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

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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
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

Engel et al, J.Hydro. Met.2017, Lefore et al, QJRMS 2017
Mathon et al, J Appl. Met. 2002

Cloud-top temperatures from the Ouagadougou storm

Ouagadougou 2009
Can we use Meteosat to look at extreme Sahelian rainfall?

Yes! 85% of extreme daily gauge totals associated with large (>25,000 km²), cold (<-40°C) systems

Likelihood of extreme rain within MCS rises with decreasing T

Mean MCS Temperature (°C) from Meteosat
Data from 1640 coincident overpasses

Taylor et al, Nature 2017
Klein et al, JGR-Atmos 2018
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
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
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

How does Saharan temperature affect Sahel MCS intensity?
Spatial distribution of MCS intensification

Strong intensification trend during JJAS limited to Sahel

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

In prep
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

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

As in Sahel, intense Feb MCS in Congo occur on days with strong meridional T gradient
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
More arid regions warming more rapidly than moister regions

Linked to increasing water vapour in very dry regions

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

Rapid rise in PW ahead of MCS

More intense MCS: more rapid rise just ahead of MCS

More intense
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
MCS and T trends in February

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In prep
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
Impact of shear on instability of lifted layer

Alfaro, JAS 2017
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

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

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MCS getting colder

Taylor et al, Nature 2017
The 30 year TAMSAT African Rainfall Climatology And Time series (TARCAT) data set

### Table 2. Brightness Temperature Summary Statistics (Mean, Standard Deviation (SD) and Standard Error (SE)) for Each of the Satellites

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Mean BT (K)</th>
<th>SD</th>
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Note: SD denotes Standard Deviation.