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# ADVANCES IN FORECASTING MONSOONAL UPPER TROPOSPHERIC LOWS: POTENTIAL VORTICITY DISTURBANCES

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## 1. INTRODUCTION

During the North American Monsoon Experiment (NAME) in 2004, quasi-stationary or westward-moving upper tropospheric lows were recognized as a key modulator of monsoon-related convection. In an attempt to build on considerable past research on these upper tropospheric lows over the Gulf of Mexico, tropical Atlantic, and tropical Pacific, Pytlak, et al. (2005) proposed a conceptual model for these features in a differential vorticity and mass conservation framework as they entered the North American Monsoon flow regime. While it adequately described some of the underlying atmospheric processes, it had one key shortcoming. The hypothesis assumed the systems were quasi-barotropic, and thus it did not include the possibility of baroclinic evolution or the development of vertical wind shear. Finch and Johnson (2010), though, showed convincingly that these upper lows not only induce many of the atmospheric responses predicted by the original hypothesis, but they also induce mid level shear on the west flank of these disturbances. This suggests that alterations in the lower levels of the troposphere induced by the disturbances may be more important that the impacts these systems impart on the upper troposphere.

Building on this and other more recent research, this paper proposes an update to the conceptual model using a potential vorticity and dynamic tropopause framework. It also suggests diagnostic and forecasting tools which can be used to better predict the likelihood, coverage, and location of convective outbreaks associated with these upper lows as they interact with the monsoon flow regime.

## 2. POST-NAME CLIMATOLOGICAL AND SYNOPTIC RESEARCH

Beida, et al. (2009) found that westward moving upper-level disturbances generally enhance monsoon-related convection and disrupt the usual diurnal convective cycle. Thunderstorms tend to develop earlier in the day, grow more organized, propagate farther west into the lower deserts, and persist well past the diurnal maximum. This convective enhancement and diurnal pattern disruption, in addition to findings from Finch and Johnson (2010), implies that additional forcing induced by the upper low is aiding in thunderstorm organization and upscale growth.

To account for the possibility of baroclinic processes operating in the moist, conditionally unstable monsoon environment, Sukup, (2010), Melino (2010) and Sukup, et al. (2010) evaluated these systems using dynamic tropopause (DT) diagnostics. This approach also conveniently allows for disturbance strength and depth to be quickly ascertained with respect to the surrounding environment. Because the DT can be evaluated in an environment-relative sense using potential vorticity diagnostics, there is less of a need for operational forecasters to view a series of constant height charts which may not adequately capture the system's kinematic or thermal structure.

Recasting these lows in a DT framework, some components of the original hypothesis are confirmed. The vast majority of these systems have relatively cold mid level cores, with convective enhancement more likely on the peripheries of the circulations, especially on the west/leading flank. While convection is also frequently found on the east/trailing flanks, the core of these systems is typically free of strong, organized activity. Most of these upper lows originate in the midlatitudes, and either fracture off the Atlantic Tropical Upper Tropospheric Trough (TUTT), or off a longwave trough over the central or eastern U.S. before traveling west into the monsoon region.

One key finding is that the deeper these systems extend downward into the middle troposphere, the more likely that mid level winds and shear will increase on the west side of low as it approaches the core monsoon region. Figure 1 is a cross-sectional example of how these systems can be viewed using potential vorticity and vertical wind profiles Most of these lows can also be seen in plan view as

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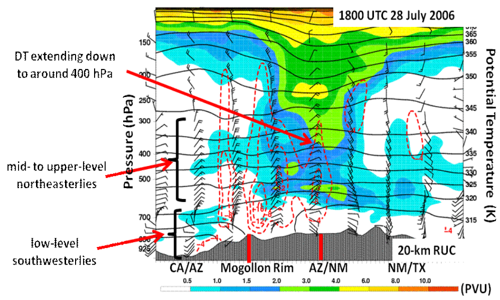


**Figure 1:** Cross section analysis of potential temperature (°K), potential vorticity (PVU), wind (m $s^{-1}$) and upward vertical motion (hPa $s^{-1}$) of an upper level low over Arizona. Data from Rapid Update Cycle (RUC) initialization 1800 UTC 28 July 2006. From Sukup, S. M.S. thesis presentation (2010).

depressions on the 1.0, 1.5 or 2.0 PVU surfaces coincident with the circulation on water vapor imagery.

The more recent research also strongly suggests that systems which extend more deeply into the troposphere (i.e. below 400 hPa), instead of being barotropic as assumed in the initial research in 2005, are at least weakly baroclinic. For example, in case studies by Sukup (2010) and Melino (2010) areas of lower-level quasi-geostrophic forcing, and presumably weak upward vertical motion, are detected ahead of the lows as increased easterly or northeasterly flow induces weak warm advection off higher terrain (Figure 2a). This forcing, while weak, is helpful in lifting conditionally unstable parcels to reach the level of free convection earlier in the day and over larger areas – both near the mountains and in lower elevations. They also found that in stronger systems, quasi-geostrophic forcing actually supported *downward* vertical motion in the 300-200mb layer on the west side of a southward-, or westward-drifting of upper tropospheric lows (Figure 2b), where Pytlak, et al. (2005) typically found 300-200mb divergence and upward vertical motion using purely kinematic calculations from NAME data in 2003 and 2004. This, along with the work from Finch and Johnson (2010), calls into question the relative importance of upper-level divergence in supporting large-scale convective organization, versus the impact deeper disturbances appear to impart on the lower troposphere.

## 3. REVISED HYPOTHESIS AND FORECAST IMPROVEMENTS

The original hypothesis is included in Figure 3, with revised hypothesis proposed in Figure 4. In this revision, we propose a terminology change to "Potential Vorticity Disturbance" which acknowledges that although these systems are rooted at the top of the troposphere, the degree to which they extend into the lower troposphere has critical implications. The deeper these disturbances can extend into the middle

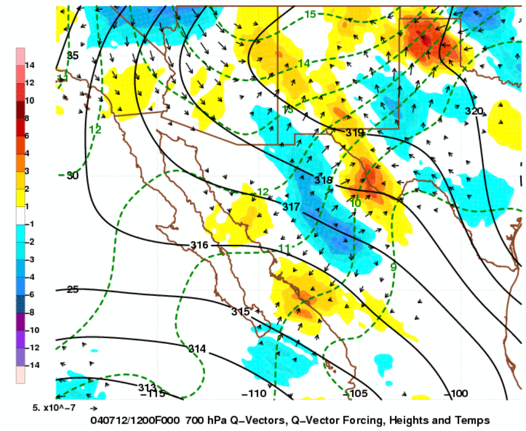


**Figure 2a:** 700mb Q-vectors, Q-vector forcing (shading in $10^{-12}$ Pa $M^{-2}$ $s^{-1}$), heights (m) and temperature (°C) from a westward-moving PVD over northwest Mexico, 1200 UTC 12 July 2004. Note the weak downward forcing on the west side of the PVD.

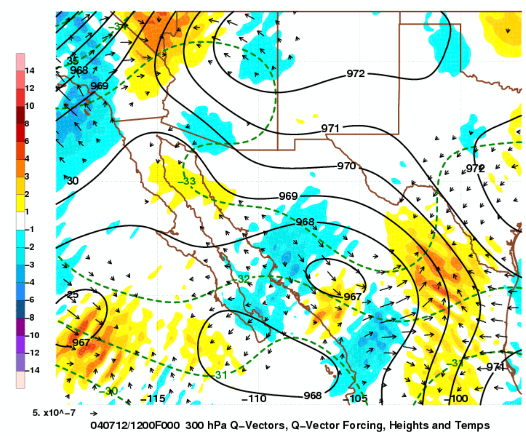


**Figure 2b:** Same analysis as Figure 2a, but at 300 hPa.

troposphere, the more likely they are to increase mid level flow, increase lower level vertical shear, and induce lower-level QG forcing. All of these impacts on the lower troposphere in turn help to support, enhance, and maintain organized monsoon-related convection above and beyond the climatological temporal and spacial distribution. This agrees with companion work by Bosart et al. (2011) which further explains application of this hypothesis in a potential vorticity framework.

We emphasize that for these potential vorticity disturbances to organize convection, the atmosphere must be sufficiently moist and unstable to support convection. This is a frequent occurrence within the monsoon regime, but is not a given, particularly as the large scale monsoon circulation pattern develops at the beginning of the season, or after a significant intraseasonal monsoon break.

Building on the refined and improved hypothesis, diagnostic and forecast tools using existing numerical weather prediction models can be offered. DT charts

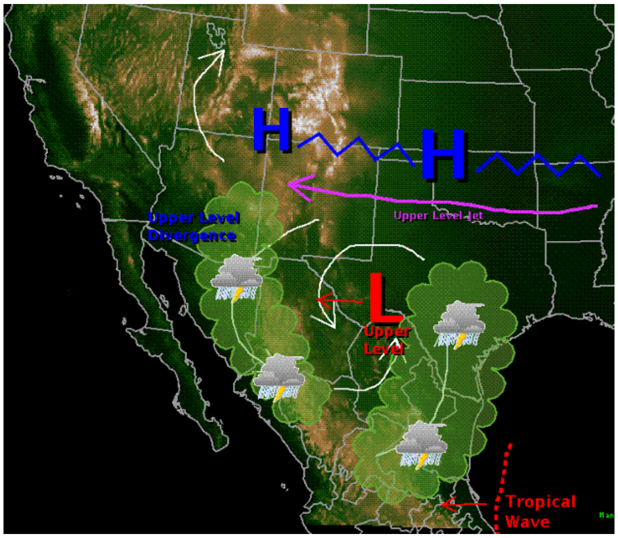


**Figure 3:** Original upper tropospheric low hypothesis, from Pytlak, et al. (2005).

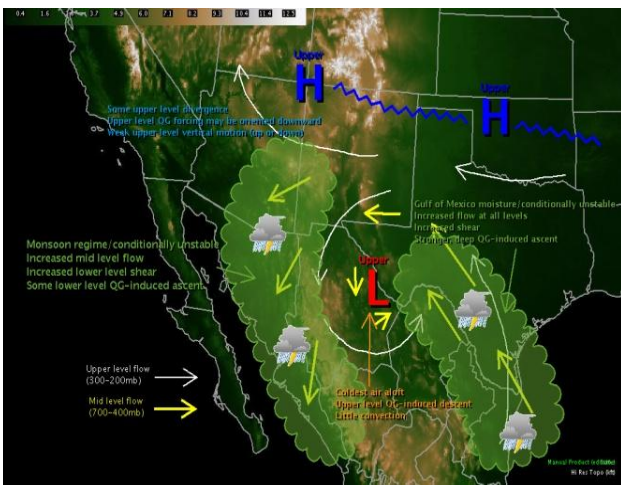


**Figure 4:** Revised conceptual model of monsoonal Potential Vorticity Disturbances (PVD).

developed at University of Albany/SUNY are easily accessed and interpreted. (http://www.atmos.albany.edu/facstaff/rmctc/DTmaps/animSelect.php). Similar charts evaluating 1.0, 1.5and 2.0 Potential Vorticity Units (PVU) on potential temperature surfaces, in conjunction with traditional thermodynamic, Q-vector and vertical shear diagnostics, can be generated using common meteorological software (Figure 5). In this framework, it is easier to quickly assess system depth and intensity, and the degree to which the low will affect deep layer stability. If mid level flow increases in response to the potential vorticity disturbance, an increase in vertical shear in the cloud bearing layer is likely, along with an increase in convective coverage, organization, and intensity.

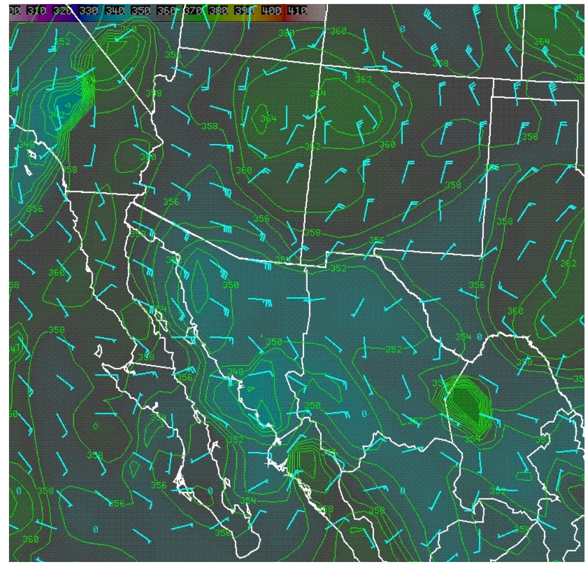

**Figure 5:** Example of H+66 GFS model forecast for PVD over southern Sonora, Mexico. Included are potential temperature (°K) of the 1.5 PVU surface highlighting the expected location of the upper low, and 700-500mb bulk shear vectors (kts).

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