

UPPER TROPOSPHERIC TROUGHS AND THEIR INTERACTION WITH THE NORTH AMERICAN MONSOON

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ABSTRACT

Data from the North American Monsoon Experiment (NAME) in 2003 and 2004 was examined with respect to upper tropospheric troughs and the role they may play in modulating both the coverage and intensity of mesoscale convective systems (MCSs) in northwest Mexico and the Southwest U.S. These upper level potential vorticity anomalies, which originate in a variety of ways and generally follow the subtropical easterlies, appear to be ubiquitous in the warm season and generally track across the North American Monsoon region. As these systems interact with both topography and monsoon moisture plume, their associated dynamics appear to enhance MCS development. Past research on Tropical Upper Tropospheric Trough (TUTT) cells and subtropical upper tropospheric lows suggest that by tracking the development and evolution of these synoptic-scale features via satellite and real-time upper air data, forecasters may be able to better predict significant convective outbreaks in the North American Monsoon region.

1. INTRODUCTION

The North American Monsoon (NAM) is a seasonal change in mean flow pattern across the desert Southwest U.S. and much of Mexico. The switch from polar westerlies to subtropical easterlies results in a significant increase in warm season thunderstorm activity across this region and a pronounced rainfall maximum (Douglas et al. 1993). One of the primary mechanisms which enhance monsoon-related convection in the NAM region is the Gulf of California Surge. Although many questions remain with respect to the dynamic mechanics of these surges, they are well researched and clearly linked to enhanced precipitation in the NAM region (Douglas 1995; Stensrud et al. 1997; Zehnder 2004). However, Wallace et al. (1999) found that such surges do not necessarily precede significant convective outbreaks in central Arizona. This suggests other important forcing mechanisms play a role in modulating monsoon-related convection. Upper level divergence is generally enhanced near and south of the subtropical high (Higgins et al. 1997), while Watson, et al. (1994) found that convective "bursts" were more likely when the upper level subtropical ridge axis was

shifted to the north, placing areas to the south in moist tropical easterlies. This suggests upper level forcing mechanisms are probably just as important in enhancing convection as other well-known mechanisms such as Gulf of California moisture surges. Keenan and Brody (1988) describe upper level troughs amplifying equatorward and enhancing monsoonal convection in Australia.

In 2003 and 2004, both lower- and upper-tropospheric features were intensely monitored in conjunction with the North American Monsoon Experiment (NAME). The purpose of this eight year experiment is to improve the ability to forecast monsoon-related precipitation on temporal scales ranging from a few hours to interannually (NAME Science Plan 2004). A Forecast Operations Center (FOC) was created to provide daily weather forecasts during the NAME 2004 Field Campaign. NAME planners used the forecasts to optimize the allocation and deployment of aircraft and of frequent rawinsonde launches. During the 2003 practice exercise, forecasters realized that numerous upper tropospheric circulation systems not only passed frequently across the NAM region, but they also played a significant role in modulating the development of Mesoscale Convective Systems (MCSs). These upper level systems originated in a variety of locations and formed in response to a variety of forcing mechanisms in both the tropics and polar westerlies. Because these features generally moved westerly underneath the subtropical ridge, they were broadly referred to as "inverted troughs." These circulation systems increased the forecast challenge because they generally developed and/or moved across areas that are generally lacking in upper air rawinsonde data, particularly the Gulf of Mexico and the coastal eastern Pacific.

2. TRACKING THE PROPOSED FORCING MECHANISM

During the NAME practice forecast period in 2003 and the NAME Field Campaign in 2004, the FOC sequentially numbered and tracked these upper level inverted troughs as they interacted with the monsoon flow regime. Figure 1 and Table 1 show the tracks and dates of these upper level circulation centers in 2004. A majority of these features originated over the Gulf of Mexico. This is a known genesis area for cold upper level lows associated with the Tropical Upper-Tropospheric Trough (TUTT). Whitfield and Lyons (1992) studied these features in depth and concluded that they were a significant source of heavy precipitation

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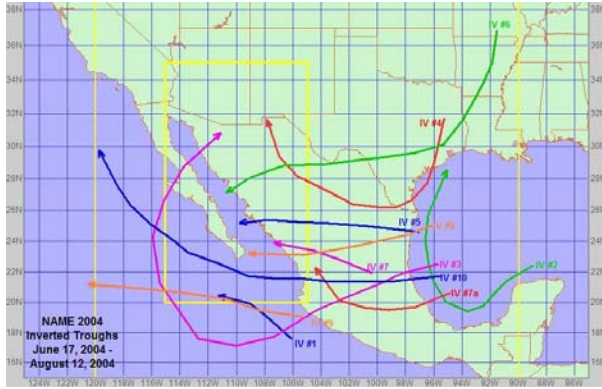


Figure 1: Inverted trough tracks from NAME 2004 Field Campaign. The tracks were determined by inspection of water vapor satellite imagery. In one case, the FOC did not detect one of the inverted troughs, so it was numbered in post-analysis (IV# 7A). In another case, the FOC numbered an inverted trough, but it veered away from the NAM region as it was captured by a short wave in the polar westerlies (IV#2).

| Inverted Trough (IV#) | Start | End |
|-----------------------|----------|-----------|
| 1 | June 17 | June 20 |
| 2 | June 18 | June 21 |
| 3 | July 5 | July 10 |
| 4 | July 8 | July 13 |
| 5 | July 15 | July 18 |
| 6 | July 20 | July 25 |
| 7 | July 29 | July 31 |
| 7a | July 30 | August 2 |
| 8 | August 2 | August 4 |
| 9 | August 7 | August 10 |
| 10 | August 7 | August 12 |

Table 1: Inverted trough formation and dissipation dates in 2004 (relating to Figure 1).

over Texas. Kelley and Mock (1982) showed that subtropical upper tropospheric lows in the western north Pacific were characterized by 1) maximum circulation strength near 200mb; 2) maximum upward vertical motion near 300mb; and 3) downward vertical circulation extent to around 700mb. In general they also showed that subsidence and relatively cloud-free areas existed on the northwestern (leading) quadrant and in the circulation core. Whitfield and Lyons (1992) confirmed the Kelley and Mock findings, but also found an area of significant upward motion on the west quadrant of a TUTT cell. They concluded using NMC analyses that the vertical motion was probably orographic in nature. However the movement of the upper level TUTT cell in relation to the subtropical high and monsoon regime farther west could have also resulted in either significant upper level divergence or stretching deformation. The divergence and presumably upward vertical motion could then enhance convection in an area of an upper trough previously thought to be an area of large scale subsidence.

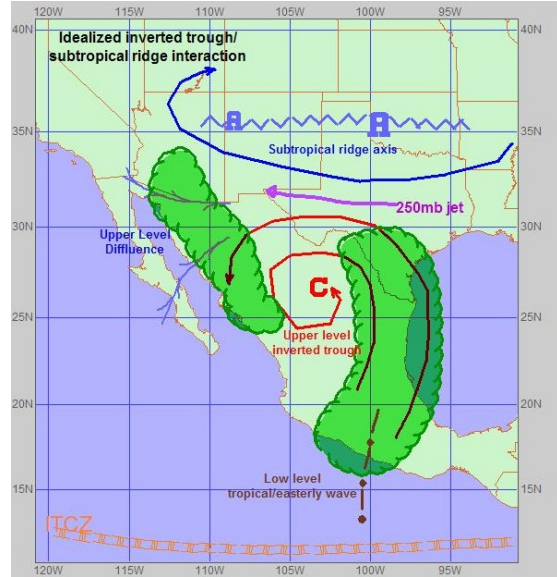


Figure 2: Hypothetical structure of an upper tropospheric (inverted trough) approaching the edge of the subtropical ridge and monsoon flow regime.

A hypothetical conceptual model is presented in Figure 2 in which an upper level closed circulation could approach the southwest edge of the subtropical ridge and create an area of upper level divergence and/or deformation. An event on 2 August 2004 shows how convection with these cold upper level TUTT troughs can occur in both the leading and trailing flanks (Figure 3). Upper air analyses using the NAME dataset depicted two distinct areas of upper level divergence and mid level upward vertical motion on both the leading (west) the trailing (east) quadrants (Figure 4). Both areas were coincident with developing convection that eventually organized into MCSs. In an example from 2003, most of the organized convection actually

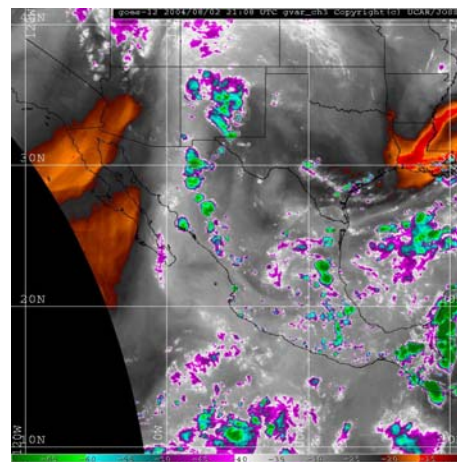


Figure 3: Water vapor satellite image of IV#8 (centered near 21.0N 110.5W), 2108 UTC 2 August 2004. Note convection developing both ahead and behind the IV center.

occurred on the leading (west) quadrant (Figure 5), with little activity on the trailing (east) quadrant. In both 2003 and 2004 there were a few upper level circulation systems which did not originate in the Gulf of Mexico TUTT. Instead, these upper level systems originated in the polar westerlies as short wave troughs. These features tended to drop southeast through the Mississippi Valley, but instead of proceeding into a longwave trough over the eastern U.S., they wrapped underneath the subtropical ridge and became caught in the tropical easterlies. These features also exhibited characteristics of TUTT cells in which convection was typically concentrated on the east flanks of these cells, with a relative minimum in the cold and subsident centers (Figure 6). However, thunderstorms were also frequently noted on the west or northwest quadrants of these upper tropospheric features.

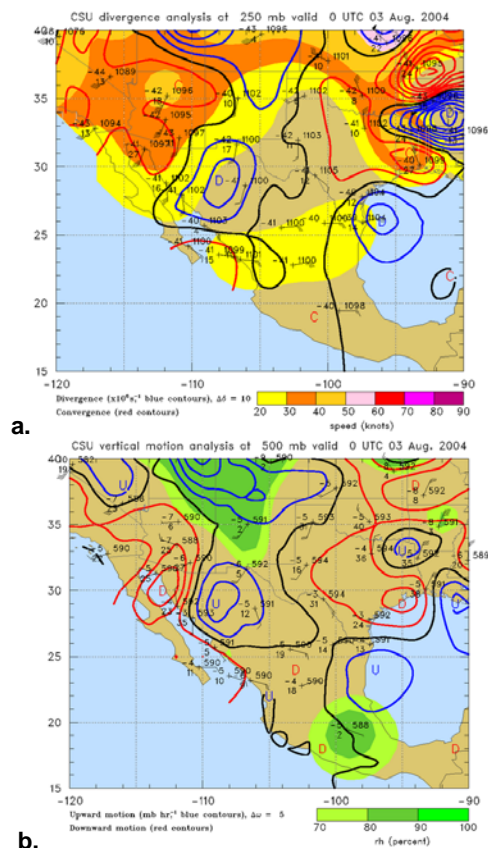


Figure 4: (a) 250mb raw data, isotachs (kts) and divergence (10^{-6} s^{-1}); and (b) 500mb raw data, relative humidity, and omega (mb hr^{-1}) from IV#8 case, 0000 UTC 3 August 2004.

Other smaller-scale circulation centers were observed in 2003 on the south side of the subtropical ridge (Figure 7). These features appeared to form in response to shearing caused by a strong tropical easterly jet (Figure 8). These also appeared to aid in monsoon-related thunderstorm development. However it is not immediately clear if the large scale dynamics interactions are similar to what is typically observed with TUTT cells.

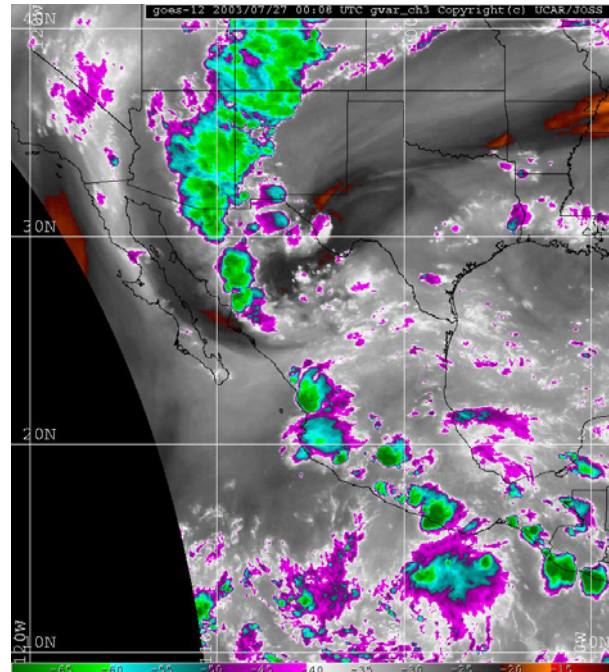
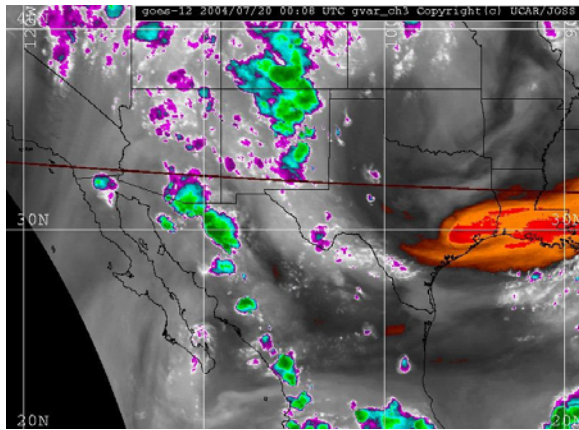


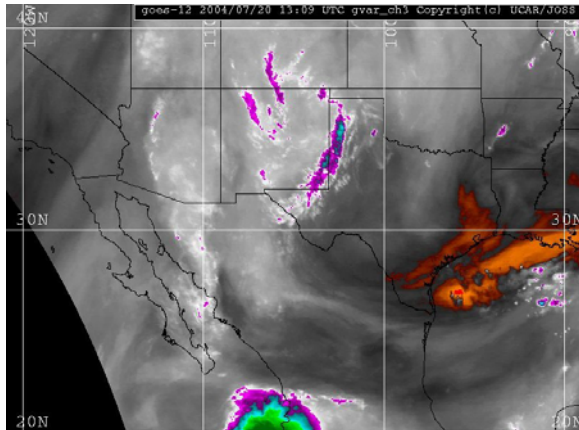
Figure 5: Water vapor satellite image of inverted trough (IV#8) during NAME 2003 Practice Exercise 27 July 2004, 0008 UTC

3. SUMMARY

These preliminary results from the NAME Field Campaign suggest a probable synoptic-scale mechanism for modulating monsoon-related convection in the North American Monsoon region. As implied in previous works, these mechanisms are rooted in the upper levels of the troposphere. These upper level inverted troughs, though originating from a variety of locations and caused by a variety of mechanisms, appear to mimic the dynamics characteristics of upper lows originating from the mean Gulf of Mexico Tropical Upper Tropospheric Trough (TUTT cells). However, as these upper tropospheric systems interact with the monsoon regime, the conceptual model of where convection is likely to form may need to be altered to account for the location of the subtropical ridge and monsoon flow regime. It appears that when these upper level features interact with the North American Monsoon, both leading *and* trailing portions of these upper level systems can play a critical role in initiating and organizing convection into MCSs. The interactions are complex and will require considerable investigation to compare the cause and effect of these upper level features with respect to the monsoon flow regime. The enhanced NAME upper air dataset that was deployed in an area that is typically data-sparse may offer new insights into how these complex interactions evolve, and in turn increase the predictability of monsoon-related convective outbreaks farther in advance.



a.



b.

Figure 6: Water vapor imagery from (a) 0008 UTC and (b) 1309 UTC, 20 July 2004. Weak upper level disturbances over Missouri, Arkansas, and east Texas become trapped under the subtropical ridge and begin to consolidate into IV#6.

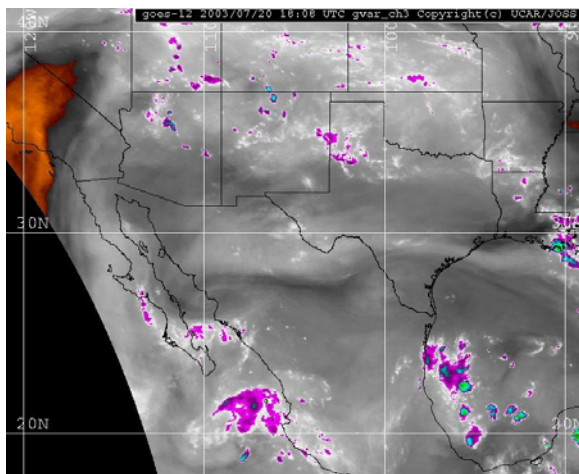


Figure 7: Water vapor imagery showing smaller scale vortices underneath subtropical ridge, 1808 UTC 20 July 2003.

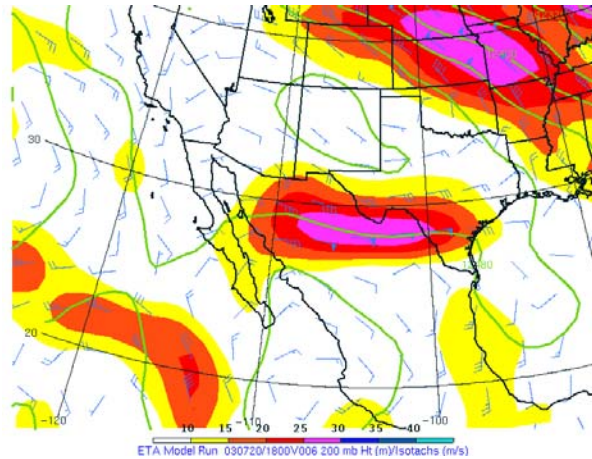


Figure 8: Eta H+06 hour 200mb forecast of heights (m), wind vectors (m s^{-1}) and isotachs (m s^{-1}), valid 1800UTC 20 July 2003. Note location of the subtropical easterly jet in relation to the small scale vortices.

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