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11-15-92

Technical Attachment

USING CAUTION WHEN ANALYZING Q-VECTORS

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The past decade has seen an increasing emphasis placed on Q-vector analyses as a method of determining synoptic scale vertical motion. As discussed by Bluestein (1986), Q-vectors represent ageostrophic forcing in the atmosphere resulting from hydrostatic and geostrophic imbalances. Regions where Q-vectors exhibit significant divergence theoretically experience quasi-geostrophic forcing in the vertical. For the majority of synoptic scale weather systems through which winds flow in near geostrophic balance, Q-vector diagnosis should prove applicable in inferring vertical motion (Barnes, 1986). In other words, Q-vector convergence is directly proportional to upward motion. This vertical motion is an ageostrophic wind response to geostrophic flow which attempts to balance the thermal wind which has been thrown out-of balance by geostrophic advection processes.

However, there are certain synoptic and mesoscale circulation systems for which winds have a large ageostrophic component. These include any strongly curved flow, rapidly developing synoptic scale mid-latitude cyclones, jet streaks (Uccellini and Johnson, 1979), developing and weakening fronts (Bluestein, 1986), and mesoscale convective systems. Because the flow comprising such weather features will substantially deviate from geostrophic balance, Q-vector analyses may greatly underestimate the magnitude of vertical forcing in their vicinity and, in rare cases, may even give the opposite sign during small mesoscale events! As illustrated below, divergence of the Q-vector pattern and its magnitude give a vague indication of where convection and upward motion occurred on May 12, 1992.

During the late afternoon and early evening of May 11, 1992, a squall line developed over portions of the Southern Plains, with severe thunderstorms erupting over northwest Arkansas, eastern Oklahoma, and northeast Texas.

In most instances, conditions favorable for severe weather are evident the time and place it occurred. In Fig. 1, the Little Rock sounding data show a moderately unstable air mass including a CAPE of 1323 J/kg and a -4 lifted index. Convective enhancement is likely from the vertical wind shear as directions veer and speeds increase from the surface to 4000 meters. The combination of shear and buoyancy results in a Bulk Richardson Number (BRN) of 35, suggesting an environment conducive for strong squall line activity with a risk of isolated supercells (Weisman and Klemp, 1984).

The 0000 UTC surface analysis (Fig. 2) shows a low pressure trough over the high plains and high pressure covering the eastern third of the United States. The resultant southerly flow across the Mississippi Valley and the Southern Plains transports warm humid air into the region from the Gulf of Mexico. At 850 mb (Fig. 3), warm air advection is evident in the vicinity of northeast Texas and near the Oklahoma-Arkansas border. Finally, the 0000 UTC 500 mb height-vorticity chart (Fig. 4) clearly exhibits well-defined PVA over most of the area severe weather developed. Note that vorticity in Fig. 4 is computed from the total wind field and hence includes both geostrophic and ageostrophic wind contributions.

When the 2335 UTC NWS radar summary is overlaid with the 0000 UTC 500 mb profiler winds, correcting for time differences, it is seen that intense storms are along or just east of the 500 mb trough axis where forcing appears significant (Fig. 5). Kinematic computations from the UA program (Fig. 6 and 7) shows this same region also experiences very strong divergence at 300 mb and convergence at 850 mb. All evidence therefore indicates thunderstorms are located where upward motion is quite significant. SELS accordingly issues timely watch boxes covering eastern Oklahoma, western Arkansas and northeast Texas where storms produced damaging straight-line winds and large hail.

Despite most parameters inferring strong upward motion around the squall line, the 700 mb Qvector divergence (Fig. 8) characterizes any such forcing as comparatively negligible. Divergence values are only slightly negative suggesting that, while upward motion may still be present, it is rather feeble.

Wetzel, et. al. (1983), have illustrated how deep convection can induce a well-defined upper tropospheric convergence-divergence couplet similar to the one shown in Fig. 6. They concluded that the horizontal winds may adjust ageostrophically upon encountering deep convection, since vigorous updrafts can act as obstacles to the flow aloft. Additionally, raincooled outflow boundaries in the vicinity of thunderstorms may enhance convergence in the lower troposphere. In contrast, as stated above, Q-vectors are valid for quasi-geostrophic flows which must be primarily non-divergent. Thus, information provided by Q-vector fields will be misleading where weather phenomena, such as deep convection, produce significant amounts of ageostrophic wind.

A second factor to consider is Q-vectors are related to the amount of frontogenetic forcing through a layer of the atmosphere (Bluestein, 1986). In regions of relatively weak temperature gradients, Q-vectors will not indicate meaningful forcing. For this particular case, the atmosphere from northwest Arkansas to northeast Texas is only slightly baroclinic. Consequently, Q-vector divergence at both 700 mb (Fig. 8) and 500 mb (not shown) implies little synoptic scale quasi-geostrophic forcing.

All forecasters should attempt to estimate whether winds are in quasi-geostrophic balance in order to anticipate the reliability of Q-vector diagnostics before they are applied. One quick way to estimate whether the total wind has a significant ageostrophic wind component is to overlay wind and height fields at various pressure levels. If wind directions are not parallel to height contours, there is likely a significant ageostrophic wind component. Note that this quick method does not give an estimate of the magnitude of ageostrophic flow along the height contours associated with the wind speed field, and hence should be only a crude estimate of ageostrophic flow.

Q-vectors can still play an important role in alerting forecasters to where quasi-geostrophic forcing is inducing synoptic-scale upward vertical motion. In many cases, simple PVA analyses do not adequately represent the vertical motion field, whereas Q-vector analyses do. The difference is due to the type and accuracy of assumptions upon which the analyses are based. However, as this case illustrates, dynamic and kinematic elements associated with ageostrophic weather systems must also be examined, since Q-vectors alone provide an incomplete representation of atmospheric processes.

References

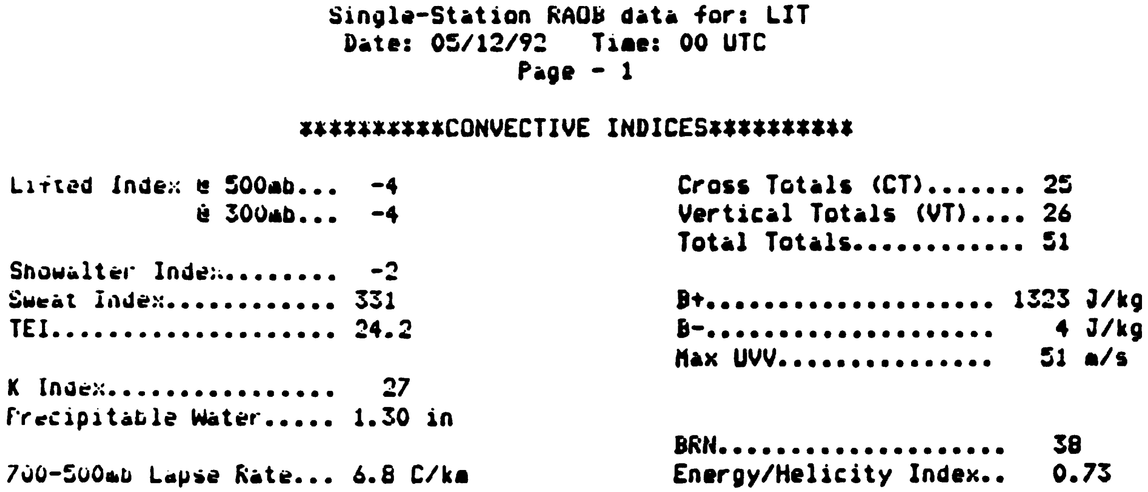
Barnes, S.L., 1987: *Analyses of quasi-geostrophic forcing during the AIMCS project*. Volume 1: Discussion. NOAA Tech. Memo. ERL NSSL-62, Norman, Ok., 60 pp.

Bluestein, H.B., 1986: *Jet streaks: A theoretical perspective. Mesoscale Meteorology and Forecasting*, Amer. Meteor. Soc., Boston, MA, 173-215.

Uccellini, L.W., and D.R. Johnson, 1979: The coupling of upper and lower tropospheric jet streaks and implications for development of severe convective storms. *Mon. Wea. Rev.*, 107, 682-703.

Weisman, M.L., and J.B. Klemp, 1994: The direction and classification of numerically simulated convective storms in directionally varying wind shear. *Mon. Wea. Rev.*, 112, 2479-2498.

Wetzel, P.J., W.R. Cotton and R.L. McAnelly, 1983: A long-lived mesoscale convective complex. Part 11: Evolution and structure of the mature complex. *Mon. Wea. Rev.*, 111, 1919-1937.



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                    Single-Station RAOB data for: LIT
                     Date: 05/12/92   Time: 00 UTC
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                  **********CONVECTIVE INDICES**********

Lifted Index @ 500mb...   -4            Cross Totals (CT)....... 25
             @ 300mb...   -4            Vertical Totals (VT).... 26
                                        Total Totals............ 51
Showalter Index........   -2
Sweat Index............ 331             B+.................... 1323 J/kg
TEI.................... 24.2            B-....................    4 J/kg
                                        Max UVV...............   51 m/s
K Index................   27
Precipitable Water..... 1.30 in
                                        BRN...................   38
700-500mb Lapse Rate... 6.8 C/km        Energy/Helicity Index..  0.73
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Figure 1. Thermodynamic and convective energy data for Little Rock on 00Z May 12 1992 as derived on the SHARP Workstation.

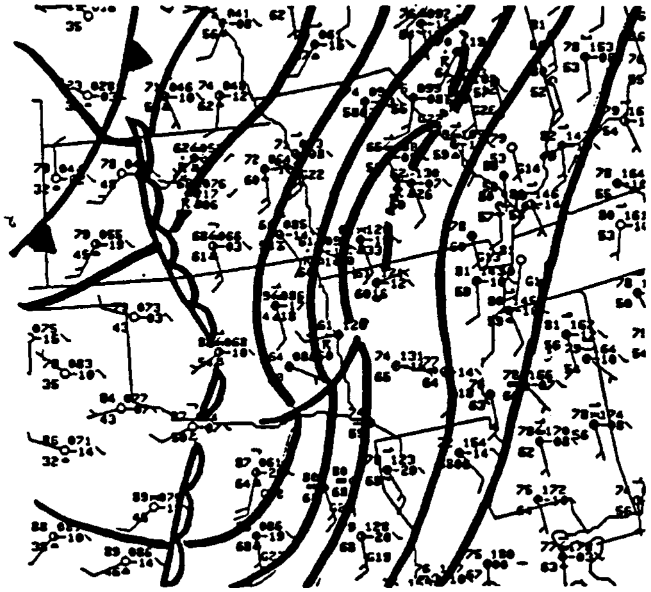

Figure 2. Surface analysis for 00Z May 12 1992. Isobars contoured every 2 mb.

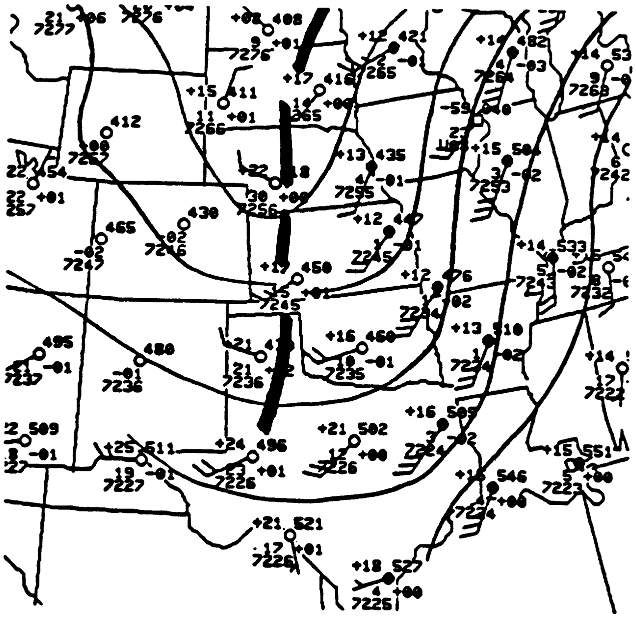

Figure 3. 850 mb regional analyses for 00Z May 12 1992.

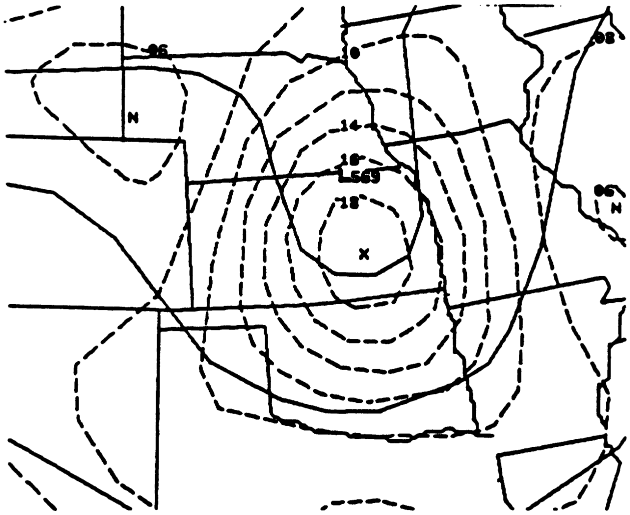

Figure 4. 500 mb hight-vorticity map for 00Z May 12 1992.

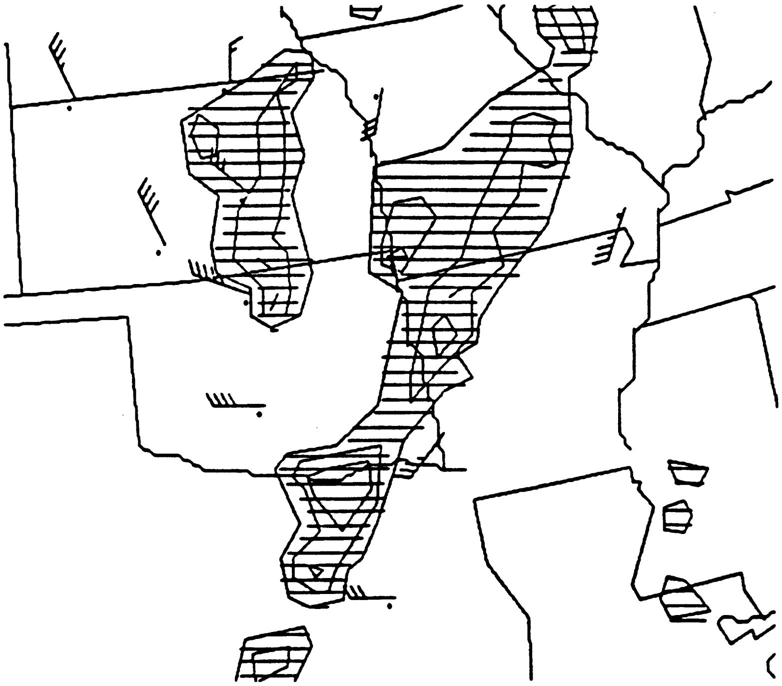

Figure 5. 2335Z NWS radar summary overlaid with 00Z regional 500 mb profile winds.

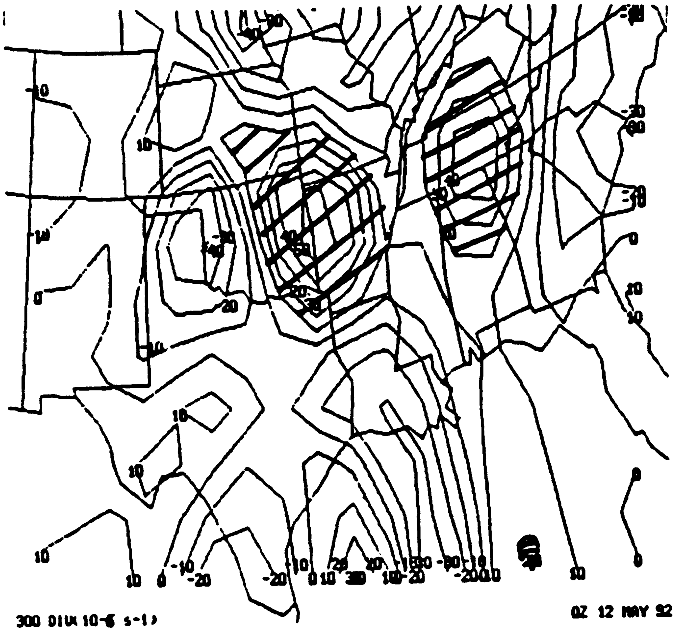

Figure 6. 300 mb divergence at 00Z May 12 1992.

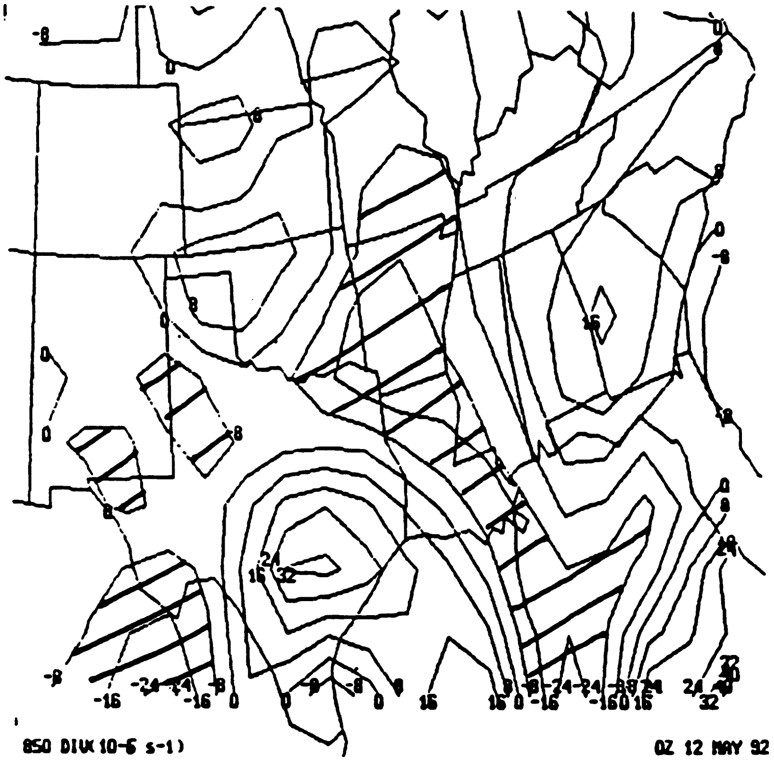

Figure 7. 850 mb divergence 00Z May 12 1992.

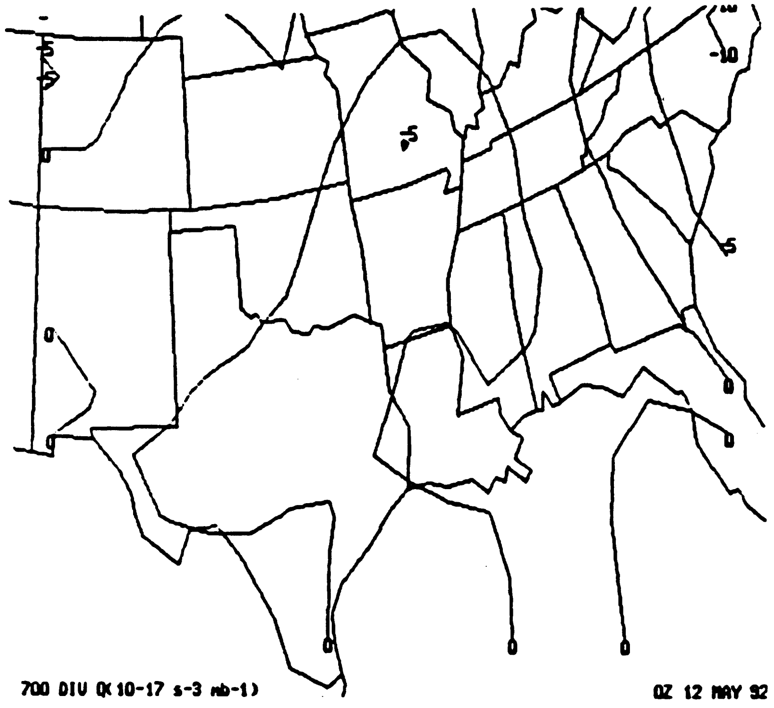

Figure 8. 700 mb Q-vector divergence 00Z May 12 1992.