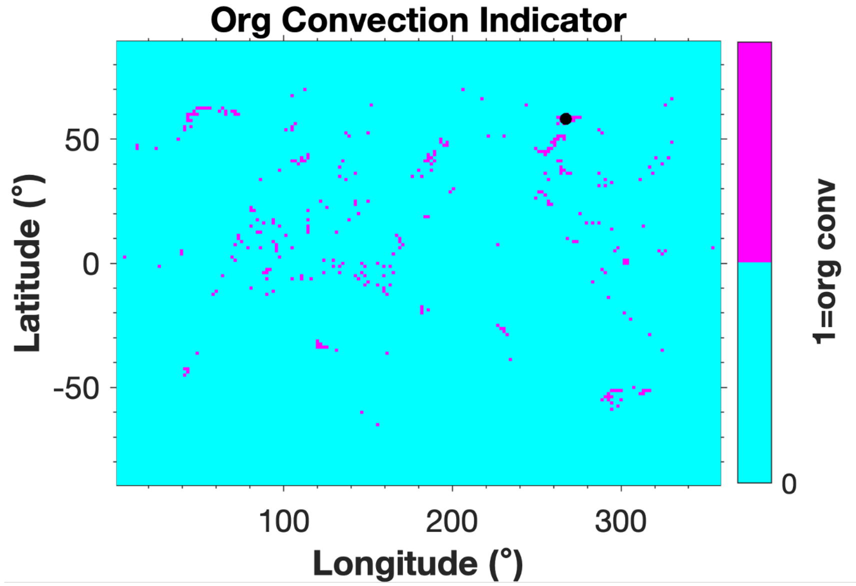
Clearly demonstrates importance of representing MCS

Triggering conditions





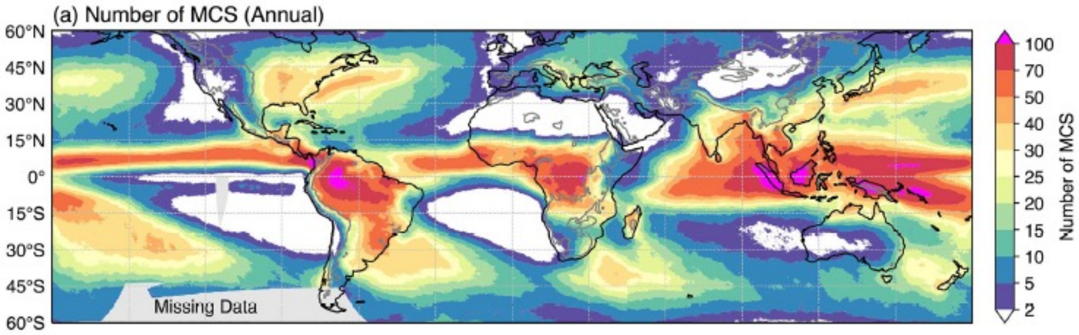
Meet both deep and shear indicator >

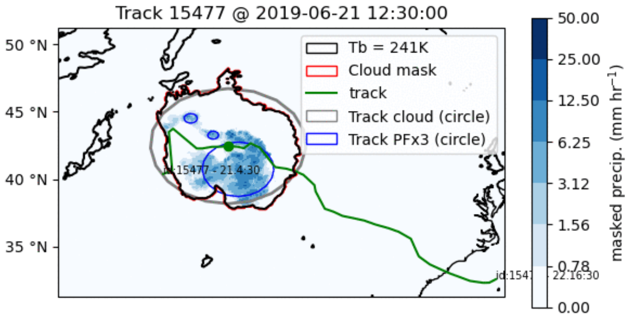


Work by Mark Muetzelfeldt

2. Assess environmental conditions for MCS

- Use a global MCS dataset (Feng et al., 2021) to identify where MCSs occur



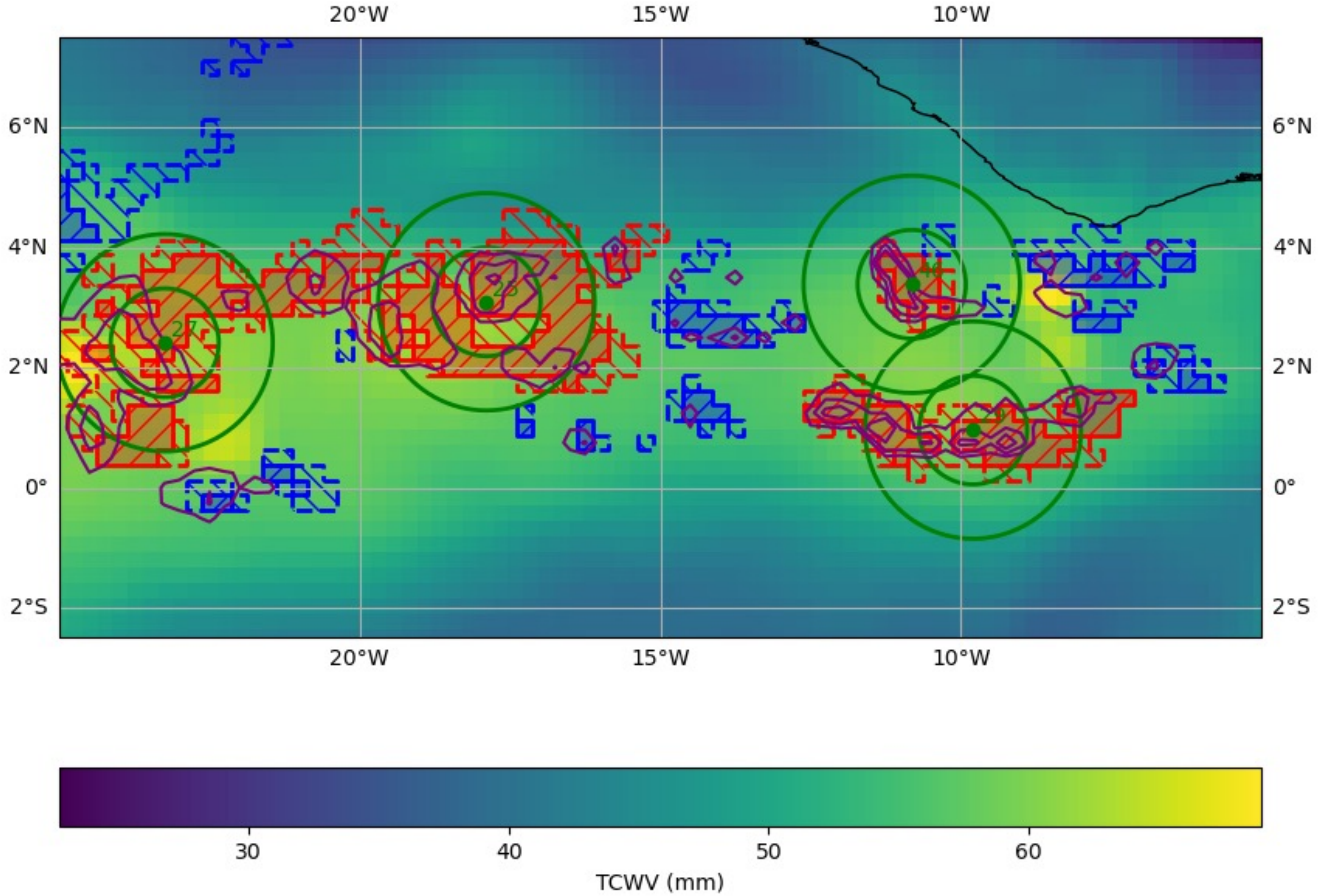


- Match tracked MCSs to ERA5 conditions
  - **CAPE**
  - Total Column Water Vapour (**TCWV**)
  - Moisture Flux Convergence (**MFC**)
  - Low-Level Shear (**LLS**, surf-800hPa)

Work by Mark Muetzelfeldt

Analysis regions overlayed on TCWV

Taken from MCS tracking dataset



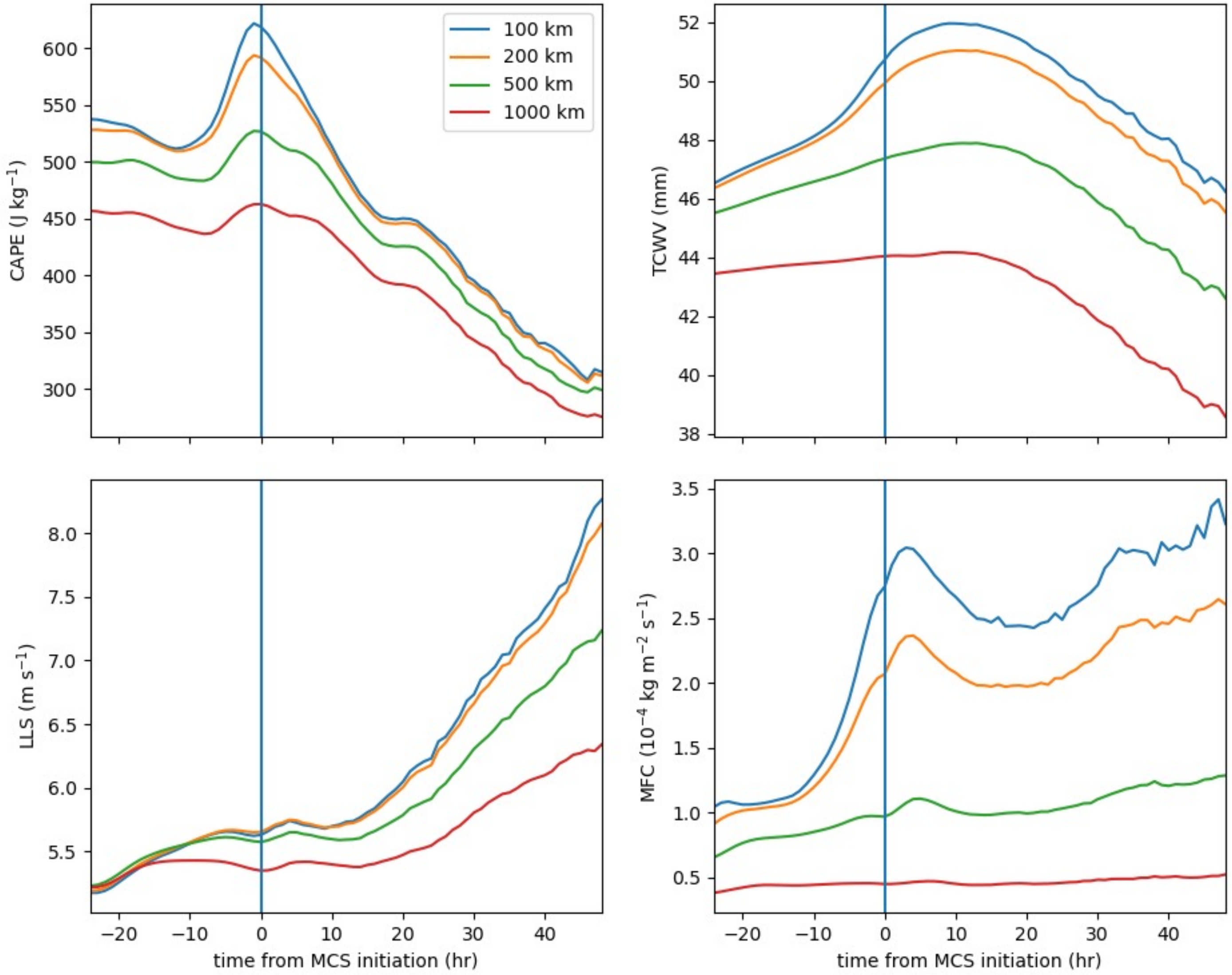
- Shield < 241K (dashed)
- Core < 225K (solid)
- MCS: red
- non-MCS: blue

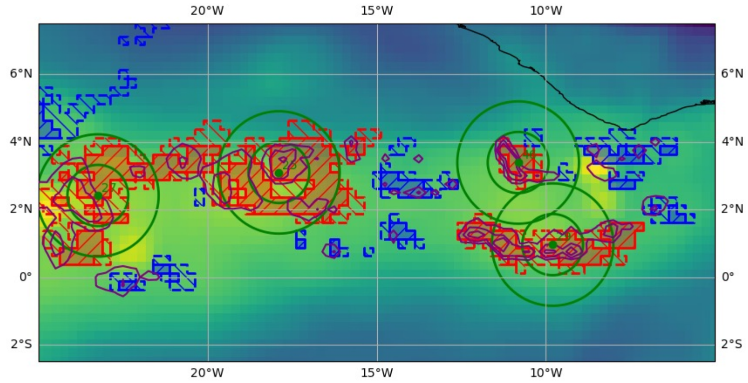
- Green
  - Dot: MCS centroid
  - Circles: 100km, 200km

- Purple contours: precip.

Work by Mark Muetzelfeldt

Precursor environments





- Before MCS initiation, use first MCS centoid +100km, 200km, 500km, 1000km
- After MCS initiation, use MCS track centroid

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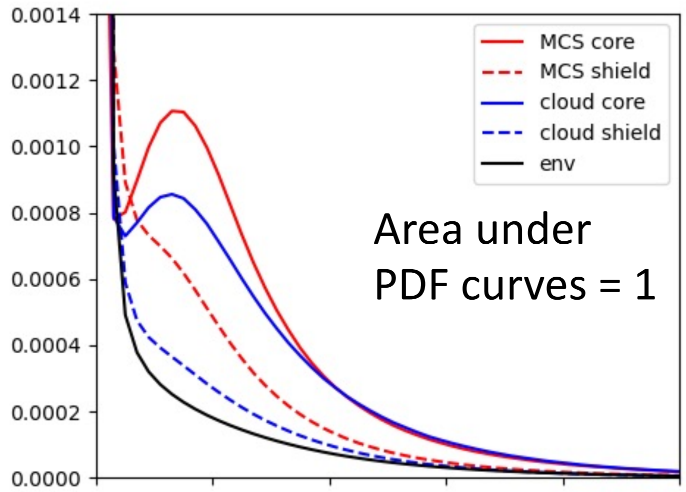
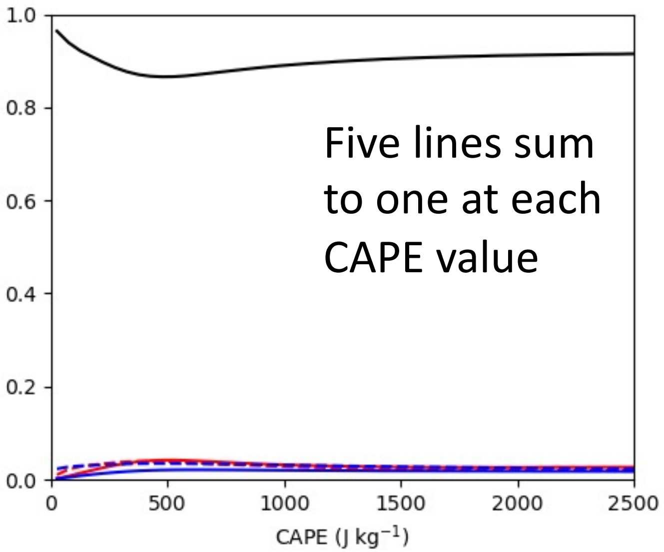
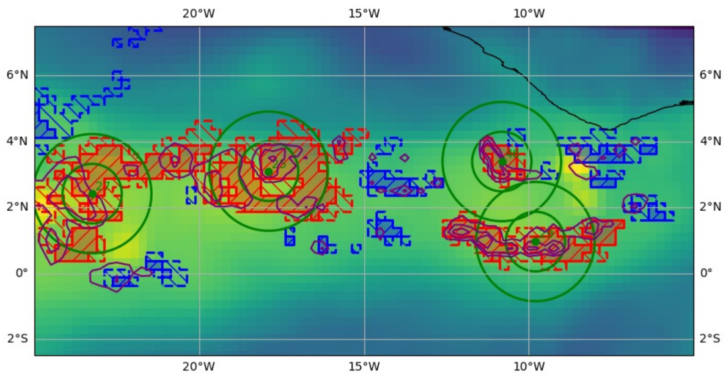
CAPE distributions in 5 regions







Dashed: within MCS shield
Solid: within MCS core

Blue: Isolated convection
Red: tracked MCS

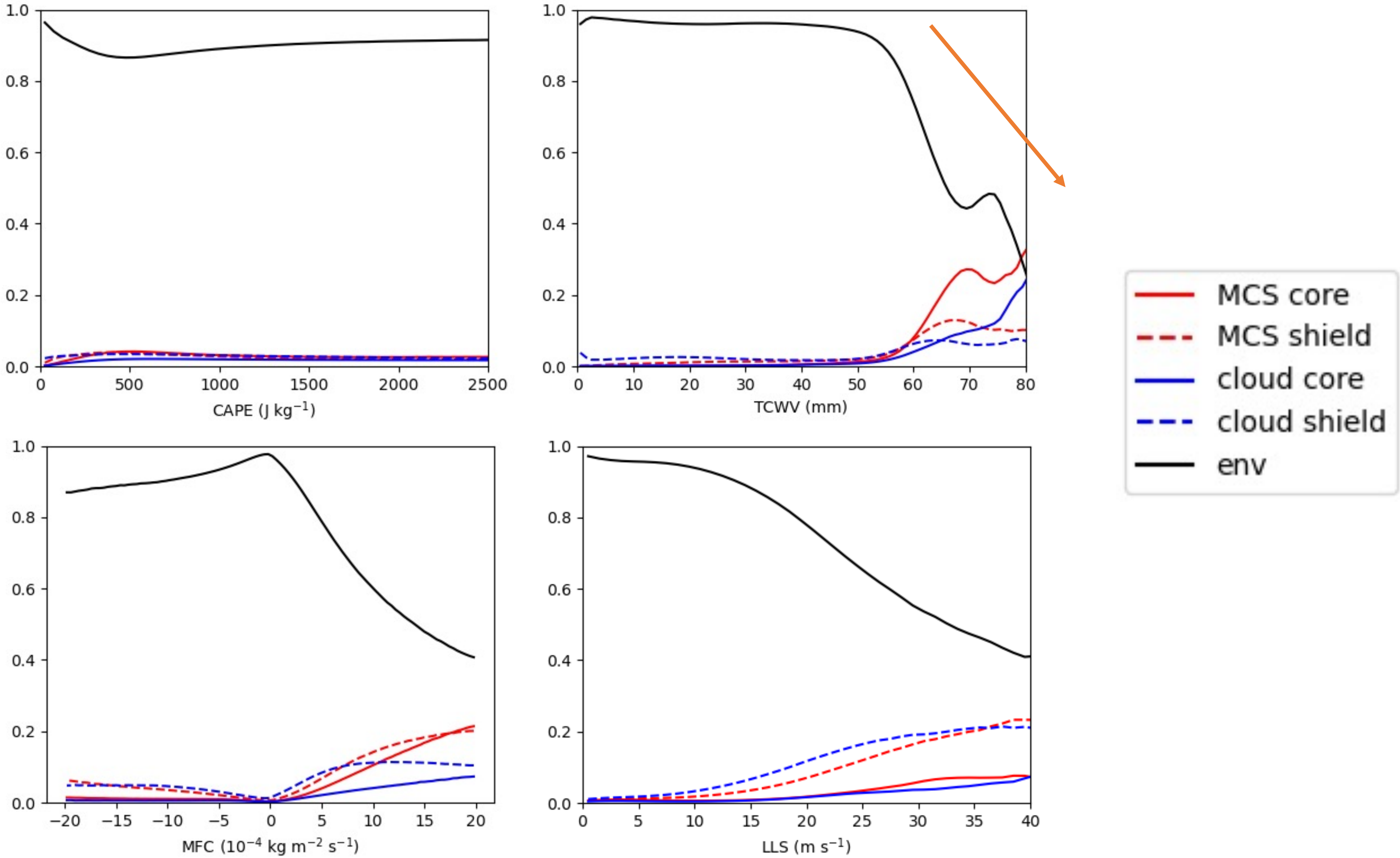
Top: distn within each region
Bottom: prob of being in each region

Work by Mark Muetzelfeldt

CAPE shows smaller signal than other variables

P(region type | variable)

P(region type | variable)



Conditioning on convection

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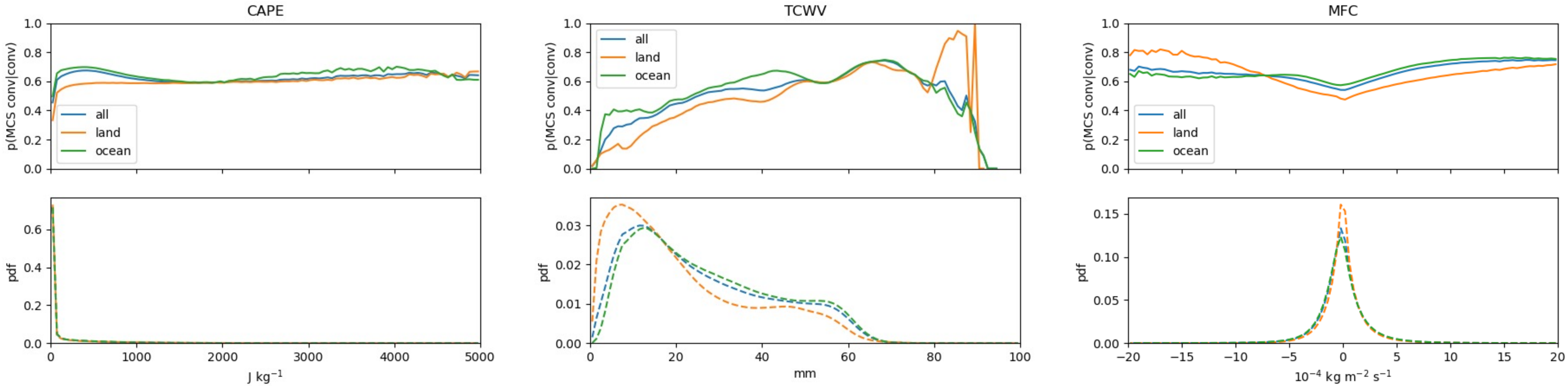


Question must be carefully posed to give useful information for parametrization:

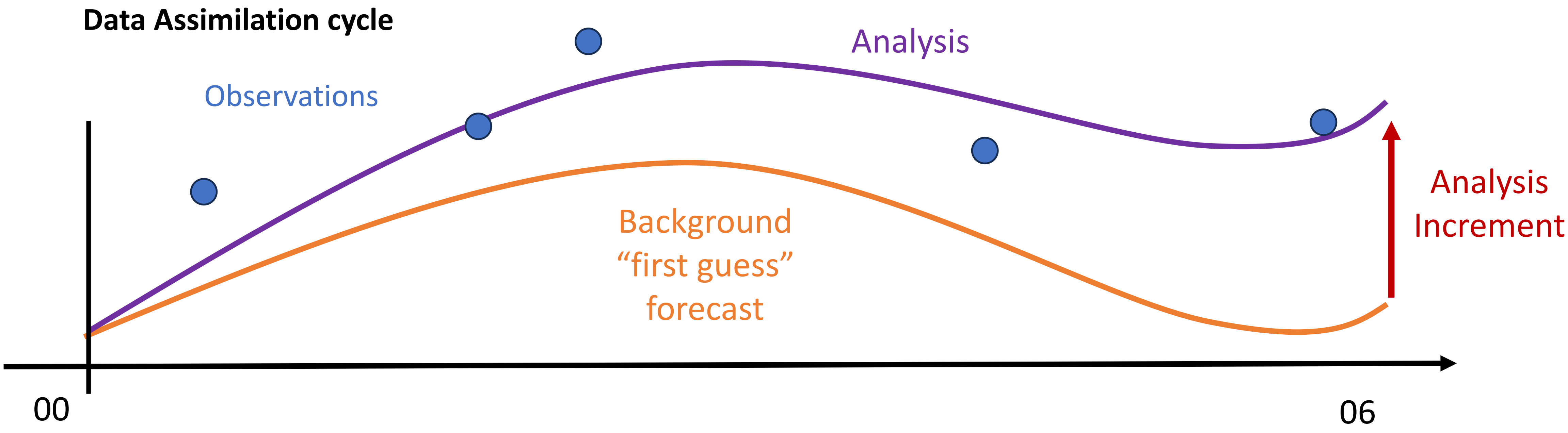
> Need to know **P(MCS|<env_cond>, convection)**

Conclusions

- **Large potential benefits of MCS scheme in UKMO model, but existing shear threshold inappropriate**
  - Impacts on precipitation and MJO
- **Increase in environmental variables 5-10 hours before MCS initiation**
  - Different environmental variables have different lead/lag relationships
  - Shear appears to feedback onto the environment most notably, affecting the largest scales analysed
- **MCS core/shield distributions of environmental variables is distinct from non-MCS core/shield distributions**
  - Both are distinct from the wider environment
  - When taking into account relative areas, only some variables show predictive power
- **TCWV has the clearest signal for distinguishing MCS vs non-MCS convection**
  - Points to its use as a predictor in an MCS parametrization scheme

Future work

- Use Analysis Increment dataset to uncover upscale impact of MCS missing in current model



Future work

- Use Analysis Increment dataset to uncover upscale impact of MCS missing in current model
- Two-step improvement of “vanilla” MCS scheme
  - Include ERA5 derived MCS predictors
  - Include Analysis Increment derived realistic upscale impacts

Thanks for listening!

Extra slides

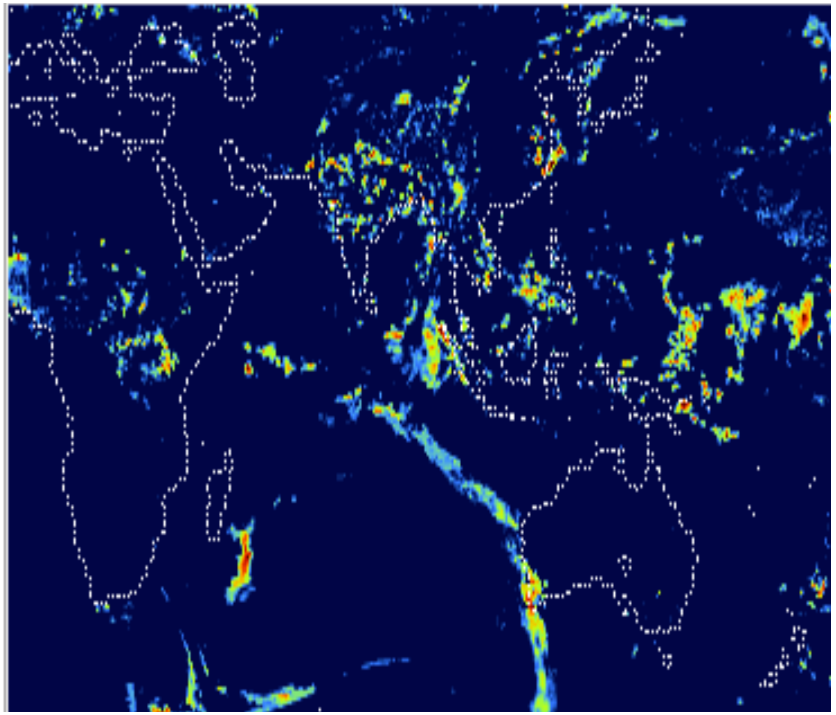
CoMorph

- New mass flux scheme for the UM, currently in trials
- Developed through large MO / university partnership, ParaCon, but especially by Mike Whitall
- Improved functionality includes:
  - Single-moment in-plume microphysics scheme, that allows for the mixed phase and graupel
  - Representation of in-cloud w, allowing convective overshoots
  - Separate consideration of cloud-mean and cloud-core properties in detrainment calculations
  - Simple representation of cold-pool effects, providing memory
  - Initiation of mass at any level, proportional to buoyant instability

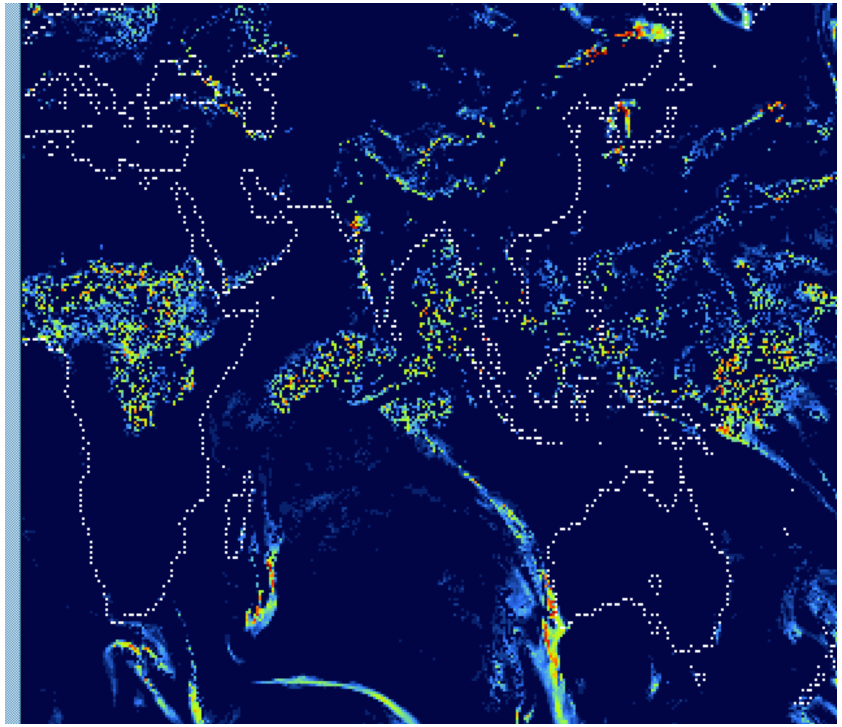
- And much better numerics to prevent artificial on/off behaviours

Snapshot of rain rates

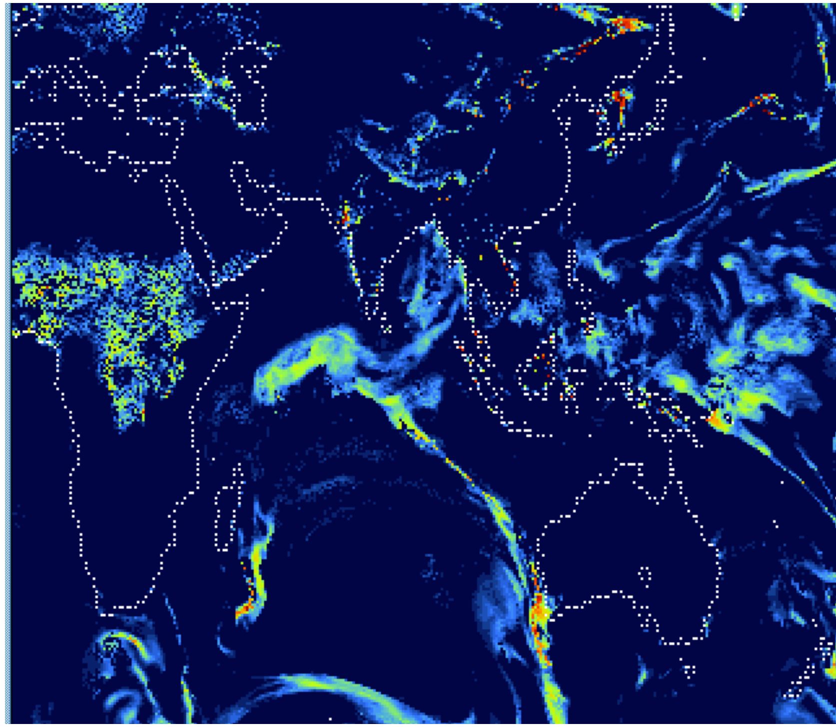
Many common closures (e.g. based on CAPE) have problems with intermittency



TRMM data



Old scheme, CAPE closure

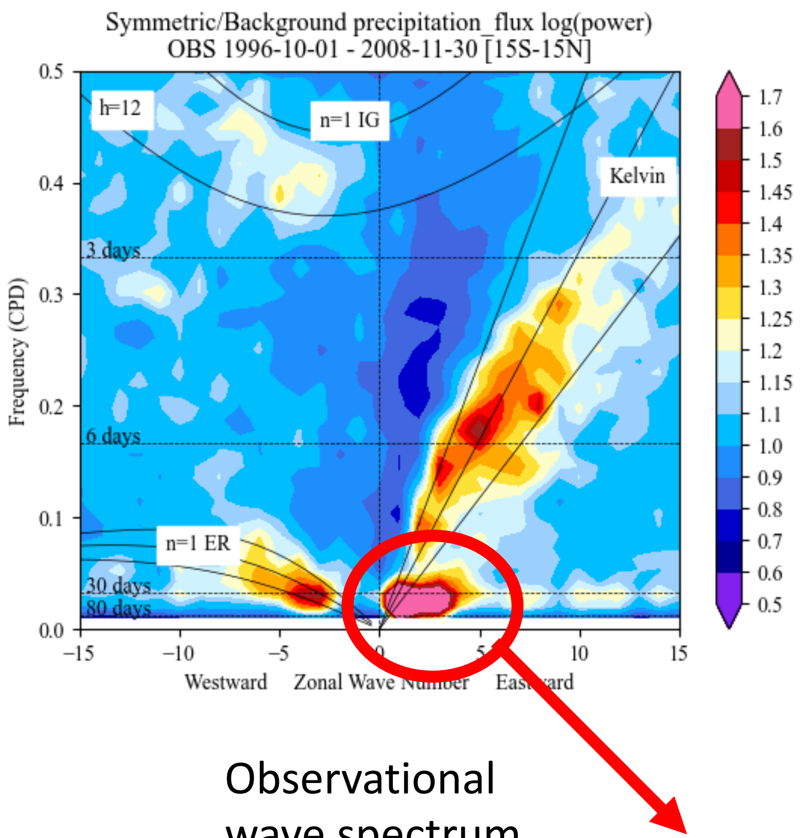


A Comorph test

Mike Whitall

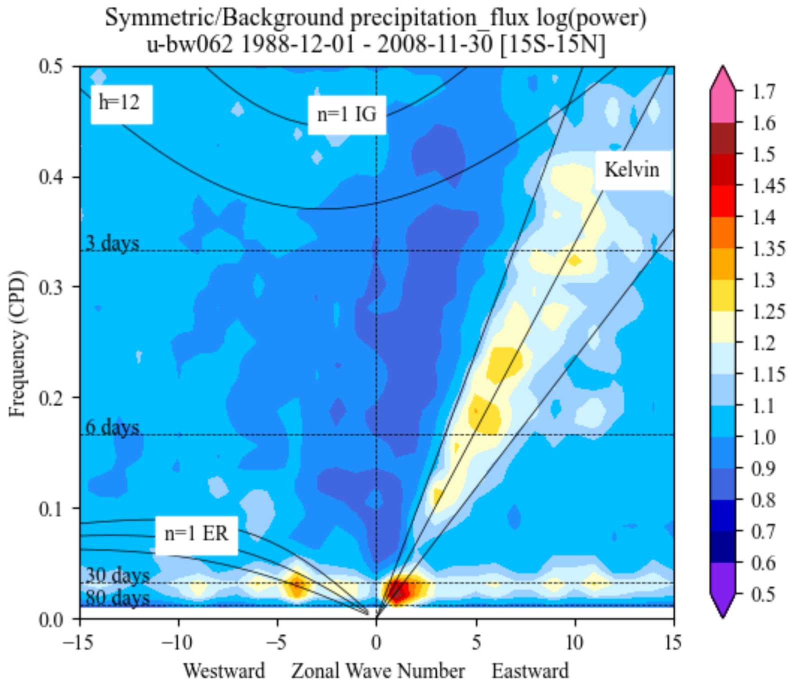
Tropical Waves and the MJO

Good improvements, especially in capturing the MJO

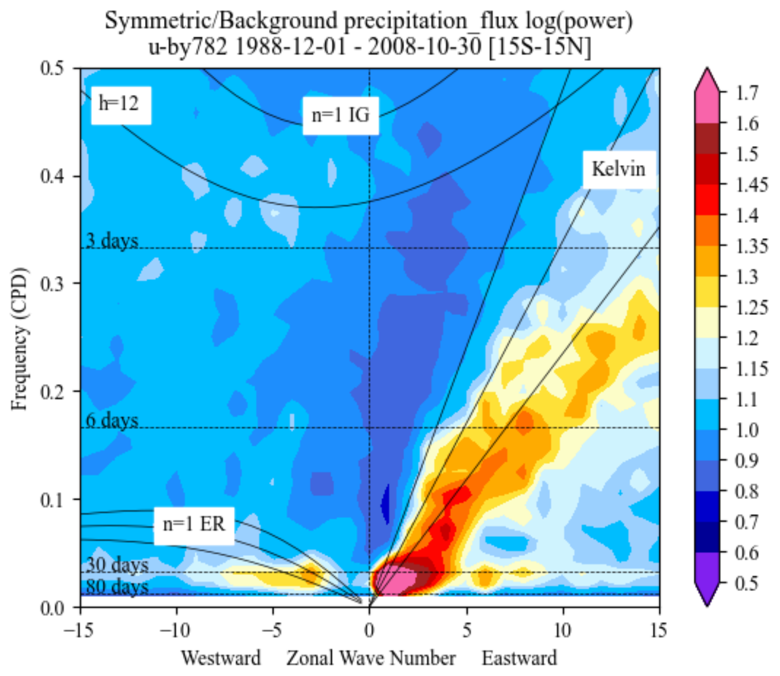


Observational wave spectrum

MJO



Old scheme



A Comorph, better sensitivity to environmental moisture

Prince Xavier, Sally Lavender

Controlling Equations

$$Input\ convection\ heating\ profile: \Delta T_{conv}(p) = \Delta\theta_{CoMorph}(p)\left(\frac{p}{p_s}\right)^{\frac{R}{C_p}}$$

$$Assume\ stratiform\ integrated\ heating\ tendency = \alpha \sum_{p_{surf}}^{p_{top}} \Delta T_{conv}(p)$$

Stratiform $tendency\ profile$:

$$\Delta T_{strat}(p) = \sin\left(2\pi \frac{p - p_{top}}{p_{surf} - p_{top}}\right)\left(\frac{1}{p_{surf} - p_{top}} \alpha \sum_{p_{surf}}^{p_{top}} \Delta T_{conv}(p)\right)$$

$$Energy\ fixer: \Delta T_{correction} = \frac{1}{p_{surf} - p_{top}} \sum_{p_{surf}}^{p_{top}} \Delta T_{strat}(p)$$

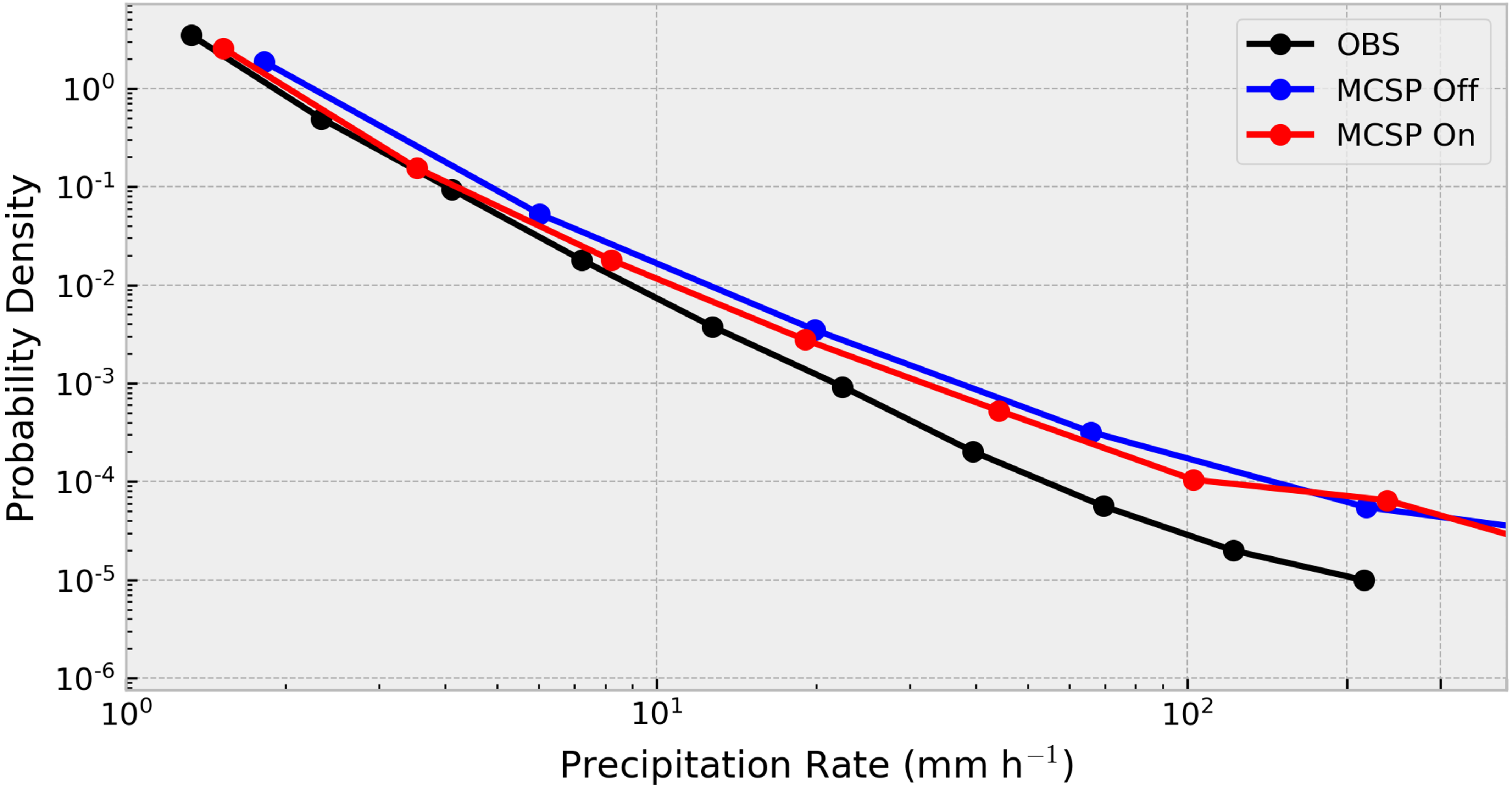
$$Output\ tendency: \Delta\theta_{MCS}(p) = \left(\frac{p_s}{p}\right)^{\frac{R}{C_p}} \left(\Delta T_{conv}(p) + \Delta T_{strat}(p) - \Delta T_{correction}\right)$$

Coupling Method

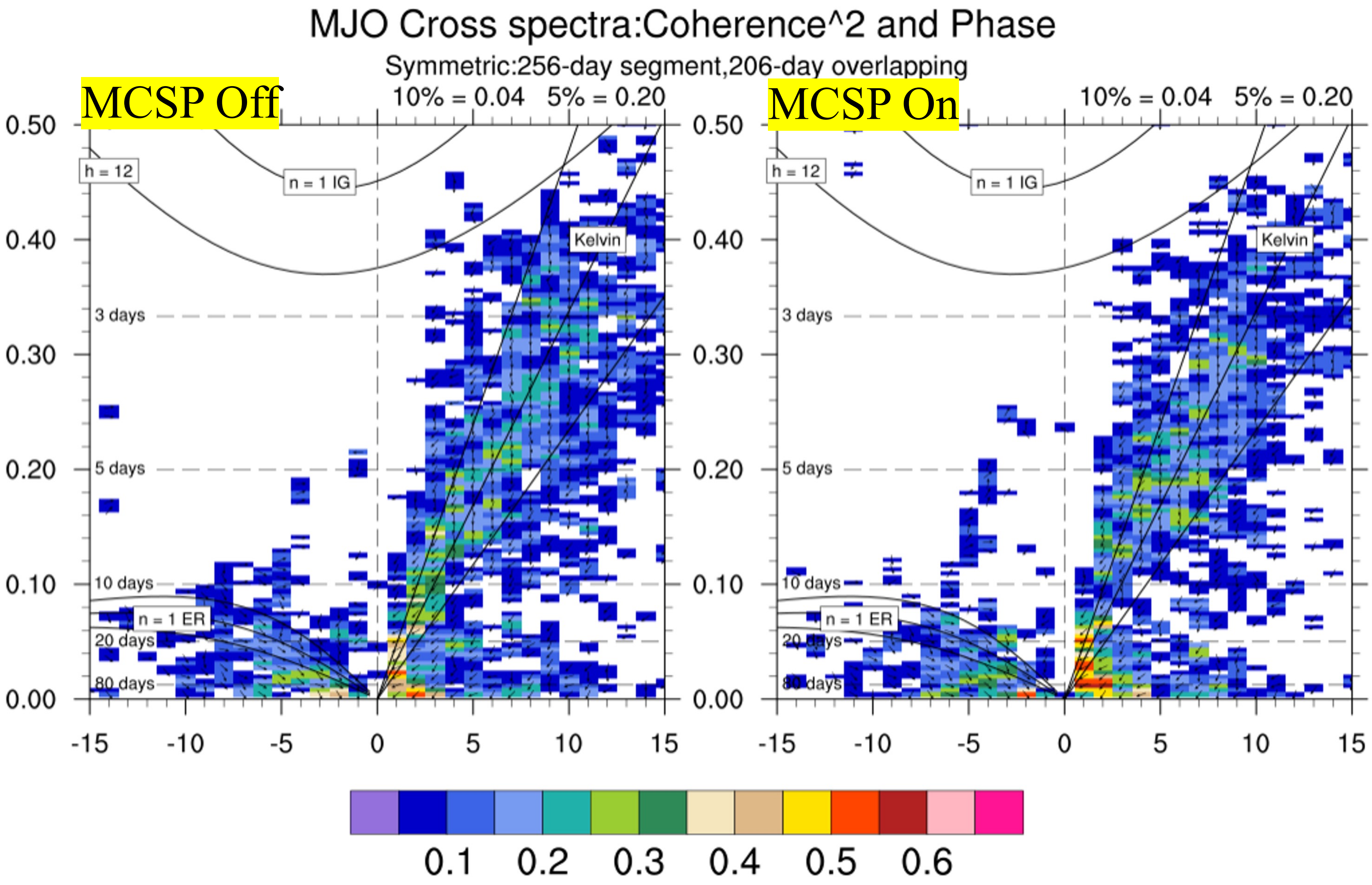
```
CALL atmos_physics1
        READ CoMorph prognostics
        CALL large-scale microphysics
CALL atmos_physics2
       CALL other_conv_ctl…
                  ELSE IF ( using CoMorph ) THEN
                      CALL comorph_interface_um(CoMorph)
                  END IF
                  CALL org_conv (heating from comorph)
                  CALL PC2 (large-scale cloud scheme)
                  SPT for convection (dT, dQ)
```

Latest code: https://code.metoffice.gov.uk/trac/um/changeset/117880

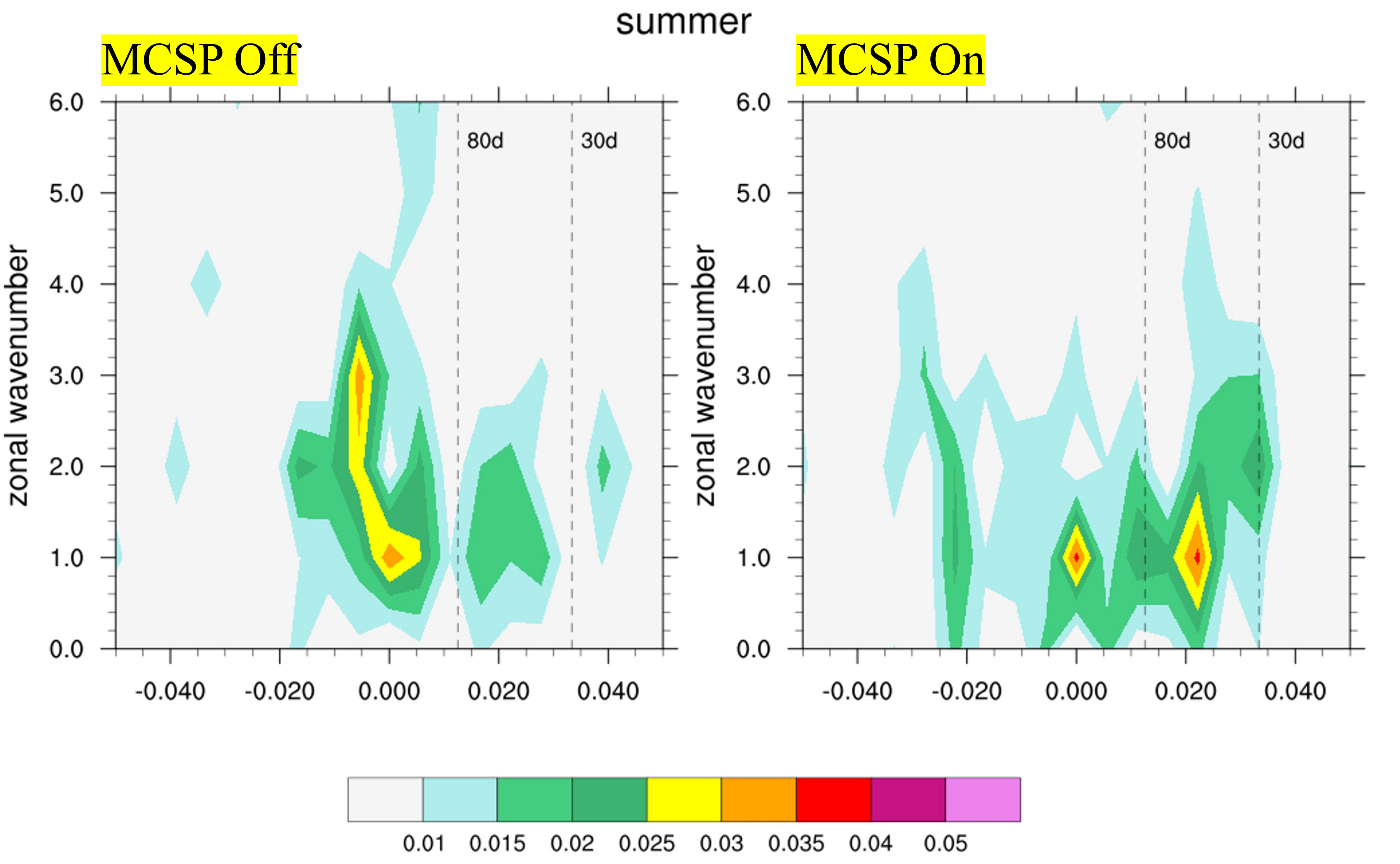
Rain Rate PDFs (2003-2008)



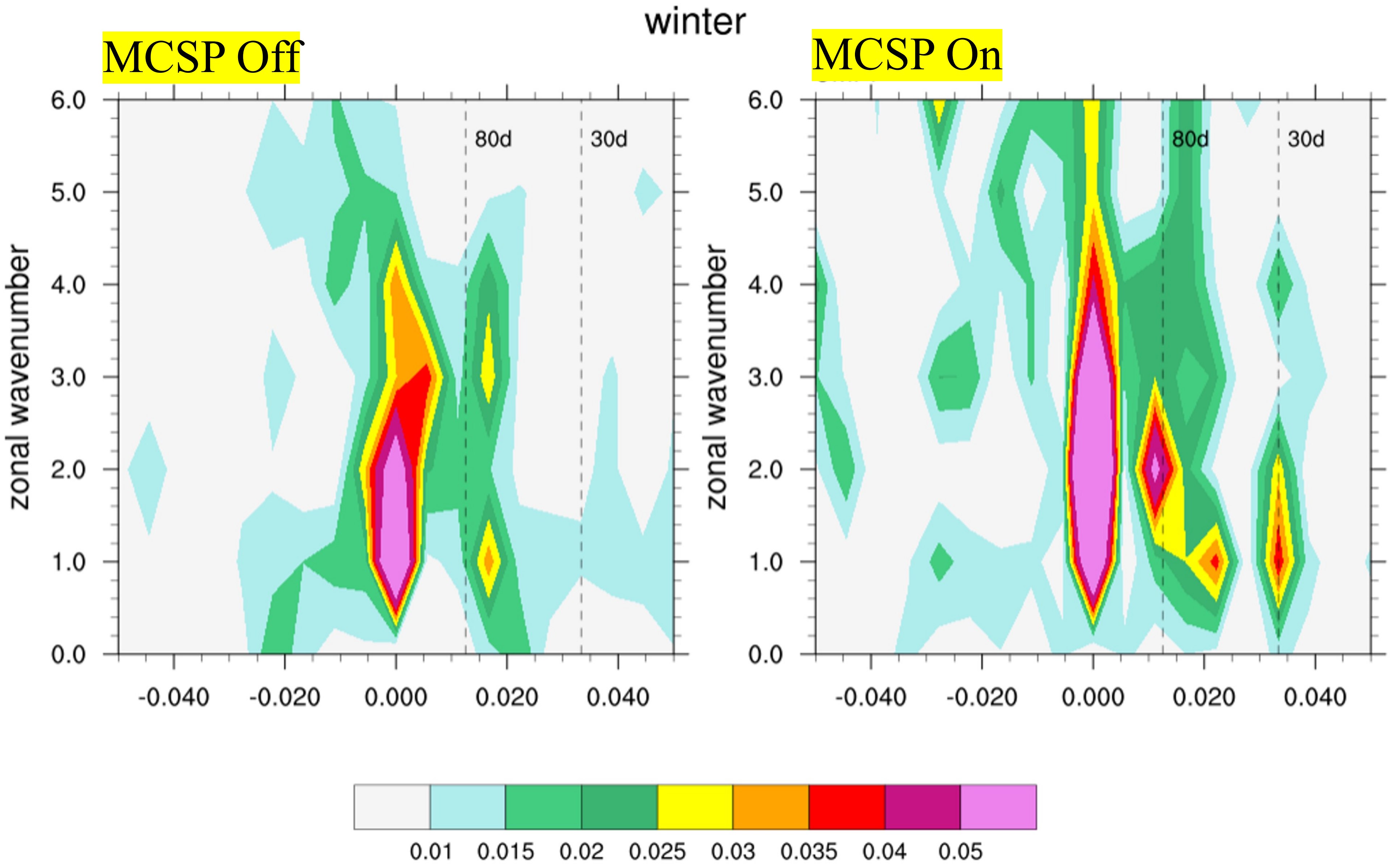
Cross Spectra Symmetric (OLR, U, 2004-2007)



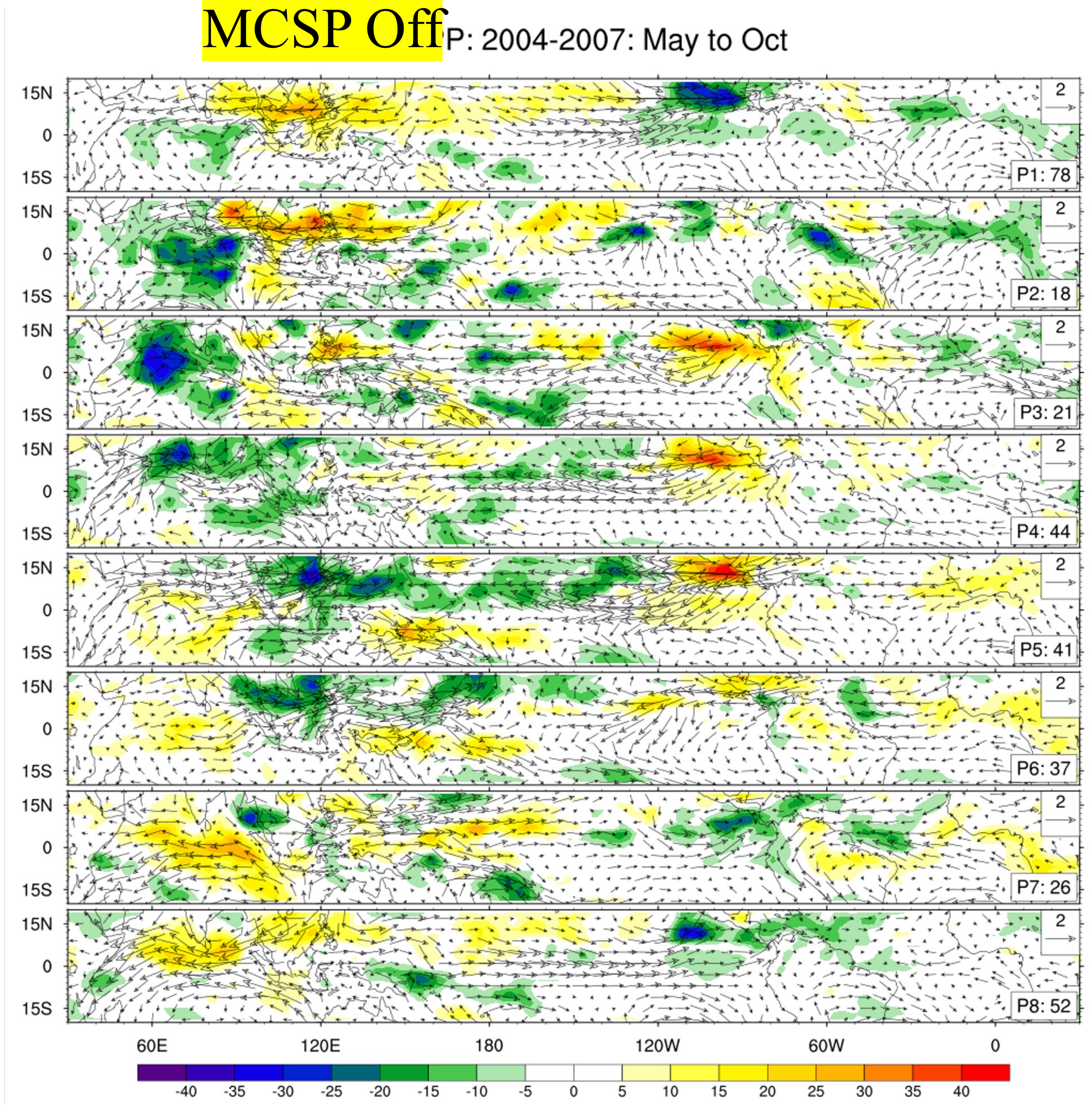
Wave Frequency Summer (Rain 2004-2007)

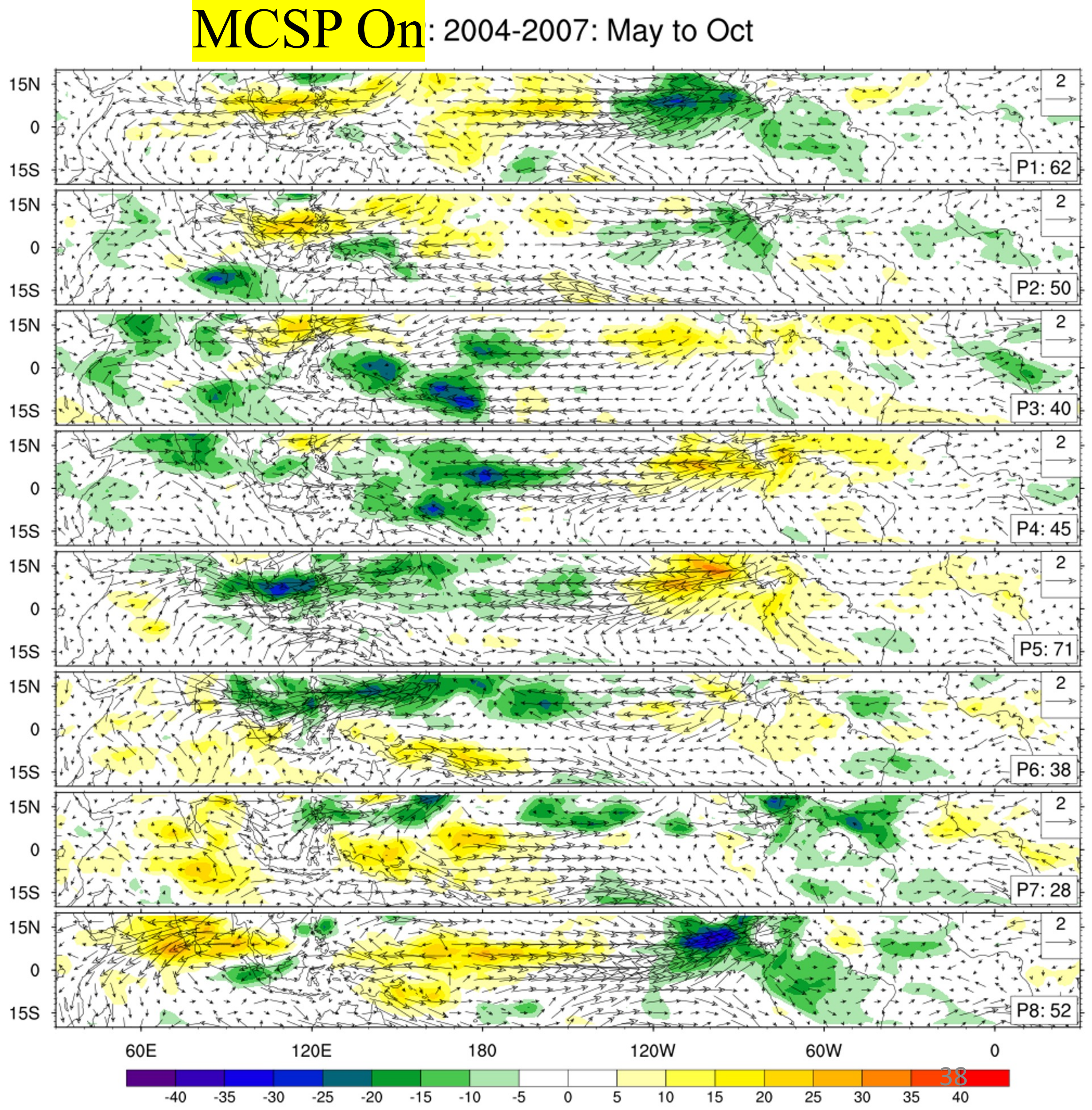


Wave Frequency Winter (Rain 2004-2007)

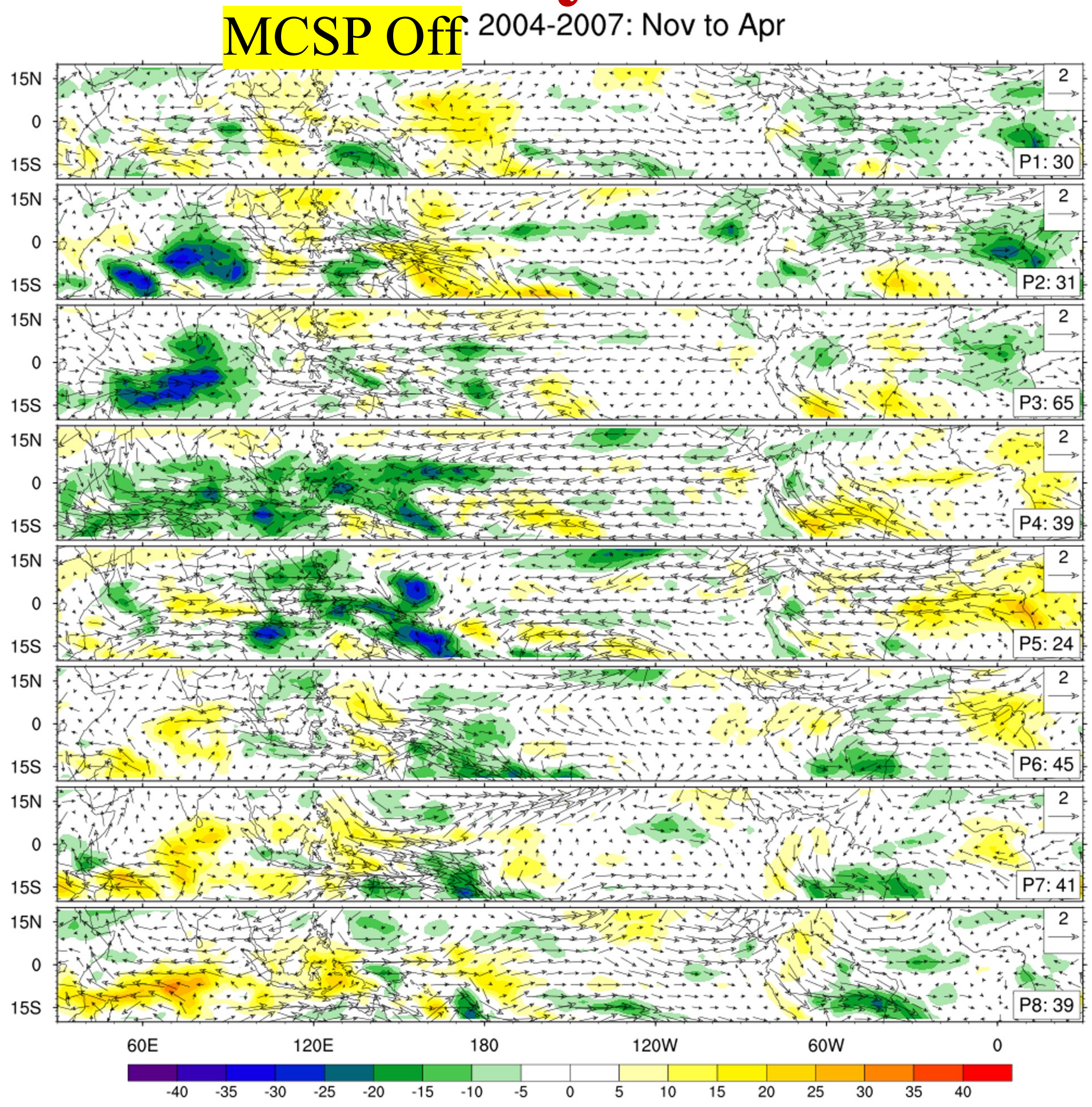


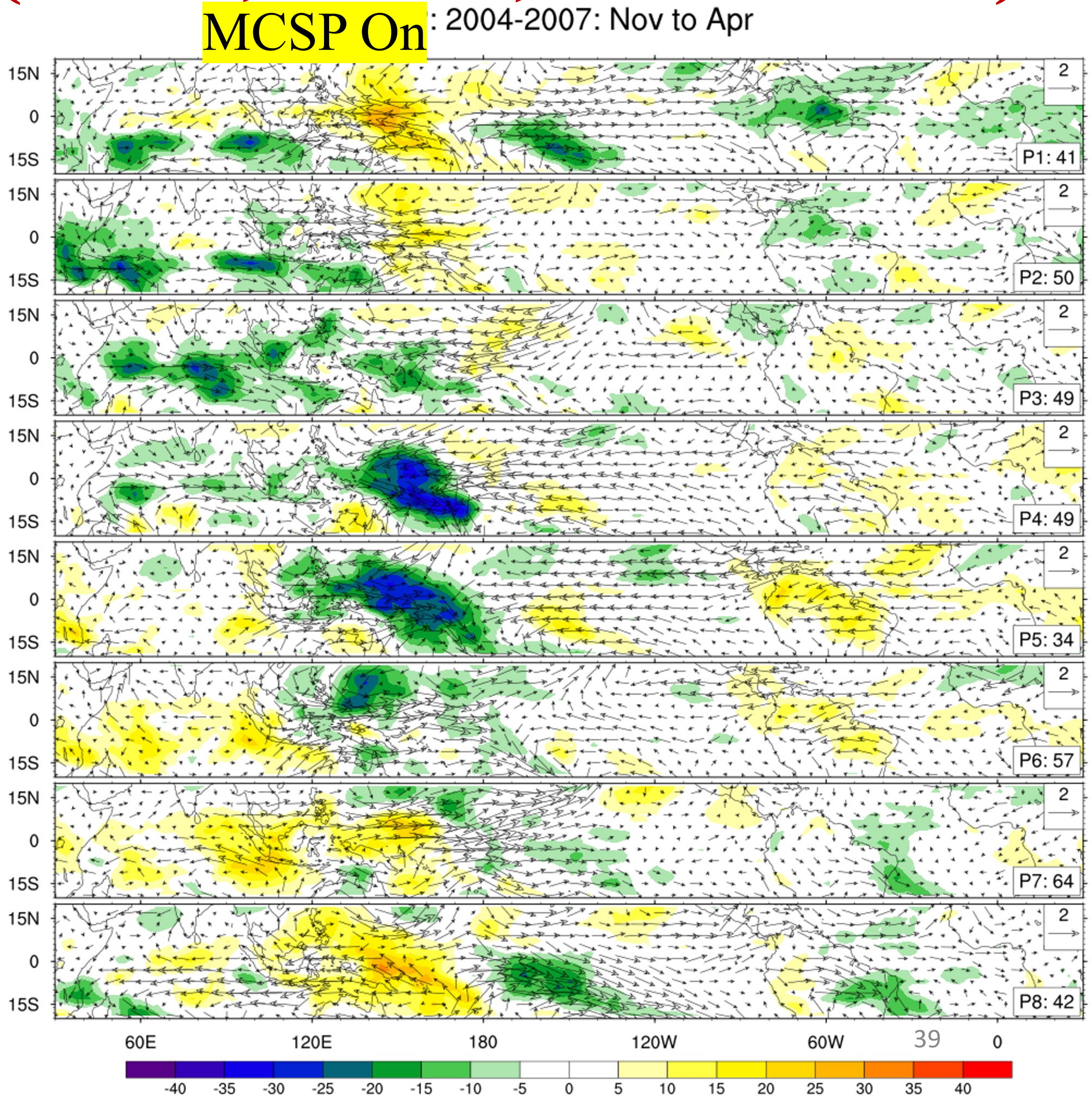
MJO Life Cycle Summer (OLR, U850, 2004-2007)





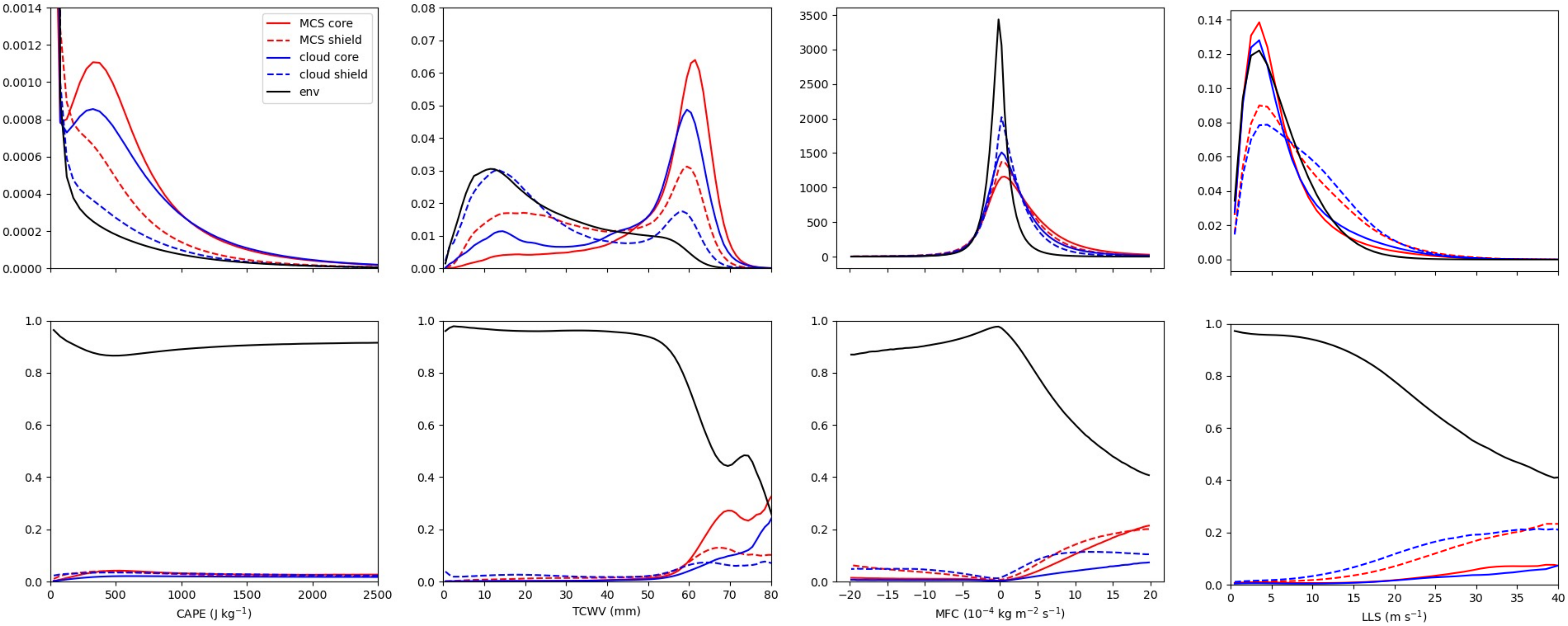
MJO Life Cycle Winter (OLR, U850, 2004-2007)



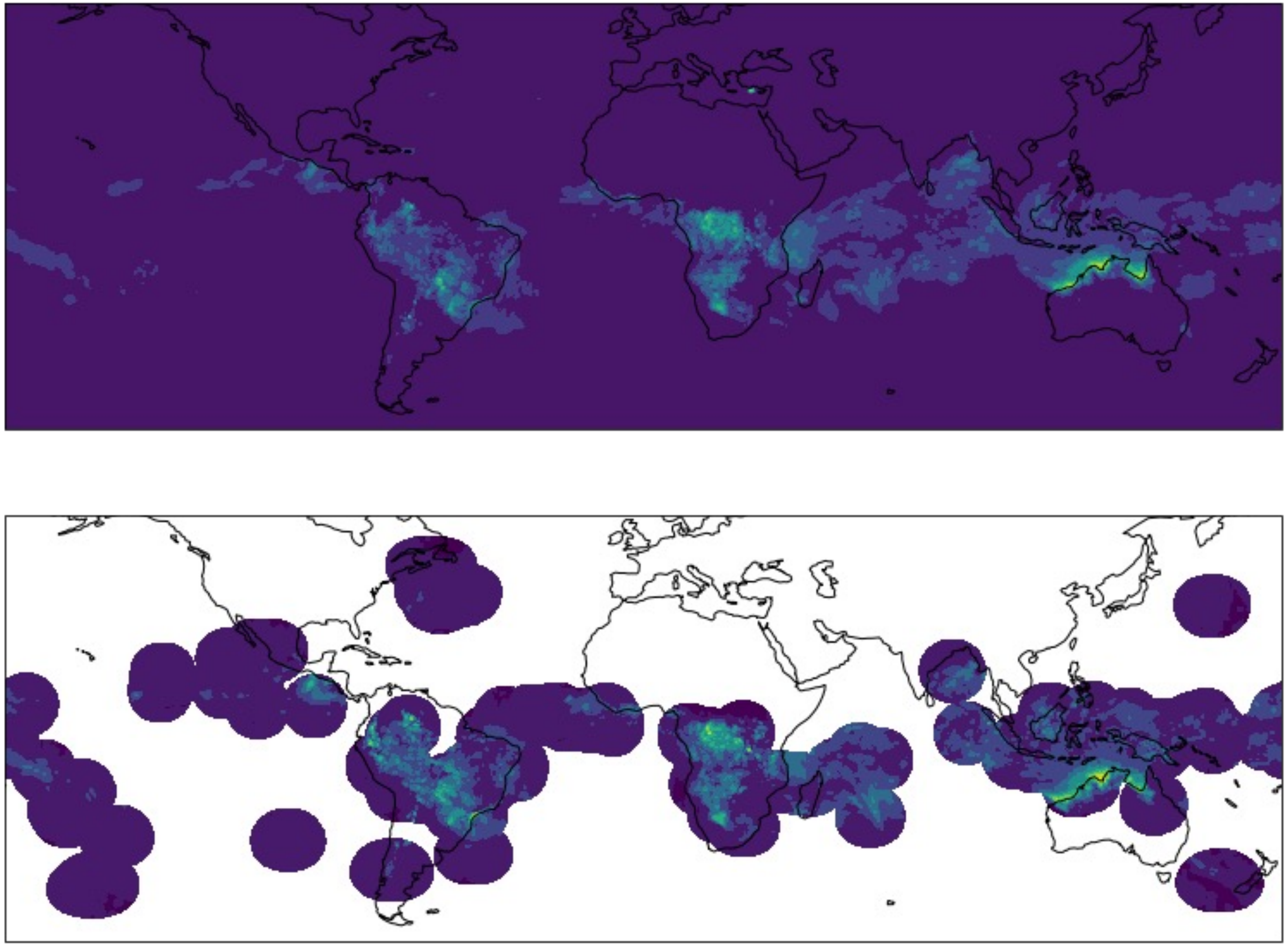


Work by Mark Muetzelfeldt

CAPE shows smaller signal than other variables



MCS local env

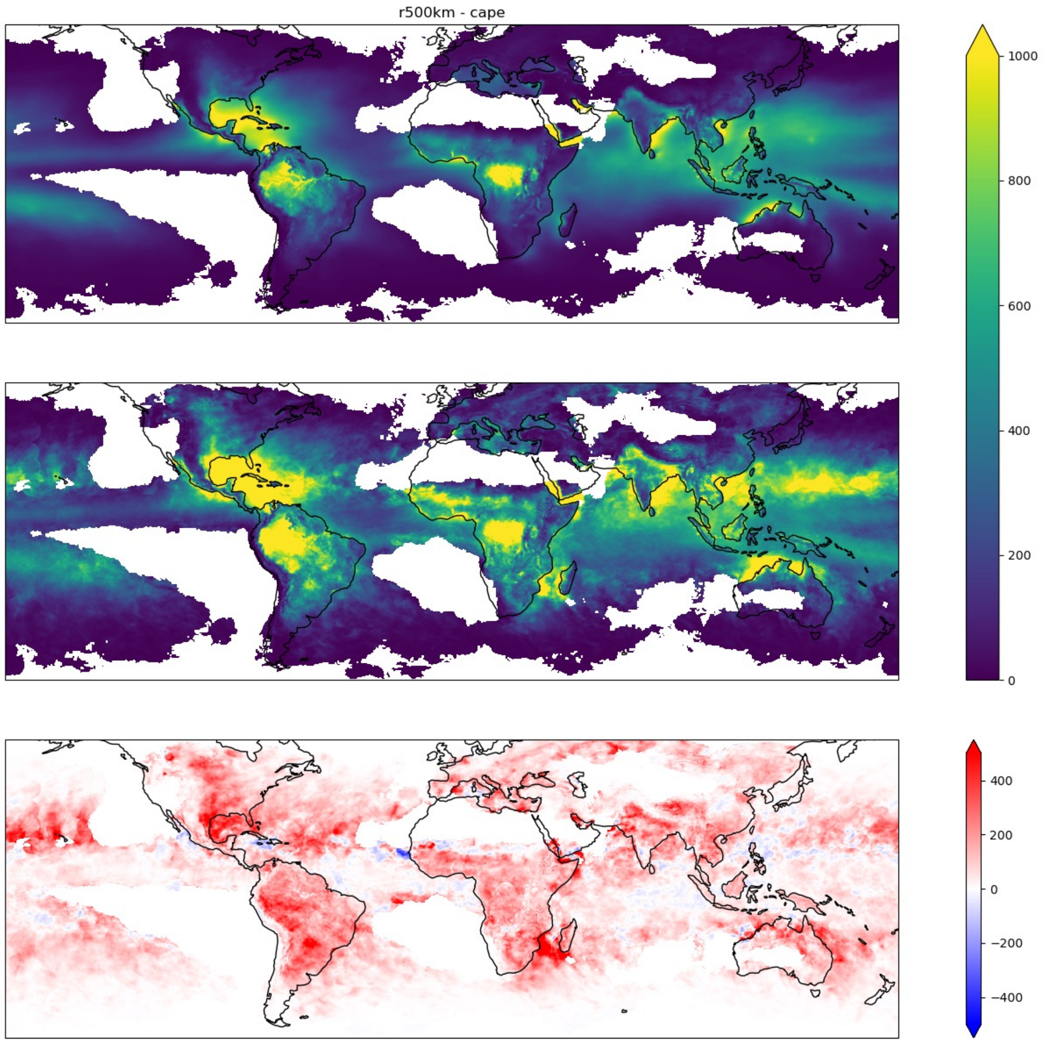


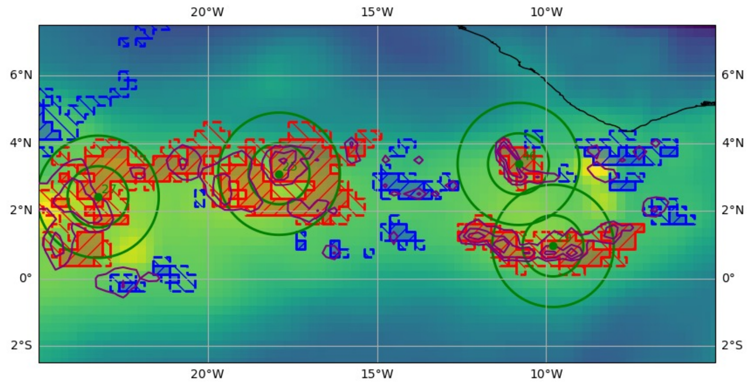
Idea: produce composite of local env (here within 500km) of MCS initiation

Top: CAPE field (1-day mean)
Bottom: CAPE within radius of MCS init (1-day mean)

Usage: produce anomaly with mean, explore regional differences in local drivers, potentially implement same analysis in model for comparison.

MCS initiation environments





- Anomaly is calculated based on a difference from the monthly mean for each field to remove seasonal variation.

MCS initiation environments