Evaluating forecasts of central US mesoscale convective systems in a GCM with explicit embedded convection

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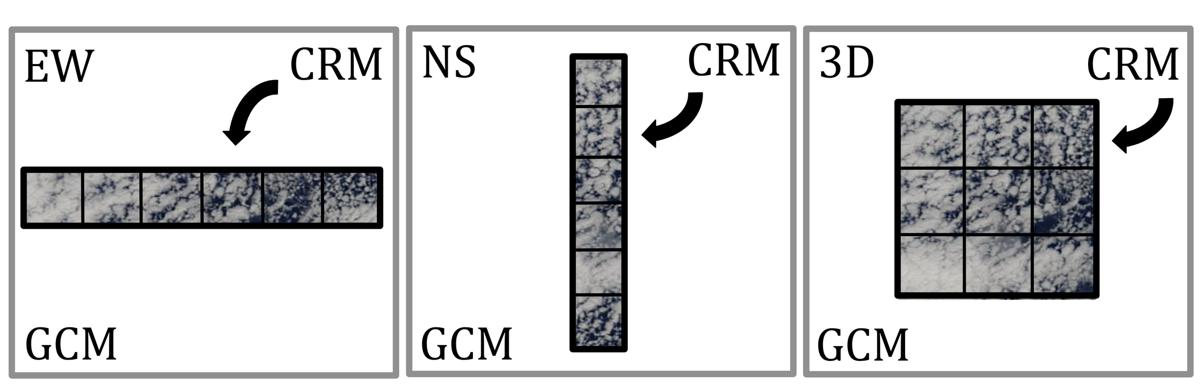
1. Overview

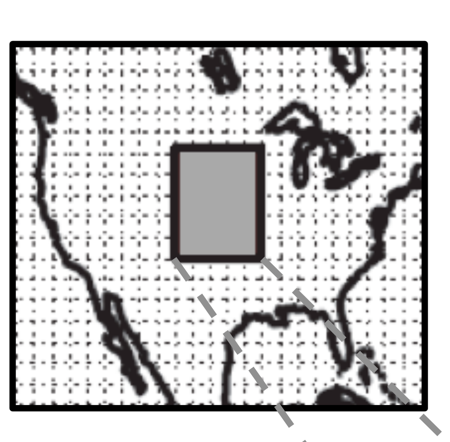
Conventional climate models do a poor job simulating an important class of organized mesoscale convective system (MCS) that forms during summer downwind of mountain ranges worldwide. MCSs can span areas hundreds of thousands of square kilometers, persist longer than the lifetime of individual clouds, and are responsible for up to 60% of the rainfall during summer months. Capturing and assessing the representation of these storms is critical to improving future climate projections. Recently, it has been qualitatively demonstrated that propagating MCSs are simulated in a new type of climate model called a Multiscale Modeling Framework. In this study, a forecast approach is applied to quantitatively evaluate the representation of these storms against high value observations. Sensitivity tests, varying model configuration and forecast initialization, are carried out to assess the robustness of the result and investigate the mechanisms responsible for generating and sustaining these storm systems in the model.

2. Multiscale modeling framework

Multiscale modeling framework (MMF) is a new approach to global climate modeling (GCM) in which idealized cloud resolving models (CRMs) are embedded in each grid column of a GCM to explicitly represent sub-grid convection rather than rely on simplified statistical parameterizations. The MMF used in this experiment is a modified version of the NCAR Community Atmosphere Model (CAM) version 3.5 and was developed by the Center for Multiscale Model of Atmospheric Processes. CAM is run at 1.9°x2.5° horizontal resolution with 30 hybrid vertical levels. The embedded CRM is run at 1km resolution with 64 columns and vertical levels co-located with CAM levels. The CRM can be realized in two (1x64) or three dimensions (8x8; 3D) and oriented in zonal (EW) or meridional (NS) directions. All three configurations (below) are evaluated here, but primarily analysis is focused on the NS configuration.



3. Propagating US convection



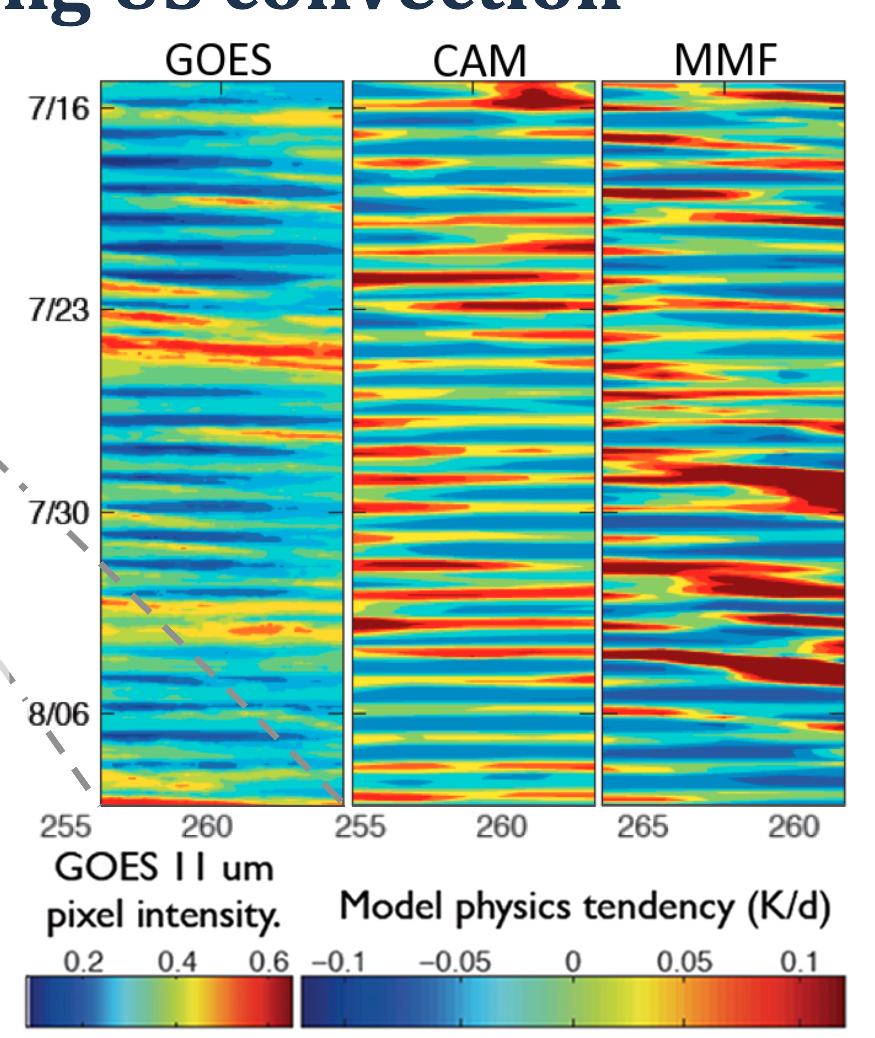


Figure 1. Hovmöller diagrams of warm season convection in the lee of the Rocky Mountains between 35°N and 45°N from GOES imagers and model temperature tendencies.

Pritchard et al. (2011) demonstrated that the central US organized nocturnal eastward propagating mode of convection is captured in free-running simulations with the MMF in EW configuration. Propagation is evident from the tilted phase lines seen in GOES and the MMF, but not in CAM in Figure 1. In these simulations the CRM was aligned with the preferred direction for horizontal wind shear, which was thought to have played an important role. It was hypothesized that propagation of CRM scale disturbances were mediated through their influence on the GCM scale first baroclinic mode. A composite MCS was found to have realistic propagation speed and relative flow.

4. Reality of forecasted storm

$$\frac{\partial X_M}{\partial t} = \ldots - \left(\frac{X_M - X_O}{\tau}\right) \qquad \textbf{Equation 1.}$$

Conventional GCM forecasts can be initialized directly from reanalyzed observations, but initializing the embedded 1km CRM for MMF forecasts adds a new challenge. Here the outer GCM of the MMF is relaxed toward observations (Eq. 1.), allowing the CRM to spin up in response to an observationally constrained large scale forcing. In Equation 1, X_M is the model field, X_O is the observed field, and τ is a relaxation parameter. Once spun up, the MMF is run freely in forecast mode.

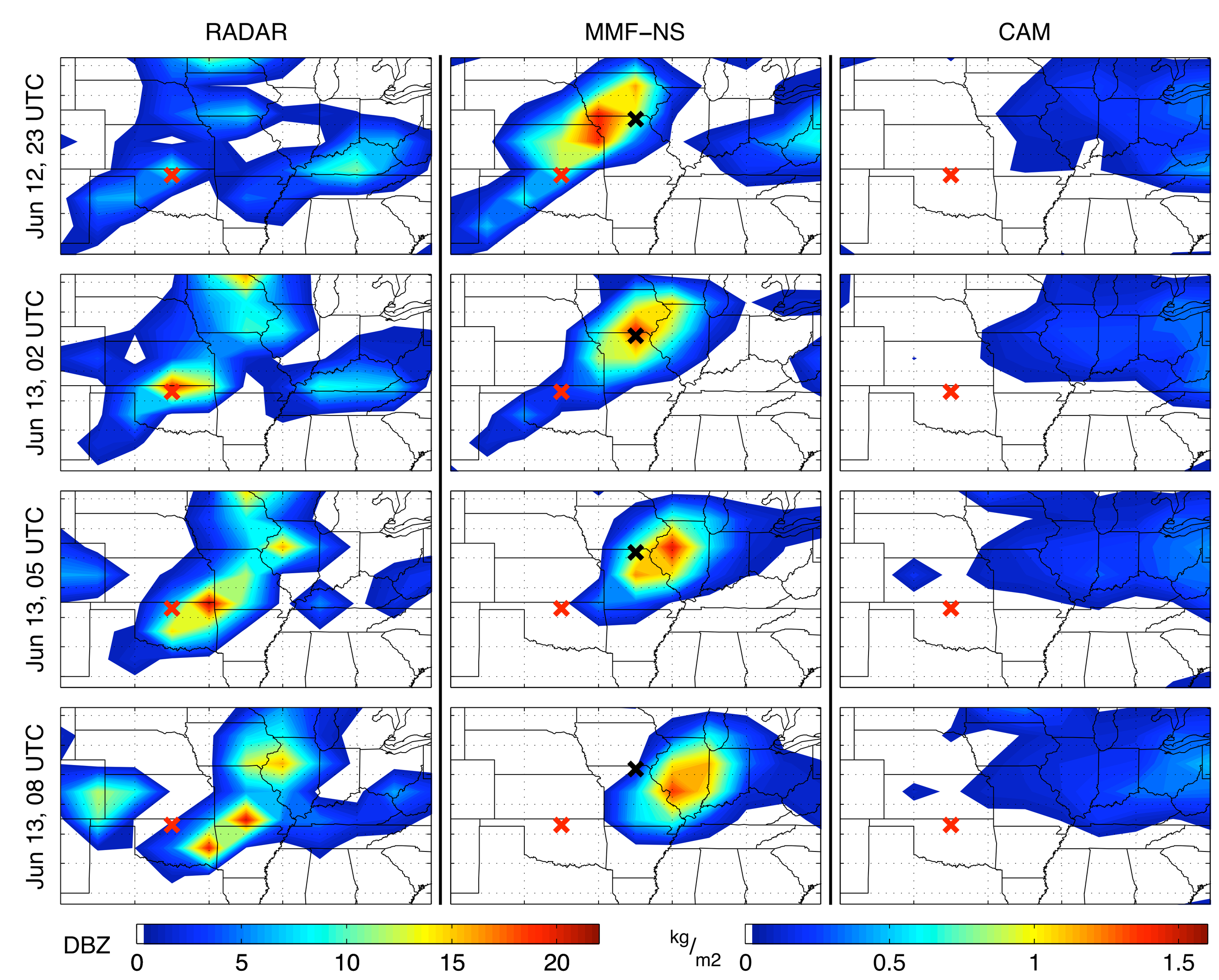


Figure 2. Storm trajectory from observations (radar reflectivity - NOWRAD) and simulations (cloud water path) on June 2002.

Forecasts with the MMF and CAM starting on June 12, 2002 0 UTC are shown in Figure 2. The MMF forecasts a large propagating storm system in the region, while CAM does not. The storm is offset to the north relative to observations, but moves across the region with a realistic propagation speed.

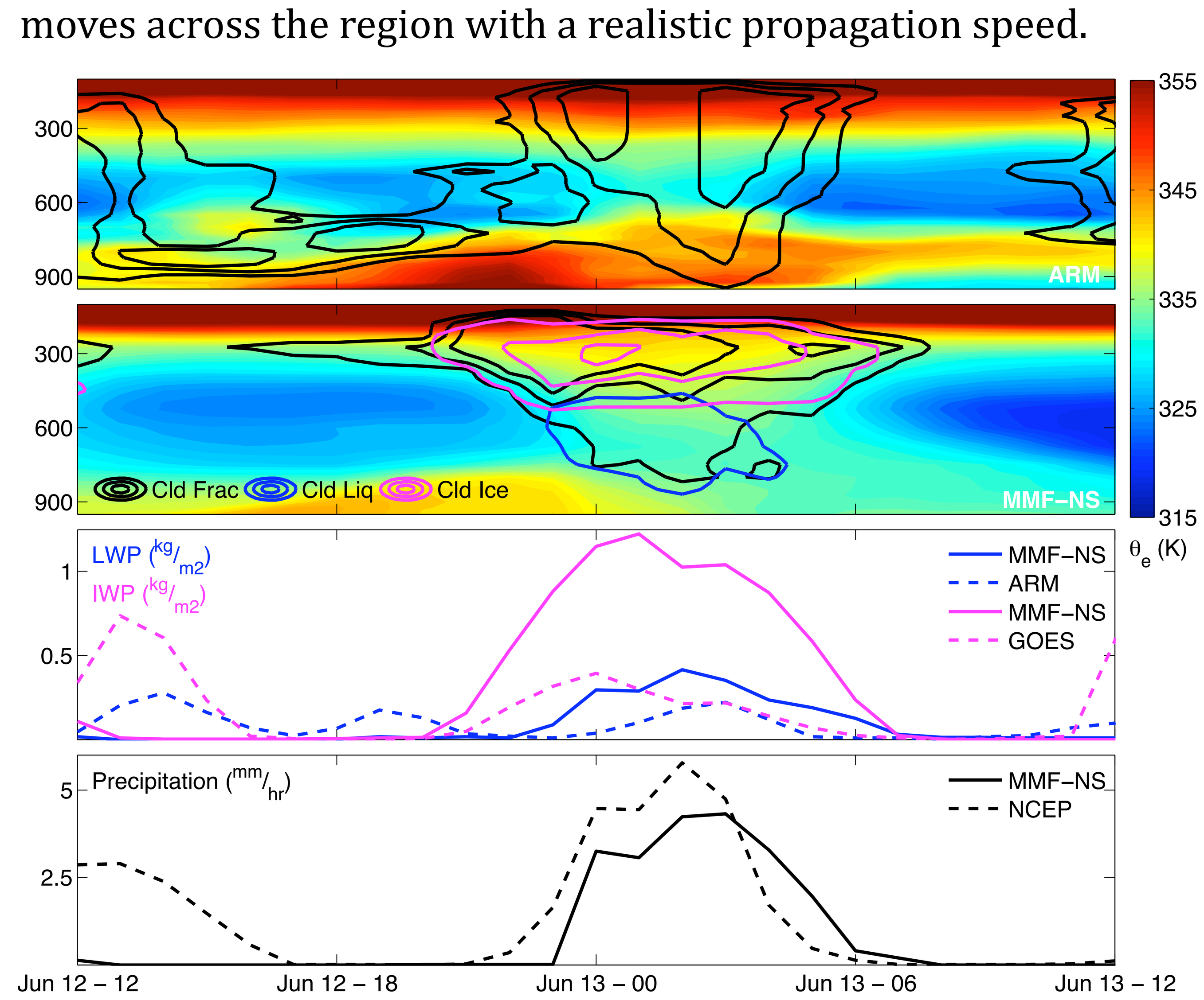


Figure 3. Time series at ARM SGP site (**X** Fig 2.) and simulated relative storm location (**X** Fig 2.). Top panels show equivalent potential temperature and contours of cloud fraction (RUC reanalysis and ARSCL). The third panel is liquid/ice water paths (surface LWP / satellite IWP). The fourth panel is precipitation.

Although the storm is offset to the north and generates earlier than observed, its duration compares well to observations. Rapid Uptake Cycle equivalent potential temperature shows stronger build up ahead of the storm and more drying/cooling following than is simulated. Ice (liquid) water is over simulated compared to satellite (surface) retrieval. The MMF's response to weaker column energy is an unrealistically large ice storm. However, the resulting surface precipitation compares well to NCEP S4 combined gauge-radar.

5. Forecast sensitivity tests

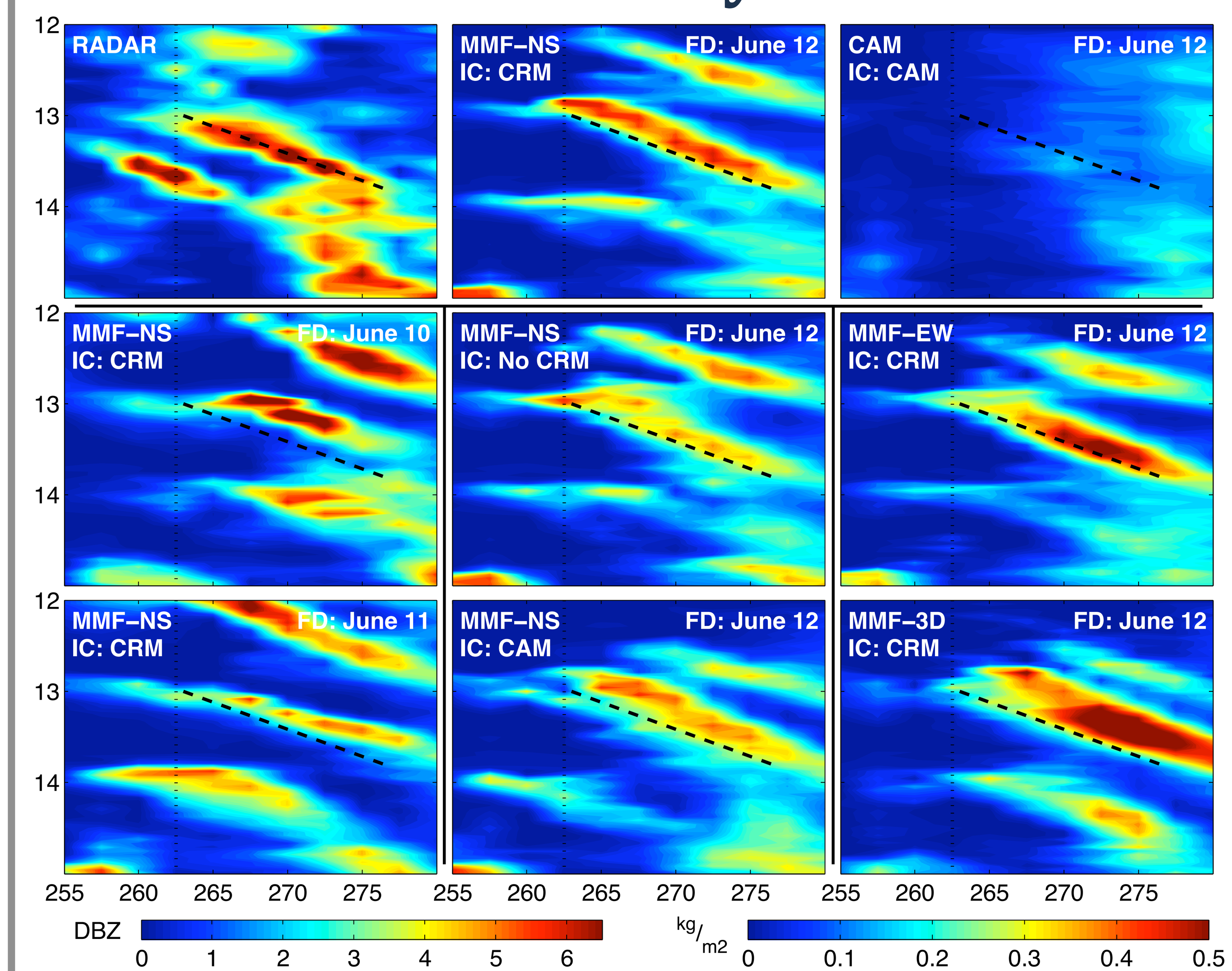


Figure 4. Hovmöller diagrams of the storm from NOWRAD radar and MMF/CAM simulations (cloud water path). Bottom two rows show sensitivity to forecast lead time (left), forecast initialization (center), and CRM orientation (right). IC refers to initial conditions and FD refers to forecast start day.

Propagating storms are simulated with several days lead time and only depend on initializing the large scale component of the model. The MMF produces the storm on June 13th with all CRM configurations, although there is more water simulated in the 3D CRM. MMF-NS initialized from a nudged CAM simulation (bottom-center) produces the storm, while CAM with the same initial conditions (top-right) does not. The propagation speed compares well to radar reflectivity, as indicated by the slope.

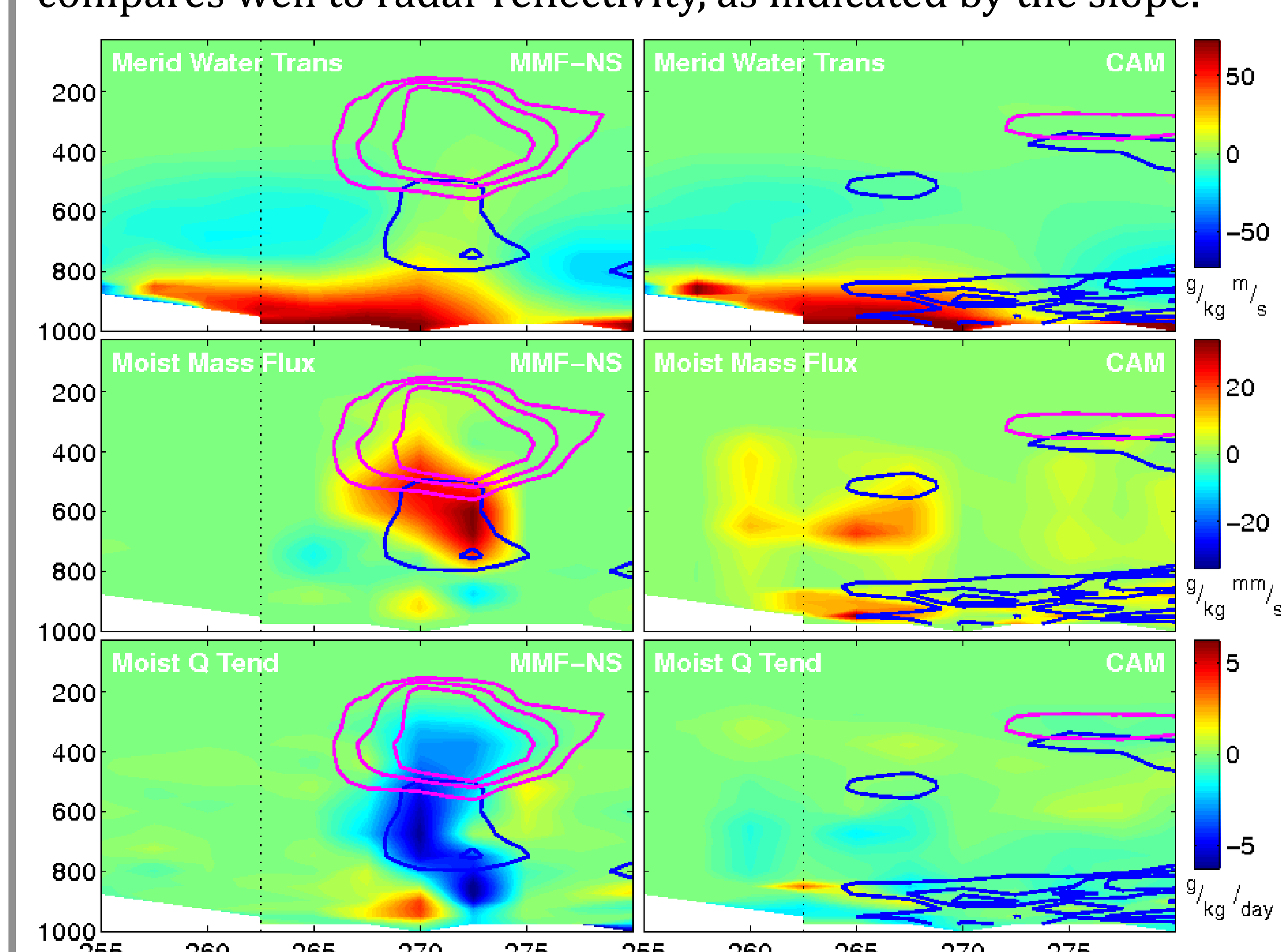


Figure 5. MMF-NS and CAM height-lon cross section snapshots at 8 UTC on June 13, 2002. The top panels are meridional water vapor transport, the middle panels are convective mass flux, and the bottom panels are convective humidity tendencies.

Both the MMF and CAM simulate low level meridional water vapor flux into the region, but the MMF has stronger vertical mass flux and effectively converts lifted water vapor into liquid and ice condensate. CAM shows little evidence of convection.

6. Conclusions

Organized propagating convection in the central US is a robust feature of the MMF and does not depend on the CRM orientation. Over simulated ice and weak equivalent potential temperature indicate errors in the representation of cloud microphysics. MMF resolved convection is more sensitive to elevated water/energy than conventional parameterization, providing a pathway to simulate a class of storm not driven primarily by surface heating. Forecasted storms without CRM initialization indicate large (GCM) scale processes may play the dominant role in generating this storm system in the MMF.

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