1.0 INTRODUCTION

This paper presents a preliminary analysis of an interesting case study involving three tornadoes which occurred in northeastern Illinois on 28 August 1990. The special methods employed for the analysis of the TIROS Operational Vertical Sounder (TOVS) data have been previously used to analyze VISSR Atmospheric Sounder (VAS) data from the GOES series of satellites.

2.0 HIRS/2 DATA

The HIRS/2 data locations for this case study are shown in Figure 1. The area of concern is over the central U.S. with the state of Illinois just to the right of the center of the image. The NOAA-11 overpass provided high-density data at about 1930 UTC. The locations of the corresponding MSU components of the TOVS data are shown in Figure 2. Whenever HIRS/2 measurements were used to produce retrievals, the closest MSU FOV was combined with each HIRS/2 FOV. The International TOVS Processing (ITP) software/data package from CIMSS was used for all retrievals (Achter, et al, 1990). Only full-HIRS/2 (clear) retrievals were performed.

3.0 CLUSTERING VERSUS NORMAL RETRIEVALS

A method to minimize the number of retrievals while maximizing the differences between retrievals was applied to this case study and compared to retrievals produced in a normal manner but grouped into two different retrieval densities. The advantage of this particular clustering technique is that the members of a cluster are similar to within the noise levels of the measurements in the HIRS/2 channels used to determine the cluster, and differences between clusters are greater than the noise levels of the measurements. This acts to reinforce mesoscale features and maintain gradients in the analysis compared to retrievals grouped arbitrarily. Details on the clustering technique can be found in Hillger and Purdom (1990).

3.1 Noise Levels

The basis for clustering is a determination of the noise levels of the various HIRS/2 channels. The noise levels were determined by spatial structure function analysis on the same HIRS/2 data employed in this study. Details on the determination of noise levels by spatial structure analysis can be found in Hillger and Vonder Haar (1988) and Hillger, et al (1991). Figure 3 shows the noise levels as well as the signal level in each of the HIRS/2 channels. Two noise levels are given, a minimum and a maximum estimate from structure analysis. Note that the signal and noise levels vary from channel to channel, with the HIRS/2 window channels (8, 18, and 19) having the largest signals. On top of each signal bar is a number giving the signal-to-noise ratio for each channel, which is simply the
Figure 1: HIRS/2 Field-of-view (FOV) locations for the 28 August 1990 Illinois tornado case study shown as a satellite projection to stretch FOV spacing near nadir. There are 7 full-width scan lines of 56 elements each between two HIRS/2 calibration periods (which define the top and bottom lines of the data).

Figure 2: MSU FOV locations for the same area as in Figure 1. The closest MSU FOV is matched with each HIRS/2 FOV for retrieval purposes. Circles are far smaller than microwave FOV size.
Figure 3: Signal and noise levels of the HIRS/2 infrared channels from spatial structure analysis of the data used in this case study. The noise levels are compared to the 'signal' levels (standard deviations of the measurements in each HIRS/2 channel) for the entire data set. A comparison of the signal level to the noise levels gives the signal-to-noise ratios, the numbers on top of the longer signal bars.

Figure 4: Signal and noise levels of the principal components (PCs) formed from the HIRS/2 measurements for this case study. Organization is that same as in Figure 3. Note the steady decrease in signal with increasing PC number, whereas the noise level can vary, causing some higher-ordered PCs to contain more signal-to-noise than lower-ordered PCs.
ratio of the signal and noise levels. All of the HIRS/2 channels have significant signal above noise, unlike some of the VAS channels (Hillger, et al, 1991).

An alternative to determining the noise levels by structure analysis would be to use standard single-sample noise levels provided for the HIRS/2 instrument. Variations in the magnitude of the noise levels would change the size of the resulting clusters, with lower noise levels resulting in smaller clusters and higher noise levels resulting in larger clusters.

3.2 Principal Component Analysis

Because of the large number of redundant HIRS/2 channels, it is desirable to reduce the number of variables upon which to cluster the data. This was accomplished by Principal Component (PC) analysis (Preisendorfer, 1988). PC (also called Empirical Orthogonal Function [EOF]) analysis creates independent functions which represent the data in a more concentrated form. However, to use PCs in instead of HIRS/2 channels directly, the noise levels of the PCs must be known. Figure 4 shows the noise levels of the HIRS/2 PCs determined by the same spatial structure analysis used for the HIRS/2 channels. It is interesting to note that while the signal level of the PCs decreases for increasing component number, the noise level of the PCs does not necessarily decrease. In particular, the noise level for PC-2 is smaller than the noise level for PC-3, indicating that the signal-to-noise ratio for PC-2 is much greater than that for PC-3, and greater than even PC-1.

Again, an alternative method for determining the PC noise levels is to use the same eigenvector (EV) transformation from HIRS/2 channels to PCs to transform the noise levels for the channels into noise levels for the PCs. Variations in the PC noise levels results in cluster size variations, in the same manner as if clusters were based on the channel noise levels directly.

The transformation to PCs produces components which are unlike the channels from which they were produced. Figure 5 shows the first four EVs, or the transformation vectors used to produce the first four PCs. These EVs show which HIRS/2 channels contribute most of the information to each PC, helping to explain their meaning. The first EV contains contributions with a similar sign from all HIRS/2 channels except those above the tropopause, where temperatures are reversed. This PC contains information on gross temperature features over the whole area. The second EV has more vertical gradient information, with large and opposite signs for the contributions from the surface and middle level HIRS/2 channels (6 and 15). The third EV contains even more detailed vertical information with particularly large and opposite signs for the contributions from two of the HIRS/2 water vapor channels (10 and 12). The first three PCs explain over 95% of the information in all 19 HIRS/2 infrared channels. The fourth EV was not used in this analysis.

Figure 6 shows a scatter plot of the HIRS/2 FOVs in PC-1,2,3 (measurement) space. Some obvious groupings of the data are apparent. Cluster analysis produces the cluster boundaries (ellipsoids) in Figure 7. Each cluster is a fixed size determined by the noise levels of the data. The members of a cluster are therefore similar to within their uncertainty. The cluster location in PC space, however, is indicative of variations in the measurements above noise, with each cluster representing a significant change from all other clusters, if only in one of the PC dimensions. Each FOV with its cluster designation is shown in real space in Figure 8. This indicates the spatial relationships between the clusters. A slight smoothing was applied to the PCs before clustering to add a small amount of spatial continuity, just as Switzer (1983) used pre-smoothing to take
Figure 5: The first 4 eigenvectors (EVs) of the 19 HIRS/2 infrared channels (without visible channel 20). The percentage of explained variance for each EV is given, with the first 4 EVs explaining over 98% of the total variance in the HIRS/2 channels.
Figure 6: Scatter plot of HIRS/2 FOVs in PC-1,2,3 space (with cluster membership designated by letters A-Z).

Figure 7: Clusters in PC-1,2,3 space formed by grouping the HIRS/2 FOVs in Figure 6 into fixed-size ellipsoids whose volume is determined by the noise level along each of the 3 PC axes. The 26 clusters are designated A-Z. On the right-hand side the number of FOVs in each cluster is given.
Figure 8: Cluster designations for each HIRS/2 FOV at its location in real space. Cloud-contaminated FOVs are designated by stars ('*'), and un-clustered FOVs are designated by pluses ('+').

Figure 11: Density of HIRS/2 retrievals by applying clustering to minimize the number of retrievals and maximize the differences between retrievals. Clustering stopped at 26 retrievals (A-Z), but if continued to include all FOVs would have resulted in about 40 retrievals.
advantage of spatial autocorrelations to improve the classification of satellite remote-sensing data. Cloud-contaminated FOVs ("*") were eliminated before clustering by employing a threshold of 288 K (15 deg C) in the 11 um HIRS/2 window channel. Shading is used to better indicate the cloudy regions which were eliminated from the clustered retrievals.

4.0 ITP SOFTWARE MODIFICATIONS

The most obvious difference between retrievals produced by clustering and by normal blocking is the reduced density of resulting retrievals. Figure 9 shows the HIRS/2 retrieval locations for normal retrievals produced with line and element increments of 5 FOVs. The ITP software finds the clearest sounding location within each 5 by 5 FOV block of measurements (25 FOVs) and puts the sounding at that location. This resolution resulted in 96 retrievals. Even greater retrieval density was obtained by producing retrievals with line and element increments of 3 FOVs (a block of 9 FOVs). This density is shown in Figure 10 with 246 retrievals. Only 26 retrievals were produced (designated A-Z), representing nearly all the FOVs in the area. A few FOVs ("+"s) were outside of the clusters, but were not considered to be of importance for this analysis. To include these additional FOVs would have increased the cluster count to about 40.

The retrieved cluster locations in Figure 11 are only the measurement centers of the clusters. Information on each FOV's relationship to the cluster center was maintained, and was used below to objectively produce a retrieval at any FOV from the retrievals produced at the cluster centers. This important objective analysis information considers measurements similarity only, not spatial relationships. This results in soundings which are smoothed less in space and which are reinforced by adjacent measurements which are similar.

4.1 Individual Clustered Retrievals

Retrievals were produced for each of the HIRS/2 clusters (A-Z). Of particular interest is the area around the tornadoes in northeastern Illinois. Figure 12 shows two retrievals (for clusters G and M), just to the south and west of the huge convective storm which spawned the tornadoes starting about 2000 UTC. Retrievals for these cluster have a moist boundary layer. Locations and extent of these clusters can be seen by referring back to Figure 8. Retrievals are also available to the north of the convective cell in the clear slot through southern Wisconsin. These retrievals (for clusters F and K) in Figure 13 are much drier at low levels. High density surface observations for this area indicated high surface dew point temperatures similar to those further south, but the soundings in this area are basically drier and cooler than those to the south. It was along the deep moist boundary between these two sets of soundings that the destructive convective storm formed.

4.2 Horizontal Analysis Fields

Horizontal fields of stability and precipitable water information were produced by objective analysis on the HIRS/2 retrievals for both the clustered and non-clustered (blocked) cases. Two non-clustered cases were generated with blocking into groups of 5 by 5 FOVs and 3 by 3 FOVs.

Figure 14 shows the analysis of lifted-index stability for the clustered retrievals. A large area of the most unstable air (-10 deg C) exits over southern Illinois and Missouri, with equally unstable air over Michigan and Ohio and northwest Iowa. Air to the north, however, is very stable (positive lifted index) over Minnesota and Wisconsin. In contrast
Figure 9: Density of HIRS/2 retrievals produced from the 'normal' ITP software with retrieval increments of 5 lines by 5 elements (blocks of 25 FOVs). This retrieval increment resulted in 96 retrievals.

Figure 10: Same as Figure 9 but for retrieval increments of 3 lines by 3 elements (blocks of 9 FOVs). This retrieval increment resulted in 246 retrievals.
Figure 12: Skew-T,log-P plot of TOVS retrievals for clusters G and M, just to the south and west of the tornado area in northeastern Illinois. Shown are both the regression first guess profiles (thin) and the final temperature and dew point retrievals (thick).
Figure 13: Same as Figure 12, but for clusters F and K, to the north of the tornado area in northeastern Illinois.
Figure 14: Lifted-index stability field produced from an objective analysis of 26 retrievals on clustered HIRS/2 data.

Figure 15: Same as Figure 14, but for 96 retrievals on HIRS/2 data grouped into 5 line by 5 element blocks (25 FOVs).
to the clustered-retrieval case, the lifted-index analysis for the 5 by 5 
FOV blocks of retrievals in Figure 15 shows less unstable air (-5 deg C) 
over Illinois and Missouri and the most unstable air over Iowa and 
Kentucky/Tennessee. In the third case, the lifted-index stability for the 
higher-density 3 by 3 FOV blocks of retrievals in Figure 16 shows a line of 
maximum instability across Iowa, northern Illinois, and northern Indiana. 
So all three retrieval schemes provided different analyses using the same 
input data. Since conventional data has not yet been analyzed for this 
case, it is only clear that significant differences exist. However, by 
comparing the objectively analyzed field to the shaded cloudy regions in 
Figure 8, it appears that cloud contamination of HIRS/2 FOVs may be a real 
problem, especially for the highest density soundings in Figure 16.

A similar comparison of retrievals from the three methods are shown in 
Figures 17, 18, and 19, but for the total precipitable water. Patterns are 
similar to those for the lifted-index stability. Again, large differences 
in absolute values and gradients exist between the three analyses.

5. CONCLUSIONS

Significant differences between clustered and non-clustered (blocked) 
retrievals are solely the result of the way the input data is treated. 
This case study continues to prove that satellite sounding measurements can 
produce reasonable retrievals, but it is important that the input data be 
handled properly. With proper treatment of the input by clustering, the 
results can be more reflective of the mesoscale air masses surrounding 
severe storms. Without proper handling, the retrievals can appear like bad 
data. No wonder satellite retrievals have a bad name. Is it better to 
produce lots of potentially bad retrievals or to produce a few improved 
retrievals which involve more effort to obtain?

6. FUTURE WORK

This work is only the preliminary analysis of this case study. 
Conventional data (soundings and surface observations) have not been fully 
analyzed. In addition, MSU data was not used actively in the clustering 
process. These avenues will be explored and results will be presented at 
the next Satellite Conference.

7. ACKNOWLEDGEMENTS

Mr. Hal Woolf at CIMSS kindly provided a VAX version of the ITP 
package for use at CIRA. Debra Lubich provided computing assistance. This 
work was supported by NOAA Grant NA85RAH05045.

7. REFERENCES

Achter, T., H. Woolf, and A. Schreiner, 1990: User’s guide to the 
International TOVS processing package, CIMSS, University of 
Wisconsin–Madison, August, 11-p.

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

of special 10-spin-per-channel VAS data. NOAA Technical Report 
NESDIS-56, February, 50-p.
Figure 16: Same as Figure 14, but for 246 retrievals on HIRS/2 data grouped into 3 line by 3 element blocks (9 FOVs).

Figure 17: Total precipitable water field produced from an objective analysis of 26 retrievals on clustered HIRS/2 data.
Figure 18: Same as Figure 17, but for 96 retrievals on HIRS/2 data grouped into 5 line by 5 element blocks (25 FOVs).

Figure 19: Same as Figure 17, but for 246 retrievals on HIRS/2 data grouped into 3 line by 3 element blocks (9 FOVs).


TECHNICAL PROCEEDINGS OF THE
SIXTH INTERNATIONAL TOVS STUDY CONFERENCE

AIRLIE, VIRGINIA

1-6 MAY 1991

Edited by

W. P. Menzel

Cooperative Institute for Meteorological Satellite Studies
Space Science and Engineering Center
University of Wisconsin
1225 West Dayton Street
Madison, Wisconsin

July 1991