Vertical and Temporal Structures of the MJO

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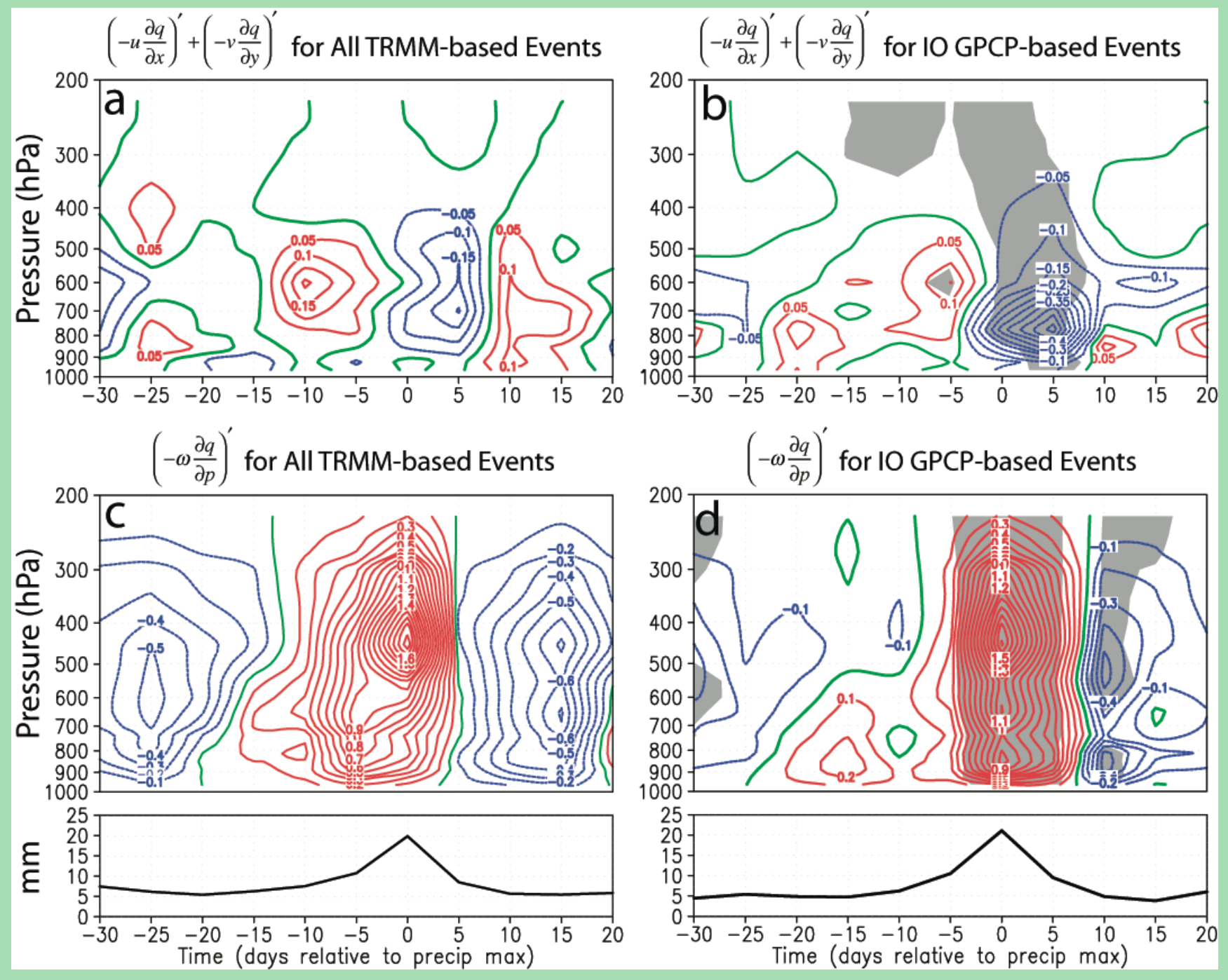
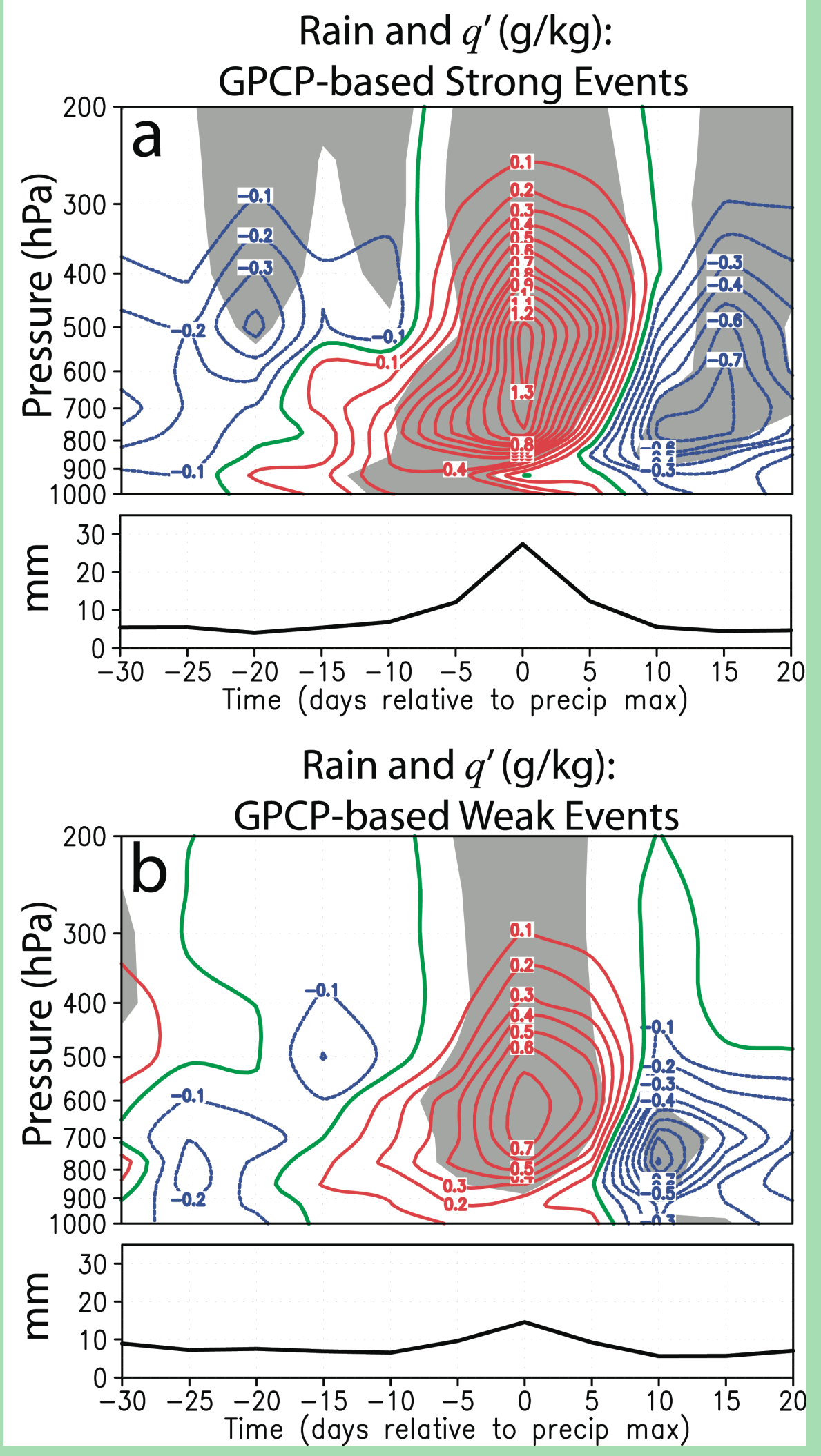
1. Background

The Madden-Julian Oscillation (MJO), an eastward-moving weather system most active in the equatorial Eastern Hemisphere, is characterized by cycles of intense and suppressed convection. The MJO involves cloud and precipitation processes spanning a wide range of space and time scales. Its impact on radiation, heat, and moisture budgets over large spatial scales as well as its ties to the higher latitudes attest to the importance of the MJO. Despite decades of research, the combination of a poor representation of this tropical disturbance in most current general circulation models (GCMs) and a lack of comprehensive understanding of several of its mechanisms highlights the need for continued exploration of the MJO. No single theory of yet has been able to accurately synthesize *all* of the prominent features of the MJO, including its formation in the west-central Indian Ocean, its detailed vertical structure, and its eastward propagation.

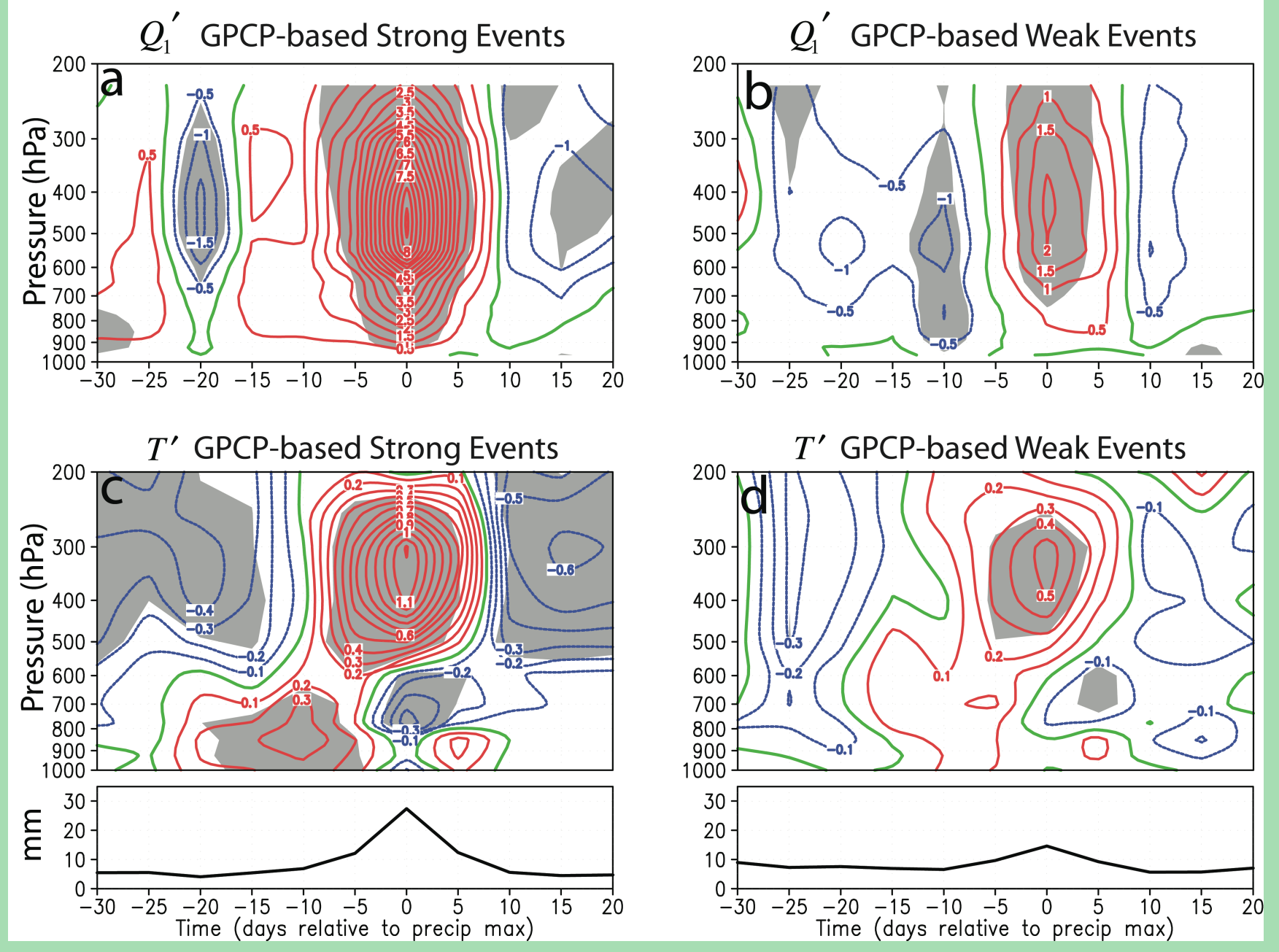
2. Vertical-Temporal Composite MJO Structure



In an upcoming paper (*Observed Characteristics of the MJO Relative to Maximum Rainfall*, JAS), we average numerous MJO convective episodes together to obtain a composite picture of processes such as convective heating and moisture transport. These MJO events are selected based on filtered TRMM and GPCP rainfall, and ECMWF 40-yr reanalyses are matched to the date and location of maximum rainfall. Time-height cross sections (right) of all TRMM-based events (left column) reveal that drying (blue contours) following intense convection is first accomplished by horizontal advection (panel *a*) and later deep subsidence (panel *c*). This drying sequence is particularly striking for MJO events in the Indian Ocean (right column, gray shading is 90% statistical significance).

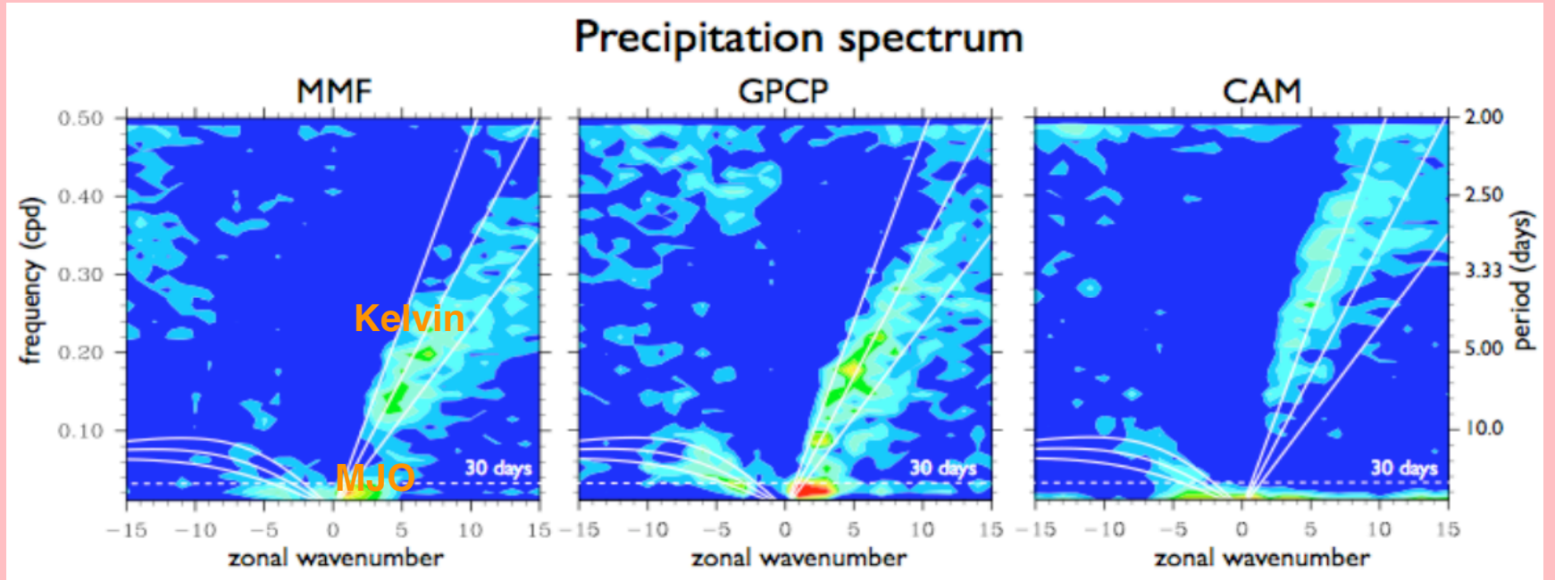


Composite MJO events are also subdivided based on their rainfall intensity ("strong" events have day-0 rain amounts greater than 0.75 standard deviations from the day-0 mean of all events). Vigorous MJO events exhibit a step-like pattern of deepening moisture preceding the heaviest rainfall (left, panel *a*, days -20 to -7). Interestingly, these moisture "tiers" are located at preferentially stable layers in the troposphere: the trade inversion (850 hPa) and the freezing level (550 hPa). Weak events (panel *b*) have a more gradual progression of moisture lofting.



We also investigate the structures of convective heating and temperature related to strong and weak MJO events (left). Comparison of panels *a* and *c* indicates that low-level convective heating (*a*) occurs in concert with positive temperature anomalies (*c*) 1-3 weeks before maximum rainfall. Such observations relate to eddy available potential energy (EAPE) generation. Supporting evidence from moisture and vertical velocity profiles (not shown) strongly suggests that shallow and mid-level cumuli play a critical role in generating and maintaining vigorous MJO events. Weak MJO events (right column), the deficiency of some GCMs, have a distinct lack of convective heating 1-3 weeks before maximum rainfall. This reiterates the need for GCMs to accurately parameterize or explicitly simulate low-level cumuli.

4. On the Horizon



An important aspect of CMMAP is the improvement and utilization of "superparameterized" GCMs (the Multiscale Modeling Framework, or MMF) to more accurately simulate cloud systems. An upcoming paper (Khairoutdinov et al., JC) presents results from a recent 19-yr simulation by CSU's MMF. A comparison of wave signals in MMF, observations, and the standard GCM (above, l-r) illustrates that the MMF more accurately depicts the MJO and Kelvin wave rain characteristics than the standard GCM. While spectrally similar to observations, future work will involve examining the vertical-temporal structure of the modeled MJO in a method similar to that discussed in Section 2 (left column). Additionally, MMF output and reanalysis data will be used to explore MJO initiation in the Indian Ocean and the role of extratropical influences.

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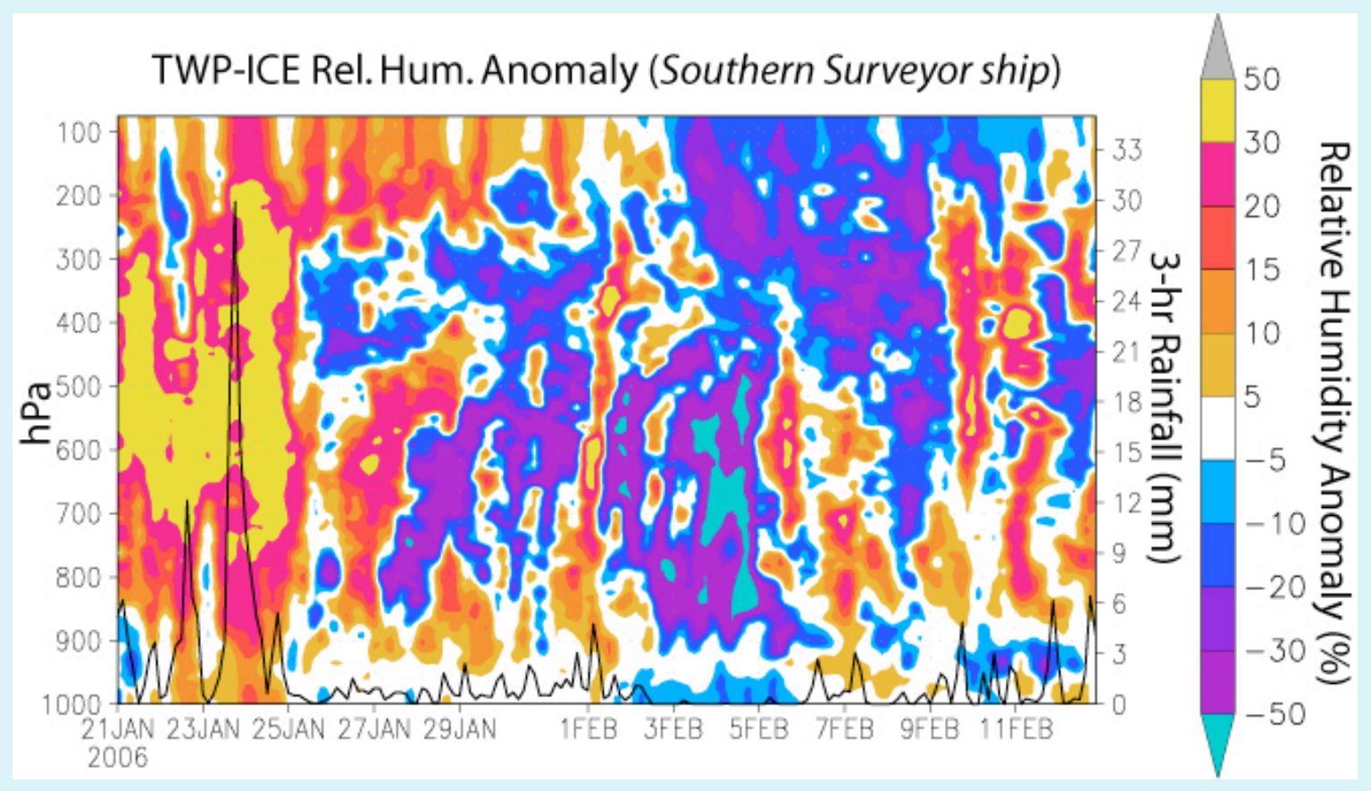
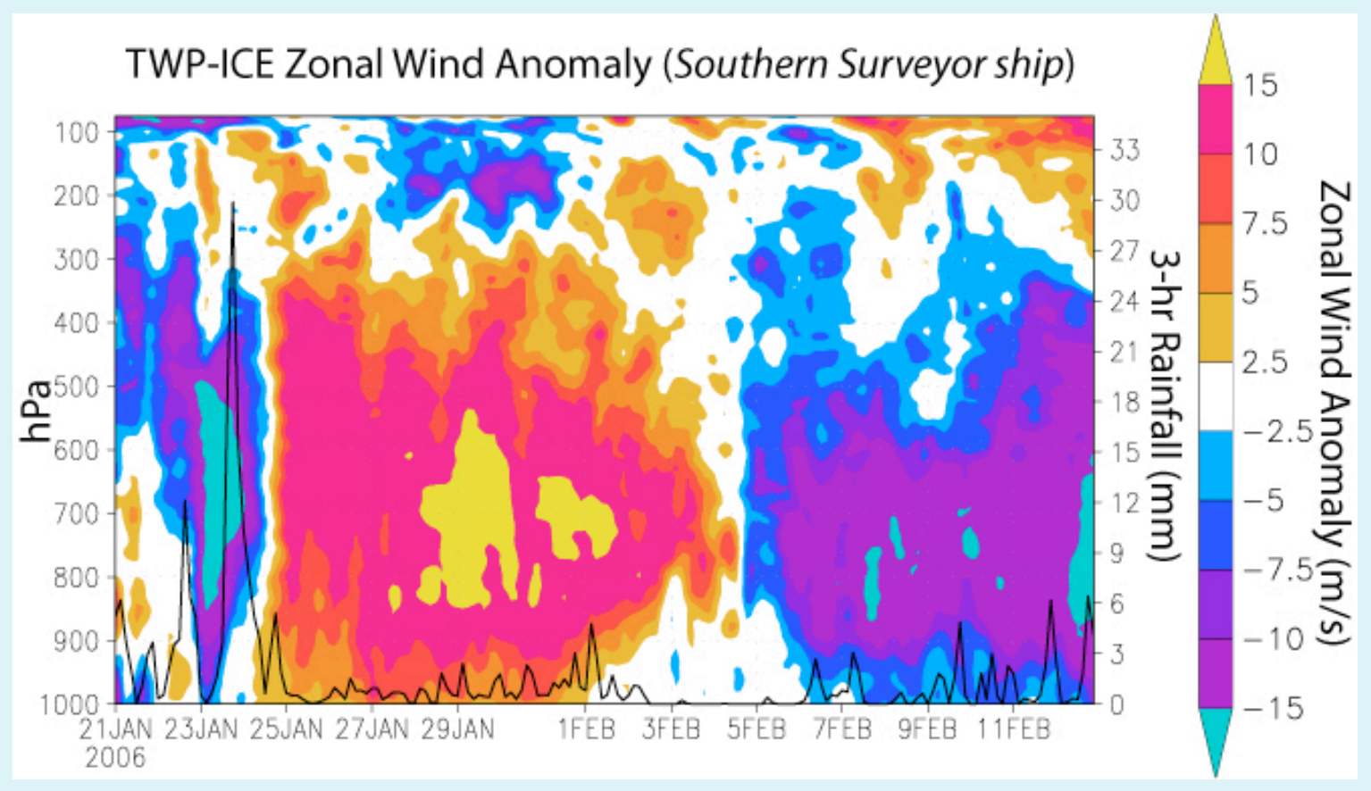
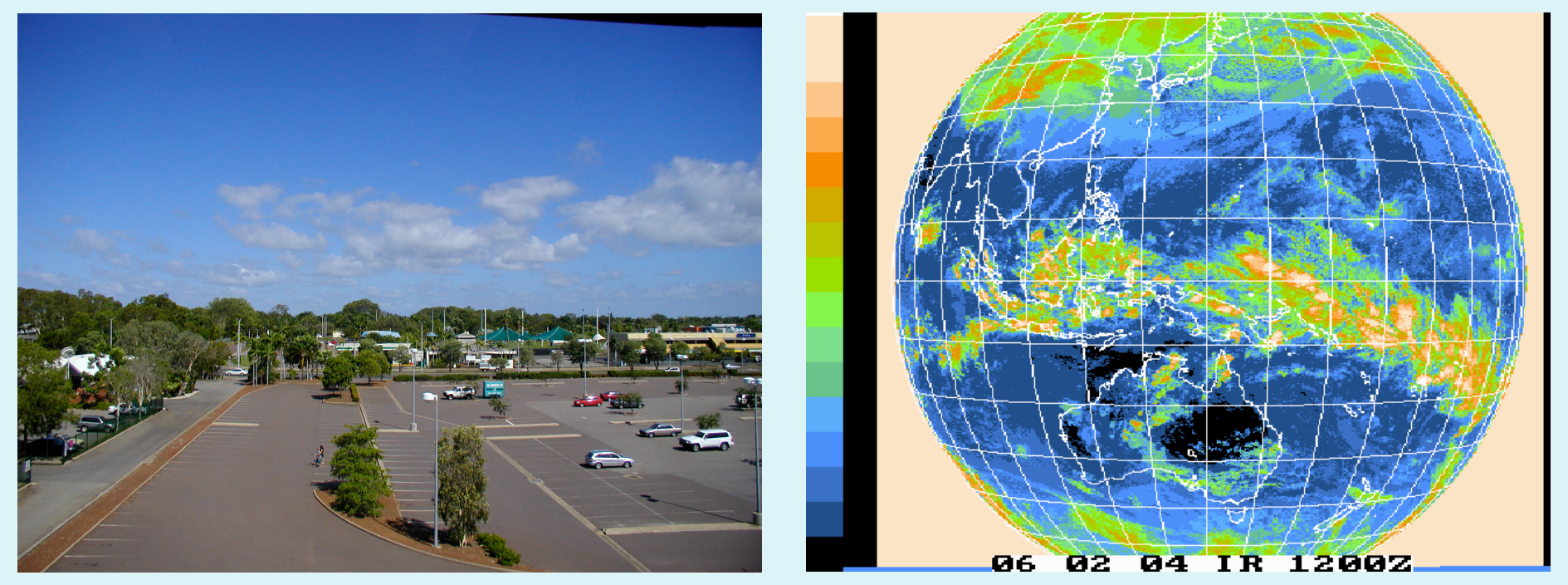
3. TWP-ICE: The MJO in Action!

The Tropical Warm Pool International Cloud Experiment (TWP-ICE; Jan-Feb 2006) was conducted in Darwin, Australia. The field campaign occurred during a time of intense MJO-related convective activity followed by a transition to the suppressed phase. The TWP-ICE weather balloon array provides sounding data of very high temporal resolution (3 hour), offering a detailed look at the wet-to-dry phase transition. Myself and other members of the CSU Atmospheric Science Department, among many other institutions, participated in the project.

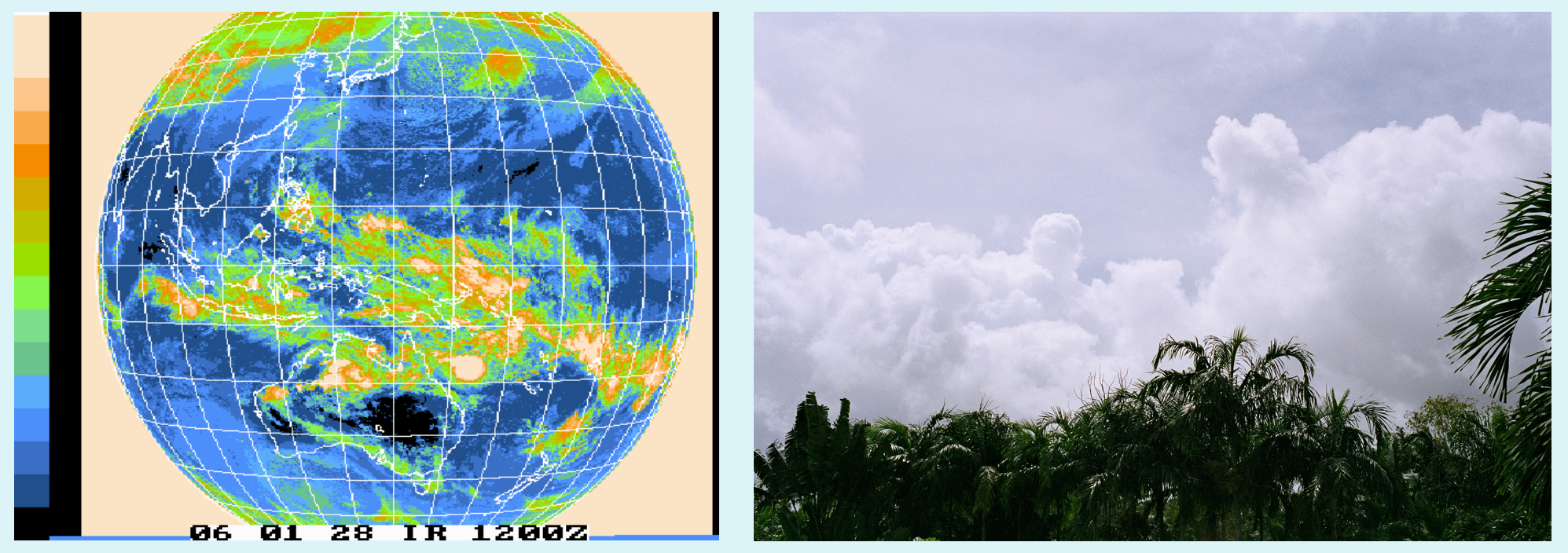




(Above) The timeseries of rainfall (above, black lines) and relative humidity (shaded, above left) from the *Southern Surveyor* ship indicate the presence of deep convection and its transition to the dry phase as westerly zonal wind anomalies (shaded, right) develop. Increased upper-tropospheric moisture, likely evidence of cirrus anvils, extends one week beyond peak rainfall and is captured nicely in the "Week 2" photograph at left (overlying residual convective clouds). At this time, the strongest westerlies are observed. After deep-layer drying in week 3, a general increase in low-level relative humidity occurs with anomalous low-level easterlies (above, right).

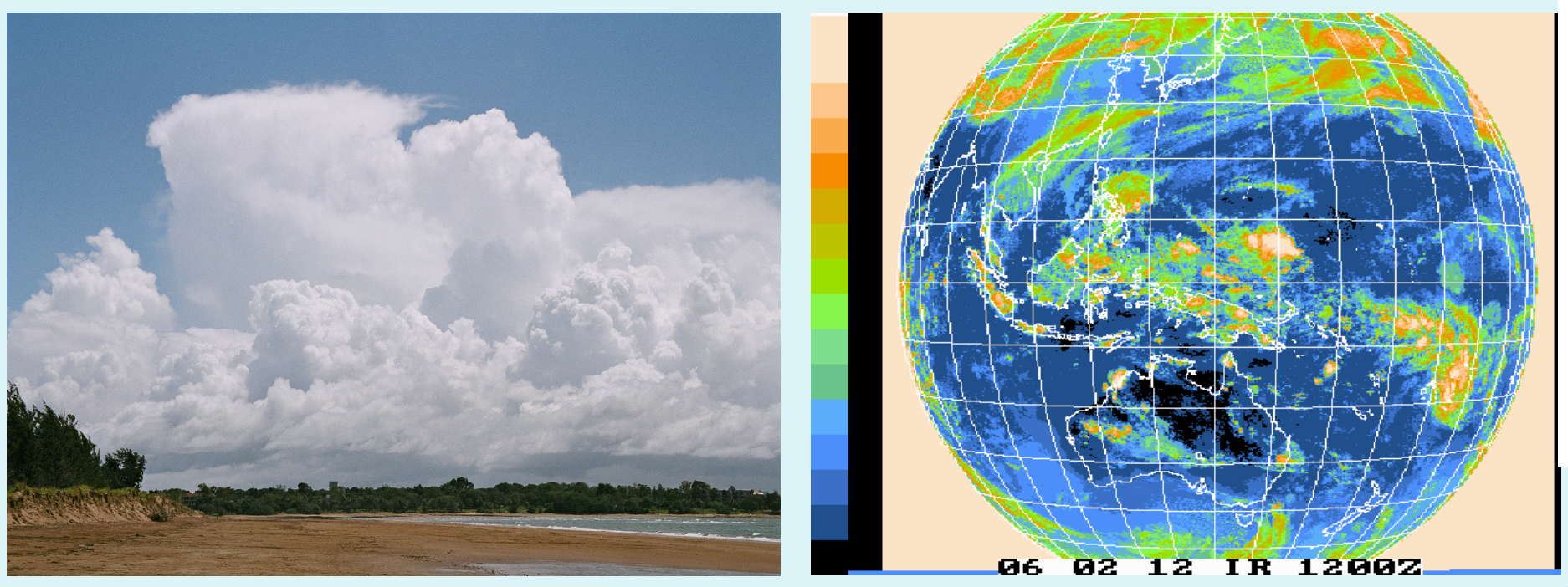


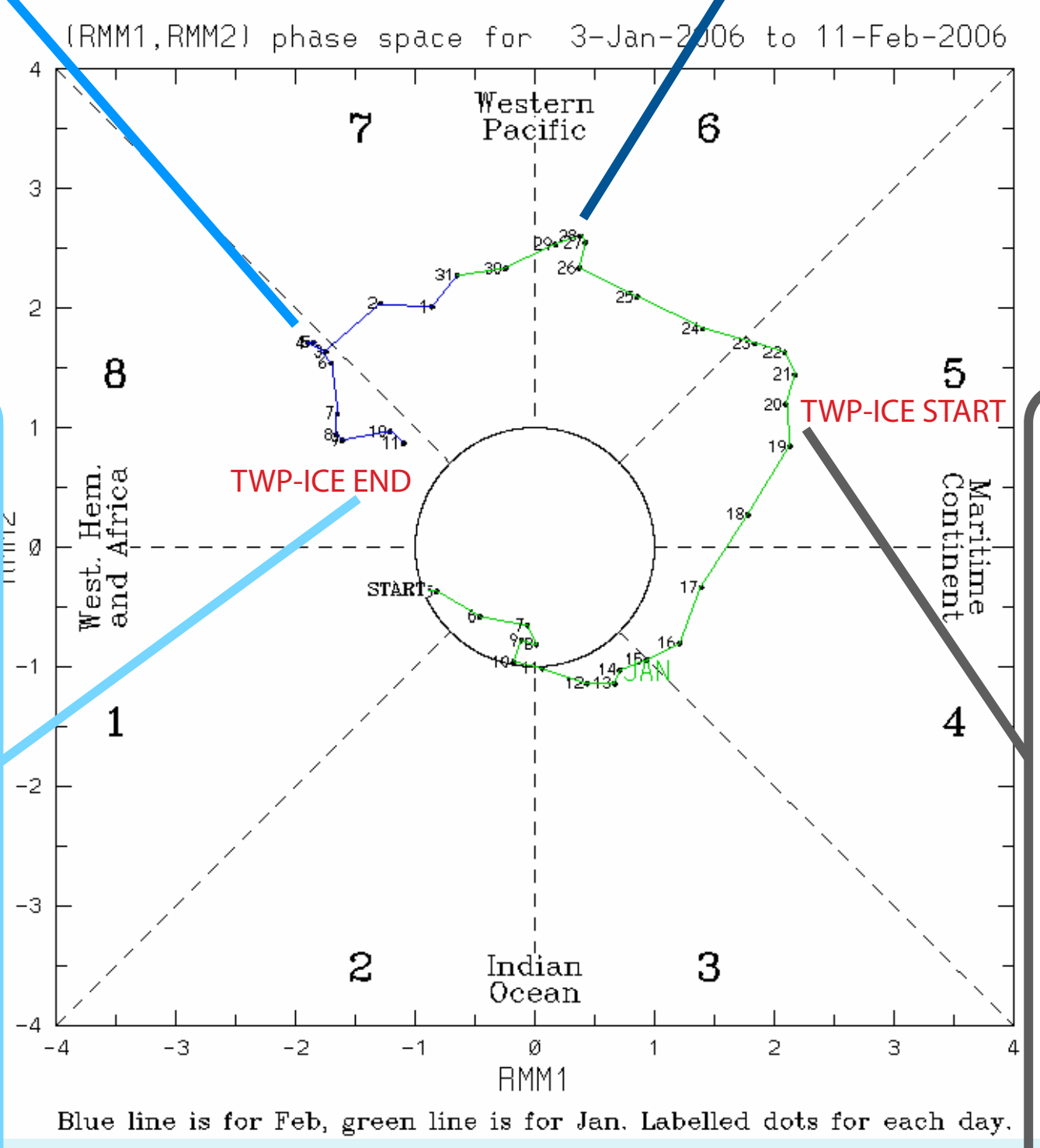
Week 3: *Very isolated rain showers with highly-localized deep convection ("Hector"); shallow cumuli; weak west winds*



Week 2: *Lighter rainfall; less deep convection, but abundant stratus and cirrus; strong west winds*

Week 4: *Climatological (land-based) deep convective clouds and rainfall; gust fronts, sea breeze fronts; general light easterly winds*





(Above) Diagram of MJO index; distance from center of circle represents amplitude of MJO, quadrant represents geographic location of maximum deep convection. (Diagram courtesy of M. Wheeler at BMRC)

Week 1: *Frequent, intense rainfall; continuous cloud cover; moderate but gusty winds*