# What is driving observed trends in intense convective systems over tropical North Africa?


**Christopher Taylor**

**Danijel Belušić, Cornelia Klein, 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)**

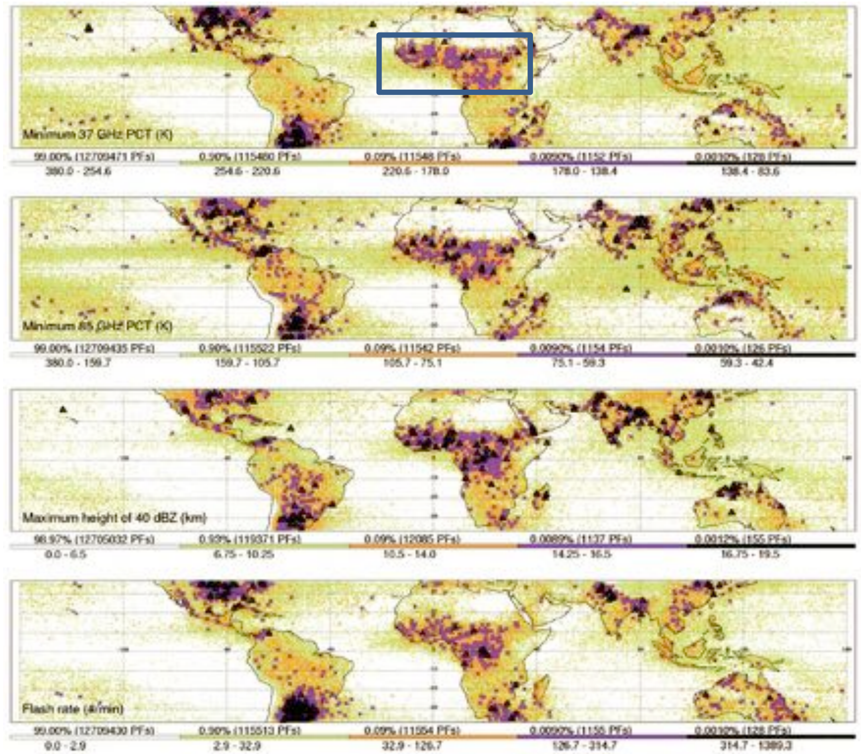
# How do intense convective systems respond to climate change?

A warmer atmosphere can hold more moisture (6-7% per degree Celsius, Clausius-Clapeyron)

First guess – expect most intense storms to increase according to this relationship.

But what if warming affects storm-scale dynamics?

Where are the most intense thunderstorms on earth?
Different measures of intense storms as viewed by TRMM




*Zipser et al, BAMS 2006*

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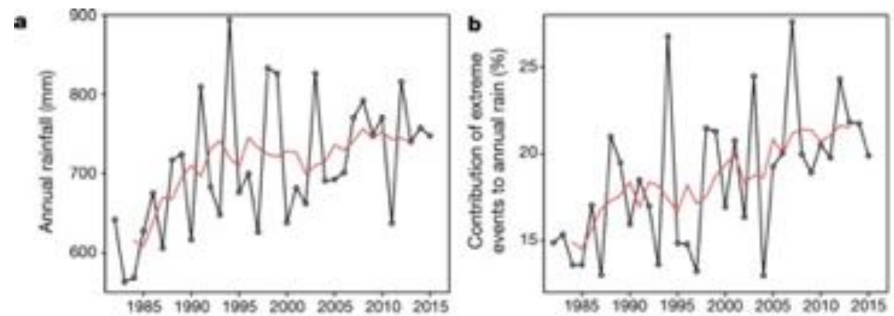
# Sahelian trends

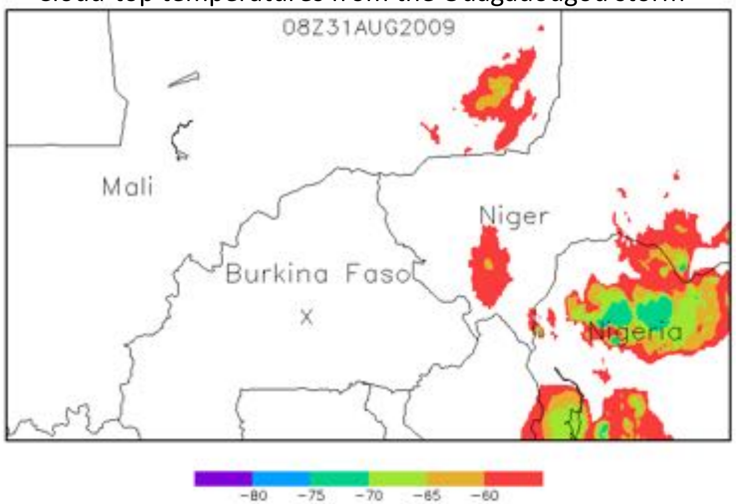
Rain gauge network shows storms getting more intense since the 1970/80s drought.

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




Ouagadougou 2009

*Panthou et al, I.J.Clim. 2014*
*Engel et al, J.Hydro. Met.2017, Lafore et al, QJRMS 2017*
*Mathon et al, J Appl. Met. 2002*

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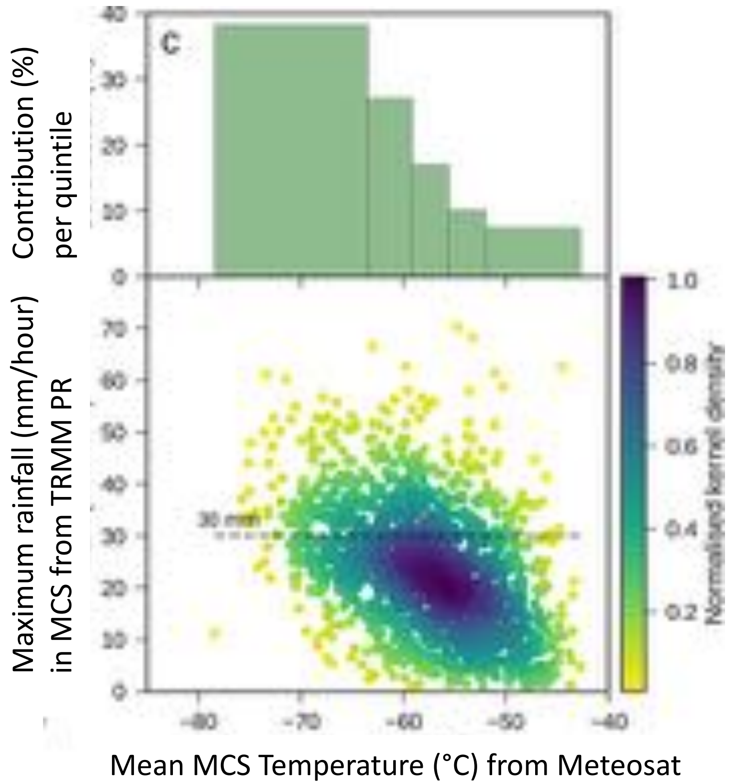
# Can we use Meteosat to look at extreme Sahelian rainfall?

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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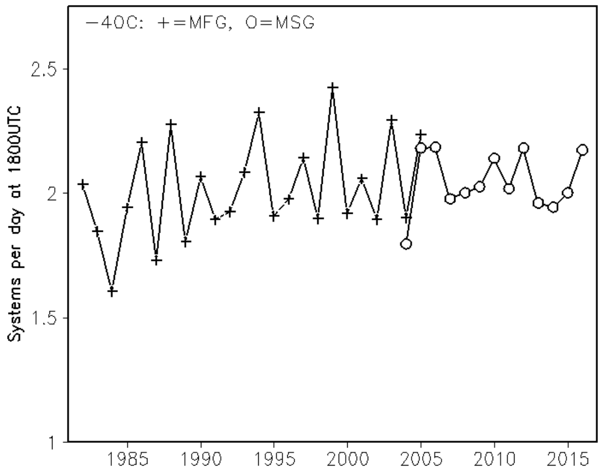
# Evolution of MCS properties over 35 years

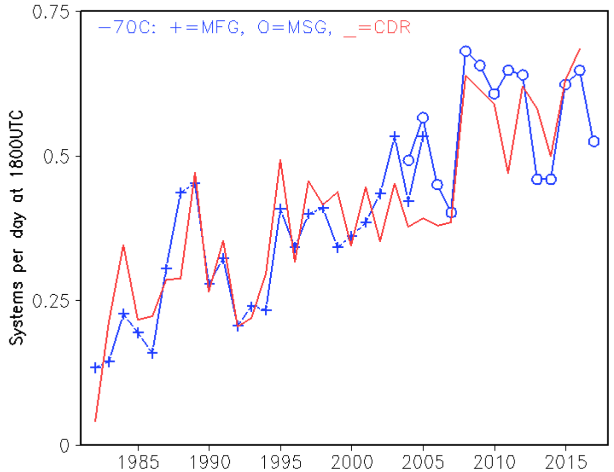
Period 1982-2016 covers 9 Meteosat satellites, including First (MFG) and Second (MSG) Generations.

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




*Taylor et al, Nature 2017*

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# Warming trends across Africa

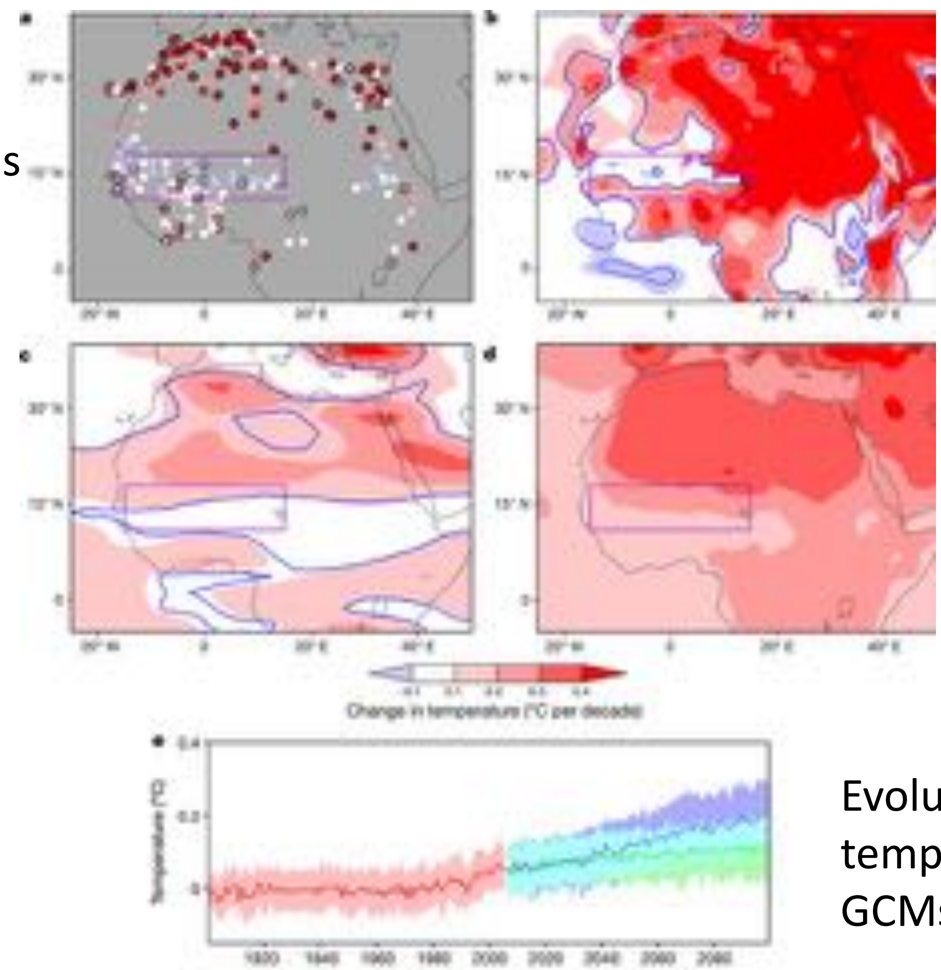
Recent JJAS temperature trends (°C/decade)

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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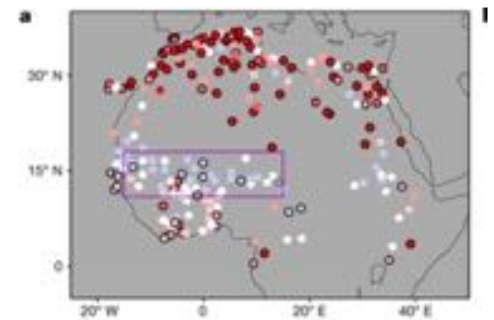
# How does Saharan temperature affect Sahel MCS intensity?



More intense MCS correlated (on both event and inter-annual time scales) with:

- Zonal wind shear (linked to temperature gradient between Sahara and Equatorial Africa)
- Warmer and drier (RH) mid-levels (the "Saharan Air Layer")

These factors known to affect MCS intensity… e.g. stronger shear associated with more efficient rainfall production (e.g. Alfaro 2017)

Surprisingly, no evidence of moisture-driven intensification in Sahelian MCS

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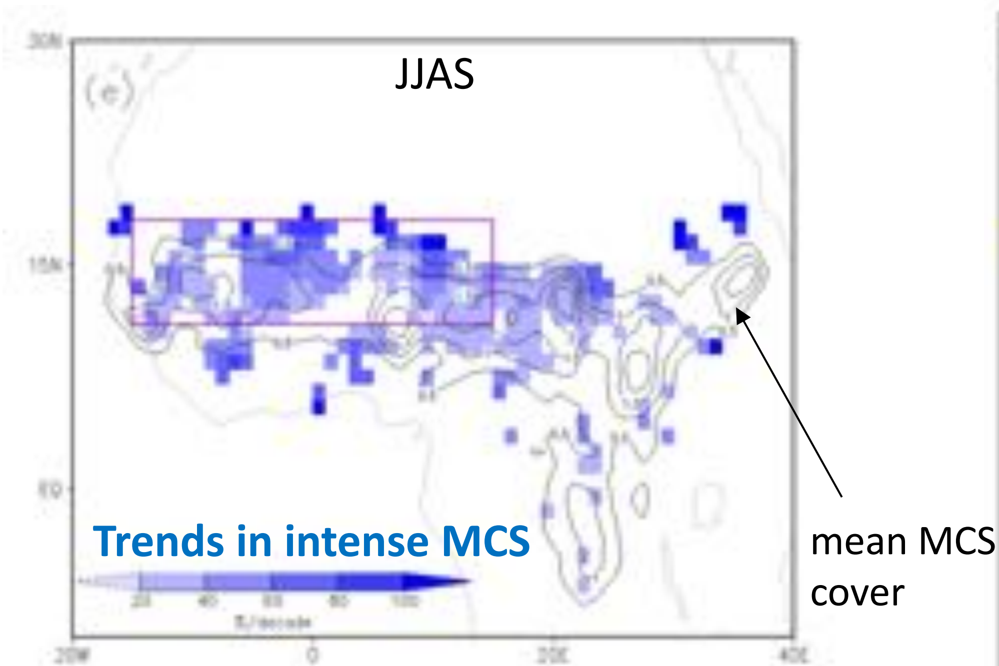
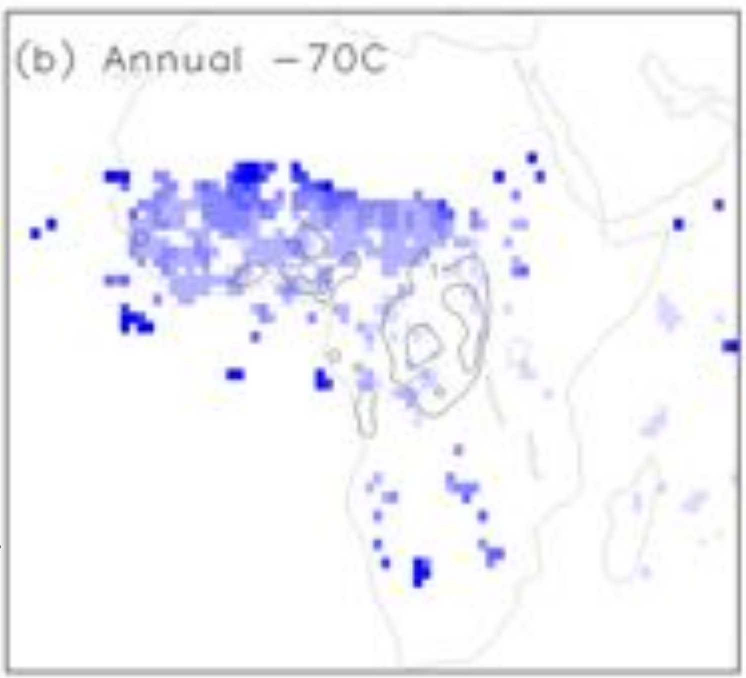
# Spatial distribution of MCS intensification




Strong intensification trend during JJAS limited to Sahel

Intensification also evident in sub-Sahelian W Africa in annual averages, but **no annual trend in Congo**

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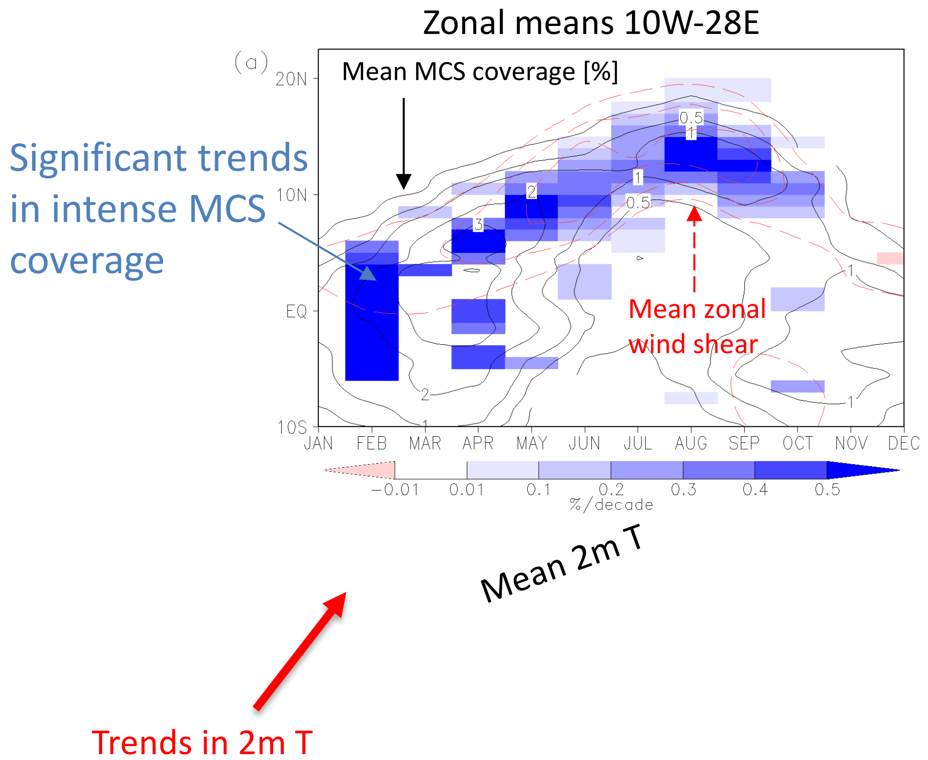
# Other times of year?

- Intense MCS frequency follows rain belt, but weaker during retreat (like wind shear)

- Curiously strong MCS intensification trend in Feb in Congo Basin

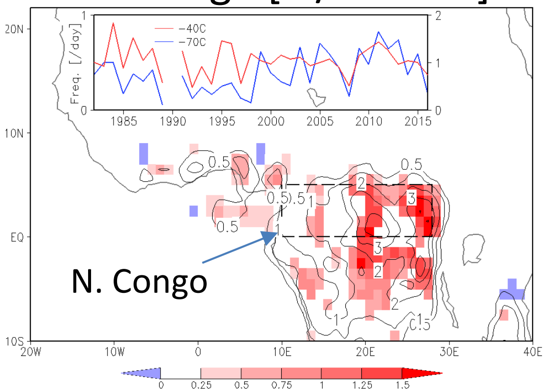
- Coincides with strong warming in Sahel



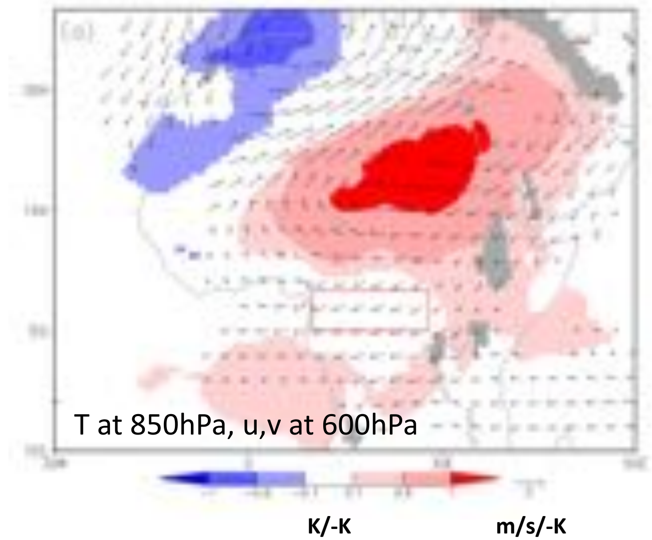

*In prep*

# MCS and T trends in February

Trend in intense MCS coverage [%/decade]




Interannual correlations with N Congo MCS intensity




Intensification of Congo MCS since late 1990s correlated with warmer conditions to north

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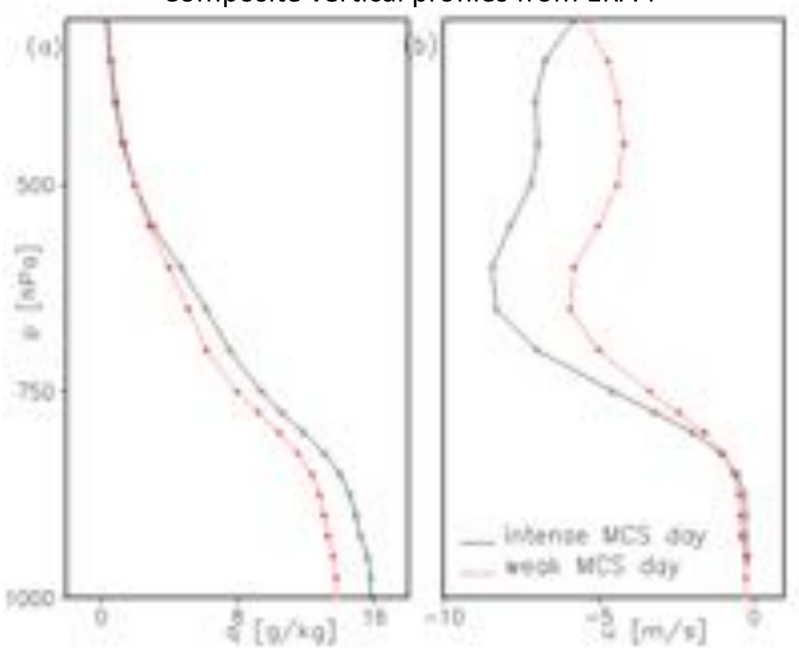
# Event-based composite analysis

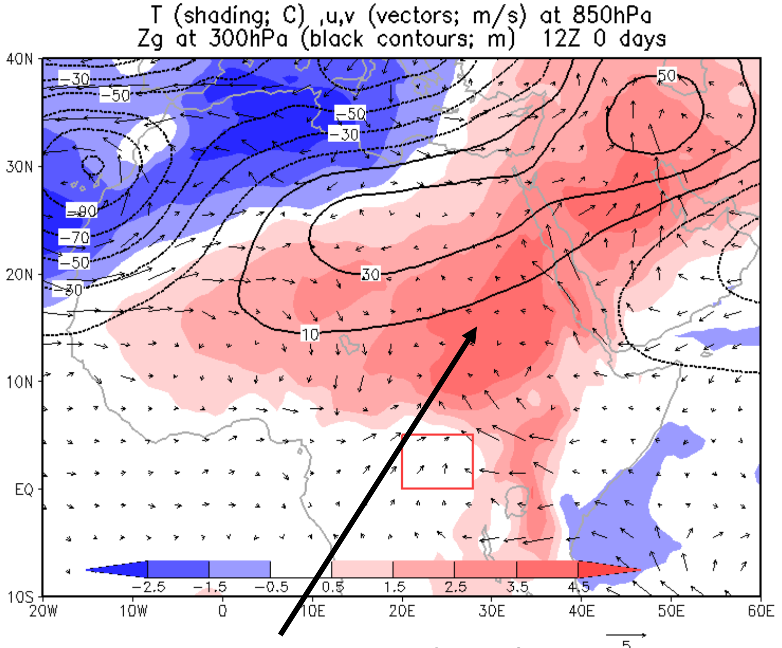
Use observed MCS T to identify days with most/least intense Feb MCS in NE Congo

Intense – weak MCS composites in ERA-I

Composite vertical profiles from ERA-I




**Environment in NE Congo is moister and more sheared on intense days**




**Intense Congo MCS occur on days when E Sahel/Sahara ~4°C warmer compared to weak days**

As in Sahel, intense Feb MCS in Congo occur on days with strong meridional T gradient

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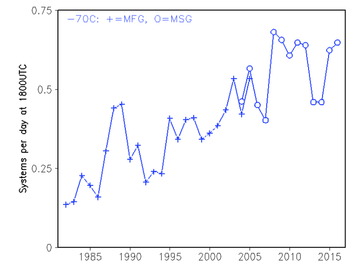
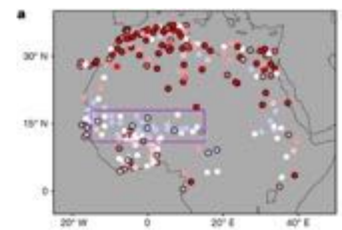
# Summary

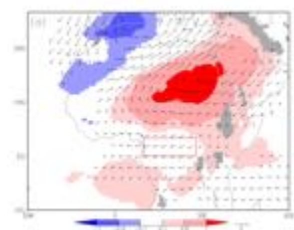
- Meteosat reveals surprisingly strong increase in frequency of intense MCS over Sahel in last 35 years



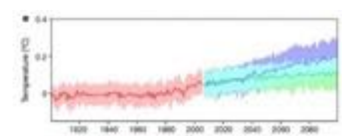

- Suggests link between MCS intensity and meridional temperature gradient



- Supported by similar relationship between intensity and temperature gradient in Congo in Feb



- GCMs project strongest warming in arid and semi-arid regions – likely to further enhance temperature gradients



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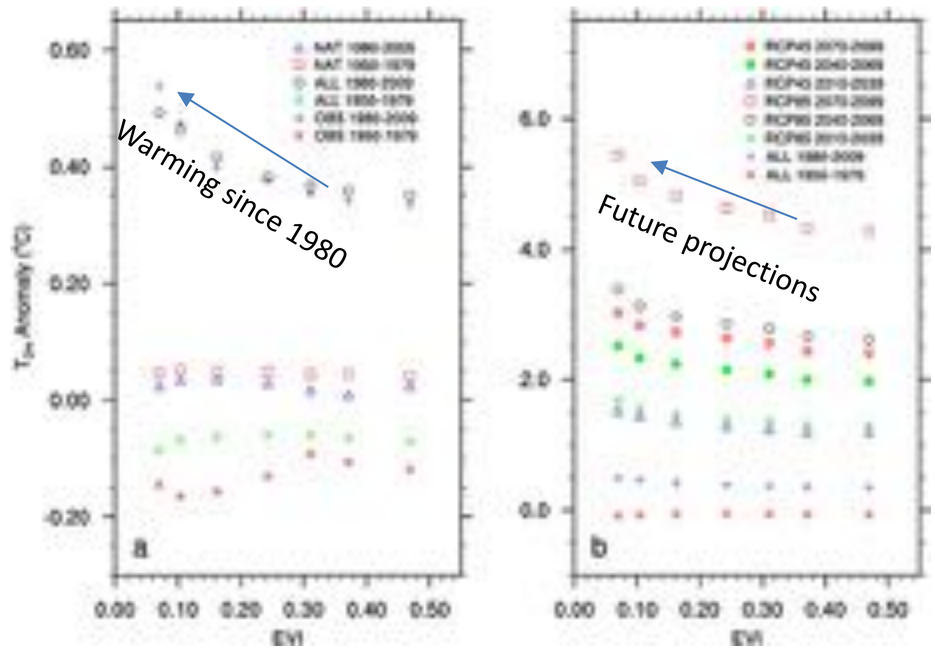
# Desert Amplification

More arid regions warming more rapidly than moister regions

Linked to increasing water vapour in very dry regions




Proxy for aridity

*Zhou, Sci. Rep. 2016*
*Wei et al, Sci. Rep. 2017*

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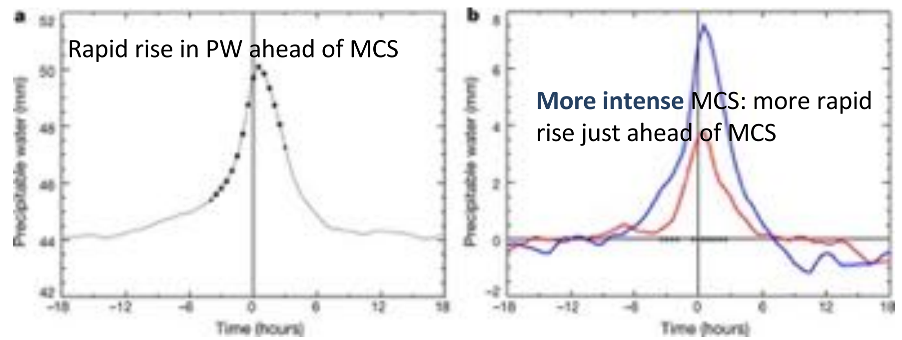
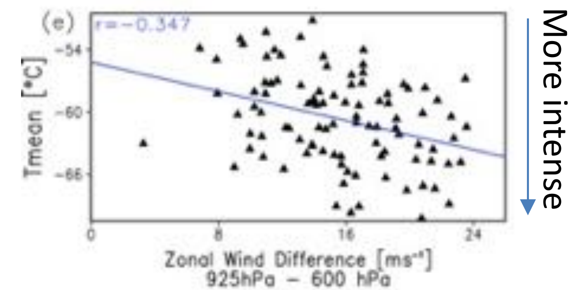
# What controls Sahel MCS intensity? Event-based analysis

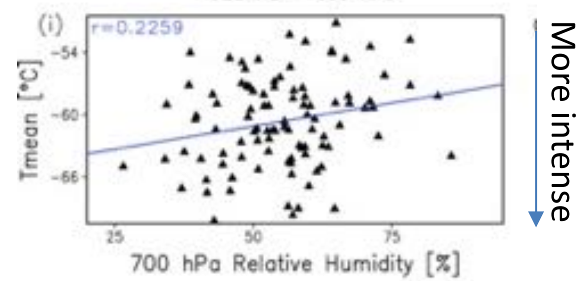
More intense MCS have been linked to increased moisture, wind shear, synoptic conditions, mid-level dryness…

- No correlation between MCS "intensity" (cloud-top temperature) and pre-event moisture (6 hours ahead).
- Find tendency for more intense MCS when zonal wind shear larger, mid-level RH lower, African Easterly Waves…

GPS measurements of precipitable water relative to MCS arrival time

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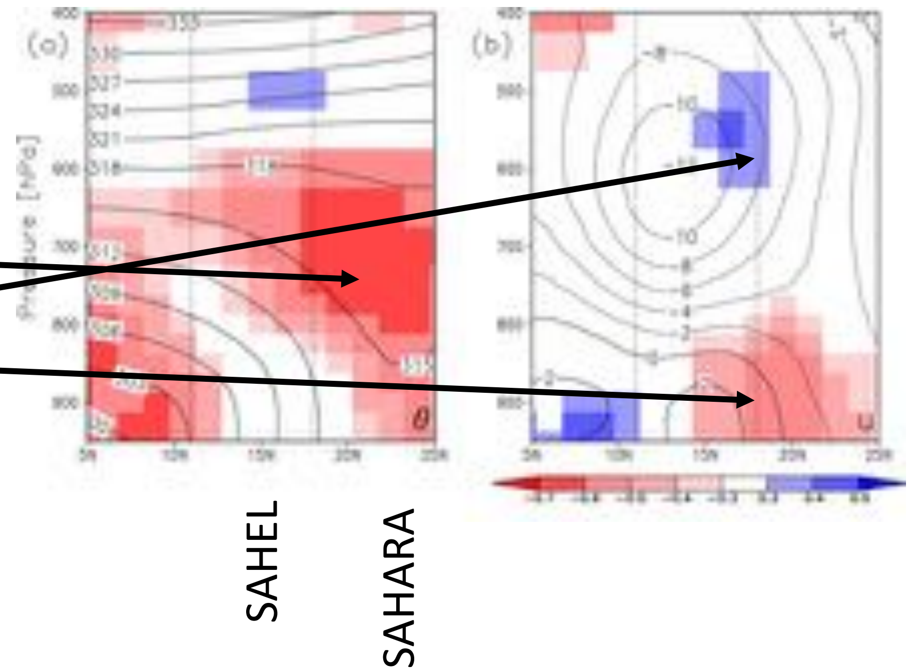
# What controls Sahel MCS intensity? Inter-annual analysis

Correlations between MCS temperature and atmospheric variables (ERA-Interim) show years with more intense systems have:

- Warmer air to north and at mid-levels in Sahel
- Stronger wind shear
- Also more synoptic activity, drier mid-levels




All are known drivers of more intense MCS

All are responses to Saharan warming

No evidence of moisture-driven intensification in Sahelian MCS

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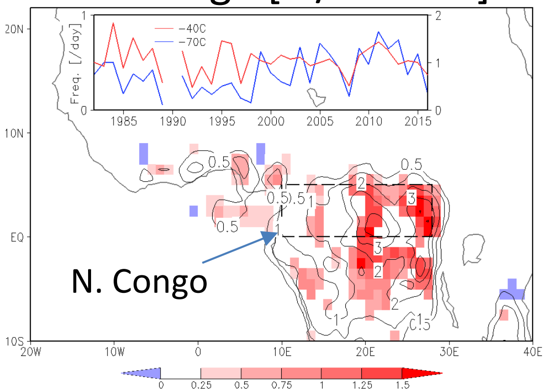
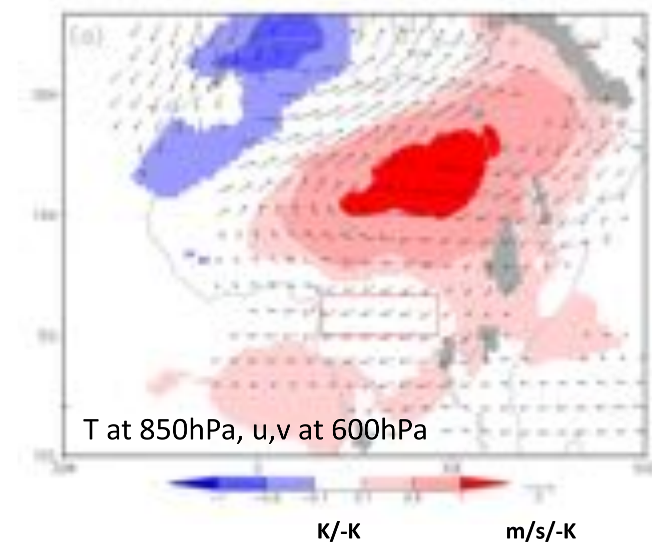



Interannual correlations with N Congo MCS intensity

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*In prep*

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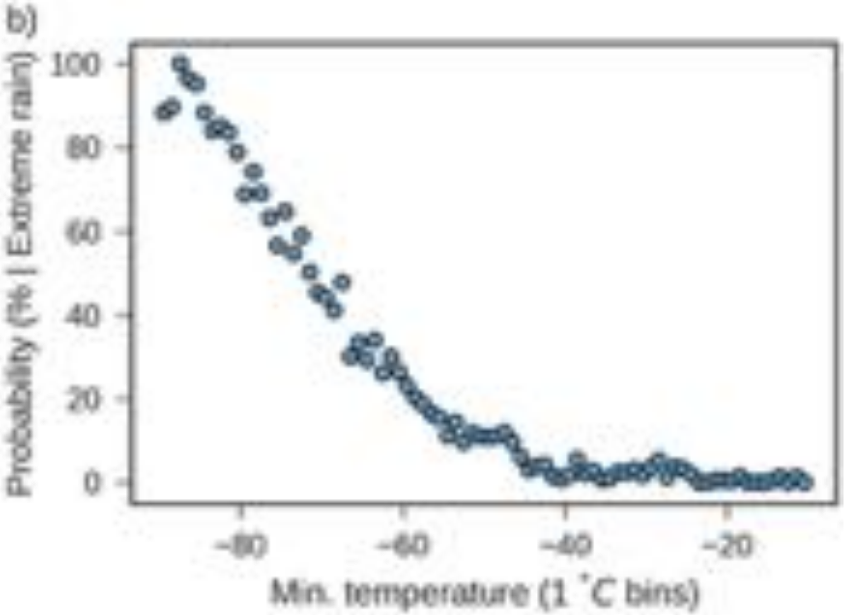
# Likelihood of extreme rainfall rate with cloud-top temperature




83.7% of the storms that reach a minimum temperature below 80°C are associated with extreme rain.

Probability for rainfall above 30 mm h−1 (99th percentile) per cloud as a function on minimum cloud-top temperature

**Wavelet Scale Analysis of Mesoscale Convective Systems for Detecting Deep Convection From Infrared Imagery, Volume: 123, Issue: 6, Pages: 3035-3050, First published: 07 March 2018, DOI: (10.1002/2017JD027432)**

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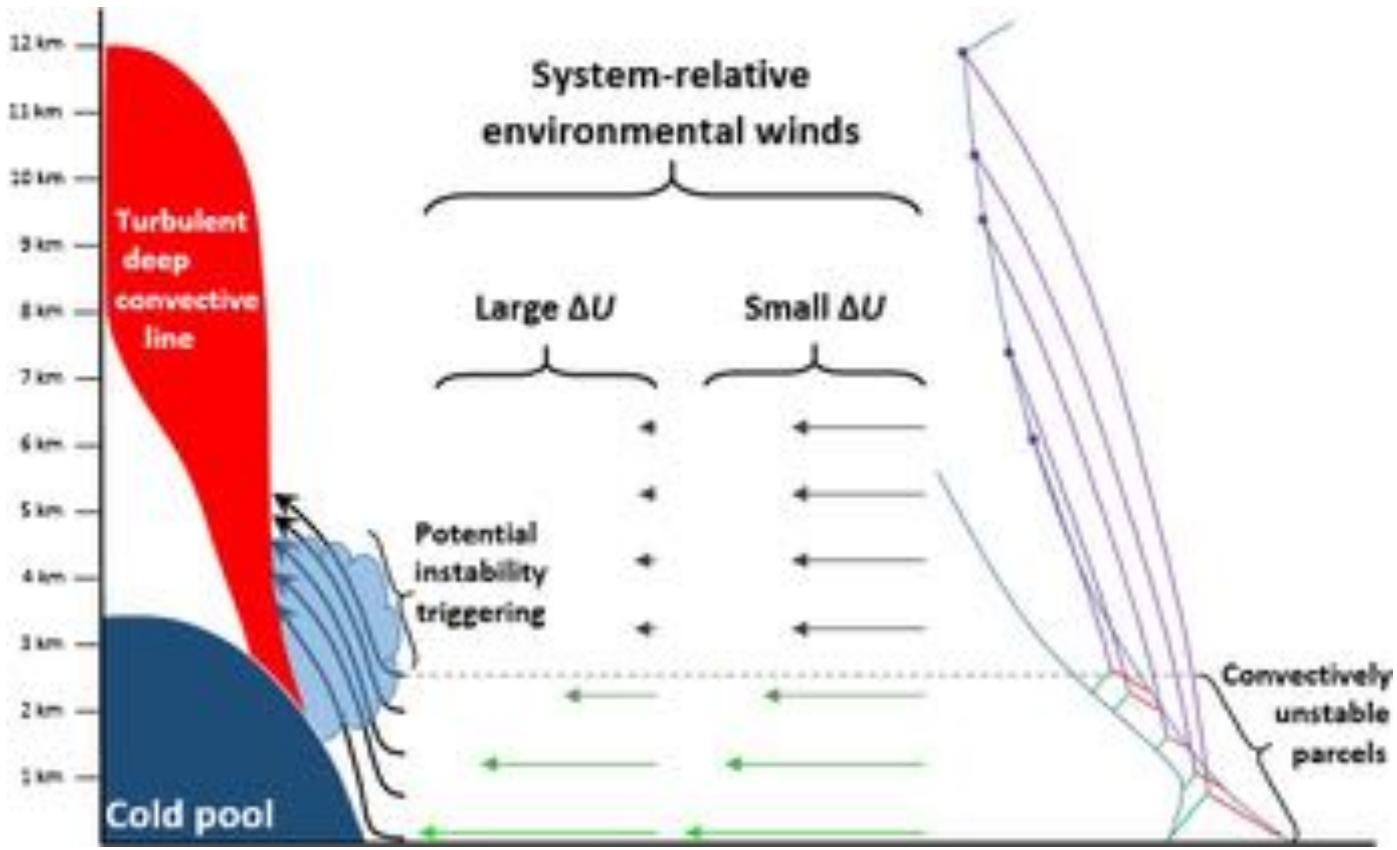
# Impact of shear on instability of lifted layer




*Alfaro, JAS 2017*

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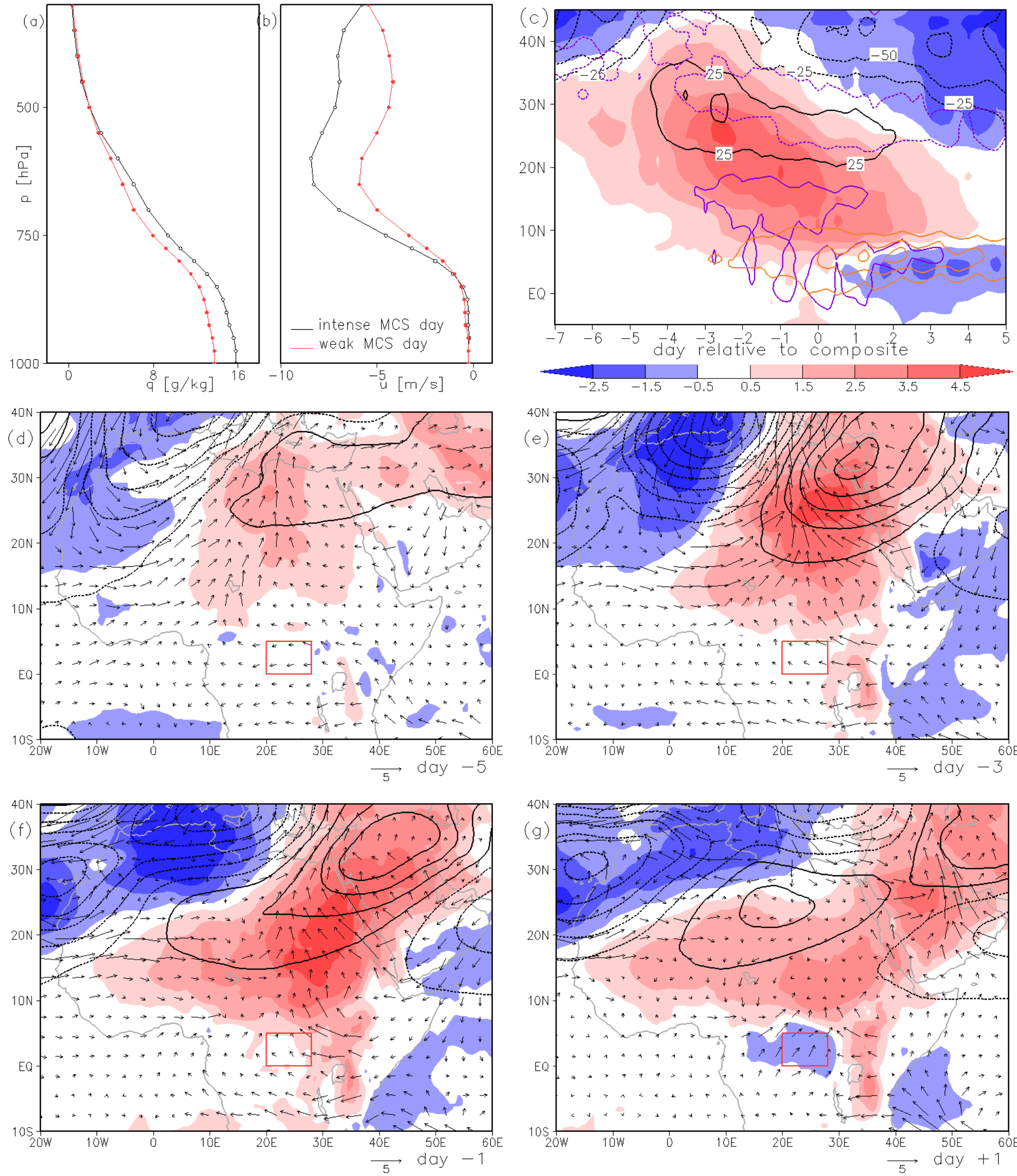


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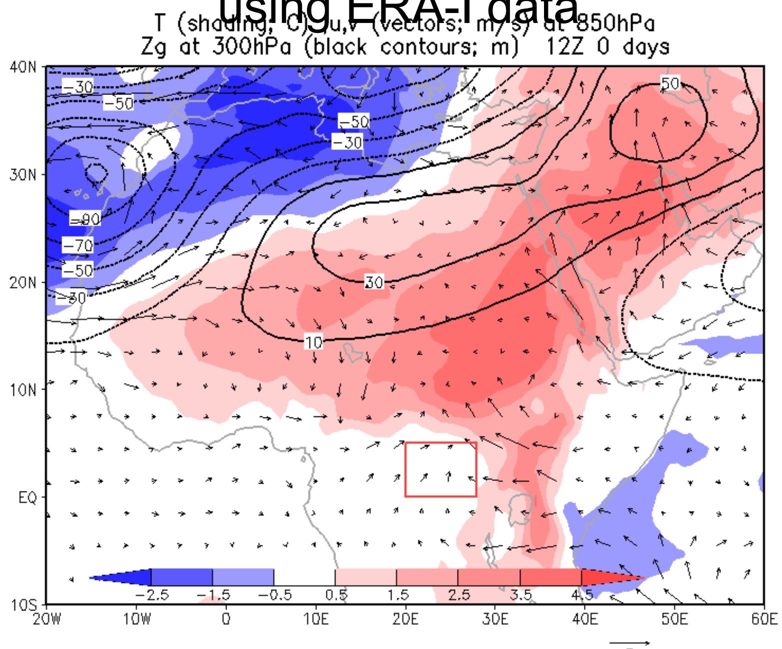
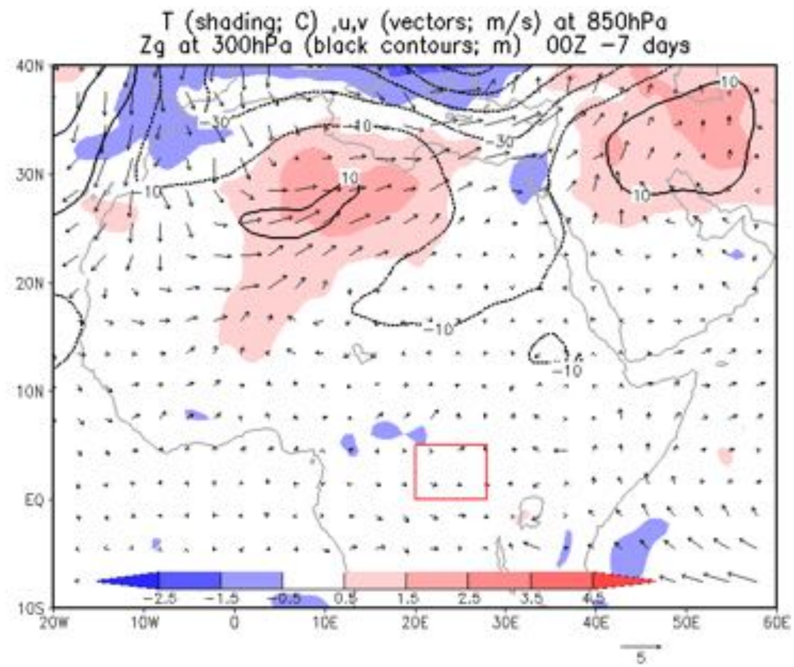
Use observed MCS T to identify days with most/least intense MCS in NE Congo

Intense – weak MCS composites using ERA-I data




Intense Congo MCS in Feb occur on days with strong meridional T gradient
Consistent with Sahelian MCS

*Taylor et al, in prep*

# Evolution of MCS properties over 35 years

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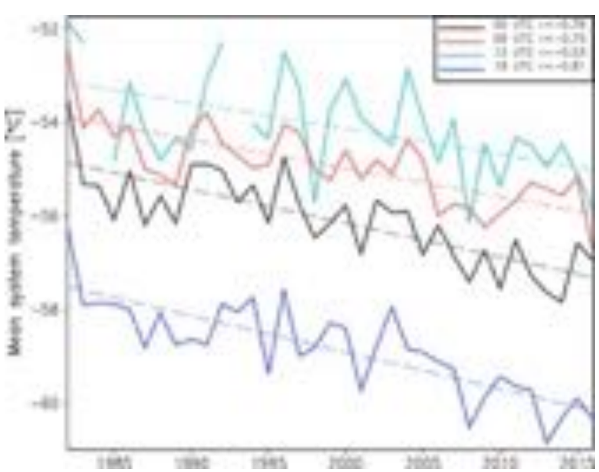
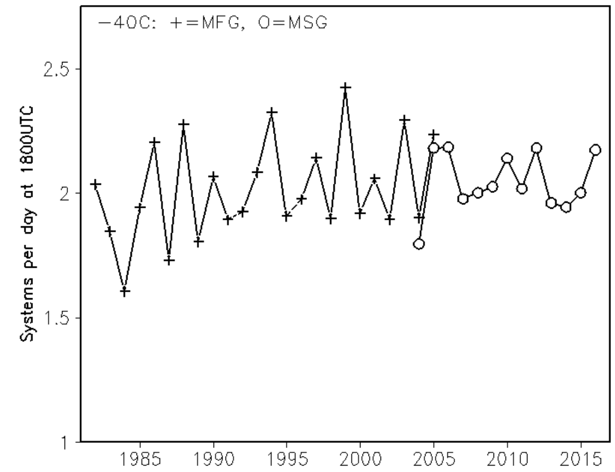
Number of MCS at threshold of -40°C well-correlated with seasonal rainfall (r=0.88)

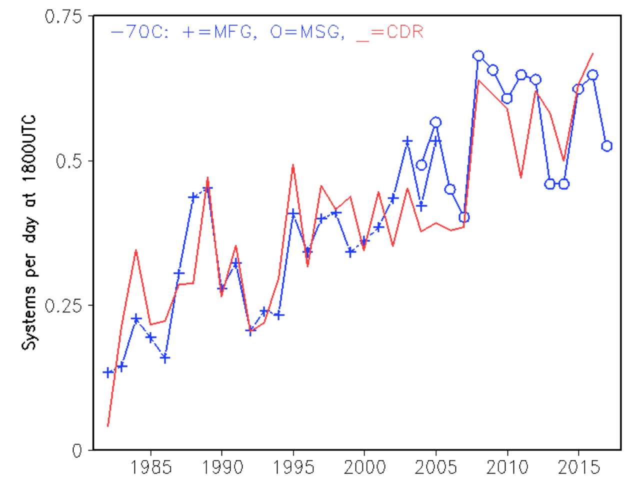
More linear increase at lower threshold (-70°C). Well-correlated to global mean temperature

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

MCS getting colder






*Taylor et al, Nature 2017*

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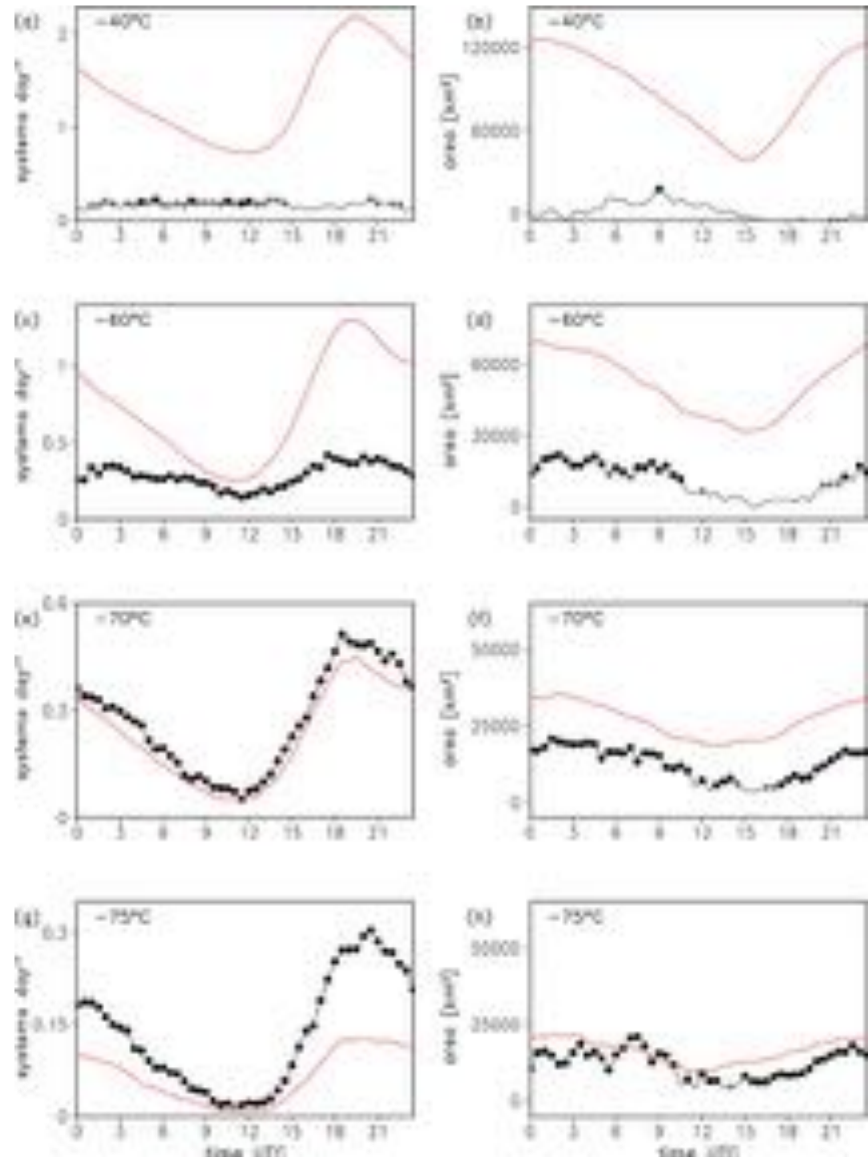


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## The 30 year TAMSAT African Rainfall Climatology And Time series (TARCAT) data set

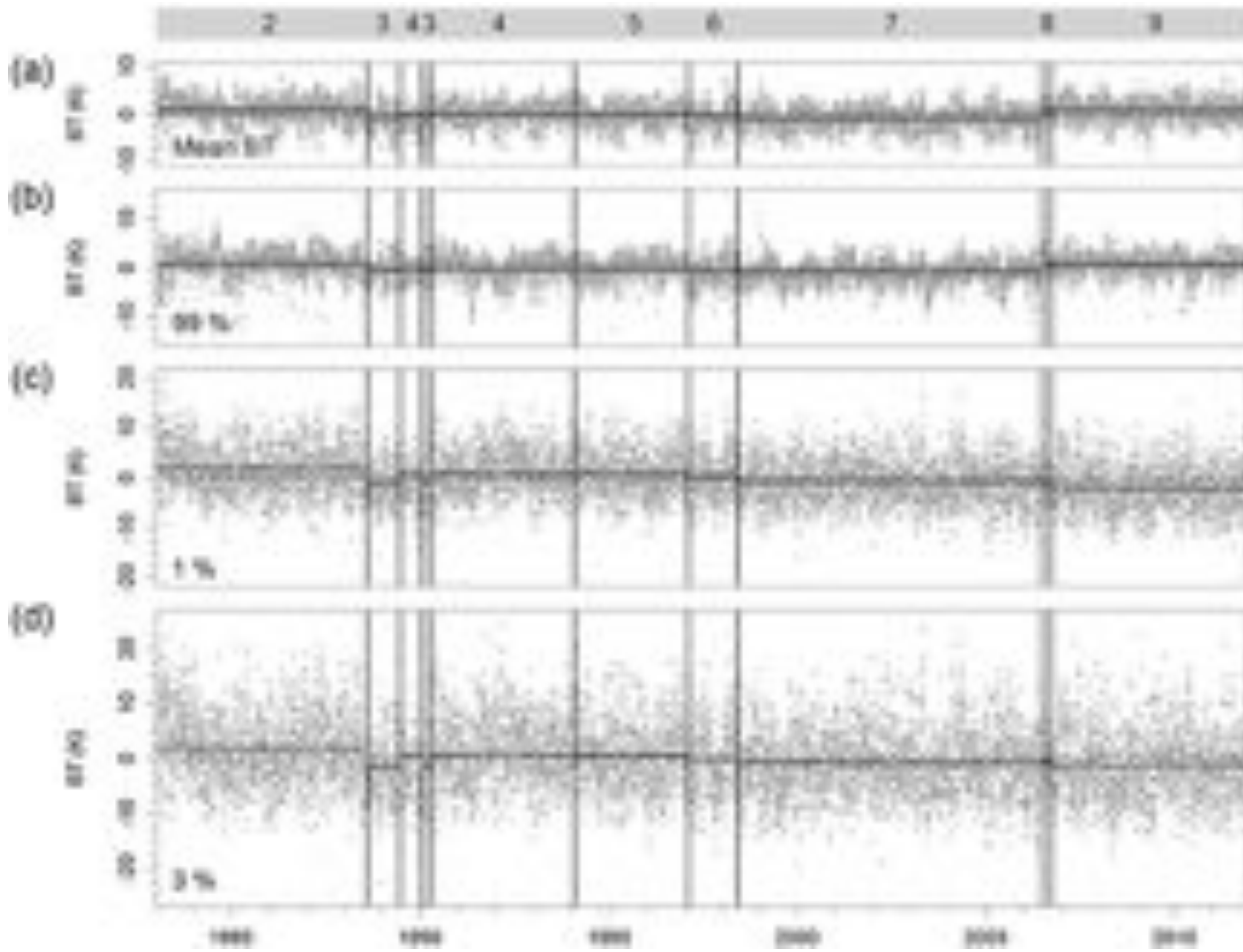


Table 2. Brig
Deviation (S
for Each of t

| Satellite | Mean BT (K) | |
|---|---|---|
| | Mean | SD |
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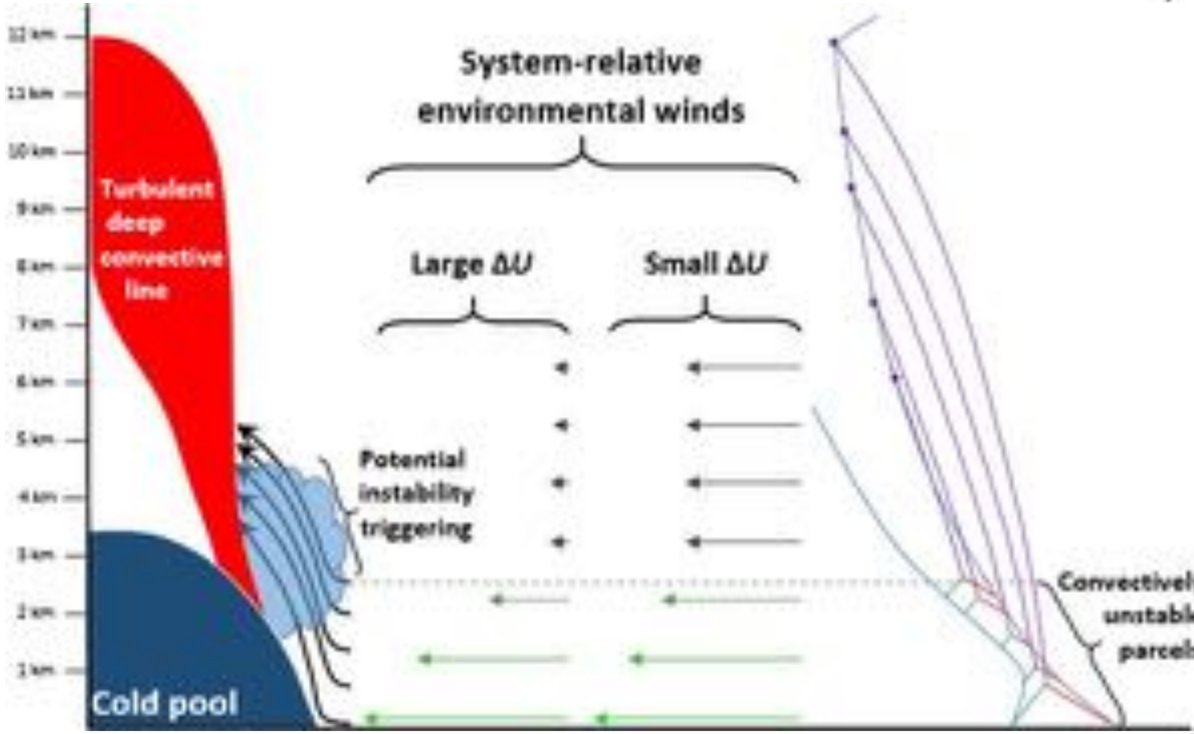
| 2 | 282.93 | 2.65 |
| 3 | 281.06 | 2.81 |
| 4 | 281.88 | 2.29 |
| 5 | 281.78 | 2.37 |
| 6 | 281.44 | 2.90 |
| 7 | 280.95 | 2.45 |
| 8 | 282.46 | 2.16 |
| 9 | 282.70 | 2.26 |

**Journal of Geophysical Research: Atmospheres**
Volume 119, Issue 18, pages 10,619-10,644, 22 SEP 2014 DOI: 10.1002/2014JD021927
http://onlinelibrary.wiley.com/doi/10.1002/2014JD021927/full#jgrd51570-fig-0001


12 km
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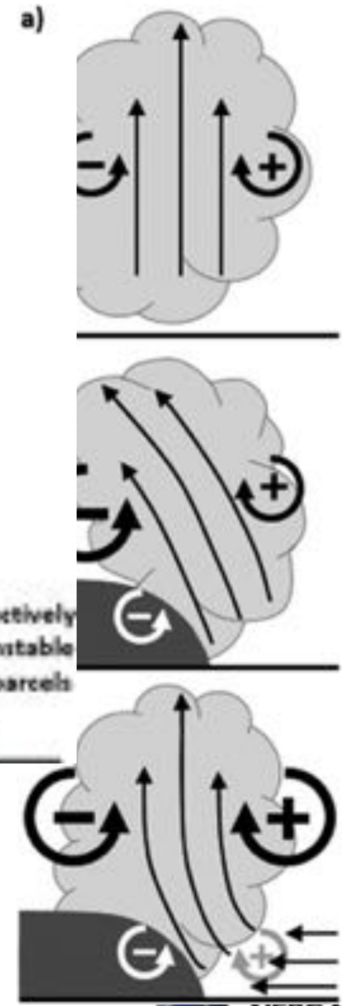
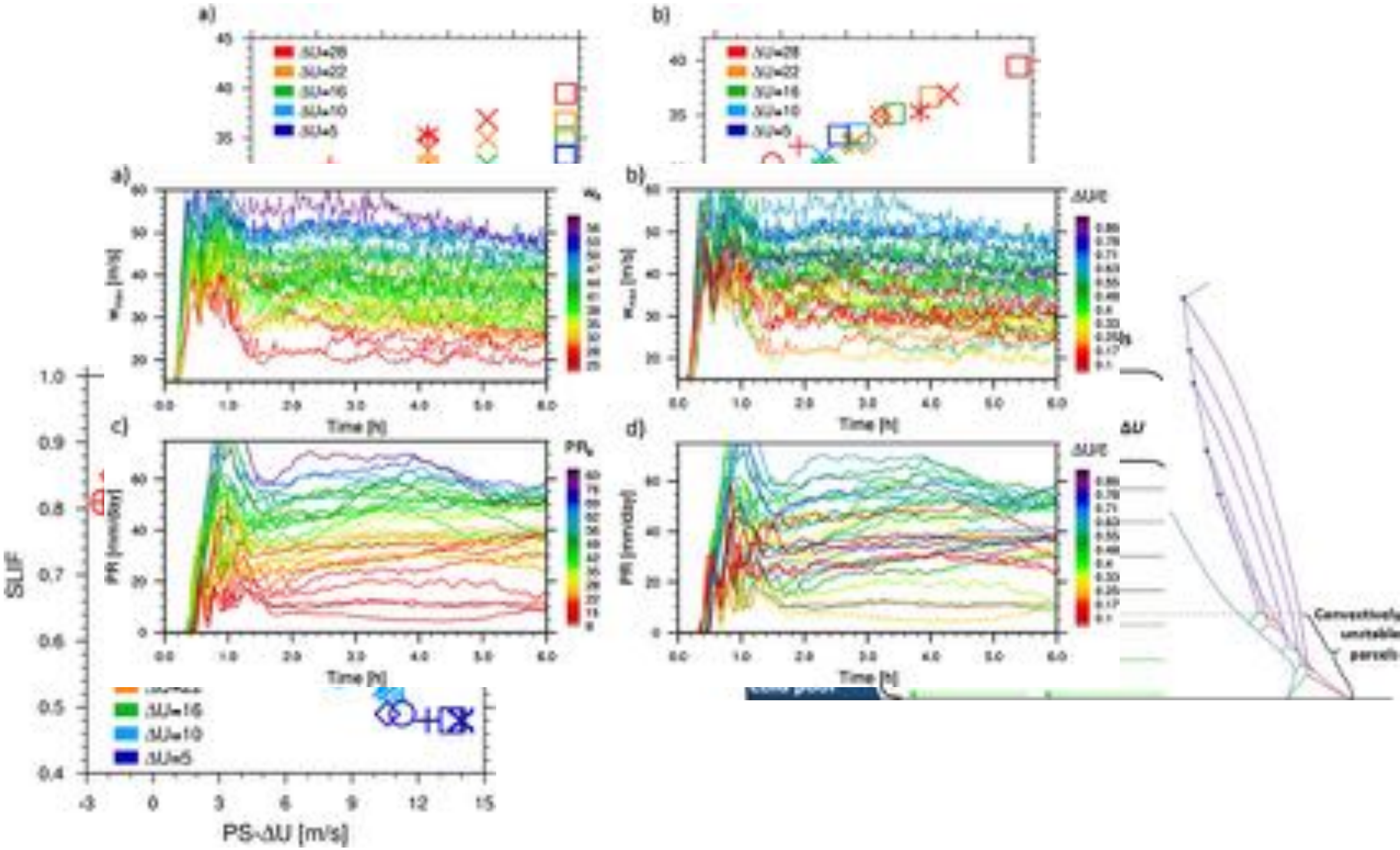
Turbulent deep convective line
Cold pool
System-relative environmental winds
Large ΔU
Small ΔU
Potential instability triggering
Convectively unstable parcels


a)

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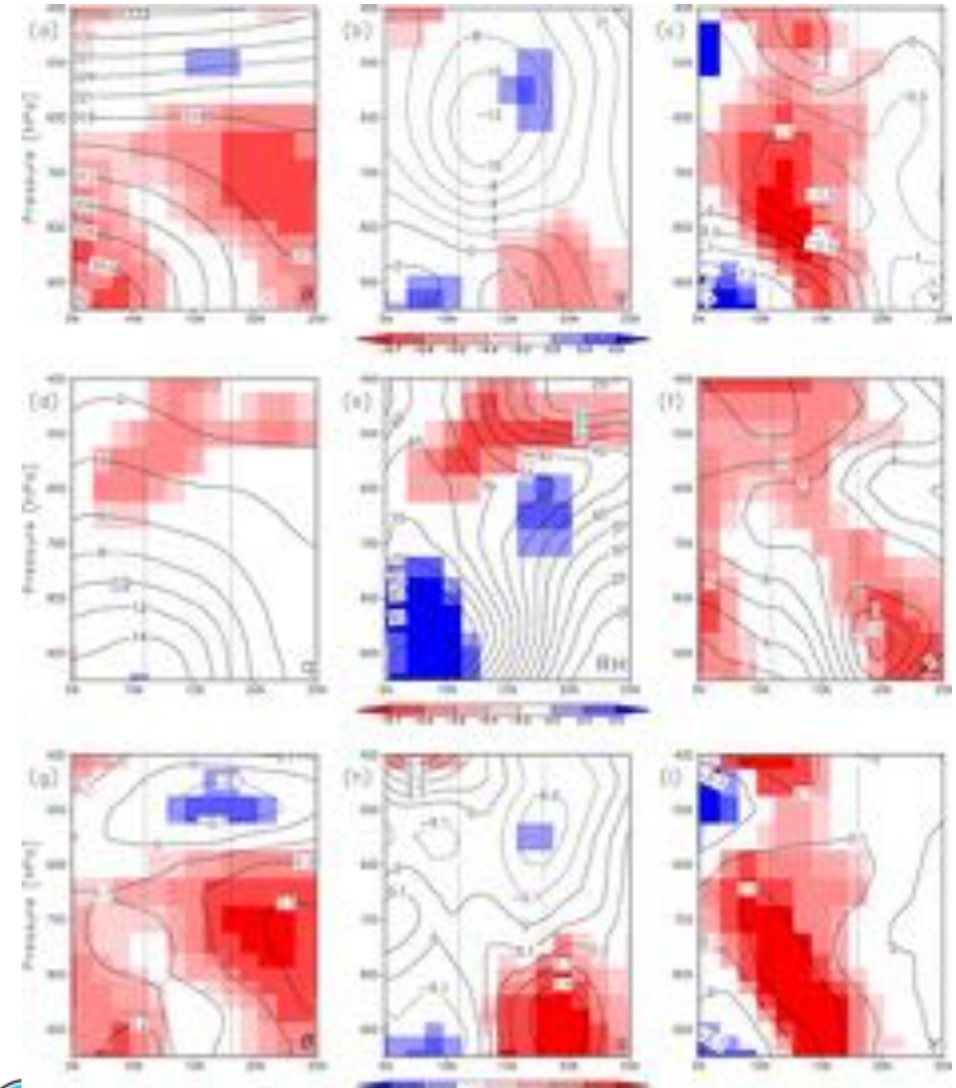

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