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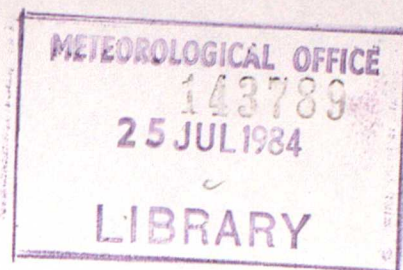
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MET.O.19 BRANCH MEMORANDUM No. 69



LOCAL AREA SOUNDING SYSTEM
DECEMBER 1981
RESULTS

by

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AUGUST 1983

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LOCAL AREA SOUNDING SYSTEM

A CASE STUDY

DECEMBER 1981

1. INTRODUCTION

During early 1981 the Steering Group on Satellite Meteorology decided to mount two campaigns to collect a body of data from the Tiros Operational Vertical Sounder (TOVS). One to be a summer period during June 1981 the other a winter period during December 1981. The purpose of these two campaigns was to provide a continuous body of local area sounding data that would be suitable for use in the preparation of analyses for numerical models and hence to assess the potential impact of an operational product on numerical forecasts. The data for June was unfortunately marred by hardware problems at the reception station at Lasham and most of the data was rendered useless. What little data that was usable was processed and the results published in "Weather" Nov 1982. The winter period was much more successful as the hardware worked properly and it covered a period of unusual Meteorological interest. The 3th Dec 1981 was the start of a period of heavy snow falls in Britain which, with only brief respites, continued into January 1982. Exceptionally low values of ground level temperatures were observed in central England on several nights.

2. SOUNDING INSTRUMENTS

The data analysed are taken from the High-resolution Infra-red Sounder (HIRS) and the Microwave Sounding Unit (MSU) on board the NOAA 6 and NOAA 7 spacecraft. The HIRS instrument has 19 channels in the infra-red and one visible channel. Seven of the IR channels are in the $15 \mu\text{m CO}_2$ band and five in the $4.3 \mu\text{m}$

CO₂ band. These channels are used to obtain temperature profiles. A further three channels around 7.3 μm are used for computing water vapour profiles. Three window channels at 11.1, 3.7 and 4.0 μm are used for surface temperature measurement and cloud detection. The four MSU channels are at 50.31, 53.73, 54.96 and 57.95 GHz and are also used to evaluate atmospheric temperature. The microwave channels are much less influenced by cloud than are the IR channels but have a lower resolving power in both the vertical and the horizontal. The weighting function peaks for the 15 μm channels range from the surface to 20 mb and define the broad temperature structure from the surface to the lower stratosphere. The weighting functions of the 4.3 μm channels have peaks that are concentrated in the lower troposphere, enhancing the resolution close to the ground by providing greater sensitivity in the warmer temperatures in this region than is possible with the 15 μm channels. Figure 1 is copied from (Smith et al., 1979) and shows the region of the atmosphere to which each channel is most responsive. The Stratospheric Sounding Unit (SSU), developed by Met Office, does not form part of the software used because its channels peak above the levels of interest for tropospheric work.

3. RESOLUTION

Resolution will be defined to be the distance between adjacent fields of view of the instrument. Across the sub-orbital track the horizontal resolution of the HIRS instrument ranges from 20 km at the sub-satellite point to 60 km at the edge of the scan. The MSU instrument has a resolution of 100 km at the nadir decreasing to 300 km at the scan edge. Along the track the resolution is 42 km and 170 km respectively, (see figure 2, taken

from NOAA Tech. Mem. NESS 95, 1978).

4. PRODUCTS CONSIDERED

Attention has been concentrated on the 1000-500 mb thickness because analyses of this field for the North Atlantic are routinely produced at 0000Z and 1200Z daily by the Central Forecasting Office (CFO), using observations from radio-sondes and a few SATEMs (the U.S. operational temperature soundings which are distributed to national meteorological centres worldwide). Over Europe the density of these observations is high enough to resolve synoptic scale features. Over the North Atlantic however there are insufficient observations to resolve all the features of interest, and it is here particularly that high resolution satellite soundings would be most useful. Over the ocean the quality of these soundings is higher than over the land; soundings over the sea are affected less by uncertainties in surface emissivities, surface topography and by steep lapse rates close to very hot or cold surfaces.

5. RECEPTION

The telemetry from the satellite was received at the R.A.E. satellite tracking station at Lasham, where it was recorded on analogue instrument tapes. This was then copied to computer compatible tape for delivery to Met 0 19 daily.

6. PROCESSING

To avoid the problems that were encountered in June the incoming tapes were first quality controlled to enable rapid feedback to Lasham should anything be wrong with the data. This

was done by the program TOVQC which recalculates the cyclic redundancy check characters transmitted in each minor frame. The output of the program showed the total number of minor frames with errors, and the distribution of the errors through the data.

A typical pass would show errors at the beginning and end of the data, with little or no errors in between. These errors were associated with poor reception conditions at the rising and setting of the satellite and were not a problem.

However, about 4 passes out of about 250 had errors occurring throughout the length of the pass in sufficient numbers to render the pass useless; three of these were associated with extreme weather conditions during 14th and 15th Dec 1981.

Minor frames that are found to have a CRC error are not discarded. Because only about half of the transmitted frame is used for HIRS/MSU data, there is a 50-50 chance that any error in a frame is not significant. Should the error be in a data word that is required in processing, corruption of a less significant bit is unlikely to produce an error in the final product greater than the likely error due to the many approximations used. If the corruption is of a more significant bit, we rely on the numerous error and consistency checks that are performed at all stages of the processing to eliminate the affected sounding.

7. DECOMMUTATION OF TOVS DATA

The first step of the processing chain is to decommutate the data. This consists of extracting from each minor frame those items of information that are packed together to form composite words for the purposes of data compression. Also to build up a separate frame of microwave data that is spread over several minor frames because of the lower resolution of MSU and its

slower scanning speed. The data so extracted consists of instrument counts, coded times and field of view position indicators, (see Figure 3 also taken from NOAA Tech. Mem. NESS 95, 1978). The program that performs these functions is called PREING i.e. PRE INGeSt. The output from PREING is then picked up by the next step.

8. EARTH LOCATION AND CALIBRATION

The next step INGTOV i.e. INGeSt TOVs searches for a minor frame zero which contains the date and time of the observation. This is required to earth locate the individual fields of view using the TBUS Brower mean orbital elements broadcast on the GTS. The second function of INGTOV is to calibrate the raw instrument counts into radiance units. This is done using a calibration sequence transmitted in the telemetry consisting of three lines of 64 fields of view each, which look at internal warm & cold targets and deep space. The internal targets have embedded thermistors whose counts are also part of the telemetry. From this information a linear relationship between counts and radiance is assumed and the slope and intercept calculated.

The output from this step is a dataset of calibrated earth-located radiances.

9. BASIC CORRECTIONS

At this stage there are several corrections that have to be made to the radiances. Both the HIRS and MSU instruments scan out to large angles either side of nadir, the thickness of atmosphere traversed by the radiation emitted at a particular level increases the closer the field of view is to the limb. The net effect of this is to increase the height of the weighting

function peaks with increasing nadir angle. A correction is applied to reduce all fields of view to their equivalent nadir view.

The MSU instrument has significant sensitivity in side lobes, the affects of which have to be removed. An asymmetrical bias error, thought to be due to the proximity of other parts of the spacecraft affecting the field of view seen by these side lobes, is also removed at this stage with an empirical correction.

10. CLOUD CLEARING AND RETRIEVAL

Before a temperature retrieval can be attempted the affect of cloud in a field of view has to be removed. The effect of any cloud present in the field of view is to reduce the observed brightness temperature in proportion to the fractional coverage and cloud top temperature. In temperate latitudes clouds are present in most fields of view and almost always in the areas of greatest interest to a forecaster. A solution to this problem developed by McMillin (1978) is used: adjacent fields of view are compared to identify partly cloudy areas and to calculate a clear column radiance. The cold air behind a cold front is a good example of the kind of cloudy conditions that the scheme appears to handle well. In these conditions the resolution of the HIRS instrument is too low to allow completely clear fields of view between the cumuliiform clouds and very few of the fields of view will be completely clear. The method breaks down however when the area is covered by a uniform layer of cloud, or when there are multiple layers of cloud. Use of this technique reduces the horizontal resolution to about 80 km. In fully overcast conditions the microwave channels are used alone, with a

consequent further decrease in the resolution achievable.

The retrieval scheme used is a non-physical eigenvector regression technique (minimum variance) which produces the most acceptable profiles so far, making the best use of a priori statistics of the atmosphere (Smith and Woolf, 1976). A major part of the data-processing software was developed by the NOAA/NESS Development Laboratory at the University of Wisconsin, Madison, and has also been made available to several groups working in this field in Europe, Australia and New Zealand. The regression coefficients for the case study were provided by NOAA/NESS Washington and were identical to those used for the generation of SATEMs.

11. QUALITY CONTROL

After the retrieval step some quality control is performed. While some quality control checks are performed at all stages of the processing on individual soundings, it is the FILRET step that checks for horizontal consistency of neighbouring soundings. It checks for rogue values at all retrieved levels, flagging those soundings that are incompatible with a smooth surface fitted to its neighbouring points. After eliminating suspect values identified during this pass over the data; the search is done again with stricter criteria for discarding points.

12. MICROWAVE ONLY SOUNDINGS

The quality control performed in the previous steps, particularly in areas with extensive sheets of cloud, will have left large gaps in the horizontal coverage, these areas can be filled in with soundings derived from the microwave instrument only. The ENHRET step fills in these gaps and forces horizontal

consistency with the HIRS/MSU soundings by adjusting the retrieved thickness at 100 mb to lie on the interpolated surface of HIRS/MSU 100 mb thicknesses, then adjusting the thicknesses from 1000 mb to other levels on a pro rata basis.

13. THERMAL WINDS

In areas with a high density of soundings it is possible to calculate the local gradient of the thickness field and hence a "thermal wind". This calculated quantity is not an independent measurement as is the case with a radio-sonde wind, and should not be treated as such. The winds calculated during December have an exaggerated northerly component due to a bug in the program which has subsequently been rectified. Note also that the wind speeds in the tape datasets are in m/sec not kts.

14. ELIMINATION OF REDUNDANT SOUNDINGS

In clear areas the density of retrieved soundings can be higher than that necessary to adequately define the thermal surface. In these cases it is useful to remove any redundant soundings from the dataset, reducing the number of soundings by one third in many cases.

15. COMPRESSION OF DATASET

The final step in the processing before plotting out the data on calcomp and archiving to tape compresses the data file overwriting soundings flagged by FILRET and REDRET.

16. COVERAGE IN TIME AND SPACE

The nature of the orbits into which the two satellites are placed determine the temporal and spatial coverage of "earth view" data. The high orbital inclination together with the

satellites altitude ensures sun-synchronous global coverage twice each day. However the position of the ascending node determines where the satellite is in longitude at a specific Greenwich Mean Time. It would be useful if one of the satellites were to be in the vicinity of the Greenwich meridian at 00z and 12z each day but this is not the case. One spacecraft is selected to overfly the United States at 00z & 12z and the ascending node of the other has to be approximately 90 degrees further east giving coverage every six hours. This orbital geometry leads to poor coverage over the U.K. and Europe at the time when most of the Radio-Sondes are launched and the conventional analyses of thickness are made. Figure 4 shows the distribution of the number of soundings/hour throughout 24 hours made within 2000 km of Lasham and averaged over the 21 days. This leads to two main problems affecting the results and their interpretation. Firstly the conventional charts used for comparison are not for the same nominal time. Secondly the Radio-Sondes used for the calculation of the regression coefficients are characteristic of the continental U.S.A. and China not maritime Europe. The first problem probably has no universally popular solution, although it may be possible to devise a method of forecasting numerically the radiances for a few hours ahead, before attempting to make retrievals on radiances valid at main synoptic hours. The second problem may be ameliorated by the calculation of regression coefficients based on European Radio-sonde ascents. This cannot be performed by the same method adopted by the U.S.A. because of the lack of colocated satellite sounding and Radio-Sondes required, caused by the first problem. Work is however going ahead to use a large set of historic Radio-Sondes and

corresponding synthetic radiances, calculated from the radiative transfer equation, to produce seasonal regression coefficients for our own area.

The area of coverage is within approximately 2500 km of Lasham. This usually allows three consecutive orbits to be received for each satellite over a period of three hours before receiving three orbits of the second satellite. Figure 5 shows the spatial coverage achievable from a single reception site.

17. CASE STUDY

From 1 to 3 Dec the weather in the eastern North Atlantic was dominated by a large anticyclone having a central pressure of about 1036 mb located to the south west of Ireland, with low pressure systems moving around it to the north and then moving southwards across Europe. Between 5 and 7 Dec the anticyclone moved slowly south westward allowing the low pressure systems to move south-eastwards across Britain. On 7 DEC the anticyclone began to decay rapidly, while over Greenland pressure rose equally as fast bringing a northerly air stream across Iceland. A low of 990 mb in mid-Atlantic began to deepen and was steered quickly south-east in a strong north-westerly thermal gradient. By midday on 8 Dec it had deposited several inches of snow on most of England and Wales.

The charts in figures 6 to 11 have been chosen to illustrate some aspects of the comparison between satellite and conventional radio-sonde analyses during the period. On charts of satellite soundings the thicknesses are expressed in decametres with the leading digit dropped for clarity (usually a '5', sometimes a '4' in the far north). The charts of conventional data are copies of the hand-drawn operational analyses of radio-sonde

observations produced by CFO.

Figure 6A is the CFO analysis for 0000z on 5 DEC showing a broad north-westerly baroclinic zone over the UK. Looking at the two soundings over Ireland and the two weather ships 'L' and 'R' at about 18 W, it is apparent that not enough weight was placed on them in the CFO analysis; the gradient at 47 N-17 W is too slack for the reported thermal wind speed. The wind at Long Kesh, Northern Ireland, has been largely ignored as has the thickness value at Valentia, Eire. Perhaps a more accurate analysis is shown in figure 6B, drawn before reference was made to the satellite soundings. Figure 7 is the analysis of data retrieved from NOAA-7 around 0300z on the same day. A thermal trough is apparent to the west of Ireland at about 15 W with a strong NNW'ly thermal gradient on its western flank. The pattern shown supports the conventional analysis of figure 6B and allows a more precise location of the trough position to be made. Inspection of the corresponding IR images shows a bright mass of convective cloud around 50-53 N, 10-15 W, consistent with the presence of instability and dynamical uplift which would be expected ahead of a marked thermal trough. It should be pointed out that the operational forecaster works to a deadline which often does not allow full consideration to be given to the detailed interpretation of each observation. However, the satellite data showing a clearly defined trough would have helped the forecaster reconcile the conventional Irish observations.

Figures 8 and 9 have been selected to illustrate the agreement that can be achieved. Figure 8 depicts the same feature 48 hours later. The southern portion of the thermal trough appears to be cut off near Gibraltar with the northern part

relaxing and moving east. The thermal wind of the Gibraltar radio-sonde indicates that the thermal vorticity centre is to the south of Gibraltar. This is in good agreement with the satellite analysis in figure 9 and is also consistent with continuity considerations.

The third case has been chosen to show how even quite large features in the Atlantic can remain unobserved by conventional observations with so few islands and ships from which soundings can be made, and by the coarse network of SATEMs. Figure 10 is the analysis for 0000z on 8 Dec. It shows a broad thermal ridge between 40-50 N and 15-35 W. In the absence of new observations the analysis in this area would have leaned heavily upon the previous days forecast for the area. In contrast, figure 11 is a set of NOAA-7 passes around 0400z on the same day which shows a marked thermal trough, with a possible cut off cold pool near 42 N-27 W. Reference to the corresponding images for the satellite reveals a bright, coma-shaped cloud structure with a centre at 42 N-25 W. This is consistent with the forced uplift of convectively unstable air ahead of such a cold pool.

18. ERROR STATISTICS

A comparison of the charts of 1000-500 mb thickness satellite retrievals with the closest conventional analyses reveal some small biases in the absolute values of soundings, probably because of the deficiencies in the regression coefficients already mentioned. There are also some localized problem areas on the charts due to high topography, for instance over Greenland and the Alps, for which accurate soundings cannot be produced with such a general regression method. The sharp gradients along frontal zones tend to be relaxed slightly due to inadequate

vertical resolution.

The r.m.s. errors of standard level temperature of the SATEMs produced by NOAA/NESS have been shown to be of the order of 2 K (Phillips,1981) with the greatest error occurring close to the surface and near the tropopause. The errors of retrieved level temperature for December 1981, Figure 12, show broadly the same characteristics as those described by Phillips, the large error close to the surface possibly due to the different relationship of surface air temperature to effective temperature of the radiating surface over Europe compared to that over the U.S.A..

Figure 13 shows the mean and standard deviation of the error in thickness between 1000 mb and the other standard levels averaged over the whole period. The r.m.s. error for 1000-500 mb of around 4 Dm is slightly less than the interval between thickness lines on a conventional chart. Figure 14 shows the error statistics of the dew-point retrievals and figure 15 the detailed variation of thickness errors with time.

19. AVAILABILITY OF ARCHIVED DATA

The processed data are available on magnetic tapes for general use, figures 16 & 17 give the details of record formats. A catalogue listing the data on tape is also available, on request from Met O 19, along with plotted charts for 1000-850,1000-700, 1000-500 and 1000-300 mb thicknesses on 35 mm film.

20. REFERENCES

Eyre J R, Jerrett D., (1982): Local-area atmospheric soundings from satellites. Weather,37, 314-322.

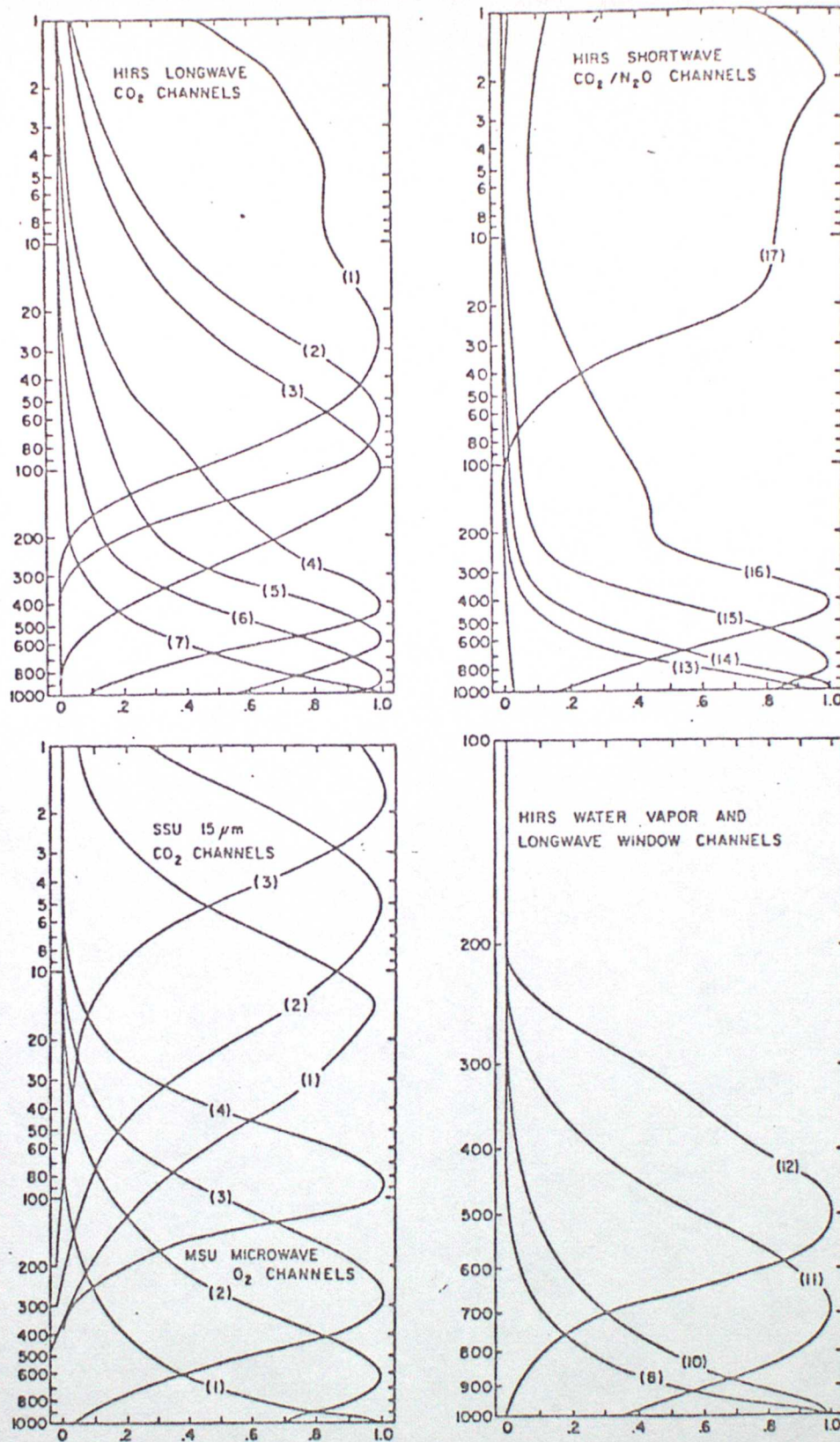
Smith W L, Woolf H M, Hayden C M, Wark D Q, McMillin L M.,

(1979): The TIROS-N Operational Vertical Sounder. BULL. Am. Met. Soc., 60, 1177-1187.

McMillin L M., (1978): An improved technique for obtaining clear column radiances from cloud contaminated radiances. Mon. Wea. Rev., 106, 1590-1597.

Smith W L and Woolf H M., (1976): The use of eigenvectors of statistical covariance matrices for interpreting satellite sounding radiometer observations. J. Atmos. Sci., 33, 1127-1140

Phillips N A., (1981): Cloudy winter satellite temperature retrievals over extratropical northern hemisphere oceans. M.W.R., 109, 652-659.



TOVS weighting functions (normalized).

Fig 1.

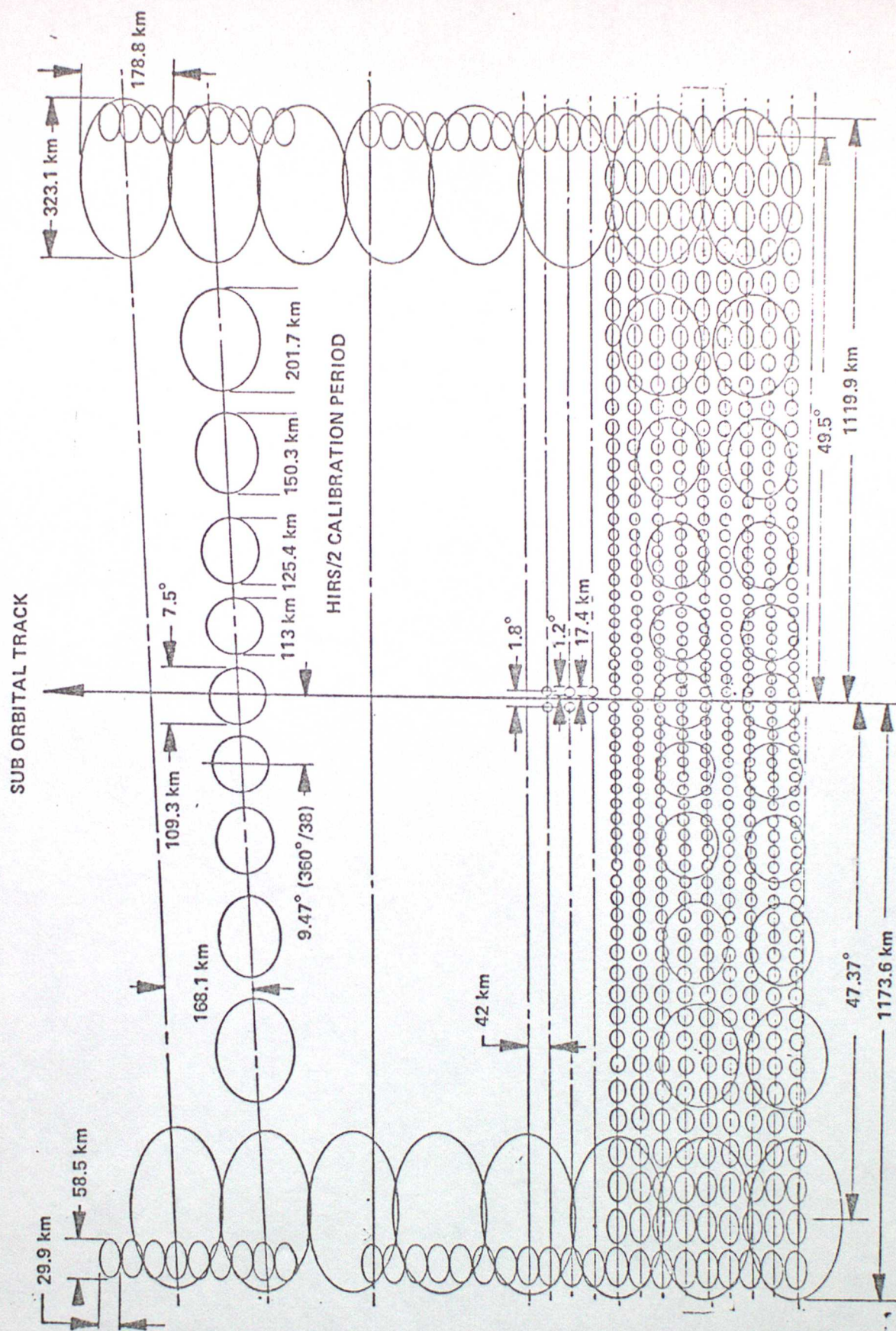


Figure 2.--TIROS Operational Vertical Sounder HIRS/2 and MSU scan patterns projected on earth



NOTES: NUMBER IN UPPER LEFT HAND CORNER INDICATES MINOR FRAME WORD NUMBER.
 TIME CODE DATA SHALL APPEAR DURING MINOR FRAME "0" WORD LOCATIONS 8 THROUGH 12.
 // WORD LOCATIONS ARE SPARE AND CONTAIN CODE 01010101.
 • THE SUBCOMMUTATION FUNCTION IS ACCOMPLISHED IN THE EXTERNAL UNIT.

---TIP minor frame format

Fig 3.

DISTRIBUTION OF SOUNDINGS RETRIEVED BY HOUR

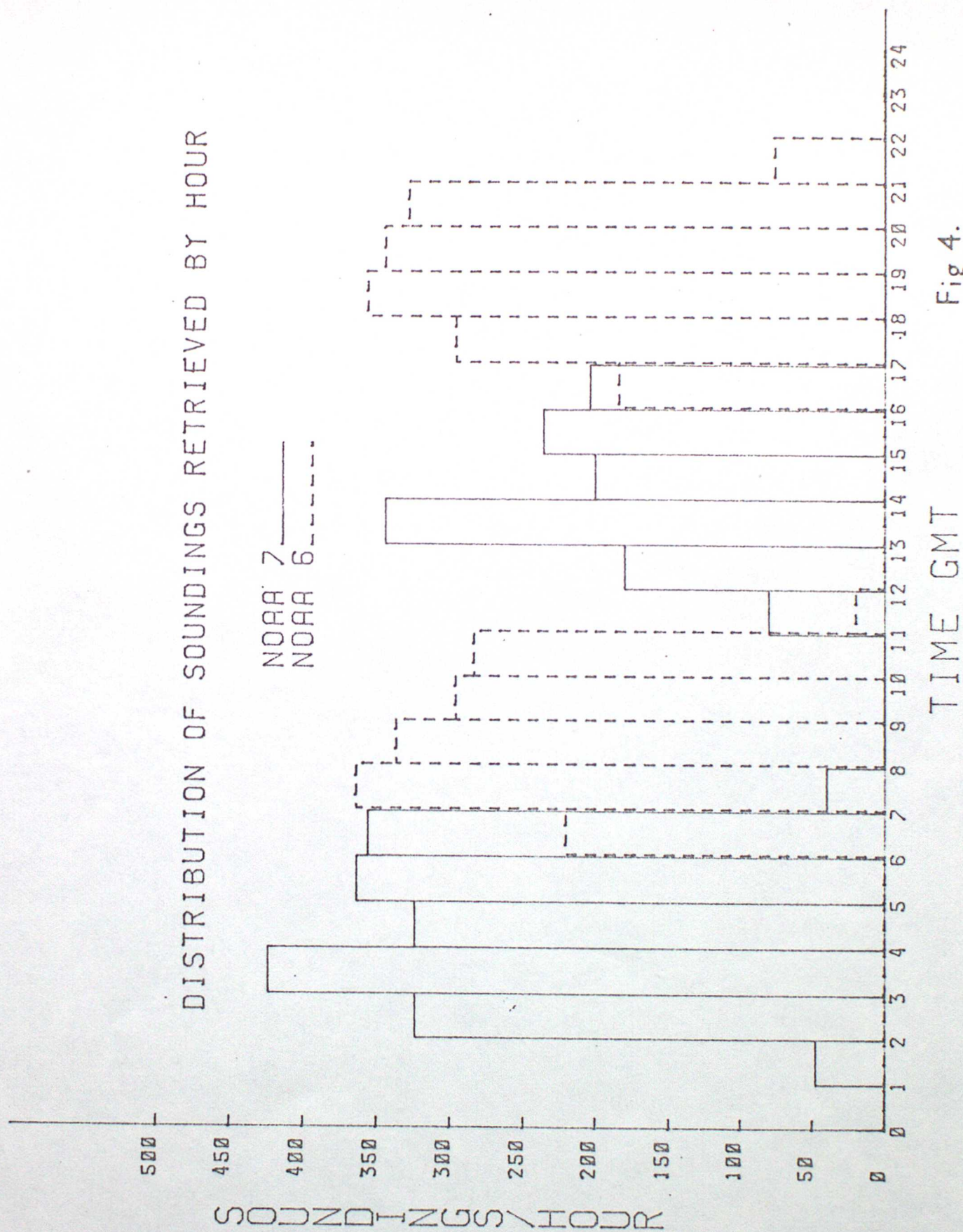


Fig 4.

Typical coverage from Lasham

5. 60

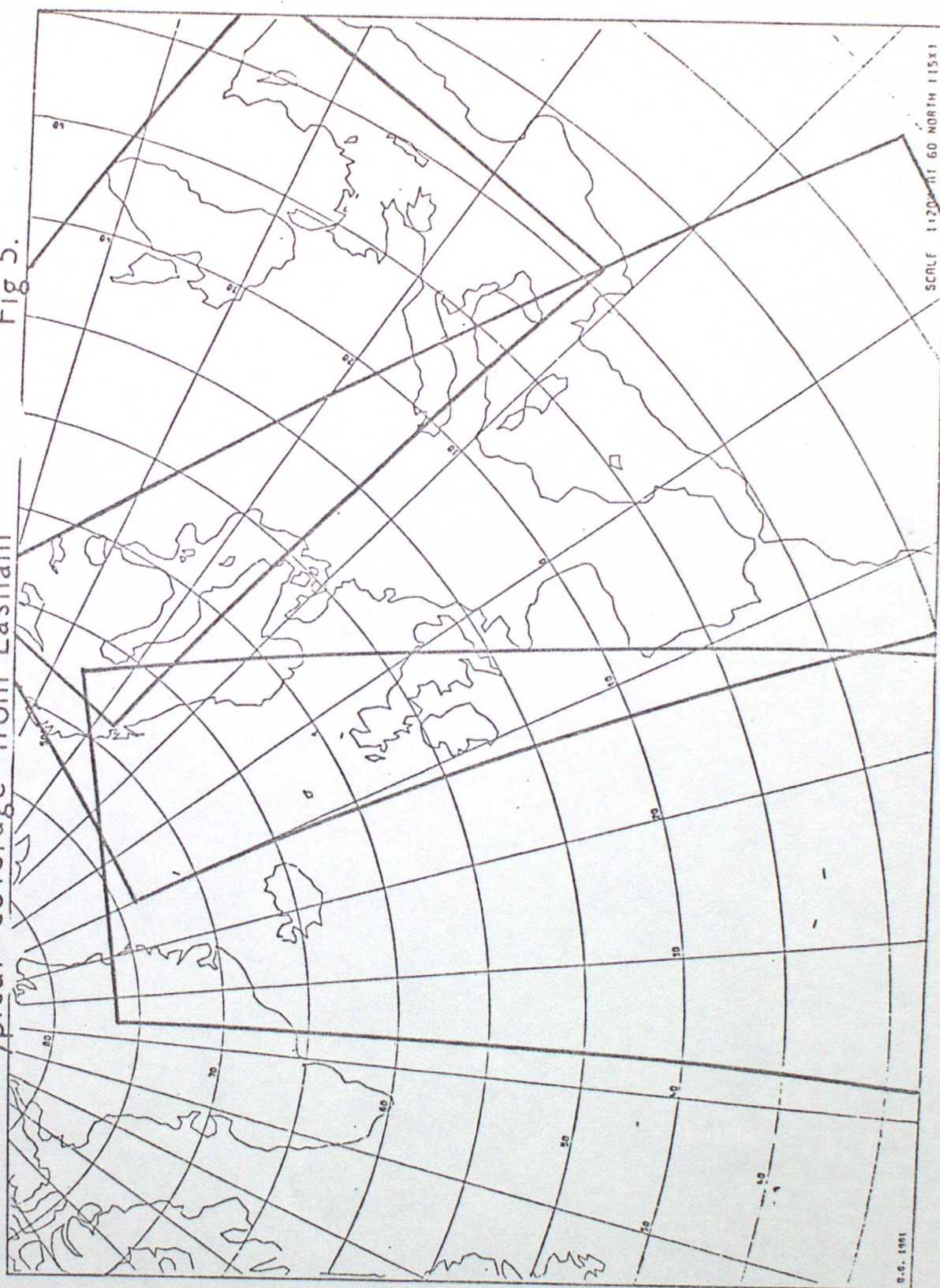


Figure 6a. 1000–500 mb Thicknesses and Thermal Winds 00Z 5 December 1981 (SATEMS & R/S)

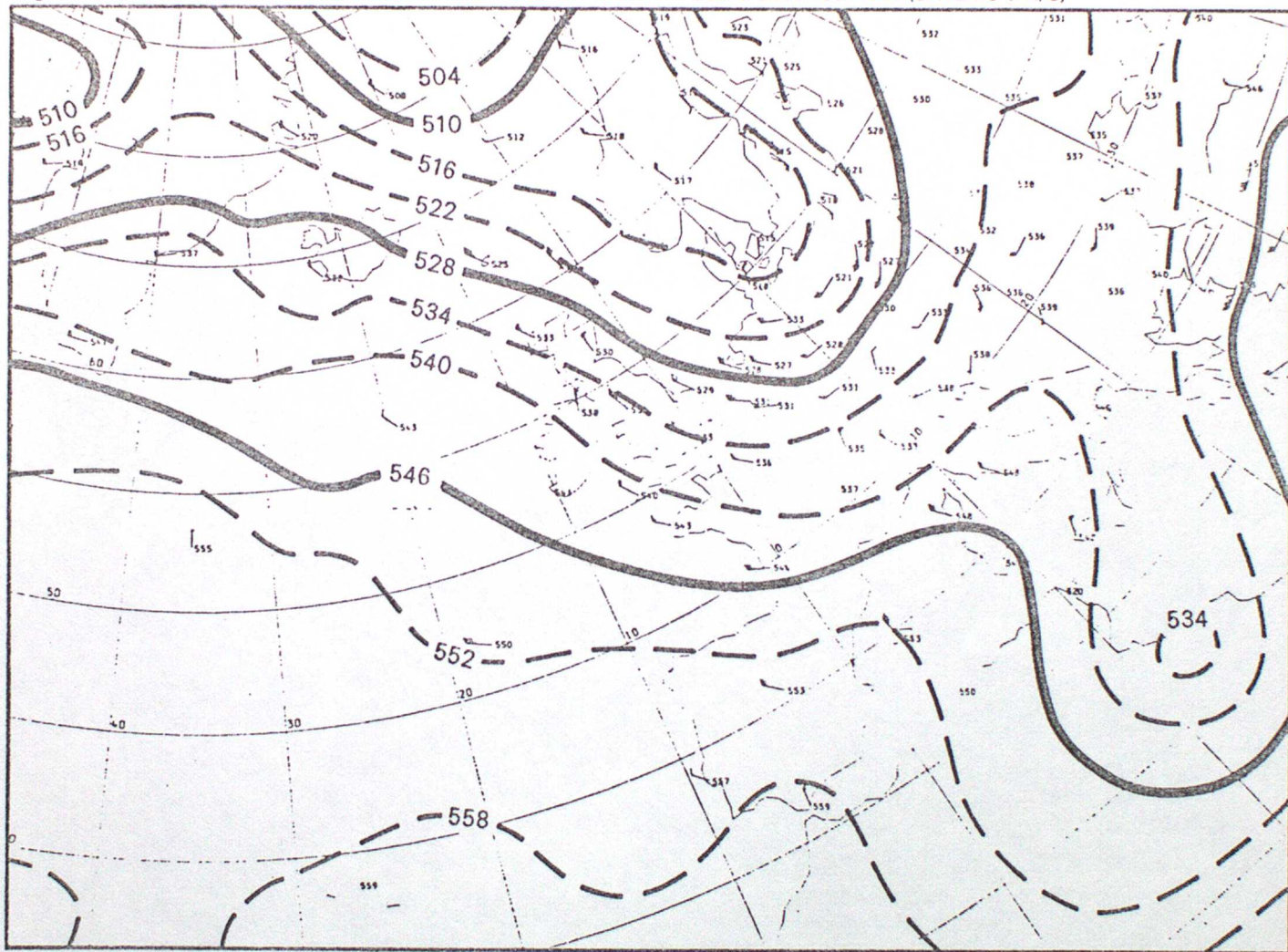


Figure 6b. 1000–500 mb Thicknesses and Thermal Winds 00Z 5 December 1981 (SATEMS & R/S)

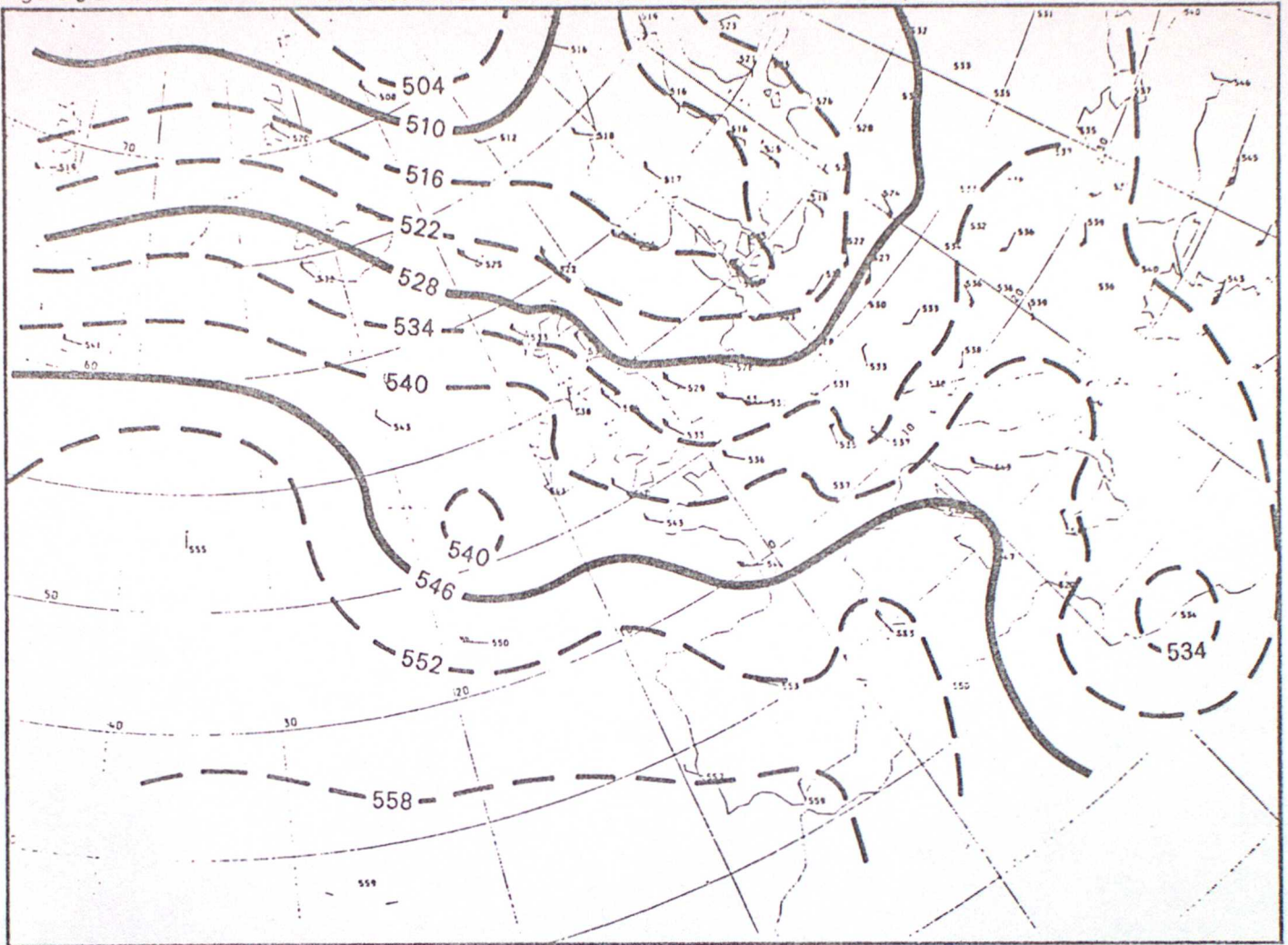


Figure 7 1000–500 mb Thickness First pass: 5 December 1981 0108Z NOAA-7

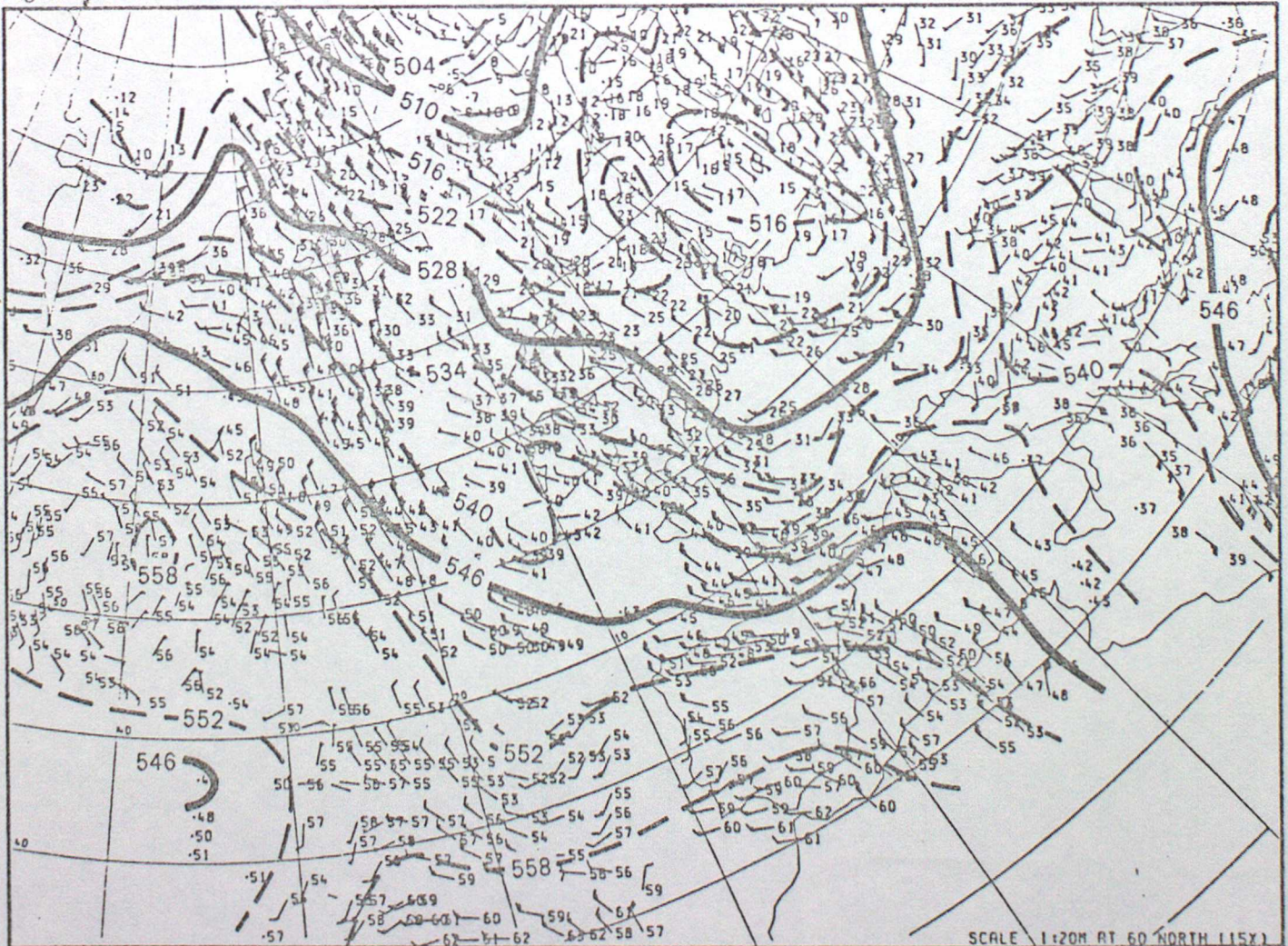


Figure 8 1000–500 mb Thicknesses and Thermal Winds 00Z 7 December 1981 (SATEMS & R/S)

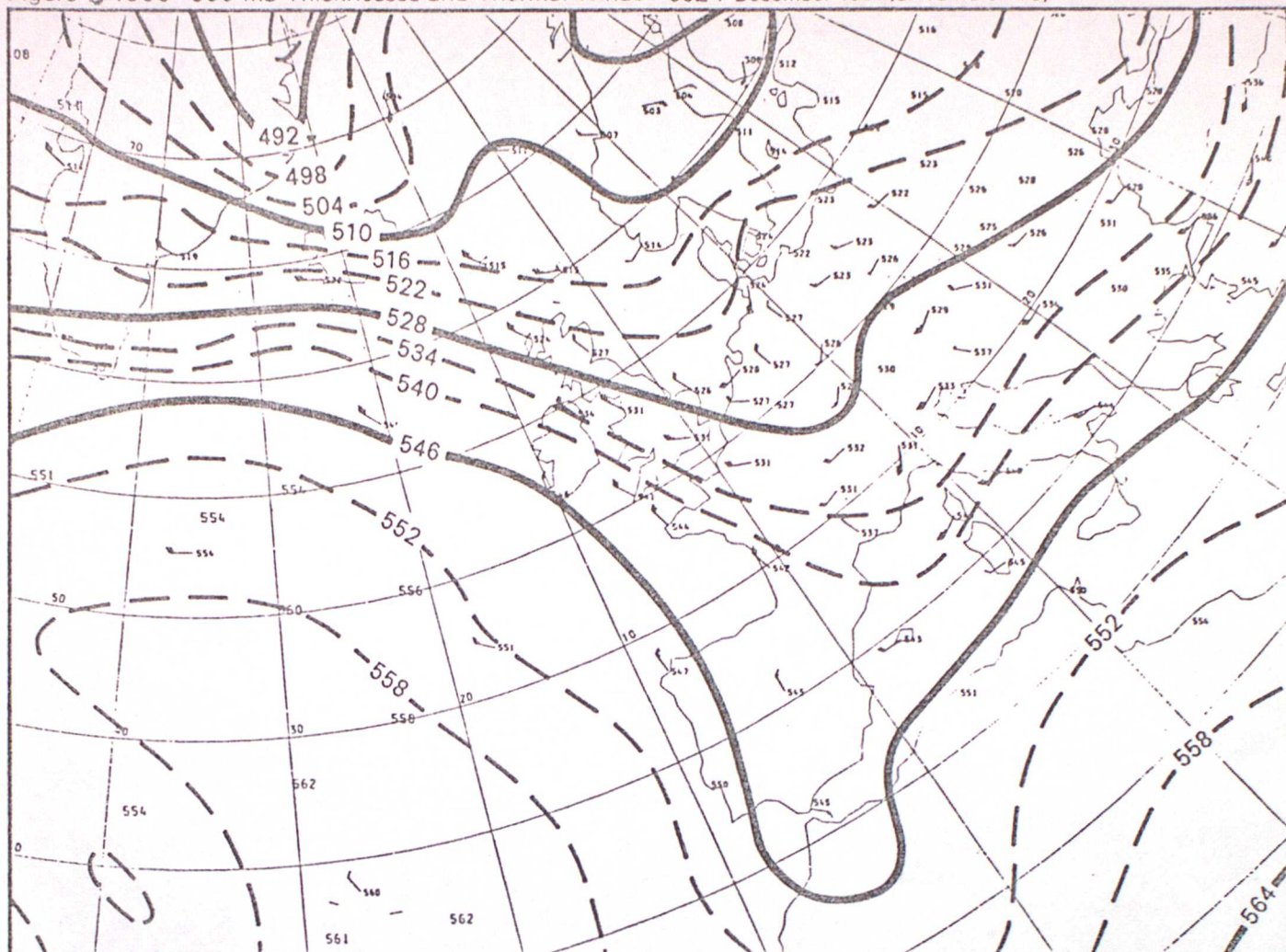


Figure 9 1000–500 mb Thickness First pass: 6 December 1981 1736Z NOAA-6

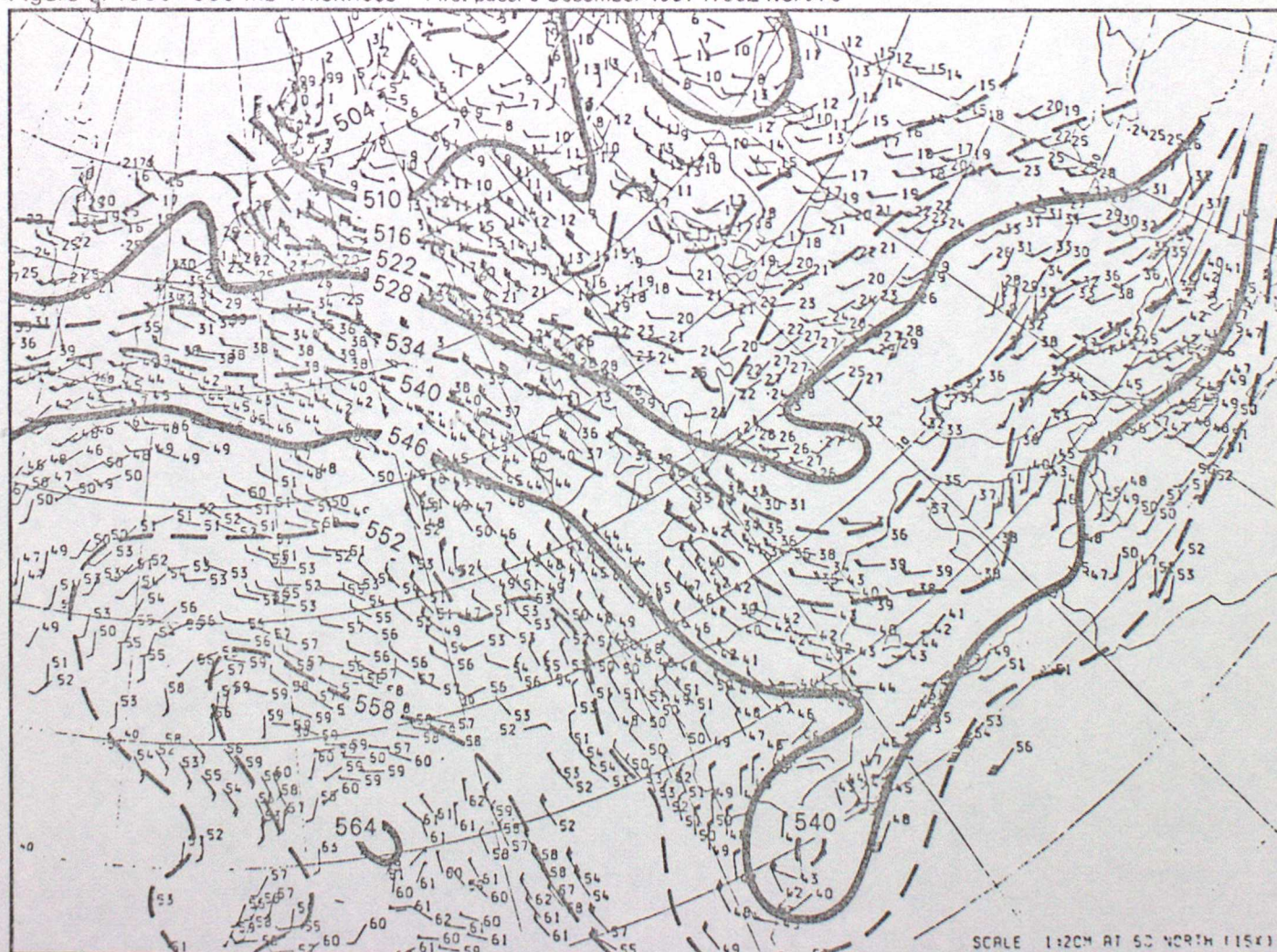


Figure 10 1000-500 mb Thicknesses and Thermal Winds 00Z 8 December 1981 (SATEMS & R/S)

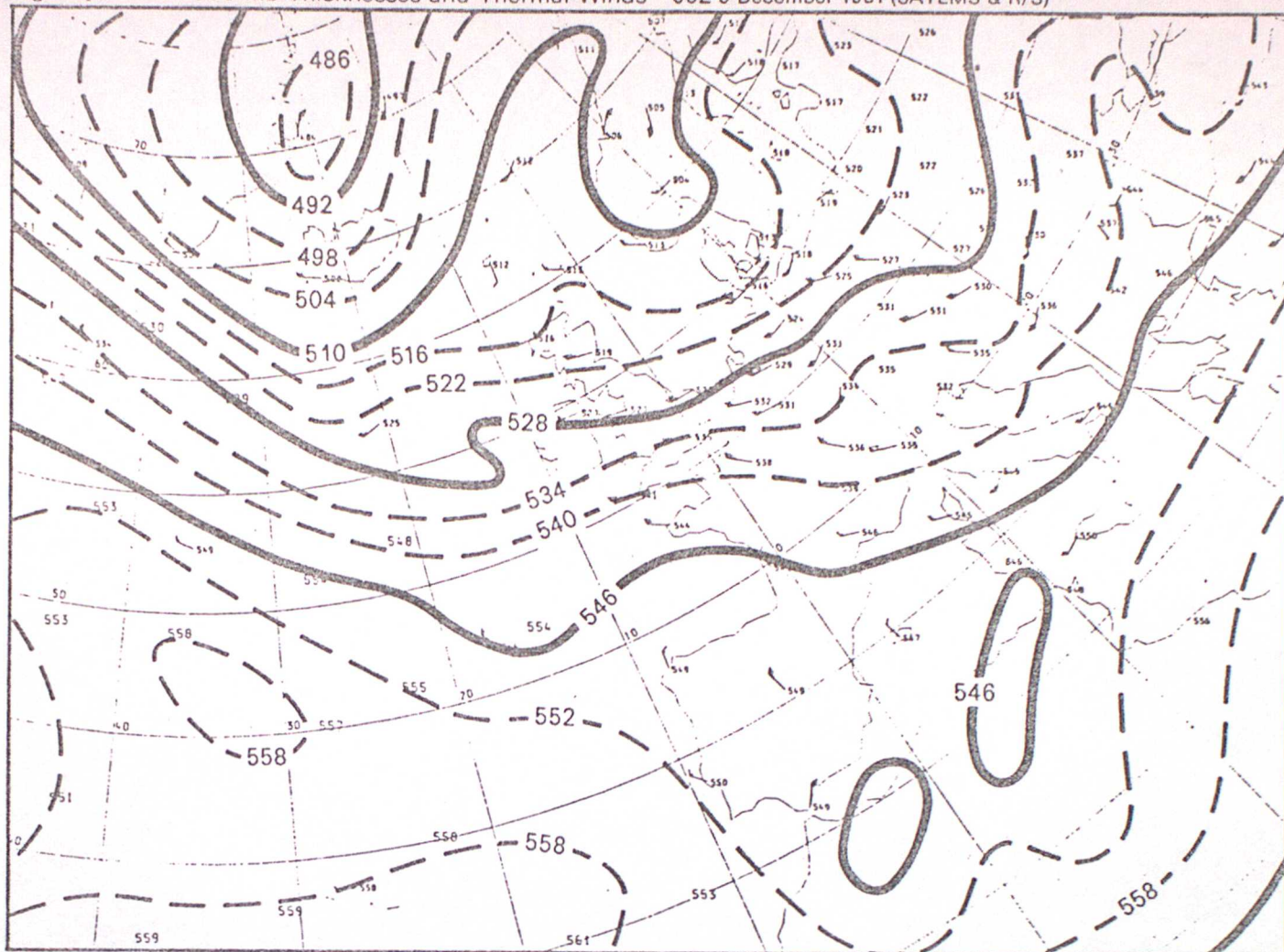
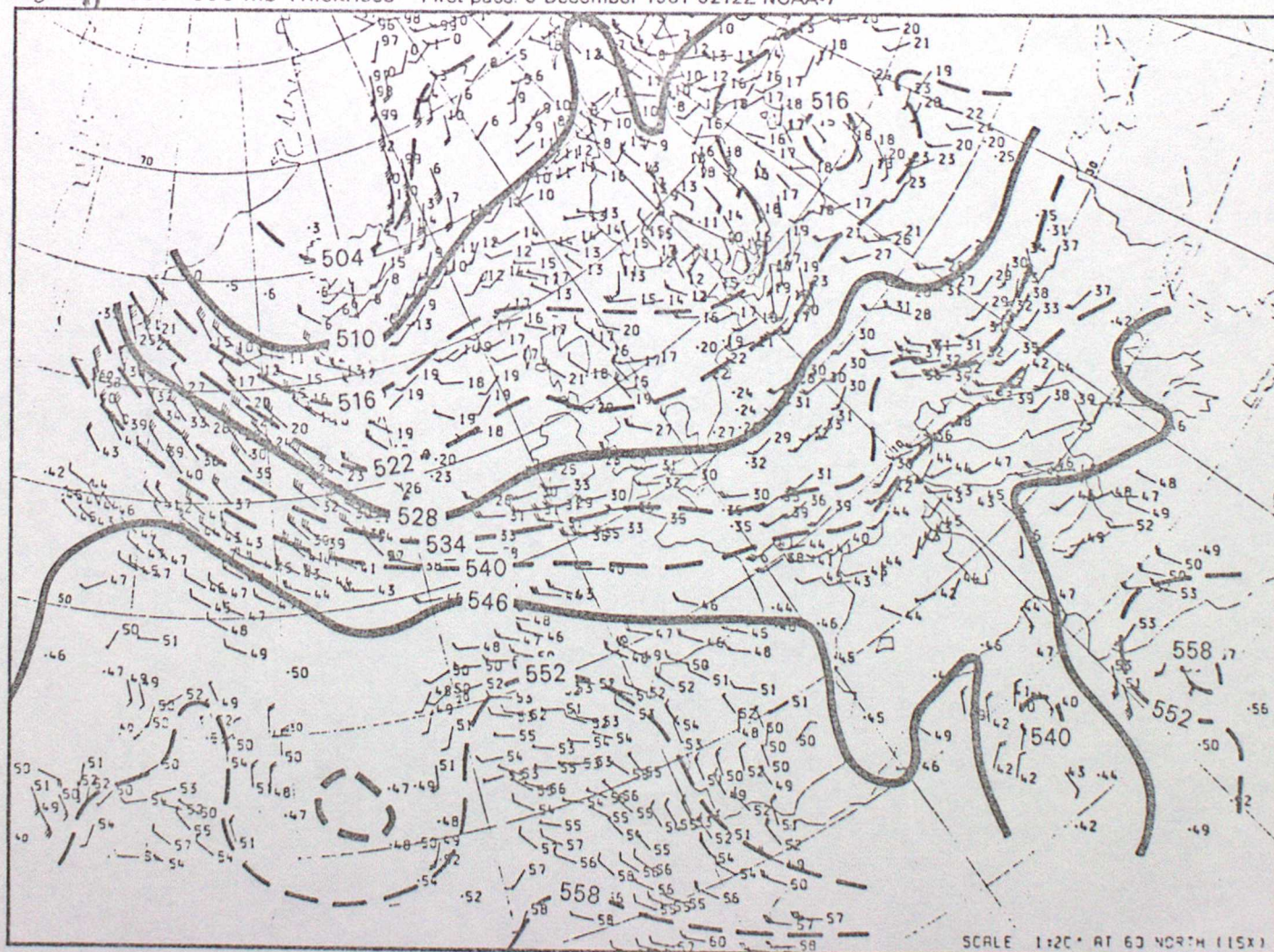
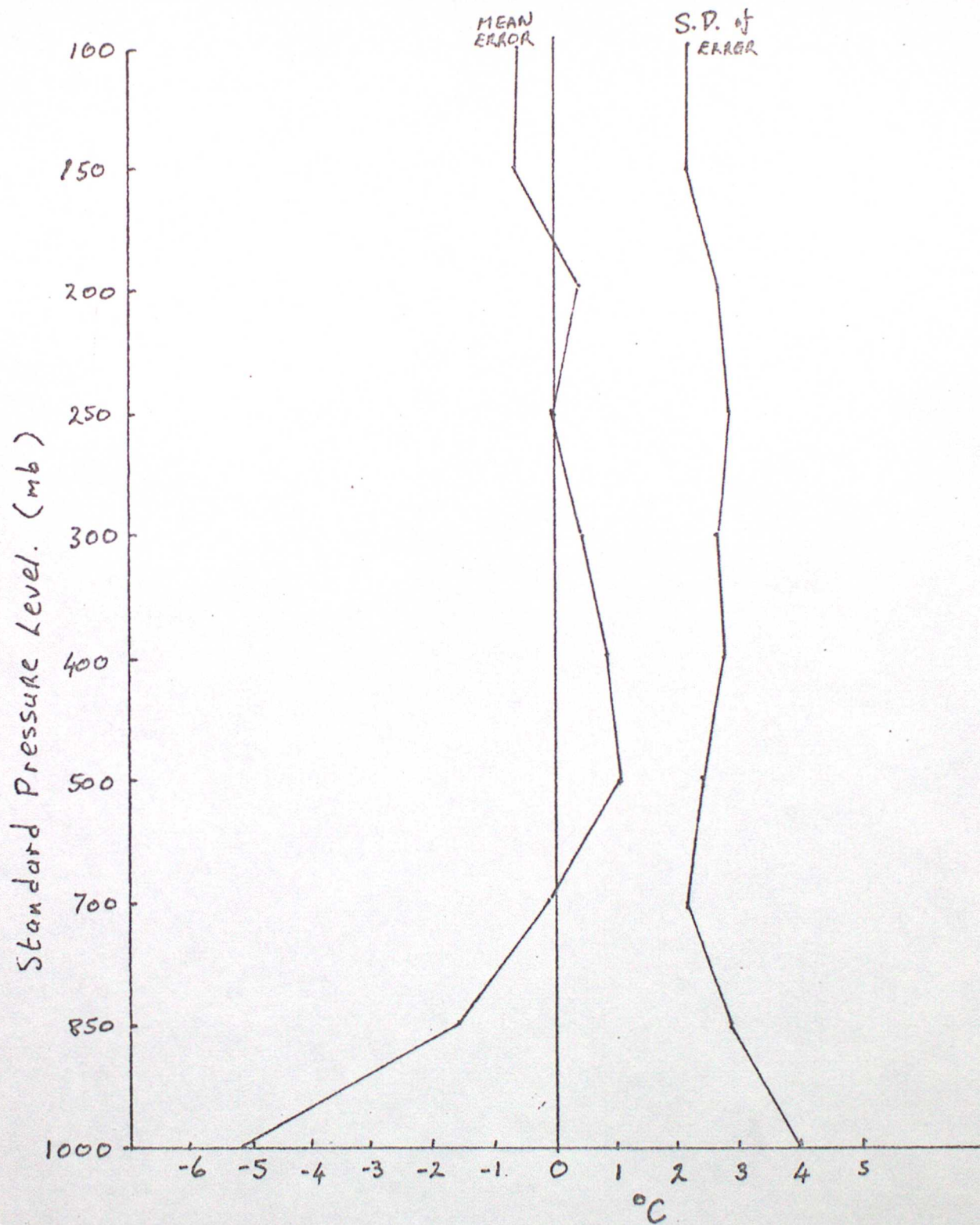


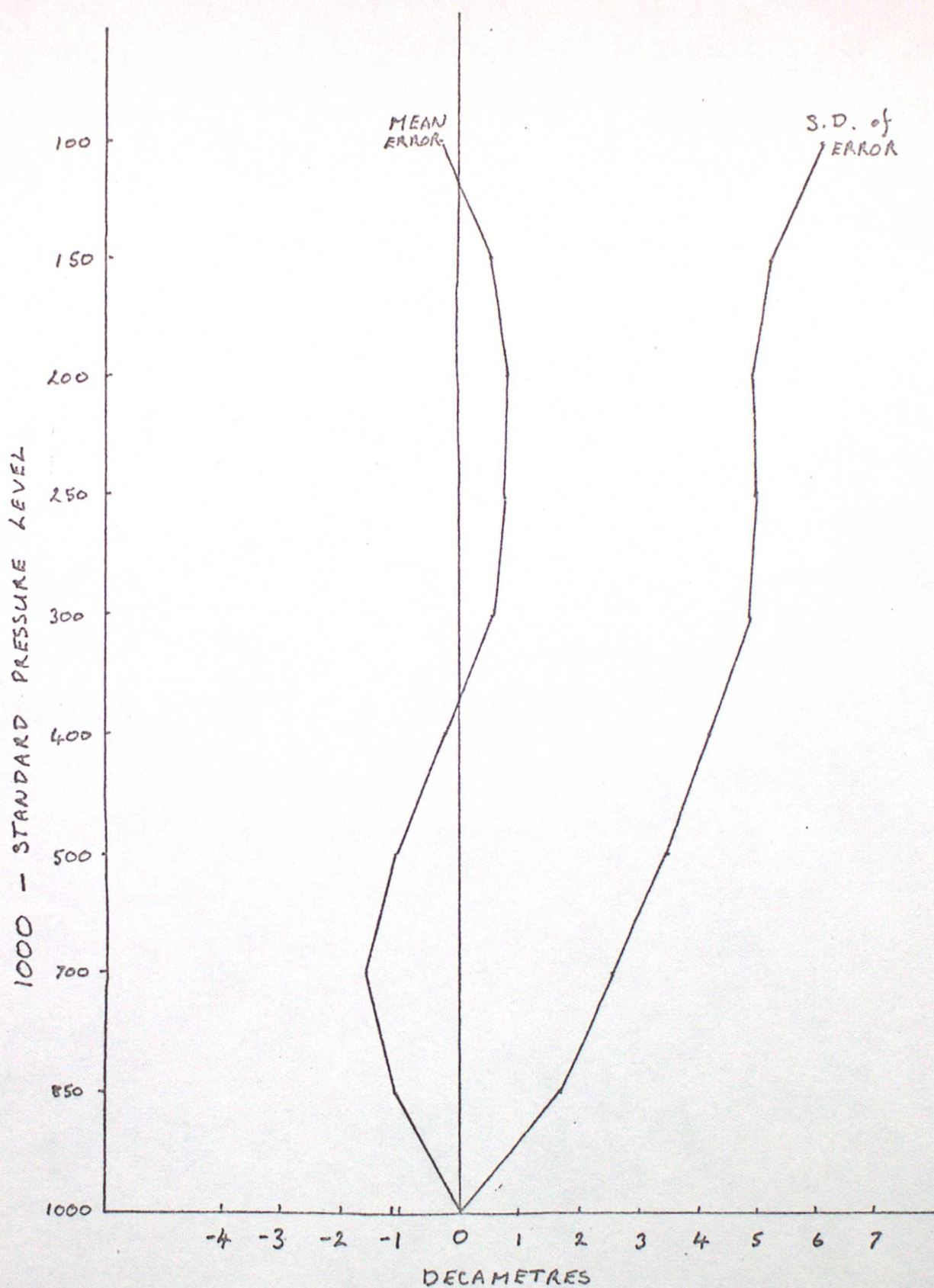
Figure 11 1000-500 mb Thickness First pass: 8 December 1981 0212Z NOAA-7





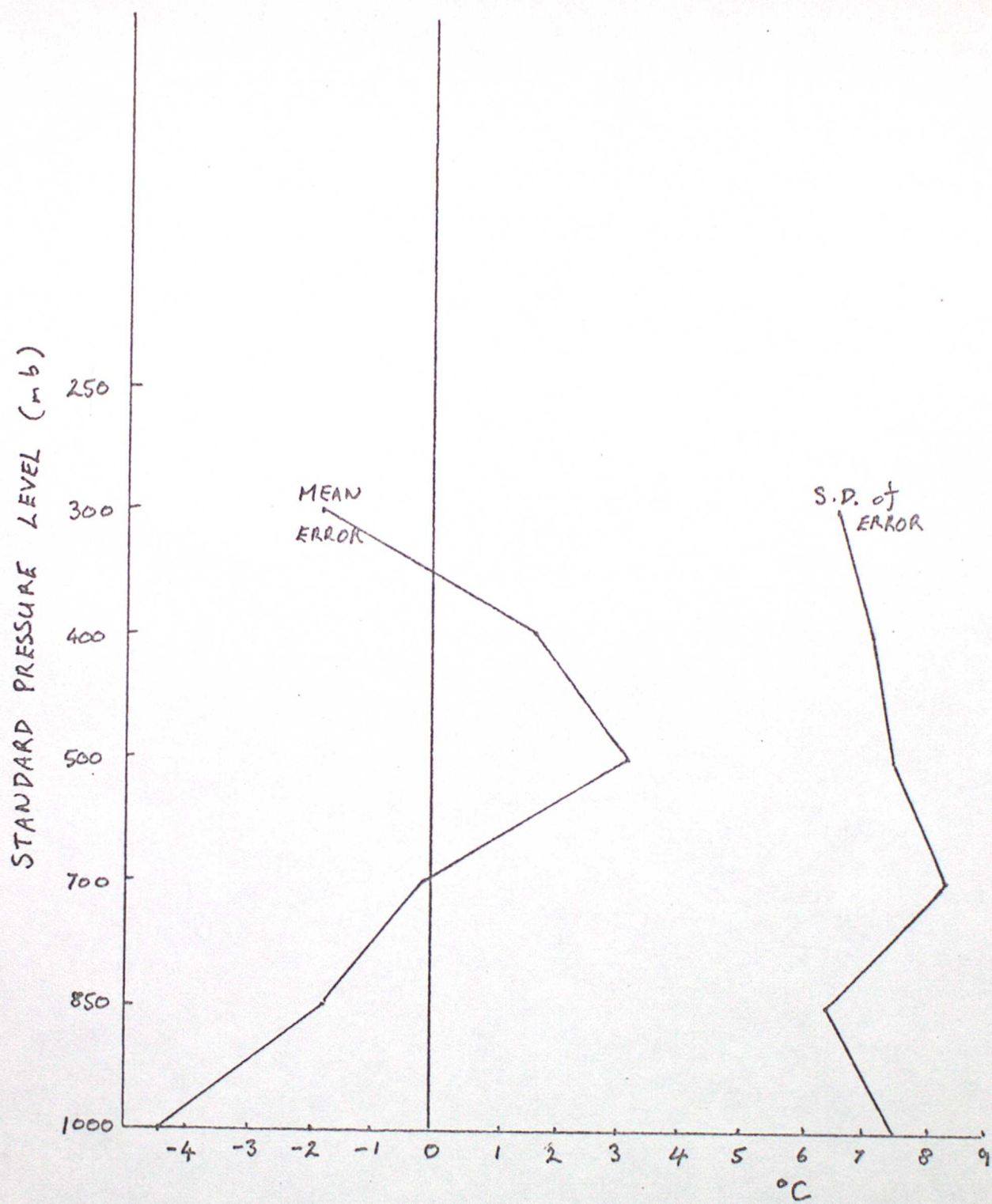
RETRIEVAL - R/S TEMPERATURES vs LEVEL

Fig 12.



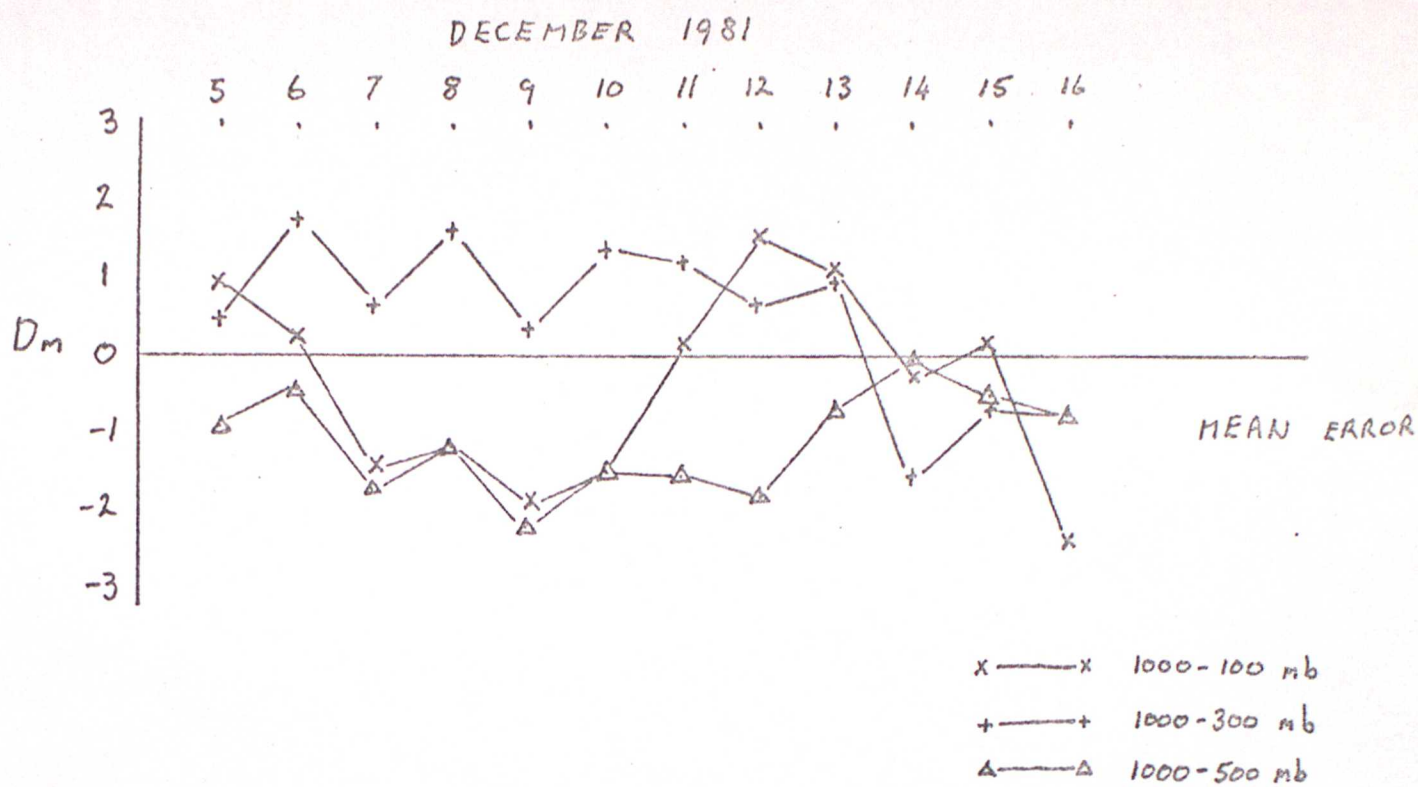
RETRIEVAL - R/S THICKNESSES V.S. LEVEL

Fig 13.



RETRIEVAL - R/S DEW POINTS vs LEVEL

Fig 14.



RETRIEVAL - R/S THICKNESSES (DAILY)

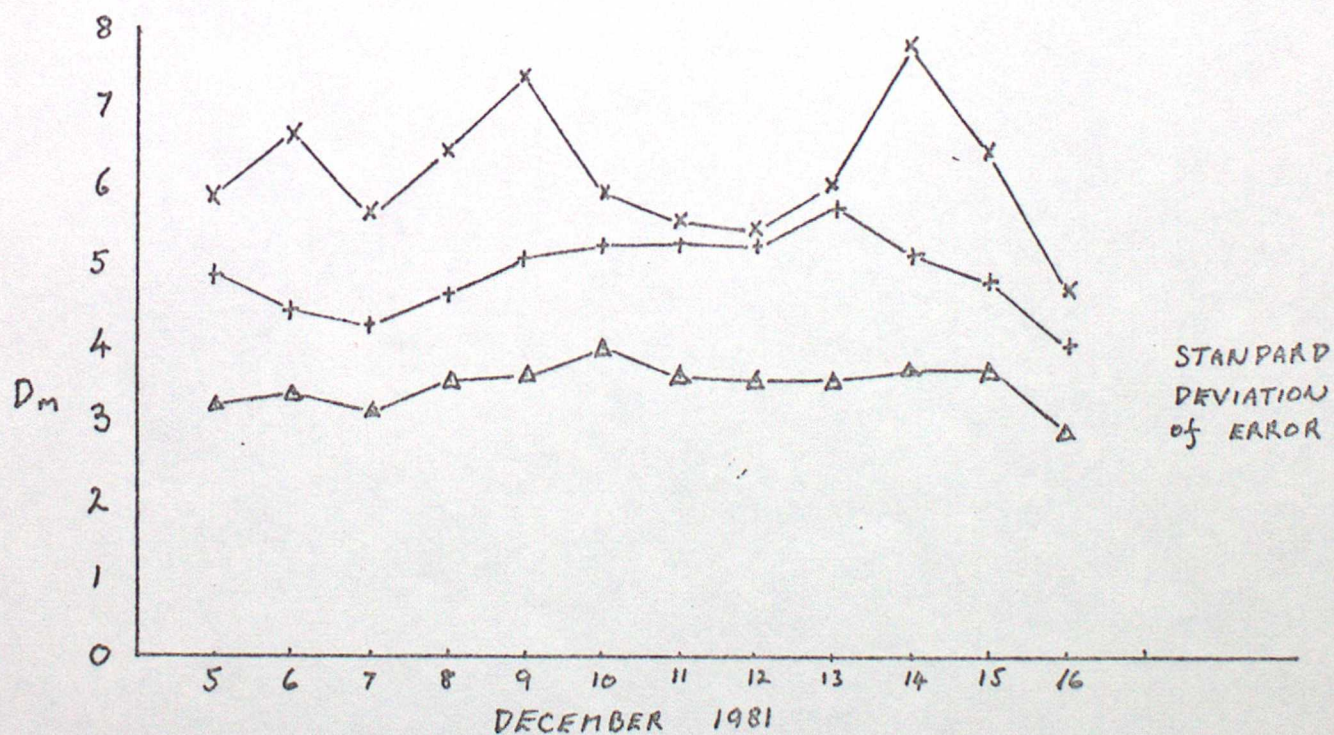


Fig 15.

DATA RECORD FORMAT 112 INTEGER * 4 WORDS

1	2	3	4	5	6	7	8	9	10	11	12	13	14
LAT	LON	ITIME	IEL	15 1000/1000	THICKNESSES -850	7 -700	BETWEEN -500	1000 MB -400	2 -300	BELOW LEVELS -250	12 -200	13 -150	14 -100
15	16	17	18	19	20	21	22	23	24	25	26	27	28
-70	-50	-30	-20	-10	1000	15	HIRS 700	POINTS 500	TEMPERATURES 400	X 100 300	250	200	150
29							DEW 850	X 100 700				CHANNEL 1	42
100	70	50	30	20	10	1000	850	500	400	300	200	100	50
43		19	HIRS	BRIGHTNESS	TEMPERATURES	(CLOUD CLEAR)	X 100						
3	4	5	6	7	8	9	10	11	12	13	14	15	16
57			60	MSU	BR. TEMPS X 100	4	SURFACE PRESSURE	LINE NUMBER	ELEMENT NUMBER	STATION PRESSURE	1000	850	700
17	18	19	CH 1	TEMPERATURES X 100	150	100	70	50	30	20	10		
500	400	300	250	200	150	100	70	50	30	20	10		
85													
99	100	101	102	103	104	105	106	107	108	109	110	111	112
			MTYPX10	SOLAR ZENITH ANGLE	1000/850	1900	THERMAL WINDS	1400	1300	1250	1200	1150	1100

1) LAT X 100 2) LON X 100 (EAST IS POSITIVE)

3) ITIME TIME FOR LINE HHMM

4) IEL ELEVATION IN METRES

5) 60 19) THICKNESSES IN METRES

103) ISZA X 100 SOLAR ZENITH ANGLE

102) MTYPX10 TYPE OF RETRIEVAL: 10 - CLEAR,

20 - CLOUD CLEARED, 30 - MICROWAVE ONLY

Fig 16.

File format.

The output file produced by the retrieval scheme is described fully in the Hermes documentation, reference F024.

The file has a maximum of 1235 records of 112 integer*4 words. Record 1 contains header information.

word 1	-	year*1000+month*100+day
2	-	start time - hours*1000+mins*100+sec
3	-	end time
4	-	number of HIRS lines
5	-	satellite ID (1-NOAA 7,2-NOAA 6)
6	-	processor status (1)
7	-	direction node (1 = Northbound, 2= Southbound)
8-111	-	not used
112	-	number of records in the file.