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SHORT-RANGE FORECASTS OF UPPER-TROPOSPHERIC DIVERGENCE USING 250 MB PARCEL TRAJECTORIES

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1. INTRODUCTION

Upper-tropospheric divergence is generally recognized as an ingredient for severe thunderstorms. There are certainly clear indications that on occasion the observed divergence is produced by the convection (Maddox, 1980; Ninomiya, 1971). Thus, using rawinsonde data to diagnose divergence (e.g., McNulty, 1977) is dangerous, since it may be contaminated by the effects one is trying to forecast. On the other hand, it sometimes appears that pre-existing (before convection) areas of divergence aloft moving through the flow are instrumental in creating a favorable environment for convection.

Since the divergence associated with NWP models is confined to large scales, the models cannot reasonably be expected to reveal much about the nature of the small-scale flow features. Rawinsonde data, as already suggested, can be contaminated by convection. Such contamination renders questionable the use of the divergence tendency equation (see Schaefer, 1977) for short-range forecasting. Since wind fields show little continuity in their small-scale detail (Doswell and Lemon, 1979), simple extrapolation of the observed divergence is of questionable value.

What is needed is a method to forecast the development and movement of upper-tropospheric divergence regions. The approach chosen must be capable of resolving relatively small-scale detail. We suspect that such detail is actually present in the flow and is a major factor in delineating areas of convection.

2. THE METHOD

A trajectory approach is used since an inherent feature of fluid flow is its *deformation* (Fjortoft, 1960). When using Lagrangian methods, one must consider how to deal with vertical motions. Petersen and Uccellini's (1979) trajectory model uses isentropic coordinates, which allows the incorporation of adiabatic vertical motions. Here, attention is confined to the upper troposphere, so net vertical displacements over the short time spans involved are small, and an *isobaric* trajectory is not likely to be too far in error (Wilson, 1977).

Accordingly, the isobaric momentum equations used can be written:

$$\frac{du}{dt} = fv - m\frac{\partial\phi}{\partial x} - \kappa u, \qquad (1a)$$

$$\frac{dv}{dt} = -fu - m\frac{\partial\phi}{\partial y} - \kappa v, \qquad (1b)$$

where m is the map factor, u and v are the x and y coordinate velocity components on the grid (Fig. 1), f is the Coriolis parameter, ϕ the geopotential and κ the friction parameter (explained below). Note that the velocity components

$$u = m^{-1}\, dx/dt,\quad v = m^{-1}\, dy/dt, \qquad (2)$$

are not the zonal and meridional components and that terms in (1) involving the gradients of m have been neglected.

On a large grid (Fig. 1), which is a subset of the LFM-1 (or "half-JNWP") grid, a single-pass Gaussian interpolation (e.g., Barnes, 1964) of the rawinsonde data at 250 mb is done to produce fields of ϕ, u, and v at the initial time. Then, a small subset of this grid (also shown in Fig. 1) is used to define a set of points. These points are the initial positions of those parcels for which time integration is performed. Testing has suggested that the scheme described by Petersen and Uccellini (1979) is superior to centered time differencing and so that method was chosen. A time step of 600 s (10 min) is used and results are for 36 time steps, or 6 h.

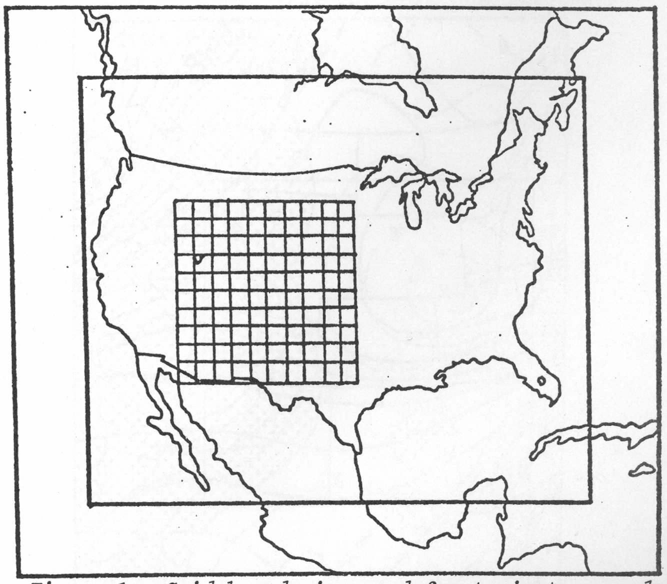

Figure 1. Grid boundaries used for trajectory analysis. Outer grid boundary is that upon which wind and height fields are analyzed, while the inner subset (showing the actual grid box size) defines the initial parcel locations for which trajectories are computed.

Initial runs were for inviscid flow; $\kappa \equiv 0$. However, it became evident that some sort of frictional damping was needed. The Guldberg-Mohn closure scheme (e.g., Schaefer and Doswell, 1980) offers the advantage of simplicity, provided one can estimate κ in a reasonable way. While Schaefer and Doswell use the isobaric crossing angles to estimate κ for surface lows, this is not practical in the upper troposphere. Instead, the damping has been made proportional to the square of the vorticity (at the start of the current time step):

$$\kappa = C\zeta^2, \qquad (3)$$

where C for these preliminary experiments was arbitrarily set to a value of 5.0×10^4 s. Using this parameterization, the damping is largely confined to those zones where the deformations (and, hence, mixing) are most intense. Within the model, κ is constrained to have a magnitude no larger than the local value of f.

For the evaluation of divergence and vorticity, the line integral technique is ideally suited to Lagrangian methods. This follows very closely the description by Schaefer and Doswell (1979), except quadrilaterals are used (rather than triangles), defined by the four points of the original grid squares.

For testing, a series of increasingly complex trajectory forecasts is run with initial conditions from 1200 GMT, 17 March 1981 data (Fig. 2). These are described in Table 1. Note that the height gradients are interpolated to parcel positions after the initial time (and velocity components to parcel positions for the kinematic trajectories) via Newtonian divided differences (see e.g., Hildebrand, 1956, p. 44), using the gridded analyses. Further, the height changes in the unsteady forecast are derived by linear interpolation of the observed 12 h height changes (see Fig. 2) to each time step, even though this gives only a rough approximation to the instantaneous height tendency at each time step (Saucier, 1955, p. 243).

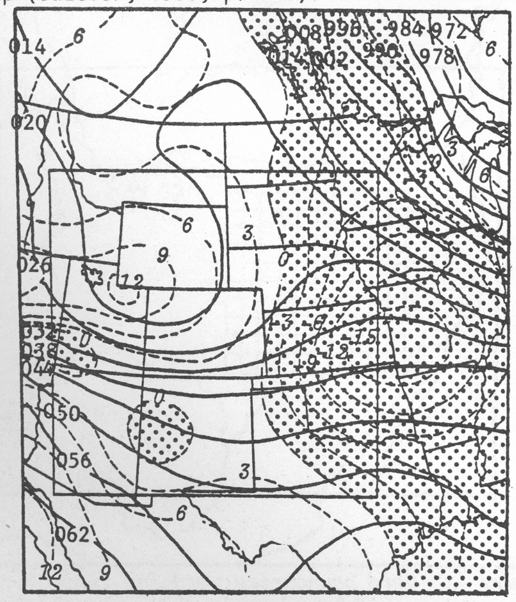

Figure 2. Height analysis for 250 mb (solid lines, dam) at 1200 GMT 17 March 1981 and 12-h height change (dashed line, dam) between that time and 0000 GMT 18 March 1981. Height falls are stippled.

TABLE 1
DESCRIPTION OF TRAJECTORY FORECAST EXPERIMENTS

Experiment	Equations	Features
Kinematic	(2)	
Inviscid Dynamic	(1)	κ=0 steady heights
Viscous Dynamic	(1)	$\kappa \neq 0$ steady heights
Unsteady Dynamic	(1)	$\kappa \neq 0$ unsteady heights

3. RESULTS OF THE EXPERIMENTS

The initial divergence and vorticity are shown in Figures 3 and 4, respectively. For comparison, the IR satellite image at 1200 GMT is shown in Fig. 5. The "comma cloud" through central Kansas into western Oklahoma and the Texas panhandle is located roughly along the zero relative vorticity line in Fig. 4. The head of the comma is in a divergence area centered in southern Nebraska.

The *viscous dynamic* version is shown in Fig. 6 (Space does not permit showing the kinematic and inviscid dynamic trajectory forecasts.). Note the divergence center in southern Kansas and the quasi-linear structure of the field. A long, narrow zone of large convergence is present in east central New Mexico, with rather intense gradients.

The *unsteady dynamic* forecast is shown in Fig. 7. While the final parcel positions are only slightly influenced by the isallohypsic contribution, the divergence field has some major differences from that of Fig. 6. The tendency for linear features has been enhanced by including the moving height field. Further, a convergence maximum has replaced the divergence in western Oklahoma.

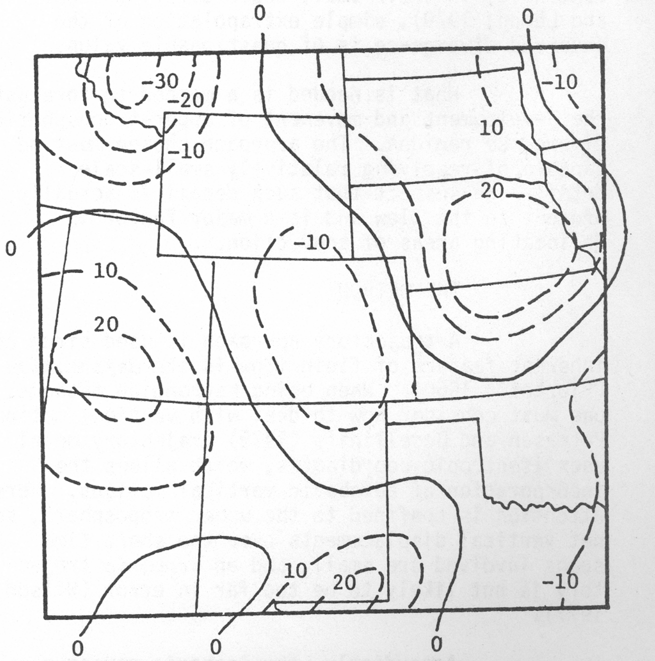

Figure 3. Initial divergence analysis (times 10^{-6} s^{-1}, so that /f/~100) at 1200 GMT, 17 March 1981.

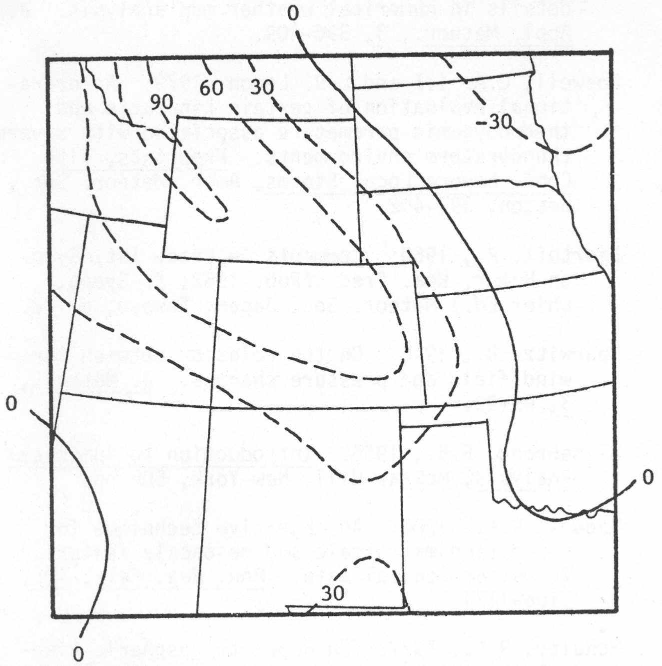

Figure 4. As in Fig. 3, except for relative vorticity.

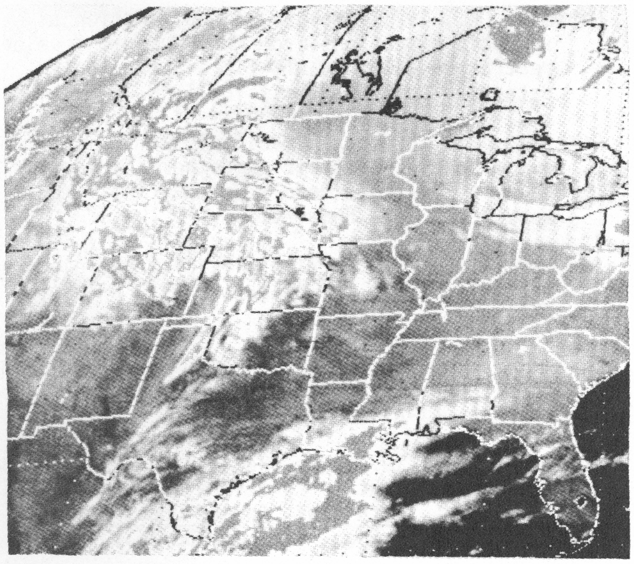

Figure 5. Enhanced IR satellite image at 1200 GMT, 17 March 1981.

4. DISCUSSION OF THE RESULTS

While there are many aspects of these results worthy of attention, the most dramatic feature is revealed in comparing Fig. 8, the satellite image taken at the valid time of the 6 h forecasts, with Fig. 7. Of particular importance is the location of the comma cloud. The unsteady dynamic forecast reveals this feature to coincide with a divergence axis, and has put a zone of upper-tropospheric convergence in the wake of the comma cloud in the cloud-free area to the rear of the comma cloud. Behind this convergence feature, a second divergence axis appears, entering the Texas panhandle. This second feature is significant because thunderstorms developed about 3 h after this forecast time in southwestern Oklahoma

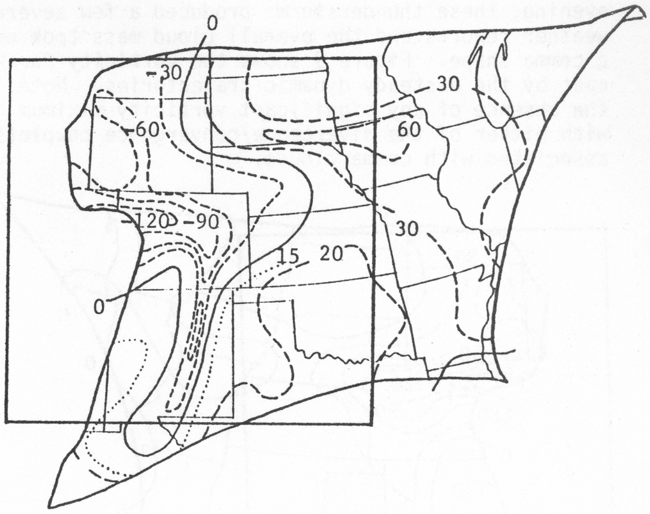

Figure 6. Viscous dynamic trajectory forecast of divergence (times 10^{-6} s^{-1}) valid at 1800 GMT 17 March 1981.

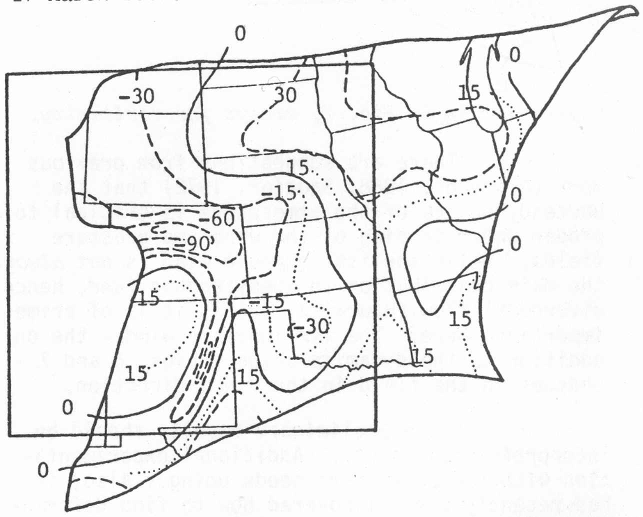

Figure 7. As in Fig. 5, except for the unsteady dynamic trajectory forecast.

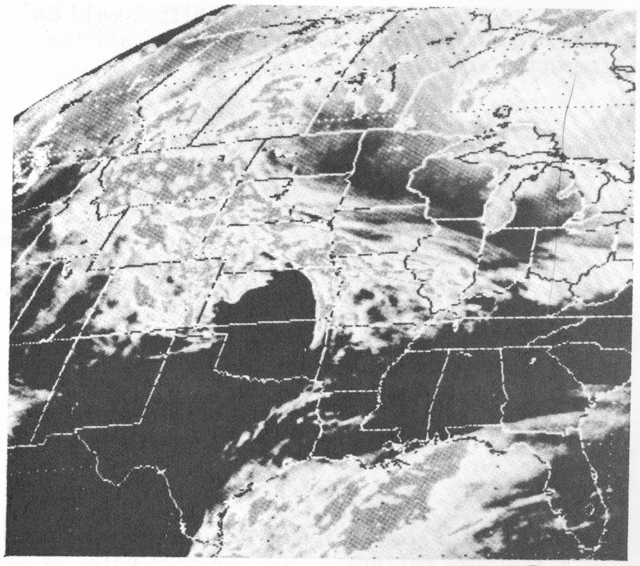

Figure 8. As in Fig. 5, except at 1800 GMT.

and the eastern panhandle of Texas. Later that evening, these thunderstorms produced a few severe weather reports and the overall cloud mass took on a comma shape. Figure 9 shows the vorticity forecast by the unsteady dynamic trajectories. Note the absence of any significant vorticity maximum with either of the divergence/convergence couplets associated with comma clouds.

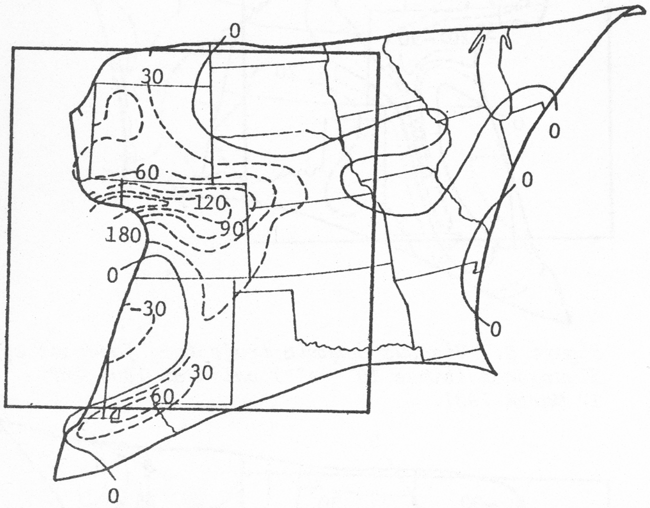

Figure 9. As in Fig. 7, except for voriticity.

There are suggestions from previous work (Albrecht, 1968; Saucier, 1972) that the unsteady nature of the atmosphere is critical to a proper understanding of the wind and pressure fields. While the isallohypsic wind is not *always* the main contribution to ageostrophic (and, hence, divergent) flow (Haurwitz, 1946), it is of prime importance here. The isallohypsic wind - the only addition to the dynamics between Figs. 6 and 7 - changes in the field in the right direction.

These preliminary results should be interpreted cautiously. Additional experimentation with the parameters needs doing. Also, it has recently been discovered how to find deformation via line integrals. This, it is possible to use deformation, rather than vorticity, in the viscosity parameterization. Since it is more accepted to use deformation, results should be compared. This work is underway, and will be reported upon at the conference.

Further, if the originally smooth fields can be deformed in 6 h to the extent shown, then the initial field is probably a very poor representation of the actual situation. This is an inescapable aspect to Eulerian analysis; linear features created by deforming fluid flow are wiped out by forcing the fields onto a regular grid. What is so surprising about these early findings is how well the unsteady dynamics forecast has done in moving and developing the divergence field, given the fact that the initial field is likely a highly smoothed version of reality. Perhaps such success is fortuitous, but only further testing can resolve the issue.

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