

P3.4 WATER VAPOR WINDS IN VICINITY OF CONVECTION AND WINTER STORMS

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1. INTRODUCTION

Forecast applications of water vapor imagery have relied on the subjective interpretation of upper-level features from imagery (Weldon and Holmes, 1991) and comparison with their location and intensity in forecast models. Winds obtained from tracking features in the imagery have been used to improve analyses and forecasts over ocean areas. In order to explore the use of target-tracked winds in nowcasting over land, the water vapor wind tracking algorithm developed at CIMSS (Velden et al., 1997) has been applied to GOES-8 data on an experimental basis at 30-minute intervals in near real-time over much of the U.S. This is about 6 times more frequent than the operational water vapor wind products, which are produced at 3-hourly intervals. More importantly, the amount of wind vector editing has been greatly reduced in order to include larger deviations from the model 'guess' fields. This allows the detection of perturbed flow aloft due to convection and other mesoscale features not correctly captured by models.

This paper examines the upper level wind fields deduced from water vapor imagery for a variety of winter storms and summertime convective events. The analysis technique is briefly described in Section 2. Results are presented in Section 3. The study is summarized in Section 4.

2. METHOD

The first wind tracking techniques required manual interaction with the computer to identify common cloud features in successive satellite images. Wind vectors were then estimated from the displacement of features and the time interval between images. The height of each wind vector was estimated from cloud top temperature (from the window channel radiance) and vertical soundings of temperature. More recently, the process has been automated and expanded to track features in water vapor imagery. The automated technique is described in Velden et al. (1997). It consists of target identification, height assignment, wind calculation, and editing. The automated technique relies on a background wind field to facilitate the location of common features between successive images. The Navy Operational Global Atmospheric Prediction System (NOGAPS) model (Rosmond, 1992) is used as the

background field. By employing a lower resolution model such as the NOGAPS, the addition of higher resolution winds from the satellite is more clearly identifiable. For most of the cases presented in this paper, the background wind field was updated only every 6 hours. Current implementation utilizes time interpolation to provide hourly updates of the background wind field between forecast output times. It is important to note that the winds from features tracked from water vapor imagery (other than clouds) are not associated with a single altitude. Rather, these winds are representative of layers, weighted in the vertical in accordance with the weighting function of the 6.7 micron GOES image channel. Typically, most of the weight comes from a layer 200-300 hPa deep. The altitude of the weighting functions varies directly with upper level moisture. Typically, mean layer heights vary from 400 hPa in dry areas to 200 hPa where upper level moisture is high. Wind vectors directly associated with thick high clouds, such as anvil tops, are from a single level near cloud top.

Since the mean height of wind vectors vary over a given region, it is necessary to interpolate the values to a constant altitude before evaluation of horizontal gradients required in the computation of kinematic parameters such as vorticity and divergence. For this purpose, an objective analysis is used which combines available wind vectors with the background wind field at constant pressure levels from the NOGAPS forecast model. For purposes of this study, analyses centered at 300 hPa are used for evaluation of divergence, absolute and relative vorticity, and wind speed. This layer includes the anvil region of deep convection where upper level divergence can be strong and related to the mesoscale upward air motion. Because of the vertical weighting of the water vapor winds, the derived quantities such as divergence and vorticity represent vertical averages centered near 300 hPa. Caution should be observed in interpreting the kinematic properties near dry areas where no satellite winds may be available near 300 hPa. The objective analysis will be based mainly on the background wind field in such areas. A map of wind vectors should be examined to ensure adequate coverage.

3. ANALYSES

Analyses from the wind fields include the display of wind vectors and objectively analyzed divergence, absolute and relative vorticity, and isotachs at 300 hPa. The output of these products are available in real time on the Web and includes interactive displays (<http://zonda.ssec.wisc.edu/~rabin/real.html>). Comparisons are also available between the analyzed fields of divergence, vorticity, and isotachs and those

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from the NOGAPS and Rapid Update Cycle (RUC-2) model (Benjamin et al., 1998).

3.1 Winter Storms

On 26 January 2000, a widespread area of snow developed across central Oklahoma producing 10-15 cm of accumulation (~12-23 UTC). The snowfall appeared to be related to isentropic lift associated with warm air advection. This snow event was not well predicted. It occurred well downstream of an upper level trough which moved across the region on 27 January. Snow had been forecasted to begin after 00 UTC on the 27th. This upper system produced convective precipitation further east on the 27th. Freezing rain and ice pellets effected north Texas & the heaviest snow fell over parts of eastern Oklahoma with as much as 17" reported in Eufaula, Oklahoma.

In general, the RUC-2 wind fields contain more structure than the satellite winds because of the model's high resolution. The RUC-2's upper level divergence field seems to match the location of the snow band on 26 January more consistently than the satellite analysis. The divergence visible from satellite may have been limited due to the shallow nature of the upward motion during the warm air advection phase of the storm.

A strong divergence couplet develops with the upper low as it tracks across Oklahoma by 16 UTC on 27 January (Fig. 1). The most intense divergence is located over the convective cloud region centered near the southeast tip of Oklahoma. Strong convergence is located to the west near the leading edge of a dry band aloft. The RUC-2 and the background NOGAPS fields indicate the divergence further west in western Oklahoma. The background field was 3 hours old at the time of the analysis. Despite this, the satellite analysis captured the eastward movement and evolution of intensity.

Two significant snowstorms effected the upper Midwest on 11 and 18 December 2000. The early stages of these storms appear to have similarities from satellite imagery. Maximum divergence developed in the central Plains ahead of an upper level trough, convergence behind it in the Great Basin. As the storms moved east, upper level divergence was elongated from southern Minnesota to Michigan. In the case of 18 December, a double maximum occurred: a western one just ahead of the upper trough and an eastern one near a speed gradient well north of the surface system. Both systems also exhibited an area of upper level convergence and drying to the southwest. On the 11th, the divergence was to the north of an east-west band of maximum vorticity. A jet maximum was approximately 700 km to the south of the divergence maximum. Radar echoes were widespread through the area of divergence, although only the backside appeared to be convective from the satellite imagery. On both days, the highest radar reflectivities were south of the area with maximum divergence. On 18 December, the heaviest snowfall was in vicinity of the strongest divergence (east central Wisconsin). In this case, the high reflectivities to the south may have been due to mixed precipitation in these areas. However on 11

December, the heaviest snowfall occurred near the Illinois-Wisconsin border, about 100-200 km south of the maximum divergence. Here, displacement of the divergence pattern may have been due to a slope of upward air motion to the north with height.

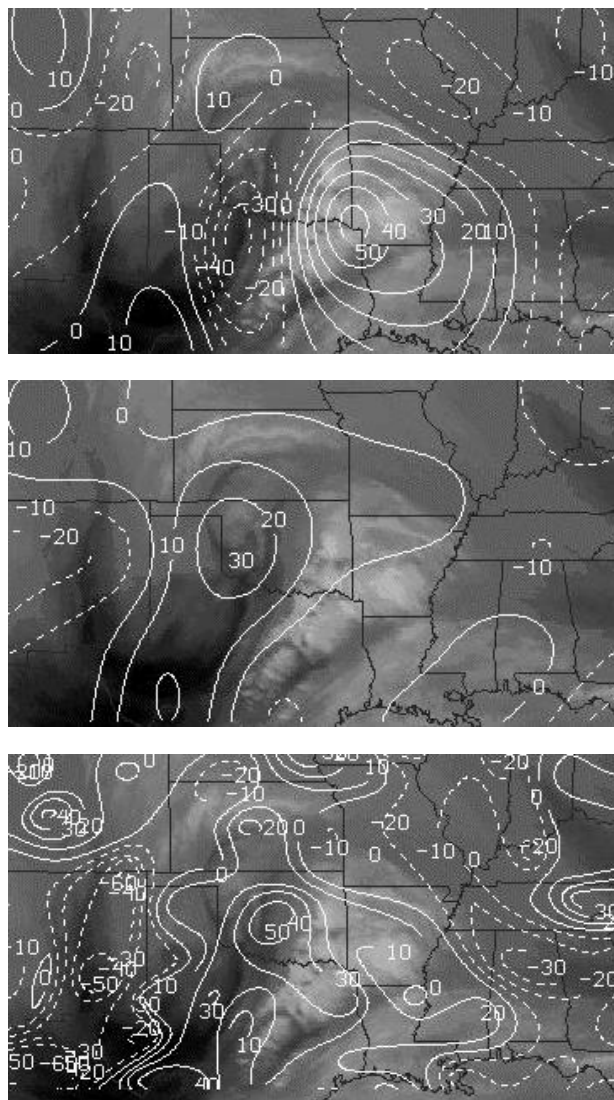


Fig.1 Water vapor image and divergence at 300 hPa ($10^{-6} s^{-1}$) at 16 UTC, 27 January 2000 from water vapor winds (top), background wind field (middle) and RUC-2 (lower).

A severe ice storm effected parts of Oklahoma and Arkansas on 25-26 December 2000. On the 25th at 1845 UTC, a strong upper level system was located in Arizona. Far to the east, convective precipitation commenced from northeast Texas to western Arkansas. Vorticity gradients were weak in this area, yet a strong divergence signature had developed above the convection. From the isotach field, the divergence appeared to result from a considerable speed gradient near the top of a ridge aloft. By the 26th at 0345 UTC,

the upper low dropped slightly to the southeast as convection and strong divergence aloft developed to its east in New Mexico. Convection and divergence continued to form in northeast Texas in an area of strong warm air advection under the upper level ridge. The speed gradient appeared to be weak by this time. A third band of convection developed between the two other bands. Initially, upper level divergence was weak over this area. By 0945 UTC, this band expanded eastward and had large divergence associated with it. In this case, the divergence resulted from a considerable speed gradient ahead of the upper level low as it moved eastward. Over the next several hours, the upper level circulation moved east and developed a couplet of divergence, with the divergence and heavy precipitation in Arkansas. By this time, parts of Oklahoma and Arkansas had experienced significant upper level lifting for as much as 36 hrs. Given subfreezing surface temperatures and plentiful moisture, ice accumulations of several inches resulted in considerable tree and power line damage in many locations.

3.2 Warm Season Convection

An example of strong mesoscale forcing occurred in Oklahoma and Kansas on 3-4 May 1999. Multiple supercell thunderstorms produced over 70 tornadoes after 2100 UTC on 3 May. Of interest was a wind maximum near the Oklahoma and Texas panhandles about 500 km to the west-northwest of the convection at the time of early development (2145 UTC). An upper level trough was centered to the west in New Mexico and Colorado. The trough and wind maximum had moved from south central Arizona and southwest New Mexico respectively at 1200 UTC. The convection formed on the anticyclonic side of the wind maximum near a minimum in relative vorticity ($-2 \times 10^{-5} \text{ s}^{-1}$). Peaks in divergence developed over the convection and ahead of the main trough in eastern New Mexico, however the intensity was not unusually strong as compared to other convective events. By 4 May 0045 UTC, the wind maximum had shifted east and was near the western edge of the active convection. Also, the convection was centered between a couplet of cyclonic-anticyclonic vorticity. Comparisons of upper level fields were made with the operational ETA (Black, 1994) and RUC-2 models. The models did well in depicting the divergence above the convection and the vorticity couplet at 00 and 06 UTC on 04 May. Earlier, there are differences between the satellite, RUC-2 and ETA fields.

Mesoscale Convective Systems (MCS) often develop under weak upper forcing during the summer months in the U.S. Fueled by moisture and warm air advection in the low levels, they typically occur in vicinity of upper level ridges. Blanchard et al. (1998) proposed a role of inertial instability in the growth of MCSs by enhancement of upper level divergence. Using upper wind analyses from rawinsonde data, the occurrence of negative absolute vorticity, a necessary condition for inertial instability, accompanied the onset of large systems. The absolute vorticity was examined here using the satellite wind analyses for events with weak forcing.

The time series of maximum divergence was examined for a large MCS lasting 14 hours on 20 July 1995. This system was associated with a frontal boundary and had an elongated shape rather than the more circular pattern typical of Mesoscale Convective Complexes (MCC). In this case, the time trend of maximum divergence appeared related to the evolution of the MCS as observed from the coverage of the cold cloud shield in the infrared satellite imagery. The strongest divergence was near the end of the mature phase (2-5 UTC). There was a rapid decline after 0530 UTC, near the onset of decay. However, the decline in divergence did not continue during the decay phase (5-8 UTC) when values remained nearly constant at $6 \times 10^{-5} \text{ s}^{-1}$. During the early stages of development (23-03 UTC), the minimum absolute vorticity was just southeast of the convection. Perhaps this was a factor in the observed expansion of the cloud shield to the southeast. During the mature phase, the minimum absolute vorticity was aligned roughly with the convection, however the minimum was located downwind (northeast) from the most active area. In these areas, the absolute vorticity became negative. During the decay phase, the minimum remained aligned with the convective cloud, but was slightly positive.

Another smaller, long-lived MCS formed on 15 July 2001. The first individual convective cells formed to the west of the upper ridge axis at 21:45 UTC. Weak divergence was first detected at 22:15 UTC over an individual storm in the Texas panhandle. As a speed maximum spread northeast into Colorado, the speed shear increased and a minimum in absolute vorticity ($6-8 \times 10^{-5} \text{ s}^{-1}$) approached the storms from southwest. By 01:15 UTC on 16 July, the system was comprised of a cluster of individual cells with strong divergence at times, and absolute vorticity near $6 \times 10^{-5} \text{ s}^{-1}$. During the period 02:45-08:15 UTC, as the cluster expanded in coverage, the divergence was moderately high. The MCS was located near a minimum in absolute vorticity ($2-4 \times 10^{-5} \text{ s}^{-1}$) in southwesterly flow. This was on the anticyclonic side of a speed maximum where the speed shear was highest. There was a vorticity maximum embedded in the ridge further to the south, but that region was void of convective development. The MCS moved eastward over the ridge axis during 08:45-11:15 UTC. During this period, the divergence was steady ($3 \times 10^{-5} \text{ s}^{-1}$). Also, the southern end moved away from minimum absolute vorticity and weakened. The remaining portion weakened during 11:45-14:15 UTC except for regeneration of cells near the southeast end, along the southern edge of the speed shear. During 14:45-17:15 UTC, dissipation into cirrus occurred. Divergence was weak during this period.

The upper air features from a long-lived MCS on 20 July 2000 tracked south of the westerlies and appeared to be associated with new convective development after its demise. The first system formed at 00:45 UTC and propagated along a ribbon of uniform gradient of absolute vorticity. This was near the northern edge of the maximum speed shear. Impressive divergence was first detected at 10:45 UTC. Convergence developed ahead of the convection and the divergence couplet persisted for several hours. After dissipation of the MCS (14:45 UTC), remaining cirrus

tracked southeast where new convection developed from 18:45-22:45 UTC. This convection exhibited strong divergence at times and was accompanied by a minimum in absolute vorticity ($2 \times 10^{-5} \text{ s}^{-1}$).

An example of an MCS associated with a weak vorticity maximum occurred on 19 July 2000. The first isolated convection formed in northeast Colorado at 00:45 UTC and was accompanied by localized divergence. The speed maximum was located just east of this location. As the MCS reached a mature stage by 07:45 UTC, the wind speed maximum moved further east leaving a weak speed gradient near the convection. The convection occurred within a region of relatively high absolute vorticity with a weak vorticity maximum nearby. The MCS decayed between 08:45-10:45 UTC in Kansas. Divergence appeared to be quite variable during the lifecycle of this MCS.

A set of shorter-lived MCSs was also examined. These all occurred near the periphery of an upper level ridge centered near the high plains.

On 3 July 2000, an MCS formed at about 03:45 UTC near the top of the ridge. It rapidly intensified an hour later and dissipated by 08:45. The absolute vorticity became negative near the time of intensification. Moving southeastward, the convection was on the anticyclonic side of a wind maximum (right entrance region of the jet), located on the east side of the upper ridge. After the demise of the convection, cirrus debris persisted at least another 13 hours. The cirrus remained centered on the location of minimum vorticity as it propagated southeast. Scattered new convection formed underneath this area by afternoon (21:45 UTC).

Another short-lived event developed near the top of the ridge on 11 July 2000. Convection initiated in southern Colorado at about 20 UTC and dissipated by 03 UTC the following day. The area of formation was collocated with a minimum in absolute vorticity ($< 4 \times 10^{-5}$) in a region of broad speed shear. However, that feature moved east of the convection and was replaced with increasing values ($> 8 \times 10^{-5}$) by dissipation time. There was no local wind maximum present in this case.

4. SUMMARY AND CONCLUSIONS

The CIMSS water vapor wind tracking algorithm has been implemented to allow the detection of perturbed flow aloft due to convection and other mesoscale features. The horizontal resolution of wind fields is limited by the density of targets identified by the automated technique, and the resolution of the objective analysis. For example, the fields of divergence and vorticity do not contain as much detail as RUC-2 analyses.

Examination of winter storm cases usually revealed a consistent relation between divergence aloft and precipitation evolution, especially near convective cloud tops. In some cases, the divergence can be displaced downwind due to shear. Areas where air ascent is limited to shallow layers may not be detectable.

Investigation of several MCS's confirm the lack of significant vorticity or divergence perturbations aloft before convective development. With areal growth of these systems, divergence and vorticity signatures

emerge and occasionally persist after the demise of the active convection. Given the presence of divergence aloft on a scale of at least 200-300 km, the thunderstorm clusters usually persist for several hours over similar horizontal scales. In contrast, isolated thunderstorms are often too small to be resolved by the satellite wind analysis and appear to develop in areas with no preferred sign of divergence. However, the rapid intensification of divergence is observed occasionally with the explosive growth of a single storm.

The absolute vorticity was examined using the satellite wind analyses for events with weak forcing. In many cases, convective systems developed in the vicinity of upper ridges near minima in absolute vorticity (with values $< 4 \times 10^{-5} \text{ s}^{-1}$). These values were only slightly above the threshold for inertial stability, suggesting a possible role of this mechanism in MCS growth. However, it is important to note that inertial instability can be ruled out in other cases where absolute vorticity was relatively high.

Derived wind fields have been made available to the NOAA Storm Prediction Center (SPC) on an experimental basis. The operational value of these products in forecasting storm evolution remains to be determined. The principal limitations of the water vapor wind analysis are the variable nature of the target heights and lack of vertical profiling. The future implementation of the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) by NASA has the potential to provide analysis of water vapor winds at multiple levels.

5. REFERENCES

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