The Case of the Follow-On Short Wave
A WES Case from the March 2-5, 2004 Winter Storm

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Determining the timing and intensity of major winter storms can be quite a challenge when a pair of systems interact with each other. This was the case in the first week of March 2004. As documented in a previous TA-Lite (Meyer 2004), a well-defined cutoff low off the southern California coast was expected for several days to move east along the U.S.-Mexico border as an upstream "kicker" system passed across the southern Great Basin. This lead system had all the "desirable" characteristics of a decent southern Arizona winter storm: slow movement, moderate to strong dynamics, a southern track along the international border, sufficient moisture, and a slight negative tilt. Scattered showers developed on schedule over south central Arizona on the evening of March 2nd, and increased in earnest by afternoon on the 3rd as the low began to move east (Figure 1). This part of the storm was well anticipated. Outlooks were issued 4 days ahead of precipitation onset, and Winter Storm Watches were issued with over 36 hours of lead time for mountain snow accumulations up to 18 inches. By the morning of the 3rd, 12 inches of snow had already fallen on Kitt Peak, which is located about 50 miles west of Tucson. A map of key locations is in Figure 2.

This TA-Lite focuses on the second phase of this event as the upstream "kicker" prolonged the precipitation with this major winter storm. The challenge in a "kick-out" type of situation is that the kicker itself can be just as significant in terms of precipitation production as the leading upper low. By the morning of March 4th, a 140kt upper jet had topped the eastern Pacific ridge, with another vorticity lobe forming in its left exit region (Figure 3). By this time, southern Arizona had already received considerable precipitation, with 0.25 to 0.75 inches of rain in the valleys and deserts, to 1.25 inches of liquid equivalent in the mountains. Not only was the surface-500mb layer nearly saturated, but θe cross sections indicated that this same layer was approaching a conditionally unstable state (Figure 4). Meanwhile, the parent upper low had tilted so strongly negative along the Rio Grande River that a Trough of Warm Air Aloft (TROWAL) had wrapped all the way from the southern Plains back into east central Arizona (Figure 5).

The combination of renewed mid level warm advection and arrival of the next short wave was depicted well in layer **Q**-vector convergence charts (Figure 6). Just as the deformation zone from the main low was exiting southeast Arizona, another round of heavy showers and isolated thunderstorms redeveloped with the secondary disturbance as it moved in behind the parent low (Figure 7). Not only did this renew the heavy snow in the mountains, but with additional heavy rain falling on the valleys, forecasters also had to deal with minor flood problems in some low water crossings around Tucson. Finally, as the second wave moved directly overhead on the evening of the 4th, the lower temperatures aloft and onset of darkness pushed snow levels to as low as 3000 feet east of Tucson. Accumulating snow fell along Interstate 10 and other well-traveled highways.

The one-two punch resulted in impressive storm totals in the mountains, despite looking like the entire event would be a "near miss" just 24 hours earlier. Total accumulations of 1 to 2 feet were common above 6000 feet, with 26 inches at the

Palisades Ranger Station on Mt. Lemmon northeast of Tucson. In the lower elevations, up to 7 inches was recorded at Chiricahua National Monument (5500 feet), with a half an inch in Tombstone (4610ft) and Oracle (4510ft), and even flurries in Safford (29550ft). Water equivalents were also impressive, especially in the southern White Mountains. Hannagan Meadow received over 3 inches of liquid over the 3-day event. Their total snow accumulation of 20 inches may have been held down by a combination of compaction and lower liquid-snow ratios as they remained in the nose of the TROWAL for several hours and surface temperatures hovered just below freezing.

This case is very useful from a training perspective because it exhibited many of the forecast problems we typically encounter with winter storms in a single event. While it is easy to focus on the nice, neat, “good looking” upper low, the ejection by an upstream “kicker” can also prolong the event if the kicker becomes absorbed into the upper low, or as in this case, the kicker works on an already moist and unstable environment to reinvigorate precipitation and turn a run-of-the-mill winter storm into a major one. The good news is that despite the numerous model problems indicated in Meyer (2004), most of the tools we use to *diagnose* classic closed-low storms like Q-vectors, potential temperature depictions, and model cross sections also help to monitor more subtle, follow-on, or “sleeper” features.

Reference:

Meyer, J., 2004: March 2-4 2004 Winter Storm, Southeast Arizona – A WES Case. NWS WR TA-Lite 04-43.

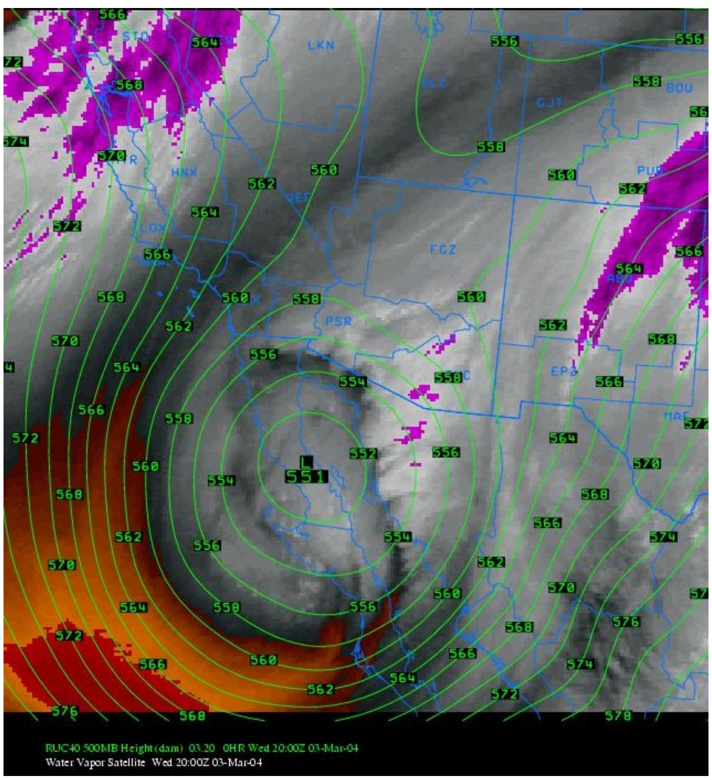

Figure 1: Water vapor satellite imagery and 500mb height (m) from 00hr RUC forecast, 2000 UTC March 3, 2004.

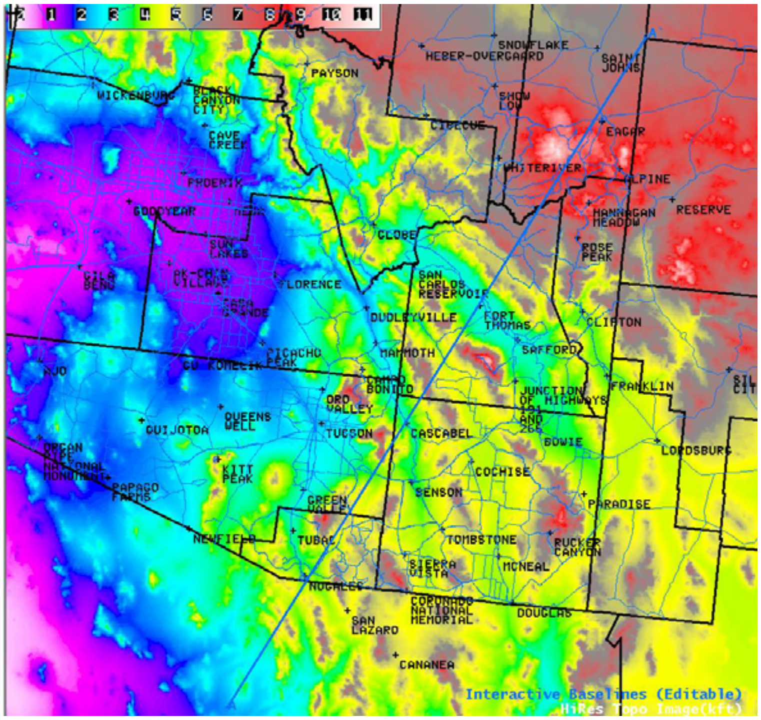

Figure 2: Map of Tucson County Warning Area, with topography, points of interest, and highways. The cross section line for Figure 4 is included.

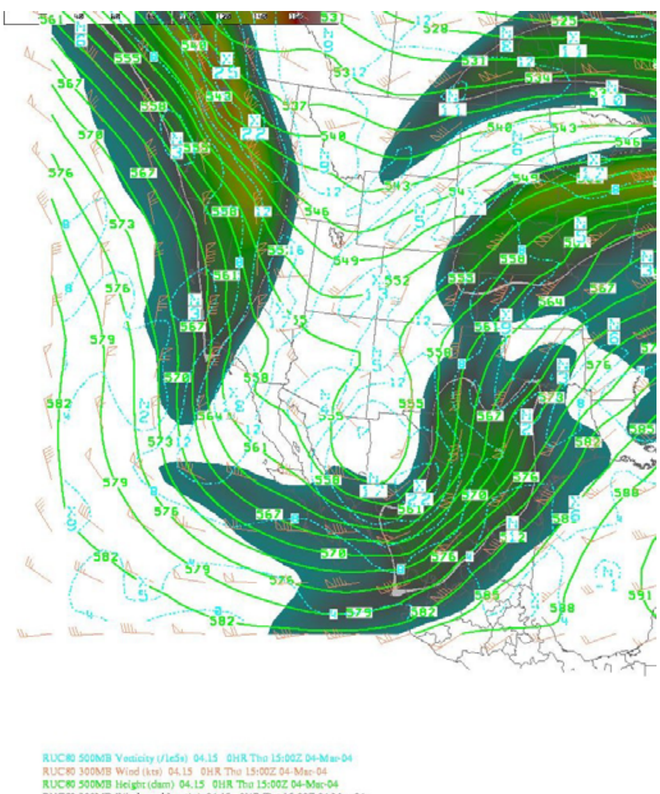

Figure 3: 500mb height (m) and vorticity (s-1), and 300mb wind (kts) from 00hr RUC forecast, 1500 UTC March 4, 2004.

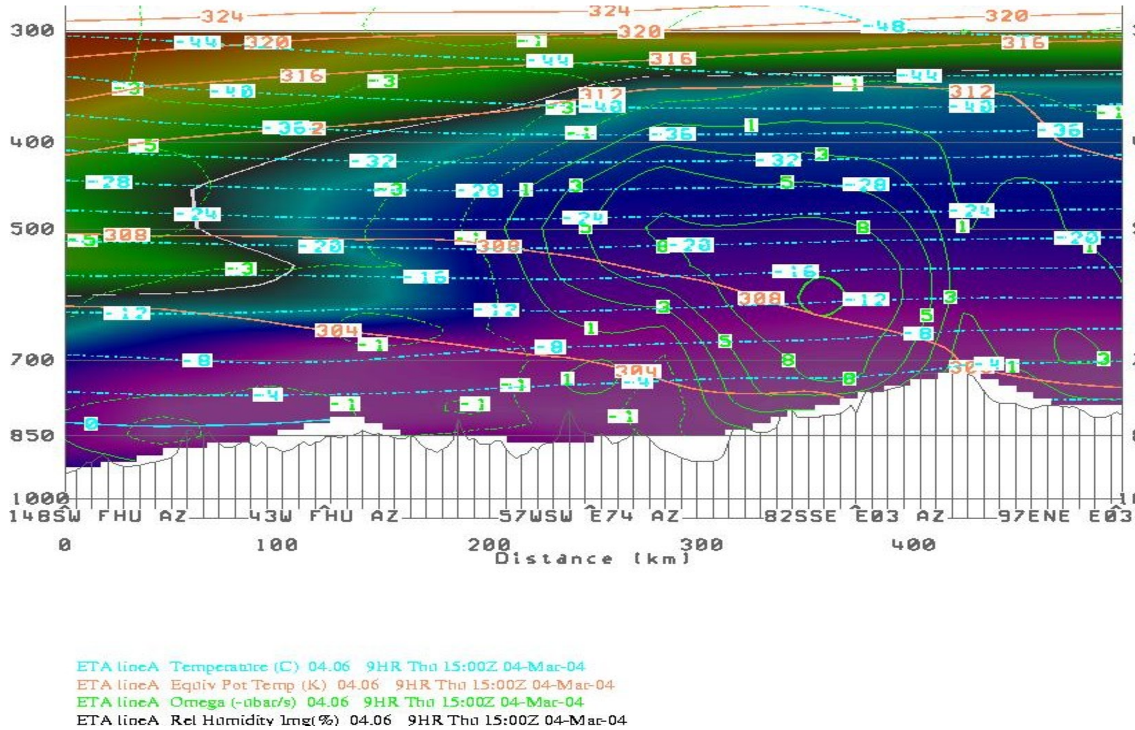

Figure 4: Spacial cross section of temperature (°C), equivalent potential temperature (°K), omega (μbar/s), and relative humidity (purple color approaching 100 %) from 9hr Eta model forecast, valid 1500 UTC March 4, 2004. Cross sections follows line A in Figure 2, left side south, right side north.

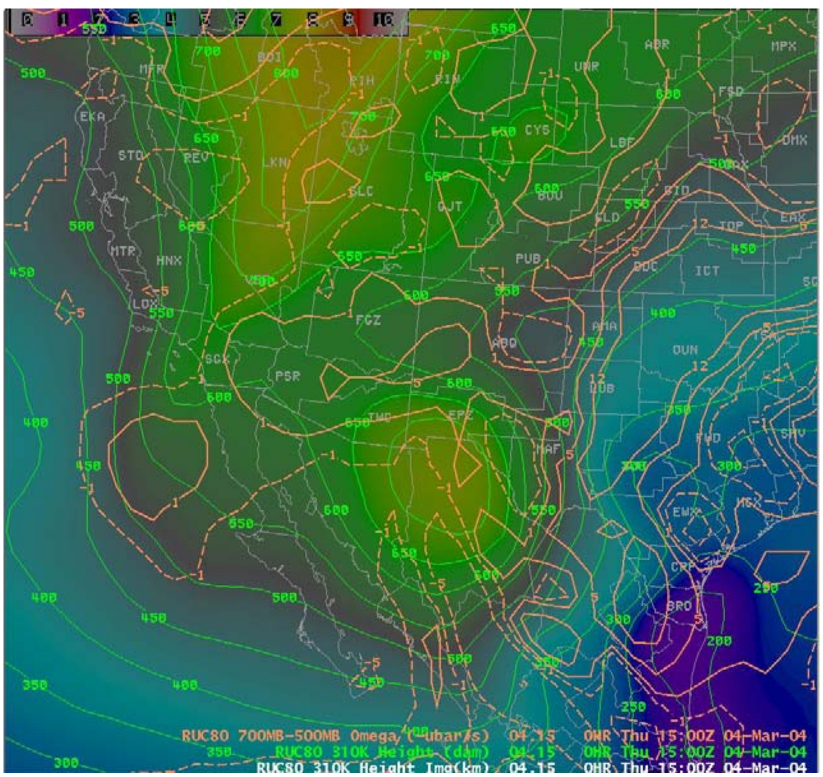

Figure 5: 310K potential temperature heights (dam) and 700-500mb omega (μbar/s) from 00hr RUC forecast 1500 UTC March 4. Note TROWAL extending from Gulf of Mexico into northern New Mexico, and wrapping back into east central Arizona.

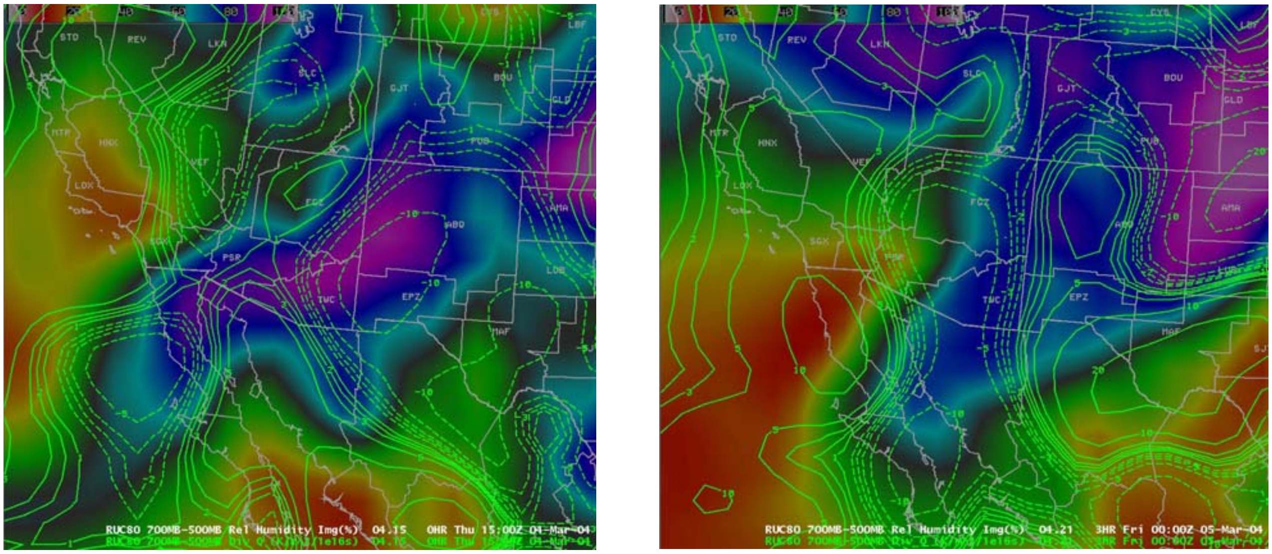

Figure 6: 700-500mb Q-vector divergence ($^{\circ}K/m^2/s^{16}$) and relative humidity (purple colors approaching 100%) from 00hr RUC forecast 1500 UTC March 4(right) and 09hr RUC forecast valid 0000 UTC March 5 (left).

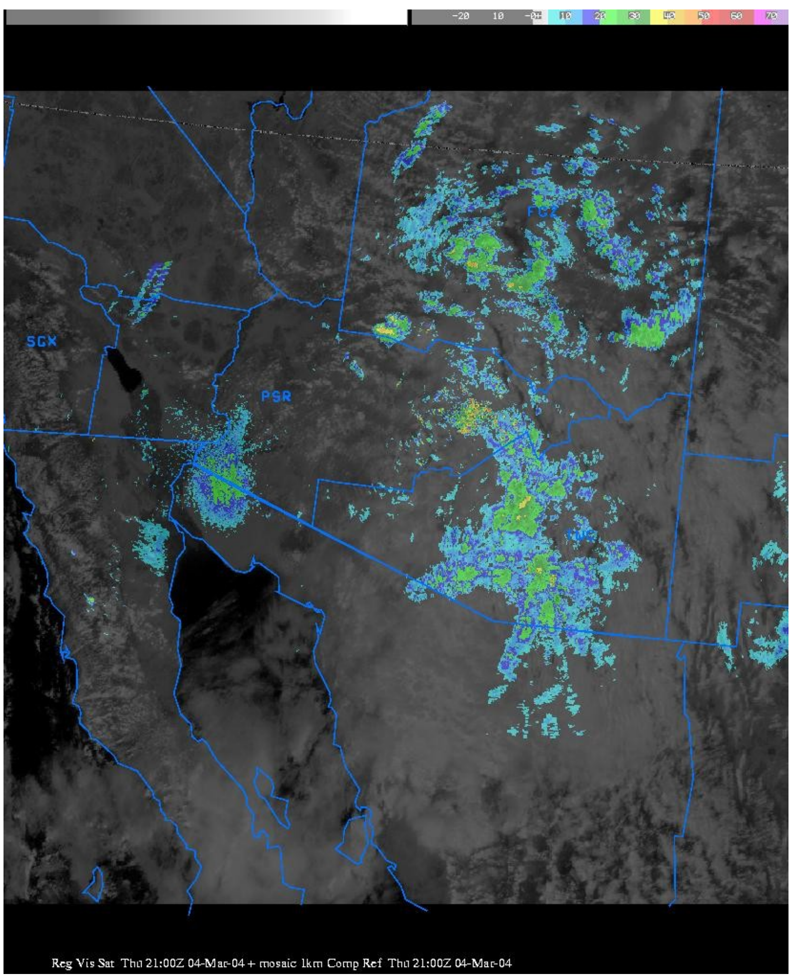

Figure 7: Visible satellite imagery, overlaid with KEMX composite reflectivity (dBZ), 2100 UTC March 4.