Local and regional controls on rainfall within African Mesoscale Convective Systems

Christopher Taylor , Cornelia Klein

Danijel Belušić, Phil Harris (CEH),

Doug Parker (U. Leeds), Andreas Fink (KIT), Françoise Guichard (CNRM), Théo Vischel, Gérémy Panthou (U. Grenoble-Alpes), Olivier Bock (U. Paris Diderot), Serge Janicot (U. Pierre et Marie Curie, Paris)

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Intense rainfall in West Africa

AMMA-2050 project working with decision-makers in W Africa to provide robust climate information on 5-40 year time scale

Strong demand for more knowledge on flooding, intense rain and links to climate change

1. Has it been changing, and if so why?
2. What does this suggest about the future?
3. Does land surface state affect rainfall intensity?

Ouagadougou 2009
Engel et al, J.Hydro. Met.2017,
Lafore et al, QJRMS 2017

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FUTURE CLIMATE FOR AFRICA

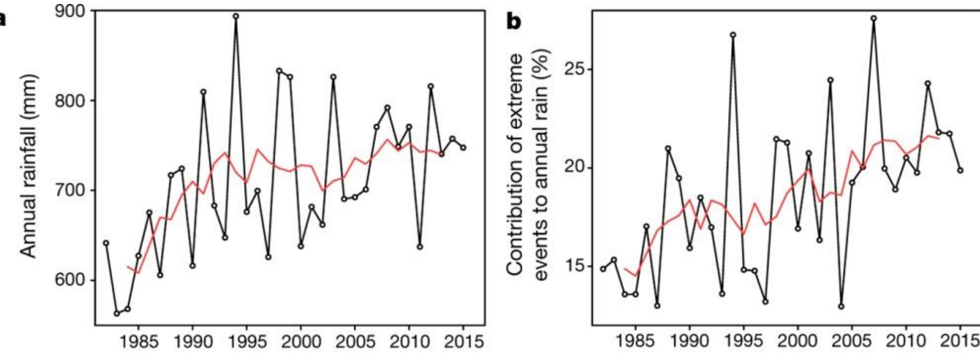
NERC SCIENCE OF THE ENVIRONMENT

UKaid from the British people

AMMA-2050

1. Is intense rainfall changing in Sahel?

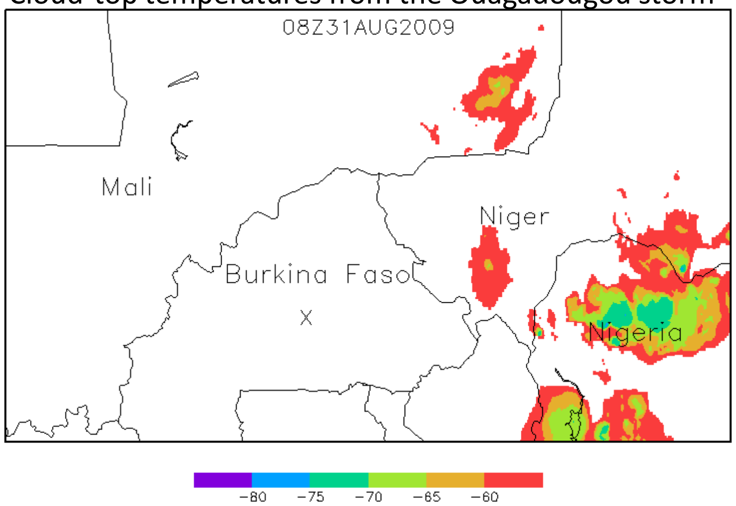
Rain gauge network shows **storms getting more intense** since the 1970/80s drought.



Long-term Meteosat satellite record:

- Sub-hourly cloud-top temperatures since 1982
- Mesoscale Convective Systems (MCS) produce ~90% of Sahel rain
- Readily identified as large, cold systems

Cloud-top temperatures from the Ouagadougou storm



Panthou et al, I.J.Clim. 2014

Mathon et al, J Appl. Met. 2002

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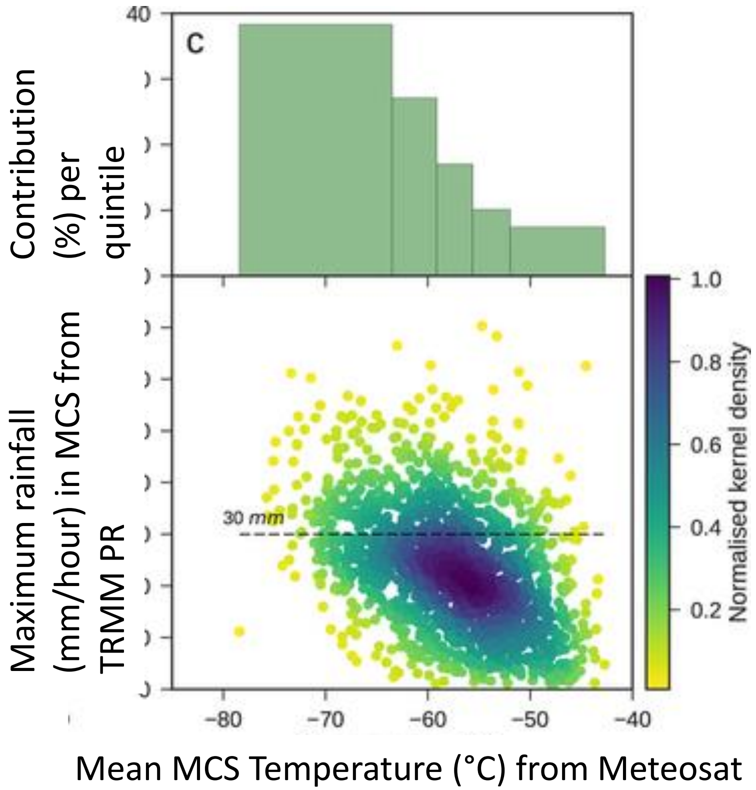
Can we use Meteosat to look at extreme Sahelian rainfall?

Yes…85% of extreme daily gauge totals associated with large (>25,000 km^2), cold (<-40°C) systems

Likelihood of extreme rain within MCS rises with decreasing T



Data from 1640 coincident overpasses

Taylor et al, Nature 2017

Klein et al, JGR-Atmos 2018

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Evolution of MCS properties over 35 years

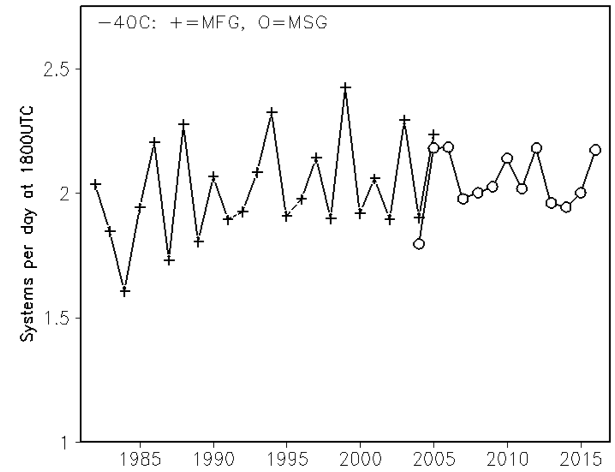
Period 1982-2016 covers 9 Meteosat satellites, including First (MFG) and Second (MSG) Generations.

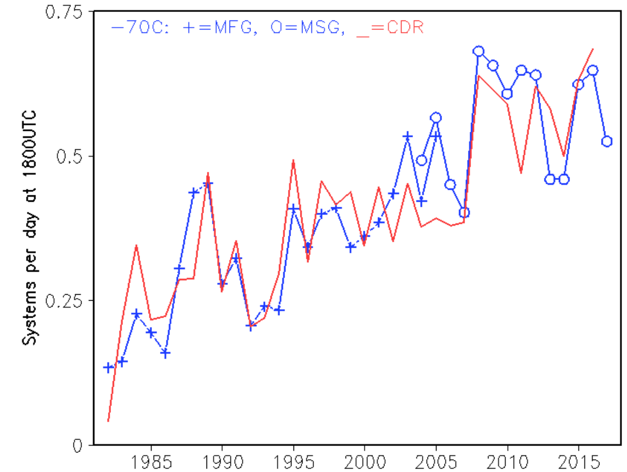
Number of MCS at threshold of -40°C well-correlated with seasonal rainfall (r=0.88)

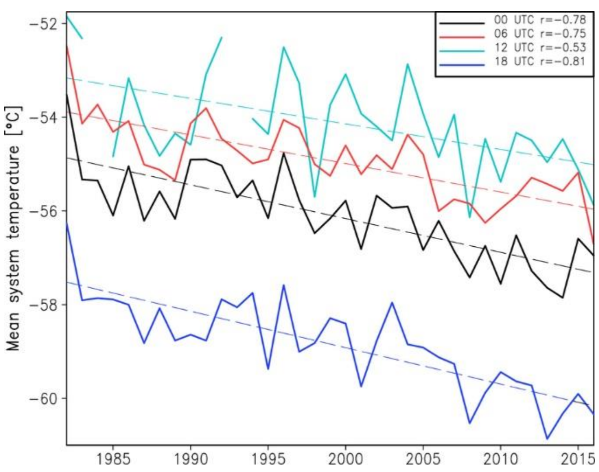
More linear increase at lower threshold (-70°C). Well-correlated to global mean temperature

Cross-calibrated Climate Data Record (GridSat) confirms trend in cold system frequency

MCSs getting colder







Taylor et al, Nature 2017

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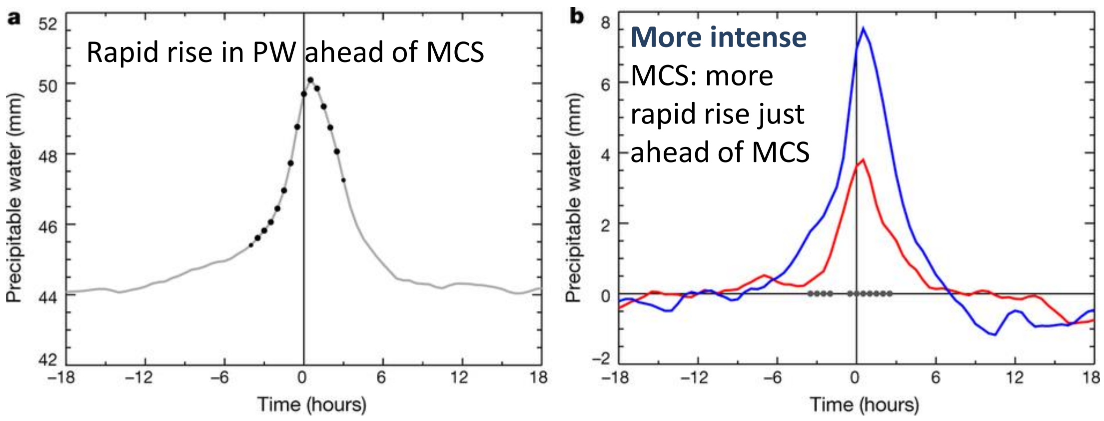
Why is rainfall intensity changing?

Sahelian boundary layer hasn't been getting warmer or moister during wet season since 1980s

At event time scale, there is no correlation between MCS "intensity" (cloud-top temperature) and pre-event moisture (6 hours ahead).

But correlations with intensity do exist for zonal wind shear and mid-level dryness

GPS measurements of precipitable water relative to MCS arrival time



Taylor et al, Nature 2017

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Warming trends across Africa

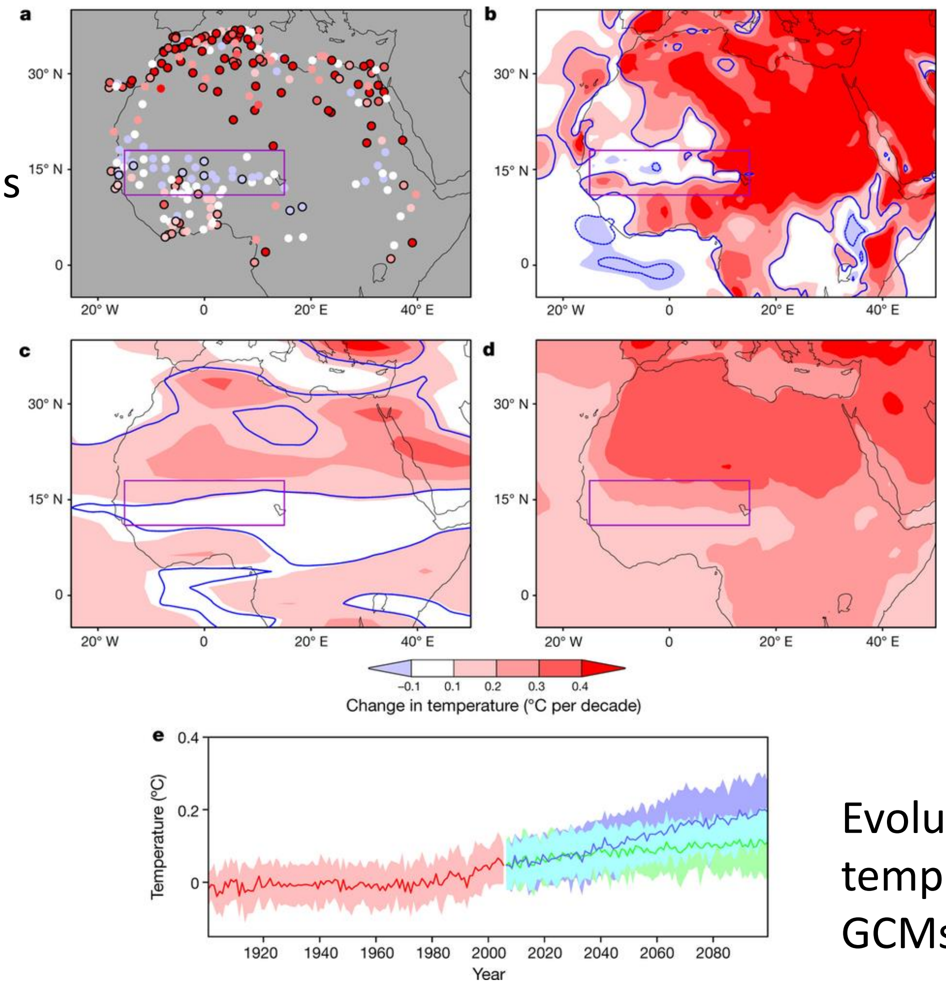
Recent JJAS temperature trends (°C/decade)

Synoptic stations

ERA-Interim

MSU lower troposphere

Historical CMIP5 simulations



Evolution of meridional temperature difference in CMIP5 GCMs

Taylor et al, Nature 2017

Cook and Vizy, J Clim 2015, Zhou, Sci. Rep. 2016

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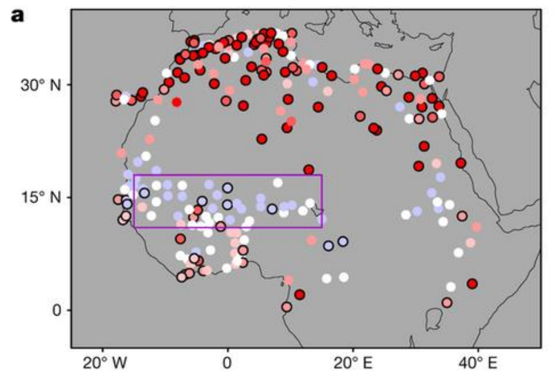
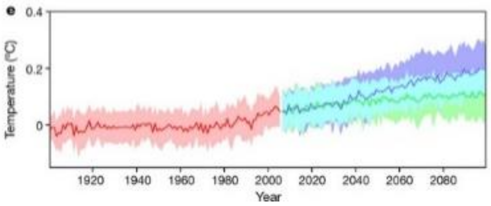
Warmer Sahara: increased shear, warmer Saharan Air Layer with lower RH, and (in principle) impact on easterly waves

2.What does this suggest about the future?

Whatever else happens to West African Monsoon, expect meridional temperature gradient to continue to increase

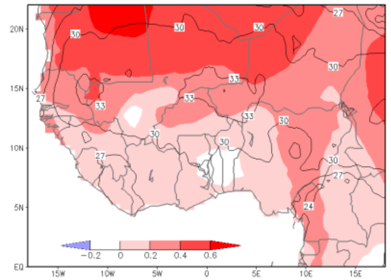


Impact on MCSs (via shear, mid-level RH decreases, easterly waves?) expected to continue to produce strong intensification – effects (largely) not captured by GCMs

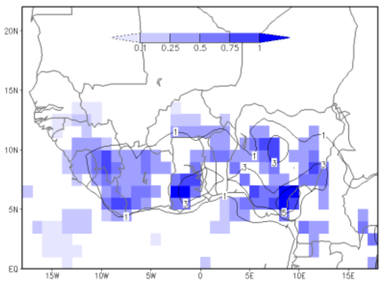


Similar processes may also already be influencing convection in pre-monsoon months further south

Temperature trends



Intense MCS trends



March-April-May

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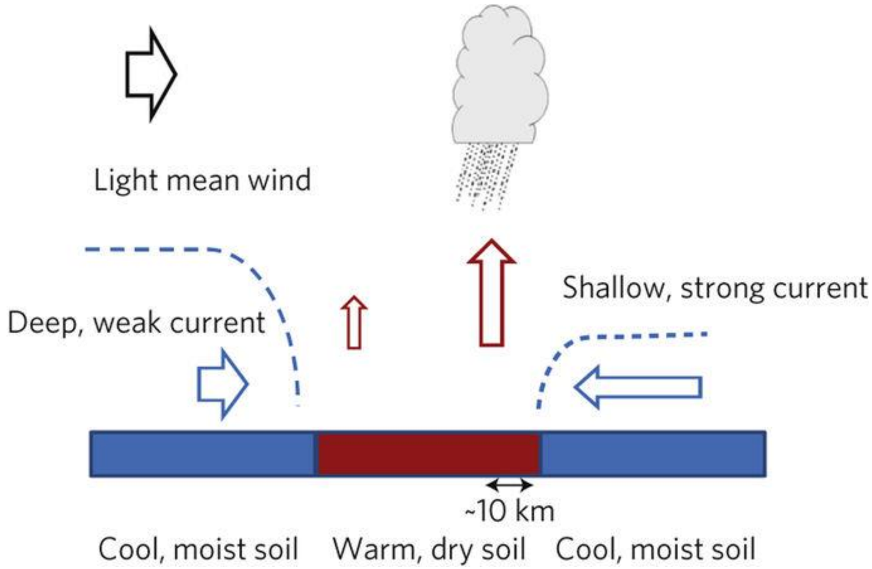
3. Does land surface state affect rainfall intensity?

We know from previous studies in Sahel that MCS initiation is favoured in regions with mesoscale heterogeneity (soil moisture, wetlands, forest cover…)

Can land surface also affect convection within mature MCSs?

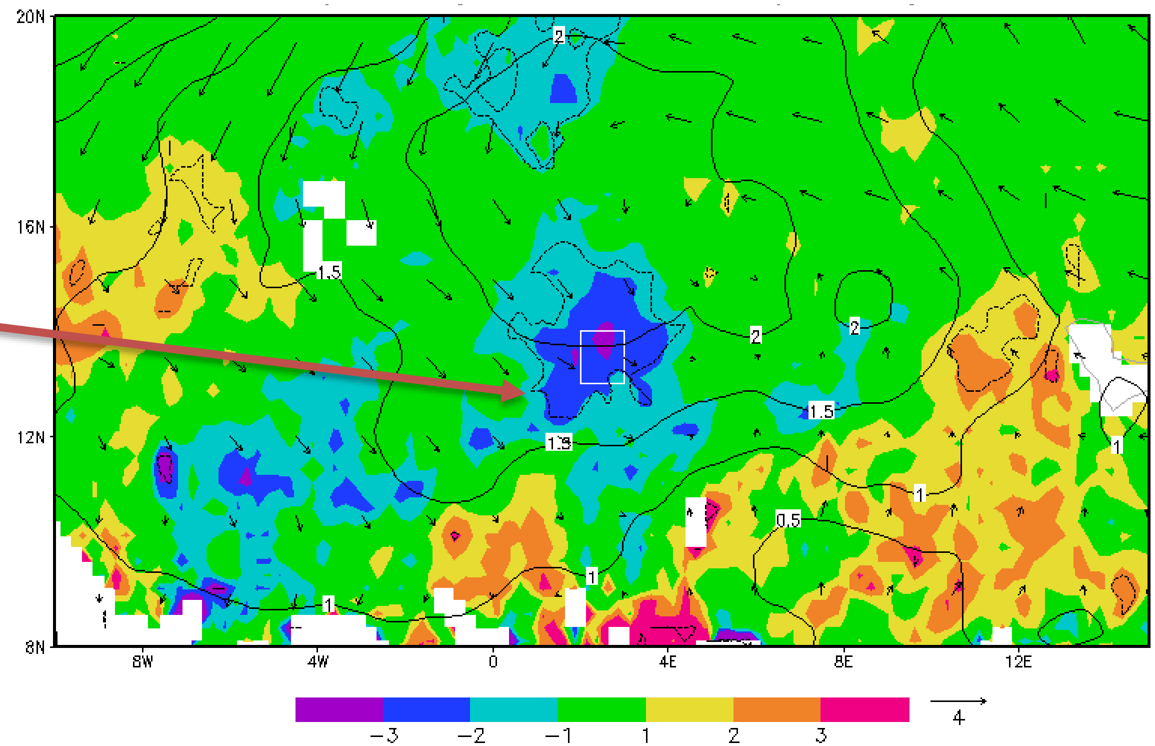


Taylor et al., Nat. Geosci. 2011, Garcia-Carreras et al, JGR-Atmos 2010, Taylor et al, QJRMS 2018

At scale of MCS (25,000+km^2)…

More intense MCSs tend to occur over *drier* soils Indicative of feedback on MCS intensity

Composite evening MCS at Niamey (box): differences between days with coldest and warmest quartile events



AMSR-E soil moisture differences [% volumetric];

Dashed line: 95% significance between intense and weak MCSs
Contours and vectors: ERA-I Temp [K] and u,v [m/s] differences at 925hPa

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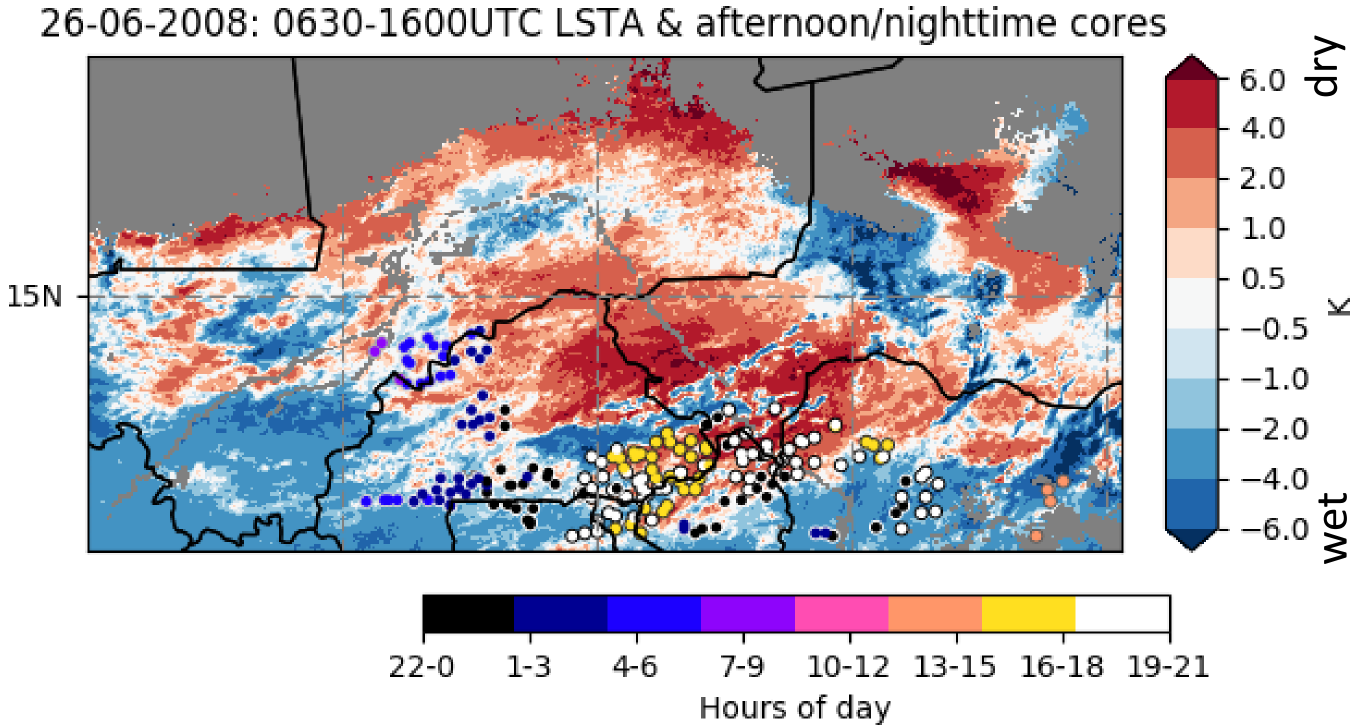
What about smaller scales?

Apply 2D wavelet decomposition to cloud-top temperatures to identify convective cores within MCS (Klein et al, JGR-Atmos, 2018)



Example case of locations of convective cores (circles) within MCS, relative to pre-MCS land surface temperature features (proxy for soil moisture)

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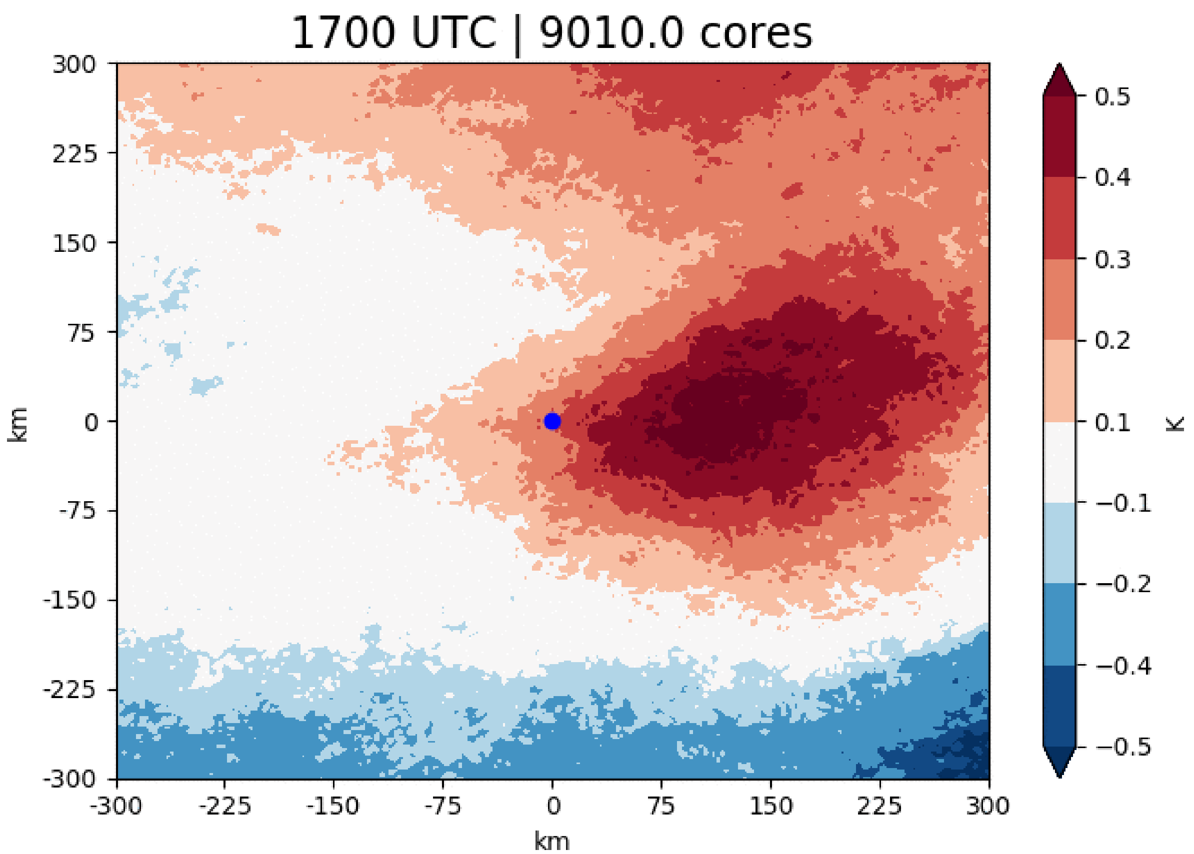
Composites of surface conditions centred on convective cores

Land surface temperature anomalies

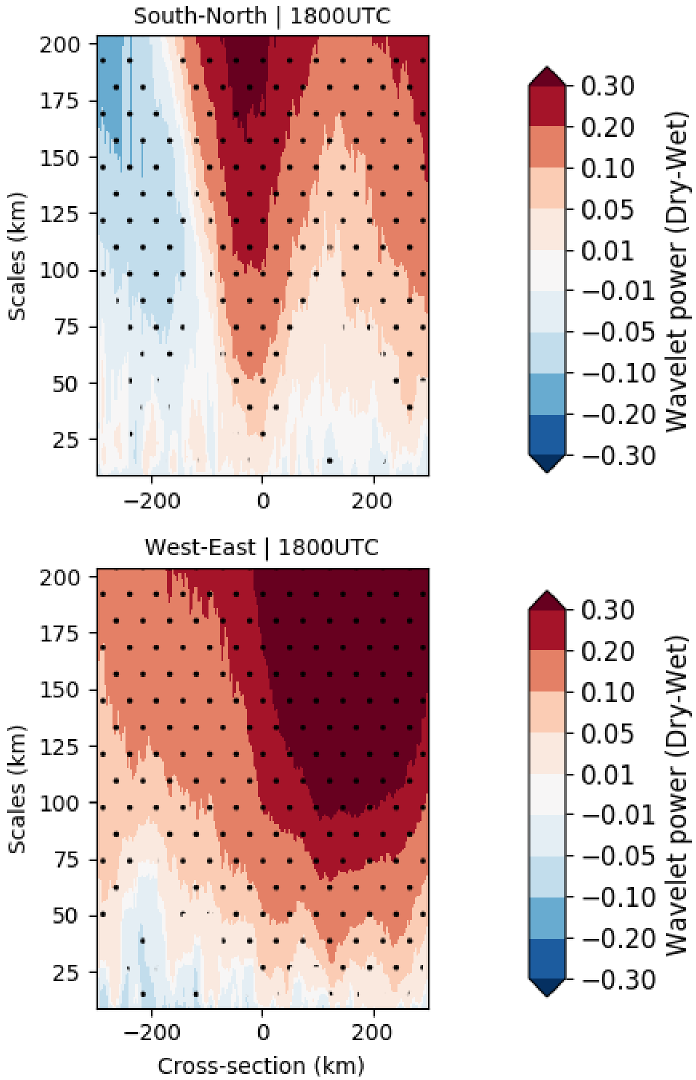


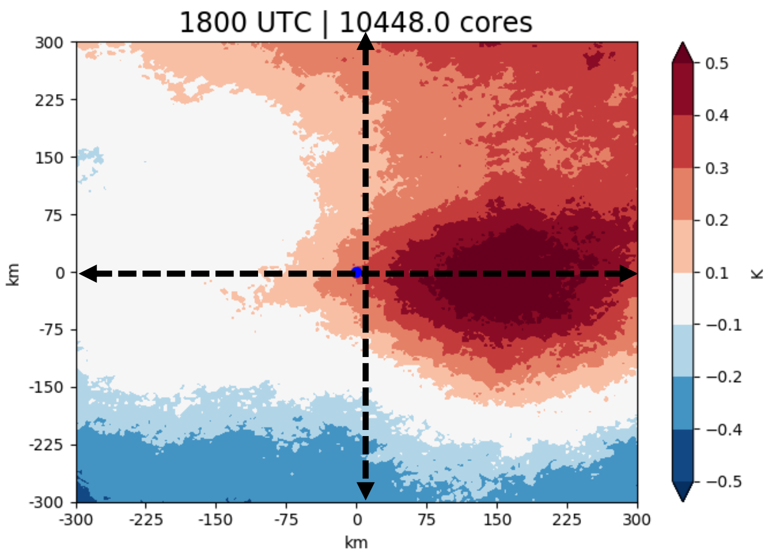
- ‘stationary’ ~2-3 hours warm upstream feature
- Persistent dry signal into nighttime hours

Klein et al, in prep

Scales of surface features throughout the day

Difference of wavelet powers for dry and wet LST anomalies centred on convective cores:

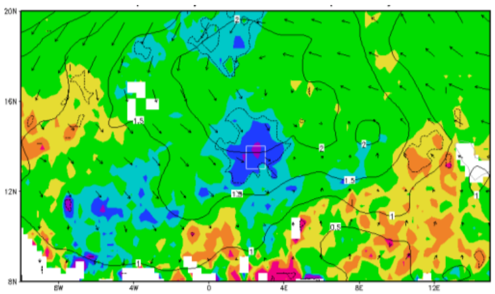




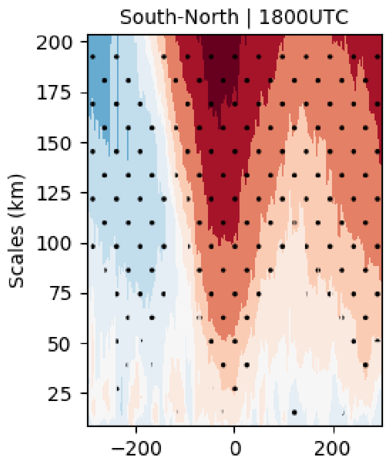
- Strong meridional temperature gradient down to ~25km as part of the larger W-E feature
- Signals still evident at larger scales (though weakening) after midnight (preliminary analysis)

Summary: Does land surface state affect rainfall intensity?

- Yes… convection within MCSs sensitive to soil moisture on range of length scales



- Dominant signal indicates cells favoured in regions with drier soil, presumably associated with lower CIN and increased convergence



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