6.9 INITIATION OF PRECIPITATION EPISODES RELATIVE TO ELEVATED TERRAIN

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1 INTRODUCTION

Over the U.S., time-longitude composites of precipitation frequency for 1996-2001 indicate a strong dependence on the phase of the diurnal cycle. There is a smooth transition from a distinct late afternoon maximum near 105 W to an early morning maximum near 93 W. The eastward propagating precipitation episodes responsible for this pattern often initiate just downstream from the apex of the Rocky Mountains. Since the western edge of this transition zone coincides with the eastern edge of the Rocky Mountains in Colorado and Arizona, this suggests an active role for continental-scale orography in initiating precipitation episodes.

However, the 2002 warm season rainfall exhibits no such coherent rainfall signal in Hovmoller space. Consequently, the mountains appear less important to precipitation episode initiation. Nevertheless, a simple coordinate transformation restores the general pattern. The observations were remapped to a coordinate system relative to the eastern edge of the Rocky Mountains, thereby restoring the eastward-propagating peak in the precipitation diurnal cycle. Once again, this supports the claim that elevated terrain such as the Rockies govern the downstream initiation of precipitation episodes. The northward bias of the 2002 storm track and geometry of the Rocky Mountains allowed this hypothesis to be indirectly tested.

2 BACKGROUND

Time-longitude plots, or Hovmoller diagrams, of warm season precipitation over the United States indicate long-lived coherent episodes that span the continent (Carbone et al., 2002). These sequences of precipitating convection, or precipitation episodes, maintain their identity for upward of 48 h, and are prevalent during the heart of the warm season. Their existence speaks to a heretofore-unseen predictability inherent in warm season rainfall beyond the time scale of individual convective systems.

Considering that individual mesoscale convective complexes (MCC), the longest-lived mode of organized convection in the midlatitudes, last around 10 h, it was surprising to discover coherent structures in the Hovmoller diagrams with durations frequently exceeding 24h. According to Carbone et al. (2002), the longest-lived rain streaks, or precipitation episodes, were often attributable to serial mesoscale convective systems, but the underlying mechanisms were unknown. These eastward-moving envelopes of enhanced activity could undergo several cycles of intensification and dissipation as squall lines or mesoscale convective complexes propagated through. Their zonal phase speed varied from 10-20 m/s and in most cases surpassed the environmental wind speed below 40 hPa.

In addition to longevity, another important aspect of warm season rainfall presented by Carbone et al. (2002) was its diurnal cycle. There is a well-known proclivity for afternoon rainfall over the western U.S. and southeastern coastal plains, and a tendency for nocturnal rainfall across the intervening Great Plains (Dai et al, 1999). This pattern was evident in our radar data (Fig. 1, top panel). Over the elevated terrain of the Rocky Mountains, precipitating convection initiates early in the afternoon and rapidly dissipates after sunset. This explains the sharp peak in rainfall frequency centered on 23 UTC (about 1800 local solar time) west of 105 W. Progressively eastward, the precipitation peak occurs later and later in the night. This steady shift to later times is consistent with eastward translating convective elements initiated in the lee of the mountains near 105 W and 23 UTC. The remarkable regularity is captured nicely in the diurnal composite (Fig. 1, top panel).

The organized precipitation episodes responsible for this pattern often initiate just downstream from the continental divide of the Rocky Mountains. Since the western edge of this transition zone coincides with the eastern edge of the Rocky Mountains over a considerable latitude range, this suggests a strong role for continental-scale orography in initiating precipitation episodes. However, this argument is not supported by the corresponding time-longitude composite for 2002 (Fig 1, bottom panel). The coherent phase shift from west to east is not immediately apparent. The reason for this is explored in the Results section.

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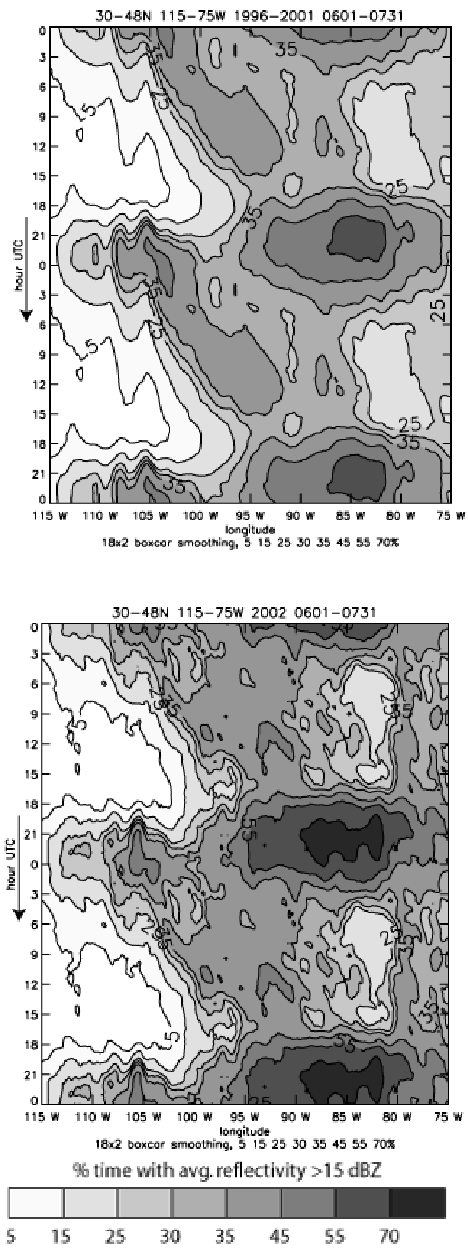

Fig. 1. Time-longitude diurnal composites of precipitation frequency for June and July 1996-2001 (top panel) and 2002 (bottom panel). The diurnal cycle is repeated for clarity. In the 1996-2001 composite, the peak shifts smoothly from the afternoon (22 UTC) to the early morning (12 UTC) as one moves east from 105 to 93 W, whereas the 2002 composite offers no clear signal. The criterion for a precipitation event is described in the Methodology section.

3 METHODOLOGY

Carbone et al. (2002) analyzed precipitation over the continental U.S. using national composites of NIDS radar reflectivity. Radar reflectivity from WSI's NOWrad product was transformed to rainfall rate using a Z-R relationship and averaged along one spatial dimension. Plotted with respect to time, these longitude-time Hovmoller diagrams contain rain streaks and patterns that were identified and documented by an automated algorithm. For further details on this algorithm and the Hovmoller diagrams, see NCAR Tech Note 448+STR (Ahijevych et al., 2001).

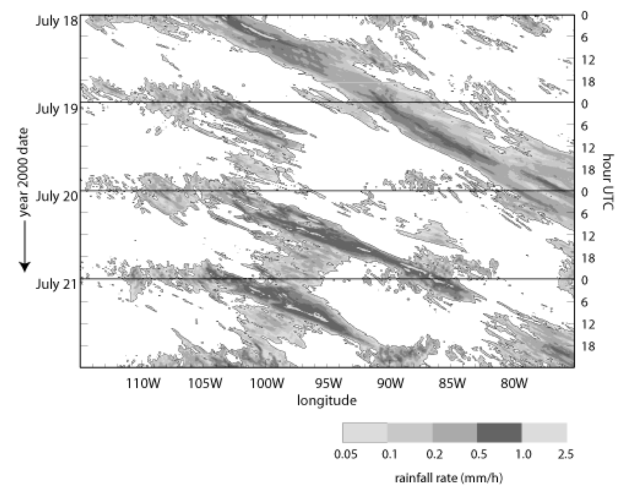

Fig. 2. Radar-estimated rainfall rate averaged between 30 and 48 N for July 2000. Three significant precipitation episodes are evident, all starting at approximately 22 UTC, 105 W on July 18, 20, and 21. As precipitating systems move eastward, they appear as narrow streaks of enhanced rainfall sloping downward from left to right in the Hovmoller diagram.

Hovmoller data from multiple days were also integrated to produce time-longitude and time-latitude composites of the diurnal cycle (e.g. Fig 1 and Fig 4). At each time-space coordinate, the probability of precipitation was defined as the probability of radar reflectivity 15 dBZ or higher.

To simulate the realignment of the eastern edge of the Rocky Mountains, the coordinates of the radar data were skewed along a zonal axis. For simplicity, a two-piece definition of the eastern edge of the mountain range was employed. It corresponds roughly with the 1000-1200 m MSL elevation contour. North of the 42nd parallel, longitude coordinates were remapped as a function of latitude such that

$$lon_{new} = lon_{old} + (lat - 42)*(10/7).$$

This is illustrated in Fig. 3. South of 42N, no changes were made.

South of 42N, the zonal topography profile is relatively independent of latitude (Fig 3). However, as one moves north, the steep transition zone between the rugged Rocky Mountain cordillera and the gentle slope of the Great Plains occurs further west. Realizing that this put the storm track in a latitude band with a much different longitude for the eastern edge of the Rocky

Mts., we artificially shifted the topography and recalculated the Hovmoller diagrams.

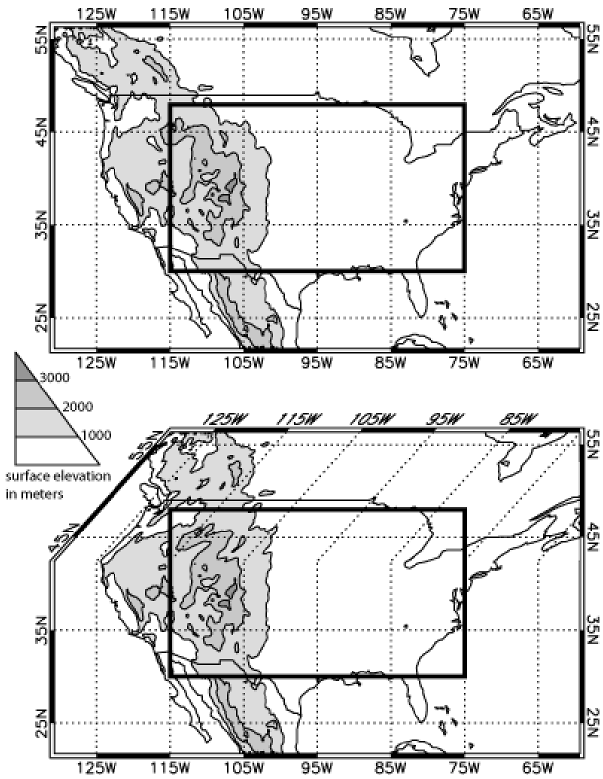

Fig. 3. North of 42N, radar reflectivity data were skewed along a zonal axis to align the eastern edge of the Rocky Mountains approximately north south. These two panels illustrate the underlying surface elevation (m) before (top) and after (bottom) the coordinate transformation. The computational domain of the Hovmoller diagrams in Figs. 1 and 4 is denoted by the bold, interior rectangle. Note that within the domain of interest, the variation of surface elevation across a given longitude is less pronounced in the bottom panel.

4 RESULTS

With a seven-year time series, one can begin to address issues of inter-annual variability. In time-longitude space, the diurnally modulated precipitation probability was relatively static among the six years preceding 2002. Why did 2002 behave differently? Why did so few precipitation streaks initiate near 105 W in the zonal Hovmoller diagrams? Any attempt to attribute the extraordinary behavior of the 2002 warm season to extraordinary conditions in the tropical Pacific is stymied by the unspectacular state of the El-Nino Southern Oscillation (ENSO) index for 2002. A weak El-Nino characterized 2002, falling well within the ENSO range bounded by the 1997 (warm) and 1999 (cold) seasons covered by our dataset.

Regardless of ENSO, the 2002 warm season was quite dry across Colorado and Nebraska and exceptionally moist in Minnesota and Wisconsin. The nocturnal thunderstorms that typically grace the Central Plains were often relegated to the northern tier of the U.S. This is illustrated by the time-latitude diurnal composites shown in Fig. 4.

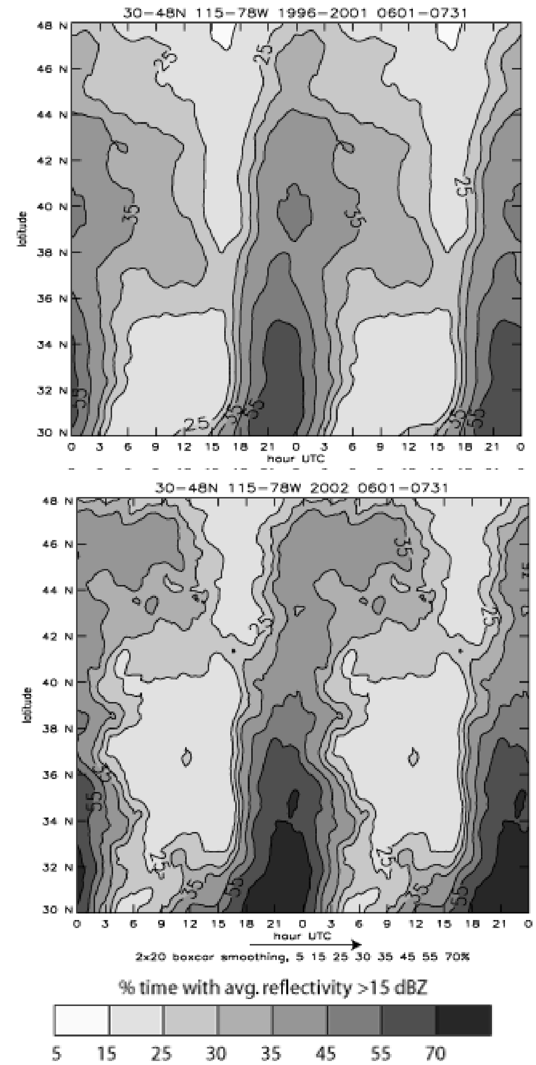

Fig. 4. Time-latitude diurnal composites of precipitation frequency for June and July a) 1996-2001 and b) 2002. The diurnal cycle is repeated for clarity. The nocturnal precipitation in 2002 (3-12 UTC) tended to occur further north than in 1996-2001.

In both panels of Fig 4, afternoon and early evening thunderstorms over the Gulf of Mexico coastal region and the elevated terrain of the Rocky Mountains lead to a sharp precipitation maximum between 22 and 2 UTC. In the six-year climatology (top panel), the afternoon/evening maximum is followed by nocturnal rainfall between 35 and 45N (3-12 UTC). However, nocturnal precipitation is relegated poleward of 42 N in 2002. This northward shift has important ramifications for our zonal Hovmoller diagrams (time-longitude composites) (Fig 1).

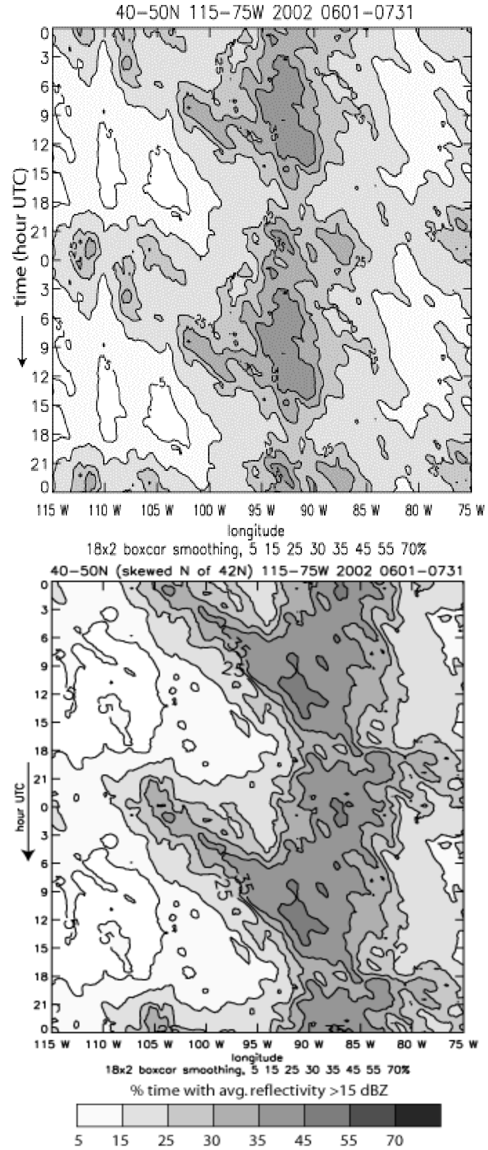

Fig. 5. Time-longitude composite of precipitation probability for 2002 before (top panel) and after (bottom panel) skewing the topography north of 42 N. For clarity, a smaller averaging interval has been used (40-50N) than in Fig 1. This highlights the nocturnal signal and eliminates most of the sea-breeze regime.

After shifting the topography, an eastward propagating precipitation peak reemerges from the time-longitude composite of precipitation probability (Fig 5, bottom panel), echoing the pattern in the six-year climatology (Fig. 1, top panel).

The time longitude diagram is particularly useful for summarizing quasi-two- dimensional regimes. While the Hovmoller diagram can summarize massive amounts of data in concise fashion, important information is lost in the averaging process. No distinction is made between an event in Texas and an event on the U.S. Canadian border. Without considering the geometry of the Rocky Mountains, the different results from 2002 suggest that the problem of replicating the precipitation episodes in numerical models is hopelessly three-dimensional, and one must carefully consider latitude. However, this study suggests that latitude is not as important as longitudinal topography in governing the initiation of precipitation episodes, and one must seriously consider the merit of two-dimensional simulations with much higher resolution.

5 SUMMARY

In the absence of synoptic scale disturbances, the initiation of organized precipitation appears to be governed by large-scale topography and the diurnal cycle. In the absence of mountains the precipitation episodes would probably not be fixed to particular times of day and longitudes, as observed. We have also demonstrated how latitudinal variations in topography may mask the inherent two-dimensionality of the mountain-plains system when viewed in time-longitude space.

6 REFERENCES

Ahijevych, D. A., R. E. Carbone, J. D. Tuttle, 2001: Radar data and climatological statistics associated with warm season precipitation episodes over the continental United States. NCAR/Tech. Note-448+STR.

Carbone, R. E., J. D. Tuttle, D. A. Ahijevych, and S. B. Trier, 2002: Inferences of predictability associated with warm season precipitation episodes. J. Atmos. Sci., 59 (13), 2033-2056.

Dai, A., F. Giorgi, and K. E. Trenberth, 1999: Observed and model-simulated diurnal cycles of precipitation over the contiguous United States. J. Geo. Res., 104, 6377-6402.

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