Wind, rain, and the transition from closed to open mesoscale cellular convection

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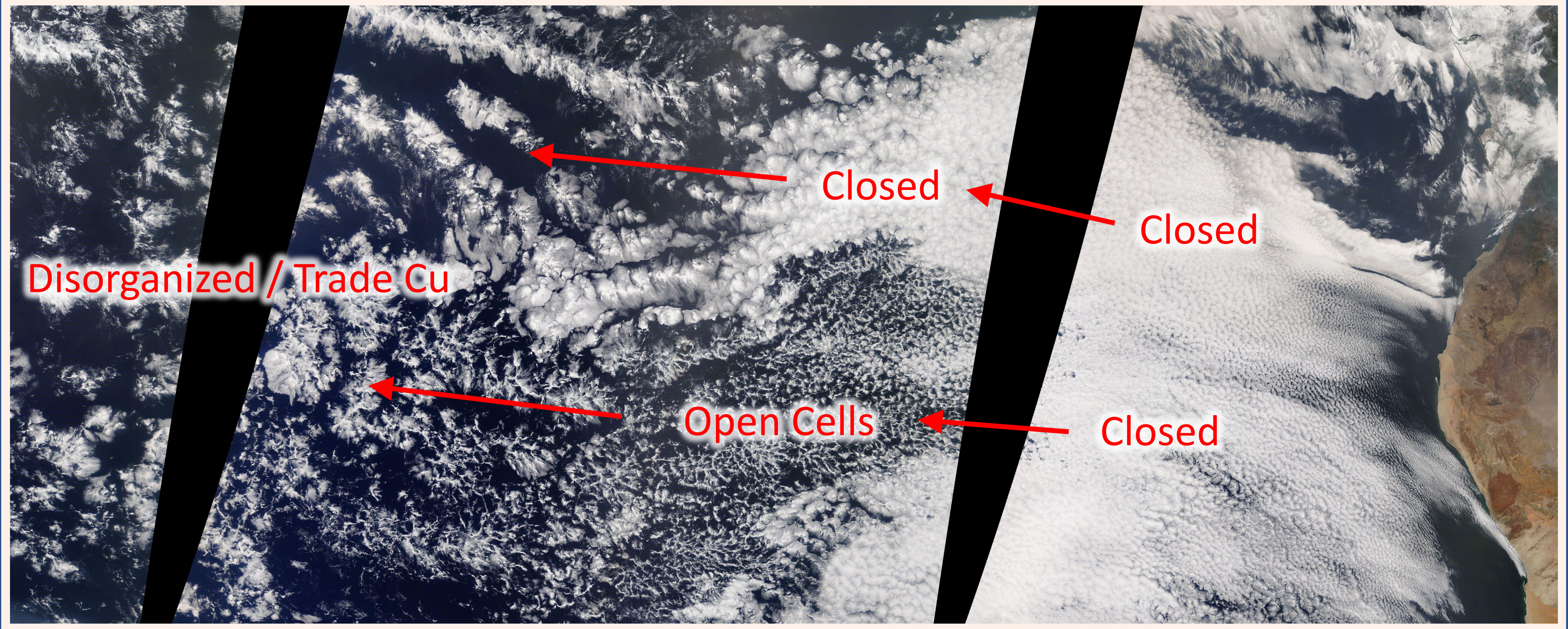
Background & Dataset

Stratocumulus (Sc) tend to form in archetypal patterns based on distinct states of mesoscale cellular convection (MCC). As Sc evolve in the easterly trade winds in the eastern subtropical oceans, distinct regions of MCC are apparent. This work is concerned with the transition from overcast closed cell MCC seen near to coast, into the large patches of open cell MCC seen near the image center. We investigate what is different about closed cells that evolve into open cells versus those that remain closed.

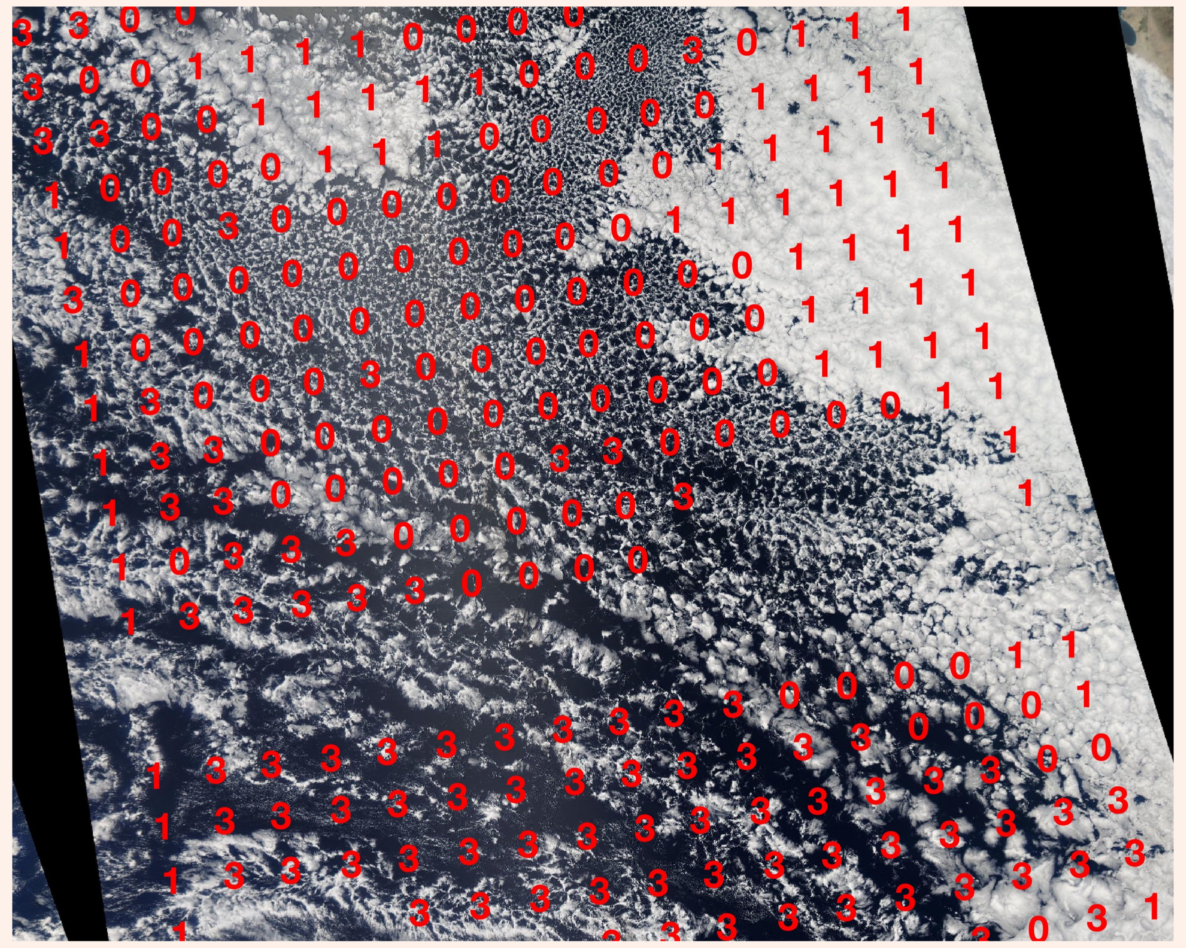


Classifying MCC

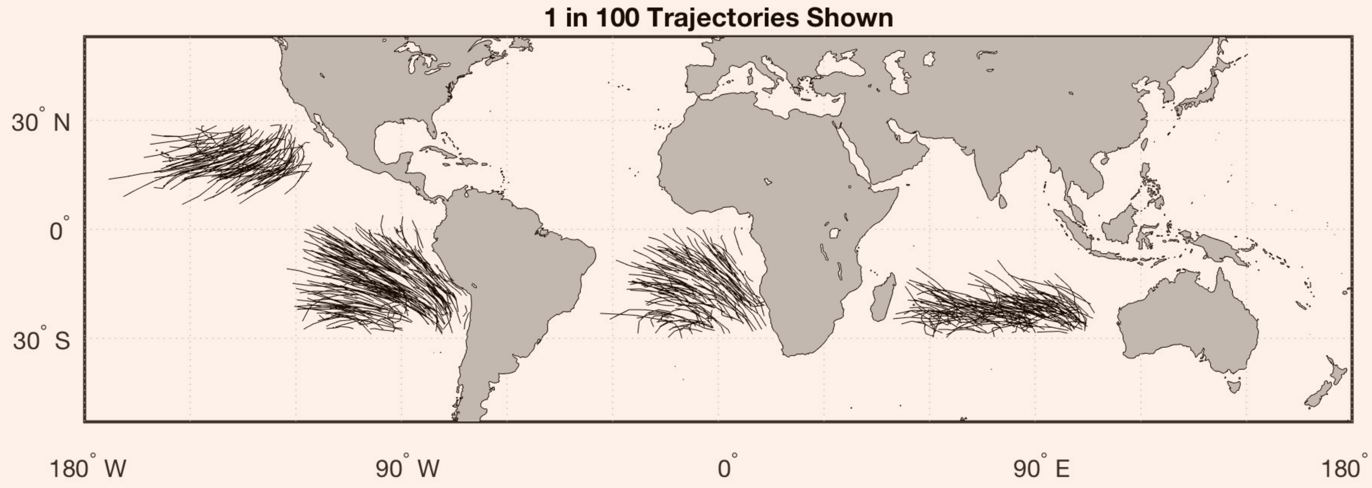
A human-trained neural network algorithm distinguishes between closed cell MCC (1) from open cell MCC (0) and cellular, but disorganized MCC (3). This routine uses the MODIS Aqua, swath-level, daytime-only cloud liquid water path field to assign an MCC classification. Classifications are made in 256 km square boxes, centered 128 km apart, allowing for overlap between scenes. High cloud scenes are filtered out of the analysis. Data are available from 2003 through 2018.

Wood, R., & D. L. Hartmann, 2006: Spatial variability of liquid water path in marine low cloud: The importance of mesoscale cellular convection. *Journal of Climate*, **19**(9), 1748– 1764.

McCoy, I. L., R. Wood J. K. Fletcher, 2017: Identifying Meteorological Controls on Open and Closed Mesoscale Cellular Convection Associated with Marine Cold Air Outbreaks, *Journal of Geophysical Research: Atmospheres*, **122**, 11, 678–11,702.



Large Scale Trajectory Analysis

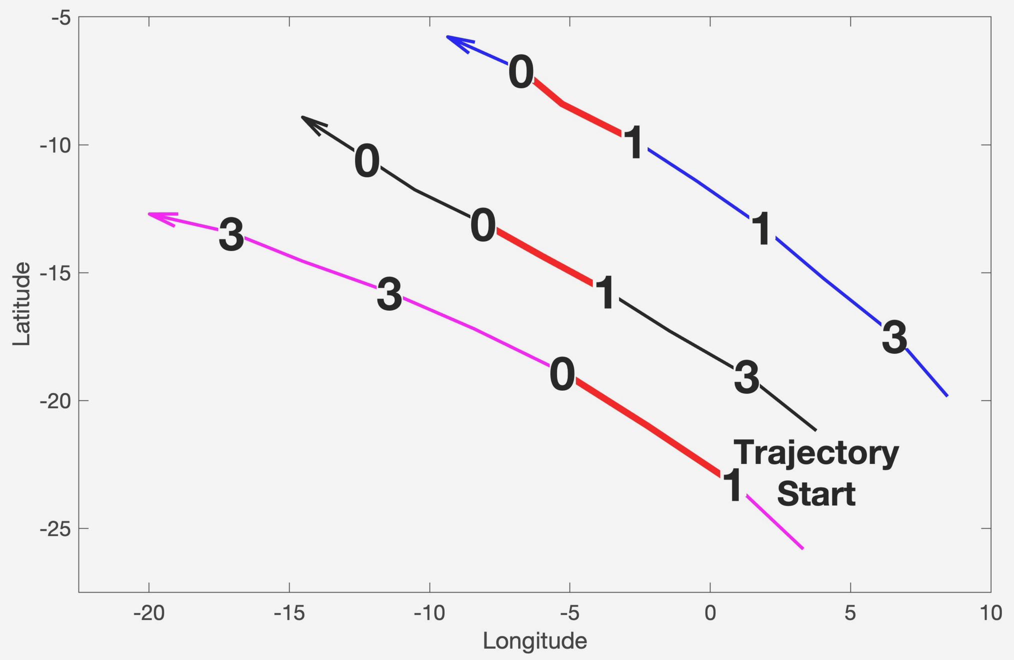


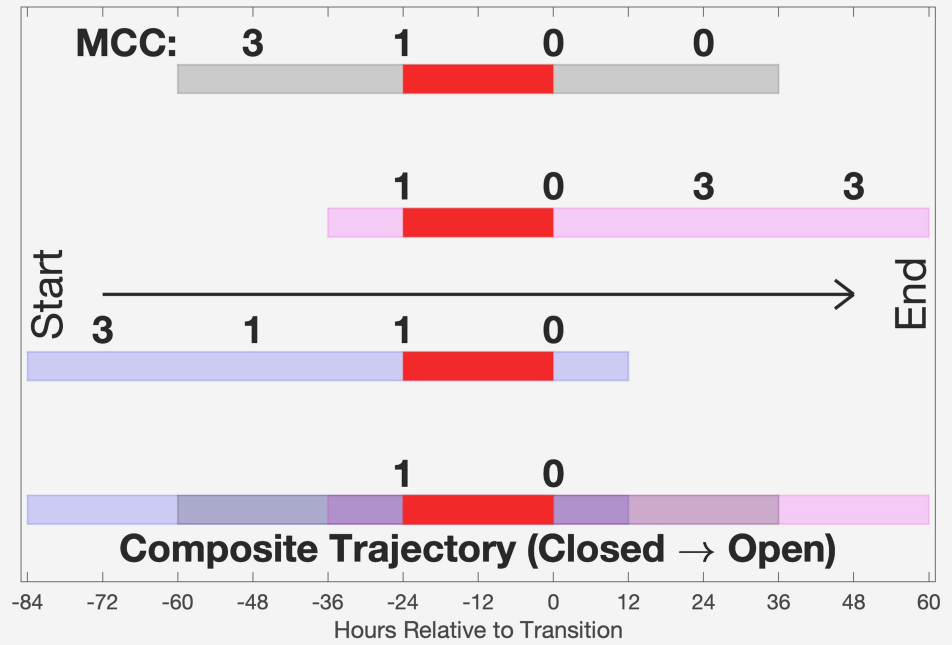
Over 160,000 96-hour trajectories have been computed using 2-D ERA-I winds at 925 hPa for years 2007-2010 in four eastern subtropic ocean basins. Study regions (left) are chosen due to their climatological maxima in marine Sc. Regions are wide enough to capture the Sc maxima as well as the declining cloud cover gradient offshore where transitions between MCC types are common.

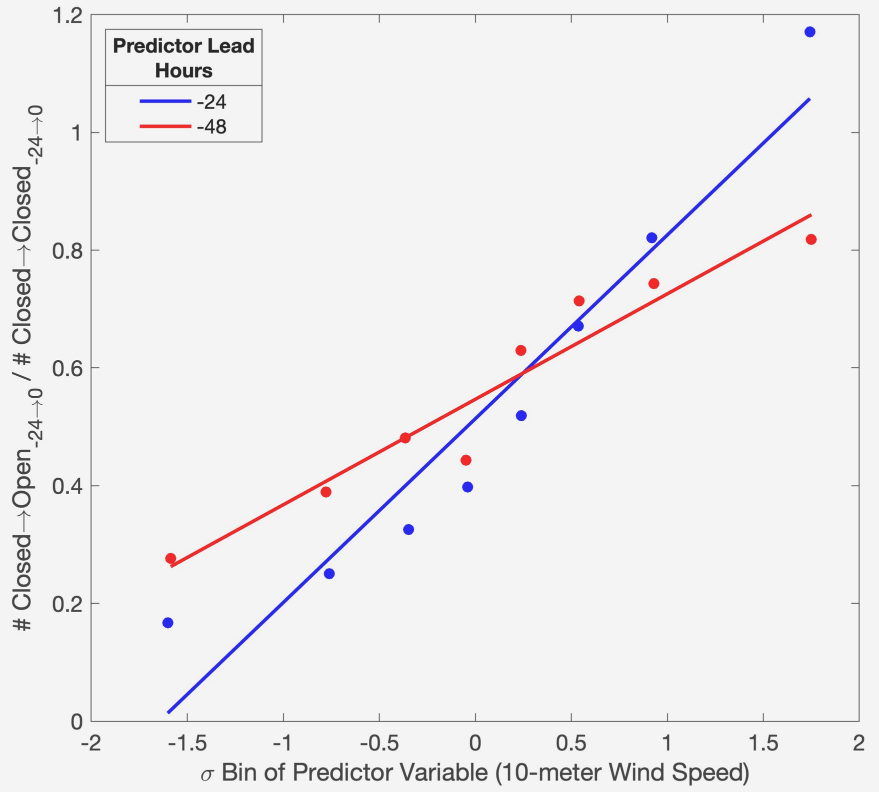
Composite Trajectories

Trajectories are composited based on their observed MCC evolution (right). MCC is assessed by MODIS on Aqua at ~13:30 LT. A 24-hour transition from closed (MCC=1) to open (MCC=0) assigns the hour T = 0 to the open observation and the hour T = -24 to the closed observation. Composites are generated by averaging all variables at each observation time T relative to the transition. A study of overnight cloud cover strongly suggests that the transition from closed to open MCC usually occurs after the overnight MODIS observation (~1:30 LT), so between T = -12 and T = 0. Only transitions occurring over 24 hours are studied here.

Cloud variables including LWP and rain rate are assessed by AMSR/E at 12 hour intervals with every A-Train overpass (1:30 and 13:30 LT) and droplet concentration is assessed by MODIS once daily at 13:30 LT. Wind speed (10 meter) is sourced form the ERA5 reanalysis and ERA observations are interpolated to match the timing of the 1:30 and 13:30 LT Aqua overpasses.







Predicting MCC Evolution

The fraction of trajectories that evolve into open cells compared to the fraction that remain closed is calculated within bins of a predictor variable, in this case wind speed (left) at T = -24 and T = -48 hours. Predictor variables are standardized (divided by their standard deviation, σ).

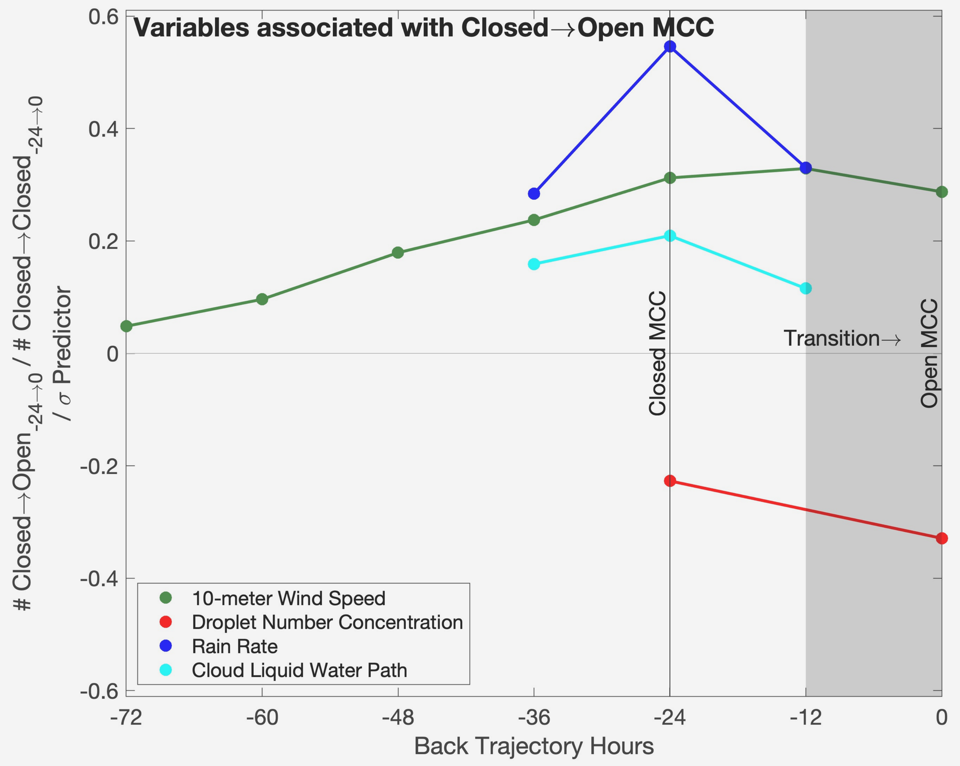
Trajectories in higher wind speed bins are shown to be more likely to evolve from closed-to-open MCC compared to trajectories in slow wind speed bins. Slopes, showing the fraction of closed-open / closed-closed trajectories can be calculated for various lead times T. If a slope is statistically significant at the 95% level, then it is plotted as shown below.

Comparing Predictors

The above wind speed analysis can be applied to multiple variables at multiple lead times on the same axes in order to compare predictor variable power on differing timescales.

Strong winds predict the closed-open transition at least 72-hours in advance, however high rain rate, low drop concentrations, and greater LWP are also shown to be strong predictors, but only at lead times of -36 to -12 hours. Rain rate appears to most strongly predict the closed-open transition.

This analysis suggests that wind and rain may act on multiple timescales, and motivates the question, how are winds driving the closed-open MCC transition?



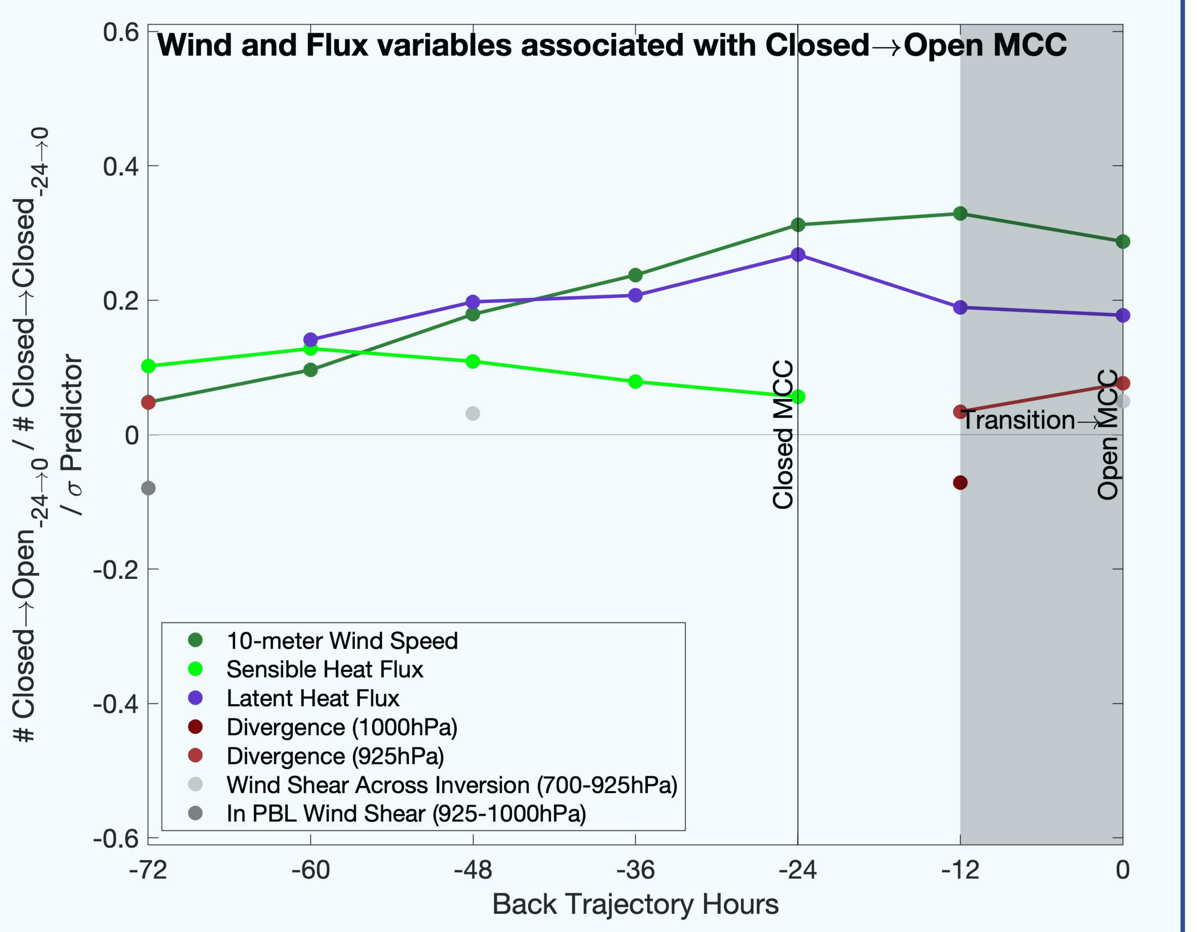
Testing wind variables

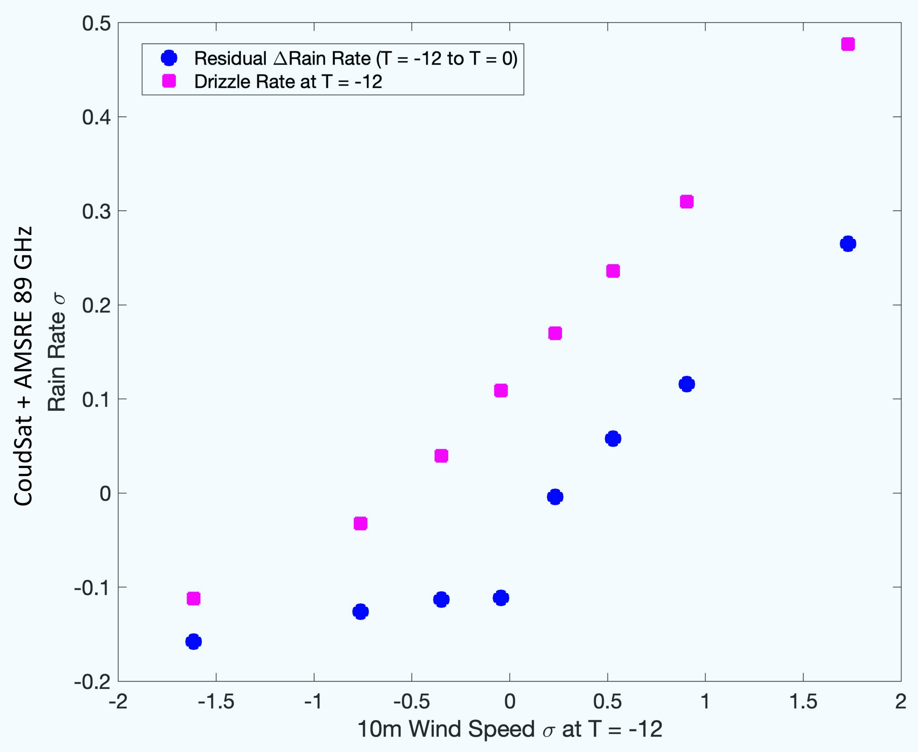
Using the predictor analysis from before to answer the question: **What is it about wind that causes closed-open transitions?** Is it mechanical (divergence, shear) or is it related to heat and/or moisture fluxes driving changes in rainfall?

Results indicate that the mechanical variables, including surface and cloud-level divergence, or the magnitude of wind shear within the PBL or across the inversion are not strong predictors of the closed-open MCC transitions.

Heat and moisture flux appear to have a stronger influence at ~60 hour lead times. Is it possible that increases in moisture flux lead to increased rainfall? The following latent heat flux equation an be rearranged to show that wind speed can be thought of as the product of RH and LHF, meaning strong wind is akin to increased moisture flux and/or content.

LHF ≈ Wind x 1/RH -OR- Wind ≈ RH x LHF



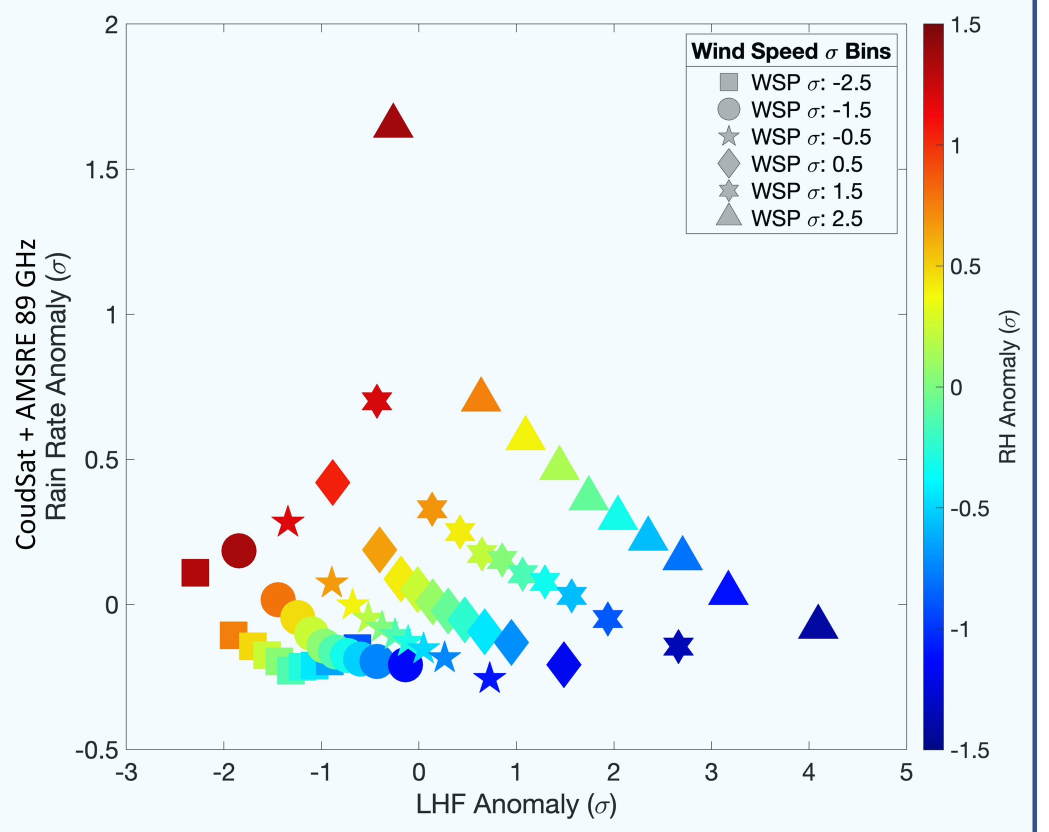


Wind and Rain

As a test of this mechanism, we can use this Lagrangian framework to show that when wind is strong, rain rates are greater, and subsequent 12-hour changes to rain rates are positive (left). This plot is generated only for closed cell MCC, where the wind & rain relationship is strongest.

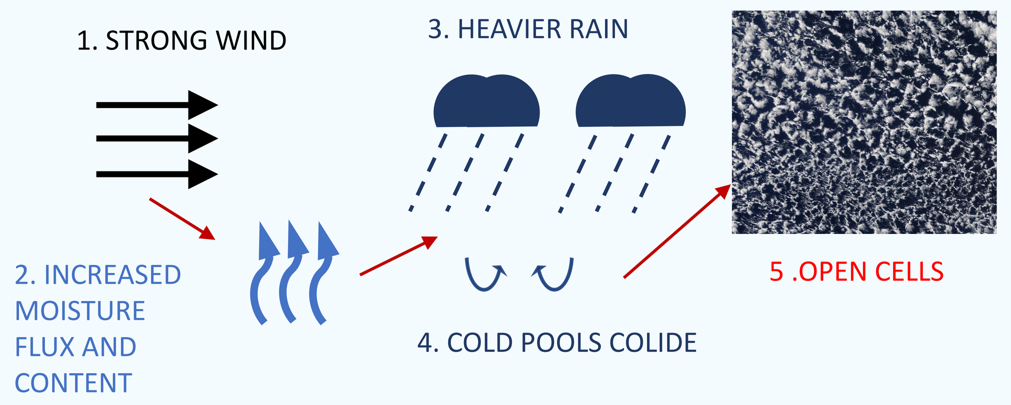
Wind, Moisture Flux, Moisture Content, and Rain

This 4-Dimensional plot details the complex relationship between moisture flux and content, rain rate, and wind speed. Wind is held constant within bins, shown by shape. Strong winds are associated with both higher rain rates and stronger moisture fluxes. Within each constant wind speed bin, rain rate increases with RH (1000 hPa, shown by the color fill).



Results suggest that wind speed is driving stronger moisture fluxes and heavier rain rates. Cold pool convergence between raining cells may initiate the transition between closed and open cell MCC, as suggested by numerous prior studies.

Mechanism:



Additional background: Eastman, R. I. L. McCoy, R. Wood, 2021: Environmental and internal controls on Lagrangian transitions from closed cell mesoscale cellular convection over subtropical oceans, J. Atmos. Sci., 78, 2367-2383.