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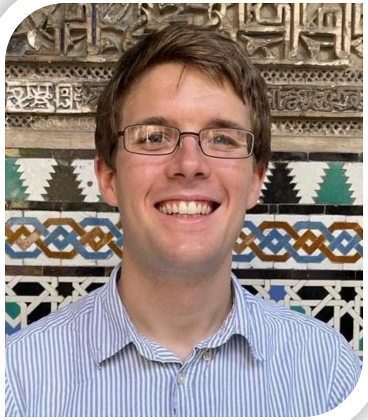

Wind shear controls on mature MCSs: role of entrainment and cold pools

Ben Maybee[1], John Marsham[1], Conni Klein[2], Doug Parker[3,4], Emma Barton[2,5], Chris Taylor[2,5], Huw Lewis[6], Claudio Sanchez[6], Richard W Jones[6], James Warner[6], James Bassford[1] & Paul Field[1,6]

b.w.maybee@leeds.ac.uk

1) School of Earth and Environment, University of Leeds
2) Centre for Ecology and Hydrology (CEH), Wallingford
3) NCAS, University of Leeds
4) NORCE Norwegian Research Centre AS, Bergen
5) National Centre for Earth Observation, Wallingford
6) Met Office, Exeter

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UKRI Natural Environment Research Council

Part of LMCS project

Motivation

b.w.maybee@leeds.ac.uk

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Mesoscale Convective Systems (MCSs) contribute over 50% of tropical rainfall.

Roca et al, *J.Clim* 2014; Feng et al, *GRL* 2023

→ accurate simulation is a key test of convection-permitting models. Requires understanding their physics.

Taylor et al, *Nature* 2017

LETTER

doi:10.1038/nature22069

Frequency of extreme Sahelian storms tripled since 1982 in satellite observations

Christopher M. Taylor[1,2], Danijel Belušić[1,3], Françoise Guichard[4], Douglas J. Parker[5], Théo Vischel[6], Olivier Bock[7], Phil P. Harris[1,2], Serge Janicot[8], Cornelia Klein[1] & Gérémy Panthou[6]

"We argue that Saharan warming intensifies convection within Sahelian MCSs through increased wind shear"

Problem: CP models can fail to capture the response of MCS rainfall to shear - Senior *et al*, *BAMS* 2021

Datasets

b.w.maybee@leeds.ac.uk

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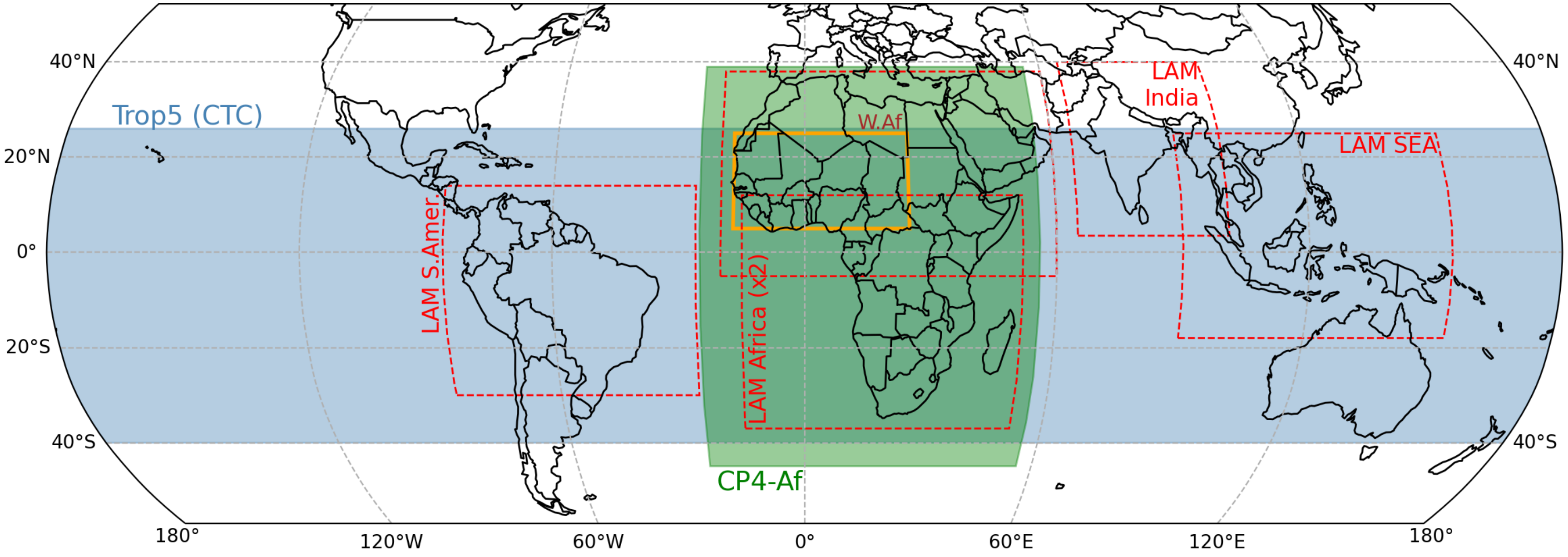
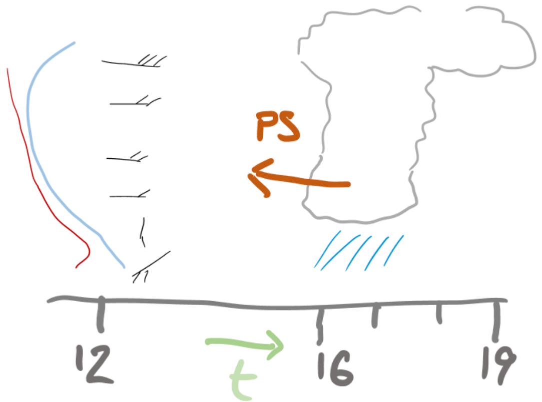
Met Office **k-scale** project: hierarchy of new summer and winter 40 day kilometre scale model runs, covering global to regional domains, using latest MetUM configurations.

In this study:

- **Trop5-exp*:** CP cyclic tropical channel (CTC) ~5km, 40 days.
- **Trop5-param*:** CTC with parameterised convection.
- **LAM2.2*:** CP regional model, 2.2km, 40 days.
- **CP4-Af** – previous generation CP regional model: 4.5km, 10 years.
- **OBS** – 20 years Meteosat brightness temps + GPM-IMERGv06B HQ + ERA5



Date range: 01/08 – 09/09,
* = latest MetUM models, 2016 only



Main methods: detect MCSs hourly from 16 – 21UTC, West Africa. Sample precursor 12UTC environmental fields at storm location.

MCS max rainfall increases with shear

b.w.maybee@leeds.ac.uk

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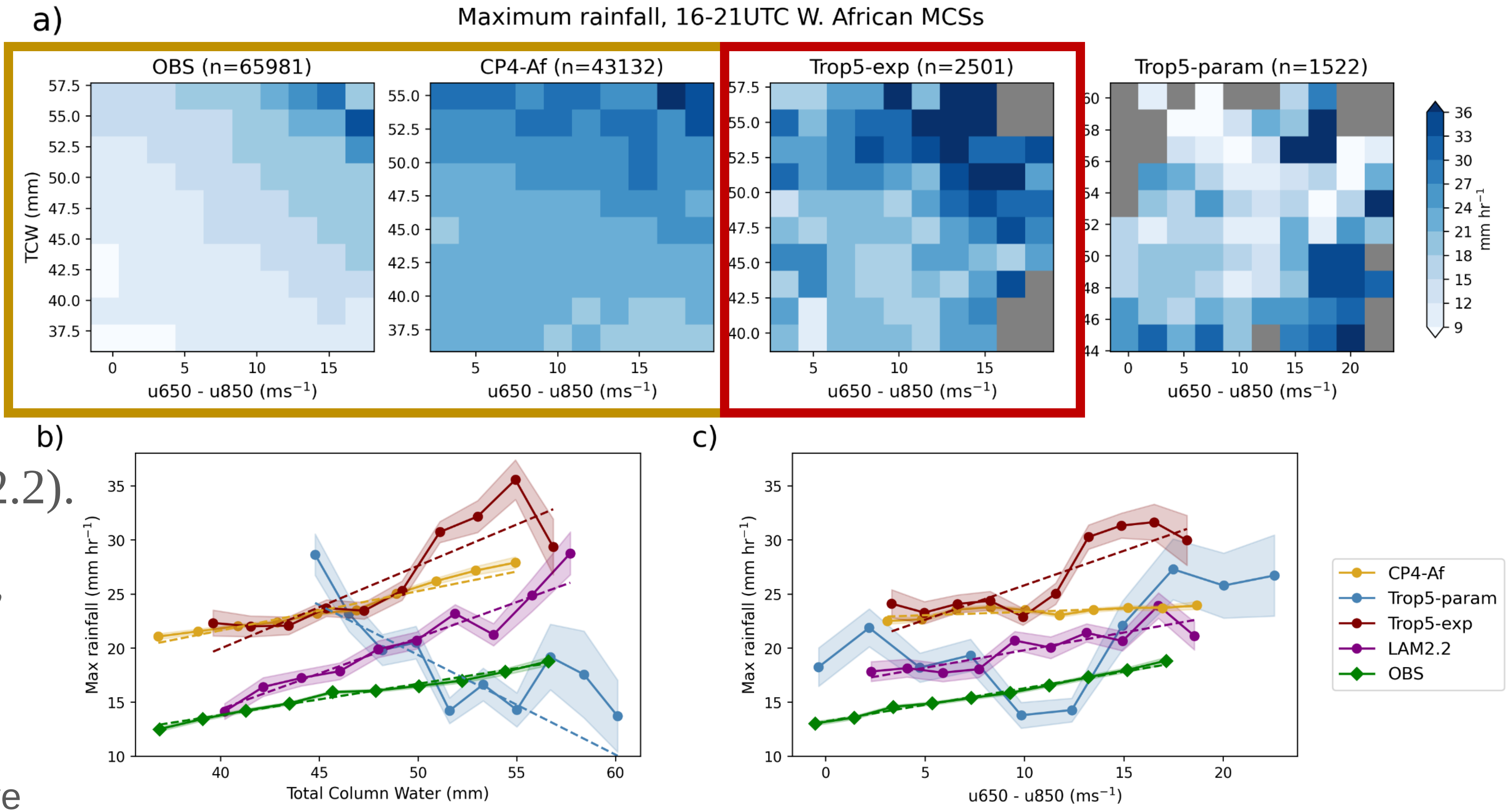
CP4-Af does not show a rainfall-shear response.

Senior et al, *BAMS* 2021

Strong response to shear found in current CP models (Trop5-exp, LAM2.2).

→ *extends to many key MCS characteristics.*



MetUM MCSs too sensitive too environmental moisture

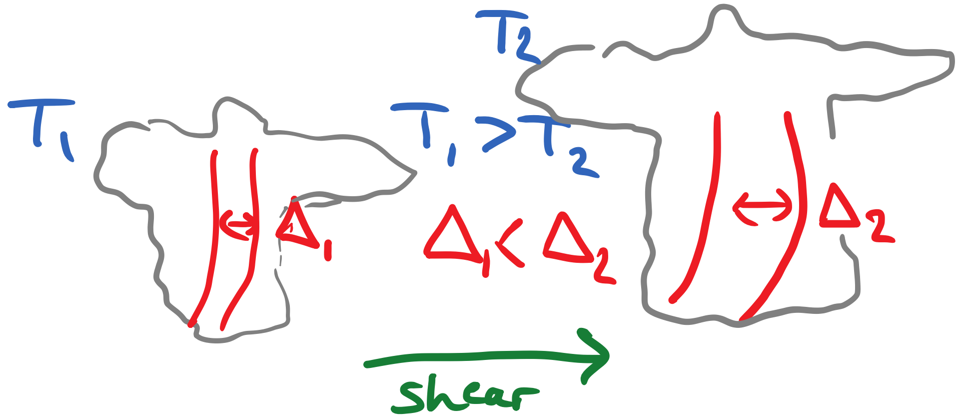
MCSMIP, Feng *et al, in rev.*

Rain/shear scalings:

- T5-param: $\delta / \delta_{OBS} = 0.343$
- T5-exp: $\delta / \delta_{OBS} = 2.159$
- Lam2.2: $\delta / \delta_{OBS} = 1.063$
- CP4-Af: $\delta / \delta_{OBS} = 0.203$

Entrainment scalings

Idealised MCS cores are larger in high low-level shear environments, and subsequently show decreased entrainment.
Mulholland *et al*, *JAS* 2021
Dynamical impact on rainfall: Abramian *et al*, *JAMES* 2023.
Negative thermodynamic scaling: Becker & Hohenegger, *MWR* 2021.



Mulholland *et al*, *JAS* 2021:

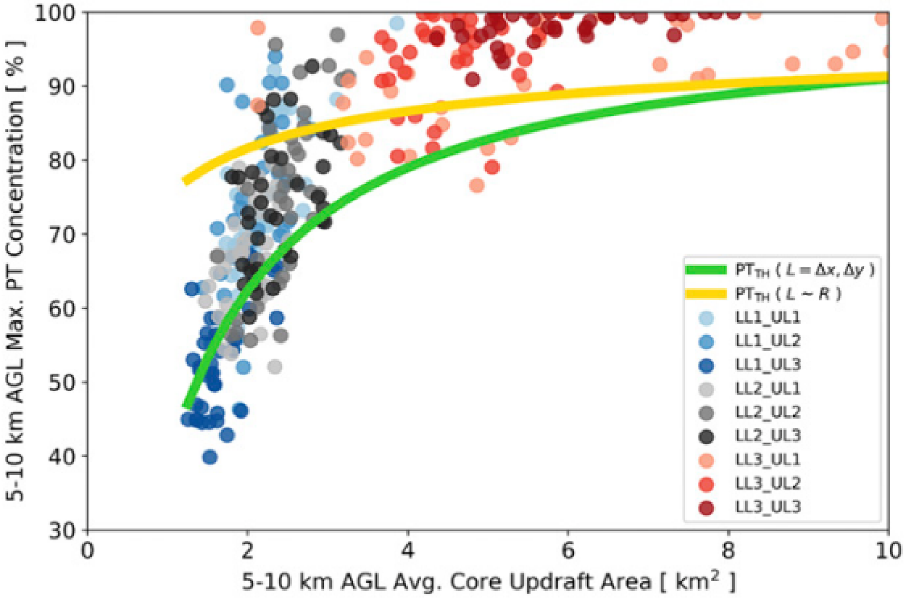


FIG. 10. As in Fig. 7, but of 4–7-h 5–10 km AGL layer maximum PT concentration (*y* axis; %) versus 4–7-h average contiguous 5–10 km AGL core updraft area (*x* axis; km^2). The green line is now

Diagnose in our CP models via proxies for bulk entrainment ε:

$\downarrow \varepsilon \sim \uparrow w_{\mathrm{eff}}$

$$W_{eff} := \frac{w500_{max}}{\sqrt{CAPE_{env}}}$$

Efficiency of CAPE conversion

$$BT_{diff} := T_{anvil} - LNB_{env}$$

$\downarrow \varepsilon \sim \downarrow \mathrm{BT}_{\mathrm{diff}}$

Difference between anvil and LNB heights

Entrainment decreases with shear

b.w.maybee@leeds.ac.uk

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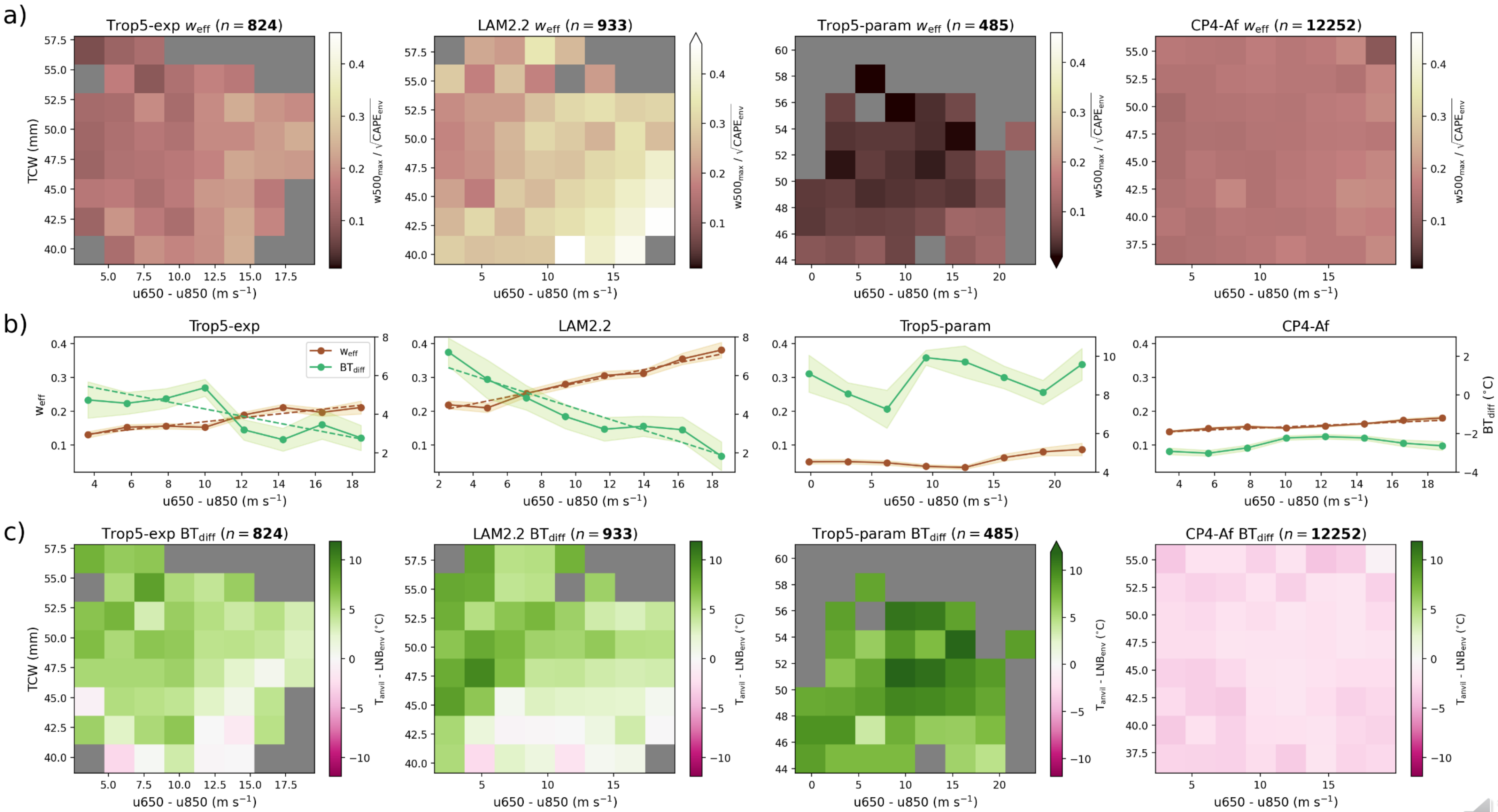
w_{eff}

Reduced entrainment = ↑

18+21UTC MCSs only

BT_{diff}

Reduced entrainment = ↓



Current-generation CP models show environmental controls on entrainment; param and CP4 *do not*.

Role of cold pools?

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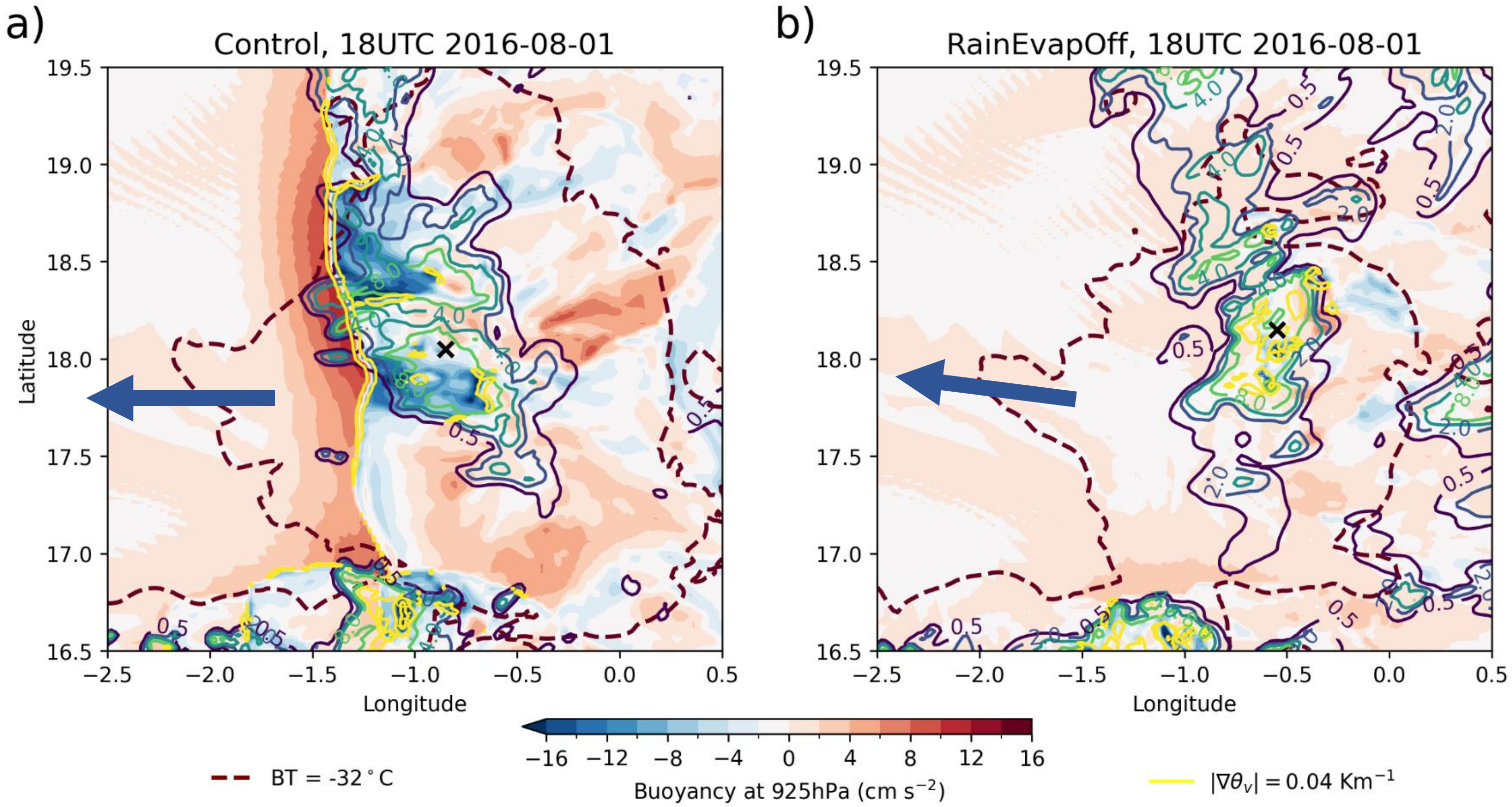
RAL3 physics includes two-moment **CASIM microphysics** scheme → key role in forming <u>cold pools</u>.
Field *et al*, *QJRMS* 2023

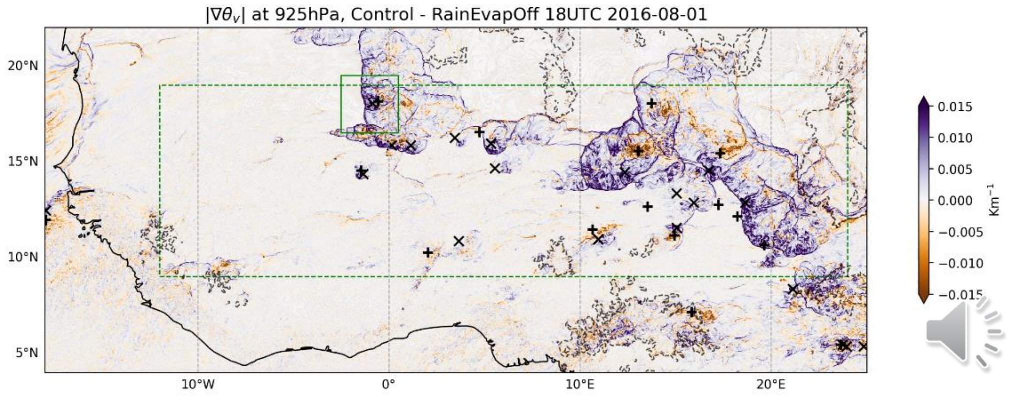
Target role via sensitivity expt:

- **Control:** LAM2.2
- **RainEvapOff:** control w. modified microphysics – no evaporation from <u>rainfall</u>.

[Conv. permitting, 40 days, 2.2km]



→ <u>Cold pools suppressed</u> in RainEvapOff
eg Grant *et al*, *JAS* 2018; Trier *et al*, *JAS* 2011



Track full MCS lifecycles with simpleTrack algorithm
Stein *et al*, *MWR* 2014. **Restrict to Sahel.**

Cold pools don't explain shear response

b.w.maybee@leeds.ac.uk

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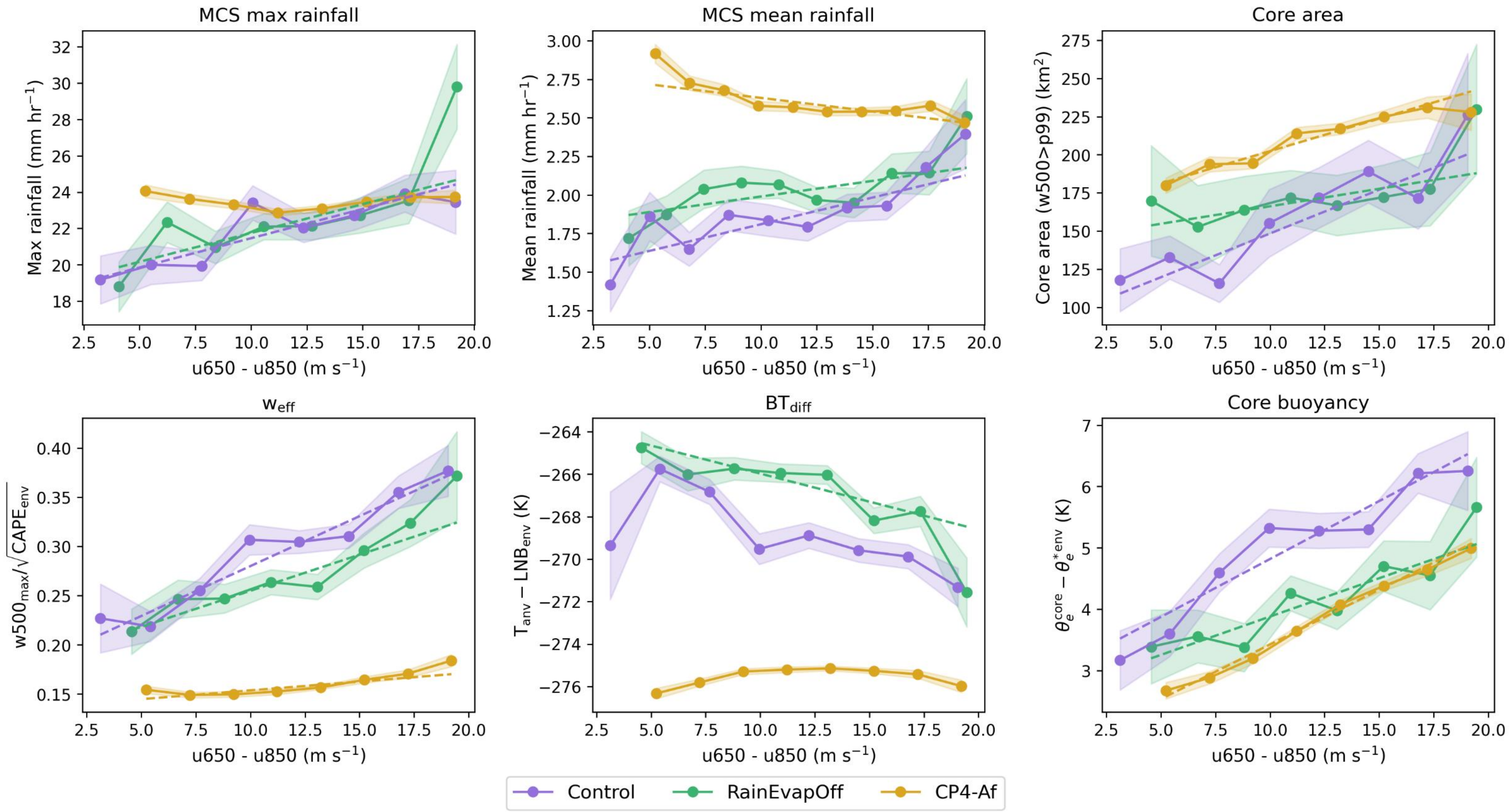


Sahel latitudes, 9°-19°N

RainEvapOff shear response remains similar to Control, improved over CP4-Af.

MCS mean rainfall + upscale impacts

- MCS bulk rainfall observed to depend on environmental conditions – Chen et al, *GRL* 2023.

  → new CP models show too stronger positive influence of shear; CP4-Af shows *negative* control. Stronger relationship with TCW.

Distribution of % bias of MCS mean rainfall anomalies vs OBS is explained by shear *(zonal correlations)*:

LAM2.2: r=0.67 (0.01)

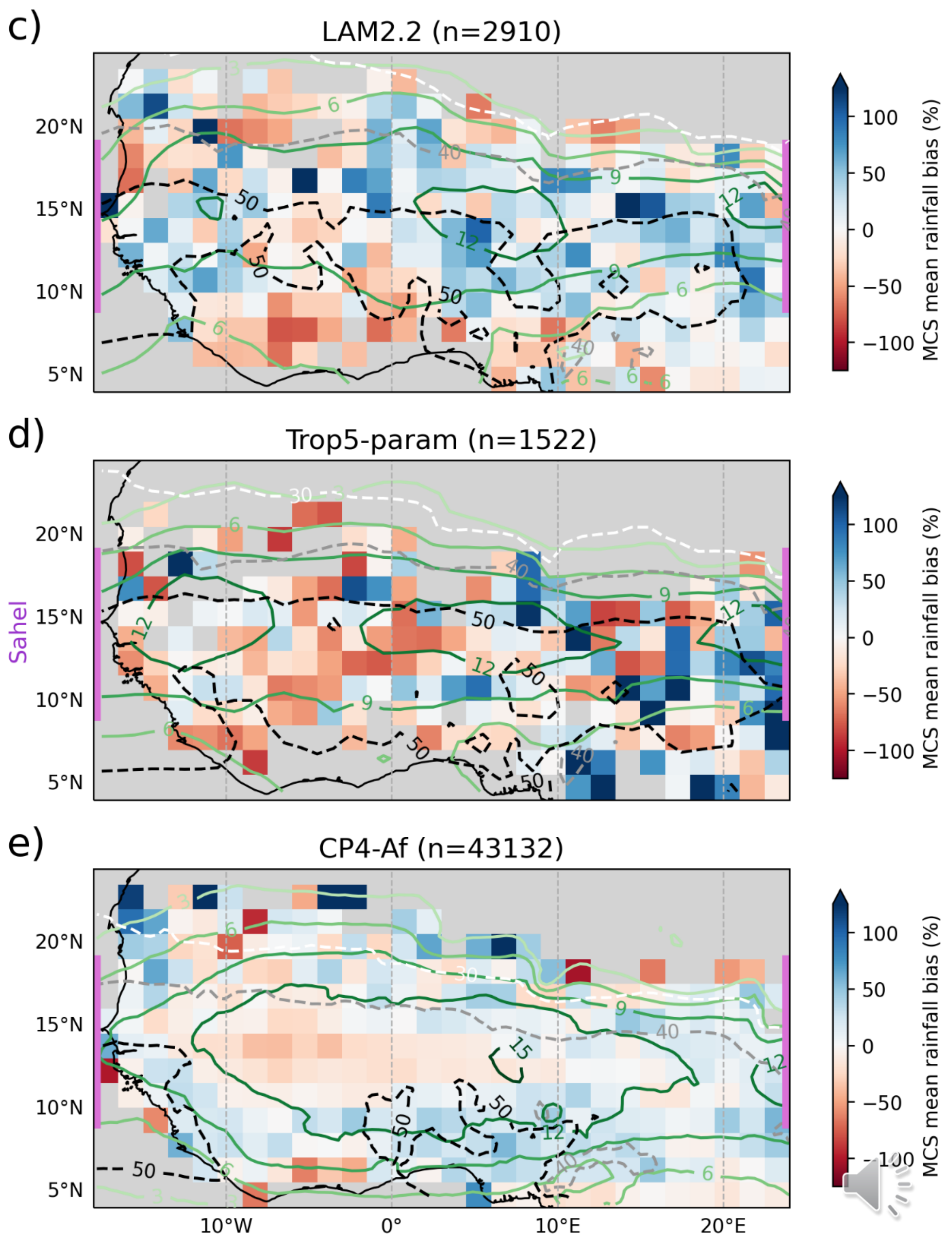
T5-param: r = 0.26

CP4-Af: r=-0.57 (0.04)

12Z mean shear

12Z mean TCW

Mean rainfall ↔ latent heating.
Thus shear influence extends to heating distribution → *forcing of tropical circulation.*



Conclusions

b.w.maybee@leeds.ac.uk

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- Current generation convection-permitting MetUM configurations capture response of MCSs to moisture and shear in West Africa.
- Strong shear gives larger cores, reduced entrainment and greater maximum and mean rainfall.
- Shear response has upscale impacts through control of zonal distribution of biases in storm mean rainfall and heating.
  - ➢ *Incorrect MCS shear responses can cause significant upscale errors.*
- RainEvapOff experiment suppressing cold pools has surprisingly little effect on MCS rainfall-shear response, MCS propagation and MCS diurnal cycle.
  - ➢ *Enhanced large-scale convergence facilitates overnight propagation.*

GRL accepted

Next steps:

- Quantify how well theoretical models of MCS dynamics explain CP-model results.
- Land-atmosphere interactions: what surface scales are important for MCS dynamics?