THE UNIVERSITY OF ALBERTA

Synoptic Study of Two Intense, Cold-core Cyclonic Storms

by

© Chi Dinh Nguyen

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Synoptic Study of Two Intense, Cold-core Cyclonic Storms submitted by Chi Dinh Nguyen in partial fulfilment of the requirements for the degree of Master of Science in Meteorology.

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Date 7 October 1987

Dedication

To my parents, neither time nor distance could lessen their loving support.

and

To Nguyệt Trần, Dũng and Chương with love.

Abstract

Two major storms which brought heavy precipitation to wide sections of Alberta in May and July, 1986 are described and illustrated by means of maps, satellite images and radar scans. Both storms originated in cold lows from the North Pacific which, on reaching Alberta, produced vigorous lee cyclogenesis at the surface.

Though different in the initial development, both storms subsequently produced copious amounts of rain and snow in Western Alberta, and lesser amounts in the eastern districts.

On the basis of the evidence studied and presented, it is postulated that the heavy precipitation was caused by synoptic-scale, deep-upslope flow, generated and maintained in the easterly circulation to the north of the centre of the cold-low system.

Acknowledgement

I would like to express my heartfelt gratitude to Dr. E.R. Reinelt, my departmental supervisor. His time, warm guidance, advice and encouragement through the course of the preparation of this thesis are greatly appreciated; it would have been impossible to complete it without him.

Appreciation is also extended to Dr. R.B. Charlton, of the Meteorology Division, and to Dr. F.W. Jones of the Department of Physics who, with Dr. Reinelt, served on my examing committee.

I wish to extend my appreciation to Dr. E.P. Lozowski for his kindness and help whenever I needed it.

Special thanks are extended to Dennis Oracheski who made numerous useful comments on the satellite meteorology used in this study. Thanks are also due to Mr. Dave Burnett and the staff at the Alberta Weather Centre for much help and the use of their materials.

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1. INTRODUCTION, INSTRUMENTATION AND OBSERVATION

1.1 Introduction

This study is concerned with two memorable 1986 weather events: the late spring snow storm in the Calgary area, and the heavy rains in July that caused extensive flooding in West-Central Alberta, including the City of Edmonton. The area of interest of this investigation includes Alberta, Saskatchewan and, to a lesser extent Manitoba, where the storms ultimately moved and dissipated.

This chapter presents a description of instrumentation and the materials used : Satellite, Radar and weather stations, providing cloud imagery, precipitation scans and conventional synoptic charts. The method by which data were selected and processed is given in Chapter 2. Chapter 3 deals with the intense spring snow storm in the Calgary region. This is followed by the case study of the summer rain storm in Edmonton in Chapter 4. Finally, a summary and conclusions are presented in Chapter 5.

1.2 Instrumentation and observation

The two major sources of data used in this study are imagery obtained from satellite NOAA-9 (or NOAA-F), in the series of the third-generation operational, polar-orbiting environmental system, and conventional surface and upper-air data. Radar, a supplementary source of data was available only for the analysis of the July storm.

1.2.1 The NOAA Satellite System

Only a general description of the NOAA-9 Automatic Picture Transmission (APT) is given here, inasmuch as comprehensive discussions of the TIROS-N/NOAA satellite system can be found in Schwalb (1978), and Barnes & Smallwood (1982).

NOAA-9 was launched on December 12, 1985 at 1042Z. Figure 1.1 shows the craft in space and Figure 1.2 shows the main parts of the satellite vehicle.

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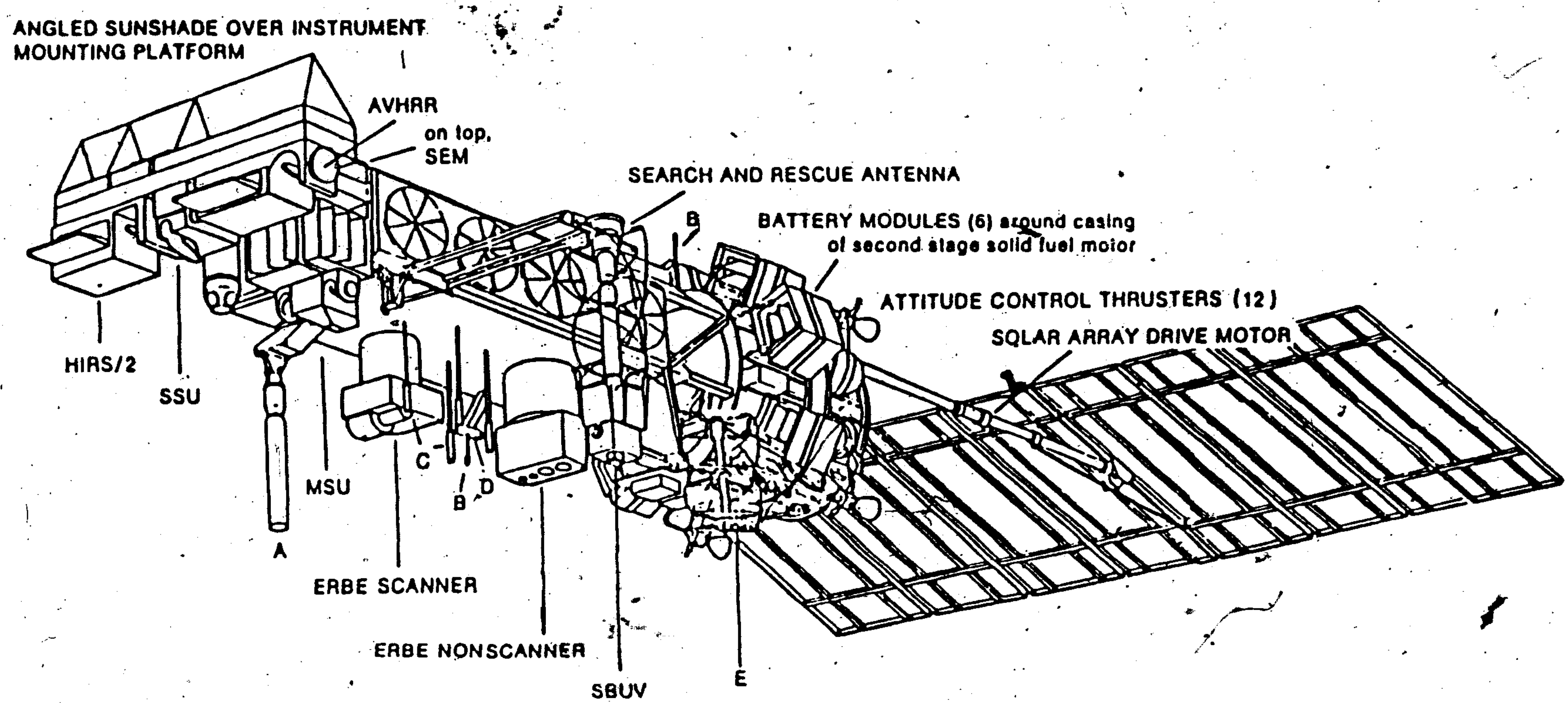
Figure 1.1 The spacecraft in space. (Taken from Environment Canada Poster)



Antennas identified by letters:
A—UHF for the DCS.
B—S-band omni antennas.
C—Four S-band antennas.
D—Beacon command antenna.
E—VHF real-time antenna.

Figure 1.2 The main parts of the NOAA-9 vehicle.(after Schwalb, 1982)

The polar orbiting satellite is placed in a sun-synchronous orbit, i.e. the satellite passes over any given longitude at the same time each day. This satellite has a period of approximately 102 minutes with an inclination angle of about 99°. It orbits at an average height of 865.0 km with a nodal regression of 25.51° i.e the satellite shifts westward 25.51 degrees of longitude per orbit at the equator. The NOAA-9 satellite was launched with a northbound equator crossing between 1400 and 1800 Local Solar Time (LST). Figure 1.3 shows the equator crossing time geometry of NOAA-9.

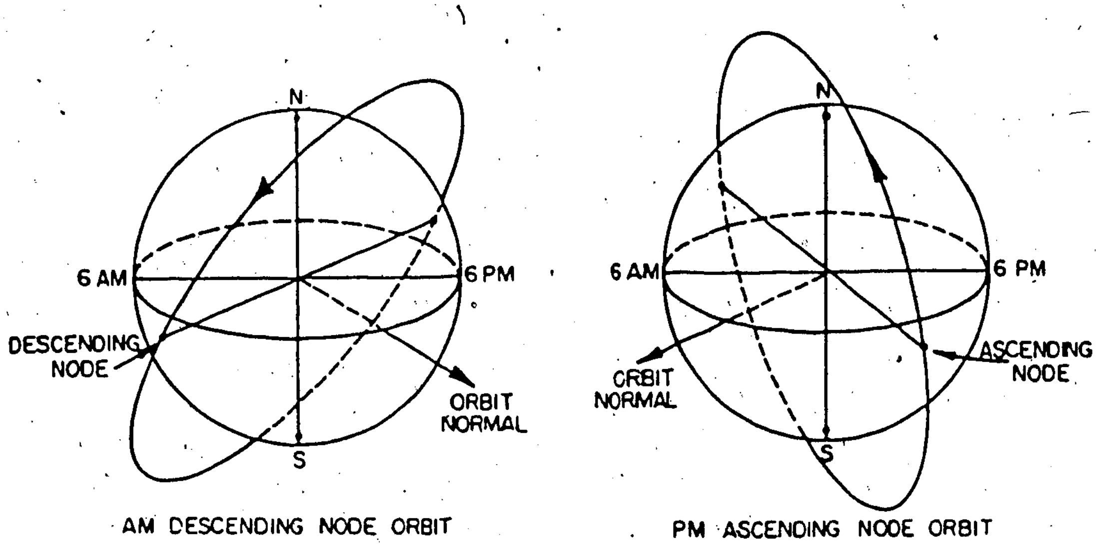


Figure 1.3 The equator crossing time geometry of NOAA-9.

NOAA-9 provides only infrared imagery during the early morning (0600 through 1000 LST) when moving southbound, but both visible and infrared imagery during the afternoon (1400 through 1800 LST) when moving northbound.

The satellite precesses at rate of about one degree per day, so that the orbit maintains a nearly constant orientation with respect to the Sun over the course of the year.

1.2.2 Satellite Scanning

The satellite carries on board an Advanced Very High Resolution Radiometer (AVHRR)[1] instrument which provides image data for the real time Automatic Picture Transmission (APT) service. The instrument senses radiation in four spectral channels (see Table 1.1).

Table 1.1 NOAA-9 AVHRR Channel Characteristics.

Channel	Resolution at Subpoint (km)	Wavelength (μm)	Primary Use
1	1	0.55 - 0.90	Daytime cloud and surface mapping
2	1	0.73 - 1.10	Surface water delineation
3	1	3.55 - 3.93	Sea surface temperature (SST), night time cloud mapping
4	1	10.5 - 11.5	Sea surface temperature, day/ night cloud mapping
5	1	11.5 - 12.5	Sea surface temperature

AVHRR channels 1 and 2 can be used to discern clouds, land-water boundaries, snow and ice. When data from the two channels are compared, an indication of ice/snow melt inception is obtained. The data from channel 4 (Infrared window) can be used to measure cloud distribution day and night and to determine the temperature of the radiating surface. Channels 3, 4 and 5 can be used to determine the sea surface temperature (SST). Examples of imagery from AVHRR are given by Figs. 3.6 and 3.7.

[1] AVHRR or AVHRR/1 indicates NOAA-9 is equipped with a four-channel instrument, while AVHRR/2 indicates that the satellite is eqipped with a five-channel instrument.

The APT signal consists of any two of the AVHRR channels: normally channels 2 and 4 are transmitted during the daylight portion of the orbit, and channels 3 and 4 during the night portion. In this study, channel 2 provides visible imagery during daylight and channel 4 provides infrared imagery during both day and night.

These channels are pre-processed to achieve both bandwidth reduction and geometric correction, and then are time-division multiplexed into an output data stream. The AVHRR mirror rotates at the rate of 360 revolutions per minute. The bandwidth reduction algorithm involves sending one of every three scanlines to the APT transmitter, thus the effective rotation of the APT signal is 120 scanlines per minute or 2 scanlines per second. Each AVHRR scanline contains 2048 pixels per channel which samples radiation from 55.4° on each side of nadir[2]; for a satellite at a height of 865 km, the 55.4° nadir angle corresponds to approximately 13.5° great-circle arc length on the earth's surface. For APT transmission the 2048 pixels are reduced to 909, using the algorithm summarized in Table 1.2 and shown in Figure 1.4. The geometric corrections are performed to maintain constant resolution along the scanline.

Table 1.2 APT linearization regions.

Region 1	±16.9° from nadir	Average four continuous samples
Region 2	16.9° to 34.8° either side of nadir	Average two samples; skip one and repeat
Region 3	34.8° to 43.8° either side of nadir	Average two samples
Region 4	43.8° to 48.8° either side of nadir	Average 1 1/2 samples ($\frac{A+B}{2}:\frac{B+C}{2}$)
Region 5	48.8° to 55.4° either side of nadir	Retain original resolution

Since the satellite regresses, (i.e. shifts westward) at the rate of 25.51 degrees of longitude per orbit, there is a two-degree longitude overlap between each two consecutive

[2]Nadir is the point vertically below the satellite, and the nadir angle is the angle measured at the satellite between a specific axis or ray and the local vertical.

orbits at the equator. Since the scanline of the mirror is perpendicular to the satellite's path, its sweep combined with the motion of the satellite gives complete coverage of the area in the field-of-view of the radiometer. This coverage corresponds to an arc length of about 27.0° (2997 km) on the ground at the equator, and increases to approximately 55 degrees of longitude at 50° N latitude.

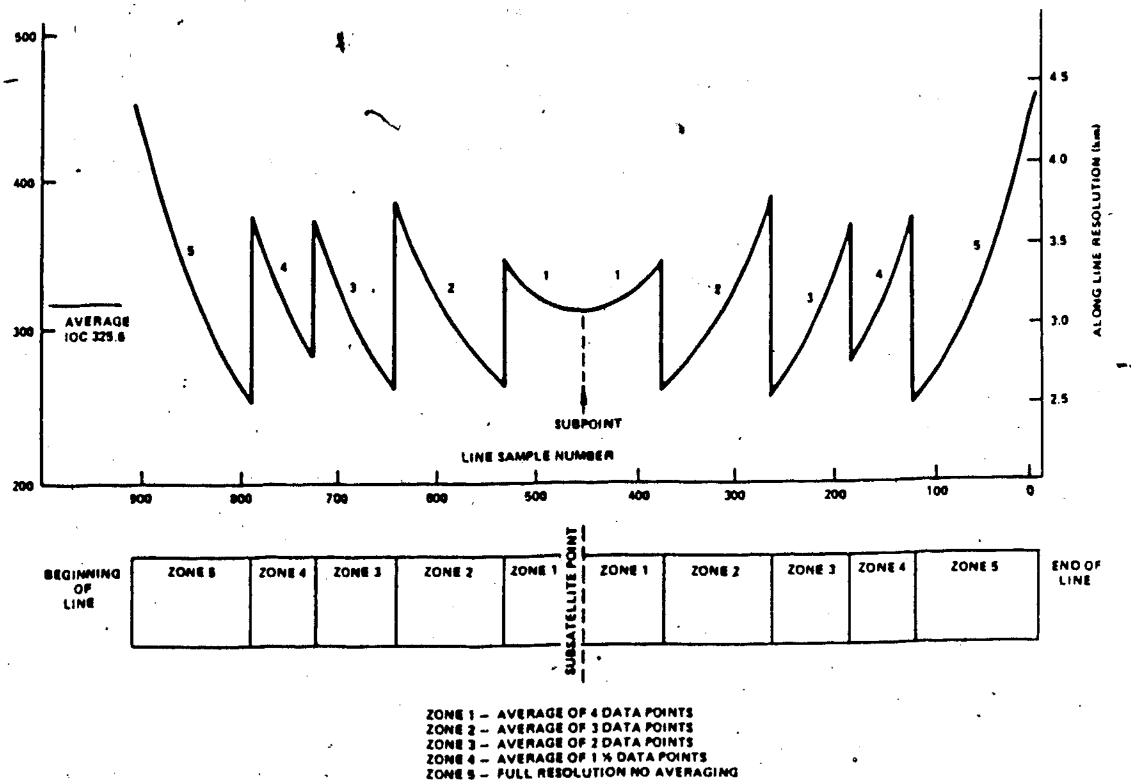


Figure 1.4 . APT linearization regions and resolution.(after Schwalb, 1978)

1.2.3 Satellite Resolution

For a given altitude, the resolution of a line-scan device, such as AVHRR, is a function of the instantaneous field-of-view of the sensor (spot size on the Earth). As the sensor scans outward from the satellite subpoint, the spot size on the surface of the Earth increases in size.

The NOAA-9 AVHRR has a field-of-view of 0.0013 radians. With this field-of-view and a satellite height of 865 km, the subpoint resolution is approximately 1.0 km and the resolution at the edge of the data swath is approximately 4 km.

The University of Alberta's satellite laboratory is equipped to receive the analog APT signal and convert it to digital counts between 0 and 255 at a digitizing rate of 3200 Hertz. High counts correspond to high reflectivity and low temperature for the visible and infrared band respectively.

The visible and infrared data are represented along a scan by one half second or 1600 pixels. Only 1530 are saved; of this 1400 contain infrared and visible image data (700 for each channel), 130 are telemetry and synchronization data. The remaining 70 are for digitizing resynchronization and are not collected. An example of one scanline of APT data is given in Figure 1.5.

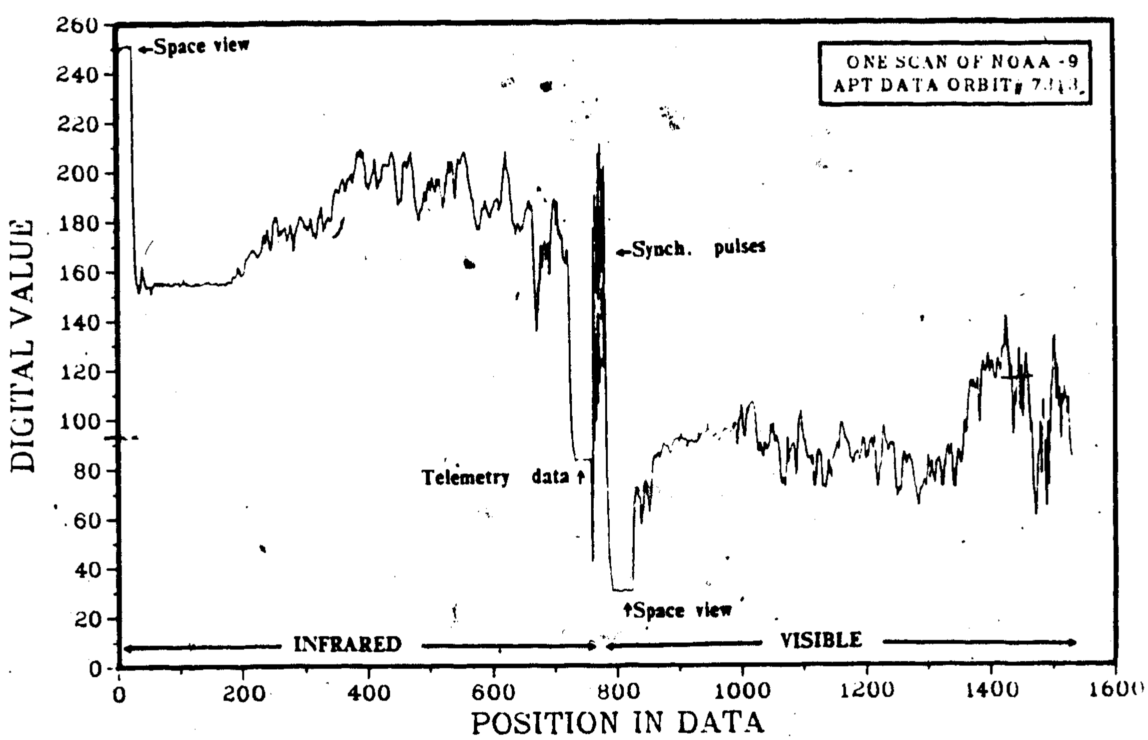


Figure 1.5 Example of one scanline of NOAA-9 APT data.

1.2.4 Calibration of Infrared Data

In order to calibrate the infrared data, it is necessary to relate the recorded APT signal to AVHRR data. Calibration data are sent from the satellite with each scanline. There are 16 pieces of calibration data, each repeated over 8 lines, so that a total of 128 lines are needed to receive all information (an example of ouput data can be found in Appendix D). This is known as a telemetry frame, as shown in Figure 1.6.

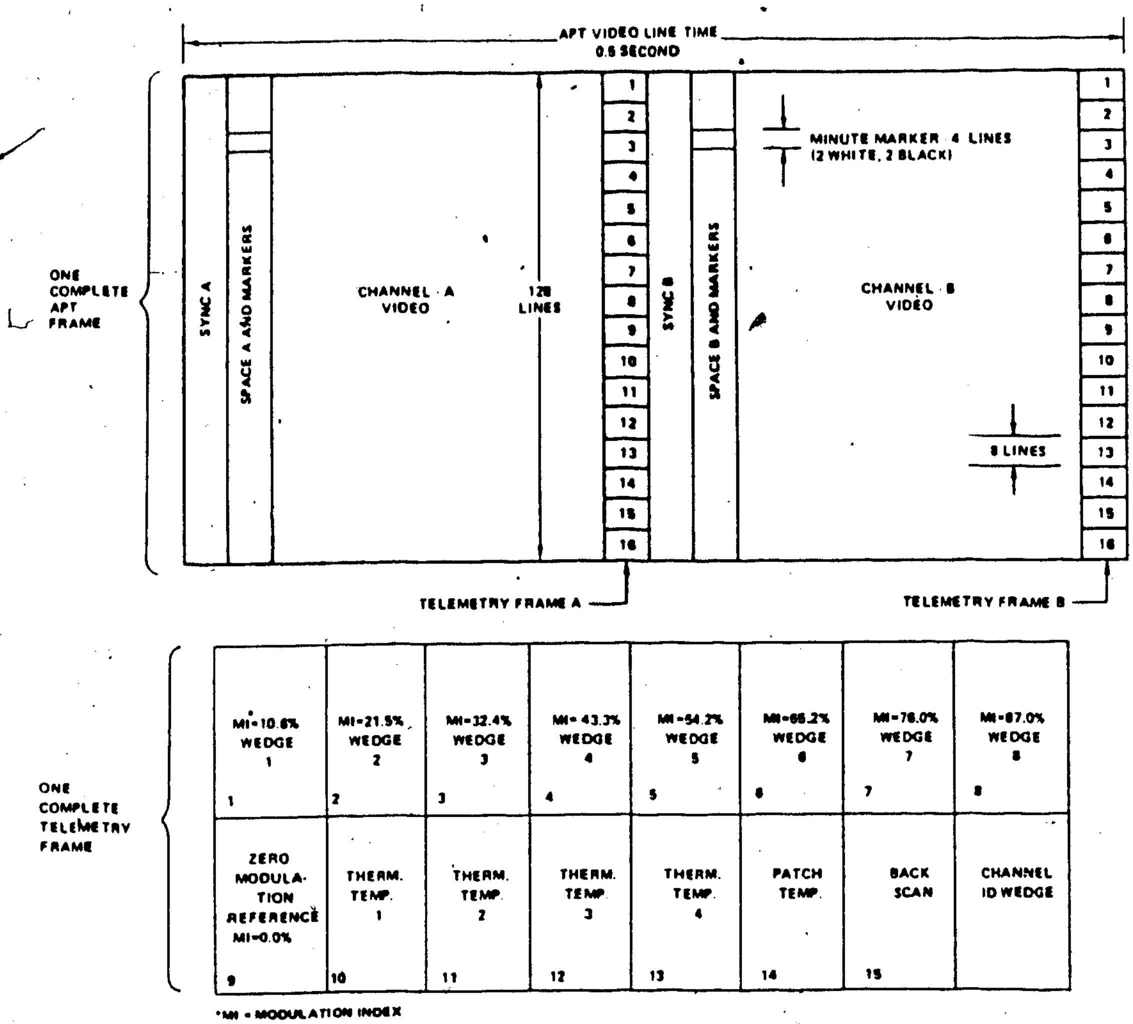


Figure 1.6 APT frame format.(after Schwalb, 1978)

From this figure, the first 9 boxes consist of wedge values. Each wedge is assigned a known digital count before the satellite is launched. Boxes 10, 11, 12 and 13 are digital counts from the radiometer viewing four Platimum Resistance Thermometers (PRTs) embedded in its housing, which is designed to be a black body. Box 14 contains Patch temperature, Box 15 counts for the sensor viewing the black body and Box 16 contains channel identification.

By comparing digital wedge values received on the ground to the expected values, it is possible to relate ground-received digital counts for cloud top temperature and brightness to satellite measured counts. The relationship between received digital counts and wedge levels is shown in Figure 1.7.

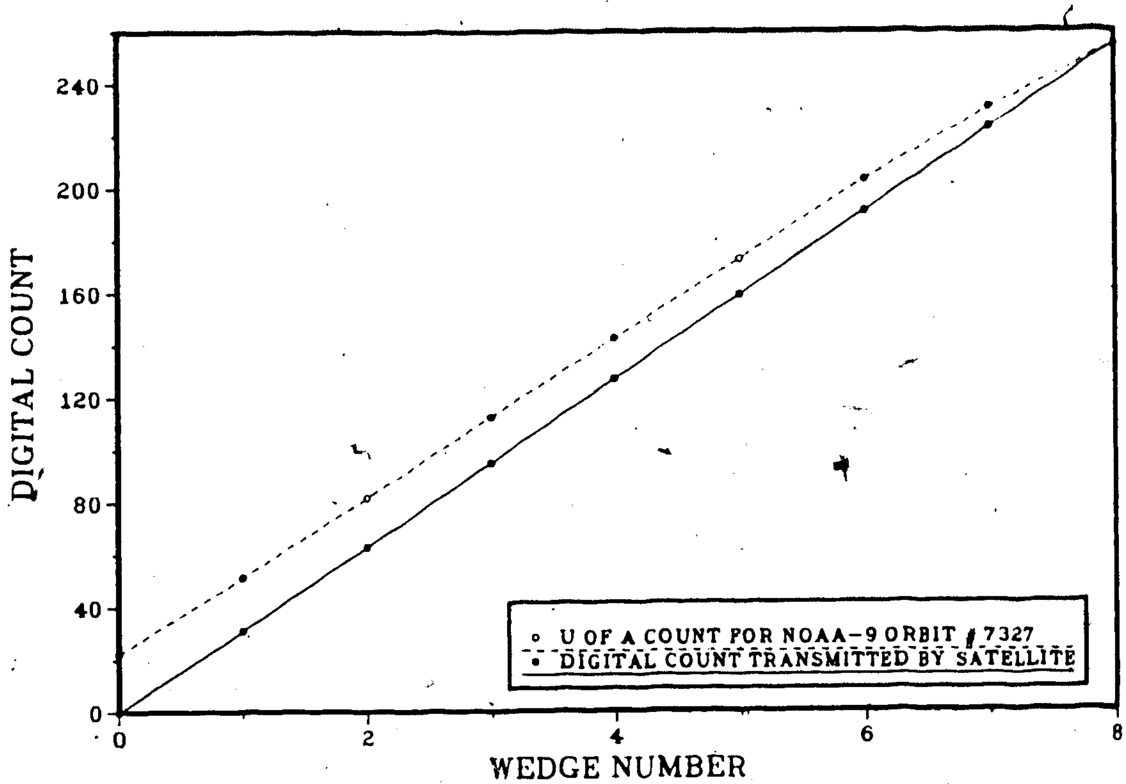


Figure 1.7 The relationship between received digital counts and wedge levels.

The discrepancy between the two sets of data is due to the digital-analog-digital conversion that takes place during the transfer of the data from satellite to the ground. A cubic spline fit between these two data sets was performed by Subroutine ICSICU that is available from IMSL (International Mathematical and Statistical Libraries) at the University of Alberta. The coefficients obtained from this procedure were then used to determine the average temperature of PRTs. A second cubic spline fit was then performed in order to find the recorded University of Alberta digital values corresponding to the average PRT temperatures. Once the relationship between the onboard calibration wedge level and those recorded at the University of Alberta is known, the infrared data may be calibrated to obtain the temperature field, using the infrared calibration technique described by Wieler(1981) and repeated here in Appendix A.

On Figure 1.8, Case Study # 1, the plot of digital counts versus temperature for 4 different satellite orbits shows that the change in temperature difference over the range 200° K to 270° K is only about ± 0.5° K. This is also supported by Case Study # 2 for 3 different satellite orbits (Fig. 1.9). Hence, a separate spline curve is not necessary for each orbit.

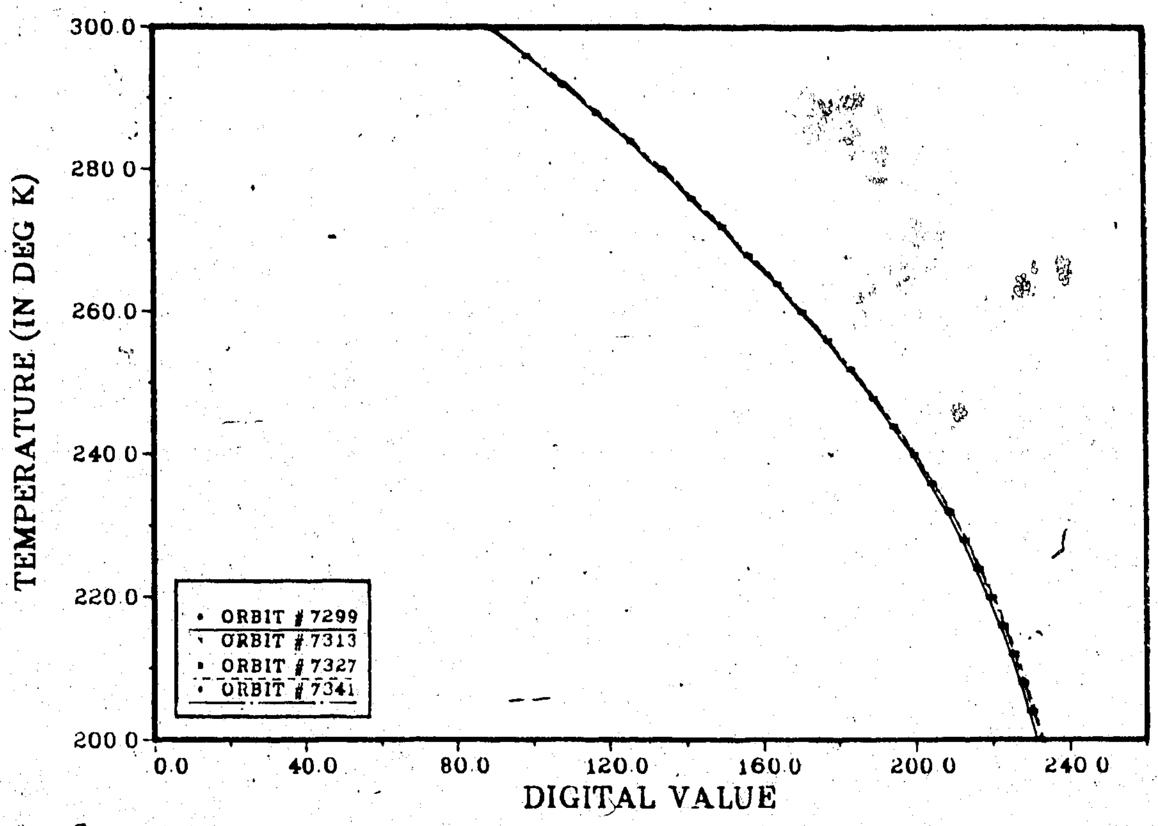


Figure 1.8 Calibration temperature curve for Case Study # 1.

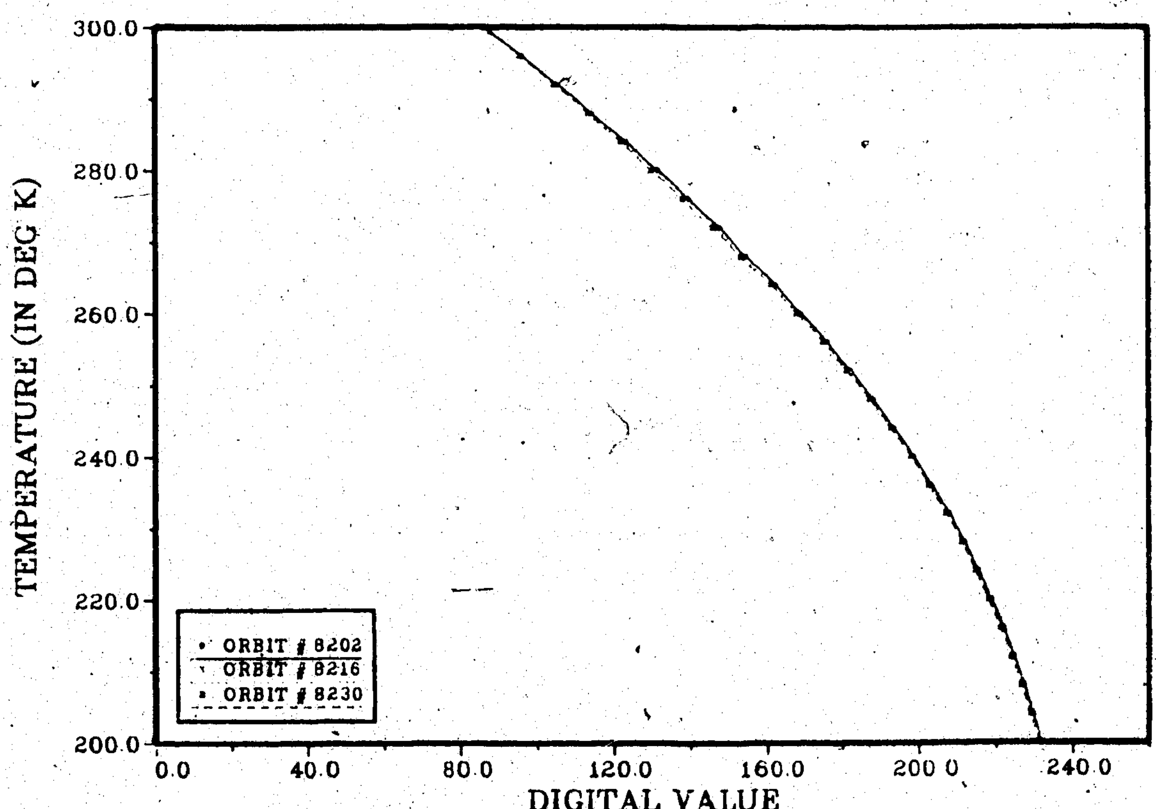


Figure 1.9 Calibration temperature curve for Case Study # 2.

1.3 Radar

There are many different kinds of radar systems. The CWSR-81 System is a late model weather radar employed by the Atmospheric Environment Service (A.E.S) of Canada. The Edmonton District radar is located at Carvel, near Stony Plain, about 30 miles West of Edmonton, Alberta. The following summary is based on material abstracted from training manuals (Bendell, 1985), unpublished notes and manuscripts (Smith & Rogers, 1970).

1.3.1 Fundamentals of Radar

Radar (Radio Detection And Ranging) is based on the principle that an electromagnetic wave is propagated through space at the speed of light, 2.998×10^8 m/sec, and then that its energy is scattered and reflected by objects in the environment. Targets may be defined as anything that will reflect a detectable amount of energy back to the antenna, such as terrain (hills, mountains, etc.), rain, snow, hail and sometimes drizzle.

By means of an antenna producing a narrow beam in the manner of a searchlight, one can scan with the antenna for reflect signals, and determine the direction and distance of the reflecting object. An elementary Radar system is shown in Figure 1.10.

By measuring the time interval between the transmission of the signal and the reception of the echoes[3], the range (or distance) of the object can be calculated as follows:

$$R = c \times \frac{\Delta t}{2}$$

where R is the range (m)

c is the speed of light (m)

Δt is the time interval (sec)

1.3.2 Major Components of Radar

Figure 1.11 shows the main components of a radar system. It consists of four subsystems: the transmitter, the antenna system, the receiver, and the processor and displays.

[3]The scattered signals received from the targets are referred to as "echoes".

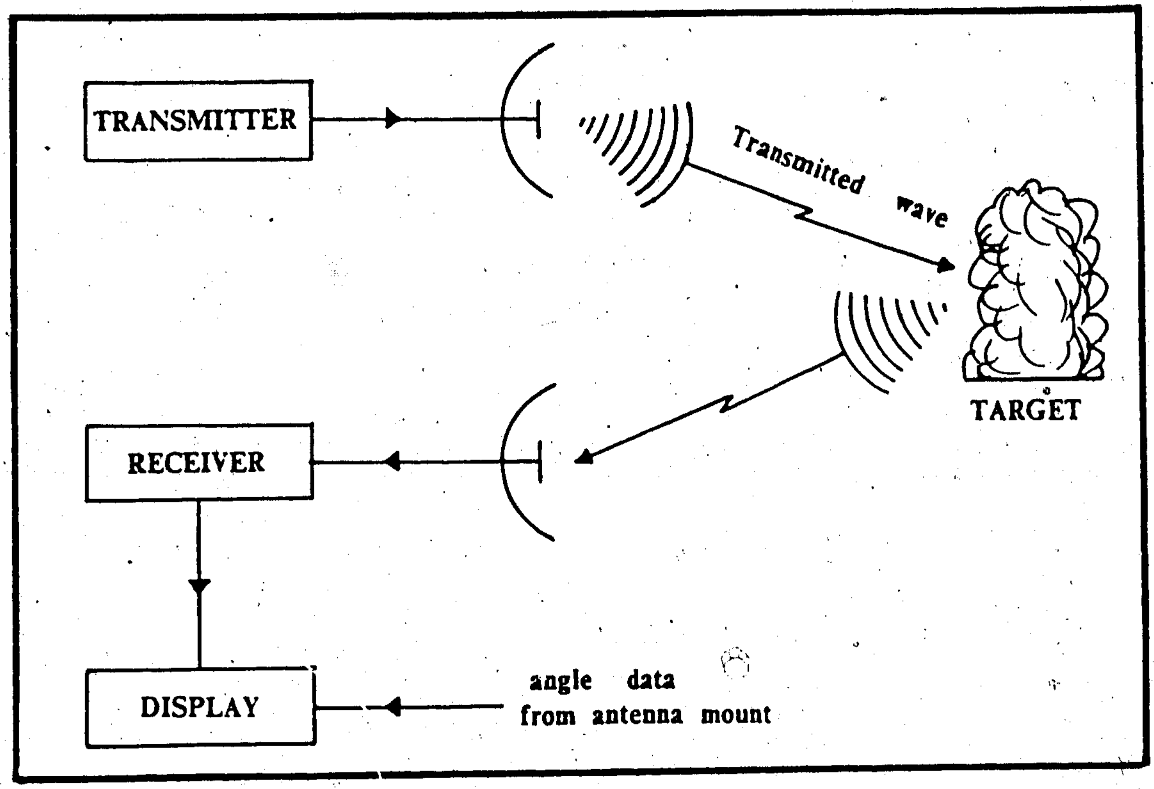


Figure 1.10 An elementary Radar System.

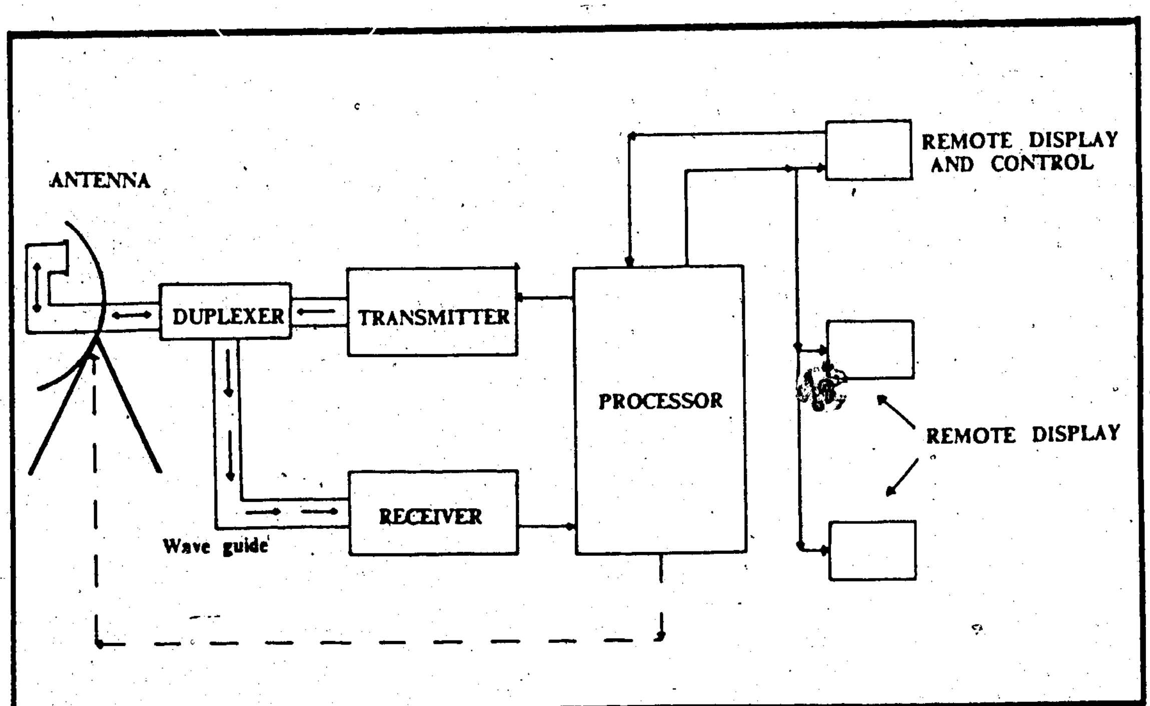


Figure 1.11 The main components of a Radar System.

The transmitter produces pulses of energy of the desired frequency and duration. It consists of a power supply, a synchronizer, a module for converting Alternating Current (A.C) to Direct Current (D.C), and a self-excited oscillator called a magnetron which produces the actual burst of microwave energy that is transmitted to the antenna system via a wave guide.

The antenna system focuses the energy and directs it to the appropriate azimuth and elevation, and then receives and concentrates energy reflected from targets. It consists of a paraboloid reflector, a horn antenna and a fast-acting switch, called a duplexer, that alternately connects the antenna to the transmitter and the receiver.

The returned energy from the antenna system is amplified and converted to a video signal by the receiver, analogous to the picture information contained in an ordinary television signal. The video signal is amplified before being fed to the display. The receiver consists of a mixer, a non-linear device, usually a crystal diode, used to convert the Radio Frequency (RF) echo to a lower frequency, called Intermediate Frequency (IF), an IF amplifier, and a detector to detect the shape of the signal and remove background noise.

The returned signal is automatically corrected for range attenuation out to 230 km and is given in units of dBZ. These intensities are converted into 6 precipitation levels in mm/hr using the empirical equation of Marshall-Palmer (Smith & Rogers, 1970).

The Plan Position Indicator (PPI) displays the location of the echoes returned by ground objects and precipitation. The PPI display is an AED COLOWARE 767 Color Graphics Display Terminal and a hard copy output is produced by an Advanced Color Technology Chromajet ACT II color printer.

The processor may allow for remote control of the antenna or may itself control the antenna directly. It also processes the analogue video signal from the receiver into a digitized intensity enhanced video signal, to be transmitted to the displays.

An example of output of the CWSR-81 Radar System is shown in Figure 1.12. The date and time (UTC) are shown in the lower right corner. The actual time of the start of the scan at the Radar site, the elevation angle of the antenna and the six Digital Video Integrator and Processor (D.V.I.P) levels (see Table 1.3) representing the rate of precipitation in mm per hour are in the upper left corner. The background represents the geographical features in the area of coverage. The range rings mark 100-200 km distances in the short range, and 200-400 km in the long range; they are independent of the background.

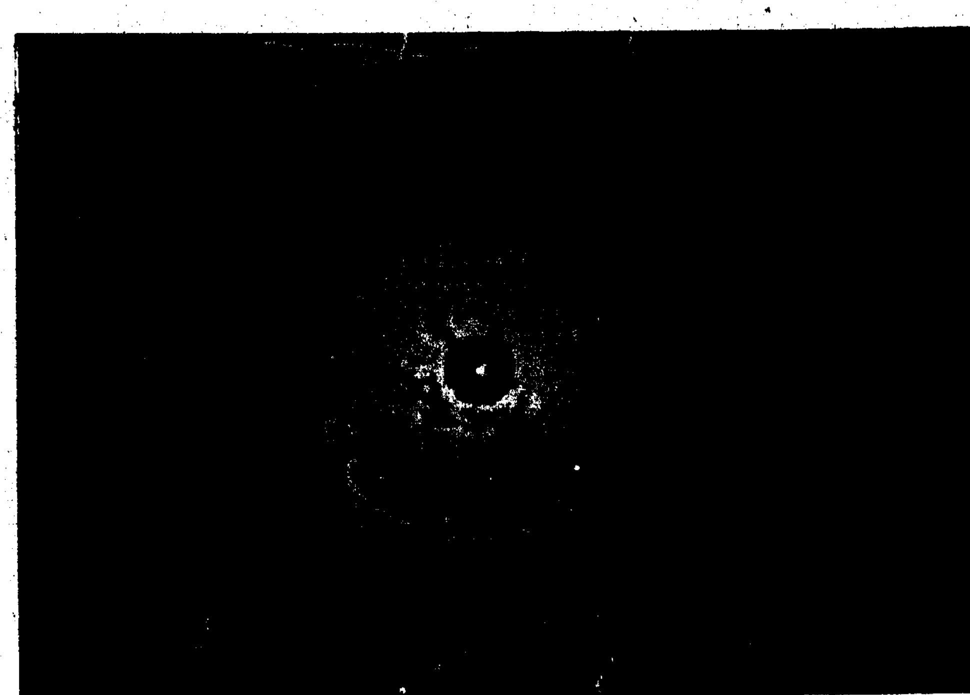


Figure 1.12 PPI radar scan on July 17, 1986, 1343Z at elevation 3°.

Table 1.3 DVIP Precipitation Rate (mm/hr) Level.

DVIP Level	Summer	Winter
1	<2.0	<1.0
2	2.0-4.9	1.0-2.4
3	5.0-13.9	2.5-6.9
4	14.0-39.9	7.0-19.9
5	40.0-99.9	20.0-49.9
6	≥100.0	≥50.0

1.3.3 Radar Wavelengths

It is common practice in radar meteorology to describe a radar in terms of its wavelength rather than its frequency.

The wavelengths used in most radar systems fall within the microwave portion of the electromagnetic spectrum, which extends from less than one cm to 23 cm or about 30 to 1.3 GHz[4] in frequency. Radar bands, range of wavelengths (λ), and frequencies (f) are listed in Table 1.4.

The factors governing the choice of wavelength to be used in a particular radar set are many. They include considerations of sensitivity resolution requirements, the nature of the targets to be studied, and the effects of the intervening atmosphere on the echo.

[4] 1 GHz is one billion Hertz, or 10^9 Hz.

Table 1.4 Radar bands, wavelengths, most popular wavelengths and their primary uses.

Band	λ (cm)	Most popular λ (cm)	f (GHz)	Primary Use
L	15.00-30.00	23.00	1.3	Air Trafic Control.
S	7.50-15.00	10.00	3	Weather Surveillance. Terminal Air Traffic Control.
C	3.75-7.50	5.00	6	Weather Surveillance.
X	2.40-3.75	3.00	10	Weather Surveillance - Ships.
K_u	1.67-2.40	2.00	15	Weather Avoidance.
K	1.13-1.67	1.00	30	Small Aircraft.
K_a	0.75-1.13	0.86	35	Cloud Detection Research.

1.3.4 Beam Width

The antenna beam pattern shown in Figure 1.13, consists of a "Main Lobe" along the beam axis[5], and a number of smaller lobes, called "Side Lobes". The smaller lobe in direction nearly opposite to the beam axis are often referred to as "Back Lobe". The angular width of the main lobe is called the beamwidth. It is usually defined as the angle between two directions (in the principal plane) where the antenna gain function is one-half or 3dB less than its maximum value.

The resolution capacity of a radar system is related to the concentration of the transmitted power by the antenna into a narrow beam. The maximum concentration of energy (Pmax) occurs along the beam axis. As one moves perpendicularly away from the axis, the energy level becomes less until a point is reached where energy level is one-half that measured at the axis, called a half power point ($\frac{Pmax}{2}$).

[5]The direction of the maximum gain is called the beam axis.

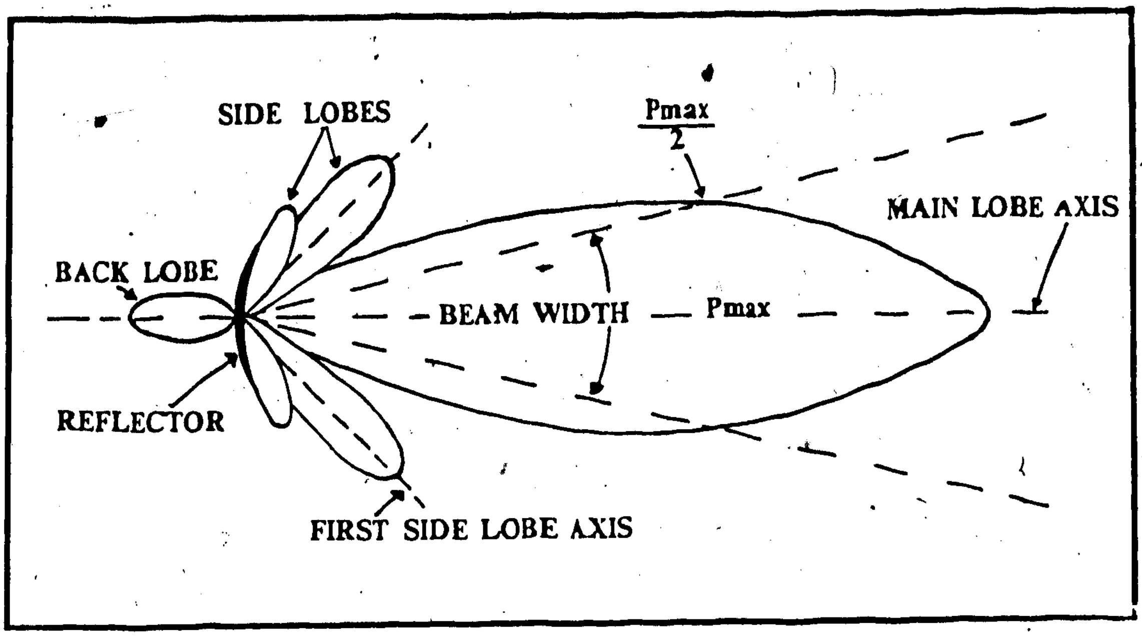


Figure 1.13 The Antenna Beam Width Pattern of a Radar System.

1.3.5 Characteristics of The CWSR-81 Radar System

The Table 1.5 below gives some characteristics of the CWRS-81 radar system

Table 1.5 Characteristics of The CWSR-81 system.

Transmitter	Wavelength	5.3 cm
	Frequency	5600 Mhz
	Peak Power	250 KW
	Pulse length	2.0 μsec
	Pulse repetition frequency	250 pps
Receiver	Sensitivity	-106 dBm
	Dynamic range	80 dB
	Sensitivity Time Control law	r^2
	Sensitivity Time Control range	230 km
Antenna	Type	Paraboloid
	Diameter	3.7 m
	Gain	43 dB
	Beam width at 3 dB	1.1°
	Rotation	0-3-6 RPM
	Elevation range	-2° to 60°

1.4 Conventional Surface and Upper-air Weather Maps

The weather maps used in this study are surface and upper-air maps. Both types are Polar Stereographic Secant Projection maps, true at 60° North.

The map factor is defined as the ratio of image distance on the secant plane which cuts the globe at 60° North, and actual earth distance. It is calculated by the following formula:

$$\sigma = \frac{1 + \text{Sin } 60°}{1 + \text{Sin } \Phi}$$

where Φ is the latitude at a given point.

The reduction scale of map or map scale is defined as the ratio of the distance on the map at standard latitude 60° N to the corresponding distance on the Earth.

The charts are issued by the Canadian Meteorological Centre (CMC), and received at the University of Alberta on a facsimile recorder. The scale of the surface chart is 1:10,000,000 and that of the upper-air charts is 1:20,000,000. The charts received include the surface, 850-mb, 700-mb, 500-mb and 250-mb charts. The Alberta Weather Centre also issues surface charts for the province of Alberta area at six-hour intervals.

2. SELECTING AND ANALYSING DATA

2.1 Introduction

Figure 2.1 shows the three Prairie Provinces and British Columbia, and the area normally covered by two consecutive satellite passes of NOAA-9, which are being recorded and processed on a regular, daily basis each afternoon by the University of Alberta Satellite Laboratory.

2.2 Source and treatment of Data

The analysis of data was carried out in the following order: Synoptic data are studied first, next the Satellite data and then Radar video data where available. Finally the three sources of data are integrated and examined in relation to each other.

To define the geographical area on facsimile maps produced by the University of Alberta Satellite Laboratory, Reinelt et al. (1975) calculate latitude and longitude intersections from known satellite orbital parameters. These intersections can be transferred directly to satellite images in the form of fiducial marks, as shown in Figure 3.6. The equations used for this calculation can be found in the Subroutine ITERA of program SCANNING (Appendix C). Townsites, landmarks, and other geographic features can be located by the same method.

2.2.1 Synoptic Data

a. The surface synoptic charts compiled at 6-hour intervals from data collected at 0000Z, 0600Z, 1200Z and 1800Z were obtained from the Alberta Weather Centre.

b. The 1200Z 850-mb and 700-mb maps prepared by the Canadian Meteorological Centre (CMC) were used to examine the patterns of warm and cold air advection, vertical motion and fronts in the lower and middle-levels of the atmosphere.

c. The 500-mb maps at 12-hour intervals from CMC, contoured with isopleths of height and absolute vorticity, were used as mid-level indicators of the contribution by vorticity advection to the vertical motion field.

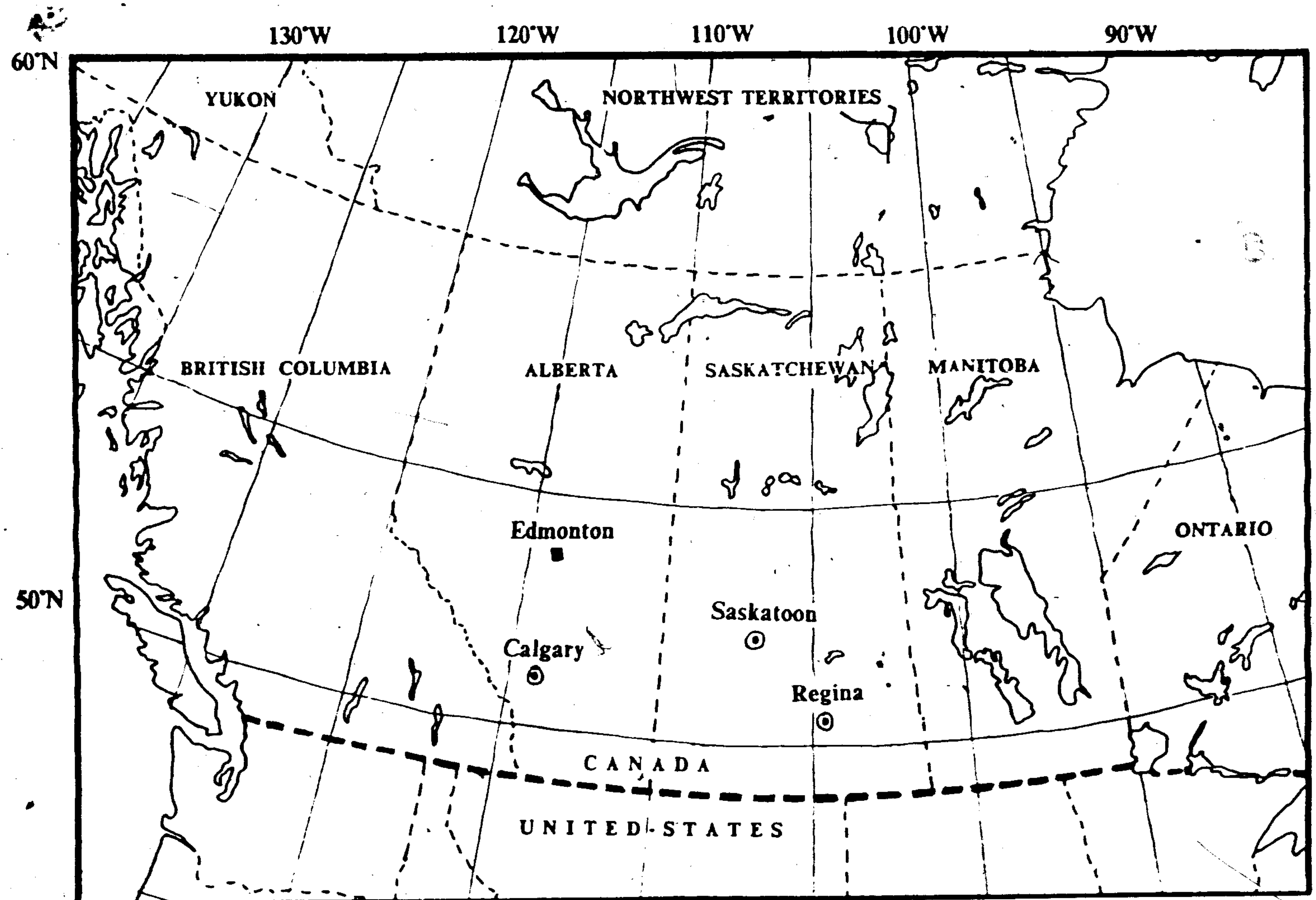


Figure 2.1 The area of study of the spring snow storm of May, and the heavy summer rainfall of July, 1986.

2.2.2 Storm tracks

For each of the two cases studied, the tracks and 12-hourly positions of the 500-mb lows and upper troughs were plotted at 00Z and 12Z. Similiar charts were prepared for the location and tracks of the surface lows.

On 500-mb charts, as shown in Figure 2.2, the symbol ⊗ indicates a low with at least one closed height contour, or a major trough with the symbol positioned approximately at the centre of the vorticity maximum.

On the surface chart, as shown in Figure 2.3, the centre of a low is also indicated by the symbol ⊗.

2.2.3 Satellite Data

The University of Alberta Satellite Laboratory records two NOAA-9 passes every afternoon. Data used in this study were recorded in May and July of 1986.

The following four steps are necessary to process the satellite data:

a. By counting the number of tick marks in the margin of a facsimile map (left side for VIS map, right side for IR map), the number of scans are determined by one tick mark equal to 10 scans

b. Since the orbital parameters are known, the number of scans to be skipped and the number of scans to be selected for analysis can be determined. The program READTAPE is then run in order to produce the telemetry data for the Infrared as well as the Visible band.

An example of one processed scan of data is shown in Figure 1.5 of Chapter 1.

c. The program SCANNING is then run in order to smooth, calibrate and convert the digital counts of the infrared data to cloud-top temperature. The program also converts the visible band data to equivalent brightness.

Programs READTAPE and SCANNING are modified version of programs used by Wieler (1981).

The calibration wedge levels, means and standard deviations, the latitude and longitude lines, the location of townsites are calculated by this program.

Examples of the program output are given in Appendix D.

d. The latitude-longitude data, the coordinates of townsites, on either infrared or visible data are used as input of program PL.FIELD.CL to produce either a cloud-top temperature (i.e. isotherm) map (Fig. 3.26) or a map of reflectivity isopleths (Fig. 3.27). It will be noted that latitude and longitude lines are not straight because the linearization (see Table 2.2) introduces jumps in the map scale. Lines are straight within each linearization region, but a discontinuity occurs at the regional boundaries.

2.2.4 Precipitation

Precipitation measurements are made and recorded at several different times of the day, depending on the requirements of the agency collecting the data. For climatological purposes, daily precipitation is measured in 24-hour periods. For AES stations in Alberta, the period in summer is from midnight to midnight Mountain Daylight Saving Time (MDT).

In the Calgary storm, most of East Central Alberta area received only rain, but the higher ground to the west received snow, as did many southern districts (Fig. 2.5). The precipitation pattern does show a topographic influence, especially in the area northwest of Calgary. Table 2.1 lists the stations with 40 millimetres of precipitation (with water equivalent for snow) or more over 48 hours on May 13 and 14, 1986. The maximum amount of precipitation (81.8 mm) shown on this table was recorded at Blindman station, located near the headwaters of the Blindman River northwest of Rimbey.

In the July rain storm, Table 2.2 shows that the 24-hour maximum precipitation was recorded at Carrot Creek (104.5 mm) which was the greatest amount reported in 42 years. Figure 2.6 shows the isohyets of 24-hour precipitation for the July storm.

Two examples of radar scans of heavy precipitation, both recorded on July 17th, are shown in Figures 2.7 and 2.8.

Table 2.1 Stations with 40 mm of precipitation (water equivalent) or more over 48 hours, May 13 and 14, 1986. (After Paruk, 1986)

Station	Amount (mm)
Big Valley	46.4
Blindman	81.8
Brightview	53.2
Cameron Falls	48.0
Camrose	51.2
Camrose 2	54.1
Cooking Lake Airport	50.6
Dakota West	67.0
Edmonton International Airport	40.8
Evan Thomas Creek	46.1
Fallentimber	51.8
Gwynn	69.4
Hailstone Butte Lookout	40.5
Huxley	60.8
James River Headwaters	45.4
Ksituan	50.0
Lacombe CDA	54.4
Lavoy	45.4
Madden	44.1
Markerville	57.6
Medicine Lodge	44.2
Mirror	58.4
Mossleigh	45.0
Ponoka South	62.1
Red Deer Airport	42.9
Rimbey	62.6
Scalp Creek	78.7
Stettler North	63.0
Strathmore East	52.7
Sundre Garrington	45.9
Sundre South	43.7
Sylvan Lake	71.4
Three Hills South	50.5
Trochu Equity	49.0
Trochu Town	49.6
Vulcan	53.4
Warwick	44.0
Wetaskiwin South	61.6

Table 2.2 24-hour precipitation amounts for July 17, 1986 and comparable 24-hour long-term precipitation records. (After Paruk, 1987)

Station	24-hour Record Rainfall(mm)	Actual 24-hour Rainfall (mm)	Years of Record
Banff	53.1	4.2	91
Brazeau	80.8	42.0	43
Carrot Creek	73.4	104.5	42
Clearwater	95.8	66.0	28
Edson (Airport)	68.6	37.6	63
Jasper	86.6	18.4	53
Lovett	94.2	63.0	41
Mayberne	79.8	61.1	39
Obed	67.8	43.6	26
Red Deer	85.3	16.4	47
Rocky Mountain House	76.7	72.0	37
Whitecourt	90.6	72.0	43

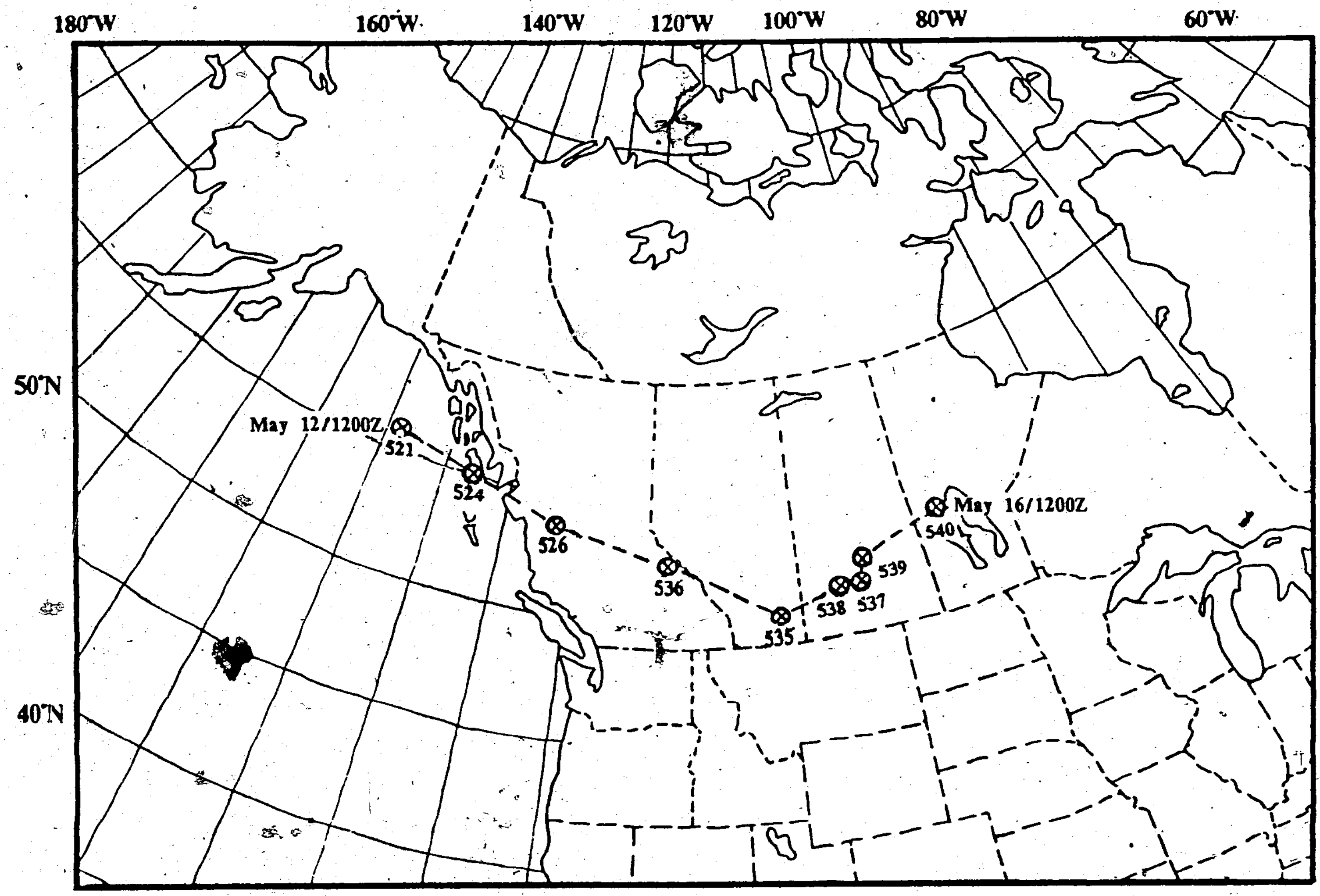


Figure 2.2 12-hour interval track positions of the 500-mb low of the spring storm, from 1200Z May 12 to 1200Z May 16, 1986. The numbers indicate the contour height of the low centre in decametres (dam).

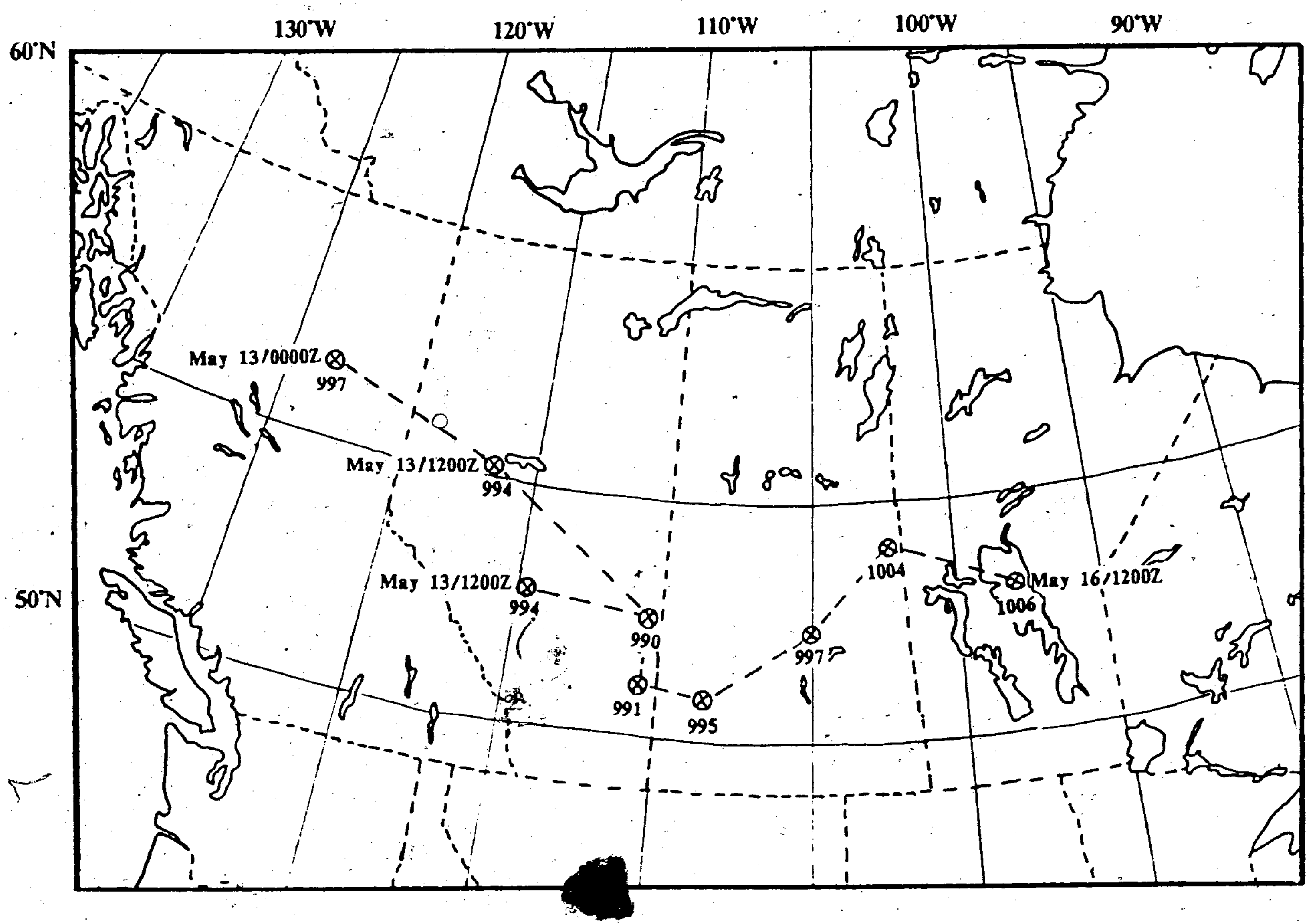


Figure 2.3 The track of the Surface low of the spring storm from 0000Z May 13 to 1200Z May 16, 1986. The 12-hourly positions of the low are marked with the central pressure in mb.

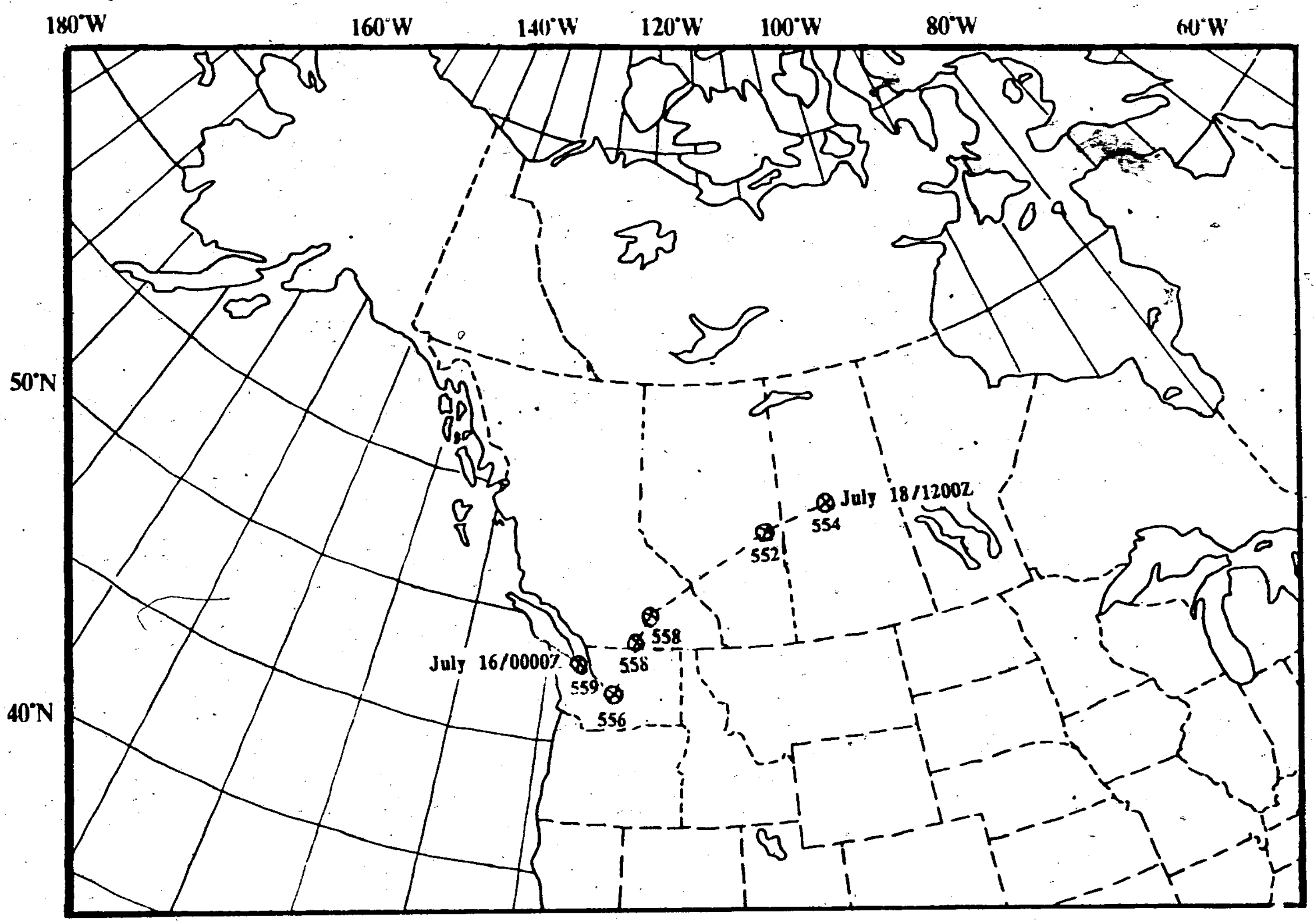


Figure 2.4 12-hour interval track positions of the 500-mb low of the July rain storm, from 1200Z July 16 to 1200Z July 18, 1986. The numbers indicate the contour height of the low centre in decametres (dam).

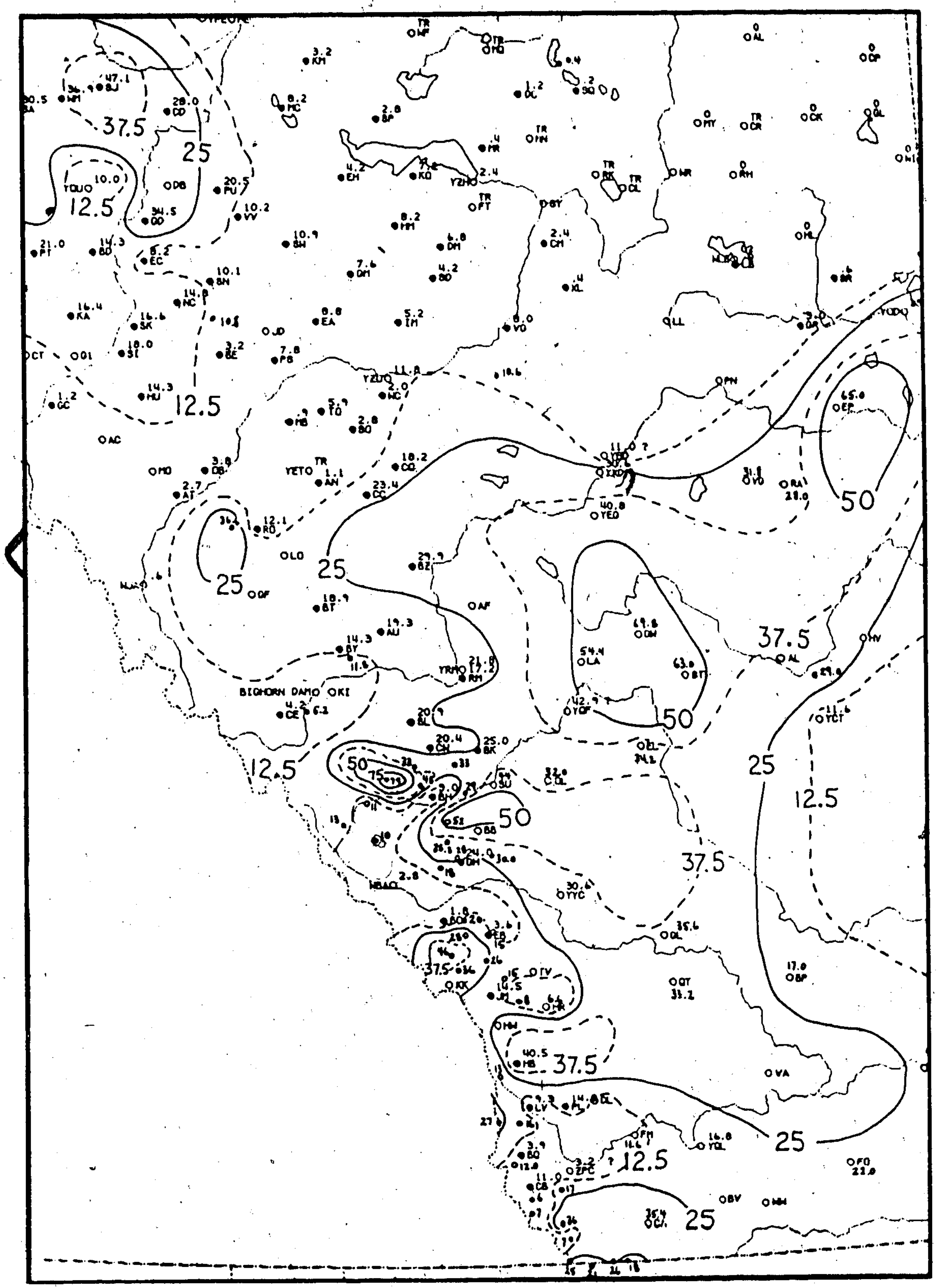


Figure 2.5 48-hour precipitation totals of the May, 1986, snow storm (from 13/1800Z to 15/1800Z). The isohyets are labelled in mm. (After A.E.S. Edmonton precipitation analysis)

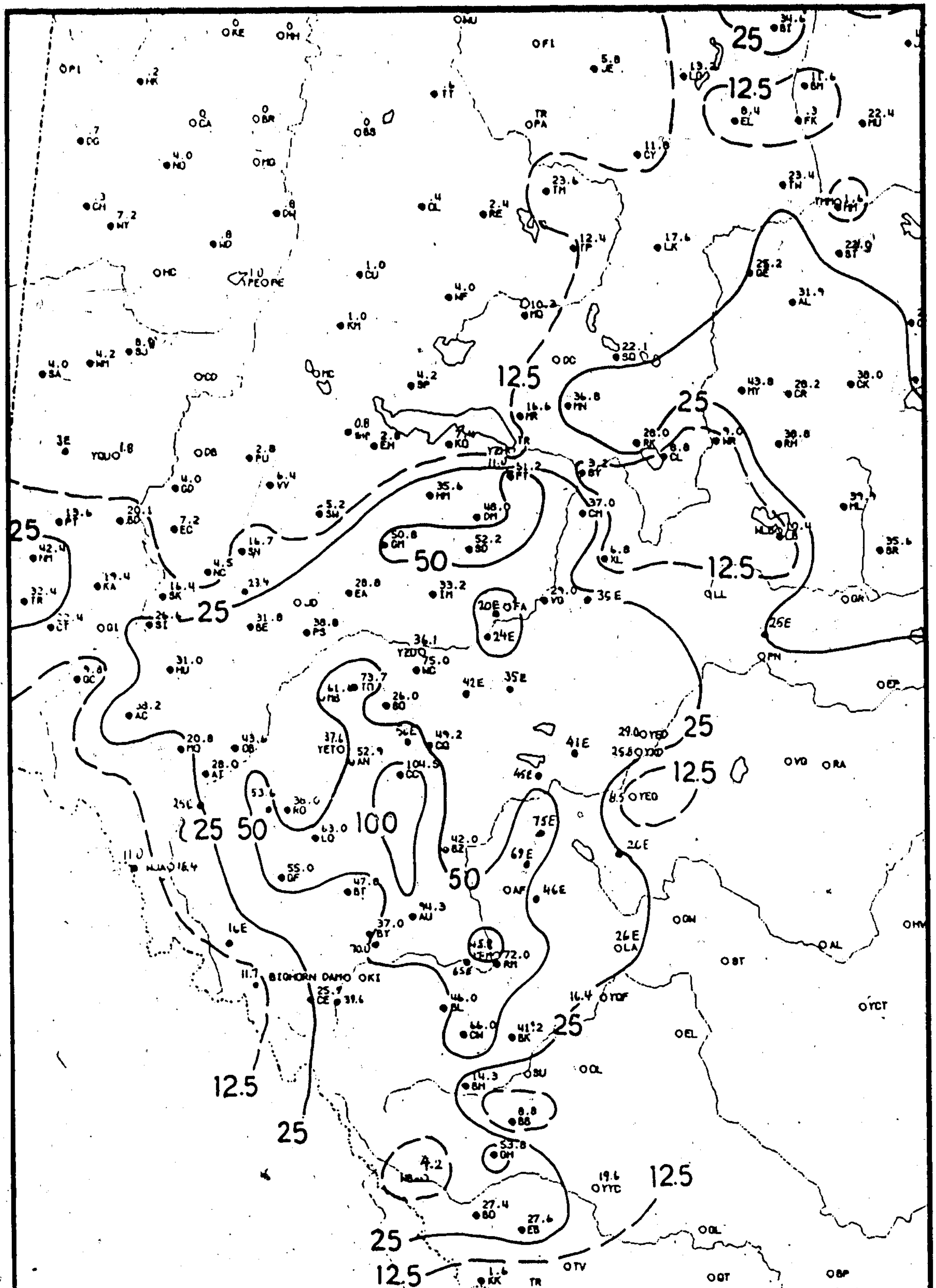


Figure 2.6 24-hour precipitation totals of the July, 1986, rain storm (from 17/1800Z to 18/1800Z). The isohyets are labelled in mm. (After A.E.S. Edmonton precipitation analysis)

Figure 2.7 Radar scan of heavy precipitation south and west of the Carvel site, July 17, 1986 at 1240Z (06:40 MDT).

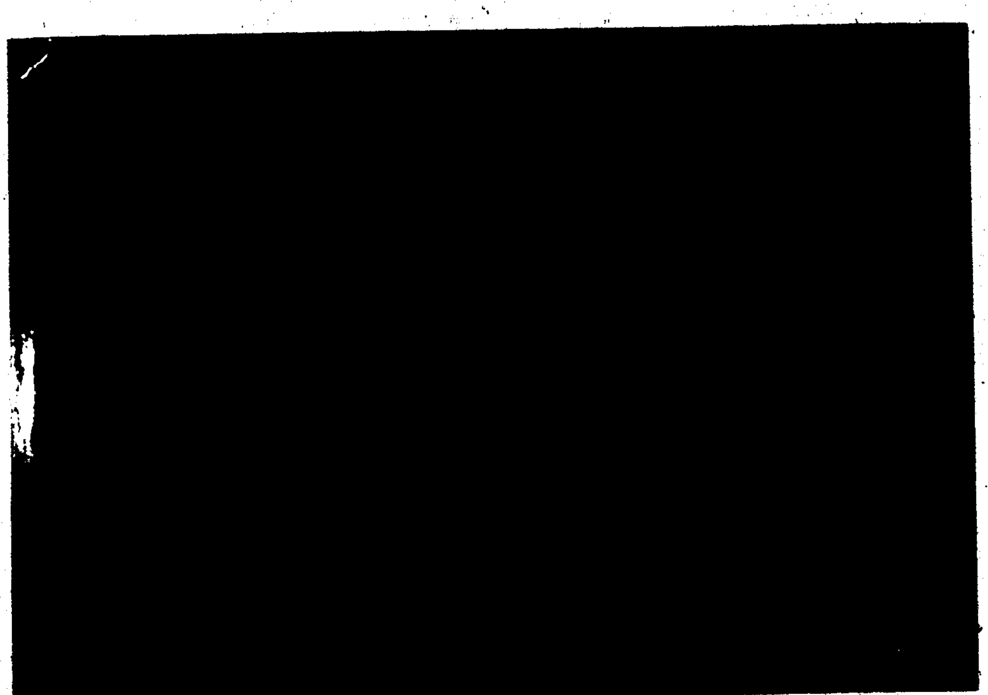


Figure 2.8 Detail of radar scan of bands of heavy precipitation NW and SE of the site, July 17, 1986 at 1938Z (13:38 MDT).

3. CASE STUDY ~~#1:~~ THE SPRING SNOW STORM OF MAY, 1986

3.1 Introduction

The purpose of this case study is to examine cloud patterns on satellite images and correlate them with synoptic features such as lows, troughs and trowals as well as with the distribution of precipitation, vorticity and vertical velocity. A tape of radar data from this storm was unfortunately erased before it could be obtained for this study.

3.2 Synoptic Description

3.2.1 May 13, 1986

Figure 3.1 (May 12, 1986 1200Z) shows the cold low centre at 521 decametres (dam) over the Gulf of Alaska. By May 13, 0000Z, 12 hours later, the low centre has filled to 524 dam and moved southeastward toward the coast of British Columbia (B.C.), just north of the Queen Charlottes, at about 17 knots (Fig. 3.2).

Twelve hours later (1200Z May 13), the 500-mb cold low had filled to 526 dam (Fig. 3.3) and moved southeastward into Central B.C. at about 20 knots, while the vorticity centre decelerated to a mean speed of about 17 knots.

Vigorous positive vorticity advection is occuring over southern B.C. and in the Lee of the Alberta Rockies.

The 500-mb vorticity advection field can be estimated from the area of quadrilaterals and parallelograms formed by the intersecting height contours and vorticity isopleths. The smaller and more numerous the parallelograms, the stronger the vorticity advection is likely to be.

As the cold, unstable maritime air masses moved into central B.C. later in the day, a new surface low centre of 995 mb developed over northern B.C. (not shown here) and began moving southeastward at about 15 knots. Figure 3.4 shows that the low subsequently filled to 997 mb, while a broad, deepening trough spread across most of Alberta, a forerunner of impending Lee Cyclogenesis.

By 1200Z May 13, the low had deepened to 994 mb and moved from Central B.C. to Lesser Slave Lake and the Peace region, as seen in Figure 3.5. Simultaneously, a second low (994 mb) developed rapidly between Whitecourt and Red Deer. Both of these systems moved southeastward at about 20 knots to the Coronation region by late in the day, where they amalgamated into a single active low (Fig. 3.9).

Figures 3.6 and 3.7 are the infrared and visible images, respectively, of orbit 7299 at 2047-2102Z on May 13, 1986.

In Figure 3.6 the Cumulonimbus (Cb) and Towering Cumulus (TCu) clouds have a bright, white tone in area A. The cloud tops in area C are not high as those of the Cb at A, but the embedded convective cells are producing scattered showers in the Coronation district.

In the visible image (Fig. 3.7), the cloud band consisting largely of Cb and TCu clouds in area A has very white uniform tops. Altocumulus (Ac) appears white in area B due to its high reflectivity but, being middle cloud, shows a mottled grey in the infrared images. The light grey shades joining the brighter masses of Cb, Cu and Ac at C, D, E and F suggest that thin Cirrostratus (Cs) cloud lies over the mid-level cloud. The cloud arc associated with vorticity advection at the 500-mb level has a marked cyclonic curvature (A-C-D-E-F).

The 1800Z surface chart (not reproduced here) shows overcast skies with light rain showers at Jasper (WJA) and obscured sky conditions with light snow at Banff (WBA). At Calgary (YYC), the surface pressure had dropped to 993.9 mb, broken TCu and Ac fill most of the sky, and the Radar shows Acc tops to 16,000 feet to the northwest. Numerous showers are being reported by the station in southern B.C.

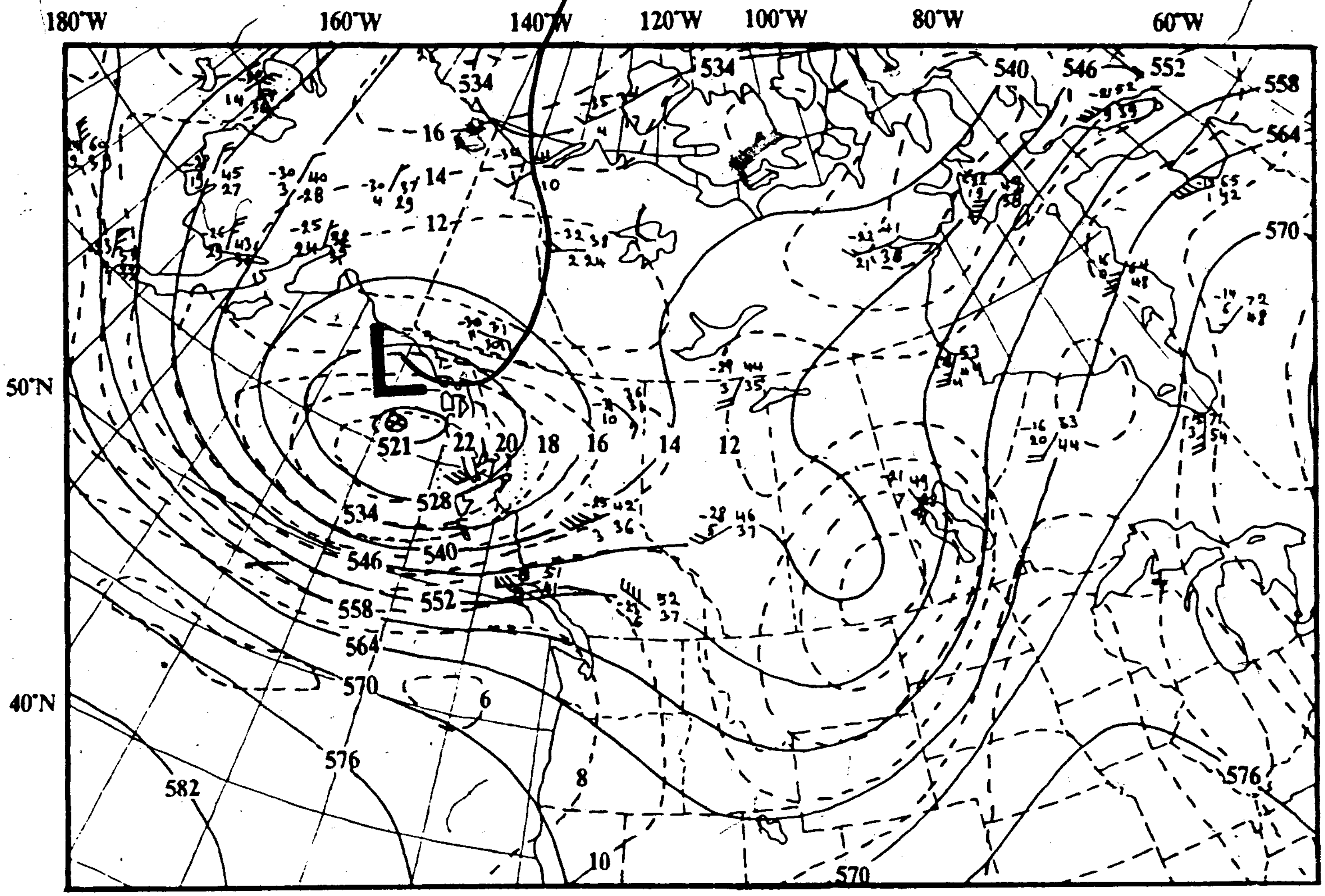


Figure 3.1 500-mb map for 1200Z May 12, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of 2×10^{-5} rad sec^{-1}.

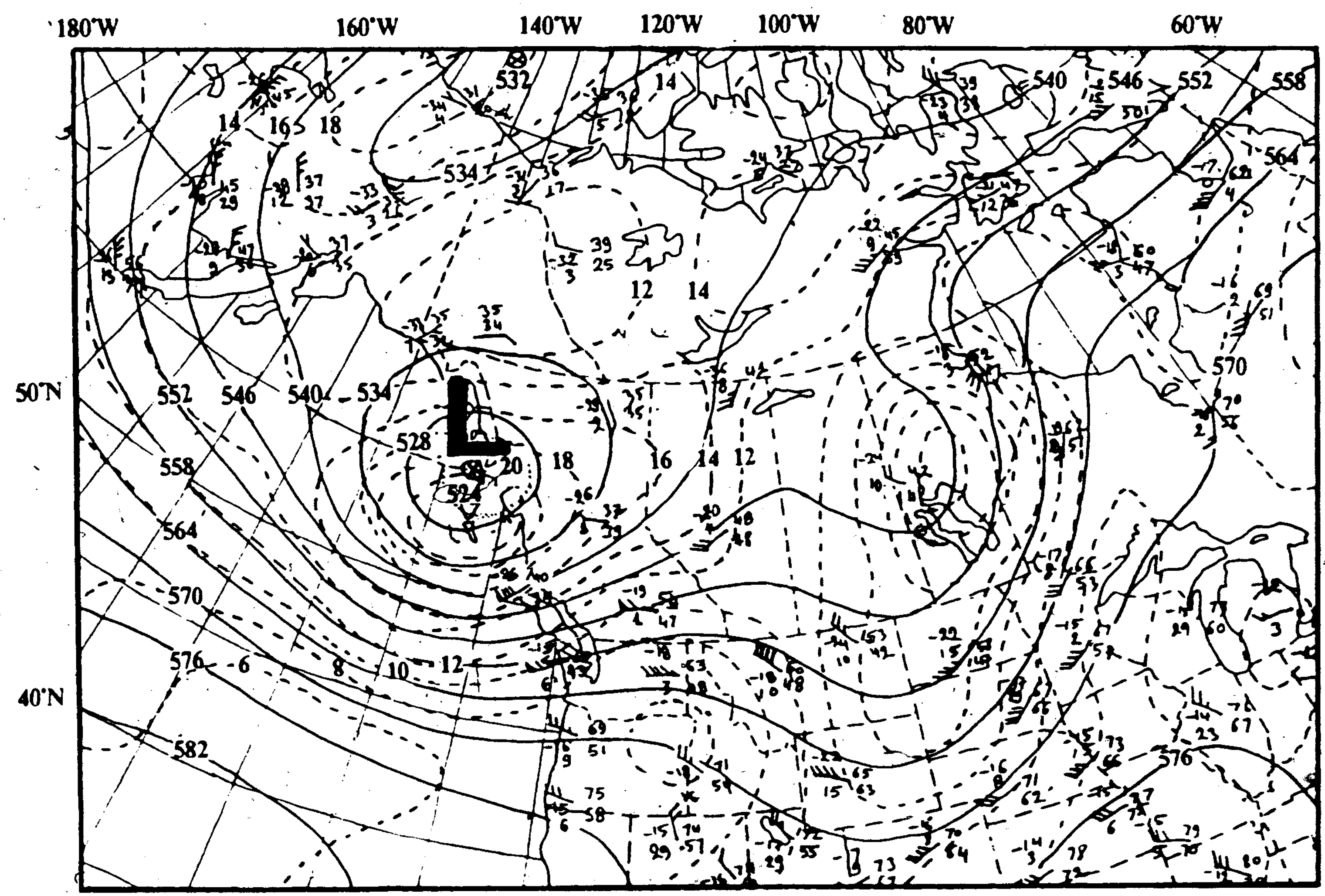


Figure 3.2 500-mb map for 0000Z May 13, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of 2×10^{-5} rad sec^{-1}.

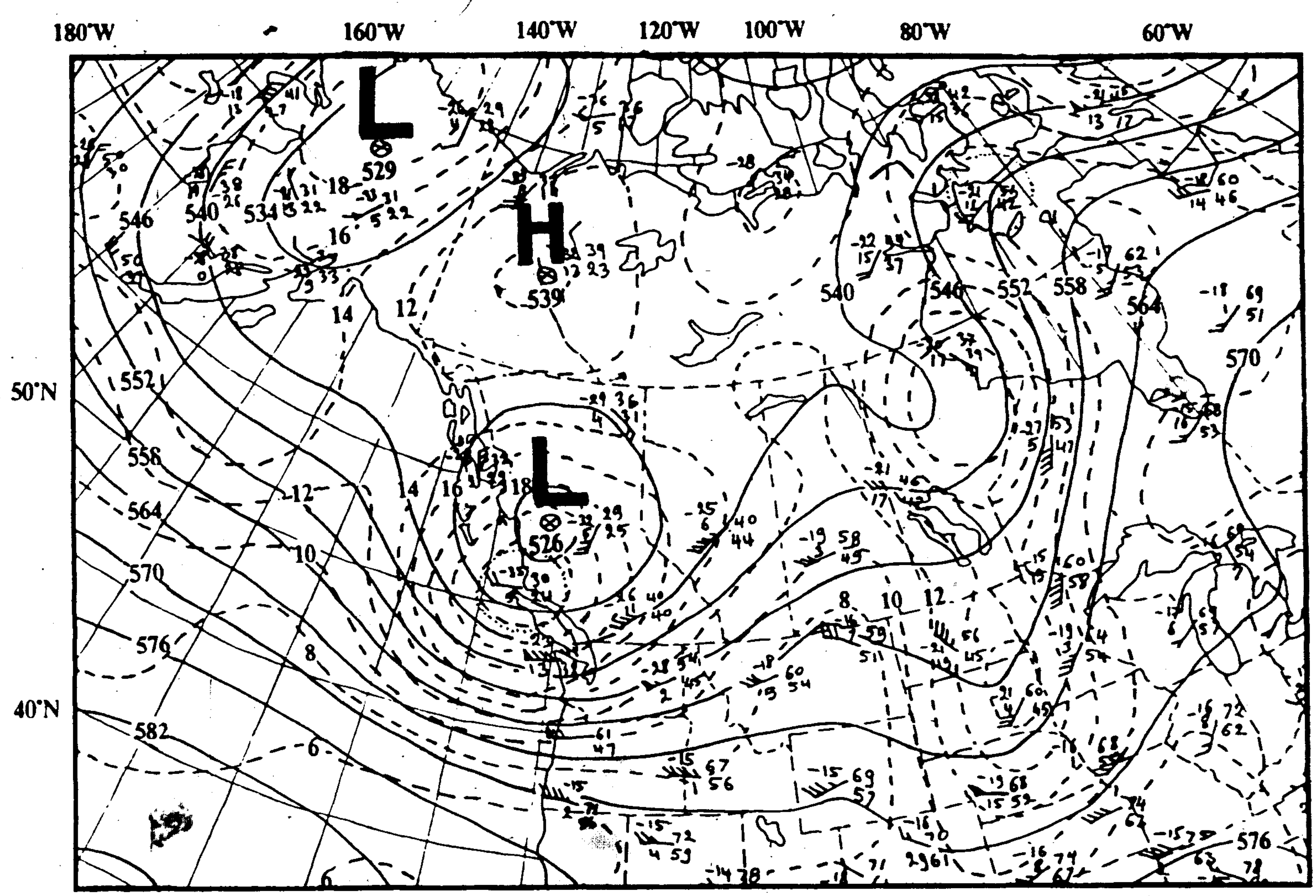


Figure 3.3 500-mb map for 1200Z May 13, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

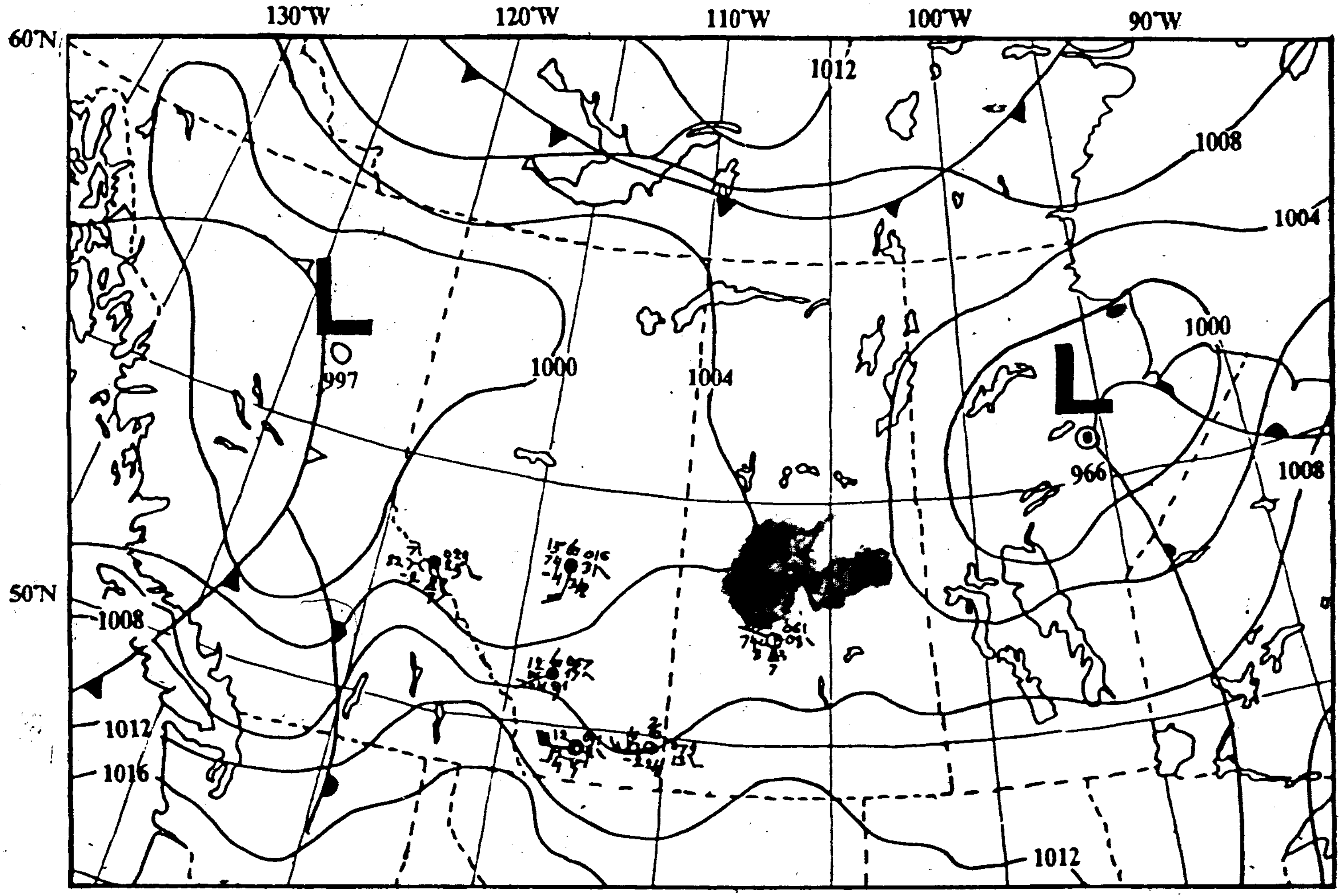


Figure 3.4 Surface Analysis map for 0000Z May 13, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

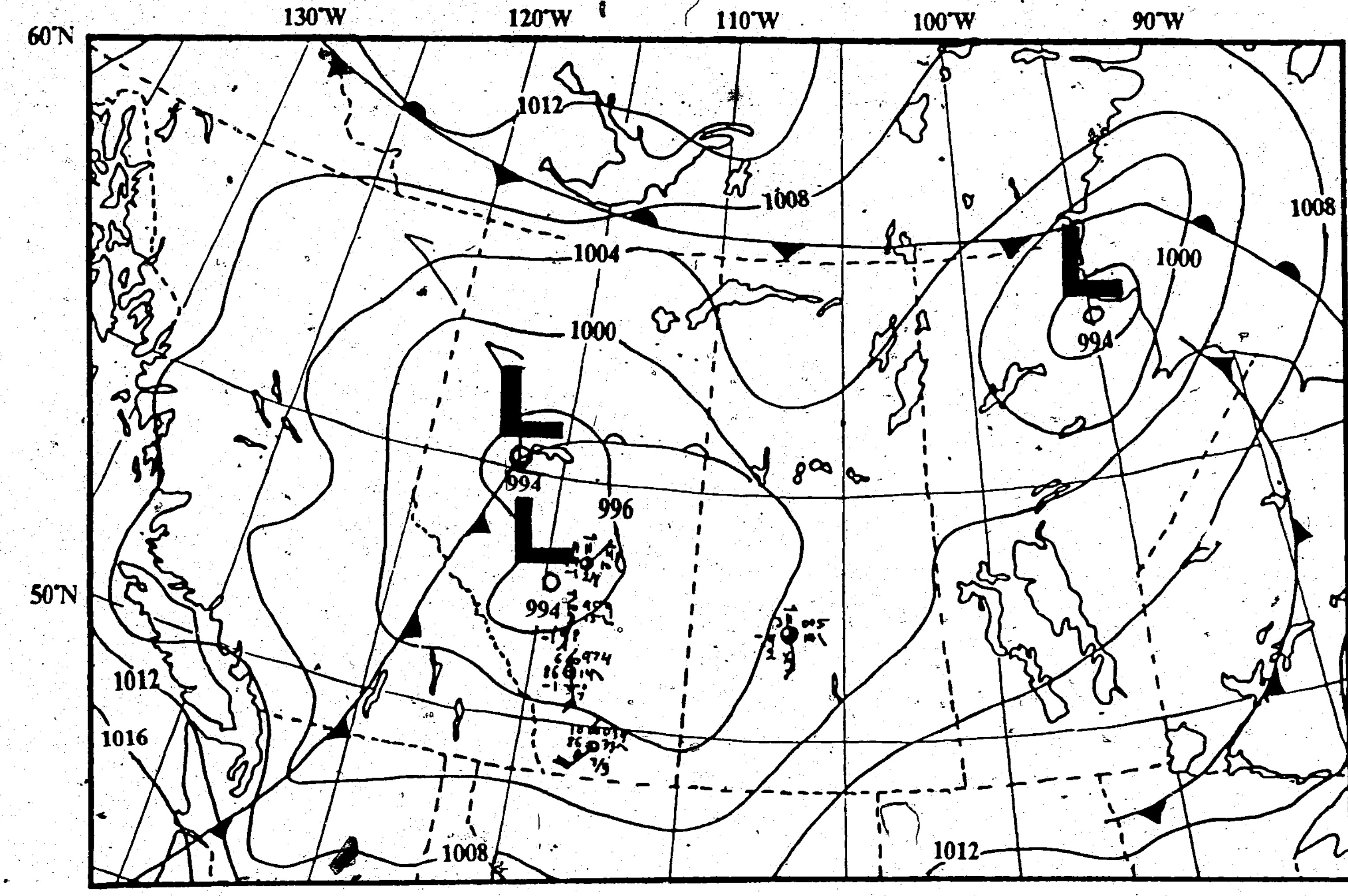


Figure 3.5 Surface Analysis map for 1200Z May 13, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

Figure 3.6 Infrared Image of May 13, 1986 at 2047-2102Z, NOAA-9 orbit 7299.

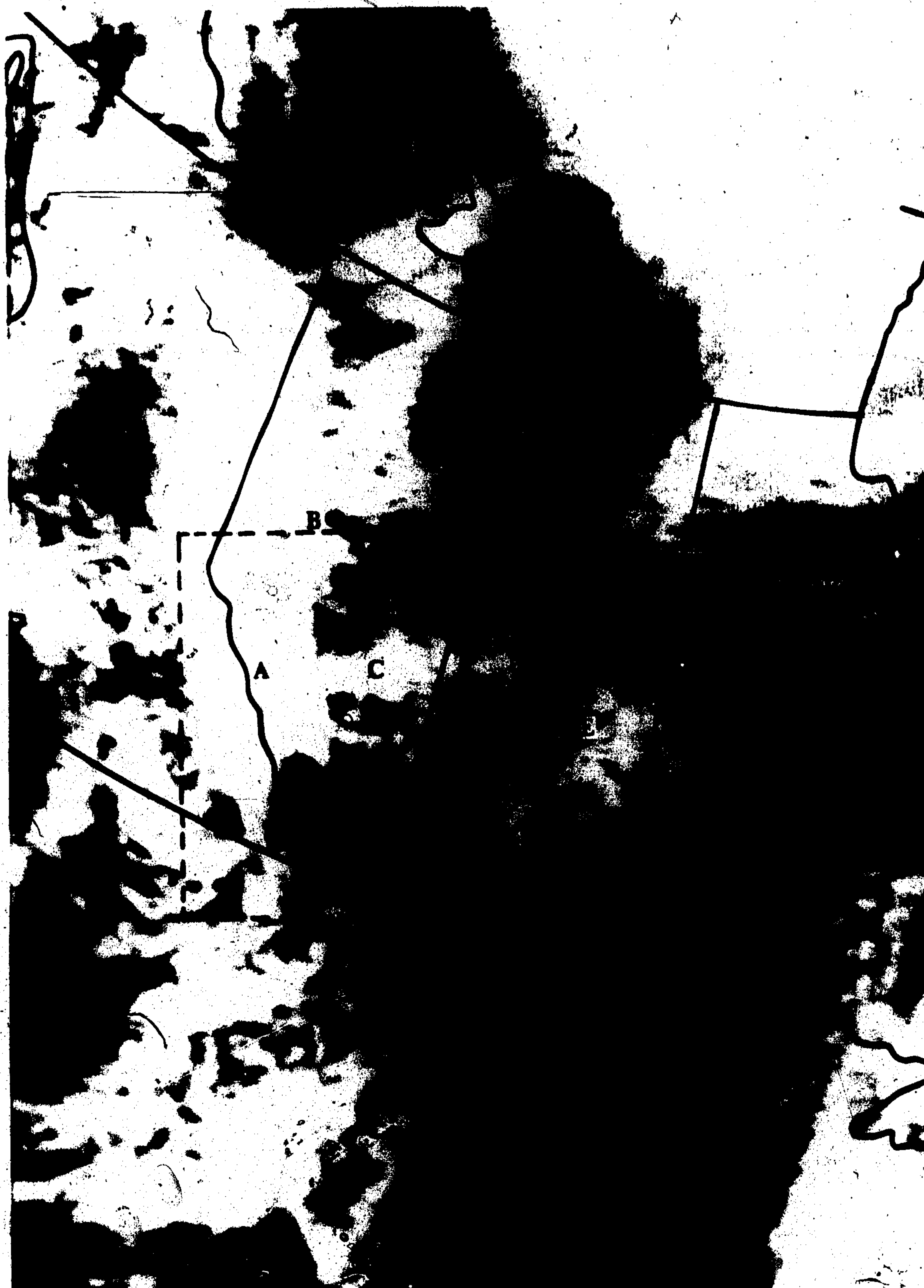


Figure 3.7 Visible Image of May 13, 1986 at 2047-2102Z, NOAA-9 orbit 7299.

3.2.2 May 14, 1986

The 500-mb chart of May 14, 0000Z (Fig. 3.8) drawn about 3 hours after the satellite image was recorded, shows the vorticity centre over southern B.C. with a strong cyclonic circulation over Washington, Idaho and Montana, and rapid cold-air advection over southern B.C. and Alberta.

Located near Jasper, the cold low has filled to 536 dam and moved southeast at about 24 knots, preceded by the vorticity maximum at about 27 knots. Since the trough is concave to the flow, southward transport of momentum results in strengthening of the westerlies at the south end of the trough, while maintaining strong diffluence to the east of the trough line.

By May 14, at 1200Z, the 500-mb low had moved into southeastern of Alberta at about 25 knots, and filled to 535 decametres over the Medicine Hat area (Fig. 3.9) while the associated vorticity centre moved southeast at 26 knots.

During this 12-hour period, 0000Z (Fig. 3.10) to 1200Z May 14, the southern surface became dominant and the resulting single vortex turned sharply southward to just North of Medicine Hat, intensifying and deepening to 990 mb, directly below the 500-mb cold low (Fig. 3.11).

The satellite images of May 14, confirm that intense lee cyclogenesis has taken place in southeastern Alberta. On the infrared image (Fig. 3.12), the well-developed cloud spiral includes several very bright convective bands, indicative of very high and cold cloud tops. The vortex centre C of the spiral, an area of mottled grey, contains lower bands of middle cloud, better resolved in the visible image (Fig. 3.13)

In this image, the section of the cloud spiral associated with the cold front has a well-defined rear edge, behind which there is a clearing zone A. The forward edge of the cloud mass is diffuse. South of area B, Cirrus (Ci) plumes trailing from the cloud spiral are clearly visible. The lines of Cu and TCu at A that curve toward the vortex centre, now an open, cellular cloud field, have developed within the cold maritime air in the region of cyclonic vorticity maximum at C. Altocumulus (Ac) and Stratocumulus (Sc) are reported in surface observation at B. In the visible image these clouds are very bright and have a wavy structure.

The centre of the cloud vortex coincides with the centre of the surface cyclone at 1800Z, 3 hours before the satellite pass (not shown here). This cloud structure is typical of well-developed, moving cyclones (pressure at the centre was 996 mb) with speeds of about 25 knots.

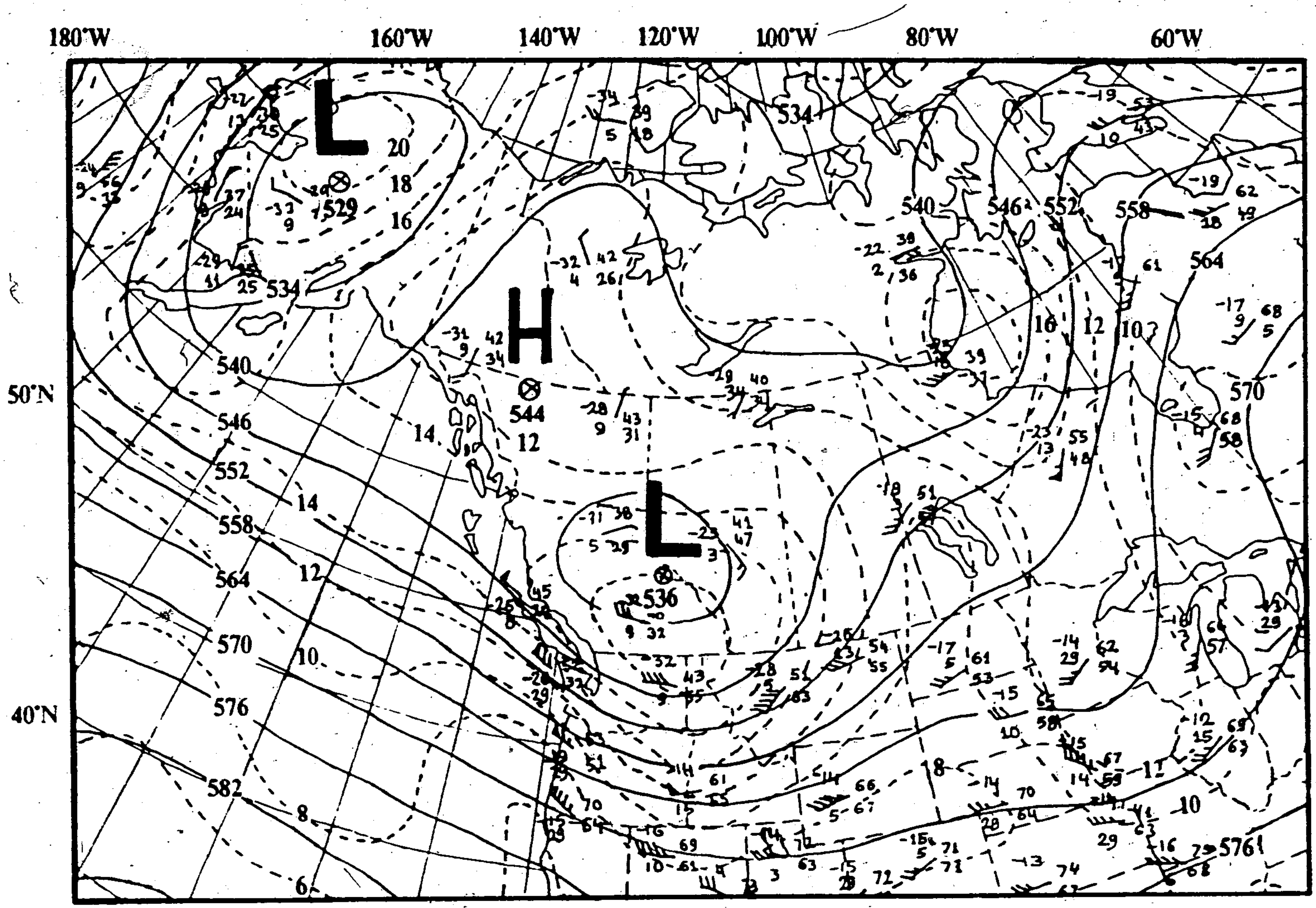


Figure 3.8 500-mb map for 0000Z May 14, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

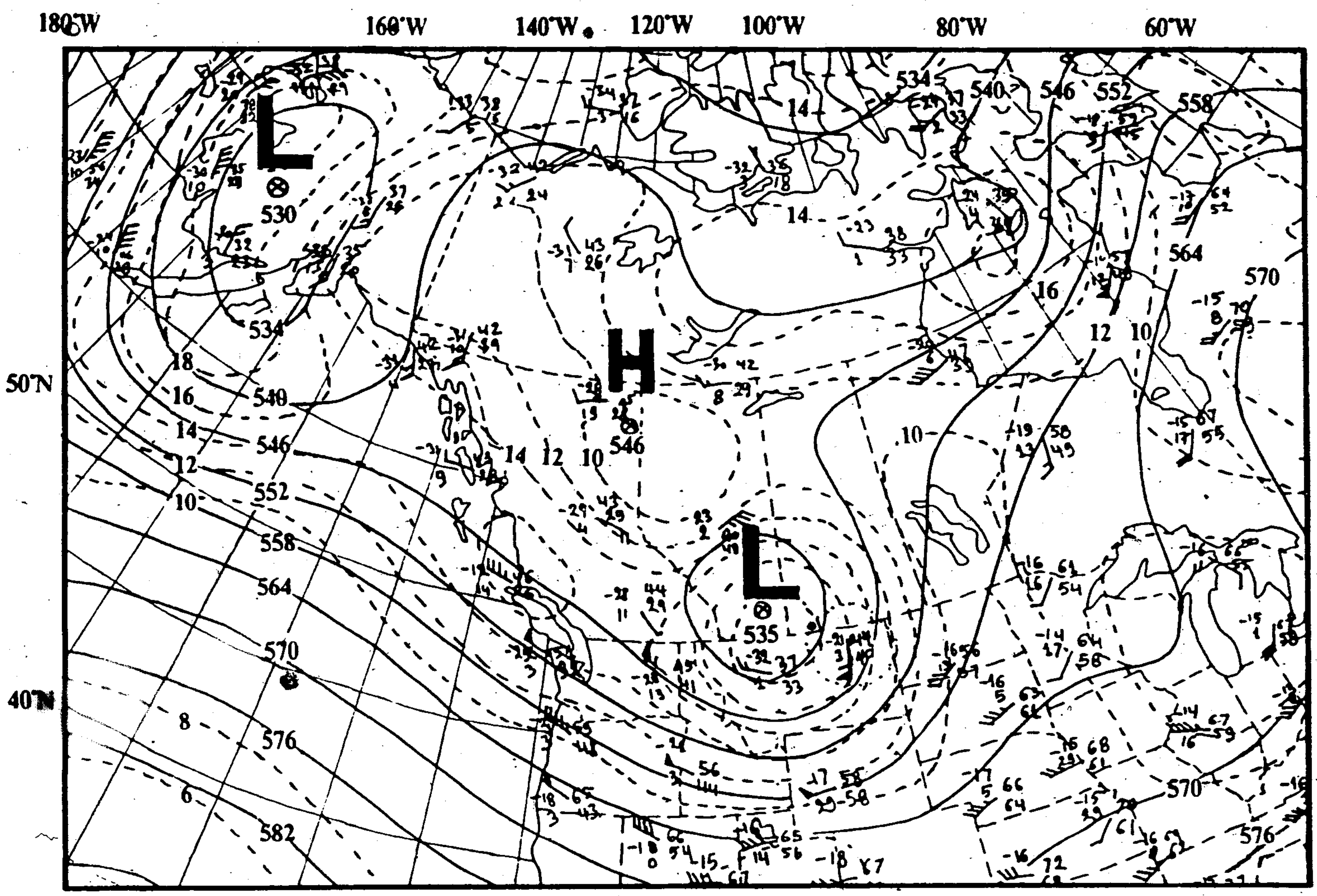


Figure 3.9 500-mb map for 1200Z May 14, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of 2×10^{-5} rad sec^{-1}.

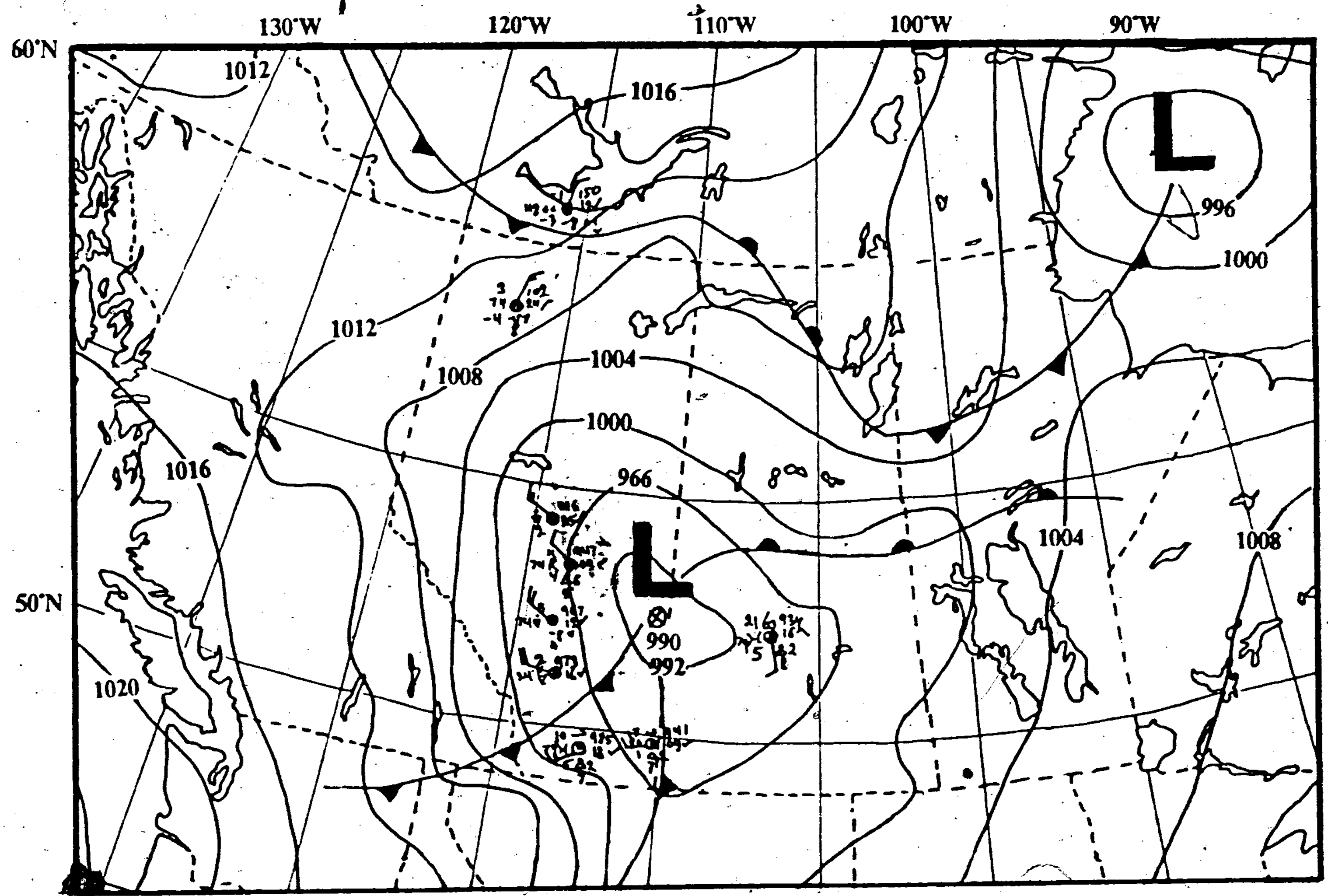


Figure 3.10 Surface Analysis map for 0000Z May 14, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

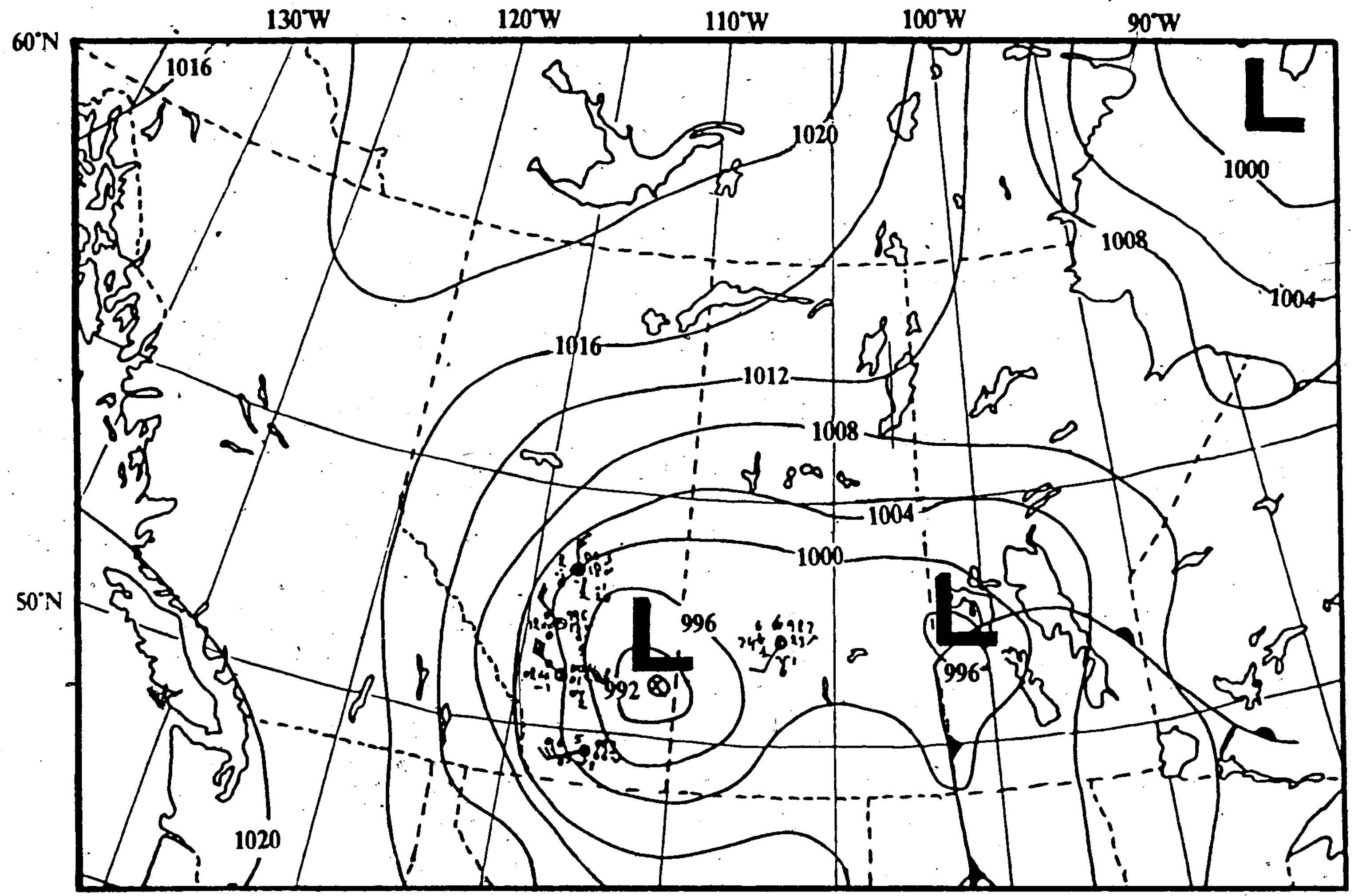


Figure 3.11 Surface Analysis map for 1200Z May 14, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

Figure 3.12 Infrared Image of May 14, 1986 at 2036-2051Z, NOAA-9 orbit 7313.

Figure 3.13 Visible Image of May 14, 1986 at 2036-2051Z, NOAA-9 orbit 7313.

3.2.3 May 15, 1986

The 500-mb map of May 15, 0000Z (about 3 hours after the satellite pass) shows the southeastward shift of the vortex centre (Fig. 3.14). The speed of the cold low has dropped to 14 knots and the speed of the vorticity centre to 17 knots. The low is now centred in southwestern Saskatchewan with a tilted trough NW-SE, and a strong southerly circulation over Manitoba.

By May 15 (1200Z), the cold trough had drifted very slowly to the east (Fig. 3.15) at about 4 knots. It continued to move toward northern Saskatchewan and had filled to 539 decametres by the afternoon of May 15.

The surface low has also moved into southern Saskatchewan at about 10 knots and had a central pressure of 995 mb by 0000Z May 15 (Fig. 3.16). During the next 12 hours it continued northeastward, filling to 997 mb by the early morning of May 15, (Fig. 3.17). The cyclone has now reached maturity and is beginning to dissipate (Figs. 3.18 and 3.19). The main cloud band of the occlusion has shifted to northern Saskatchewan and northeastern Manitoba.

Figure 3.18 shows the main branch of the spiral north-northeast of the vortex centre, now located East of Regina. The cellular cloud pattern indicates cold air advection and cyclonic flow in the lower levels behind the cold front. The larger cumuliform cloud elements (A) represent a region of upward vertical motion in advance of the vorticity centre.

The brightness from E to D in both marks a band of Cirrostratus (Cs) and Altostratus (As) with streamers of Ci over Hudson Bay. The dark grey area at F and H in the infrared (Fig. 3.18), but bright in the visible picture (Fig. 3.19), indicates broken low cloud, such as Sc. The light grey shades in the IR at C and G, but also bright in the visible, consist largely of middle cloud (As and Ac) above a deck of St and Sc.

Figure 3.18 also shows a cellular cloud pattern of Cu at B1 that is lower than the Cu and TCu cloud at B2 whose elements are both larger and brighter.

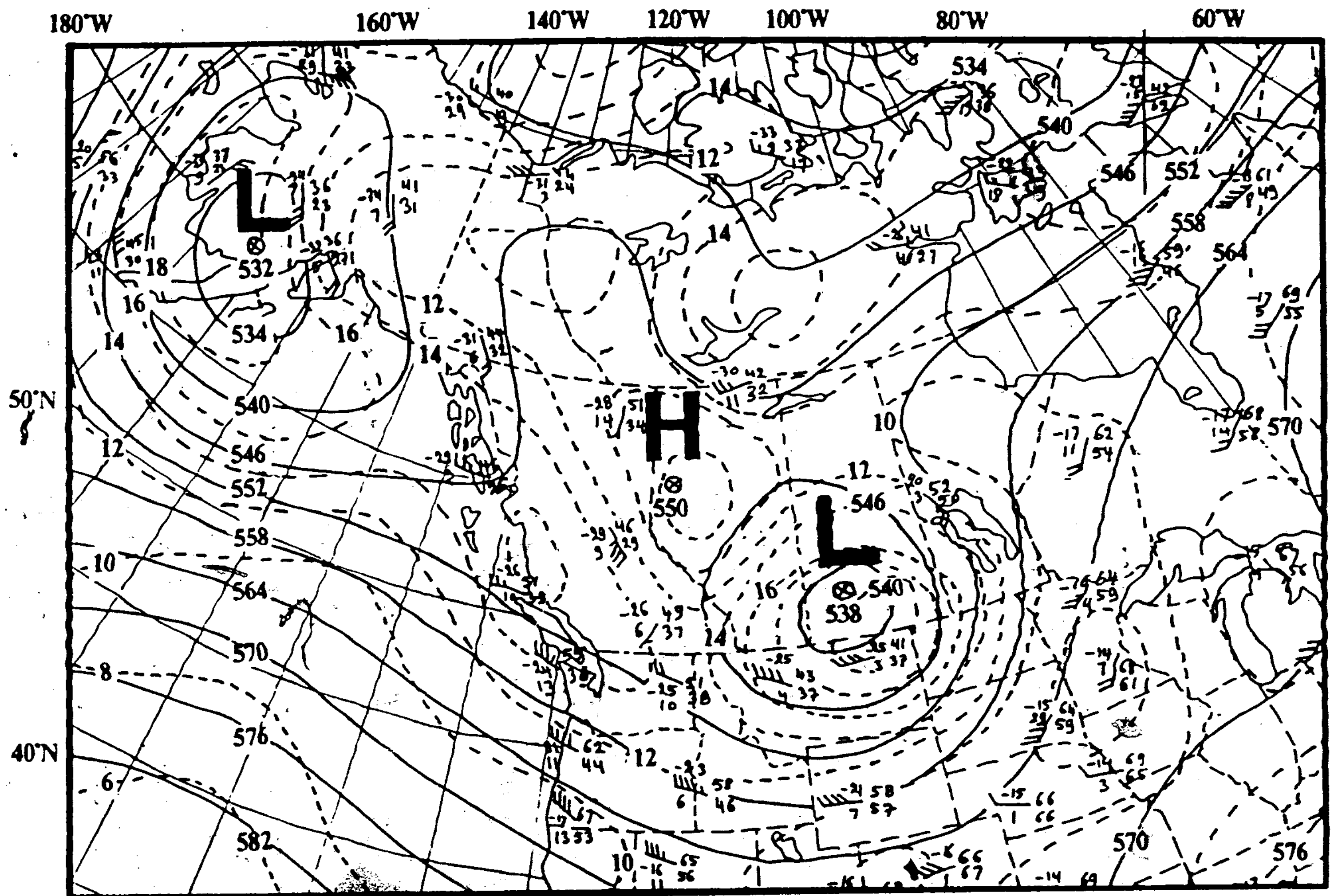


Figure 3.14. 500 mb map for 0000Z May 15, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

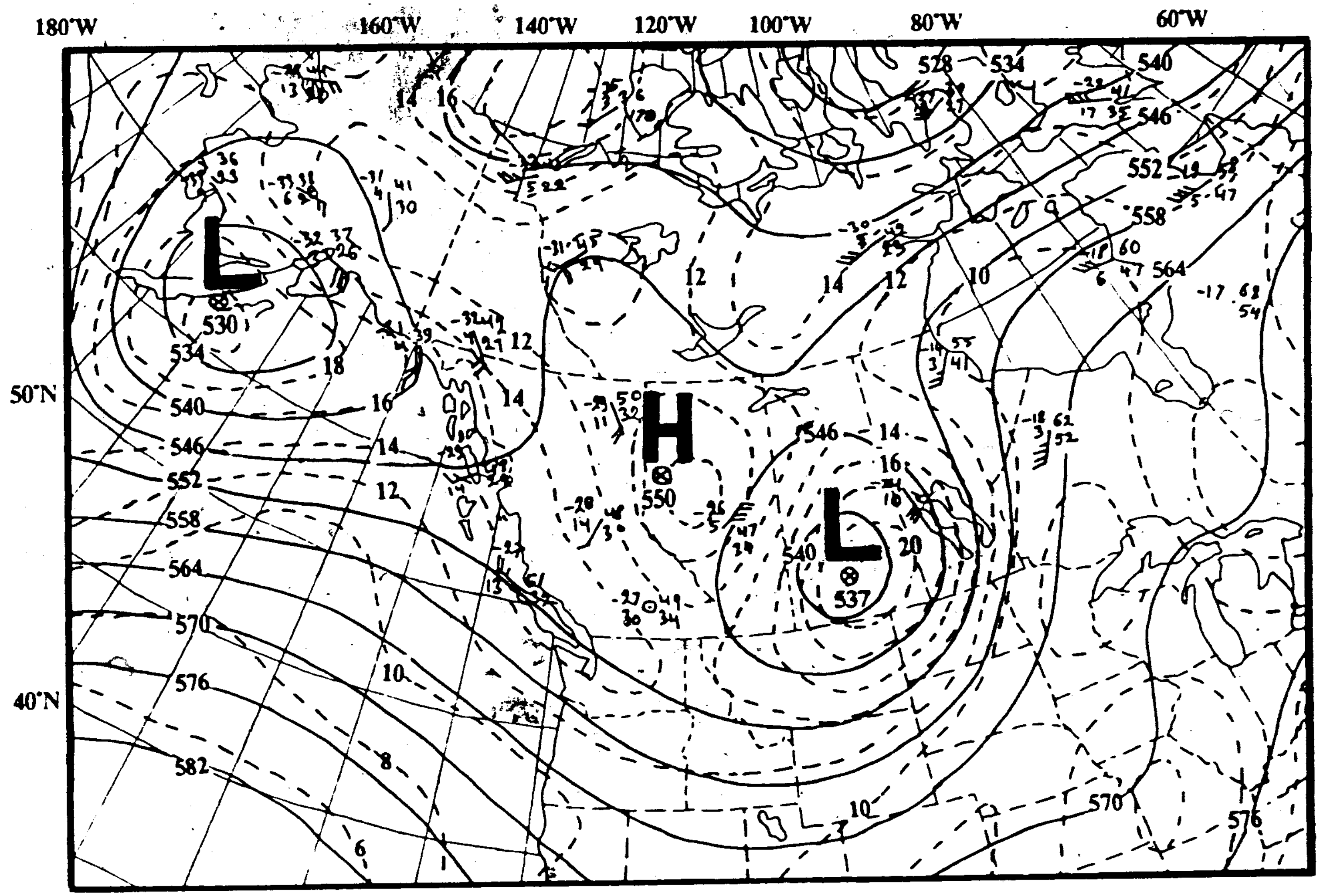


Figure 3.15 500-mb map for 1200Z May 15, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

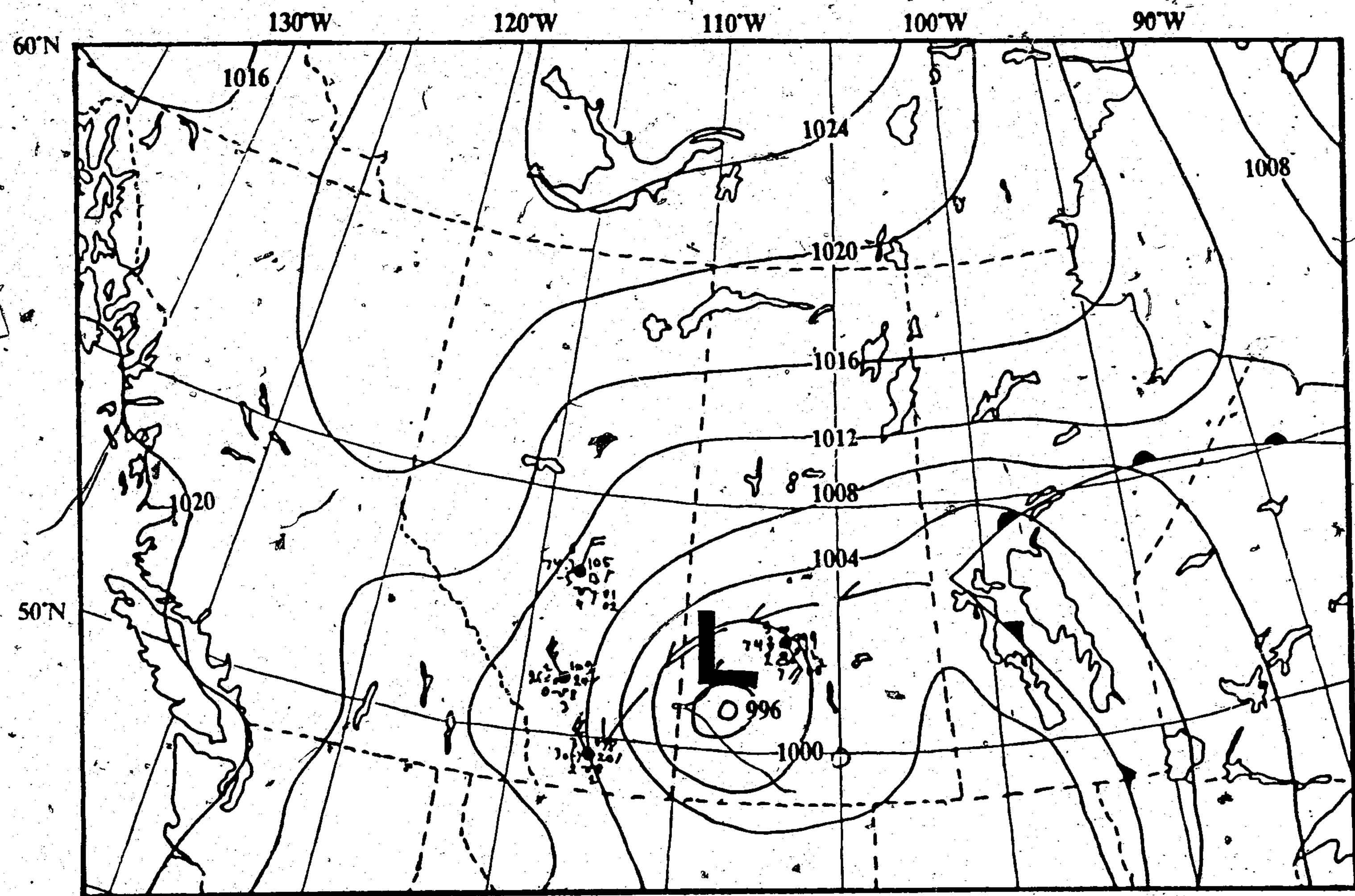


Figure 3.16 Surface Analysis map for 0000Z May 15, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

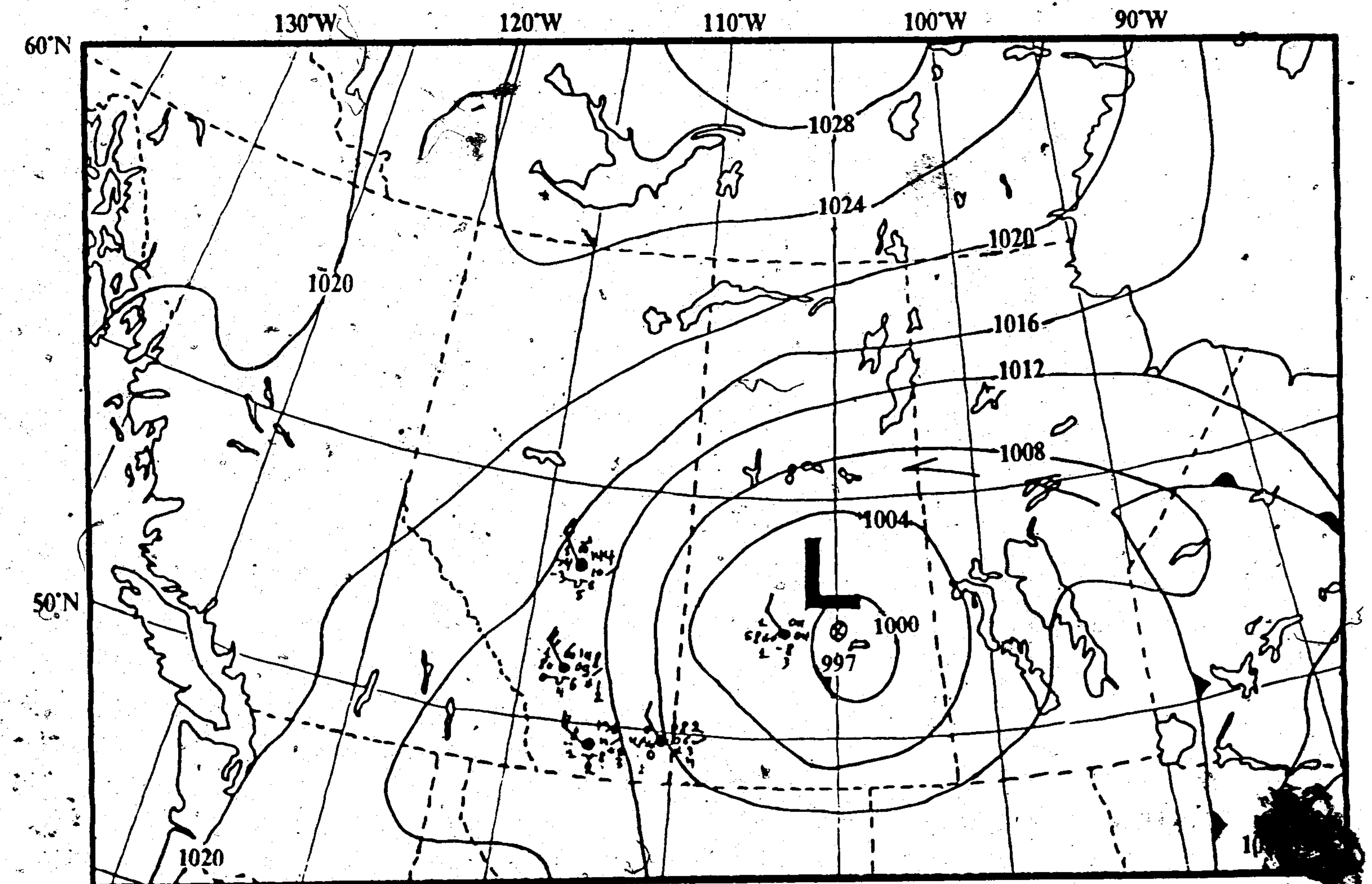


Figure 3.17 Surface Analysis map for 1200Z May 15, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

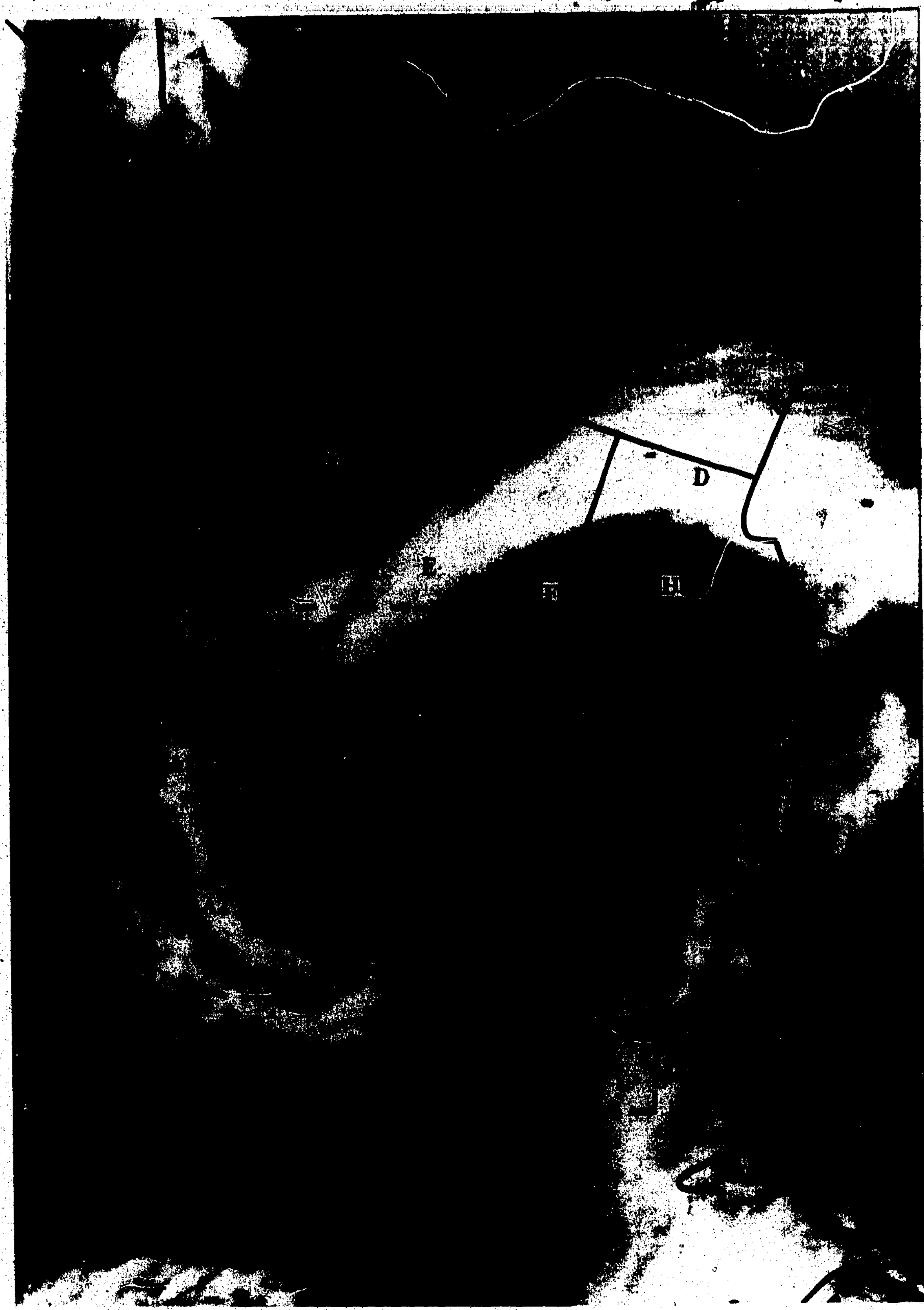


Figure 3.18 Infrared Image of May 15, 1986 at 2025-2040Z, NOAA-9 orbit 7327.

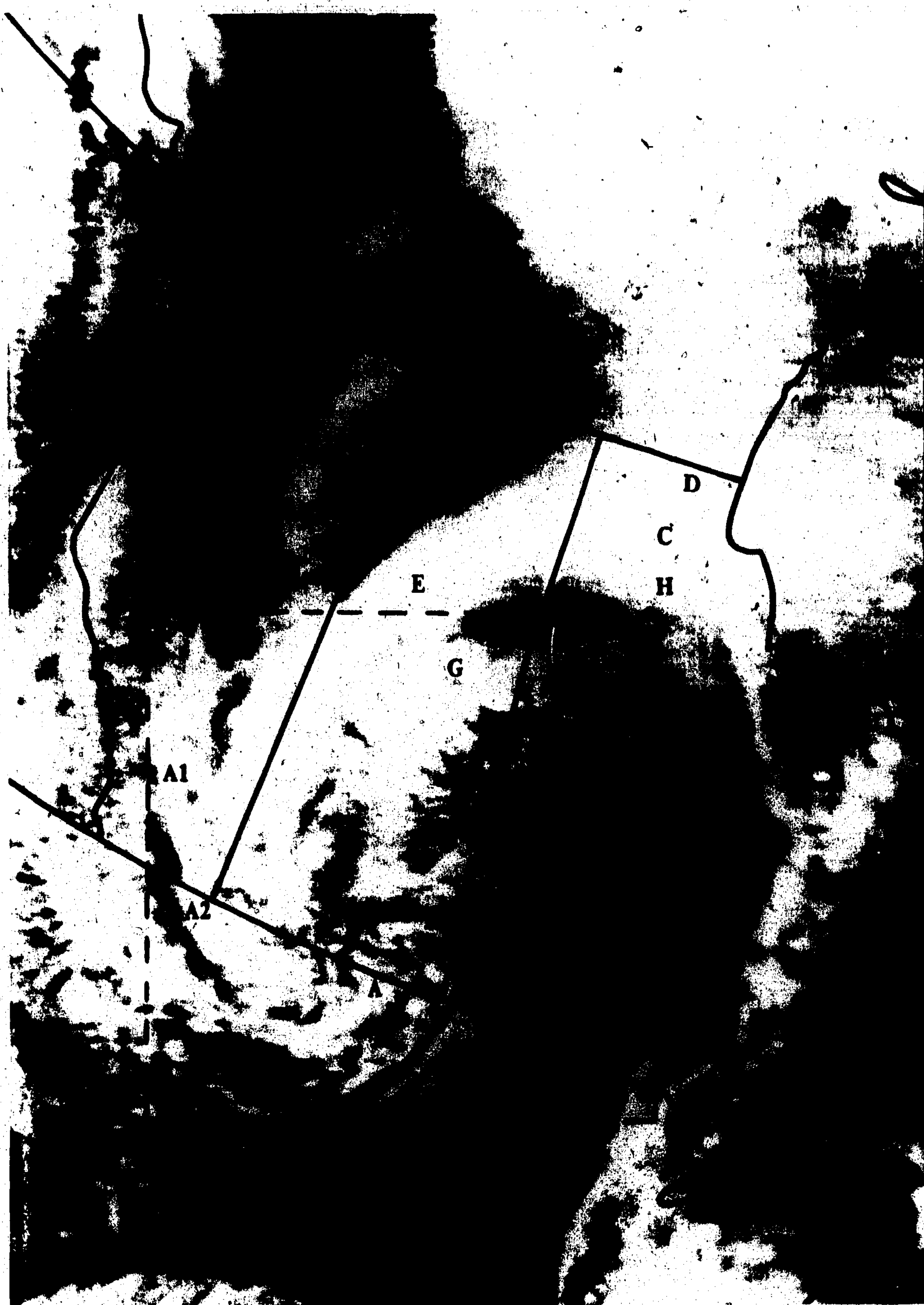


Figure 3.19 Visible Image of May 15, 1986 at 2025-2040Z, NOAA-9 orbit 7327.

3.2.4 May 16, 1986

During the next 12 hours, the speed of the cold low dropped to to 5 knots, while the vorticity centre weakened further and slowed to 7 knots. The low reached Central Manitoba by the early morning of May 16 (Fig. 3.20), had degenerated into a trough 12 hours later (Fig. 3.21) .

The surface low reached the eastern border of Saskatchewan by 0000Z on May 16 (Fig. 3.22), and filled to 1004 mb; it moved to Central of Manitoba by the early morning on May 16 (Fig.3.23) at about 18 knots and soon thereafter lost its distinct, cyclonic character by being incorporated into an amorphous trough extending westward from Ontario.

The vortex cloud of the dissipating cyclone moved northeastward and was located just east of Lake Winnipeg 24 hours later (Figs. 3.24 and 3.25).

The NW-SE extended cloud band is associated with high Ci, apparent by the uniform bright tone in both displays between between 53°N, 123°W and 60°N, 127°W in area A.

On the visible image (Fig. 3.25), area C is brighter than the surrounding cloud while in the IR (Fig. 3.24) it is darker, indicating the presence of Stratocumulus clouds.

Figure 3.24 shows that in areas G and H, cold high clouds sharply contrast with the warmer Sc. The clouds in the area H are decayed Cb anvils. This is indicated by the gray response in the visible and nearly white shade in the infrared pictures. The Cb tops are very bright in both displays, indicating an area of active thunderstorms. The medium gray shade in the infrared picture (D, E, F) indicates the presence of several cloud layers in these areas.

At G, the relatively thin Cirrus has a low albedo in the visible picture, so there is very low contrast between areas covered with thin Cirrus and clear areas.

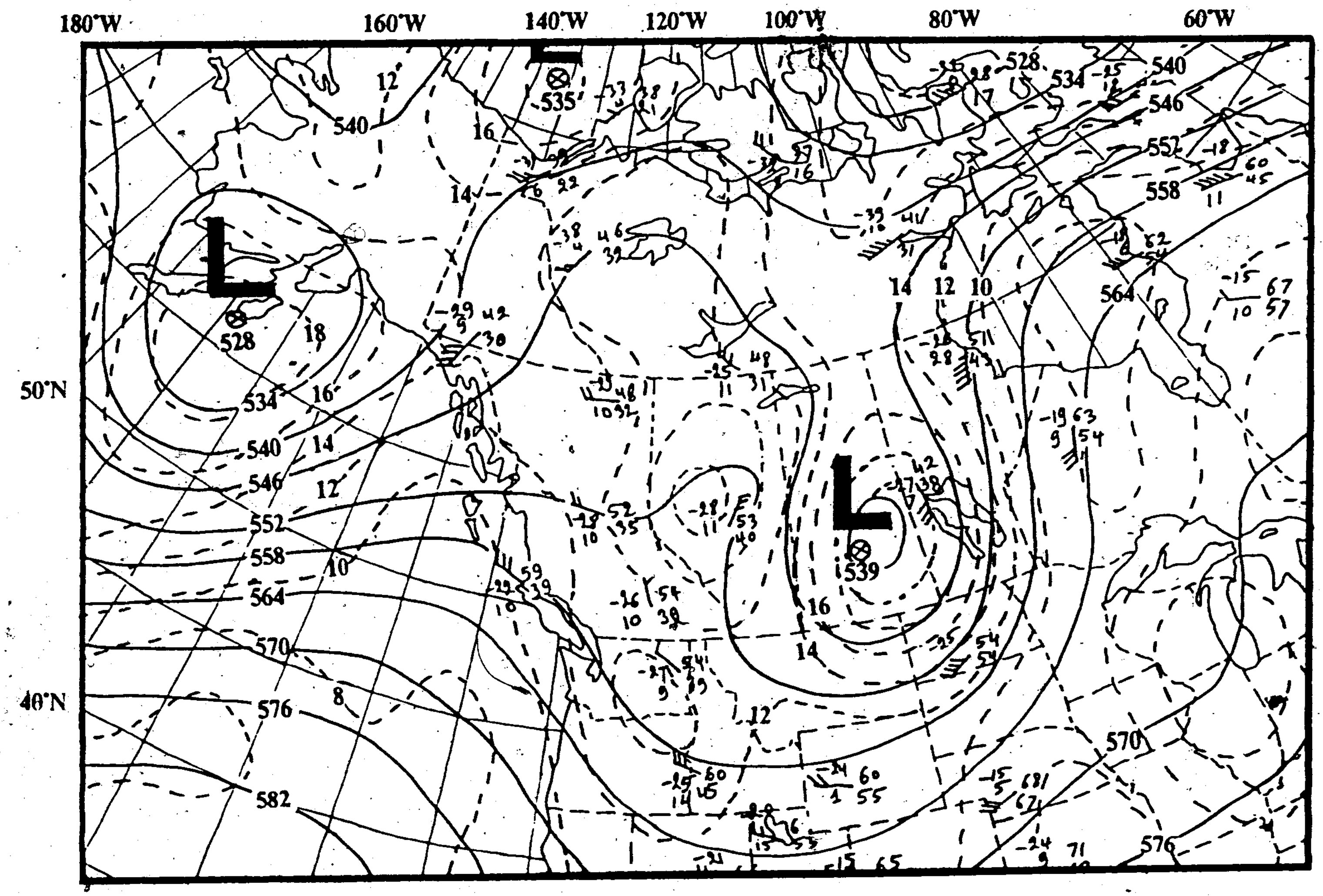


Figure 3.20 500-mb map for 0000Z May 16, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

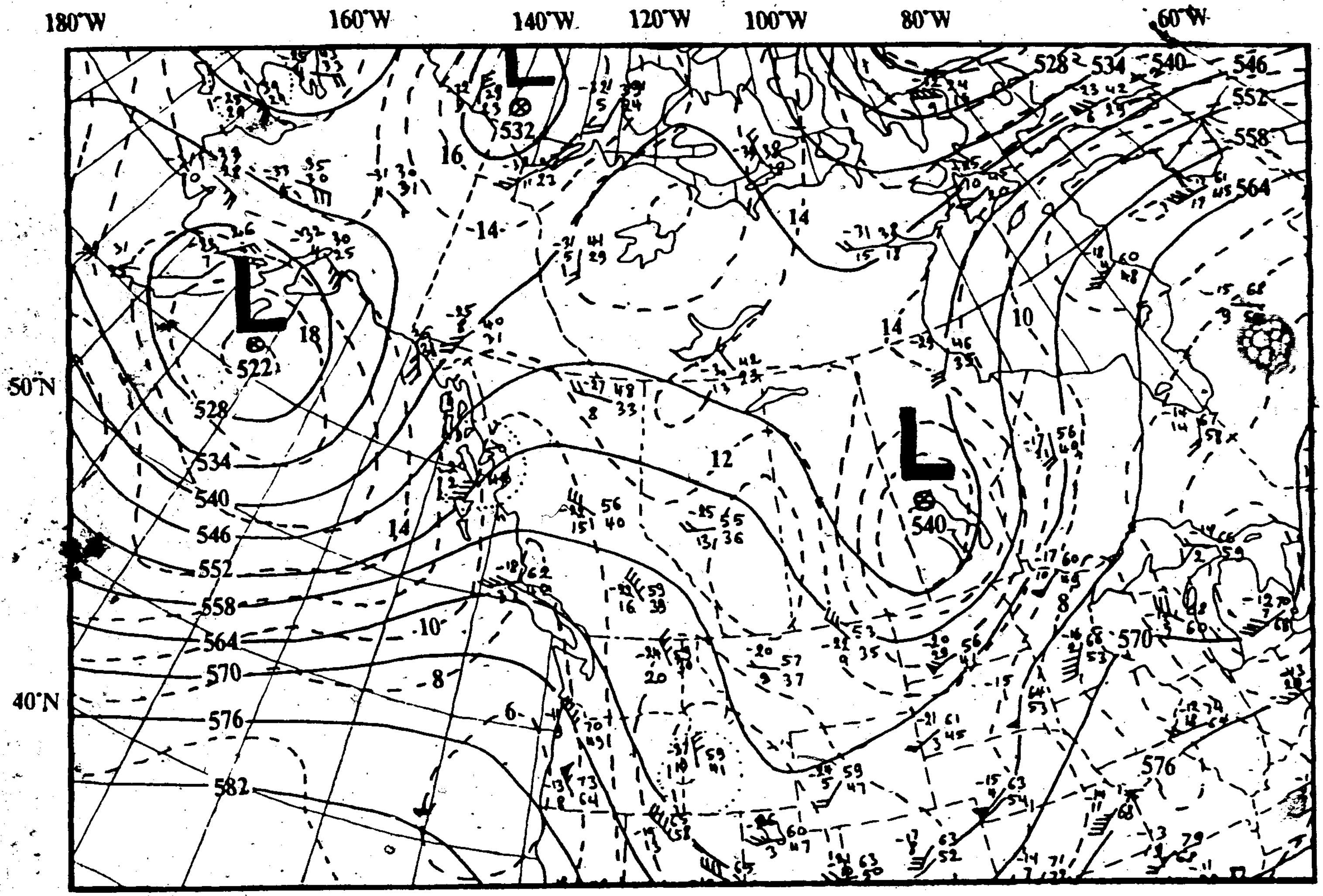


Figure 3.21 500-mb map for 1200Z May 16, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

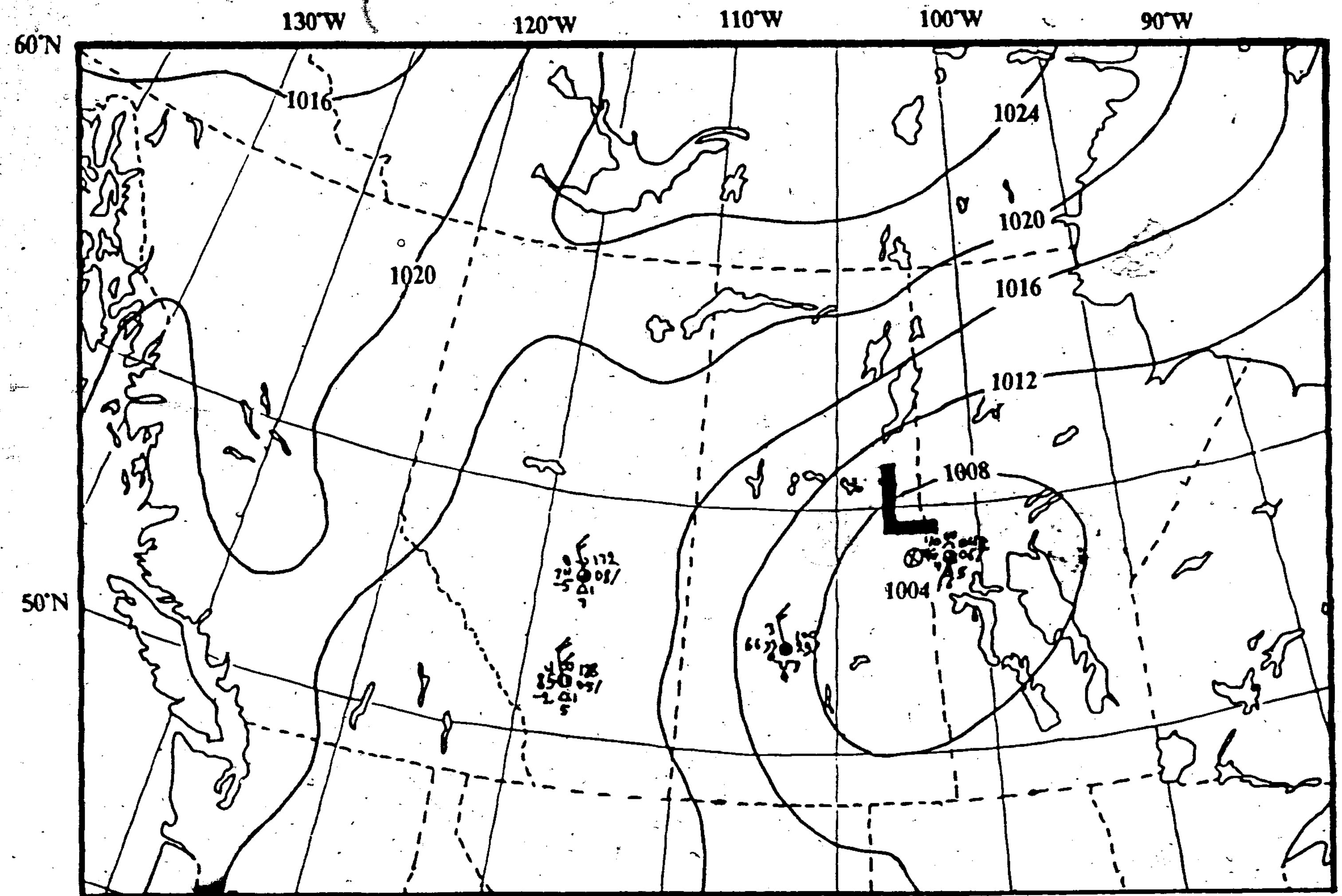


Figure 3.22 Surface Analysis map for 0000Z May 16, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

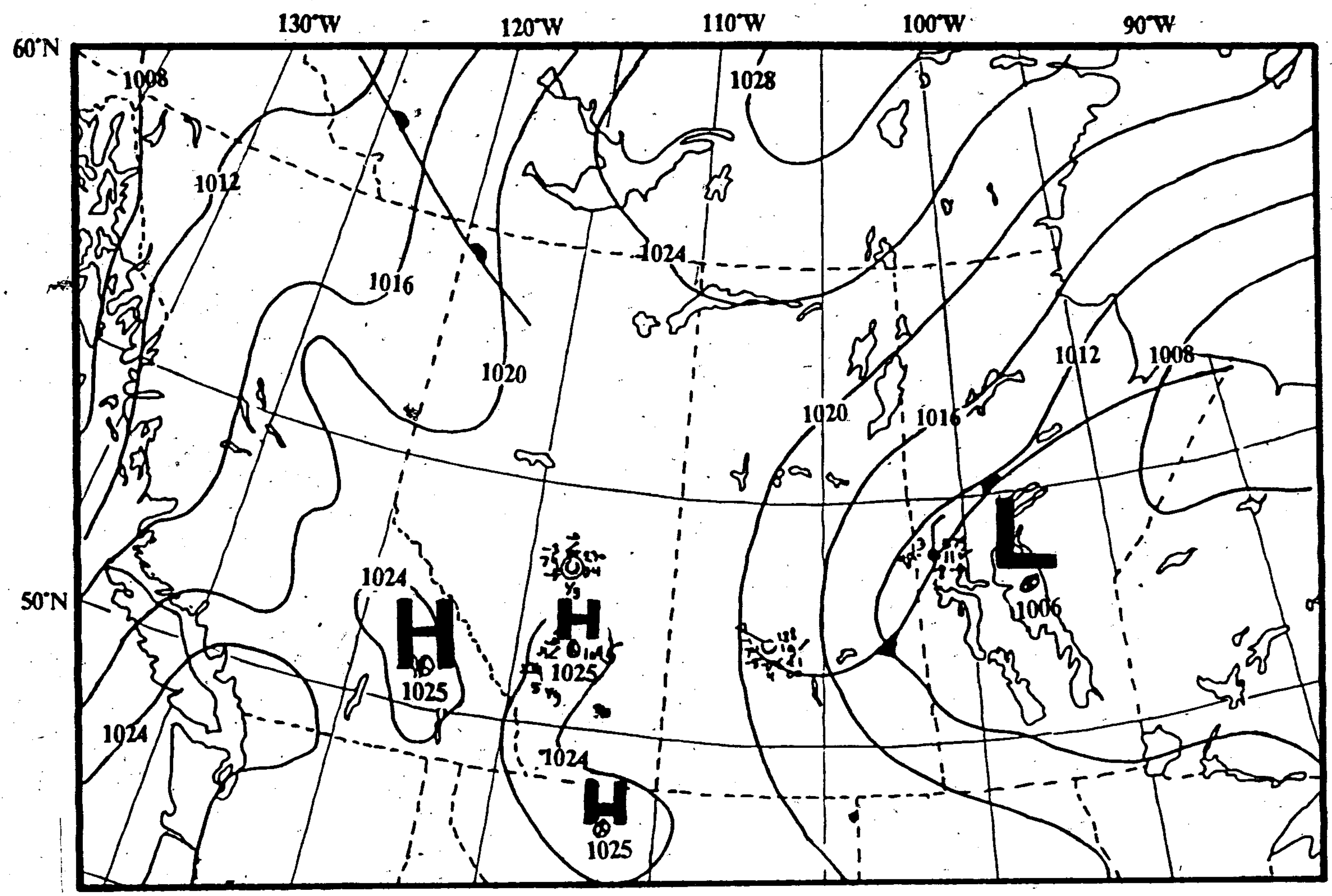


Figure 3.23 Surface Analysis map for 1200Z May 16, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

Figure 3.24 Infrared Image of May 16, 1986 at 2015-2030Z, NOAA-9 orbit 7341.

Figure 3.25 Visible Image of May 16, 1986 at 2015-2030Z, NOAA-9 orbit 7341.

3.3 Numerical Analysis and Graphical Display of Satellite Imagery

To help with the interpretation of satellite-derived digital data displays of temperature and brightness, such as Figures 3.18 and 3.19, a few guidelines and general comments will be useful, since they apply equally to similar plots in this chapter, and in the next.

The isotherms have been plotted at the relatively large intervals of 20°C, rather than, say 5°C, for two reasons. First, the structure of a thermal field is so complicated, and the gradients so tight near the edges of clouds, that any useful plot has to be of considerable size, perhaps 60x100 cm, if all the detail is to be resolved and shown to advantage. Considering the size restrictions that apply to thesis presentations, such large-scale plots would, at best, be awkward to include and integrate with the text. Making a virtue of necessity not only removes the size limitation, but justifies the 20°C interval by providing a clearer view of the essential features of the thermal structure--- the second reason -- at least on the synoptic scale, and of mesoscale features of the order of tens of kilometres. Moreover, a judicious choice of "principal" isotherms makes it also possible to display the three basic cloud types in their "natural", ascending hierarchy of elevation, namely as low, middle and high cloud.

Though not exact, but of the right order, we consider the following correspondences to hold between isotherms, cloud types and cloud-top heights:

0°C isotherm (black)	Low cloud (St, Sc, Cu), etc. Tops to ≈2500 m ASL.
-20°C isotherm (green)	Middle cloud (As, Ac, Ns). Tops to ≈5000 m ASL.
-40°C isotherm (blue)	High cloud (Ci, Cs) and TCu, Cb anvils. Tops to ≈7500 m or higher
+20°C isotherm (red)	generally clear areas of warm ground, including at times patches of scattered cloud.

The 0°C isotherm has a special significance in that it marks the freezing level, an important quantity to pilots and flight dispatchers. To be sure, the freezing level could be lower in cold air hidden beneath a cloud (or below inversions) and it could also be at ground level in a region of melting snow.

Though less useful in meteorogical practice than isotherms, similar comments can be made about brightness isopleths, and equivalences established between brightness, cloud reflectivity, and thickness, extent of cloud and albedo. But going by brightness alone, it may be difficult to distinguish between cloud and snow-covered ground, although recourse to an IR plot will usually resolve any ambiguity.

Cloud-free areas of low albedo, such as fields and woodlands, are easily distinguished by low digital counts. Problems arise, however, with clouds because of complications such as orientation of the cloud surfaces, angle and elevation of the sun, density and size of the cloud, shadows cast by the cloud, etc.

Since no absolute measurements of brightness have been attempted, the "rule-of-thumb" equivalences suggested below should be considered only as relative but practical estimates in aid of nephanalysis.

90 DC (red) isopleth	Light, thin, cloudiness, broken or in patches and within the red isopleth, e.g. scattered to broken St, Sc and Cu. Also thin, translucent layers of As, Ci and Cs.
110 DC (black) isopleth	Encloses all opaque cloudy areas, including broken Cumulus, and possibly snow.
130 DC (green) isopleth	Solid covers of low, middle and hight cloud, guigly and in layers.
150 DC (blue) isopleth	Heavy, thick cloud, e.g. Nimbostratus, embedded or isolated convective turrets and anvils of TCu and Cb.

Areas giving digital counts less than 90 and ouside the 90 DC red isopleth are essentially clear with at most scattered, thin low cloud, such as St, Sc and Cu over open areas, fields and woodlands.

The problem of too many lines and complex detail may be overcome to some extent by the 3-dimensional "stretched net" representation of a thermal surface. Though perhaps of limited usefulness in practice, a few examples of pertinent thermal fields have been plotted using this technique. Such 3-D displays can be useful, however, in providing not only spatial continuity, but also a direct, graphic view of the content of a large data set. They also draw attention to the distribution and location of extreme values of a property such as, in the present case, of maximum and minimum temperatures in a thermal field.

3.3.1 May 13, 1986

Figures 3.26 and 3.27 show the thermal field (isotherms) and brightness isopleths deduced from data within the square areas outlined in Figs. 3.18 and 3.19, respectively.

Both figures will be considered together, since they complement each other. Fig. 3.26 shows warm, mainly clear areas in Southern Alberta and West-central Saskatchewan, with surface temperatures in excess of 20°C. Two small, warm clear pockets are also present NE of Edmonton. The clear areas are surrounded by large patches of low cloud, and by a semi-circular arc of middle cloud, and scattered shower clouds (TCu and Cb). But the main storm clouds have gathered over the Alberta Rockies, with very cold, bright tops in excess of 7500 m. In the Jasper area (WJA), cloud-top temperatures below -55°C can be deduced from the satellite data. This suggests Cb tops which have reached or penetrated the tropopause level at a height of some 9-10 km. Though not shown in Fig. 3.26, since temperatures lower than -40°C are not plotted, this is supported by the radiosonde ascent from Stony Plain (WSE), (Fig. 3.29), about 30 miles west of the City of Edmonton, at 0000Z May 14, 1986 (near to the time of the satellite pass) which puts the tropopause at about 9 km. It also shows upper-air temperatures close to the satellite-derived temperatures (Fig. 3.26) for cloud-tops between 4.2 km and 6.3 km (about -30°C), indicating the presence of middle cloud, interspersed with convective cells (Fig. 3.18). Cloud-top temperatures north Calgary (YYC) reached minima of -35°C. Such temperatures can be found in Fig. 3.28, a 3-dimensional representation of the area 49-53°N, 107-115°W which covers a range from -35°C at cloud tops to a maximum surface temperature of 28°C north of Lethbridge (YQL). Such a maximum may seem high, but it must be remembered that the satellite measures the temperature of the radiating surface, namely ground temperature, rather than air temperature at screen level.

By 2100Z (15:00 MDT) Jasper and Banff are reporting light snow from overcast skies, and near freezing temperatures (2°C). Numerous showers have developed along the leading edge of the cloudbank to the west (Pincher Creek-Calgary-Red Deer-Edmonton) and the rainshowers turned to snow at Calgary three hours later.

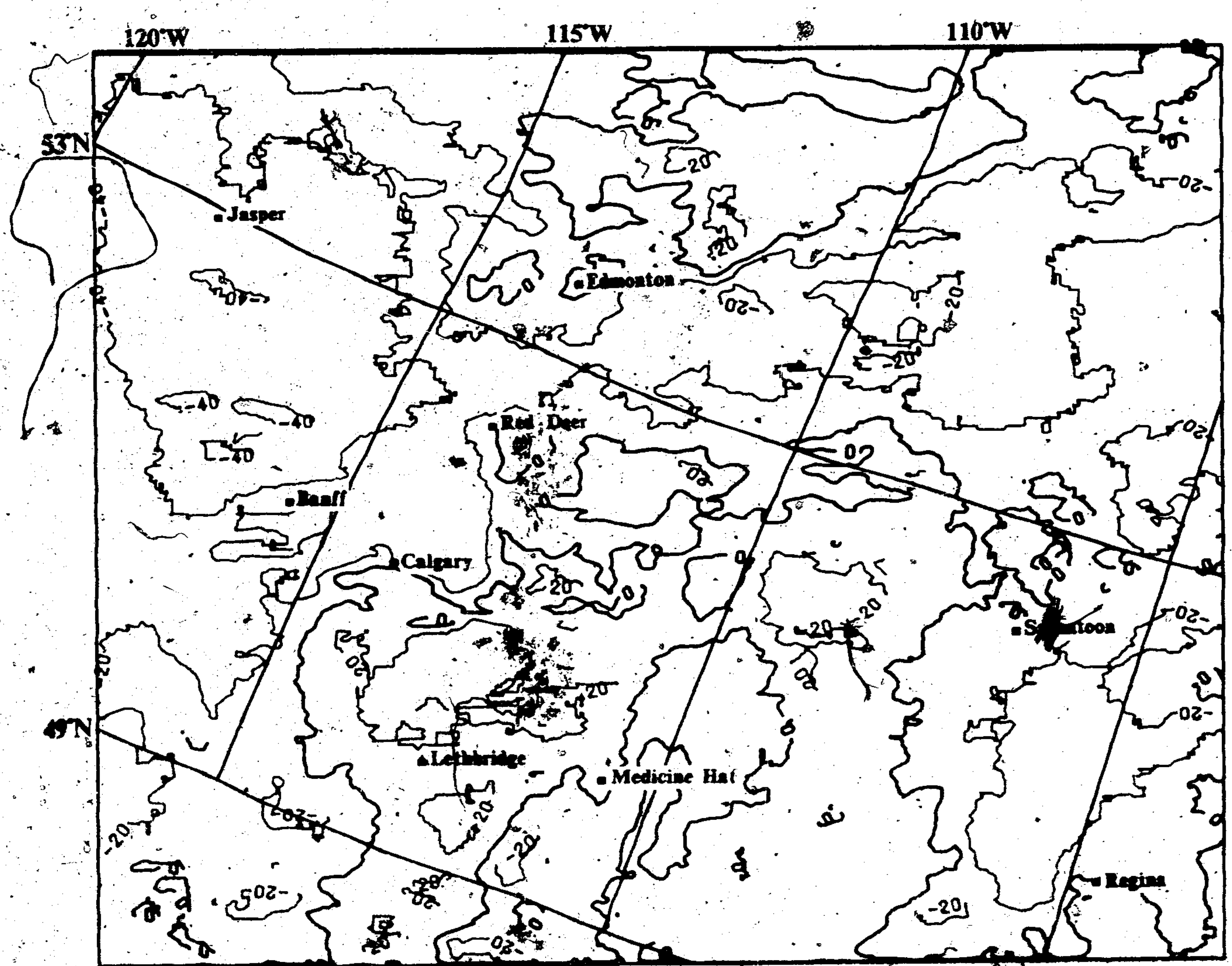


Figure 3.26 IR-derived isotherms for May 13, 1986 at 2047-2102Z, NOAA-9 orbit 7299, temperature (T) in °C, with isotherm interval 20°C.

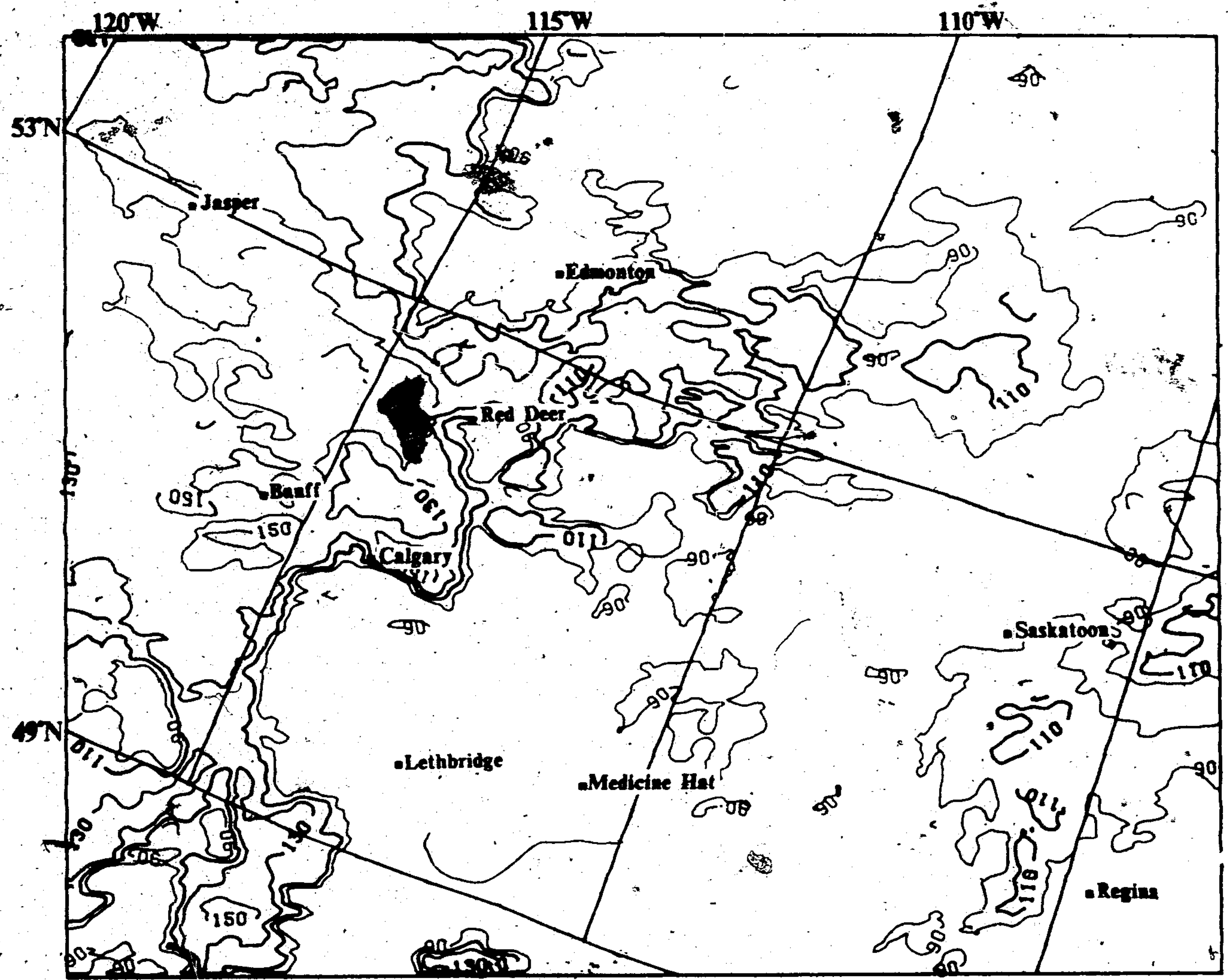


Figure 3.27 Brightness isopleths for May 13, 1986 at 2047-2102Z, NOAA-9 orbit 7299, isopleth interval 20 counts.

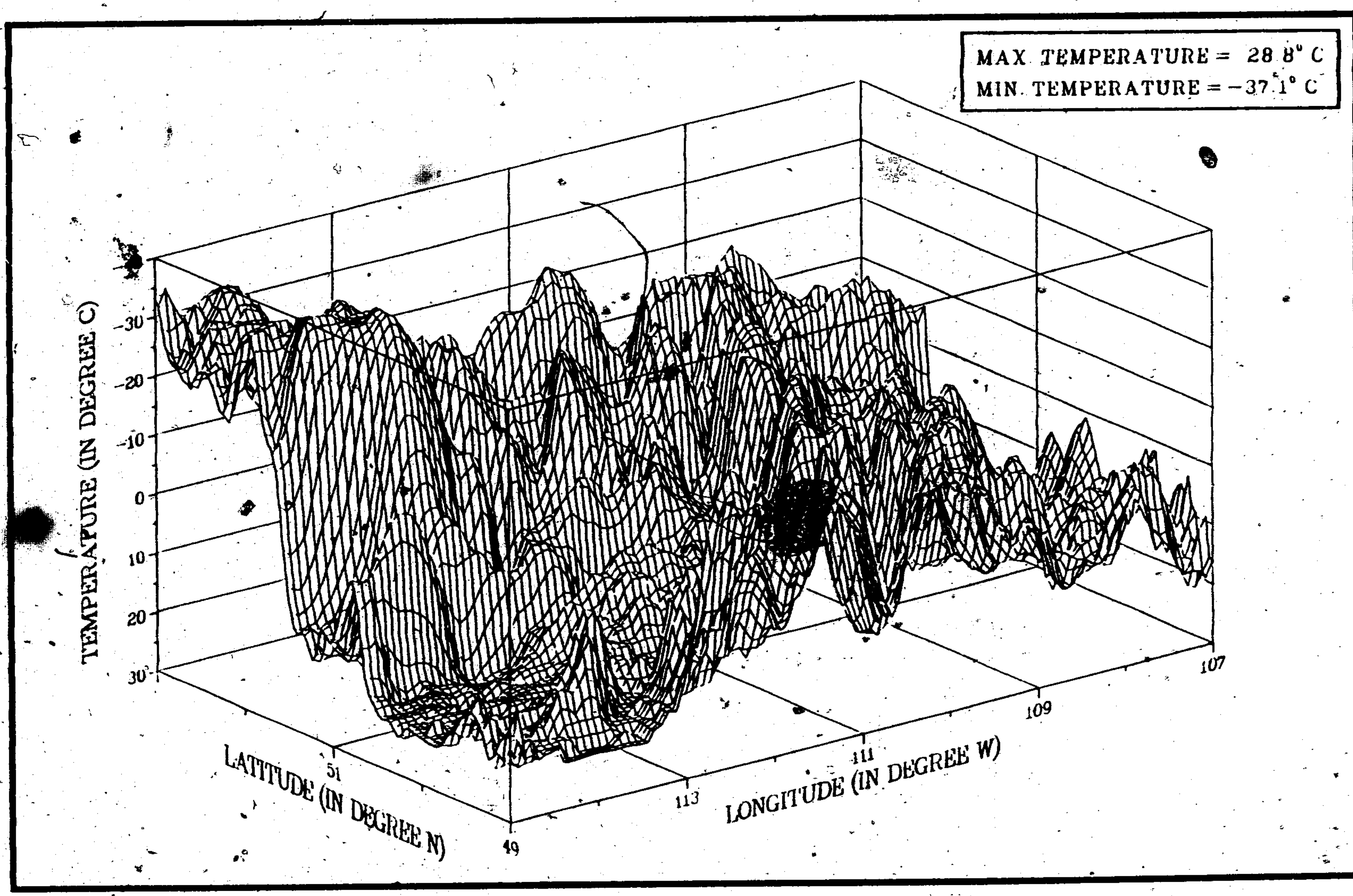


Figure 3.28 IR-derived 3 Dimensional temperature field of the cold-low area (49-53°N, 107-115°W) for May 13, 1986 at 2047-2102Z, NOAA-9 orbit 7299.

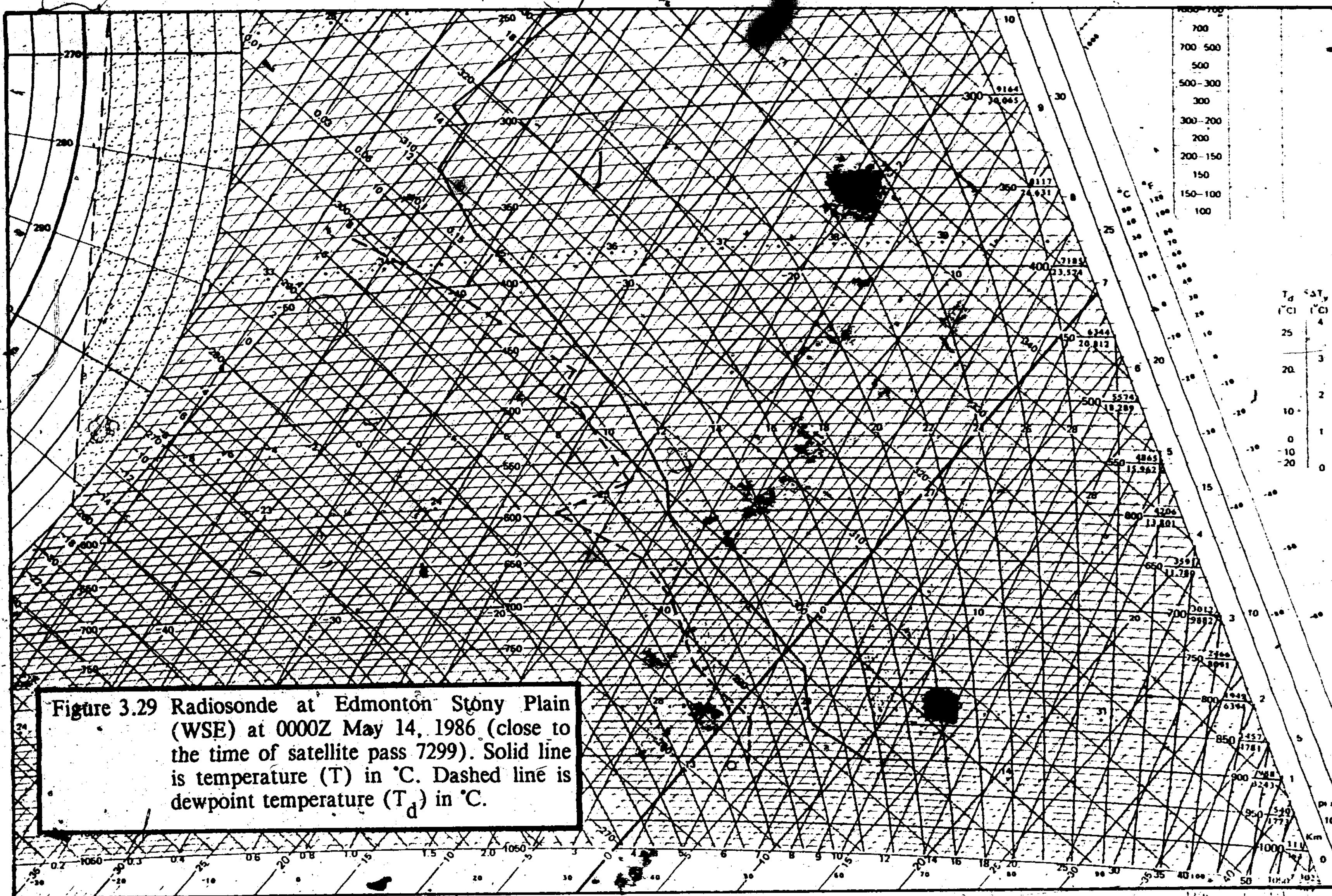


Figure 3.29 Radiosonde at Edmonton Stony Plain (WSE) at 0000Z May 14, 1986 (close to the time of satellite pass 7299). Solid line is temperature (T) in °C. Dashed line is dewpoint temperature (T_d) in °C.

3.3.2 May 14, 1986

Figures 3.30 and 3.31 show the isotherms and brightness isopleths for 2036Z (NOAA-9 orbit 7313). Both figures show the bright, cold and well-developed comma cloud curving from Lethbridge through the western Calgary and Red Deer regions and then southeastward to Saskatchewan and Regina with the vortex centre located at 51°N, 110°W. Cumulonimbus cells are embedded along the rear edge of the comma cloud. The "dry slot" marked by surface temperatures from 10°C to 15°C contains stil several bands of Cu and TCu with scattered showers. The coldest and highest clou-tops with temperatures lower than [illegible] are found in Central and Western Alberta and in northern Saskatoon, NE of [illegible] and over Lake Winnipeg. Most of the heavier and continous precipitation is [illegible] the Edmonton-Red Deer-Lethbridge region with snow [illegible] being blown a[illegible] by gusty 38-knot northwesterly winds.

The radiosonde released at 0000Z on May [illegible] Stony Plain (Fig. 3.33) supports the temperature and cloud structure in the Edmonton District. (No regularly scheduled ascents a[illegible]ailable from Calgary). In the 750 to 600-mb layer the temperature-dewpoint depression is zero, indicating complete saturation and solid cloud to at least 4.5 km with convective tops likely to 8 km. The 3-D isotherm plot of Fig. [illegible] indicates minimum cloud-top temperatures of -56.9°C at 56°N, 115°W, and a maximum at 18.7°C in northern Montana.

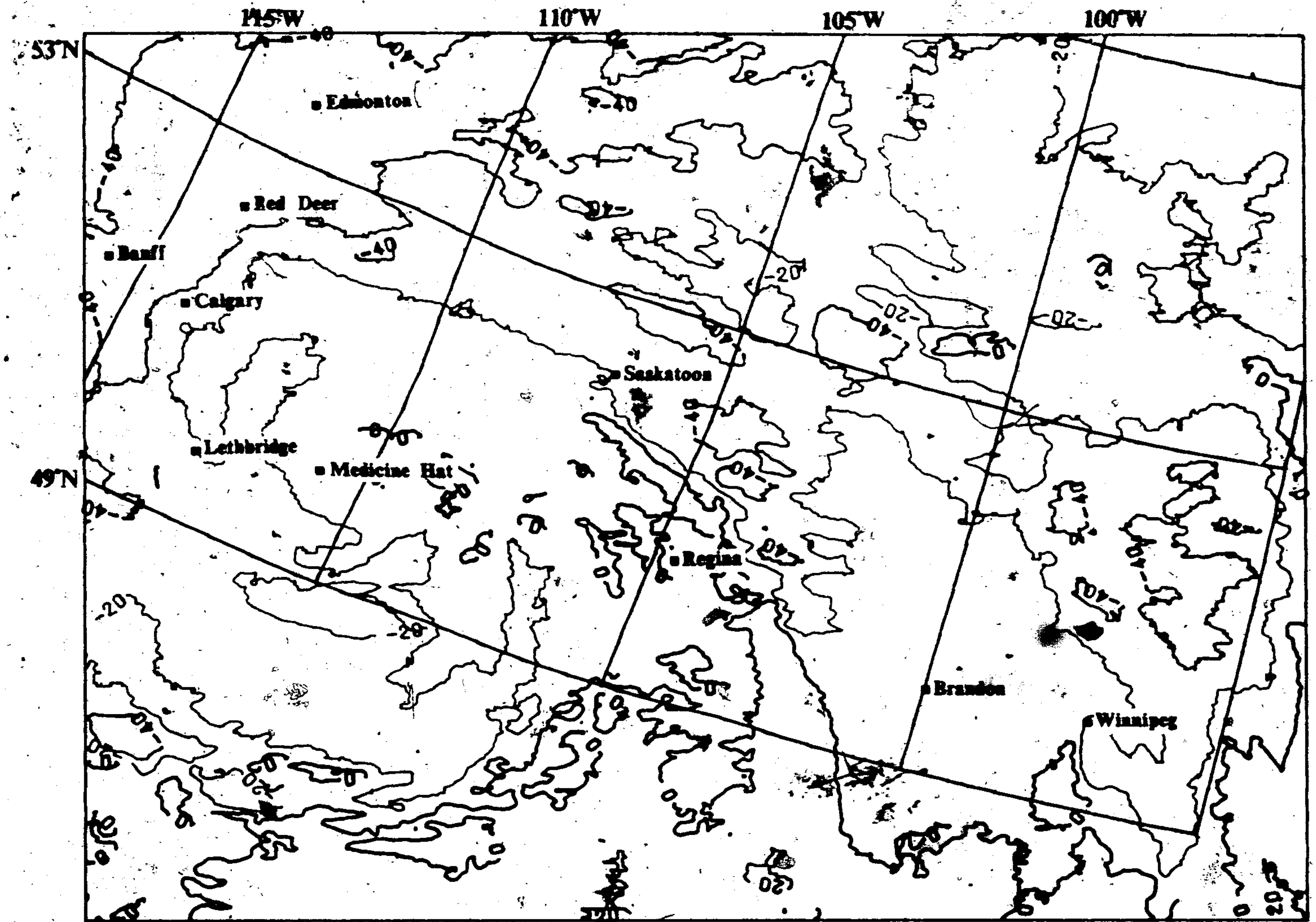


Figure 3.30 IR-derived isotherms for May 14, 1986 at 2036-20[illegible]Z, NOAA-9 orbit 7313, temperature (T) in °C, with isotherm interval 20°C.

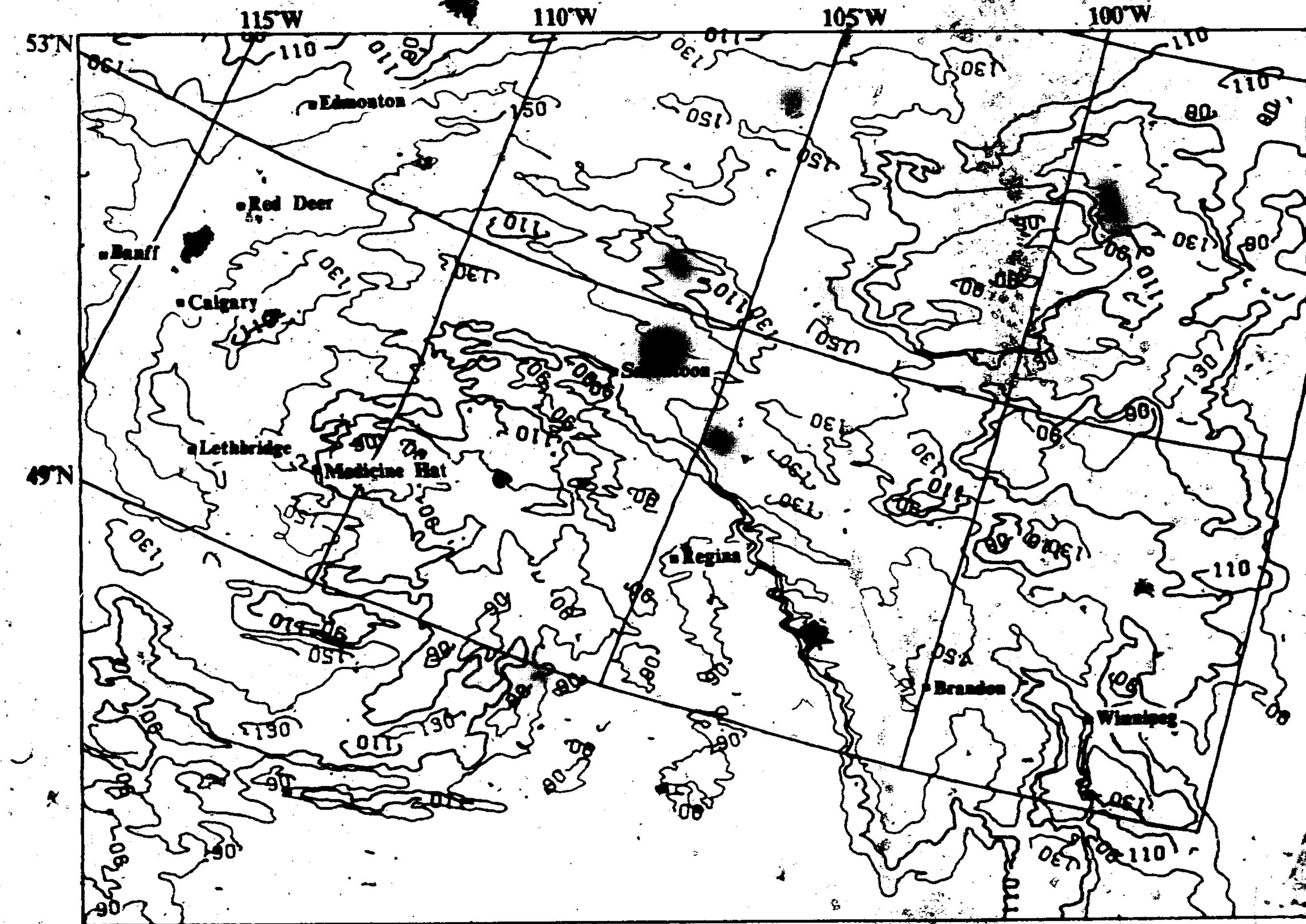


Figure 3.31 Brightness isopleths for May 14, 1986 at 2036-2051Z, NOAA-9 orbit 7313, isopleth interval 20 counts.

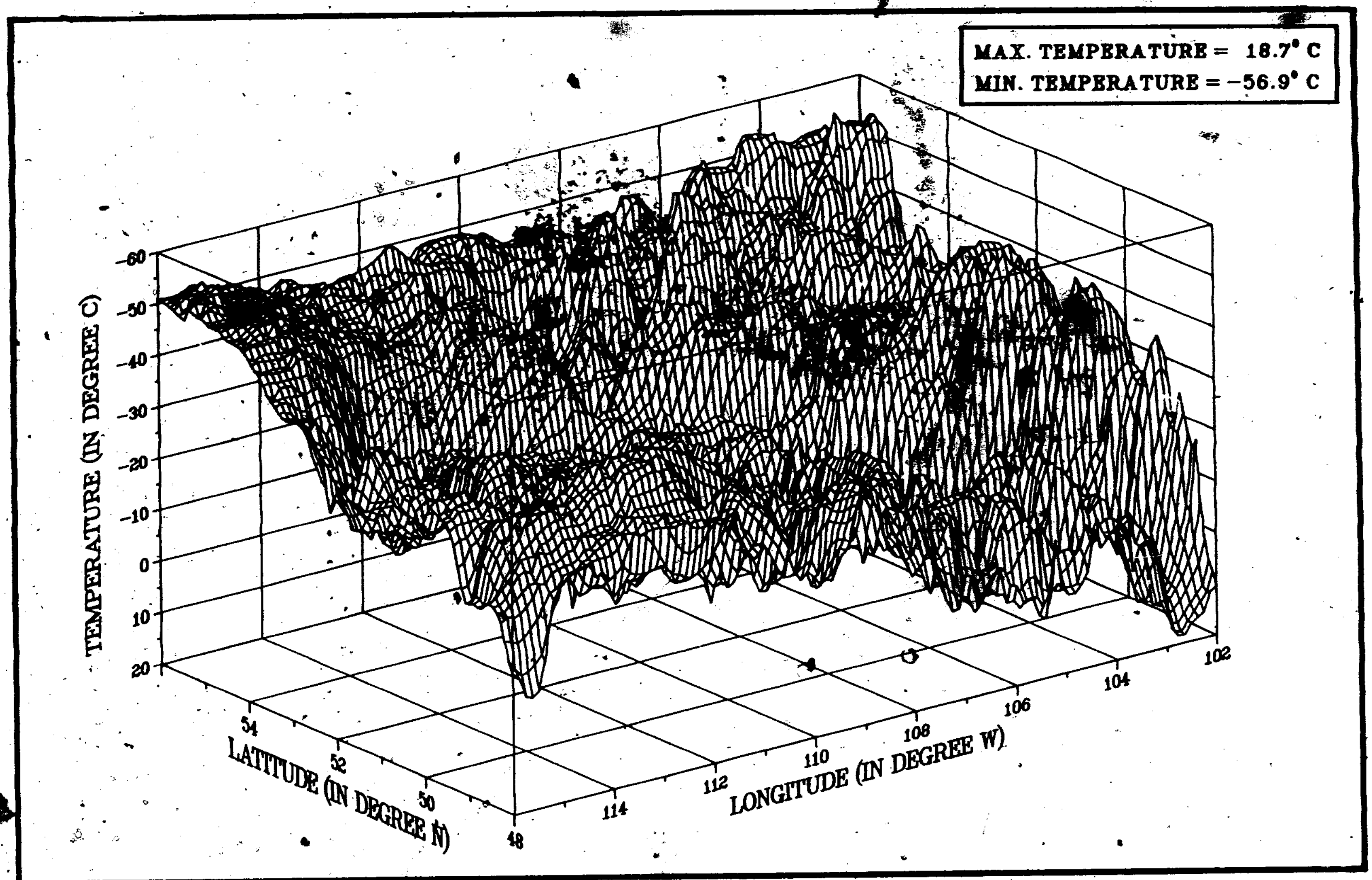


Figure 3.32 IR-derived 3 Dimensional temperature field of the cold-low area (48-56°N, 102-116°W) for May 14, 1986 at 2036-2051Z, NOAA-9 orbit 7313.

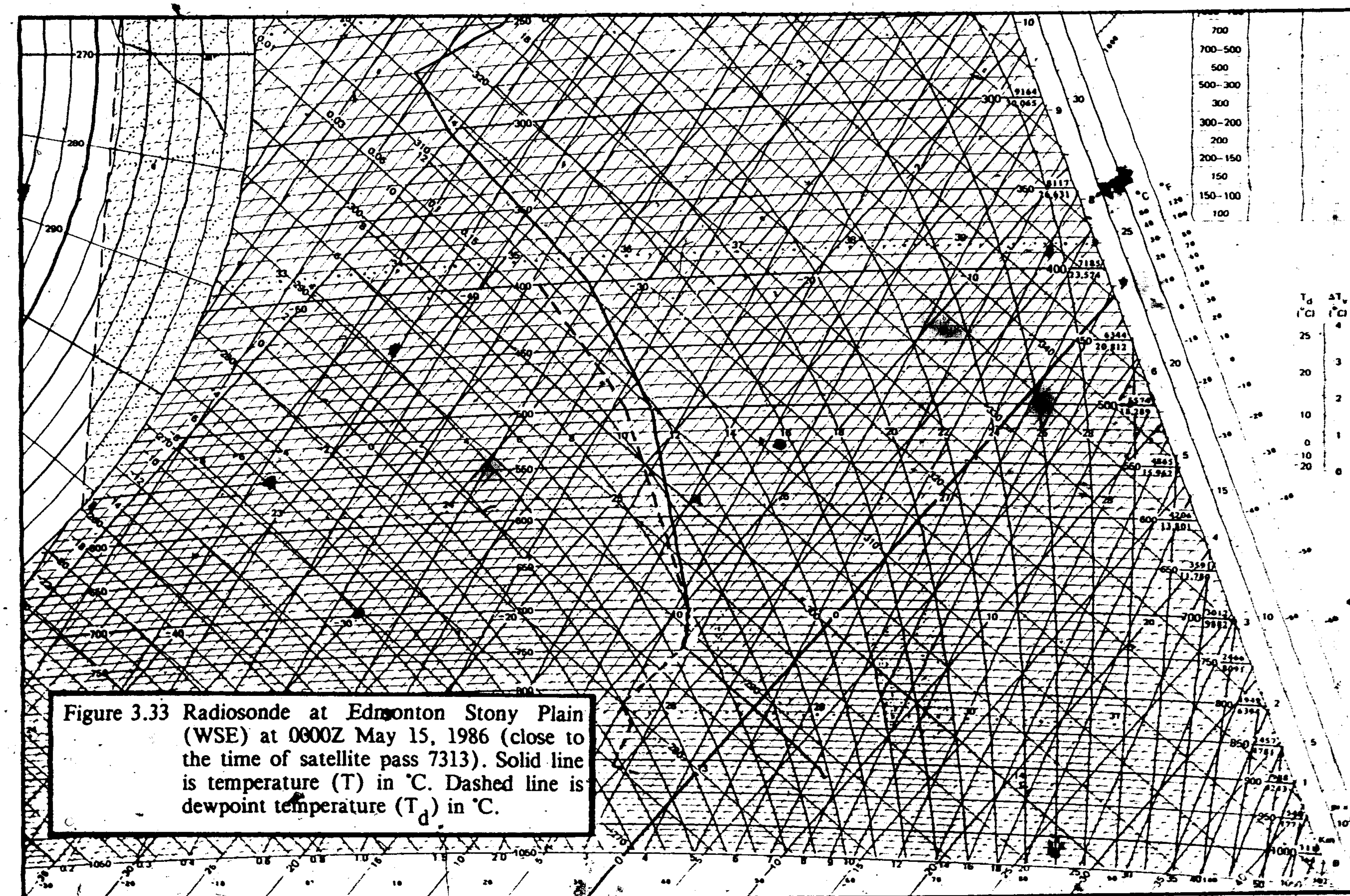


Figure 3.33 Radiosonde at Edmonton Stony Plain (WSE) at 0000Z May 15, 1986 (close to the time of satellite pass 7313). Solid line is temperature (T) in °C. Dashed line is dewpoint temperature (T_d) in °C.

3.3.3 May 15, 1986

Figures 3.34 and 3.35 show the isotherm pattern and and brightness isopleths on mid-afternoon, 15 May 1986, for the square areas outlined in the satellite images of Figs. 3.22 and 3.23, respctively. Comparing the snow opened-up cloud spiral with the tightly-wound spiral of the previous day, it is obvious that the system has passed maturity and is approaching the end of its life cycle.

The western loop through Alberta and northern Montana still contains the brightest coldest and most active clouds. The snow has ended in western Alberta, but continues in eastern areas from Lloydminster to Coronation and Medicine Hat. Snow is also falling in western Saskatchewan, between North Battleford and Swift Current, with rain further east in a band from Saskatoon to Regina.

The eastern branch of the spiral is breaking up rapidly over western Ontario. The "dry slot" over Manitoba has widened and become filled with scattered low and middle cloud (Cu, Ac, Acc). Afternoon temperatures in this warm sector are in the 15-20°C ra[illegible]nly 0-8°C in the cold air to the west.

The 3-D representation of Fig. 3.36 of the smaller block within 46-54°N, 100-114°W shows the coldest cloud tops at -47.1°C, and a surface temperature maximum of 18.7°C.

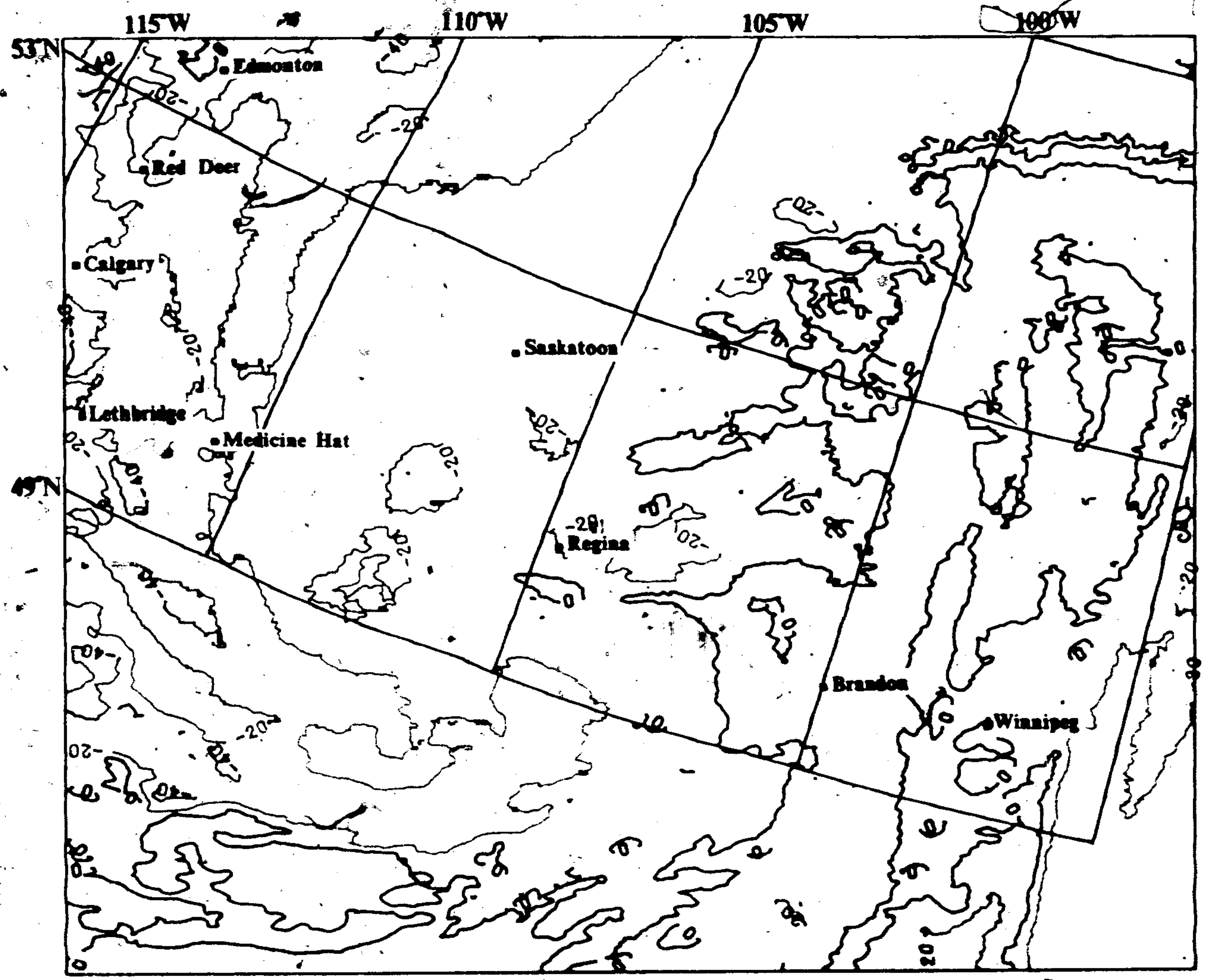


Figure 3.34 IR-derived isotherms for May 15, 1986 at 2025-2040Z, NOAA-9 orbit 7327, temperature (T) in °C, with isotherm interval 20°C.

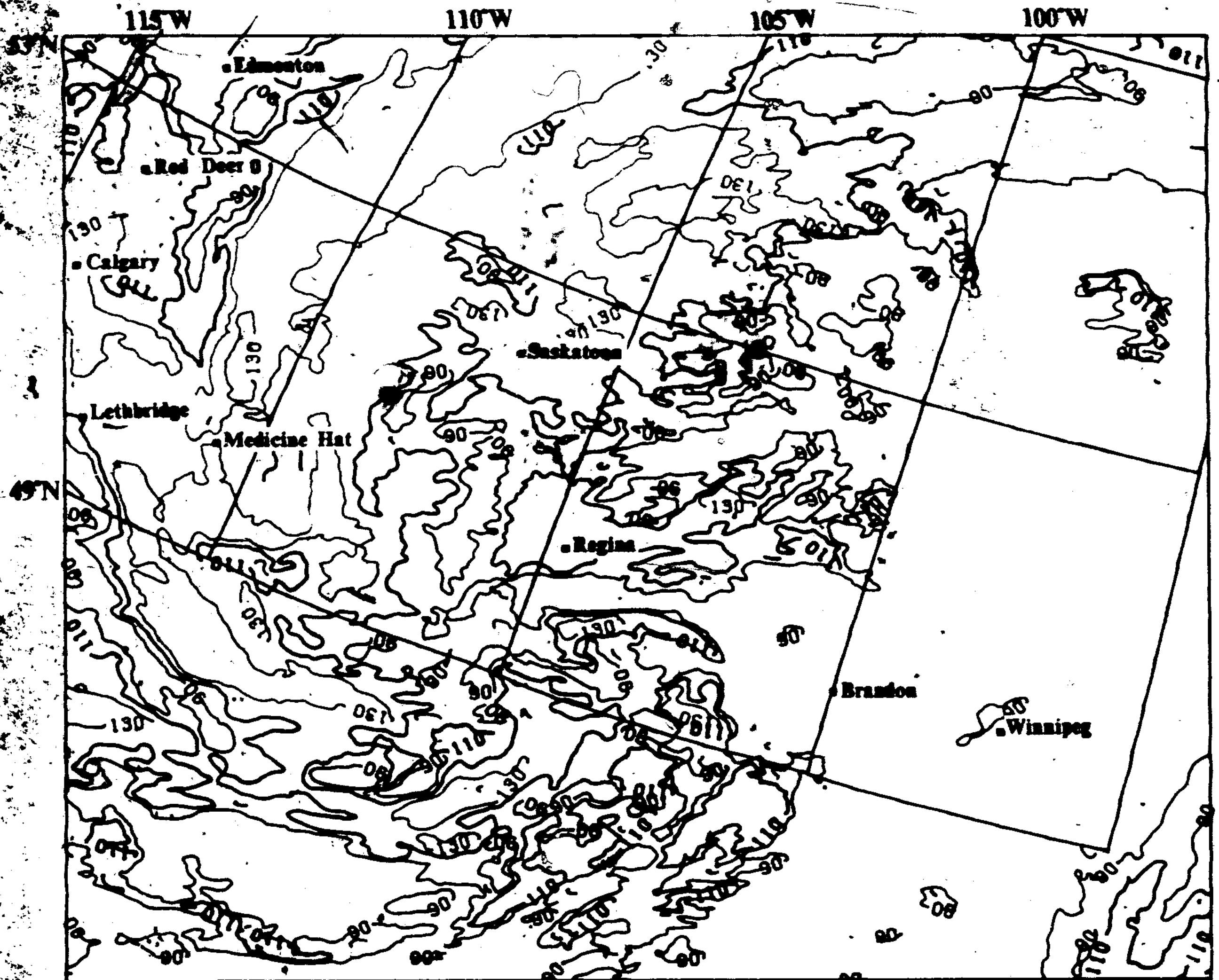


Figure 3.35 Brightness isopleths for May 15, 1986 at 2025-2040Z, NOAA-9 orbit 7327, isopleth interval 20 counts.

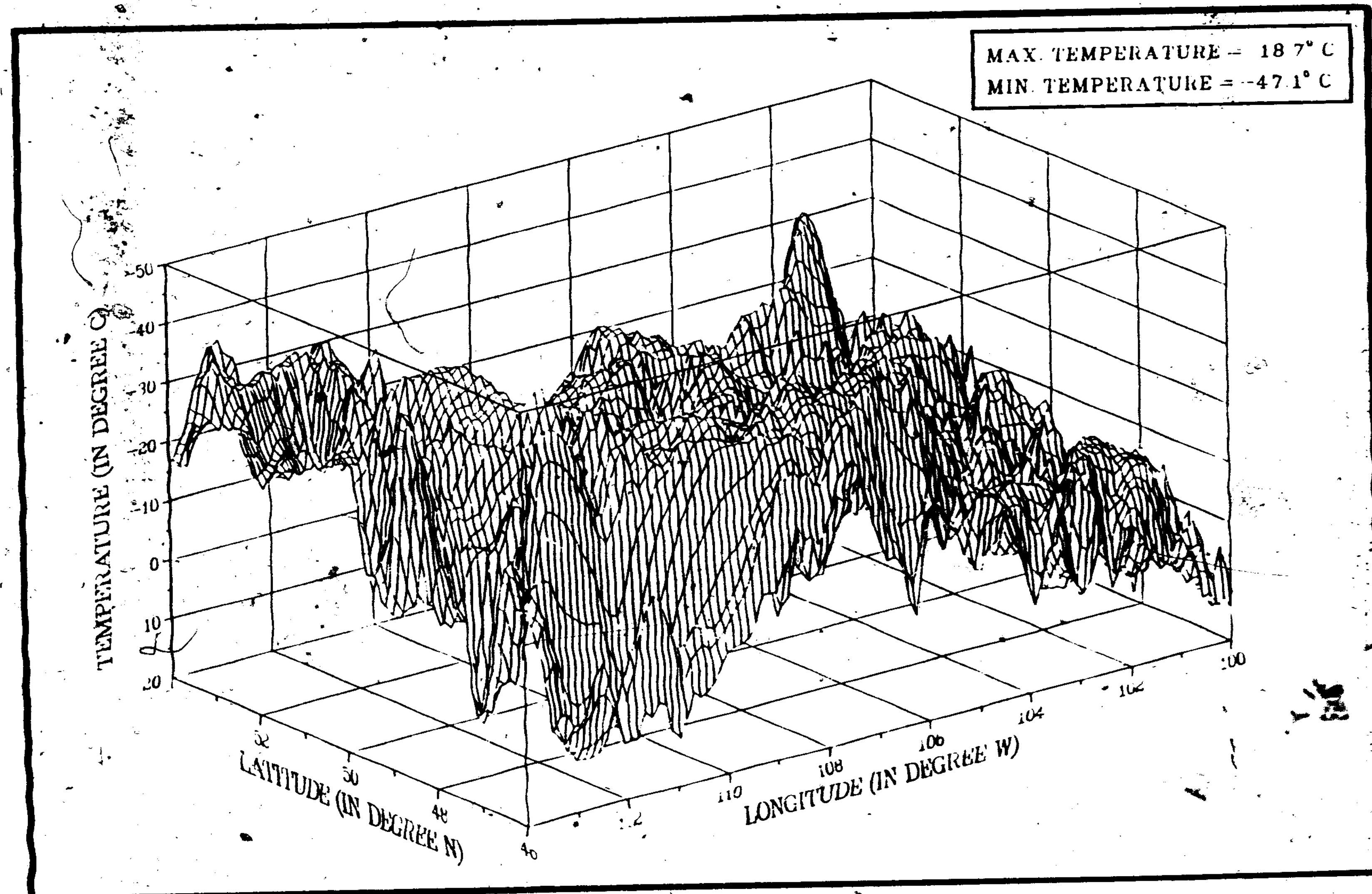


Figure 3.36 IR-derived 3 Dimensional temperature field of the cold-low area (46-54°N, 100-114°W) for May 15, 1986 at 2025-2040Z. NOAA-9 orbit 7327.

3.3.4 May 16, 1986

The dissipating remains of the vortex, now located over southern Manitoba, consists mainly of cumuliform low cloud (Sc, Cu). Figures 3.37 and 3.38, the thermal and brightness representations of the area enclosed within the squares on the satellite images Figures 3.24 and 3.25, respectively, show that this cloud is still organized into several bands, interspersed with numerous clear breaks; this is seen best in the brightness analysis of Fig. 3.25.

The heavy masses of cloud are reduced to one large complex giving snow to NE Manitoba. A smaller patch of middle cloud (Ac, Acc) is present in southern Saskatchewan. The 3-D representation of the area 48-56°N, 91-101°W shows the highest and coldest (-47.1°C) cloud confined to the southwest, with surface temperatures near 20°C in the cloud-free areas.

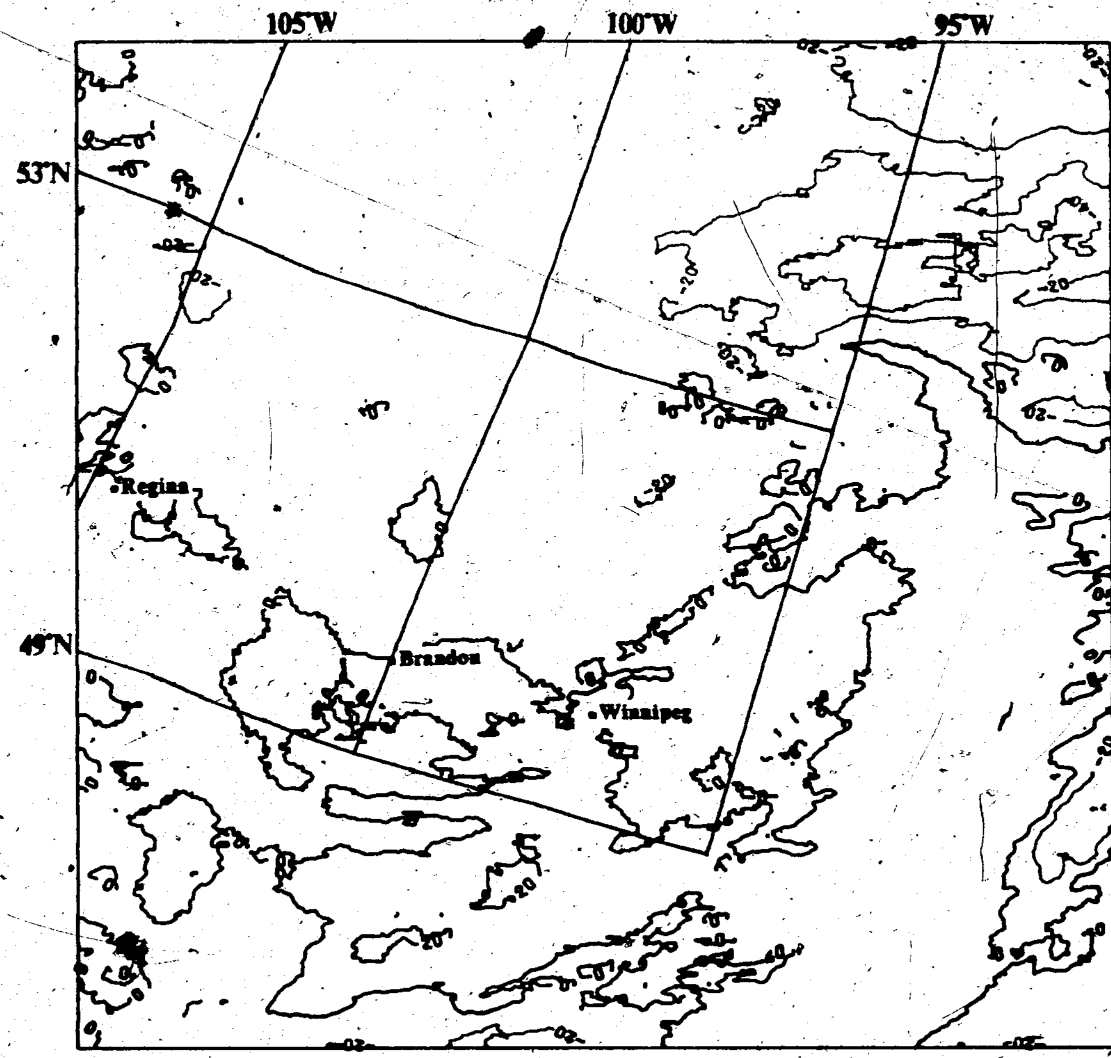


Figure 3.37 IR-derived isotherms for May 16, 1986 at 2015-2030Z, NOAA-9 orbit 7341, temperature (T) in °C, with isotherm interval 20°C.

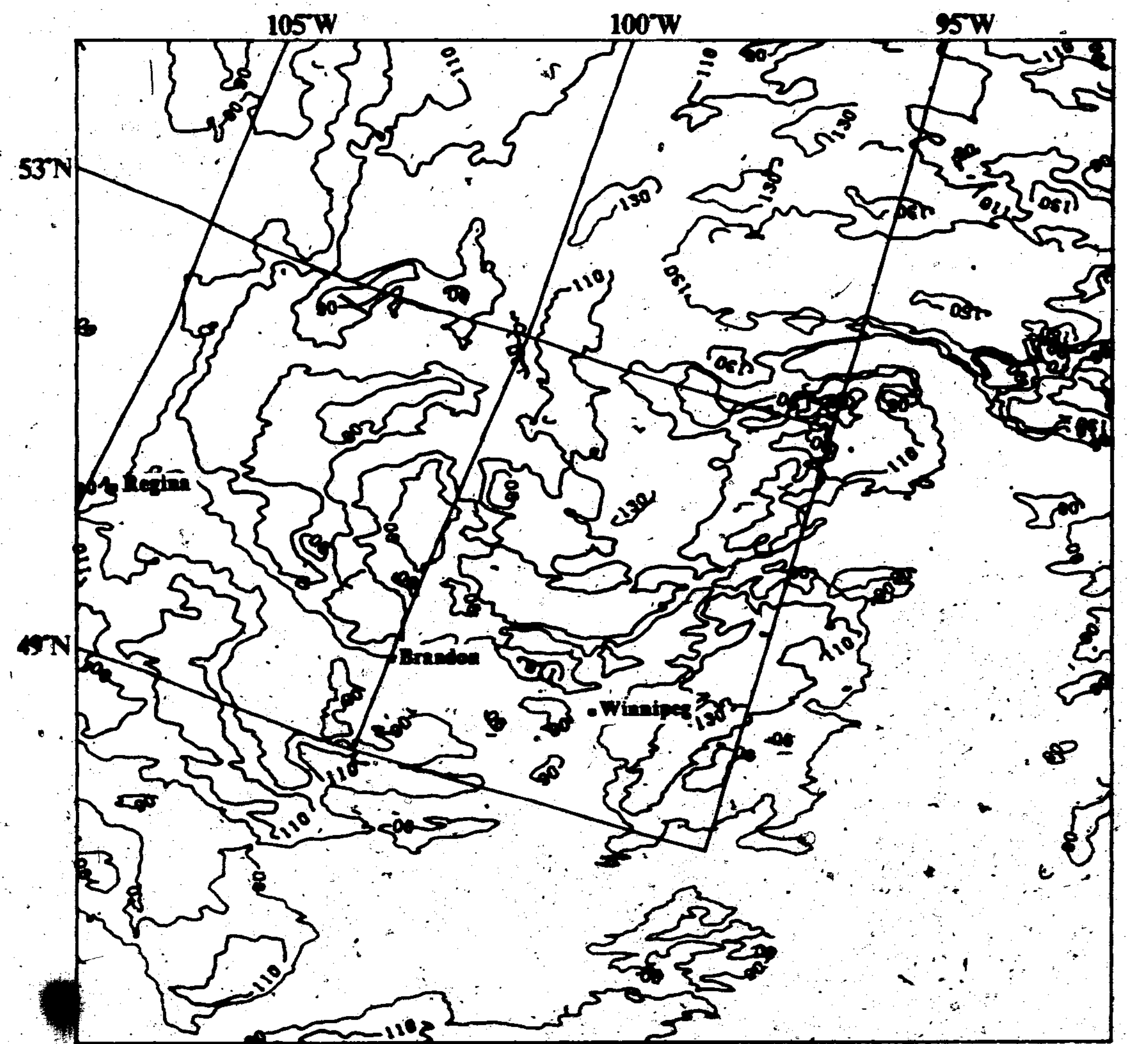


Figure 3.38 Brightness isopleths for May 16, 1986 at 2015-2030Z, NOAA-9 orbit 7341, isopleth interval 20 counts.

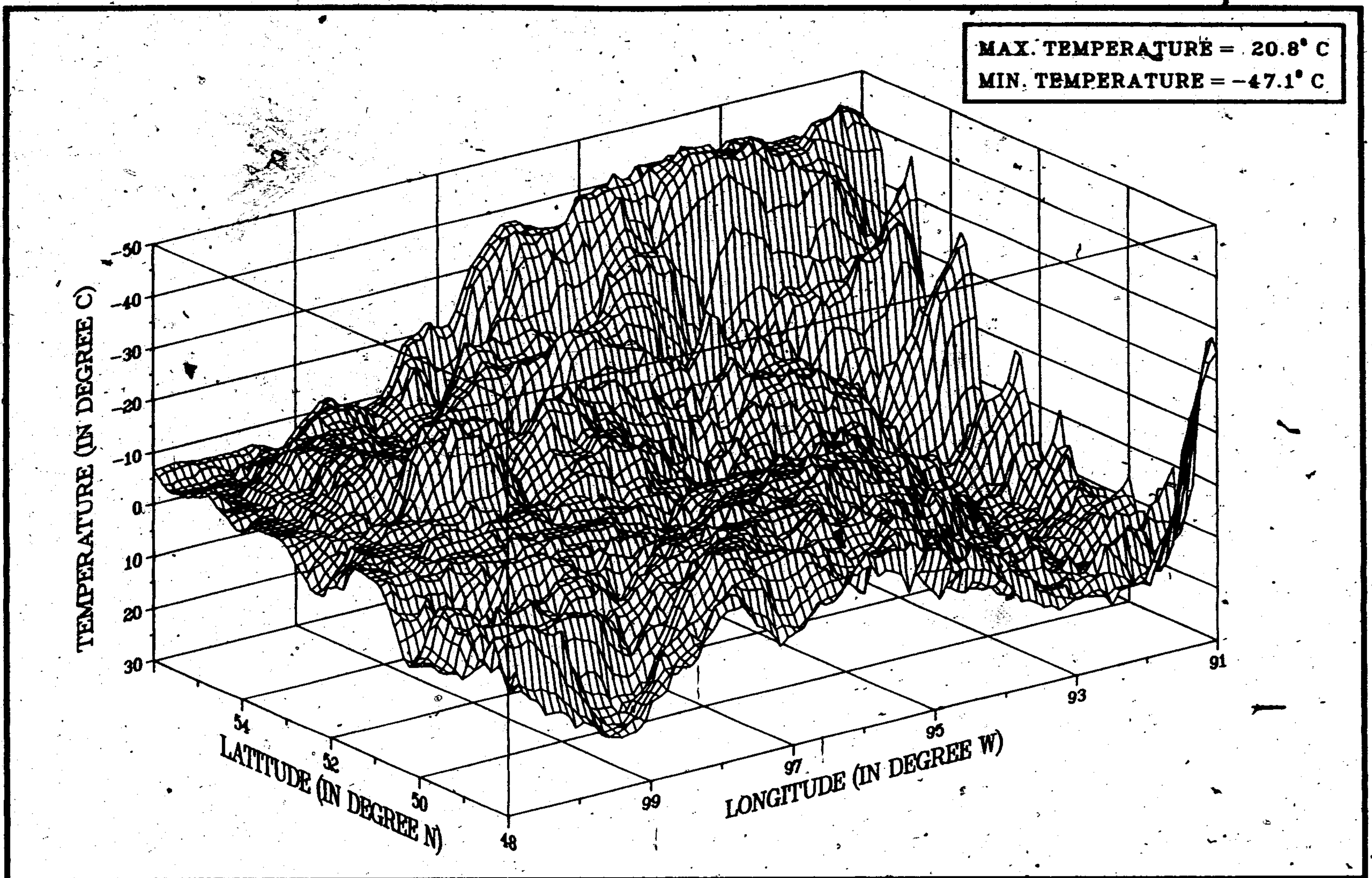


Figure 3.39 IR-derived 3 Dimensional temperature field of the cold-low area (48-56°N, 91-101°W) for May 16, 1986 at 2015-2030Z, NOAA-9 orbit 7341.

4. CASE STUDY #2 : HEAVY RAIN STORM OF JULY, 1986

4.1 Introduction

This case study examines the conditions leading to the intensification of the cold low that produced heavy rainfall in Central Alberta in July, 1986. Cloud patterns on satellite images, synoptic maps and radar scans are compared and correlated, and physical processes described that resulted in exceptionally heavy precipitation over the North Saskatchewan River Basin.

4.2 Synoptic Description

4.2.1 July 16, 1986

Figure 4.1 (July 16, 1986 0000Z) shows the cold low at a central depth of 559 dam, located near Port Angeles (Washington, USA), with a long trough sloping northeastward to Edmonton and Ft. Churchill. The corresponding surface map (0000Z, late afternoon, not reproduced here but similar to Fig. 4.3) shows that numerous Cb, TCu and showers have developed over the interior of B.C. and in western Alberta. During the next 12 hours the cold low has moved to Central Washington at about 8 knots and deepened to 556 dam (Fig. 4.2). The vorticity centre moved at about 13 knots.

The July 16, 1200Z surface map (Fig. 4.3) shows a meandering S-shaped isobar pattern, B.C.-Alberta-Saskatchewan, and two large but inactive low-pressure cells over the western U.S. Though still early morning, showery conditions prevail in the Cold Lake-Edmonton-Jasper regions, indicating that the showers were due to causes other than simple day-time heating. This was borne out by events later in the day, when the precipitation area spread north as far as Peace River and Ft. McMurray, and south to Calgary and Coronation.

The afternoon satellite images, Figures 4.4 and 4.5, reveal a very complicated and diverse cloud structure.

At D1, the clouds are equally bright on both infrared and visible images, indicative of cold, high cloud, which is composed largely of the anvil tops of Cb embedded in a large expanse of Cs. Note the "scalloped" western edge of this cloud mass (on the IR image), clearly outlining individual convective cells, which are drifting northeastward in the southerly flow aloft (see Fig. 4.6)

Layers of Ac, As, Sc are present below the high cloud D1 (as reported by weather stations) which appear as a moderate shade of grey in the IR (Fig. 4.4) where not covered by an upper deck, such as at B1-B2-B3, D2 and F. The light grey cellular pattern over the much darker shades at H (northern Saskatchewan) indicates patches of Ac above a large expanse of much lower cumuliform (Sc, Cu) cloud.

The cloud edge C1-C2-C3 marks the incipient head of the comma cloud of the developing storm, while the band of Cirrus A1-A2-B3 is associated with wide-spread convective activity (Cb, Cu, showers and thunderstorms) in southeastern B.C. and the Peace River country. There are many small breaks between the larger cloud complexes, best seen on the visible image as dark areas, because of their low albedo.

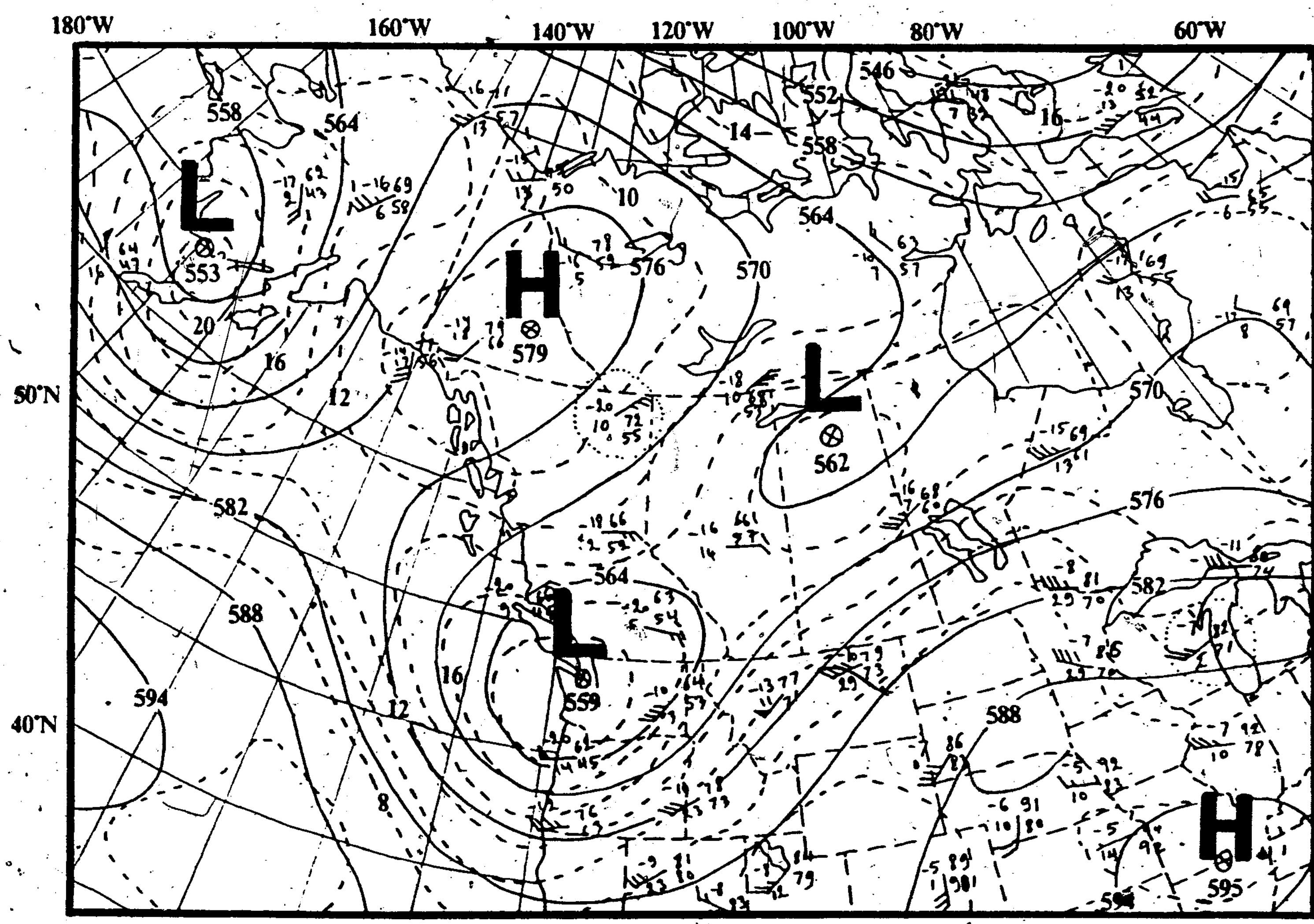


Figure 4.1 500-mb map for 0000Z July 16, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of 2×10^{-5} rad sec^{-1}.

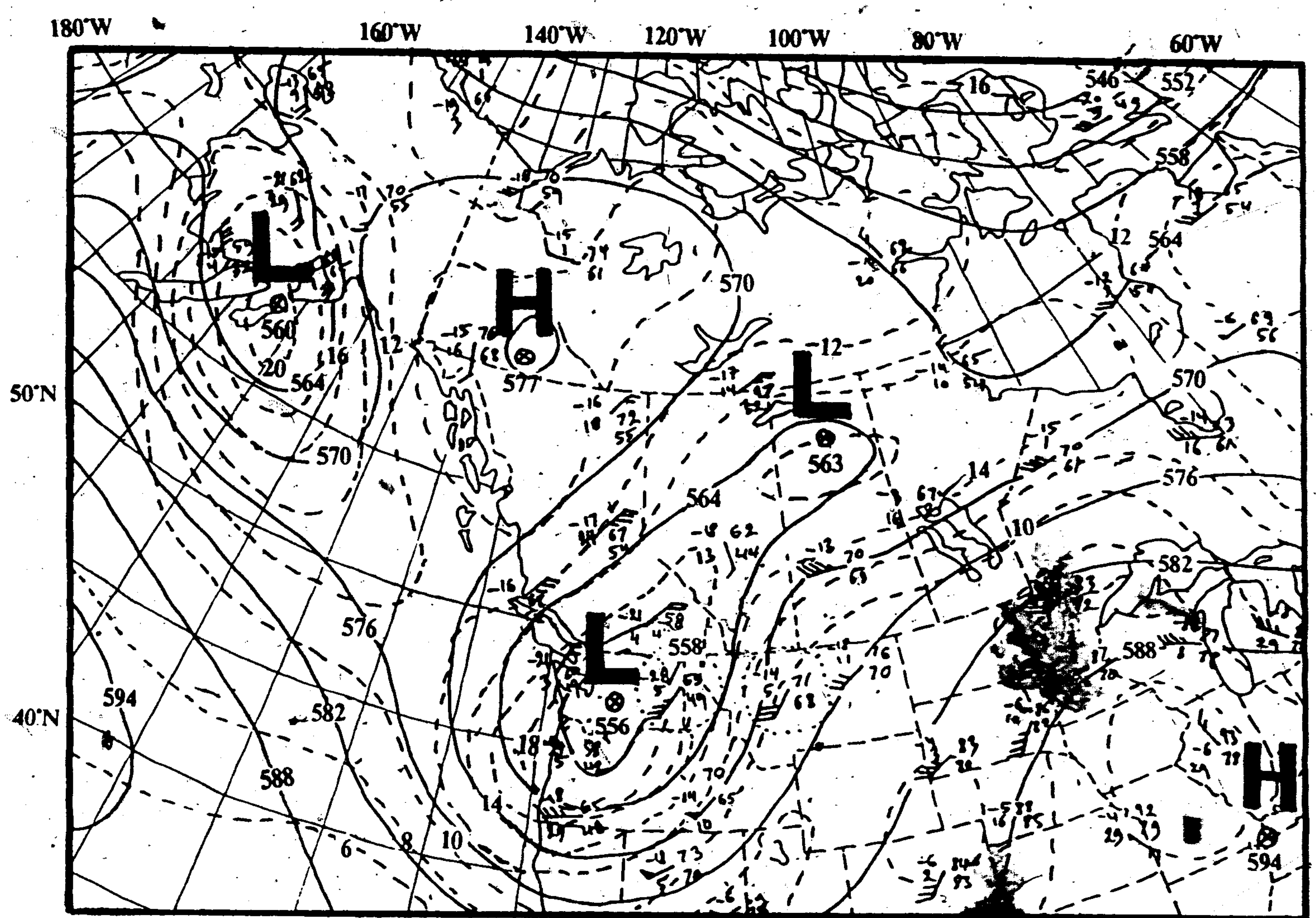


Figure 4.2 500-mb map for 1200Z July 16, 1986. Redrawn CMC height and vorticity analysis [illegible] lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ ra[illegible].

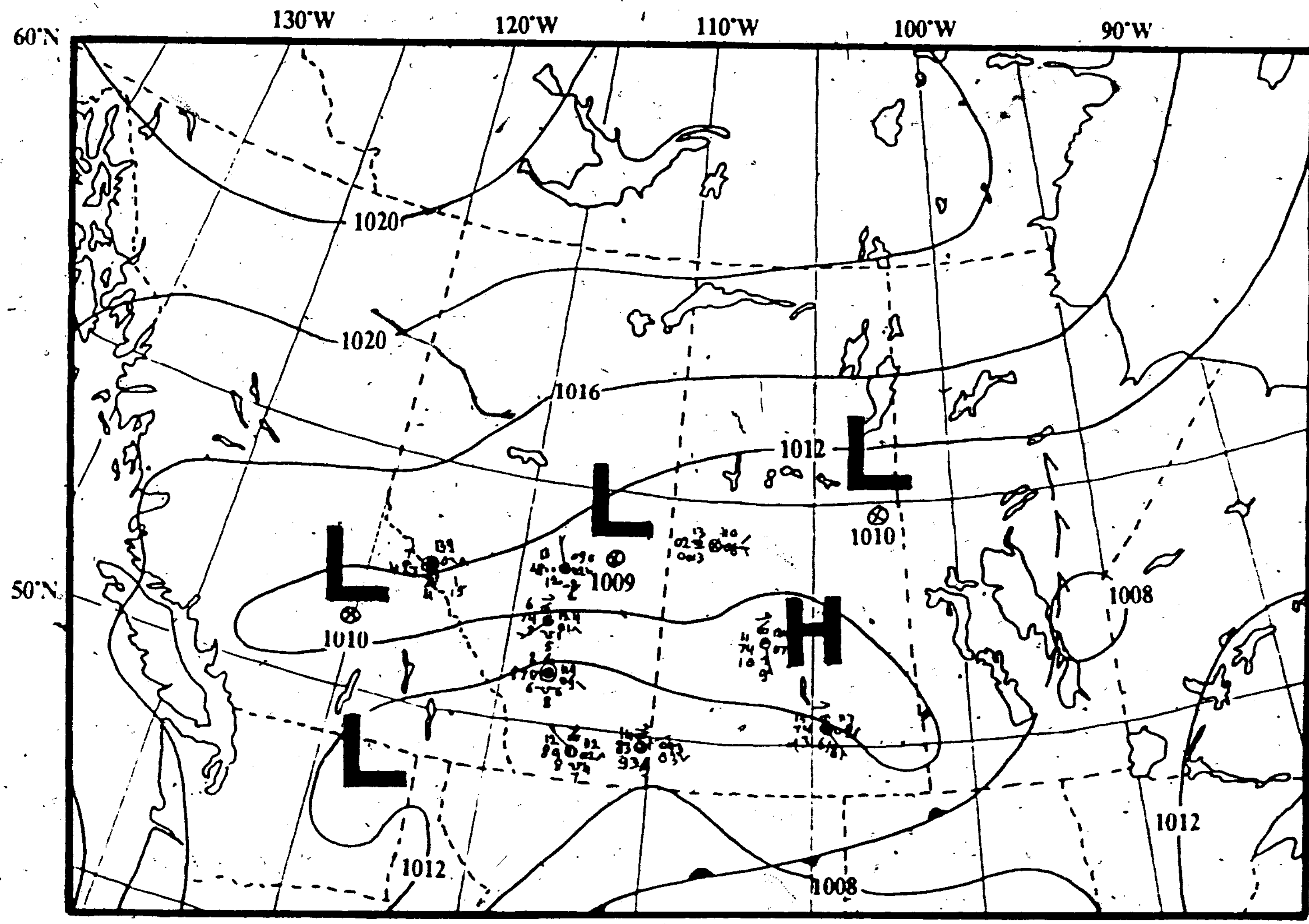


Figure 4.3 Surface Analysis map for 1200Z July 16, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

Figure 4.4 Infrared Image of July 16, 1986 at 2105-2121Z, NOAA-9 orbit 8202.

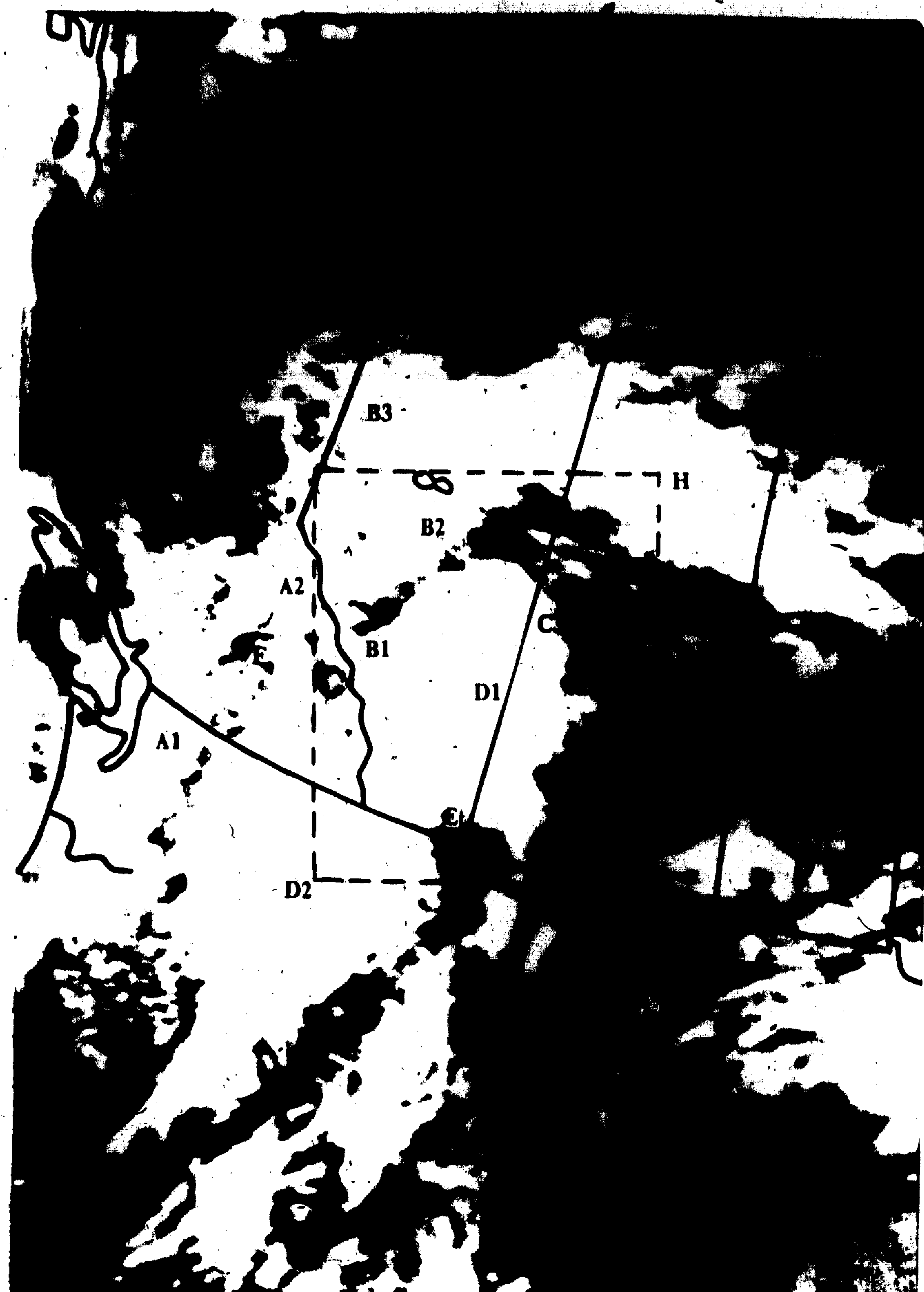


Figure 4.5 Visible Image of July 16, 1986 at 2105-2121Z, NOAA-9 orbit 8202.

4.2.2 July 17, 1986

By July 17, 0000Z (Fig. 4.6, 500-mb chart) the cold low (now filled to 558 dam), a the vorticity centre have moved north-northeastward at about 10 knots.

Twelve hours later (Fig. 4.7, 500-mb chart), the cold low has drifted northeastwa to the Washington-B.C. border at about 7 knots, its central depth unchanged at 558 da However, the vorticity centre has increased its speed to 23 knots as it rotated cyclonically the strong, southwesterly flow about the cold core.

The late-afternoon (0000Z) surface map is much more organized than the previ maps. Its most prominent feature is the long NW-SE trough, stretching from Central B.C.

of 12 km. The grey shades C1-C2 in the tail of the comma (IR, Fig. 4.10) indicate the top surface of a lower layer of the middle clouds, mostly As, but with higher turrets of Acc visible near C1. Both images also show the clearing zone D, an open area of low albedo containing a curved band of Ac and TCu, and a scattering of lower cumuliform cloud.

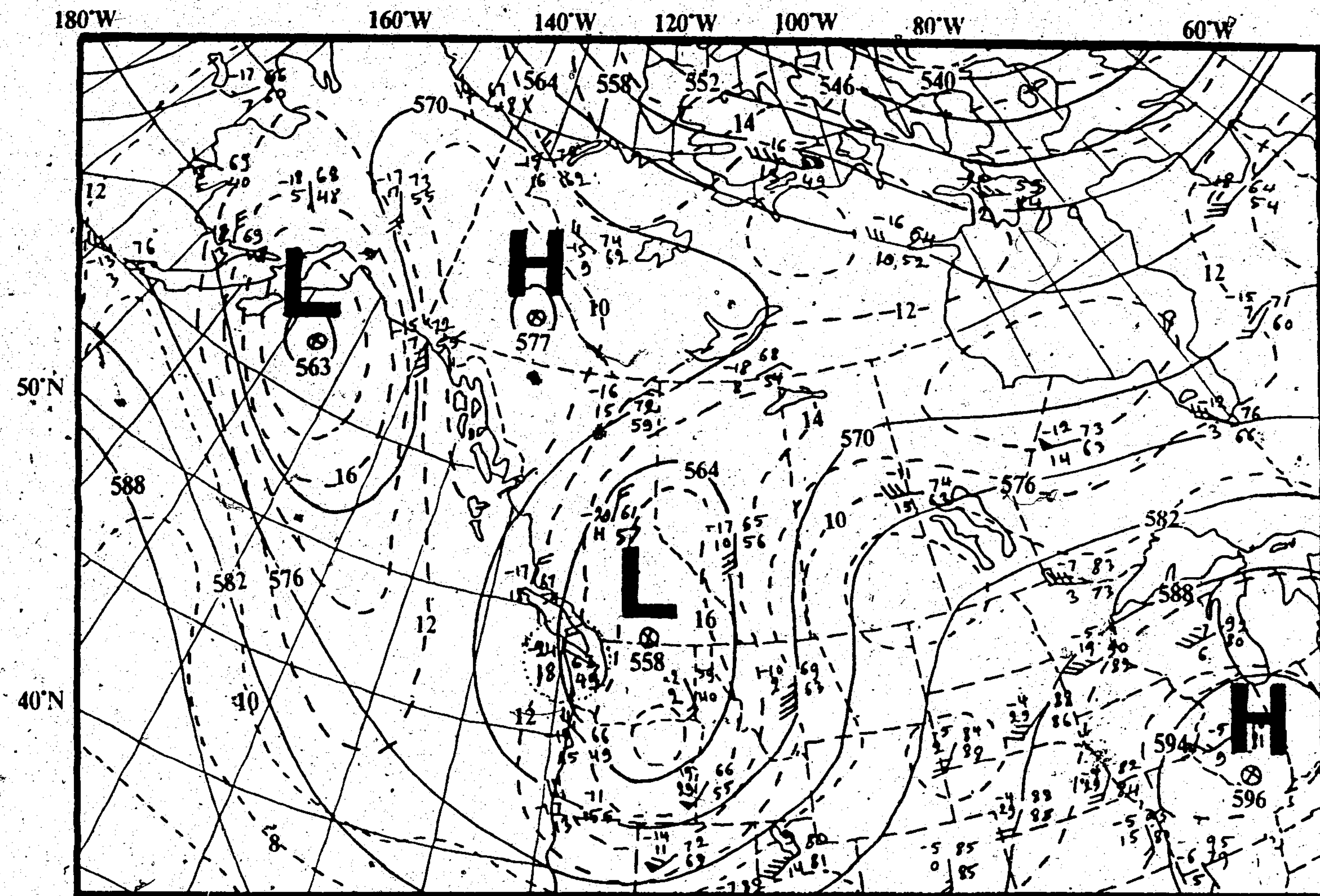


Figure 4.6 500-mb map for 0000Z July 17, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of 2×10^{-5} rad sec^{-1}.

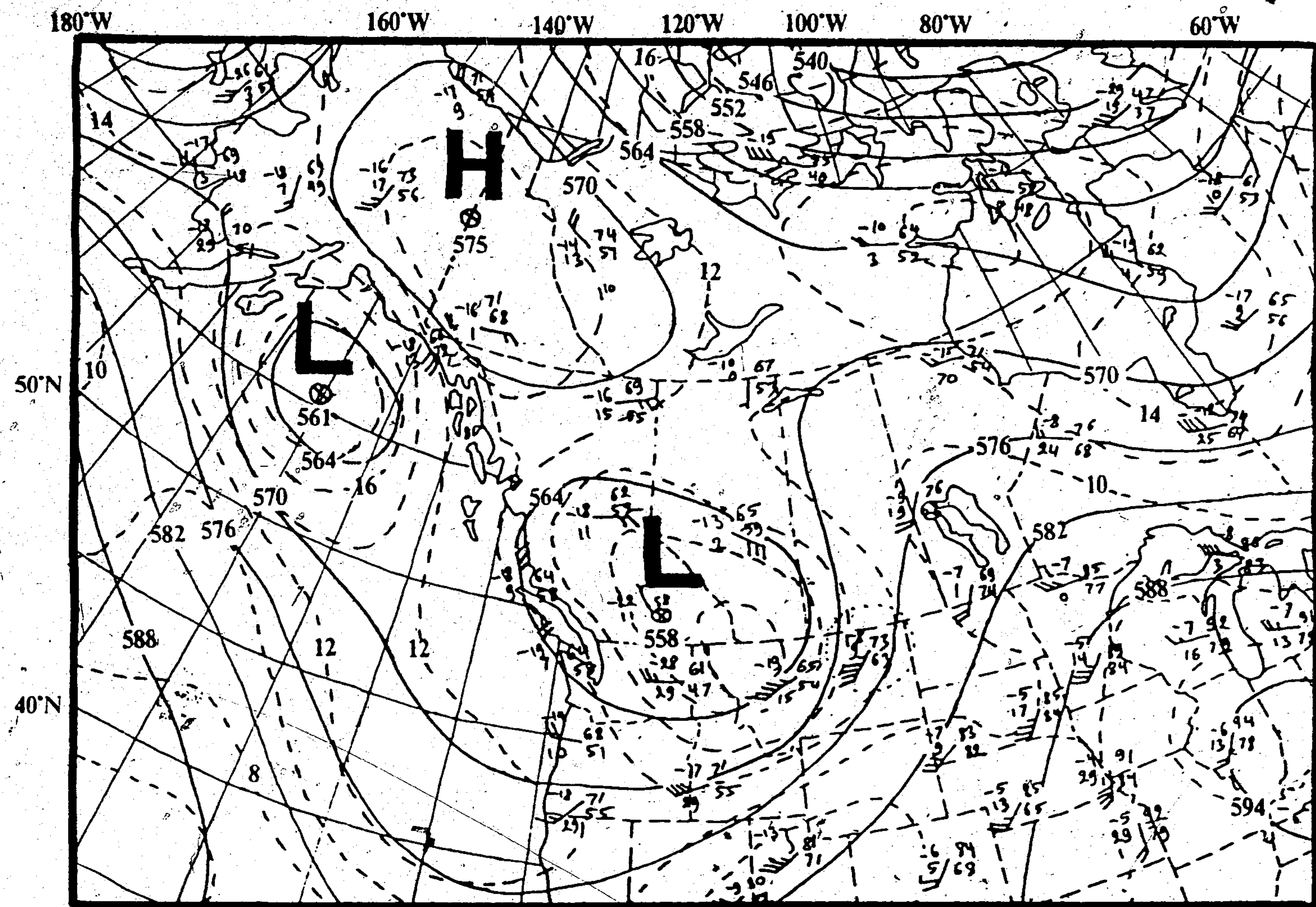


Figure 4.7 500-mb map for 1200Z July 17, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of 2×10^{-5} rad sec^{-1}.

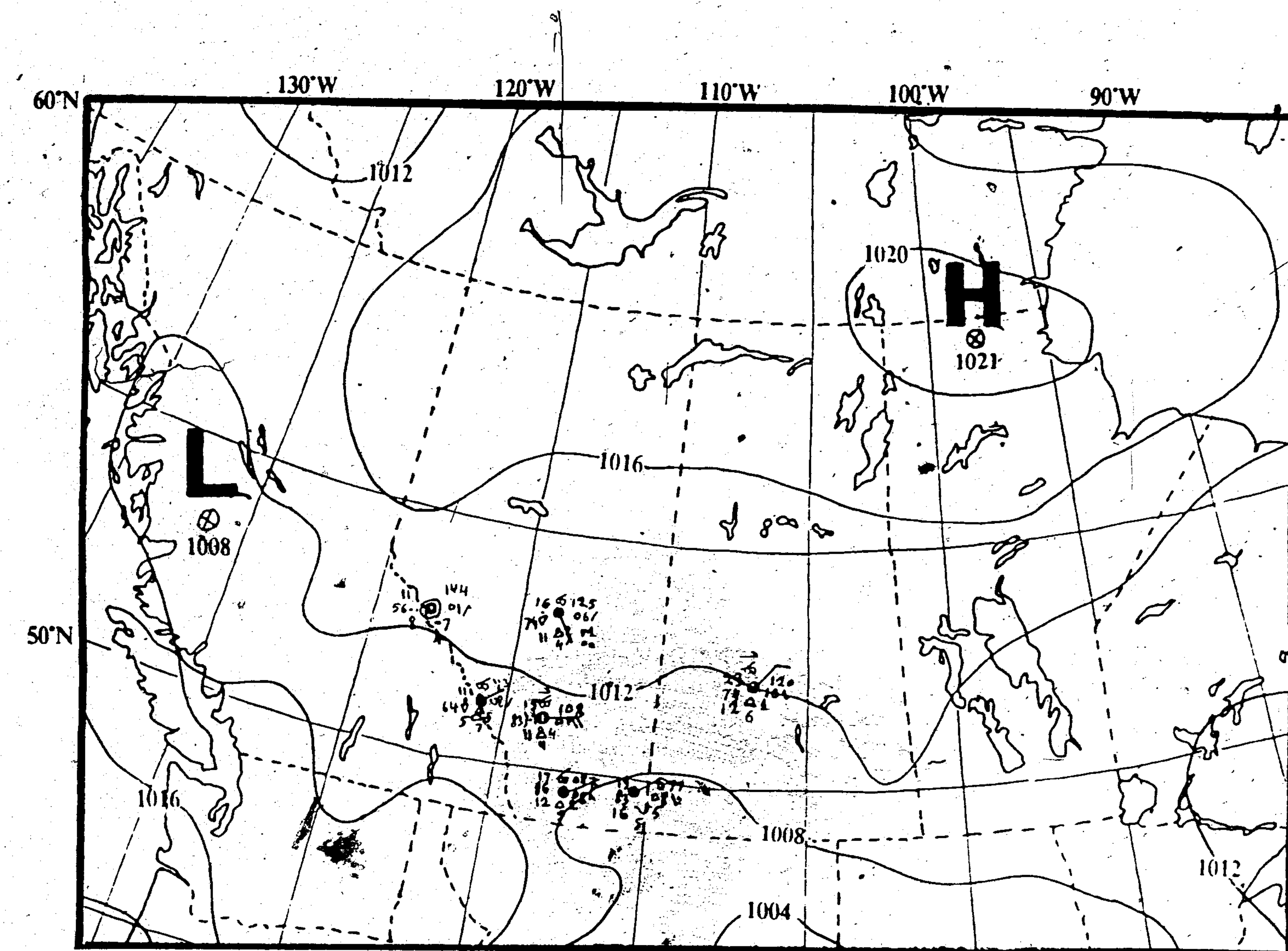


Figure 4.8 Surface Analysis map for 0000Z July 17, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

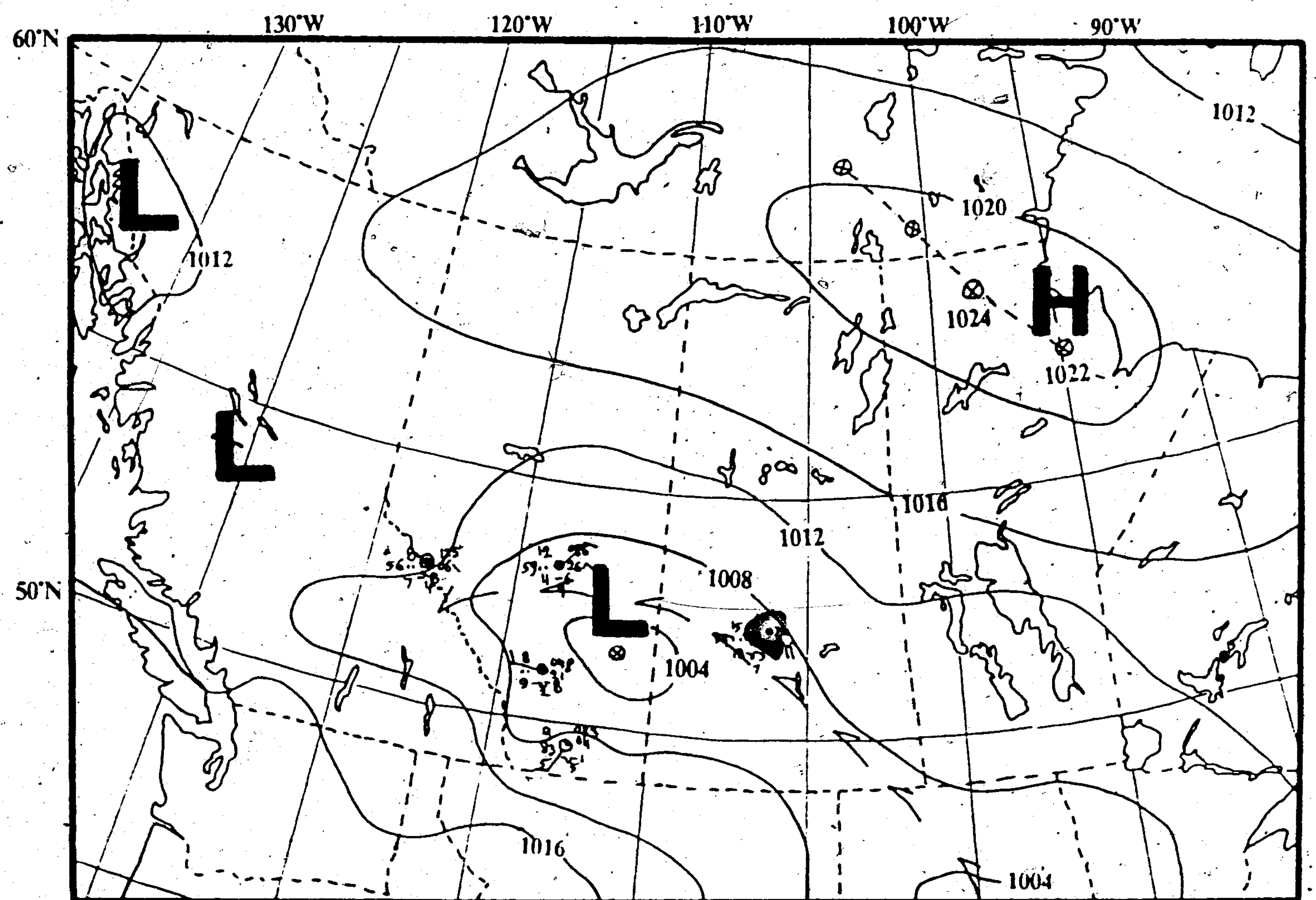


Figure 4.9 Surface Analysis map for 1200Z July 17, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

Figure 4.10 Infrared Image of July 17, 1986 at 2054-2110Z, NOAA-9 orbit 8216.

Figure 4.11 Visible Image of July 17, 1986 at 2054-2110Z, NOAA-9 orbit 8216.

4.2.3 July 18, 1986

During the next 12 hours the cold low suddenly deepened to 552 dam, intensifying as it crossed the Rocky Mountains near Pincher Creek at 29 knots, while the vorticity centre lagged behind at 22 knots. By late afternoon (0000Z, July 10) the cold core has passed to the east of Edmonton (Fig. 4.12). Continuing eastward, the cold core reached Saskatchewan by early morning (Fig. 4.13), the system has now entered the dissipating stage, filling rapidly and becoming absorbed into the major long-wave trough dominant in the Hudson Bay-Lake Winnipeg ~~region~~.

The surface maps for this period (Figs. 4.14 and 4.15) reflect and closely follow the events in the upper air. In phase with the cold-core intensification, the surface centre has reached maximum develpoment by 0600Z, July 18 (chart not shown) but thereafter, though grown in size, the low has entered a guiescent stage as it moved rapidly toward Hudson Bay.

The satellite images from the afternoon pass of NOAA-9 (Figs. 4.16 and 4.17) show the well advanced breakup of the storm. The spreading canopy of the comma cloud is still discernable over northern Manitoba and Hudson Bay, ending in a diffuse tail west of James Bay. A large, generally clear area, has opened up to the southwest.

The small, circular dark area near E marks the eye of the aging cyclonic system. The convoluted, bright region CF in both images represents the remains of the comma head-cold, high cloud of Cb tops and embedded, cells of Cb and Cu⁺.

Bright (and cold) cyclonic streamers of Cirrus are visible in the IR (Fig. 4.16) over northern Saskatchewan and eastern Alberta. Below the Cirrus (and best seen in the visible-band image, Fig. 4.17) are numerous cellular masses of Sc, Cu, Cu⁺ and Cb. This convective cloud developed in the northerly flow of a cold, unstable air mass, the result of cold-air advection in the wake of the storm.

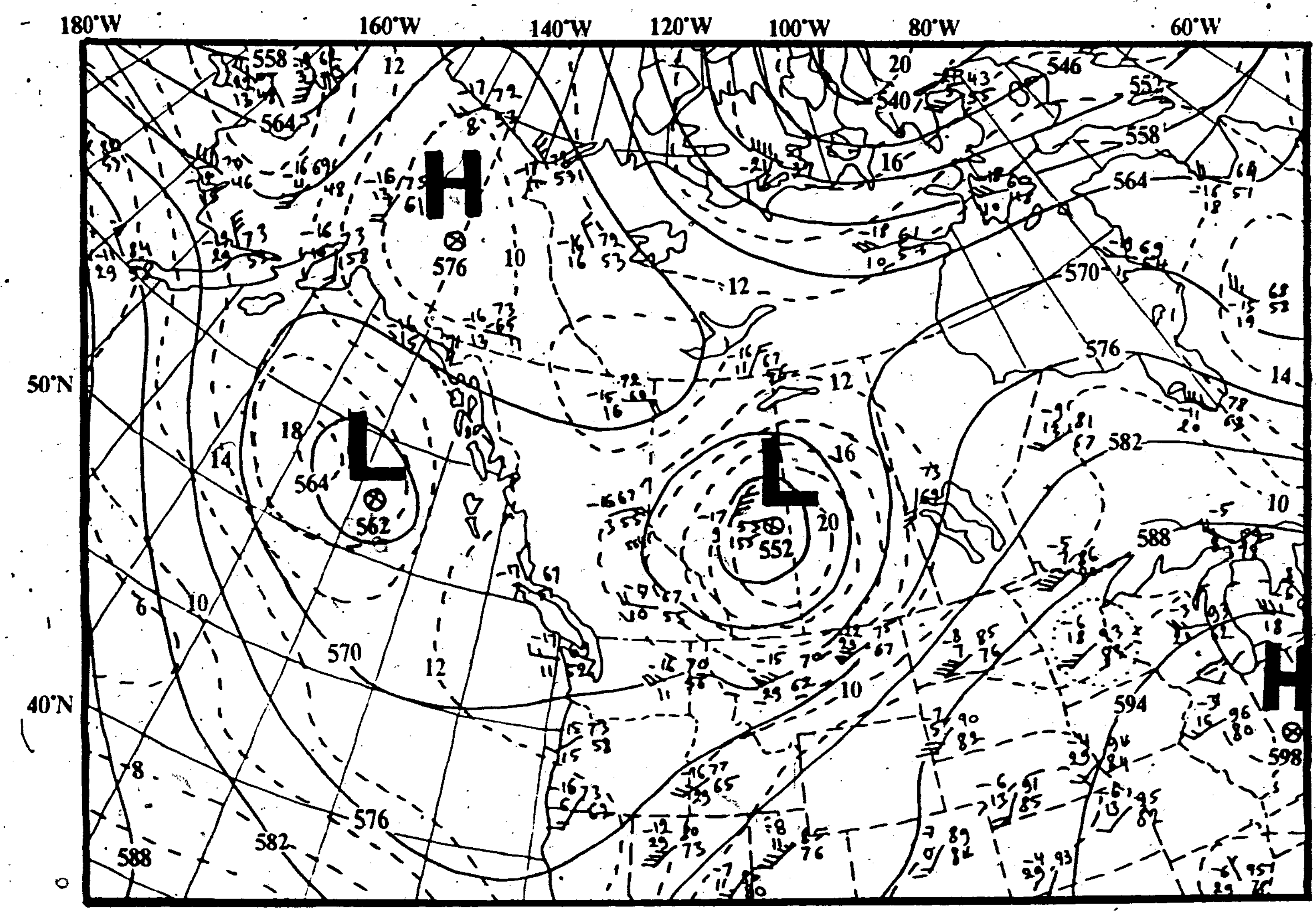


Figure 4.12 500-mb map for 0000Z July 18, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

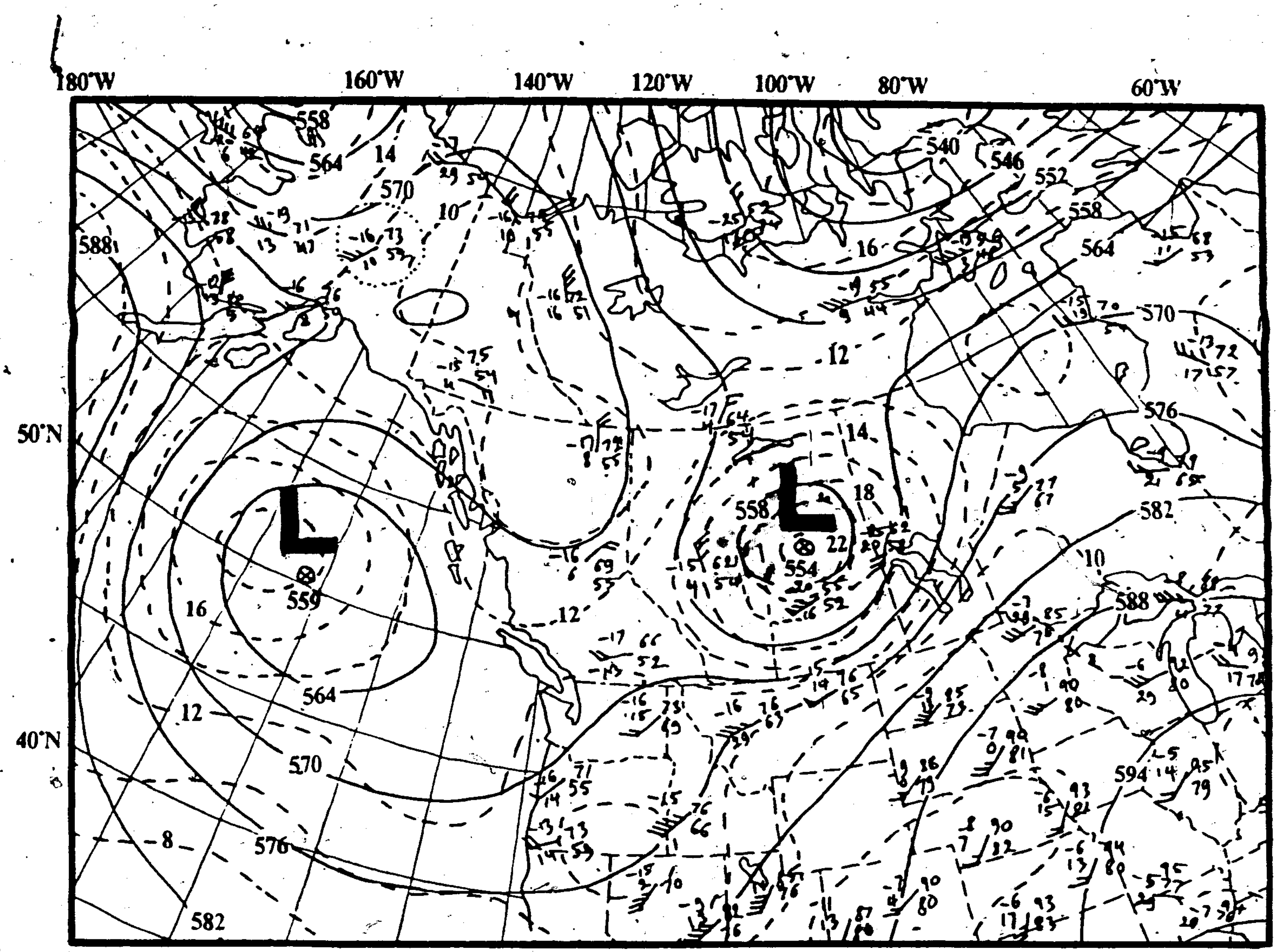


Figure 4.13 500-mb map for 1200Z July 18, 1986. Redrawn CMC height and vorticity analysis. Solid lines are geopotential height contours at 60 m intervals. Dashed lines are vorticity contours at intervals of $2x10^{-5}$ rad sec^{-1}.

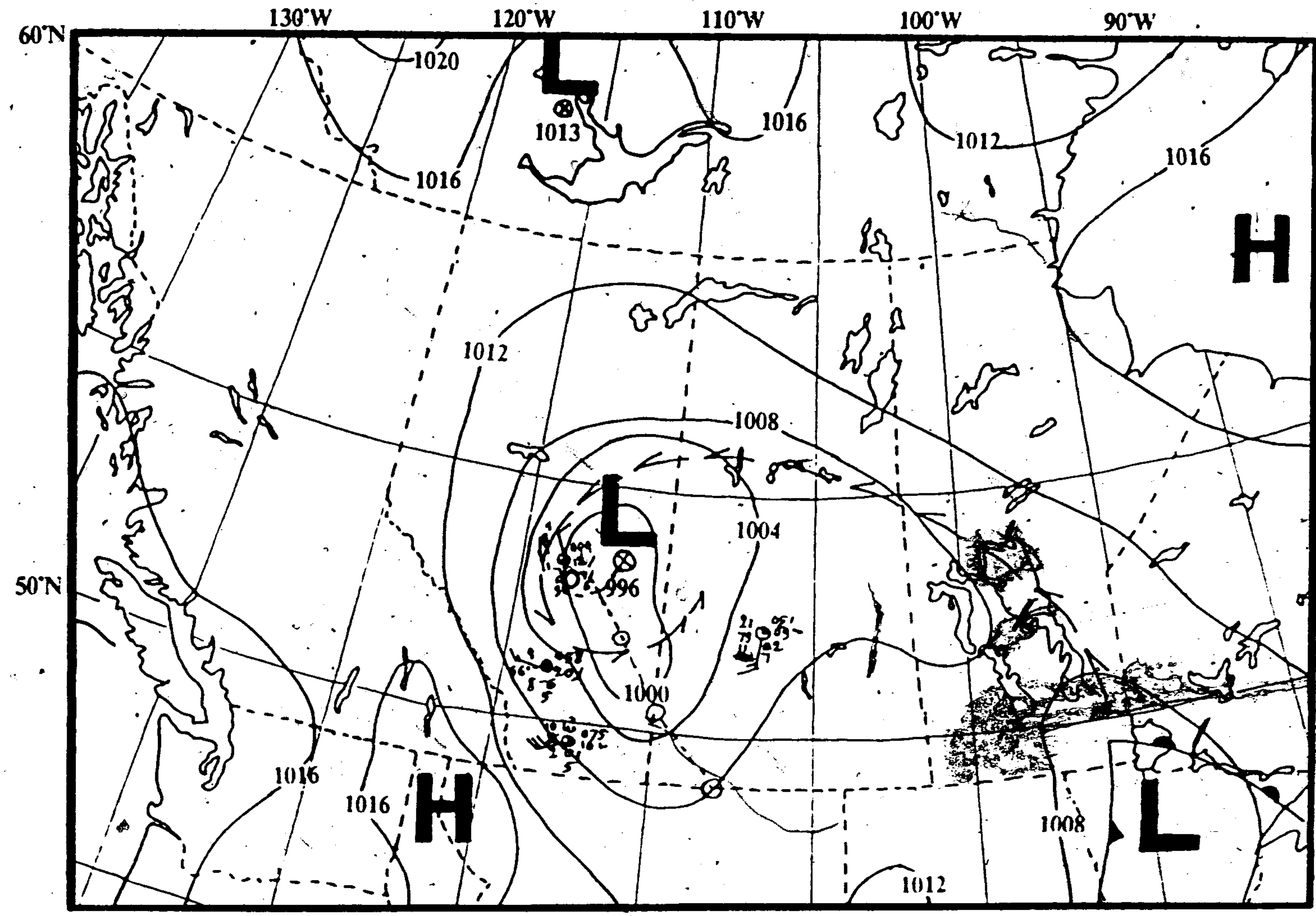


Figure 4.14 Surface Analysis map for 0000Z July 18, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

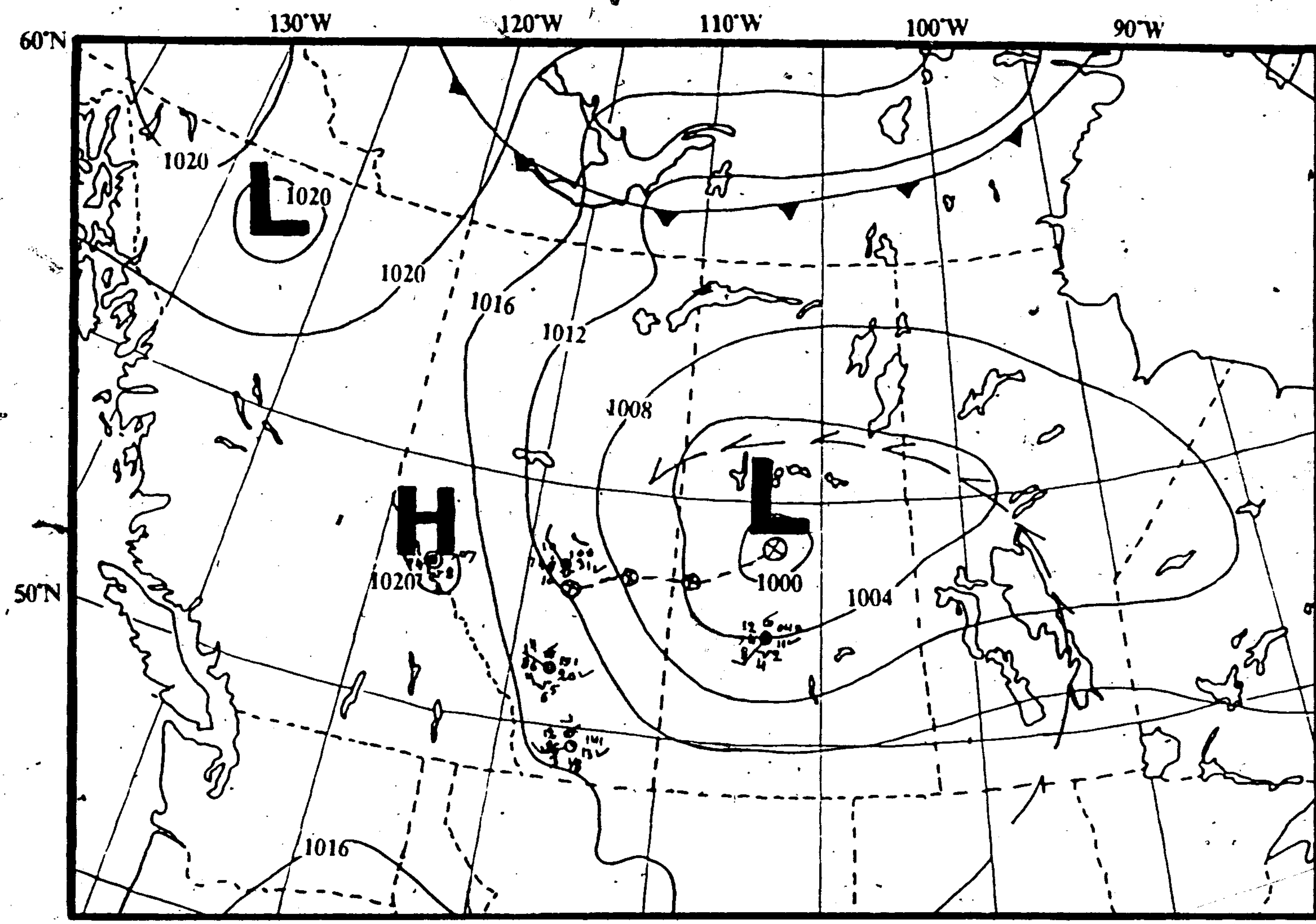


Figure 4.15 Surface Analysis map for 1200Z July 18, 1986. Redrawn AWC Sea-level isobars at 4 mb intervals.

Figure 4.16 Infrared Image of July 18, 1986 at 2044-2059Z, NOAA-9 orbit 8230.

Figure 4.17 Visible Image of July 18, 1986 at 2044-2059Z, NOAA-9 orbit 8230.

4.3 Numerical Analysis and Graphical Display of the July Storm

The equivalences introduced in Chapter 3 are still considered to be valid in July, even though the convective clouds in mid-summer are likely to be more numerous and build up to greater altitudes. Most active Cbs reach or even penetrate the tropopause which over Edmonton (Stony Plain), before the arrival of the cold core, was located at a height of 11.2 km. Radiosondes sampling the cold core, such as at Vernon B.C. (see Fig. 4.21) measured the tropopause at 8.5 km.

Surface temperatures in the warm, largely clear areas would also be higher in July than in May. This in turn would normally lead to higher dewpoints and increasing moisture in a warmer and convectively unstable air mass. These differences are important and have been considered in the analysis of the July storm.

Heavy snow, not unknown in July, fell on the higher ground of the western foothills, but on the open prairie most of the precipitation come in the form of rain and occasional streaks of hail.

4.3.1 July 16, 1986

The thermal and brightness features within the squares outlined in the satellite images of Figures 4.4 and 4.5 have been analysed and plotted in Figures 4.18 and 4.19, respectively.

The area shown does not contain the cold core itself, but a large complex of cloud, covering much of east-central Alberta and Saskatchewan. This thick and very bright mass has cloud-top temperatures as low as -55°C, an indication that most of it extends right to the tropopause level. Judging by the surface reports, the cloud complex was made up of a thick layer of Ac and Acc, interspersed with numerous TCu and Cbs. Frequent showers and thunderstorms were experienced in all districts throughout the day, with the heaviest rain in the Edmonton-Whitecourt region, and snow in the foothills.

The isotherm and brightness patterns also hint at the formation of the comma cloud. The broad, warm sector in Saskatchewan (surface temperatures 25 - 28°C) narrows and curves westward toward Edmonton and Banff, indicating the presence of a southeasterly circulation in advance of the approaching cold low, and the influx of warm, moist air.

The 3-D representation of the thermal field (Fig. 4.20) shows the extent and texture of the cloud complex, with many peaks projecting to the -55°C tropopause level. Also shown clearly is the steep "cliff" of the cloud bank (in the vicinity of the 114°W meridian) and the steep descent to the lower deck of much warmer cloud to the west. The warmest surface air is present in southern Saskatchewan, with maximum values as high as 28.8°C

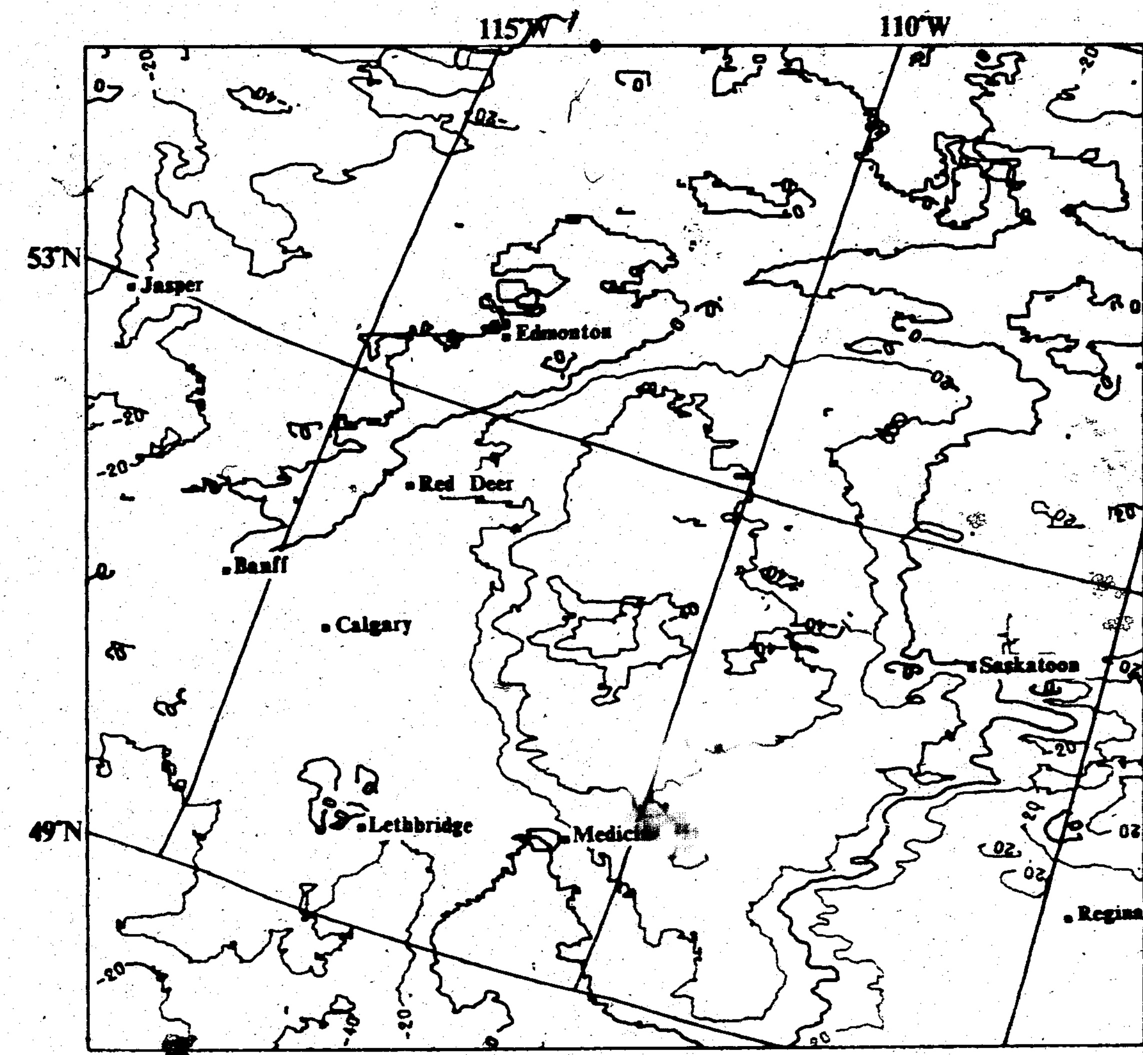


Figure 4.18 IR-derived isotherms for July 16, 1986 at 2105-2121Z, NOAA-9 orbit 8202, temperature (T) in °C, with isotherm interval 20°C.

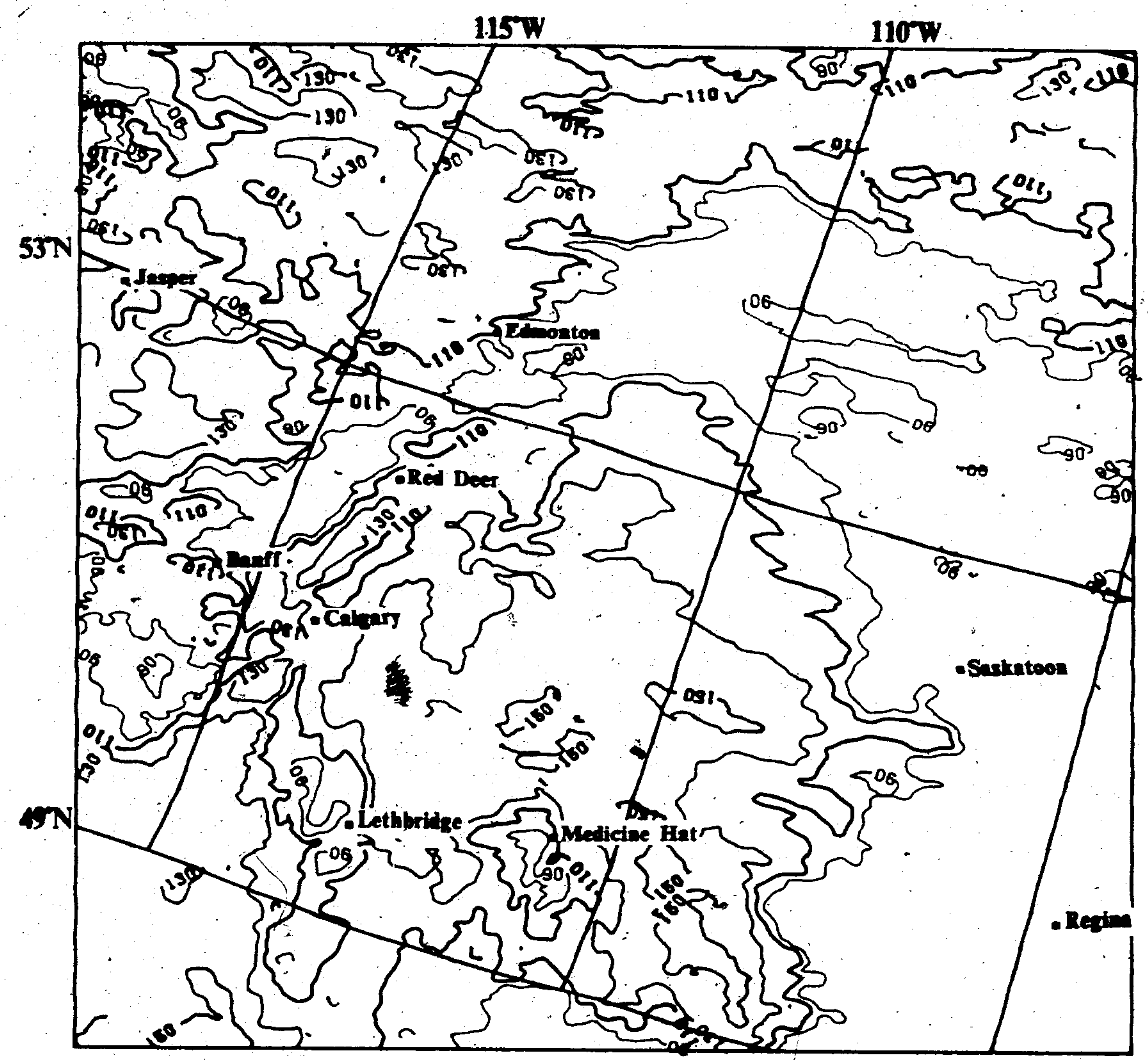


Figure 4.19 Brightness isopleths for July 16, 1986 at 2105-2121Z, NOAA-9 orbit 8202, isopleth interval 20 counts.

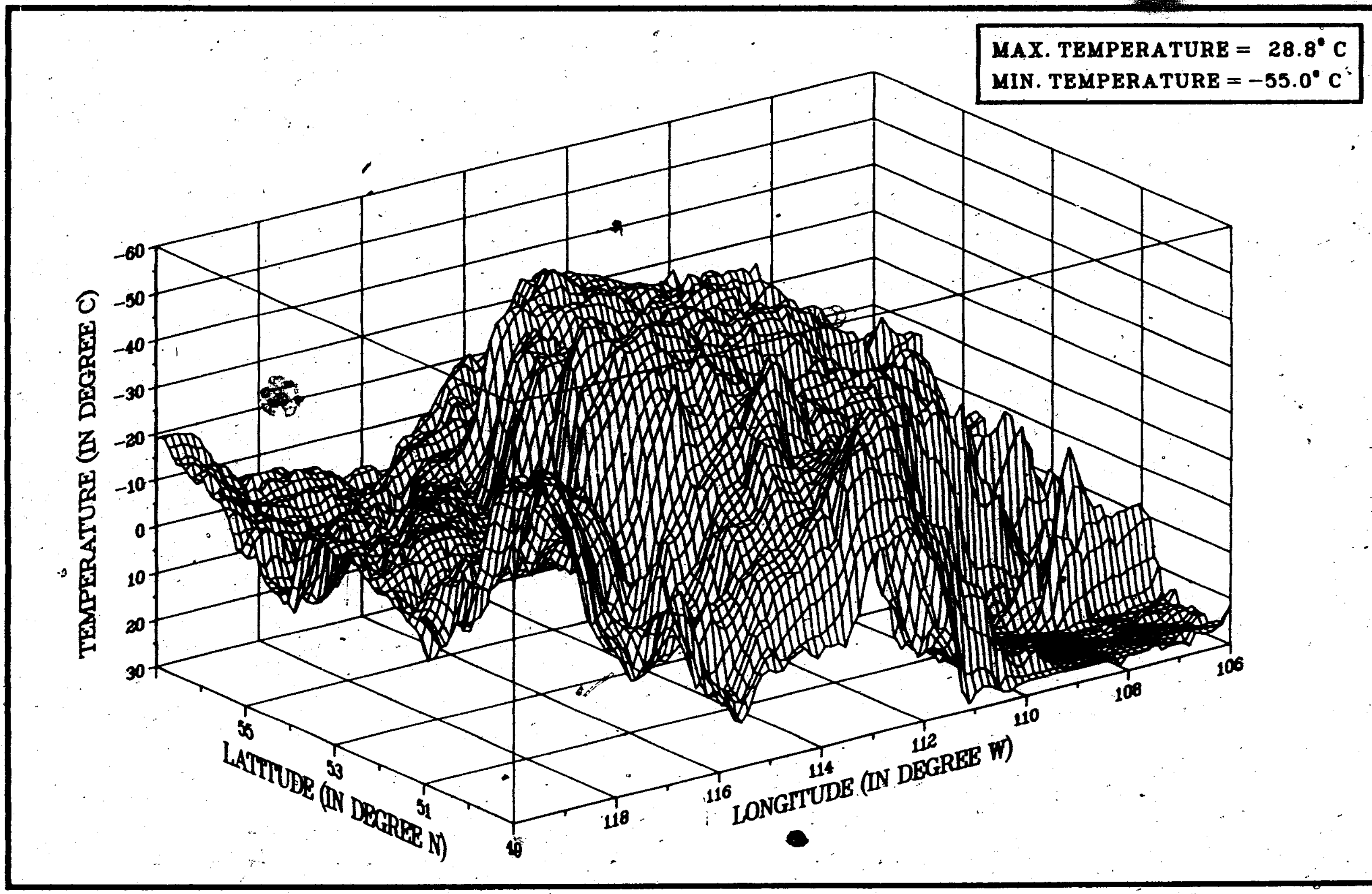


Figure 4.20 IR-derived 3 Dimensional temperature field of the cold-low area (49-57°N, 106-120°W) for July 16, 1986 at 2105-2121Z, NOAA-9 orbit 8202.

4.3.2 July 17, 1986

The now "classical" open spiral of the comma cloud is the dominant feature in Figs. 4.22 and 4.23, the thermal and brightness plots of the area marked on the respective images of Fig. 4.10 and 4.11. The storm, though still well organized and mature, has however gone past the stage of maximum development when judged by the size of the precipitation area. This is shown better on the series of radar scans, presented in Section 4.4.

The brightest, thickest and coldest cloud extends in a well-formed arc from the comma head SE of Calgary, to the west of Edmonton, then NE to the Cold Lake area and eastward into Saskatchewan. The prominent warm sector "dry slot" is particularly well defined in the brightness plot (Fig. 4.23) by the sharp edge of the cloud curving through Saskatchewan. Distinct bands of cumuliform cloud are visible in the northern and western rim of the warm sector.

The IR-derived plot of Fig. 4.24 shows most of the spiral, including the extensive, high bank of the main complex to the north and east, topped by many peaks and turrets at temperatures lower than -55°C. The massive cloud composing the head of the comma is separated from it by a col, and hides from view the steep western bar [illegible] f the warm-sector.

As mentioned earlier with respect to tropopause heights, Fig. 4.21, the 1200Z radiosonde plot from Vernon, B.C., is of interest in that it shows an ascent close to the cold core. It will be noted that, except for some mid-level moisture in the 750 - 700-mb layer, the air mass is very dry above 600 mb. This is an indication that the moisture flux feeding the storm came from the southeast (i.e. Saskatchewan) rather than from the cold core.

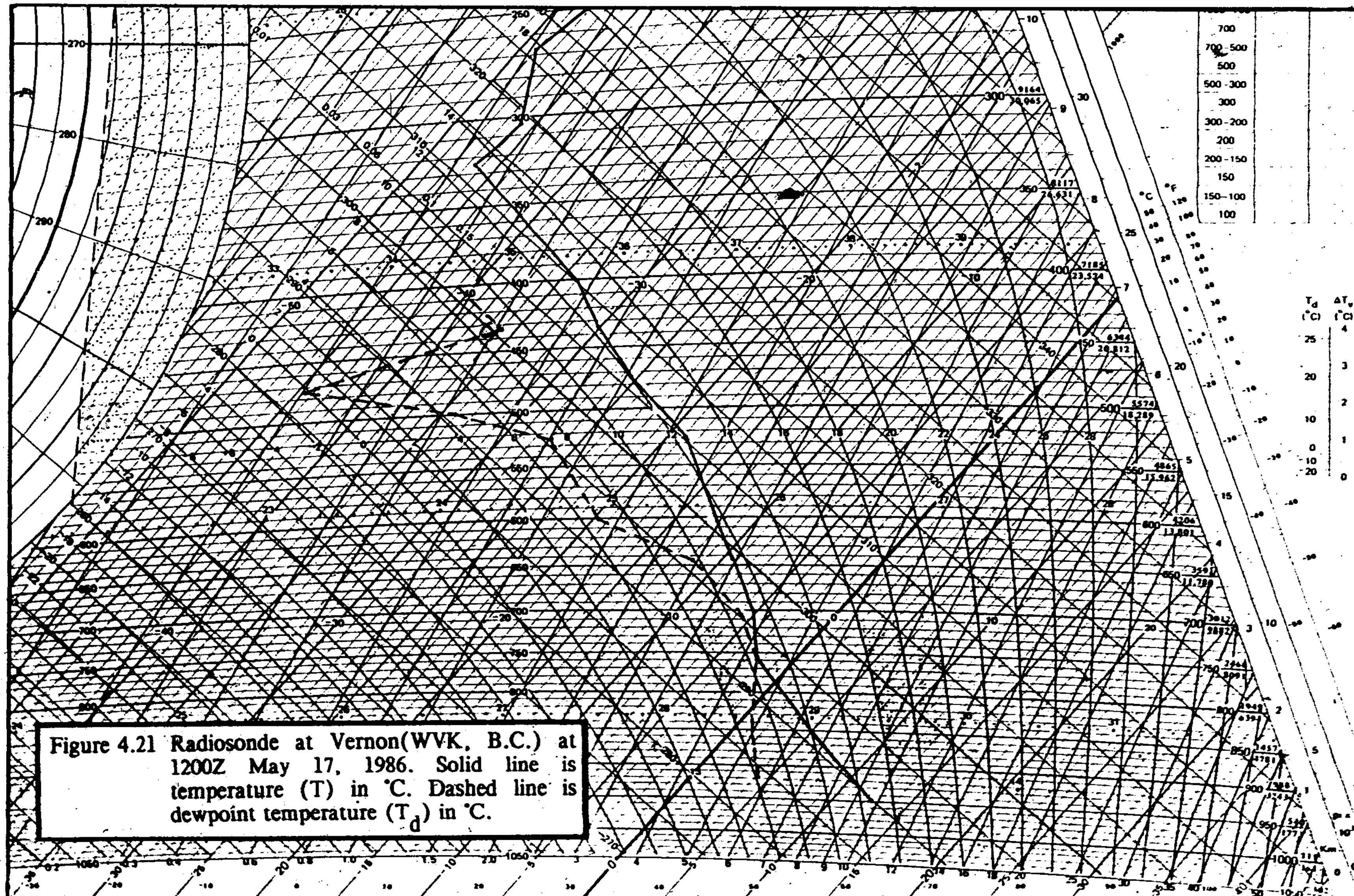


Figure 4.21 Radiosonde at Vernon(WVK, B.C.) at 1200Z May 17, 1986. Solid line is temperature (T) in °C. Dashed line is dewpoint temperature (T_d) in °C.

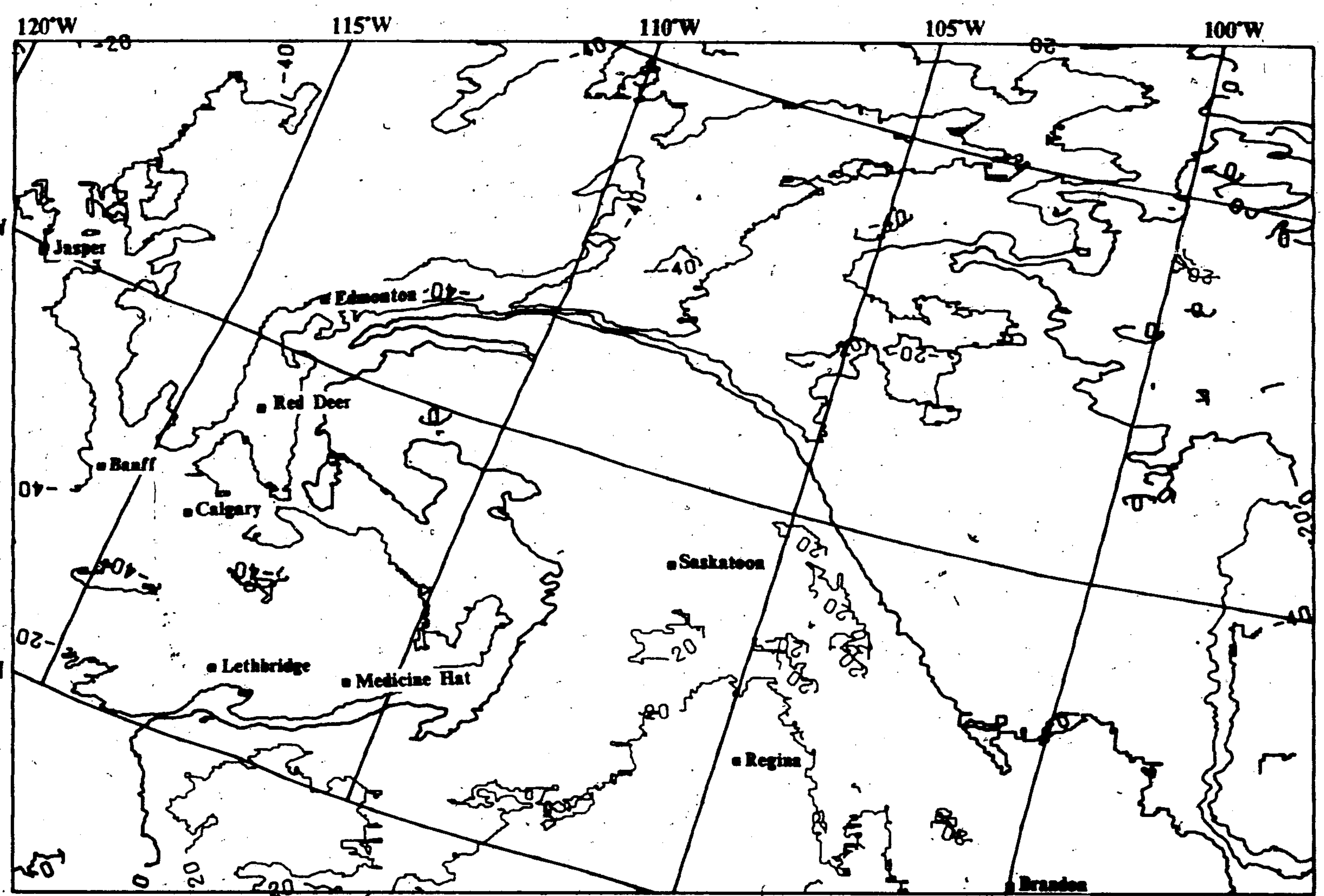


Figure 4.22 IR-derived isotherms for July 17, 1986 at 2054-2110Z, NOAA-9 orbit 8216, temperature (T) in °C, with isotherm interval 20°C.

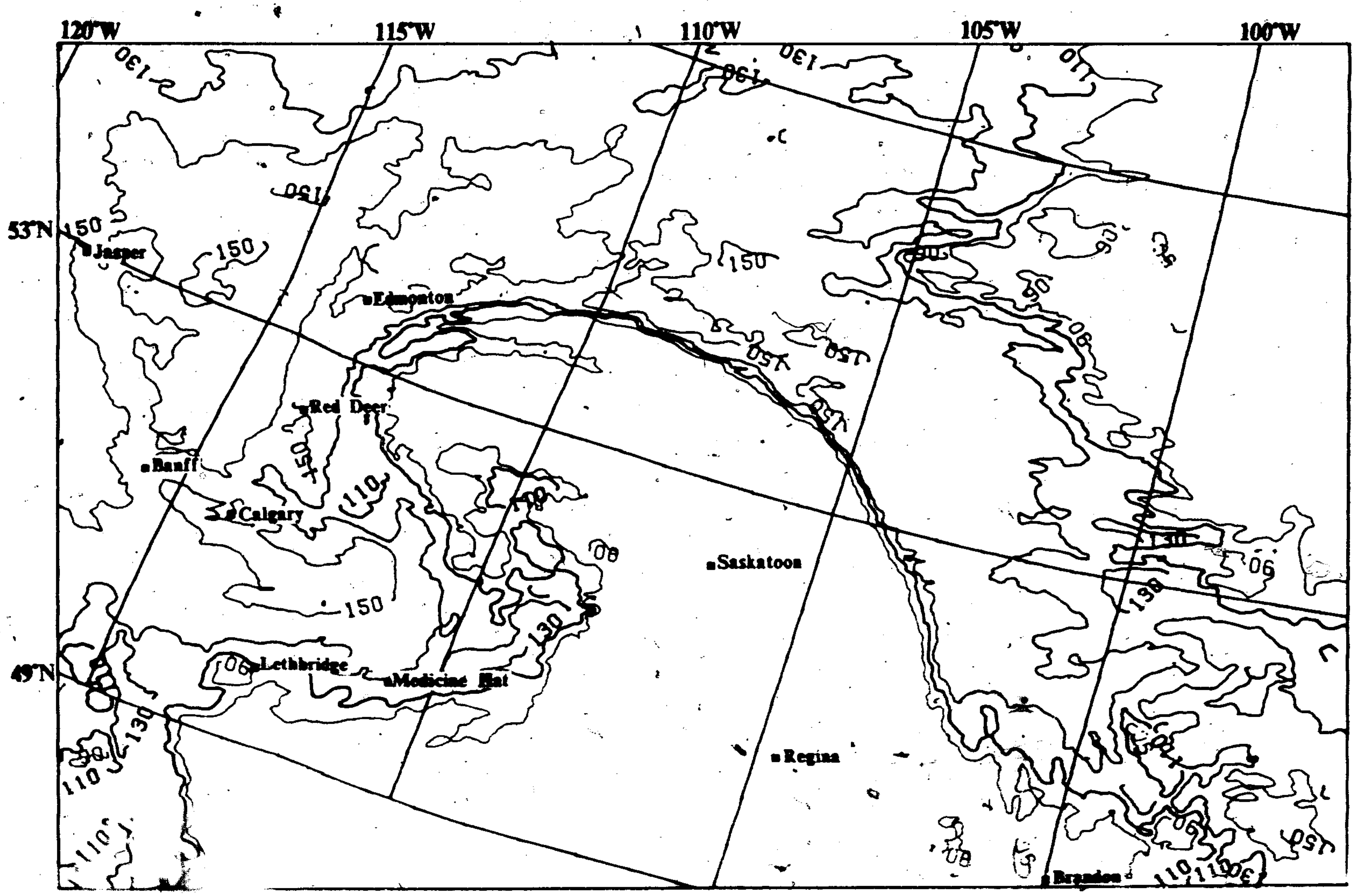


Figure : Brightness isopleths for July 17, 1986 at 2054-2110Z, NOAA-9 orbit 8216, isopleth interval 20 counts.

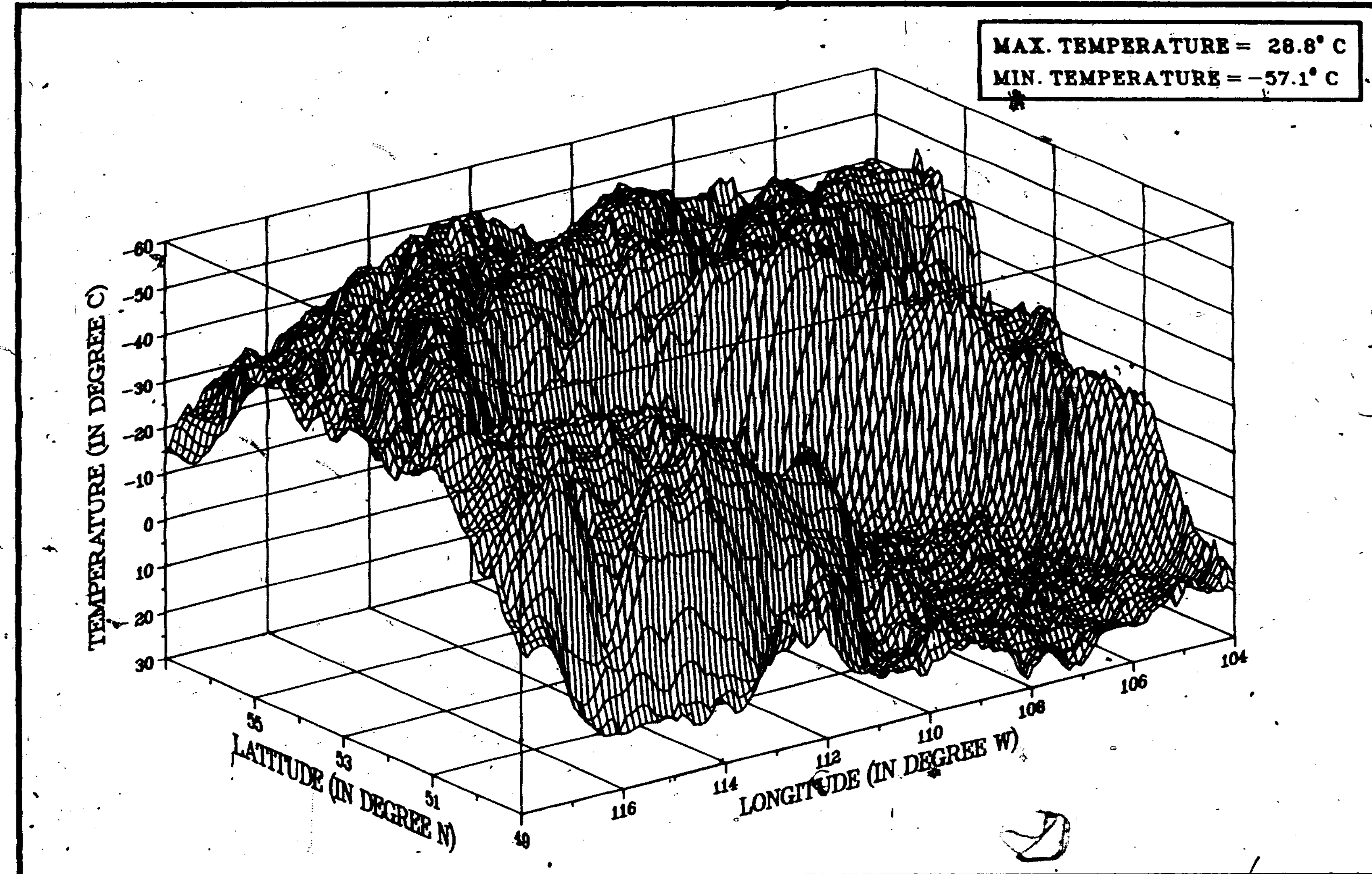


Figure 4.24 IR-derived 3 Dimensional temperature field of the cold-low area (49-57°N, 104-118°W) for July 17, 1986 at 2054-2110Z, NOAA-9 orbit 8216.

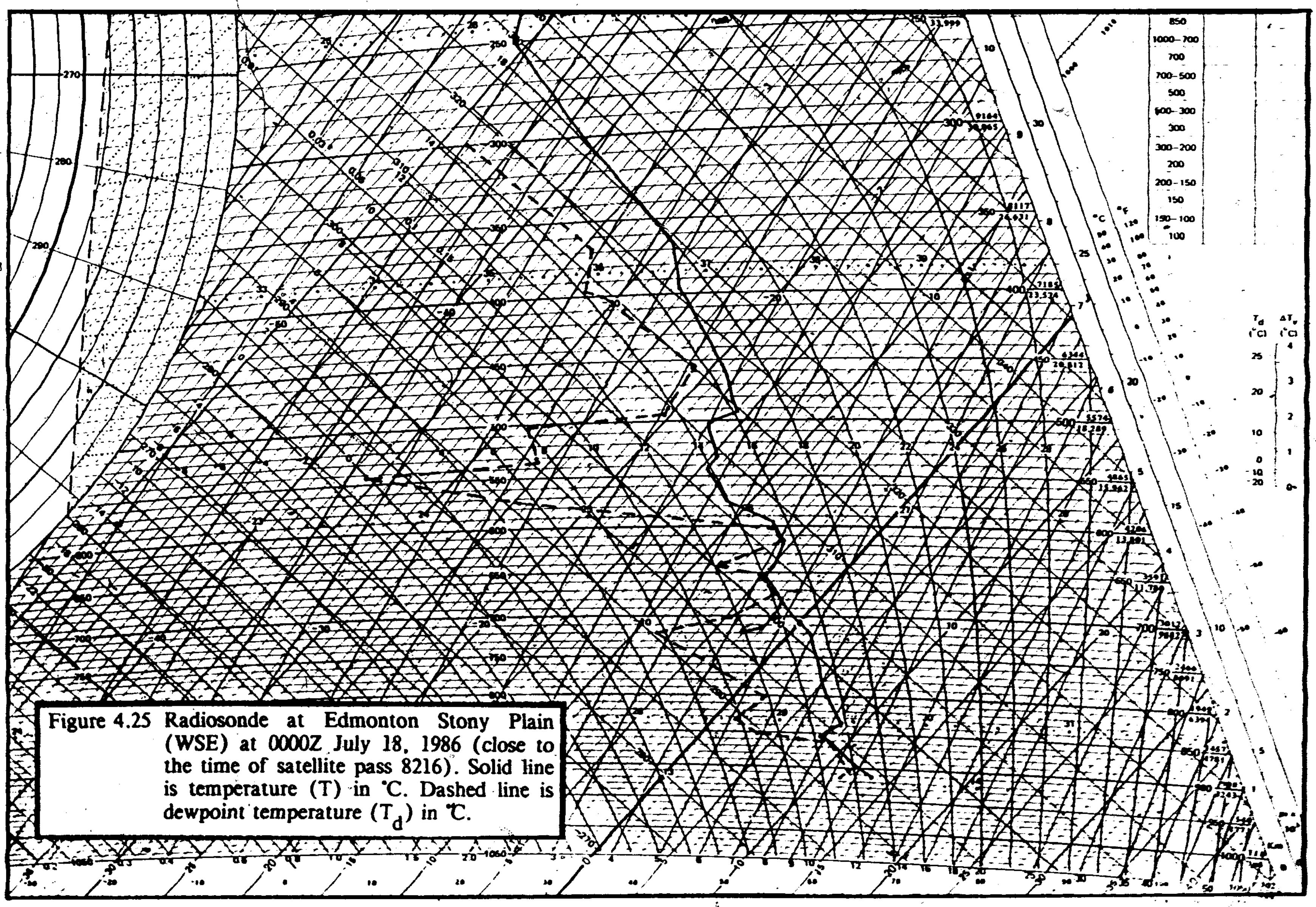


Figure 4.25 Radiosonde at Edmonton Stony Plain (WSE) at 0000Z July 18, 1986 (close to the time of satellite pass 8216). Solid line is temperature (T) in °C. Dashed line is dewpoint temperature (T_d) in °C.

4.3.3 July 18, 1986

By 0000Z, July 18 (18:00 MDT, July 17) the cold core had crossed the Rockies, slipped to the south of Edmonton, and superimposed itself onto the surface low. Thereafter, the combined system accelerated and moved rapidly across Saskatchewan, as the cold core began to weaken. Twenty-four hours later (0000Z, July 19) it had all but dissipated and been absorbed into the long-wave trough over Manitoba.

The mid-afternoon July 18 advanced phase of the breakup is depicted in the thermal and brightness plots of Figs. 4.26 and 4.27. The principal cloud mass has moved to Manitoba and become associated with the long-wave trough. To the west, the skies are filled with broken clouds, most of it cumuliform, which developed in the cool, unstable air left in the wake of the storm. Many of these clouds have grown to the shower stage, and a few into active thunderstorms. Only vestiges of Ac and Cs are left behind, as reminders that the cold low has truly passed. The sounding from WSE (Fig. 4.26) on July 18, 0000Z (close to the time of the satellite pass 8216), indicates that cumuliform cloud (Fc, Cu, Sc) is present in the surface layer with tops to about 1.3 km (840 mb). A thin stable inversion layer extends for about 200 m above the unstable layer. Two saturated layers are also present between 670 - 650 mb and 620 - 600 mb. Thin broken decks of Ac and As are indicated with bases, respectively, at 3400 and 4000 metres and each about 200 m thick. A Cs layer has its base at 5.5 km and top at 6.3 km. The cloud-top temperature of this layer is at about -18°C, which is close to the satellite-derived temperature (about -20°C). The height of the tropopause is about 10.4 km. Decreasing dewpoints are characteristic of subsidence of the air mass in at least two layers, namely 1.5 to 2.8 km, and 4.2 to 4.8 km.

Figure 4.28, the 3-D representation of the thermal field, provides a parting view of what is left of the comma -- now an amorphous shape no longer as high and cold (just -49.1°C) as 24 hours earliers. Descending westward and breaking up into an assortment of cumulus and shower clouds which developed in the cooler air, it passes away as all storms must.

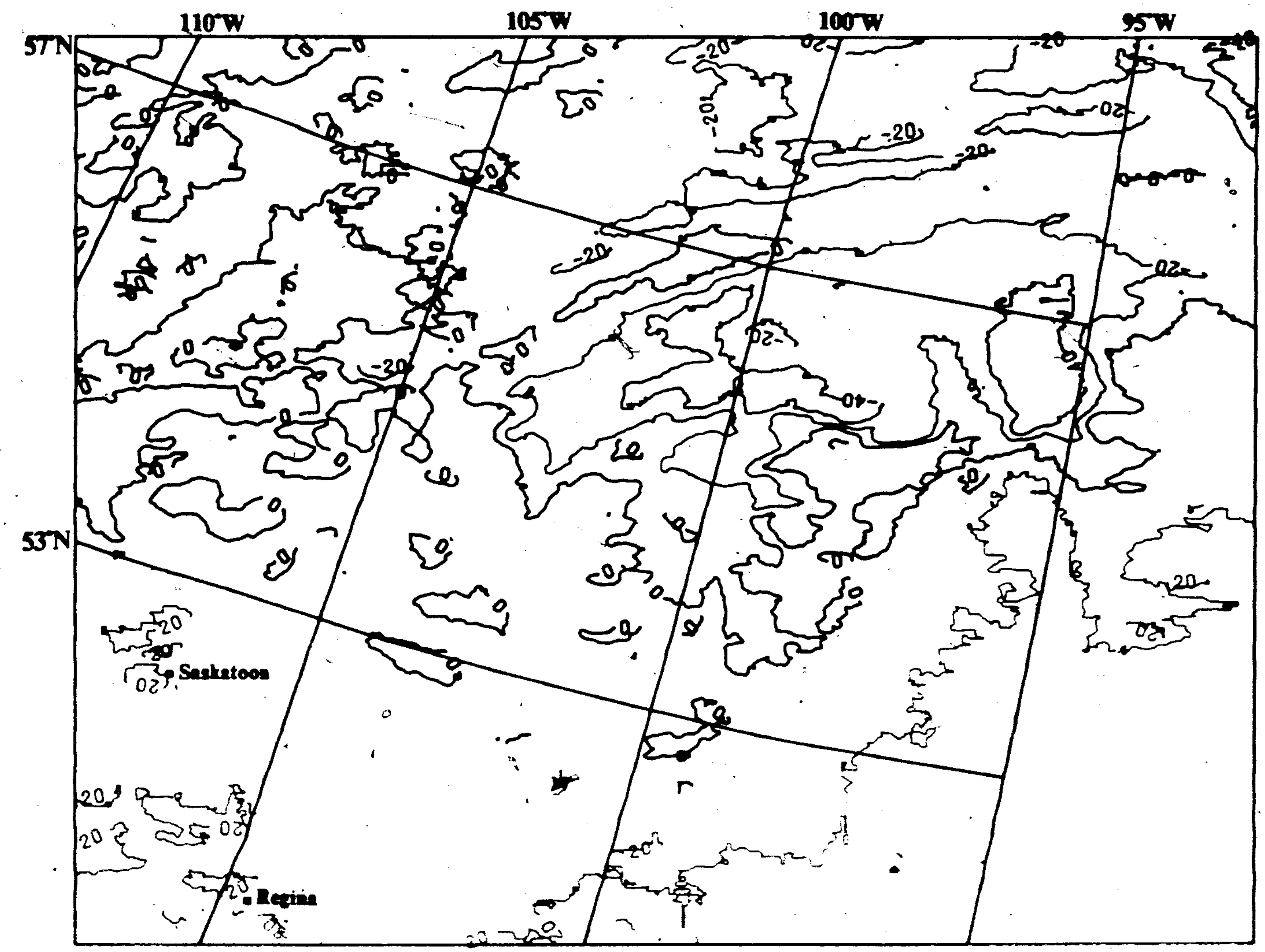


Figure 4.26 IR-derived isotherms for July 18, 1986 at 2044-2059Z, NOAA-9 orbit 8230, temperature (T) in °C, with isotherm interval 20°C.

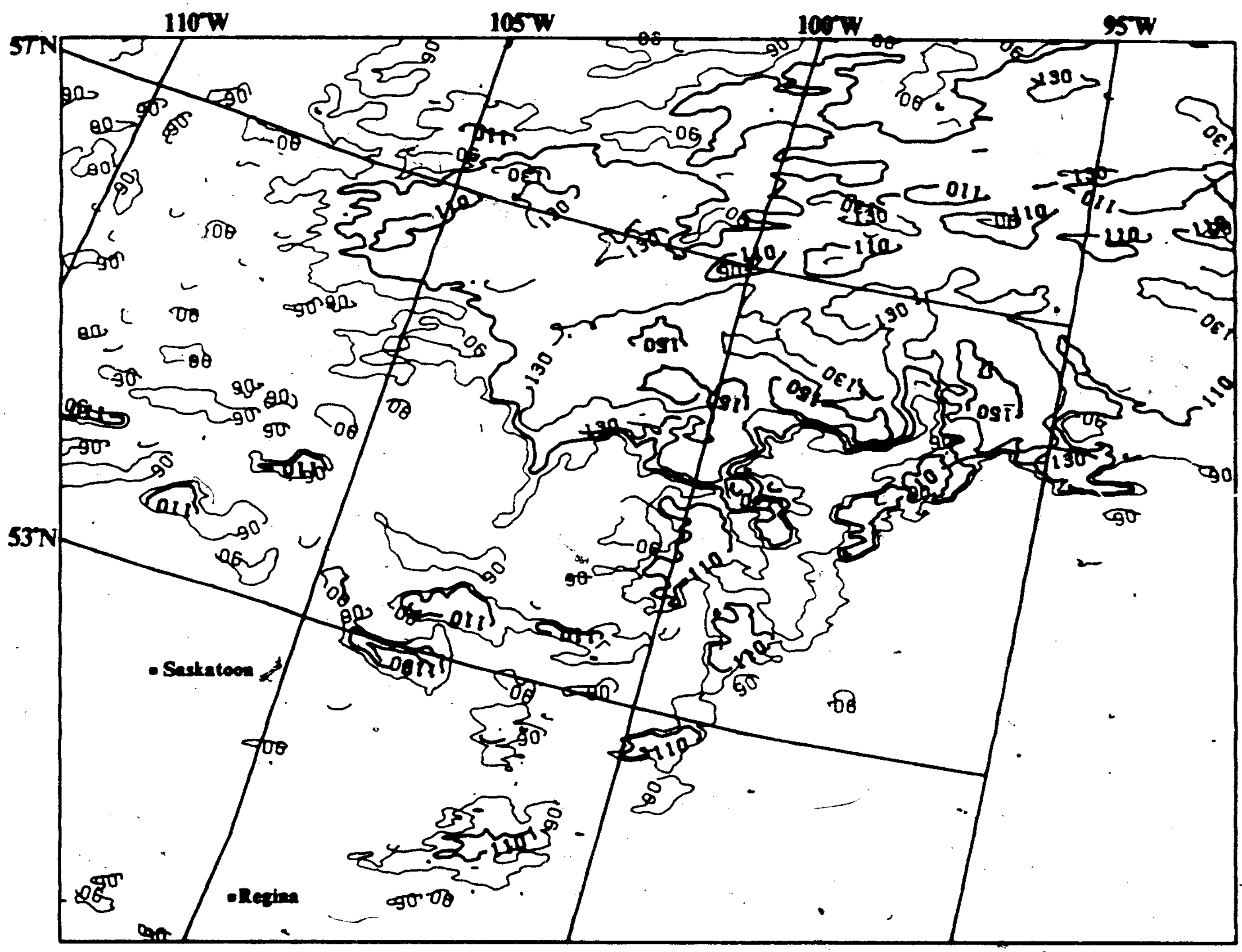


Figure 4.27 Brightness isopleths for July 18, 1986 at 2044-2059Z, NOAA-9 orbit 8230, isopleth interval 20 counts.

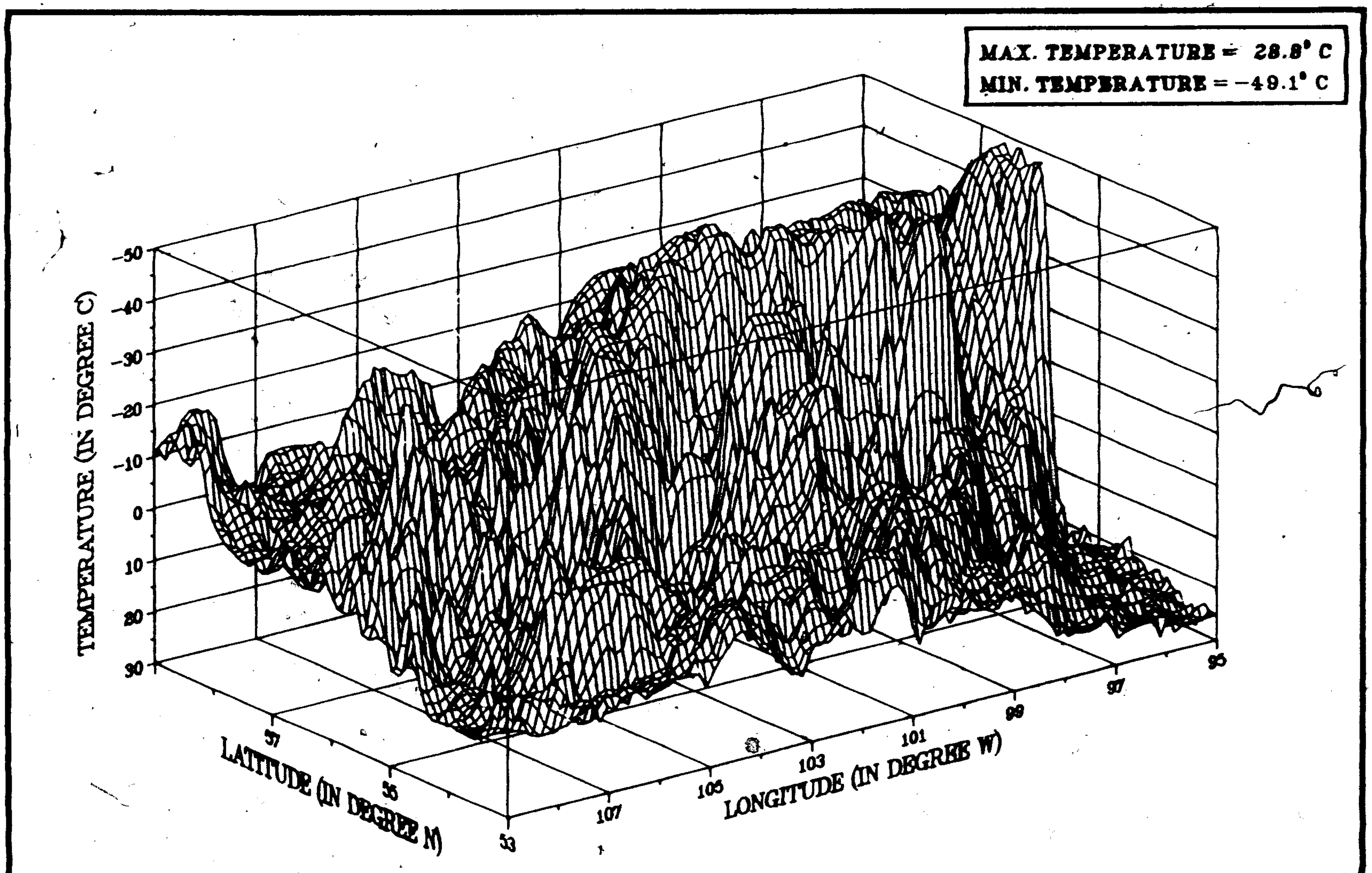


Figure 4.28 IR-derived 3 Dimensional temperature field of the cold-low area (53-59°N, 95-109°W) for July 18, 1986 at 2044-2059Z. *NOAA-9 orbit 8230.*

4.4 Radar History of the July Storm

Like most pictures, the series of radar scans presented in the next pages pretty well tell their own story. Only brief comments are therefore necessary, a few general remarks and short references to specific details. Moreover, some basic information on the radar system has been given already in Chapter 1 and Chapter 2.

For ease in comparison, all the images in the series have been scanned at elevation angles of 0.6°. Because of technical problems in producing hard copies of the CRT displays, some of the color values are not as pure as they should be, and some shift in color hues is noticeable as well.

It is also important to realize that the radar at Carvel was unable to sample the entire storm at maximum development, because of natural limits imposed on the range by topography, the distribution of the cloud and rain, the operating power and elevation angle of the radar beam, among others. Edson (ET) to the west and Vermillion (VG) to the east mark the practical working range for the July storm.

The intensity of the precipitation is displayed as follows:

L1	Yellow	<2.0 mm/hr
L2	Blue	2.0 - 4.9 "
L3	Off white	5.0 - 13.9 "
L4	Pink	14.0 - 39.9 "

The time of each scan is noted on the image and also in the figure caption.

The first series of four scans, Figures 4.29 to 4.32, show the precipitation area in the growth stage, at approximately half-hour intervals for the first three, and one hour between the third and fourth. The most interesting feature in this set is the generation of a new cell SW of VG, its growth and subsequent amalgamation with the main body of precipitation, the net effect being a substantial expansion of the rain area to eastern Alberta. The heaviest precipitation is generally falling from large cells to the south and west of the radar site.

Figure 4.29 Radar scan of July 17, 1986, 1012Z (04:12 MDT) at elevation angle 0.6°.

Figure 4.30 Radar scan of July 17, 1986, 1042Z (04:42 MDT) at elevation angle 0.6°.

Figure 4.31 Radar scan of July 17, 1986, 1111Z (05:11 MDT) at elevation angle 0.6°.

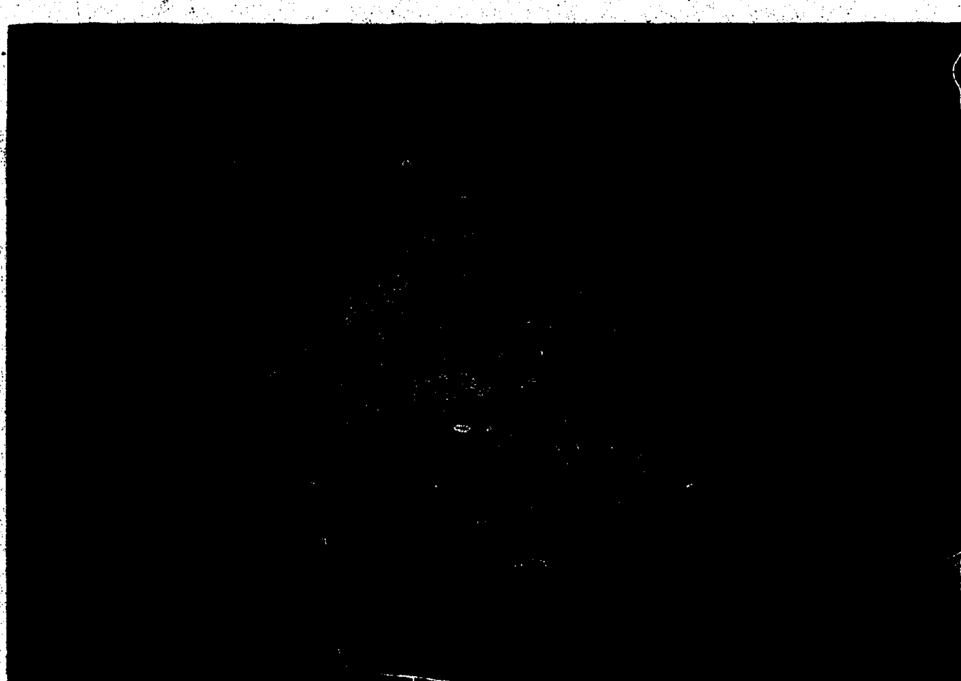


Figure 4.32 Radar scan of July 17, 1986, 1210Z (06:10 MDT) at elevation angle 0.6°.

The second set of six scans (Fig. 4.33 to Fig. 4.38) records the extent of the precipitation in the morning (7:11 - 11:36 MDT) when the low-pressure system was approaching Edmonton from the south. At this stage the storm had attained full maturity and the area affected by the storm had reached maximum size. There is precipitation falling in all quadrants beyond the range of detection of the beam at the elevation angles of 0.6°, as reported by weather stations outside the 200 km ring. The reason that the areas of intense (L4) precipitation are confined apparently to the inner 100 km circle is a consequence of the radar beam sampling the more distant clouds at elevations of 2 - 3 km above the ground, where the precipitation intensity is normally less.

Moderate to heavy rain was falling at Edmonton and the surrounding districts to the SW and SE throughout the period as the storm intensified.

The last print in this set (Fig. 4.38) records the stage when the deepening eye of the storm just passed Edmonton. The heavy rain band has shifted to the west of the radar site, and the precipitation area in the SE sector has developed a bulge, and is decreasing rapidly as the storm began to the accelerate and move eastward.

Figure 4.33 Radar scan of July 17, 1986, 1313Z (07:13 MDT) at elevation angle 0.6°.

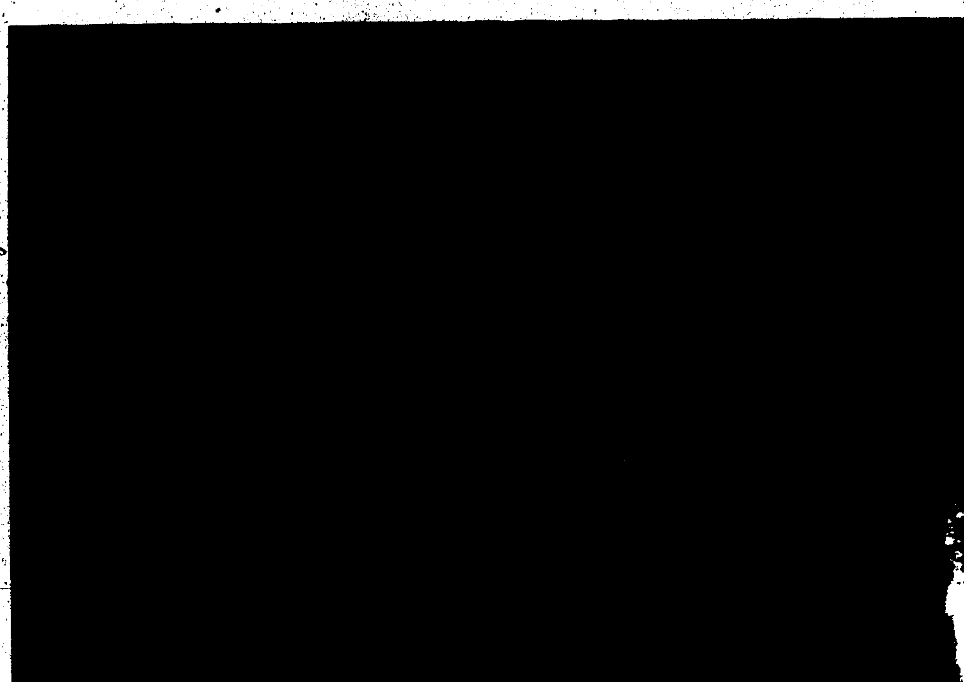


Figure 4.34 Radar scan of July 17, 1986, 1412Z (08:12 MDT) at elevation angle 0.6°.

Figure 4.35 Radar scan of July 17, 1986, 1442Z (08:42 MDT) at elevation angle 0.6°.

Figure 4.36 Radar scan of July 17, 1986, 1512Z (09:12 MDT) at elevation angle 0.6°.

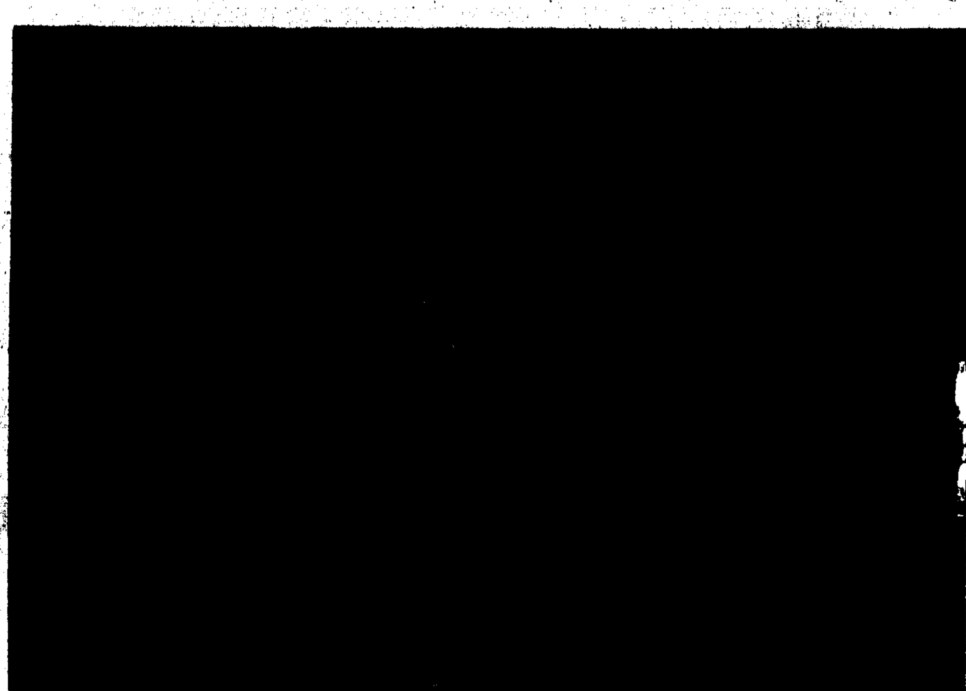


Figure 4.37. Radar scan of July 17, 1986, 1541Z (09:41 MDT) at elevation angle 0.6°.

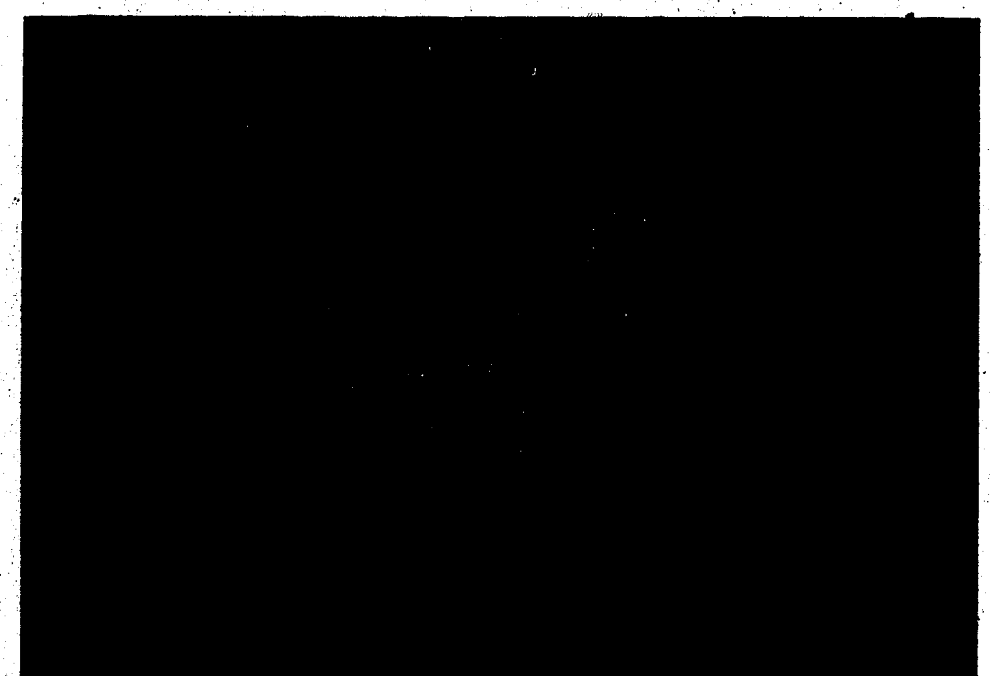


Figure 4.38 Radar scan of July 17, 1986, 1740Z (11:40 MDT) at elevation angle 0.6°.

The last set of scans, Figs. 4.39 to 4.42, close in time to the 2200Z afternoon satellite pass, (Figs. 4.4 and 4.5) provide a record of the weakening and breakup of the storm system. Two major rain bands slowly dissolve into separate cells. The breakup proceeds from east to west, in the direction opposite to the motion of the storm. This is as it should be, because the warm, humid air circulation to the north of the cold core is from the east, resulting in continuous upslope flow west of the Edmonton, as well as on the higher ground to the north and south. The details of this mechanism will be described in the synthesis of Chapter 5.

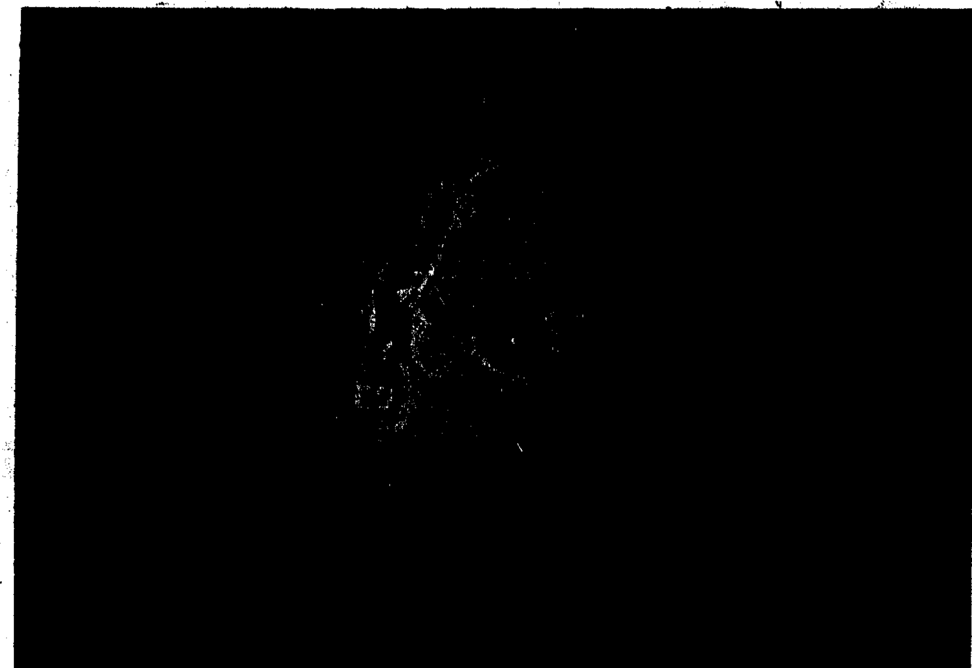


Figure 4.39 Radar scan of July 17, 1986, 2037Z (14:37 MDT) at elevation angle 0.6°.

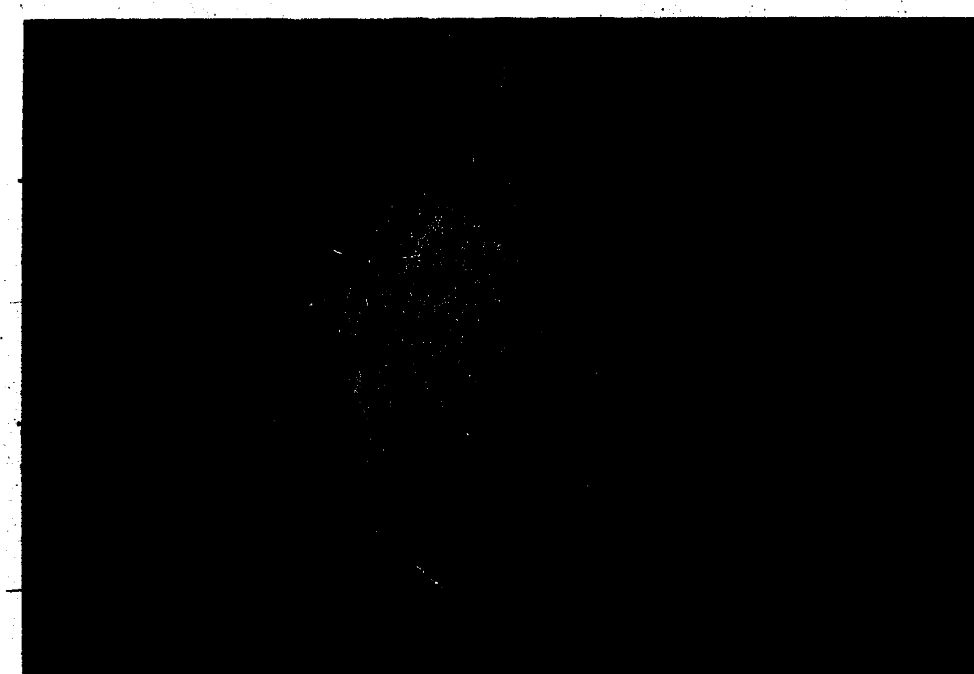


Figure 4.40 Radar scan of July 17, 1986, 2107Z (15:07 MDT) at elevation angle 0.6°.

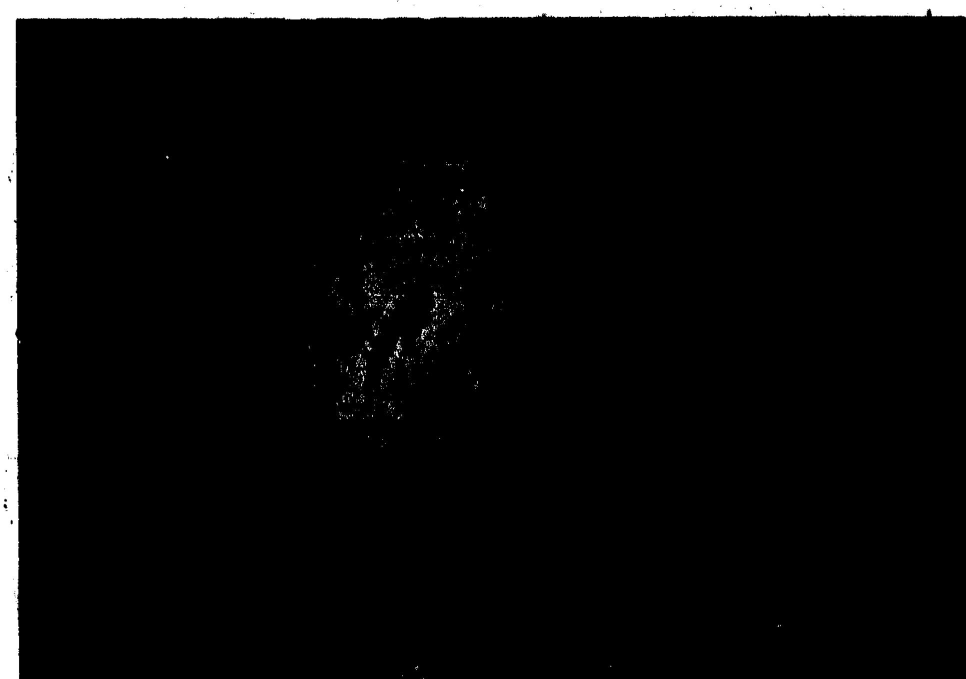


Figure 4.41 Radar scan of July 17, 1986, 2236Z (16:36 MDT) at elevation angle 0.6°.

Figure 4.42 Radar scan of July 18, 1986, 0004Z (18:04 MDT) at elevation angle 0.6°.

5. DISCUSSION AND SYNTHESIS

Though always interesting to the meteorologist, neither the May nor the July storms were exceptional as Alberta storms go. That both are nevertheless noteworthy is due to the fact that, by coming at the "wrong" time, they caused considerable hardship and heavy financial losses to many people. Both produced copious amounts of rain and snow, but not in quantities that set new records, except at a few forestry stations in the foothills which were buried in snow e.g. 75 cm at Grave Flats (elevation 2074 m ASL) during the July storm, and 3-metre deep snow drifts in southwestern Alberta in May (Paruk 1986, 1987). Reference should be made to the tables of storm precipitation and the isohyet plots of Chapter 2 for most of the details.

Any substantial snowfall in May will cause problems for most people. Farmers with seeding completed may welcome the extra moisture, but ranchers at calving time will not, and neither will motorists, gardeners and fruit growers. Heavy, wet snows in the spring always cause much more damage, especially to gardens, trees and power lines, than equal amounts of dry snow in winter. On the other hand, rains in the growing season usually come at the right time for most, and only at the wrong time for holidayers looking for Sun.

Why then did the 1986 July storm come at the wrong time? Because the first two weeks were quite wet throughout West-Central Alberta, to the point that the ground was already saturated, the catchments and storage basins full, and the rivers high, when the storm struck and dumped the extra water masses which could not be stored, and then caused wide-spread flooding of the North Saskatchewan, The Athabasca, The Red Deer, and several other rivers.

On the synoptic scale, and as an important contributor to the climate of Alberta, the function of a cold low is twofold: generating a deep, easterly circulation of moist air north of its centre, and increasing the instability of the atmosphere by moving cold air aloft over the warm surface air. Without cold lows, the principal agents of wide-spread rains on the

Western Prairie, Alberta would be much drier than it is, and climatologically an arid region. It is fortunate that the heavy precipitation usually comes when it is most needed: in the early stages of the growing season of June and July.

Though similar in action and members of the same class of weather systems, every cold low is unique, and therefore difficult to predict with confidence. Migrant pools of cold air aloft (≃500 mb) from the North Pacific, they behave erratically on reaching and moving over land, as the tracks of the two lows plotted in Figures 2.2 and 2.4 clearly show. They have, in a sense, lives of their own: temporarily cut off from the main stream long-wave pattern, they are independent, rotating cores of cold air with relatively long life spans (5 - 10 days). This is a consequence of their sense of rotation, which is cyclonic, a necessary condition if such cores are to survive for more than a day or two. Rotating as they do, they carry with them a large amount of cyclonic vorticity, usually concentrated in well-defined vorticity centres. Positive vorticity advection normally occurs to the east of such centres, which makes them favourable locations for the generation of surface lows.

Both of the cold-low systems analysed in the previous chapters possessed these characteristics, but yet they differed considerally in their development to the mature stage. It may have been noted that, while cold-core tracks were plotted for both storms (Figs. 2.2 and 2.4) and the track of the surface centre of the May storm was plotted as well (Fig. 2.3) no track chart was prepared for the July storm. The reason for the missing chart is simple: there was nothing comparable to plot, because there was no pre-existing surface low as in the May storm. Only later, after the cold core had generated its own surface low could there be a track, two sections of which have been plotted on the surface maps of Figs.4.14 and 4.15.

Both cold lows are similar in that they produced surface lows by the process of lee cyclogenesis, and developed into major storms. But the May storm was in essence a redevelopment of an old Pacific storm, whereas the July storm was a local development without an antecedent surface low.

Having presented many pages of evidence, what may one deduce from them as to the root cause, the principal mechanism responsible for the heavy precipitation?

Any appreciable amount of wide-spread precipitation (as distinct from local convective showers) requires the presence of a moist ascending air mass in a synoptic-scale flow. In Alberta, any circulation from the northeasterly quadrant will potentially lead to an upslope condition, as the air mass is forced to move over the increasingly higher ground to the west. This is a frequent occurrence with shallow flows close to the surface, which usually results in the formation of relatively thin layers of cloud (such as St and Sc) in the foothills and, over gently-sloping terrain as well.

A cold low and its associated surface low, once formed, also produce upslope conditions in the easterly circulation to the north of the centre, but on a much larger scale and throughout a much thicker layer, a process that Reinelt (1970) has called "deep upslope". Such circulations, when continuing over a period of several hours, will lift moist air to saturation and so result in the formation of cloud. Continuing for a day or more, this process will produce an extensive and very thick layer of cloud, which in time will become convectively unstable as the heat of condensation is added to the ascending air. In the end, a major storm will cover a wide area with continous precipitation, interrupted by periods of heavy dowpours as bands and cells of embedded thunderhead Cbs sweep across the land.

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APPENDIX A

Infrared Calibration Technique.

Assume that the output of each channel (in counts) is a linear function of the sensed radiance. Then, the relationship between counts and radiances is:

$$N = GX + I$$

where N is the radiance of the target at count value X,

G and I are channel gain and channel intercept, respectively.

The channel gain is calculated by :

$$G = \frac{N_{sp} - N_t}{X_{sp} - X_t}$$

The channel intercept is calculated by:

$$I = N_{sp} - G \bullet X_{sp}$$

where G is the channel gain in radiance per unit count,

N_{sp}, N_t are the radiances of space and of the internal target, respectively.

X_{sp} and X_t are the mean output count values, when the radiometer views space, and the internal target, respectively.

In reality, the response of the channel in the 11 μm region is slightly non-linear due to the physical properties of the detectors employed in this channel. The coefficient of the radiance of space can be found in Appendix B.

The Planck function is then integrated with the spectral response function of the radiometer and evaluated every two degree intervals in the range 200°K-300°K. This process gives a digital count value for each temperature. The temperature of each pixel is then found by a linear interpolation on the temperature versus digital count.

APPENDIX B

THE NOAA-9 Coefficients.

1. Platium Resistance Thermometers (PRTs).

a_{ij} - coefficients to convert PRT counts to temperature (K).

PRT	a_0	a_1	a_2	a_3	a_4
1	277.018	0.05128	0.0	0.0	0.0
2	276.750	0.05128	0.0	0.0	0.0
3	276.862	0.05128	0.0	0.0	0.0
4	[illegible]	0.05128	0.0	0.0	0.0

2. Radiance of Space.

N_{sp} is the radiance of space including non-linearity correction

Channel	N_{sp}(mW/srM²cm⁻¹)
3	0.0
4	-3.384
5	-2.313

3. AVHRR/1 Channel 4.

The value of ν (wave number), $\Delta\nu$ and 60 values of normalized response function ϕ for NOAA-9 used to determining the black body radiance are:

ν = 862.06885 cm^{-1} $\Delta\nu$ = 2.37812

0.0	0.30603E-4	0.64563E-4	0.10523E-3	0.17057E-3
0.37139E-3	0.85488E-3	0.17526E-2	0.29947E-2	0.43718E-2
0.56739E-2	0.67844E-2	0.77153E-2	0.84881E-2	0.91222E-2
0.96298E-2	0.10022E-1	0.10310E-1	0.10525E-1	0.10708E-1
0.10903E-1	0.11130E-1	0.11370E-1	0.11596E-1	0.11786E-1
0.11949E-1	0.12111E-1	0.12299E-1	0.12523E-1	0.12746E-1
0.12926E-1	0.13022E-1	0.13039E-1	0.13030E-1	0.13047E-1
0.13135E-1	0.13274E-1	0.13419E-1	0.13522E-1	0.13518E-1
0.13274E-1	0.12640E-1	0.11466E-1	0.97239E-2	0.76698E-2
0.56031E-2	0.38225E-2	0.25039E-2	0.15835E-2	0.97002E-3
0.57192E-3	0.31626E-3	0.16604E-3	0.88422E-4	0.50625E-4
0.27594E-4	0.13455E-4	0.52455E-5	0.53119E-9	0.0

APPENDIX C

COMPUTER PROGRAMS

```
*************** FILE READTAPE ***************
$EMPTY -READ OK
$R *FORTG SPUNCH=-READ T=1
C
C     PROGRAM FOR IDENTIFYING SATELLITE SCAN INFORMATION AND
C     CONVERTING MAG TAPE INFORMATION TO COMPUTER USEABLE FORM
C     INPUT DATA IS FORMAT FREE, DIVIDED BY COMMAS
C
C INPUT UNIT  1 = RAW TAPE DATA IN ONE BYTE INTEGER FORM.
C             5 = PROGRAM PARAMETERS.
C OUTPUT UNIT 3 = RAW TAPE DATA IN ONE BYTE INTEGER FORM
C             6 = TAPE DOCUMENTATION, TAPE DATA IN INTEGER FORM.
C             7 = TELEMETRY WEDGE LEVELS. (IF KOUT = 3)
C               = ONE SCAN DATA OF NOAA-9 APT (IF KOUT = 6)
C*********************************************************************
C
      REAL*8 IROV(2)
      INTEGER BPS, SPB, NX(10)
      INTEGER*2 IA(4096), LREV /5/, LFWD /3/
      INTEGER*2 LEN, ISC(64), LL(18), DOC(52), NSC(12), ID(2512)
      INTEGER*4 LRN
      EQUIVALENCE (IA(1),DTXT,FL,LA)
      LOGICAL*1 FREE(1) /'*'/, FL(18), DTXT(52), LA(8192)
      DATA YES1/'Y'/
C
      DATA IROV/8HINFRARED, 8H VISIBLE/
      DATA ISC/1H , 1H!, 1H", 1H#, 1H$, 1H%, 1H&, 1H', 1H(, 1H), 1H*, 1H+,
     & 1H,, 1H-, 1H., 1H/, 1H0, 1H1, 1H2, 1H3, 1H4, 1H5, 1H6, 1H7, 1H8, 1H9, 1H:,
     & 1H;, 1H., 1H=, 1H>, 1H?, 1H@, 1HA, 1HB, 1HC, 1HD, 1HE, 1HF, 1HG, 1HH, 1HI,
     & 1HJ, 1HK, 1HL, 1HM, 1HN, 1HO, 1HP, 1HQ, 1HR, 1HS, 1HT, 1HU, 1HV, 1HW, 1HX,
     & 1HY, 1HZ, 1H(, 1H/, 1H), 1H|, 1H_/
      CALL FTNCMD('ASSIGN 5=*SOURCE*', 17)
      CALL DESTRY('-3 ')
      CALL DESTRY('-6 ')
      CALL DESTRY('-7 ')
      CALL SETLIO('3         ','-3 ')
      CALL SETLIO('6         ','-6 ')
      CALL SETLIO('7         ','-7 ')
C
      WRITE (5,10)
   10 FORMAT (1X, 'IS THIS MAG FILE ? (Y/N) :')
      READ (5,20) ANS1
   20 FORMAT (A4)
      WRITE (5,70)
   70 FORMAT (1X,'INPUT NORBIT,ITYPE(IR=1,VIS=2),NFS,NBS,NBR,KOUT:')
      READ (5,FREE) NORBIT, ITYPE, NFS, NBS, NBR, KOUT
      WRITE (6,80) NORBIT, IROV(ITYPE)
   80 FORMAT ('***** FILE',I5,1X, A8, ' *****')
C
C        NFS  = NUMBER OF FILES TO BE SKIPPED
C        NBS  = NUMBER OF BLOCKS TO BE SKIPPED
C        NBR  = NUMBER OF BLOCKS TO BE READ AND OUTPUTTED
C        KOUT = 3 OUTPUTS UNFORMATTED BLOCKS TO UNIT 3
C                 (FILE OR MAG TAPE FOR USE IN PROGRAM SCAN).
C             = 6 OUTPUTS FORMATTED BLOCKS TO UNIT 6
C
C  FOR UNIT 3 OUTPUT ONLY:
C      ITYPE = 1 OUTPUTS INFRARED DATA (THE TELEMETRY DATA IS
C                OUTPUTTED TO UNIT 7 WITH OPTIONAL CALIBRATION)
C            = 2 OUTPUTS VISIBLE DATA (NO CALIBRATION REQUIRED)
C
      WRITE (6,90)
   90 FORMAT ('1', 10X, 'INPUT PARAMETERS')
```

```
      WRITE (6,100) NFS, NBS, NBR, KOUT
  100 FORMAT ('0', 4X,'FILES SKIPPED =',I3, 4X, 'BLOCKS SKIPPED =',
     &       I3, 4X, 'BLOCKS READ=', I4, 4X, 'OUTPUT OPTION =', I2)
      IF (KOUT .EQ. 6) GO TO 120
C
C UNIT 3 : THERE ARE 800 SAMPLES PER CHANNEL(IR&VIS)
C
      IF (ITYPE .EQ. 2) GO TO 108
      IBGN = 0
      WRITE (7,81) NORBIT
   81 FORMAT ('***** FILE',I5,'.TELEM *****')
      GO TO 109
C
  108 IBGN = 800
  109 WRITE (6,110) IROV(ITYPE)
  110 FORMAT ('0', 4X, A8, ' INFORMATION TRANSFERRED TO UNIT 3')
      GO TO 127
  120 WRITE (7,125) NORBIT
  125 FORMAT ('***** ONE SCAN DATA OF NOAA-9 APT ORBIT',I5,' *****')
  127 IF (ANS1 .EQ. YES1)REWIND 1
C
C SKIP TO FILE
C
      CALL SKIP(NFS, 0, 1, &480)
C
C READ AND INTERPRET FILE LABEL
C FILE IS IN ASCII, 1ST LOOP CONVERT TO EBCDIC CHARACTERS
C 2ND LOOP CONVERT 4 DIGITS TO BINARY NUMBER.
C NOTE .... DIGITS ARE IN 8 LEFTMOST BITS OF INTEGER*2 VALUE
C           SO MUST DIVIDE BY 256 TO MOVE TO 8 RIGHTMOST BITS.
C
C        LEN = LENGTH OF ANY BLOCK
C        LRN = INTERNAL COUNTER FOR DATA INPUT
C
  130 CALL READ(FL, LEN, 0, LRN, 1, &190)
C
      DO 140 L = 1, LEN
        ID(L) = IBYTE(FL(L))
        INDEX = ID(L) - 31
        IF (INDEX .LT. 1) INDEX = 1
        IF (INDEX .GT. 64) INDEX = 1
        LL(L) = ISC(INDEX)
  140 CONTINUE
C
      IF (ANS1 .NE. YES1) GO TO 170
      NPASS=0
      DO 145 L = 1, 4
        INDEX = L + 1
        IF (MOD(L,2).EQ. 0) INDEX = L - 1
        INDEX = (LL(INDEX) - ISC(17))/256
        IF (INDEX .GE. 0 .AND. INDEX .LE. 9) NPASS= 10*NPASS + INDEX
  145 CONTINUE
C
C PROGRAM CHECKS FOR CORRECT PASS NUMBER.
C PROGRAM WILL SEARCH TAPE UNTIL IT IS FOUND
C
      WRITE(5,FREE) NPASS
      IF (NPASS - NORBIT) 160, 170, 150
  150 CALL CNTRL('BSF 2', LREV, 1, RET)
  160 CALL CNTRL('FSF', LFWD, 1, RET)
      GO TO 130
  170 WRITE (6,180)(LL(K),K=1,4),LL(2),LL(1),LL(4),LL(3),LEN, LRN
  180 FORMAT ('0', 4X, 'FILE LABEL=', 4A1, 4X, 'ORBIT ', 4A1, 4X,
     &          'LENGTH=', I3, 4X, 'LRN=', I5)
C
C READ AND INTERPRET FILE DOCUMENTATION
C
  210 CALL READ(DTXT, LEN, 0, LRN, 1, &250)
C
C        ID(J) = OUTPUT IN INTEGER FORM (UNIT 6)
C        SPB = NUMBER OF SCANS PER DATA BLOCK
C        BPS = NUMBER OF BYTES PER SCAN
C
```

```
          ID(1) = JBYTE(DTXT(1))
          ID(2) = IBYTE(DTXT(2))
          ID(3) = JBYTE(DTXT(3))
          ID(4) = IBYTE(DTXT(4))
          BPS = ID(1) + ID(2)
          SPB = ID(3) + ID(4)
C
          DO 220 L = 5, LEN
            ID(L) = IBYTE(DTXT(L))
            INDEX = ID(L) - 31
            IF (INDEX .LT. 1) INDEX = 1
            IF (INDEX .GT. 64) INDEX = 1
            DOC(L) = ISC(INDEX)
      220 CONTINUE
          WRITE (6,230) (DOC(K),K=5,LEN), LEN, LRN
      230 FORMAT ('0', 4X, 'DOCUMENTATION :', 48A1, 4X, 'LENGTH=', I3,
       &          4X, 'LRN=', I5)
          WRITE (6,240) BPS, SPB
      240 FORMAT ('0', 4X, I5,' BYTES PER SCAN',4X,I2,' SCAN PER BLOCK')
C
C         LDR = LENGTH OF DATA RECORD (ONE SCAN)
C               (BPS BYTES PLUS TWO BYTES CONTAINING SCAN NUMBER)
C         LDB = LENGTH OF DATA BLOCK (SPB SCANS)
C
          LDR = BPS + 2
          LDB = SPB * LDR
          NS = LDR / 2
          GO TO 270
C
      250 WRITE (6,260)
      260 FORMAT ('0', 4X, '*** ERROR IN DOCUMENTATION INPUT ***')
C
C SKIP NBS BLOCKS OF DATA
C
      270 CALL SKIP(0, NBS, 1, &540)
          ISCAN = SPB * NBS
          MINSC = ISCAN
          NSOUT = 0
C
C READ AND CONVERT NBR BLOCKS OF DATA
C               NSOUT = NUMBER OF SCANS OUTPUTTED
C
          DO 440 KK = 1, NBR
            NBCNT = NBS + KK
C
C READ ONE BLOCK OF DATA AND CHECK TO SEE IF BLOCK LENGTH CORRECT
C (BLOCKS OF INCORRECT LENGTH ARE NOT OUTPUTTED)
C               NSC(N)= TWO BYTE NUMBER OF SCAN OUTPUTTED
C
            CALL READ(IA, LEN, 0, LRN, 1, &460)
            IF (LEN .NE. LDB) GO TO 420
            DO 330 N = 1, SPB
              IX = (N - 1) * NS + 1
              NSC(N) = IA(IX)
C
C CHECK TO SEE IF SCAN NUMBER CORRECT (MISSED SCANS ARE NOTTED)
C
              IF (NSC(N) .EQ. ISCAN) GO TO 320
              IF (NSC(N) - ISCAN .GT. 1) GO TO 290
              WRITE (6,280) ISCAN
  280         FORMAT ('0', 4X, 'MISSED SCAN =', I5)
              GO TO 310
  290         NSS = NSC(N) - 1
              WRITE (6,300) ISCAN, NSS
  300         FORMAT ('0', 4X, 'SCANS', I5, ' TO', I5, ' MISSED')
  310         ISCAN = NSC(N)
  320         ISCAN = ISCAN + 1
  330       CONTINUE
            IF (KOUT .EQ. 3) GO TO 370
C
C  UNIT 6 DATA OUTPUT, WRITE BLOCK DOCUMENTATION.
C
```

```
          WRITE (6,340) LEN, LRN, (NSC(N),N=1,SPB)
      340 FORMAT ('0', 4X, 'DATA BLOCK LENGTH=', I5, 4X, 'LRN=', I6,
     &           4X, 'SCANS', 10I5)
C
C WRITE OUT ONE BLOCK OF DATA.
C
          IF (KK .NE. NBR) GO TO 440
          DO 360 I = 1, SPB
          IF (I .NE. SPB) GO TO 360
            NJ = (I - 1) * LDR
            DO 350 J = 1, LDR
              ID(J) = IBYTE(LA(J + NJ))
      350   CONTINUE
C
C OUTPUT ONE SCAN OF DATA
C
           WRITE (7,400) I, J, ID(1), ID(2)
           WRITE (7,400) (ID(J),J=3,LDR)
            NSOUT = NSOUT + 1
      360 CONTINUE
          GO TO 440

C
C UNIT 3 DATA OUTPUT
C
      370 DO 410 I = 1, SPB
            JB = 3 + (I - 1) * LDR + IBGN
            JE = JB + 759
            WRITE (3) NSC(I), (LA(J),J=JB,JE)
C
C       LA(J) = OUTPUT IN ONE BYTE FORM (UNIT 3)
C
            NSOUT = NSOUT + 1
            IF (ITYPE .EQ. 2) GO TO 410
            JB = JB + 735
            JE = JB + 19
            KKK = 0
            DO 390 NNN = JB, JE
              KKK = KKK + 1
              NX(KKK) = IBYTE(LA(NNN))
      390   CONTINUE
            IF (KK .LT. 5 .OR. KK .GT. 60) GO TO 410
            WRITE (7,400) (NX(KKK),KKK=1,20)
      400   FORMAT (20I4)
      410 CONTINUE
          GO TO 440
C
      420 WRITE (6,430) NBCNT, LDB, LEN, LDR, BPS, SPB
      430 FORMAT ('0', 4X, '*** ERROR IN LENGTH OF DATA BLOCK', I5,
     &          ' ***', //, 4X, 'LDB=', I7, 4X, 'LEN=', I6, 4X,
     &          'LDR=',  I6, 4X, 'BPS=', I6, 4X, 'SPB=', I3)
      440 CONTINUE
C
C PRINT OUTPUT PARAMETERS
C         MAXSC = LAST SCAN OUTPUTTED
C         MINSC = FIRST SCAN OUTPUTTED
C
        MAXSC = NSC(SPB)
        WRITE (6,450) MINSC, MAXSC, NSOUT
      450 FORMAT ('0', 4X, 'FIRST SCAN OUTPUTTED =', I5, 4X,'LAST SCAN',
     &        ' OUPUTTED=', I5, 4X, 'NUMBER OF SCAN OUTPUTTED =', I5)
        IF (KOUT .EQ. 3) END FILE 3
        GC TO 560
```

```
C*********************************************************************
C ERROR DEFAULT STATEMENTS
C
  190 WRITE (6,200) NORBIT
  200 FORMAT ('0', 4X, '*** CAN NOT FIND PASS WITH LABEL',I5,' ***')
      GO TO 560
  460 WRITE (6,470) NBCNT
  470 FORMAT ('0',4X,'*** ERROR IN RECORD INPUT AT BLOCK',I5,' ***')
      GO TO 560
  480 WRITE (6,490)
  490 FORMAT ('0', 4X, '*** ERROR ON FILE SKIP ***')
      GO TO 560
  500 WRITE (6,510)
  510 FORMAT ('0', 4X, '*** ERROR ON FIRST FILE RETURN ***')
      GO TO 560
  520 WRITE (6,530)
  530 FORMAT ('0', 4X, '*** ERROR ON SECOND FILE RETURN ***')
      GO TO 560
  540 WRITE (6,550)
  550 FORMAT ('0', 4X, '*** ERROR ON DATA BLOCK SKIP ***')
  560 STOP
      END
C
C CONVERT ONE BYTE NUMBER INTO TWO BYTE INTEGER
C
      FUNCTION IBYTE(NUM)
      LOGICAL*1 NUM, INT(2)
      INTEGER*2 I /0/
      EQUIVALENCE (I,INT)
      INT(2) = NUM
      IBYTE = I
      RETURN
      END
C
C CONVERTS ONE BYTE NUMBER TO TWO BYTE MULTIPLE OF 255
C
      FUNCTION JBYTE(NUM)
      LOGICAL*1 NUM, INT(2)
      INTEGER*2 I /0/
      EQUIVALENCE (I,INT)
      INT(1) = NUM
      JBYTE = I
      RETURN
      END
$ENDFILE
$IF RC>4 $SOURCE PREVIOUS
```

```
*************** FILE SCANNING ***************
$EMPTY -SC3 OK
$R *FORTG SPUNCH=-SC3 T=2
C
C PROGRAM TO CONVERT NOAA-9 TAPE INFORMATION TO A GRIDDED DATA
C FILED, GENERATE GRID POINT LOCATION OF LATITUDE AND LONGITUDE
C LINES FOR USE IN CALCOMP PLOTTING ROUTINES.
C
C CALL SMOOTHING AND CALIBRATION SUBROUTINE WHEN NECESSARY.
C
C INPUT FROM UNITS 1,2 AND 3: LATITUDE - LONGITUDE COORDINATES OF
C                             OUTLINES TO BE COMPUTED
C           UNIT 4  : RAW VALUES OF SATELLITE INFORMATION.
C                             PRODUCE BY PROGRAM READTAPE
C           UNIT 8  : PROGRAM PARAMETERS
C           UNIT 7  : TELEM DATA
C
C OUTPUT TO UNIT 6 :PROGRAM PARAMETERS, CALCULATED VALUES,
C                        AND ERROR STATEMENTS
C            UNIT 9 :WEDGE LEVELS AND CALIBRATION DATA FOR PLOTTING
C           UNIT 10 :OUTPUT OF TELEMETRY WEDGE LEVELS
C           UNIT 11 :GRID COORDINATES OF LATITUDE AND LONGITUDE LINES
C           UNIT 13 :OUTPUT OF DATA FIELD
C           UNIT 15 :POSTING OF NORTH POLE AND OTHER LOCATIONS
C           UNIT 16 :GRID COORDINATES OF OUTLINES
C*****************************************************************
C
C 1/. INPUT TYPE AND INCREMENTS
C ITYPE = 0 NO INPUT DATA FROM UNIT 3. USED TO CHECK POSITIONS OR
C            OUTPUT LAT-LON LINES ONLY
C       = 1 IR DATA FROM FILE SOURCE
C       = 2 VISIBLE DATA FROM FILE SOURCE
C BSCAN = SCAN NUMBER TO BEGIN PROCESSING
C ESCAN = SCAN NUMBER TO END PROCESSING
C KB    = FIRST POSITION TO BE PROCESSED
C KE    = LAST POSITION TO BE PROCESSED
C SMFACT= MAP SCALING FACTOR(1:10,000,000 INPUTTED AS 10E6)
C*****************************************************************
C
C 2/. ORBITAL DATA
C NORBIT= NUMBER OF ORBIT
C NYEAR = YEAR OF ORBIT
C NMO   = MONTH OF ORBIT
C NDAY  = DAY OF ORBIT
C GRID  = NUMBER OF SCANS BETWEEN LAST EQUATOR CROSSING
C         AND FIRST ARRIVAL OF SATELLITE
C*****************************************************************
C
C 3/. ORBITAL DATA FOR REFERENCE ORBIT
C RORBIT= NUMBER OF REFRENCE ORBIT
C RHR  = HOUR OF REFRENCE ORBIT (Z)
C RMIN  = MINUTE OF REFERENCE ORBIT
C RSEC  = SECOND OF REFERENCE ORBIT
C RQ    = QUADRANT OF REFERENCE ORBIT EQUATOR CROSSING
C       = 0(5) 0 TO 90 DEGREES LONGITUDE WEST
C       = 1 (6) 90 TO 180 DEGREES LONGITUDES WEST
C       = 2 (7) 90 TO 180 DEGREES LONGITUDES EAST
C       = 3 (8) 0 TO 90 DEGREES LONGITUDES EAST
C     0,1,2,3 ARE QUADRANTS FOR NORTHERN HEMISPHERE
C     5,6,7,8 ARE QUADRANTS FOR SOUTHERN HEMISPHERE
C RLONG = LONGITUDE OF REFERENCE ORBIT EQUATOR CROSSING.
C         RQ AND RLONG ARE CODED VALUES READ DIRECTLY FROM T-BUS.
C         THE PROGRAM CALCULATES RLONGC FROM THESE VALUES BY
C         ASSUMING RIGHT ASCENSION OF THE ORBIT, THAT IS, LONGITUDES
C         IS TAKEN TO BE POSITIVE TO EAST AND NEGATIVE TO WEST
C        (THESE PARAMETERS WERE OBTAINED FROM T-BUS AND
C         T-BUS CODE ASSUMES 0 TO 180 DEGREES EAST AND WEST)
C*****************************************************************
C
C 4/. SATELLITE PARAMETERS
C PERIOD = ORBITAL PERIOD IN MINUTES
C REGRES = LONGITUDENAL DISPLACEMENT PER ORBIT IN DEG LONG TO WEST
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C           (REGRESSION)
C HEIGHT = HEIGHT OF SATELLITE AT FIRST SCAN IN KM
C ORINCL = INCLINATION OF SATELLITE AT FIRST SCAN IN DEGREES
C SSPP   = SATELLITE SUB-POINT PIXEL NUMBER (NADIR POINT IN SCAN)
C*****************************************************************
C
C 5/. DATA INPUT PARAMETERS (NOT REQUIRED IF ITYPE=0)
C LSMOOT= 0 NO SMOOTHING IS DONE
C       = 1 SMOOTHING IS CARRIED OUT
C LCALIB= 0 NO CALIBRATION IS DONE
C       = 1 CALIBRATION IS CARRIED OUT
C*****************************************************************
C
C 6/. CHECKING PARAMETERS
C CHECK1 = 0 FIRST LAT-LON LINES ARE NOT COMPUTED
C        = 1 FIRST LAT-LON LINES ARE COMPUTED
C OUT1   = 0 NO OUTLINES ARE COMPUTED
C        = 1, 2 OR 3  ONE, TWO OR THREE OUTLINES ARE COMPUTED
C             (MAX 3 OUTLINES ALLOWED)
C*****************************************************************
C
C 7/. OUTLINE TYPE (NOT REQUIRED IF OUT1=0)
C EACH OUTLINE REQUIRES A SEPARATE OUT2 PARAMETER.
C OUT2 = 1 INPUTTED POINTS OUTPUTTED TO UNIT 6. CALCULATED GRID
C          POINT LOCATIONS OUTPUTTED TO UNIT 16
C      = 2 NO OUTPUT OF INPUTTED POINTS. CALCULATED GRID POINT
C          LOCATIONS OUTPUTTED TO UNIT 16
C          MAXIMUM AND MINIMUM ROW AND COLUMN OF GRID LOCATIONS
C          CALCULATED AND OUTPUTTED.
C      = 3 NO OUTPUT OF INPUTTED POINTS.  MAXIMUM AND MINIMUM ROW
C          AND COLUMN OF GRID LOCATIONS CALCULATED AND OUTPUTTED.
C      = 4 INPUTTED POINTS OUTPUTTED TO UNIT 6. CALCULATED GRID
C          POINT LOCATIONS OUTPUTTED TO UNIT 15 FOR POSTING
C      = 5 INPUTTED POINTS WITHIN GRID FIELD OUTPUTTED TO UNIT 6
C          CALCULATED GRID POINT LOCATIONS OUTPUTTED TO UNIT 6
C
C LENGTH OF OUTPUT (NUMBER OF COLUMNS) IS GIVEN BY PARAMETER MAXSC.
C                  MAXIMUM LENGTH IS 600 SCANS.
C WIDTH OF OUTPUT (NUMBER OF ROWS) IS GIVEN BY IPOS (AND XPOS).
C                  MAXIMUM WIDTH IS 401 POSITIONS, WHICH CORRESPONDS
C                  TO SLIGHTLY LESS THAN ONE HALF THE SCAN WIDTH.
C SIZE OF OUTPUT IS GIVEN BY MTMAT ( MAXSC*IPOS )
C*****************************************************************
C
C 8/. LATITUDE AND LONGITUDE INCREMENTS (NOT REQUIRED IF CHECK1=0)
C LAINCR = INCREMENT FOR LATITUDE LINES (IN DEGREES)
C LOINCR = INCREMENT FOR LONGIUDE LINES (IN DEGREES)
C CHECK2 = SECOND LATITUDE-LONGITUDE CHECKING PARAMETER
C        = 0 DEFAULT VALUES FOR LATITUDE AND LONGITUDE PLOTTING USED
C        = 1 VALUES FOR LATITUDE AND LONGITUDE PLOTTING MUST BE INPUTTED.
C THE DEFAULT VALUES ARE LATITUDES FROM 0 TO 90 DEGREES NORTH,
C LONGITUDES FROM 0 TO 360 DEGREES EAST. POINTS ARE CALCULATED FOR
C EVERY LATITUDE-LONGITUDE INTERSECTION, BUT IF THE OUTPUTTED AREA
C IS SMALL, MOST OF THESE POINTS ARE NOT USED. THEREFORE, JUDICIOUS
C CHOICE OF LATITUDE AND LONGITUDE PARAMETERS LEADS TO GREAT TIME SAVING.
C*****************************************************************
C
C 9/. LATITUDE AND LONGITUDE PLOTTING VALUES.
C  (NOT REQUIRED IF CHECK1=0 OR CHECK2=0)
C
C LABGN = LATITUDE TO BEGIN PLOTTTING
C LAEND = LATITUDE TO END PLOTTTING
C LOBGN = LONGITUDE TO BEGIN PLOTTING
C LOEND = LONGITUDE TO END PLOTTING
C LHEM  = 1 LONGITUDE INPUTTES AS DEGREES EAST
C       = 2 LONGITUDE INPUTTES AS DEGREES WEST
C LATITUDES ARE EXPRESSED IN DEGREES NORTH
C LONGITUDES ARE EXPRESSED IN DEGREES EAST OR WEST
C A MAXIMUM OF 500 POINTS ALLOWED FOR EACH LINE
C*****************************************************************
C
```

```
C 10/. SMOOTHING PARAMETERS (NOT REQUIREDD IF ITYPE=0 OR LSMOOT=0)
C*********************************************************************
C
C 11/. CALIBRATION PARAMETERS (NOT REQUIREDD IF ITYPE=0 OR LCALIB=0)
C*********************************************************************
      DIMENSION FNAME(15),SCAN(800),POSN(800)
      LOGICAL*1 FREE(1) /'*'/, LA(780), LONAME(200,20)
      INTEGER RORBIT,RQ,RHR,RMIN,RSEC,CHECK1,CHECK2,OUT1,OUT2(3)
      INTEGER*2 HSCAN, BSCAN, ESCAN
      REAL LAINCR, LOINCR, SLAT(200), SLONG(200)
      REAL*8 IROV, POSI, IR, VISIBL, BLANK
      REAL*8 QUAD, EAST, WEST, HEAD, NORTH, SOUTH, POLE, MONTH(12)
C
      COMMON /TFIELD/ TEMP(401,800)
      COMMON /CORREC/ CORR(401,800)
      COMMON /SFIELD/ STEMP(401,800)
      COMMON /CONSTO/ RRL, R, PI, PIB2, SB, XKB, C4, C5
      COMMON /CONSTS/ RTSC, HEIGHT, SSPP, SRPM, SINCL, CINCL
C
      DATA POSI /'POSITION'/, IR /'INFRARED'/, VISIBL /' VISIBLE'/,
     &   EAST /' EAST   '/, WEST /' WEST   '/, NORTH /' NORTH  '/,
     &   SOUTH /' SOUTH  '/, POLE /' AT POLE'/
      DATA MONTH /' JANUARY', 'FEBRUARY', '   MARCH', '   APRIL',
     &   '     MAY', '    JUNE', '    JULY', '  AUGUST', 'SEPTEMBR',
     &   ' OCTOBER', 'NOVEMBER', 'DECEMBER'/
      DATA MZERO /0/, ZERO /0.0/, YES /'Y'/, STOP /'ST'/, STO1 /' '/
C
      CALL DESTRY('-6 ')
      CALL DESTRY('-11 ')
      CALL DESTRY('-13 ')
      CALL DESTRY('-16 ')
      CALL FTNCMD('ASSIGN 6=-6', 11)
      CALL FTNCMD('ASSIGN 11=-11', 13)
      CALL FTNCMD('ASSIGN 13=-13', 13)
      CALL FTNCMD('ASSIGN 16=-16', 13)
C
      PI = 3.1415927
      R = 6367.65
      PIB2 = PI / 2.0
      SRPM = 360.0
      ESRPM = 120.0
      LHEM = 2
C
C SRPM = SCAN RATE OF SATELLITE IN REVOLUTIONS PER MINUTE
C        (ONE REVOLUTION = ONE SCAN)
C ESRPM= EFFECTIVE SRPM
C
      READ (8,FREE) ITYPE, BSCAN, ESCAN, KB, KE, SMFACT
      READ (8,FREE) NORBIT, NYEAR, NMO, NDAY, GRID
      READ (8,FREE) RORBIT, RHR, RMIN, RSEC, RQ, RLONG
      READ (8,FREE) PERIOD, REGRES, HEIGHT, ORINCL, SSPP
      READ (8,FREE) LSMOOT, LCALIB, CHECK1, OUT1, (OUT2(I),I=1,OUT1)
      IF (CHECK1 .EQ. 0) GO TO 130
      READ (8,FREE) LAINCR, LOINCR, CHECK2
      IF (CHECK2 .EQ. 0) GO TO 120
      READ (8,FREE) LABGN, LAEND, LOBGN, LOEND
C
C CONVERT LONGITUDE TO DEGREES EAST AND CONVERT BEGINNING AND ENDING
C LATITUDES AND LONGITUDES TO VALUES USED IN LOOPS
C
      IF (LAEND .LT. LABGN) GO TO 50
      GO TO 70
C
   50 WRITE (6,60)
   60 FORMAT ('0', '*** ERROR   LATITUDE TO BEGIN PLOTTING ',
     &        'GREATER THAN LATITUDE TO END PLOTTING ***')
      LAST = LAEND
      LAEND = LABGN
      LABGN = LAST
C
   70 LABGN = LABGN * 10 + 10
```

```
          LAEND = LAEND * 10 + 10
          IF (LOEND .LT. LOBGN) GO TO 80
          GO TO 100
C
       80 WRITE (6,90)
       90 FORMAT ('0', '*** ERROR   LONGITUDE TO BEGIN PLOTTING ',
        &        'GREATER THAN LONGITUDE TO END PLOTTING ***')
          LOST = LOEND
          LOEND = LOBGN
          LOBGN = LOST
      100 IF (LHEM .NE. 2) GO TO 110
          LOST = LOEND
          LOEND = 360 - LOBGN
          LOBGN = 360 - LOST
      110 LOBGN = LOBGN * 10 + 10
          LOEND = LOEND * 10 + 10
          GO TO 130
C
      120 LABGN = 10
          LAEND = 810
          LOBGN = 10
          LOEND = 3610
C*** DETERMINE OUTPUT TYPE ***
      130 IROV = POSI
          IF (ITYPE .EQ. 1) IROV = IR
          IF (ITYPE .EQ. 2) IROV = VISIBL
C*** CALCULATE PROGRAM CONSTANTS FROM INPUT PARAMETERS ***
          IF (RQ.EQ.0 .OR. RQ.EQ.5) RLONGC = 360. - RLONG
          IF ((RQ.EQ.1 .OR. RQ.EQ.6) .AND. RLONG.GE.90.) RLONGC = 360.-RLONG
          IF ((RQ.EQ.1 .OR. RQ.EQ.6) .AND. RLONG.LT.90.)
        &RLONGC = 360. - RLONG - 100.
          IF ((RQ .EQ. 2 .OR. RQ .EQ. 7) .AND. RLONG .LT. 90.)
        &RLONGC = RLONG + 100.
          IF ((RQ.EQ.2 .OR. RQ.EQ.7) .AND. RLONG.GE.90.) RLONGC = RLONG
          IF (RQ.EQ.3 .OR. RQ.EQ.8) RLONGC = RLONG
C*** CALCULATE LONGITUDE OF LAST EQUATOR CROSSING ***
          RL = RLONGC - (NORBIT-RORBIT) * REGRES
          RL = AMOD(RL, 360.0)
          IF (RL .LT. 0.0) RL = RL + 360.0
          RRL = RL * PI / 180.0
C*** CONVERT TO EAST-WEST LONGITUDE FOR OUTPUT ONLY ***
          QUAD = EAST
          RLOUT = RL
          IF (180.0 - RL) 140, 150, 160
      140 QUAD = WEST
          RLOUT = 360.0 - RL
          GO TO 160
      150 QUAD = BLANK
C*** DETERMINE TIME AT FIRST OUTPUTTED SCAN OF ORBIT ***
      160 RTIME = RHR * 60 + RMIN + RSEC / 60.0
          STIME = RTIME + (NORBIT-RORBIT)*PERIOD + (GRID + BSCAN)/SRPM
          SHR = AMOD(STIME,1440.0)
          IF (SHR .LT. 0.0) SHR = SHR + 1440.0
          NHR = SHR / 60.0
          TIMIN = SHR - NHR * 60.0
          NMIN = TIMIN
          SSEC = TIMIN - NMIN
          NSEC = SSEC * 60.0
          XKB = FLOAT(KB)
C*** DETERMINE GRID LENGTH, WIDTH AND SIZE OF FINAL OUTPUT ***
          IPOS = (KE - KB) + 1
          XPOS = FLOAT(IPOS)
          MAXSC = ESCAN - BSCAN + 1
          IF (ITYPE .EQ. 0) GO TO 170
          IF (MAXSC .GT. 600) GO TO 1080
          IF (IPOS .GT. 401) GO TO 1100
          MTMAT = MAXSC * IPOS
          RTMAT = MTMAT / 1000.0
          SCAMIN = 0.0
          POSMIN = 0.0
C
```

```
      C DETERMINE NUMBER OF SCANCS PER RADIANT OF ORBIT AND
      C CONVERT BSCAN AND ESCAN TO RADIAN ANGLES
      C
        170 RTSC = PERIOD * ESRPM / (PI * 2.0)
            SB = (BSCAN + GRID) / RTSC
            SE = (ESCAN + GRID) / RTSC
      C*** DETERMINE LIMITS FOR POSITIONS AND SCANS OF LAT-LON LINES ***
            DPOS = 0.050 * XPOS
            PB1 = 1.0 - DPOS
            PB2 = PB1 - 2.0 * DPOS
            PE1 = XPOS + DPOS + 1
            PE2 = PE1 + 2 * DPOS
            DSCAN = 0.050 * (SE - SB)
            SB1 = SB - DSCAN
            SB2 = SB1 - 2.0 * DSCAN
            SB3 = SB2 - 2.0 * DSCAN
            SE1 = SE + DSCAN
            SE2 = SE1 + 2.0 * DSCAN
            SE3 = SE2 + 2.0 * DSCAN
      C*** DETERMINE SATELLITE HEADING ***
            HEAD = POLE
            IF (SB.LT.PIB2 .AND. SE.LT.PIB2) HEAD = NORTH
            IF (SB.GT.PIB2 .AND. SE.GT.PIB2) HEAD = SOUTH
      C
      C DETERMINE SCALING FACTORS (IN GRID UNITS PER INCH)
      C THESE FACTORS DUE TO THE FACT THAT PIXELS ARE NOT SQUARE
      C
            SMFACT = SMFACT * 1E-6
            DISTP = 4.28
            DISTS = 3.31
            C3 = 2.54
      C*** C3  = CONVERSION FACTOR CM TO INCHES ***
            SCALP = SMFACT * 10.0 * C3 / DISTP
            SCALS = SMFACT * 10.0 * C3 / DISTS
      C*** DETERMINE IF OUTPUT WIDTH IS WIDE ***
            IF (XPOS/SCALP .GT. 32.0) GO TO 1100
      C*** SATELLITE INCLINATION ***
        180 RINC = ORINCL * PI / 180.0
            SINCL = SIN(RINC)
            CINCL = COS(RINC)
      C*** PRINT INPUT DATA AND PRELIMINARY CALCULATIONS ***
            WRITE (6,190) IROV,NORBIT,MONTH(NMO),NDAY,NYEAR,NHR,NMIN,NSEC
        190 FORMAT ('1', /, 5X, A8, ' INFORMATION FROM ORBIT', I6, ' OF ',
           &        'SATELLITE NOAA-9 ON ', A8, I3, I5, /, 5X,
           &        'TIME OF FIRST SCAN', I3, ':', I2, ':', I2, ' Z', /)
      C
            WRITE (6,200) HEAD, GRID, RLOUT, QUAD, RORBIT
        200 FORMAT (/, 5X, 'SATELLITE HEADING IS ', A8, //, 5X, F6.1,
           &        ' SCANS PASSED SINCE SATELLITE LAST CROSSED EQUATOR', /
           &        /, 5X, 'AT LONGITUDE', F7.2, ' DEGREES', A8, ///, 5X,
           &        'REFERENCE ORBIT', I6, //)
      C
            WRITE (6,210) RLONGC, RHR, RMIN, RSEC
        210 FORMAT (5X,'CROSSED EQUATOR AT LONGITUDE',F7.2,' DEGREES EAST'
           &        , 5X, 'AT TIME', I3, ':', I2, ':', I2, ' Z', //)
      C
            WRITE (6,220) PERIOD, REGRES, HEIGHT, R, ORINCL, SRPM
        220 FORMAT (5X, 'ORBITAL PERIOD =', F10.5, ' MIN', //, 5X,
           &        'LONGITUDNAL INCREMENT =', F6.2,' DEGREES TO WEST', //,
           &        5X, 'HEIGHT OF SATELLITE AT EQUATOR =', F6.0, ' KM',5X,
           &        'RADIUS', ' OF EARTH =', F6.0, ' KM', //, 5X,
           &        'ORBITAL INCLINATION =', F7.2, ' DEG', 5X,
           &        'SCANNING RATE =', F4.0, ' SCANS PER MINUTE')
      C
            WRITE (6,230) BSCAN, ESCAN, KB, KE, SSPP
        230 FORMAT ('-', /5X, 'SCANNING BEGINS AT', I5,' AND ENDS AT',I5,/
           &        /, 5X, 'OUPUT TAKES UP', I4, ' TO', I4,
           &        ' OF AVAILABLE WIDTH', //, 5X,
           &        'SATELLITE SUBPOINT PIXEL NUMBER =', F7.2, //)
      C
```

```
      WRITE (6,240) DISTS, SCALS, DISTP, SCALP, SMFACT
  240 FORMAT (5X, 'DISTANCE BETWEEN SCANS =', F5.2, ' KM', //, 5X,
     &  'SCALING =', 1PE11.4, ' GRID UNITS PER INCH IN X DIRECTION',
     &    //, 5X, 'DISTANCE BETWEEN POINTS =',OPF5.2, ' KM', //, 5X,
     &  'SCALING =', 1PE11.4, ' GRID UNITS PER INCH IN Y DIRECTION',
     &    //, 5X, 'MAP SCALE = 1:', OPF5.2, ' MILLION')
C
      IF (ITYPE .EQ. 0) GO TO 430
C
C INPUT LOOP FOR DATA FIELD
C READ AND INPUT SCANS BETWEEN BSCAN AND ESCAN
C
C HSCAN= NUMBER OF SCANS SINCE FIRST ARRIVAL OF SATELLITE SIGNAL,
C    FROM PROGRAM TAPEREAD. IT IS READ DIRECTLY FROM UNIT 3 FOR EACH
C    SCAN. IF SCAN NUMBER CORRESPONDING WITH BSCAN IS NOT AVAILABLE
C    FROM UNIT 3, PROGRAM WILL BEGIN READING FIRST SCAN AVAILABLE.
C    IF ESCAN IS LARGER THAN THE LAST SCAN TRANSFERRED BY PROGRAM
C    TAPEREAD TO UNIT 3, AN END OF FILE MARK WILLE BE ENCOUNTERED.
C    BOTH CASES RESULT IN PROGRAM FAILURE
C
  270 READ (4,END=1260) HSCAN, LA
      IF (HSCAN .LT. BSCAN) GO TO 270
      IF (HSCAN .GT. ESCAN) GO TO 290
      MSCAN = HSCAN - BSCAN + 1
      ICNT = 0
      DO 280 JP = KB, KE
        ICNT = ICNT + 1
        DATUM = FLOAT(IBYTE(LA(JP)))
        IF (DATUM .LT. 1.0) DATUM = 1.0E35
        TEMP(ICNT,MSCAN) = DATUM
  280 CONTINUE
      IF (ICNT .NE. IPOS) GO TO 1140
      GO TO 270
  290 IF (MAXSC - MSCAN) 300, 320, 300
  300 WRITE (6,310) MSCAN
  310 FORMAT ('0', '*** ERROR   INCORRECT DATA LENGTH ', 5X, I7,
     &        ' SCANS IN OUTPUT ***')
      IF (MSCAN .GT. 600) GO TO 1280
      MAXSC = MSCAN
  320 WRITE (6,330)
  330 FORMAT ('-', /, 10X, 'DATA FIELD PARAMETERS')
C*** SMOOTHING OF DATA FIELD ***
      IF (LSMOOT .EQ. 0) GO TO 340
      CALL SMOOTH(MAXSC, IPOS)
      GO TO 360
  340 WRITE (6,350)
  350 FORMAT ('-', 14X, 'NO SMOOTHING OF DATA FIELD USED')
C*** CALIBRATION OF DATA FIELD ***
  360 IF (ITYPE .EQ. 1) GO TO 365
      GO TO 370
  365 IF (LCALIB .EQ. 0) GO TO 370
      CALL CALIBR(MAXSC, IPOS)
      GO TO 390
  370 WRITE (6,380)
  380 FORMAT ('-', 14X, 'NO CALIBRATION OF DATA FIELD USED')
C*** WRITE CALIBRATED FIELD TO UNIT 13 ***
  390 WRITE (13) IPOS, MAXSC
      DO 400 JJ = 1, MAXSC
  400 WRITE (13) (TEMP(II,JJ),II=1,IPOS)
C*** CHECK DATA FIELD FOR MAX AND MIN VALUES ***
      TMIN = 500.0
      TMAX = -500.0
C*** FIND MAXIMUM AND MINIMUM OF DATA FIELD ***
      DO 410 JJ = 1, MAXSC
        DO 410 II = 1, IPOS
          IF (TEMP(II,JJ) .LT. TMIN) TMIN = TEMP(II,JJ)
          IF (TEMP(II,JJ) .GT. TMAX) TMAX = TEMP(II,JJ)
  410 CONTINUE
      WRITE (6,420) MAXSC, IPOS, RTMAT, TMIN, TMAX
  420 FORMAT ('-', //, 5X, 'GRID DIMENSIONS : COLUMNS 1 TO', I5, 5X,
     &  'ROWS 1 TO', I5, //, 5X, 'GRID SIZE =', F6.2, 'K ELEMENTS',
     &  //, 5X, 'EXTREME VALUES OF DATA FIELD', /, 5X,
     &  ' MINIMUM =', F6.1, 5X, 'MAXIMUM =', F6.1)
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  430 IF (CHECK1 .EQ. 0) GO TO 640
C*** DETERMINE INCREMENTS FOR FINDING LATITUDE AND LONGITUDE CURVES ***
      LALAT = LAINCR * 10 + 0.50
      IF (LALAT .LT. 1) LALAT = 1
      LOLAT = LAINCR * 2 + 0.50
      IF (LOLAT .LT. 1) LOLAT = 1
      LOLON = LOINCR * 10 + 0.50
      IF (LOLON .LT. 1) LOLON = 1
      LALON = LOINCR * 1 + 0.50
      IF (LALON .LT. 1) LALON = 1
      WRITE (6,440) LAINCR, LOINCR
  440 FORMAT ('-', 10X, 'LATITUDE-LON[illegible]PARAMETERS', ///, 5X,
     &        'LATITUDE LINES GENERATED EVERY', F5.1, ' DEGREES', 4X,
     &        '500 POINTS ALLOWED FOR EACH LINE', //, 5X,
     &        'LONGITUDE LINES GENERATED EVERY', F5.1, ' DEGREES',4X,
     4        '500 POINTS ALLOWED FOR EACH LINE')
C
C OUTLINES AND LATITUDE, LONGITUDE LINE COMPUTATIONS (THE FOLLOWING
C MAY BE SIGNIFICANTLY SIMPLIFIED BY RESTRICTING THE INPUT-OUTPUT OPTIONS.)
C
      CALL EQNS(REGRES)
      WRITE (6,450)
  450 FORMAT ('-', 14X, 'LATITUDE-LONGITUDE LINES OUTPUTTED TO UNIT 11')
      KCHECK = 0
C*** DETERMINE POINTS FOR LATITUDE LINES ***
      WRITE (6,460)
  460 FORMAT ('0', 7X, 'LATITUDE LINES', /)
C*** INCREMENT LATITUDE LINES TO BE FOUND ***
      DO 530 LAT = LABGN, LAEND, LALAT
        ALAT = (LAT - 10) / 10.0
        LLAT = IFIX(ALAT)
        LOLATA = LOLAT
C
C ONLY ONE-FIFTH NUMBER OF POINTS USED IN
C LATITUDE LINES NORTH OF 80 DEGREES
C
        IF (ALAT .GT. 80.0) LOLATA = 5 * LOLAT
        IF (ALAT .GT. 90.0) GO TO 540
        MM = 1
C*** INCREMENT LONGITUDE INTERSECTIONS TO DETERMINE EACH LATITUDE LINE ***
        CALL ITERL(ALAT)
        DO 480 LONG = LOBGN, LOEND, LOLATA
          BLONG = (LONG - 10) / 10.0
          CALL ITERA(BLONG, SCAN(MM), POSN(MM), MCHECK, SB1, SB2,
     &          SE1, SE2, PB1, PE1)
          IF (MCHECK .EQ. 1) GO TO 470
          IF (MM .EQ. 1) GO TO 480
          KCHECK = KCHECK + 1
          GO TO 490
  470     IF (SCAN(MM) .LT. SCAMIN) SCAMIN = SCAN(MM)
          IF (SCAN(MM) .GT. SCAMAX) SCAMAX = SCAN(MM)
          IF (POSN(MM) .LT. POSMIN) POSMIN = POSN(MM)
          IF (POSN(MM) .GT. POSMAX) POSMAX = POSN(MM)
          MM = MM + 1
  480   CONTINUE
  490   MM = MM - 1
        IF (MM .LE. 2) GO TO 530
C*** OUTPUT LATITUDE LINE SEGMENT ***
        WRITE (6,500) ALAT, MM
  500   FORMAT (' ', 5X, 'LATITUDE =', F5.1, ' DEGREES NORTH', 5X,
     &          'POINTS IN LATITUDE LINE =', I4)
        WRITE (11,510) MM, MZERO, LLAT
  510   FORMAT (3I4)
        WRITE (11,520) (SCAN(I),POSN(I),I=1,MM)
  520   FORMAT (2F7.2)
        KCHECK = KCHECK + 1
  530 CONTINUE
      GO TO 560
C*** DETERMINE POINTS FOR LONGITUDE LINES ***
  540 WRITE (6,550)
  550 FORMAT ('0', '*** ERROR , END VALUE FOR FINAL LATITUDE LINE',
     &        ' LARGER THAN 90 DEGREES ***')
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      560 WRITE (6,570)
      570 FORMAT ('0', 7X, 'LONGITUDE LINES', /)
C*** INCREMENT LONGITUDE LINES TO BE FOUND ***
          DO 620 LONG = LOBGN, LOEND, LOLON
            ALONG = (LONG - 10) / 10.0
            LLONG = IFIX(ALONG)
            IF (ALONG .GT. 360.0) GO TO 1160
            VLONG = ALONG / (2.0*LOLON) - IFIX(ALONG/(2.0*LOLON))
            MM = 1
C*** INCREMENT LATITUDE INTERSECTIONS TO DETERMINE EACH LONGITUDE LINE ***
            DO 590 LAT = LABGN, LAEND, LALON
              BLAT = (LAT - 10) / 10.0
C
C EXTEND ONLY EVERY SECOND LONGITUDE LINE PAST 85 DEGREES NORTH
C TO AVOID CROWDING
C
              IF (BLAT .GT. 85. .AND. VLONG .GT. 0.1) GO TO 620
              CALL ITERL(BLAT)
              CALL ITERA(ALONG, SCAN(MM), POSN(MM), MCHECK, SB2, SB3,
     &                   SE2, SE3, PB2, PE2)
              IF (MCHECK .EQ. 1) GO TO 580
              IF (MM .EQ. 1) GO TO 590
              KCHECK = KCHECK + 1
              GO TO 600
  580         IF (SCAN(MM) .LT. SCAMIN) SCAMIN = SCAN(MM)
              IF (SCAN(MM) .GT. SCAMAX) SCAMAX = SCAN(MM)
              IF (POSN(MM) .LT. POSMIN) POSMIN = POSN(MM)
              IF (POSN(MM) .GT. POSMAX) POSMAX = POSN(MM)
              MM = MM + 1
  590       CONTINUE
  600       MM = MM - 1
            IF (MM .LE. 2) GO TO 620
C
C OUTPUT LONGITUDE LINE SEGMENT
C(ONLY ONE SEGMENT POSSIBLE FOR EACH LONGITUDE LINE)
C
            WRITE (6,610) ALONG, MM
  610       FORMAT (' ', 5X, 'LONGITUDE =', F6.1, ' DEGREES EAST', 5X,
     &              'POINTS IN LONGITUDE LINE =', I4)
            WRITE (11,510) MM, MZERO, LLONG
            WRITE (11,520) (SCAN(I),POSN(I),I=1,MM)
  620 CONTINUE
C
          WRITE (6,630) KCHECK, SCAMIN, SCAMAX, POSMIN, POSMAX
  630 FORMAT ('0', 7X, I4, ' LATITUDE-LONGITUDE LINES OUTPUTTED TO ',
     &        'UNIT 11', //, 5X, 'LAT LON LINES FORM BOX: COLUMNS',
     &        F5.0, ' TO', F5.0, ' ROWS', F5.0, ' TO', F5.0)
          GO TO 660
  640 WRITE (6,650)
  650 FORMAT ('-', /, 10X, 'NO LATITUDE LONGITUDE LINES GENERATED')
C*** DETERMINE GRID COORDINATES OF INPUTTED LAT-LON POINTS ***
  660 IF (OUT1 .EQ. 0) GO TO 1000
      WRITE (6,670)
  670 FORMAT ('-', /, 10X, 'OUTLINE PARAMETERS ', //)
C
          CALL EQNS(REGRES)
          DO 990 LUNIT = 1, OUT1
            IF (LUNIT .GT. 3) GO TO 1180
            WRITE (6,690) LUNIT
  690       FORMAT (' ', 14X, 'LAT-LON POINTS FROM UNIT', I3, /)
            IF (OUT2(LUNIT) .LT. 1 .OR. OUT2(LUNIT) .GT. 5) GO TO 1220
            READ (LUNIT,700) (FNAME(I),I=1,15)
  700       FORMAT (15A4)
            II = 0
            MM = 0
            KCHECK = 0
C*** INPUT LOOP FOR LAT-LON OUTLINE INTERSECTIONS ***
  710       II = II + 1
            MM = MM + 1
            MCHECK = 0
            READ (LUNIT,715,END=850,ERR=1200) XLAT,XLON,(LONAME(II,J),J=1,20)
  715       FORMAT(F6.2,1X,F6.2,4X,20A1)
C
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C XLAT = LATITUDE COORDINATE OF POINT (IN DEGREES AND MINUTES)
C XLON = LONGITUDE COORDINATE OF POINT (IN DEGREES AND MINUTES)
C
C CONVERT DEGREES AND MINUTES TO DECIMAL DEGREES
C
      SLAT(II) = IFIX(XLAT) + ((XLAT - IFIX(XLAT))*100./60.)
      SLONG(II) = IFIX(XLON) + ((XLON - IFIX(XLON))*100./60.)
      IF (LHEM .EQ. 2) SLONG(II) = 360.0 - SLONG(II)
      CALL ITERL(SLAT(II))
      CALL ITERA(SLONG(II), SCAN(MM), POSN(MM), MCHECK, SB2, SB3,
     &   SE2,SE3, PB2, PE2)
      IF (MCHECK.EQ.1 .OR. MM.LE.1) GO TO 710
      IF (OUT2(LUNIT) .EQ. 3) GO TO 930
C*** OUTPUT OUTLINE SEGMENT ***
      KCHECK = KCHECK + 1
      MM = MM - 1
      IF (OUT2(LUNIT) - 4) 720, 750, 780
  720 WRITE (6,730) MM
  730 FORMAT ('0', 4X, I4, ' GRID COORDINATE POINTS OF OUTLINE',
     &        ' TRANSFERRED TO UNIT 16')
      WRITE (16,740) MM
  740 FORMAT (I4)
      WRITE (16,745) (SCAN(I),POSN(I),(LONAME(I,J),J=1,20),I=1,MM)
  745 FORMAT (2F7.2,1X,20A1)
      GO TO 820
  750 WRITE (6,760) MM
  760 FORMAT('0',4X,I4,' GRID COORDINATE POINTS CONTAINED IN UNIT',
     &       , ' 16, OUTPUT AREA TRANSFERRED TO UNIT 15 FOR POSTING')
      WRITE (15,770) (SCAN(I),POSN(I),ZERO,I=1,MM)
  770 FORMAT (3F7.2)
      GO TO 820
  780 WRITE (6,790)
  790 FORMAT ('0', 4X, 'INPUTTED POINTS', /)
      WRITE (6,800) (SLAT(I),SLONG(I),I=1,MM)
  800 FORMAT (' ',8(F7.2,F7.2,3X))
      WRITE (6,810)
  810 FORMAT ('0', 4X, 'GRID COORDINATES', /)
      WRITE (6,800) (SCAN(I),POSN(I),I=1,MM)
  820 MM = 0
      GO TO 710
C*** END OF OUTLINE FILE GO ON ***
  850 II = II - 1
      IF (MCHECK.EQ.0 .AND. MM.LE.1) GO TO 900
      KCHECK = KCHECK + 1
      IF (OUT2(LUNIT) - 4) 860, 870, 890
  860 IF (OUT2(LUNIT) .EQ. 3) GO TO 900
      MM = MM - 1
      WRITE (6,730) MM
      WRITE (16,740) MM
      WRITE (16,745) (SCAN(I),POSN(I),(LONAME(I,J),J=1,20),I=1,MM)
      IF (OUT2(LUNIT) - 2) 880, 900, 900
  870 WRITE (6,760) MM
      WRITE (15,770) (SCAN(I),POSN(I),ZERO,I=1,MM)
  880 WRITE (6,790)
      WRITE (6,800) (SLAT(I),SLONG(I),I=1,II)
      GO TO 950
  890 WRITE (6,790)
      WRITE (6,800) (SLAT(I),SLONG(I),I=1,MM)
      WRITE (6,810)
      WRITE (6,800) (SCAN(I),POSN(I),I=1,MM)
      GO TO 950
C
C DETERMINE MAXIMUM AND MINIMUM SCAN AND POSITION VALUES
C OF LAT-LON INTERSECTION WITHIN EXTENDED LIMITS OF GRID
C
  900 SCAMIN = 1.0E30
      SCAMAX = -1.0E30
      POSMIN = 1.0E30
      POSMAX = -1.0E30
      DO 910 JI = 1, MM
        IF (SCAN(JI) .LT. SCAMIN) SCAMIN = SCAN(JI)
        IF (SCAN(JI) .GT. SCAMAX) SCAMAX = SCAN(JI)
```

```
          IF (POSN(JI) .LT. POSMIN) POSMIN = POSN(JI)
          IF (POSN(JI) .GT. POSMAX) POSMAX = POSN(JI)
  910   CONTINUE
        WRITE (6,920) SCAMIN, SCAMAX, POSMIN, POSMAX
  920   FORMAT ('0',4X,'OUTLINE OCCUPIES BOX CONTAINING SCANS',F5.0,
     &        ' TO', F5.0, 4X, 'AND POSITIONS', F5.0, ' TO', F5.0)
        GO TO 950
  930   WRITE (6,940)
  940   FORMAT ('0','*** ERROR   OUTLINE EXCEEDS LIMITS OF DATA FIELD ***')
  950   IF (KCHECK .EQ. 0) GO TO 1240
        IF (OUT2(LUNIT).EQ.1 .OR. OUT2(LUNIT).EQ.2)WRITE(6,960)
  960   FORMAT ('0',4X,'GRID POINT POSITIONS OF OUTLINE TRANSFERRED'
     &        , ' TO UNIT 16')
        IF (OUT2(LUNIT) .EQ. 3 .OR. OUT2(LUNIT) .EQ. 5) GO TO 970
  970   WRITE (6,980)
  980   FORMAT ('0')
  990 CONTINUE
 1000 STOP
C
C *****************   ERROR DEFAULT STATEMENTS    *****************
C
 1060 WRITE (6,1070)
 1070 FORMAT ('0', '*** ERROR   INVALID PARAMETERS FOR WIDTH OF',
     &        ' OUTPUTTED FIELD ***')
      GO TO 1280
 1080 WRITE (6,1090) MAXSC
 1090 FORMAT ('0','*** ERROR   OUTPUT TOO LONG',5X, I6,' SCANS IN',
     &        ' OUTPUT, FORMAT ALLOWS ONLY 600 SCANS ***')
      GO TO 1280
 1100 WRITE (6,1110) IPOS
 1110 FORMAT ('0','*** ERROR   OUTPUT TOO WIDE',5X, I6,' POSITIONS',
     &        ' IN OUTPUT. FORMAT ALLOWS ONLY 401 POSITIONS ***')
      GO TO 1280
 1140 WRITE (6,1150) HSCAN
 1150 FORMAT ('0', '*** ERROR   INCORRECT DATA LENGTH FOR SCAN', I6, ***')
      GO TO 1280
 1160 WRITE (6,1170)
 1170 FORMAT ('0', '*** ERROR   END VALUE FOR FINAL LONGITUDE LINE',
     &        ' LARGER THAN 360 DEGREES ***')
      GO TO 1280
 1180 WRITE (6,1190)
 1190 FORMAT ('0', '*** ERROR   TOO MANY OUTPUT UNITS CALLED FOR',
     &        ' OUTLINE  PROCEDURE ***')
      GO TO 1280
 1200 WRITE (6,1210) LUNIT
 1210 FORMAT ('0', '*** ERROR   IN UNIT', I2, ' READ ***')
      GO TO 1280
 1220 WRITE (6,1230) OUT2(LUNIT)
 1230 FORMAT ('0', '*** ERROR   OUTLINE TYPE OUT2 INCORRECTLY',
     &        ' SPECIFIED AS', I6, ' ***')
      GO TO 1280
 1240 WRITE (6,1250)
 1250 FORMAT ('0', '*** ERROR   FAILURE IN OUTLINE PROCEDURE, NO',
     &        ' POINTS FOUND WITHIN GRID LIMITS ***')
      GO TO 1280
 1260 WRITE (6,1270)
 1270 FORMAT ('0', '*** ERROR   END OF FILE ON UNIT 4 ***')
      STOP 99
 1280 STOP
      END
C
C     CONVERT ONE BYTE NUMBER INTO TWO BYTE INTEGER
C
      FUNCTION IBYTE(NUM)
      LOGICAL*1 NUM, INT(2)
      INTEGER*2 I /0/
      EQUIVALENCE (I,INT)
      INT(2) = NUM
      IBYTE = I
      RETURN
      END
```

```
C
C ******************************************************************
C
      SUBROUTINE ITERA(ALONG, SCAN, POSN, MCHECK, SBA, SBAA,
     &                 SEA, SEAA, POSB, POSE)
C
C SUBROUTINE FOR DETERMINING IF LAT - LON INTERSECTION IS
C WITHIN EXTENDED LIMITS OF GRID, AND FOR DETERMINING
C EXACT LOCATION IF IT IS
C
C ALAT   = LATITUDE OF LAT - LON INTERSECTION
C ALONG  = LONGITUDE OF LAT - LON INTERSECTION
C MCHECK = 0 POINT OUTSIDE EXTENDED LIMITS OF GRID
C        = 1 POINT INSIDE EXTENDED LIMITS OF GRID
C SBA    = EXTENDED SCAN TO BEGIN OUTPUT
C SBAA   = OVER EXTENDED SCAN TO BEGIN OUTPUT (FIRST CHECK ONLY)
C SEA    = EXTENDED SCAN TO END OUTPUT
C SEAA   = OVER EXTENDED SCAN TO END OUTPUT (FIRST CHECK ONLY)
C POSB   = EXTENDED POSITION TO BEGIN OUTPUT
C POSE   = EXTENDED POSITION TO END OUTPUT
C SCAN   = SCAN LOCATION OF ITH POINT IN LINE
C POSN   = POSITION LOCATION OF ITH POINT IN LINE
C
C APT GEOMETRIC CORRECTION DATA
C
      COMMON/ CONSTO/ RRL, R, PI, PIB2, SB, XKB, C4, C5
      COMMON/ CONSTS/ RTSC, HEIGHT, ZDRP, SBPM, SI, CI
      DIMENSION XNR(4), XAV(5)
      LOGICAL*1 FREE(1)/'*'/
      DATA XNR/312.0, 330.0, 166.0, 93.0/
      DATA XAV/4.0, 3.0, 2.0, 1.5, 1.0/
C
      MCHECK = 0
      THETA = RRL - (ALONG * PI/180.0)
C
      X1 = SI * SLAT + SIN(THETA - TPL * SP) * ( - CI) * CLAT
      X2 = COS(THETA - TPL * SP) * CLAT
      SNT = ATAN2(X1, X2)
      IF(SNT.LT.0.0 .AND. SP.GT.PIB2) SNT = SNT + (PI * 2.0)
      IF(SNT.GE.SBAA .AND. SNT.LE.SEAA) GO TO 10
      SP = SNT
      RETURN
C*** ITERATE TO FIND SATELLITE PATH LENGTH  FROM EQUATOR ***
   10 DO 20 J = 1, 10
      ST = THETA - TPL * SNT
      CT = COS(ST)
      ST = SIN(ST)
      CSNT = COS(SNT)
      SSNT = SIN(SNT)
      X1 = CLAT * (SSNT*CT + CI*CSNT*ST) - SI * SLAT * CSNT
      X2 = CLAT * ((1.-TPL*CI)*CSNT*CT + (TPL-CI)*SSNT*ST)+SI*SLAT*SSNT
      SP = SNT - X1/X2
C*** SIN(EARTH ARC LENGTH FROM SUBPOINT) ***
      ST = SIN(THETA - TPL*SP) * SI * CLAT + CI * SLAT
C*** CHECK TO SEE IF NADIR ANGLE > FALSE HORIZON ***
      IF(ABS(ST) .GT. SGH) RETURN
      IF(ABS(SNT - SP) .LT. 1E-6) GO TO 40
      SNT = SP
   20 CONTINUE
      WRITE(6, 30) ALAT, ALONG
   30 FORMAT(1H ,'**** ERROR NO CONVERGENCE TO POINT AT LATITUDE',
     & F7.1, '  AND LONGITUDE', F7.1, '  DEGREES ****')
      RETURN
C
   40 IF(SNT .LT. SBA .OR. SNT .GT. SEA) RETURN
C*** CALCULATE SENSOR NADIR ANGLE (FROM SUBPOINT) ANGLE AT EARTH'S CENTER ***
      X3 = R * ST
      X4 = HEIGHT + R * (1.0 - SQRT(1.0 - ST*ST))
      Y = ATAN(X3/X4)
C
C NOAA-9  : DATA POSITION ALONG AVHRR SCAN.  40000HZ @ 6SCANS/SEC
C FIND (4160HZ) APT POSITION FROM AVERAGED AVHRR DATA CONVERT
C TO 3200HZ DIGITIZE RAT[illegible]USING C5), CE[illegible]60
```

```
C RESTRICT 0 < IPOS < 700 = (2 * ZDRP):
C
C DIGF = DIGITIZING FREQUENCY OF SATELLITE IN DATA VALUES PER SECOND
C C4   = CONVERSION FACTOR (AHVRR RADIAN SCAN ANGLE TO DATA VALUE
C        POSITION). THE ZERO DEGREE REFERENCE FOR SATELLITE IS
C        DIRECTLY ABOVE THE SUBPOINT AT DATA VALUE SSPP. SCANNING IS
C        RESTRICTED TO WITHIN 54' OF SATELLITE SUBPOINT FOR TIROS-N/
C        NOAA A-9 SATELLITES. EACH DATA RECORD (EITHER IR OR VISIBLE
C        DATA) CONTAINS 699 DATA VALUES (PLUS SCAN NUMBER). MIDPOINT
C        IS AT DATA VALUE SSPP. THEREFORE, ALL VALUES MEASURED FROM
C        ZERO DEGREE REFERENCE ARE CONVERTED TO DATA VALUE POSITIONS
C        BY MULTIPLYING BY C4 AND ADDING SSPP.
C        C4 IS INITIALIZED IN 'ENTRY EQNS' IN ITERA
C
      Y = C4 * ABS(Y)
      IF(Y .GT. 1025.0) RETURN
      SNT = 0.0
      DO 50 J = 1, 4
      SGN = XNR(J)
      IF(Y .LT. SGN) GO TO 60
      SNT = SNT + SGN / XAV(J)
      Y = Y - SGN
   50 CONTINUE
       J = 5
   60 Y = SNT + Y / XAV(J)
      IF(ST .LT. 0.0) Y =  - Y
C*** NOAA-9 : CALCULATE  POSITION FOR DIGITIZING FREQUENCY ***
      SCAN = (SP - SB) * RTSC + 1.0
      POSN = Y * C5 + ZDRP - XKB
      IF(POSN.LT.POSB .OR. POSN.GT.POSE) RETURN
      MCHECK = 1
      RETURN
C
      ENTRY EQNS(REGRES)
C*** HORIZON ANGLE ***
      TPL = REGRES / 360.0
C*** SIN(HORIZON EARTH ARC) ***
      SGH = SIN(15.0 * PI/180.0)
      C4 = 40000.0 / (6.0 * 2.0 * PI)
      C5 = 3200.0 / 4160.0
      AA = R + HEIGHT
      RETURN
C*** CHANGE GEODETIC LATITUDE TO GEOCENTRIC ***
      ENTRY ITERL(ALAT)
      SP = ALAT * PI/180.0
      TANSP = TAN(SP)
      TEM = 1.0 + 43.02466 / AA
      IF(ALAT .LT. 90.0) SP = ATAN(TANSP/TEM)
      CLAT = COS(SP)
      SLAT = SIN(SP)
C*** CHANGE IN EARTH 'S RADIUS VERY SMALL FACTOR. ***
      R = 6367.65 + 10.738 * COS(2.0 * SP)
      HEIGHT = AA - R
      RETURN
      END
C
C ********************************************************************
C
     SUBROUTINE SMOOTH(MAXSC, IPOS)
C
C SUBROUTINE TO SMOOTH AND ELIMINATE NOISE FROM DATA FIELD
C
     LOGICAL*1 FREE(1) /'*'/
     REAL RESID(600), BS(60), SMT(10)
     COMMON /TFIELD/ TEMP(401,600)
     COMMON /CORREC/ CORR(401,600)
     COMMON /SFIELD/ STEMP(401,600)
C
C INPUT DATA
C
C NSMT       = NUMBER OF SMOOTHING OPERATIONS TO BE CARRIED OUT
C              ON GRID FIELD BEFORE OUTPUT
C SMT(I)     = SMOOTHING PARAMETER FOR EACH OPERATION
```

```
C MAXSC      = NUMBER OF COLUMNS IN DATA FIELD
C IPOS       = NUMBER OF ROWS IN DATA FIELD
C TEMP(I,J) = DATA VALUE AT EACH POINT (I, J)
C
      READ(8,FREE) NSMT, (SMT(I),I=1,NSMT)
      WRITE (6,10)
   10 FORMAT ('-', 14X, 'SMOOTHING PARAMETERS')
C*** BEGIN SMOOTHING LOOP ***
      DO 200 KK = 1, NSMT
        SM = SMT(KK) + 1.0
        SMT4 = SMT(KK) / 4.0
        SMT3 = SMT(KK) / 3.0
        SMT2 = SMT(KK) / 2.0
        IPOS2 = IPOS - 1
        MAXSC2 = MAXSC - 1
C*** TWO POINTS SMOOTHING IS USED AT CORNERS OF GRID ***
        CORR(1,1) = SMT2 * (TEMP(2,1) + TEMP(1,2))
        CORR(1,MAXSC) = SMT2 * (TEMP(2,MAXSC) + TEMP(1,MAXSC2))
        CORR(IPOS,1) = SMT2 * (TEMP(IPOS2,1) + TEMP(IPOS,2))
        CORR(IPOS,MAXSC) =SMT2*(TEMP(IPOS2,MAXSC)+TEMP(IPOS,MAXSC2))
C*** THREE POINT SMOOTHING IS USED ON SIDES OF GRID ***
        DO 20 J = 2, MAXSC2
          CORR(1,J) = SMT3 * (TEMP(1,J-1)+TEMP(2,J)+TEMP(1,J+1))
          CORR(IPOS,J) = SMT3 * (TEMP(IPOS,J-1)+TEMP(IPOS2,J)+TEMP(IPOS,J+1))
   20   CONTINUE
C
        DO 30 J = 2, IPOS2
          CORR(I,1) = SMT3 * (TEMP(I+1,1)+TEMP(I,2)+TEMP(I-1,1))
          CORR(I,MAXSC) = SMT3 * (TEMP(I+1,MAXSC)+TEMP(I,MAXSC2)+TEMP(I-1,MAXSC))
   30   CONTINUE
C*** FOUR POINT SMOOTHING IS USED IN INTERIOR OF GRID ***
        DO 40 J = 2, MAXSC2
        DO 40 I = 2, IPOS2
          CORR(I,J) = SMT4*(TEMP(I+1,J)+TEMP(I,J+1)+TEMP(I-1,J)+TEMP(I,J-1))
   40   CONTINUE
C
C SMOOTHING CORRECTION IS APPLIED TO EACH GRID POINT AND THE DIFFERENCES
C BETWEEN ORIGINAL AND  SMOOTHED TEMPERATURE FIELDS IS FOUND
C
        KOUNT = 0
        S = 0.0
        DO 60 J = 1, MAXSC
          SUM = 0.0
          DO 50 I = 1, IPOS
            STEMP(I,J) = (TEMP(I,J) + CORR(I,J)) / SM
            DT = ABS(TEMP(I,J) - STEMP(I,J))
            SUM = SUM + DT
   50     CONTINUE
C*** RESID IS THE MEAN DIFFERENCE BETWEEN FIELDS ***
          RESID(J) = SUM / IPOS
          S = S + RESID(J)
   60   CONTINUE
C
C COMPUTE THE MEAN AND STANDARD DEVIATION OF SMOOTH VS. ORIGINAL FIELDS
C IN ORDER TO DISTINGUISH NOISE, AND OBSERVE THE EFFECTS OF SMOOTHING
C
        SSQ = 0.0
        AVE = S / MAXSC
        DO 70 J = 1, MAXSC
          SSQ = SSQ + (RESID(J) - AVE) * (RESID(J) - AVE)
   70   CONTINUE
        STDEV = SQRT(SSQ/(MAXSC - 1))
        ERRP2 = AVE + STDEV
        ERRM2 = AVE - STDEV
C*** FIRST SMOOTHING USED TO ELEMINATE NOISE ***
        IF (KK .GT. 1) GO TO 120
        DO 110 J = 2, MAXSC2
          IF (RESID(J).GT.ERRM2 .AND. RESID(J).LT. ERRP2) GO TO 90
          KOUNT = KOUNT + 1
          BS(KOUNT) = J
C
C REPLACE BAD SCAN WITH THE AVERAGE OF SCAN-2, AND SCAN-3
C REPLACE PREVIOUS SCAN IN CASE OF CONTAMINATION
```

```
C REPLACE NEXT SCAN IN CASE OF CONTAMINATION
C
            DO 80 II = 1, IPOS
            TEMP(II,J - 1) = (STEMP(II,J - 3)+STEMP(II,J-2))/2
            TEMP(II,J)     = (STEMP(II,J - 3)+STEMP(II,J-2))/2
            TEMP(II,J + 1) = (STEMP(II,J - 3)+STEMP(II,J-2))/2
   80       CONTINUE
            J = J+1
            GO TO 110
   90       DO 100 I = 1, IPOS
  100       TEMP(I,J) = STEMP(I,J)
  110     CONTINUE
          GO TO 140
C
  120     DO 130 J = 1, MAXSC
            DO 130 I = 1, IPOS
  130     TEMP(I,J) = STEMP(I,J)
          WRITE (6,150) KK, SMT(KK)
          GO TO 200
  140     WRITE (6,150) KK, SMT(KK)
  150     FORMAT ('0', 4X, 'SMOOTHING OPERATION NUMBER', I3, 5X,
     &            'SMOOTHING PARAMETER = ', F6.2)
          WRITE (6,160) AVE, STDEV
  160     FORMAT ('0', 4X, 'MEAN OF FIELD DIFFERENCES  =', F8.3, //,
     &            5X, 'STANDARD DEVIATION', 9X, '=', F8.3)
          WRITE (6,170) MAXSC
  170     FORMAT ('0', 4X, 'NUMBER OF SCANS IN WINDOW  =', I8)
          WRITE (6,180) KOUNT
  180     FORMAT ('0',4X,'SCAN LINES REJECTED DUE TO SYNCH PROBLEM = ',I4)
          IF (KOUNT .GT. 0) WRITE (6,190) (BS(J),J=1,KOUNT)
  190     FORMAT ('0',4X,'SCAN LINES REJECTED  =', 5X,10(3F6.0,/,31X))
  200 CONTINUE
      RETURN
      END
C
C *******************************************************************
C
      SUBROUTINE CALIBR(MAXSC, IPOS)
C
C THIS SUBROUTINE IS USED TO DETERMINE AVERAGE DATA VALUES OF
C CALIBRATION LEVELS AND CALIBRATE THE INFRARED DATA OBTAINED
C FROM NOAA-9.THE ONBOARD COMPUTER IS CALLED A MANIPULATION
C INFORMATION PROCESSOR OR MIRP FOR SHORT. A DIGITAL COUNT FROM
C MIRP IS WHAT IS CONVERTED TO AN ANALOG SIGNAL AND TRANSMITTED
C TO APT STATIONS. THE PROBLEM INVOLVED IN CALIBRATING THE
C INFRARED DATA IS DETERMINING THE RELATIONSHIP BETWEEN
C THE U OF A DIGITAL COUNT AND THE MIRP DIGITAL COUNT.
C
C INPUT  UNIT 7  = TELEMETRY WEDGE LEVELS DATA
C                  FROM OUTPUT OF PROGRAM READTAPE.
C OUTPUT UNIT 9  = WEDGE LEVEL AND CALIBRATION DATA FOR PLOTTING
C                  PROGRAM PL.WEDGE AND PL.CALIBR.
C                  (SEE APPENDICES C.5 AND C.6)
C            10 = CALIBRATION WEDGE LEVELS, MEAN AND STANDARD
C                  DEVIATION VALUES
C
C    DETERMINE RELATION BETWEEN U OF A DIGITAL VALUE AND B.B. TEMP.
C        THE FIRST 9 VALUES IN UOFA ARE WEDGE LEVELS VALUES
C        THE LAST 5 VALUES IN UOFA ARE BLACK BODY THERMISTER
C                AVERAGES  AND SPACE VIEW.
C CUTOM = COEFFICIENTS OF THE CUBIC SPLINE FITTING UOFA TO MIRP DATA
C CMTOU = COEFFICIENTS OF THE CUBIC SPLINE FITTING MIRP TO UOFA DATA
C TUOFA = DATA VALUES CORRESPONDING TO
C TMIRP = MIRP DATA VALUES FROM THERMISTERS
C OBTAIN COEFFICIENTS FROM CUBIC SPLINE Y=F(X) CMIRP = F(UOFA)
C OBTAIN COEFFICIENTS FROM CUBIC SPLINE Y=F(X) UOFA = F(CMIRP)
C
      INTEGER TELM(160), WEDGE
      LOGICAL*1 FREE(1) /'*'/
      REAL MEAN(16), T(52), CA(52), CMR(52), IN, BPAR(4) /4*0.0/,
     &     CUTOM(8,3), CMTOU(8,3), TUOFA(5), TMIRP(5), UOFA(14),
     &     CMIRP(9)/0., 31., 63., 95., 127., 159., 191., 223., 255./
```

```
      COMMON /TFIELD/ TEMP(401,600)
      CALL DESTRY('-9 ')
      CALL DESTRY('-10 ')
      CALL FTNCMD('ASSIGN 9=-9', 11)
      CALL FTNCMD('ASSIGN 10=-10', 13)
C
      READ(7,30) NOBIT
   30 FORMAT(11X,I4)
      WRITE (10,34) NOBIT
   34 FORMAT ('***** FILE',I5,'.WEDGE *****')
      WRITE (10,35) NOBIT
   35 FORMAT ('-',10X,'TELEMETRY WEDGE LEVELS FOR ORBIT NUMBER',I5)
      DO 70 WEDGE = 1, 16
        TD = 0.0
        SUM = 0.0
        READ (7,FREE) (TELM(I),I=1,160)
        DO 40 I = 1, 160
          SUM = SUM + TELM(I)
   40   CONTINUE
        MEAN(WEDGE) = SUM / 160.
        DO 50 K = 1, 160
          TD = TD + (TELM(K) - MEAN(WEDGE)) ** 2
   50   CONTINUE
        STDEV = SQRT(TD/159.0)
C*** OUTPUT CALIBRATION WEDGE LEVELS, MEANS AND STANDARD DEVIATIONS ***
        WRITE (10,60) WEDGE, MEAN(WEDGE), STDEV
   60   FORMAT ('-', 5X, 'WEDGE NUMBER', I3, 4X, 'MEAN', F7.2, 4X,
     &          'STD DEVIATION', F7.2)
   70 CONTINUE
C
C DUMP THEMISTER AVERAGES AND SPACE VIEW INTP PROPER ARRAY POSITIONS IN UOFA.
C
      UOFA(1) = MEAN(9)
      UOFA(14) = MEAN(15)
      K = ;
      DO 80 I = 1, 8
        K = K + 1
   80 UOFA(K) = MEAN(I)
      DO 90 I = 10, 13
   90 UOFA(I) = MEAN(I)
C
C WRITE UOFA, CMIRP, DATA LEVELS AND TEMPERATURES TO UNIT 9 FOR
C USE IN PLOTTING  PROGRAM
C
      WRITE(9,95) NOBIT
   95 FORMAT('***** FILE',I5,'.WED-CAL *****')
      DO 100 I = 1, 9
  100 WRITE (9,110) UOFA(I), CMIRP(I)
  110 FORMAT (2F8.2)
C
      NCAL = 52
      IER = 0
C
C NCAL = NUMBER OF CALIBRATION LEVELS USED
C IER  = ERROR IN IMSL ROUTINE FOR CUBIC SPLINES
C
      CALL ICSICU(UOFA, CMIRP, 9, BPAR, CUTOM, 8, IER)
      CALL ICSICU(CMIRP, UOFA, 9, BPAR, CMTOU, 8, IER)
      K = 0
      DO 120 J = 10, 14
        K = K + 1
        TUOFA(K) = UOFA(J)
  120 CONTINUE
C
C EVALUATE CUBIC SPLINE TO OBTAIN CMIRP COUNT RELATING TO
C RADIOMETER HOUSING TEMPERATURE.
C
      CALL ICSEVU(UOFA, CMIRP, 9, CUTOM, 8, TUOFA, TMIRP, 5, IER)
C
C CONVERT TMIRP TO TEMPERATURE. UOFA RECORDS 8 BIT NUMBERS, FACTOR
C OF 4 IN THE FOLLOWING EQUATIONS IS CONVERTING BACK TO ORIGINAL
C TO 10 BIT NUMBERS.
C
```

```
      T1 = 277.018 + 4 * 0.05128 * TMIRP(1)
      T2 = 276.750 + 4 * 0.05128 * TMIRP(2)
      T3 = 276.862 + 4 * 0.05128 * TMIRP(3)
      T4 = 276.546 + 4 * 0.05128 * TMIRP(4)
C
C TAKE AVERAGE OF PRT TEMP'S
C TBB IS THE ACTUAL TEMPERATURE OF THE RADIOMETER HOUSING.
C
      TBB = (T1 + T2 + T3 + T4) * 0.25
      CALL PLANCK(TBB, QN)
C
C TO ACCOUNT FOR NON-LINEARITIES ASSUME THE RADIANCE
C OF SPACE = -3.384, CMSP = 250.0 (SEE APPENDIX B)
C
      SP = -3.384
      CMSP = 250.0
C
C FROM N = G*CM + IN
C
      G = (SP - QN) / (CMSP - TMIRP(5))
      IN = SP - G * CMSP
C
C NOW WORK BACKWARDS - FIND N FOR EVERY TWO-DEGREE INTERVALS
C FROM -73  TO 30 DEGREES C
C
      J = 0
      DO 130 K = 200, 304, 2
        J = J + 1
        T(J) = K
        CALL PLANCK(T(J), QN)
        CMR(J) = (QN - IN) / G
  130 CONTINUE
C
C
C EVALUATE CUBIC SPLINE CONVERTING CMR(J) TO UOFA COUNT FOR
C LINEAR INTERPOLATION.
C
      CALL ICSEVU(CMIRP, UOFA, 9, CMTOU, 8, CMR, CA, 52, IER)
C
      WRITE (9,140)
  140 FORMAT ('***** DATA FOR CALIBRATION CURVES BEGIN *****')
      DO 150 I = 1, NCAL, 2
  150 WRITE (9,110) CA(I), T(I)
C
C CA(I), T(I) = DATA VALUES AND CORRESPONDING TEMPERATURE VALUES
C                FOR EACH CALIBRATION LEVEL (IN PAIRS)
C
      WRITE (6,160) (CA(I),T(I),I=1,NCAL,5)
  160 FORMAT ('-',14X,'CALIBRATION PARAMETERS',//,5X,'CALIBRATION ',
     &  'CURVATURE:     DATA LEVELS     TEMPERATURES (IN DEG K)',//,
     &   70(31X,F8.2,14X,F7.2,/))
C
C CALIBRATE EACH GRID POINT
C MAXSC = NUMBER OF COLUMS IN DATA FIELD
C IPOS  = NUMBER OF ROWS IN DATA FIELD
C TEMP(I,J) =  DATA VALUE AT EACH POINT(I,J)
C
      DO 190 J = 1, MAXSC
      DO 190 I = 1, IPOS
C
C SET VALUES OUTSIDE OF TEMP RANGE TO EXTREME VALUES OF TEMPERATURE
C RANGE. (IMPLEMENTED INFREQUENTLY)
C
        IF (TEMP(I,J) .GT. CA(1)) TEMP(I,J) = CA(1)
        IF (TEMP(I,J) .LT. CA(NCAL)) TEMP(I,J) = CA(NCAL)
        DO 170 K = 1, 51
         IF (TEMP(I,J).LT.CA(K) .AND. TEMP(I,J).GE.CA(K+1)) GO TO 180
  170   CONTINUE
C*** PERFORM LINEAR INTERPOLATION ***
  180   DUM = (TEMP(I,J) - CA(K + 1)) / (CA(K) - CA(K + 1))
        DUM2 = - DUM * (T(K) - T(K + 1)) + T(K)
```

```
C*** CONVERT TO DEGREE C ***
      *   TEMP(I,J) = DUM2 - 273.15
  190 CONTINUE
      RETURN
      END
C
      SUBROUTINE PLANCK(TEMK, QN)
      DIMENSION PHI(60)
C
C THIS SECTION DETERMINES THE RADIANCE OF BLACK BODY WITH
C TEMPERATURE T IN THE 11 MICRON BAND (ALL CONSTANTS WERE
C OBTAINED FROM NOAA-9 WRITE UP, SEE APPENDIX B)
C
      DATA PHI /0.0, 0.30603E-4, 0.64563E-4, 0.10523E-3, 0.17057E-3,
     &   0.37139E-3, 0.85488E-3, 0.17526E-2, 0.29947E-2, 0.43718E-2,
     &   0.56739E-2, 0.67844E-2, 0.77153E-2, 0.84881E-2, 0.91222E-2,
     &   0.96298E-2, 0.10022E-1, 0.10310E-1, 0.10525E-1, 0.10708E-1,
     &   0.10903E-1, 0.11130E-1, 0.11370E-1, 0.11596E-1, 0.11786E-1,
     &   0.11949E-1, 0.12111E-1, 0.12299E-1, 0.12523E-1, 0.12746E-1,
     &   0.12926E-1, 0.13022E-1, 0.13039E-1, 0.13030E-1, 0.13047E-1,
     &   0.13135E-1, 0.13274E-1, 0.13419E-1, 0.13522E-1, 0.13518E-1,
     &   0.13274E-1, 0.12640E-1, 0.11466E-1, 0.97239E-2, 0.76698E-2,
     &   0.56031E-2, 0.38225E-2, 0.25039E-2, 0.15835E-2, 0.97002E-3,
     &   0.57192E-3, 0.31626E-3, 0.16604E-3, 0.88422E-4, 0.50625E-4,
     &   0.27594E-4, 0.13455E-4, 0.52455E-5, 0.53119E-9, 0.0/
C
C INITIAL VALUE OF V IS V = 862.06885
C
      V = 862.06885
      DV = 2.37812
      QN = 0.0
C*** CALCULATE PLANCK FUNCTION ***
      DO 10 I = 1, 60
        V = V + DV
        PLANK = (1.1910659E-5*(V**3)) / (EXP(1.438833*V/TEMK) - 1)
        QN = QN + PLANK * PHI(I) * DV
   10 CONTINUE
      RETURN
      END
$ENDFILE
$IF RC>4 $SOURCE PREVIOUS
```

```
*************** FILE PL.FIELD.CL ***************
$EMPTY -PL.F OK
$R *FORTG SPUNCH=-PL.F T=1
C
C PROGRAM PLOTS EITHER CLOUD TOP TEMPERATURE OR
C       REFLECTIVITY CONTOURS IN 2-DIMENSIONS
C
        DIMENSION FIELD(600,400),CVAL(50),THICK(3)
        COMMON /PASS/ XMIN,YMIN,XMAX,YMAX
        LOGICAL*1 FREE(1)/'*'/, NAME(12), SQUARE/Z9F/
        REAL NO/'N  '/
        INTEGER IOP(8)/1, 1, 0, 1, 1, 0, 1, 1/
        REAL    VOP(8)/4*0.0, -1.0, 2*0.0, 0.025/
        CALL FTNCMD('ASSIGN 5=*MSOURCE*', 18)
        CALL DESTRY('-9FIELD ')
        CALL SETLIO('9          ','-9FIELD ')
C
C  READ IN DATA FROM UNIT 13
C
        READ(13) IPOS, MAXSC
        WRITE(6,FREE) IPOS, MAXSC
        DO 10 I = 1, MAXSC
           READ(13) (FIELD(I, J), J = 1, IPOS)
   10   CONTINUE
        SCALS = 76.737
        SCALP = 59.346
        XSIZE = MAXSC/SCALS
        YSIZE = IPOS/SCALP
        XMIN=0.
        XMAX=XSIZE
        YMIN=0.
        YMAX=YSIZE
C
C  CALCULATE SCALING FACTOR, HEIGHT OF CONTOUR VALUE
C  AND PAGESIZE SCALE (21.5 X 13.5 CM)
C  (THE MAXIMUM WIDTH OF CALCOMP PLOTTER IS 76.0 CM)
C
        FAC = 76.0/YSIZE
        IF (FAC .GT. 50.0) FAC = 50.0
        VOP(8) = 0.80/FAC
        HI = 0.85/FAC
        CALMS1 = AMIN1(21.50/(YSIZE*FAC),13.50/(XSIZE*FAC))
        CALMS2 = AMIN1(21.50/(YSIZE*FAC),27.00/(XSIZE*FAC))
C
        WRITE (6, 35) XSIZE, YSIZE, FAC, CALMS1, CALMS2
   35   FORMAT (' THE PLOT IS',F6.2,' X',F6.2,' CM, FACTOR=',F6.2,
     &         ' PAGESIZE SCALE=',2F7.4 )
        WRITE (6,20)
   20   FORMAT('ENTER MIN, MAX AND INTERVAL CONTOUR VALUES')
        READ (5,FREE) AMIN, AMAX, CINT
        WRITE (6,25)
   25   FORMAT('ENTER THICK CONTOUR VALUES (3 VALUES)')
        READ (5,FREE) THICK1,THICK2,THICK3
        THICK(1) = THICK1
        THICK(2) = THICK2
        THICK(3) = THICK3
C
        CALL PLOTS
        CALL XLIMIT(200.0)
        CALL FACTOR(FAC)
        CALL PLOT(0.2, 0.2, -3)
        NC = IFIX((AMAX-AMIN)/CINT)+1
        CSET = AMIN
        DO 30 I = 1, NC
           CVAL(I) = CSET
           CSET = CSET+CINT
   30   CONTINUE
        CALL CONTUR (XSIZE,YSIZE,FIELD,600,MAXSC,IPOS,
     &             CVAL,NC,IOP,VOP,THICK)
C
C PLOT CITY LOCATIONS FROM UNIT 16
C
```

```
   40 READ (16, FREE, END=54) MM
      DO 50 I = 1, MM
           READ (16, 45) XP, YP, (NAME(J),J = 1,12)
   45      FORMAT(2F7.2,1X,12A1)
           XP = XP/SCALS
           YP = YP/SCALP
           IF (XP.LT.0.0 .OR. XP.GT.XSIZE) GO TO 50
           IF (YP.LT.0.0 .OR. YP.GT.YSIZE) GO TO 50
           CALL PALPHA ('GREEK.1 ', 0)
           CALL PSYM (XP, YP, HI, SQUARE,-90.0, 1)
C***       CALL PALPHA ('SANSERIF.2 ', 0)
C***       CALL PSYM (XP, YP-HI, HI, NAME,-90.0, 12)
   50 CONTINUE
      GO TO 40
C
   54 WRITE (6, 55)
   55 FORMAT ('PLOT LATITUDE - LONGITUDE LINES ? (Y/N)')
      READ (5, 56) ANS2
   56 FORMAT (A4)
      IF (ANS2 .EQ. NO) GO TO 80
C
C DRAW LAT-LON LINES FROM UNIT 11
C
   60 READ (11, 65, END=80) NPTS, MZERO, LATLON
   65 FORMAT (3I4)
      DO 90 I = 1, NPTS
           READ (11, FREE) XL, YL
           XL = XL/SCALS
           YL = YL/SCALP
           IF (I .EQ. 1) CALL PLOT2 (XL, YL, 3)
           IF (I .NE. 1) CALL PLOT2 (XL, YL, 2)
   90 CONTINUE
      GO TO 60
C
C  TERMINATING PLOT
C
   80 CALL PLOT (0.0, 0.0, 999)
      STOP
      END
C
      SUBROUTINE CONTUR(XSIZE,YSIZE,ZP,IDIMX,M,N,
     &                  CVALS,NC,IOP,VOP,THICK)
C
C     MODIFIED BY CHI NGUYEN ON JAN. 1987 TO FIT WITH
C     THE SATELLITE DATA FOR JAN 28,1977 VERSION.
C
      COMMON/ COM031/ TOUR,IRP,JRP,ISP,JSP,NX,NY,EXPN,CONHT
      COMMON/ COM033/ BUF(40003),IPBUF,NDEC,SCLX,SCLY,ZM,FWRITE
      LOGICAL FWRITE
      DATA TOL/1.0E-10/
      VAL = VALL
      DIMENSION CVALS(1),IOP(1),VOP(1),ZP(IDIMX,1),THICK(1)
      ZMAX = -1.0E75
      ZMIN = 1.0E75
      DO 40 J = 1,N
      DO 42 I = 1,M
           IF(ZP(I,J) .LT. ZMIN) ZMIN = ZP(I,J)
           IF(ZP(I,J) .GT. ZMAX) ZMAX = ZP(I,J)
   42 CONTINUE
   40 CONTINUE
      ZMAXK = ZMAX
      ZMINK = ZMIN
      NS = NC+1
      CI = (ZMAX-ZMIN)/NS*0.99999
   44 NS = NS-1
      IF(NS .EQ. 0) GO TO 150
      ZMAX = ZMAX-CI
      IVC = NC-NS+1
      IF (IOP(2).NE.1) GO TO 47
      ZMAX = CVALS(IVC)
      IF(ZMAX.LE.ZMAXK .AND. ZMAX.GE.ZMINK) GO TO 48
```

```
          WRITE(6,905) ZMAX
  905     FORMAT(23HO-WARNING-CONTOUR VALUE,G9.3,14HDOES NOT EXIST)
          GO TO 44
   47     CVALS(IVC) = ZMAX
          GO TO 49
   48     IPEN=1
          IF (ZMAX.GE.(THICK(1)-TOL).AND.ZMAX.LE.(THICK(1)-TOL))IPEN=2
          IF (ZMAX.GE.(THICK(2)-TOL).AND.ZMAX.LE.(THICK(2)-TOL))IPEN=3
          IF (ZMAX.GE.(THICK(3)-TOL).AND.ZMAX.LE.(THICK(3)-TOL))IPEN=4
          CALL NEWPEN(IPEN)
   49     CALL AUX099 (XSIZE,YSIZE,ZP,IDIMX,M,N,ZMAX,IOP,VOP)
          GO TO 44
  150     IF(IOP(3).NE.1 .OR. IPBUF.EQ.3) GO TO 60
   60     IF(IOP(1).NE.1) GO TO 99
          CALL NEWPEN(1)
          CALL PLOT (0.0,0.0,3)
          CALL PLOT (XSIZE,0.0,2)
          CALL PLOT (XSIZE,YSIZE,2)
          CALL PLOT (0.0,YSIZE,2)
          CALL PLOT (0.0,0.0,2)
   99     RETURN
          END
C
          SUBROUTINE AUX099(XSIZE,YSIZE,ZP,IDIMX,NXX,NYY,TOURR,IOP,VOP)
C
C   C O N T O U R   P L O T T I N G   O F   A   G R I D
C
C   XP = ARRAY OF X VALUES - SINGLE DIMENSION
C   YP = ARRAY OF Y VALUES - SINGLE DIMENION,
C   ZP = DOUBLE DIMENSION ARRAY(IDIMX BY .....) CONTAINING THE
C          Z VALUES (Z = F(X, Y)) TO BE CONTOURED.
C   NX, NY, = THE CONTOURING GRID IS NX LONG BY NY WIDE .
C   I. E. THE GRID MAY BE SMALLER THAN THE ARRAY WHICH CONTAINS IT.
C   'VAL' IS AN INDICATOR FOR PLOTTING NUMBERS ON THE LINES.
C   IF ABS(VAL) .LT. 1.0E-75 THEN NO NUMBERS ARE PLOTTED
C   IF NEGATIVE NEGATIVE VALUES ON THE GRID ARE NOT PLOTTED AT ALL.
C
C   CVAL IS THE VALUE OF THE NUMBER TO BE PLACED ON THE CONTOUR.
C   NDC - NUMBER OF DECIMAL PLACES OF NUMBERS ON CONTOURS
C   IF NDC = -1 THEN NUMBERS WILL BE PLOTTED WITHOUT DECIMAL
C
         DIMENSION XP(600), YP(600), ZP(IDIMX ,1) ,IOP(1), VOP(1)
         COMMON/ COM031/ TOUR,IRP,JRP,ISP,JSP,NX,NY,EXPN,CONHT
         COMMON/ COM032/ IPEN,VAL,XVAL,SEP,PLACE,POS,DSEP,DSEP2,SEPSQ
         COMMON/ COM033/ BUF(40003),IPBUF,NDEC,SCLX,SCLY,ZM,FWRITE,INIT
     & ,CENTR,SMOOT
         LOGICAL FWRITE,INIT ,CENTR,SMOOT, PLACE, POS
         INIT = .FALSE.
         GAP = CONHT
         ZM = 999.0
         IPBUF = 3
         FWRITE = .FALSE.
         IF(IOP(3) .EQ. 1) FWRITE = .TRUE.
         VALL = 1.0E-76
         IF(IOP(4) .EQ. 2) VALL = 3.0
         IF(IOP(4) .EQ. 3) VALL = VOP(4)
         CENTR = .FALSE.
         IF(IOP(4) .NE. 1) GO TO 3
         CENTR = .TRUE.
         VALL = 1.0E-75
   3     NDC = 2
         IF(IOP(5) .EQ. 1) NDC = VOP(5)
         IF(NDC .GT. 5) NDC = 5
         IF(IOP(6) .EQ. 1) VALL = -VALL
         CVAL = TOURR
         SMOOT = .FALSE.
         IF(IOP(7) .EQ. 1) SMOOT = .TRUE.
         CONHT = 0.07
         IF(IOP(8) .EQ. 1) CONHT = VOP(8)
         DO 50 I = 1, NXX
             XP(I) = I-1
  50     CONTINUE
```

```
      DO 52 J = 1, NYY
         YP(J) = J-1
 52   CONTINUE
      SCLX = XSIZE/(NXX-1)
      SCLY = YSIZE/(NYY-1)
      VAL = VALL
      TOUR = TOURR
      NX = NXX
      NY = NYY
C*** INITIALIZE FOR PLACING NUMBERS ON THE CONTOURS ***
      PLACE = .FALSE.
      SEP = ABS(VAL)
      SEPSQ = SEP**2
      IF (SEP .LT. 1.0E-75) GO TO 195
      EXPN = 999.0
      NDEC = NDC
      PLACE = .TRUE.
      TEMP = AMAX1(0.0,FLOAT(NDEC))
      IF(ABS(CVAL)+.000001 .LT. 10.**(-TEMP)) GO TO 190
C*** CVAL IS THE NUMBER TO BE PLACED ON THE CONTOURS ***
      XVAL = CVAL
C*** CALCULATE THE NUMBER OF DIGITS IN THE NUMBER ***
      TEMP = INT(ALOG10(ABS(CVAL))) + 1.0
C*** ADD PLACES FOR DECIMAL PT. AND DIGITS AFTER DECIMAL PT.***
      TEMP = TEMP+1.0+NDEC
C*** IF MORE THAN 6 DIGITS USE THE OTHER METHOD ***
      IF(TEMP .GT. 6.0) GO TO 190
      TEMP2 = TEMP
      IF(TEMP .GT. 1.0) GO TO 191
      TEMP2 = NDEC+2
C*** THE WIDTH OF THE NUMBER IN PLOT INCHES ***
 191  DSEP = TEMP2*CONHT
      IF (CVAL .GT. 0.0) GO TO 195
      GO TO 1935
C*** WE PLOT THE NUMBER IN EXPONENTIAL FORM ***
 190  CONTINUE
      XVAL = 0.0
      DSEP = CONHT
      IF (CVAL .EQ. 0.0) GO TO 195
      TEMP = ALOG10(ABS(CVAL))
      EXPN = FLOAT(INT(TEMP))
      TEMP = TEMP-EXPN
      IF (TEMP.GE.0.0) GO TO 189
      TEMP = TEMP+1.0
      EXPN = EXPN-1.0
 189  XVAL = 10.0 ** TEMP
      NDEC = 2
      ITEMP = NDEC+4
      IF(EXPN .LT. 0.0) ITEMP = ITEMP+1
      IF(ABS(EXPN).GE.10.0) ITEMP = ITEMP+1
      DSEP = ITEMP*CONHT
      IF (CVAL .GT. 0.0) GO TO 195
 193  XVAL = -XVAL
 1935 DSEP = DSEP + CONHT
 195  CONTINUE
      DSEP2 = DSEP+GAP
      POS = .FALSE.
      IF (VAL .GE. 0.0) POS = .TRUE.
C
C     THIS SUBROUTINE INITIALIZES AND CONDUCTS THE SEARCH
C*** F I R S T  C L E A R  A L L  S W I T C H E S ***
      ITEMP = AUX098(NX, NY, -1)
C*** S E A R C H  F O R  A  B O T T O M  E D G E  C O N T O U R ***
      JRP = 1
      JSP = 1
      DO 1 I = 2, NX
         IF (ZP(I, 1) .LE. TOUR) GO TO 1
         J = I - 1
         IF (ZP(J, 1) .GT. TOUR) GO TO 1
         IRP = I
         ISP = J
         CALL AUX096 (IDIMX, XP, YP, ZP)
 1    CONTINUE
```

```
C*** S E A R C H   T H E   R I G H T   E D G E ***
         ISP = NX
         IRP = NX
         DO 15 I = 2, NY
              IF (ZP(NX, I) .LE. TOUR) GO TO 15
              J = I - 1
              IF (ZP(NX, J) .GT. TOUR) GO TO 15
              JSP = J
              JRP = I
              CALL AUX096 (IDIMX, XP, YP, ZP)
   15    CONTINUE
C*** S E A R C H   T H E   T O P   E D G E ***
         ITEMP = NX - 1
         JRP = NY
         JSP = NY
         DO 2 I = 1, ITEMP
              II = NX - I
              IF (ZP(II, NY) .LE. TOUR) GO TO 2
              J = II + 1
              IF (ZP(J, NY) .GT. TOUR) GO TO 2
              IRP = II
              ISP = J
              CALL AUX096 (IDIMX, XP, YP, ZP)
    2    CONTINUE
C*** S E A R C H   F O R   A   L E F T   E D G E   C O N T O U R ***
         JTEMP = NY - 1
         IRP = 1
         ISP = 1
         DO 25 I = 1, JTEMP
              II = NY - I
              IF (ZP(1, II) .LE. TOUR) GO TO 25
              J = II + 1
              IF (ZP(1, J) .GT. TOUR) GO TO 25
              JRP = II
              JSP = J
              CALL AUX096 (IDIMX, XP, YP, ZP)
   25    CONTINUE
C*** S E A R C H   T H E   R E S T   O F   T H E   A R R A Y ***
         DO 30 I = 2, JTEMP
         DO 26 J = 2, NX
              JJ = J - 1
              IF (ZP(J, I) .LE. TOUR)GO TO 26
              IF (ZP(JJ, I) .GT. TOUR) GO TO 26
              IF (AUX098(J, I, 0) .EQ. 1) GO TO 26
              IRP = J
              ISP = JJ
              JRP = I
              JSP = I
              CALL AUX096 (IDIMX, XP, YP, ZP)
         CONTINUE
         CONTINUE
         IPEN = 3
C*** DUMMY CALL TO GET BUFFER PLOTTED OR WRITTEN ***
         CALL AUX097 (0.0,0.0,1.0,0.0,0.0,0.0)
         INIT = .FALSE.
         RETURN
         END
C
         SUBROUTINE AUX096 (NNX, XP, YP, ZP)
         COMMON/ COM031/ TOUR,IIRP,JJRP,IISP,JJSP,NX,NY,CONHT
         COMMON/ COM032/ IPEN,VAL,NVAL,SEP,PLACE,POS,DSEP,DSEP2
C
C    TOUR = THE CONTOUR VALUE
C    IRP, JRP  = REFERENCE POINT
C    ISP, JSP  = POINT WE ARE CONTOURING TO
C
         DIMENSION XP(2), YP(2), ZP(NNX, 2)
         DIMENSION IT(9), JT(9)
         DATA IT / 0, 1, 1, 0, 9, 0, -1, -1, 0 /
         DATA JT / -1, 0, 0, -1, 9, 1, 0, 0, 1 /
         LOGICAL DTEST(9)
         DATA DTEST / .FALSE., .TRUE., .FALSE., .TRUE., .FALSE.,
      &  .TRUE., .FALSE., .TRUE., .FALSE.                        /
```

```
      IRP = IIRP
      JRP = JJRP
      ISP = IISP
      JSP = JJSP
      IPEN = +3
      GO TO 5
C*** S W I T C H   P O I N T S ***
 95   IRP = IN
      JRP = JN
 5    CONTINUE
      CALL AUXO97 (XP(IRP), YP(JRP), ZP(IRP, JRP),
     & XP(ISP), YP(JSP), ZP(ISP, JSP))
C*** FIND THE NEXT POINT TO CHECK THROUGH A TABLE LOOKUP ***
      LOCATE = 3*(JRP - JSP) + IRP - ISP + 5
C*** IN, JN = THE NEW POINT ***
      IN = ISP + IT(LOCATE)
      JN = JSP + JT(LOCATE)
C*** T E S T   F O R   A N   E D G E ***
      IF (IN.GT.NX .OR. IN.LT.1 .OR. JN.GT.NY .OR. JN.LT.1) RETURN
C*** I T   M A Y   B E   A   D I A G O N A L ***
      IF (LOCATE .NE. 6) GO TO 60
      IF (AUXO98(IRP, JRP, +1) .EQ. 1) RETURN
 60   IF (DTEST(LOCATE)) GO TO 97
C*** DETERMINE IF IT IS A CONTOUR OR SWITCH POINTS ***
      ZPP = ZP(IN, JN)
      IF (ZPP .GT. TOUR) GO TO 95
      ISP = IN
      JSP = JN
      GO TO 5
C*** D I A G O N A L S   G E T   S P E C I A L   T R E A T M E N T ***
C*** CALCULATE THE HEIGHT AND LOCATION OF THE MIDPOINT ***
 97   CONTINUE
      VX = (XP(IRP) + XP(IN))*0.5
      VY = (YP(JRP) + YP(JN))*0.5
      LOCATE = 3*(JRP - JN) + IRP - IN + 5
      INN = IN + IT(LOCATE)
      JNN = JN + JT(LOCATE)
      HTM = (ZP(IRP,JRP) + ZP(ISP,JSP) + ZP(IN,JN) + ZP(INN,JNN))/4.0
      IF (HTM .GT. TOUR) GO TO 975
C*** M I D P O I N T   L E S S   T H A N   C O N T O U R ***
      CALL AUXO97 (XP(IRP), YP(JRP), ZP(IRP, JRP), VX, VY, HTM)
      IF (ZP(INN, JNN) .GT. TOUR) GO TO 9715
C*** T U R N O F F   S H A R P   R I G H T ***
      ISP = INN
      JSP = JNN
      GO TO 5
 9715 CONTINUE
      CALL AUXO97 (XP(INN), YP(JNN), ZP(INN, JNN), VX, VY, HTM)
      IF (ZP(IN, JN) .GT. TOUR) GO TO 9716
C*** C O N T I N U E   S T R A I G H T   T H R O U G H ***
      IRP = INN
      JRP = JNN
      ISP = IN
      JSP = JN
      GO TO 5
C*** W I D E   L E F T   T U R N ***
 9716 CONTINUE
      CALL AUXO97 (XP(IN), YP(JN), ZP(IN, JN), VX, VY, HTM)
      GO TO 95
C*** M I D P O I N T   G R E A T E R   T H A N   C O N T O U R ***
 975  CONTINUE
      CALL AUXO97 (VX, VY, HTM, XP(ISP), YP(JSP), ZP(ISP, JSP))
C*** I T   M A Y   B E   A   S H A R P   L E F T   T U R N ***
      IF (ZP(IN, JN) .GT. TOUR) GO TO 95
      CALL AUXO97 (VX, VY, HTM, XP(IN), YP(JN), ZP(IN, JN))
      IF (ZP(INN, JNN) .GT. TOUR) GO TO 976
C*** W I D E   R I G H T   T U R N ***
      CALL AUXO97 (VX, VY, HTM, XP(INN), YP(JNN), ZP(INN, JNN))
      ISP = INN
      JSP = JNN
      GO TO [illegible]
C*** C O N T I N U E   S T R A I G H T   T H R O U G H ***
 976  ISP = [illegible]
```

```
      JSP = JNN
      IRP = INN
      JRP = JNN
      GO TO 5
      END
C
      FUNCTION AUX098 (NI, NJ, IND)
C
C             - C A U T I O N -
C     THIS SUBROUTINE HAS THE TWO MACHINE DEPENDANT
C   FUNCTION SUBPROGRAMS 'AND' AND 'OR' .   IT MAY NOT
C   RUN PROPERLY ON MACHINES OTHER THAN THE IBM 360/67.
C
      DIMENSION IARRAY(40000), IMASK(32)
      DATA IMASK /Z1, Z2, Z4, Z8, Z10, Z20, Z40, Z80,
     & Z100, Z200, Z400, Z800, Z1000, Z2000, Z4000,
     & Z8000, Z10000, Z20000, Z40000, Z80000,
     & Z100000, Z200000, Z400000, Z800000,
     & Z1000000, Z2000000, Z4000000, Z8000000,
     & Z10000000, Z20000000, Z40000000, Z80000000 /
      EQUIVALENCE (TEMP,ITEMP)
C
C  IF IND =    -1 THEN CLEAR THE ARRAY
C              0 THEN CHECK THE FLAG ONLY
C             +1 THEN CHECK THE FLAG AND SET IT TO 1
C
      IF (IND .NE. (-1)) GO TO 1
      DO 100 I = 1, 40000
  100    IARRAY(I) = 0
      NN = NI
      AUX098 = 0
      RETURN
    1 CONTINUE
      IPOS = (NJ - 1) * NN + NI
      IWORD = IPOS / 32
      IBIT = IPOS - IWORD * 32  + 1
      IWORD = IWORD + 1
      TEMP = AND(IARRAY(IWORD), IMASK(IBIT))
      AUX098 = 1
      IF (IND .EQ. 0) GO TO 200
      IF (ITEMP .NE. 0) RETURN
      AUX098 = 0
      TEMP = OR(IARRAY(IWORD), IMASK(IBIT))
      IARRAY(IWORD) = ITEMP
      RETURN
  200 CONTINUE
      IF (ITEMP .EQ. 0) AUX098 = 0
      RETURN
      END
C
      SUBROUTINE AUX097 (XRR, YRR, HR, XSS, YSS, HS)
      COMMON / COM032/ IPEN,VAL,XVAL,SEP,PLACE,POS,DSEP,DSEP2,SEPSQ
      LOGICAL PLACE, POS,NUMIN
      COMMON/ COM031/ TOUR,IRP,JRP,ISP,JSP,NX,NY,EXPN,CONHT
      COMMON/ COM033/ BUF(40003),IPBUF,NDEC,SCLX,SCLY,ZM,FWRITE,INIT
     & ,CENTR,SMOOT
      DIMENSION XPLTN(2), YPLTN(2), BUF2(40000)
      LOGICAL FWRITE, INIT, CENTR, SMOOT
      EQUIVALENCE (BUF(4), BUF2(1))
      DATA NUMIN/ .FALSE. /
      IF (POS .OR. HS .NE. 1.0E35) GO TO 100
      IPEN = +3
      RETURN
  100 CONTINUE
      XR = XRR
      YR = YRR
      XS = XSS
      YS = YSS
C*** LINEAR INTERPOLATION FOR THE CONTOUR ***
      DDX = XR - XS
      DDY = YR - YS
      FRAC = (HR - TOUR) / (HR - HS)
      XPLOT = XR - FRAC*DDX
```

```
            YPLOT = YR - FRAC*DDY
            IF(IPEN.EQ.3 .AND. INIT) GO TO 20
      10    IPBUF = IPBUF+2
            IF(IPBUF .LE. 40001) GO TO 30
            WRITE(6,103)
      103   FORMAT('0NO. OF POINTS IN CONTOUR EXCEEDS 40000')
            RETURN
      30    BUF(IPBUF-1) = XPLOT
            BUF(IPBUF) = YPLOT
            INIT = .TRUE.
            IPEN = 2
            OTOUR = TOUR
            OXVAL = XVAL
            RETURN
      20    BUF(1) = TOUR
            BUF(2) = XVAL
            ICSM = (IPBUF-3)/2
            BUF(3) = ICSM
            IF(FWRITE) WRITE(8) IPBUF,(BUF(I),BUF(I+1),I=1,IPBUF,2)
            N = IPBUF-3
            IPBUF = 3
            NH = N/2
            IC = 3
C***  FOLLOWING 2 STATEMENTS NECESSARY [illegible]VIDE IN SMOOTH RTN. ***
            DO 1002 I = 1,N,2
                  XPLOT2 = BUF2(I)
                  YPLOT2 = BUF2(I+1)
C***  CALL TRANSF[illegible]UTINE IF USER SUPPLIES IT ***
C***  OTHERWISE E[illegible]MY ROUTINE ***
                  CALL [illegible]XPLOT2, YPLOT2)
C***  PATCH TO PL[illegible] ON THE CONTOURS - WJC ***
                  IF [illegible]E) GO TO 1000
C***  START OF [illegible]TOUR ... ***
                  IF (I[illegible]1) GO TO 900
                  DXNUM[illegible]X*(XPLOT2-XST)
                  DYNUM = SCLY*(YPLOT2-YST)
                  SQ1 = (DXNUM)**2+(DYNUM)**2
C***  ARE WE ALREADY SPACING FOR THE LABEL ... ***
                  IF (NUMIN) GO TO 950
C***  SHOULD WE PLOT THE LABEL ... ***
C***  ARE WE PLOTTING CENTERED NUMBERS ON CONTOURS ***
                  IF(CENTR) GO TO 910
C***  ARE WE 'SEP' UNITS FROM THE LAST LABEL PLOTTED ***
                  IF(SQ1 .LT. SEPSQ) [illegible] 1000
C***  OR 'SEP' UNITS FROM THE FIRST NUMBER PLOTTED ***
                  DISTX = SCLX*(XPLOT2-XFST)
                  DISTY = SCLY*(YPLOT2-YFST)
                  IF((DISTX**2+DISTY**2) .LT. SEPSQ) GO TO 1000
             GO TO 940
      910   IF(I .LT. NH) GO TO 1000
C***  THE FIRST NUMBER ON EACH CONTOUR IS SAVED FOR CHECKING ***
                  NUMIN = .TRUE.
             GO TO 942
      900   CONTINUE
                  XFST = XPLOT2
                  YFST = YPLOT2
C***  START A NEW NUMBER ***
      940   CONTINUE
                  IF(.NOT.CENTR) NUMIN = .TRUE.
      942         XST = XPLOT2
                  YST = YPLOT2
                  IF(SMOOT) ICSM = -25
             GO TO 1000
C***  IS THE SPACE BIG ENOUGH ***
      950   CONTINUE
                  SQ2 = SQRT(SQ1)
                  IF(CENTR) GO TO 952
                  IF(I .LT. (N-1)) GO TO 952
C***  THIS PATH PREVENTS GAPS AT END OF CONTOUR LINE ***
                  IC = 2
             GO TO 1001
      952         IF(SQ2 .LT. DSEP2) GO TO 1002
```

```
              SINANG = DYNUM/SQ2
              COSANG = DXNUM/SQ2
              ISW = 1
              ANGNUM = 180.0/3.14159*ARSIN(SINANG)
              IF(DXNUM .GT. 0.0) GO TO 110
              ISW = 2
              ANGNUM = -ANGNUM
              COSANG = -COSANG
              SINANG = -SINANG
  110         XPLTN(ISW) = XST *SCLX
              ISW3 = 3-ISW
              XPLTN(ISW3) = XPLOT2 *SCLX
              YPLTN(ISW) = YST *SCLY
              YPLTN(ISW3) = YPLOT2 *SCLY
              GAP = (SQ2-DSEP)/2.0
              IF (XVAL .LT. 0.0) GAP = GAP+(CONHT/2.0)
              XN = XPLTN(1)+GAP*COSANG+CONHT/2.0*SINANG
              YN = YPLTN(1)+GAP*SINANG-CONHT/2.0*COSANG
              CALL NUMBER(XN, YN, CONHT, XVAL, ANGNUM, NDEC)
              IF(EXPN .EQ. 999.0) GO TO 976
              CALL SYMBOL (ZM, ZM, CONHT, 1HE, ANGNUM, 1)
              CALL NUMBER (ZM, ZM, CONHT, EXPN, ANGNUM, -1)
  976         IC = 3
              CALL PLOT (XPLTN(ISW3), YPLTN(ISW3), IC)
  995         NUMIN = .FALSE.
              NH = N
  1000        IF(.NOT.SMOOT) GO TO 1001
              XPLTN(1) = SCLX*XPLOT2
              YPLTN(1) = SCLY*YPLOT2
              IF(IC.NE.2) GO TO 1004
              IF(I .EQ. (N-1)) ICSM = -25
C*** FOLLOWING LINES PREVENTS PROBLEM WITH SMOOTH WITH IDENTICAL POINTS ***
  1005        ABTX = ABS((XPLOT2-OSMX)*SCLX)
              ABTY = ABS((YPLOT2-OSMY)*SCLY)
              IF(ABTX .LT. .0020.OR.ABTY .LT. .0020) GO TO 2001
              IF (ICSMO.EQ.0 .AND. ICSM.EQ.25) GO TO 1006
  2000        CALL SMOOTH (XPLTN(1), YPLTN(1), ICSM)
              OSMX = XPLOT2
              OSMY = YPLOT2
          GO TO 2002
  2001        CALL PLOT (SCLX*OSMX, SCLY*OSMY, 2)
              CALL PLOT (XPLTN(1), YPLTN(1), 2)
              OSMX = XPLOT2
              OSMY = YPLOT2
              ICSM = 0
          GO TO 2000
  2002        ICSMO = ICSM
              ICSM = -2
          GO TO 1006
  1004        ICSM = 0
              CALL PLOT (XPLTN(1), YPLTN(1), 3)
          GO TO 2000
  1001        CALL PLOT (SCLX*XPLOT2 ,SCLY*YPLOT2, IC)
  1006        IC = +2
  1002    CONTINUE
          IF(IPEN .NE. 3) GO TO 1007
          IPBUF = 5
          GO TO 30
  1007    IPEN = +2
  99      RETURN
          END
C
          SUBROUTINE CONTTR (XPLOT2, YPLOT2)
          RETURN
          END
C
          SUBROUTINE PLOT2(XT,YT,IC)
          COMMON /PASS/ XMIN,YMIN,XMAX,YMAX
          LOGICAL*1 INIT/.FALSE./,IN
          X=XT
          Y=YT
          IF(INIT) GO TO 10
```

```
      CALL WHERE(XOLD,YOLD,FCT)
      INIT=.TRUE.
   10 CONTINUE
      XKEEP=X
      YKEEP=Y
      CALL CLIP$(XOLD,YOLD,X,Y,XMIN,XMAX,YMIN,YMAX,IN)
      IF (.NOT.IN) GO TO 20
      CALL PLOT(XOLD,YOLD,3)
      CALL PLOT(X,Y,IC)
   20 XOLD=XKEEP
      YOLD=YKEEP
      RETURN
      END
$ENDFILE
$IF RC>4 $SOURCE PREVIOUS
```

```
**************** FILE PL.3FIELDF ***************
$EMPTY -PL.3F OK
$R *FORTG SPUNCH=-PL.3F T=2
C
C PROGRAM PLOTS CLOUD TOP TEMPERATURES IN 3-DIMENSIONS.
C
            DIMENSION FIELD1(400, 600), FIELD(300, 400)
            LOGICAL*1 FREE(1)/'*'/
            CALL FTNCMD('ASSIGN 5=*MSOURCE*', 18)
            CALL DESTRY('-93FIELD ')
            CALL SETLIO('9       ','-93FIELD ')
C
C    READ IN DATA FROM UNIT 13
C
            READ(13) IPO, MA
            WRITE(6,FREE) IPO, MA
            WRITE(6, 5)
    5       FORMAT('ENTER IPOBGN, IPOEND, ISKIP, MAXBGN, MAXEND, MSKIP')
            READ(5,FREE) IPOBGN, IPOEND, ISKIP, MAXBGN, MAXEND, MSKIP
            IF (IPOEND.GT.IPO .OR. MAXEND.GT.MA) GO TO 99
C
            DO 10 I = 1, MA
                     READ(13) (FIELD1(I, J), J = 1, IPO)
   10       CONTINUE
            TEMMIN =  100.0
            TEMMAX = -100.0
            II = 1
            DO 30 I = MAXBGN, MAXEND, MSKIP
            JJ = 1
            DO 20 J = IPOBGN, IPOEND, ISKIP
                     FIELD(II, JJ) = FIELD1(I, J)
                     TEMMIN = AMIN1(FIELD(II, JJ), TEMMIN)
                     TEMMAX = AMAX1(FIELD(II, JJ), TEMMAX)
                JJ = JJ +1
   20       CONTINUE
              II = II + 1
   30       CONTINUE
            IPOS = JJ - 1
            MAXSC = II - 1
C
            WRITE(6,35)
   35       FORMAT('ENTER XLOMIN, XLOMAX, YLAMIN, YLAMAX')
            READ(5,FREE) XLOMIN, XLOMAX, YLAMIN, YLAMAX
            ZMAX = (AINT(TEMMAX/10.0)+1.0)*10.0
            ZMIN = (AINT(TEMMIN/10.0)-1.0)*10.0
            ZSTP = 10.0
            WRITE(6,37) IPOS, MAXSC, TEMMIN, TEMMAX, ZMIN, ZMAX
   37       FORMAT('IPOS=', I3,'  MAXSC=',I3 ,'  TEMMIN=', F6.2,
         &'  TEMMAX=', F6.2,'  ZMIN=', F6.2,'  ZMAX=', F6.2)
C
            CALL DSPDEV('PLOTTER ')
            CALL PAGE(11.0, 8.5)
            CALL NOBRDR
            XSIZE = 8.50
            YSIZE = 5.50
            CALL AREA2D(XSIZE, YSIZE)
            CALL SCMPLX
            CALL INTAXS
            CALL ZAXANG(-90.0)
            CALL HEIGHT(0.12)
            CALL XTICKS(2)
            CALL YTICKS(2)
            CALL ZTICKS(2)
            CALL X3NAME('LONGITUDE (IN DEGREE W)$', 100)
            CALL Y3NAME('LATITUDE (IN DEGREE N)$', 100)
            CALL Z3NAME('TEMPERATURE (IN DEGREE C)$', 100)
            CALL BLSUR
            XVO = 12.0
            YVO =  8.0
            ZVO =  6.0
            CALL VOLM3D(XVO, YVO, ZVO)
            CALL VUABS (1200., 1600., 700.)
```

```
      CALL GRAF3D(XLOMIN, 2.0, XLOMAX, YLAMAX, -2.0, YLAMIN,
     &            ZMAX, -ZSTP, ZMIN)
C
C  DRAW WORKBOX OUTLINE IN ABSOLUTE WORKBOX UNITS
C
      CALL VECTR3(XVO, O., ZVO, XVO, YVO, ZVO, 0020)
      CALL VECTR3(XVO, YVO, ZVO, O., YVO, ZVO, 0020)
      CALL VECTR3(XVO, YVO, O., XVO, YVO, ZVO, 0020)
C
C PLOT SURFACE OF CLOUD TOP TEMPERATURE IN 3 DIMENSIONS
C
      CALL BGNMAT(MAXSC, IPOS)
      DO 40 I = 1, MAXSC
         YLA = ((YLAMAX-YLAMIN)/MAXSC)*(I-1)+YLAMIN
      DO 50 J = 1, IPOS
         XLO = ((XLOMAX-XLOMIN)/IPOS)*(J-1)+XLOMIN
         ZM = FIELD(I, J)
      CALL GETMAT(XLO, YLA, ZM, 1, O)
   50 CONTINUE
   40 CONTINUE
      CALL ENDMAT(FIELD, O)
      CALL SURMAT(FIELD, 1, MAXSC, 1, IPOS, O)
C
C  WRITE OUT MAX. AND MIN. TEMPERATURES IN A BOX
C
      CALL HEIGHT(O.08)
      CALL MIXALF('INSTRU')
      CALL MESSAG('MAX. TEMPERATURE = $',100,XSIZE-2.40,YSIZE-0.30)
      CALL REALNO(TEMMAX, 1, 'ABUT', 'ABUT')
      CALL MESSAG('(EH.5)O(EXHX) C$', 100, 'ABUT', 'ABUT')
      CALL MESSAG('MIN. TEMPERATURE = $',100,XSIZE-2.40,YSIZE-0.50)
      CALL REALNO(TEMMIN, 1, 'ABUT', 'ABUT')
      CALL MESSAG('(EH.5)O(EXHX) C$', 100, 'ABUT', 'ABUT')
      CALL BLREC(XSIZE-2.50, YSIZE-0.6, 2.40, 0.50, 0.02)
C
C  PLOT SUBPOT ON FLOOR OF WORKBOX
C
      CALL GRFITI(O., O., O., XVO, O., O., O., YVO, O.)
      CALL AREA2D(XVO, YVO)
      CALL GRAF(XLOMIN, 2.0, XLOMAX, YLAMAX, -2.0, YLAMIN)
      CALL GRID(1, 1)
      CALL END3GR(O)
C
C  PLOT SUBPLOT ON RIGHT SIDE WALL
C
      CALL GRFITI(O., O., O., O., YVO, O., O., O., ZVO)
      CALL AREA2D(YVO, ZVO)
      CALL GRAF(YLAMAX, -2.0, YLAMIN, ZMAX, -ZSTP, ZMIN)
      CALL GRID(1, 1)
      CALL END3GR(O)
C
C  PLOT SUBPLOT ON BACK WALL OF WORKBOX
C
      CALL GRFITI(O., O., O.,XVO, O., O., O., O., ZVO)
      CALL AREA2D(XVO, ZVO)
      CALL GRAF(XLOMIN, 2.0, XLOMAX, ZMAX, -ZSTP, ZMIN)
      CALL GRID(1, 1)
      CALL END3GR(O)
C
C TERMINATE PLOT
C
      CALL FRAME
      CALL DONEPL
   99 STOP
      END
$ENDFILE
$IF RC>4 $SOURCE PREVIOUS
```

APPENDIX D

INPUT AND OUTPUT EXAMPLES

```
*************** FILE BAT.READ ***************
$R *BATCH SCARDS=*SOURCE*
$SIG * PRIO=D 9TP=3 T=30 ROUTE=CNTR RETURN=TORY
MOUNT 00[illegible]592 9TP *T1* WRITE=NO SIZE=32767 POSN=*6*
$R READ3.O 1=*T1*
Y
7327,1,5,98,81,3,
$TRUNCATE -3
$TRUNCATE -4
$TRUNCATE -7
$RENAME -3 7327.IR
$RENAME -4 7327.OURED.I
$RENAME -7 7327.TELEM
```

```
*************** FILE BAT.SCAN8216 ***************
$R *BATCH SCARDS=*SOURCE*
$SIG * PRIO=D T=30 ROUTE=CNTR RETURN=TORY
$R SCAN3.O+*IMSLLIB 8=*SOURCE* 4=8216.IR 7=8216.TELEM 1=CITY T=20
1         590       980       237       591 [illegible] 10E6
8216      1986      07        17        11[illegible]
8185      16        01        52        0[illegible]8.28
102.0803  25.51     849.0     98.999    373[illegible]
1         1         1         1         1
4         5         1
49        61        95        120
2         0.75      0.75
$TRUNCATE -6 OK
$TRUNCATE -9 OK
$TRUNCATE -10 OK
$TRUNCATE -11 OK
$TRUNCATE -13 OK
$TRUNCATE -16 OK
$RENAME -6 8216.OUT.IR
$RENAME -9 8216.WED-CAL
$RENAME -10 8216.WEDGE
$RENAME -11 8216.LATLON
$RENAME -13 8216.TEMP
$RENAME -16 8216.POST
```

```
*************** FILE 7299.OUT.IR ***************

INFRARED INFORMATION FROM ORBIT  7299 OF SATELLITE NOAA-9 ON      MAY 13,1986
TIME OF FIRST SCAN 20:43: 7 Z

SATELLITE HEADING IS  NORTH
1101.0 SCANS PASSED SINCE SATELLITE LAST CROSSED EQUATOR
AT LONGITUDE -88.29 DEGREES WEST

REFERENCE ORBIT  7282

CROSSED EQUATOR AT LONGITUDE 345.38 DEGREES EAST      AT TIME 15:42:56 Z
ORBITAL PERIOD =  102.08121 MIN
LONGITUDONAL INCREMENT = 25.51 DEGREES TO WEST
HEIGHT OF SATELLITE AT EQUATOR =  865. KM     RADIUS OF EARTH = 6368. KM
ORBITAL INCLINATION =  99.00 DEG     SCANNING RATE =360. SCANS PER MINUTE
SCANNING BEGINS AT  630 AND ENDS AT  870
OUPUT TAKES UP 375 TO 601 OF AVAILABLE WIDTH
SATELLITE SUBPOINT PIXEL NUMBER = 373.00

DISTANCE BETWEEN SCANS = 3.31 KM
SCALING = 7.6737E+01 GRID UNITS PER INCH IN X DIRECTION
DISTANCE BETWEEN POINTS = 4.28 KM
SCALING = 5.9346E+01 GRID UNITS PER INCH IN Y DIRECTION
MAP SCALE = 1:10.00 MILLION

          DATA FIELD PARAMETERS
               SMOOTHING PARAMETERS
SMOOTHING OPERATION NUMBER  1      SMOOTHING PARAMETER =    0.75
MEAN OF FIELD DIFFERENCES  =    1.431
STANDARD DEVIATION         =    5.965
NUMBER OF SCANS IN WINDOW  =      241
SCAN LINES REJECTED DUE TO SYNCH PROBLEM =     0
SMOOTHING OPERATION NUMBER  2      SMOOTHING PARAMETER =    0.75
               CALIBRATION PARAMETERS
CALIBRATION CURVATURE:      DATA LEVELS     TEMPERATURES (IN DEG K)

                             231.45              200.00
                             225.80              210.00
                             218.73              220.00
                             209.98              230.00
                             199.15              240.00
                             185.84              250.00
                             170.15              260.00
                             152.49              270.00
                             133.24              280.00
                             112.36              290.00
                              89.15              300.00

GRID DIMENSIONS : COLUMNS 1 TO  241     ROWS 1 TO  227
GRID SIZE = 54.71K ELEMENTS
EXTREME VALUES OF DATA FIELD
 MINIMUM = -51.1      MAXIMUM =  28.8
       LATITUDE-LONGITUDE PARAMETERS

LATITUDE LINES GENERATED EVERY  4.0 DEGREES    500 POINTS ALLOWED FOR EACH LINE
LONGITUDE LINES GENERATED EVERY  5.0 DEGREES    500 POINTS ALLOWED FOR EACH LINI
               LATITUDE-LONGITUDE LINES OUTPUTTED TO UNIT 11

    LATITUDE LINES
  LATITUDE = 49.0 DEGREES NORTH     POINTS IN LATITUDE LINE =  13
  LATITUDE = 53.0 DEGREES NORTH     POINTS IN LATITUDE LINE =  21
  LATITUDE = 57.0 DEGREES NORTH     POINTS IN LATITUDE LINE =  3[illegible]

    LONGITUDE LINES
  LONGITUDE = 240.0 DEGREES EAST    POINTS IN LONGITUDE LINE =  10
  LONGITUDE = 245.0 DEGREES EAST    POINTS IN LONGITUDE LINE =  15
  LONGITUDE = 250.0 DEGREES EAST    POINTS IN LONGITUDE LINE =  17
  LONGITUDE = 255.0 DEGREES EAST    POINTS IN LONGITUDE LINE =  19
      10 LATITUDE-LONGITUDE LINES OUTPUTTED TO UNIT 11
 LAT LON LINES FORM BOX: COLUMNS -25. TO 277. ROWS -29. TO 258.
      OUTLINE PARAMETERS
```

```
                LAT-LON POINTS FROM UNIT   1
      9 GRID COORDINATE POINTS OF OUTLINE TRANSFERRED TO UNIT 16
 INPUTTED POINTS
      53.55 246.53       52.27 246.20       51.05 245.92       49.70 247.22
      50.05 249.33       52.88 241.92       51.17 244.43       52.12 253.37
      50.42 255.35
 GRID POINT POSITIONS OF OUTLINE TRANSFERRED TO UNIT 16
```

```
 ***** FILE 7299.WED-CAL *****
      22.04     0.0
      51.55    31.00
      81.44    63.00
     111.20    95.00
     140.63   127.00
     171.17   159.00
     201.57   191.00
     228.77   223.00
     254.49   255.00
 ***** DATA FOR CALIBRATION CURVES BEGIN *****
     231.45   200.00
     229.34   204.00
     227.03   208.00
     224.50   212.00
     221.74   216.00
     218.73   220.00
     215.46   224.00
     211.89   228.00
     208.00   232.00
     203.77   236.00
     199.15   240.00
     194.13   244.00
     188.70   248.00
     182.88   252.00
     176.69   256.00
     170.15   260.00
     163.30   264.00
     156.16   268.00
     148.76   272.00
     141.11   276.00
     133.24   280.00
     125.13   284.00
     116.71   288.00
     107.92   292.00
      98.73   296.00
      89.16   300.00
```

```
**************** FILE 7313.WEDGE ****************
      TELEMETRY WEDGE LEVELS FOR ORBIT NUMBER 7313
 WEDGE NUMBER  1     MEAN   50.84     STD DEVIATION    0.71
 WEDGE NUMBER  2     MEAN   81.44     STD DEVIATION    0.60
 WEDGE NUMBER  3     MEAN  112.12     STD DEVIATION    0.36
 WEDGE NUMBER  4     MEAN  141.99     STD DEVIATION    0.69
 WEDGE NUMBER  5     MEAN  171.49     STD DEVIATION    0.94
 WEDGE NUMBER  6     MEAN  202.01     STD DEVIATION    1.08
 WEDGE NUMBER  7     MEAN  229.14     STD DEVIATION    1.18
 WEDGE NUMBER  8     MEAN  254.15     STD DEVIATION    0.93
 WEDGE NUMBER  9     MEAN   22.06     STD DEVIATION    0.72
 WEDGE NUMBER 10     MEAN   92.10     STD DEVIATION    0.60
 WEDGE NUMBER 11     MEAN   92.84     STD DEVIATION    0.42
 WEDGE NUMBER 12     MEAN   92.09     STD DEVIATION    0.39
 WEDGE NUMBER 13     MEAN   93.91     STD DEVIATION    0.70
 WEDGE NUMBER 14     MEAN  132.20     STD DEVIATION    0.78
 WEDGE NUMBER 15     MEAN  107.31     STD DEVIATION    0.53
 WEDGE NUMBER 16     MEAN  142.67     STD DEVIATION    0.77
```