

SEVERE WEATHER

THE SURFACE CROSS TOTALS INDEX: AN ALTERNATIVE FOR DIAGNOSING INSTABILITY USING HOURLY SURFACE DATA

Jon Davies (1) Davies/The Harvester Co., Inc.
Pratt, Kansas 67124

ABSTRACT

An easily calculated surface-based instability index, the surface cross totals index (SCT), is presented, similar to the established cross totals index. The SCT is shown to be a useful high-resolution parameter in diagnosing instability when forecasting severe thunderstorms. Because of its simplicity, the SCT is suitable for manual calculation from hourly surface data, an advantage for meteorologists who do not have automation or software readily available. In an automated work station environment, the SCT may prove useful as a supplement to the surface-based lifted index (SLI).

1. INTRODUCTION

The cross totals index (Miller, 2), by itself or as a component of the total totals index, has been generally accepted as one of the many useful indices calculated from rawinsonde data for measuring instability. Some advantages of the cross totals index (CT) are its easy calculation (simple subtraction of the 500-mb temperature from the 850-mb dew point), and the fact that it combines steepness of lapse rate and moisture availability into one index. A disadvantage is that significant moisture may lie below the 850-mb level so that the CT can "overlook" it. Also, the CT can only be calculated at 1200 GMT and 0000 GMT using low-resolution rawinsonde data.

The author was recently involved with a project where a surface-based high-resolution instability parameter was desirable, but the automation that helps make the surface lifted index (SLI) from surface lifted parcel temperatures (Hales and Doswell, 3) such a beneficial tool in real-time was not available due to equipment and software constraints. As Hales and Doswell point out, surface data may not always be representative of changes aloft, but any information that adds to the diagnosis of instability is valuable to the forecaster.

It was decided to experiment with a similar surface-based estimation technique using simply two variables, surface dew point and manually interpolated 500-mb temperature, to calculate a surface-based cross totals index (SCT) such that:

$$SCT = T_{d_{fc}} - T_{500mb} \text{ (degrees Celsius).}$$

It would be expected that threshold values for severe thunderstorms with the SCT would be higher than with the CT, owing to the use of surface data which, outside of overrunning situations, would normally be warmer and more moist.

Using a current regional surface plot from hourly SA data, a recent or forecast-adjusted 500-mb temperature analysis, and a calculator (for Fahrenheit to Celsius conversion), the author found SCT estimated values were easily calculable in minutes for a manual analysis over a regional area. Admittedly, such an approach seems simplistic: the SCT, in using only surface dew point (not surface temperature), does not measure diurnal variation in instability through surface heating as does the SLI.

On the other hand, the SCT should do a reasonable job outlining areas of "potential" instability, apart from or before the onset of surface heating. The SCT does reflect the small diurnal changes associated with dew point (typically less than 5° F). It also will reflect changes in instability due to moisture advection.

Over a two month test period, SCT values in cases where severe thunderstorms occurred were found to be reasonably consistent, and therefore useful as a short-term forecasting/nowcasting parameter.

Table 1 shows representative SCT values for a set of severe

Table 1. A general survey of SCT values on 24 days in May 1988 when significant severe weather was reported. SCT ranges are representative of SCT values calculated over the area of severe occurrences using representative surface dew points and 500-mb data closest in time and space to that area. Cases where the area of severe occurrences overlapped into terrain west of the 100th meridian (High Plains) are so indicated.

Date	General area of severe reports	Representative range of SCT's
5/2/88 PM	OK/KS	29-34
5/3/88 PM	AR/TN/NC	30-31
5/4/88 PM	GA/SC/NC	30-31
5/6/88 PM	MT/WY/SD/ND (High Plains)	24-25
5/7/88 PM	MN/IA/ND	27-29
5/8/88 AM-PM	KS/MO/IA/WI/IL/AR	30-34
5/9/88 PM	MI/IL/IN/OH/PA/KY/TN/AL/MS	30-32
5/10/88 AM	AL	32-33
5/10/88 PM	GA/NC	31-34
5/11/88 PM	TX	31-32
5/15/88 PM	IL/MI/IN/OH	29-30
5/15/88 PM	OK	29-30
5/16/88 PM	Mid-Atlantic States	29-32
5/17/88 PM	Mid-Atlantic States and Southeast	28-32
5/18/88 PM	Mid-Atlantic States and Southeast	28-31
5/19/88 PM	NM/TX (High Plains)	28-29
5/19/88 PM	NE/SD	28-29
5/20/88 PM	NE/SD	28-29
5/20/88 PM	NM/TX (High Plains)	29-30
5/21/88 AM-PM	TX/LA	29-32
5/22/88 PM	MS/AL/TN	30-32
5/23/88 PM	Mid-Atlantic States and Southeast	30-34
5/24/88 PM	GA/NC/SC/FL	30-32
5/27/88 PM	KS/NE/SD/ND (High Plains)	27-29
5/28/88 PM	ND/MN	30-31
5/28/88 PM	NM/TX (High Plains)	30-31
5/29/88 PM	TX (High Plains)	28-29
5/30/88 PM	NM/TX (High Plains)	27-28
5/30/88 PM	NE	27-28
5/31/88 PM	TX/OK/KS	30-31

from the 2300 GMT surface data (evening 500-mb data later showed this assumption to be correct as 500-mb temperatures at both Topeka and Omaha varied only 0.2°C from the morning data). Converting the surface dew-point values in Figure 1A to Celsius, and subtracting from them visually interpolated 500-mb temperatures for the same approximate points from Figure 1B, produces the SCT values in Figure 1C (rounded to 0.5°C increments). Figure 1C took the author less than 5 min to produce in real time after the 2300 GMT data was available.

It is interesting to note the 29.5 SCT maximum over Omaha in Figure 1C. Around 2300 GMT, thunderstorms that had developed along a north-south convergence line (heavy dashed line in Figs. 1A and 1C) produced several reports of winds in excess of 50 kt in and just north of the Omaha area, with damage to trees and power lines. Further south along the same convergence line, where SCT values were less than 28, thunderstorms in southeast Nebraska and northeast Kansas remained below severe limits. In this very marginal situation, Figure 1C would have provided useful information to a forecaster/nowcaster in Topeka or Omaha as to the short-term future severe potential of the storms that formed along the convergence line.

For purposes of this study, the SCT serves as a simple gauge of estimated atmospheric instability as input to answer the question, "If thunderstorms form, will they be severe?". Because more than instability is required to generate thunderstorms, the SCT (or any other stability index) is not a direct predictor of severe thunderstorms. As with SLI's, the SCT is intended to be useful in conjunction with (not as a substitute for) parameters such as streamline or moisture convergence, low-level warm advection, etc. that help the forecaster delineate where thunderstorms will form.

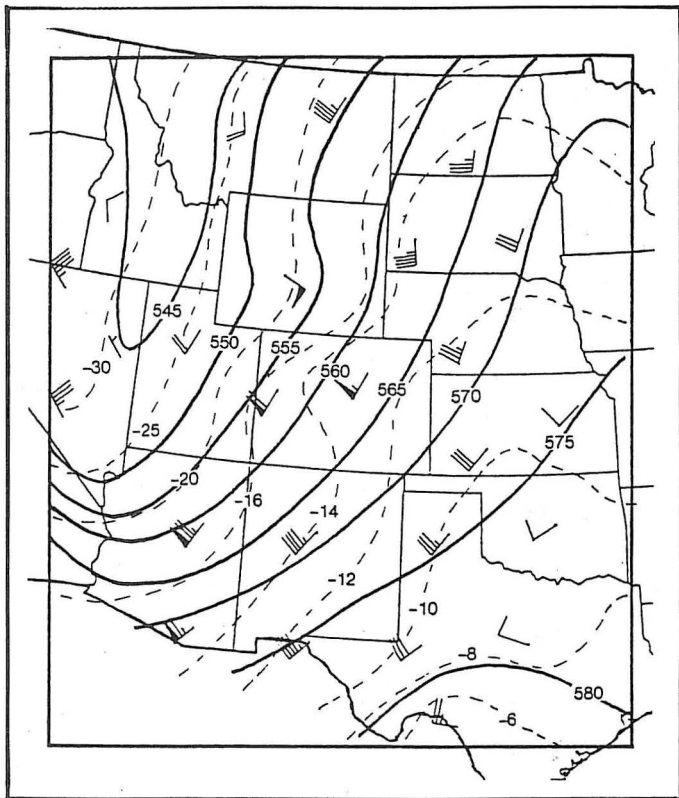


Fig. 2A. 500-mb features 1200 GMT 1 May 1988 Heights solid (ten's of meters), significant isotherms dashed (°C), wind (full barb = 10 kt).

Three case studies showing the surface-based cross totals as a useful instability index are presented, and comparisons with the surface-based lifted index are made.

3. CASE STUDY 1—MAY 1, 1988

On this day, a slow-moving 500-mb trough was over the intermountain region (Fig. 2A). Dew points in the 50's were present over the Texas panhandle during the early afternoon (Fig. 2B) with a well-defined dry line in place over extreme eastern New Mexico and eastern Colorado. With the proximity of the polar jet, surface heating, and a moisture convergence center near Dalhart, convection began to build over northeast New Mexico and the northwest Texas panhandle around 2030 GMT. A tornado watch was issued at 2048 GMT over northwest Texas into southwest Kansas and southeast Colorado.

SLI's generated manually from 2000 GMT surface data and 1200 GMT 500-mb temperatures (Fig. 2C) were -4 approaching -5 over the Texas panhandle, indicating a moderately unstable atmosphere. In contrast, SCT's generated from the same data (Fig. 2D) were only 22–24 over the same area, *below SCT severe threshold values* previously discussed, even considering the elevation of the terrain.

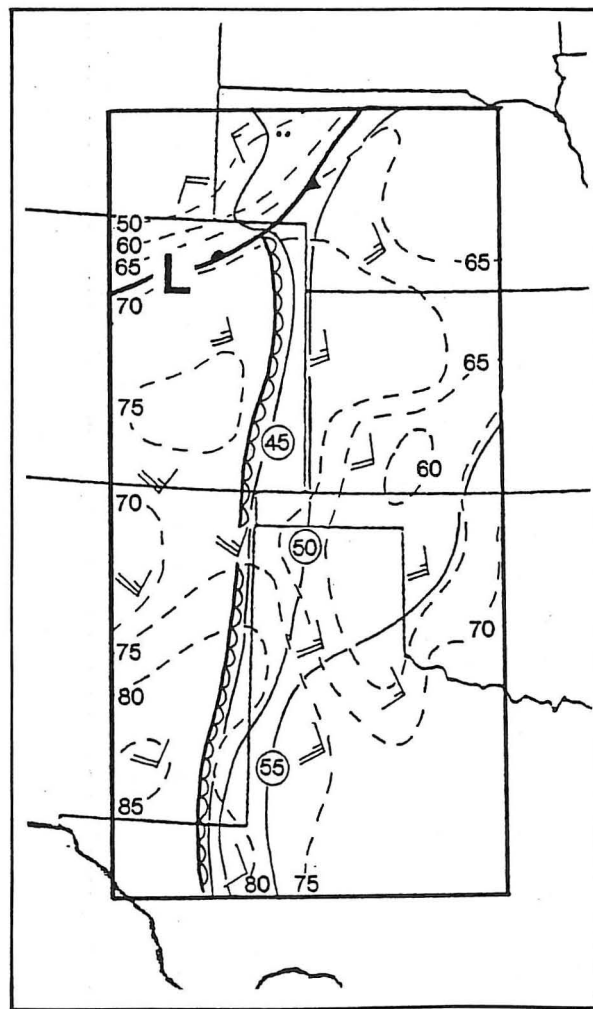


Fig. 2B. Surface map 1800 GMT 1 May 1988. Surface features (conventional), significant isotherms dashed (°F), significant isodrosotherms solid (°F, labels circled), wind (full barb = 10 kt).

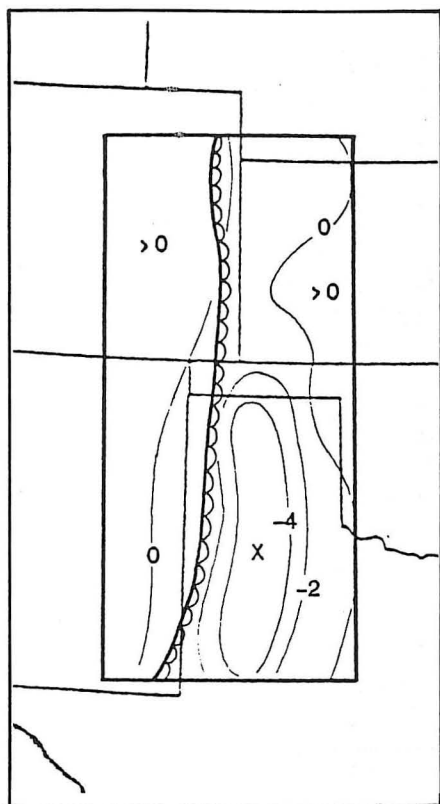


Fig. 2C. Surface-based lifted index (SLI's) from 2000 GMT 1 May 1988 surface data and 1200 GMT 1 May 1988 500 mb data. 'X' denotes maximum. 2000 GMT dryline (conventional) also indicated.

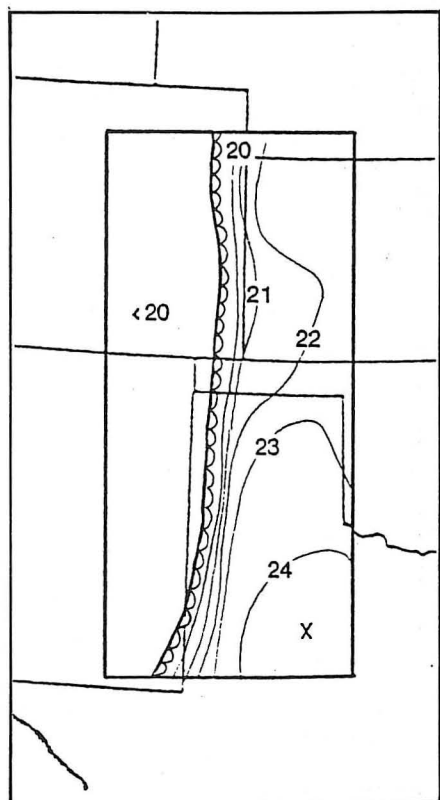


Fig. 2D. Surface-based cross totals index (SCT's) from same data as Figure 2C. 'X' denotes maximum.

Thunderstorms blossomed during the late afternoon and evening from the northern Texas panhandle into southeast Colorado and southwest Kansas, but no severe reports were documented in the watch area. It appears that sufficient instability was lacking for storms to reach severe limits. In this case, the SCT's were a good clue to this lack of instability, seemingly more so than the SLI's.

4. CASE STUDY 2—MAY 2, 1988

This following day, a closed 500-mb Low which had developed from the digging trough of case 1 and was moving eastward accompanied by a strong south-north polar jet through the central plains (Fig. 3A). A strong surface dry push was evident southeast of the Low across western Oklahoma into southwest/south central Kansas through the afternoon. As on the previous day, moisture again was marginal with only a narrow band of higher dew points advecting northward ahead of the surface dry line at 2100 GMT (Fig. 3B).

A mid-afternoon SELS discussion noted that SLI's calculated using 2000 GMT surface data and the morning LFM 12-hour 500-mb forecast were around 0 (stable) along the dry line. Similarly, manually generated SLI's using 2100 GMT surface data and 1200 GMT 500-mb temperatures were only 0 to -1 (marginally unstable) near developing convection in south central Oklahoma (Fig. 3C). All this seemed to indicate a lack of strong instability.

However, SCT's from the same data (Fig. 3D) were more revealing; they showed a maximum value near Ardmore of over 30, indicating considerable instability. After 2200 GMT, the developing convection near Ardmore intensified and pro-

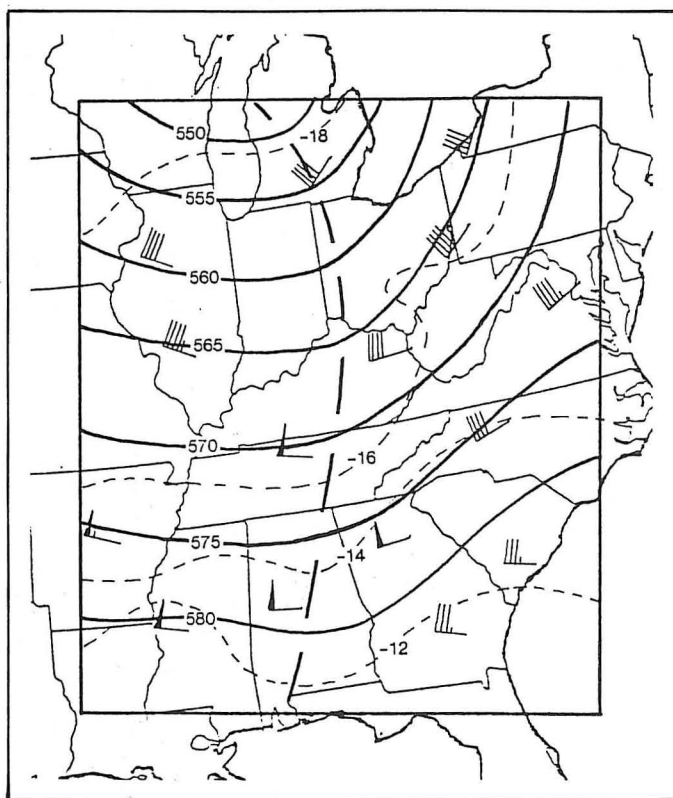


Fig. 3A. 500-mb features as in Figure 2A, except 1200 GMT 2 May 1988.

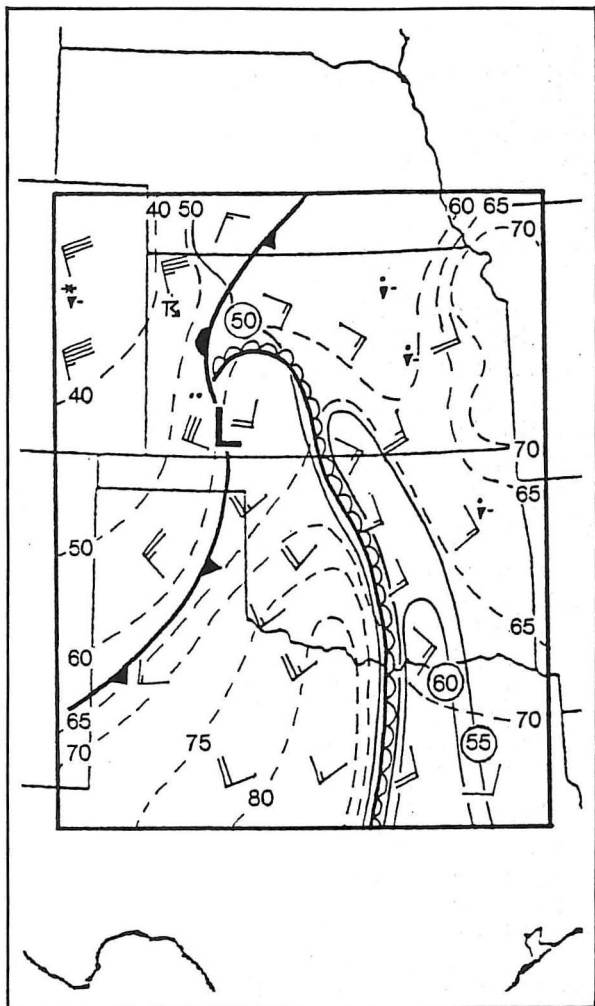


Fig. 3B. Surface map as in Figure 2B, except 2100 GMT 2 May 1988.

duced a tornado around 2245 GMT. Wind damage and golf ball-size hail were also reported.

This particular situation is interesting in that the 500-mb Low at 1200 GMT over Colorado was forecast by the NGM and AVN models to take a northeasterly track (most morning forecast discussions agreed with this solution). Instead, the upper Low and cold pool moved east-southeast during the day, resulting in 500-mb temperatures 3° to 4°C colder than expected over central and south central Oklahoma at 0000 GMT 3 May 1988 (SCT near 34 at Ardmore, not shown). In spite of the underforecast 500-mb temperatures, the SCT analysis from available data at 2100 GMT 2 May 1988 still hinted strongly at the instability present in the vicinity of the developing convection.

Weak "cold pool aloft"-type tornadoes occurred with thunderstorms in south central Kansas after 0000 GMT 3 May 1988 (some damage was reported) where SCT values from 0000 GMT 500-mb and surface data were in the 29–32 range (not shown).

5. CASE STUDY 3—MAY 9, 1988, EVENING

The 0000 GMT 500-mb analysis (Fig. 4A) located a short wave passing across a surface front (Fig. 4B) from Ohio to Tennessee, continuing to support a broken line of thunderstorms extending from north central Tennessee through south

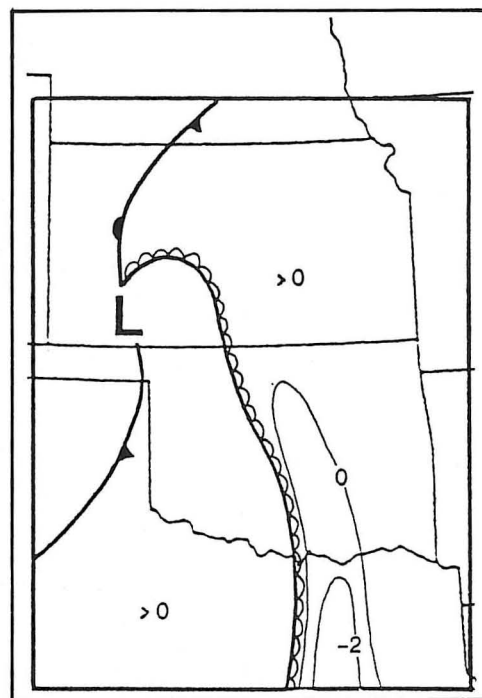


Fig. 3C. SLI's from 2100 GMT 2 May 1988 surface data and 1200 GMT 2 May 1988 500-mb data. 2100 GMT surface features (conventional) also indicated.

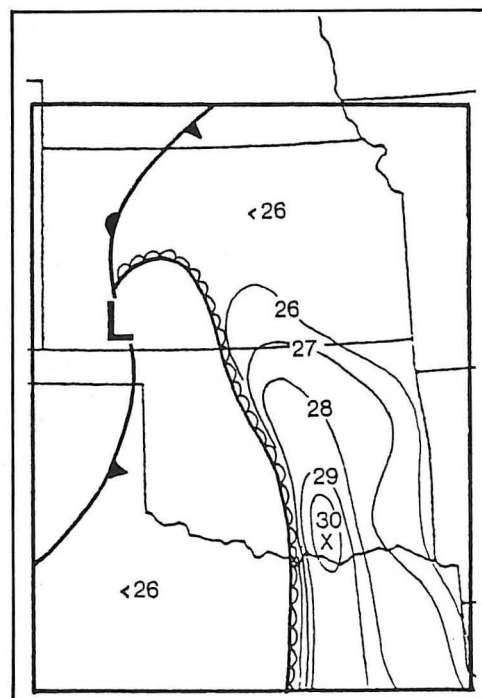


Fig. 3D. SCT's from same data as Figure 3C. 'X' denotes maximum.

central and southeast Kentucky to eastern Ohio. Other heavy thunderstorms were occurring in eastern and northeast Alabama. Numerous severe weather reports had been received during the day over the Ohio Valley from the same system. However, by 0000 GMT all watches had expired, and activity seemed to be on a downhill trend.

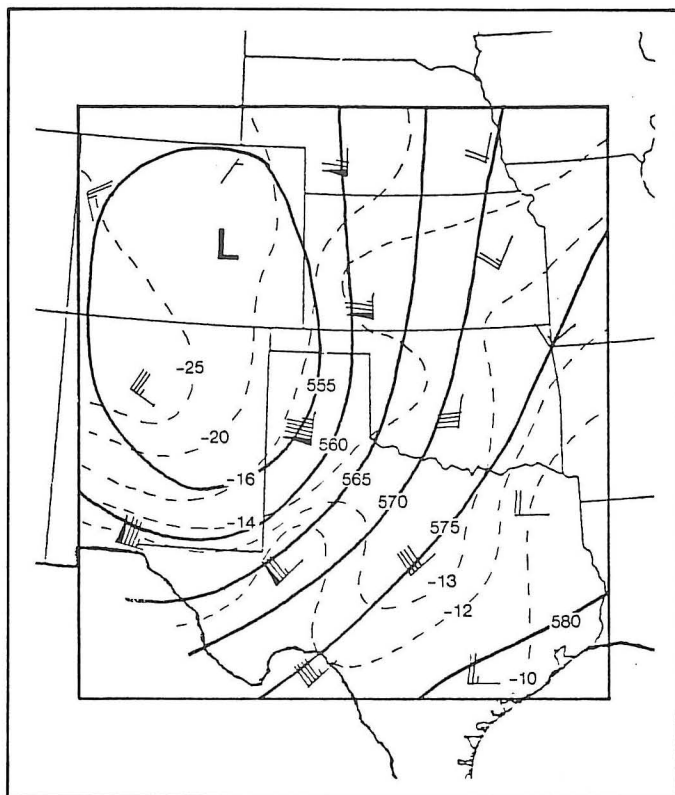


Fig. 4A. 500-mb features as in Figure 2A, except 0000 GMT 10 May 1988. Heavy dashed line marks position of significant short wave.

Figures 4C and 4D show manually generated SLI's and SCT's, respectively, from 0000 GMT surface and 500-mb data. Both analyses outline the same general instability axis, and both have their strong and weak points.

The SCT depiction seems to fit better with the severe reports north and west of Nashville. Also, the area of maximum values > 31 and 32 extending northward into south central and southeast Kentucky on the SCT analysis seems to imply greater instability there than does the SLI analysis with moderately unstable -3 to -4 values and a maximum further south. During the evening, a tornado struck Middlesboro in southeast Kentucky killing one person, injuring several others, and causing extensive damage.

On the other hand, the SCT maximum over central Ohio is misleading. It is located behind the main line of thunderstorms but ahead of the cold front in an area probably "worked over" by earlier thunderstorm passage. Post-squall line subsidence is probably doing its part in this area where no thunderstorms are occurring. SCT values may also overestimate the instability in this slightly cooler and moistened post-thunderstorm environment. This underlines the fact that judgment and other data must certainly be used in evaluating the applicability of the SCT in a given forecast situation.

6. CONCLUSIONS

From the testing performed, it seems apparent that the surface cross totals index calculated from hourly surface data provides valuable information, by itself or as a supplement to other indices, in diagnosing instability for the severe thunderstorm forecaster. As shown in the case studies, the SCT may be useful as a "second opinion" on instability in many cases.

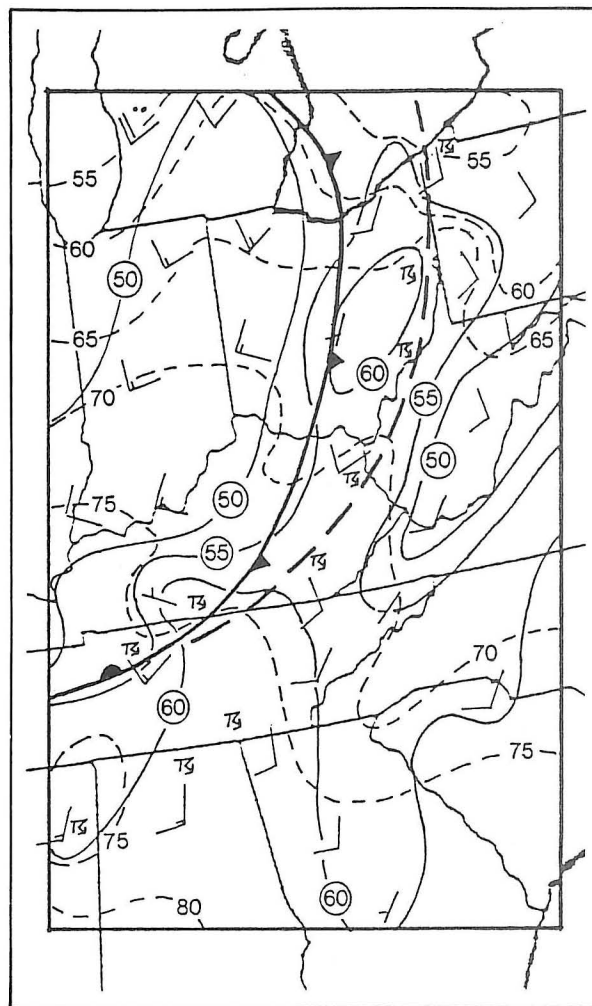


Fig. 4B. Surface map as in Figure 2B, except 0000 GMT 10 May 1988.

It is important to keep in mind that the SCT will overestimate instability in relatively cool but moist areas with little or no surface heating. It also will tend to be overly high in very tropical air masses (i.e., Gulf Coast late spring and summer) where high surface moisture content dominates the calculation, overcompensating for warm mid-level temperatures not associated with severe weather.

A significant benefit of the SCT is the simplicity of calculation. Many private meteorologists do not yet have automated meteorological work stations available, and do not have the benefit of ADAP (Bothwell, 5) or CSIS (Anthony et al., 6) products at the NWS/NSSFC level. The SCT provides a reasonably fast manual technique in real time to either spot check or monitor in detail the hourly instability in severe thunderstorm forecasting/nowcasting situations.

Furthermore, because the SCT involves only two variables, it is a relatively simple matter to watch for surface moisture and 500-mb temperature areas to come together for the creation of significant convective instability. For example, in case 2 presented above, morning dew points in south central Oklahoma were only in the upper 40's. Given morning 500-mb temperatures of near -13°C , and neutral/weak 500-mb cold advection expected during the day, it is not hard to calculate that dew points of around 60°F or greater are needed to generate significant instability (i.e. SCT's > 28). Dew

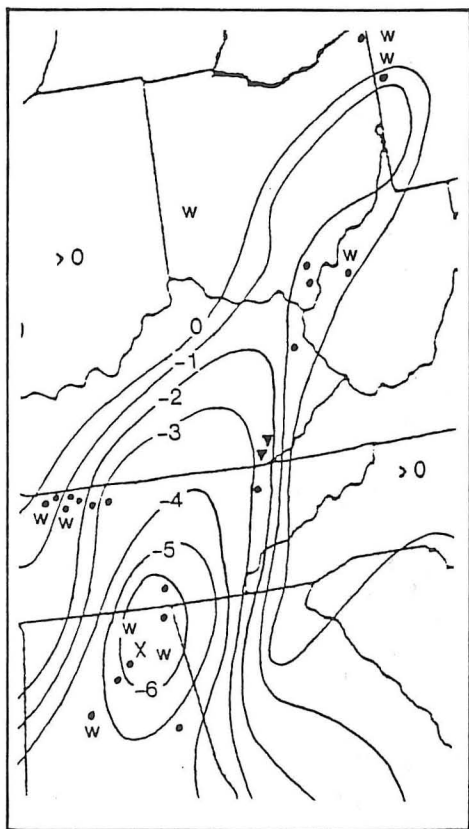


Fig. 4C. SLI's from 0000 GMT surface and 500-mb data. 'X' denotes maximum. Severe reports from SELS preliminary log for period 2200 GMT to 0300 GMT 10 May 1988 also indicated (▼ = tornado, ● = large hail, w = damaging winds).

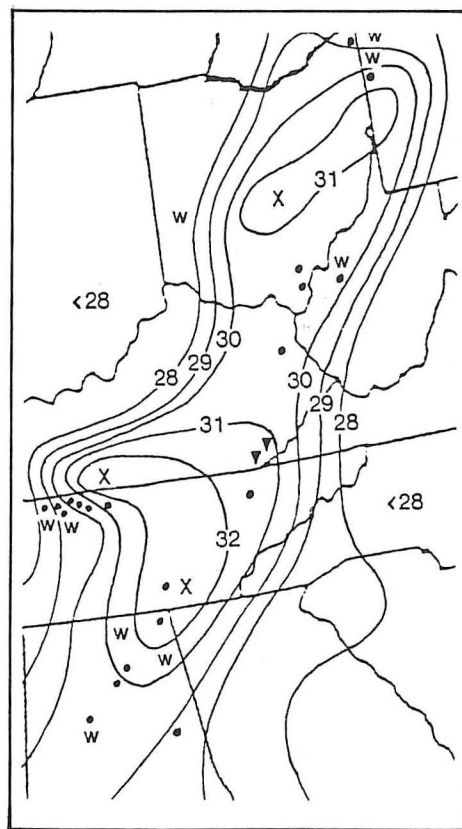


Fig. 4D. SCT's from same data as Figure 4C. 'X' denotes maximum. Severe reports as in Figure 4C.

points in the low 60's did indeed advect into the area during the afternoon, a tip-off that significant instability had developed.

The research performed suggests that further testing be pursued during significant convective episodes in the summer months and at other times of the year to determine the effectiveness of the surface cross totals index in a variety of seasonal and synoptic settings.

Acknowledgements

Many thanks to Richard McNulty, National Weather Service, Topeka, Kansas, and Jeff Lazalier, KJRH-TV, Tulsa, Oklahoma, for their helpful suggestions and review of this paper.

NOTES AND REFERENCES

1. Jon Davies has worked as a meteorologist for The Weather Channel in Atlanta, GA; Kansas State Network and Mid Continent Weather Service in Wichita, KS; KCGR-TV in Cedar Rapids, IA; and KTSB-TV in Topeka, KS. He received his B.G.S. Degree in Meteorology from the University of Kansas in 1980, supplemented by coursework through Pennsylvania State University. He currently owns and operates a medical equipment dealership/distributorship in Pratt, KS, and is assisting infor-

mally with a meteorological project at the University of Kansas in his spare time.

2. Miller, R.C., 1972: Notes on analysis and severe storm forecasting procedures of the Air Force Global Weather Central. AWS Tech. Report 200 (Rev.), Air Weather Service (MAC), U.S.A.F., 120 pp.

3. Hales, J. E. Jr., and Doswell, C. A. III, 1982: High resolution diagnosis of instability using hourly surface lifted parcel temperatures. Preprints 12th Conf. on Severe Local Storms (San Antonio), AMS, Boston, MA, pp. 172-175.

4. Johns, R. H., 1982: Severe weather occurring in areas of low surface dew points. Preprints, 12th Conf. on Severe Local Storms (San Antonio), AMS, Boston, MA, pp. 143-146.

5. Bothwell, P. D., 1988: AFOS data analysis programs. NOAA Technical Memorandum NWS SR-114, Fort Worth, Texas. 73 pp.

6. Anthony, R., W. Carle, J. Schaefer, R. Livingston, A. Siebers, F. Mosher, J. Young, and T. Whitaker, 1982: The centralized storm information system at the NOAA Kansas City complex. Preprints 9th Conf. on Weather Forecasting and Analysis (Seattle), AMS, Boston, MA, pp. 40-43.

Johns, R. H., S. J. Weiss, S. K. Beckman: A basic tornado and severe thunderstorm forecast checklist. Unpublished training workshop manuscript, NSSFC, Kansas City, MO.