

AN APPLICATION OF AVHRR DATA TO TOVS RETRIEVALS

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1. INTRODUCTION

Since the inception of the improved TIROS series of polar orbiting satellites, beginning with TIROS-N launched in 1979, the Advanced Very High Resolution Radiometer (AVHRR) has been included. This instrument provides measurements at a special resolution of 1.1 km at Nadir in four or five (depending on the satellite) wave-length channels. The instrument has been used primarily to obtain sea surface temperatures (McClain and Strong, 1984) and for agricultural applications (Taylor, et al., 1985). There is also, however, an obvious opportunity for its application to the retrieval of temperature and moisture profiles. Precise definitions of surface temperature and cloud state are crucial to retrieval accuracy, and precision is difficult to achieve with the 35 km field-of-view of the high resolution infrared sounding instrument (HIRS) used with the NOAA satellites. The AVHRR, with its complement of visible and infrared window channels, offers promise in determining these factors. Only in Japan are the HIRS and AVHRR routinely integrated in the retrieval procedure (Aoki, 1980). The U.S. has not followed suit, primarily because of logistical problems in performing the task on global sounding sets. Also, in terms of large scale weather patterns, to which the TOVS data are primarily addressed, it is questionable that the AVHRR would have significant impact since the cloud problem is largely alleviated by microwave measurements. On the mesoscale, however, the situation is different, and as remote sounding development turns increasingly in this direction, it is appropriate to investigate further an AVHRR/HIRS amalgamation.

In this paper, a single case study is described. It is shown that the AVHRR data can be successfully merged with the HIRS to provide improved cloud identification and correction. The effect on final profiles of temperature and moisture is not dramatic, indicating that further tuning of the retrieval algorithm, which is currently highly biased to the microwave, is probably required. There is, however, strong evidence that the AVHRR has a positive impact, especially on the low level moisture field.

2. COLOCATION AND PROCESSING OF AVHRR

Colocation of the AVHRR with the HIRS field-of-view is a non-trivial problem since the instruments scan in opposite directions at different rates. This question has been treated by Aoki (1980) and we have used his technique as described in a companion paper (Taylor, et al.). As reported, statistical and imaged comparisons of "pseudo" HIRS averaged from the AVHRR have convinced us that the method works accurately, at least for the case investigated here.

For each HIRS field of view, three channels of AVHRR are processed: the visible, 11 micrometer, and 3.7 micrometer. As reported by Taylor, et al., a series of tests is performed to determine the "scene" within the HIRS, and as many as three radiance values may be returned for each channel, if the scene is determined to consist of two uniform targets (e.g. uniform cloud and surface or two uniform cloud decks). The three values correspond to the two uniform temperatures and the average of these. Failing a two scene scenario, a single uniform temperature, if it exists, and the average (which will be the same) are returned. Failing the single and the two scene tests, only the average is returned. In the last condition, no retrieval is attempted.

3. METHOD OF AMALGAMATION

The basic resolution element for a TOVS retrieval is 3x3 HIRS FOV. For each of the nine spots, given that the AVHRR and TOVS are accurately collocated and that the former has been processed to determine a one or two uniform scene within the TOVS FOV, the following procedures are followed:

- If the scene is uniform, the TOVS radiances are passed as measured.

- If the scene is two-fold, a cloud correction via the "adjacent pair" method (McMillan, 1978) is attempted. Since the processing of a retrieval involves a 3x3 array of FOV, there are as many as 35 independent "adjacent pair" comparisons. It should be recalled that in the "adjacent pair" method, there are two fundamental assumptions: that the same type of cloud exists in both fields; and that the clouds are at a single level. The role of the AVHRR is to determine that the assumptions are upheld. Violation of either invalidates the method as demonstrated by McMillan (loc cit.).

In our processing, it is required that both cold and warm uniform scene radiances in the two FOV be similar (within five degrees of brightness temperature in the 11 micrometer channel). If so, an "N*" is determined and the "adjacent pair" correction is made as follows:

$$N = (\hat{I} - I_H) / (I_L - I_H) \quad (1)$$

$$N^* = N_1/N_2 \quad (2)$$

$$I_{c1} = (I_1 + N^*I_2) / (1 - N^*) \quad (3)$$

where N is cloud amount, I_{c1} is the corrected clear column radiance, \hat{I} is the TOVS measurement and I_H and I_L are "HIRS equivalent" measurements for the two uniform scenes determined from the AVHRR. The subscripts (admittedly confusing) represent "higher" or "lower" in brightness temperature corresponding to clear and cloudy scenes; or two uniform cloud levels. Subscripts 1 and 2 refer to the two HIRS FOV. "HIRS equivalence" is accomplished by a local regression analysis which relates HIRS measurements to the averaged AVHRR measurements for the 3x3 HIRS FOV. In these regressions, we usually find correlations to be .95 or higher.

Cloud amount N can be determined from the visible or infrared window channels (3.7 and 11 micrometer) of the AVHRR. There is no guarantee that similar amounts will result from different frequencies, and in fact, they often don't. The shortwave infrared in the presence of reflected sunlight is especially troublesome. As in so many other decisions made in retrieval processing, there is no clear cut way of sorting out the confusion of computed N^* . We have chosen to put highest reliance on the 11 micrometer determination, ordering the FOV such that N^* lies between zero and 0.75 for this frequency. N^* for the 3.7 micrometer channel is then constrained to be within 0.2 of the 11 micrometer estimate (but again limited to less than 0.75) or the shortwave HIRS measurements for the pair are not used in the retrieval.

Any pair which survives the adjacent pair testing is subjected to an extrapolation constraint. By this, the corrected brightness temperature for either window channel is not permitted to exceed the averaged warm uniform value by more than two degrees.

Finally, all survivors from the 3x3 array, whether uniform or N^* , are averaged, weighted by their clearness (1-N). The final radiance estimates are accepted if the sum ($\sum_j (1-N_j)$) exceeds 0.5. The final estimates are examined to determine whether the retrieval will take the "clear" or "cloudy" path. This decision is determined from the TOVS measurements of bi-directional reflectance and a variety of comparisons between the three (11, 3.7 and 4 micrometer) windows and the surface air temperature. The latter is obtained from the surface network of reporting stations.

4. CASE STUDY

The data treated in this study is a four minute swath of AVHRR over the central U.S. near 1345 GMT on 7 June 1984. The synoptic situation was characterized by a large low pressure system centered over southern Canada with a weak stationary front extending eastward along the Canada/U.S. border and a second stationary front with waves

stretching from Lake Superior across Wisconsin and Iowa and dropping down through South Dakota and Nebraska to a low pressure system forming over Kansas and Oklahoma. To the east of this front, a large pool of warm, moist air contained considerable cloudiness of several types as can be seen in Figures 1 and 2. Figure 1 is an image of the water vapor sensed by the VISSR Atmospheric Sounder (VAS) 6.7 micrometer channel carried on GOES-5. The surface pressure and 500 mb geopotential contours from the National Weather Service analyses at 1200 GMT are superimposed. Strong southwesterly flow aloft contributed to the development of a wave over Kansas and convection along and ahead of the front to the northeast later in the day.

The area covered by the TOVS data is indicated by the plotted values in Figure 2 which also shows an image of the VAS 11 micrometer window. The considerable and varied cloudiness of the situation offers a challenge to the AVHRR/HIRS amalgamation although the loose gradients of temperature and moisture make verification of mesoscale detail very difficult.

5. RESULTS

The TOVS data for 7 June 1984 was processed with and without the AVHRR. The yield was very similar in both cases as can be seen by contrasting Figures 3 and 4. The former represents the run using AVHRR. It has slightly fewer retrievals because of the decision to skip scenes where no uniform temperature is available from the AVHRR. In the "No-AVHRR" version, a retrieval is always attempted (an expression of confidence in the microwave measurements) although it may fail internal consistency checks.

Our primary objective in this exercise was to obtain more clear and cloud corrected soundings using the AVHRR. In this we were successful. The brighter numbers of Figure 3 and 4 represent the clear or partly cloudy, while the fainter entries represent overcast determinations. Judging by the cloud imagery, the algorithm has performed as expected.

Several parameters in the AVHRR amalgamation were varied to test sensitivity. One of these was the uniformity constraint imposed on the warm and cold scenes of paired FOV. The total yield of soundings turned out to be rather insensitive. The constraint was varied from three to five to seven degrees with the result shown in Table 1. Note, however, that the number of partly cloudy retrievals increases systematically as the gate is widened. The increase is at the expense of previously uniform retrievals (both clear and overcast) when additional N* samples are added in the averaging over the 3x3 array.

Table 1. Uniformity constraint variation and retrieval yield. Limit is in degrees of brightness temperature for 11 and 3.7 micrometers.

<u>Limit</u>	<u>Total Soundings</u>	<u>Total N*</u>
3	164	15
5	164	22
7	167	27

We find that failure in the adjacent field of view testing is usually caused by the colder scene comparison. The AVHRR processing has been tuned to provide two scene estimates a majority of the time (see Taylor, et al.), but the spacial variation of the cold scene is marked. This can be seen in the image shown in Figure 5. In the figure, each square represents a TOVS field-of-view. The black squares show where no second scene was obtained. Otherwise, the shading depicts the change in the scene temperature, with lightest being coldest. "Uniform" 3x3 arrays are rather rare.

The change from uniform to partly cloudy retrievals as shown in Table 1 has rather little effect on retrieval quality. This is unquestionably because of the extrapolation constraint imposed on all N^* estimates such that they cannot vary from the warm uniform estimate by more than two degrees. When this constraint was loosened, the soundings became noisy showing that the N^* estimates certainly need this or an equivalent filter.

The goal in introducing AVHRR data into the TOVS retrieval processing is to provide better profiles of temperatures and moisture, particularly in partly cloudy situations. Achievement of this goal has proven to be elusive. There is the usual paucity of ground truth to verify the subtle modifications caused by the AVHRR, and the modifications introduced are indeed small. The types of change introduced by the AVHRR seem correct in principal. The retrieval process (the "simultaneous" algorithm described by Smith, et al. in a companion paper) is basically a two pass procedure where the first pass is primarily a microwave retrieval with the transparent HIRS channels suppressed. The second pass adjusts the first retrieval, to a greater or lesser extent according to cloud determination. We find that with AVHRR included, the second pass retrieval produces significantly larger changes to the first pass in the lower layers of the atmosphere. However, the changes are rarely greater than a degree, which put them below the sensitivity of available verification.

Figure 6 shows analyses of the 850 mb dewpoint derived from the processing with and without AVHRR. The fields are quite amorphous as should be anticipated in this weather situation. There are three areas where there are marked differences in the analyses. In the Mississippi Valley south of Illinois, the field with AVHRR shows a distinct moisture minimum which is not present in the other analysis. Also, over the Georgia/Alabama border the No-AVHRR field shows a moisture maximum which is absent in the AVHRR version. Finally, over Michigan and Lake Huron, the AVHRR analysis is drier. In all instances, the differences are caused by the change from "overcast" to "partly-cloudy" retrievals, as can be seen in Figures 3 and 4; and in all instances the AVHRR versions appear to be more correct, as deduced from the water vapor imagery of Figure 1. There is, in fact, good coherence between the AVHRR analysis and the dry/moist areas visible in the VAS image; much better than for the No-AVHRR analysis. Thus, at least qualitatively we can show improvement in the retrievals when the AVHRR is used.

5. SUMMARY

This paper reports the early findings of a research project which is far from complete. Both the techniques for extracting AVHRR information at HIRS FOV and the methods of incorporating this in the retrieval algorithm need further development. Also, more than a single case study must be addressed. Nevertheless, progress to date is highly encouraging. There is little doubt that the high resolution data are having their anticipated effect in resolving the infrared cloud problem, and that they are improving, albeit marginally, the final products of temperature and moisture generated from the TOVS retrievals.

5.1 References

- Aoki, T., 1980: A method for matching the HIRS/2 and AVHRR pictures of TIROS-N satellites. Tech. Note No. 2, Met. Sat. Center, Japan, 15-26.
- McClain, E. P., and A. E. Strong, 1984: Improved ocean surface temperatures from space--comparisons with drifting buoys. Bull. Am. Meteorol. Soc., 65, 138-142.
- McMillan, L. M., 1978: An improved technique for obtaining clear radiances from cloud contaminated radiances. Mon. Wea. Rev., 11, 1590-1597.
- Smith, W. L., H. M. Woolf, C. M. Hayden and A. J. Schreiner: The simultaneous retrieval export package (companion paper).
- Taylor, B. F., P. W. Dmi, and J. W. Kidson, 1984: Vegetation index of New Zealand pasture from NOAA-7: seasonal and interannual variation. Submitted to Remote Sensing of the Environment.
- Taylor, B. F., C. M. Hayden, and W. L. Smith: The determination of HIRS scene temperatures from AVHRR data (companion paper).



Figure 1. The VISSR Atmospheric Sounder image of the 6.7 micrometer (water vapor) channel for 7 June 1984 1400 GMT. Analyses of 500 mb geopotential (solid) and surface pressure (dashed) for 1200 GMT, obtained from the National Meteorological Service, are overlaid.

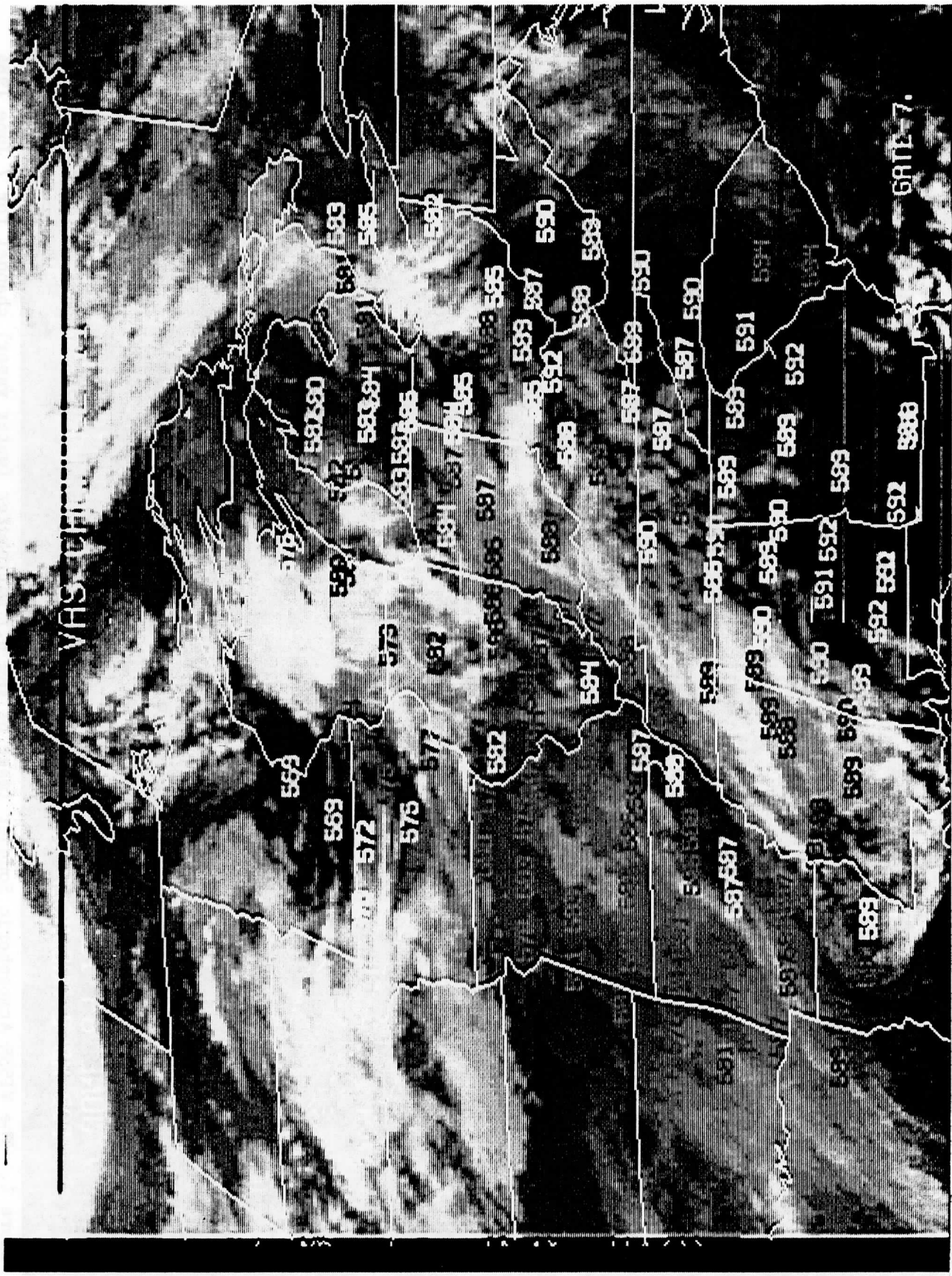


Figure 2. TOVS retrievals of 500 mb geopotential displayed over the VISSR 11 micrometer image. Dark (faint) numerals indicate "overcast" whereas brighter and brightest numerals indicate "clear" and "partly-cloudy" as determined by the AVHRR processing algorithm.

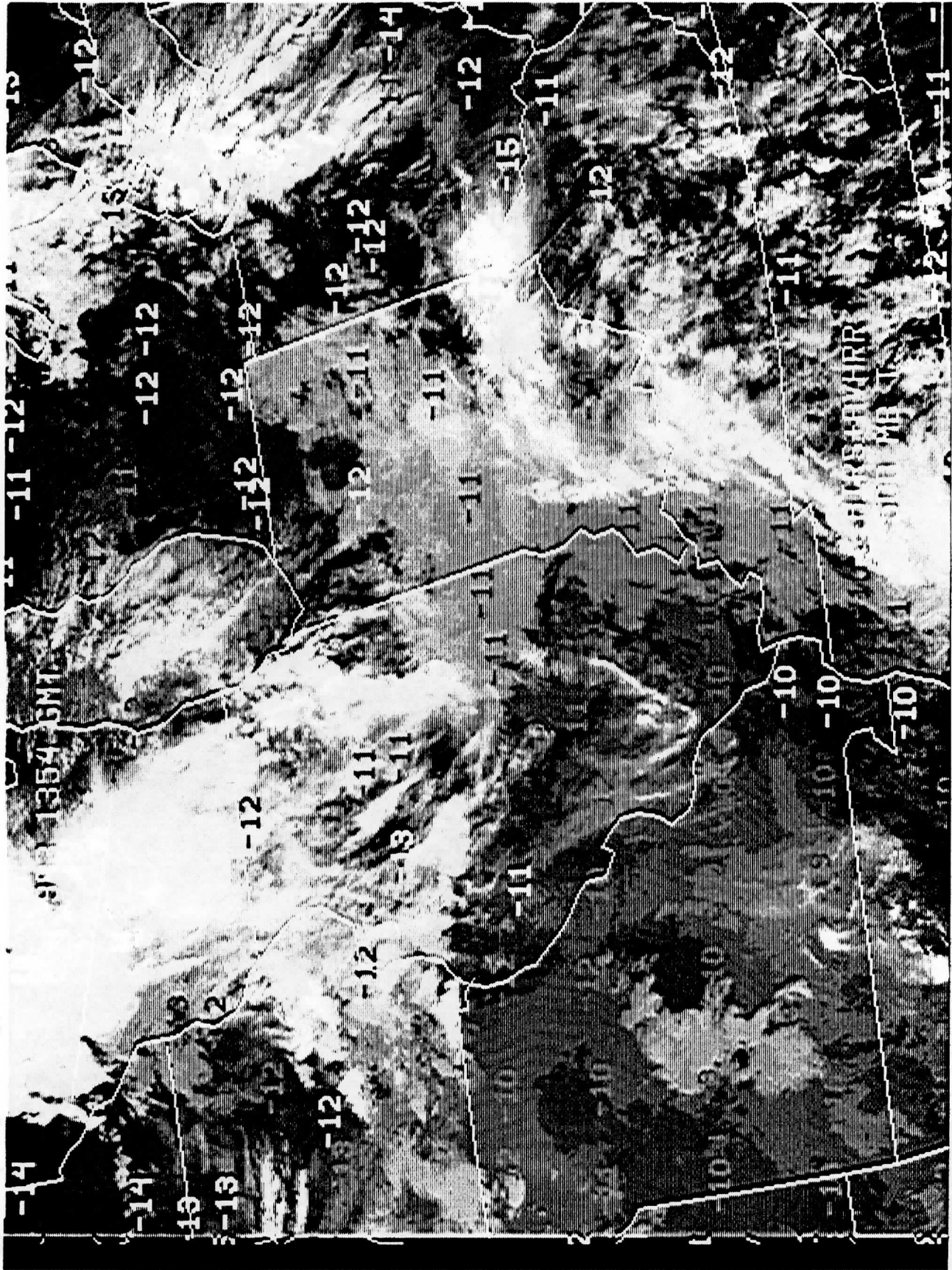


Figure 3. TOVS retrievals of 500 mb temperature displayed over the AVHRR 11 micrometer image. Retrievals were processed without AVHRR. Brightness of digits represents perceived cloud conditions as in Figure 2.



Figure 4. Same as Figure 3, except that retrievals were processed with AVHRR data.

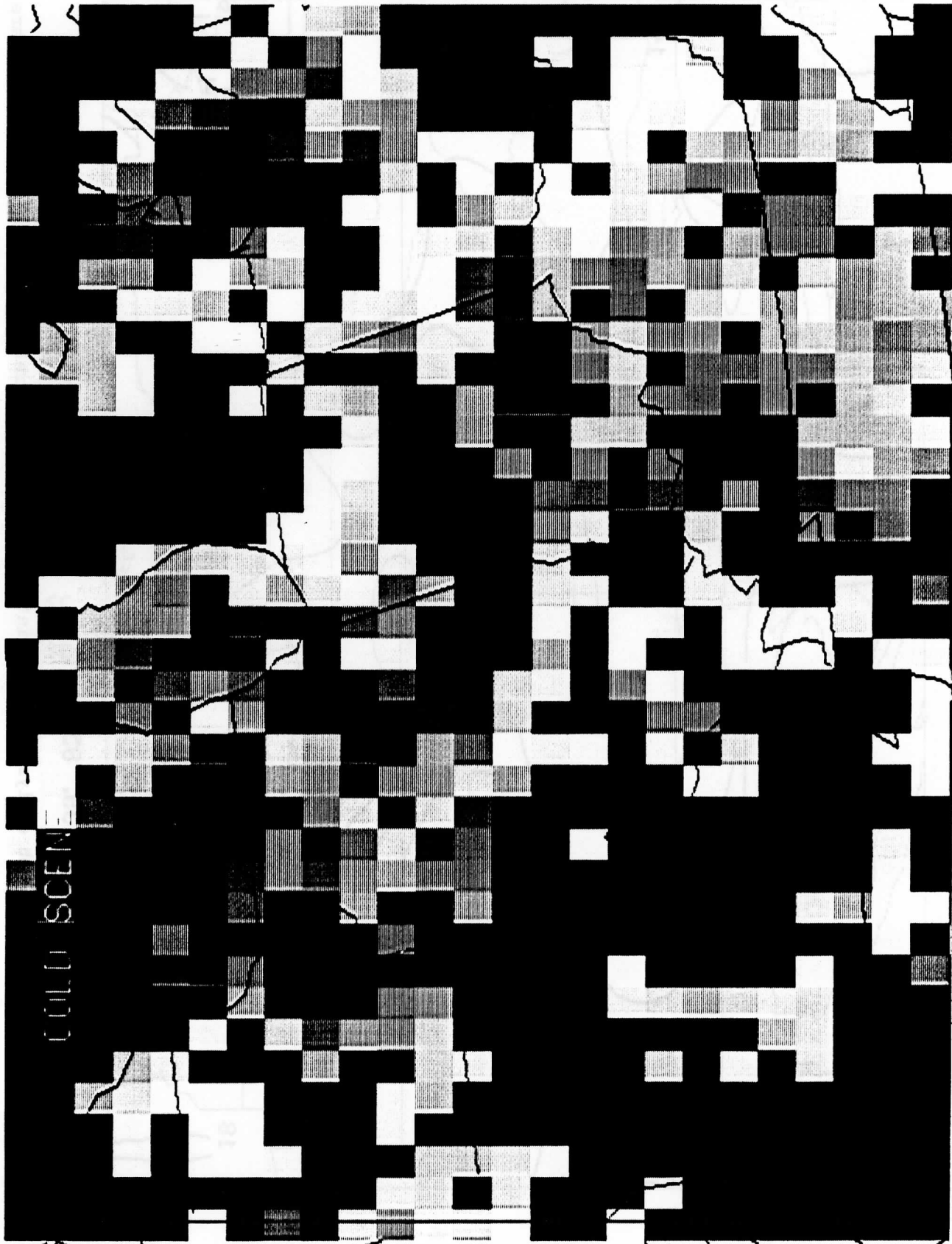
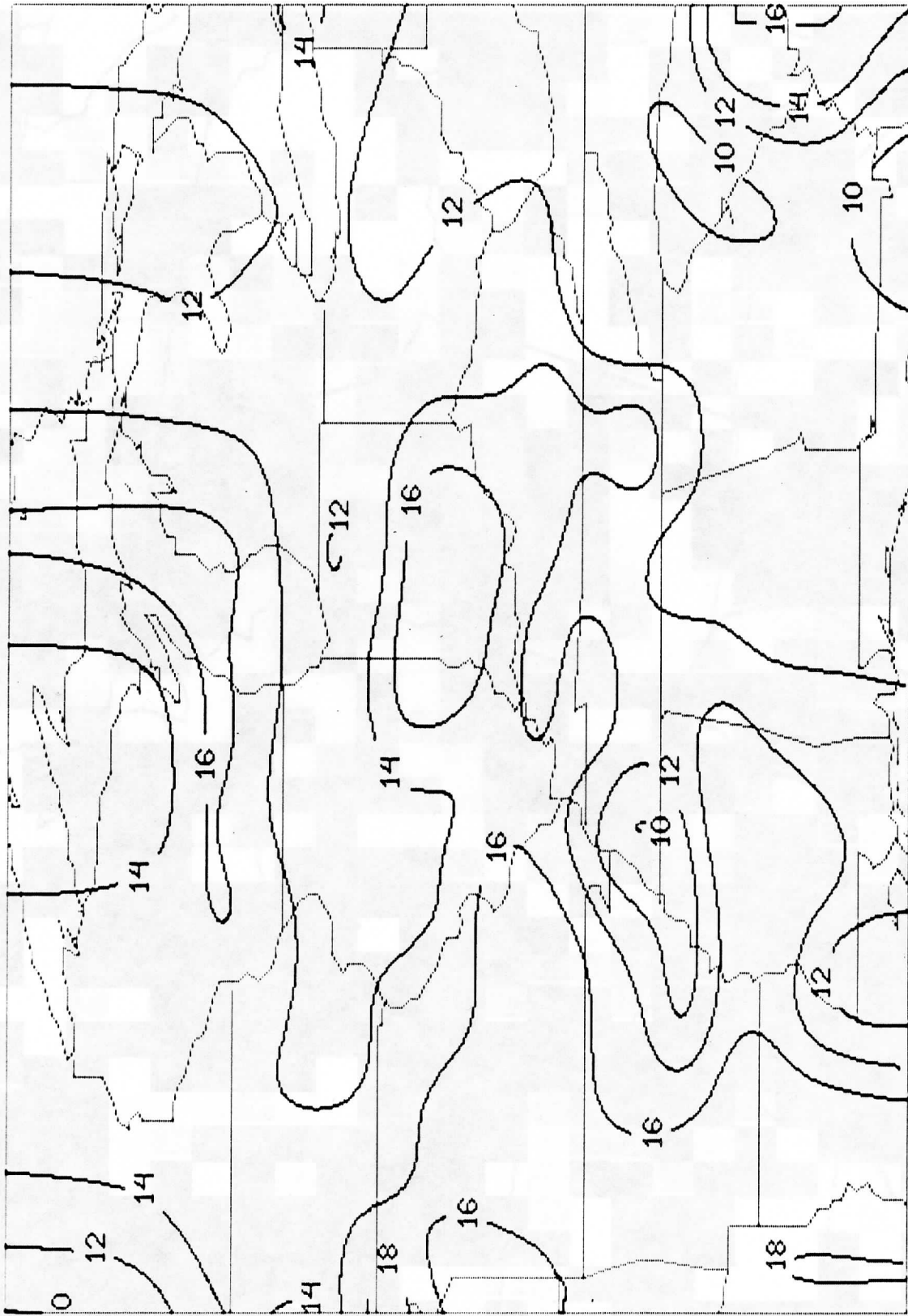
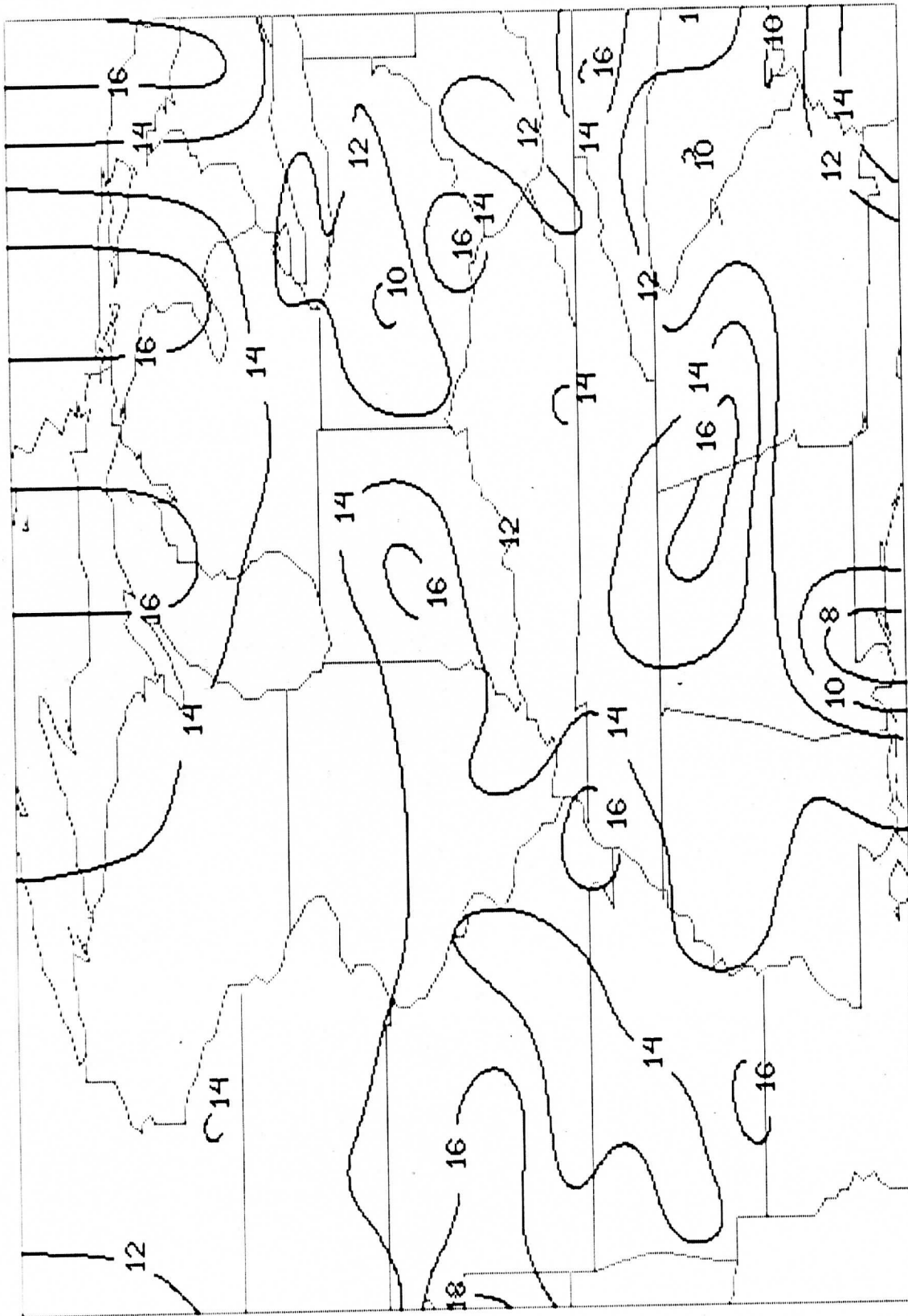


Figure 5. AVHRR estimates of "cold scene" temperatures at HIRS FOV resolution (represented by squares). Black indicates that two scene identification could not be made. Shading indicates temperature of scene (white coldest).



TO (K) TIME 13. DAY 84159. 850. WITH AVHRR

Figure 6. (With AVHRR) 850 mb analyses of dewpoint derived from TOVS retrievals with AVHRR. Units are K.



TO (K) TIME 13. DAY 84159. 850. WITHOUT AVHRR

W W W W W
W W W W W

Figure 6. (Without AVHRR) 850 mb analyses of dewpoint derived from TOVS retrievals without AVHRR. Units are K.

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