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Temporal Evolution of 700-500 mb Lapse Rate as a Forecasting Tool -- A Case Study

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Introduction

As anyone who has ever tried it knows, forecasting convection can tax one's forecasting abilities to the utmost. Lacking complete theoretical foundations, forecasting convection has developed mostly through empirical approaches, making extensive use of "rules of thumb" which offer some predictive value in lieu of physical understanding.

Our research aims to replace empiricisms with understanding, wherever possible. There always will be a continuing need for rule-based forecasting and intuition gained through experience, but the power and flexibility of scientifically-based forecasting approaches seem self-evidently desirable. This paper will illustrate some of the value in lapse rate diagnosis via a case study example. We shall follow the evolution of a particular severe thunderstorm event -- a tornadic supercell in the Texas Panhandle, the storm scale aspects of which have been described in Jensen *et al.* (1983). We are particularly concerned with the processes by which an environment with the potential for extremely intense convection arises.

The Pampa Storm Case

1. Preceding Events

During the afternoon of 18 May 1982, thunderstorms developed in eastern New Mexico, in a region with warm temperatures and strong warm thermal advection (geostrophic) at low levels (say, surface to 700 mb). Low-level moisture is scanty in this region, although 700 mb dewpoints >0 deg. C are present, suggesting that the first convection is relatively high-based and weak.

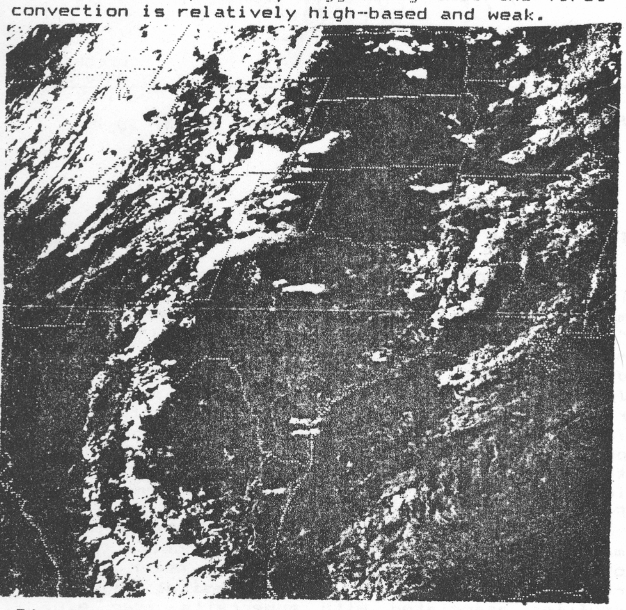

Fig. 1. Visible satellite image at 2330 GMT on 18 May 1982.

At 00 GMT on 19 May, new storms develop in the Texas Panhandle and southwestern Kansas (Fig. 1), while the first storms in New Mexico are dissipating. These new storms become a Mesoscale Convective System (MCS), which continues on through most of the night and into the morning across Oklahoma and southern Kansas. From Fig. 2, it can be seen that a region of high lapse rates in the 700-500 mb layer exists over much of the high terrain from western Colorado southward into Mexico. Low-level (850 mb) moisture is well east of the high lapse rate region, and the convection develops between the moisture and lapse rate axes, moving into more stable lapse rates. As it turns

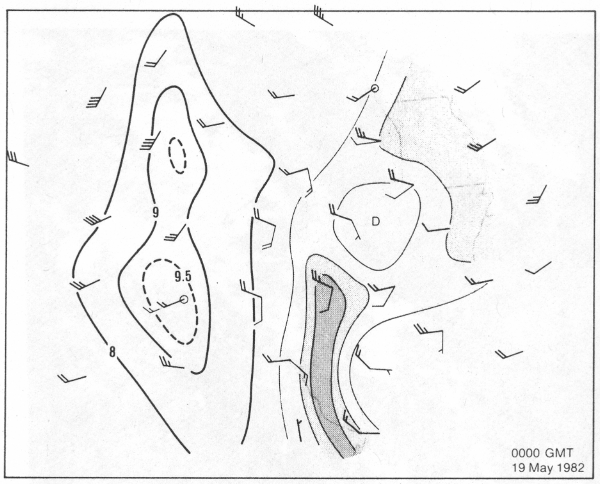

Fig. 2. Overlay of 700-500 mb lapse rates (heavy solid lines -- deg. C km^{-1}) and 850 mb moisture analysis (T_d at 850 mb in deg. C), for 00 GMT 19 May.

out, the nocturnal convection produces little in the way of severe weather, but has some role in the next day's events.

2. The morning of the event

By 12 GMT 19 May, the MCS which began roughly 12 h earlier in west Texas is now in central Oklahoma, and is about to dissipate. The soundings reveal that this activity has not had a detrimental effect on low-level moisture in western Oklahoma and the Texas Panhandle (Fig. 3). Further, the high lapse rate region has moved into much closer proximity with the moisture. The advance of the high lapse rate air coincides with the advance of a short-wave trough at 500 mb, which has a jet streak entering its base. Several hours later (Fig. 4), the MCS has nearly gone away, leaving relatively cool and moist surface air behind, and a streak of cloudiness to its west (apparently an axis of enhanced low-level moisture, as indicated by surface dewpoint temperatures [not shown]).

3. Near the time of the event

New convection begins in the Texas Panhandle about 20 GMT, along a north-south line west of Amarillo. By 00 GMT, a cell along this line has grown explosively (Fig. 5). This is the tornadic supercell, with the first tornado touchdown at about 23 GMT. There are several other intense cells in an arc-shaped pattern north of the Pampa storm, just ahead of the region of high 700-500 mb lapse rates. From Fig. 6, it can be seen that the

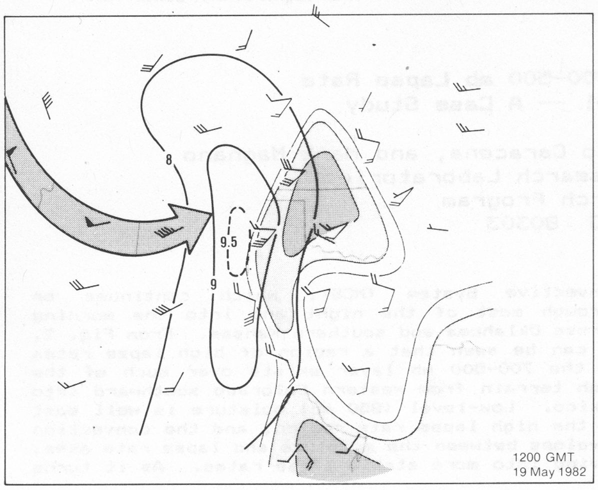

Fig. 3. As in Fig. 2, except for 12 GMT 19 May.

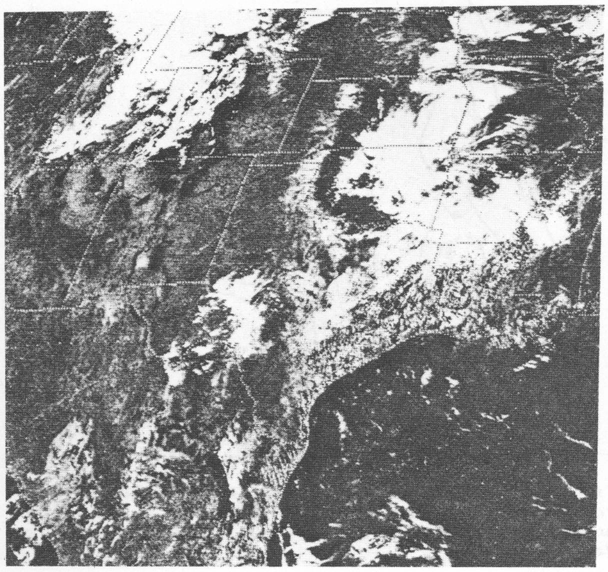

Fig. 4. As in Fig. 1, except for 1630 GMT 19 May. Note streak of low cloudiness along the southwestern boundary of Oklahoma.

high lapse rates are in two distinct regions, both intruding over the western boundary of low-level moisture. Although the 500 mb jet streak is weaker than it was at 12 GMT, note that it passes between the two lapse rate maxima and has propagated southeastward. Further, the intrusion of dry air at 850 mb seems to lie under the exit region of this jet. There has been substantial backing of the 850 mb winds in the moist air.

4. *Following the event*

By 12 GMT 20 May, the strong activity of the previous evening has all but dissipated over Texas and Oklahoma, but continues in south central Kansas. The soundings reveal that the convection at 12 GMT is situated in a lapse rate maximum (Fig. 7), along the low-level moisture axis (Fig. 8). No activity develops during the following afternoon and evening over Oklahoma and Texas, although an MCS does commence in Oklahoma after 00 GMT. The afternoon re-developments are in central Kansas, but these are not of concern here.

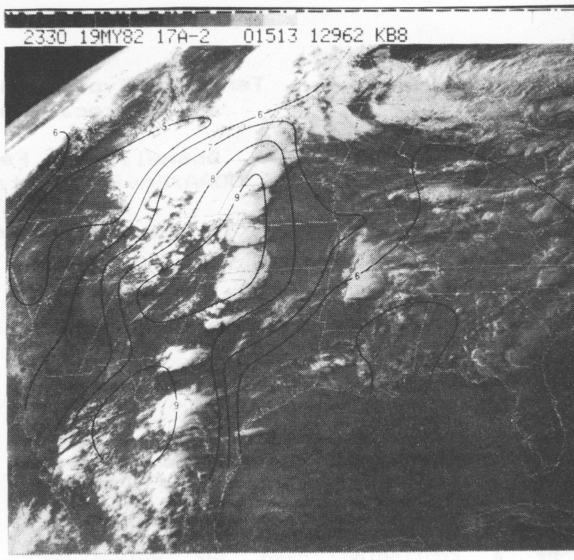

Fig. 5. Visible satellite image at 2330 GMT on 19 May 1982, with superimposed analysis of 700-500 mb lapse rates (in deg. C km^{-1}).

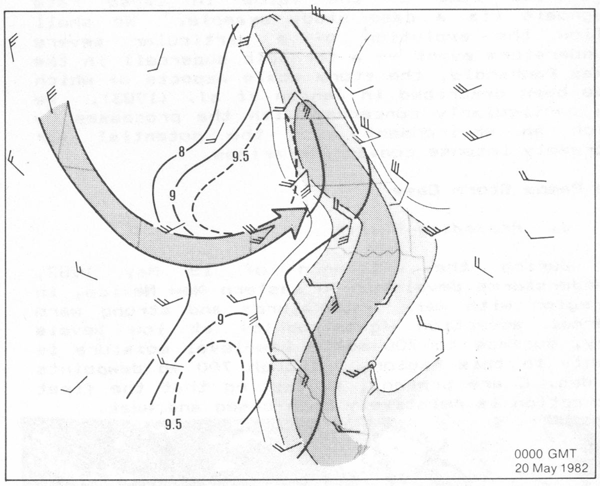

Fig. 6. As in Fig. 2, except for 00 GMT 20 May.

Implications and Discussion

Our conceptual model represents a slight but important shift in the emphasis from previous models. Instead of an "air mass" awaiting the "trigger" of an approaching short-wave trough, a more realistic description is that *the trough's dynamics create a region of high mid-tropospheric lapse rates (or enhance and maintain high lapse rates created by diabatic processes), bringing it into superposition with low-level moisture.* This process also is associated with modifications to the vertical wind shear profile, producing the ideal conditions for supercell development (see Fig. 6).

We feel that the application of the term "air mass" to the structure in which supercells (or any other form of intense convection) occur can be rather misleading -- the classical sounding profiles associated with supercells (see e.g., Fawbush and Miller, 1954) are not characteristic of airmasses, in the sense that an "airmass" is a rather homogeneous region. As clearly delineated in our case study, the vertical superposition of high lapse rates in mid-troposphere above low-level moisture is a dynamic process, which is unlikely to occur in regions of horizontal homogeneity.

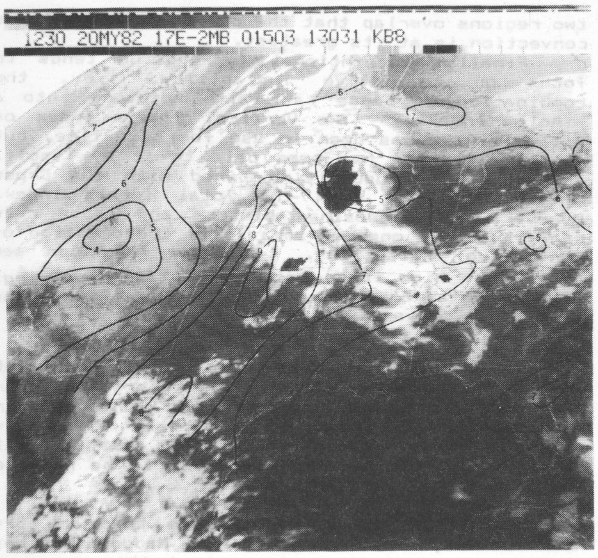

Fig. 7. As in Fig. 5, except for 12 GMT 20 May.

It is clear that the high terrain of the southern Rocky Mountains can generate high lapse rates via *diabatic* processes. However, if one compares Fig. 3 with Fig. 6 it is obvious that the high lapse rate region which is feeding the intense cells from the Texas Panhandle northward could not been created by simply advecting the high lapse rates seen 12 h earlier into that location. We think it significnat that the area of high lapse rates is in the *left exit region of the 500 mb jet streak*. As discussed by Hovanec and Horn (1975), this is a favored location (with respect to the large scale system) for decreasing the stability.

We suggest that *this is the primary connection between the large-scale circulations and intense convection*. That is, the main role of the large scale motions is to prepare the environment through lapse rate (and vertical wind shear) changes. It is hard to imagine vertical motions of a few cm s^{-1} serving as a "trigger" for convection.

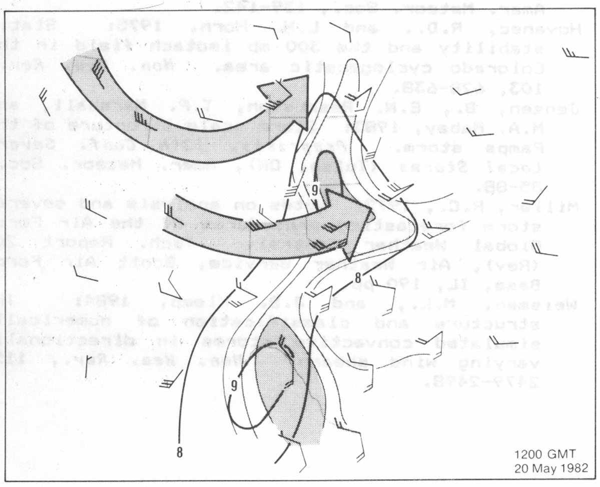

Fig. 8. As in Fig. 2, except for 12 GMT 20 May.

However, it is worth noting that the core regions of really high lapse rate tend to be rather confined. If one considers *dry static stability as a measure of resistance to vertical motion* (Hovanec and Horn, 1975), then a feedback (nonlinear) can develop between stability and vertical motion, to create subsynoptic regions of low static stability and enhanced vertical motion.

As further evidence of the interaction between static stability and large-scale flow, Q-vector diagnostic fields show a dramatic increase in the forcing function for quasi-geostrophic vertical motion (Fig. 9) just as the trough encounters the high lapse rate region (originally created by diabatic heating over the elevated terrain). Also,it seems unlikely that the *decrease* in quasi-geostrophic forcing by 12 GMT 20 May, following the intense convection, is purely accidental. We think, rather, that *lapse rates can have a significant influence on synoptic scale systems*, especially in terms of spatial and temporal *variations* in stability.

As seen in our case study, the action of convection can produce regions of low lapse rate in rather short order (Fritsch *et al.*, 1976), so the lapse rate field can "parameterize" the convection, in a *diagnostic* sense. For large long-lived convective systems, this convectively-processed air can cover a relatively large area. If new convection is to develop, it must occur on the *margins* of the convectively-altered area, or some process must act to reduce the static stability once again. As seen in Fig. 7, new convection often is found on the *strong lapse rate gradients*, between upstream high lapse rates and downstream, convectively-processed low lapse rates. Further, *long-lived convection requires that convective instability be maintained by large-scale processes*, since intense convection "uses up" this vertical stratification on such short time scales.

Intense mid-latitude convection typically occurs with rather high values of convective instability (e.g., Hales, 1982), and it is almost impossible to achieve large convective instability without having large temperature lapse rates. Hence, we feel it is somewhat misleading to envision a mid-tropospheric region of high potential temperature (and nearly dry adiabatic lapse rates) primarily as a mechanism for *restraining* convection (e.g., Carlson *et al.*, 1983). Instead, it can serve as a *basic ingredient* for intense convection. Whether or not such a layer constitutes a restraint on convection depends on the characteristics of the moist air over which it is brought and the presence and intensity of subsynoptic sources of lift (see Doswell, 1984), but without high lapse rates, intense convection is unlikely.

Further, the association between hot, dry intrusions and severe thunderstorms has long been recognized and thought to be related to downdraft enhancement. Numerical cloud modeling experiments (e.g., Weisman and Klemp, 1984), show that simulated storms do not seem to require this very dry air aloft to develop realistic downdraft/outflow characteristics. In high lapse rate regions with substantial moisture, intense convection usually develops, so a high lapse rate in moist conditions is likely to be only a temporary structure. Thus, *the dryness of the air is only critically important insofar as it allows the maintenance of high lapse rates.*

Once formed, regions of high lapse rate do not tend to dissipate rapidly, except via deep, moist convection. Thus, if for some reason, the convective potential associated with a region of high mid-tropospheric lapse rate is *not* released on a given day (perhaps owing to an improper phasing with other ingredients), the synoptic system can maintain or enhance this high-lapse rate region. In this way, a sort of "time bomb" is created that may be released one or more days later.

The often-observed development of convection *between* the moisture and thermal ridges at low levels indicates that it is this region which has the proper combination of dry static stability and moisture. The low-level thermal ridge upstream often is associated with the highest lapse rates but is low in moisture, while the low-level axis of high moisture downstream often has only modest conditional instability above it. It is when the

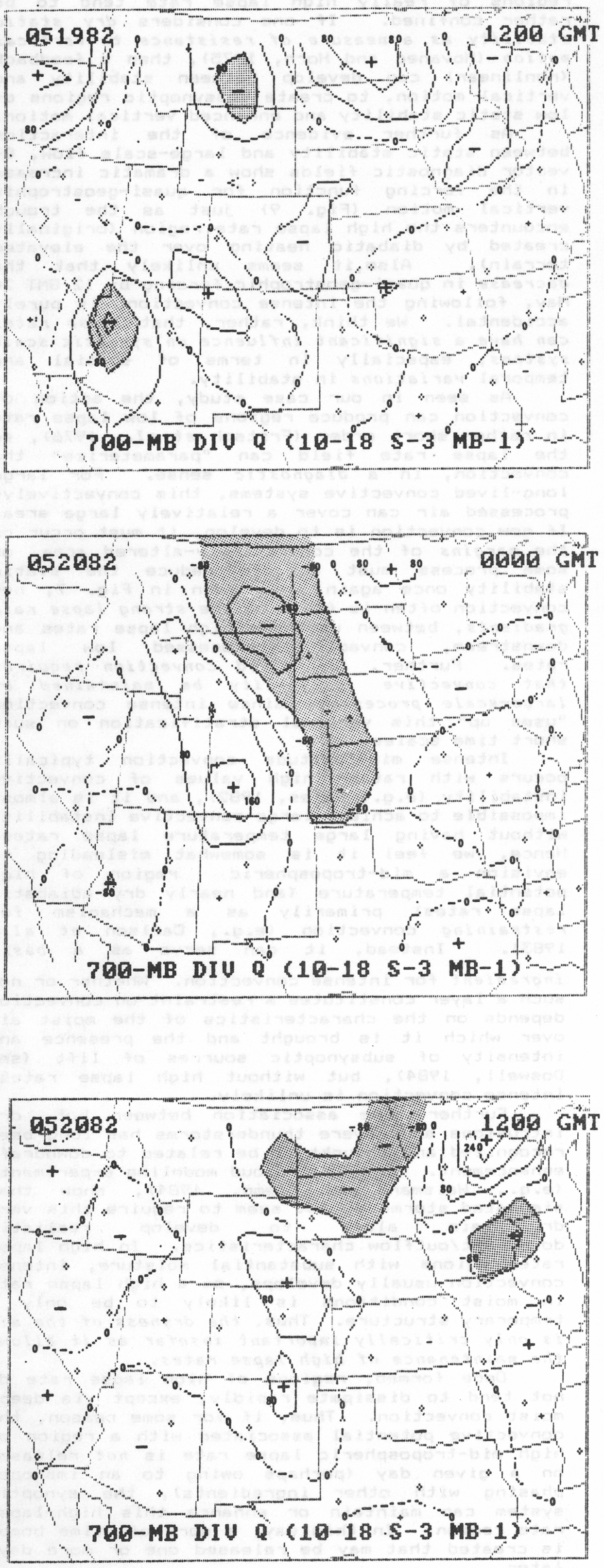

Fig. 9. Forcing function for quasi-geostrophic vertical motion at (a) 12 GMT 19 May, (b) 00 GMT 20 May, and (c) 12 GMT 20 May. Note that this is not vertical motion, but should be roughly proportional to it.

two regions overlap that the potential for intense convection is at its greatest.

Finally, conventional forecasting tends to focus on convective instability (i.e., the combination of lapse rate with moisture into a single "index"). The Vertical Totals Index of Miller (1972) has been in use for some time, but little attention has been paid to it by itself. Instead, it is usually combined with the Cross Totals Index to form the Total Totals Index. However, by diagnosing moisture and lapse rate *independently,* one can *anticipate* the creation of convective instability. That is, one can see regions of high lapse rate moving (and evolving) toward low-level moisture *before* the two combine to produce convective instability.

We believe that mid-tropospheric lapse rate can be valuable *by itself* both for forecasting and for the more abstract task of understanding atmospheric processes on a variety of scales. What we have presented here is but a small fraction of the ongoing research, to be reported on in detail in the future.

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