Published in the preprint volume of the **17th Conference on Severe Local Storms**, 4-8 October 1993, St. Louis, MO by the American Meteorological Society, Boston, MA.

3.5

ANALYSIS OF THE CONVECTIVE ENVIRONMENT UTILIZING CLUSTERED VAS RETRIEVALS

Donald W. Hillger and John F. Weaver

NOAA/NESDIS/RAMM Branch
CIRA/Colorado State University
Fort Collins, CO 80523-0033

1. INTRODUCTION.

An important factor in determining the intensity of thunderstorms is the amount of Convective Available Potential Energy (CAPE) in the local storm environment. Historically, this important parameter has been calculated utilizing upper-air observations taken at 12 h intervals from locations separated by roughly 250 km, and updated using data from hourly surface observing sites spaced about 125 km apart. However, fields of both temperature and dewpoint (and therefore CAPE) often vary on appreciably smaller scales than these. While attempts have been made to assess this complex variation through use of numerical models, there has been little observational data to define the convective environment precisely.

In recent years, radiance measurements obtained from Geostationary Operational Environmental Satellites (GOES) have been used to generate soundings at high horizontal-resolution. These measurements produce data arrays in fields of view (FOVs) which are approximately 16 km square. The problem has been that the signal-to-noise ratios in these so-called 'retrievals' is low. In order to increase this ratio, retrievals are often spatially averaged. This approach leads to another problem; namely, averaging can 'smear' gradient information in the sounding measurements, particularly if the averaging is arbitrary. However, when soundings are sorted by similarity in measurements, smearing is minimized and patterns in these so-called 'clustered' retrievals reveal differences in air mass characteristics more clearly.

In this paper we show that clustered soundings produced from GOES at high spatial and temporal resolution have the capacity to bring out the mesoscale detail needed for accurate thunderstorm nowcasting/forecasting. In particular, satellite sounding measurements, coupled with spatial clustering techniques, are used in a case study to analyze a convective event which occurred on the High Plains of the United States during the summer of 1992. Horizontal fields of lowest-100 hPa equivalent potential temperature fields are used to isolate regions of highest convective potential within the forecast area. Specific convective threat is assessed by applying time-tendencies in vertical profiles of temperature and dewpoint (as identified by clustered retrievals) to morning proximity rawinsonde data through an interactive sounding analysis program.

2. CLUSTERING.

As noted above, the high spatial resolution of satellite soundings makes them a desirable data source for analyzing the evolving thunderstorm environment. By clustering these remote sounding measurements into groups having similar characteristics, one not only maintains horizontal air mass gradients, but also reduces the number of retrievals necessary to define a given cluster. That is, clustering is a method used to minimize the number of satellite retrievals while maximizing the differences between the retrievals. The members of a single cluster are similar to within the noise levels of the measurements in the satellite sounding channels and therefore one sounding is sufficient to represent the group. Also, differences between clusters are greater than the noise levels of the measurements, producing soundings which are significantly different for each cluster. This process not only maintains gradients in the analyzed field, but often reinforces mesoscale features. Details on the clustering technique can be found in Hillger and Purdom (1990).

The size of clusters used for a given sounding set is determined by the noise levels of the various sounding channels. These noise levels are estimated by spatial structure function analysis on the same satellite data employed for clustering. A complete description of the structure function analysis technique can be found in Hillger and Vonder Haar (1988).

Another aspect of the clustering process is a reduction in the number of independent variables being analyzed. Because the satellite sounding channels are highly redundant, it is possible to compress these data into fewer variables. This is accomplished by Principal Component (PC) analysis. PC (also called Empirical Orthogonal Function [EOF]) analysis creates independent functions which represent the data in a more concentrated form. However, to use PCs instead of satellite sounding channels directly, the noise levels of the PCs must also be known. These noise levels are determined using the same eigenvector (EV) transformation used to convert the satellite sounding channels to PCs. A slight smoothing is applied to the PCs before clustering to add a small amount of spatial continuity. The smoothing allows us to take advantage of spatial autocorrelations which, in turn, allows for improved classification of satellite remote-sensing data.

The end result of the clustering process is a set of spatially-averaged satellite sounding channels, one set for each cluster. Temperatures and dew points are retrieved from these cluster-averaged sounding measurements. A horizontal analysis field is then reconstructed from the clustered retrievals using objective analysis to produce a retrieval at each satellite measurement location. The resulting field looks similar to doing retrievals at each satellite location. The advantage is that the signal-to-noise of the measurements has been increased and mesoscale gradient information has not been smoothed out by arbitrary averaging.

3. SELECTION OF A CASE DAY FOR PRESENTATION.

The case of 28 July 1992 was selected for several reasons. First, large regions of the central High Plains were conditionally unstable. For example, the Rapid City, South Dakota (RAP) morning rawinsonde data in Figure 1 yields a CAPE value of 1,140 J/kg given a (reasonable) forecast afternoon temperature and dewpoint of 31.7/8.3 deg C (89/47 deg F), respectively. A rawinsonde-analysis expert system called CONVEX (Weaver and Phillips, 1989) finds that a storm with these input parameters would support hail on the order of 0.75 cm (0.3 in.) at the surface and outflow winds gusting to as high as 31.5 m/s (60 kt). In fact, later activity did produce 0.5 in. hail and winds approaching 50 kt.

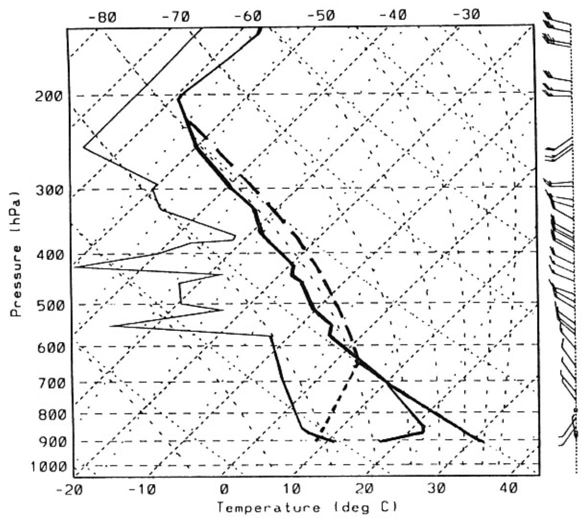

Figure 1. Rawinsonde data from Rapid City, SD at 1200 UTC, 28 July 1992 plotted on a Skew-T/Log-P diagram. Rightmost solid line is temperature, left is dewpoint. Dashed line represents lifted parcel for conditions as they were estimated to be later in the day (see text). Wind barbs are in m/s.

The second reason for selecting the case was that, being late summer, flow aloft was relatively weak. The advantage to using a relatively quiescent situation is that short range forecasts based on extrapolation of computed time-tendencies are less likely to be complicated by advection.

The last factor affecting the choice of our case day was that on 28 July, a late summer cool front was entering the region from the north (Figure 2). This weak front triggered an overnight mesoscale convective system (MCS) which subsequently moved southeastward across eastern Wyoming, northern Nebraska and southern South Dakota. The combination of the air mass difference across the front, as well as the mesoscale region of cold air behind the overnight activity, made for a more interesting analysis situation and provided triggering mechanisms for convection later in the day.

4. 28 JULY 1992 CASE STUDY.

Figure 3 shows two visible wavelength satellite

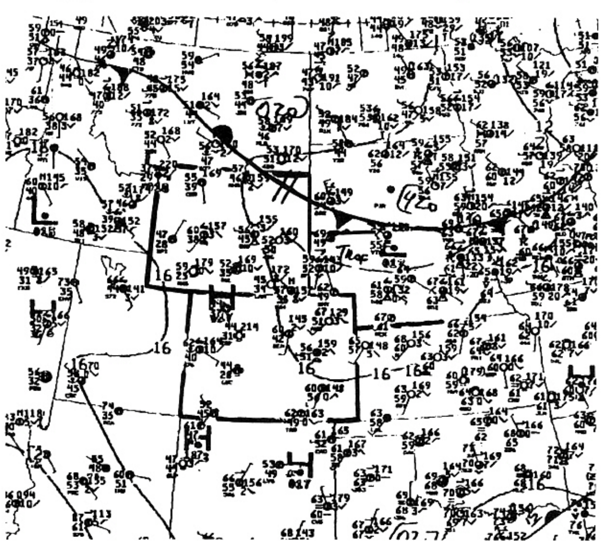

Figure 2. Subsection of NMC surface analysis from 1200 UTC, 28 July 1992. Station models and symbols are conventional. Enhanced state outlines are Wyoming (top) and Colorado (beneath).

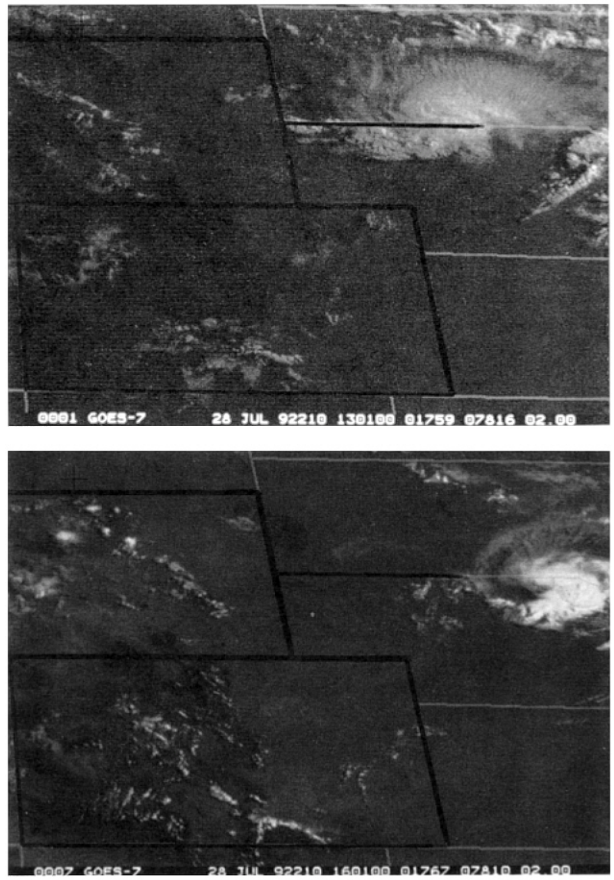

Figure 3. Visible wavelength satelltite imagery taken from GOES-7 on 28 July 1992 at a) 1301 UTC, and b) 1601 UTC.

images from the morning of 28 July. Note the MCS moving across northern Nebraska (NE) and southern South Dakota (SD). Also notice the line of towering cumulus in eastern Wyoming (WY) which develops into small thunderstorms by 1801 UTC. This new development will be discussed below.

Dwell sounding scans were taken at 1550 UTC. The data were filtered and clustered as described above, then plots of several different parameters were generated. However, the real-time analyses did not represent the atmosphere in a manner consistent with what was observed on visible and IR wavelength satellite imagery. The problem was determined to be a lack of baseline information in the individual retrievals. It was found that much improved analyses could be generated by adding detailed topographic data and by initializing each retrieval with objectively-analyzed, hourly surface observations from standard SAO sites.

Figure 4a is a plot of the lowest 100 hPa dewpoint field at 1550 UTC with topography and surface data added. A subjective comparison of this analysis with the visible satellite image in Figure 3b and the surface analysis (Figure 2) finds a similarity in broadscale characteristics. Note, for example, the strong gradient stretching from northeastern Wyoming to the Nebraska panhandle. This feature marks the line separating cool, moist MCS-modified air from the unaffected air to its south. The gradient does not appear in the analysis of the lowest 100 hPa equivalent potential temperature (theta-e, Figure 4b) due to offsetting cooler temperatures in the rain-modified air. Also, notice the strong dewpoint gradient in central Colorado (CO). This gradient is situated along the sharp change in terrain height which occurs along the eastern edge of the Colorado Rocky Mountains.

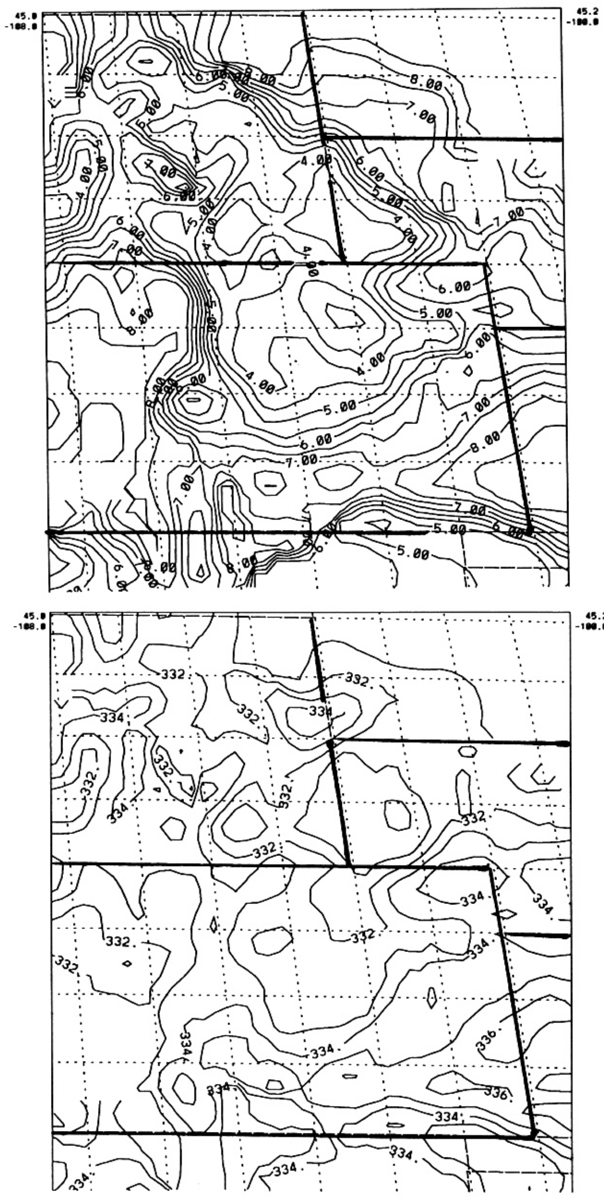

Figure 4. Objective analysis of a) lowest 100 hPa dewpoints (deg C) and b) lowest 100 hPa theta-e (K) computed from VAS sounding data taken at 1500 UTC, 28 July 1992.

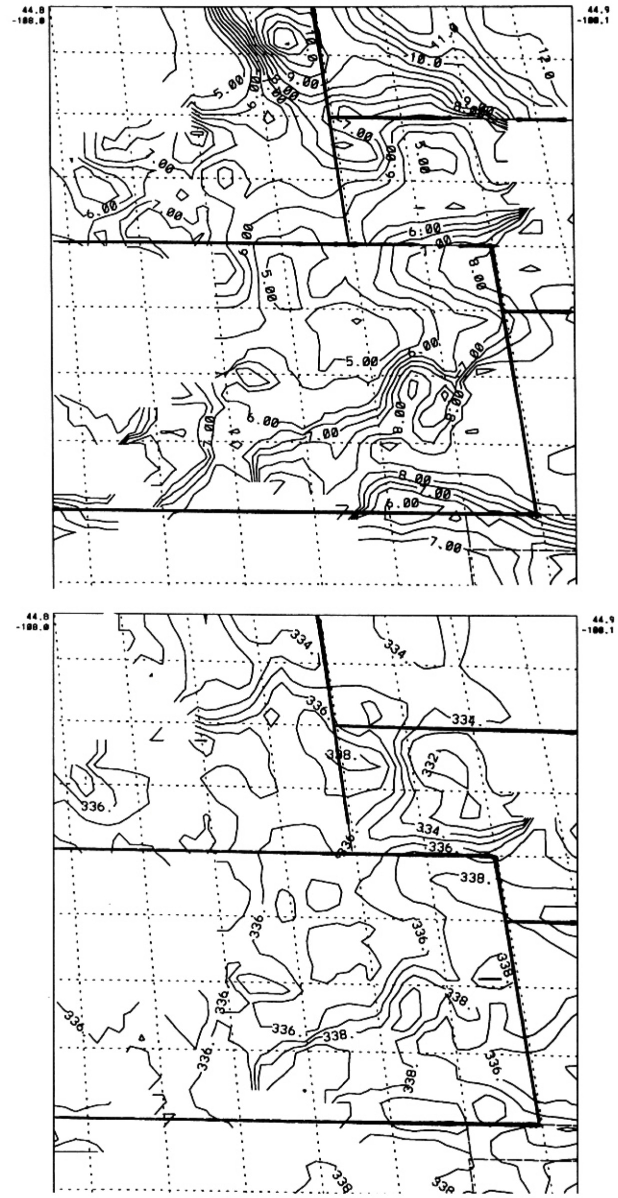

Figure 5. Same as Figure 4, except that time is 1720 UTC, 28 July 1992.

As a final example of identifiable features in Figure 4a, consider the moist tongue appearing in southeastern Colorado. This feature is situated along and near the Arkansas River. It may be due to evapotranspiration, or may represent moist air advecting into the river valley from southwestern Kansas (KS).

Figure 5 shows the lowest 100 hPa dewpoint and theta-e fields at 1720 UTC. Notice that the gradient of dewpoint, which had earlier stretched from northeast Wyoming into the Nebraska panhandle, has apparently moved north on its eastern end. The gradient now runs from northeastern Wyoming into extreme southern South Dakota. That location matches the synoptic, surface front at 1800 UTC (analysis not shown). We interpret this change to mean that the cold, outflow air had probably been shallow and had "mixed out" by 1720 UTC.

Also note the ridge of higher theta-e values developing in extreme east central Wyoming. A glance at the visible satellite imagery at this time shows deep convection on the western edge of this high energy air. Convection also appears to be developing along the northwestern edge of the theta-e ridge in southeastern Colorado. The fact that deep convection would develop in such regions is not new or surprising. What is important here is the ability to identify these regions from remote sensors.

Figure 6 shows a "forecast" field of lowest 100 hPa theta-e for around 1900 UTC. Gridpoint values are simple linear extrapolations from the 1550 and 1720 UTC analyses. In the present situation, where there is very little advection at any level, such an extrapolation seems to represent a reasonable first guess forecast. Here, we see that the extrapolated field seems to accurately reflect regions with potential for convective development throughout the area of interest. Comparing Figures 6 and 7, for example, shows that thunderstorms have developed in extreme eastern Wyoming near a large pocket of high energy air. Also, compare the development areas in southeast and southern Colorado. It is clear that the field of 100 hPa theta-e has identified most of the regions where convection has developed. Note that no convection has appeared in extreme northeastern Colorado within the high theta-e region found there. However, within three hours of this time, weak convection which formed just south of the southeastern Wyoming border moved east and intensified as it reached that location.

One final point. Several papers have been written concerning the use of theta-e computed from surface data alone to represent the low-level energy. However, at least in this case, that field is not quite as accurate as the VAS-derived results. Figure 8 shows extrapolated theta-e values computed from surface data. Note that the highest energy air on that analysis is in southeastern Colorado; while the 100 hPa analysis suggests a minimum. In point of fact, the moisture in the Arkansas River Valley was shallow and no convection formed in that region on 28 July. Other comparisons can also be made (e.g., the storm in extreme northeastern Wyoming becomes quite large by 2000 UTC where a tongue of higher energy air is seen on the 100 hPa map and a minimum is found on the surface analysis.

CONCLUDING REMARKS.

Preliminary tests of a technique utilizing VAS retrievals and standard surface observational data to define the convective boundary layer have been conducted. These tests clearly demonstrate the feasibility of statistically clustering VAS retrievals in real-time.

Some potential applications of VAS sounding data in the short-range forecast time-frame were developed. It was found that linearly extrapolated fields of various derived parameters seem to fairly accurately portray regions having convective potential, at least in the several non-advective situations studied.

The results of the 1992 testing seem to indicate that VAS retrievals can be used to identify mesoscale features in the boundary layer. There are several questions which remain. How often, for example, do VAS retrievals accurately reflect the convective boundary layer? How can VAS-derived fields be applied in situations where advection is strong? How much of a problem results from the fact that VAS retrievals cannot be made in cloudy regions? How often does the cloudy pixel problem occur? These and other such questions must still be addressed. Thus, the authors plan to collect data during the spring and early summer of 1993, when flow patterns are more robust. Hopefully, many of the above questions will find an answer through those efforts.

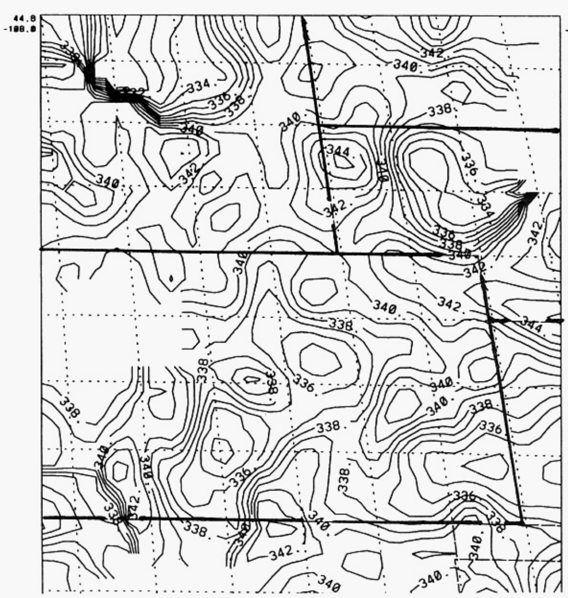

Figure 6. Lowest 100 hPa theta-e extrapolated to 1848 UTC. The extrapolation is a linear extension of the tendency from 1550 to 1720 UTC.

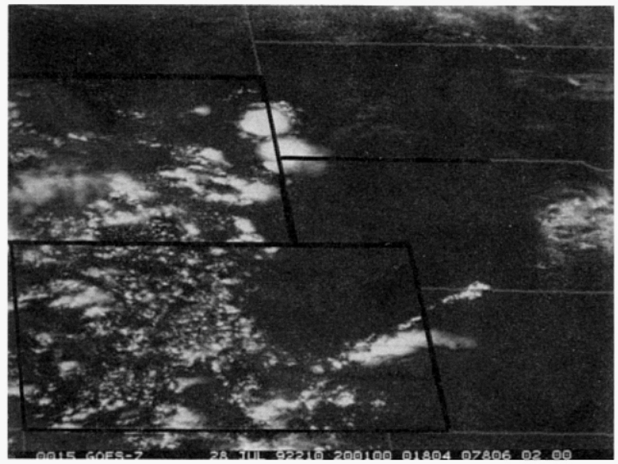

Figure 7. Same as Figure 3 except image time is 1900 UTC on 28 July 1992.

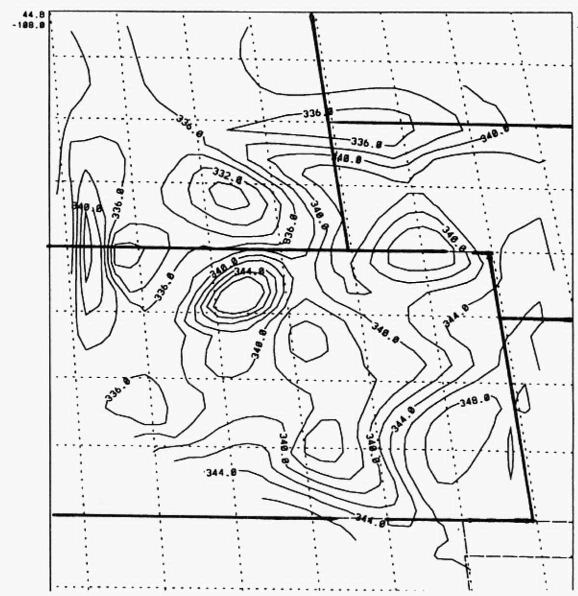

Figure 8. Objectively analyzed field of surface-based theta-e (K). Values are extrapolated linearly from standard SAO surface observations made at 1600 UTC and 1800 UTC.

ACKNOWLEDGEMENTS

This work was supported by NOAA Grant NA85RAH05045.

REFERENCES

Hillger,D.W., and J.F.W.Purdom, 1990: Clustering of satellite sounding radiances to enhance mesoscale meteorological retrievals. J. Appl. Meteor., 29, 1344-1351.

Hillger,D.W., and T.H.Vonder Haar, 1988: Estimating noise levels of remotely-sensed measurements from satellites using spatial structure analysis. J. Atmos. Ocean. Tech., 5, 206-214.

Weaver,J.F. and R.S.Phillips, 1989: Mesoscale thunderstorm forecasting using an expert system. 12th Conf. on Wea. Anal. and Forecasting, J65-67. Amer. Meteor. Soc., Monterey, CA.