School of Earth and Environment
INSTITUTE FOR CLIMATE & ATMOSPHERIC SCIENCE

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Total Column Vapour Bimodality in Pan-Tropical km-Scale Models

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With thanks to Leeds Dynamics Group and Met Office RMED

Distribution of Atmospheric Moisture

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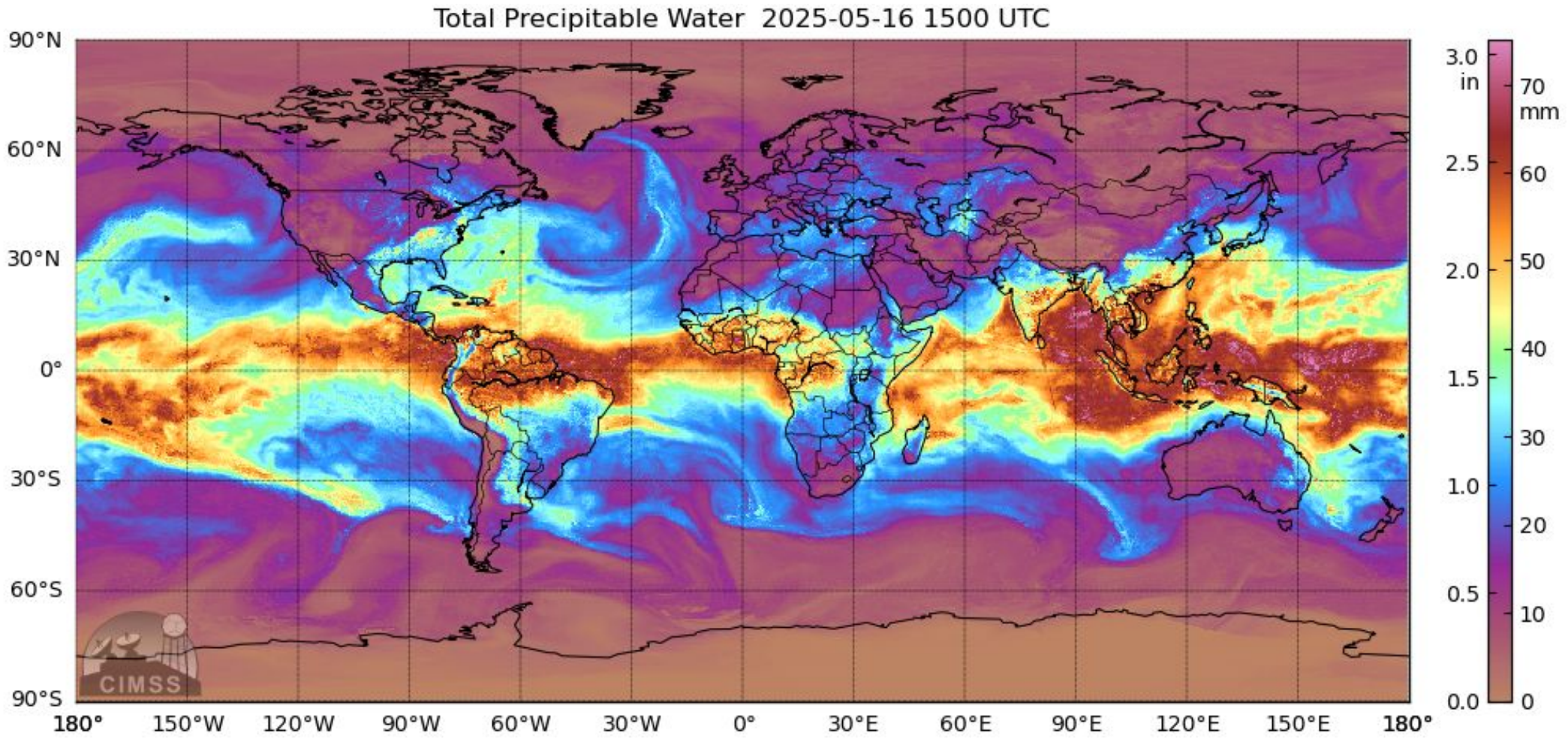

Distribution of Atmospheric Moisture in the Tropics

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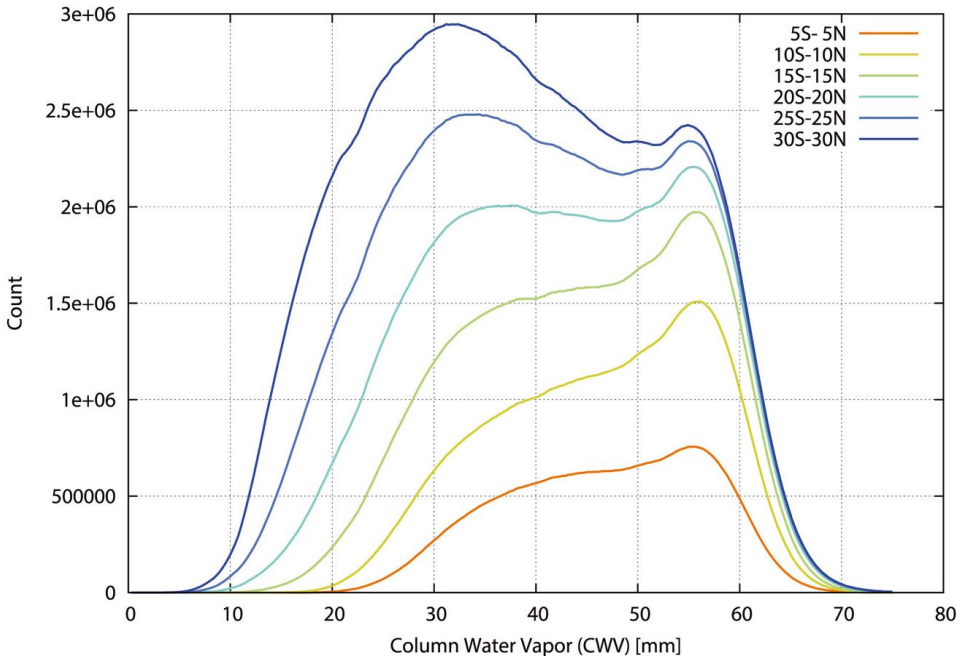
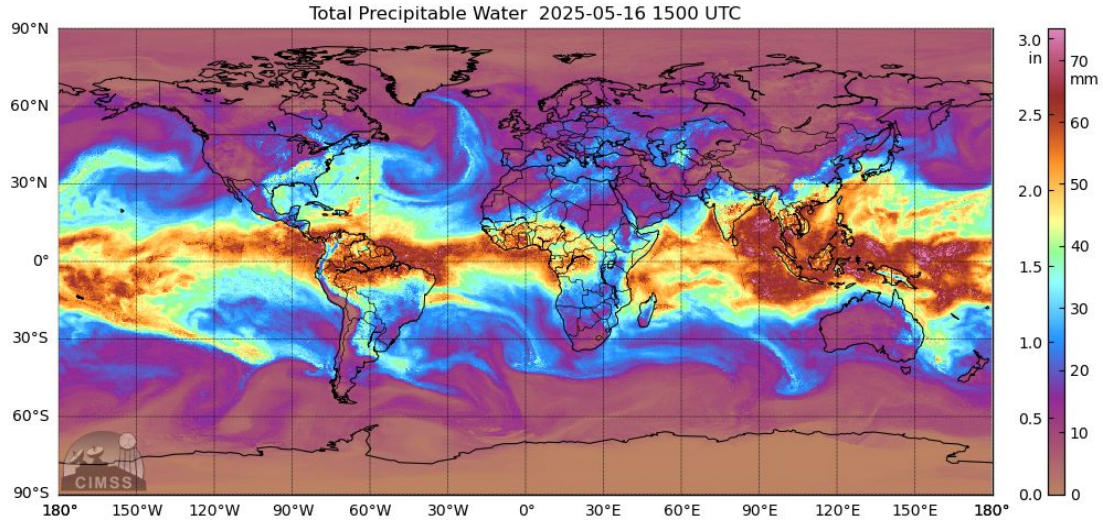
Frequency distributions



Mapes et al. 2018, GRL

Spatial gradients



https://tropic.ssec.wisc.edu/real-time/mtpw2/product.php?color_type=tpw&prod=global×pan=120hrs&anim=html5

Bimodality, the Moist Margin, and Rainfall

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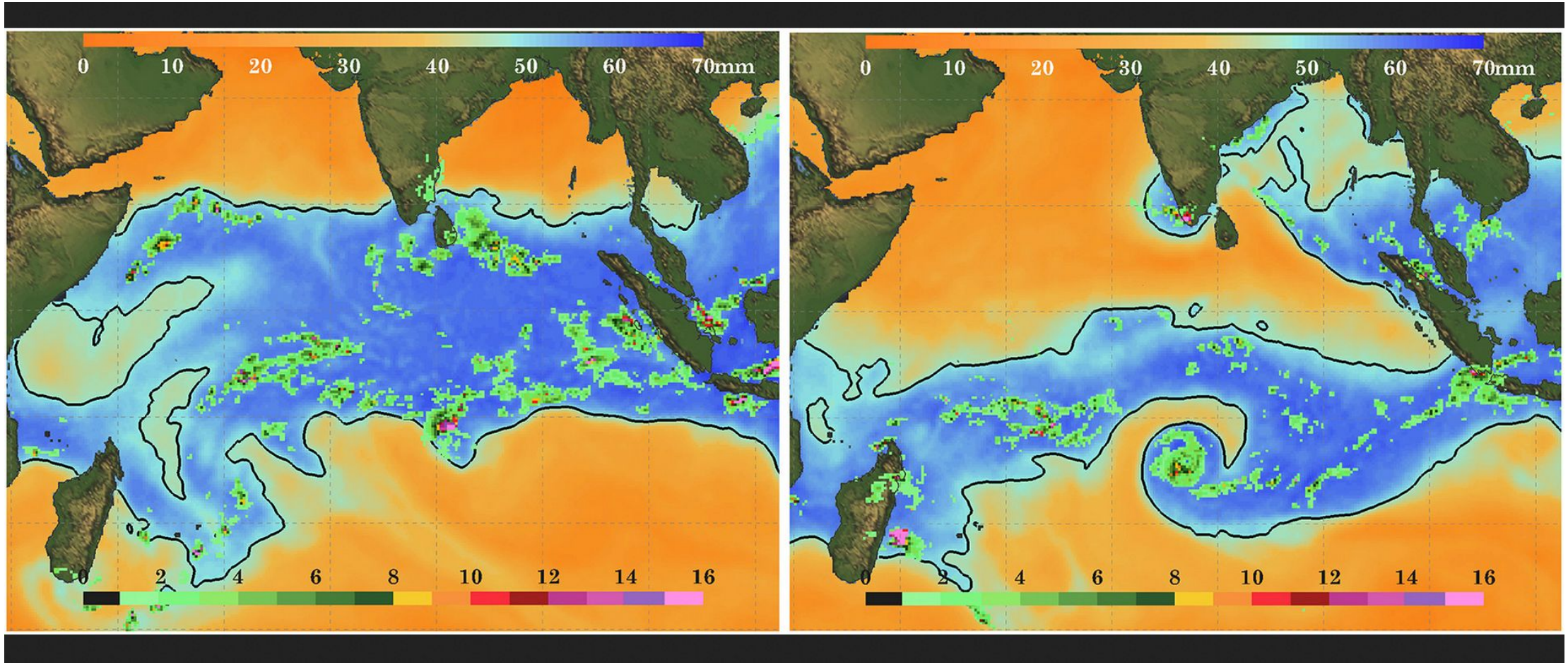
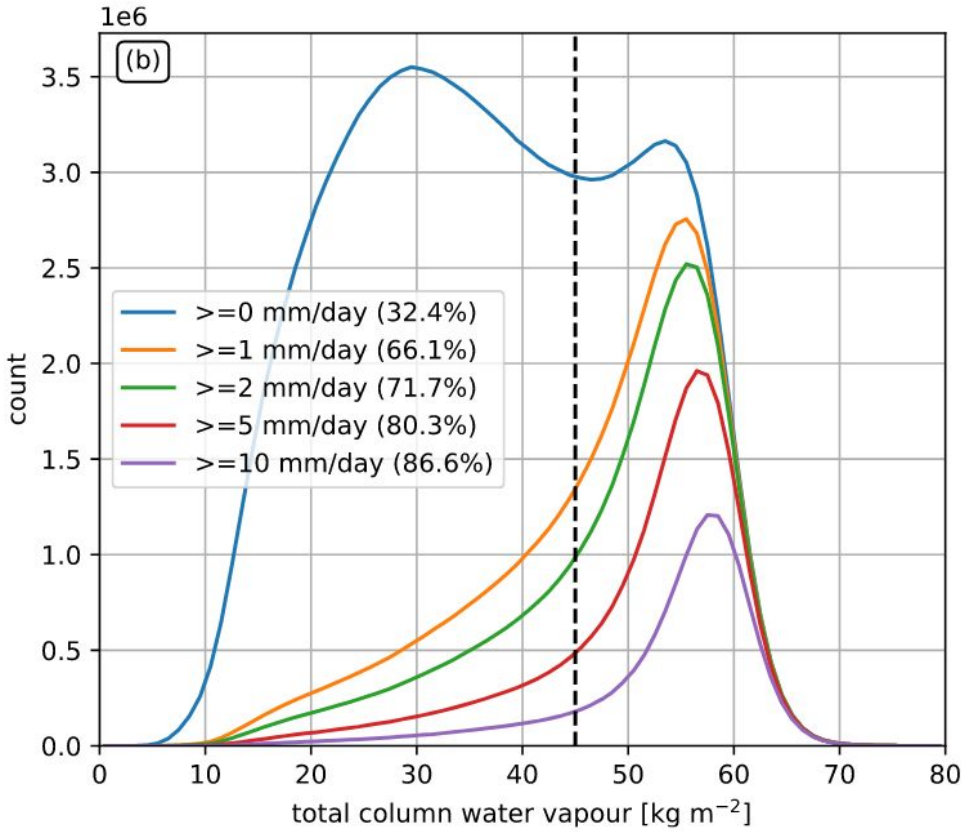
Two days from the same December



Mapes et al. 2018

Bimodality and Rainfall 2



Robinson et al 2024.
Data: ERA5 and IMERG over tropical oceans

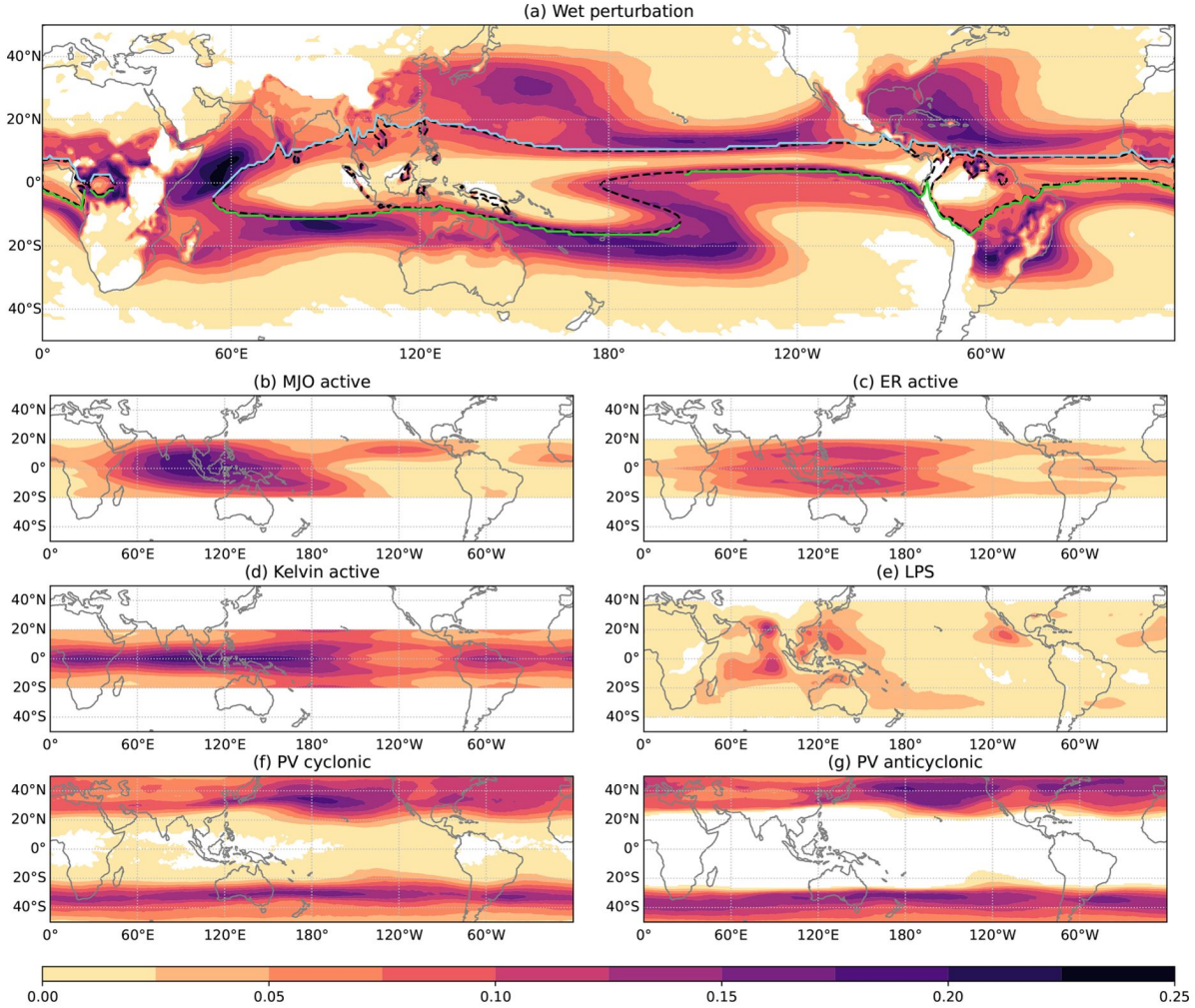
Over the tropical oceans there are;

1. Two peaks in overall TCV PDF.
2. One peak when filtering by rainfall rate.
3. Indicates dry peak ~30 kgm-2 should be mostly 'rain free'.

Almost all rain occurs in the moist mode > 48kgm-2

This will be important later...

Synoptic Variability and Weather Impacts



Robinson, C. et al. 2025: *Weather systems associated with synoptic variability in the moist margin.* WCD, https://doi.org/10.5194/wcd-6-369-2025

1. TCV in and around Africa modulated strongly by both CCEWs and Extratropical PV anomalies, depending on season and latitude.

2. Correctly resolving the TCV distribution therefore critical for prediction and statistical analysis of perturbations/high impact variability.

Why diagnose this in seamless models?

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The margin and the associated bimodality...

1. Exists spatially at daily and sub-daily timescales (opportunity for model process evaluation).

2. Is structurally coherent with spatial variability at synoptic timescales (predictability, impacts on weather systems etc.)

3. Bimodality persists as a feature of the frequency distribution on annual timescales (relevant to longer-range rainfall projections, vital for stakeholders in the tropics)

Is bimodality present in km-scale models?

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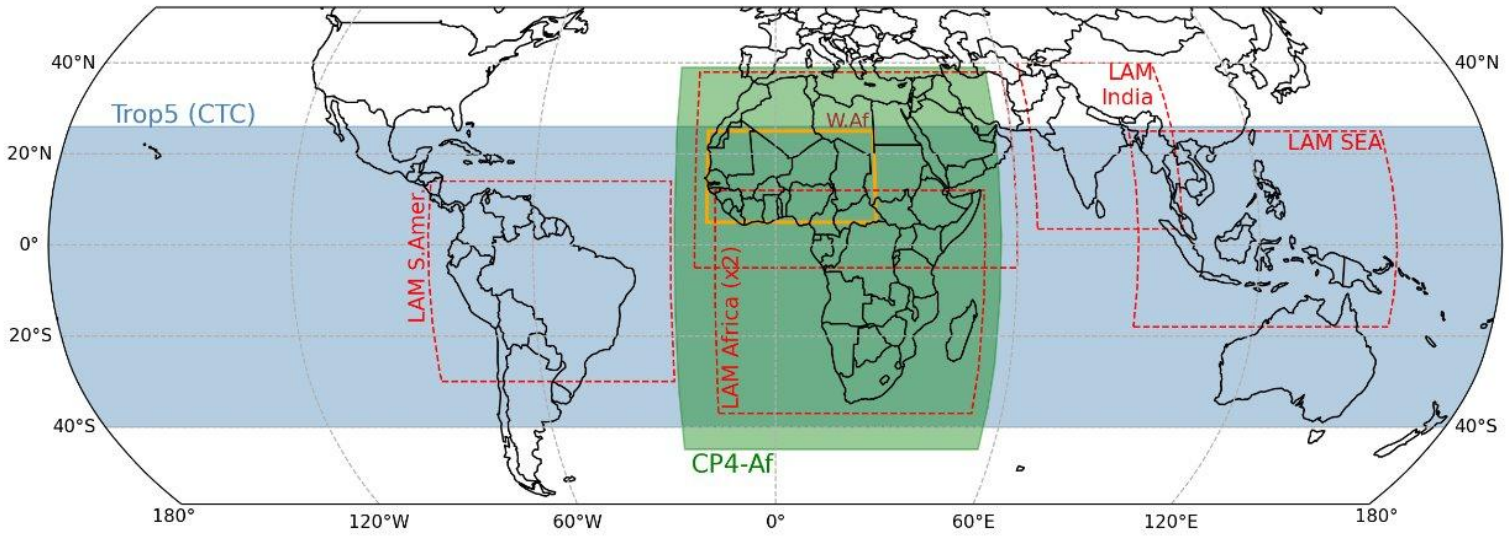
KScale DYAMOND hierarchy



We focus on the tropical oceans in the **N2560 Cyclic Tropical Channel (Blue Shading);**

1. Whole tropics approx. ~5km resolution.
2. 40 day runs from August 2016 (DYAMOND Summer)
3. One run has parameterized convection (GAL9), and the other is explicit (RAL3.2)

Is bimodality present in km-scale models?

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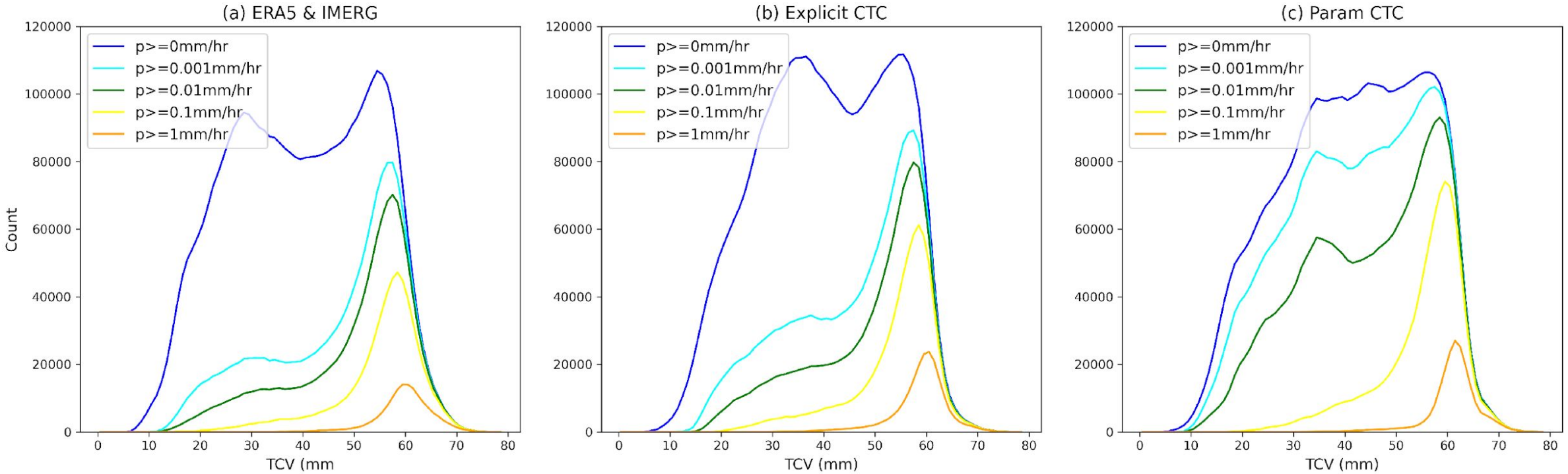

Is bimodality present in km-scale models?

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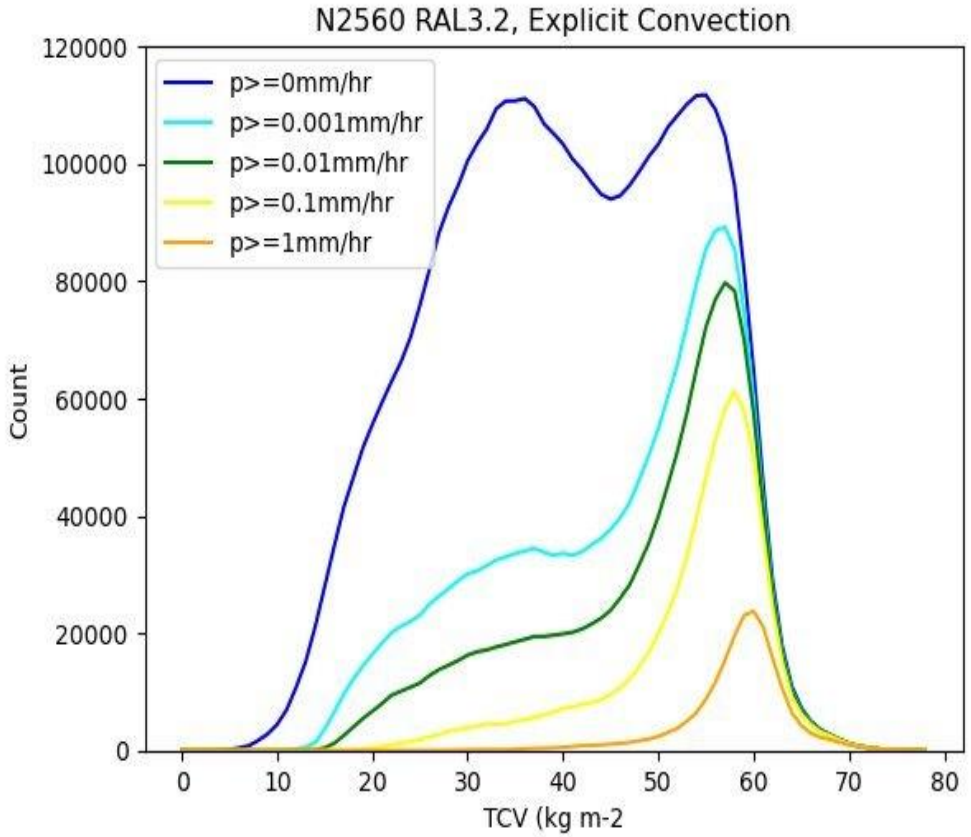

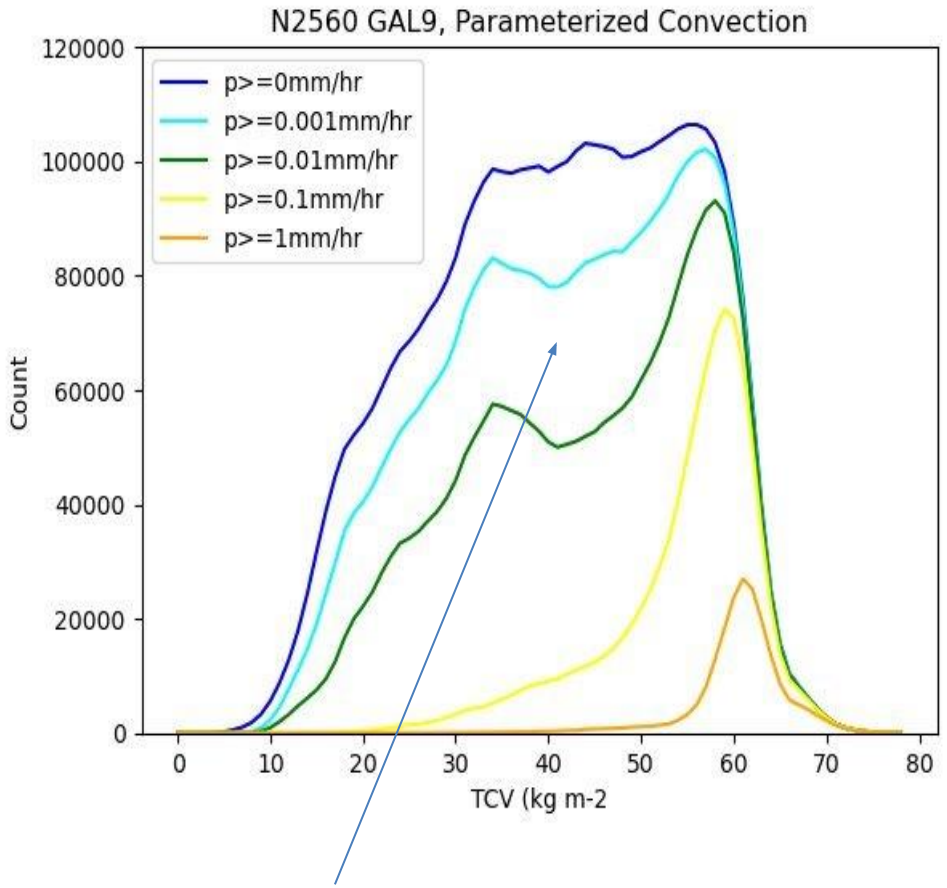

Two peaks in overall distribution, one where raining.

Param has too much weak rainfall in low moisture locations.

Moisture budget in low rainfall environments

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$$\frac{dTCV}{dt} = E - P - MFD$$

Moisture budget in low rainfall environments

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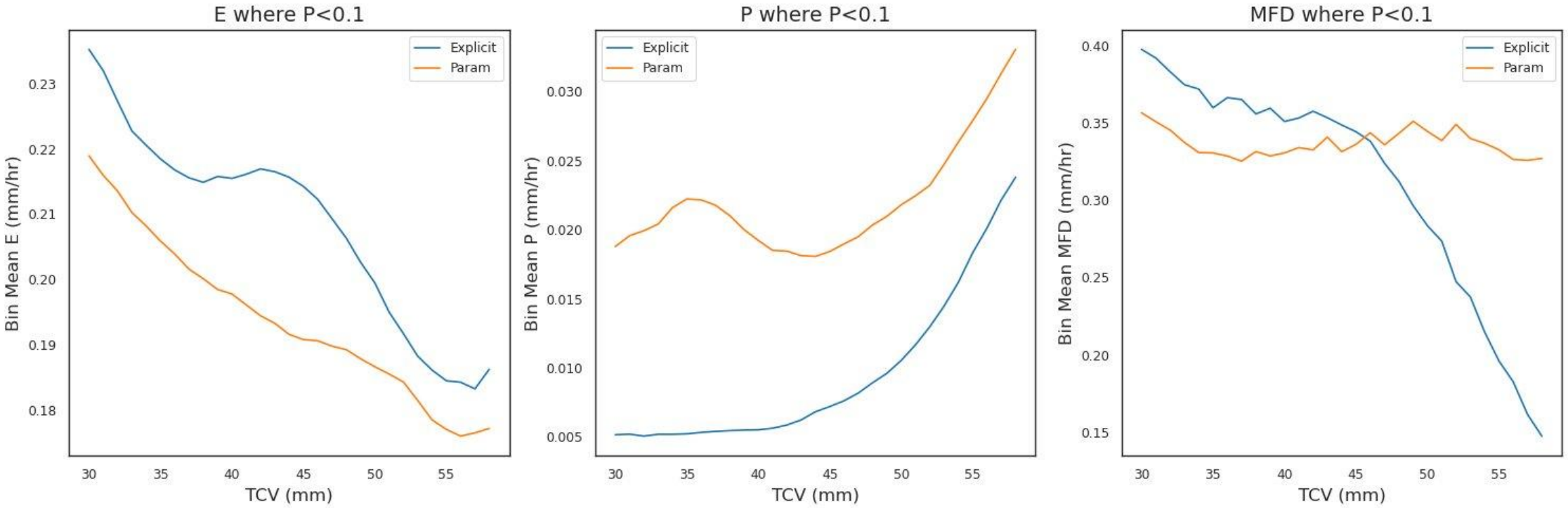
$$\frac{dTCV}{dt} \approx E - MFD$$

Where P is low!



P scale order of magnitude smaller.

Moisture budget in low rainfall environments

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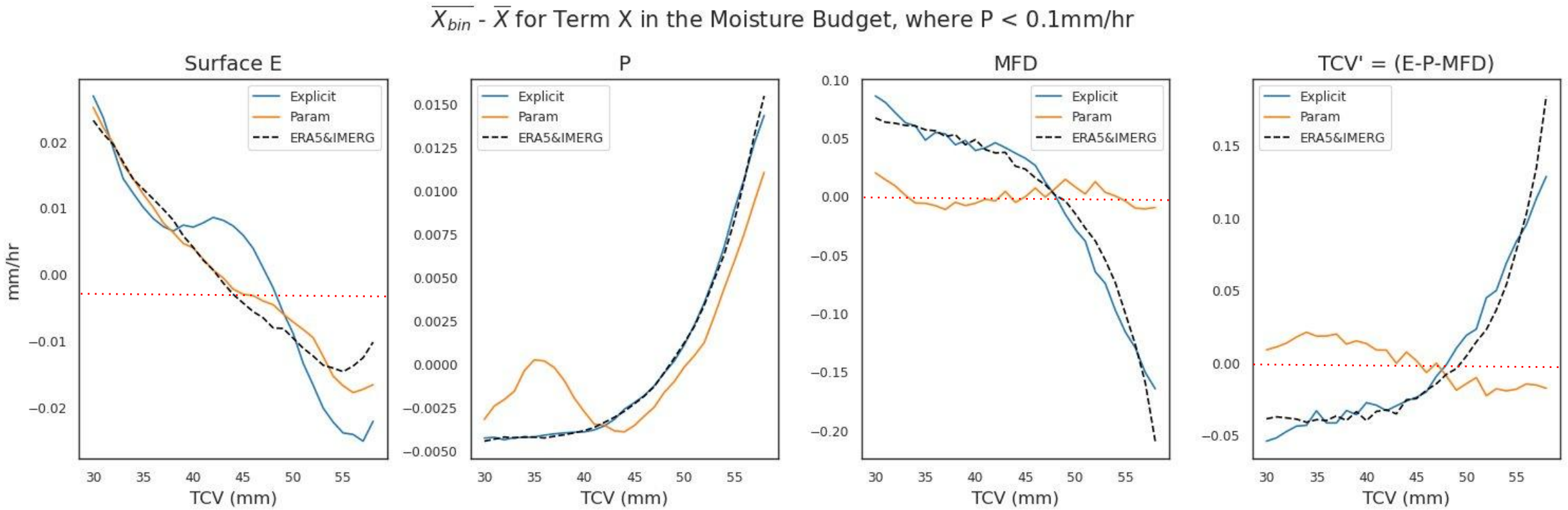
Now bin anomalies, i.e. removing linear model biases.



Sign changes at moist margin value between 45-50mm of TCV

Moisture budget in low rainfall environments

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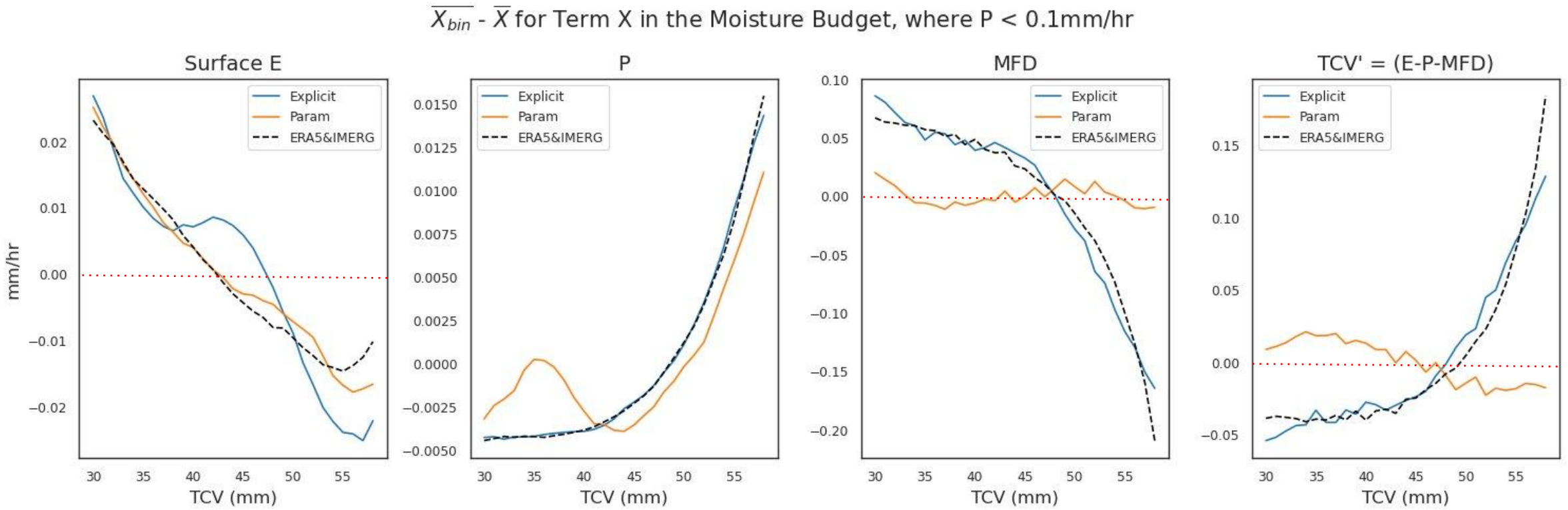

1. Param model is missing an exponential sensitivity of MFD to moisture where rainfall is low.
2. The result is a TCV tendency that has the opposite sign change across the moist margin.
3. This allows more columns to be stable in the moderate TCV environment around the margin, which leads to an unrealistically flat overall TCV distribution.

Consequences for Modality

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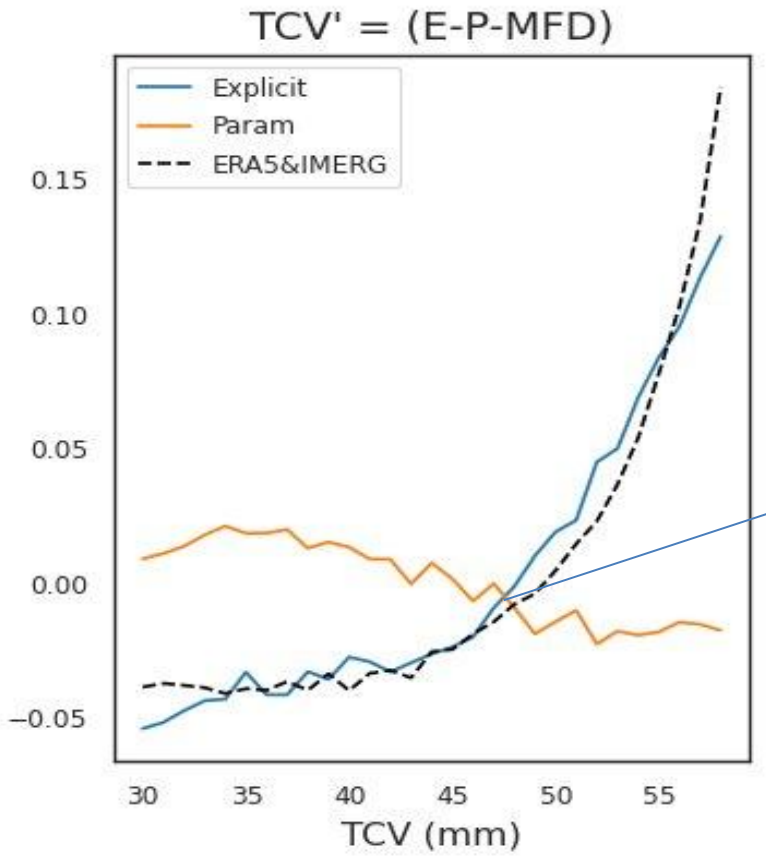
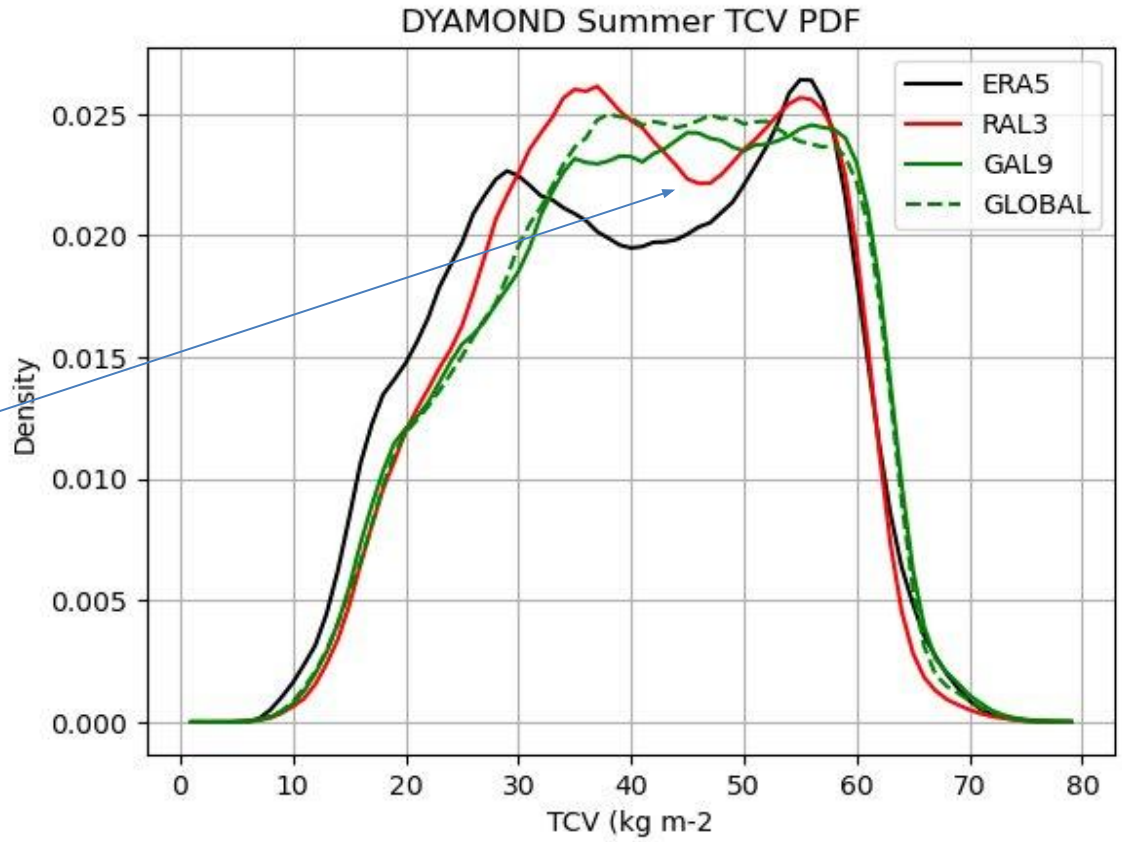
Still only where P is low!



Sign changes at moist margin value between 45-50mm of TCV

Sign change in tendency anomaly associated with frequency minima



Consequences for Regional Models

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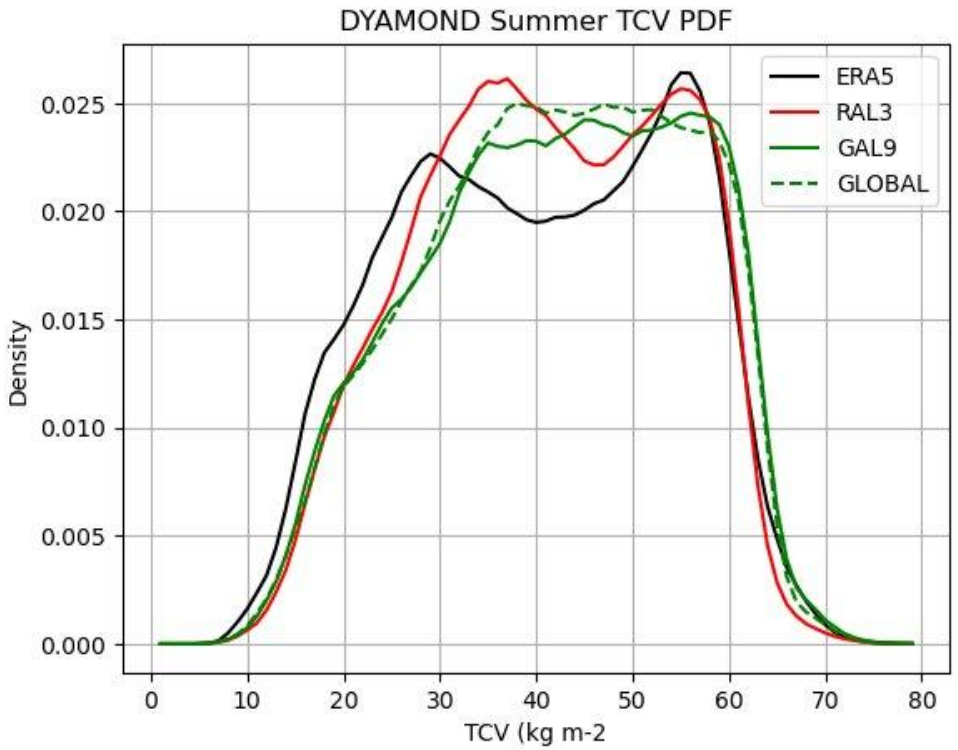
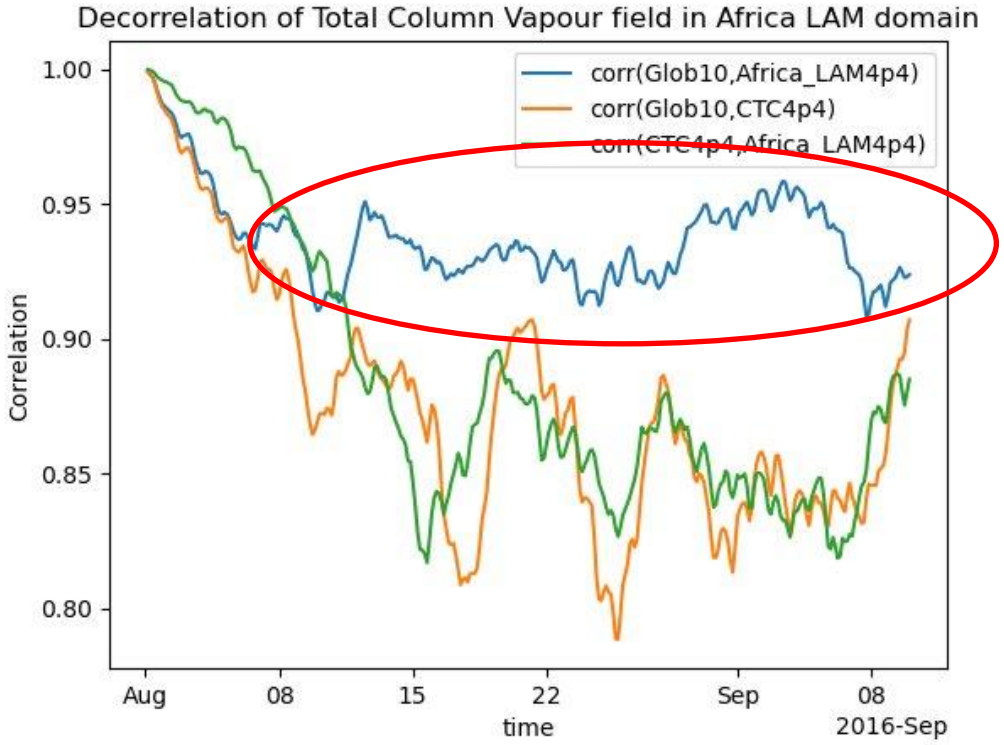
The global models used to drive regional simulations also fails to capture bimodality of TCV. This will have consequences for the circulations (e.g. moist monsoon flow) within regional models. Precipitation distribution in the regional models will therefore be affected, even if they have explicit convection locally.



Increased resolution from 10km global to 5km tropics not enough to resolve bimodality - physics more important?



Africa LAM TCV field stays close to global driver, with little synoptic variability.

Summary

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- The spatial distribution of moisture in the tropics is fundamentally bimodal.
- The use of explicit convection, not just increased resolution, shows promise in rectifying this issue.
- These improvements are associated with better coupling between moisture and dynamics where rainfall is low, e.g. cloud-radiatively driven circulation (Masunaga and Mapes 2020).
- Global models with parameterized convection provide unrealistic TCV boundary conditions to regional models, with implications for rainfall variability.