MCS:PRIME - Mesoscale Convective Systems: Probabilistic forecasting and upscale IMpacts in the grey zonE

MCS:PRIME - Environmental Precursors to Mesoscale Convective Systems

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The environments under which Mesoscale Convective Systems (MCSs) form are often studied over specific regions[1,2]. However, fewer studies have investigated these environments globally[3,4]. Here, we perform a global analysis of MCS precursor and contemporaneous environments. This is done by comparing the locations of tracked MCSs to their environmental conditions, using a set of atmospheric variables which control the formation and maintenance of MCSs, including CAPE, shear and moisture availability.

The goals are to a) produce a global analysis of environments present before and during MCS occurrence, and b) determine the probability of finding an MCS for a given environmental condition. The second goal is tightly aligned with those of our project MCS:PRIME, as we aim to develop a parametrization scheme for MCSs which is aware of the environmental conditions.

Methods

MCS Tracking Dataset:

- **Feng et al. (2021)[5] MCS tracking dataset is used.**
- Covers 60°S-60°N from 2000-2020.
- Based on NASA Global Merged IR V1 infrared brightness temperature, T_b < 241 K for cloud shield, Tb < 225 K for cloud core, as well as IMERG precipitation.
- MCS area > 4 x 10^4 km^2, duration > 4 hr, as well as other lifetime-dependent thresholds.

ERA5 Environment:

- Use several variables affecting the formation of MCSs:
  - **CAPE**
  - **TCWV** (Total Column Water Vapour)
  - **MFC** (vertically integrated Moisture Flux Convergence)
  - **LLS** (Low-Level Shear – surface to 800 hPa)
  - **MLS** (Mid-Level Shear – surface to 600 hPa)
  - **L2MLS** (Low-To-Mid-Level Shear – 800 to 600 hPa)
- Shear is calculated as the magnitude of the vector difference between two levels.

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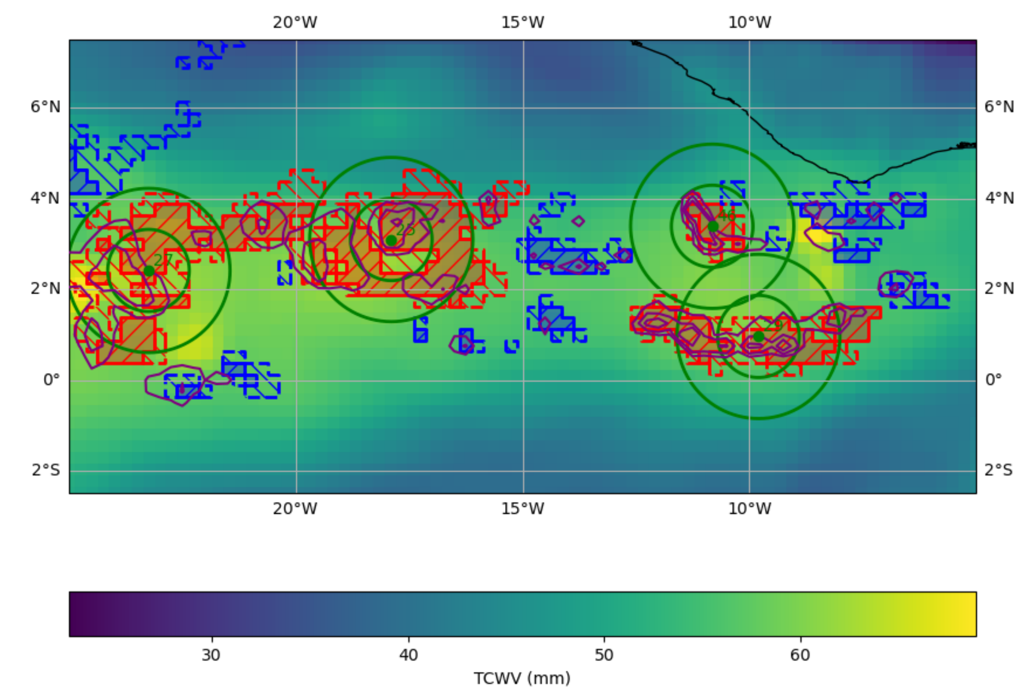

Figure 1. MCS activity and corresponding environment off the west coast of Africa, shown to illustrate the 5 regions used in subsequent analysis. TCWV (colours) on the ERA5 grid, as well as IMERG precipitation (contours at 2, 5 and 10 mm hr^{-1}). Green dot and circles: MCS centroid, and 100 km and 200 km radii (500 km and 1000 km not shown). Red dashed – MCS cloud shield, red solid – MCS cloud core. Blue dashed – non-MCS cloud shield, blue solid – non-MCS cloud core. In both cases, core and shield are defined by Tb < 225 K and Tb < 241 K respectively (sometimes MCS shield is expanded by the presence of precipitation[5]). Both have been interpolated to the ERA5 grid.

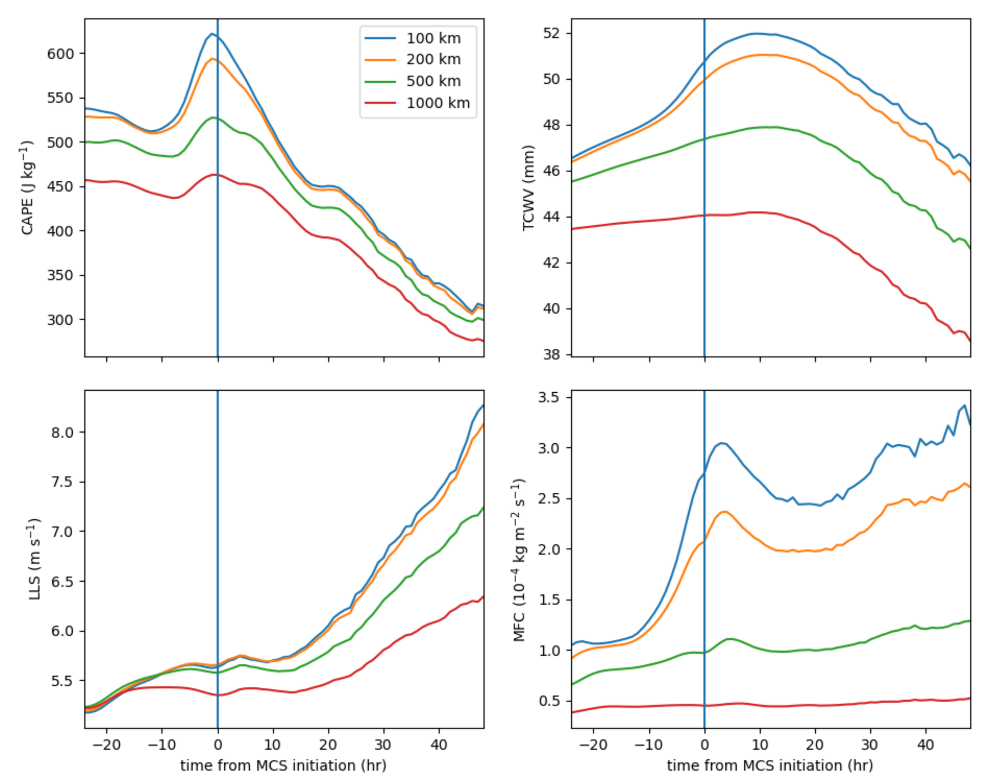

Figure 2. Environmental conditions relative to MCS initiation time at 4 different radii, for CAPE, TCWV, LLS, and MFC. Results for MLS and L2MLS are similar to those for LLS (not shown). Before MCS initiation, the precursor environment is calculated by taking the mean environment at radii centred on the location of the MCS initiation centroid. After MCS initiation, the radii are centred on the centroid of the MCS as it moves.

Clear increases in activity seen for CAPE, TCWV and MFC 5-10 hr before MCS initiation. Smallest spatial scale has the largest response. Difference in timing of peaks.

CAPE, TCWV and MFC all appear to be resources that are consumed by MCSs. LLS is **created** by MCS – suggests countergradient momentum transport.

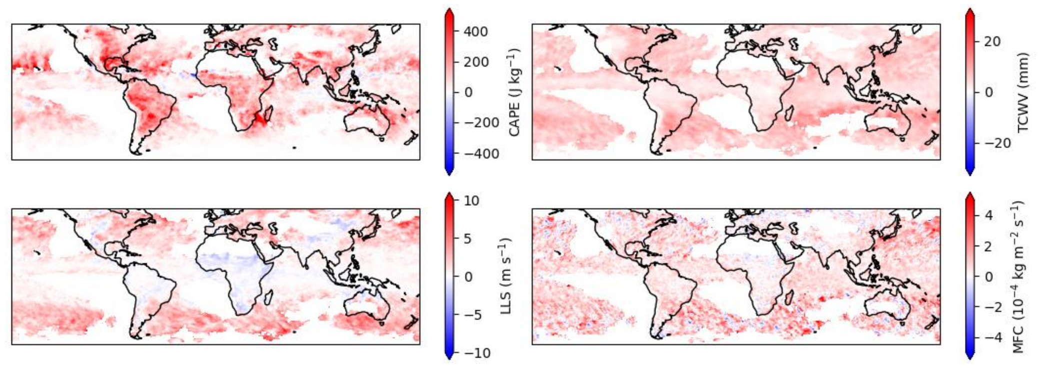

Figure 3. Composite environmental condition anomalies at MCS initiation. MCS-initiation composites are calculated by taking a 500 km circle centred on the MCS initiation point and calculating the environment surrounding this point. The monthly time-mean of these composites is then differenced with the monthly mean of the environmental field to produce an anomaly.

All four variables are higher than the background over oceans and most land regions.

CAPE particularly high over US, Gulf of Mexico, South America. Shear lower than background over Africa, parts of US and Asia.

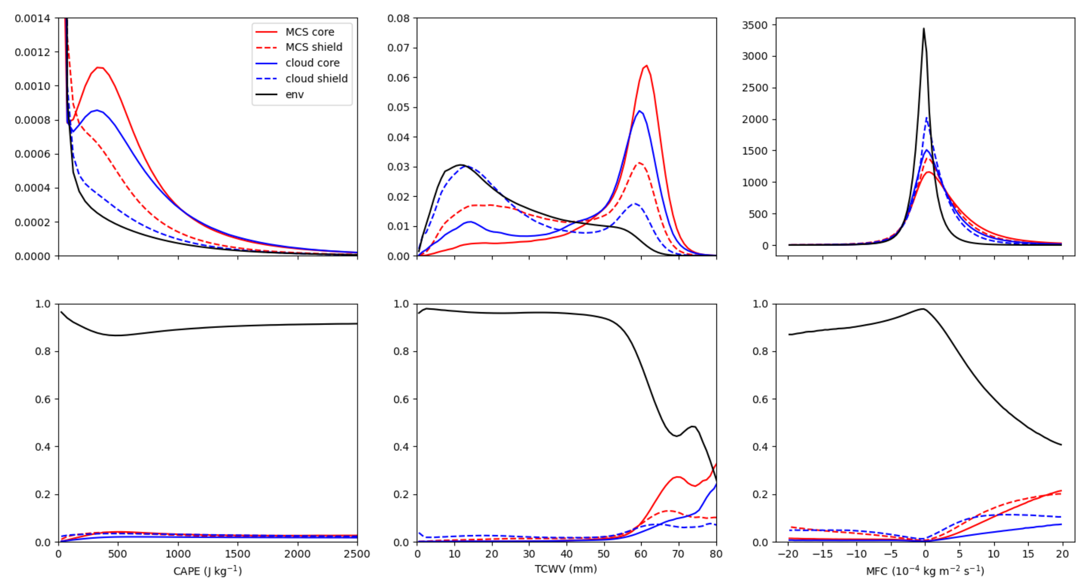

Figure 4. PDFs of environmental variables within different MCS regions. Top: PDF normalized within each region. Bottom: PDF normalized taking into account area of each region (note, environment has a far larger area than the others), giving a probability of being in a particular region for a given value of environmental variable. Regions as in Fig. 1.

(Top) There is a clear distinction between the PDFs within convective cores and within surrounding shields for all variables, with MCSs having higher modes for CAPE and TCWV, and a higher tail for MFC.

(Bottom) Very little variation of probability of being in each region as a function of CAPE. Far more for TCWV and MFC, with TCWV in particular showing some regions where there is a high chance of being in an MCS convective core.

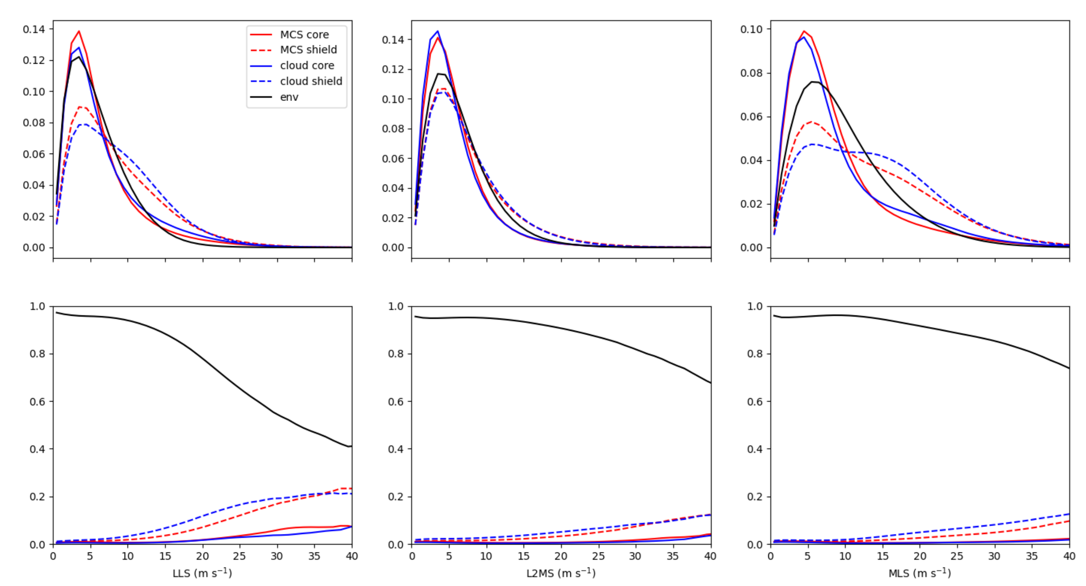

Figure 5. As figure 4, but for shear.

(Top) Less clear signal for all 3 shear variables being different from each other in different regions. (Bottom) Only substantial differences in far tail of shear distribution.

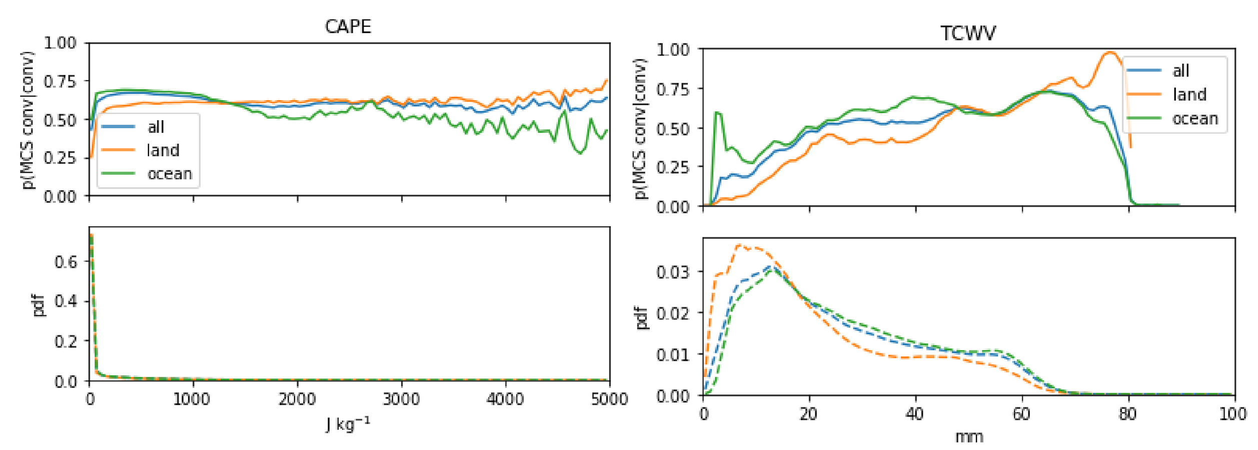

Figure 6. Conditional probability of p(MCS convection|convection), calculated by dividing the MCS convection in Fig. 4 by the sum of MCS and non-MCS convection. Top: conditional probabilities over entire domain, land and ocean for CAPE and TCWV. Bottom: complete distribution of each variable, shown to give an illustration of where the top distributions will be important.

Almost no change in conditional probability of being in an MCS convective region given there is convection as a function of CAPE, with a typical value of around 0.7.

Far stronger relationship for change in probability as a function of TCWV.

Conclusions

Fig 2: The 3 thermodynamic variables, CAPE, TCWV (Total Column Water Vapour) and MFC (vertically integrated Mass Flux convergence), show clear increases 5-10 hours before MCS initiation, particularly at the 100 km and 200 km spatial scales. LLS (Low-Level Shear) shows a weak increase, but unlike the other variables shows a strong increase across all scales after around 15 hours after initiation. The strong gradient and high value of MFC suggest that it this is a good contender for further analysis.

Fig. 3: Globally, the composite environments at MCS initiation indicate that all variables are generally increased at MCS formation. There are some interesting regional signals (e.g., reduced LLS over Africa) that require further investigation.

Figs. 4, 5: The PDFs of environmental variables within the 5 regions (see Fig. 1) show that there are distinct differences within each region, however these are only strong for TCWV when the relative area of each region is taken into account.

Fig. 6: Conditional MCS convection probability shows a clear dependence on TCWV, indicating a potential route for including environmental conditions in an MCS parametrization scheme.

Further Work

In MCS:PRIME, we aim to develop an MCS parametrization scheme based on the Multiscale Coherent Structure Parametrization[6] (MCSP). See the complementary poster by Zhixiao Zhang for our current work implementing this. We aim to include the TCWV relationship found here to make this scheme aware of its environment.

References

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