USE OF TOVS IN CANADA

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1. Introduction

TOVS stands for TIROS Operational Vertical Sounder. MSRB Aerospace Meteorology Division developed an interactive TOVS processor in 1981. The purpose of the AES TOVS processor is to invert the radiance data obtained from the polar orbiting satellites to obtain vertical temperature and moisture profiles of the atmosphere. Due to the high horizontal and temporal resolution of the data, we hope to use them to improve mesoscale forecasts or input the data into mesoscale numerical prediction models.

Section 2 describes briefly the TOVS instruments. Section 3 describes briefly the different modules of the AES TOVS processor. Section 4 describes the results of a statistical study comparing satellite retrieved temperature and moisture with collocated radiosonde data. In section 5 we will discuss briefly the shortcomings of the present system and plans for future improvement and development. Section 6 is the conclusion.

2. TOVS Instruments

TOVS consists of 3 instruments; namely, the second version of the High Resolution Infrared Radiation Sounder (HIRS-2), the Microwave Sounding Unit (MSU) and the Stratospheric Sounding Unit (SSU).

Table 1 summarizes the characteristics of the TOVS sounding channels. The infrared signals received by the HIRS-2 channels are strongly affected by clouds. The microwave emissions are not affected by clouds but are absorbed by heavy precipitation.

Figure 1 shows the vertical resolution observed within each channel and the correlations between all channels. Figure 2 compares the horizontal resolution of the HIRS-2 instruments resolutions. In the figures, each oval represents a scan spot. Interested readers are referred to Smith et al. (1979) and A. Schwalb (1978) for more detailed descriptions of the TOVS instrument.

3. AES TOVS Processor

The current AES TOVS processor consists of 3 components; the preprocessing module, the coefficient generation module and the assimilation module. Figure 4 shows a summary of these components.

The main function of the preprocessing module is to extract the HIRS and MSU data, timing and calibration information from the digitized statellite data. Calibration equations are applied to the digital counts, converting them to radiances in the form of equivalent blackbody brightness temperatures. Each HIRS scan spot is earth located and the MSU measurements are interpolated to the HIRS grid. Algorithms are applied to the radiances to correct for limb effects. In the case of MSU measurements, the antenna side lobe and surface emissivity effects are corrected. Provisions are also made to correct the IR window channels for reflected solar radiation and water vapour absorption. The Cooperative Institute for Meteorological Satellite Studies in Madison, WI supplied us with the software to do the latter four effects.

The AES processor uses a statistical method for coefficient generation. The inversion problem is solved using simple multi-linear regression. The regression coefficients for temperature and moisture are obtained from a dependent sample of current radiosonde measurements regressed against brightness temperatures calculated from the same radiosonde measurements, with a realistic instrumental noise estimate added. The software for computing the brightness temperatures (synthetic clear radiances) from radiosonde data was obtained from CIMSS. Regression coefficients are updated weekly using radiosonde data from the past 3 weeks.

The assimilation module is an interactive system. The operator can select a specific area within the orbit to retrieve temperature and moisture at a specific pressure level. Editing is available for the operator to delete meteorologically inconsistent retrievals. In the present configuration, the assimilation module can retrieve temperatures at 20 levels from 1000 mb to 115 mb, and moistures at 15 levels, from 1000 mb to 300 mb. Table 2 shows the different pressure levels where temperature and moisture retrievals are available. Derived values of stability indices (Showalter and Total-Totals) and thickness can also be displayed.

The retrievals are divided into 3 categories: (a) clear retrievals in cloud-free areas, (b) cloudy retrievals in partly cloudy areas in which special algorithms can be applied to correct for the cloud contamination, (c) overcast retrievals in areas where cloud corrections cannot be done and the MSU data alone are used to obtain temperature profiles. In this case, moisture data cannot be obtained.

Table 3 summarizes all the products one can obtain from the AES-TOVS processor. Figure 5 is a typical NOAA-7 TOVS orbit. The operator can enlarge any portion of the orbit and display it on the video display unit. Figure 6 shows the 850 mb IR temperature analysis of Ontario region. Note that temperature and moisture retrievals can be obtained at each pixel.

4. Statistical Studies

A statistical study was conducted for a 3 week period from Sept. 7 - 28, 1982, using NOAA-7 satellite morning orbits (from 0755 GMT to 1025 GMT) over eastern and central North America.

The verification for temperature was divided into 3 parts; clear, cloudy and overcast retrievals. Figure 7 and Figure 8 are two examples of comparisons between radiosonde temperature and moisture, and satellite retrieved data. In the clear cases, the major discrepancies are from surface to about 850 mb and from 350 mb to 200 mb. In general, the shapes of the 2 curves correspond fairly well. For moisture retrievals, the general trends are there, but the retrievals miss the sharp gradients of the RAOBS at different levels. Similar features are apparent in the cloudy and overcast cases.

Figure 9 shows the RMS differences in °K for the 3 categories. The sample sizes are 120 for the clear case, 76 for the cloudy case and 73 for the overcast case. The retrieved temperatures compared best with radiosondes from 700 mb to 350 mb. The RMS differences are about 1.6 to 2.5 at mid-troposphere. The retrievals missed the low level inversion and the tropopause. The MSU retrievals were better than the cloudy retrievals but not as good as the clear retrievals. This may be due to several factors:

- the MSU channels have poor vertical and horizontal resolution;

- the lowest MSU channel peaks at 600 mb;

- coefficients are generated from clear radiances, thus, under cloudy conditions, the coefficients may not be representative;

- MSU channels are poor in heavily precipitating areas (this accounts for about 10% of the cloudy soundings);

- radiosondes are treated as perfect, however, there are errors. [Hoehne (1980) found a standard deviation of 0.67°C for 2 radiosondes flown on the same balloon. Frith (1948) showed that an error of 1°C can occur within 15 - 50 km of the radiosonde site. Brewer (1951) found that radiosonde data may not be representative of the air mass];

- radiosonde data was not time interpolated to the satellite retrieval time in this study; and

- radiosonde data are essentially point measurements and TOVS retrievals are volume measurements, so it is difficult to justify the comparison of the two.

Figure 10 shows the results obtained by Gruber (1982) for the verification of the NWS operational TOVS. The results are similar to ours except that they used a larger sample size. For clear retrievals, there are 2,850 points and for cloudy retrievals, there are 900 points. At mid-troposphere, their RMS error is 1.5 to 2.5 degrees Centigrade.

5. Future Improvement and Development

We are now working on improving the regression coefficients, so that better retrievals can be obtained. Better cloud detection routines are also being investigated.

The moisture retrievals results are not very satisfactory. The main problem is that the radiation signals chosen to do the moisture retrievals depend on both the atmospheric temperature and water vapour concentration. Since the transmittance depends on the water vapour concentration, the position of the weighting function peak will change according to the water vapour concentration. We are now looking into ways to improve the moisture retrieval algorithm. One method suggested by Hayden et al. (1981) to incorporate surface data into the retrieval routine will be looked into in detail.

6. Conclusion

In conclusion, the AES-TOVS processor is capable of producing vertical temperature profiles from 1000 mb to 115 mb and moisture profiles from 1000 mb to 300 mb. The RMS differences between the retrieved temperatures and the radiosonde temperatures are about 1.6 to 2.5°C at mid-troposphere. The moisture retrievals are not very satisfactory and different ways of improving them are now being looked into. Due to the high horizontal resolution of the TOVS retrievals, there is a potential to use the results in short range mesoscale forecasts or as input into a mesoscale numerical forecast model.

We are presently running a summer experiment providing limited amounts of processed TOVS data to the Ontario and Prairie Weather Centres. We hope that this will result in further suggestions for improving the AES-TOVS processor.

References

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HIRS Channel number	Channel central wavenumber	Central wavelength (μm)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	668	15.00	CO_2	30 mb	*Temperature sounding.* The 15-μm band channels provide better sensitivity to the temperature of relatively cold regions of the atmosphere than can be achieved with the 4.3-μm band channels. Radiances in Channels 5, 6, and 7 are also used to calculate the heights and amounts of cloud within the HIRS field of view.
2	679	14.70	CO_2	60 mb	
3	691	14.50	CO_2	100 mb	
4	704	14.20	CO_2	400 mb	
5	716	14.00	CO_2	600 mb	
6	732	13.70	CO_2/H_2O	800 mb	
7	748	13.40	CO_2/H_2O	900 mb	
8	898	11.10	Window	Surface	*Surface temperature* and cloud detection.
9	1 028	9.70	O_3	25 mb	*Total ozone* concentration.
10	1 217	8.30	H_2O	900 mb	*Water vapor sounding.* Provides water vapor corrections for CO_2 and window channels. The 6.7-μm channel is also used to detect thin cirrus cloud.
11	1 364	7.30	H_2O	700 mb	
12	1 484	6.70	H_2O	500 mb	
13	2 190	4.57	N_2O	1 000 mb	*Temperature sounding.* The 4.3-μm band channels provide better sensitivity to the temperature of relatively warm regions of the atmosphere than can be achieved with the 15-μm band channels. Also, the short-wavelength radiances are less sensitive to clouds than those for the 15-μm region.
14	2 213	4.52	N_2O	950 mb	
15	2 240	4.46	CO_2/N_2O	700 mb	
16	2 276	4.40	CO_2/N_2O	400 mb	
17	2 361	4.24	CO_2	5 mb	
18	2 512	4.00	Window	Surface	*Surface temperature.* Much less sensitive to clouds and H_2O than the 11-μm window. Used with 11-μm channel to detect cloud contamination and derive surface temperature under partly cloudy sky conditions. Simultaneous 3.7- and 4.0-μm data enable reflected solar contribution to be eliminated from observations.
19	2 671	3.70	Window	Surface	
20	14 367	0.70	Window	Cloud	*Cloud detection.* Used during the day with 4.0- and 11-μm window channels to define clear fields of view.

MSU	Frequency (GHz)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	50.31	Window	Surface	*Surface emissivity* and *cloud attenuation* determination.
2	53.73	O_2	700 mb	*Temperature sounding.* The microwave channels probe through clouds and can be used to alleviate the influence of clouds on the 4.3- and 15-μm sounding channels.
3	54.96	O_2	300 mb	
4	57.95	O_2	90 mb	

SSU	Wavelength (μm)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	15.0	CO_2	15.0 mb	*Temperature sounding.* Using CO_2 gas cells and pressure modulation, the SSU observes thermal emissions from the stratosphere.
2	15.0	CO_2	4.0 mb	
3	15.0	CO_2	1.5 mb	

Table 1. Characteristics of TOV Sounding Channels.

TEMPERATURE RETRIEVAL LEVEL	PRESSURE
1	115 mb
2	135 mb
3	150 mb
4	200 mb
5	250 mb
6	300 mb
7	350 mb
8	400 mb
9	430 mb
10	475 mb
11	500 mb
12	570 mb
13	620 mb
14	670 mb
15	700 mb
16	780 mb
17	850 mb
18	920 mb
19	950 mb
20	1000 mb

MOISTURE RETRIEVAL LEVEL	PRESSURE
1	300 mb
2	350 mb
3	400 mb
4	430 mb
5	475 mb
6	500 mb
7	570 mb
8	620 mb
9	670 mb
10	700 mb
11	780 mb
12	850 mb
13	920 mb
14	950 mb
15	1000 mb

Table 2

Table 3

Products available from AES-TOVS processor:

(1) 20 levels of temperatures can be computed from either MSU or HIRS channels. (See Table 2 for the pressure levels). MSU channels are not affected by clouds. Thus, temperatures can always be obtained from these channels. The main drawbacks of the MSU channels are (i) poor horizontal and vertical resolutions, (ii) no moisture retrievals can be done, (iii) MSU channels are affected strongly by heavy precipitation. Figure 11 is an example of MSU temperature output. For the explanations of the headers of the pictures, refer to Table 4. Figure 12 is an example of HIRS temperature retrievals. A pure number signifies clear retrievals. A number with an "M" signifies overcast area. The "M" retrievals are obtained by extrapolating or interpolating the MSU/HIRS bias in the cloud-free or partly cloudy areas to the overcast areas and adding the bias to the MSU temperatures to make them more compatible with the HIRS temperatures of the partly cloudy or clear area.

(2) Thickness can be obtained in any combinations of the 20 temperature levels. Figure 13 is an example of thickness (850 mb - 500 mb) obtained using the HIRS channels. The unit is in decameters.

(3) Moisture can be obtained for 15 levels (see Table 2). Figure 14 is an example of 850 mb relative humidity retrievals in percentage. "F" denotes overcast area for which no moisture retrievals can be calculated.

(4) Instability indices can be derived too. Figure 15 is an example of total-totals indices. "F" denotes overcast areas. Figure 16 is an example of Showalter indices. "F" denotes overcast areas.

Table 4

Explanations for the header of the figures.

TN MMMMM PPP XXX YR/MN/DA TIME

TN	=	TIROS-N satellites (NOAA-7, NOAA-8)
MMMMM	=	Orbit number
PPP	=	Pressure level in mb (in case of thickness, it will be the top and bottom pressure levels of the layer).

XXXX can be:

- TMSU - MSU temperatures in °C
- THRS - HIRS temperatures in °C
- WVC - relative humidity in %
- HRTK - HIRS derived thickness in decameters
- MSTK - MSU derived thickness in decameters
- TTOT STAB - total-totals instability indices
- SHOW STAB - Showalter instability indices.

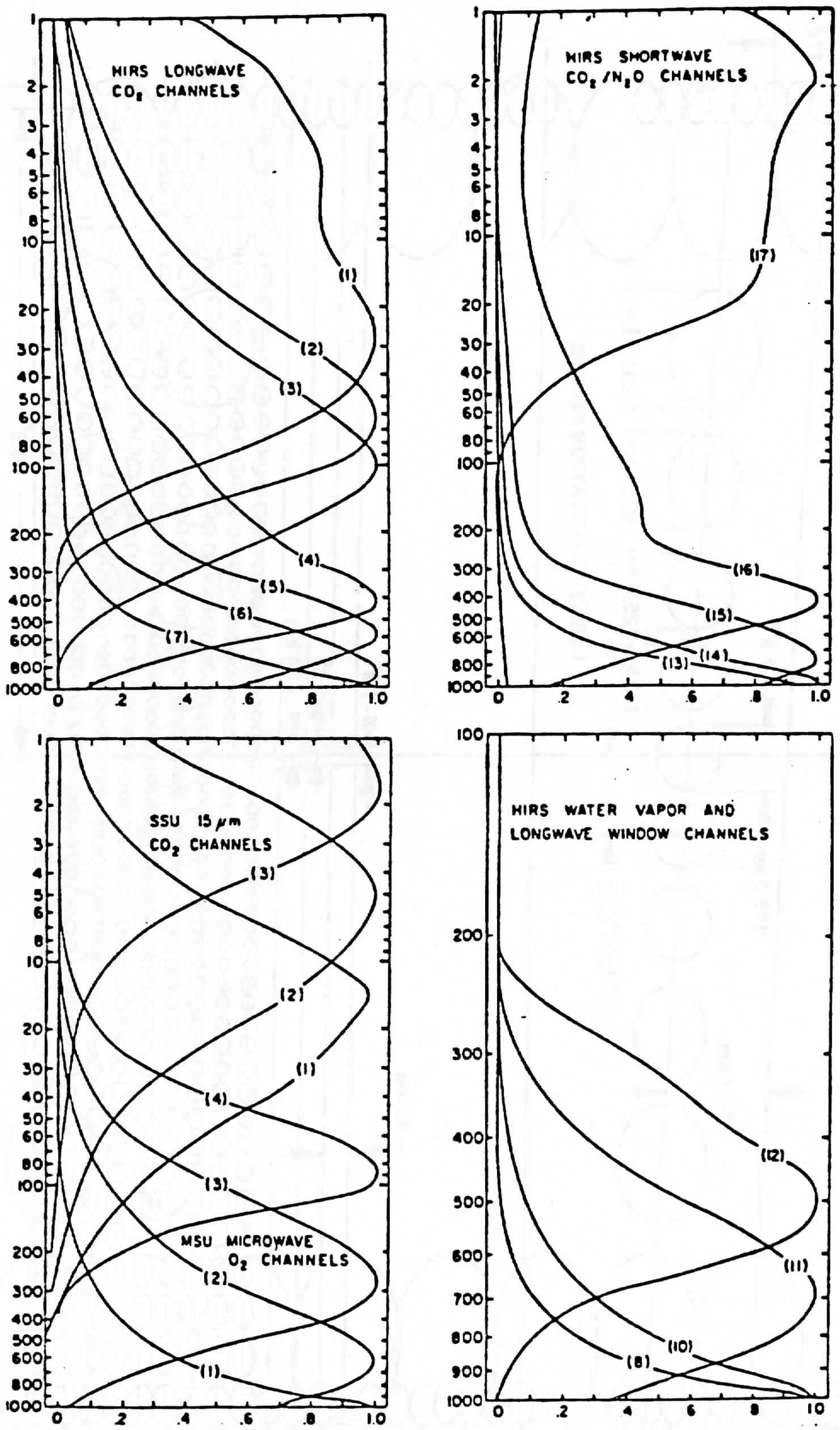

Figure 1. TOVS weighting functions (normalized).

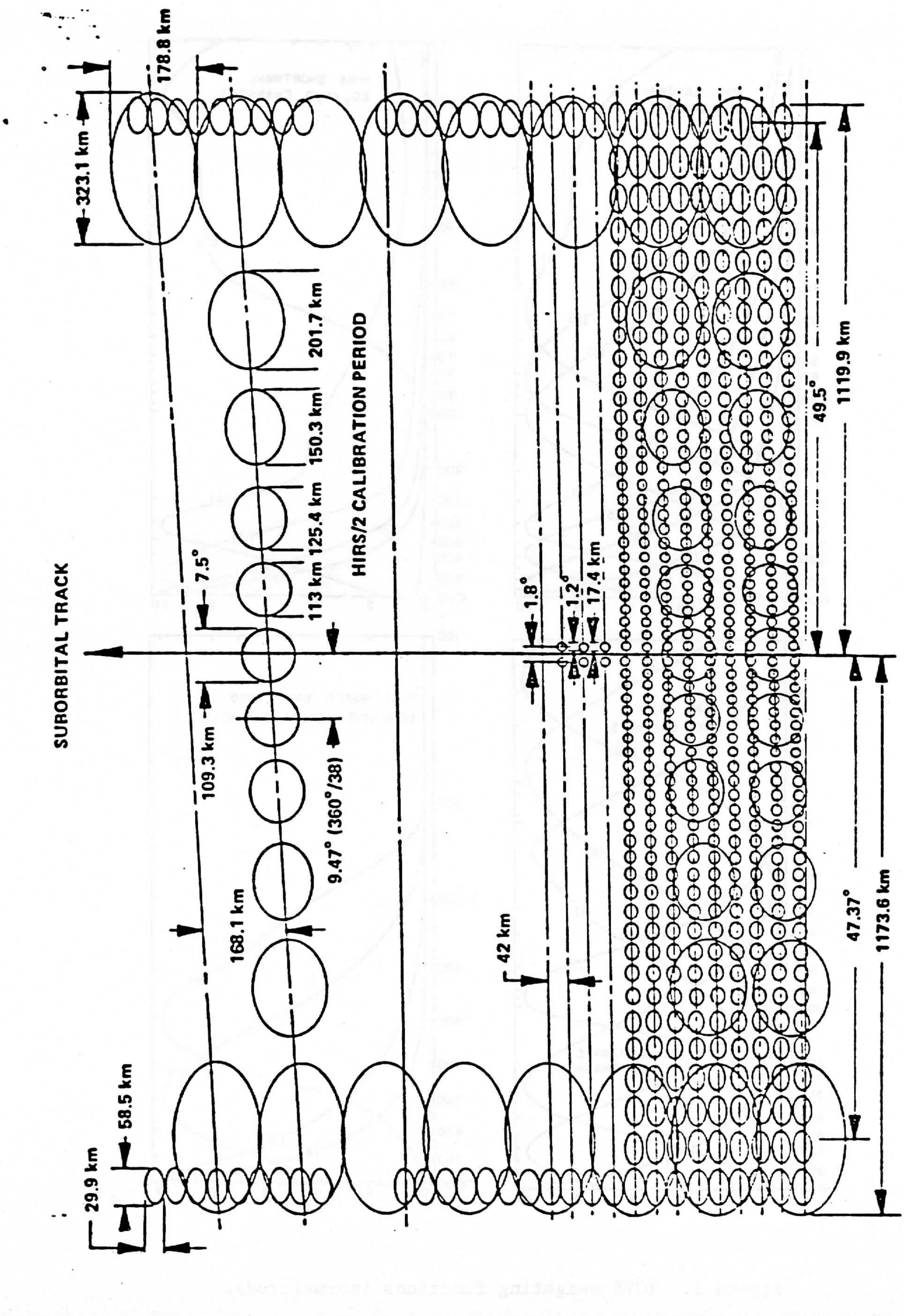

Figure 2. TIROS Operational Vertical Sounder HIRS/2 and MSU Scan Patterns Projected on Earth.

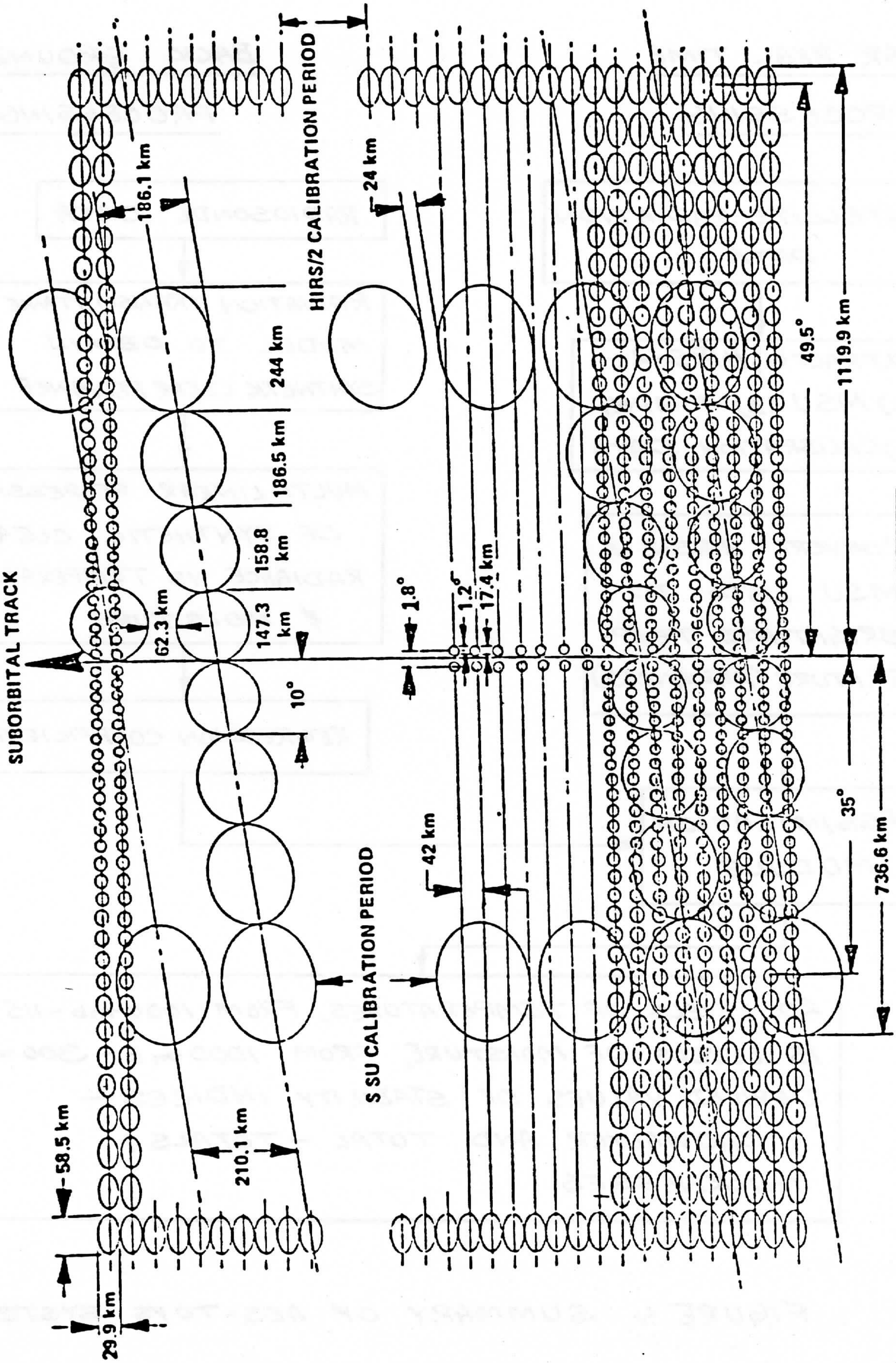

Figure 3. TIROS Operational Vertical Sounder HIRS/2 and SSU Scan Patterns Projected on Earth.

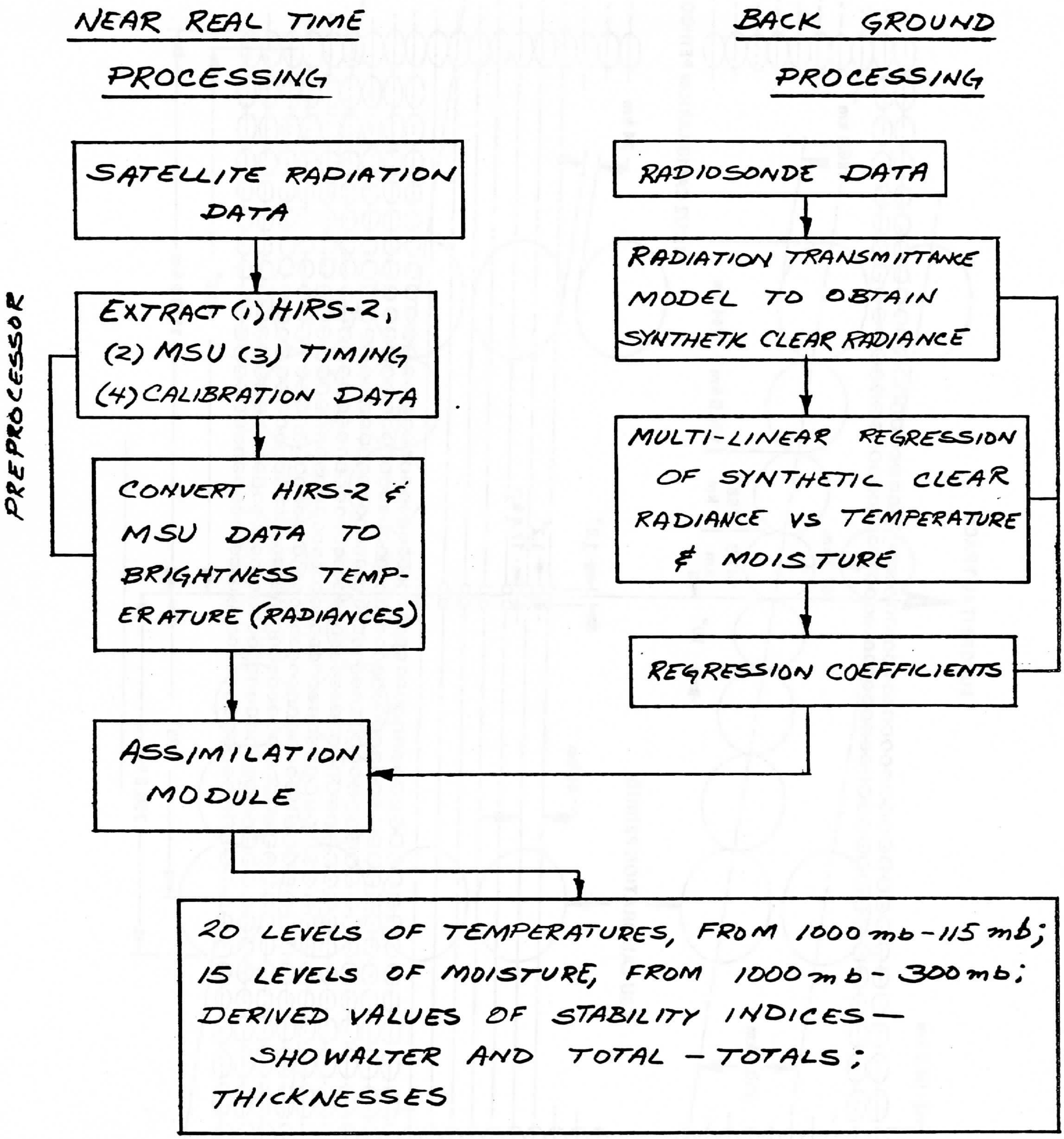

FIGURE 4 SUMMARY OF AES-TOVS SYSTEM

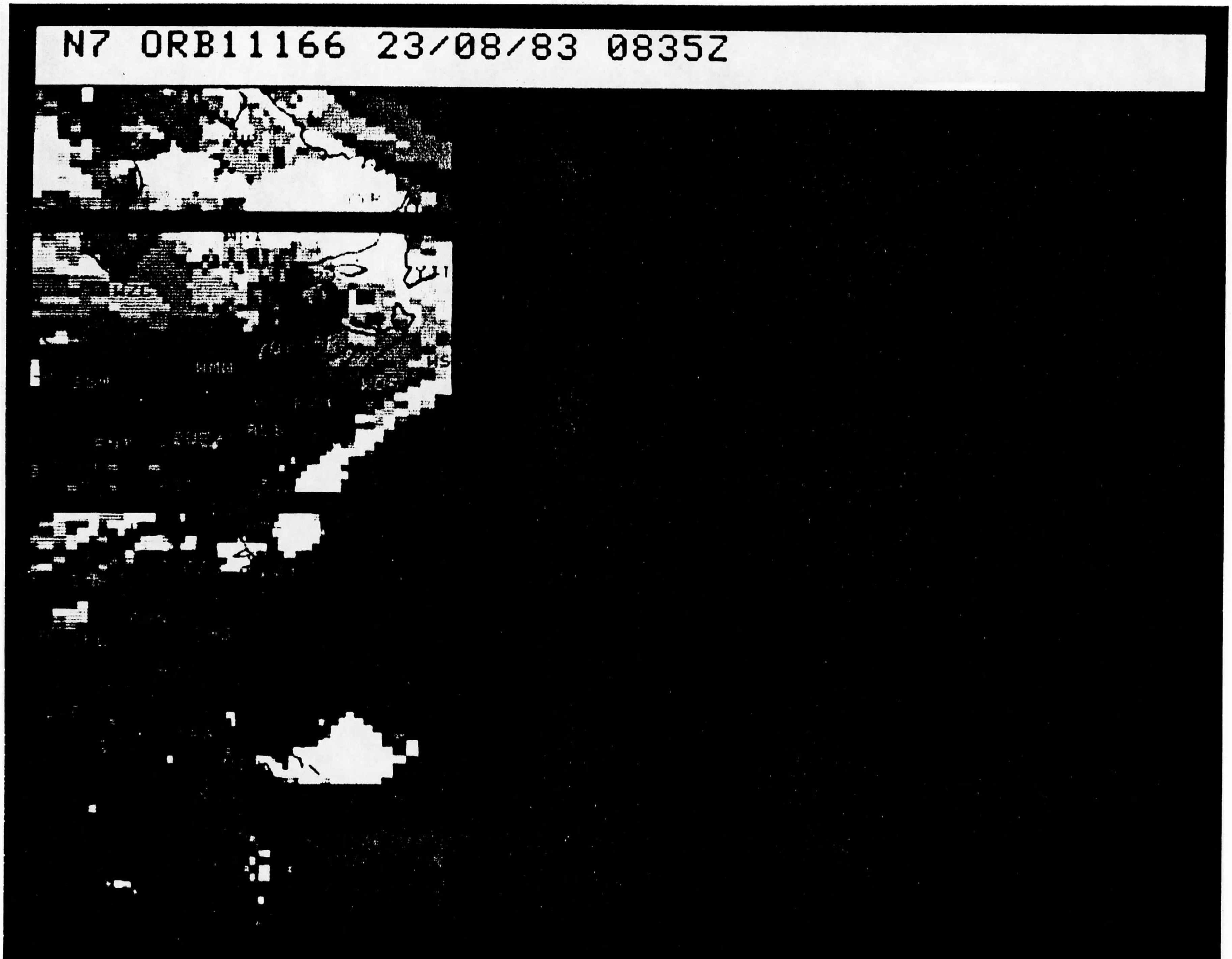

Figure 5

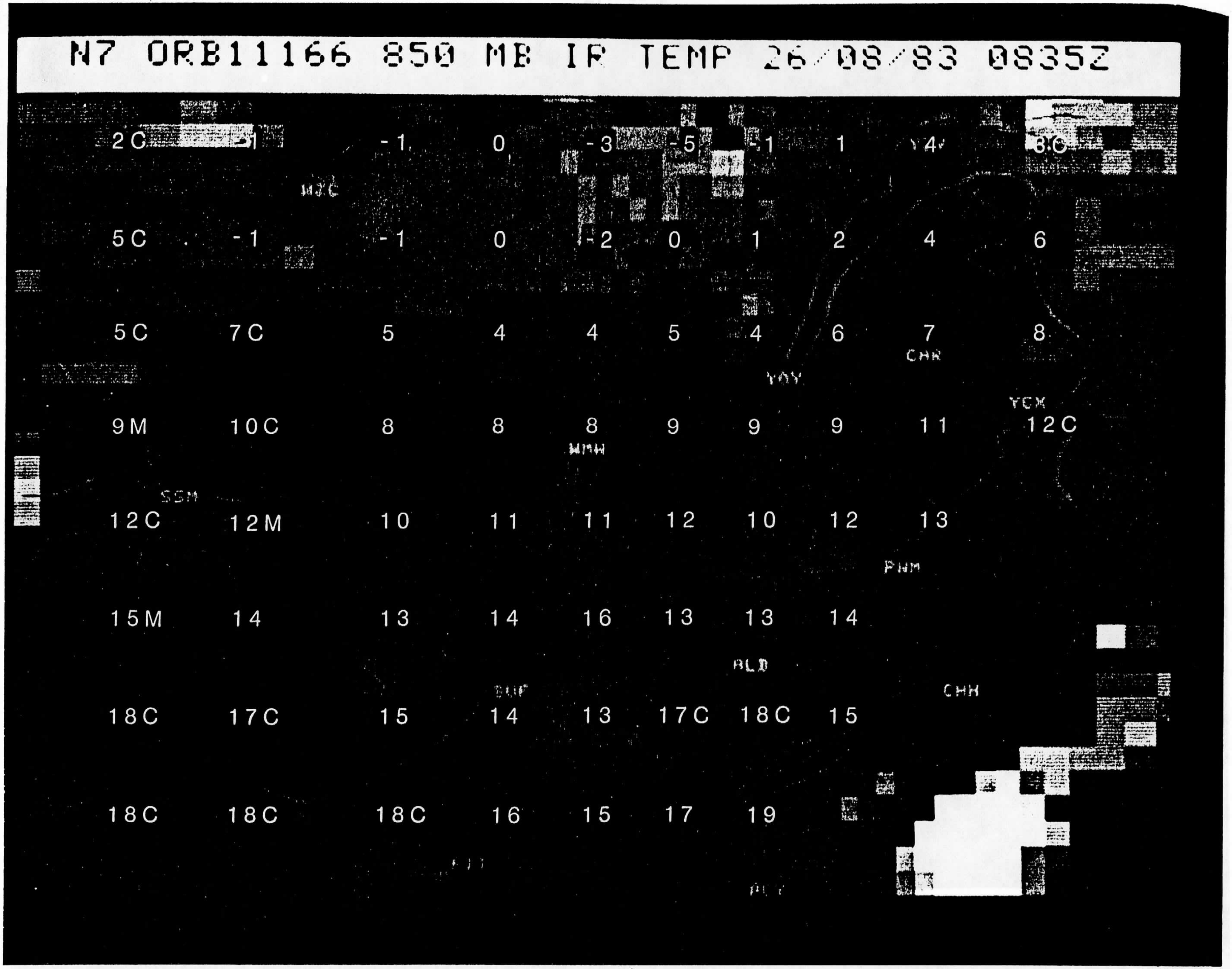
N7 ORB11166 850 MB IR TEMP 26/08/83 0835Z
2C -1 -1 0 -3 -5 -1 1 4 3C
MJC
5C -1 -1 0 -2 0 1 2 4 6
5C 7C 5 4 4 5 4 6 7 8
CHR
YAY
YCX
9M 10C 8 8 8 9 9 9 11 12C
MMH
SSM
12C 12M 10 11 11 12 10 12 13
PHM
15M 14 13 14 16 13 13 14
ALD
SUF
CHR
18C 17C 15 14 13 17C 18C 15
18C 18C 18C 16 15 17 19

Figure 6

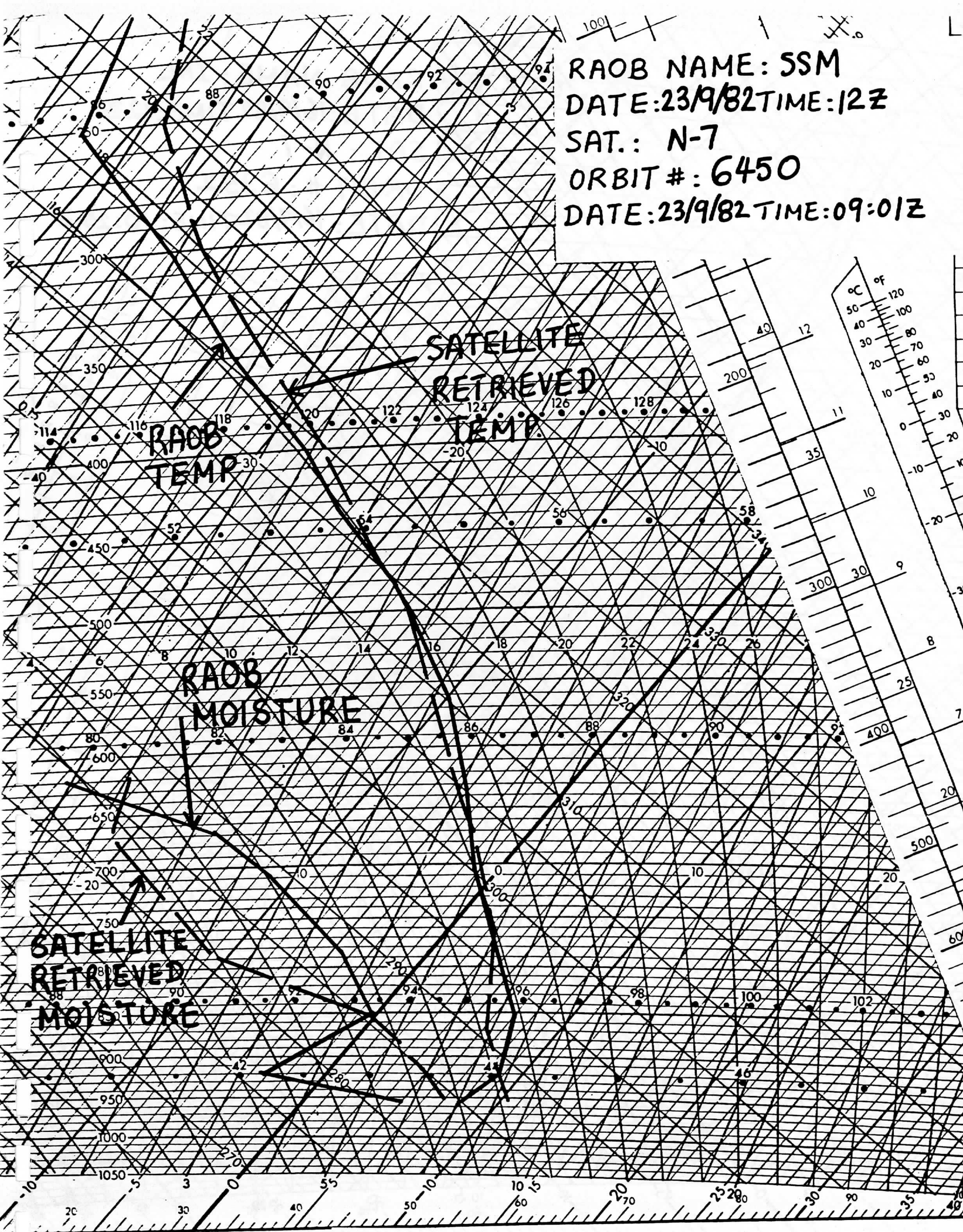

Figure 7. Clear

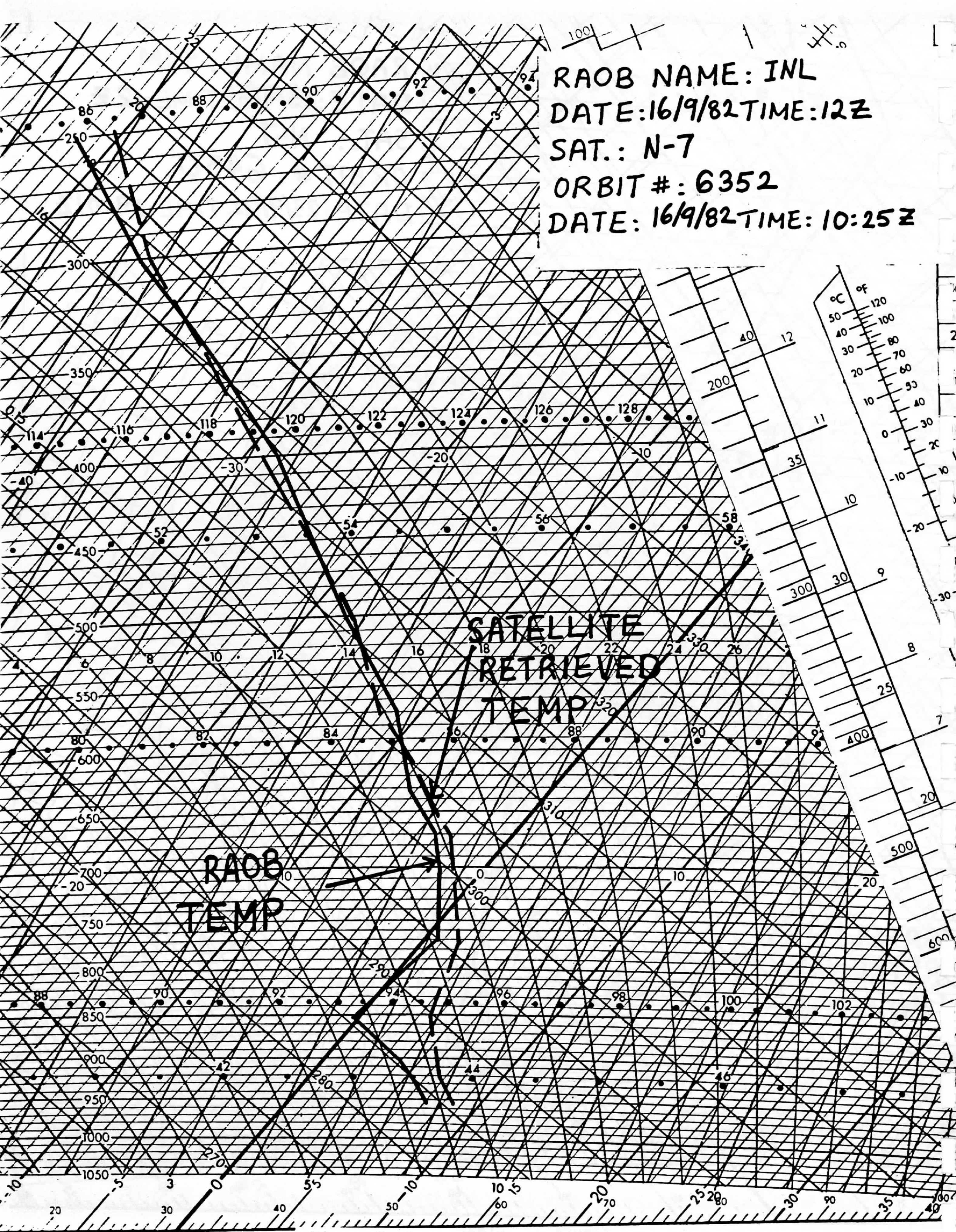

Figure 8. Overcast

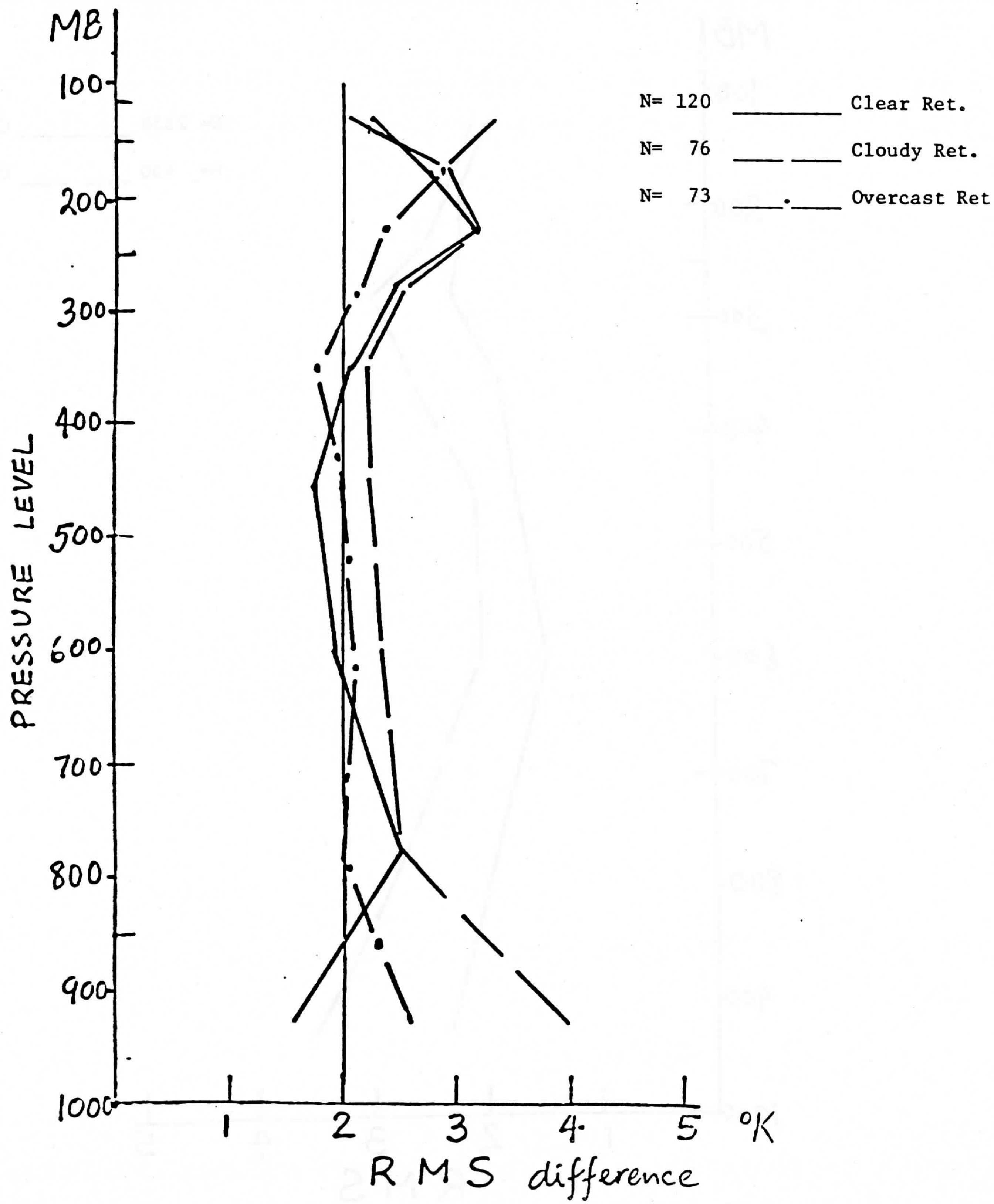

Figure 9. Statistical Assessment of N-7 Satellite Soundings. September 7-28, 1982.

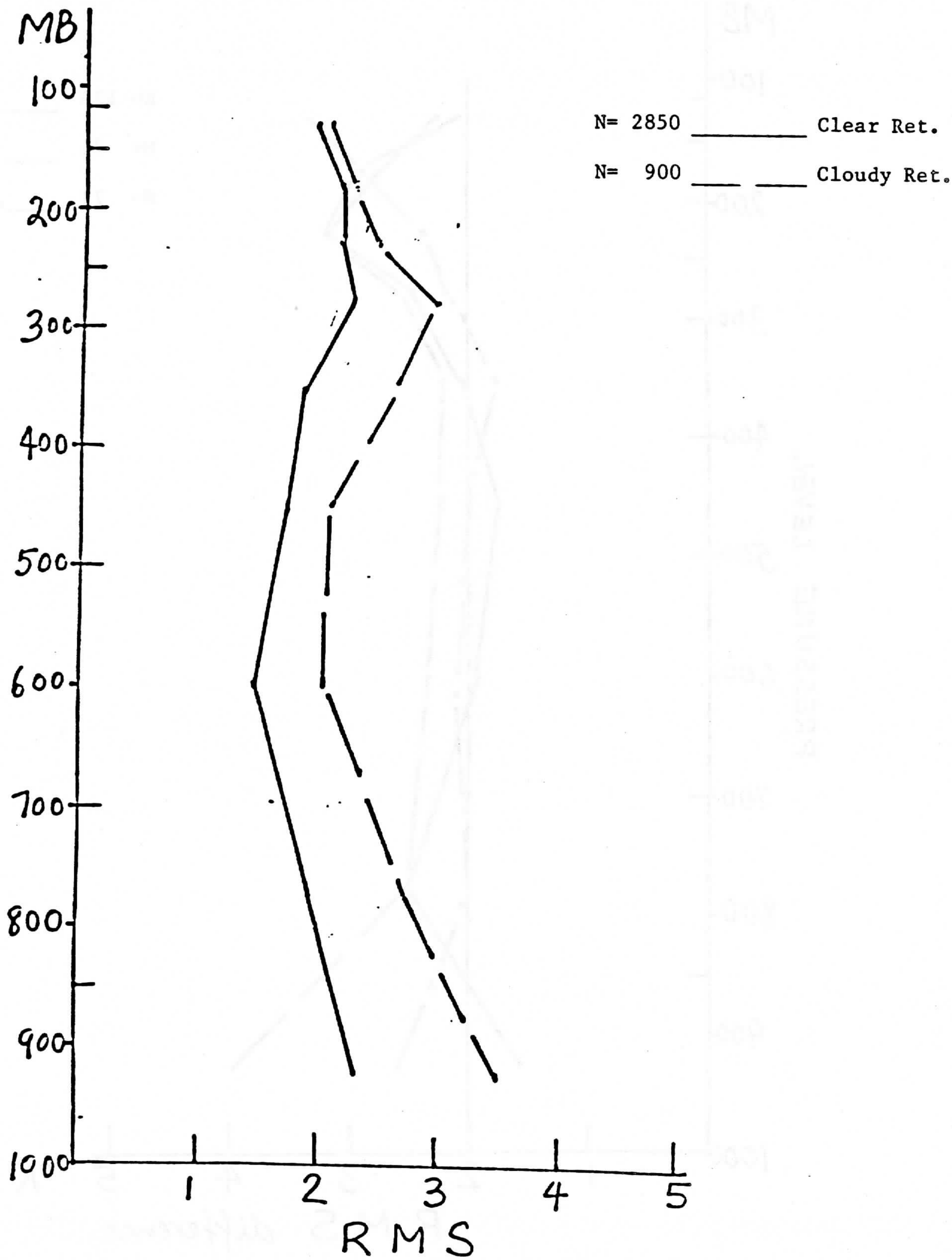

Figure 10. Statistical Assessment of N-6 Satellite Soundings. Fall 1979. (A. Gruber Etal, 1982).

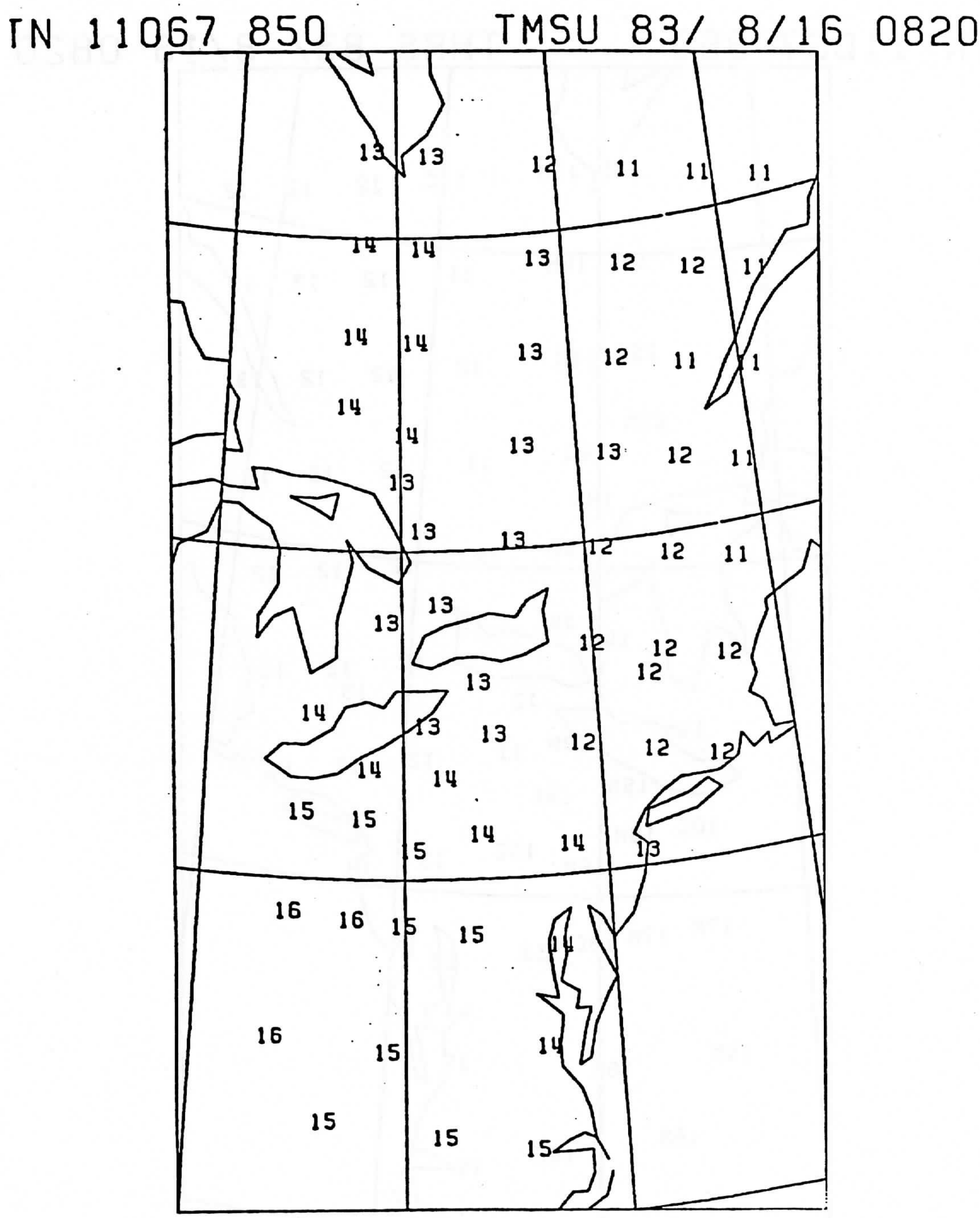

Figure 11. (Output from Versatec)

TN 11067 850 THRS 83/ 8/16 0820

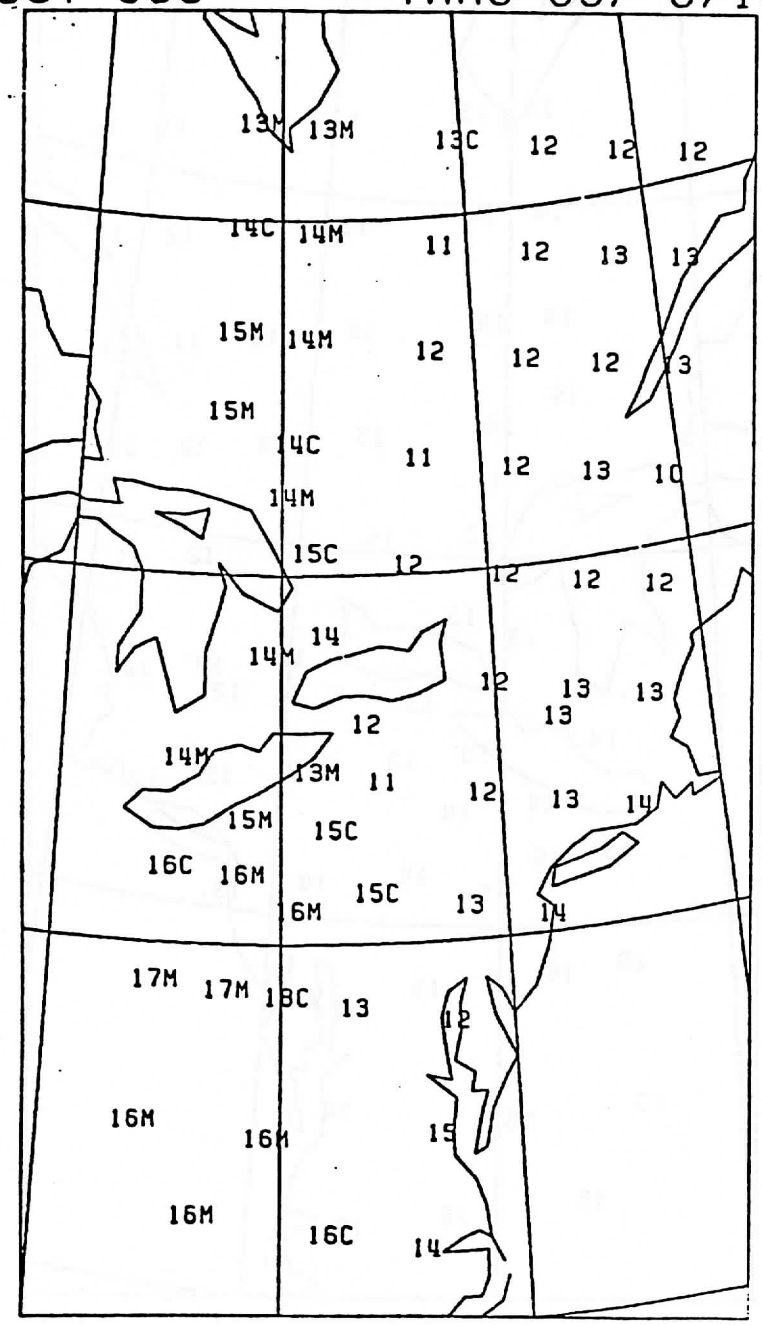

Figure 12

TN 11067 850 -500 HRTK 83/ 8/16 0820

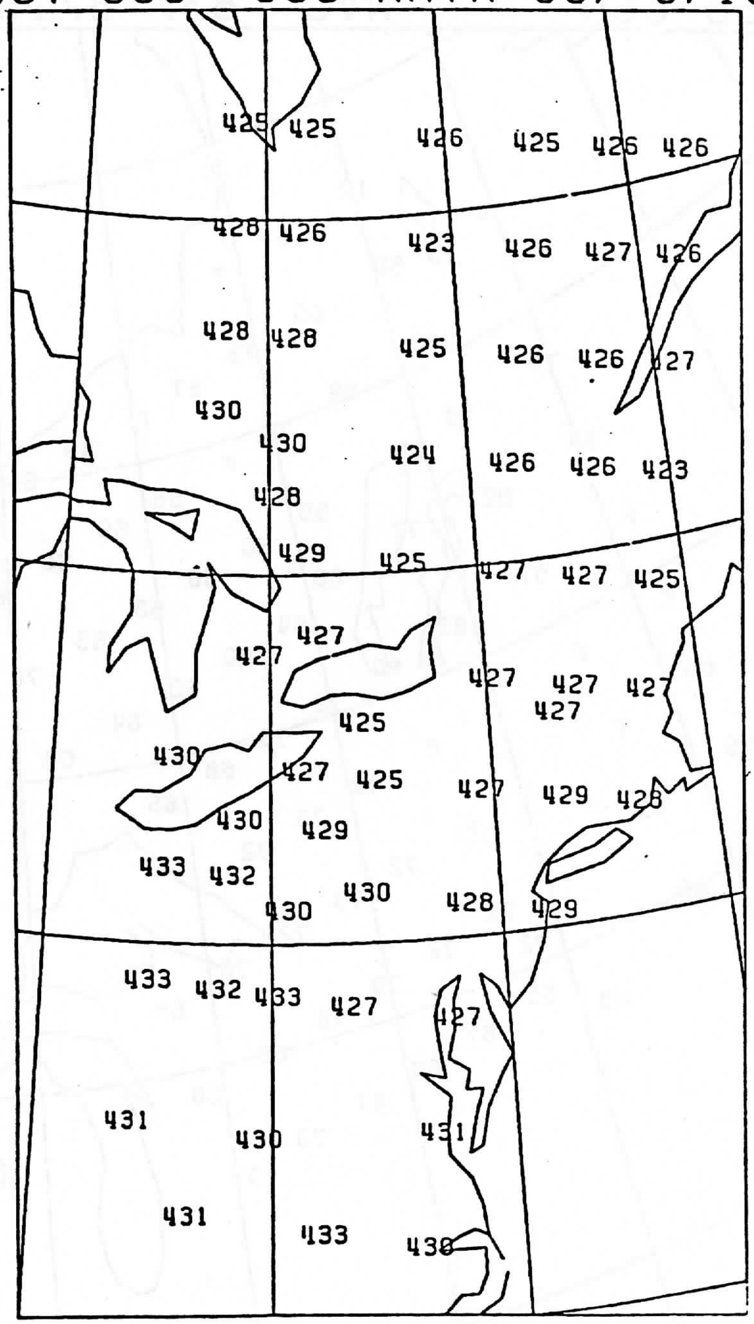

Figure 13

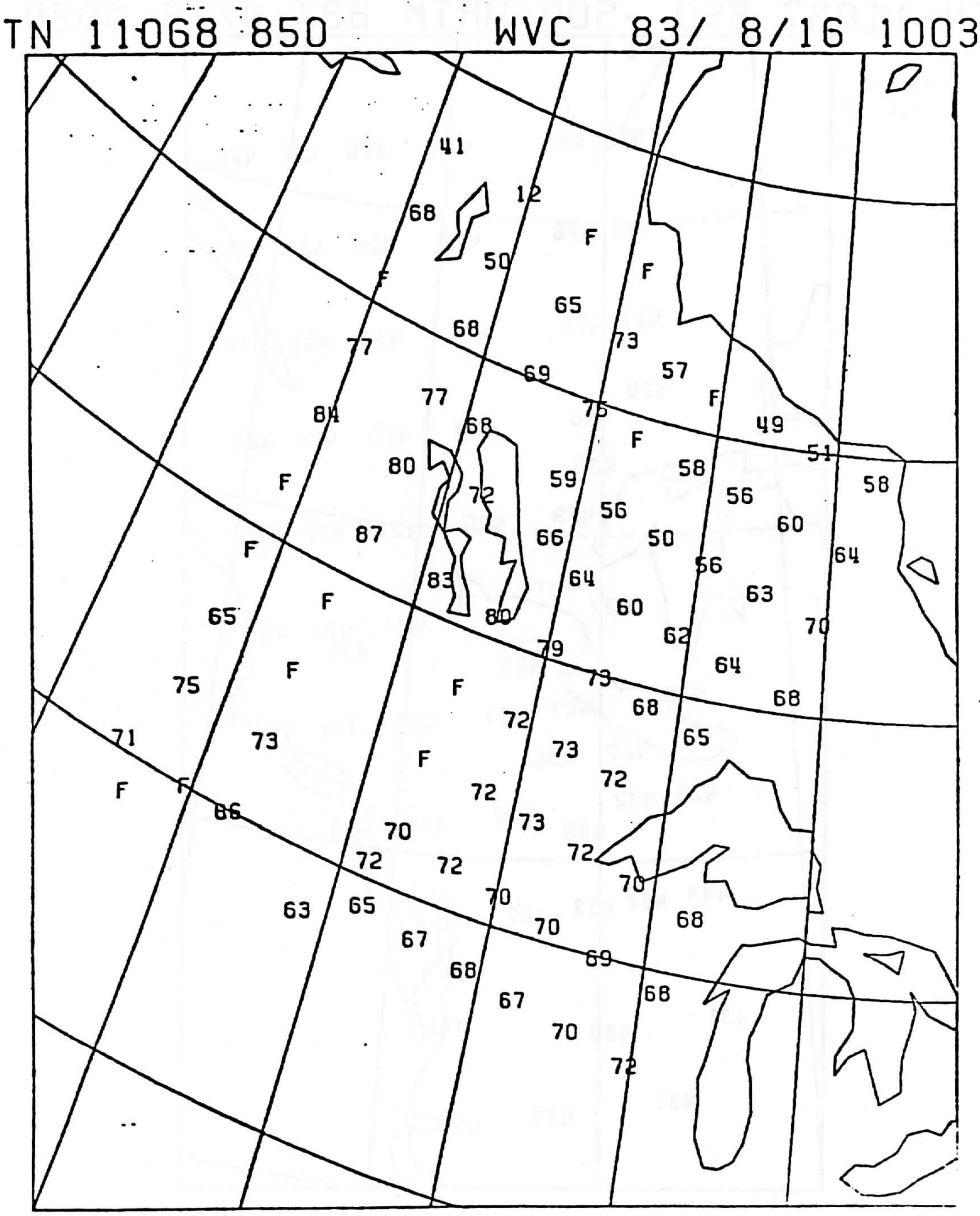

Figure 14

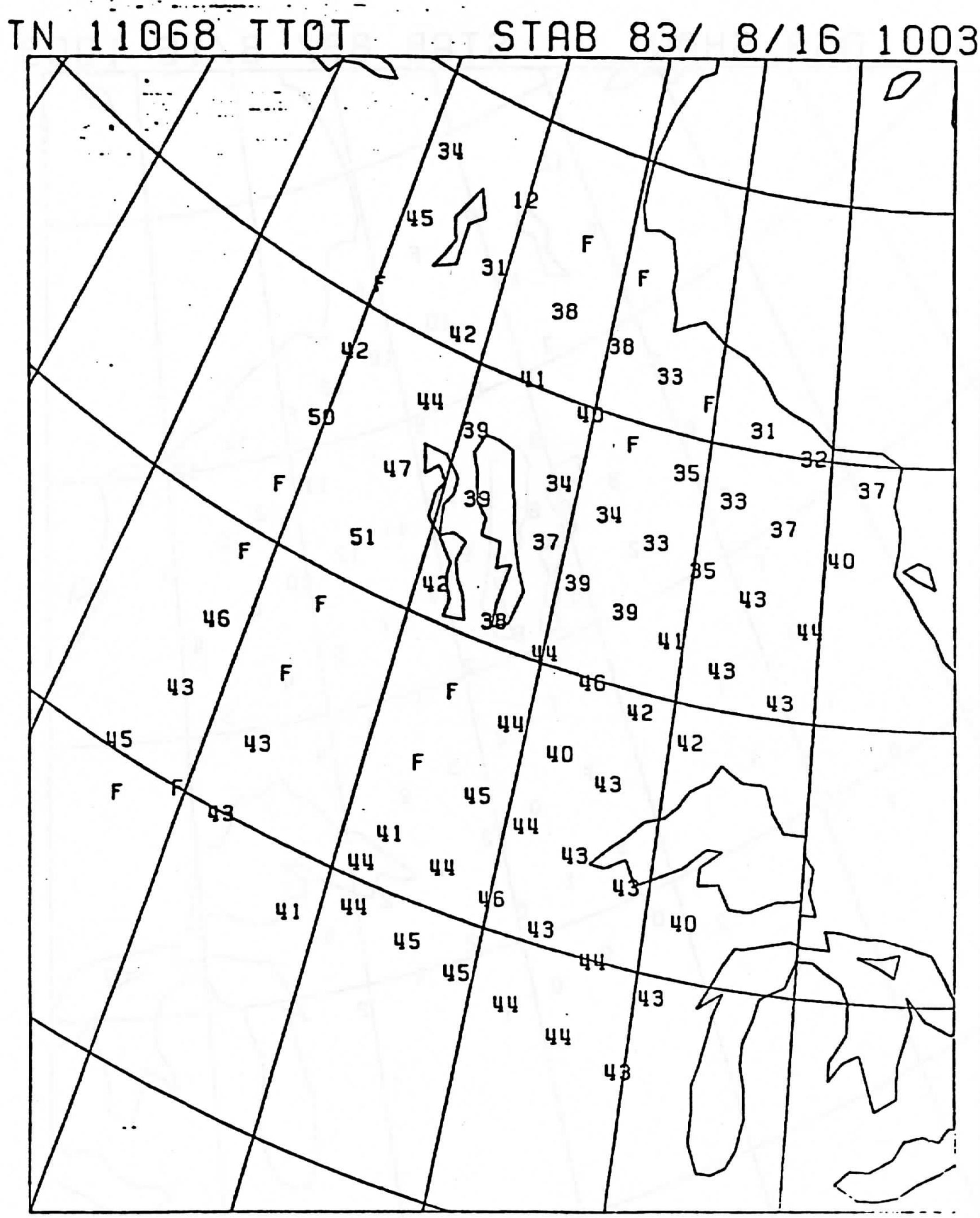

Figure 15

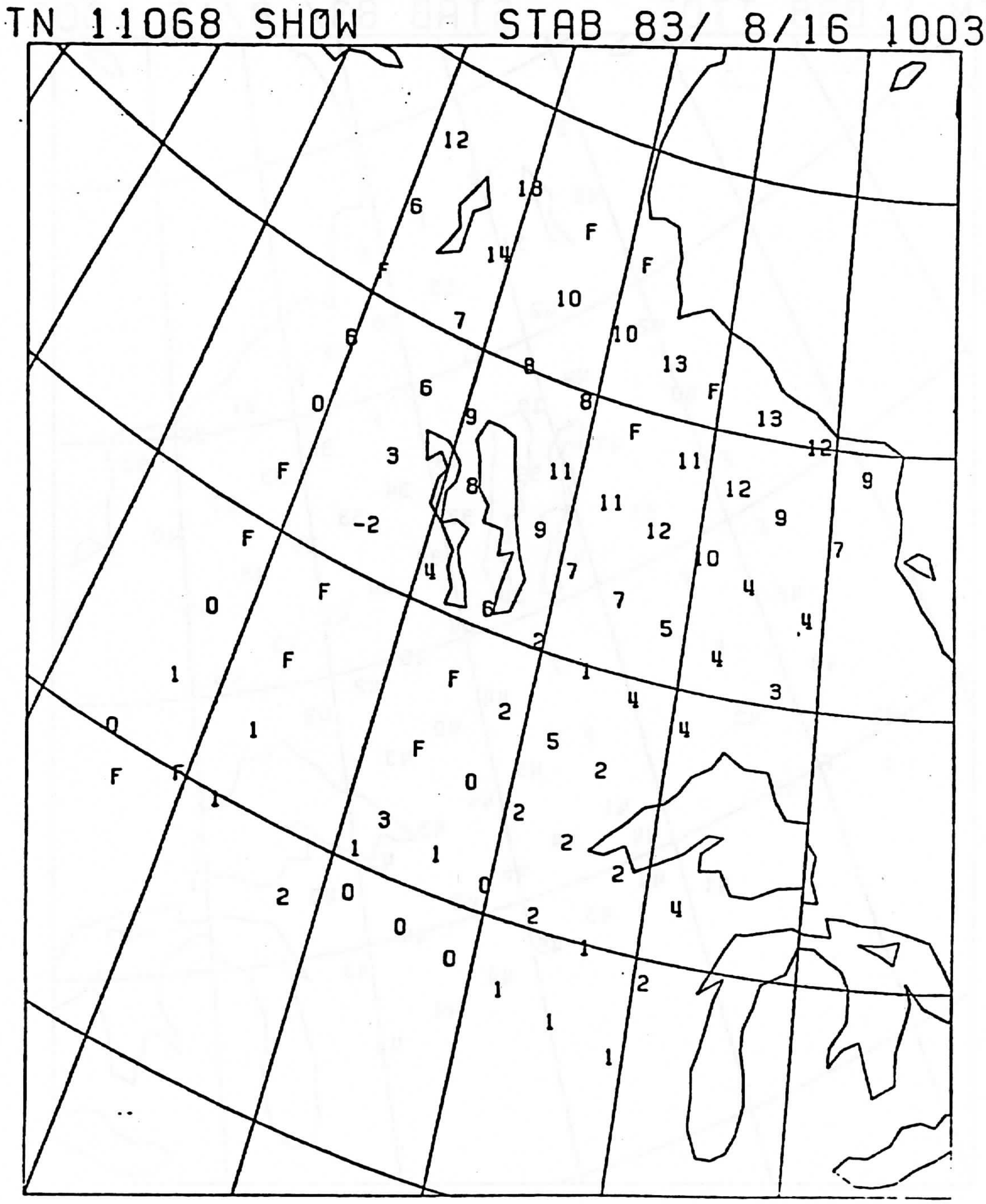

Figure 16

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