University: University at Albany/SUNY (UA)

Name of University Researcher Preparing Report: Lance F. Bosart, Tim Melino and Scott Sukup

NWS Office: Storm Prediction Center, Norman, OK and NWS/WFO Tucson, AZ

Name of NWS Researcher Preparing Report: Steve Weiss, Russell Schneider, Erik Pytlak, and Jon Racy

Project Title: Transient Upper-level Disturbances and their Influence on Warm Season Mesoscale Convective Systems Over the Southwestern United States

Partners or Cooperative Project: NA06NWS4670013 UCAR Award No.: S07-66811

Date: 3 September 2010 (Final Report)

SECTION 1: SUMMARY of PROJECT OBJECTIVES

1.1: UA

The focus of the research was on determining what role transient subsynoptic-scale and mesoscale upper-level potential vorticity disturbances (PVDs) play in triggering severe weather-producing mesoscale convective systems (MCSs) over the Southwest (and Arizona in particular) during the North American summer monsoon. The research had three components: 1) a climatological analysis of PVDs, 2) a composite and case study analysis of PVDs associated with severe weather-producing MCSs, and 3) WRF model simulations of selected PVD-triggered severe weather-producing MCS events. The research was done in close collaboration with Storm Prediction Center (SPC) meteorologists Steve Weiss, Jon Racy, and Russell Schneider and NWS WFO TUS meteorologist Erik Pytlak. The project provided research support for three UAlbany students, Jamie Matusiak, Tim Melino, and Scott Sukup, for their M.S. theses. Matusiak completed her M.S. thesis in 2009. She is now an intern at NWS WFO Charleston, WV. Melino and Sukup completed their M.S. degrees in August 2010. Research accomplishments were summarized in our previous six-month reports and will not be repeated here. Details of the student research contributions can be found in the following web links contain the Matusiak, Melino, and Sukup M.S. theses. An additional link contains access to selected PowerPoint presentations by the students and PI Bosart at AMS/NWA conferences, the SPC, and the 2010 NWS PHX Weather Workshop.

Jamie Matusiak Completed M.S. Thesis:

http://www.atmos.albany.edu/student/matusiak/thesis

Tim Melino Completed M.S. Thesis and Presentations:

http://www.atmos.albany.edu/student/melino (click on master's presentation 2010)

Scott Sukup and Lance Bosart Presentations:

http://www.atmos.albany.edu/student/sukup/index.html (click on presentations)

Scott Sukup Completed M.S. Thesis:

http://www.atmos.albany.edu/student/sukup/index.html (click on thesis)

1.2: NWS/WFO-TUS

The project's objective to better define, track, and ascertain the potential impact of transient upper tropospheric lows interacting with the monsoon flow regime has been met. This project has not only given us a better understanding of system structure in a potential vorticity framework, but it has also identified tools that operational forecasters can use to better predict which PVDs are more likely to enhance MCS activity than others. The project also partially resolved issues regarding where these systems originate, and whether the original hypothesis proposed in 2005 was correct in that the vast majority of these systems are cold-core in nature, similar to TUTT-cells (which are a large subset of these PVD anomalies). The work also has contributed to the larger body of research that clearly identifies these lows as the most predominant modulator of convective outbreaks in the North American Monsoon regime, and can significant disrupt the usual convective diurnal cycle.

Using the published works and presentations identified in this report, we have disseminated the findings widely to NWS field offices in the southwest U.S., media, academia, and US Air Force Operational Weather Squadrons. During the 2010 monsoon season, forecasters have been using dynamic tropopause and potential vorticity cross sections to ascertain system depth and the quality of Numerical Weather Prediction (NWP) model initialization, and have been using these diagnostics to adjust Probability of Precipitation (PoP) forecasts, Quantitative Precipitation Forecasts (QPF), and qualitative forecast wording/verbiage to describe the potential for convective enhancement and severe thunderstorm outbreaks as these systems approached and traversed the monsoon region.

Finally, the work done with this COMET project, in concert with other post-North American Monsoon Experiment research, is leading to a significant revision of the original upper tropospheric low hypothesis. The revision is being prepared for the AMS Weather and Forecasting Conference to be held in Seattle in January 2011. Lance Bosart, Tim Melino and Scott Sukup are all co-authors on this significant revision.

1.2: SPC

Operational forecasting of severe convective weather in association with the Southwest Monsoon has historically been very difficult, owing in part to weak dynamic forcing mechanisms when viewed in a traditional constant pressure perspective, as well as limited knowledge concerning factors favoring upscale growth of convective elements into MCSs producing organized significant weather. The project has identified and classified upper tropospheric disturbances using a potential vorticity/dynamic tropopause (PV/DT) conceptual framework, in order to determine if a relationship exists between PV disturbances and subsequent MCS development. Further, it is valuable for forecasters to be able to discriminate between MCSs that have higher probability to produce severe weather and those producing primarily heavy rain/flooding, so examination of the ambient thermodynamic and kinematic environment in conjunction with Storm Data events was utilized to address these topics. The use of operationally available observational data (e.g., satellite imagery, soundings) and model data (such as GFS and RUC analyses, WRF forecasts) in the research makes the findings particularly applicable to SPC operations.

SECTION 2: PROJECT ACCOMPLISHMENTS AND FINDINGS

2.1 UA

Thesis titles and abstracts are included for Jamie Matusiak, Tim Melino, and Scott Sukup in this section (web links to the theses are included in section 1.1). The abstracts are meant to be a summary of our principle research findings. Details are contained in the aforementioned web links.

Jamie Matusiak M.S. Thesis Title:

Upper-level Potential Vorticity Disturbances and their Impact on Warm Season Southwest United States Severe Weather (2009)

Abstract

The southwestern United States (US) receives the majority of its precipitation between July and mid-September from mesoscale convective systems (MCSs) that can also produce severe weather and/or flash floods. However, these MCSs that are responsible for the severe weather in the southwest US are extremely difficult to forecast. Although previous studies have shown that upper-level potential vorticity disturbances (PVDs) are an important factor in severe weather forecasting, to date applications of "PV thinking" to the southwestern US severe weather problem have been limited. The purpose of this study is to use the results of a subjective analysis of upper-level PVDs that traversed the Southwestern US during the 2004, 2007, and 2008 warm seasons to construct a limited-PVD climatology and to help determine the role that upper-level PVDs play in creating favorable environments for severe weather events by means of case studies. The 2004 warm season was included in the investigation because results from the 2004 North American Monsoon Experiment provided additional data not available in 2007 and 2008.

Individual PVDs were identified on dynamic tropopause (DT) maps created from NCEP 0.5° GFS gridded analyses for 2007 and 2008. DT maps were also created for 2004 from NCEP 1.0° GFS gridded analyses because 0.5° GFS gridded analyses were not available for 2004. A PVD on a DT map is manifest by an area of lower potential temperature (higher pressure) relative to the surrounding environment. PVD events are individual PVDs that entered the Southwest from their point of origin until they exited the Southwest or dissipated within the Southwest, and a limited-PVD climatology was constructed for the three warms season by subjectively tracking these PVD events. The climatology also included information on PVD type (e.g., PV trough, PV tail, or PV fracture), PVD duration within the Southwest, and overall PVD lifespan. The limited-PVD climatology revealed that at least one PVD was present within the Southwestern US every day during the warm season.

A temporal statistical analysis was performed on the limited-PVD climatology to visualize the number of hours PVD events, PV troughs, PV tails, and PV fractures spent within the Southwestern US domain and determine the amount of inter-annual variability that was

associated with PVD events, PV troughs, PV tails, and PV fractures. A spatial statistical analysis was performed on the limited-PVD climatology to determine how PVDs moved through the Southwestern US domain, which showed that PVD movement was directly related to the location of the upper-level subtropical anticyclone. PVDs were also compared to Storm Prediction Center severe storm reports and National Climatic Data Center Storm Data to ascertain what percentage of PVDs were associated with severe weather and what percentage of severe storm reports were associated with PVDs.

Two case studies and two null cases reveal what environmental characteristics were necessary for Southwestern US severe weather to occur. One null case was a case in which the presence of a PVD did not result in severe weather, while the second null case was a case where severe weather occurred with no obvious relation to a PVD. In the two cases and one null case where severe weather occurred with no obvious relation to a PVD, the convection followed the typical Arizona convective cycle where convection initiates over the eastern Arizona high terrain, is pushed off of the high terrain by strong 500-hPa steering-level winds toward the west Arizona deserts, and grows upscale over the deserts. The results from these representative case studies are shown to demonstrate how PVDs influenced convective development. A conceptual model for Southwestern US severe weather is presented.

Tim Melino M.S. Thesis Title:

Influence of Upper-Level Potential Vorticity Disturbances on Warm Season Convective Organization in the Desert Southwest (2010)

Abstract

Transient upper-level subsynoptic-scale and mesoscale potential vorticity disturbances (PVDs) can aid development of severe weather-producing mesoscale convective systems (MCSs) over much of the Southwest during the North American Monsoon (NAM). Severe weather development over the southwest U.S. during the NAM can often be difficult to forecast in the presence of weak dynamical forcing over complex terrain, where deep convection responds primarily to the diurnal heating cycle. Over Arizona, MCSs tends to develop along two distinct pathways. The first MCS development pathway occurs when convection develops over the higher terrain (Mogollon Rim) of central Arizona. This terrain-induced convection can organize into southwestward-moving MCSs during the evening and overnight hours. These MCSs are often accompanied by severe weather and reach their peak intensity over the lower elevation valley locations near the Tucson and Phoenix metropolitan areas. The second MCS development pathway occurs when convection develops over higher terrain to the east of Tucson and Phoenix during the afternoon. Deep convection that follows this second pathway may organize into MCSs that can become severe shortly after sundown as they migrate westward into the lowland valleys to the west of Tucson.

The purpose of this work is to use the results of detailed case studies to show how transient subsynoptic-scale and mesoscale PVDs in combination with regional terrain act to provide a favorable environment for the development and maintenance of severe MCSs as a function of the MCS pathways identified above. A dynamical tropopause (DT) and potential

vorticity (PV) analysis perspective is adopted for investigative and diagnostic purposes to better identify these MCS-organizing PVDs. A critical finding is that upper-level northeasterly winds located to the west of PVDs, when superimposed on diurnally driven low-level westerly flow in the presence of adequate moisture, can provide sufficient deep-layer vertical wind shear to sustain organized MCSs that form over higher terrain and enable them to become severe as they propagate southwestward toward lower elevation urban corridors in the Phoenix and Tucson metro areas.

The results from high-resolution (4 km) WRF-ARW model numerical simulations of severe weather-producing MCSs illustrate the physical processes associated with MCS development over complex terrain in environments of weak dynamical forcing and show the importance of subsynoptic and mesoscale PVDs to MCS formation, organization, and intensification. Additionally, coarser resolution model runs (~25 km) were used to show that the WRF model was capable of predicting the track and timing of westward-propagation PVDs that were associated with severe weather from 84-h forecasts

Scott Sukup M.S. Thesis Title:

The Influence of Upper-Level Potential Vorticity Disturbances on Convection and Severe Weather in the Southwest (2010)

During the North American monsoon (NAM) season, the Southwest experiences episodes of severe weather and flash flooding produced by mesoscale convective systems (MCSs). These severe weather and flash flooding events can be difficult to forecast because they often occur in regions of weak dynamical forcing over complex terrain. This thesis investigates the relationship between weak dynamical forcing associated with upper-level potential vorticity disturbances (PVDs) and the development of severe weather-producing MCSs. PVDs are cold-core upper-level cyclonic circulations that are trackable on the dynamic tropopause (DT).

An important forecast challenge during the NAM is distinguishing between days that will and will not have severe weather-producing MCSs in similar large-scale environments. A PVD climatology for the Southwest was completed for the dates 1 June – 15 October and the years 2004-2009 to address this challenge. The PVD climatology demonstrates which subset of PVDs are most likely to produce severe weather based upon their location and direction of motion through the Southwest, PVD strength and associated deep-layer wind shear, along with the amount of environmental moisture and convective available potential energy (CAPE). Five case studies illustrate the results of the PVD climatology and the dynamics associated with PVD-related MCSs and severe weather.

Quasi-stationary and westward-moving PVDs located east of Phoenix, AZ are associated with low-level quasi-geostrophic (QG) forcing for ascent to the south and west of the Mogollon Rim. This low-level QG forcing for ascent arises from warm air advection associated with northeasterly winds on the northwestern flank of the PVD as warm air at low-levels is advected southwestward off the semi-arid elevated terrain. Differential cyclonic vorticity advection can also contribute to low-level forcing for ascent for the strongest PVDs. Overall; QG diagnostics proves to be a useful tool to evaluate the potential of a PVD to trigger severe weather over

Arizona. With sufficient low-level moisture and a lowered level of free convection, very little low-level forcing for ascent is needed to intensify convection.

We next highlight a few results to provide an overview of the principle findings from the research. The figures that follow are taken from Scott Sukup's M.S. thesis (available at the above link). A PVD climatology was constructed for 2004-2009 to take advantage of the availability of 1.0 deg NCEP/GFS analyses. PVDs were tracked if they entered the Southwest US domain, a rectangular box centered on Arizona that extended from 25-39 N and 119-103 W, and were present for at least two consecutive 6 h analysis times. The interannual variability of in-domain PVDs, and PVD days is shown in Sukup Fig. 2.5. Considerable interannual variability of PVDs and PVD days is apparent with a peak in 2007. The NAME year (2004) was quite "ordinary" in this context. The intraseasonal variability in the number PVD days is strongly peaked toward the second half of July (Sukup Fig. 2.7). The origin points of all 44 PVDs (equating to 95 PVD days in the Southwest US domain), color-coded by the number of severe weather reports received, is shown in Sukup Fig. 2.8. PVDs associated with severe weather in the Southwest US domain originate preferentially to the south of Arizona and are more likely to form to the east of Arizona.

For a severe weather report to be associated with a PVD, the report had to be within 400 km of a closed 350 K contour (PV maximum) on the dynamic tropopause and downstream of a transient PVD. Of the 857 warm season severe weather reports received from 2004-2009, 157 (18.0%) could be directly attributed to a PVD. The 44 PVDs were further stratified on the basis of the number of severe weather reports received as a function of whether the PVDs were westward-, eastward-, or northward-moving. A histogram showing the percentage of PVD-days having a PVD associated with severe weather greater than or equal to the number of reports for westward-moving (type A), eastward-moving (type B), northward-moving (type C) PVD days and non-PVD days is shown in Sukup Fig. 2.10. The stratification of PVD days by their direction of movement and number of severe weather reports reveals that the highest number of severe weather reports in Arizona on a given day is likely to occur in conjunction with westward-moving PVDs. Although severe weather reports can occur on non-PVD-days, they tend to be fewer in number. For additional perspective, note that 6 out of the 37 (16.2%) westward-moving PVD-days (type A) had at least six severe weather reports between 1 July and 15 September whereas only 24 out of the 368 non-PVD-days (6.5%) had at least six severe weather reports over the entire severe weather domain. Thus, it is more than twice as likely for a westward-moving PVD day to produce $\geq$6 reports compared to a non-PVD day. This is very relevant for SPC outlook and watch forecast products.

A critical finding from our collective analyses was that westward-moving PVDs favored the establishment of deep northeasterly and easterly shear over Arizona. Northerly and northeasterly flow in the middle and upper troposphere to the west of westward-moving PVDs when superimposed above diurnally driven late afternoon and evening low-level westerly flow created 25-40 kt deep layer northeasterly shear profiles over Arizona. These shear magnitudes were supportive of MCS formation and organization in response to the diurnal heating cycle over the Mogollon Rim of central Arizona and the highlands of southeastern Arizona. These shear directions were supportive of organizing MCSs moving southwestward and westward off the higher terrain toward the populated lowland valleys of southern and southwestern Arizona. MCSs that initiated under these circumstances can contain embedded supercells with attendant potential to produce severe weather as they moved toward lower elevations and encountered increasingly more moist and unstable air. In multiday events, severe weather would be most common on the first day while flash flooding would be more common on subsequent days after the boundary layer stabilized and moistened, especially when tropical moisture was present from decaying tropical cyclones in the eastern Pacific. Schematic figures summarizing our results are shown in Sukup Figs. 4.4a, b.

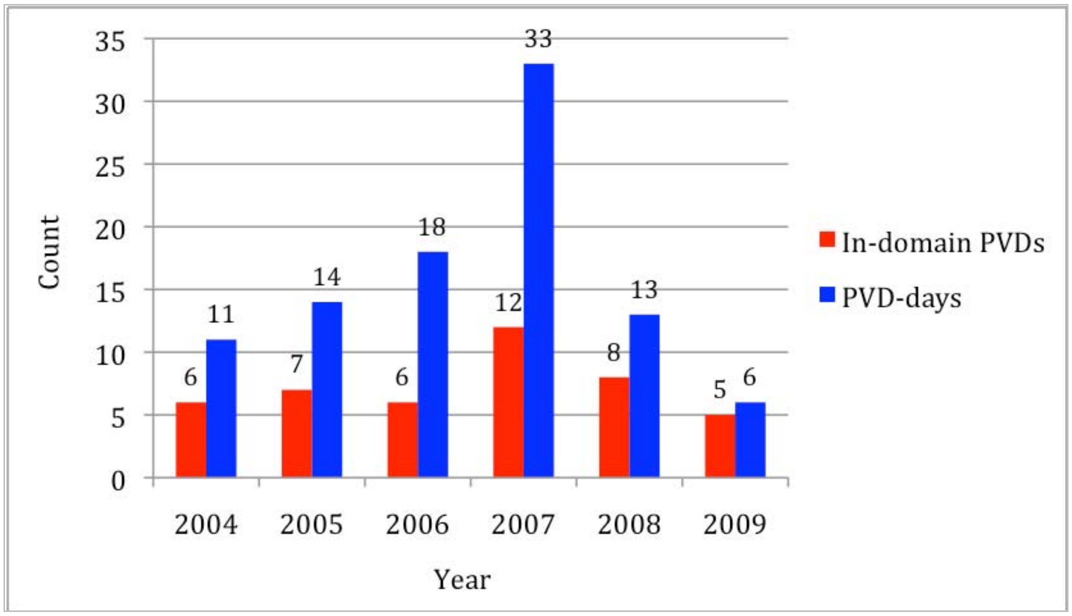

Fig. 2.5. Histogram showing the interannual variability of the number of in-domain PVDs and resultant PVD-days for the 6 years included in the PVD climatology (2004-2009).

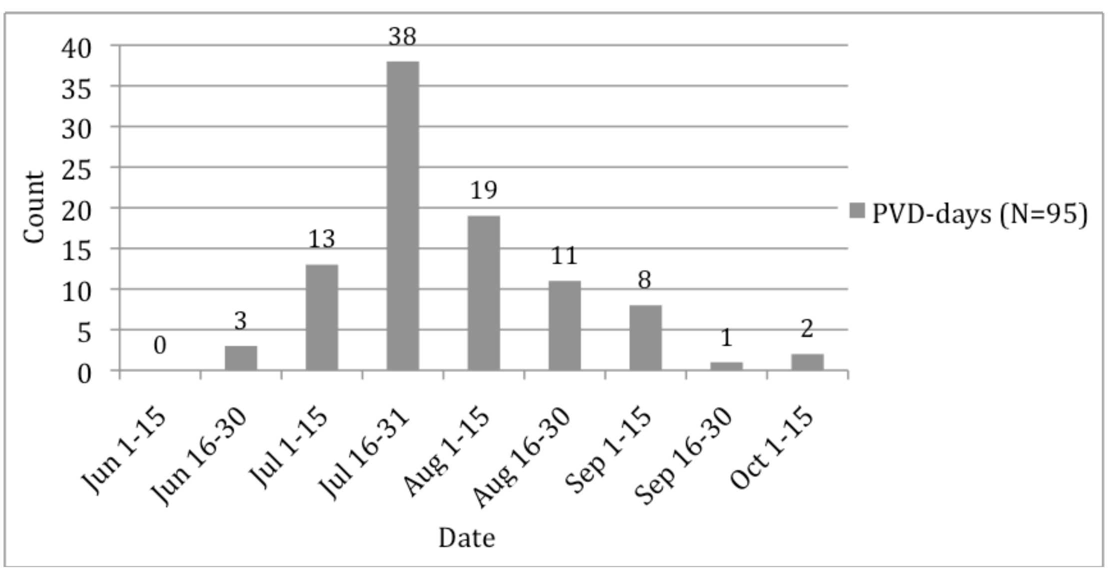

Fig. 2.7. Histogram showing the intraseasonal variability of the number of PVD-days.

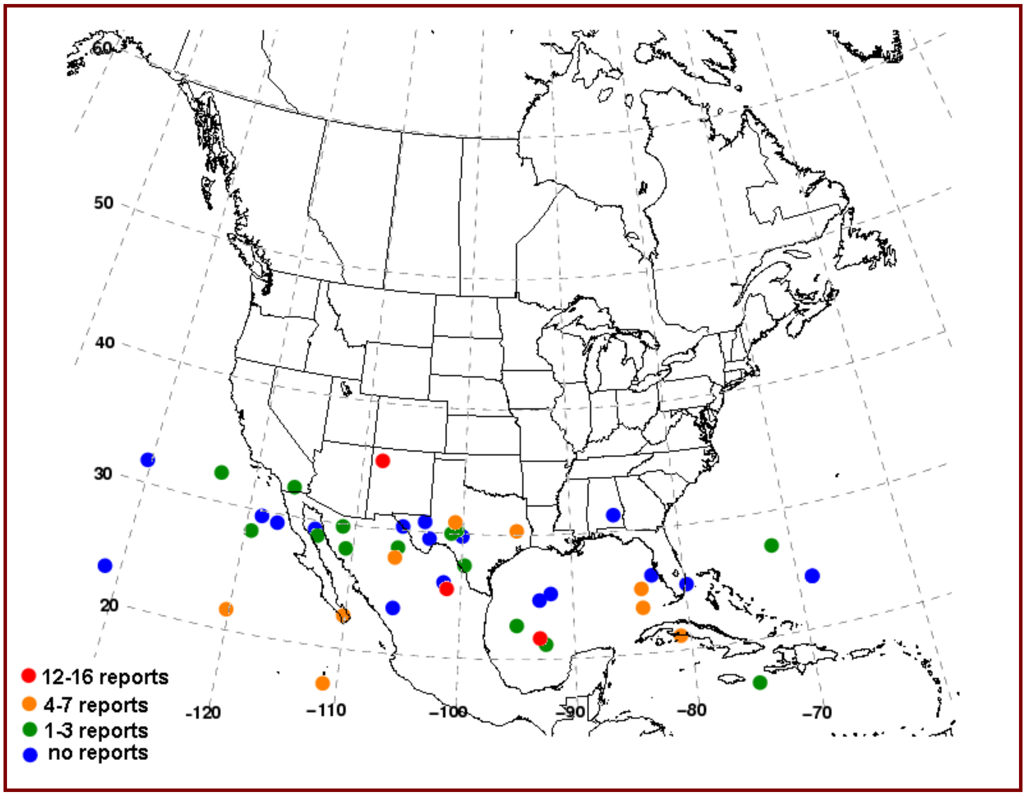

Fig. 2.8. The points of origin for all 44 PVDs included in the PVD climatology. The dots indicate the point of origin for each PVD and are color coded according to the largest severe weather event they produced on a given PVD-day.

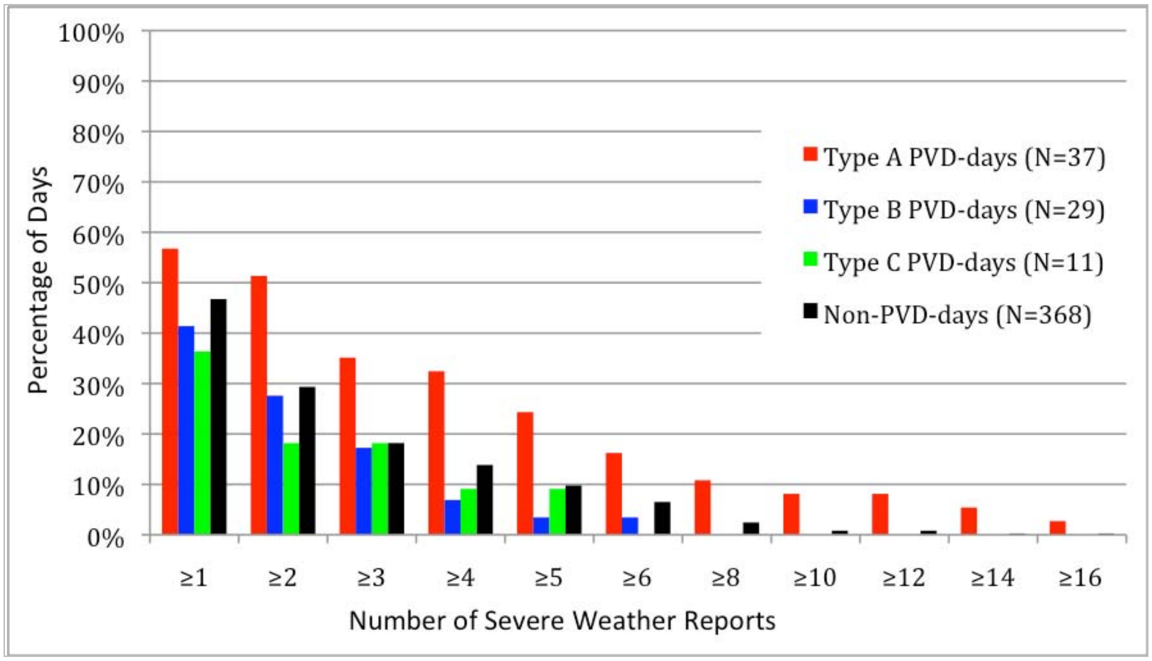

Fig. 2.10. Histogram showing the percentage of PVD-days having a PVD associated with severe weather greater than or equal to a specified number of reports for Type A (red – westward moving), Type B (blue – eastward moving), and Type C (green – northward moving) PVD-days. Also shown is the percentage of days between 1 July and 15 September when a PVD was not in-domain (non-PVD-days), with a number of severe weather reports greater than or equal to a specified number of reports over the entire severe weather domain (black).

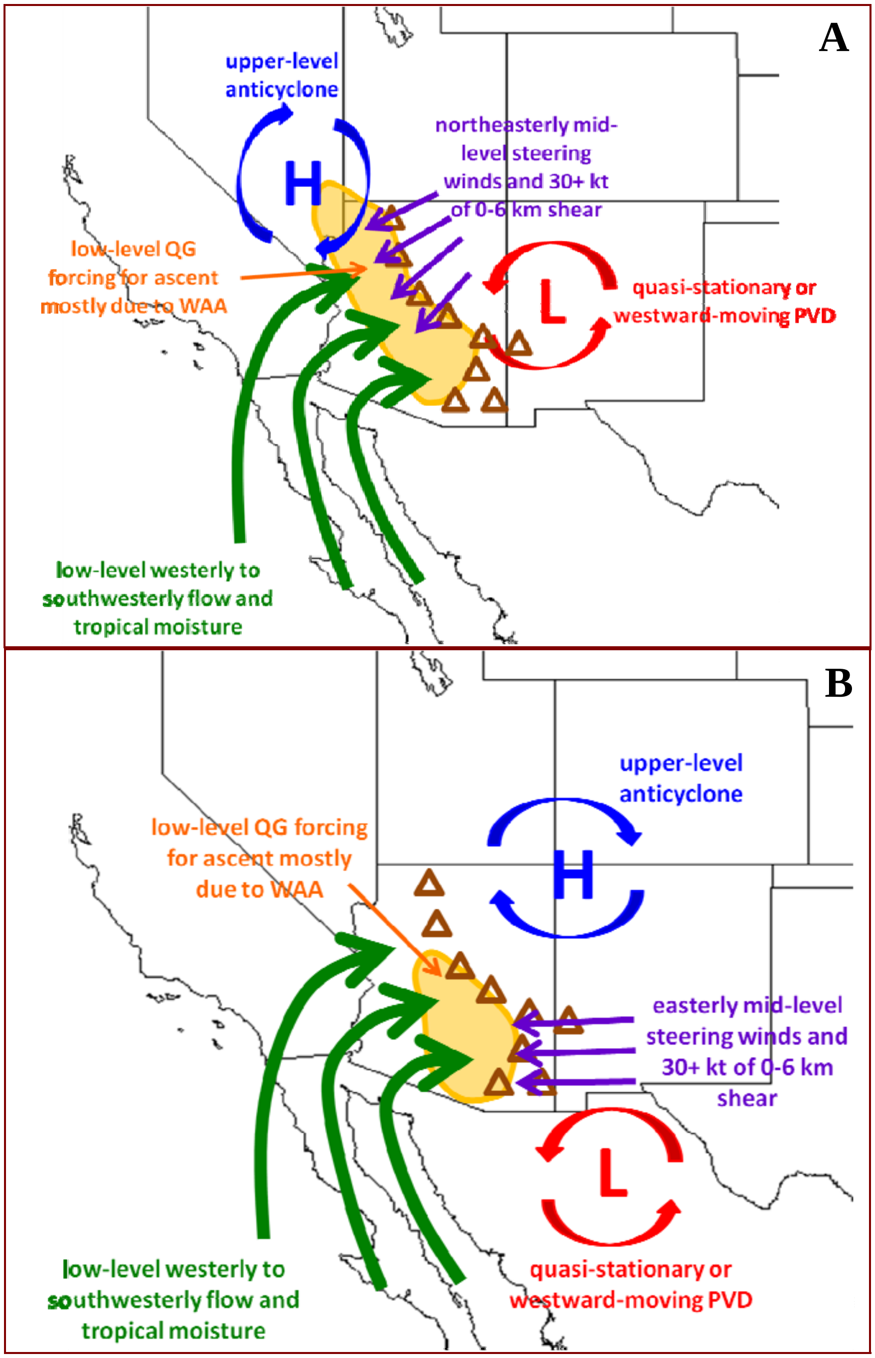

Fig. 4.4. Idealized schematics for PVD-related severe weather events in the southwest United States for a) northeasterly shear environments and b) easterly shear environments. See text for details.

2.2: NWS/WFO TUS

From the NWS Tucson perspective, there were several key findings from these works:

- Upper tropospheric lows (occasionally referred to as inverted troughs) are more readily tracked and diagnosed in a potential vorticity and dynamics tropopause framework
- System depth and intensity trends can be more readily monitored in this framework
- If these systems penetrate below about 400mb, cloud bearing shear is likely to increase, which in turn increases the risk of convective organization and maintenance – sometimes well after sunset and into the nighttime hours.
- That the original hypothesis proposed in 2005 was correct in that the vast majority of severe thunderstorm and convective outbreaks occur on the leading edge of these systems. While this enhancement on the leading flanks of these lows cannot be explained in a differential vorticity advection framework alone, these outbreaks are more fully explained in a potential vorticity framework.
- Potential vorticity-based diagnostic tools, many of which are already available in meteorological software packages, can be easily used to forecast system evolution and impacts on thunderstorm development, even in situations where the NWP models may be slow to fully capture these systems.

A concern arose during the project in that some upper tropospheric lows appeared to be missed by the upper air network over Mexico which at the time of the initial research was inactive. This missing data could have hindered researcher efforts to better define these systems or obtain enough cases to increase confidence in any conclusions. This concern, which turned out to be a more limited one than previous feared, was addressed satisfactorily in a companion COMET Partners Project.

2.2: SPC

The project addressed a key forecast challenge from an operational SPC forecasting perspective; namely, identify key synoptic features and physical processes that can lead to improved prediction of MCSs and subsequent hazardous weather threats over the southwest. During the summer monsoon period, SPC is also responsible for addressing very widespread severe weather threats across much of the CONUS, especially east of the Rockies. This requires forecaster knowledge of specific synoptic/mesoscale patterns and processes favorable for deep convection that have differing regional characteristics. The identification and refinement of relevant dynamic features utilizing a PV/DT framework and associated synoptic/mesoscale patterns and physical processes conducive for MCS will allow SPC to better anticipate convective events over the southwest. SPC has developed in-house tools within the N-AWIPS workstation to track PVDs in operational model gridded datasets that may be supportive of subsequent MCS development, and forecasters have access to the DT/PVD “history tracking” web pages produced by UA. For both analysis displays, we will be examining the ability of the new higher resolution (T574) GFS model to resolve and predict PVDs during the warm season. Finally, the interactions between UA and the SPC during this COMET project have resulted in the transfer of applied research knowledge to operations in a most cost-effective and direct manner.

SECTION 3: BENEFITS AND LESSONS LEARNED: OPERATIONAL PARTNER PERSPECTIVE

3.1 NWS WFO-Tucson:

In addition to the forecasting benefits, NWS Tucson was honored to work with three very bright SUNY graduate students, demonstrate to them some of the challenges of forecasting in an operational environment during the monsoon, and share ideas on how potential vorticity diagnostics could potentially be used to track weak atmospheric disturbances that may not show themselves in traditional analyses. Through this project, our belief was confirmed that COMET Cooperative Projects are an ideal venue for investigating complex, difficult forecast issues which could not normally be investigated by a busy WFO staff, while exposing students to NWS field operations, and the "messy" reality of forecasting outside of the classroom.

We also learned that while it is tempting for the WFO side of a COMET Cooperative Project to step back and just let the research be done, it would be a disservice to do so. Frequent communication between the participants allowed concerns or problems to be handled quickly, and facilitated quick infusion of these finding into forecast operations – even before completion of the project. The communication aspects of this project cannot be underemphasized. It provided a valuable skill-building exercise for the graduate students participating in grant-directed research like this, particularly in an era where communication skills are rapidly becoming a key requirement for those seeking post-graduation employment, particularly for those seeking employment in the National Weather Service.

3.2 Storm Prediction Center:

SPC places high value on collaboration activities that involve the research and university communities, and the COMET program has greatly facilitated these types of interactions. A particularly valuable component of this project has been the sharing of real-world, operational challenges with members of the UA community, especially graduate students whose education is enhanced by the real-world perspective. We are very fortunate to have the opportunity to work with the PI and UA students who have been involved in this project.

We also acknowledge the overall education SPC forecasters have obtained through the participation in the project, through helping to formulate and assess the validity of the project goals and methodology, to the application of new ideas and concepts in operational practice. For example, prior to this project, use of PV/DT concepts in convective forecasting at the SPC was very limited at best. This project has allowed us to expand our "forecast technique toolbox" that has permitted us to assess MCS potential over the southwest in new and innovative ways.

SECTION 4: BENEFITS AND LESSONS LEARNED: UNIVERSITY PARTNER PERSPECTIVE

4.1: UA

This project, and a related COMET partner's project, supported three graduate students (Matusiak, Melino, and Sukup) and enabled them to complete M.S. theses and their M.S. degrees. Matusiak graduated in August 2009 and is employed by the NWS WFO in Charleston, WV. Melino and Sukup are graduating in August 2010. PI Bosart and his three project-supported graduate students continue to benefit professionally and educationally from our comprehensive project-related group research effort. The research findings related to the organization and evolution of convective systems in the Southwest are being used to sharpen and focus hypotheses about the origin and structure of monsoon-related convective weather systems and will be used in future endeavors. The research findings from this COMET Cooperative Project have already been incorporated into PI Bosart's mesoscale meteorology teaching materials and adapted for his undergraduate and graduate classes. PI Bosart also gave a seminar on project-supported research findings at the SPC on 9 June 2010. His presentation will serve as the basis for a two-part classroom lecture on warm season severe convection. Finally, PI Bosart and graduate students Melino and Sukup had the opportunity to give a three-way oral presentation by video conference at the NWS Phoenix Weather Workshop on 25 May 2010. Again, the materials used for these presentations will be incorporated into UA mesoscale meteorology classes.

This project was also very valuable to UA because it enabled the three supported graduate students and PI Bosart to present their results at American Meteorological Society (AMS) and National Weather Association (NWA) conferences as well as regional and local conferences. For example, Tim Melino and Scott Sukup both attended and presented at the 34th annual meeting of the National Weather Association that was held in Norfolk, Virginia, from 17-22 October 2009. While in Norfolk, Melino, Sukup, and the PI met with Steve Weiss (SPC) and Erik Pytlak (WFO TUS) to review research progress and scope out new research. In particular, we talked about the best techniques for removing Mexican soundings from various cases of interest to determine the impact of the "missing" upper-air data on WRF model forecasts. PI Bosart gave an oral presentation on project findings at the 13th AMS Conference on Mesoscale Processes that was held in Salt Lake City, UT, from 17-20 August 2009. He will give another oral presentation on project findings at the upcoming 25th AMS Conference on Severe Local Storms to be held in Denver, CO, from 11-14 October 2010. Matusiak, Melino, and Sukup gave oral presentations on their results at the 34th and 35th Annual Northeastern Storm Conferences that were held in Springfield, MA, and Saratoga Springs, NY, respectively, on 6-8 March 2009, and 5-7 March 2010. The collective result of the student oral presentations supported by the COMET project was that the students gained considerable confidence in their ability to stand up in front of an audience and tell people what new science they learned, why it was important, and what its operational relevance was.

This project was also invaluable to the PI and his graduate students because working with the SPC and NWS/WFO-TUS participants gave us a much better appreciation of the operational aspects of the research and the operational constraints governing how to best transfer research to operations. It is extremely gratifying to see how the results from this research are being transferred to operations (e.g., the 2010 Phoenix Weather Workshop held on 25 May 2010) and how SPC forecasters have contributed their knowledge and experience to refining and improving the science and its application to operations.

SECTION 5: PUBLICATIONS AND PRESENTATIONS

5.1: UA

Master's thesis abstracts by graduate students Jamie Matusiak, Tim Melino, and Scott Sukup were included in section 2. Links to their completed theses follow.

Jamie Matusiak Completed M.S. Thesis:

http://www.atmos.albany.edu/student/matusiak/thesis

Tim Melino Completed M.S. Thesis and Presentations:

http://www.atmos.albany.edu/student/melino (click on master's presentation 2010)

Scott Sukup and Lance Bosart Presentations:

http://www.atmos.albany.edu/student/sukup/index.html (click on presentations)

Scott Sukup Completed M.S. Thesis:

http://www.atmos.albany.edu/student/sukup/index.html (click on thesis)

The following project-related presentations were made:

Matusiak, J., 2009: Upper-level potential vorticity anomalies and their impact on warm season Southwestern United States severe weather. Oral presentation, *34th Annual Northeastern Storm Conference*, 6-8 March 2009, Springfield, MA., sponsored by Lyndon State College and the American Meteorological Society.

Matusiak, J.E., 2009: Upper-level potential vorticity disturbances and their impact on warm season Southwest United States severe weather. *M.S. thesis seminar presentation*, 22 June 2009, University at Albany, State University of New York, Department of Atmospheric and Environmental Sciences.

Bosart, L.F., T. Melino, S. Sukup, J. Matusiak, S.J. Weiss, J. Racy, R. Schneider, D. Bright, and E. Pytlak. 2009: Dynamic tropopause mesoscale disturbances as triggers of warm season severe weather episodes in the Southwest. Oral presentation, *13th American Meteorological Society Conference on Mesoscale Processes*, 17-20 August 2009, Salt Lake City, UT

Sukup, S., T. Melino, L.F. Bosart, J. Matusiak, S.J. Weiss, J. Racy, R. Schneider, D. Bright, and E. Pytlak. 2009: The influence of subsynoptic-scale dynamic tropopause potential vorticity disturbances on severe weather in the southwestern United States during the North American monsoon season. Oral presentation at the *34th Annual Meeting of the National Weather Association*, 17-22 October 2009, Norfolk, VA

Sukup, S., T. Melino, L.F. Bosart, J. Matusiak, S.J. Weiss, J. Racy, R. Schneider, D. Bright, and E. Pytlak. 2009: The influence of upper-level subsynoptic-scale potential vorticity disturbances on severe weather in the southwestern United States. Oral presentation at *the Eleventh Northeast Regional Operational Workshop (NROW)*, 4-5 November 2009, Albany, NY, National Weather Service, University at Albany Department of Atmospheric and Environmental Sciences, and Amer. Meteor. Soc.

Sukup, S., T. Melino, L.F. Bosart, J. Matusiak, S.J. Weiss, J. Racy, R. Schneider, D. Bright, and E. Pytlak 2010: The influence of upper-level subsynoptic-scale potential vorticity disturbances on severe weather in the Southwest. Part I: A climatological perspective. Oral presentation at *35th Annual Northeastern Storm Conference*, 5-7 March 2010, Springfield, MA, sponsored by Lyndon State College and the American Meteorological Society.

Melino, T., S. Sukup, L.F. Bosart, J. Matusiak, S.J. Weiss, J. Racy, R. Schneider, D. Bright, and E. Pytlak 2010: The influence of upper-level subsynoptic-scale potential vorticity disturbances on severe weather in the Southwest. Part II: Case study. Oral presentation at *35th Annual Northeastern Storm Conference*, 5-7 March 2010, Springfield, MA., sponsored by Lyndon State College and the American Meteorological Society.

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A revision of the original upper tropospheric low hypothesis is to be proposed at the AMS Weather and Forecasting Conference in January, 2011. The abstract has been submitted to the AMS for consideration.

SECTION 6: SUMMARY OF UNIVERSITY/OPERATIONAL PARTNER INTERACTIONS AND ROLES:

6.1: UA

As noted above, this project featured considerable interactions between the UA, SPC and WFO-TUS participants. These interactions occurred during conferences and workshops as summarized above, via email, and through occasional phone calls. PI Bosart is a regular participant in the annual SPC Testbed Experiment. Over the lifetime of the project he interacted with the SPC participants during his visits through direct talks and seminars. He also took advantage of his participation in the AMS hurricane and tropical meteorology conference, held 10-14 May 2010 in Tucson, AZ, to discuss project-related research and operational findings with Erik Pytlak.

6.2: NWS WFO-Tucson

NWS Tucson interacted with all SUNY and SPC parties frequently throughout the three year project. This frequent interaction, sharing of possible investigatory cases, and meetings at SPC, NWS Tucson, and national conferences allowed us to evaluate progress, offer suggestions when concerns arose, and helped to lead to a successful conclusion.

6.3: Storm Prediction Center

SPC collaborated routinely with the PI, UA students, and WFO-TUS during the project, especially at workshops and conferences when informal discussions and planning meetings took place. A key positive aspect of the project was the enhanced spirit of collaborative investigation where the academic and operational partners were focused on finding scientifically-based results that benefit all parties (forecasters, students, and PI).