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EXAMINATION OF UPPER-AIR DATA RESOLUTION USING STABILITY INDICES

by

(C) CHRISTOPHER MAURICE SACKIW

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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NAME OF AUTHOR: Christopher Maurice Sackiw

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Chris Sackiw

Permanent address: 12231-86th Street
Edmonton, Alberta,
T5B 3K8

Date: 23 January, 1986

THE UNIVERSITY OF ALBERTA

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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 DETERMINATION OF UPPER-AIR DATA RESOLUTION USING STABILITY INDICES, submitted by CHRISTOPHER M. SACKIW in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in Meteorology.

E Reinelt

Supervisor

Edward Lozowski

Date: 23 January, 1986

DEDICATION

To my parents,

for all their love, understanding and encouragement over the years.

ABSTRACT

The purpose of this study is to examine network requirements that would allow the resolution of mesoscale phenomena, by thermodynamic changes in the atmosphere, from data obtained during radiosonde ascents. The existing global radiosonde network makes upper-air soundings twice daily with a typical station spacing of 500 km over the continents in the Northern Hemisphere. Synoptic-scale phenomena, with life cycles of days and length scales of 1000 km or more, are adequately resolved. However, even larger sub-synoptic phenomena such as mesoscale convective complexes can not be properly resolved.

To investigate thermodynamic changes in the atmosphere an upper-air field study was conducted in central Alberta on three consecutive summer days (18, 19 and 20 August, 1981) by and within the Alberta Research Council Hail Project. Five upper-air sites, in a line with spacing of 40 km, made releases every 1 1/2 or 3 hours. Additionally, comparison tests between upper-air equipment used in the study were carried out on 14 October, 1981 at Red Deer, Alberta. Previous comparison tests are reviewed and considered along with the results of the Red Deer tests. An error analysis covering radiosondes and the extraction, processing and analysis of the data is discussed.

The method used to examine changes in the upper-air data was to calculate and compare values from a number of stability indices. They are means to incorporate the thermodynamic variables reported by radiosondes (pressure, temperature and moisture) and are also a means of predicting mesoscale convective activity.

This study was able to determine intervals in space and time over which significant changes in stability indices occurred on days with weak thunderstorms. A change in the the value of an index was considered significant if the difference between two soundings was greater than the sum of the uncertainties.

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Finally, I would like to extend my sincerest gratitude to Dr. G.S. Strong for a wealth of suggestions, numerous discussions and his unfailing enthusiasm and encouragement.

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ADAS	AIR data acquisition system
AES	Atmospheric Environment Service
AIR	Atmospheric Instrumentation Research
AQF	Red Deer Industrial Airport
BLIE	Boulder Low-Level Intercomparison Experiment
C	Degrees celsius
CB	Cumulo-nimbus
CCOPE	Cooperative Convective Precipitation Experiment
CTI	Cross-Totals Index
GATE	Global Atmospheric Tropical Experiment
KI	K Index
km	Kilometer(s)
LI	Lifted Index
LIMEX	Limestone Mountain Experiment
mb	millibar
MHz	Megahertz
MORAS	Mobile Rawinsonde System
NSSL	National Severe Storms Laboratory
Ordinate	Chart paper is divided into 100 divisions called ordinates
RH	Relative Humidity
RMS	Root Mean Square
SC4	Synoptic Index of Convection
SESAME	Severe Environmental Storms and Mesoscale Experiment
SONDEX	Radiosonde intercomparison, Switzerland, 1981
TTI	Total-Totals Index

Td	Dewpoint Temperature
UTC	Universal Coordinated Time
VTI	Vertical-Totals Index
YRM	Rocky Mountain House

CHAPTER 1

INTRODUCTION

Radiosondes are released twice daily, at 0000 and 1200 UCT, from synoptic upper-air stations around the globe. Data are collected to determine the condition of the atmosphere and are used for objective analyses at various levels and for forecasting. Forecast uses include local weather prediction as well as initialization of numerical models. These upper-air stations are typically spaced an average of 500 kilometers (km) apart over the continents. The resolution and accuracy of these data adequately describe synoptic scale weather systems but are too sparse, both temporally and spatially, to define sub-synoptic scale phenomena such as thunderstorms. Various smaller scale networks have been operated to support mesoscale research objectives (for example, there have been NSSL, GATE, SESAME, CCOPE and LIMEX-85*1). These networks have had average spacings of 25-250 km, and sounding intervals of 1-6 hours. Network requirements are dictated by the scale of the phenomenon being studied. The space and time intervals of such networks are ultimately limited by sensor accuracy, weather conditions, human capabilities and cost.

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*1 NSSL - National Severe Storms Laboratory, Norman, Oklahoma;
GATE - Global Atmospheric Tropical Experiment, South Atlantic;
SESAME - Severe Environmental Storms and Mesoscale Experiment, Okalahoma;
CCOPE - Cooperative Convective Precipitation Experiment, Montana;
LIMEX-85 - LImestone Mountain EXperiment 1985, Alberta.

1.1 Purpose And Objective

The problem then, is to find space and time intervals which can be used for the design of research upper-air networks to study mesoscale phenomena. The purpose of this thesis is to investigate network requirements for resolving thermodynamic changes in the atmosphere from data obtained during upper-air soundings. The results may then be incorporated into the design of optimized mesoscale upper-air networks in the future. The term optimized is used to denote the minimum interval for which measurements will yield non-redundant data with respect to the limits of sensor accuracy and to the type of weather conditions to be encountered.

To study thermodynamic change of the atmosphere, several variables must be incorporated. Pressure, temperature and moisture are the parameters obtained from atmospheric sounding devices. Stability indices are a means to do this and are also a means of predicting mesoscale convective intensity. A stability index is a numerical measure of the stability of the atmosphere, assumed to be in hydrostatic equilibrium, and usually based on temperature and moisture at two levels.

Some indices also take winds in addition to thermodynamics into account. The approach used in this study was to investigate the variation of several stability indices in space and time using field data obtained in serial line releases. Not all stability indices are considered suitable for predicting all ranges of thunderstorm intensity, since some were designed to discriminate severe thunderstorms. Miller et al. (1971) suggest that indices such as the "Lifted Index" or

"Total-Totals" would be more applicable for predicting less intense thunderstorms.

This is a simpler approach than other prediction techniques, such as the Synoptic Index of Convection (SC4, Strong and Wilson, 1983), which combines both the thermodynamic and kinematic fields into a composite state of the atmosphere. This current study, however, is limited to investigating the thermodynamic aspects of prediction, using simpler, derived stability indices. In this way, an optimum upper-air network density may be inferred by using standard North American "synoptic" radiosondes and a newly developed sounding system (AIR[*2] sonde) for the study of small-scale atmospheric features in Alberta.

1.2 Upper-air Data

The existing global network of radiosonde stations is designed to obtain information on synoptic-scale phenomena in the atmosphere. These features, several thousand kilometers in horizontal extent with life cycles measured in days, are adequately resolved (Oort, 1978) with station spacings of the order of 500 km and 12-hour temporal resolution.

Atmospheric phenomena of smaller scales, such as mesoscale convective complexes (Maddox, 1980), squall lines and convective storms are poorly resolved or not at all. If these mesoscale features of length scales as small as tens of kilometers can be adequately measured, then theoretically, they can be predicted. The ability to measure is ultimately limited by instrument capabilities. The study of phenomena

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[*2] Atmospheric Instrumentation Research (AIR).

such as squall lines or convective storms require an increase in network density both in space and time.

The major atmospheric phenomena, during summer in Alberta, are mesoscale convective features that range from small non-precipitating cumulus clouds to large hail-producing thunderstorm complexes. Hence, an Alberta study in particular may require denser networks because of possible stronger local pressure and temperature gradients that occur during the summer convective storm season. These stronger gradients may result from Alberta's position in the westerlies and from short wave disturbances which normally occur at this latitude. In any event, optimizing a network with respect to the number of stations and to the number of releases made is a requirement for studying small-scale convective features.

At present, even the current synoptic upper-air network over western Canada and the United States is inadequate for sub-synoptic analyses over Alberta. It consists of Stony Plain, Alberta, Ft. Smith, North West Territories, Prince George and Vernon, British Columbia, Great Falls, Montana and Spokane, Washington. There is no upper-air site located within the province of Saskatchewan. Occasional soundings are carried out at Cold Lake and Wainwright, Alberta. For this reason, the Alberta Research Council Hail Project operates two additional radiosonde sites, at Calgary and Red Deer, to obtain more representative data for convective research and cloud seeding operations.

1.3 Previous Studies

There have been various studies conducted to determine how representative an upper-air sounding was of the surrounding area. These studies have used either single-station sequential ascents (Cherry and Rogers, 1973) or networks with minimum average station spacings down to the order of 25 km (1969 NSSL network). However, a station spacing of 25 km proved to be too dense in early studies, since the errors inherent in upper-air systems proved to be greater than the magnitude of the atmospheric gradients measured. Gleeson (1959) examined the probability of detecting an atmospheric feature as a function of the area of the feature and the number of stations randomly spaced throughout the region. House (1960) used a theoretical atmospheric model to define an optimum time and space distribution of upper-air sounding observations. He concluded that the synoptic-scale network was inadequate for properly defining a squall line, let alone a single convective storm. Kreitzberg (1968) analyzed data from Project Stormy Spring, a 1965 pilot study of mesoscale features in extratropical cyclones. It consisted of ten upper-air sites spaced about 100 km apart. He concluded that there are mesoscale features which have large amplitudes with respect to rawinsonde data errors. Thus the accuracy of calculations, of wind and temperature gradients, was limited not by instrument accuracy but the non-linearity of the data in time and space. Cherry and Rogers (1973) analyzed time-height variations of such parameters as potential temperature, moisture, convective stability, and wind velocity for serial rawinsonde ascents from Red Deer, Alberta. Though limited by single-station analysis, they were able to verify two conditions described by Ninomiya (1971) as being favourable to the development of severe local storms. These two conditions were convective instability and strong winds in both lower and upper levels. They also concluded that the sounding most representative of the air close to but unmodified by convection, is one released about two hours ahead of the storm. The National Severe Storms Laboratory headquartered in Norman, Oklahoma, commenced in 1966 to operate special upper-air networks to study sub-synoptic scale features (Barnes, et al., 1971). Fankhauser (1969, 1974) studied convective processes using data from a rawinsonde network with station spacing of 60 to 90 kilometers. He concluded that kinematic and dynamic features resolved in the study were a function of observational spacing and did not necessarily pertain to the individual convective processes.

1.4 Summer Weather Conditions In Alberta - Synoptic-scale Gradients

A check was made to confirm that synoptic-scale features are adequately resolved over North America by the existing upper-air network with average station spacing of 500 km. Summer months generally provide the weakest synoptic gradients when sub-synoptic scale phenomena, such as large convective complexes, are common. Geopotential height and temperature gradients were analyzed for July, 1980 at 700 and 500 mb. The results are summarized in Table 1 (from Sackiw and Strong, 1983). It was assumed that pressure-height and temperature measures at each synoptic station are correct to 5 meters and 0.4°C respectively. Thus, uncertainties in the gradients are of the order of +/-1.4 m/100 km for geopotential height, and +/-0.1°C for temperature.

Table 1 shows the maximum gradients between any two rawinsonde stations for each day, since the minima (absolute values) would be close to (or equal to) zero. For temperature gradients, the smallest daily

TABLE 1. Absolute values of maximum (synoptic scale) horizontal gradients of geopotential height and temperature at 700 and 500 mb over western Canada during July, 1980.

(1980)	HEIGHT GRADIENT (m/100 km)		TEMP. GRADIENT (°C/100 km)	
DAY	700 mb	500 mb	700 mb	500 mb
July 02	8	13	0.7	0.8
03	7	13	0.8	0.8
04	7	11	1.4	0.5
05	12	25	2.2	1.8
06	14	25	2.1	1.5
07	16	44	0.9	2.3
08	9	17	1.1	0.5
09	9	15	1.3	1.2
10	11	18	1.8	0.8
11	10	22	1.3	4.1
12	8	20	0.8	1.5
13	8	27	1.8	1.5
14	9	22	0.5	0.7
15	6	9	0.8	1.2
16	11	27	1.2	1.2
17	14	29	1.3	2.1
18	16	25	0.7	1.5
19	11	22	1.5	0.8
20	8	17	0.8	0.8
21	10	15	0.5	0.6
22	13	20	0.8	0.8
23	-	17	-	0.8
24	11	25	1.6	1.0
25	7	18	1.1	1.4
26	12	22	1.2	1.1
27	13	30	2.6	1.0
28	15	27	1.6	0.9
29	14	24	2.7	1.5
30	14	29	1.3	1.0
31	13	27	1.7	1.5
AUG. 01	11	20	1.3	0.5
Min.	6	9	0.5	0.5
Max.	16	44	2.7	4.1
MEAN	10.9	21.7	1.3	1.2
S.D.	2.9	7.0	0.6	0.7

maximum value for any given day (during July, 1980) is $0.5^{o}C/100$ km ($2.5^{o}C/500$ km), with an average about double this. Thus, ~~with root~~ mean square (RMS) sensor accuracy of $0.4^{o}C$ (VIZ radiosondes), one may resolve atmospheric features with length scales of 1000 km with 500-km spacings (e.g., the synoptic upper-air networks).

Table 1 provides insight into the spatial resolution possible with VIZ radiosondes and standard data extraction procedures. For example, by using VIZ radiosondes with a temperature uncertainty of $0.4^{o}C$, one is only assured of resolving a $0.8^{o}C$ temperature difference. This suggests that a site spacing of 160 km is plausible for the weakest maximum 700 mb temperature gradient condition of July 1980, since $0.5^{o}C/100$ km is $0.8^{o}C/160$ km. An average site spacing of 80-90 km was used for the early NSSL rawinsonde network (Fankhauser, 1969). The mean maximum 700 mb temperature gradient ($1.3^{o}C/100$ km) suggests a station spacing of 60 km is feasible on days favourable for convection.

During summer, severe convective weather (large thunderstorms, hail, tornadoes) tends to occur on synoptically active days when strong gradient conditions exist (Strong, 1979). This has made possible studies involving sub-synoptic scale analyses of severe convective weather using data from upper-air networks of this scale (Tsui and Kung, 1977; Fuelberg and Scoggins, 1978).

The gradients of Table 1 were derived using only synoptic scale data. ~~It~~ is conceivable that gradients around severe thunderstorm systems may be more intense over shorter distances and time periods. This complicates the problem of network site spacing and sounding release-time interval even further. An example from the 1979 SESAME

(Oklahoma) network of 20 sites with 100 km spacing was chosen. Using the AVE-V data set (Sienkiewicz et al., 1980) of 20 May, 1979 (tornado-producing thunderstorm complex), height gradients as large as 60 m/100 km were measured. This meso-scale height gradient is almost 50 percent larger than the maximum synoptic height gradient found in Table 1 and thus, suggests that gradients around severe convection are more intense.

CHAPTER 2

UPPER-AIR MEASUREMENT SYSTEMS

2.1 History

The first upper-air measurements, other than pilot balloon wind measurements, were made by Hermite and Besancon (Middleton and Spilhaus, 1953) in 1892. A number of means and instrument types have been employed to make upper-air measurements. Transport mechanisms used have included free balloons, aircraft and rockets. Manned balloons were used for a time, and several dedicated researchers and technicians lost their lives during severe weather ascents. In order to eliminate this hazard and obtain information at greater altitudes, instruments called meteorographs were devised to collect and record data. The earliest meteorographs used a clock mechanism and a combination barograph, thermograph and hygrograph that was light enough to be carried aloft by a balloon. Since clock mechanisms had difficulty operating at very low temperatures, aneroid-based systems were developed which recorded temperature and relative humidity as a function of pressure.

As far back as 1868, Buys-Ballot (Middleton and Spilhaus, 1953) advocated that meteorological information be transmitted automatically. Hearth and Robitysch (Middleton and Spilhaus, 1953), in 1917, first transmitted signals from a meteorograph attached to a kite. It was not until the development of the vacuum-tube oscillator that it became feasible to transmit signals from an instrument carried by a balloon. This was accomplished by Idrac and Bureau in 1927 (Middleton and

Spilhaus, 1953). Since then many radiosonde designs have been commercially developed. Radiosondes have a great advantage over balloon meteorographs in that the data are available shortly after the ascent, whereas the recovery of meteorographs could take days, weeks or even years before they were found and returned.

During the next decades, the study of the upper levels of the atmosphere increased, and by the 1940s the first extensive radiosonde networks became operational. Prior to this, the thermal structure of the atmosphere could only be deduced from surface charts, a few scattered balloon and meteorograph ascents, and mountain observations. The term rawinsonde is used to indicate that the ground station also tracks the sonde so that wind information may be calculated.

2.2 Upper-air Systems Around The World

2.2.1 Radiosondes

Radiosonde instruments consist of five parts: housing, meteorological sensors, radio transmitter, antenna, and batteries. The ground receiving equipment consists of an antenna (directional if winds are to be calculated), a radio receiver and a recording device (usually a chart recorder). There are four classes of radiosondes:

a) time-interval: signals are transmitted as pulses spaced in time, with the meteorological parameters evaluated from the pulse intervals,

b) code-type: signals are transmitted in a code which is interpreted as meteorological values,

c) variable-radio-frequency: the change in radio frequency from the transmitter is related to the values of the meteorological elements.

d) variable-audio-frequency: the variation of an audio signal, which is related to the meteorological values, is used to modulate the carrier wave by pulses. The meteorological information is the time between these pulses. Thus the problem of electronic drift of the carrier signal, causing data errors, is eliminated.

The meteorological section of a radiosonde is composed of pressure (e.g. aneroid or hypsometer), temperature (e.g. bimetal strip or thermistor) and moisture (e.g. hair or goldbeater's skin hygrometer, wet bulb or hygristor) sensors. The temperature and moisture elements must be exposed to the air but shielded from the sun.

A major improvement in radiosondes occurred in the mid-seventies with the incorporation of solid-state circuitry. The elimination of the vacuum tube reduced the voltage and power requirements, while providing more stable operation.

2.2.2 AIR Sonde

Atmospheric Instrumentation Research (AIR) produced the AIR sonde Data Acquisition System (ADAS) based on a tethered sounding system developed at the National Center for Atmospheric Research (Morris, et al., 1975). Unlike most existing radiosonde systems, the ground station consisted of a small receiver and microprocessor combination that received the sonde's signal (pressure, temperature, wet-bulb temperature, and reference signals) and output user-selectable parameters to one or more devices. The AIR sonde system[*3] (model 3A) was a new instrument system. If winds are desired, an optical theodolite must be used to track the balloon[*4]. The type of AIR sonde used in this study had two wings that housed the dry and wet thermistor beads and caused the unit to spin, thus increasing the ventilation rate of the thermistors above that provided by the nominal ascent rate of three meters per second.

2.2.3 Radiation Effects Upon Instruments

McInturff et al. (1979) determined that radiation effects could cause errors of up to +0.65°C at the surface, and more than 2°C at the height of normal balloon burst (<100 mb). Radiosonde manufacturers

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*3 AIR continues updating the ground unit, software and sondes. Several designs and models are currently available including the most recent sonde version which employs a VIZ hygristor for the humidity sensor. This AIR sonde model is also similar to conventional VIZ sondes with the thermistor on an outrigger and the hygristor inside a duct running through the sonde.

*4 A later model has the provision to automatically record data from a specially-equipped optical theodolite and can output wind information along with thermodynamic data levels.

handle the effects of solar radiation by different means. While some rely on reflective coatings on thermistors (e.g., VIZ sondes) or radiation shields (e.g., Vaisala sondes), others provide pre- or post-flight software corrections (Phillips et al. 1981).

Problems occur when combining data from the many types of radiosondes used routinely around the world, due to different sensor response times and accuracies (McInturff et al., 1979). Rawinsonde data in forecast offices are not corrected for sensor response time and solar radiation effects. The stability indices used in this study were developed and used with data primarily from VIZ sondes and without these corrections. Therefore, no corrections of this type have been incorporated into the data analysis made here.

2.3 North American Radiosonde

The radiosonde used routinely by weather services in North America is of the variable-audio-frequency class. Pressure information is derived from the chart trace at the points where switching between sensors occur. Switching from temperature to humidity is called contact. A factory pressure calibration strip accompanies each sonde and consists of a pressure value specified for every contact. The temperature sensor is a thin ceramic semi-conductor rod called a thermistor which has a reflective coating to help minimize solar radiation effects. An outrigger holds the thermistor up and away from the radiosonde to ensure that the sensor will not be influenced by any instrument effects upon the environmental air (e.g. thermal warming due to radiative effects on the sonde housing). The humidity element is a non-conducting plastic strip that is coated with a thin film composed mainly of carbon. Resistance of this carbon film varies inversely with the relative humidity. This sensor is positioned in a duct atop the sonde to protect it from both solar radiation and rain.

A directional antenna receives the transmitted signal. The signal is converted from frequency to voltage and finally output on a chart recorder. The chart paper is divided into 100 divisions called ordinates. An observer reads the chart to +/-0.1 ordinate.

The thermodynamic and kinematic data are linked through time. A timing strip is used to obtain the time of each data level from the chart while the balloon angle data are recorded every minute or fraction thereof.

CHAPTER 3

DATA PROCESSING

3.1 Data Sources

Data used for this study were first collected in a field experiment and subsequently from radiosonde comparison tests. Normally, instrument comparison tests are conducted on equipment before it is used in the field. However, due to the late date of acquisition of the Research Council's AIR sonde system, this was not possible. Therefore, comparison tests of the equipment did not take place until after the field study. Budgetary and manpower limitations restricted these comparison tests to the simultaneous release of three radiosondes twice during one day.

3.1.1 Comparison Flight Data

Comparison flights were made to verify the manufacturers' stated specifications, and to investigate uncertainties among different and similar radiosonde systems. Two comparison flights were made on 14 October 1981 at the industrial airport of Red Deer, Alberta. Each release consisted of two VIZ sondes (1680 MHz and 403 MHz) and an AIR sonde (403.5 MHz). For the first flight, all three radiosondes were attached with twine to the same balloon. The two VIZ sondes were placed side by side and tied together about 20 meters from the balloon. Since the AIR sonde required freedom to spin, it was attached to the VIZ sondes with a short length of twine about 5 meters long. To maintain a nominal ascent rate of five meters per second, the balloon was inflated with additional helium to compensate for the weight of the extra sondes. The large difference in frequencies of the VIZ sondes do not pose interference problems with each other. The AIR sonde frequency is crystal controlled and can not be adjusted, hence, the 403 MHz VIZ sonde was off-tuned to an extreme of its frequency range to prevent interference between the two. A five meter per second ascent rate is standard practice for VIZ radiosonde flights but the nominal ascent rate during and AIR sonde flight is three meters per second. To check if any noticeable differences in the measurement of moisture of the AIR sonde resulted from this difference in ascent rate, the second release was made with the AIR sonde attached to a separate balloon free to ascend at its nominal rate. No noticeable difference in humidity was apparent between the two flights. The VIZ 403 MHz sonde was tracked with a single METOX ground station, and the VIZ 1680 MHz sonde by two separate ground stations (an RD-65M and an RD-65A).

3.1.2 Field Experiment Data

The experimental data used for this study were collected during a short field study called the Spatial/Temporal RESolution Study (STRESS). STRESS was designed as an attempt to define the spatial and temporal resolution capability of upper-air data systems used during the summer field program of the Alberta Hail Project. The results from this test program were to be utilized in the design of a mesoscale upper-air and surface network which would be situated in central Alberta.

The study area was situated within the Alberta Hail Project operations area (Figure 1). Two possible lines of sites were chosen and surveyed. This was done so that for a given day a line of stations could be chosen which would be roughly aligned perpendicular to the 500 mb flow. Two fixed rawinsonde sites were incorporated into each line:

a) "north-south" line - Calgary and Red Deer (AQF),

b) "east-west" line - Rocky Mountain House (YRM) and Red Deer.

A third mobile rawinsonde system (Robitaille, 1977; Sackiw and Bergwall, 1977) was positioned to be an endpoint of the line chosen for the day. The other two sites had AIR sonde systems and were located between the rawinsonde stations. Station spacing was nominally 40 km for the "north-south" line and 38 km for the "east-west" line.

Due to budget, manpower and time constraints, operations for the study had to be restricted to only three consecutive days (18, 19, and 20 August, 1981). One AIR sonde unit was an older version, Model 2A (ADAS-2), on loan from the University of Calgary. Unfortunately, this unit did not allow simultaneous output to a display and a tape recorder. Many flights were thought to have been recorded, but subsequent attempts to extract data from the tapes proved to be futile. The remaining flight data could not be used in this study for two reasons. The first was severe signal-loss problems that caused large portions of some ascents to be lost. Secondly, although this system was not available for the comparison tests, it became obvious when the ascents were plotted that large measurement errors had occurred as well.

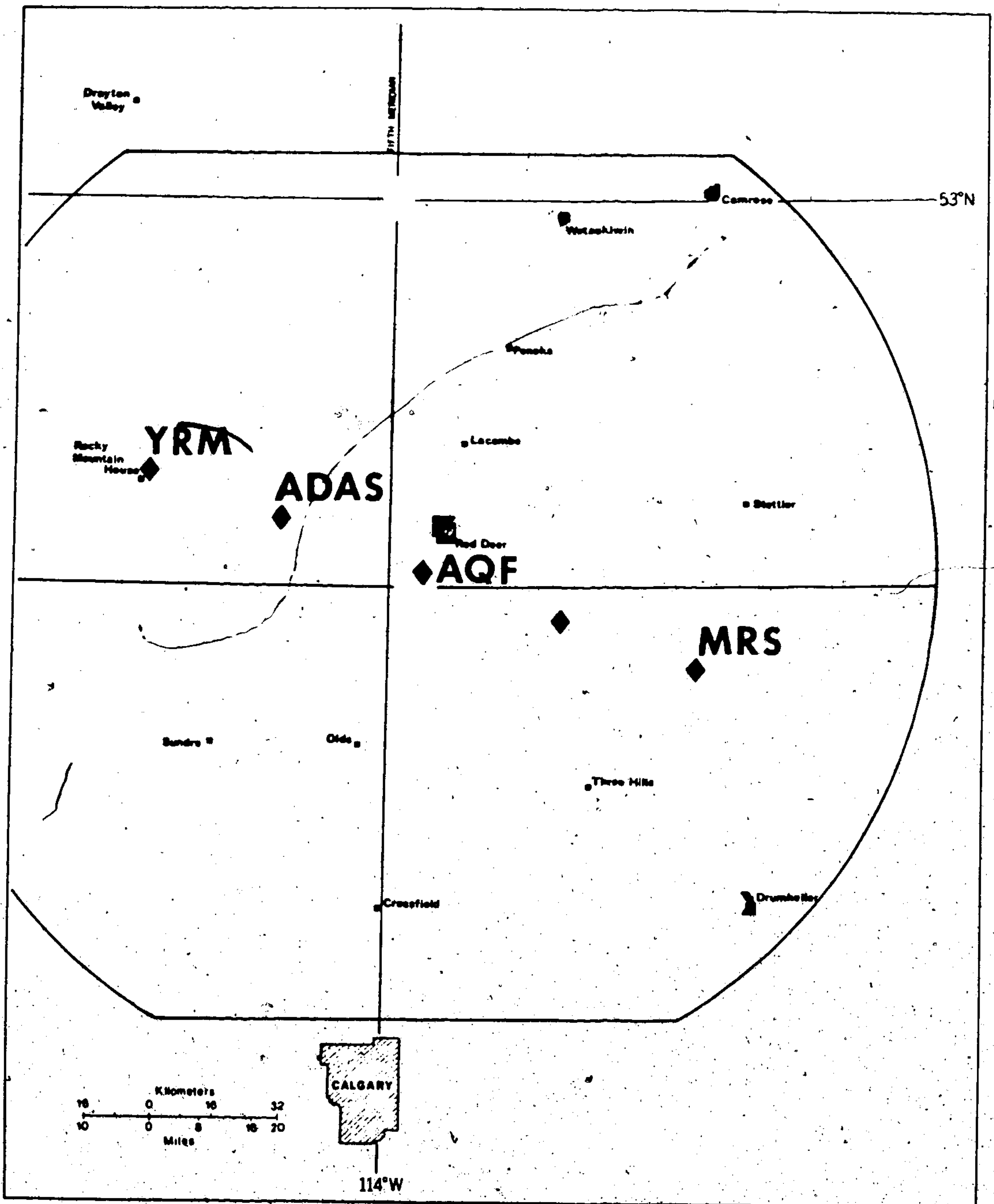

Figure 1. Location of upper-air sites during STRESS: YRM, ADAS, AQF and MRS.

Since the ADAS-2 flight data were not used in this study, reference to ADAS or AIR sonde refers to the Model 3A (ADAS-3) which was located between YRM and AQF in the STRESS line. Similar signal-loss problems also occurred with the model 3A and not all flights could be used. Several releases at the mobile rawinsonde site were not made due to power problems on the 19 August. Table 2 contains a list of all the ascents used in this study.

TABLE 2. Table of STRESS soundings used in analysis.

FLIGHTS ON 19 AUGUST 1981

(UTC)	YRM	ADAS-3	QF	MORAS	
1130	*		*	*	
1430	*	*	*		3
1730	*	*	*		hourly
2030	*				
2330	*		*	*	
0100	*		*	*	1 1/2
0230	*	*	*	*	hourly
0400	*	*	*	*	

FLIGHTS ON 20 AUGUST 1981

(UCT)	YRM	ADAS-3	QF	MORAS	
1730	*	*	*	*	
1900	*	*	*	*	1 1/2
2030	*		*	*	hourly
2200	*		*	*	
2330	*		*	*	

Flights were made either every one and one-half hours or every three hours during times that appeared most favourable for the formation of severe weather during the three-day period. The severe weather conditions which were hoped to form or pass through the line of sites, unfortunately, never materialized. Two weak storms formed along the

STRESS line during the afternoon of 19 August when operations had been called off. On 20 August, a storm was reported at YRM after operations ended.

3.2 Calibration Of The Instrument Sondes

Standard VIZ radiosondes must be calibrated before each flight. The chart recorder is first set to zero and then a sensitivity check performed. A pressure reading is obtained and the baroswitch is set to correspond to this pressure. The radiosonde is then placed into a calibration chamber called a baseline box, and is automatically cycled through each of the radiosonde circuits (high reference, temperature, low reference and relative humidity). Air inside the baseline box is allowed to stabilize for a short time before the actual calibration starts. The baseline box contains a set of dry and wet-bulb thermometers, a fan which circulates the air to ensure that it is well mixed, and desiccant to keep the relative humidity within allowed limits during calibration. After the operator checks that the air within the baseline box has "stabilized", the calibration procedure begins. Data transmitted by the sonde are output to a chart recorder. The conditions which must be met for calibration are two constant temperature traces and three constant relative humidity traces (or more typically, a constant trend). Additionally, drift of the low reference signal must be less than 0.1 of an ordinate during the whole procedure. If not, the low reference is re-adjusted and calibration started over. After calibration, the sonde is set outside to allow it to acclimatize before release.

Pre-release preparations for AIR sondes differ from that of VIZ sondes. These sondes are factory calibrated and only the output from the pressure sensor may be adjusted in the field. The factory calibration coefficients, time, station altitude and pressure were entered into the receiver/processor ground station. A thermistor attached to a small water reservoir by means of a wick was the moisture sensor used in this type of AIR sonde. The manufacturer claimed that the latent heat of freezing given off by the liquid water of the wick was used as an additional automatic calibration for the moisture sensor during flight.. After the wick froze, however, moisture values became progressively worse compared to similar measurements made by radiosondes. These sondes were calibrated up to 300 mb, although few ever made it up to this altitude.

3.3 Data Collection

Rawinsonde systems (e.g. GMD-1 and ADRES) employing VIZ sondes have been used for many years. These systems make use of analog electronic technology and rely on manual extraction of data from chart recorder traces. A recent development, the AIR sonde uses digital technology to eliminate both the chart recorder and the manual extraction of data.

3.3.1 Radiosonde Data Collection

All the data transmitted by the sonde are recorded by a chart recorder. Normally, standard data extraction procedures (MANUPP, 1975) are used in the North American network and involve manual extraction of significant level data from the chart recorder trace. Data between these levels do not deviate from linearity by more than +/-0.5 of an ordinate (roughly one degree). For this study, thermodynamic data were manually extracted for each pressure contact. Typically, soundings were terminated at the 150-mb level which corresponds to about 90 data levels. The number of data levels is independent of the ascent rate of the balloon (nominally 5 m/sec). A directional antenna was used at each site to track the sonde and the azimuth and elevation angle data were recorded every 30 seconds.

3.3.2 AIR Sonde Data Collection

The AIR sonde ground equipment (Model 3A) provided simultaneous outputs to both a line printer and a tape recorder. This allowed the operators to view a hardcopy of data from the sonde in real-time while storing data on a cassette. These cassettes were later dumped onto disc for computer error editing and data processing.

Data transmission from the AIR sonde is based on time rather than on pressure. The frequency of data output from the ground unit is user selectable. A 10 second interval was chosen in order to maximize the number of data levels and to maintain dependable cassette recordings. This rate of data collection yields a much greater number of data levels than are obtained from a radiosonde flight. At the time, these sondes were often lost between 500 and 400 mb.

An optical theodolite was used to track the AIR sonde. However, the balloon was easily lost if it moved out of the field of view. Tracking the balloon and recording the angle data every 30 seconds is a two-man job unless the observer has been highly trained. During soundings, a loss of signal required the attention of one of the observers. The result was often loss of the balloon. Additional losses occurred because of clouds or the close proximity of the balloon to the sun.

3.4 Data Reduction

A radiosonde data reduction computer program (Phillips, 1980) was obtained and modified to run on the Alberta Research Council, Atmospheric Sciences, computing system. This particular program was chosen because of its modular structure. The use of the program allowed quick recalculation of flights as mistakes were discovered and corrected. All data files were manually checked against recorder charts and information contained on the computation forms filled out by the operators prior to and during the flight. Checking routines contained in the program uncovered some operator transcription mistakes. The author added other algorithms to check for proper drift corrections and sonde pressure calibration.

The AIR sonde ground station automatically outputs user-selected meteorological parameters in engineering units and thereby eliminates operator transcription mistakes. The manufacturer did not release the equations used for these calculations. Therefore, to minimize differences due to calculations, only the output values of pressure, temperature and wet-bulb temperature were used to calculate other required quantities.

Tephigrams of significant level data for all flights were plotted by hand. This allowed visual identification of transcription errors by a comparison of serial soundings at each site. Recently, software capabilities at the Research Council have improved significantly, allowing all data levels to be computer plotted. Additional errors in the manual transcription of data were found visually from plots of temperature and dewpoint values for all data levels and corrected.

CHAPTER 4

ERROR ANALYSIS

It is impossible to measure anything exactly since no instrument is capable of displaying infinite precision. Therefore, every measurement has some uncertainty associated with it. Error is defined as the uncertainty in a measurement and does not mean a mistake made by an observer that could have been prevented by more careful procedures (Gibbs, 1929).

The data used in this study have been corrected for all human mistakes that were detected, for example, mistakes that could be verified by checking data charts or meteorological data from nearby surface stations. Any data that did not seem to fit were left untouched if there was no means of verification. Finally, some data were eliminated if it was obvious that equipment had malfunctioned, thus causing spurious differences between soundings or loss of one or more of the measured parameters.

4.1 Definitions

It may be useful to review a few definitions of error analysis before proceeding further. Gill and Hexter (1972) compiled a list of definitions which they proposed be used as a standard and thereby eliminate misunderstandings in the literature:

a) Resolution: the smallest change in the environment that will cause a detectable change in the value displayed by the instrument.

b) Accuracy: the degree to which the instrument will measure the variable in terms of some accepted standard or true value.

c) Reference accuracy: the limit that errors will not exceed during standard operating conditions. It is recommended that reference accuracy be assumed for the term accuracy in performance specifications.

Errors are composed of both random and systematic components. Unlike random errors, there is no way to treat systematic errors statistically. For example, if a timing device consistently runs slow, no amount of repetition of an experimental trial will uncover this problem. Only a comparison with another timer would allow detection and assessment of the magnitude of this systematic error. The only "theory" for the treatment of systematic errors is that they should be identified and reduced until they are negligible compared to the respective observation. (Taylor, 1982)

One type of systematic error can be called a personal error, whereby an observer consistently tends to overestimate or underestimate readings. This type is self-correcting if differences between readings are considered. In the case of radiosondes, if the initial calibration readings were improperly estimated, and the rest of the chart data read similarly, then no bias would occur in the data set. However, during the calibration procedure, if the dry and wet-bulb thermometers were improperly read, then the data would have a systematic and uncorrectable error.

4.2 Error Sources In Measured Parameters (Data Uncertainty)

It is important to note that this discussion refers to random errors and does not consider systematic or biasing errors such as the effect of solar radiation on the sonde sensors (Lenhard, 1973).

4.2.1 Psychrometric Uncertainty

Psychrometric measurements were used to set the "absolute" values of temperature and relative humidity reported by the instrument. Therefore, error at this point will shift all values of the flight. Reference accuracy of a VIZ sonde was +/-0.4°C for temperature and +/-4% for relative humidity. That is, all values reported should have been within these limits if the whole radiosonde data calibration, extraction and reduction procedure had been faithfully followed. The relative data accuracy, that is from level to level, was better than the stated reference accuracy (personal communication with M. Friedman of VIZ, 1984).

Measurement of relative humidity by the psychrometric technique is more sensitive to wet-bulb depression than to dry or wet-bulb temperatures. The wet and dry bulb measurements made to calibrate the radiosonde were read to the nearest 0.1°C. Thus, the uncertainty in the wet-bulb depression that was used to calculate the dewpoint temperature was no more than 0.2°C. A difference of 0.2°C within the temperature range encountered during STRESS gave an uncertainty in relative humidity of 2 to 3 percent. This corresponds to a dewpoint uncertainty of about

0.5°C. The same was true of the psychrometric measurements used to obtain conditions at release and also used for the surface value of the soundings. Even though sondes are white, if left to sit in the sun, erroneously high temperature readings can occur because there is no ventilation of the sensors while on the ground.

4.2.2 Pressure Uncertainty

Each field site used a precision digital barometer to obtain station surface pressure, except for Rocky Mountain House which used a standard mercury barometer. Before the start of the field season all the digital units were checked for accuracy by Atmospheric Environment Service (AES) personnel in Edmonton. Surface pressure readings, therefore, had uncertainties of +/-0.1 mb (1 kPa = 10 mb). This was, of course, relative pressure accuracy, since absolute pressure at a quality pressure standard has an uncertainty of 0.25 mb (Pike, 1984).

4.2.3 Radiosonde System

An important uncertainty in radiosonde data was the observer's reading of the recorder chart. The observer estimated both temperature and relative humidity values to a tenth of an ordinate (allowed uncertainty of observer's estimate is +/-0.1 ordinate). The conversion from chart ordinates into temperature varies along the chart scale. One tenth of an ordinate converts to between 0.13°C to 0.28°C, although for the temperature range of this study (<500 mb), it was roughly 0.15°C. For relative humidity, a tenth of an ordinate amounted to as much as 0.5% for the worst case (RH from 20% to 30%) and converting into Td, amounted to 0.4°C. For relative humidity over 30%, the conversion into Td amounts to about half, or 0.2°C. Aside from the possible personal error previously mentioned, which is self-correcting for any one observer, the errors from these estimates are random.

Chart paper ordinates were not always uniformly spaced, but this amounts to an error of less than 0.1 ordinate and may be ignored. High values of humidity affect the chart paper, but since the low reference trace was used to correct the span of the measurements, any stretching of the paper was compensated for and may also be ignored. Changes in temperature cause the gain of the electronic components of the sonde to drift as it ascends and this drift must be compensated for. Every fifth contact is a reference and of these, the low references allowed the operator to correct for this drift. The magnitude of the drift correction must then be interpolated between reference levels before being applied to each data level. These corrections, although continuous, were only applied in discrete 0.1 increments. That is, if a tenth of an ordinate drift correction was required, the full 0.1 correction would be applied to any data value above the 47.5th ordinate and ignored for any data points below. The error in this kind of correction then would amount to +/-0.05 of an ordinate around the midpoint of 47.5, however, since it is small compared to the +/-0.1 observer "inaccuracy", it may be ignored.

The reference accuracy for the pressure sensor was +/-2 mb and although surface pressure measurements were recorded to a tenth of a millibar, the baroswitch assembly within VIZ sondes allowed pressure to be adjusted only in increments of roughly 0.5 mb.

4.2.4 AIR Sonde System

AIR sondes eliminate the possibility of human mistakes affecting data quality with the one exception of setting the pressure. With factory calibration and no way of adjusting the temperature or moisture values, the observer was only able to check that the data transmitted by the sonde before release were reasonably close to the psychrometric data. The temperature reported by the AIR sonde was usually higher than the psychrometer readings, typically on the order of half a degree. A query was directed to the manufacturer, who noted that this was an endpoint comparison, while the calibration coefficients supplied were designed to optimize data for the whole flight. Although the dry and wet-bulb sensors were claimed to be accurate to +/-0.2°C, the manufacturer maintained that the circuitry was designed to assure a depression accurate to within +/-0.1°C. This suggested that humidity measurements from AIR sondes should have been more accurate than from VIZ sondes.

The AIR sonde system outputs pressure to 0.1 mb but often instability in the output was evident. A slow oscillation of up to about a millibar was sometimes evident over several tens of seconds. The manufacturer claimed that the reference accuracy of pressure was within +/-3 mb if the factory calibration was used. If a high quality pressure reference was used to set the pressure before release, then a reference accuracy of +/-1 mb was supposedly achievable. The magnitude of the instability in pressure observed before release supports the manufacturers specifications.

4.3 Comparison Flights

Comparison of different radiosonde types and the publication of results is encouraged by the World Meteorological Organization. Unfortunately, these types of experiments are not carried out very frequently nor in the same manner. This tends to make direct comparisons and conclusions between tests difficult. Hoehne (1980) made recommendations on comparison of instruments to ensure reliable results. These included separation of sondes by no more than one meter vertically and ten meters horizontally and that measurements be made simultaneously. Only the Boulder Low-Level Intercomparison Experiment (BLIE) experiment appears to have followed this procedure for all tests conducted.

The BLIE and SONDEX*5 experiments were intercomparisons between different systems, while the Red Deer tests, besides comparing two radiosonde types, also compared similar VIZ sondes. The smaller RMS differences between VIZ sondes reflect the similarity of measurement by similar sondes. When the AIR sonde was compared to the VIZ sonde, greater RMS differences were expected. If comparisons were to be made between two or more AIR sondes, then their RMS differences would probably be less than when compared with other radiosondes. A comparison between AIR sondes would have required a second system and therefore could not be carried out.

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*5 The intercomparison of ten types of radiosonde at Payerne, Switzerland from 20-29 April, 1981.

4.3.1 Red Deer Comparison Flights

On 14 October, 1981 two simultaneous releases consisting of three radiosondes were made to compare the upper-air instrumentation of the Research Council. The rawinsonde ground equipment consisted of a METOX for the VIZ 403 MHz sonde and two RD65s (one manual and one auto-tracking) for the VIZ 1680 MHz sonde. The ADAS received thermodynamic transmission data but had no provision for recording the tracking data from the optical theodolite. Data were extracted at 25 mb intervals from these two flights. The analysis of the Red Deer intercomparison flights was based on pressure rather than time. This did not allow a comparison of pressure sensors but rather, it included the pressure error within the temperature and moisture errors. The reason for this is that field data can only be extracted according to pressure. Therefore, the "temperature errors" actually contain both the pressure and temperature sensor errors.

Figure 2 depicts the temperature differences of each sounding system from the reference sounding for the 2200 UTC release. The reference sounding is composed of averaged data from the two VIZ sondes (tracked by three ground stations) interpolated every 25 mb, starting from the 900-mb level. The AIR sonde was not averaged into the reference sounding because of its proportionately larger standard deviation*6 and extreme values than the other sondes (in SONDEX, five of ten sondes with the lowest standard deviation were chosen to be used for each reference data set). Since the data from the RD-65 systems were

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*6 Standard deviation is defined as the square root of the arithmetic averages of the squares of the deviations from the mean (also called the "root mean square deviation").

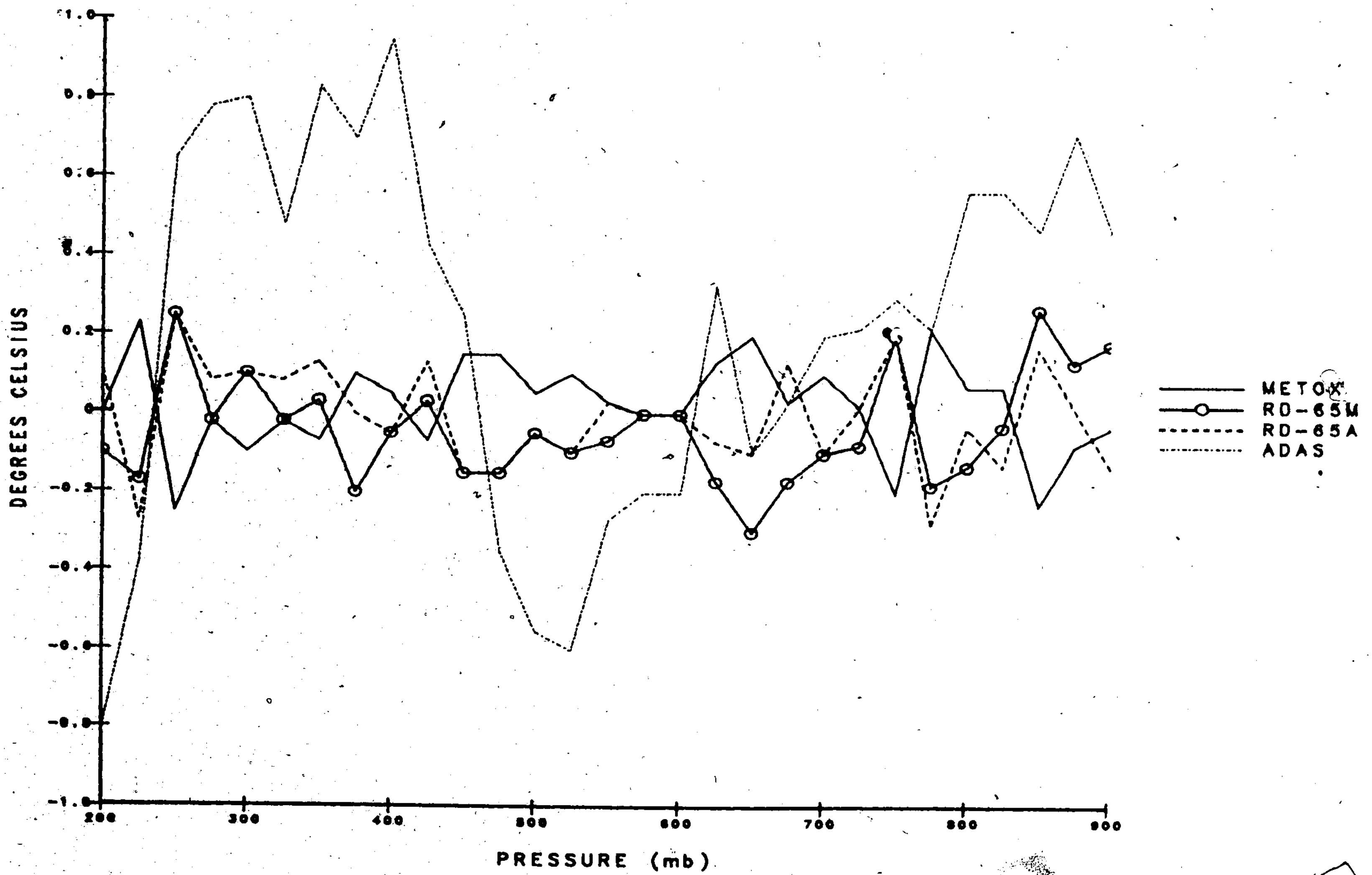

Figure 2. Plot of temperature differences of individual sondes from the reference sounding (average of the the two VIZ sondes) from the comparison flight on 14 October, 1981, 2200 UTC.

from the same sonde, using both in calculating the average temperature of a level would overweight the average in that sonde's favour. Therefore, the data from the RD-65A and RD-65M were first averaged together, and then averaged again with the data from the METOX. Variations between the two RD-65 systems were generally within +/-0.1°C. The maximum uncertainty of the dry bulb temperature for a single reading was within +/-0.3°C for VIZ sondes. The AIR sonde had maximum discrepancies over double those of the VIZ sondes (-0.80°C and 0.95°C).

On the 2000 UTC flight, AIR sonde temperature data were found to be erratic above 400 mb and so comparison was made with data up to 500 mb. The erratic values were probably due to pressure sensor problems. From personal experience, some sondes have suddenly become unstable and transmit pressures that fluctuate wildly or monotonically increase or decrease. On one occasion, a sonde reported steadily increasing pressure from the point of release! Maximum uncertainty in temperature from VIZ sondes was slightly larger (+/-0.4°C) while the AIR sonde uncertainty ranged from +0.5°C to -1.1°C. The standard deviations for these flights are summarized in Table 3.

Larger errors are to be expected in dewpoint temperature, since this parameter is calculated from both the temperature and moisture sensor data. Figure 3 shows the dewpoint temperature differences of the 2200 UTC flight for data extracted every 25 mb. The AIR sonde was designed to ensure accurate depression, but dewpoints were typically higher than those transmitted by the other sondes even in the lower levels of the flight. After the wick froze, dewpoint readings were generally unreliable. This is not surprising since this sonde was

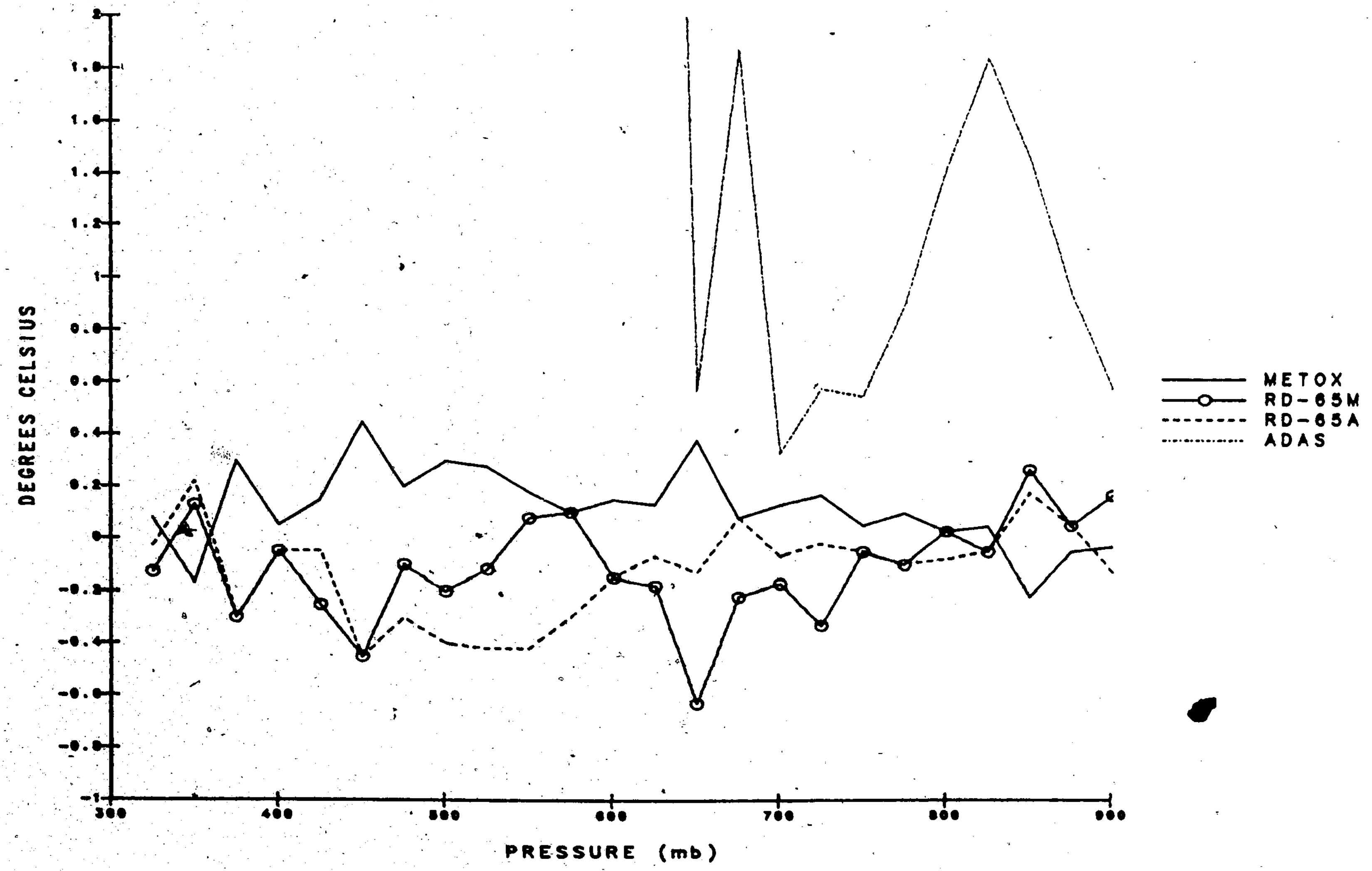

Figure 3. Plot of dewpoint temperature differences of individual sondes from the reference sounding (average of the the two VIZ sondes) from comparison flight on 14 October, 1981, 2200 UTC.

initially designed for low-level soundings. AIR sonde dewpoint data were useable up to 500 mb and 650 mb for the 2000 UTC and 2200 UTC flights, respectively. Table 3 lists the dewpoint standard deviations of the comparison flights.

TABLE 3. Standard deviations of temperature and dewpoint temperature for VIZ and AIR sondes for the Red Deer comparison flights on 14 October 1981, 2000 UTC and 2200 UTC.

2000 UTC -------- 2200 UTC	METOX	RD-65M	RD-65A	ADAS
T ($^{\circ}$C)	0.13 ------ 0.12	0.13 ------ 0.14	0.18 ------ 0.13	0.42 ------ 0.47
Td ($^{\circ}$C)	0.22 ------ 0.15	0.24 ------ 0.20	0.28 ------ 0.18	0.89 ------ 0.53

The standard deviation of data for all sondes from the reference sounding, including the AIR sonde, ranged from 0.12°C to 0.47°C for temperature and from 0.15°C to 0.89°C for dewpoint. There was no discernible difference between the two RD65 systems themselves and, indeed, between the METOX system and the RD65 systems, since allowed observer error was +/-0.1 chart ordinates, or about +/-0.15°C. All dry bulb temperatures from the VIZ sondes were within +/-0.4°C of the reference sounding. Hodge and Harmantas (1965) concluded that "the major portion of the scatter originates from sources other than the radiosonde itself" and these test comparisons, although not a large sample number, support their conclusion. The AIR sonde had significantly larger standard deviations than the VIZ sondes.

4.3.2 Other Comparison Tests

The Boulder Low-Level Intercomparison Experiment (Kaimal et al., 1980) included extensive tests of four radiosonde systems:

a) VIZ (1680 MHz)

b) Vaisala (403 MHz)

c) TDFS (403 MHz)

d) AIR (403.5 MHz).

Some results of these tests for balloon-borne sondes in flights evaluated from 10 meters to 3 kilometers for the VIZ and AIR sondes are found in Table 4. The objectives of the BLIE experiments were to make results available in statistical summaries and scatter plots. There was no attempt made to rate performance of the instrumentation.

TABLE 4. BLIE comparison results of VIZ and AIR radiosondes for temperature, relative humidity and dewpoint temperature.

	VIZ SONDE		AIR SONDE	
	DEVIATION FROM MEAN	RMS DIFFERENCE	DEVIATION FROM MEAN	RMS DIFFERENCE
T (°C)	+ 0.20	0.58	+ 0.35	0.71
RH (%)	- 1.96	3.60	+ 2.76	4.57
Td (°C)	- 0.52	1.31	+ 1.47	1.98

Phillips and Richner (1983) reported on an intercomparison of ten radiosondes (SONDEX) used by over 50 national weather services. Included in these tests were both AIR and VIZ radiosondes. The temperature data of the VIZ sondes were corrected for radiation effects (McInturff et al., 1979) before being used in the comparison (as were all sondes with software radiation corrections). Pressure data from the VIZ (and most other sonde types) varied from the mean by less than one millibar. The AIR sonde, however, had a negative difference that increased almost linearly with height to about -3.5 mb by the 500-mb level. Correspondingly, starting at an initial positive temperature difference from the sondes' mean at release (about 0.4°C), the temperature difference also decreased almost linearly with height to -0.3°C at 500 mb. This fits with the BLIE tests, as the AIR sonde reported the highest temperatures relative to the average of the sondes. The Red Deer flights also suggest a negative temperature trend. Both AIR sondes used in the Red Deer tests developed problems during flight. In the latter part of the 2000 UTC flight flight very large negative temperature differences were reported (greater than 10°C at 300 mb). Higher temperatures than the VIZ sondes were also reported after approximately 550 mb during the 2200 UTC flight.

The relative humidity of the AIR sonde was higher than the SONDEX average at the surface and continued to increase, so that by 700 mb, it was about 13% greater (Td would be 2°C to 6°C higher). This appears to be somewhat higher than the results from BLIE, which gave a mean of almost 3% higher than average. It was noted in the BLIE experiment, that one to two minutes after release, proper wet-bulb depression was achieved. This would suggest that RH difference from the AIR sonde should have been much higher than the sondes' average at release and then diminish with height. The only explanation offered is that the sensors may have been ventilated before release to eliminate this problem. The Red Deer tests basically agree with the SONDEX results as dewpoint temperatures from the AIR sonde were generally higher than the VIZ sondes' average.

4.4 Stability Indices

A stability index is an objective way of analyzing and quantifying the stability of the atmosphere. It is often described in terms of instability. The first stability indices were devised in the 1940s when upper-air data became available with the development and routine use of the rawinsonde network. Some indices are based on the algebraic difference of temperature and moisture between two reference levels (e.g. the Total-Totals Index). Others are based on parcel theory, which involves the theoretical vertical displacement of a "parcel" of air to a reference level, followed by the algebraic difference between the parcel and environmental temperatures. There are two simplifying assumptions made: a) there are no compensating air motions and b) the parcel does not mix with its environment.

4.4.1 Stability (Instability) Indices Used In This Study

Miller introduced three stability indices[7] in 1967:

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[7] The definitions of the "TOTALS" and "SWEAT" indices are taken from Johnson, 1982, since the original references are difficult to obtain.

a) Vertical-Totals Index (VTI) - temperature lapse rate (change in temperature divided by change in height) between 850 and 500 mb with no moisture involved:

$$VTI = T850 - T500\ (^{o}C)$$

where T850 is the 850 mb temperature,
and T500 is the 500 mb temperature.

Index values greater than about 26 indicate thunderstorm development.

b) Cross-Totals Index (CTI) - takes moisture into account:

$$CTI = Td850 - T500\ (^{o}C)$$

where Td850 is the 850 mb dewpoint.

The threshold value for severe weather is typically about 18.

c) Total-Totals Index (TTI) - is the arithmetic sum of the previous two indices and, therefore, combines both lapse rate and moisture:

$$TTI = (T850 + Td850) - 2(T500)\ (^{o}C)$$

The minimum threshold is about 44, with 50 or greater indicating the possibility of widespread and severe convective activity.

The K-index (KI) was developed in 1960 by Whiting and documented by George (1960). It is used to forecast air-mass thunderstorms when winds are light and there is no frontal or cyclonic influence. This index incorporates temperature lapse rate (T850 - T500), low level moisture

(Td850) and an indication of the vertical extent of moisture (700 mb dewpoint spread):

$$KI = (T850 - T500) + Td850 - (T700 - Td700) \quad (^{o}C)$$

where T700 is the 700 mb temperature,
and Td700 is the 700 mb dewpoint.

Values in the range 20 to 25 indicate isolated thunderstorms with a probability of formation up to 40%. A value of more than 35 indicates a high probability (greater than 80%) of numerous storms.

In 1970 the U.S. Air Force Global Weather Central presented an index for forecasting potentially severe convective weather such as severe thunderstorms and tornadoes. The Severe Weather Threat (SWEAT) index was subjectively derived from a study of 328 severe storm soundings, and is based on weighted, empirical parameters at the 850 and 500-mb levels:

$$SWEAT = 12(Td850) + 20(TTI - 49) + 2(WS850) + WS500$$

where WS850 is the 850 mb wind speed (knots),
and WS500 is the 500 mb wind speed (knots).

This index is always positive since no individual term may be negative. If the 850 mb dewpoint temperature is negative, it is set equal to zero. Similarly, if the Total-Totals Index is less than 49, then the second term is also set equal to zero. The threshold for severe thunderstorms is about 250.

There are a number of indices based on parcel theory. The lifted index (LI) used in this study is based on a parcel of air with the same surface temperature and moisture that was measured at the time of balloon release. The parcel is theoretically lifted vertically, first dry adiabatically until condensation occurs, then pseudo-adiabatically until the 500-mb level is reached. Finally, the difference between the temperature of the environment and that of the lifted parcel is determined:

$$LI = Tparcel - T500\ (^{o}C)$$

Unstable conditions are indicated when the index is positive, with larger positive values denoting greater instability.

4.5 Sensitivity Analysis

A limitation of stability indices is that they are based on only two or three levels of an extensive tropospheric sounding and therefore much of the detail obtained is not used. Their advantage lies in the fact that they are either not affected by or not as sensitive to the absolute value of temperature, as they are to the temperature difference between levels. Thus a bias error, such as an improperly calibrated instrument, will not have as much effect on the value of an index that is based on one sounding, than if a comparison of a variable were to be made between two or more soundings with bias errors. If RMS differences are minimized by using one type of sonde in a study, such as VIZ sondes, the uncertainty in the values obtained from stability indices will also be small. Unfortunately, logistics often dictate using different sonde types. If one has a trend (like the negative temperature trend of the

AIR sonde) then the uncertainty in the data obtained from stations using this type of sonde will be larger.

The relative accuracy of VIZ sondes is better than the manufacturer's stated reference accuracy and the AIR sonde was compared to VIZ sondes. Hence, the values determined from the Red Deer tests have been used to determine the uncertainty of index values for each sonde type. Table 5 lists the maximum standard deviation from the two Red Deer tests for both VIZ and AIR sondes.

TABLE 5. Maximum standard deviation (^{0}C) in Temperature and Dewpoint Temperature from the Red Deer comparison tests for VIZ and AIR sondes.

	VIZ	AIR
T	0.2	0.5
Td	0.3	0.9

The values in Table 5 were used to determine the uncertainties of each type of stability index used in this study. The K and SWEAT indices are not simply differences between levels, and so bias errors will have some effect. Wind errors are complex and depend on tracking geometry as well as thermodynamic data. Winds were of the order of ten meters per second at 500 mb and the RMS errors used here (Fuelberg, 1974) are 0.5 m/s and 2.0 m/s for the 850 and 500-mb levels respectively. SWEAT indices were not calculated for AIR sonde sites, since winds are required, but were not computed for the AIR sonde system. Table 6 lists the uncertainties for each index and sonde type.

TABLE 6. Uncertainty in Index Values for Data from VIZ and AIR sondes.

	VTI	CTI	TTI	KI	SWEAT	LI
VIZ	0.3	0.4	0.5	0.6	3.3	0.3
AIR	0.7	1.0	1.3	1.5	---	0.9

CHAPTER 5

ANALYSIS

Data collected from the STRESS line were plotted on tephigrams and by pressure levels on time-section plots. The graphs displaying variables in time are called time-section plots and consist of the fixed station sites along the abscissa versus time along the ordinate. Time-section plots were produced for the four levels from which data were used in the calculation of the indices. These four levels were: a) surface b) 850 mb c) 700 mb d) 500 mb. These time-section plots were contoured objectively by computer, thus eliminating the possibility of subjective contouring bias by the author. The problem of possible bias of the computer countouring package (SURFACE II) was not addressed in this study. Composite tephigrams were plotted for all release times for each station (to display temporal changes) and for all stations for each scheduled release time (to display spatial changes). These proved useful during error checking and analysis.

All flights are referred to by their scheduled release time rather than the actual release time (e.g. an actual release at 1748 UTC is referred to as a 1730 UTC flight). The change in value of an index is considered significant if the magnitude of the difference, between the two soundings, is greater than the sum of the uncertainties.

5.1 STRESS Case Study: 19 August 1981

5.1.1 Synoptic Summary 19 August

At the 500-mb level, 1200 UTC 19 August (Figure 4) a trough lay off the west coast and a broad ridge extended over the prairie provinces. Associated with the upper level trough, surface troughing extended from the territories, through B.C., and down into Oregon (Figure 5). The axis of a short-wave thickness ridge at 500 mb lay along the western boundary of Alberta. Through the day, the upper trough off the coast slowly filled, while the ridge strengthened. These large-scale features moved eastward during the day with a speed of 8 to 10 m/s so that by 0000 UTC (Figure 6) the thermal ridge axis lay through central Alberta, and about two degrees of warming had occurred over the STRESS line. Upper winds were moderate, 10-15 m/s from the southwest, while surface winds were light and southwesterly along the foothills.

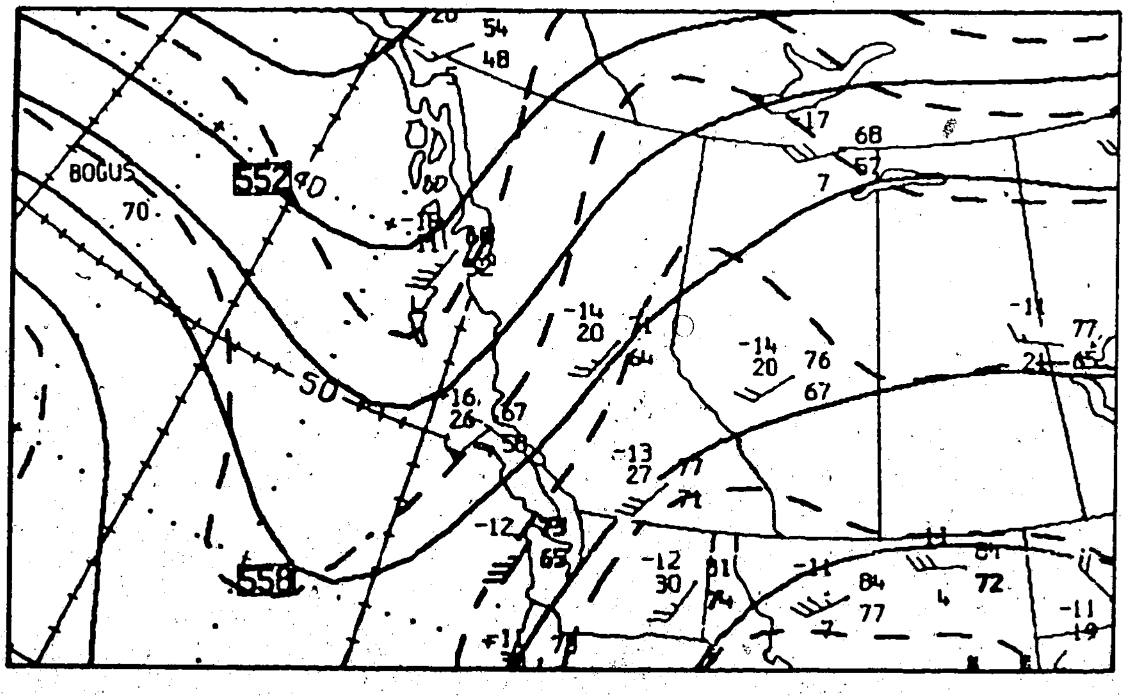


Figure 4. 500 mb analysis for 1200 UTC on 19 August 1981.

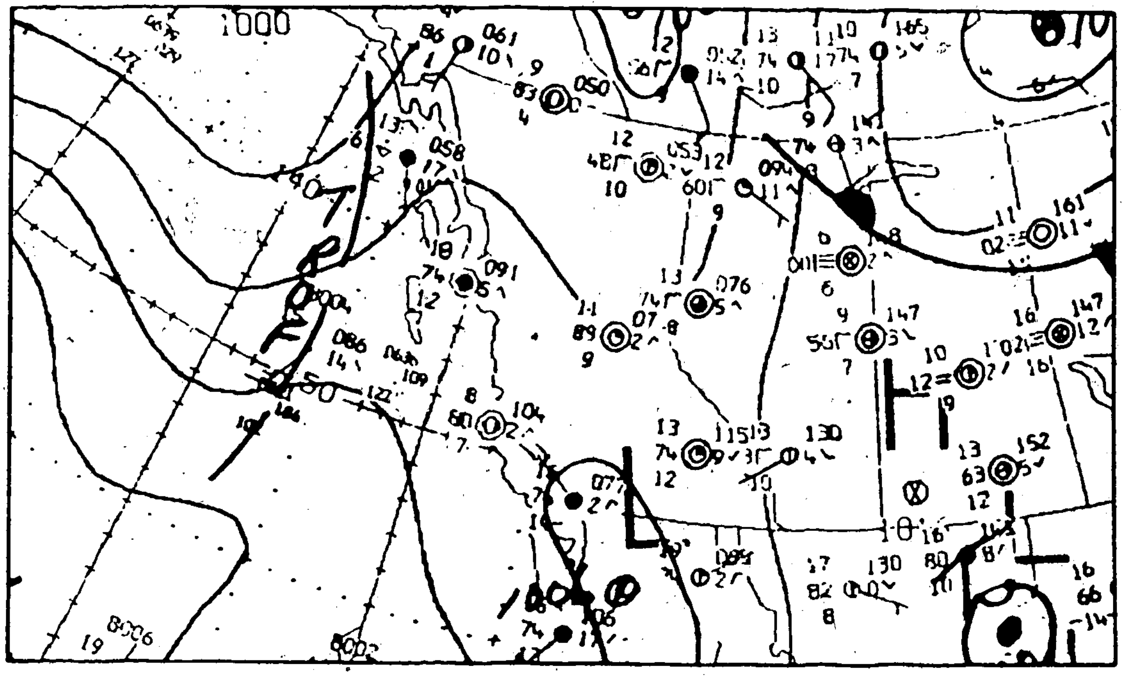


Figure 5. Surface analysis for 1200 UTC on 19 August 1981.

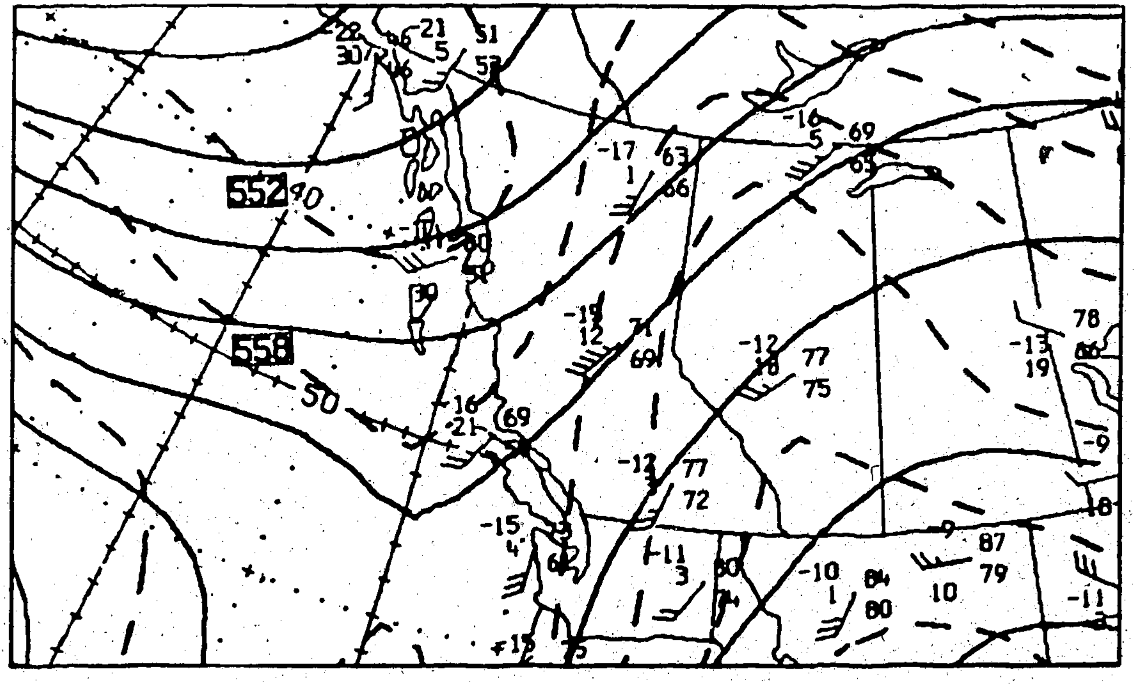


Figure 6. 500 mb analysis for 0000 UTC on 20 August 1981.

The surface pressure pattern, a trough with axis running roughly parallel to the divide, remained virtually unchanged over the southern half of Alberta during the whole day. Figure 7 is a surface map for 2200 UTC corresponding to the time a cumulo-nimbus (CB) was reported at the Rocky Mountain House station.

Thunderstorms were reported at Red Deer (AQF) at 2100 UTC and YRM at 2200 UTC. Satellite photos displayed convective cloud both along the divide and northwest of the STRESS line during the latter part of the day.

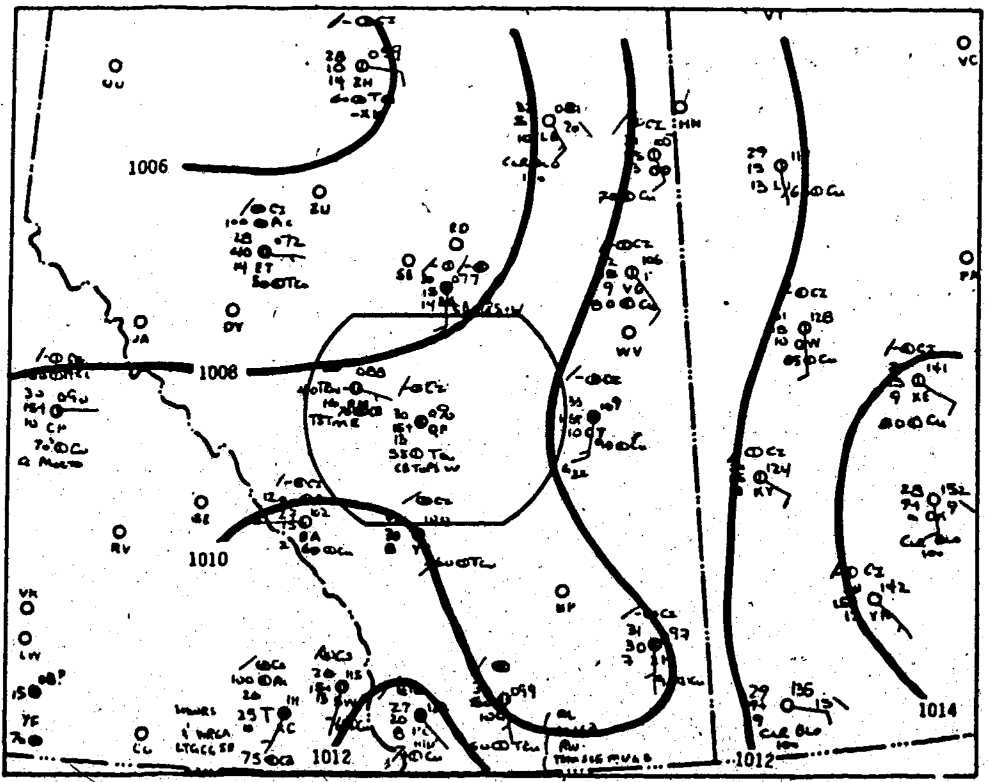


Figure 7. Surface analysis for 2200 UTC on 19 August 1981.

5.1.2 Time-section Analyses

Figure 8 is a plot of the 500 mb pressure-heights on 19 August 1981. Three of the four ADAS flights had lower heights than the adjacent stations while the fourth was greater. The flight reporting greater heights closely matched YRM's temperature trace, but had consistently higher dewpoint temperatures. This results in an overestimate of the actual height of pressure levels above the station, since moist air is less dense than dry air. Moisture values for each data level reported by the AIR sondes were often greater than values from the adjacent VIZ sondes. The pressure sensor error, resulting in the negative temperature trend reported in SONDEX, and hence, lower pressure-heights, was noticeable in two of the flights on this day.

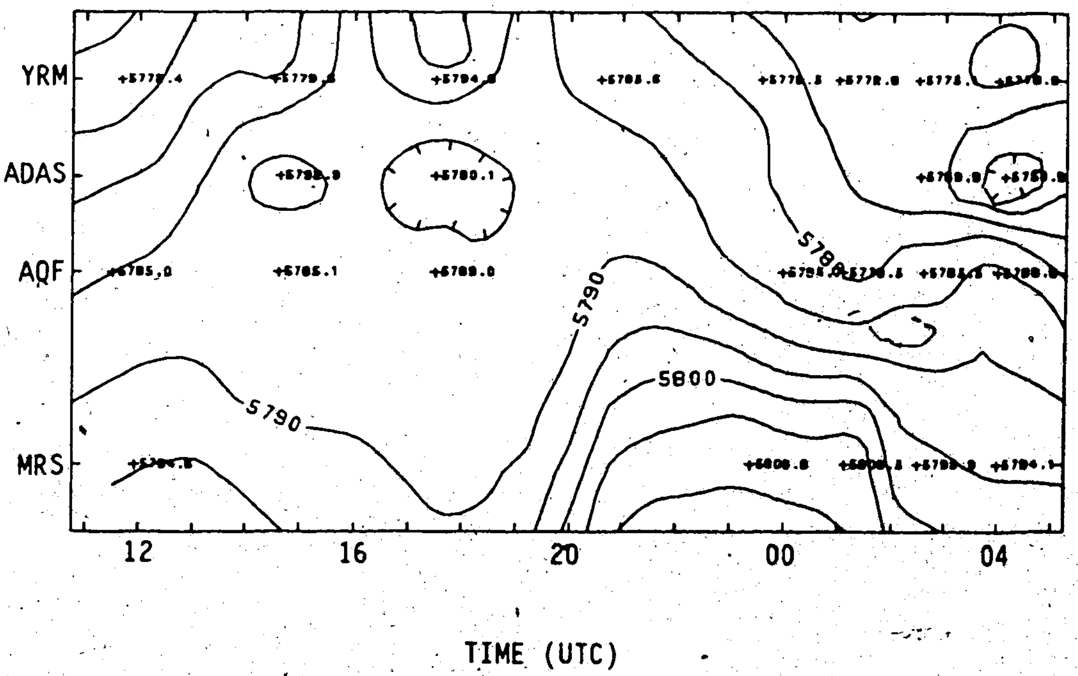
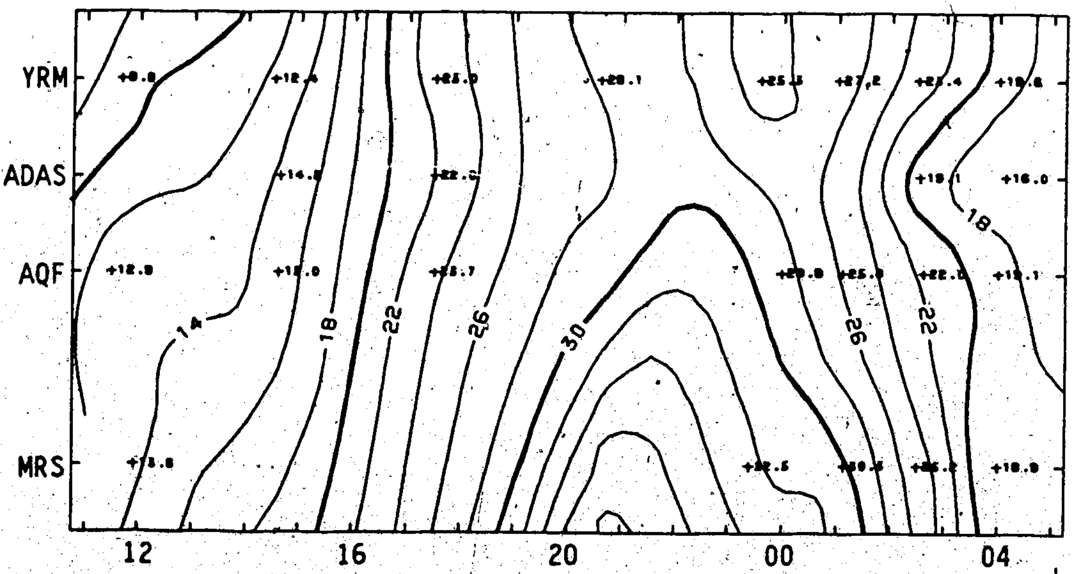


Figure 8. Time-section plot of 500 mb pressure-heights on 19 August 1981.

The operations commenced at 1130 UTC but were called off at 1730 UTC and no further flights (except those at YRM) were made until 2330 UTC. The MRS site had only one morning release at 1130 UTC on this day due to power problems. Contours in the central and left-central bottom of the time-section plots on this day are based on data interpolated over grid points that do not contain data values (no flights were made during this part of the day) and are therefore, unreliable. Thus, the following discussion ignores these areas.

The surface temperature (Figure 9) showed a weak temperature gradient along the STRESS line. The contours displayed a general warming trend from insolation at each station in the morning, followed by cooling in the evening. A lower temperature for YRM at 2330 UTC was



TIME (UTC)

Figure 9. Time-section plot of surface temperature on 19 August 1981.

associated with increased cloud cover and the CB reported on the 2200 UTC surface observation. A peculiar but apparently real temperature difference occurred at the ADAS site for the 0230 and 0400 UTC 20 August flights. The surface temperature was several degrees lower than at the adjacent sites, yet from the 850-mb level (Figure 10) upward the ADAS flight temperatures lay between the values of the adjacent stations.

The soundings for the 2330 UTC release display marked differences above 550 mb in both temperature and dewpoint (Figure 11). In comparison, YRM flights bracketing the time of the storm display less variation above 550 mb. (Figure 12).

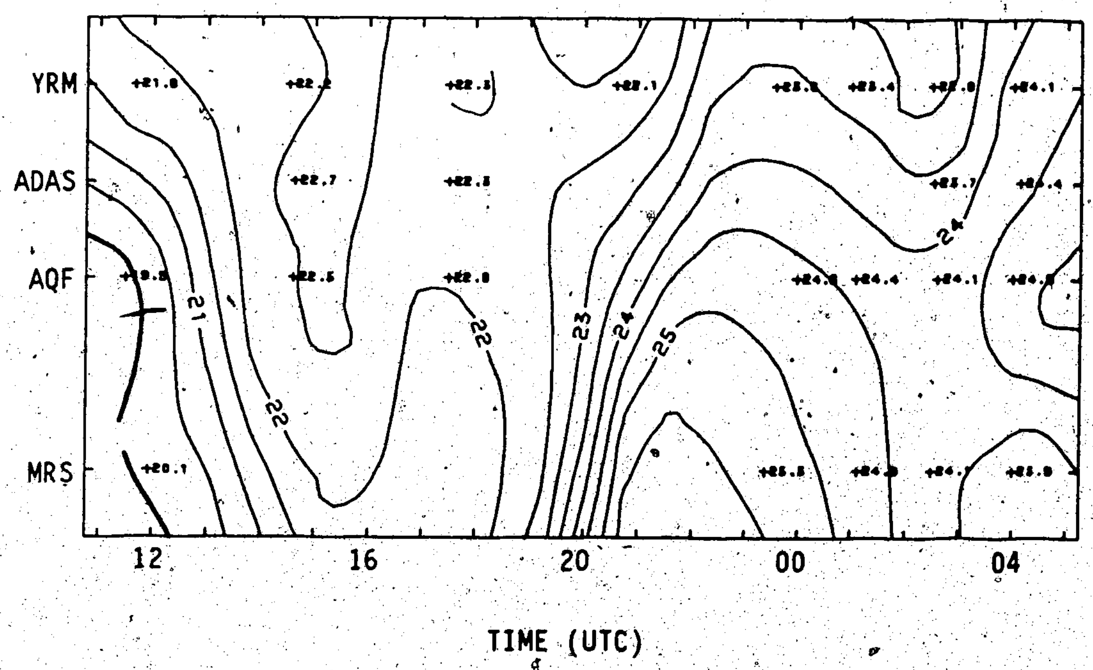


Figure 10. Time-section plot of 850 mb temperature on 19 August 1981.

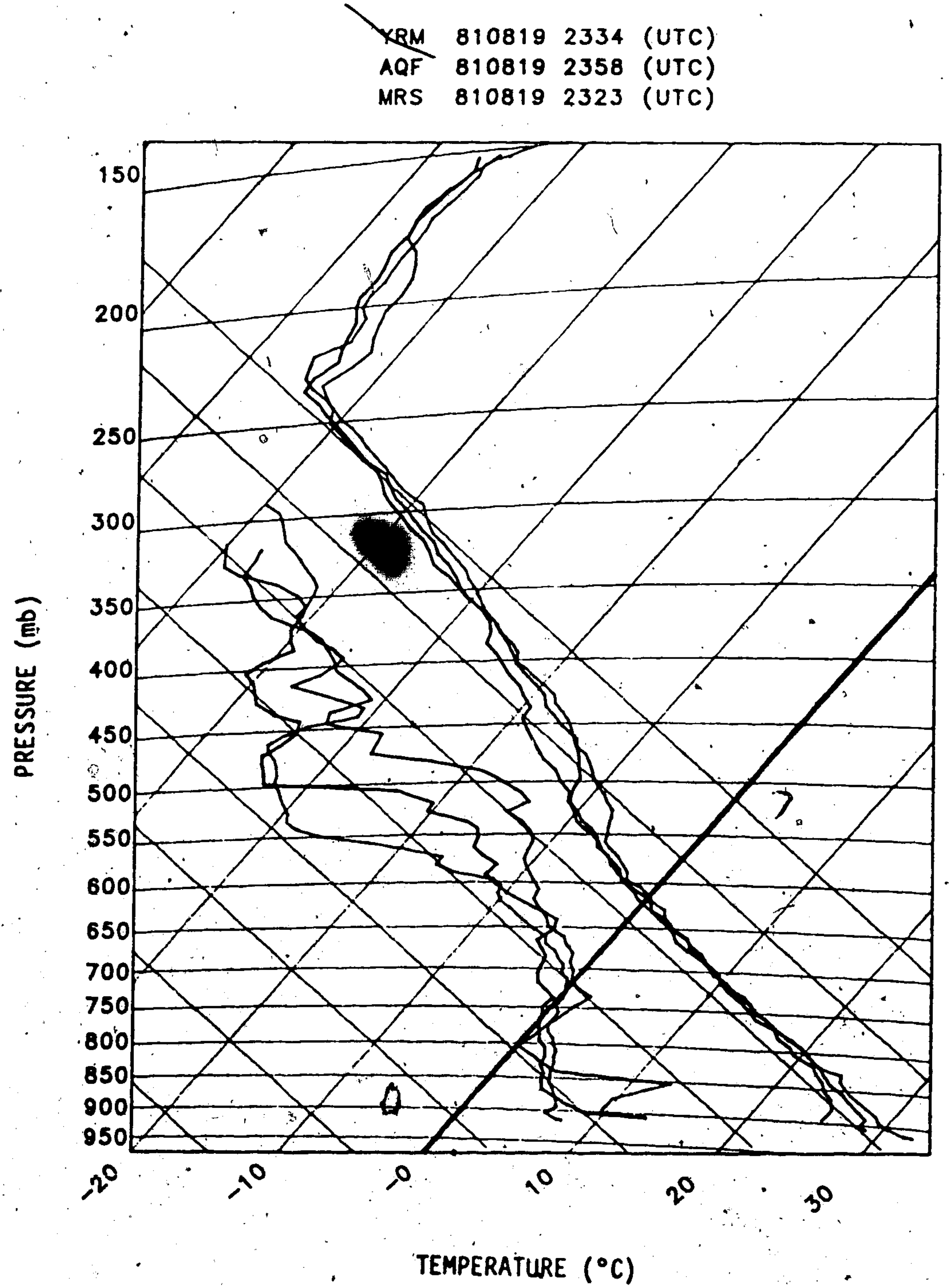


Figure 11. Tephigram composite of YRM, AQF and MRS for the 2330 UTC release on 19 August 1981.

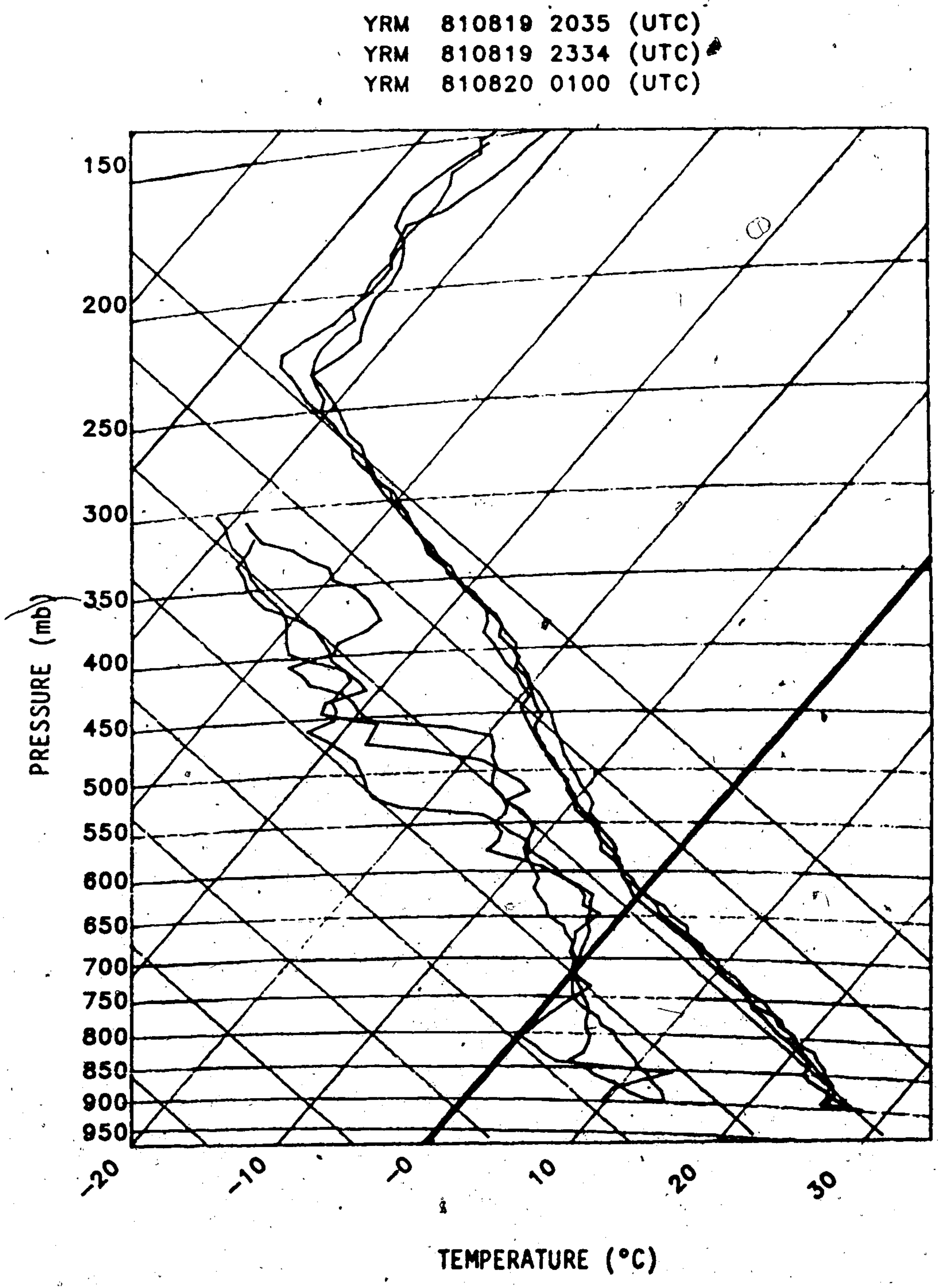
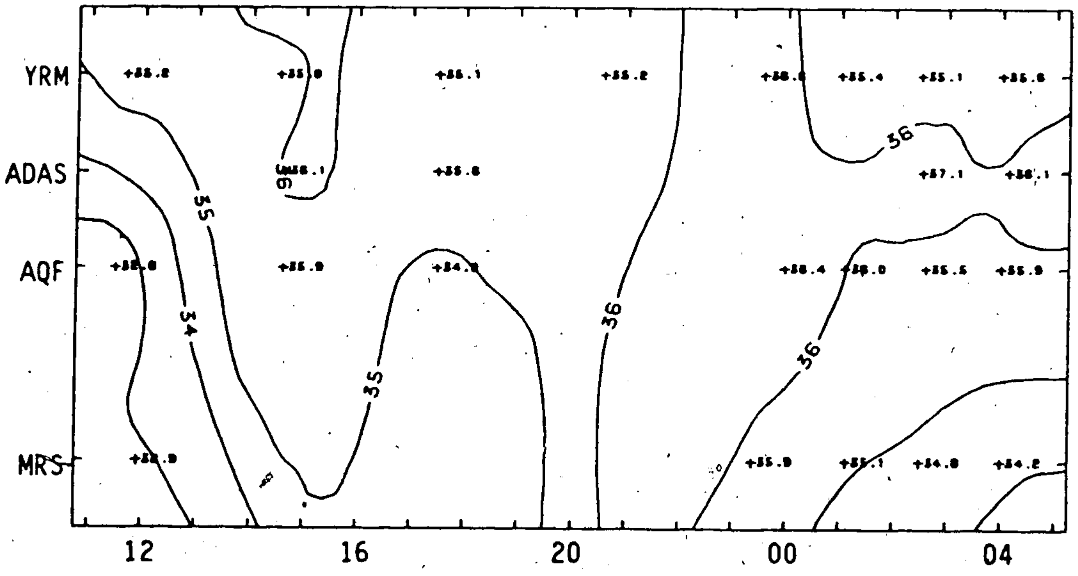


Figure 12. Tephigram composite of YRM flights for 2030, 2330 UTC on 19 August and 0100 UTC 20 August 1981.

5.1.2.1 Vertical-totals

Significant differences of the value of the vertical-totals index at (Figure 13) some stations were exhibited both spatially and temporally. These can be ascribed to warming in the low levels (insolation) during the morning and cooling in the evening (most notable at the mobile rawinsonde site (MRS), the farthest from the foothills).



TIME (UTC)

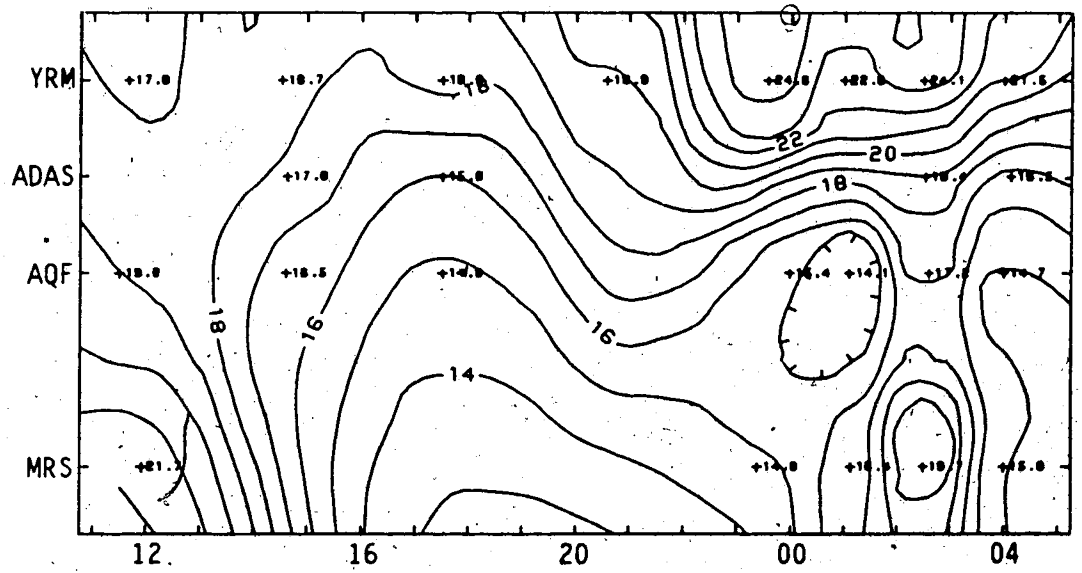
Figure 13. Time-section plot of Vertical Totals on 19 August 1981.

The threshold level for this index is about 26 and while values were all over 32, the gradients were weak. A CB was reported at YRM at 2200 UTC and a significant change in the two YRM VTIs bracketing this storm are noted (three-hour spacing). The storm at YRM was not indicated by a significant increase in the index 1 1/2 hours before it was reported and three hours after the index had returned to the pre-storm value. Only broad area instability was indicated by this index. Except for the first flight early in the morning, no significant differences occurred between YRM and AQF (76 km spacing).

Between YRM and MRS (152 km), the earliest and latest releases displayed significant differences. This was due to heating at the 850-mb level in the morning and the advection of cooler air at 500 mb in the evening. The 2330 UTC flights had a difference just slightly greater than the uncertainty and it probably is not significant.

5.1.2.2 Cross-totals

Most changes in the cross-totals index are significant for three hourly and one and one-half hourly temporal flights and for 76 km spatial separation (Figure 14). The largest change occurred between YRM and AQF after the CB was reported at YRM. Index values for all flights



TIME (UTC)

Figure 14. Time-section plot of Cross-Totals Index on 19 August 1981.

between YRM and MRS (152 km) were significantly different. The ADAS index values lay between the values of the adjacent stations. This index is rather strongly dependent on the moisture variable and so the pattern of the index contour plot bears very strong resemblance to the dewpoint contour plot at 850 mb (Figure 15). Trends of index values in time generally agreed for each station.

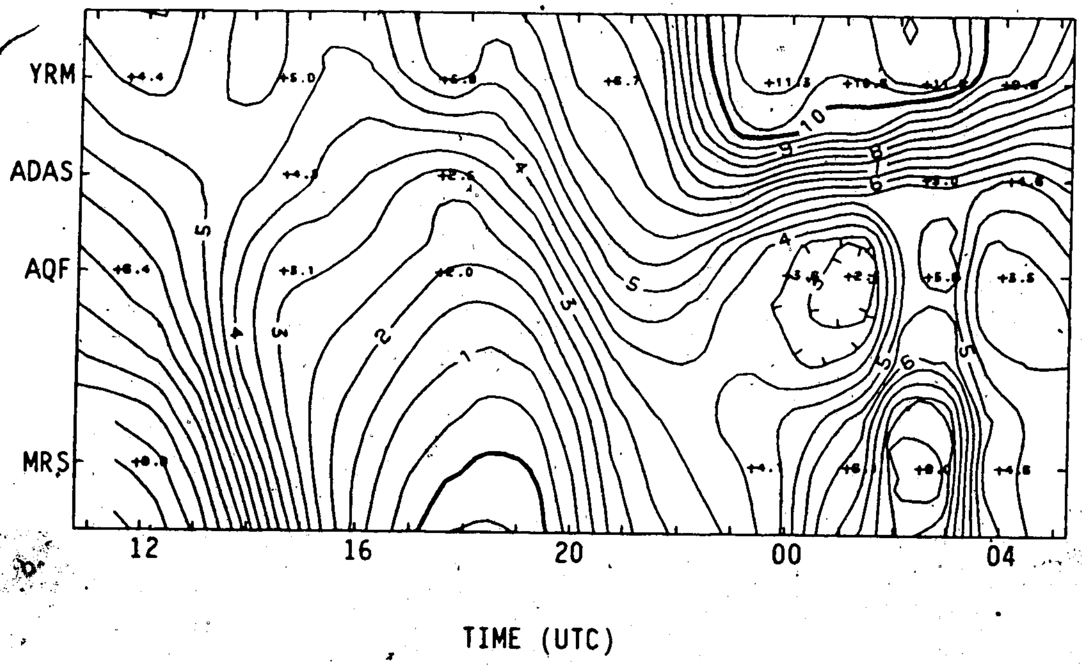


Figure 15. Time-section plot of 850 mb dewpoint temperature on 19 August 1981.

This index had its strongest gradient between YRM and AQF from 2330 UTC on and the highest index value was reported at YRM 1 1/2 hours after the storm. The threshold value of 18 was reached at YRM early in the morning and remained in the twenties for most of the day. It is interesting to note that the index decreased during the morning at AQF. A CB was reported at AQF at 2100 UTC, 3 1/2 hours after the last morning sounding. This contrasts with the VTI which increased and then decreased slightly. One would expect that a sounding closer in time would have yielded a much higher value. Due to the influence of the variable 850 mb dewpoint field after 2400 UTC, some index values at AQF were less than values at MRS.

5.1.2.3 Total-totals

The pattern of the total-totals index, like the CTI also bears a strong resemblance to the 850 mb dewpoint plot (Figure 16). This was expected, as the VTI plot had much weaker gradients than the CTI and since the TTI is the sum of the two, they should be similar.

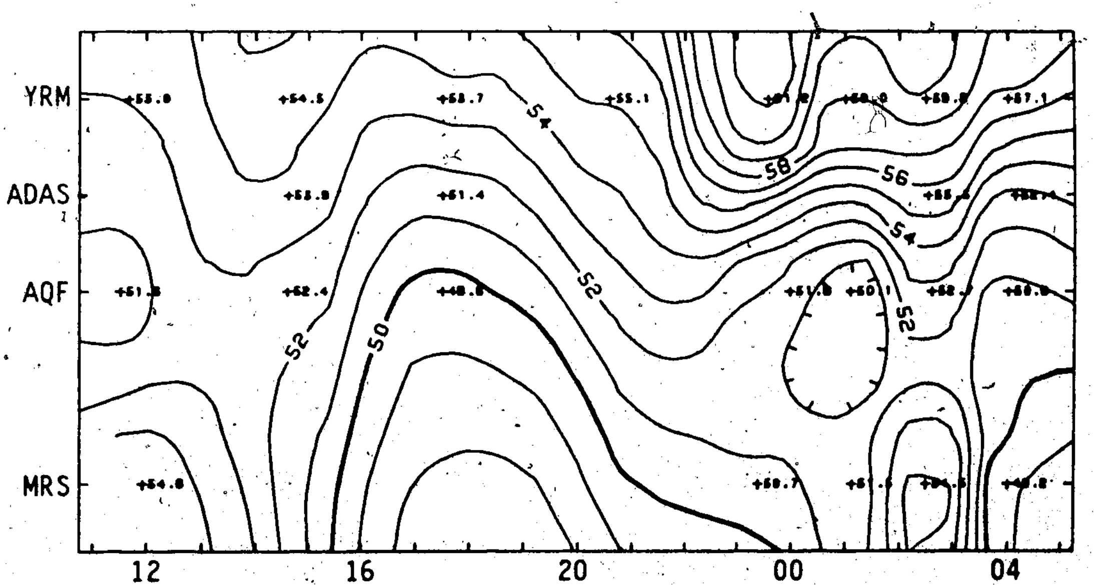


Figure 16. Time-section plot of Total-Totals Index on 19 August 1981.

All but one index value was greater than 50, the level indicating numerous and severe storms. Index values at YRM increased before the storm was reported and the maximum value occurred 1 1/2 hours after.

Almost all spatial and temporal intervals from VIZ sites displayed significant change. The index values at the ADAS site seemed to fit with values from the VIZ sites quite well. Between YRM and ADAS, the index values of the flight preceding and the two flights following the storm fluctuated by significant amounts.

5.1.2.4 K Index

Two moisture parameters are incorporated into the K index (Figure 17), the 850 mb dewpoint and the 700 mb dewpoint depression. The 700 mb data gave an indication of the vertical extent of moisture, hence, the K index pattern still retained some of the features of the 850 mb dewpoint field. A value of 33, 1 1/2 hours before the YRM storm, indicated a 60-80% probability of scattered CBs. All KI values were significantly different between YRM and AQF. Like the "totals" indices,

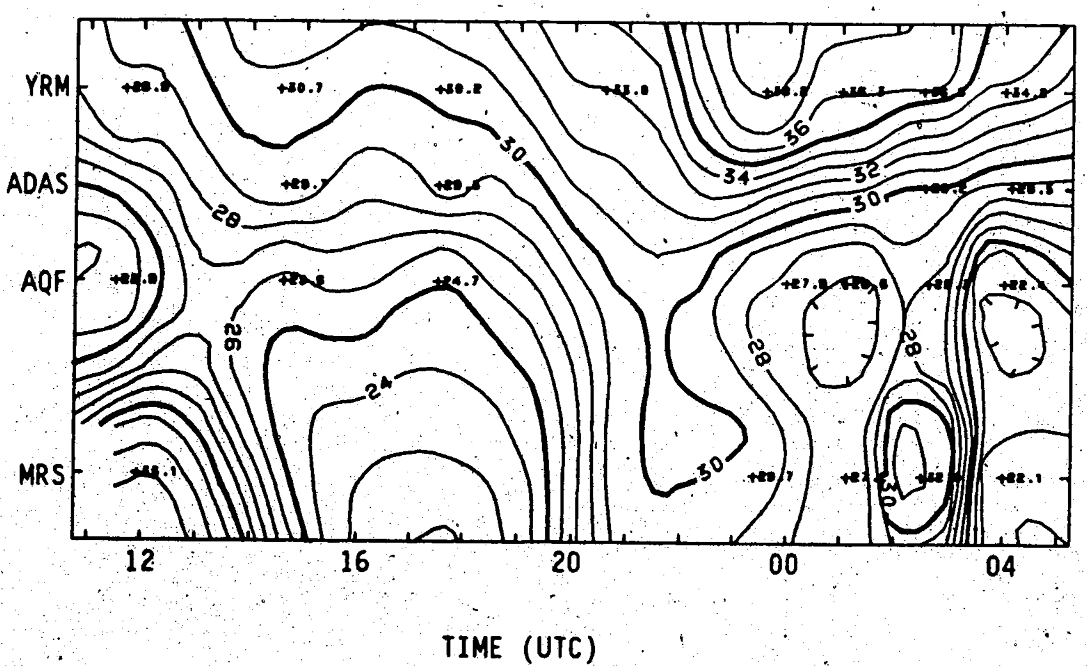


Figure 17. Time-section plot of K Index on 19 August 1981.

some of the values at AQF were less than at MRS late in the day.

5.1.2.5 SWEAT

The SWEAT index relies heavily on the TTI and 850 mb dewpoint and so essentially gives a pattern similar to that of the 850 mb dewpoint but with an exaggerated scale (Figure 18). All 3 and 1 1/2 hourly temporal and 76 km spatial intervals had significant changes. Since SWEAT could not be calculated for the ADAS sites and one of the AQF flights (1430 UTC) due to lack of wind data, the contouring package did not contour over the whole plot because minimum data criteria were not met.

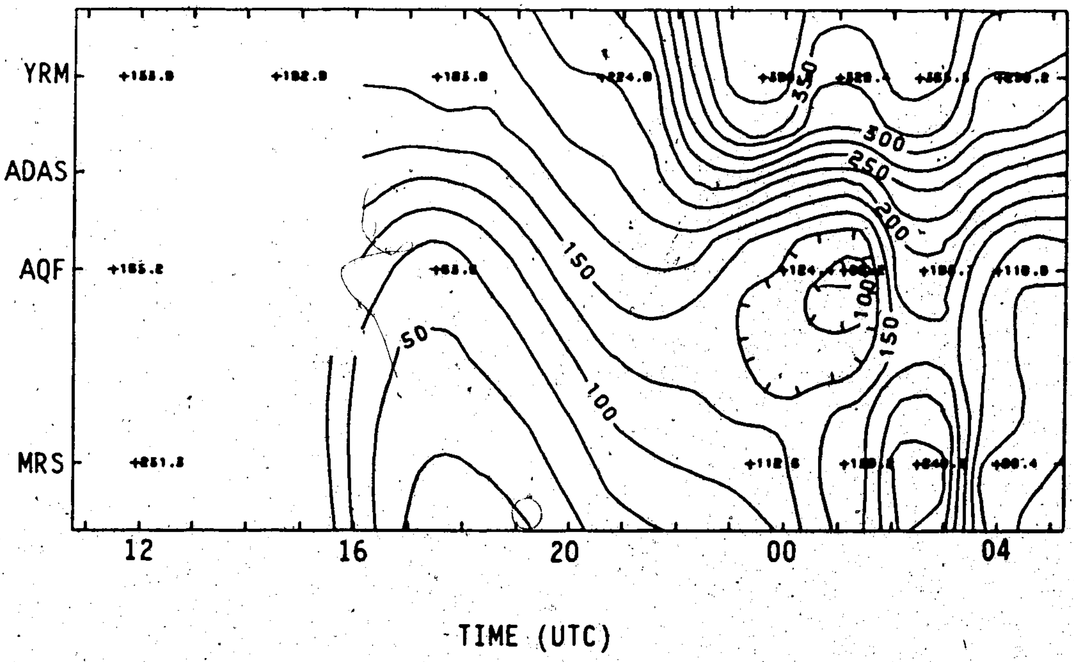


Figure 18. Time-section plot of SWEAT Index on 19 August 1981. (Note that the contouring package will not contour areas that do meet its minimum data density criteria).

5.1.2.6 Lifted Index

Temperature and moisture data at the surface are incorporated into the lifted index and it showed increased instability because of insolation during the morning but with a weak gradient of instability along the STRESS line (Figure 19). The highest value occurred at YRM (8.8) and it preceded the storm reported there. All the other indices reported their highest values after the storm. AQF also had a high index value at 1730 UTC which was 3 1/2 hours prior to a CB reported at the site. The evening cooling at the surface and at 500 mb is readily apparent as index values began to fall rapidly after 0100 UTC 20 August.

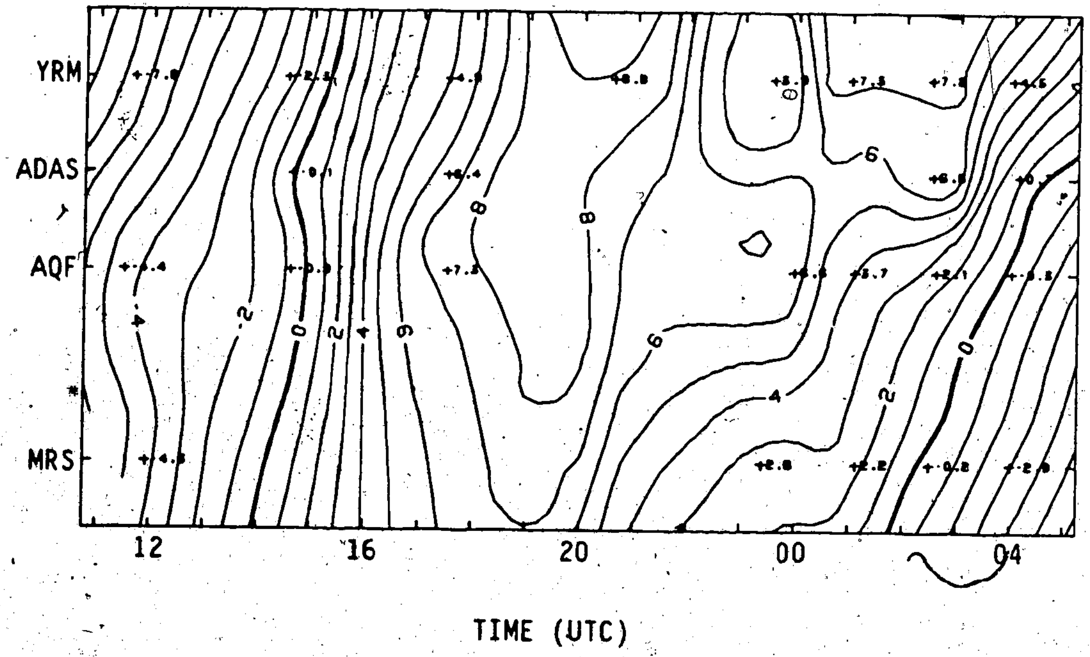


Figure 19. Time-section plot of Lifted Index on 19 August 1981.

5.2 STRESS Case Study: 20 August 1981

5.2.1 Synoptic Summary 20 August

The 500 mb features continued their eastward progression so that by 1200 UTC 20 August, the upper-level trough axis had reached the coast (Figure 20). It continued to weaken and fill throughout the day. The surface trough and an associated cold front moved from the mountains into Alberta (Figure 21). These features were at first ill-defined but by 1800 UTC a surface low had developed northeast of Edmonton. It remained almost quasi-stationary and deepened during the afternoon. Upper winds remained southwesterly throughout the day and although there was cooler air upstream, no significant change in temperature at 500 mb had occurred by 0000 UTC at the Edmonton upper-air station. The surface wind direction along the the STRESS line was generally NNWly, while the wind speed was light to moderate (Figure 22).

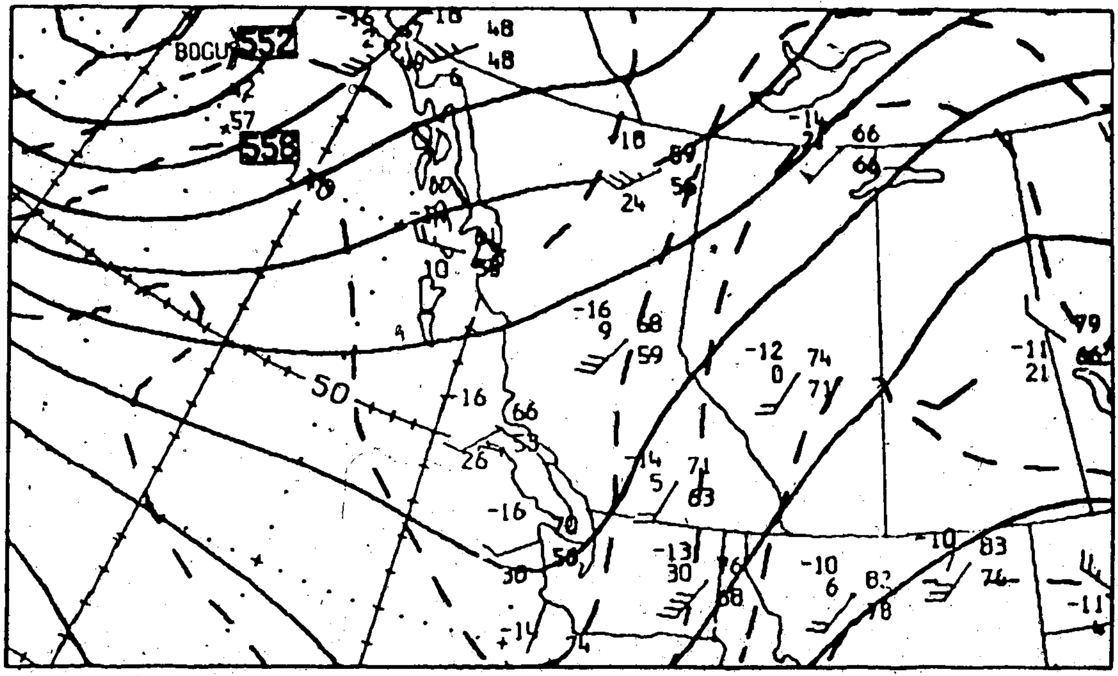


Figure 20. 500 mb analysis for 1200 UTC 20 August 1981.

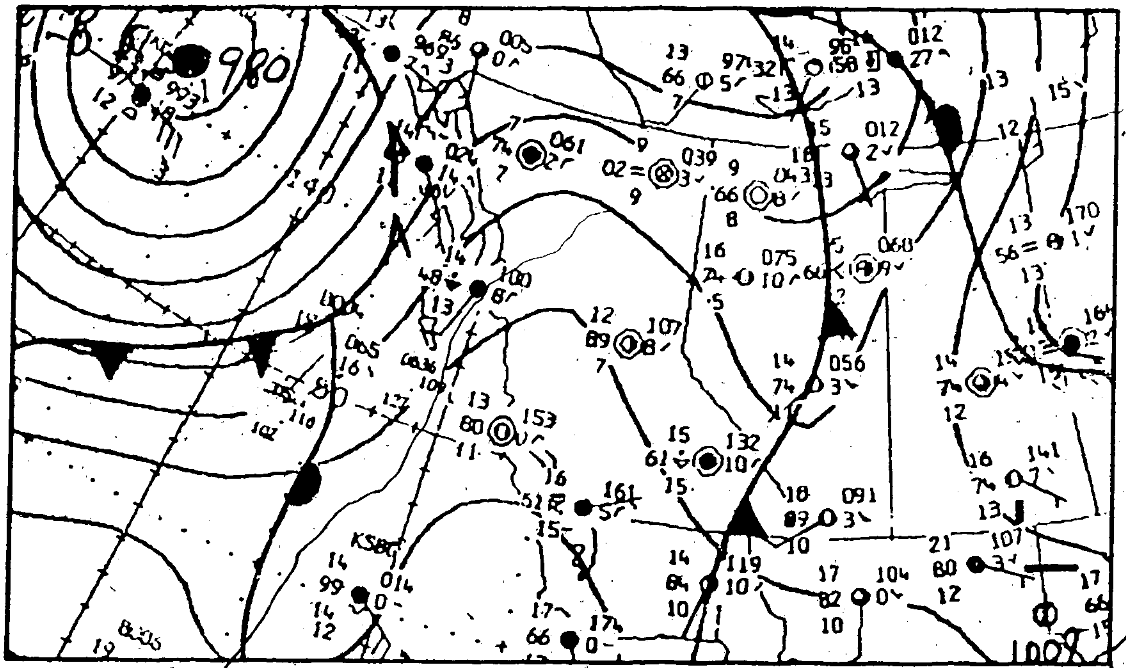


Figure 21. Surface analysis for 1200 UTC 20 August 1981.

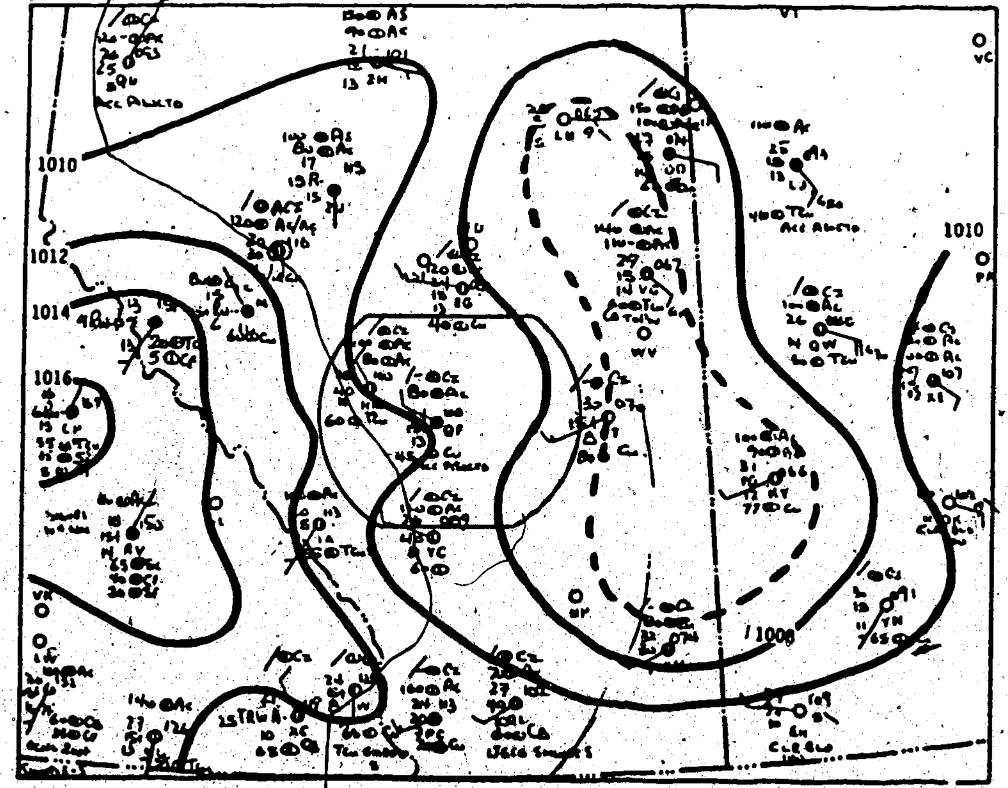


Figure 22. Surface analysis for 2200 UTC on 20 August 1981.

Rocky Mountain House reported CB tops NNW at 2100 UTC and very light rain showers at 2300 UTC. From satellite photos, convective activity was seen to have occurred during the day in a line from Jasper to the northeast corner of Alberta, and also along the cold front.

5.2.2 Time-section Analyses

On 20 August, the 500 mb pressure-heights (Figure 23) derived from the AIR sonde data fell between those of the adjacent stations, although they appear to be slightly high. There was a stronger height gradient between YRM and AQF, than between AQF and MRS at 1730 UTC, the start of operations. By the end of operations, 2400 UTC, the gradient was almost linear along the whole line. A strong surface temperature gradient was evident along the STRESS line and persisted throughout the day (Figure 24). No storms occurred along the STRESS line during operations; CB tops were reported NNW of YRM at 2100 UTC and at 0200 UTC 21 August a CB was reported west of the station. Another storm was reported at Coronation, about 90 km east of the MRS site, 1 1/2 hours after the final release.

The YRM surface pressure was found to have been improperly recorded for a number of releases and therefore a pressure bias was introduced into the flight data. Fortunately, this site was located at a regular AES surface station and it was possible to obtain the correct pressure values and modify the flights. A mistake in the surface temperature was evident on the 2200 UTC flight (Figure 25). It was apparently due to misreading of the psychrometer and may also include temperature calibration problems. Although much of the flight seems to fit with the

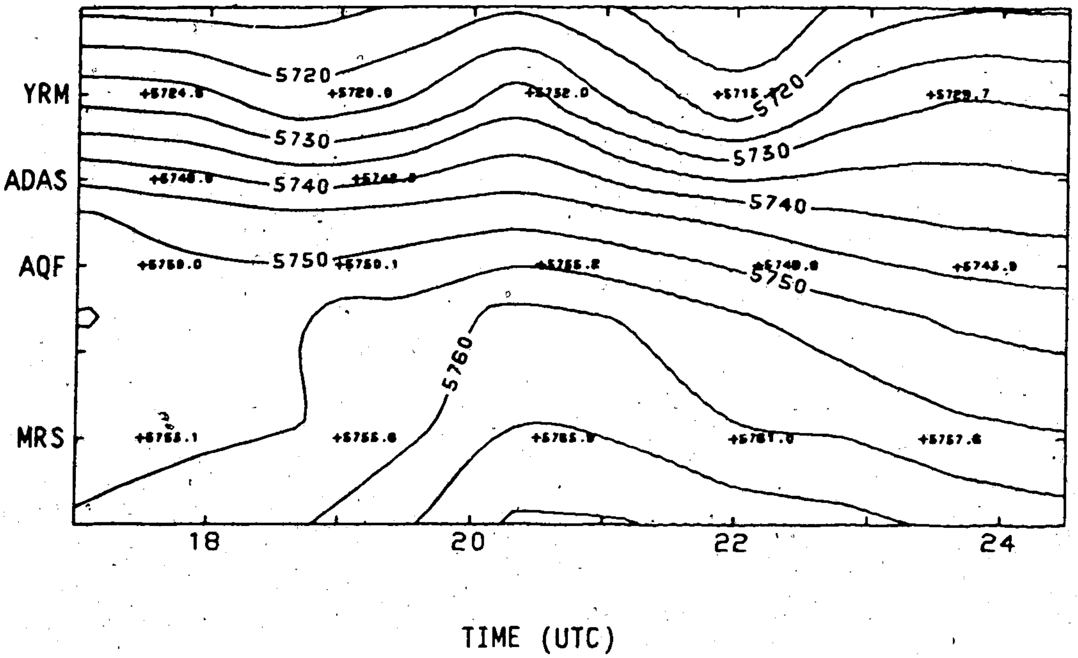


Figure 23. Time-section plot of 500 mb pressure-heights on 20 August 1981.

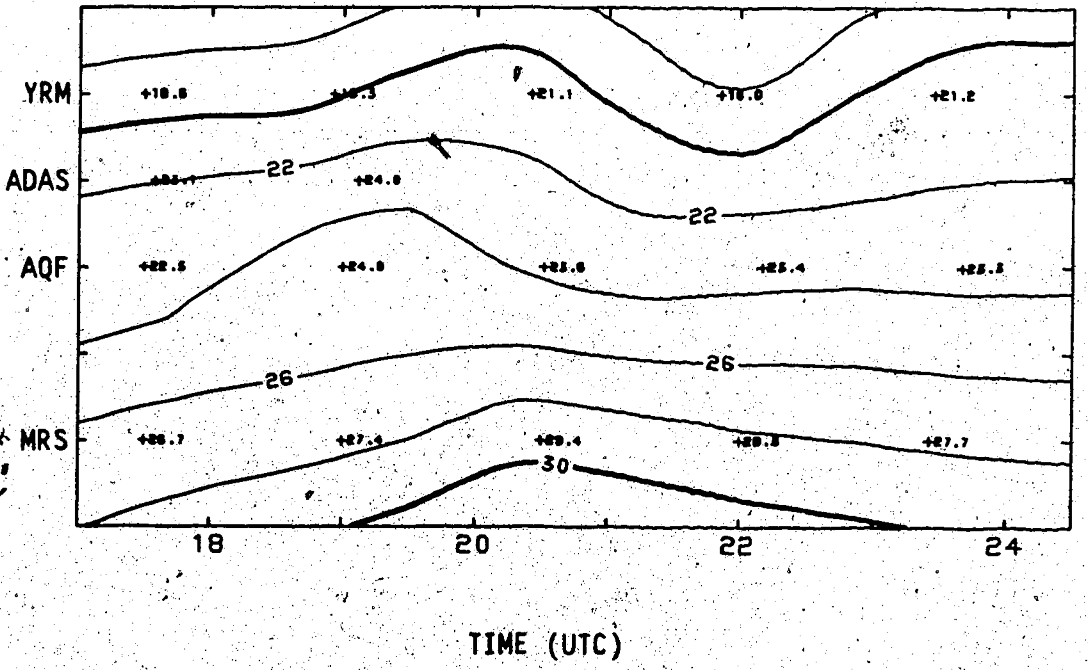


Figure 24. Time-section plot of surface temperature on 20 August 1981.

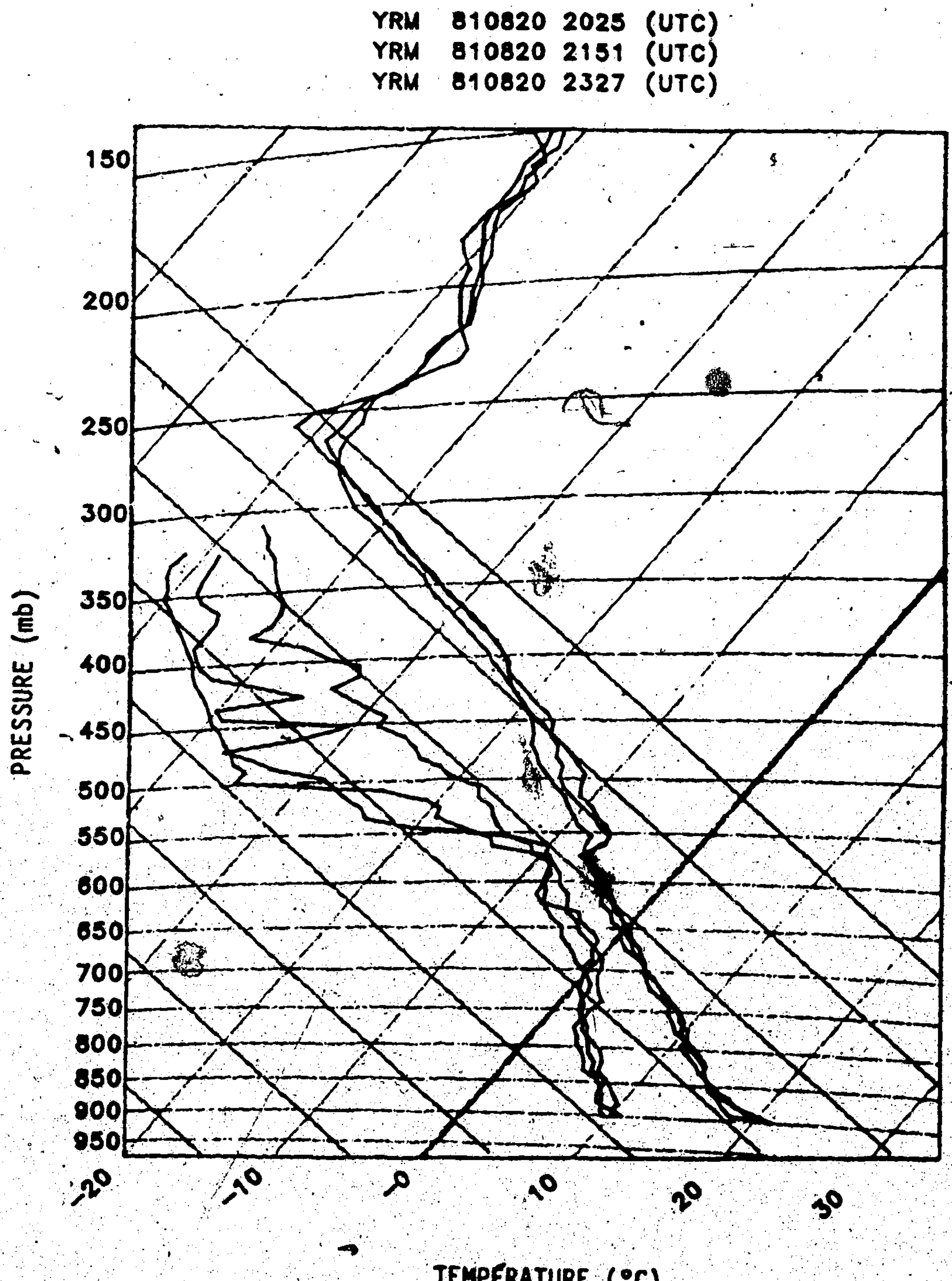


Figure 25. Tephigram composite of YRM flights for 2030, 2200 and 2330 UTC on 20 August 1981.

adjacent temporal soundings, the surface temperature was about three degrees less than that of the temporally adjacent soundings and the YRM AES station reported a temperature of 20°C at this time. Modifying the surface temperature to that of the AES station produced a superadiabatic lapse rate from the surface to the first level, so it was left unmodified for this study.

5.2.2.1 Vertical-totals

The gradient of the VTI was better defined than on the previous day (Figure 26). No indication, by a change in the gradient, was given for the storm reported west of YRM 2 1/2 hours after the final release of the day. Index values at the MRS site remained the same (within the limits of uncertainty) until the last release, which then indicated a significant positive change.

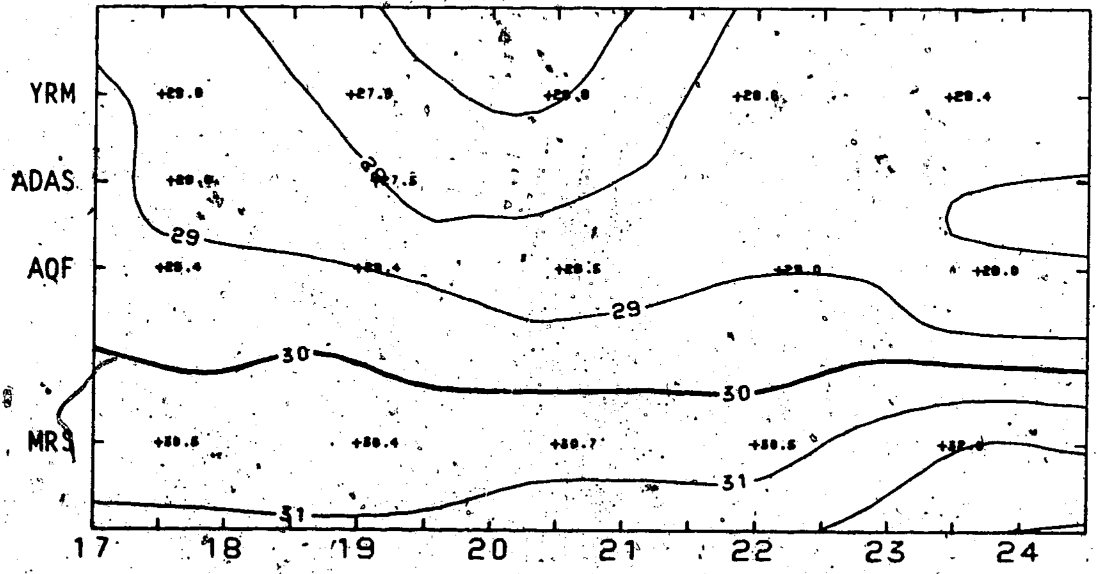


Figure 26. Time-section plot of Vertical-Totals Index on 20 August 1981.

The gradient of index values was greater between AQF and MRS than between YRM and AQF, where it was weak and generally not significant. The magnitude of the index values on this day was lower than on the previous day but still above the threshold of 26.

5.2.2.2 Cross-totals

The cross-totals index pattern (Figure 27) exhibited some resemblance to the 850 mb dewpoint pattern (Figure 28). Gradients were not strong and values were not much larger than the threshold (18), hence, no area of storm formation was indicated.

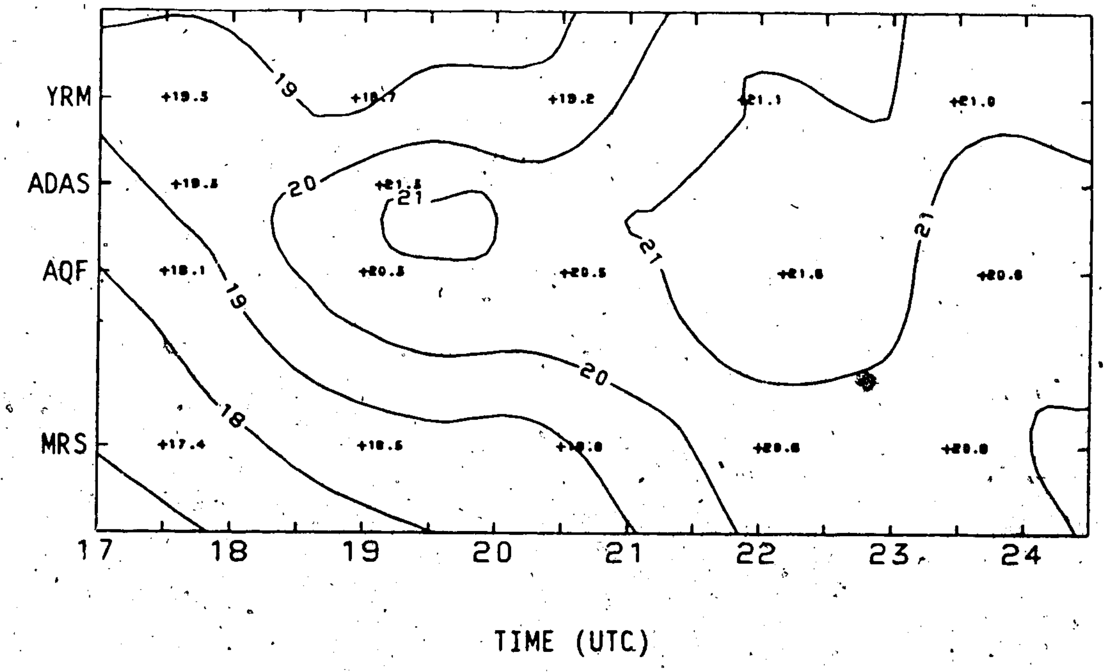


Figure 27. Time-section plot of Cross-Totals Index on 20 August 1981.

Instability increased and gradients became weak towards the end of operations. For the last flights, the index values were the same along the line and storms did occur near YRM and Coronation, several hours after operations ceased. This index gave no clear indication of change, either spatially or temporally, which could have been used to predict the area of storm formation.

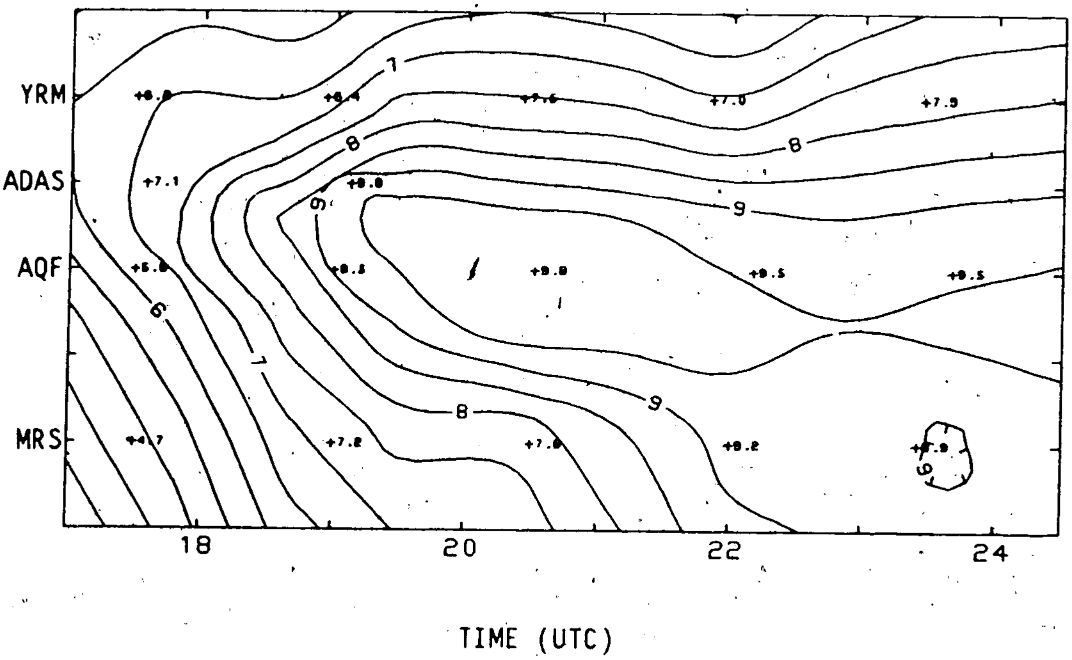


Figure 28. Time-section plot of 850 mb dewpoint temperature on 20 August 1981.

5.2.2.3 Total-totals

Generally, a significant difference in the TTI existed between YRM and MRS (152 km spacing) but not for a station spacing of 76 km (Figure 29). All index values were greater than the threshold (44) and the MRS site value increased at 2330 UTC while both AQF and YRM were not significantly different. A CB was reported at Coronation 1 1/2 hours after the last flight. No indication for the CB, which occurred west of YRM after the last flight, was evident in the data.

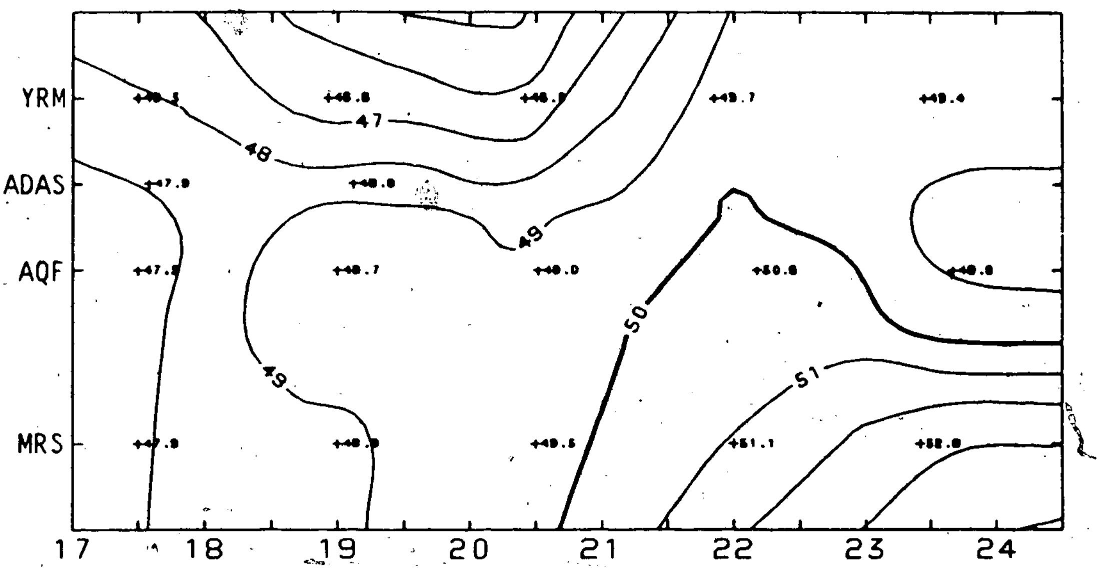


Figure 29. Time-section plot of Total-Totals Index on 20 August 1981.

5.2.2.4 K Index

Excluding the 1730 UTC release, there was generally no significant difference spatially in the K index between the VIZ stations until the last release (Figure 30). AQF did not have a significant temporal difference between the 2200 UTC and the 2330 UTC release, but both YRM and MRS did. Therefore, this index was better able to define the location of storm formation as it indicated changes at both of these sites, several hours before activity was reported.

The ADAS flights, especially at 1900 UTC, had higher values than would be expected and this was probably due to the greater amount of moisture reported at 700 mb.

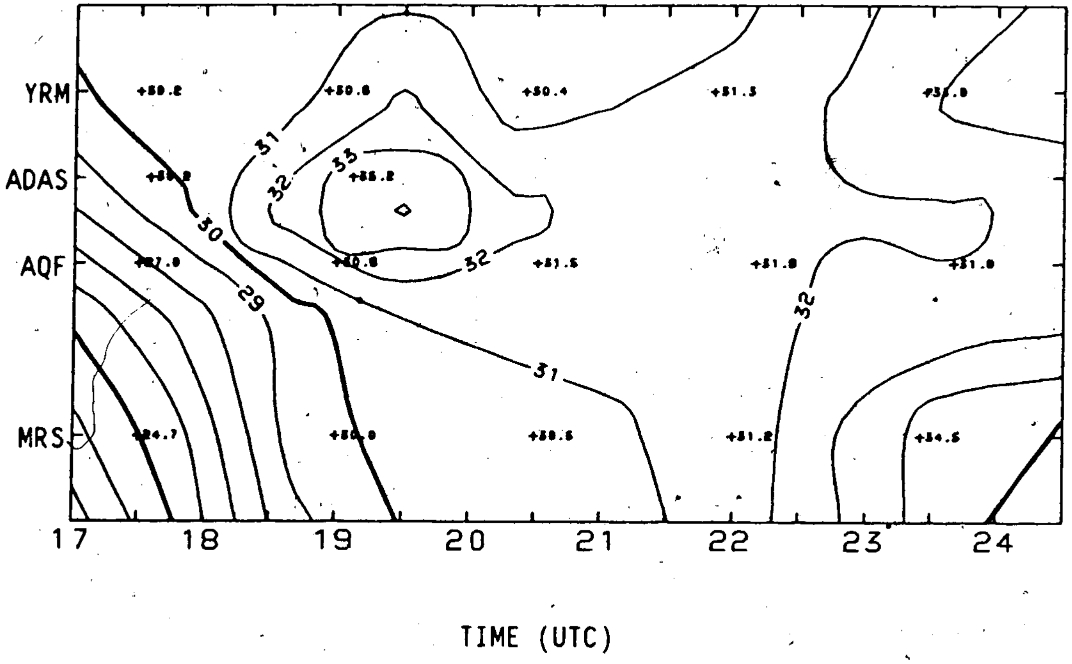


Figure 30. Time-section plot of K Index on 20 August 1981.

5.2.2.5 SWEAT Index

All values of the SWEAT index, except one, were significantly different from each other for 1 1/2 hourly and 76 km intervals (Figure 31). MRS index values increased during operations and the highest value (211) occurred at 2330 UTC. The threshold for a severe thunderstorm is about 250, so the index indicated convective activity, although not severe, 1 1/2 hours before its occurrence. No significant change occurred in the index values for the last two releases at YRM. YRM also had the lowest index value of the STRESS line's last flight, hence, this index did not indicate the possibility of the storm that occurred to the west 2 1/2 hours later.

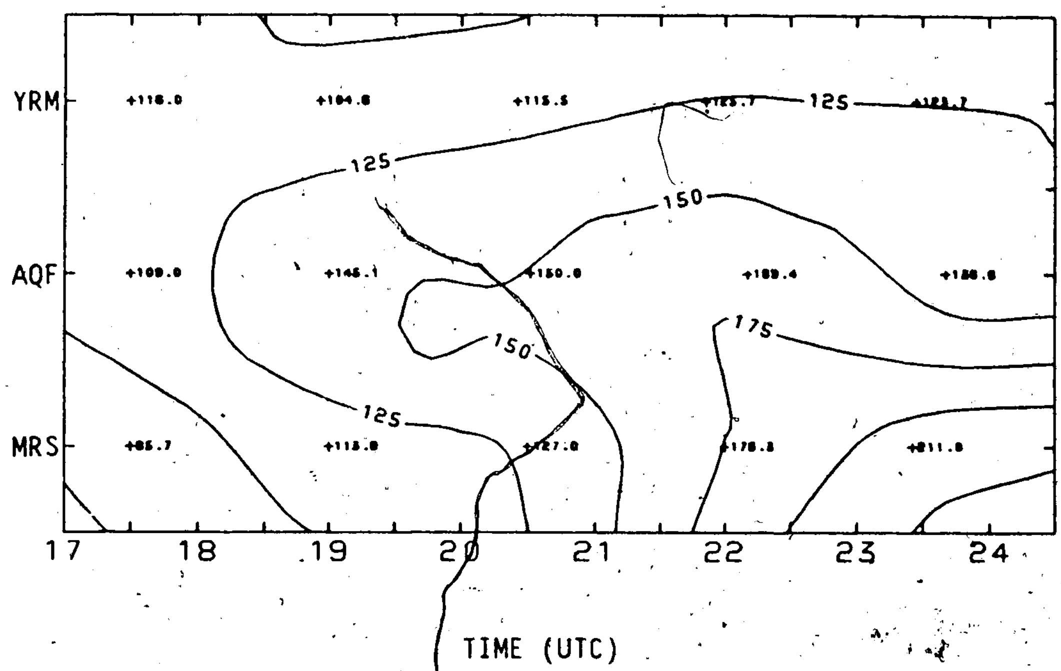


Figure 31. Time-section plot of SWEAT Index on 20 August 1981.

5.2.2.6 Lifted Index

Both AQF and MRS had maximum LI values before 2100 UTC, while at YRM it occurred at 2330 UTC, the final release (Figure 32). There was no significant change in the index between the last two flights at both YRM and MRS, whereas at AQF a significant negative difference occurred. Spatially, almost all index values were significantly different for 76 km spacing.

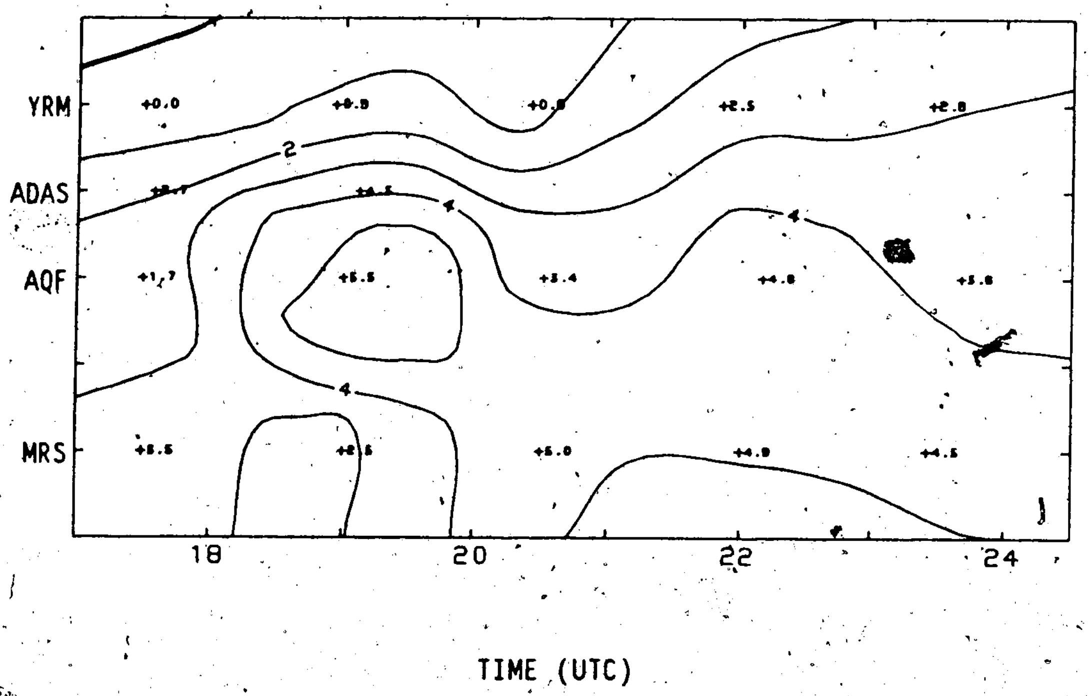


Figure 32. Time-section plot of Lifted Index on 20 August 1981.

CHAPTER 6

RESULTS AND RECOMMENDATIONS

The overall goal of this thesis was to examine the resolution in time and space of an upper-air network for the study of mesoscale phenomena. This study was able to determine intervals, both spatially and temporally, over which significant changes in stability indices occurred on days with weak thunderstorms. A change in the value of an index between the two soundings was considered significant if the magnitude of the difference was greater than the sum of the uncertainties.

6.1 General Results

The Red Deer comparison tests indicated that most of the relative error in data from VIZ sondes was a result of the human limitation of data extraction procedures. The AIR sonde, however, demonstrated errors which were more than a factor of two larger than those of the VIZ sondes. The standard deviation of temperature and dewpoint temperature from the VIZ sonde mean was 0.2°C and 0.3°C for VIZ sondes, and 0.5°C and 0.9°C for AIR sondes.

Stability indices were used as a means to study thermodynamic change of the atmosphere, for three reasons: first, to incorporate the parameters that are measured by radiosondes (pressure, dry-bulb temperature and moisture); second, to numerically quantify atmospheric instability; and third, these indices were either unaffected by or not very sensitive to bias error (such as improper calibration of a radiosonde).

The Vertical-Totals index does not take moisture into account, so that it tends to give just a broad areal indication of thermal instability. Little indication of spatial or temporal change was observed in the index values around storms. This index did not prove useful for determining spatial or temporal resolution near convection in this study.

The time-section analyses of Cross-Totals, Total-Totals, K, and SWEAT indices, all bore a strong resemblance to the 850 mb dewpoint pattern on 19 August. Significant temporal changes in these indices were found to occur over periods as small as 1 1/2 hours, the minimum interval between releases. This was due to their high dependence on moisture which is the most variable parameter measured by radiosondes. For example, the moisture fluctuated considerably following the storms on the afternoon of 19 August. It is possible that these fluctuations were an artifact of the change in release interval, from 3 hours during the pre-storm period, to 1 1/2 hours during the post-storm period. However, the releases on 20 August were made every 1 1/2 hours and no such variability was observed.

It was more difficult to determine significant change in the indices for station spacing, since the AIR sonde site generally seemed to have higher index values than the adjacent sites and it was missing during many of the line releases. Nevertheless, significant differences in index values were noted over station spacing of the order of 40 km on 19 August, after the storms had dissipated at YRM and AQF. On 20

19 August, after the storms had dissipated at YRM and AQF. On 20 August, the 850-mb level dewpoint pattern was less variable, while the Cross-Totals, Total-Totals, and K indices yielded no significant differences even for 150 km station spacing.

6.2 Significance Of Results To Mesoscale Studies

The relative accuracy obtainable from carefully checked radiosonde data is very good, about 0.2°C for temperature. Other studies have used data reduced by different personnel at each upper-air site, thereby resulting in data extraction errors of the same magnitude as those inherent in the instrument. This is the situation for the synoptic upper-air network, where each site extracts and reduces its own data, using prescribed rules. The soundings in this study have had the benefit of being verified by one person, and therefore should be more consistent than soundings from the synoptic upper-air network. Any mesoscale studies should endeavor to minimize the number of different people extracting and checking data. It is interesting to note that trends of index values in time generally agreed between stations, even when the changes were within the measurement uncertainty.

Significant changes in index values were observed over distances of the order of 40 km and time scales as small as 1 1/2 hours. Hence, a network spacing of this order of magnitude is not only feasible, but necessary in order to resolve mesoscale features. Temporal changes of index values near convection can also occur rapidly. This suggests that releases could be made more frequently than 1 1/2 hours, and still yield non-redundant data. A typical flight takes about 3/4 of an hour to attain the 150-mb level, not including the preparation time for the sounding, about 1/4 hour. Thus, with the standard VIZ sondes, the limits of temporal resolution for flights released from one upper-air system is about one hour. This time interval could be decreased by terminating the flight at a lower level, say at 400 mb. However, this is reasonable only if one wishes to study the lower part of the atmosphere. Soundings to higher elevations would be required for some experiments, such as the study of mesoscale features of jet streams, or for the calculation of vertical velocities using the kinematic method. Another way to decrease the release time interval from one site, if cost were no object, would be to locate more than one upper-air system at a site. Soundings could then be made alternatively between the systems.

6.3 Recommendations For Future Study

Radiosondes are continually being modified to improve their performance, although little information on these changes is published in the literature. Hence, it is important that comparison tests be made with all equipment and expendables that are to be used for an operation. For example, since 1981, all VIZ sondes use solid-state electronics, hygristors of slightly different composition, and more precise pressure components. AIR has now developed a new sonde similar tc the VIZ design, which incorporates the VIZ hygristor for moisture measurement.

The statistics from the Red Deer comparison flights on 14 October, 1981, were based on data extracted every 25 millibars. It is suggested that, for future comparisons, flights be made with matched sondes (VIZ type), that is, ones where the pressure values of the contacts are similar. In this way, comparisons can be made with simultaneous data rather than with interpolated values.

Other investigators have reported differences due to instrument error, rather than actual changes in the atmosphere (M. Friedman, VIZ, personal communication, 1984). The VIZ company makes premium sondes with reference accuracy of 0.1^{o}C temperature and 2% relative humidity. Friedman recommends that this type of sonde should be used in mesoscale studies, but no ground station equipment exists to take advantage of the increased sonde accuracy. Standard upper-air procedures with manual data extraction are currently unable to make use of the precision of these sondes. To circumvent this problem, a data acquisition system is presently being developed at the Alberta Research Council (Katarey, 1985) to digitally record analog data from VIZ radiosondes. In conjunction with this, a computer processing package is concurrently being developed which will identify and process these data without human intervention. This will speed up data processing, eliminate human transcription mistakes, and improve the precision of the data. If upper-air data still exhibit discrepancies even after the use of the data acquisition system being developed, then more extensive testing will be required. A series of matched-sonde pairs at two or more stations would not only allow comparisons to be made, but ensure more confidence in the observed temporal and spatial changes of temperature and humidity.

If at all possible, it is advisable to continue operations on days that are deemed synoptically favourable for convection, rather than to cease operations early. An upper-air line of even five stations quickly expends a large number of sondes when the release interval is 1 1/2 hours. The temptation is to try to conserve expendables by basing operational decisions on hourly weather trends. For example, on 19 August, 1981, operations were terminated near noon, because it did not seem likely that convection would occur. However, two small storms formed and the STRESS operation could not be reactivated until after these had dissipated. No more storms occurred near the line during the evening.

One important matter to consider for future work is the real-time verification of the surface data at each site. Ideally, each site should transmit its pressure, temperature and wet-bulb temperature to a base or central location where all network data can be validated before releases are made.

It is suggested that a network, rather than a line of stations be used in the future to study spatial and temporal resolution of upper-air data, if enough equipment is available. The Alberta Research Council now has a total of nine upper-air systems. A new mesoscale study, called the LImestone Mountain EXperiment (LIMEX-85), was conducted over the Alberta foothills during a three-week period in the summer of 1985. Its purpose was to study the effect of low-level capping inversions on the formation of thunderstorms. All nine upper-air systems were used for this network, and the data collected should prove to hold some interesting features for the type of analysis envisioned for this study. Through such studies the understanding of mesoscale processes will increase and improvements in the field of mesoscale forecasting will occur.

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