The "Short Fuse" Composite: An Operational Analysis Technique for Tornado Forecasting

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1. INTRODUCTION

The concept of composite analysis for use in prediction of severe storms is far from new and probably reached maturity in the late 1960s to early 1970s through the work of *Miller* [1972]. A real value of the composite analysis is that it leads the meteorologist through a careful analysis of the initial atmospheric conditions [*Doswell*, 1982]. The "short fuse" composite is an attempt to extend the composite method to hourly surface data sets with the explicit purpose of making a tornado forecast.

In forecasting the tornado environment it is clear that no "mandatory" or "magic" numbers will suffice. Rather, it is through the interpretation and understanding of the analyzed fields that one comes to recognize those mesoscale features which are most closely associated with an incipient tornado.

This technique is designed for use by an operational forecaster, who must function under the constraints of data sets that are often incomplete due to observation and communication failures, as well as computer run-stream priorities. It is possible that with the tremendous volume of new data sets becoming available to the forecaster, the saturation point cannot be far away. Therefore any method which allows a large set of atmospheric information to be digested simultaneously, especially on the mesoscale where the data density only compounds the problem, is worthy of consideration.

The idea of the "short fuse" composite grew from an attempt to refine the use of the Automation of Field Operations and Services (AFOS) Data Analysis Program (ADAP) to forecast only tornadoes. *Bothwell* [1988] has provided the forecaster with an excellent forecast tool which takes advantage of the density of surface observations, thus giving much finer resolution in a shorter time frame (hourly). He outlines a systematic approach to analysis of the 15 ADAP products that he presents in the form of a decision tree for forecasting convection. The "short fuse" composite uses only five of the ADAP products in a fast graphical approach to forecast only tornadoes. It is meant to be used with, not to replace, the ADAP decision tree.

2. THE "SHORT FUSE" COMPOSITE

The process begins with a typical *Miller* [1972] analysis of synoptic scale features at 0000 UTC and 1200 UTC, to which it may be helpful to add an analysis of storm-relative helicity. *Davies-Jones* [1983, 1984], *Davies-Jones et al.* [1990], and *Woodall* [1990] have shown the value of helicity as a forecast tool. Areas identified as favorable for significant rotating convection by this composite analysis are tracked hourly with the "short fuse" composite technique.

By using the analyzed parameters from ADAP, the following statement was seen to define a relatively small geographic area that contained a large proportion of the tornado occurrences.

> That area where the surface moisture flux convergence 1.5 g kg^{-1} h^{-1} isopleth overlaps the downwind side of the axis of potential temperature advection within the plateau (axis) of highest instability and where the cap inversion is less than 2°C.

Perhaps the most significant portion of the threat area so defined is with the overlapping of the downwind side of the axis of potential temperature (θ) advection by the 1.5 g kg^{-1} h^{-1} surface moisture flux convergence isopleth. It is this region where one can anticipate the greatest low-level directional shear or the greatest positive subcloud layer shear [*Davies*, 1989] to coincide with the strongest inferred upward motion and sufficient moisture for significant convection. Removal of the convective cap and inclusion of the most thermodynamically unstable air may add more to the chance of significant convection than it does to the likelihood of tornadoes. The implication is that storms developing in or moving into this environment would have the best chance of producing tornadoes.

The five charts for the composite and the parameters analyzed are as follows. (The AFOS graphics selected for

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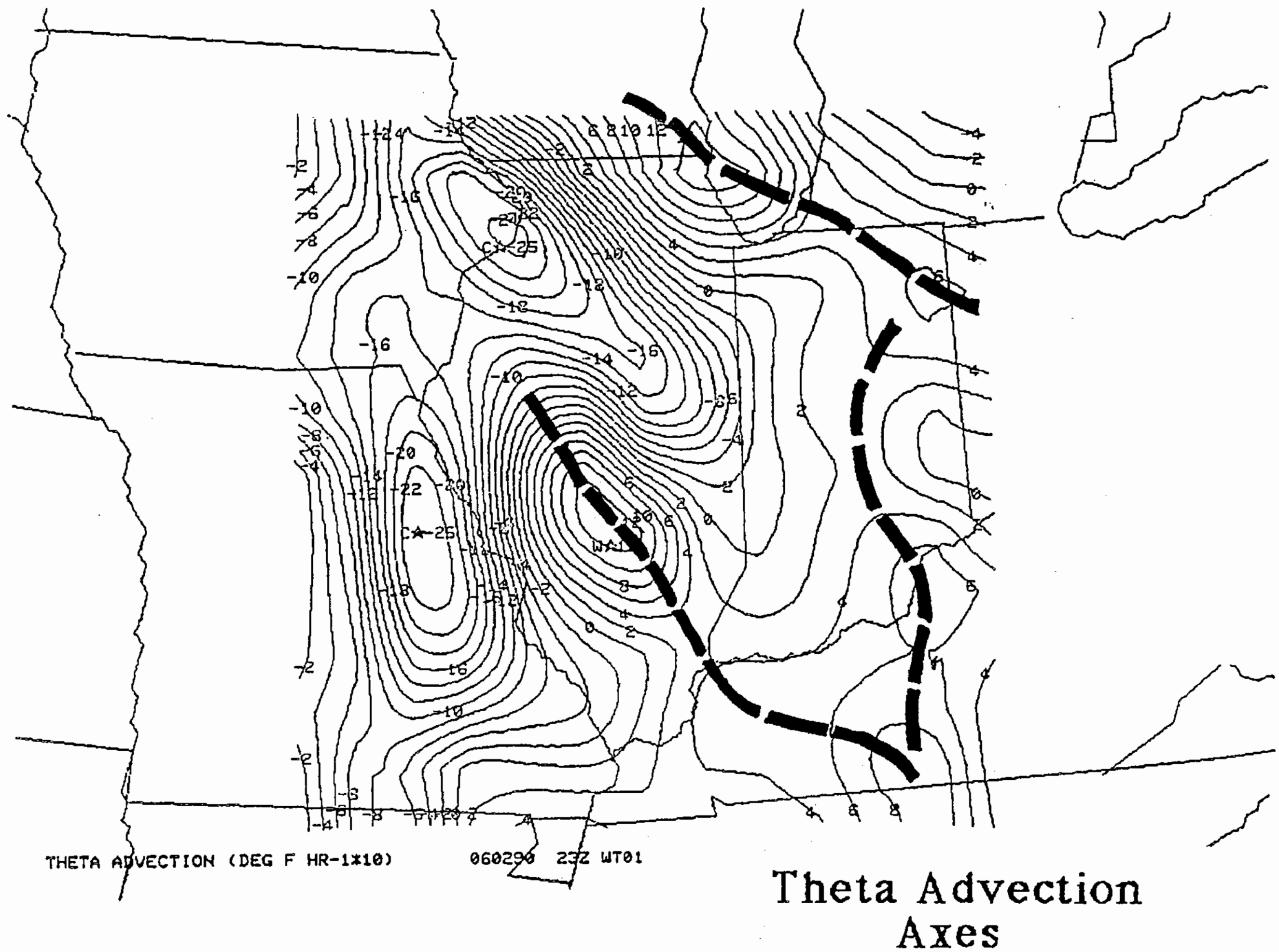

Fig. 1. The analysis of a typical θ advection (STA) graphic chart. The dashes show ridges (axes) of θ advection. It is also helpful to mark the centroid of maximum θ advection.

the composite will be identified according to the last three characters of the nine character group with the first six (NMCGPH) assumed.) (1) Surface cap inversion (SSC): select the 2°C isopleth, (2) Surface moisture flux convergence (SMC): select the 1.5 g kg^{-1} h^{-1} isopleth, (3) θ advection (STA) (Figure 1): analyze the axes of maximum θ advection values greater than zero and, using the surface wind vector streamlines (SSW), locate the downwind side of the axes, (4) Surface lifted index to 500 mbar (SSL) (Figure 2): select two or more isopleths that identify the "plateaus" (axes) of highest instability (greatest negative values). Finally, the parameters are transferred onto the composite map and the threat area is drawn in.

3. Results of the Case Studies

Since ADAP is a locally run computer applications program and is not archived (except occasionally on the local level), finding the data sets collected during actual tornado events proved to be a challenge. Twenty-seven cases were found with sufficient ADAP data to permit analysis. Several of them provided an opportunity to use the technique in real-time forecasting.

This technique is empirical; the derived fields of ADAP products were compared to a number of actual tornado events for which the data were available, and an isopleth which contained the majority of the events was selected.

The results were as follows.

Cap inversion. Of 66 tornadoes (27 cases), all but two tornadoes were first reported where the cap was weaker than 2°C during the preceding hour.

Surface moisture flux convergence. Of 66 tornadoes (27 cases), all but four tornadoes were first reported where the surface moisture flux convergence was 1.5 g kg^{-1} h^{-1} or greater during the preceding hour.

Downwind side of the θ advection ridge. Of 66 tornadoes (27 cases), all but two tornadoes were first reported on or just downwind of the axes of maximum advection of potential temperature during the preceding hour.

"Plateau" (axis) of greatest instability. Of 66 tornadoes (27 cases), all but four tornadoes were first reported upon the

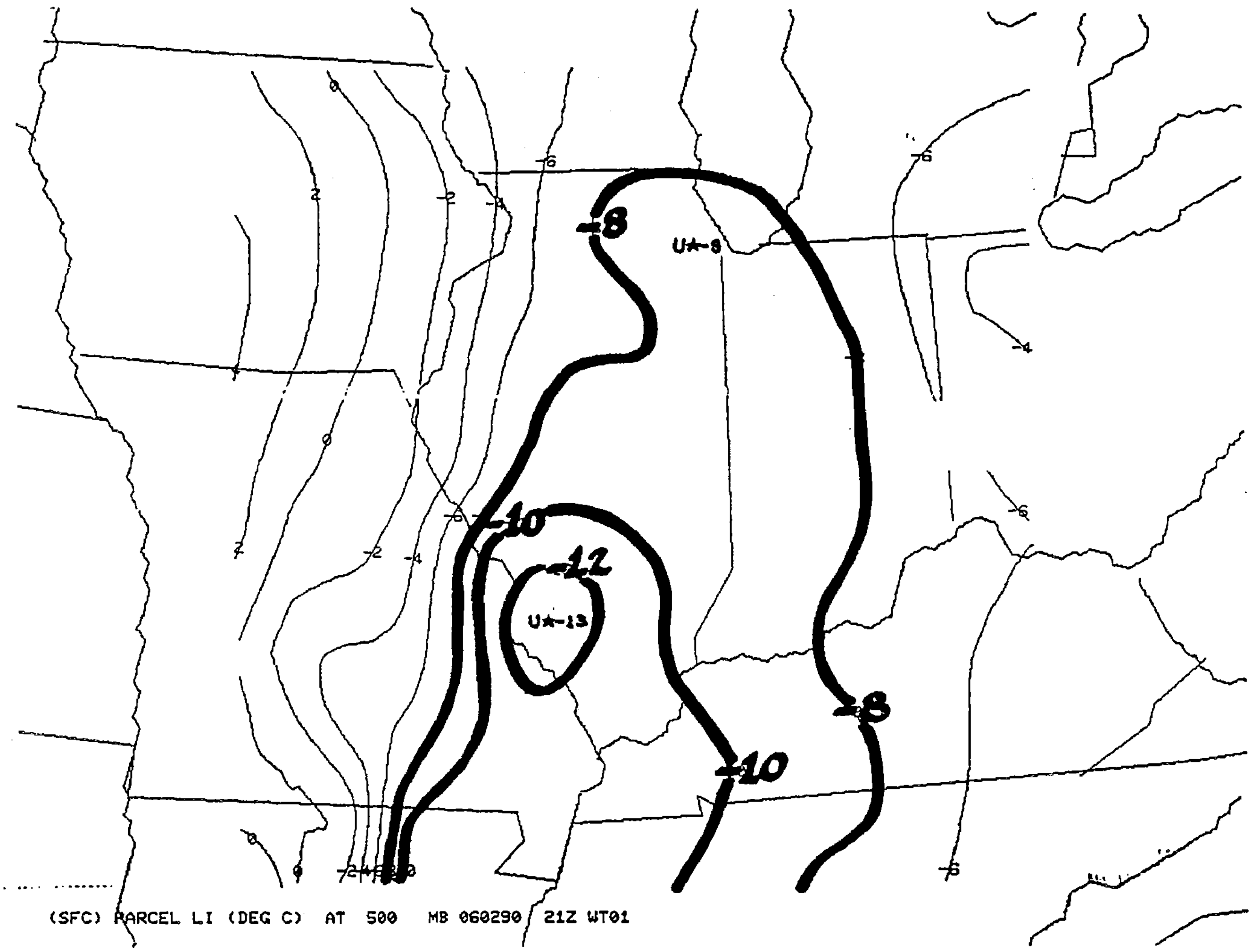

Fig. 2. The analysis of a typical surface lifted index (SSL) graphic chart. Heavier lines are the isopleths selected to define the "plateau" of greatest instability.

plateau of highest instability, with all but 14 first reported inside the isopleth of the highest instability. Again, this was from the hour immediately preceding the event.

4. Three Specific Cases

An example of a very small threat area was found November 28, 1988, at 0600 UTC (Figure 3), the day of the Raleigh-Durham tornado. Moisture was pooling along the east side of the mountains as south-southeast wind advected the θ axis into the moisture pool. Instability was not as extreme as in other cases. This storm likely would not have been forecast by the threat area on a purely subjective usage of the composite, since the threat area did not materialize until 0600 UTC, the time of the first tornado report. However, the chart-to-chart change from the preceding several hours did show the developing and nearly stationary moisture pool and the θ ridge moving northwestward into it.

In a second case, a relatively large threat area was indicated at 2200 UTC May 5, 1989 (Figure 4). Two F4 tornadoes occurred during the hour (2200–2300 UTC). It is not known if the F4 occurring at 0001 UTC would have been forecast or not since no ADAP data were available past 2200 UTC.

Composite charts from 2100 UTC and 2300 UTC on the day of the major tornado outbreak of June 2–3, 1990, are given in Figures 5 and 6. The initial tornadoes were reported on the downwind side of the strong θ advection and on the downwind side of the surface moisture flux convergence gradient [*Waldstreicher*, 1989] during the hour following the 2100 UTC composite threat area. Two hours later, the threat area had become elongated by southerly surface winds as moisture flux convergence continued to increase. During the next 2 hours, 10 tornadoes were reported. The threat area identified all but three of them, and the three misses were within a few kilometers of the threat area.

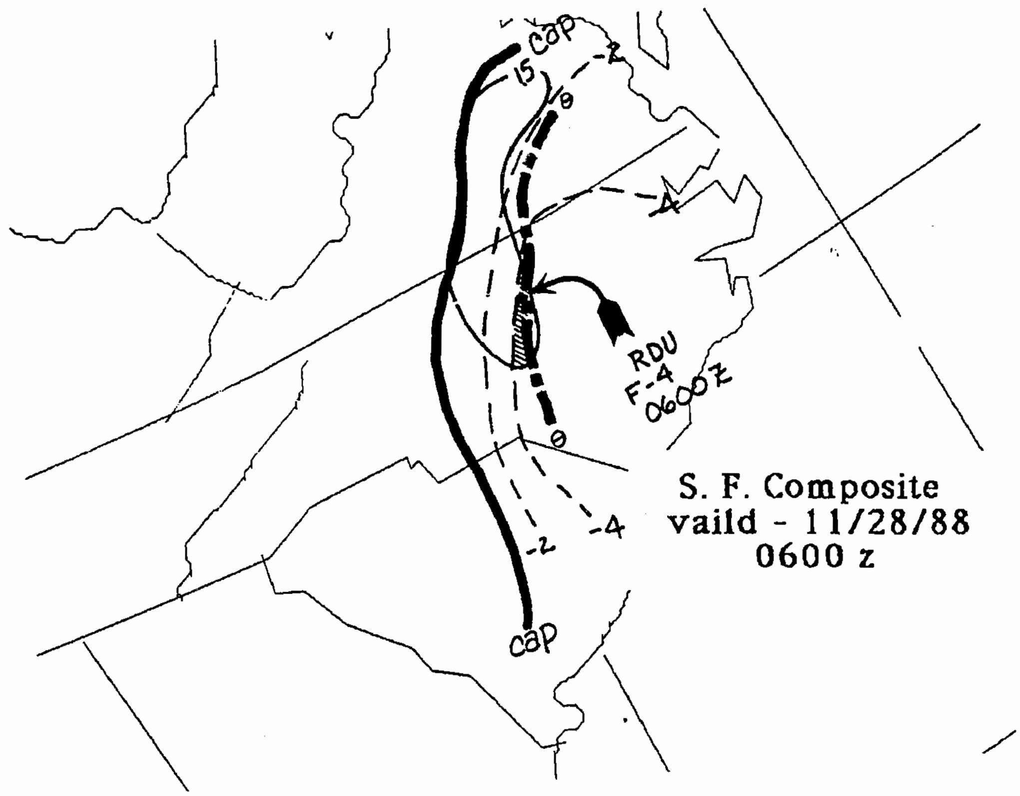

Fig. 3. A "threat area" is hatched in, while the arrow indicates the reported tornado (with time and F scale strength). Light dashes are the plateau of instability. The heavy solid line is the 2°C cap. The heavy broken line is the θ axis and the light solid line is the 1.5 g kg^{-1} h^{-1} surface moisture flux convergence isopleth. The "threat area" materialized at 0600 UTC, the time of the first tornado report.

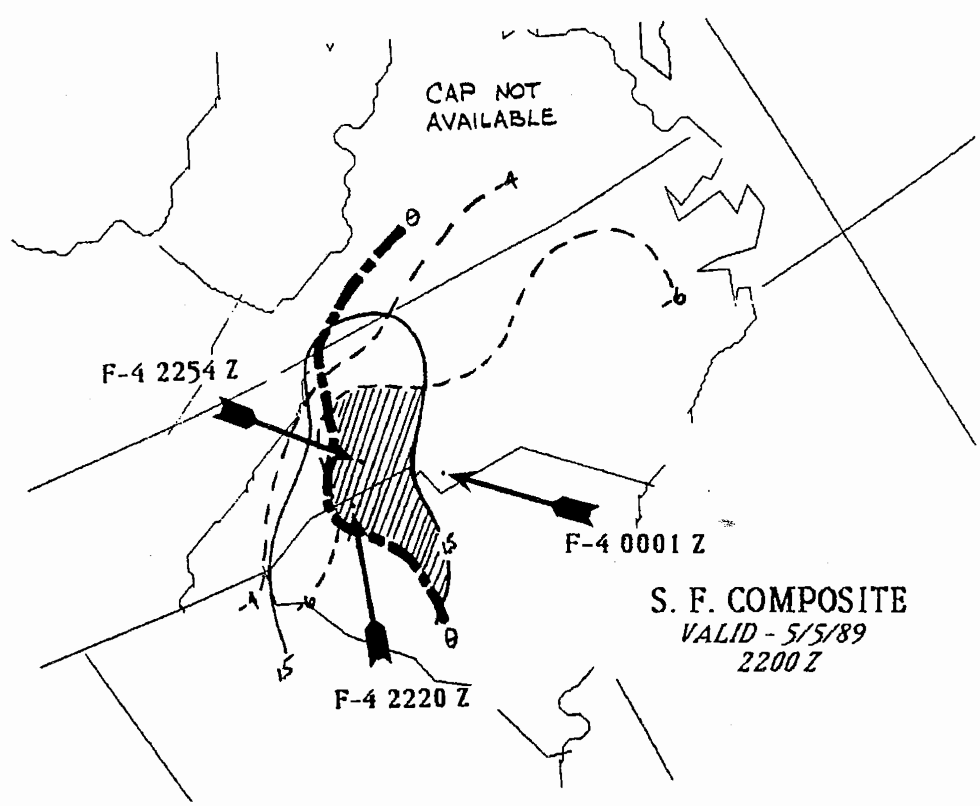

Fig. 4. Another outbreak in the Carolinas, this time with a large "threat area". The F4 tornado that occurred at 0001 UTC on May 6, 1989, was just outside the 2-hour-old "threat area." Had the cap strength (SSC) been available, perhaps the area would have been smaller.

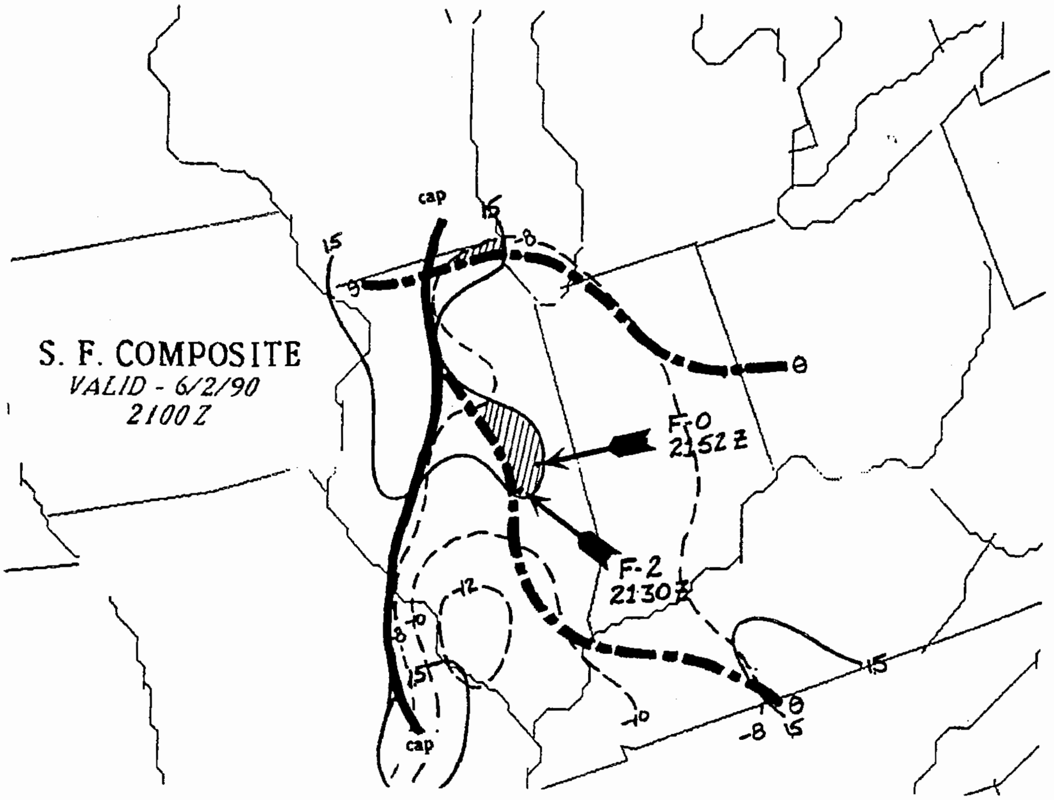

Fig. 5. Two "threat areas" are analyzed, with the northernmost being on the edge of the data fields where the objective analysis may be in some doubt. For this reason, the tornado that occurred just north of Chicago and inside this small "threat area" was not included in the verification.

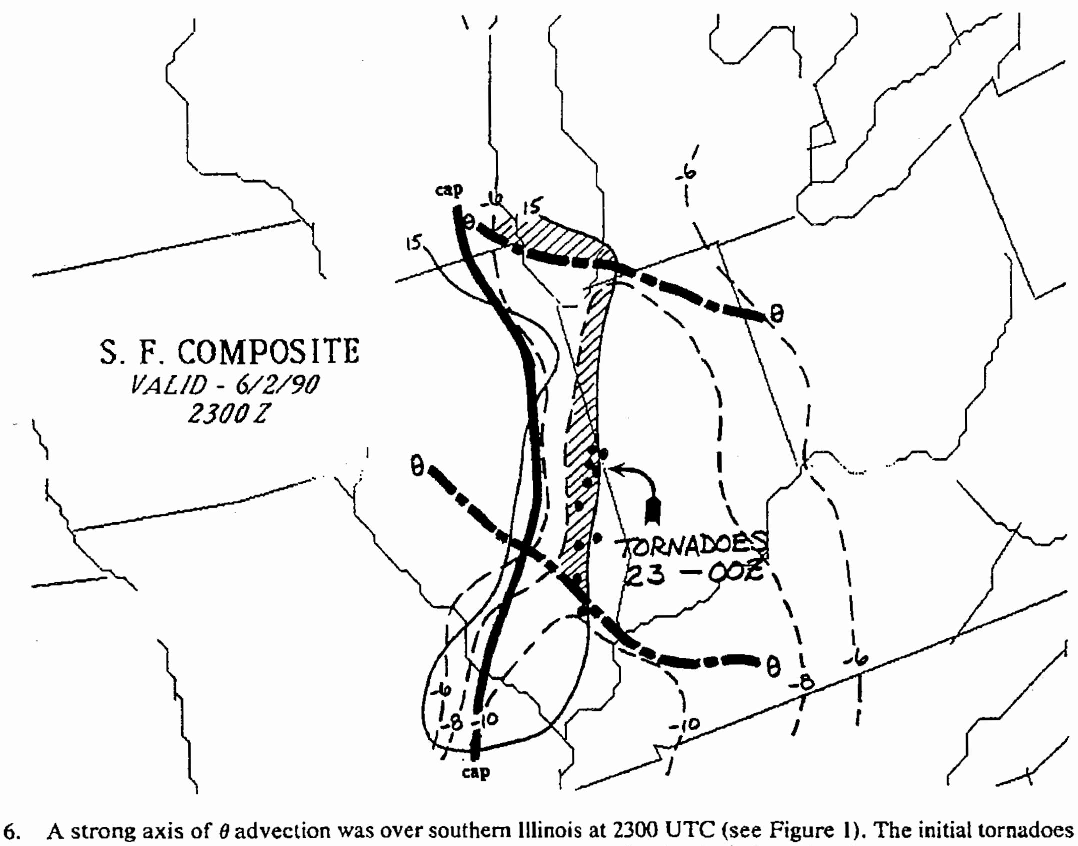

Fig. 6. A strong axis of θ advection was over southern Illinois at 2300 UTC (see Figure 1). The initial tornadoes from 2300 UTC began almost directly atop the strongest part of the θ axis. Analysis is as in Figure 3.

TABLE 1. Results of Simple Verification

	1 Hour After Composite Time	2 Hours After Composite Time
Total cases	27	9
Total tornadoes	66	26
Total within threat areas	56	17
Probability of detection	85%	65%

5. Verification of the Results

Only simple verification was attempted on the composite forecasts from the 27 cases studied. To relate the size of the threat area versus the number of tornadoes within the area is difficult since the threat areas were usually mesosynoptic to subsynoptic in scale and the tornado itself much smaller. For this reason, the only computation performed was probability of detection (POD). The POD is simply the number of correctly forecast events divided by the total number of events. The POD was computed using the number of tornadoes that occurred both in and out of the threat area for the hour immediately following the composite time and again for the hour beginning one hour after the composite time (Table 1).

As a control, two of the 27 cases had no severe thunderstorms and no tornadoes. A further six cases had severe thunderstorms but no tornadoes. The "short fuse" composite correctly indicated no tornadic activity for all of these null cases. In fact, every time a threat area developed, there was at least one tornado in it.

6. Summary

A POD of 85% for the initial hour after the composite time is quite good, even if one considers that ADAP requires 15 min to produce the analysis. Additional cases are being collected and analyzed to add more credence to the composite scheme presented here, but it bodes well for the technique that in all cases where the threat area did materialize, at least one tornado did occur within the threat area. Further, the technique often identified the initial convection that subsequently became tornadic and in several cases identified very small threat areas (of the order of 2–4 counties) in which a lone tornado was observed.

The technique presented has been in use at the weather service office in Dodge City, Kansas, for nearly six months as of this writing, and the results have continued to be encouraging. Spring 1991 was a particularly busy severe weather season, and the technique was at least partly responsible for the timely issuance of several verified tornado warnings. Most importantly, the warnings were issued before the event with a much greater degree of confidence, and use of the technique allowed probable tornado situations to be separated from probable severe thunderstorm events.

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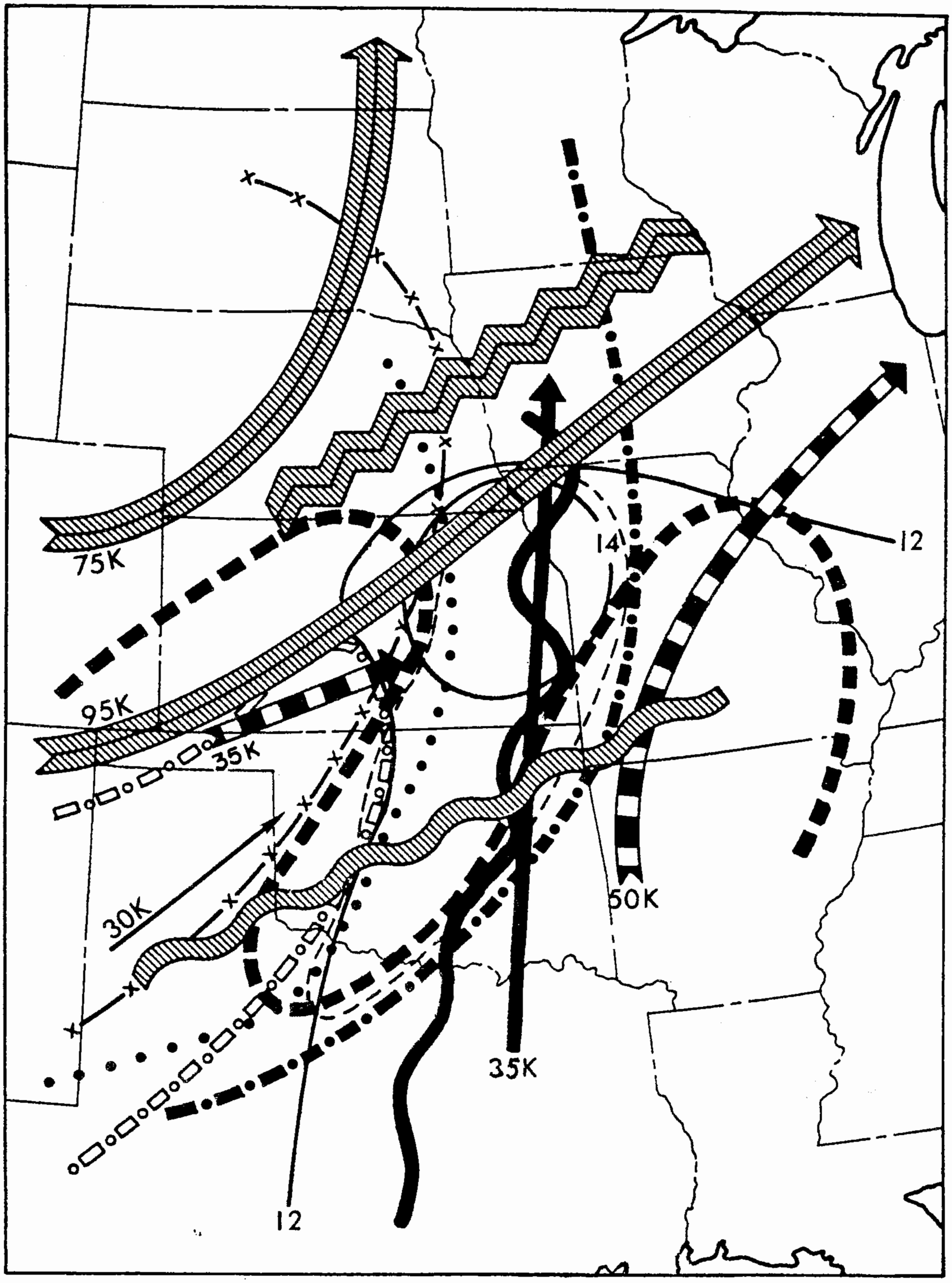

Figure 76. Composite Chart for 09/0000Z.