

## CHAPTER 10

### APPLICATIONS OF GEOSTATIONARY SATELLITE SOUNDING DATA

#### 10.1 *Detection of Temporal and Spatial Gradients*

The algorithms for deriving meteorological parameters from sounding radiance data have been implemented by NOAA/NESDIS so that real time GOES data ingest is translated into near real time (within one hour) parameter production. Some spatial averaging is done to reduce instrument noise. Soundings are performed every 50 to 100 km in clear skies. To ensure reliable detection of cloud contamination, objective cloud checking and editing of the data is performed in the automated processing prior to the spatial averaging and calculation of meteorological parameters. After completion of the automated processing, derived product images or contour analyses of the results are displayed for nowcasting or forecasting applications.

It is important to note that the major strength of satellite measurements is the detection of temporal or spatial gradients for a given parameter. Comparison of absolute values a given parameter with another technique for measuring or inferring the same parameter is often misleading. The comparison of GOES retrievals to radiosonde measurements is not ideal due to differing measurement characteristics (point versus volumetric), co-location errors (matches are restricted to 0.25 degrees), time differences (within one hour), and radiosonde errors (Pratt 1985; Schmidlin 1988). However, it has become the standard approach for GOES sounding validation. A study of the GOES retrievals for eleven months (April 1996 to February 1997) indicates that they are more accurate than the NCEP short-term, regional forecasts, for both temperature and moisture, even in the vicinity of the radiosonde where they must necessarily be verified (Schmit 1996).

The following sections present applications of GOES sounding data where gradients in space and time revealed atmospheric conditions not readily found in other measurements.

#### 10.2 *VAS Detection of Rapid Atmospheric Destabilization*

VAS data obtained on 20 July 1981 demonstrate the VAS nowcasting capabilities. Although hourly results were achieved, they are too numerous to present here; instead, three-hourly results are presented. The overall synoptic situation is shown in Figure 10.1 in the full disc (MSI) 11 micron window and 6.7 micron H<sub>2</sub>O images that were obtained on 20 July at mid-day (1730 GMT). The 11 micron image shows that the United States is largely free of clouds, except near the United States-Canadian border where a cold front persists. However, in the 6.7 micron upper tropospheric moisture image, a narrow band of moist air (delineated by the low radiance grey and white areas of the image) stretches from the Great Lakes into the southwestern United States.

Figure 10.2 shows contours of derived upper tropospheric relative humidity superimposed over the VAS 6.7 micron brightness temperature images. In this case, the narrow band of moist upper tropospheric air stretching across northern Missouri is the southern boundary of an upper tropospheric jet core (this was shown in Figure 9.2). The southeastward projection of this moist band and associated jet core is evident. The bright cloud seen along the Illinois-Missouri border in the 21 GMT water vapour image corresponds to a very intense convective storm which developed between 18 and 21 GMT and was responsible for severe hail, thunderstorms, and several tornadoes in the St. Louis, Missouri region.

An objective of the VAS real-time parameter extraction software is to provide an early delineation of atmospheric stability conditions antecedent to intense convective storm development. For this purpose, a total-totals stability index is estimated (as described in Chapter 8). On this day,

the atmosphere was moderately unstable over the entire midwestern United States, yet intense localized convection was not observed during the morning hours. In order to delineate regions of expected intense afternoon convection, three-hourly variations of stability (total-totals) were computed and displayed over the current infrared window cloud imagery on an hourly basis. Figure 10.3a shows the result for 18 GMT. A notable feature is the narrow zone of decreasing stability (positive three-hour tendency of total-totals) stretching from Oklahoma across Missouri and southern Illinois into western Indiana (the +2 contour is drawn boldly in Figure 10.3a). Also shown in Figure 10.3a are the surface reports of thunderstorms which occurred between 21 and 23 GMT. Good correspondence is seen between the past three-hour tendency toward instability and the thunderstorm activity three to five hours ahead.

Figure 10.3b shows the one-hour change in the total-totals index between 17 GMT and 18 GMT. The greatest one-hour decrease of atmospheric stability is along the border between northern Missouri and central Illinois where the tornado-producing storm developed during the subsequent three-hour period (see Figure 10.2d). The stability variation shown was the largest one-hour variation over the entire period studied, 12-21 GMT.

A few detailed sounding results will now be presented for the Missouri region. The soundings were retrieved from VAS DS data with high spatial resolution (roughly 100 km) using the interactive processing algorithms described by Smith and Woolf (1981). Figure 10.4 presents radiosonde observations of 700 mb temperature and retrievals of 700 mb temperature from GOES-5 VAS DS radiance data for a region surrounding the state of Missouri on 20 July 1981. Figure 10.5 shows a similar comparison for the 300 mb dewpoint temperature. Even though the VAS values are actually vertical mean values for layers centred about the indicated pressure levels, it can be seen from the 12 GMT observations that the VAS is broadly consistent with the available radiosondes while at the same time delineating important small scale features which cannot be resolved by the widely spaced radiosondes. This is very obvious in the case of moisture (Figure 10.5) where the horizontal gradients of dewpoint temperature are as great as 10 C over a distance of less than 100 km.

The temporal variations of the atmospheric temperature and moisture over the Missouri region are observed in detail by the three-hour interval VAS observations presented in Figures 10.4 and 10.5. For example, in the case of the 700 mb temperature, the VAS observes a warming of the lower troposphere with a tongue of warm air protruding in time from Oklahoma across southern Missouri and northern Arkansas; the maximum temperatures is observed around 18 GMT in this region. Although it is believed to be a real diurnal effect, undetected by the 12-hour interval radiosonde data, it is possible that it has been exaggerated by the influence of high skin surface temperature. This problem needs to be investigated further. The temporal variation of upper tropospheric moisture may be seen in Figure 10.5; a narrow intense moist tongue (high dewpoint temperature) across northwestern Missouri steadily propagates southeastward with time. The dewpoint temperature profile results achieved with the interactive profile retrieval algorithm are consistent with the layer relative humidity produced automatically in real time (shown in Figure 10.2). It is noteworthy that over central Missouri, where the intense convective storm developed, the VAS observed a very sharp horizontal gradient of upper tropospheric moisture just prior to and during the storm genesis between 18 and 21 GMT. Here again, the inadequacy of the radiosonde network for delineating important spatial and temporal features is obvious. The discrepancy between the 21 MT VAS and 24 GMT radiosonde observation over southern Illinois (Figure 10.5) is due to the existence of deep convective clouds. A radiosonde observed a saturated dewpoint value of -34 degrees Centigrade in the cloud while VAS was incapable of sounding through the heavily clouded area. Nevertheless, it appears that the VAS DS data provide, for the first time, the kind of atmospheric temperature and moisture observations needed for the timely initialization of a mesoscale numerical model for predicting localized weather.

Figure 9.2 shows streamlines and isotachs of 300 mb gradient winds derived from the VAS temperature profile data, where the curvature term was approximated from the geopotential

contours. There is agreement (not shown) between the VAS 12 GMT gradient winds and the few radiosonde observations in this region. As can be seen, there is a moderately intense subtropical jet stream which propagates east-southeastward with time. Note that at 18 GMT, the exit region of the jet is over the area where the severe convective storm developed. As shown by Uccellini and Kocin (1981), the mass adjustments and isallobaric forcing of a low level jet produced under the exit region of an upper tropospheric jet streak can lead to rapid development of a convectively unstable air mass within a three to six-hour time period.

Figure 10.6 shows the three-hour change of total precipitable water prior to the severe convective storm development. The instantaneous fields from which Figure 10.6 was derived showed a number of short-term variations. Nevertheless, it is probably significant that a local maximum exists over the location of the St. Louis storm prior to its development. It is suspected that the convergence of lower tropospheric water vapour is a major mechanism for the thermodynamic destabilization of the atmosphere leading to severe convection between 18 and 21 GMT along the Missouri-Illinois border.

The VAS geostationary satellite sounder demonstrated the exciting new opportunities for real-time monitoring of atmospheric processes and for providing, on a timely basis, the vertical sounding data at the spatial resolution required for initializing mesoscale weather prediction models. Results from this case study and others not reported here suggested that VAS detected, several hours in advance, the temperature, moisture, and jet streak conditions forcing severe convective development. This work was reported by Smith *et al* in 1982. The operational geostationary sounding capability demonstrated by the experimental VAS was realized with the operational GOES Sounder (Menzel and Purdom, 1994)

### **10.3 Operational GOES Sounding Applications**

An effective display of the sounding information is the derived product image (DPI) wherein a product such as total column precipitable water vapor (PW) is color coded and clouds are shown in shades of gray (Hayden et al., 1996). Routinely, three DPIs are generated by NESDIS every hour depicting atmospheric stability, atmospheric water vapor, and cloud heights. Each FOV thus contains information from the GOES sounder with the accuracy discussed in the previous sections, but the time sequences of the GOES DPI make the information regarding changes in space and time much more evident.

One example of an atmospheric stability DPI is shown in Figure 10.7. The GOES-8 lifted index (LI) image (bottom panel) indicates very unstable air over central Wisconsin at 2046 UTC on 18 July 1996. Generally unstable air (LI of -3 to -7 C) is evident along the synoptic scale cold front which ran just south of the Minnesota and Iowa border. However, the most unstable air is indicated as small local pockets in central Wisconsin (LI of -8 to -10 C). These localized regions stand in sharp contrast to the stable air (positive LIs) seen entering Wisconsin from Minnesota. Three hours later a tornado devastated Oakfield, WI. The GOES visible image clearly shows the associated cloud features (top panel). A timely tornado warning by the NWS helped to prevent any loss of life, in spite of heavy property damage. This stability information from the GOES sounder was available and supported the warning decision.

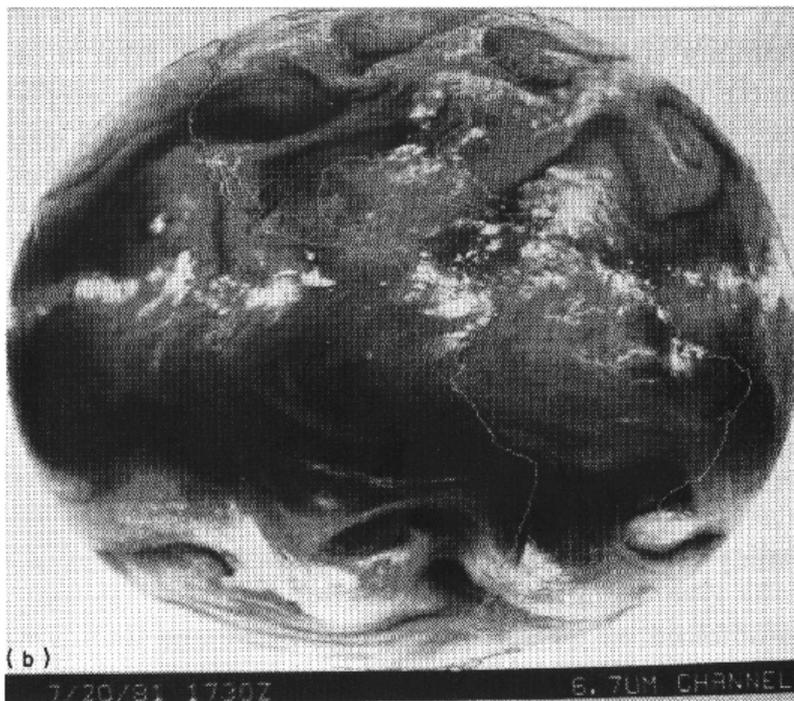
Another example of the lifted index of atmospheric stability DPI from 25 June 1998 is shown in Figure 10.8. On this afternoon a cold front moved south across the western Great Lakes; extreme instability, high moisture, surface convergence associated with the front, and an upper level vorticity pattern across Minnesota / Wisconsin all favored strong convective development. More than ten instances of severe weather (including four tornadoes) were reported that evening along the Wisconsin / Illinois border. The DPI sequence (Figure 10.8, top) shows the progression of the unstable region; at 00 UTC, radiosonde reports of lifted indices are overlaid as are the wind

reports (Figure 10.8, bottom). The GOES and the radiosonde are in close agreement, but the radiosonde network is unable to detail the area under severe weather threat.

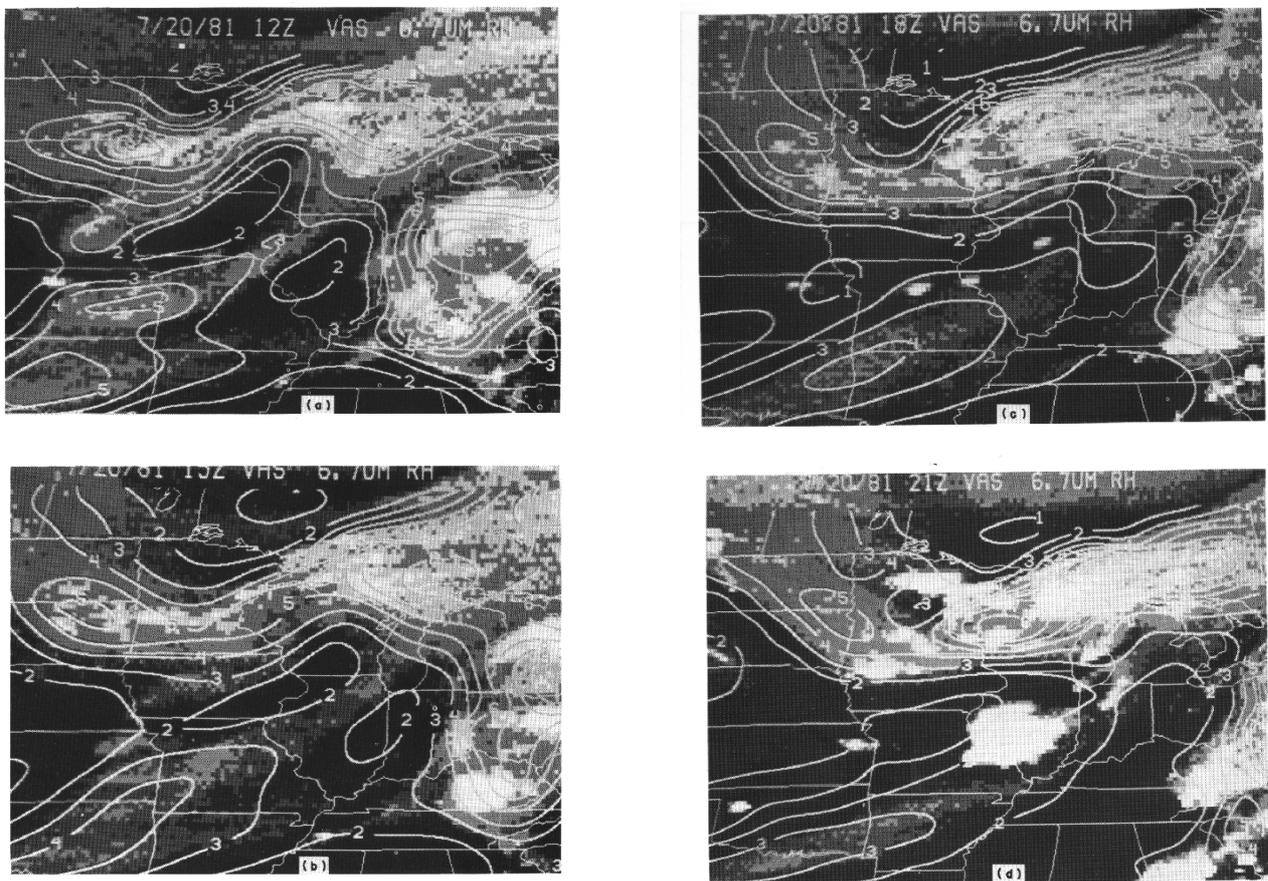
Figure 10.9 show the LI DPI from 1200 to 1800 UTC on 3 May 1999 in the south-midwestern United States. A line of unstable air is moving across Oklahoma and Texas. A tornado devastated Oklahoma City at 0000 UTC. NWS forecasters are using the GOES DPI to fill in gaps in the conventional data network. Hourly sequences of GOES DPI help to confirm atmospheric trends. The sounder is able to provide useful information to the forecaster in the nowcasting arena.

Sounder data also has been used to improve forecasts of the minimum and maximum diurnal temperatures. Using the sounder estimates of cloud heights and amounts, the 24 hour forecast of hourly changes in surface temperature can be adjusted significantly. Figure 10.10 shows an example from 20 April 1997 at Madison, WI. The forecast without sounder data indicated a maximum temperature of 64 F should be expected at 2100 UTC (9 hours after 1200 UTC). With sounder data this was changed to 59 F expected two hours earlier at 1900 UTC (7 hours after 1200 UTC). The surface observations in Madison, WI reported a maximum temperature of 58 F at 2000 UTC. This information is being produced daily for agricultural applications in various locations throughout Wisconsin; early feedback has been very positive (Diak et al. 1998).

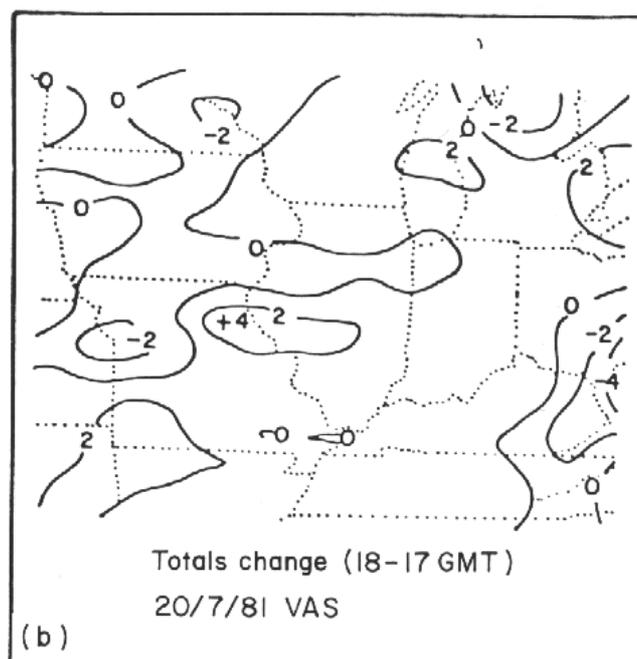
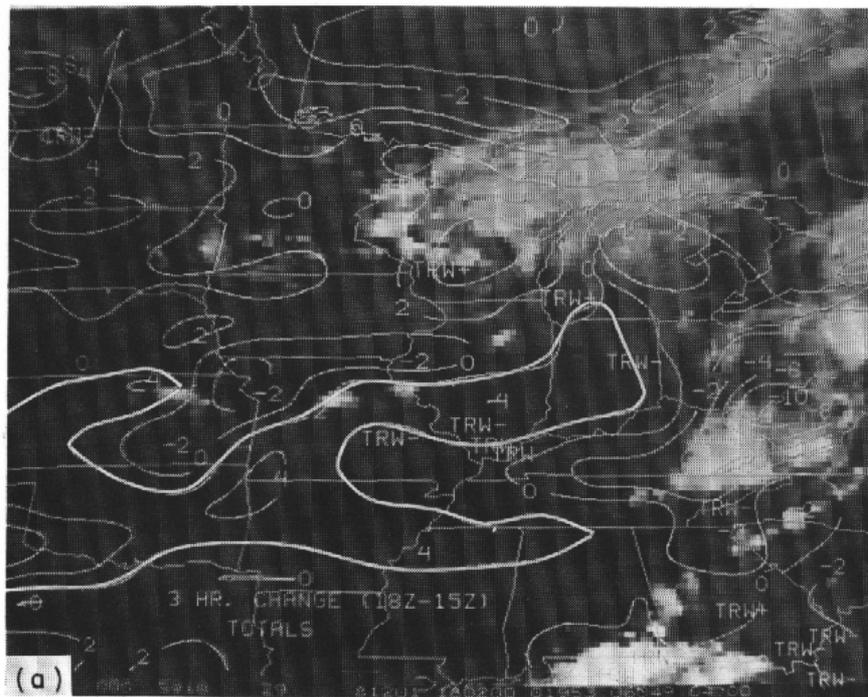
During July and August 1999 forecasters in the United States were asked to comment on their operational use of sounder data. 37 forecast offices and 4 national centers participated in the evaluation, providing 635 responses via a web based questionnaire. Forecasters used the Sounder products as tools to evaluate the potential of a wide variety of weather events, including tornadoes, severe thunderstorms, monsoon precipitation, and flash flood events. Their responses showed that in over 79% of all non-benign weather situations, the use of GOES sounder products led to improved forecasts and the issuance of improved forecast products. Overall, forecasters found the sounder products to be valuable operational tools, providing information on the vertical structure of the atmosphere, especially the moisture distribution, with a temporal and spatial resolution not available from any other source.



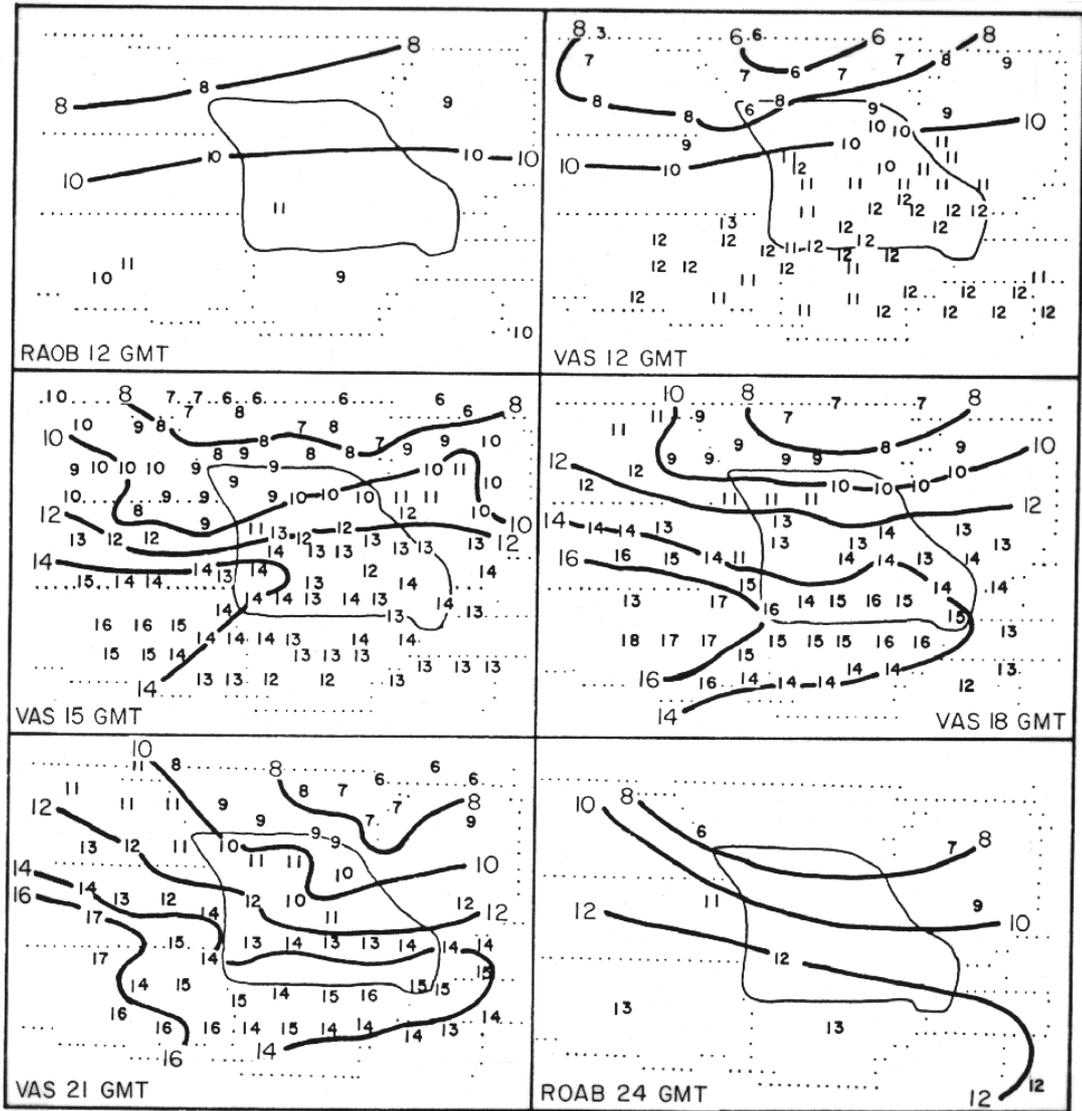
**Figure 10.1:** Full disk images obtained on 20 July 1981 between 1730 and 1800 GMT; (a) longwave infrared window at 11.2 microns, and (b) water vapour band at 6.7 microns.



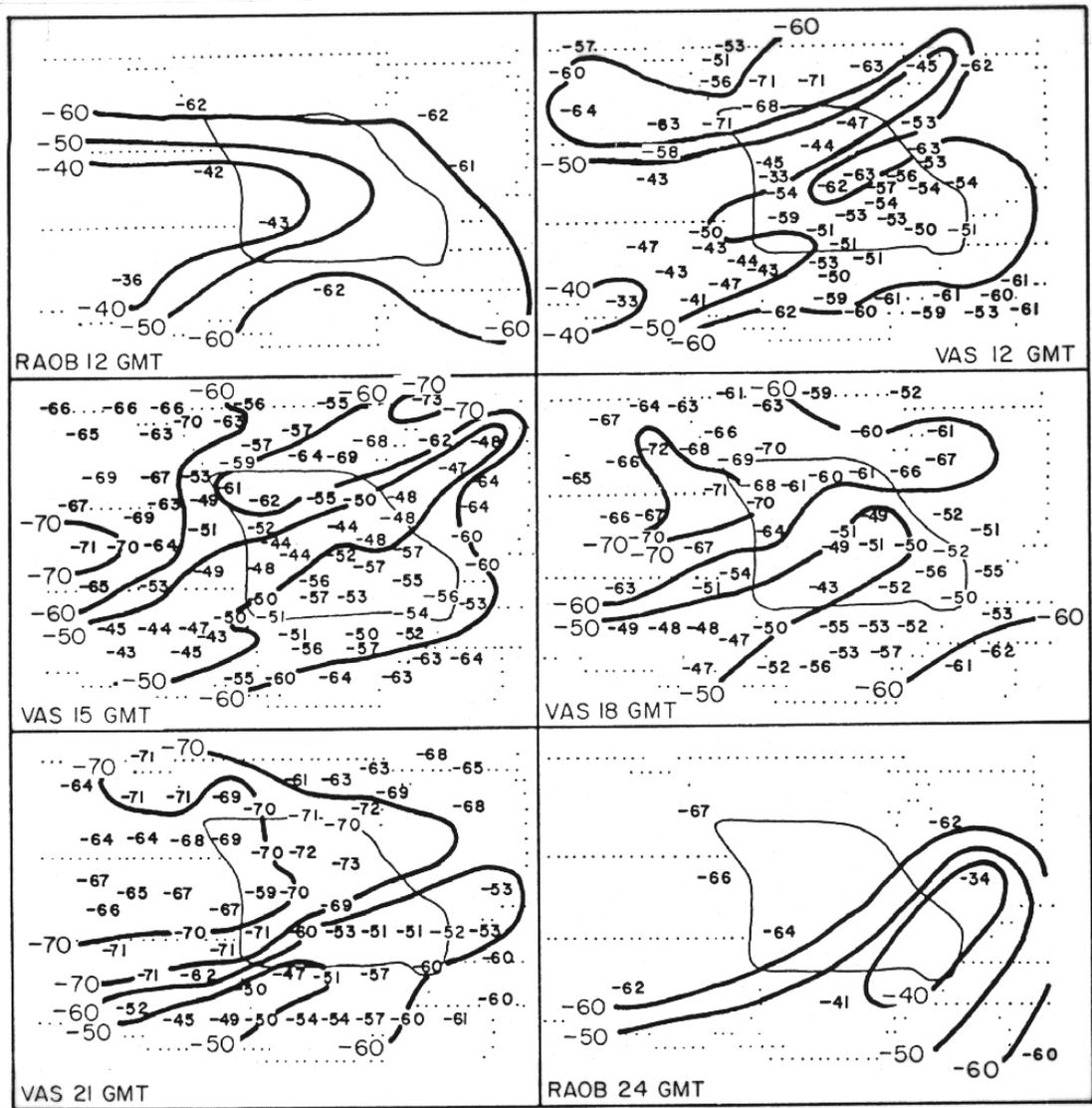
**Figure 10.2:** Upper tropospheric relative humidity (%/10) superimposed over the VAS image of 6.7 micron atmospheric water vapour radiance emission for (a) 12 GMT, (b) 15 GMT, (c) 18 GMT, and (d) 21 GMT on 20 July 1981.



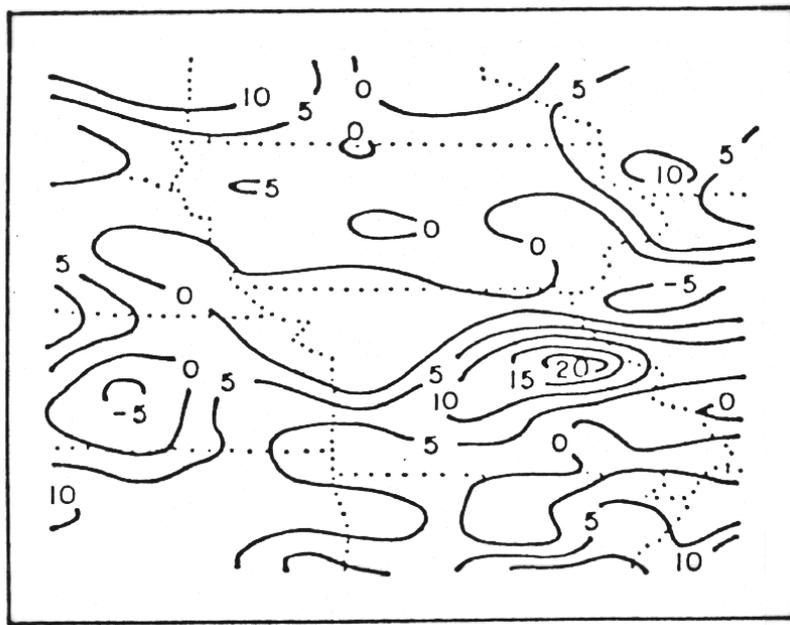
**Figure 10.3:** (a) Three hour variation of VAS derived Total-Totals Index (degree Centigrade) between 15 and 18 GMT on 20 July 1981 superimposed over the 18 GMT VAS infrared window image of cloudiness. The symbols of thunderstorms (TRW) which were observed between 20 and 23 GMT are also shown. (b) One hour variation of VAS derived Total-Totals Index (degree Centigrade) between 17 and 18 GMT on 20 July 1981 showing that the maximum one hour change (4 degrees C) occurred at the location of and just prior to the development of a severe convective storm.



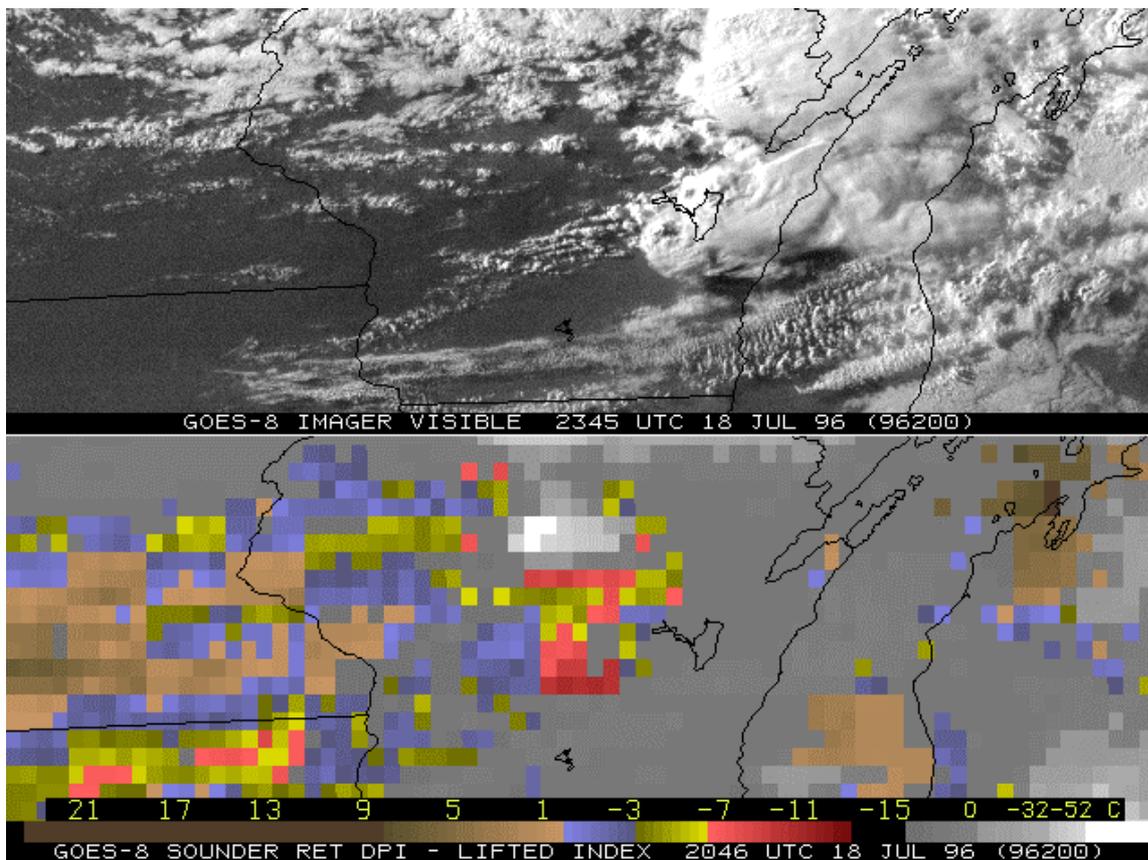
**Figure 10.4:** Radiosonde and VAS observations of 700 mb temperature (degree Centigrade) on 20 July 1981.



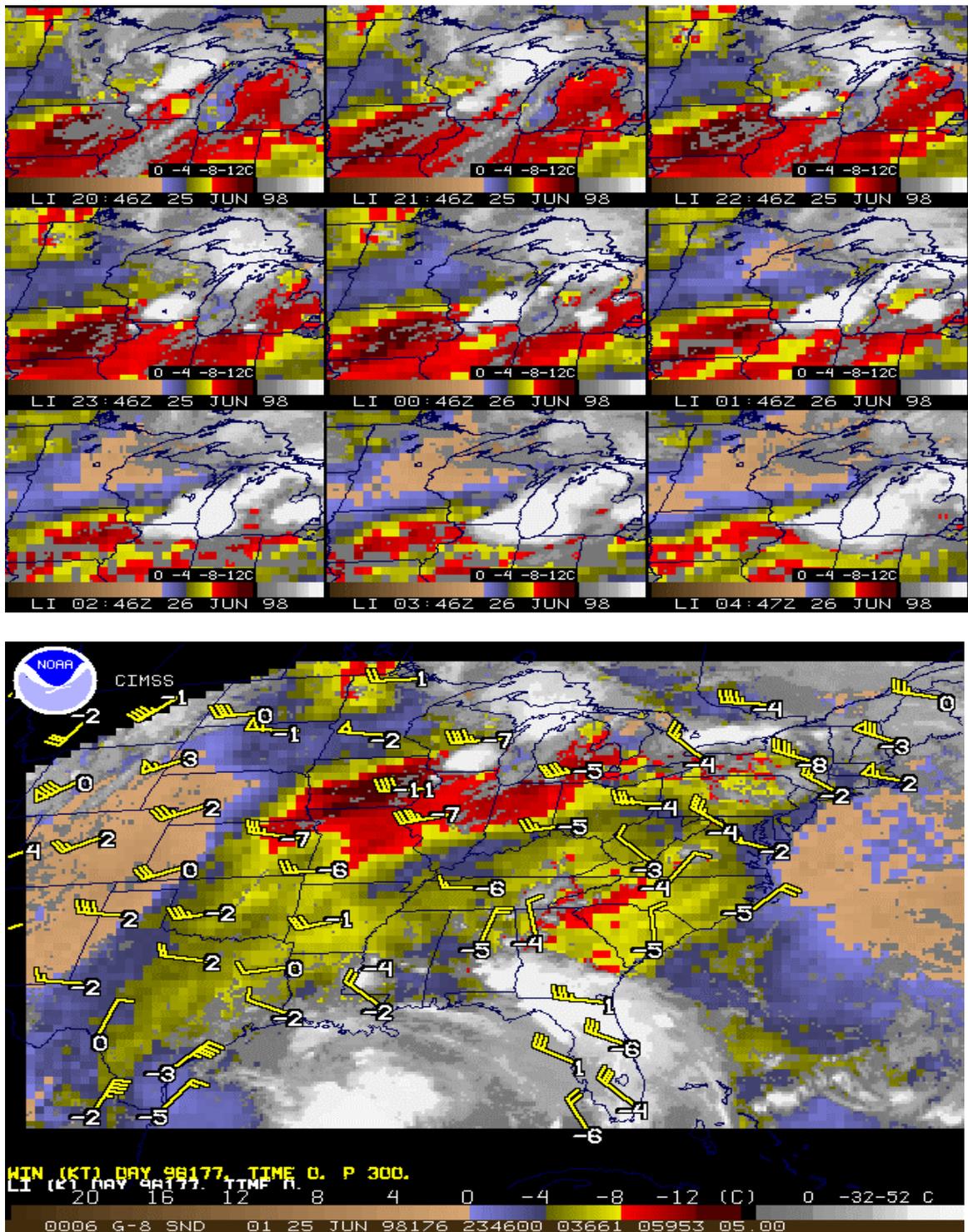
**Figure 10.5:** Radiosonde and VAS observations of 300 mb dewpoint temperature (degrees Centigrade) on 20 July 1981.



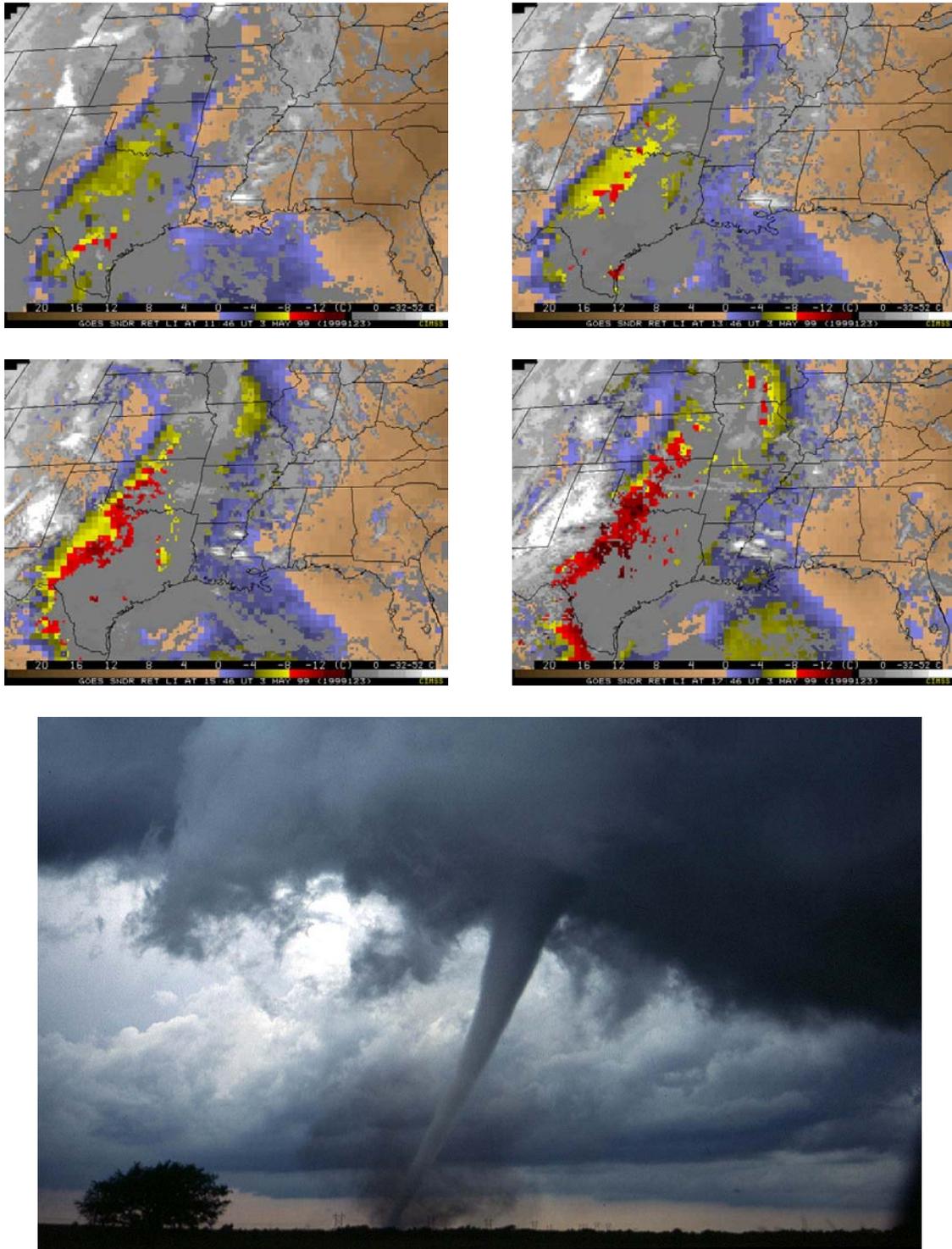
**Figure 10.6:** Three hour change of precipitable water vapour (millimetres) between 15 and 18 GMT on 29 July 1981.



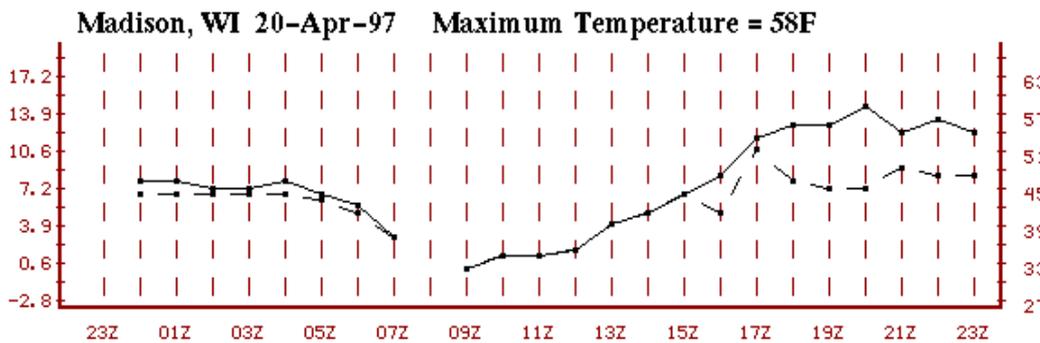
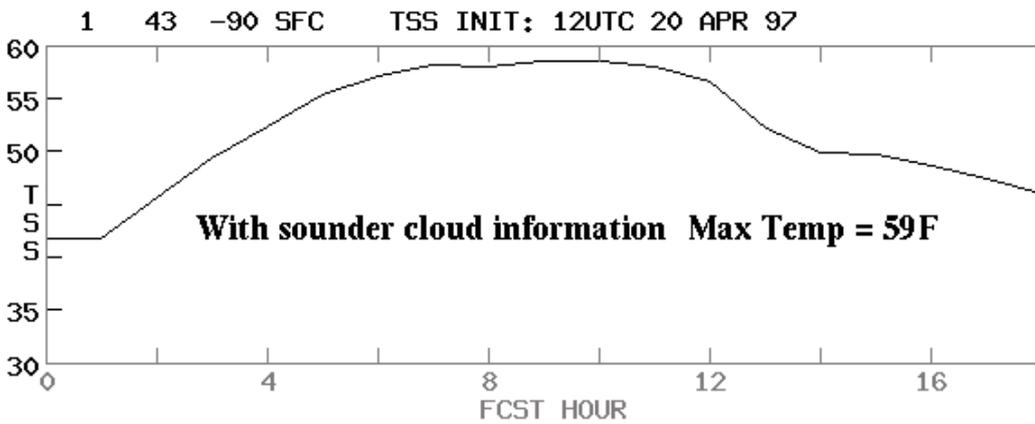
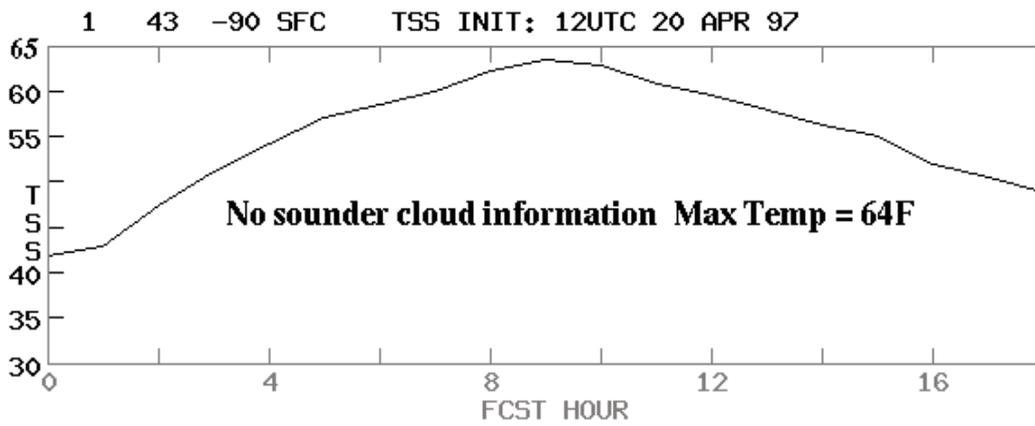
**Figure 10.7:** An example of the atmospheric stability DPI from 18 July 1996. The GOES-8 lifted index image (bottom panel) indicates very unstable air over central Wisconsin at 2046 UTC. Three hours later a tornado devastated Oakfield, Wisconsin. The GOES visible image from 2345 UTC clearly shows the associated cloud features (top panel).



**Figure 10.8:** (top) GOES DPI of Lifted Index from 2046 to 0446 UTC at 2346 UTC on 25 June 1998 show extreme instability associated with a frontal passage across Minnesota and Wisconsin. (bottom) Radiosonde reports of lifted indices are overlaid on 2346 UTC DPI as are the wind reports.



**Figure 10.9:** (top) GOES DPI of Lifted Index from 1146 to 1746 UTC on 3 May 1999 show extreme instability associated with a frontal passage across Oklahoma and Texas. (bottom) Tornado in vicinity of Oklahoma City viewed at 0000 UTC.



**Figure 10.10:** Maximum temperatures forecast with and without GOES sounder data for 20 April 1997 in Madison, WI. Without sounder data a maximum temperature of 64 degrees F at 2100 UTC was forecast (9 hours after 1200 UTC, top panel) and with sounder data the forecast was adjusted to 59 degrees F at 1900 UTC (7 hours after 1200 UTC, middle panel); the surface observations report a maximum temperature of 58 degrees F at 2000 UTC (bottom panel).