

SSEC No. 76.06.G1

THE SCHWERTFEGER LIBRARY
1225 W. Dayton Street
Madison, WI 53703

GISS/SSEC McIDAS DATA STUDY

A REPORT

from the space science and engineering center
the university of wisconsin-madison
madison, wisconsin

GISS/SSEC McIDAS DATA STUDY

Submitted by:

Verner E. Suomi, Principal Investigator
The University of Wisconsin
Space Science and Engineering Center
1225 West Dayton Street
Madison, Wisconsin 53706

FINAL TECHNICAL REPORT

ON

NGR50-002-215

FOR THE PERIOD

1 MARCH 73 - 31 MAY 76

June, 1976

CONTENTS

Section I

Report on the Wisconsin Participation in the August-September
1975 DST

Section II

Preliminary Assessment of the Cloud Tracking System Developed
at the University of Wisconsin

I. Introduction

II. GATE Wind Sets from SMS Images - An Assessment of Quality

III. Comparison of Wind Measurement Systems: Cloud Tracked Winds vs.
Rawinsonde Winds and Rawinsonde Winds vs. Rawinsonde Winds

IV. A Comparison of Windco Cloud Motion Winds from Infrared SMS
Images with Reported Radiosonde Winds over North America

3

REPORT ON THE WISCONSIN PARTICIPATION
IN THE AUGUST-SEPTEMBER 1975 DST

Frederick R. Mosher

October 1975

Space Science and Engineering Center
University of Wisconsin
1225 West Dayton Street
Madison, Wisconsin 53706

I. INTRODUCTION

The Space Science and Engineering Center (SSEC) of the University of Wisconsin participated in the August-September 1975 Data Systems Test (DST) from August 16 - September 21. Winds were derived from cloud motions using SMS-1 image data. Four data sets were produced each day. Out of a possible 142 data sets during this period, a total of 135 were produced, making an operational reporting reliability of 95%. For these 135 data sets, an average of 1046 vectors were produced for each data set, making a grand total of 141,216 wind vectors for the five week operation.

This report is intended as a summary of the operations at Wisconsin during this DST. It will cover the system used during this DST and how it differed from previous DSTs. It will cover the training and operational procedures used during this DST. Finally in the appendix will be the entire list of the number of winds produced for each time period of the DST.

II. SYSTEM CONFIGURATION FOR AUGUST-SEPTEMBER DST

The cloud motions were measured on the McIDAS (Man-computer Interactive Data Access System). This is an image storage, display, and processing system consisting of data archive, data access, video display, operator console, and computer control sections. Central to the system is a computer which controls the display section, operator console, and computer peripherals. Data enters the system from an antenna on the roof which receives the stretched SMS data. This data can either be archived on a special slant track recorder, or used in real time. The real time ingestion of data is done by using a data interface box which converts the incoming visible and IR data into 8 bit bytes, averages the elements in a line to produce equivalent 1/2, 1, 1-1/2, 2, 3, and 4 mile resolution data, packs

the data into 24 bit words, and then puts the data directly onto the digital disk in real time. The data is then reformatted by the computer into standard analog TV format and is transferred to an analog video refresh disk. The registration of images is done by using a predictive navigation system. This predictive navigation is capable of predicting the position of every pixel 24 hours in advance within an accuracy of approximately one pixel. This predictive navigation and ingestion system is capable of producing aligned sequences of images in real time so that when the satellite finishes sending the images, they are immediately ready for cloud wind tracking.

Control of the McIDAS hardware and execution of the scientist's commands are achieved through a body of special software. The operator commands the computer through a keyboard using a language requiring no knowledge of programming. Through this software it is possible by simple key-ins to enhance an image, magnify it, combine adjacent images into loops of any length, vary loop speed by up to a factor of 30, locate and track clouds in TV, image, or earth coordinates, and display the results as a vector plot superimposed on the original image. Two independent heads on the analog disk allow double looping of infrared and visible images, with instant single key transfer from one to the other, or interlacing of the two images.

Tracking may be done by either of two primary methods: cursor tracking of the cloud to the nearest TV line and element (pixel tracking), and image match tracking of the cloud to better than TV line-element resolution (correlation tracking). Pixel tracking has been facilitated by the addition of a function called the velocity cursor. The operator positions a cursor over the cloud to be tracked using a joy stick. The velocity

cursor function then automatically displaces the cursor from one picture to the next according to the position of a second joy stick. The displacement is linear within the TV line-element coordinate system, and constant from one picture to the next. The velocity cursor can be used by itself for single pixel tracking, or it can be used in conjunction with the correlation tracking. Correlation tracking requires the operator to roughly track the cloud by placing the cloud within a box for each picture in a set. The computer then performs a correlation analysis to align the brightness field and "fine tune" the operator's tracking. Correlation tracking is the more accurate, but it requires well-defined clouds moving in a single layer flow pattern. Single pixel tracking using the velocity cursor can be invoked by the operator for tracking clouds in multi-layer flow patterns, or for matching the motion of the cursor to the motion of a pattern if individual clouds cannot be tracked.

The heights of the clouds are determined using both the visible and infrared data. The visible data is used to determine the emissivity of the cloud. The infrared blackbody temperature data is then corrected for emissivity to determine the cloud top temperature. Standard atmosphere soundings corrected for the latitude and date are then used to determine the height of the cloud. For cloud tracking using only infrared images where there is no emissivity data, the blackbody temperature of the cloud is used. The cloud height function can be requested independently of the wind calculation if desired by the operator, or it can be invoked automatically by the wind computation. The operator can also specify the height if desired.

Quality control can be applied to the derived wind measurements in several ways. The measurement can be made twice using three images. Wind

measurements which do not agree within an operator set residual criteria are flagged to be in error. The height measurement also is made twice. Other quality control routines available include the best match occurrence on the matrix boundary. If during correlation, the best match of the two images occurs on the boundary of the data matrix, the data is flagged. This check is routinely used for all correlation computations. A final quality control check which is performed is the plotting of the derived wind vectors over the cloud pictures. The displayed vectors are color coded according to the height of the cloud. The operator can mark any vectors he feels which are in error. For the DST there was no conventional data comparison or large scale plot of wind vectors.

III. SYSTEM DIFFERENCES FROM PREVIOUS DST EXPERIMENTS

The August-September 1975 DST was the third in which Wisconsin participated. The first was 28 Oct.-2 Nov. 1974, the second was 25 Jan.-11 Feb. 1975, and the third was 15 Aug.-21 Sept. 1975. The basic framework of the McIDAS and the wind tracking software has been the same for all three DST experiment. However there have been significant advances between the DSTs which has advanced the McIDAS from a research tool to a tool which is capable of real time operational processing of data in a FGGE framework.

A. October 1974 DST

Any cloud tracking system has the basic components of a data ingestion system, image production system, image alignment system, cloud tracking system, cloud height determination, quality control system of derived measurements, and finally an operating system which ties together systems into a functional unit.

By October 1974, Wisconsin had developed the basic components of a

cloud tracking system in the McIDAS. The satellite data was ingested onto a slant track digital recorder which was capable of recording 10^{11} bits on one tape (almost a full day of full resolution, while earth SMS images). The data was then read off the slant track tape onto a digital disk. The digital disk then transferred the image to an analog TV refresh disk. The images were aligned using an orbit model navigation system. This navigation system required a series of pictures of a single landmark over a period of a day to define the attitude of the spacecraft. These landmark images were read off the tape, the navigation was performed, and then the images which were to be used for cloud tracking were read off. Three visible images, and one IR image were used during the October 1974 DST. All the cloud tracking was done with the visible images. The cloud heights were determined using only the one IR image. The height was automatically determined with no operator intervention. There was no height checking. The displayed vectors did not contain any height information, so there was no height quality control in the system.

There were two sets of winds produced each day during the October 1974 DST. The earth was divided into 12 sectors for display on the TV screen. It took approximately six hours to load the images, 1 hour to navigate, and five hours to process the winds. Approximately 500 vectors per data set were produced using a single terminal. The loading time prevented a full set of 3 IR images from being loaded. The data times were 12 Z and 18 Z because of the need for a visible landmark for each image. This single landmark was used for both the north-south alignment and the east-west alignment of the images. The north-south variation of the image is caused by the motions of the spacecraft and are quite regular and definable. The

east-west motions are under the control of the ground station and is changed many times a day, forcing the necessity for the landmark in each image. The alignment accuracy was quite good. Errors caused by alignment errors were on the order of 10 cm/sec.

The primary purpose of the October 1974 DST was the check out the basic system components of the Wisconsin cloud tracking system. The test showed that the basic navigation and alignment system worked very well. The Man-computer Interactive concept was demonstrated as an efficient method of processing satellite image data to produce quantitative results. Analysis of these winds by NMC's Data Assimilation Branch showed the satellite-derived winds to be as accurate as radiosonde winds, but the winds produced during the October 1974 DST had height assignment errors on some of the wind vectors. The ability to produce meaningful wind vectors in areas of multiple cloud layers was noted as being an advantage of the Wisconsin System.

B. January 1975 DST

The January 1975 DST was a two week test from 24 Jan-6 Feb. The original aim of this DST was to process sufficient data for model impact studies at NASA/GISS. Four wind sets per day for two weeks was desired. Because of the loading time problem and the use of the McIDAS at Wisconsin by other scientific users, only one time, 18 Z, was processed in real time. The 6 Z winds were produced during March 1975. The other two time never were produced for the full two week period except for 3 days of data which was produced in July 1975 as a training exercise for the August-September 1975 DST.

For the 18 Z set which was processed in real time the data ingestion, navigation, and loading and cloud tracking was done basically the same as

during the October 1974 DST. Since the NMC analysis report had not yet been published at this time, the height assignment problem of the October 1974 data was still in the 18 Z data of the January DST. For the 18 Z data, an average of approximately 1000 vectors per data set was produced. A global comparison of the cloud derived winds for this 18 Z data set with radiosonde data showed an average 5 m/sec difference between the cloud observation and the radiosonde. The same analysis applied to radiosonde vs. radiosonde showed also a 5 m/sec difference. This difference is caused by atmospheric variability and is consistent with studies of differences between simultaneously launched balloons.

The 6 Z data set had several major system advances accomplished prior to the processing of the data. The NMC analysis of the October DST data was released. The wind vector display was changed so that the displayed vectors were color coded to height, making it easier for the operator to spot a vector with an erroneous height assignment. The second advance dealt with the alignment and the requirements for landmark data. The 6 Z data had only IR images available. The SMS infrared images have a pixel size of 2 x 4 mi at the subsatellite point.

Landmarks are very difficult to measure precisely in the IR because of the poor temperature contrast between land-water boundaries at some times during the night. Hence IR only landmark data had problems with large granularity and poor contrast. To get around this problem a system was developed to determine the east-west image shift from the line documentation of the image, and extrapolate the north-south image shift from visible landmark images measurements made on the previous days data. Hence it became possible to align a sequence of images accurately without making landmark

measurements on all the images in the sequence. The error caused by the misalignment of images was only 10 cm/sec for this 0600 Z set which had no landmark measurements at all during the sequences which were used to compute the winds. An average of 700 winds per data set were produced for this 0600 Z data set.

C. August-September 1975 DST

The August-September DST was to be a one month test with four data sets per day produced in a real time operational environment mode. To accomplish this, several advances were made to the McIDAS system. The first was to expand the system into a two terminal unit with both terminals working without interference from the other. Both terminals ran off the same Datacraft computer. The second major advance was to reduce the loading time to the real time rate of the satellite transmission. This was done by ingesting the data directly onto digital disk in a navigated form. Three more digital disks were purchased making 40 megabytes available. A data interface box was made which takes the input digital data from the satellite receiver, converts the 6 bit visible data into 8 bit by left justification, converts the 9 bit IR data into 8 bit bytes by truncating the grid bit, averages the elements along a line to produce equivalent 1/2, 1, 1-1/2, 2, 3, and 4 mile resolution data, packs the data into 24 bit words and then presents the word to the computer for direct placement on the digital disk. This "byte mangler" interface box made possible the real time ingestion of data without placing much load on the computer. The computer is free to do other tasks such as loading the TV frames. A predictive navigation system was used for the ingestion. A single landmark data segment was ingested and placed on disk 8 times during the daylight hours (the landmark were designated by an operator), and a predictive navigation was put in the system for the

next 24 hours of ingestion. With the predictive navigation system, the "byte mangler," and the digital disk capacity, it was possible to ingest, align, and load the images during the time that the satellite was sending the images. When the satellite finished sending the images, the data was ready to use with no further preprocessing. The registration error due to misalignment averaged approximately 40 cm/sec for this predictive navigation process. The ingestion and loading processes were made easier for the operator by the addition of a macro expander to the system which made possible the initiation of a sequence of McIDAS commands. With a single 3 letter command, the operator could initiate the entire ingestion and loading sequence.

IV. AUGUST-SEPTEMBER 1975 OPERATIONS

A. Training of Operators

The Space Science Center did not have sufficient staff to man a 24 hr/day operation, so temporary help was hired to work as "wind getters" for the DST. Four shifts/day with 2 people per shift required a total of 12 operators working on a rotating shift basis. Ten new people were hired as operators for the DST. These new people were all meteorologists with at least a BS degree. Some were graduate students and others were recent Wisconsin graduates still located in the Madison area. While all the new people had good meteorological backgrounds, none had any experience with satellite meteorology or cloud tracking. Two training courses were conducted. One group had two weeks of training on McIDAS operation, satellite meteorology, cloud tracking, McIDAS hardware and software construction, and practice "wind getting." From this group of people, team leaders, were selected for the DST. The second group was trained for one week in McIDAS operation, satellite meteorology, cloud tracking, and

practice wind getting. Because of the push to get the new hardware working on the McIDAS, the practice wind getting sessions were minimal especially for the second group, but all the operators were able to pick up sufficient knowledge to track clouds proficiently. The operators were instructed to make measurements which would describe the meteorology of the situation with as many levels as possible. The operators were given general guidelines of what to track and what not to track, but no hard and fast "style" was imposed on the operators. They were instructed to use their own judgement as to what would produce the best results for a given situation.

B. DST Operations

The DST cloud tracking operations used equivalent 3 mi resolution data with the earth divided into 12 sectors. Fig. 1 shows the approximate coverage of each sector. One operator produced winds on sectors 1-7 and the other operator worked on sectors 8-12. The northern hemisphere sectors were displaced slightly south of the equator so that the ITCZ would be in the center of the TV screen, making it easier for the operator to determine the flow into and out of the ITCZ. The data were ingested in four swaths with sectors 1, 2, 3 being in swath 1, etc. There is a slight gap in the data between swaths. The ingestion program was changed during the DST so that when one swath finished, the next would start up without losing data between swaths. There was a gap between swaths 3 and 4 for the entire DST. This was caused by the loss of one digital disk platter during the DST, which restricted room to only 450 lines of swath 4 on the disk, rather than the normal 500.

The operating schedule for each shift started with the ingestion of the satellite data onto the disk. There was an overlap of shifts so that

DAY	DATE	WIND TIME	NUMBER OF WINDS	TOTAL FOR SHIFT	TOTAL FOR BIN	BIN	COMMENTS
260	Sept. 17	07:30 Z	857	857	857	B	
260	Sept. 17	14:00	1055	1055	1055	C	
260	Sept. 17	20:00	1053	1053	1053	D	
261	Sept. 18	01:45	411				
261	Sept. 18	02:00	584	995	995	A	
261	Sept. 18	08:00	0	0	0	B	equipment down
261	Sept. 18	14:00	0	0	0	C	equipment down
261	Sept. 18	20:45	1637	1637	1637	D	
262	Sept. 19	01:45	485				
262	Sept. 19	02:00	79	564	564	A	wrote over tape
262	Sept. 19	08:00	485				
262	Sept. 19	08:00	134				
262	Sept. 19	08:15	37	656	656	B	
262	Sept. 19	14:00	901	901	901	C	
262	Sept. 19	20:00	1040	1040	1040	D	
263	Sept. 20	01:45	487				
263	Sept. 20	02:00	150	637	637	A	
263	Sept. 20	08:00	722	722	722	B	
263	Sept. 20	13:45	635	635	635	C	
263	Sept. 20	20:00	1027				
263	Sept. 20	20:30	375				
263	Sept. 20	20:15	371	1773	1773	D	20:15 set improperly flagged; they were not transmitted
264	Sept. 21	02:00	617				
264	Sept. 21	01:45	672	1289	1289	A	
264	Sept. 21	07:30	933	933	933	B	
264	Sept. 21	14:00	1161	1161	1161	C	
264	Sept. 21	20:00	1511	1511	1511	D	

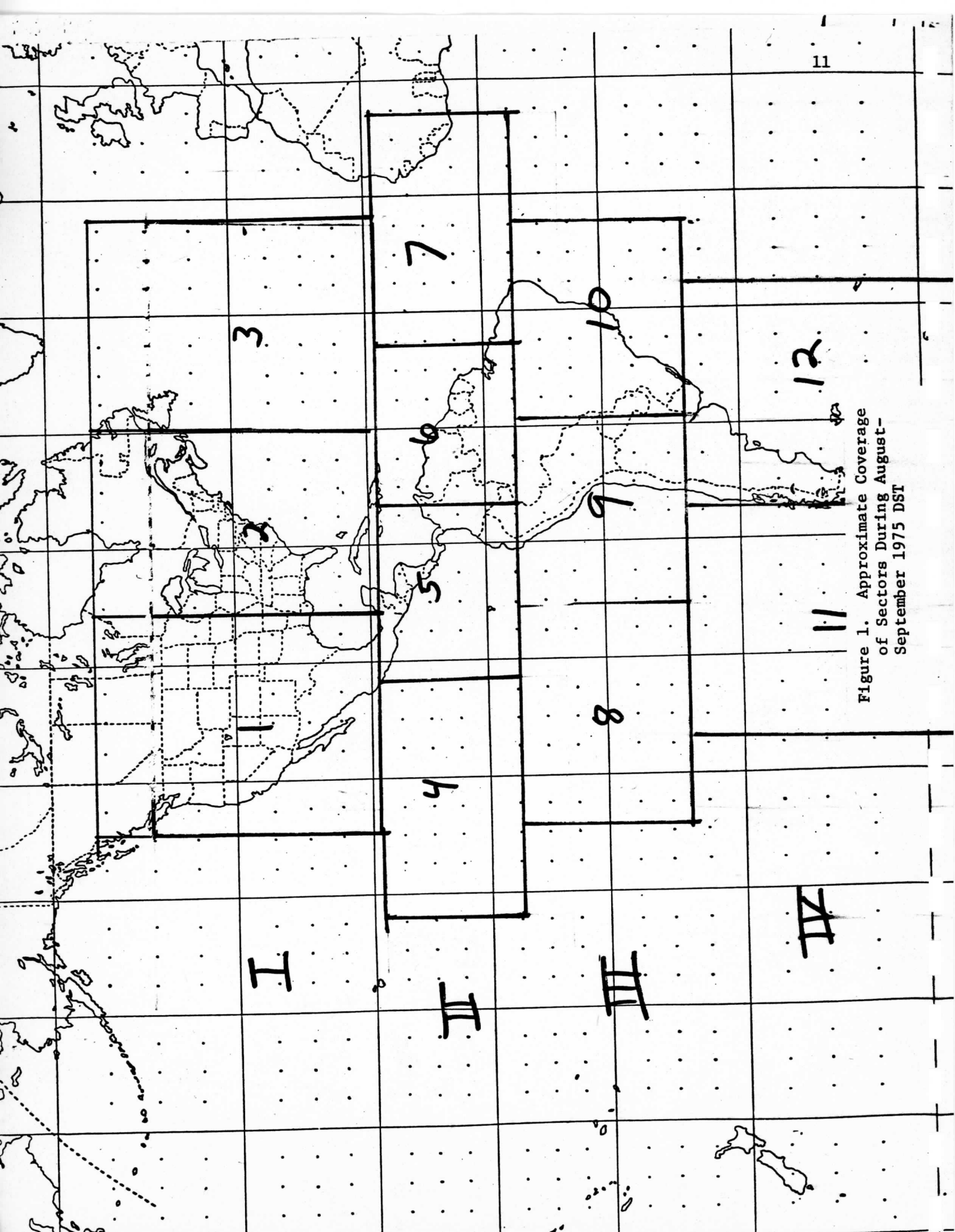


Figure 1. Approximate Coverage
of Sectors During August-
September 1975 DST

the old shift could give the new shift a synoptic briefing during the ingestion period. When data ingestion was finished, the operator with 7 sectors would start to work measuring winds. The operator with only 5 sectors to do would send off the winds measured by the previous shift to GISS. This operator would also collect the landmark images during daytime operations.

Three images were ingested for each shift. The cloud displacement was measured twice using the two picture pairs. Any correlation measurements made between the two picture pairs which did not agree within 5 m/sec for either the u or v component were flagged in error. The heights of the clouds were generally manually assigned. The operator would ask the computer the height of a cloud field being tracked, and would then assign that height to the entire field. This had the effect of speeding up the computations because the height calculation did not have to be done on every vector. However, it forced all the data in a cloud field to a particular level. In previous DST data sets there was some variability of height within a cloud field. How much of this was due to natural variations in cloud heights within the field, and how much was due to deficiencies in the cloud height algorithm is not known because the ground truth verification of the cloud height algorithm has not been completed yet.

The normal operation was to use 3 images. However if one of the images had problems, then only one picture pair was used. This fall back mode placed more responsibility on the operator for the quality control of the wind vectors because the only automatic QC check which was available was the correlation maximum on the boundary check (correlation could not find the cloud).

Appendix 1 lists the days, times, and number of winds produced during the August-September DST. Figs. 2, 3, and 4 show a typical wind set. This data was from 25 August, 2000 Z.

V. AREAS WHICH COULD USE IMPROVEMENT

The August-September 1975 DST was very successful in terms of operational gathering of large numbers of wind vectors from cloud motions. Over 4,000 vectors/day were gathered during the five week DST period. As Figs. 2, 3, and 4 show, there is a fairly good distribution of wind measurements. The McIDAS was able to perform in an operational environment in the production of the data sets. However all was not perfect, and there are several areas which still could be improved for operational use of the McIDAS for wind production.

One area is back up capability. During the DST we were able to weather two major failures without severely impacting our operations. The first failure was due to loss of one of the eight digital disk platters. The digital disks were delivered the week before the DST started, and were not operational until the day before the DST started. One of the disk platters still had a hardware error in it which was causing computer halts. This platter was disabled and we ran the DST with only 7 platters. This used up our reserve disk space and limited our flexibility in data collection, but we were still able to operate with the only real impact being a small gap of missing data in the southern hemisphere. The second major failure was the loss of one of the computer memory core cards. By rearranging the core cards we were able to gracefully degrade from 65K of core to 56K. With 65K we can run two wind programs plus other smaller programs such as the wind transmission to GISS, all at the same time

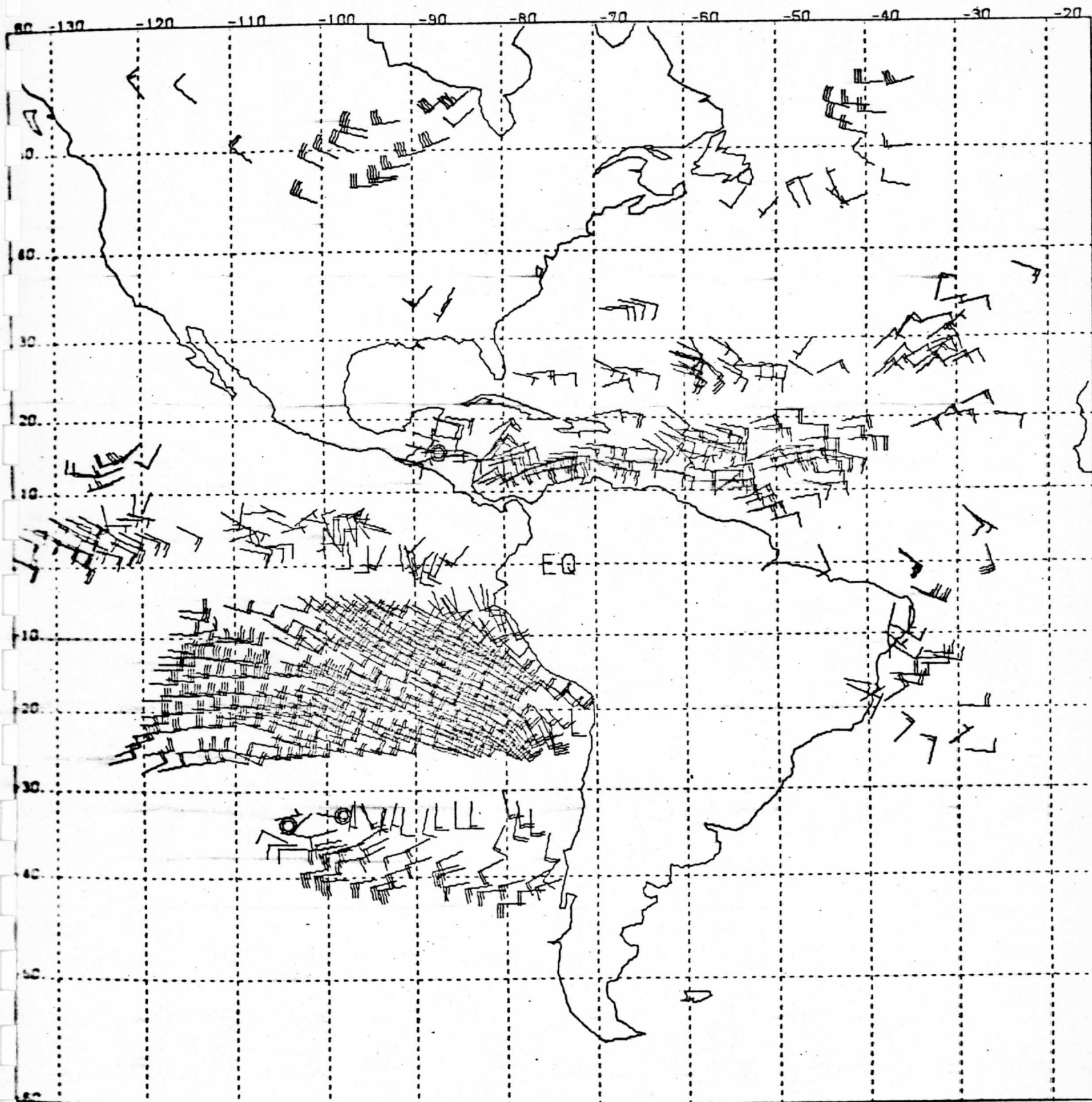


Figure 2. Low Level Winds (900-700 mb) for Aug. 25, 1975 at 20 Z. This is a typical example of the wind sets produced at Wisconsin during the Aug.-Sept. 1975 DST

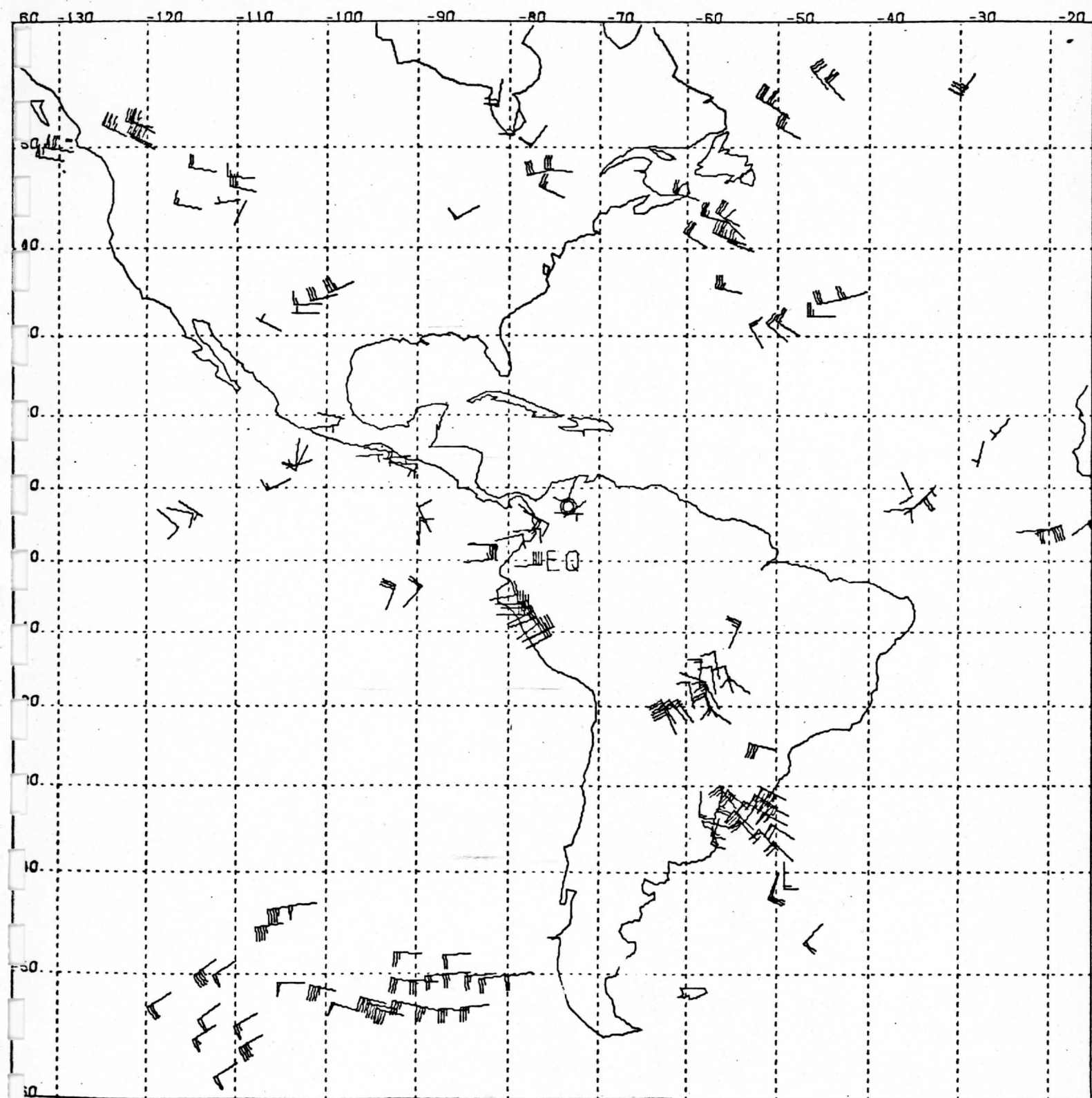


Figure 3. Mid Level Winds (600-400 mb) for Aug. 25, 1975 at 20 Z. This is a typical example of the wind sets produced at Wisconsin during the Aug.-Sept. 1975 DST.

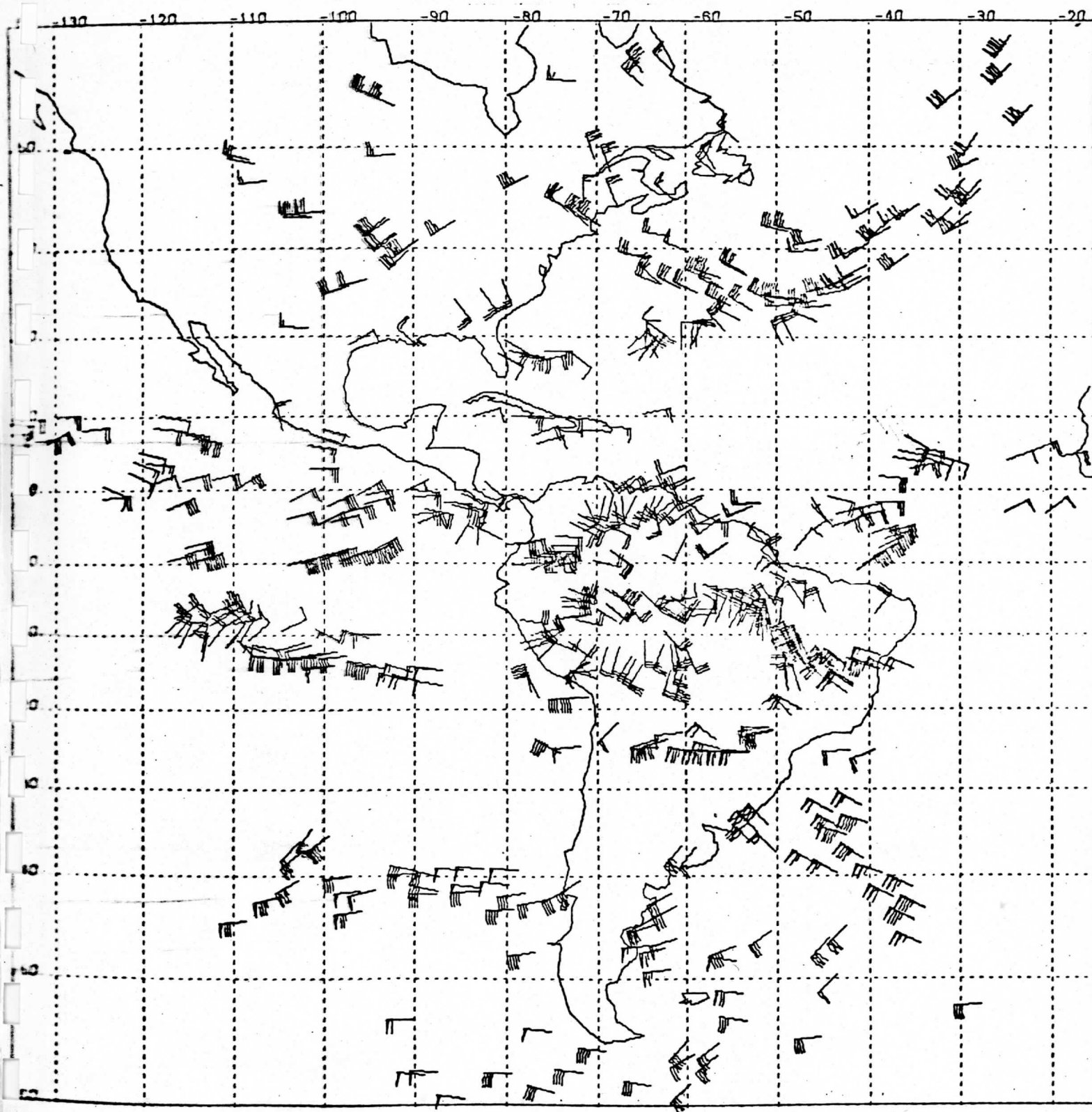


Figure 4. High Level Winds (300-200 mb) for Aug. 25, 1975 at 20 Z. This is a typical example of the wind sets produced at Wisconsin during the Aug.-Sept. 1975 DST.

without interference. With 56K of core, both wind programs would still fit, but the smaller programs would not. Consequently one of the operators had to stop measuring winds in order to transmit the winds to GISS. This was annoying. If we had lost any more computer or disk capacity, the DST operations would have halted. Having reserve capabilities is very important for any future operational use of the McIDAS. We did have a back up for the analog disk used for the TV refresh, but we did not have to use it during the DST.

During the DST there were seven full time periods when no data was processed. The last five of these took place during the end of the DST when three entire system regeneration operations were required. The cause of these failures was found during the last failure. The digital disk with programs on it had dirty heads. The system had been on a three month preventive maintenance schedule, but a shorter time between preventive maintenance was actually required.

The only other hardware failure was on 27 August when the power supply on the DMS satellite receiver was causing noise pulses which resulted in bad lines in the received image. Replacing the power supply cured the major problem of bad lines, but there were still some bad lines in the images. The SMS-1 has a very noisy signal. The full resolution data shows considerable salt and pepper in the images. When these noise bits happen during the line documentation, the entire line can be lost. On a typical image, there were at least four bad lines. This was annoying, though it did not seriously impact the cloud tracking. The problem however deserves investigation into how to improve the situation.

While there were relatively few failures in the cloud tracking operations

at the Univ. of Wisconsin, not all the winds produced reached their final destination at NMC. The Univ. of Wisconsin produced the winds, transmitted them to the NASA/GISS, who reformatted them and merged them with sounder data, and then transmitted them to NMC. Due to several problems along the way, not all the winds made it to the other end. One of the problems was outages on the 360/95 at GISS during some of the scheduled transmission times. The modem at GISS which was used to receive the Wisconsin winds was also used by Suitland. If we missed our regular transmission, then Suitland got the modem and we were further delayed. Often the collect bin at GISS was dumped before our wind set got in, resulting in a missed set for transmission to NESS. At the end of the DST, these missed sets were sent to NESS.

The actual operations of the wind set production was not perfect, and some days had more problems than others, resulting in an uneven distribution of the number of winds produced. One of the problems was computer halts, especially during the data ingestion periods. This would result in portions of an image being missed. The cause of the halts appears to be in the Datacraft operating software. An updated version of the operating software will be installed on the McIDAS after the DST completion, which should solve this problem.

Another problem was the operator waiting for the computer to complete wind calculations. The computer took approximately two seconds to calculate a wind vector, but the trained operator could generally select cloud tracers faster than that, except in difficult cloud fields. The bottleneck in the operations appears to be the time required to retrieve the digital data from the digital disks for the correlation computation. The IO access time could be improved by a new design of the disk controller, so that data from

the four disks could be collected in parallel rather than serially as is now done.

Other improvements which would aid the operational ability of the McIDAS to track clouds include off-line ingestion of the satellite data, improvements in the cloud height system by the addition of current synoptic data for the temperature to height conversion, quality control developments for single picture pair automatic QC, objective field analysis, and display of the entire wind field. The predictive navigation system also could use some refinements to try to remove some of the uncertainties associated with it. The August-September 1975 DST demonstrated the operational capability of the McIDAS, but further improvements could make it even better at operations.

APPENDIX I

Number of Winds Produced by Each Shift
During the August-September 1975 DST

This appendix lists the number of winds produced by each shift. The day is the Julian date. The wind time is the time attached to each wind. For some shifts, there are two or more times of winds, for example on August 18 there are winds for 02:15 and 02:30 Z. These two winds sets were transmitted separately to GISS. The sum of the wind sets produced by each shift is listed under the total for shift column. Generally the total for the shift is the same as the total for the bin collection at GISS. However if the Wisconsin wind sets were an hour or more late, such as August 19, 21:00 Z, the data was shifted at GISS into the next bin.

DAY	DATE	WIND TIME	NUMBER OF WINDS	TOTAL FOR SHIFT	TOTAL FOR BIN	BIN	COMMENTS
228	Aug. 16	14:00 Z	429	429	429	C	
228	Aug. 16	20:30	1014	1014	1014	D	
229	Aug. 17	02:30	589	589	589	A	
229	Aug. 17	08:00	1029	1029	1029	B	
229	Aug. 17	14:00	858	858	858	C	
229	Aug. 17	20:30	843	843	843	D	
230	Aug. 18	02:15	255				
230	Aug. 18	02:30	733	1028	1028	A	765 good 773 sent
230	Aug. 18	08:30	1002	1002	1002	B	813 good 1002 sent
230	Aug. 18	14:00	1058	1058	1058	C	
230	Aug. 18	19:45	260				
230	Aug. 18	20:00	1039	1299	1299	D	
231	Aug. 19	02:00	927				
231	Aug. 19	02:00	139	1066	1066	A	
231	Aug. 19	08:00	170				
231	Aug. 19	08:00	1050	1220	1220	B	
231	Aug. 19	14:00	929	929	929	C	
231	Aug. 19	21:00	649	649	0	D	
232	Aug. 20	02:00	963	963	1612	A	
232	Aug. 20	08:15	525	525	525	B	
232	Aug. 20	13:45	585				
232	Aug. 20	14:00	467	1052	1052	C	
232	Aug. 20	19:45	1148	1148	1148	D	
233	Aug. 21	02:00	964	964	964	A	
233	Aug. 21	07:45	145				
233	Aug. 21	08:00	908	1053	1053	B	
233	Aug. 21	14:00	779	779	779	C	
233	Aug. 21	20:00	817	817	817	D	
234	Aug. 22	02:00	1071	1071	1071	A	
234	Aug. 22	08:00	1036	1036	1036	B	
234	Aug. 22	14:00	619				
234	Aug. 22	14:30	249	868	868	C	
234	Aug. 22	20:00	642				not transmitted in time
234	Aug. 22	20:30	197	839	839	D	

DAY	DATE	WIND TIME	NUMBER OF WINDS	TOTAL FOR SHIFT	TOTAL FOR BIN	BIN	COMMENTS
235	Aug. 23	02:00 Z	871	871	871	A	
235	Aug. 23	08:00	6	6	6	B	wrote over tape
235	Aug. 23	14:30	675	675	675	C	
235	Aug. 23	20:00	1119	1119	1119	D	
236	Aug. 24	02:30	984	984	984	A	
236	Aug. 24	08:00	828	828	828	B	
236	Aug. 24	14:00	723				
236	Aug. 24	14:15	163	886	886	C	
236	Aug. 24	20:00	1188	1188	1188	D	
237	Aug. 25	02:00	1339	1339	1339	A	
237	Aug. 25	08:00	1086	1086	1086	B	
237	Aug. 25	13:45	670				
237	Aug. 25	14:00	403	1073	1073	C	
237	Aug. 25	20:00	1475	1475	1475	D	
238	Aug. 26	02:00	675	675	675	A	
238	Aug. 26	08:00	781				
238	Aug. 26	08:15	260	1041	1041	B	
238	Aug. 26	14:30	609		609	C	
238	Aug. 26	15:00	210	819			
238	Aug. 26	21:00	1095	1095	210	D	
239	Aug. 27	02:00	0	0	1095	A	equipment failure
239	Aug. 27	08:00	1226	1226	1226	B	
239	Aug. 27	14:00	1154	1154	1154	C	
239	Aug. 27	20:00	1221	1221	1221	D	
240	Aug. 28	02:00	803	803	803	A	
240	Aug. 28	08:00	1263	1263	1263	B	
240	Aug. 28	14:00	1297	1297	1297	C	
240	Aug. 28	20:00	1360	1360	1360	D	
241	Aug. 29	02:00	766	766	766	A	
241	Aug. 29	08:00	1283	1283	1283	B	
241	Aug. 29	14:00	833	833	833	C	
241	Aug. 29	20:00	778				
241	Aug. 29	20:00	690	1468	1468	D	

DAY	DATE	WIND TIME	NUMBER OF WINDS	TOTAL FOR SHIFT	TOTAL FOR BIN	BIN	COMMENTS
242	Aug. 30	02:00 Z	605				
242	Aug. 30	02:30	517	1122	1122	A	
242	Aug. 30	08:00	1480	1480	1480	B	
242	Aug. 30	14:00	833	833	833	C	
242	Aug. 30	20:00	536				
242	Aug. 30	20:30	301	837	837	D	
243	Aug. 31	02:30	978	978	978	A	
243	Aug. 31	08:00	1655	1655	1655	B	
243	Aug. 31	13:45	35				
243	Aug. 31	14:00	415				
243	Aug. 31	14:30	375	825	825	C	
243	Aug. 31	20:00	1157	1157	1157	D	
244	Sept. 1	02:00	1206	1206	1206	A	
244	Sept. 1	08:00	758	758	758	B	
244	Sept. 1	14:00	771				
244	Sept. 1	13:45	149	920	920	C	
244	Sept. 1	20:00	1056	1056	1056	D	
245	Sept. 2	02:00	1253	1253	1253	A	
245	Sept. 2	08:00	720	720	720	B	
245	Sept. 2	14:00	1139	1139	1139	C	
245	Sept. 2	20:00	951				
245	Sept. 2	20:00	164	1115	1115	D	
246	Sept. 3	02:00	829	829	829	A	
246	Sept. 3	07:45	213				
246	Sept. 3	08:00	646	859	859	B	
246	Sept. 3	15:00	783				
246	Sept. 3	15:15	244	1027	0	C	
246	Sept. 3	20:15	1861	1861	2888	D	
247	Sept. 4	02:00	1101	1101	1101	A	
247	Sept. 4	08:00	362				
247	Sept. 4	08:30	388	750	750	B	
247	Sept. 4	14:00	897				
247	Sept. 4	14:30	347	1244	1244	C	
247	Sept. 4	19:45	151				
247	Sept. 4	20:00	565				
247	Sept. 4	20:30	475	1191	1191	D	

DAY	DATE	WIND TIME	NUMBER OF WINDS	TOTAL FOR SHIFT	TOTAL FOR BIN	BIN	COMMENTS
248	Sept. 5	02:00 Z	1212	1212	1212	A	
248	Sept. 5	08:00	810				
248	Sept. 5	08:30	193	1003	1003	B	
248	Sept. 5	13:45	118				
248	Sept. 5	14:00	518				
248	Sept. 5	14:00	656	1292	1292	C	
248	Sept. 5	21:00	926	926	0	D	
249	Sept. 6	02:30	702	702	1628	A	
249	Sept. 6	08:30	1039	1039	1039	B	
249	Sept. 6	14:30	337		337	C	
249	Sept. 6	15:45	484	821			
249	Sept. 6	20:30	920	920	1404	D	
250	Sept. 7	02:00	338				
250	Sept. 7	02:30	596	934	934	A	
250	Sept. 7	08:00	1194	1194	1194	B	
250	Sept. 7	13:45	91				
250	Sept. 7	14:00	559	650	650	C	
250	Sept. 7	20:00	831				
250	Sept. 7	19:45	397	1228	1228	D	
251	Sept. 8	02:00	911	911	911	A	
251	Sept. 8	08:00	1353	1353	1353	B	
251	Sept. 8	14:00	834	834	834	C	
251	Sept. 8	20:00	565				
251	Sept. 8	20:00	535	1100	1100	D	
252	Sept. 9	02:00	945	945	945	A	
252	Sept. 9	08:00	1101				
252	Sept. 9	08:00	235	1336	1336	B	
252	Sept. 9	14:00	714				
252	Sept. 9	14:15	53	767	767	C	
252	Sept. 9	20:00	1078				
252	Sept. 9	20:00	88	1166	1166	D	
253	Sept. 10	02:00	48				
253	Sept. 10	02:15	896				
253	Sept. 10	02:30	248	1192	1192	A	

DAY	DATE	WIND TIME	NUMBER OF WINDS	TOTAL FOR SHIFT	TOTAL FOR BIN	BIN	COMMENTS
253	Sept. 10	08:00 Z	1116	1116	1116	B	
253	Sept. 10	14:00	1103	1103	1103	C	
253	Sept. 10	20:00	0	0	0	D	equipment down
254	Sept. 11	02:00	0	0	0	A	equipment down
254	Sept. 11	08:45	1497	1497	1497	B	
254	Sept. 11	14:00	1126	1126	1126	C	
254	Sept. 11	20:00	1196	1196	1196	D	
255	Sept. 12	02:00	765	765	765	A	
255	Sept. 12	08:00	470				
255	Sept. 12	07:45	1092	1562	1562	B	
255	Sept. 12	14:00	194				
255	Sept. 12	13:45	766	960	960	C	
255	Sept. 12	20:00	1026	1026	1026	D	
256	Sept. 13	02:00	945	945	945	A	
256	Sept. 13	10:00	674	674	0	B	
256	Sept. 13	14:00	1023	1023	1697	C	
256	Sept. 13	20:00	750	750	750	D	
257	Sept. 14	02:00	850	850	850	A	
257	Sept. 14	08:00	1176	1176	1176	B	
257	Sept. 14	14:00	780	780	780	C	
257	Sept. 14	20:00	824	824	824	D	
258	Sept. 15	02:00	924				
258	Sept. 15	01:45	148	1090	1090	A	
258	Sept. 15	08:00	365	365	365	B	equipment failed
258	Sept. 15	14:00	0	0	0	C	equipment down
258	Sept. 15	20:15	595				
258	Sept. 15	20:30	184	779	779	D	
259	Sept. 16	02:00	985	985	985	A	
259	Sept. 16	08:00	1117	1117	1117	B	
259	Sept. 16	13:45	214				
259	Sept. 16	14:00	886	1100	1100	C	
259	Sept. 16	20:00	1018	1018	1018	D	
260	Sept. 17	02:30	720				
260	Sept. 17	02:30	44	764	764	A	

26

ACKNOWLEDGMENTS

A great many people made this DST possible. Prof. V. E. Suomi first envisioned cloud tracked winds over a decade ago when he developed the spin scan camera. He has guided Wisconsin's cloud tracking program from its infancy into the operational system used for this DST. Tom Haig has provided the executive direction for many parts of the program. John Benson has developed much of the McIDAS system software and hardware design. John developed the concepts of real time ingestion used in this DST. Eric Smith developed much of the basic WINDCO software and Dennis Phillips developed the basic navigation software. Fred Mosher developed the height portion of WINDCO. Bruce Sawyer developed the software for the predictive navigation. J. T. Young and Gary Chatters did much of the predictive navigation design work. Ralph Dedecker developed the software for the instant display of the wind vectors on the WRRRMs. Eric Suomi developed the concepts which made the second terminal possible and provided engineering support for the McIDAS. Mike Becker provided maintenance and upkeep of the McIDAS. Much of the credit for the success of the DST goes to the operators who did the actual cloud tracking. They were Gary Chatters, Brian Auvine, John Stout, Bob Wise, Steve Kachelhoffer, Mike Fortune, Tony Schreiner, Eric Hennen, Wayne Kober, Carl Norton, Mike Pecnick, and John Stremikus. J. T. Young provided the training and acted as the navigator during the DST. Fred Mosher acted as the DST project manager. At GISS, Jim Edleman and Niel Ryan provided support in the transmission of the data. The DST was funded under NASA contract NAS5-23296 and NASA Grant NGR50-002-215.

PRELIMINARY ASSESSMENT OF THE CLOUD TRACKING SYSTEM
DEVELOPED AT THE UNIVERSITY OF WISCONSIN

Contributors:

David Suchman
David W. Martin
Frederick R. Mosher
Bruce Sawyer
Kenneth G. Bauer

29 April 1975

Space Science and Engineering Center
University of Wisconsin
Madison, Wisconsin

PRELIMINARY ASSESSMENT OF THE CLOUD TRACKING SYSTEM
DEVELOPED AT THE UNIVERSITY OF WISCONSIN

I. INTRODUCTION

One of the primary data requirements for the GARP program is accurate wind measurements on a global basis, including the ocean areas. Since conventional data sources, such as rawinsondes, are not feasible for many areas, alternative wind measurement systems are being developed for the GARP program. The cloud tracking system developed at the University of Wisconsin's Space Science and Engineering Center (SSEC) is an experimental system aimed at developing the hardware and software components which could be applied to an operational system for GARP's requirements. Since the cloud tracking system at Wisconsin is experimental, the system is in a constant state of flux. As problems or deficiencies are noted, the system is changed to remove these deficiencies. Hence, any assessment of the quality of derived wind vectors from this system is soon out of date. The assessment which will be attempted in this report will be based on data taken in the early spring of 1975.

This report will be structured into several sections. The introduction will contain a brief description of the cloud tracking system. A brief explanation of possible sources of errors, and what has been done to present to try to minimize these errors will be included in the introduction. The next section will contain a report by Dave Martin and Dave Suchman on their analysis of winds produced for the GATE period. This will include an analysis of the variability caused by different operators and a comparison of cloud tracked winds with other GATE measurement systems. The next section will be a report by Fred Mosher and Bruce Sawyer on the comparison of cloud tracked winds derived from visible images with rawinsonde data. This section will

29

will also show the comparison of rawinsonde vs. rawinsonde to show the variability present in the "reference" system. The next section will be a report by Ken Bauer on the comparison of cloud motion winds produced by infrared images with radiosonde measured winds. The final section of this report will be a summary and conclusion.

A. Cloud Tracking System Description

Wind sets are generated on SSEC's Man-Computer Interactive Data Access System (McIDAS). This is an image storage, display, and processing system consisting of data archive, data access, video display, operator console, and computer control sections (Figure 1). Central to the system is a minicomputer which controls the display section, operator console, and computer peripherals. Archive data enter the system via a slant track recorder or a nine track tape drive. They are loaded on a digital disk, then are reformatted by the computer into standard analog TV format and are transferred to an analog video disk. This analog signal feeds an enhancement unit capable of almost any conceivable manipulation of signal level. These output signals drive the guns in the color TV monitor on which the image is displayed. The operator commands the computer through a keyboard using a special language requiring no knowledge of programming. He designates subsets of the display image with a joy stick controlled cursor, invokes programs for processing the designated data, then at his option can store the results, view them on the CRT or color TV, or transfer them through the tape drive to magnetic tape or through the line printer to paper. All processing is done on the original digital data.

Control of this hardware and execution of the scientist's commands

are achieved through a body of special software. Through this software it is possible by simple key-ins to enhance an image, magnify it, combine adjacent images into loops of any length, vary loop speed by up to a factor of 30, navigate pictures, locate and track clouds in TV, image, or earth coordinates, and display the results as a vector plot superimposed on the original image. Two independent heads on the analog disk allow double looping of infrared and visible images, with instant single key transfer from one to the other, or interlacing of the two images.

Tracking may be done by either of two primary methods: cursor tracking of the cloud to the nearest TV line and element (pixel tracking), and image match tracking of the cloud to better than TV line-element resolution (correlation tracking). Pixel tracking has been facilitated by the addition of a function called the velocity cursor. The operator positions a cursor over the cloud to be tracked using a joy stick. The velocity cursor function then automatically displaces the cursor from one picture to the next according to the position of a second joy stick. The displacement is linear within the TV line-element coordinate system, and constant from one picture to the next. The velocity cursor can be used by itself for single pixel tracking, or it can be used in conjunction with the correlation tracking. Correlation tracking requires the operator to roughly track the cloud by placing the cloud within a box for each picture in a set. The computer then performs a correlation analysis to align the brightness field and "fine tune" the operator's tracking. Correlation tracking is the most accurate, but it requires well-defined clouds moving in a single layer flow pattern. Single pixel tracking using the velocity cursor can be invoked by the operator for tracking clouds in multi-layer flow patterns, or for matching the motion of the cursor to the motion of a pattern if individual

clouds cannot be tracked.

The heights of the clouds are determined using both the visible and infrared data. The visible data is used to determine the emissivity of the cloud. The infrared black body temperature data is then corrected for emissivity to determine the cloud top temperature. Standard atmosphere soundings corrected for latitude and data are then used to determine the height of the cloud. For cloud tracking using only infrared data where there is no emissivity data, the black body temperature of the cloud is used. The cloud height function can be requested independently of the wind calculation if desired by the operator, or it can be invoked automatically by the wind computation. The operator can also specify the height if desired.

Quality control can be applied to the derived wind measurements in several ways. The measurement can be made twice using three images. Wind measurements which do not agree within an operator set residual criteria are flagged to be in error. The height measurement can also be made twice if the infrared data is also available for both wind measurements. Clouds tracked prior to late spring 1975 generally had only one height measurement and no height quality control. Clouds tracked now do have height quality control. Other quality control routines available include the best match occurrence on the matrix boundary. If during correlation, the best match of the two images occurs on the boundary of the data matrix, the data is flagged. This check is routinely used for all correlation computations. Other routines which are available, but are not routinely used, are the secondary peak comparison which performs a surface analysis of the match surface to insure a good match, and an image match surface comparison which checks the stability of the cloud target over more than one interval. A final quality

control check which is performed is the plotting of the derived wind vectors over the cloud pictures. Prior to late spring 1975 there was no height discrimination of the plotted vectors. The present system however displays up to four levels at once using different colors for vectors at different levels. The operator can mark any vectors he feels which are in error. At present there is no conventional data comparisons or large scale plots of wind vectors.

B. Possible Sources of Errors in Cloud Tracked Winds

There are many possible sources of errors in determining the wind by tracking clouds. Some of these possible sources are:

1. Navigation errors
2. Height computation error
3. Clouds not moving with speed of wind
4. Resolution errors
5. Operator errors

A discussion of these errors and what has been done at Wisconsin to try to minimize these errors follows:

1. Navigation Errors

If a geostationary satellite was in a "perfect" orbit, every picture taken could be overlayed on the others in a loop and the earth would not move. However, the SMS and the old ATS satellites are not in perfect orbits, so the earth moves in the frame. This false motion is due to the satellite's motion. Navigation is the process by which the satellite's motion is removed from the cloud motion computation. There are several possible ways which this can be done. One is to manually or by computer correlation align the positions of landmarks. Another is to model the orbit and motions of the spacecraft in an

explicit type model. This has been the approach taken by Wisconsin. The "navigation" process can then convert any pixel in the image coordinate system into earth coordinates of latitude and longitude.

If there are any navigation errors causing false motions they will be systematic errors; thus, if a cloud displacement is measured between times T_1 and T_2 , and a second displacement is measured between T_2 and T_3 , navigation errors will produce a systematic difference between the two vectors calculated. Other types of errors generally are random, so if a large number of differences between T_1T_2 and T_2T_3 calculations are averaged, the resulting residual term will be due to the systematic navigation error. During the production of winds for the January 1975 DST, the residual for each day of the 6 Z (only infrared images) wind set was calculated. The average of the absolute values of the residuals was .135 m/sec for the u component of the wind and .102 m/sec for the v component. This corresponds to an average navigation error in the east-west direction of 243 meters between the two images taken 30 minutes apart, and 184 meters in the north-south direction. The visible pixel size is 1/2 mile or approximately 800 meters. The very largest residual was .38 m/sec in the u component which corresponds to a 685 m navigation error. Consequently the navigation errors and the misalignment of the images is much smaller than one visible pixel, even on infrared data which has a pixel four times as large as the visible.

2. Cloud Height Computation Errors

The variation of wind speed and direction with height can be quite large. Consequently the accurate determination of the height of the cloud being tracked is important. Since the determination of cloud height is difficult, this can be one of the largest sources of errors in the computation

of winds from cloud motions. There are several ways in which cloud heights can be determined. The operator looking at the visible cloud pictures can guess at cloud heights by identifying the cloud type, such as cirrus. In the absence of other height data, such as with the ATS images, the operator's assigned height has been shown to be good for two levels--high and low type clouds.

Another method of determining cloud heights is through the use of stereo projections from two satellites, or from a single polar orbit satellite looking ahead and behind. The height resolution is limited by the pixel size on the image, and the angular baseline displacement between the two satellites. Using this method the heights of clouds could be measured to 5 to 10 levels, but this technique has not been attempted yet in conjunction with a cloud tracking system.

Another method of determining cloud heights is using the cloud shadows, such as has been done to determine the heights of mountains on the moon. This method is limited by the resolution of the image, the knowledge of the height of the surface beneath the cloud, and the availability of shadows. This method could be used to check height determinations by other methods.

Still another method of getting cloud heights is to use the infrared sounder data to get the cloud heights. This is done on a routine basis during the inversion of satellite sounder data, but it has not been applied to any cloud tracking system. The resolution of this method is about 10 levels.

Finally, the cloud heights can be determined by use of the infrared temperature data. This is the method used by Wisconsin and most other cloud tracking systems. The infrared system uses the infrared temperature to determine the height of the cloud by use of a sounding of temperature with

height. The main problem with this method is that clouds are not necessarily black body radiators so that some of the energy reaching the sensor comes from lower down in the atmosphere, making the clouds appear warmer than they actually are. The cloud height system developed at Wisconsin uses the visible data to determine the optical thickness of the cloud. The optical thickness is then used to determine the infrared emissivity. The emissivity measurement and the fractional cloud cover measurement using the visible is then used to correct the black body temperature. If no visible data are available the height is computed assuming black body clouds. The accuracy of this emissivity cloud height determination has not been fully established, but it should be good to 10 levels. The largest sources of errors in this system appear to be the fractional cloud cover determination, and the variance in scattering caused by the finite shapes of clouds not accounted for by the multiple scattering model in the system.

Errors in the height computation can also be caused by several factors outside the basic limitations of the system. If there is thin cirrus (or "invisible" cirrus) over lower clouds, the system might track the motion of the lower cloud, but measure the height of the upper cloud, resulting in the motions of low clouds being assigned to the upper atmosphere. The reverse can happen when the system is operating in the single pixel velocity cursor mode. The motion is determined only by the operator's placement of the cursor. If the operator places the cursor over a hole in the cloud (he is tracking the motion of the hole in the cloud deck), the height system will measure the height of the lower surface, but the motion will be that of the upper atmosphere. Another source of error in the height computation can be caused by the fact that the system measures cloud top temperature. The momentum which is carrying the cloud along does not necessarily come from the

level of the top of the cloud. In the extreme case of a large convective cloud, the motion of the bright core is caused by the momentum of air from much lower down in the atmosphere.

The height of the tracked cloud probably has the largest of error of any of the parts of a cloud tracking system. To minimize this error we first brought the cloud's emissivity into the calculation of cloud height. During the October DST and during the processing of the 18 Z winds for the January DST, only one height computation was made with no checking at all on the height. However, plots of the vectors at different heights, and streamline analysis such as contained in the report by Paul Lemar and William Bonner on the "Comparisons Between NESS and Wisconsin Cloud Tracked Winds," have shown that some of the winds have been assigned at the wrong levels. In attempting to remedy this problem, several quality control steps have been put into effect. One is to plot the vectors over the cloud image in a color coded to height so that the operator can spot vectors which do not fit the flow at a level. Another is to compute the height twice, once at time T_1 and again at time T_2 . If the heights do not agree within a preset criteria, the vector is flagged as being in error. Another change to be attempted for the Fall 75 DST will be to make use of the optical thickness information generated by the visible data. Through parameterization, this can be converted to physical thickness data. The thickness of the clouds could then be subtracted from the height of the top of the cloud to determine the level of the momentum causing the cloud's motion.

3. Clouds Not Moving with the Speed of the Wind

Not all cloud motion discernible on a satellite picture movie loop is caused by the clouds drifting with the wind. Apparent motions can be caused

by growth and dissipation of cloud systems. Fujita et al. (1975) has shown that cloud type and size influence growth and dissipation stability which limits the accuracy of a cloud tracked wind measurement. Fog dissipating is another obvious example of "false" motion of clouds. Orographic effects such as mountains can also cause clouds to grow. The wind blows past the mountain, but the cloud stays over the mountain. Another serious problem in cloud tracking is gravity wave motions. Gravity waves which form on density discontinuities in the atmosphere do not move with the wind at that level, therefore, tracking clouds produced by the gravity waves may introduce large errors. Gravity waves can be a severe problem for cloud tracked winds in the vicinity of jet cores or strong inversions. Other motions of clouds which are not directly related to the wind can be caused by frontal and large scale wave propagation. The large scale motion of an upper air trough, and the weather associated with it, do not move with the same speed and direction as the wind. "Blind" tracking of these features will produce the velocity of the disturbance, not the velocity of the wind.

There are many features which should not be tracked to get good winds. The cloud tracking at Wisconsin is done only by trained meteorologists. After some initial attempts several years ago to train non-meteorologists (such as law students) to track clouds, it was determined that only highly trained meteorologists can consistently recognize the features which should not be tracked.

4. Resolution Errors

The time and spatial resolution of the image produce the ultimate limits on the accuracy of the cloud tracked winds. If data has a pixel size of two miles, and the images are taken every 30 minutes, the uncertainty of the

position of the cloud (if it does not change shape) would be two miles/ 30 min. = 4 mi/hr or 2 m/sec. Data with 3 mi resolution would have a limiting accuracy of approximately 3 m/sec, and 1/2 mi data of approximately .5 m/sec, if the cloud does not change shape. However, clouds do grow and decay. They are dynamic features which do not remain constant over time. ~~The smaller~~ the cloud, the faster the change in shape. Hence 1/2 mi data is not ideally suited for tracking clouds if the images are 30 minutes apart, because the tracers grow and decay too rapidly. Experience at Wisconsin has shown that a pixel size of 3 mi is compatible with 30 minute image intervals, 2 mi for 20 minute, and 1/2 mi for 5 minute intervals between images. At Wisconsin we try to match the pixel size to the image timing by averaging data.

5. Operator Errors

The final class of possible errors can be caused by the operator. The system developed at Wisconsin is fully under the operator's control and dependent upon the operator for successful data gathering. This is generally a very large advantage in that the human operator is very good at making decisions and judgement values. The computer in the McIDAS system is only an extension of the operator. If the operator does not try to produce a good wind set, the computer can not do it alone and the wind set will be bad. Hence, the effort at Wisconsin involves highly trained and motivated people.

References

Fujita, T., Edward W. Pearl, and William E. Shenk; "Satellite-Tracked Cumulus Velocities," Journal of Applied Meteorology, Vol. 14, No. 3, p. 407-413, April 1975.

II. GATE WIND SETS FROM SMS IMAGES--AN ASSESSMENT OF QUALITY

by David Suchman and David W. Martin

In support of the GARP Atlantic Tropical Experiment, SSEC is producing wind sets deduced from the motions of clouds in registered sequences of SMS images. Wind sets are of two types--high density, cluster (B/C) scale; and low density, wave (A) scale. Seven high density sets have been completed: three for 5 September, two for 10 September, and two for 18 September. (A low density set for 11 August is in production.) These wind sets offer three possibilities for testing tracer wind quality: (a) comparison of satellite winds with GATE ship or aircraft winds; (b) comparison of satellite winds with cloud features such as clusters, vortices, and clear areas; and (c) internal consistency of consecutive sets.

The philosophy of satellite wind verification has been discussed elsewhere. We note only that although direct comparisons of satellite winds with ground truth winds might seem most efficient in establishing satellite wind quality, it is rarely possible to achieve an adequate match in time, location, and altitude. This is especially true of GATE area comparisons, which, due to data availability, are presently limited to comparisons of satellite winds with ship and aircraft winds at the gradient level (500-600 m) and the 200 mb level.* The simplest comparison is visual--an overplot of ground based winds on the satellite wind field. Objective analysis of satellite fields would allow quantitative comparisons of u and v components; results from these comparisons are not yet available.

*Wind soundings for 12 Z on 10 September have recently been provided by Dr. David Rodenhuis. These give better altitude resolution, and are being used to measure u and v differences.

We can also learn much about the quality of satellite winds through a careful comparison of the dynamics of a field with major features represented in the clouds. Examples include the association of persisting centers of low level convergence with active cloud clusters, divergence with cloud free regions, positive vorticity with cloud bands and vortices. Finally, we can capitalize in the inertia of the atmosphere to assess quality through the persistence of larger scale features within independently produced consecutive wind fields. Changes which do occur should be closely coupled to changes in the patterns and positions of clouds.

Completed wind sets are presented as maps of vectors. These vector plots include available ship winds (when time and level differences are close enough to allow meaningful comparison). For one day (5 September) we also present grid point winds objectively analyzed from the satellite winds for one time period, and divergence and vorticity computed from the grid point winds. Except for a small group in the 18 September 1330 Z set, all winds were generated by the single pixel method, using a velocity cursor. Tracking employed visible images; however, infrared images were available for height determination. In all cases five (or more) registered frames were available for viewing; tracking was done on the middle three frames. Characteristics of individual sets are summarized in Table I. Visible and infrared picture pairs, one for each day, show the general distribution and organization of clouds.

Following the presentation and discussion of wind sets is a summary of an experiment designed to measure the human element in cloud selection and tracking. This reproducibility test is based on the 9 Z sequence for 5 September.

TABLE I
CHARACTERISTICS OF GATE WIND SETS

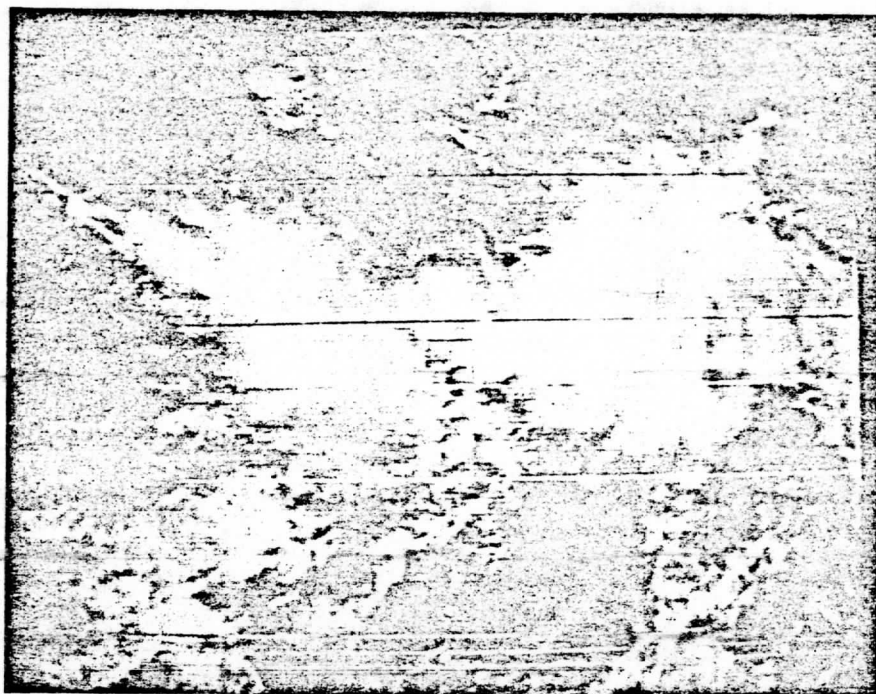
Day	Sequence	Image Interval (min)	Visible Image Resolution (km)	Load (lat)	Center (long)
5 Sept.	0830, 0900, 0930 Z	30	2	0830 N	2330 W
	1200, 1230, 1300 Z	30	2	0830 N	2330 W
	1430, 1500, 1530 Z	30	2	0830 N	2330 W
10 Sept.	1215, 1230, 1245 Z	15	1	1214 N	2314 W
	1215, 1230, 1245 Z	15	1	0830 N	2330 W
	1215, 1230, 1245 Z	15	1	0450 N	2335 W
	1445, 1500, 1515 Z	15	2	0830 N	2330 W
18 Sept.	1315, 1330, 1345	15	1	0925 N	2130 W
	1445, 1500, 1515	15	1	0925 N	2130 W

A. Wind Sets

September 5 (day 248) was one of the most convectively active days during the entire GATE period over the B-Array. A large, very active, nearly stationary well organized cluster (see Figure 1) dominated this area for much of the day. There were two distinct centers of activity associated with this cluster: one to the east that reached maturity early in the day and the one to the west that developed in the morning and began decaying by early afternoon. Although the flow characteristics were rather complicated, well defined convergence/divergence patterns were apparent. At low levels, the strong flow into the clusters in early morning (mainly from the northeast and southwest) gradually diminished as the day progressed, with the strongest inflow being in the western parts of the B-array late in the afternoon. The high level flow, initially from southeast to northwest over the northern region and northeast to southwest over the southern region, became dominated by the strong outflow from the two convective centers as the day progressed.

Figures 2 a-c and 3 a-c show the McIDAS derived cumulus and cirrus level cloud tracers for 0900 Z, 1230 Z and 1500 Z. At the time that these and the other wind sets presented in this report were produced, no information regarding the flow patterns or ground truth in the areas of interest was available. Ship sonde winds taken from recently released A-scale GATE surface and 200 mb maps at 12 Z compose the ground truth which is the basis for these comparisons. These sonde winds are plotted on Figures 2b and 3b with circles indicating the approximate ship positions.

The correspondences for low and high level winds in regions of both satellite and sonde observations appear to be good to within the usefulness of the soundings as a ground truth standard. Although low level satellite winds



1230 Z, 5 September 1974: Two times blow down of visible SMS-I photo centered on 8°30'N, 23°30'W.



1230 Z, 5 September 1974. Two times blow down of infrared SMS-I photo centered on 8°30'N, 23°30'W.

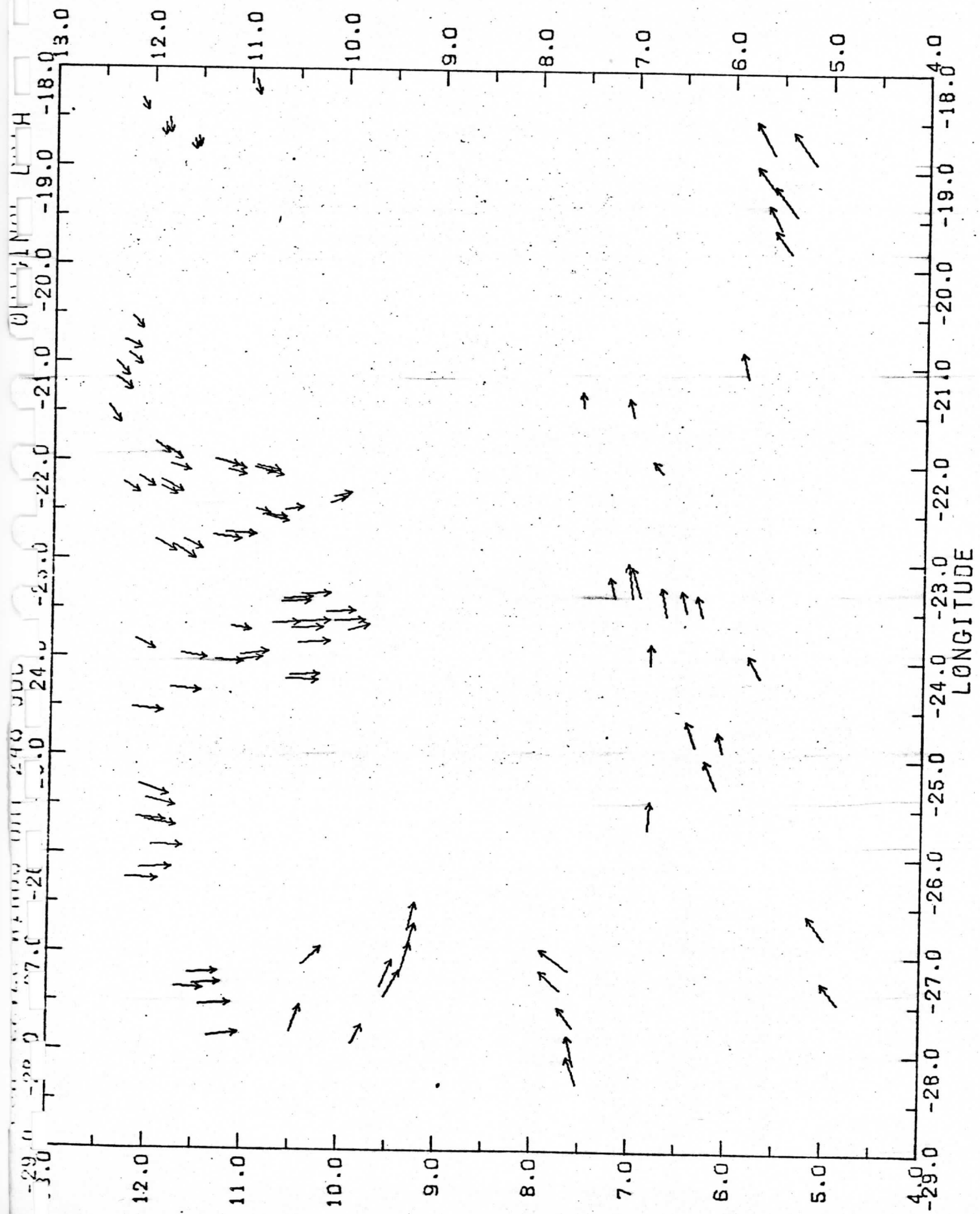


Figure 2a.

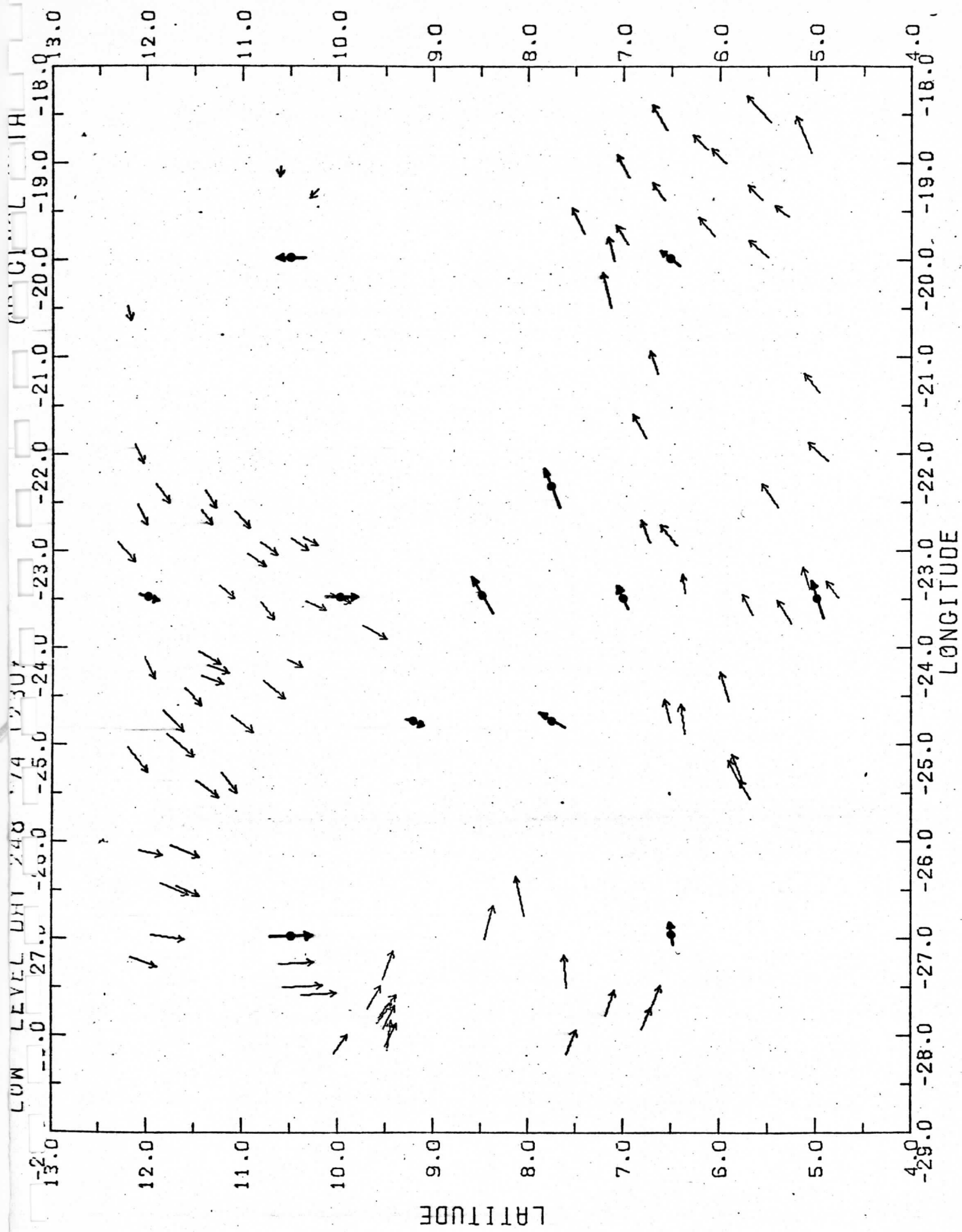


Figure 2b

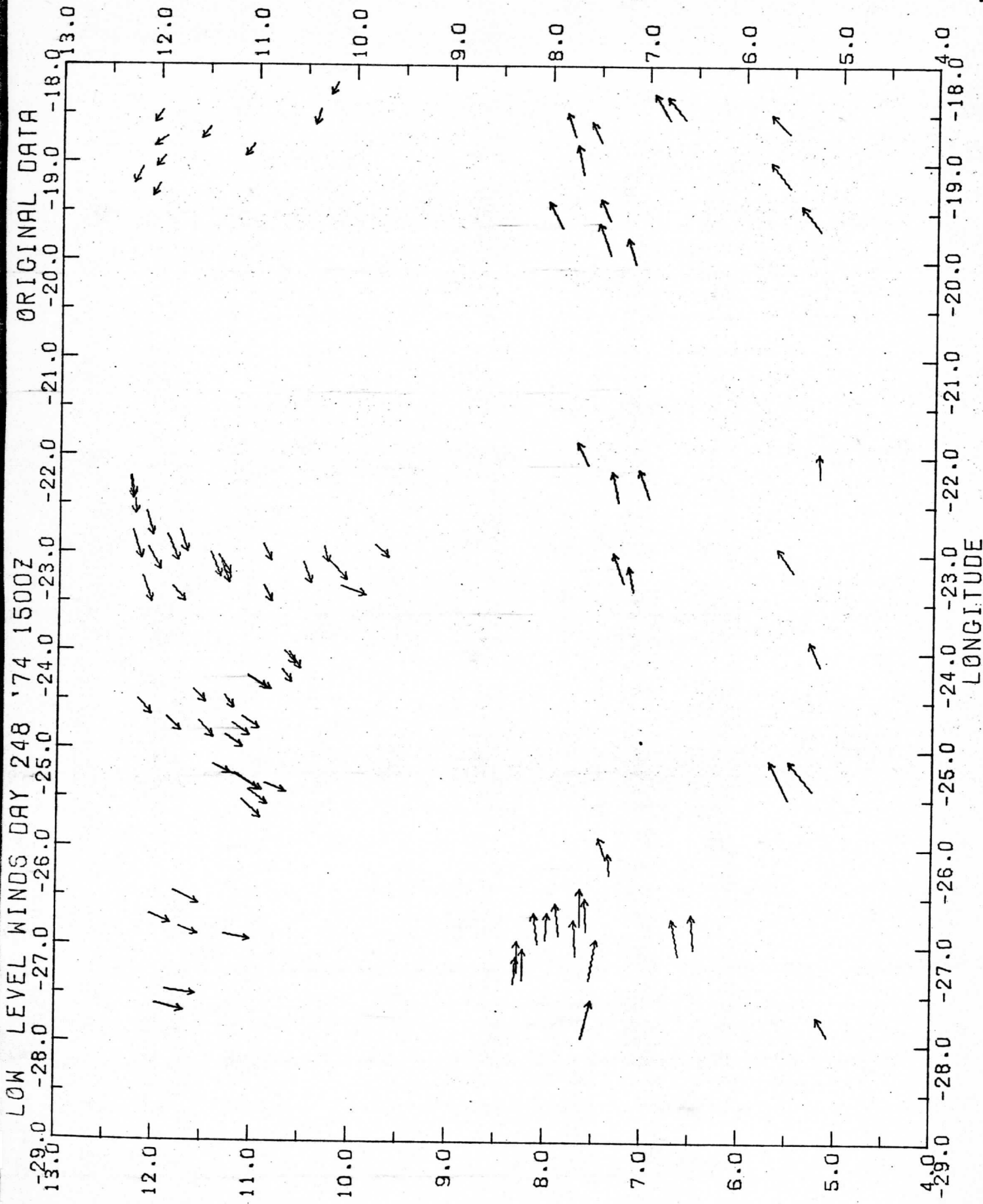


Figure 2c

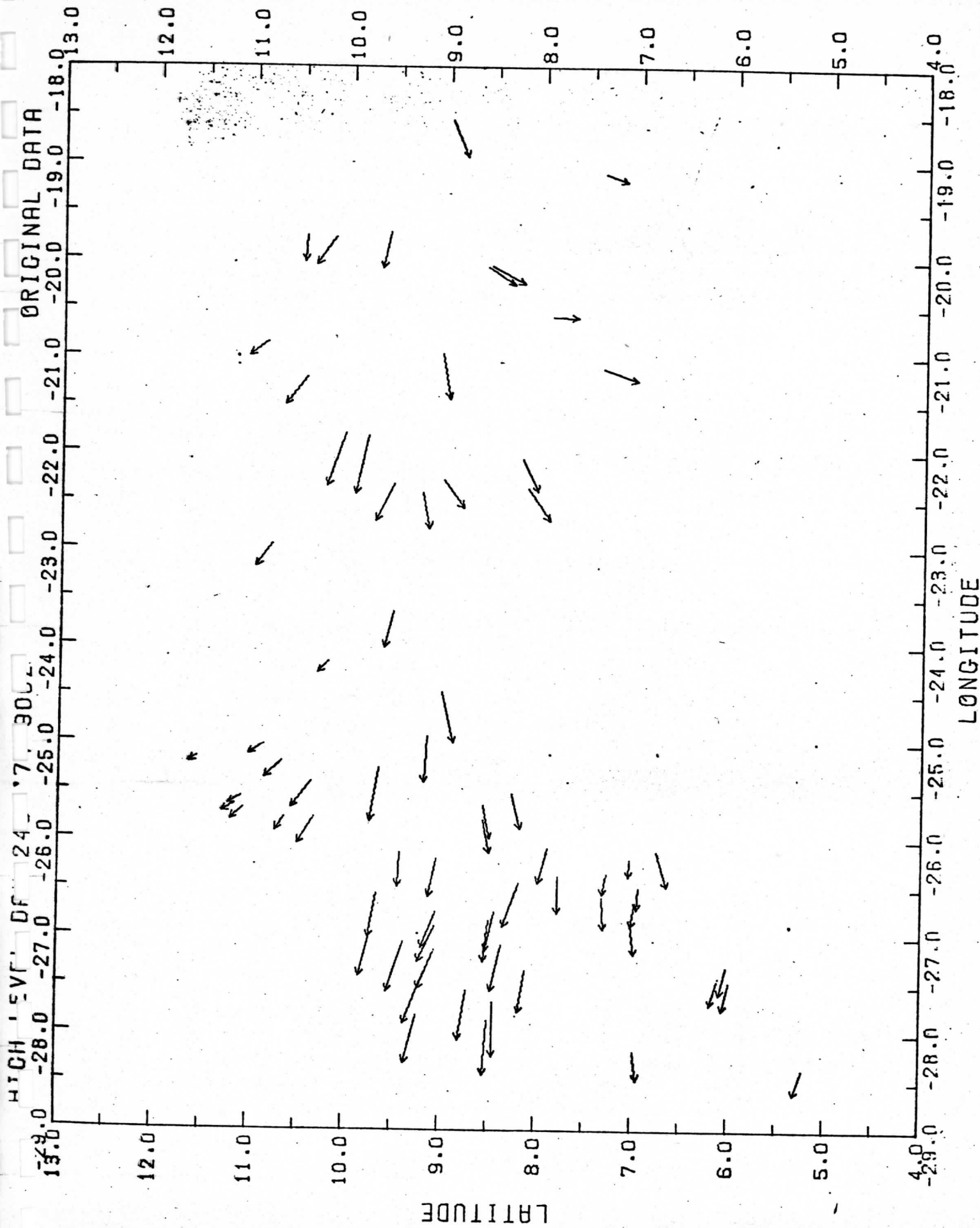


Figure 3a

HIGH LEVEL DRY 248 W 1230Z

GRIPING DPT

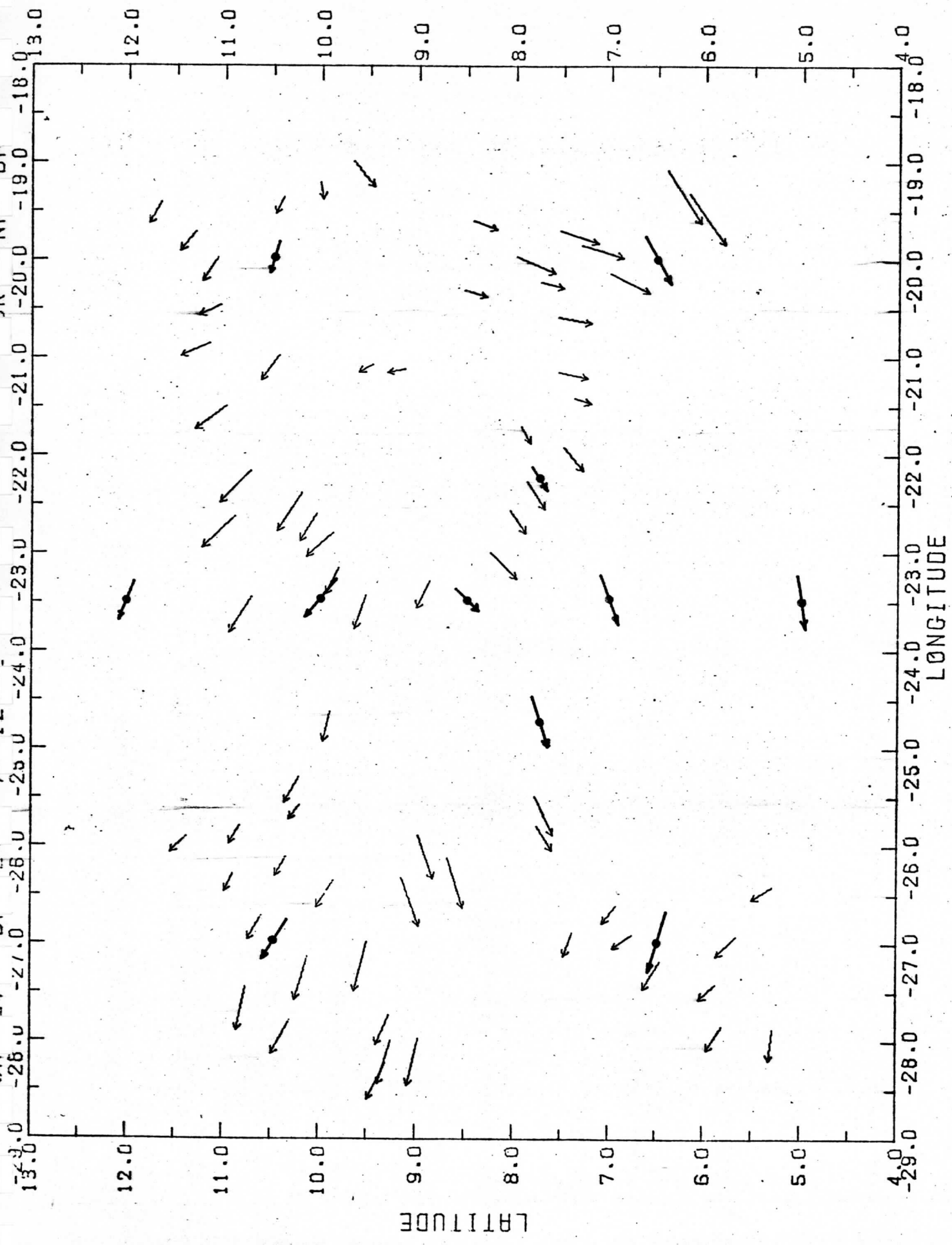


Figure 3b

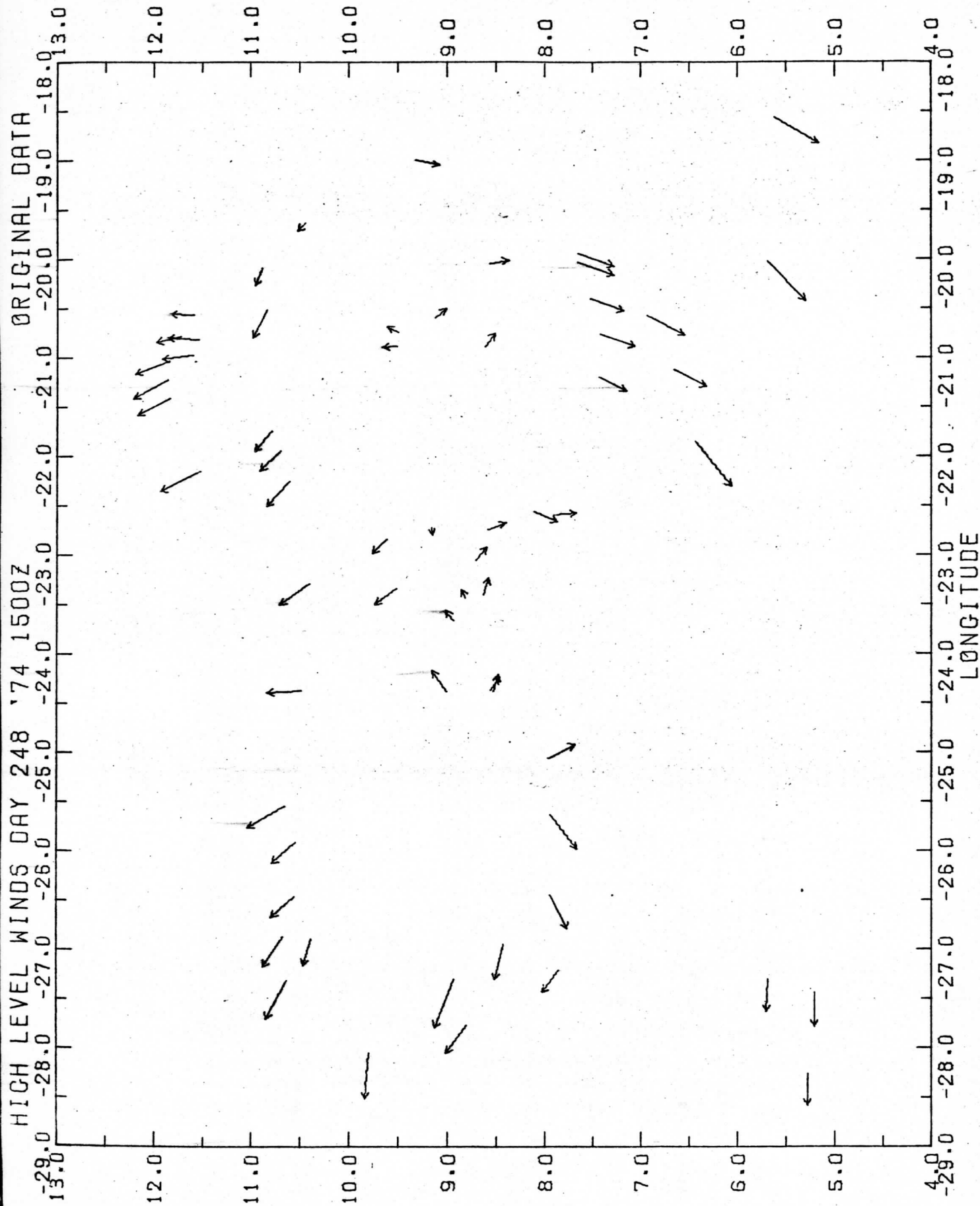


Figure 3c

are for about 950 mb; the differences between low level satellite and ship winds (Figure 2b) are so small, that most, if not all, of the differences could be accounted for by the half hour difference in measurement times, or sounding inaccuracies. The tendency for ship winds to exceed satellite winds in the southwestern part of the area at upper levels (Figure 3b) may be the result of lower layered cirrus associated with a small developing convective cell near 6°N , 27°W .

Figures 4a and 4b show the objectively analyzed grid point winds derived from the 9 Z cloud tracer field. At the cumulus level, two centers of convergence can be identified, corresponding to the two centers of convection: one at about 9°N , $20^{\circ}30'\text{W}$, and the other at 9°N , $25^{\circ}30'\text{W}$. At the cirrus level, strong divergence is evident corresponding to the eastern convective center, while no organized divergence pattern yet exists for the developing western center.

The evolution of both the low and high level divergence fields (derived from the grid-point winds) appears on Figures 5 a-c, 6 a-c while the 9 Z vorticity patterns are shown in Figures 7a and 7b. The heavy line on these figures denotes the limit of valid vorticity and divergence calculation as determined by the spatial coverage of the objectively analyzed wind field. The development of the western cluster is very clearly shown by the sequence of divergence maps: very strong low level convergence is found in the morning which gradually weakens as the day progresses—the high level divergence pattern shows a marked strengthening as the cell reaches maturity. Hence, the complete sequence of cloud tracer, divergence, and vorticity fields very clearly shows internal consistency (though these fields were not all produced by the same scientist), as well as consistency with the physical system they depict.

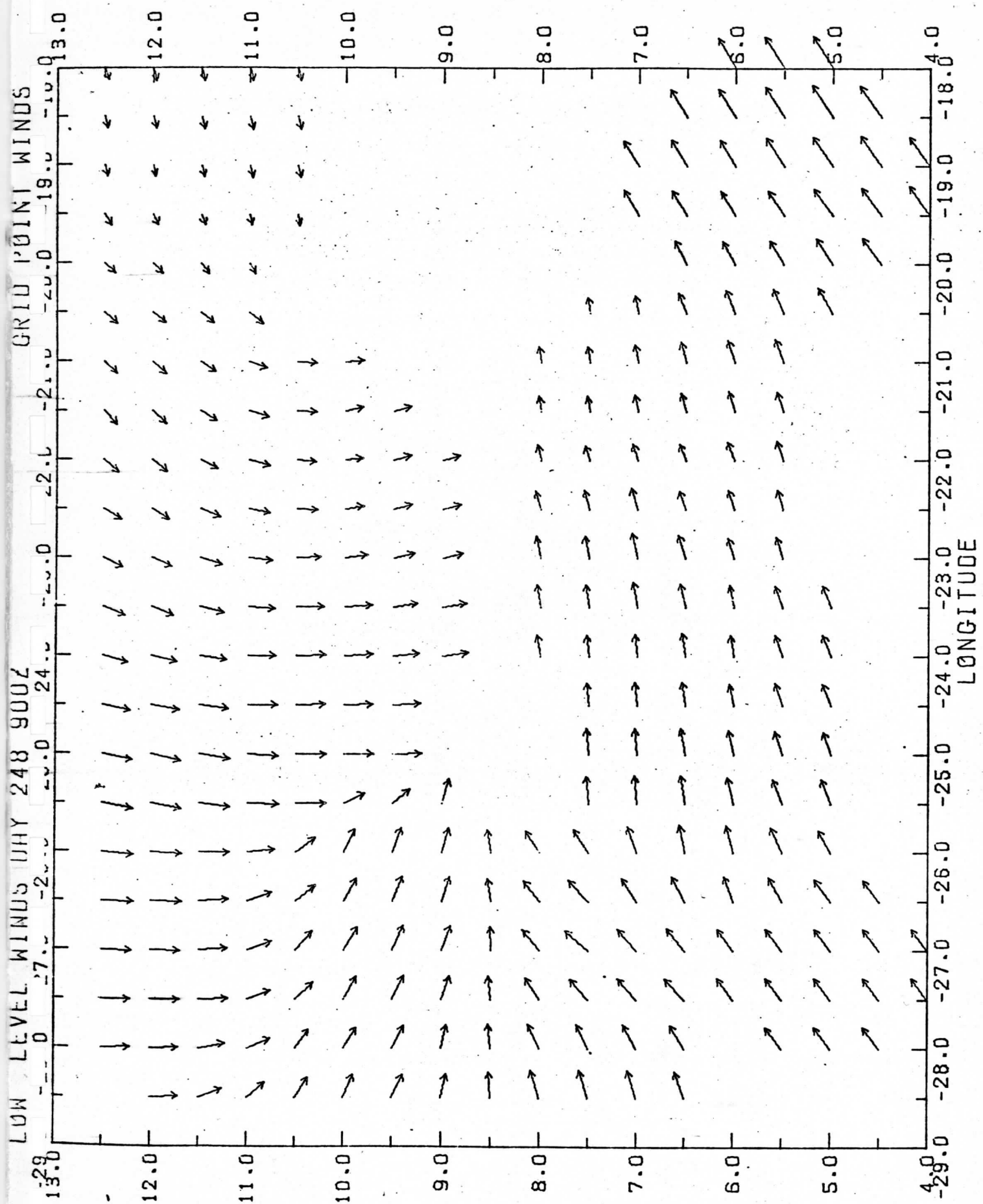


Figure 4a

HIGH LEVEL DAY 248 '74 900Z

GRID POINT WINDS

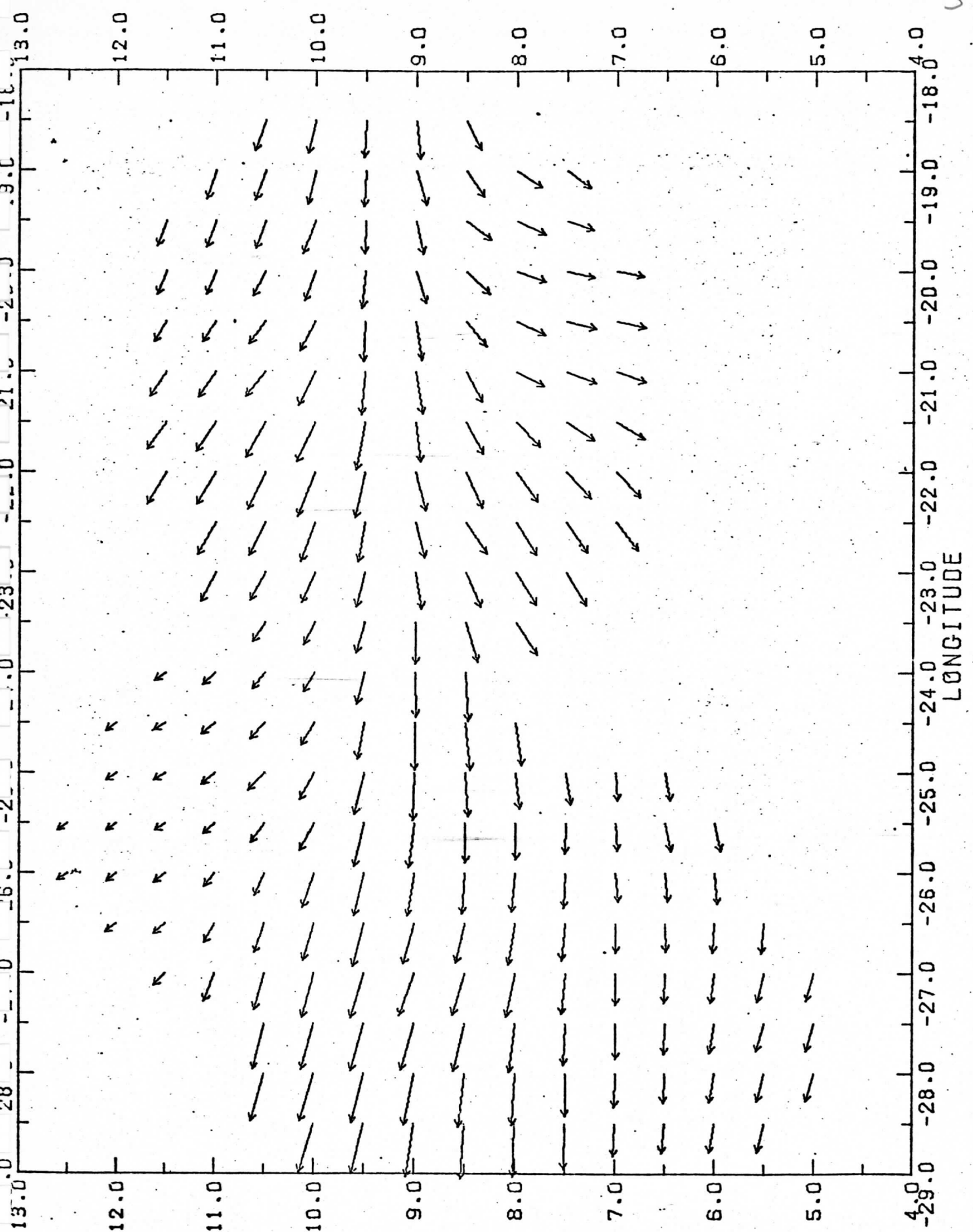


Figure 4b

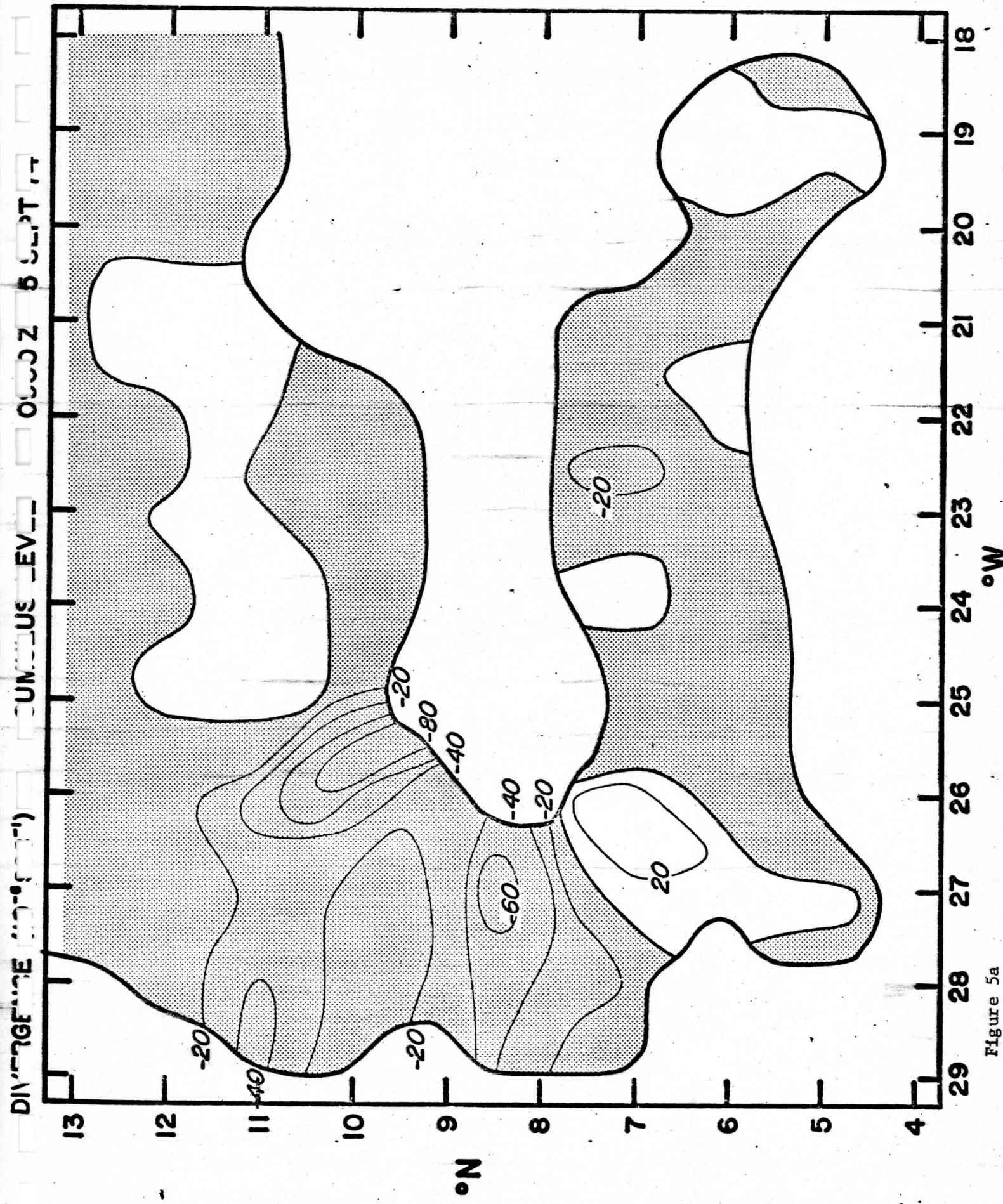


Figure 5a

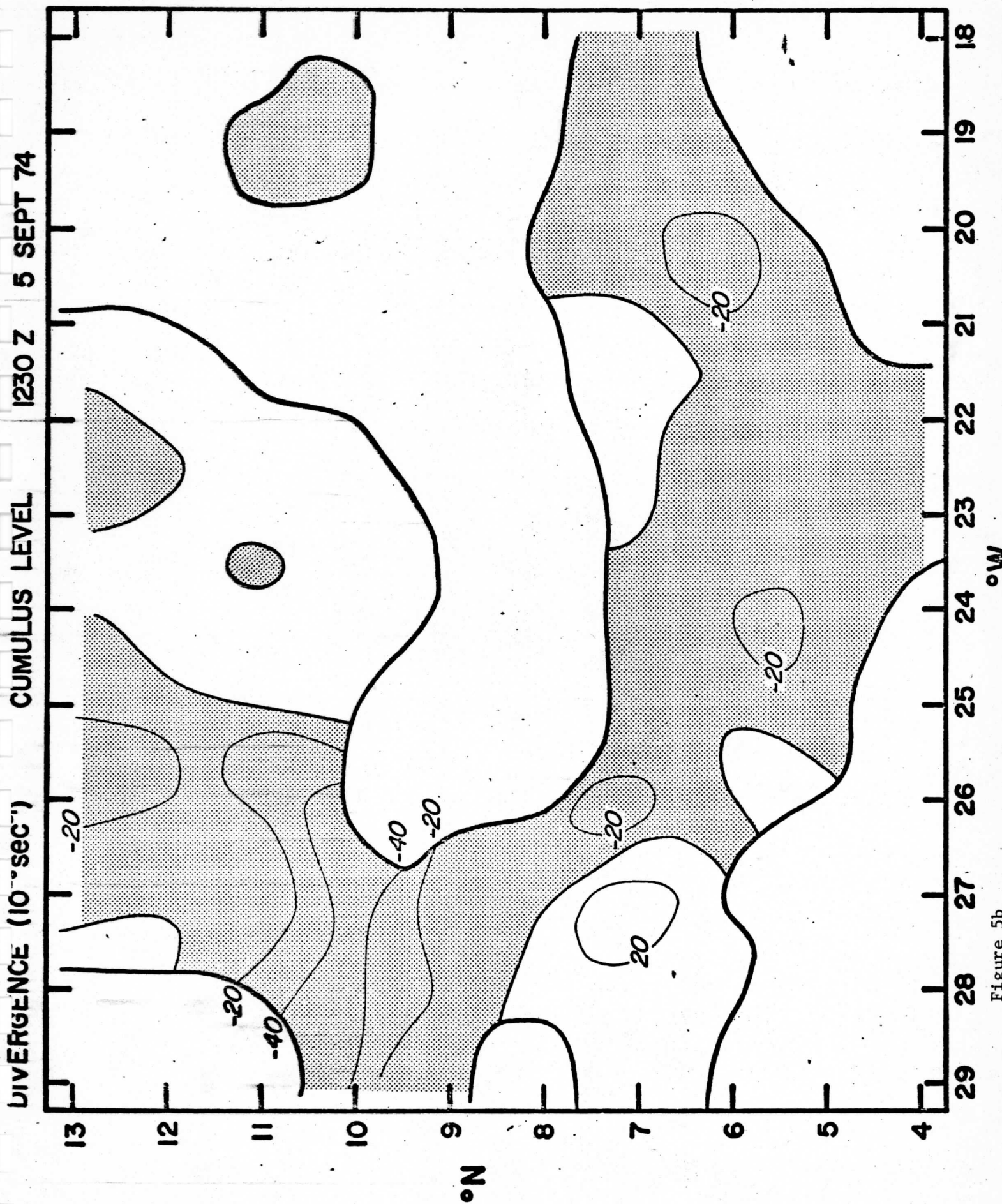


Figure 5b

DIVERGENCE (10⁻⁵ SEC⁻¹) CUMULUS LEVEL 1900Z 9 SEPT 74

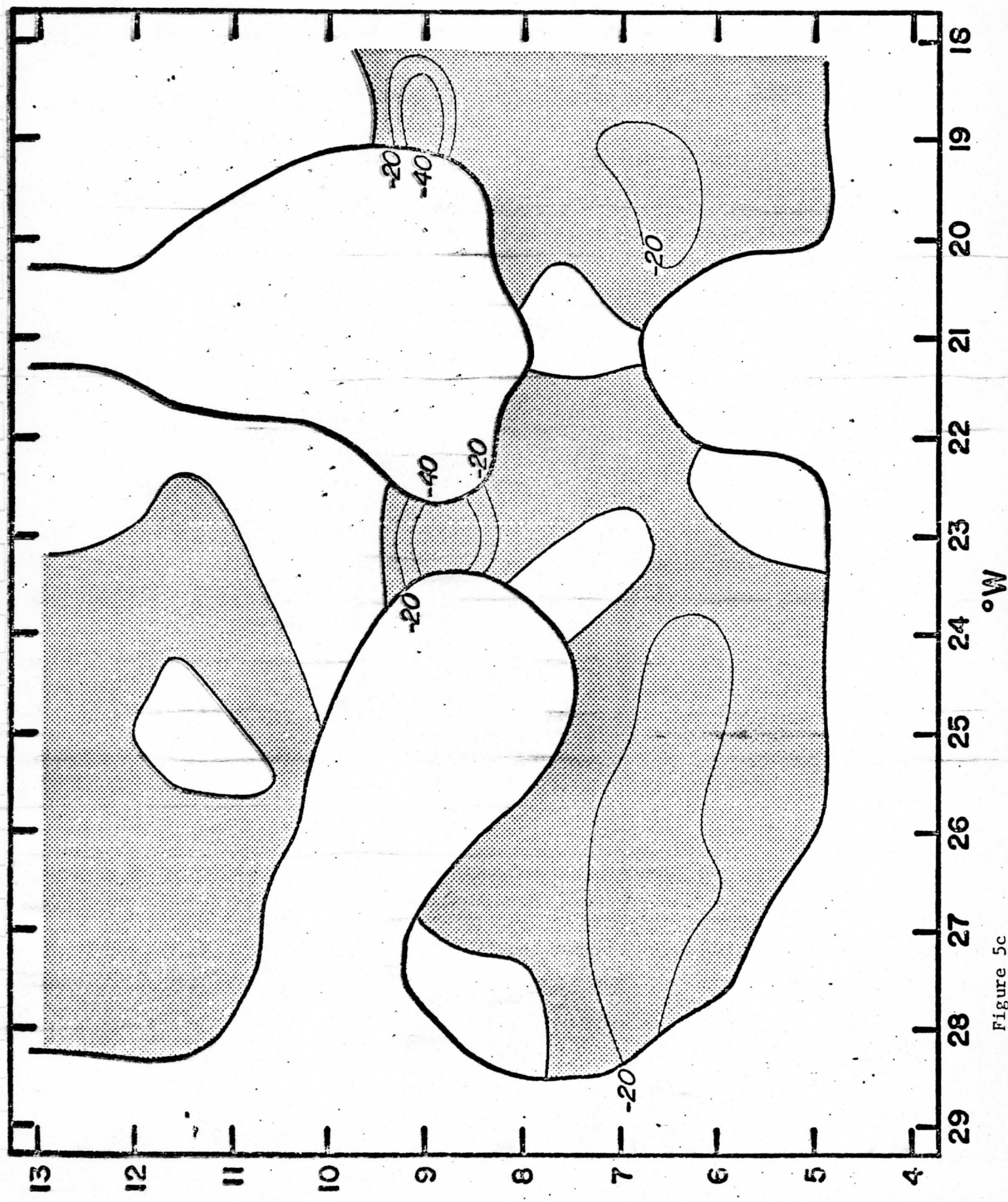


Figure 5c

DIVERGENCE (in 10^{-6} sec^{-1}) AIRRIS LEVEL 0900 Z 5 SEPT 74

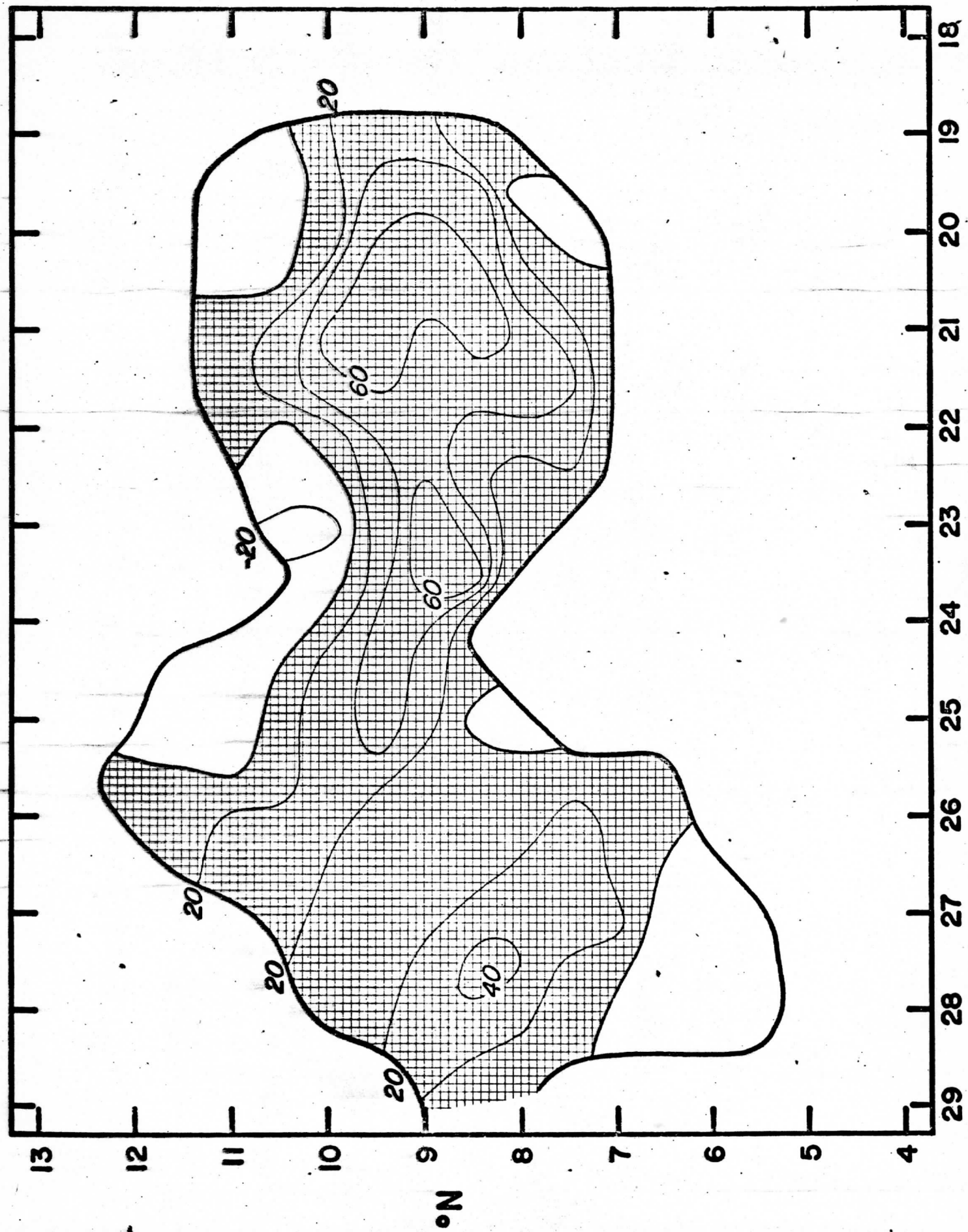


Figure 6a

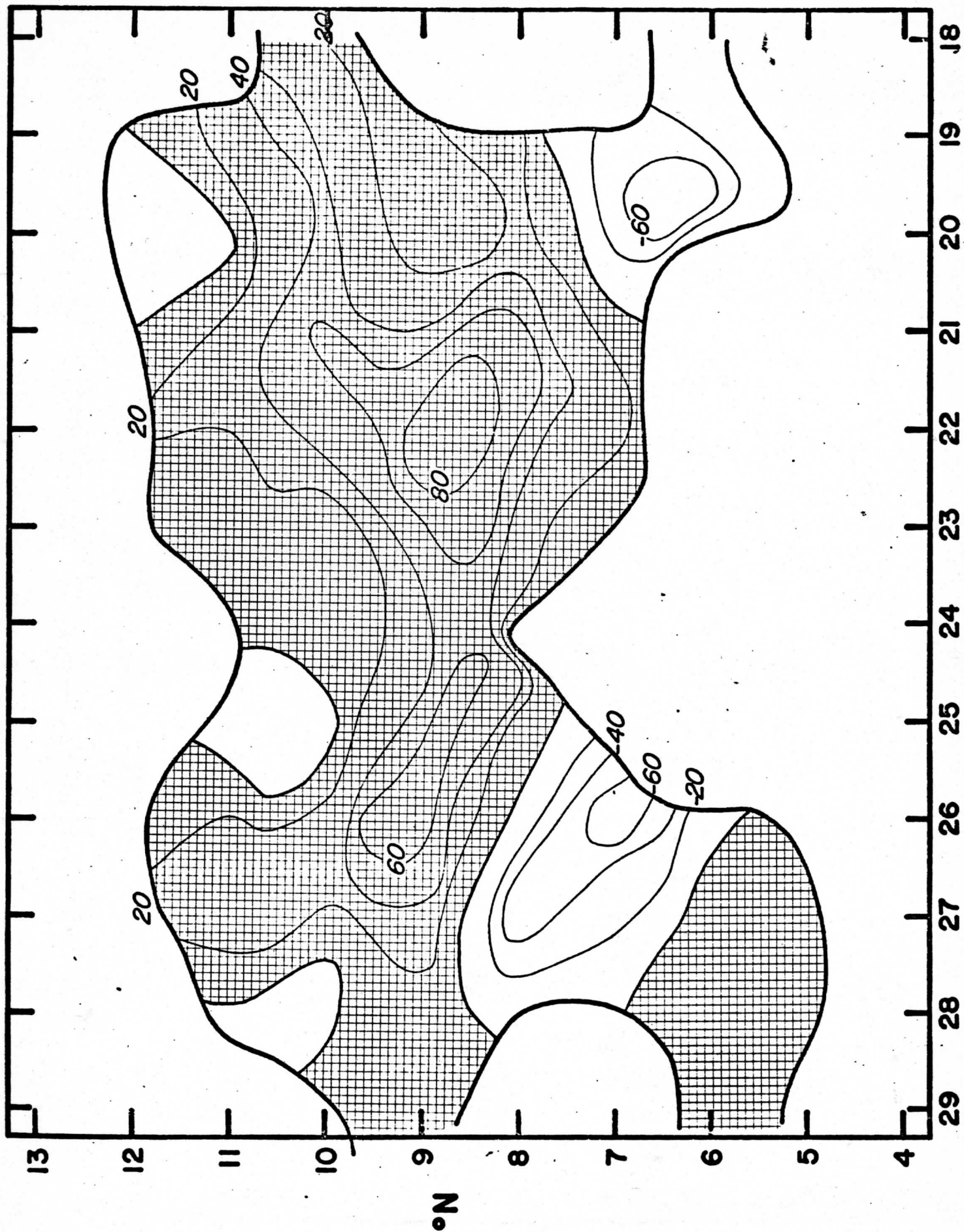


Figure 6b

DIVERGENCE (10⁻⁵ SEC) CIRRUS LEVEL 15002 3EF 74

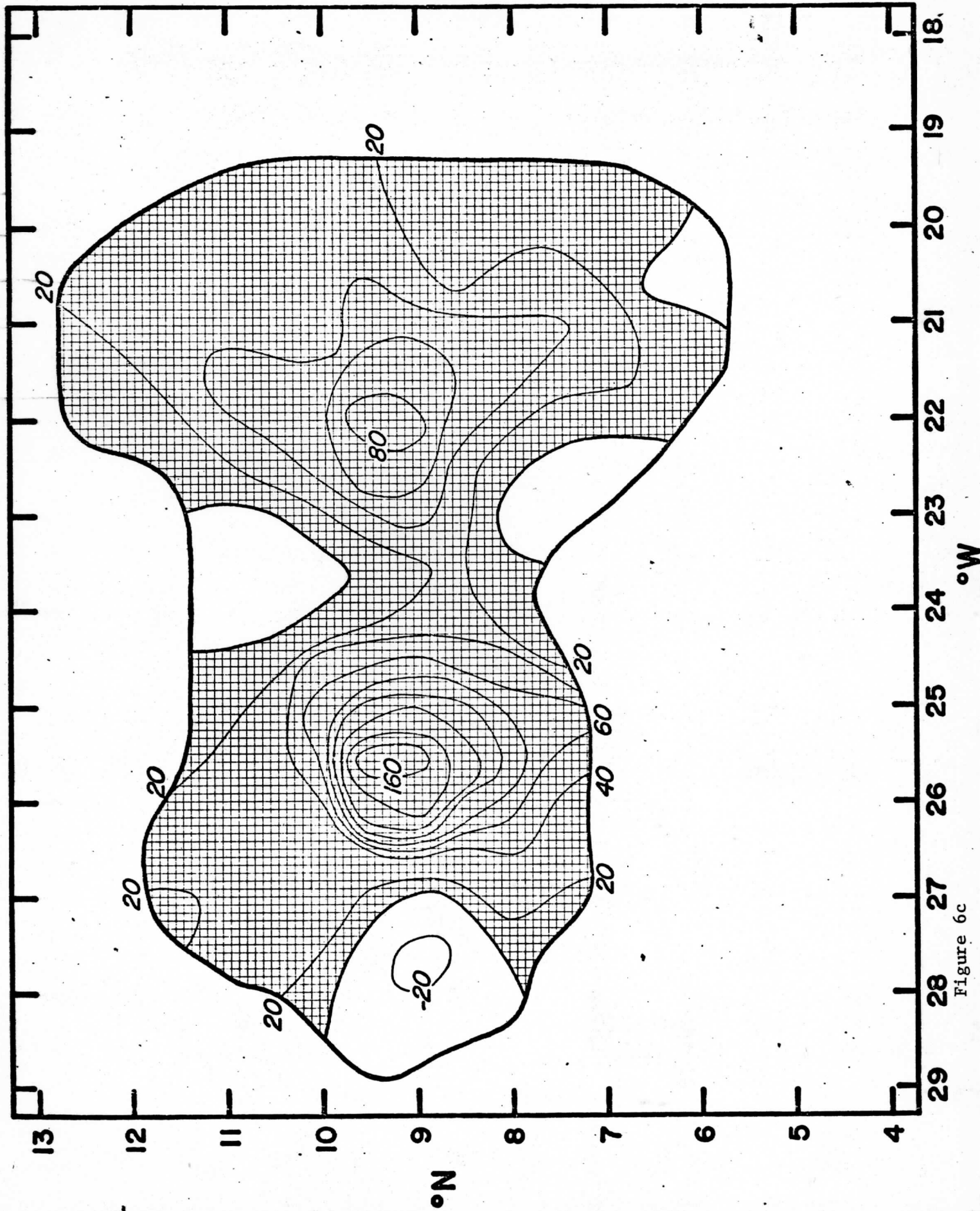


Figure 6c

RELATIVE VORTICITY (10^{-6} sec^{-1}) CUMULUS LEVEL 0900Z 15 SEPT 74

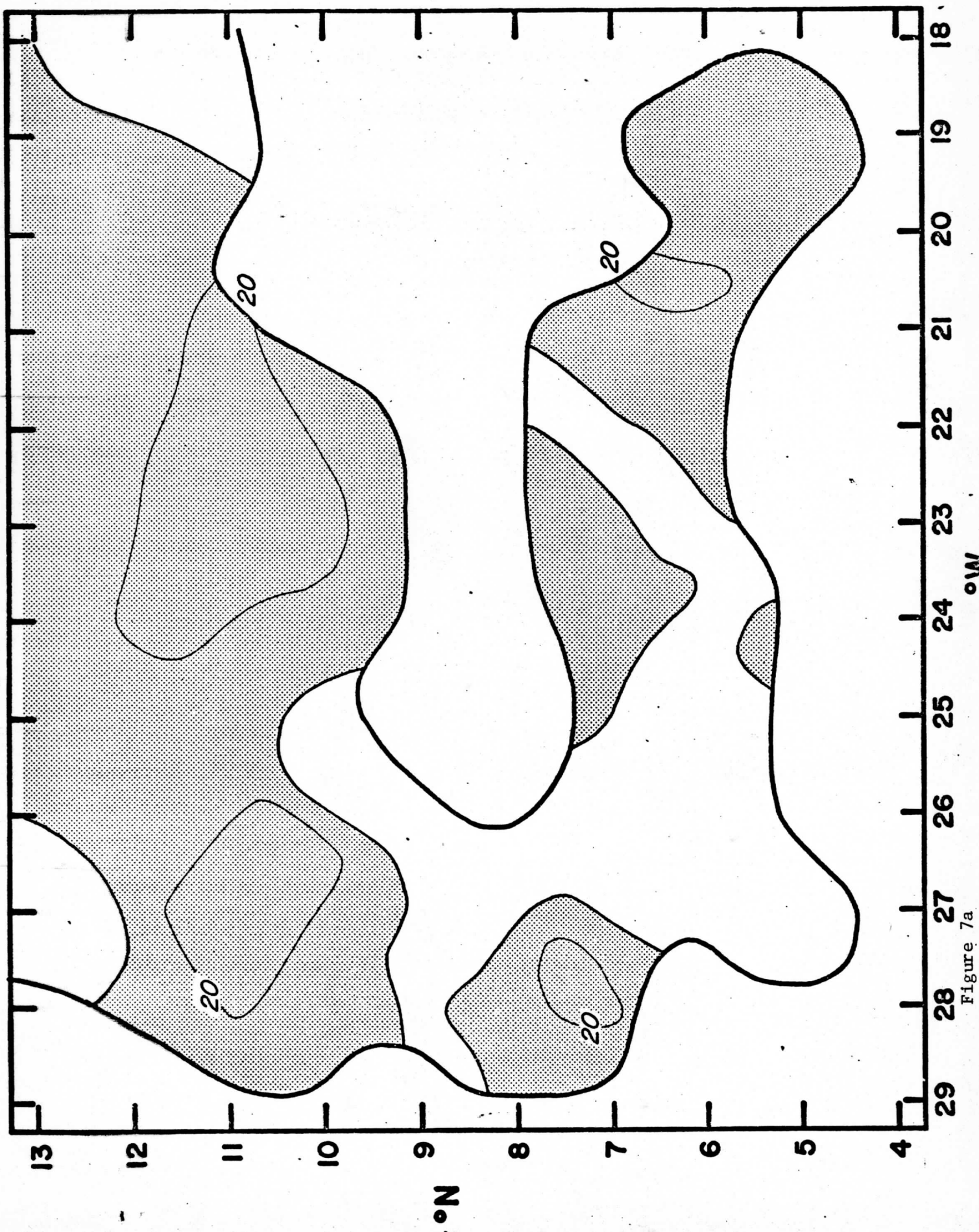


Figure 7a

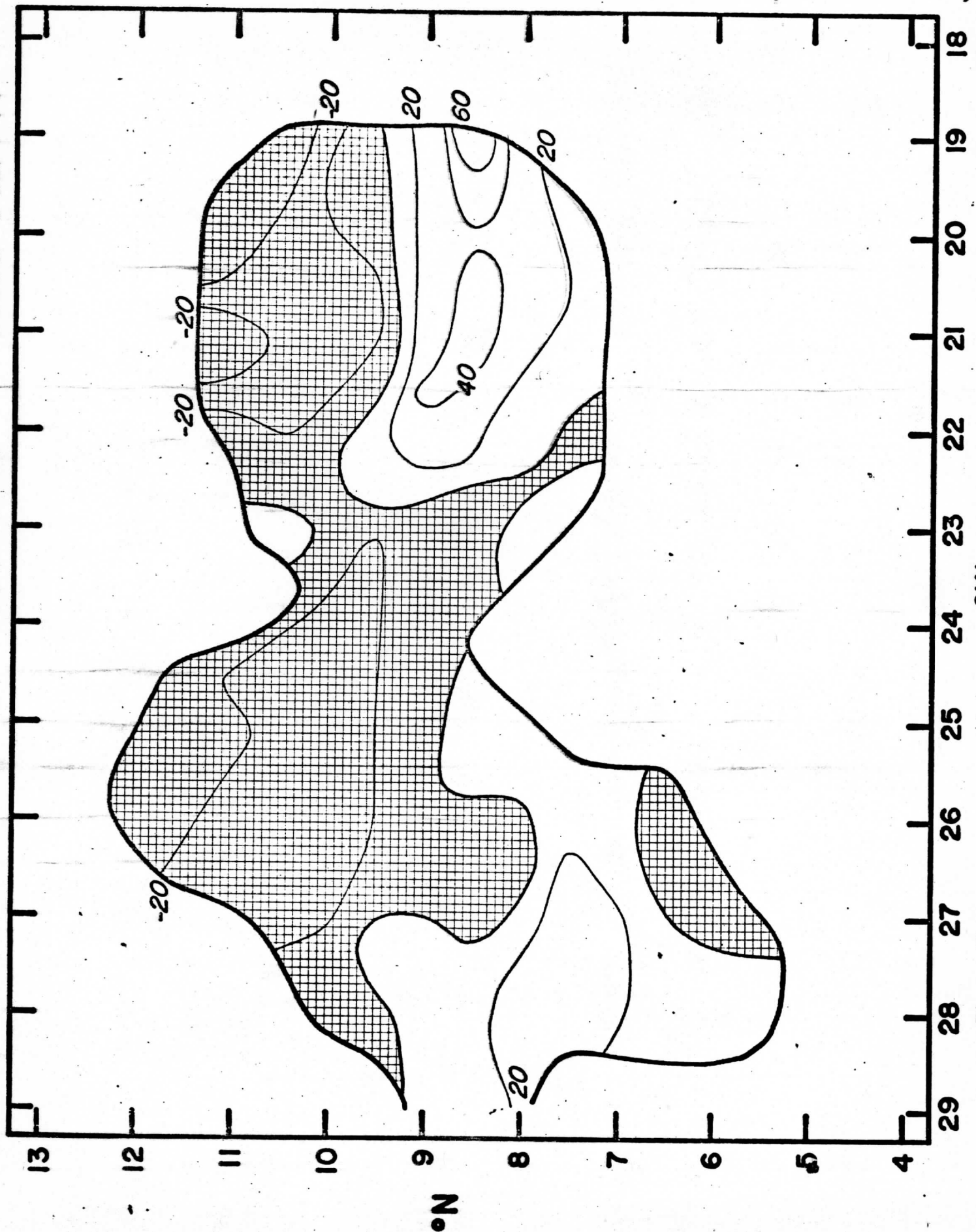


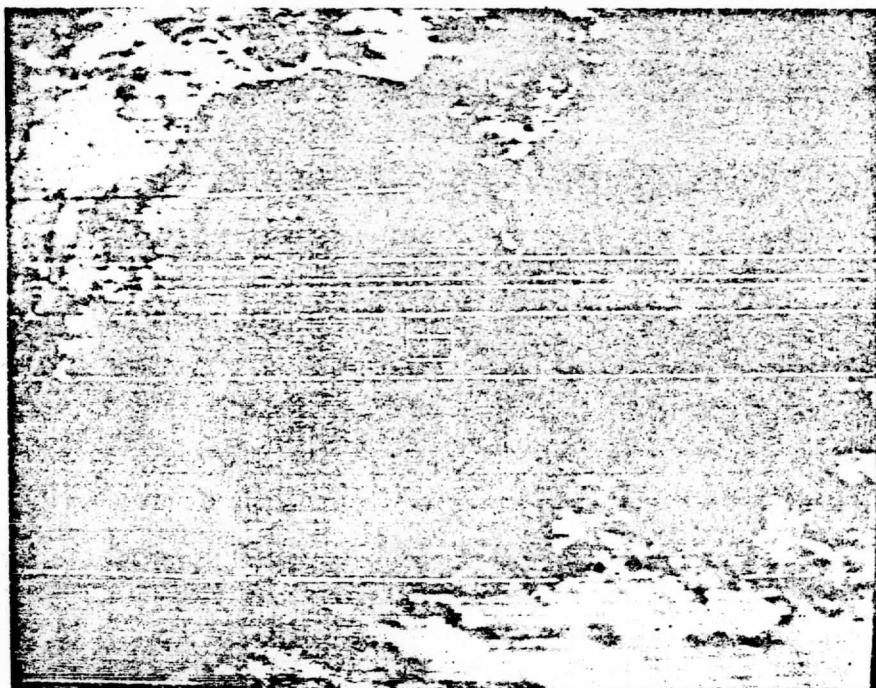
Figure 7b

September 10 (day 253) was at the opposite end of the weather spectrum. There was little convection in the B-array, and few clouds (Fig. 8). Cumulus level tracers show an elongated anticyclonic gyre at 5 and 6 N (Fig. 9a, b). Winds in the clear area across the B-array north of the gyre axis were light westerly, with a weak maximum in west northwest flow at the top of the B-array. These features appear also in the gradient level ship winds. The largest discrepancies occur in the weak wind area close to the center of the gyre.

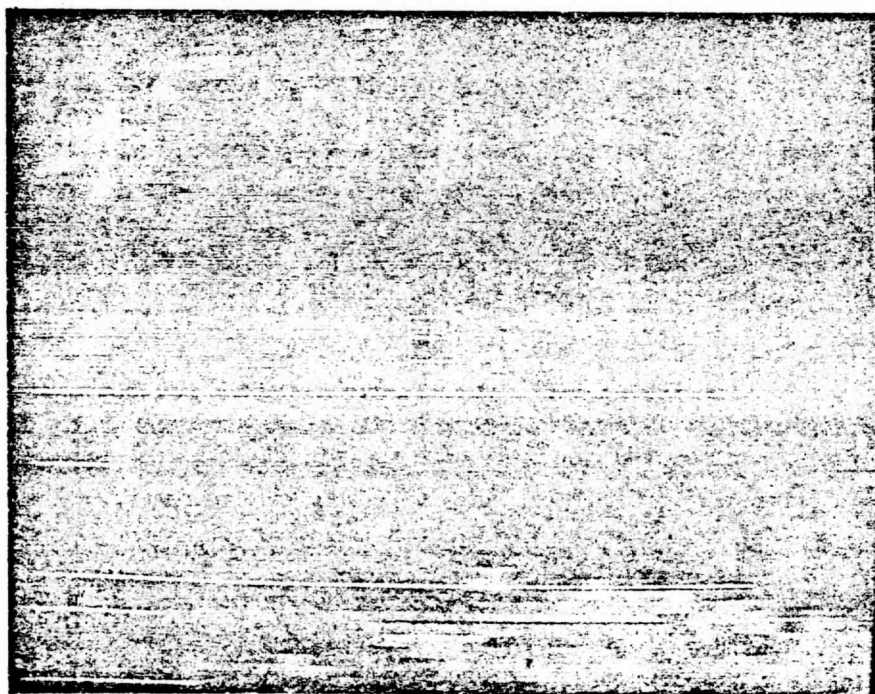
Flow at the cirrus level was generally westward. A northeast-southwest oriented cyclonic shear zone is indicated north of the B-array, with strong diffluence in the southeast over and around a mature cloud cluster between 5 and 7 N. Ship winds very closely match satellite winds in speed; however, through the center section between the shear zone and cluster, ship wind directions are more northerly, by as much as 30 degrees close to the cluster at 7N.

September 18 (day 261) was neither as suppressed as 10 September nor as active as 5 September. Clouds at the trade cumulus level were abundant. In the central and northwestern parts of the analysis area these cumuli swelled to congesti and cumulonimbi, forming two small, rather disorganized clusters (Fig. 10). The maps of low cloud tracers show that these clusters developed in an anticyclonic south to southwesterly current (Fig. 11a, b). Within this current there was a slight direction convergence, and a fairly marked speed convergence, both in the vicinity of the central cluster (at 9°20'N, 21°00'W).

Ship winds and satellite winds agree to within 10 degrees, except at the Vanguard (10N, 23°20'W), where the direction difference is about 50°. Speeds also are very close.



1230 Z, 10 September 1974. Full resolution visible SMS-I photo centered on B-array.



1230 Z, 10 September 1974; Four times full resolution infrared SMS-I photo centered on B-array.

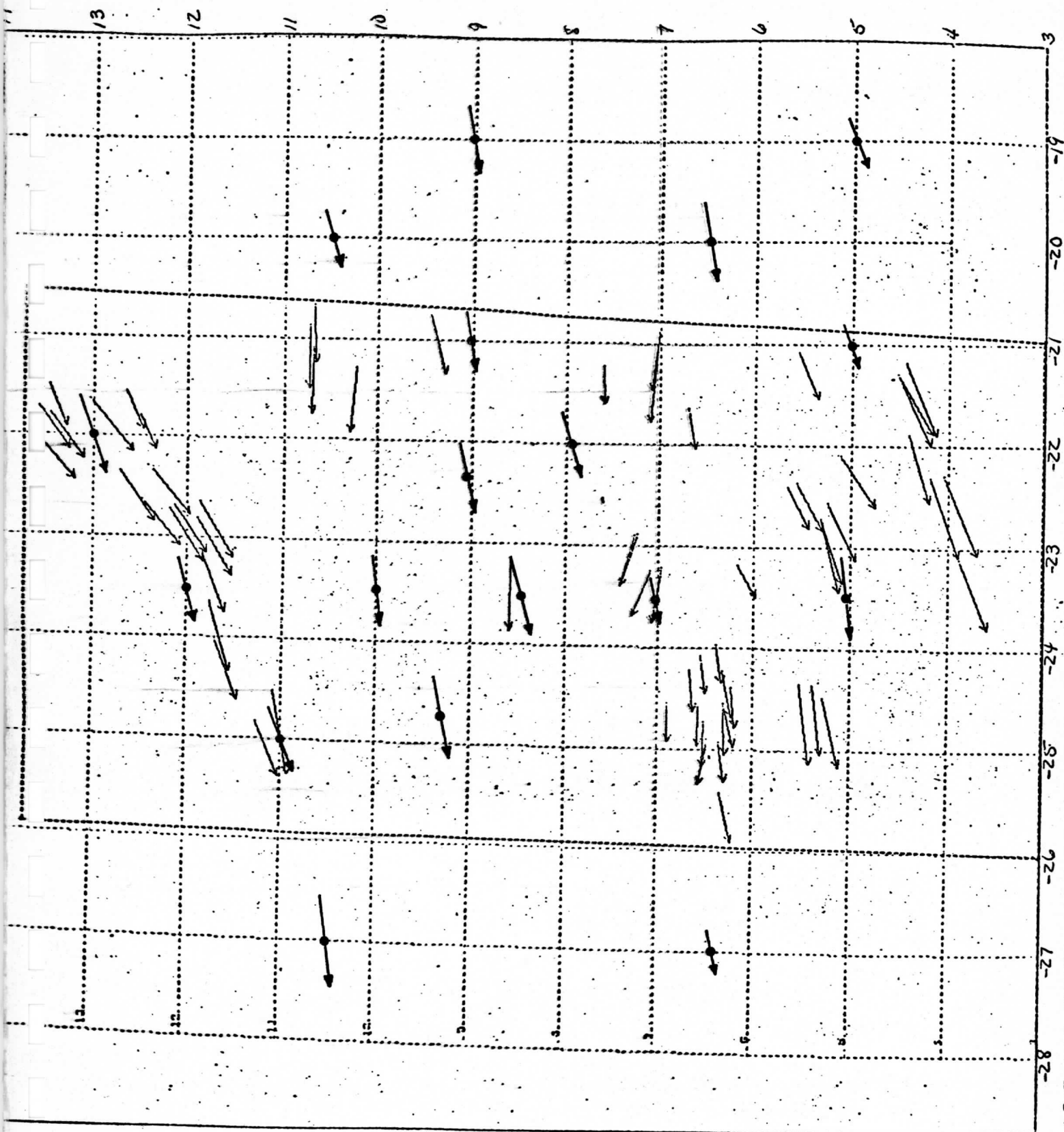


Figure 9b. HIGH LEVEL WINDS DAY 253 '74 1230Z AVE.



1330 Z, 18 September 1974. Full resolution
visible SMS-I photo centered on 9°25'N, 21°30'W.



1330 Z, 18 September 1974. Four times full resolution
infrared SMS-I photo centered on 9°25'N, 21°30'W.

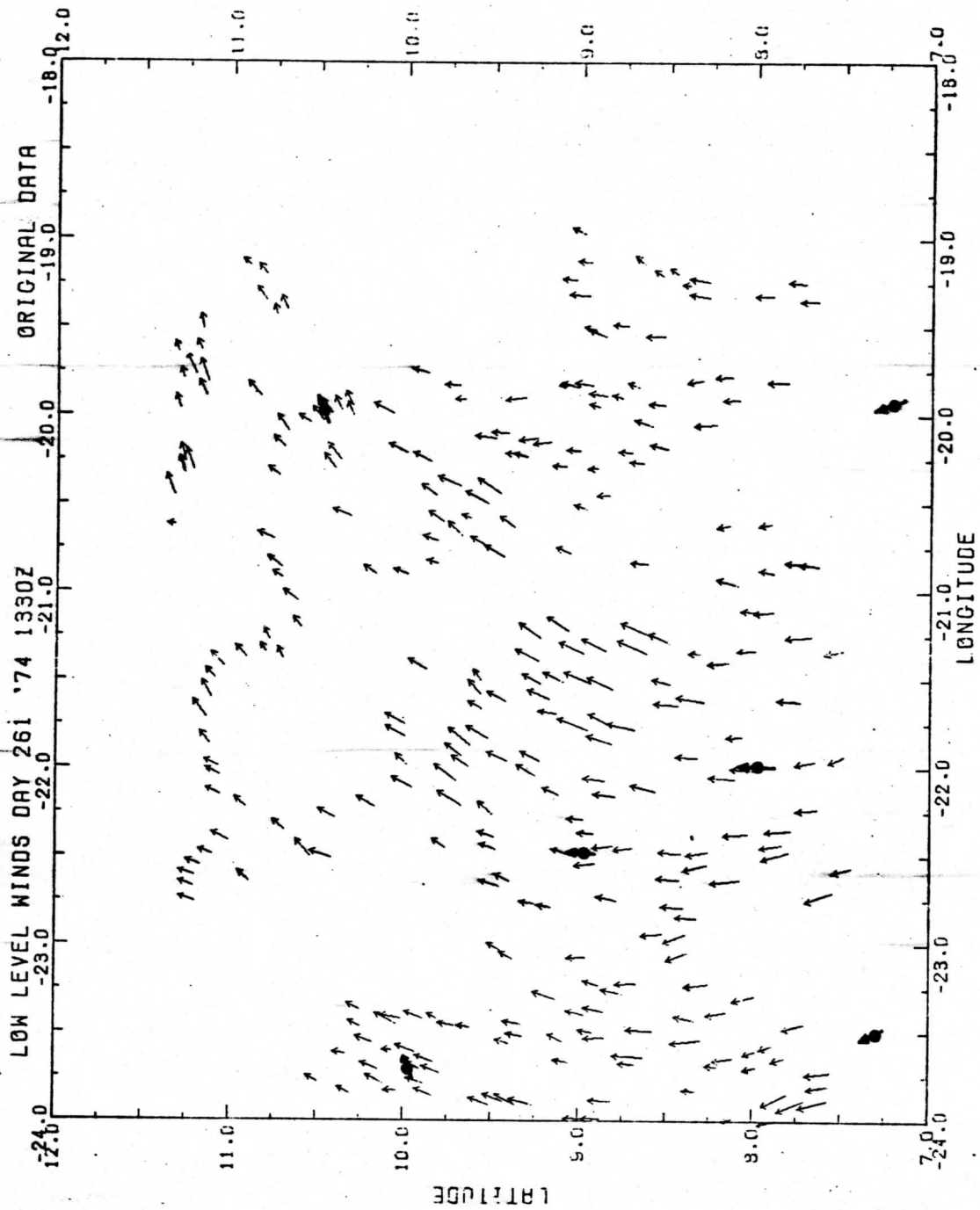


Figure 11a

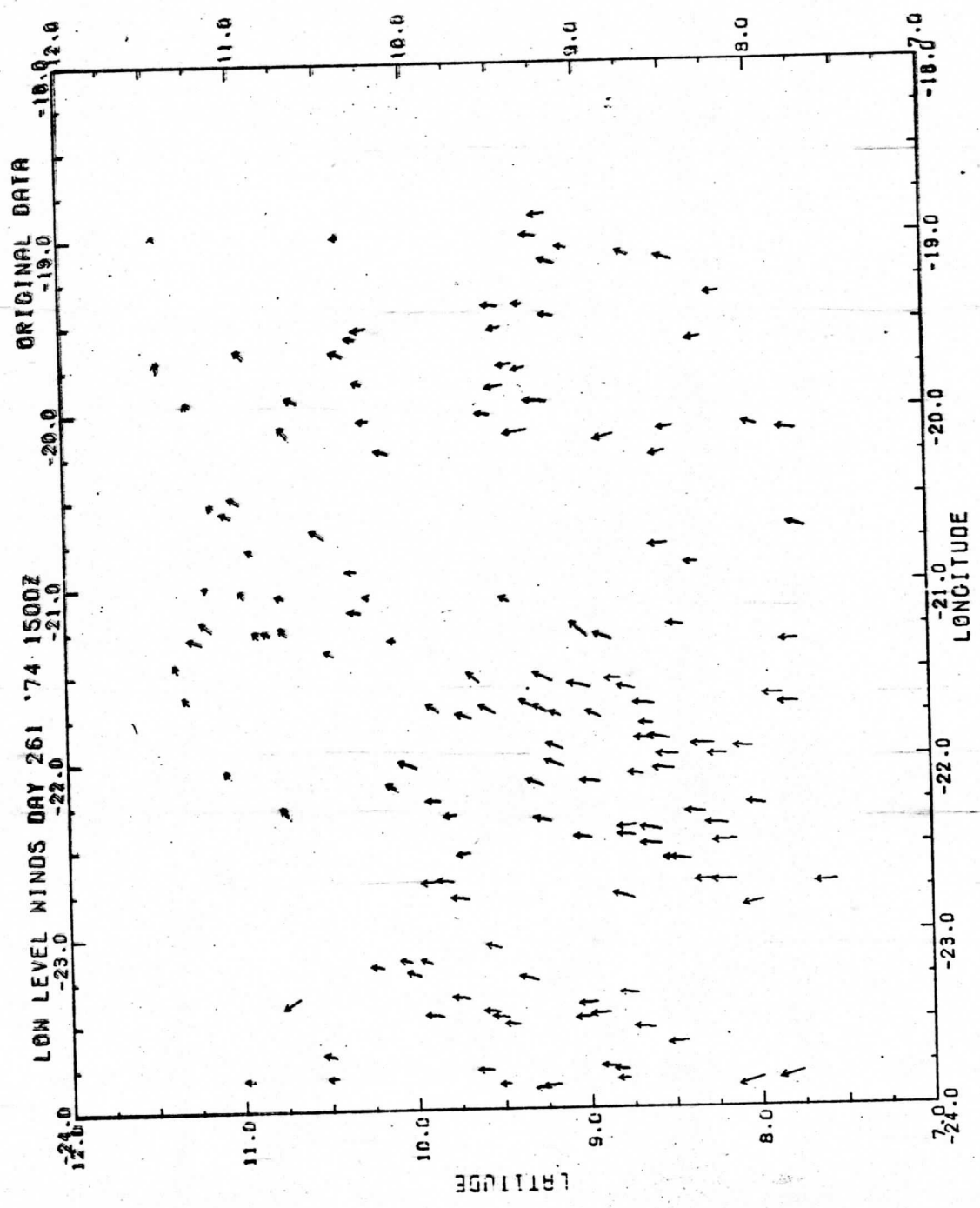


Figure 11b

Cirrus clouds were not as uniformly distributed; nevertheless, the large scale pattern is well defined (Fig. 12a, b). Flow at the cirrus level turned anticyclonically from east to southeast. There was a slight downstream decrease in speed, with a diffluent pattern west and southwest of center, and over the central cluster at 15 Z.

Although no ship winds lie close to the satellite winds, the patterns formed by each set are mutually consistent. Principal features of the satellite field—including anticyclonic flow, diffluence, and downstream deceleration—appear in the ship winds as well.

B. Reproducibility Tests

In addition to comparisons with ground truth, we have also examined the consistency of our wind sets—whether a number of different scientists tracking clouds in the same area will arrive at essentially the same wind field. The sequence chosen for this reproducibility test was centered on 9 Z 5 September 1974, when a rapidly developing cloud cluster was in the field of interest. If a high degree of reproducibility were obtained for this case, it could certainly be assumed for the less complex wind fields usually encountered.

Cumulus (~950 mb) and cirrus (~200 mb) clouds were tracked by the single pixel metric from visible and infrared pictures at 0830 Z, 0900 Z, and 0930 Z. Wind sets for 0830-0900 Z and 0900-0930 Z were then averaged. Initially, six different operators produced their own wind sets independently. These operators all had a moderate amount of experience in tracking winds.

These raw wind sets then underwent objective analysis [using a modified form of the WIND*SR1 computer program (Mancuso and Endlich, 1973) with tight restrictions on data-free regions] to obtain grid point values of the u and v velocity components, and the fields of divergence and vorticity. These

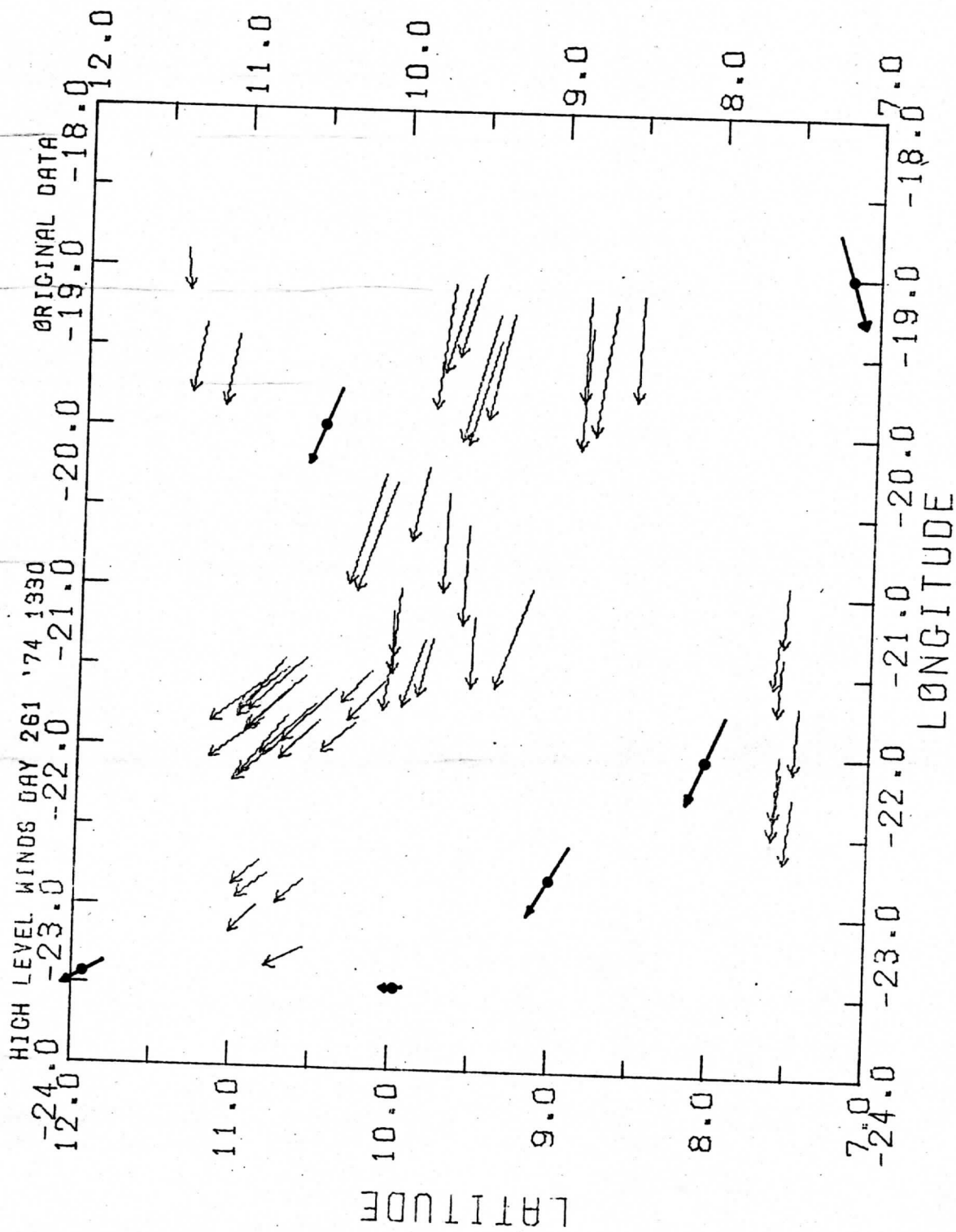


Figure 12a

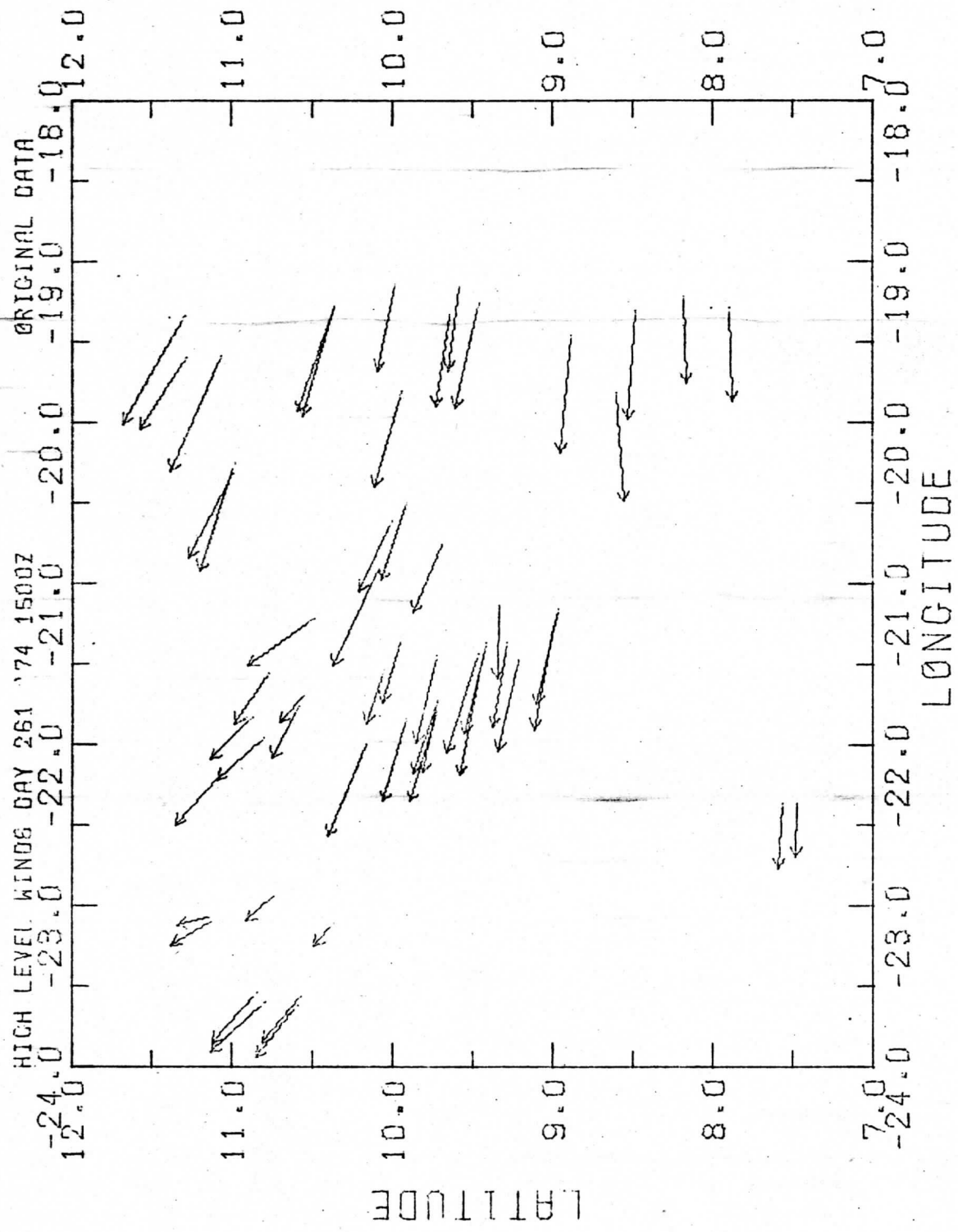


Figure 12b

grid point values were then intercompared by computer for each of the above variables for each wind set. A total of ten randomly chosen intercomparison sets were made in overlapping valid data regions (approximately 75 grid points per case for velocity, and 40 grid points per case for divergence and vorticity).

The results of this initial reproducibility test are shown in Table II. All differences are the mean of the absolute value difference between operators. No one operator appeared to be significantly better than any other.

Two possible sources of error were noticed upon inspection of the qualitative features of the difference maps: (1) a few "bad" winds in a sparse data region often accounted for a large percentage of the mean difference between operators; and (2) some of the differences were caused by the nature of the objective analysis scheme.

To explore the reasons for wind discrepancies, the four "worst" wind sets were individually displayed on McIDAS as vectors superimposed on the images used for tracking. A group of meteorologists challenged questionable vectors. If the operator who generated the wind set could not justify these winds through reference to specific clouds at the appropriate levels, they were flagged. Deleting the flagged vectors yielded four reedited wind sets. Over the same period the objective analysis scheme was improved so as to give a better representation of the wind fields: smoothing was applied in regions of large shear to avoid anomalous values in the vorticity and divergence field; restrictions were added on data sparse regions to minimize the influence of one or two bad winds; and more winds were used in the calculation of each grid point value.

Intercomparisons were repeated for the four reedited sets using the revised

TABLE II
ORIGINAL WIND REPRODUCIBILITY
 (Six Nonedited Wind Sets)

	Mean Difference Between Operators	Mean Value
Low Level Winds		
\bar{u}	0.90 m/sec	2.95 m/sec
\bar{v}	1.23 m/sec	5.17 m/sec
Total Velocity	1.49 m/sec	5.95 m/sec
		Maximum Value
Vorticity	$16.08 \times 10^{-6} \text{ sec}^{-1}$	$40 \times 10^{-6} \text{ sec}^{-1}$
Divergence	$16.47 \times 10^{-6} \text{ sec}^{-1}$	$78 \times 10^{-6} \text{ sec}^{-1}$
	Mean Difference Between Operators	Mean Value
High Level Winds		
\bar{u}	2.14 m/sec	8.02m/sec
\bar{v}	1.42 m/sec	2.62 m/sec
Total Velocity	2.57 m/sec	8.44 m/sec
		Maximum Value
Vorticity	$11.38 \times 10^{-6} \text{ sec}^{-1}$	$50 \times 10^{-6} \text{ sec}^{-1}$
Divergence	$21.80 \times 10^{-6} \text{ sec}^{-1}$	$86 \times 10^{-6} \text{ sec}^{-1}$

TABLE III
REPRODUCIBILITY OF FOUR EDITED WIND SETS

	Mean Difference Between Operators	Mean Value
Low Level Winds		
\bar{u}	0.76 m/sec	3.20 m/sec
\bar{v}	1.04 m/sec	5.25 m/sec
Total velocity	1.29 m/sec	6.15 m/sec
		Maximum Value
Vorticity	$9.93 \times 10^{-6} \text{ sec}^{-1}$	$34 \times 10^{-6} \text{ sec}^{-1}$
Divergence	$11.62 \times 10^{-6} \text{ sec}^{-1}$	$86 \times 10^{-6} \text{ sec}^{-1}$
	Mean Difference Between Operators	Mean Value
High Level Winds		
\bar{u}	1.71 m/sec	8.56 m/sec
\bar{v}	1.10 m/sec	2.32 m/sec
Total Velocity	2.03 m/sec	8.87 m/sec
		Maximum Value
Vorticity	$9.93 \times 10^{-6} \text{ sec}^{-1}$	$40 \times 10^{-6} \text{ sec}^{-1}$
Divergence	$16.09 \times 10^{-6} \text{ sec}^{-1}$	$77 \times 10^{-6} \text{ sec}^{-1}$

objective analysis scheme. These results are shown in Table III (an average of 125 grid points were compared for velocity, 75 for divergence/vorticity). After deleting the comparisons not common to both studies, the increase in velocity reproducibility averaged 28%, vorticity, 32% and divergence, 33%. Hence, improvements in the editing and objective analysis significantly aided reproducibility.

When considering the variability inherent in the differences in cloud-selection, the complexity of the case used, plus the minor inaccuracies in the single-pixel scheme, a reproducibility of 2 meters/sec for the cirrus level, and 1.3 meters/sec for the cumulus level appears to be very good. The higher level of agreement for the cumulus level clouds can be attributed to more tracers at that level, as well as to the distinct nature of trade cumulus clouds compared with the amorphous character of cirrus.

The reproducibility of the vorticity and divergence fields are such that credence is established in their qualitative features, and to a reasonable degree, their quantitative aspects. This is particularly encouraging, inasmuch as both divergence and vorticity have proven to be highly difficult to measure with any degree of certainty by conventional methods.

C. Conclusions

By a variety of tests covering several distinct flow regimes we have evaluated the accuracy, representativeness, and reproducibility of McIDAS cloud tracer wind sets produced for GATE. In every case the dominant features defined by conventional measurements are present also in the fields of satellite winds. Differences between proximate satellite and ship winds are close to noise levels in the ship winds and error levels inherent in making comparisons of such disparate measurements. In every case the satellite field

shows far more structure than the ship wind fields. This structure is consistent with major cloud features; it evolves in consecutive wind sets in parallel with these cloud features.

Reference

Mancuso, R. L., and R. M. Endlich, 1973: User's Manual, Wind Editing and Analysis Program:--Spherical Grid. (WEAP-1A), Stanford Research Institute.

III. COMPARISON OF WIND MEASUREMENT SYSTEMS: CLOUD TRACKED WINDS VS. RAWINSONDE WINDS AND RAWINSONDE WINDS VS. RAWINSONDE WINDS

by Frederick R. Mosher and Bruce Sawyer

All systems which measure winds contain errors. When one makes use of winds generated by any particular system, it is desirable to know the limitations of that system and the errors which could be expected. The purpose of this report is to try to determine the magnitude of the errors of the cloud tracked winds for the 18 Z Data Systems Test (DST) winds produced at Wisconsin. The DST ran from January 25 to February 7. Winds were computed using three visible images for cloud tracking and a single infrared image for height computations. An average of approximately 1000 vectors were produced each day for this one time period. The winds were transmitted to NASA/GISS for eventual impact studies there.

A. Interpolation Program

Because the cloud winds measured at 18 Z are not coincident in space or time with any rawinsonde measured winds, a time and space interpolation program was written so that the two different measurement systems could be compared. For each cloud tracked wind measurement this program would search the world wide radiosonde reports for that day and find the three closest radiosonde reports for both the 0Z and 12 Z reports which bracket the cloud wind report time. If any of the locations of these 6 possible reports were further than 660 km away from the cloud wind report location, they were discarded. The program first did a linear time interpolation for each radiosonde report location to the time of the cloud report. If the radiosonde station did not report for both times, the single report was used with no interpolation. The program then performed a spatial interpolation of the time interpolated radiosonde reports. The spatial interpolation was done by fitting a plane through the measurements at the three stations and solving

for the measurement at the location of the cloud wind. This spatial interpolation was done for the winds, temperatures, and the heights so as to produce an estimate of the sounding at the location of the cloud being tracked. In the spatial interpolation routine, if there were not three measurements available, the program would produce a weighted average for two reports, or simply a straight copy for one report. If the spatial interpolated measurement was more than twice the largest raw rawinsonde measurement, the spatial interpolated value was discarded as being in error.

Three different comparisons between the cloud tracked wind and the interpolated radiosonde sounding were made. The first was at the level assigned to the cloud wind. This level had been rounded to the nearest hundred millibars. If the standard reporting level of the radiosonde did not correspond to the level of the cloud wind, an interpolation was performed to bring the radiosonde to the same level as the cloud. The absolute and algebraic difference between the radiosonde wind and the cloud tracked wind was recorded. The second comparison was between the cloud tracked wind and radiosonde wind at the altitude with the same temperature as was recorded by the cloud height system. The final comparison was made between the cloud wind and the wind at the level of best fit. The program would go down two significant levels from the level of the cloud wind and would then work its way up the rawinsonde winds, dividing each level into ten subdivisions, looking for a level of best fit. The program would stop looking at two significant levels above the level of the cloud wind level. In addition to the wind velocity differences being recorded, the height difference between the level of best fit and the level of the temperature of the cloud wind was recorded.

In this comparison of cloud winds and rawinsonde winds, the rawinsonde system has been used as the "reference" system. In order to see how much of

the variability noted in the cloud vs. rawinsonde comparison was due to the variability within the rawinsonde measurements and the interpolation techniques, a comparison of rawinsonde vs. rawinsonde was made. First the rawinsonde report closest to the cloud report was found. Then the three closest radiosonde stations around the first station were found and a spatial interpolation was performed to the location of the first radiosonde station. Then all levels were compared the same way as previously noted for the cloud winds. The rawinsonde-rawinsonde comparison had no time interpolation since they were all coincident in time. By using the radiosonde station closest to the cloud wind, the rawinsonde-rawinsonde comparisons were made using the same general groups of radiosonde stations, and the same general meteorological situations as the cloud-rawinsonde comparisons.

B. Comparison of Cloud Winds vs. Rawinsonde Winds and Rawinsonde vs. Rawinsonde Winds

The comparison of cloud winds to radiosonde winds was made using the 18 Z data set produced for the DST. This data set consists of 14 days of winds with approximately 1000 vectors produced for each day. The coverage is over the entire globe as can be seen from the SMS-I satellite. The processing of the wind vectors was done in a quasi-operations mode. The earth's disc was divided into 12 sectors. The operator had to finish each sector in approximately 1/2 hour. The tracking was done on three visible images. A single IR image was used to determine the height and there was no height error checking done on this data set.

The cumulative results of the comparisons of cloud vs. radiosonde and radiosonde vs. radiosonde are shown in Table 1. The data sample is for the entire 18 Z DST data set. The cloud vs. rawinsonde comparison is for

TABLE 1

CUMULATIVE RESULTS OF COMPARISONS

	Cloud vs. Rawinsonde	Rawinsonde vs. Rawinsonde
mean distance to nearest rawinsonde station	316 km	278 km
number of comparisons	3387	28007
mean u difference at level	5.49 m/sec	5.13 m/sec
mean v difference at level	4.56 m/sec	4.33 m/sec
mean u difference at temperature level	5.04 m/sec	5.50 m/sec
mean v difference at temperature level	5.31 m/sec	5.55 m/sec
mean u difference at level of best fit	1.99 m/sec	2.60 m/sec
mean v difference at level of best fit	2.31 m/sec	2.83 m/sec
mean absolute height difference	2.0 km	1.8 km

TABLE 2

RMS VECTOR ERRORS OF AN/GMD-1A RAWIN SET

Altitude Layer	Magnitude of mean wind vector from surface to level is		
	less than 15 m/sec	15-30 m/sec	30-45 m/sec
	RMS errors (m/sec)	RMS errors	RMS errors
0-20,000 ft	1.5	3.5	7.5
20,000-40,000 ft	2.0	7.0	15.0
40,000-60,000 ft	3.0	10.5	22.5

one level. The rawinsonde vs. rawinsonde comparison is for all levels reported. As can be seen from Table 1, the two different types of comparisons yield very similar results. Both the cloud-rawinsonde and the rawinsonde-rawinsonde comparisons have cumulative differences of approximately 5 m/sec.

The variability in the rawinsonde-rawinsonde comparison can be caused by two factors. There are measurements errors caused by tracking which is less than perfect. Table 2 shows the rms vector error determined for the AN/GMD-1A rawin set used at the Atlantic Missile Range at Cape Canaveral (Walsh, 63). The second factor which could cause rawinsonde-rawinsonde differences is atmospheric variability. Measurements have been made in England (Great Britain M. O., 1940) and in the United States (Arnold, 1956) of balloon pairs released simultaneously at different distances. Atmospheric variability caused balloon pairs simultaneously launched 1 1/2 meter apart to show differences of up to one minute in reaching a certain level. These balloons drifted apart as much as 1 km during a flight. Table 3 shows the average differences in measured winds for balloons simultaneously launched at different distances from one another. (Reiter, 1961) In Table 1, the mean distance of approximately 300 km to the nearest radiosonde station for both the cloud-rawinsonde and the rawinsonde-rawinsonde comparisons results in an average difference of 5 m/sec. This is consistent with the data in Table 3 on atmospheric variability.

In addition to cumulative averages, the comparison data has been stratified into latitude zonal belts, and into height levels for each zonal belt. Table 4 shows the cumulative zonal results of both types of comparisons at the level assigned to the vectors. For both sets the differences are smallest near the equator and become progressively larger in going away from the equator.

TABLE 3

DIFFERENCES IN MEASURED WINDS FOR SIMULTANEOUSLY LAUNCHED BALLOONS

distance between launch sites (km)	0.5	5	90	110	180	480	600	720	920
differences (m/sec)	0.5	0.8	2.2	3.0	3.8	6.9	7.1	7.9	8.9

TABLE 4

CUMULATIVE ZONE RESULTS OF COMPARISONS

latitude zone	Cloud vs. Rawinsonde		Rawinsonde vs. Rawinsonde	
	mean u difference (m/sec)	mean v difference (m/sec)	mean u difference (m/sec)	mean v difference (m/sec)
50-60N	11.58	10.83	11.80	6.90
40-50N	10.95	7.82	5.69	4.84
30-40N	7.92	5.62	6.49	4.90
18-30N	5.01	4.11	4.35	4.19
0-18N	4.37	3.34	4.82	3.66
0-18S	4.15	4.35	3.30	3.44
30-18S	4.85	5.55	6.60	6.68
40-30S	6.11	5.94	6.58	9.14
50-40S	4.98	5.57	6.18	8.70

The winds generally become stronger as one progresses poleward in mid latitudes, which would explain this characteristic. The cloud vs. rawinsonde differences were generally slightly larger than the rawinsonde vs. rawinsonde differences in the northern hemisphere. The reverse was true in the southern hemisphere.

For each zone the data was segmented into levels. Table 5 shows an example of this comparison for the zone 18-30 N; which is typical of most northern hemisphere zones. In this comparison, the differences in the cloud-rawinsonde and rawinsonde-rawinsonde comparisons are comparable for the lower levels of the atmosphere. For levels above 700 mb, the rawinsonde-rawinsonde comparison yields smaller differences than does the cloud-rawinsonde comparison. Both show the differences to increase with height. Both systems have trouble tracking high level winds. For the cloud-rawinsonde comparisons, there were more low level clouds tracked than upper level clouds. Hence the cumulative averages are weighted somewhat in favor of the more accurate low level winds.

Table 6 shows the same type of data as was shown in Table 5, but for the zone 18-30 S. Here the cloud-rawinsonde differences are generally smaller than the rawinsonde-rawinsonde differences. The rawinsonde-rawinsonde differences are much larger in this Southern Hemisphere zone than in the corresponding Northern Hemisphere zone.

C. Summary of Results

The accuracy of the cloud tracked winds and the rawinsonde tracked winds appear to be comparable. This analysis showed average differences of 5 m/sec between cloud tracked winds and rawinsonde winds. The same analysis of comparison of rawinsondes against rawinsonde winds yield the same result, 5 m/sec. Studies of atmosphere variability predict this difference

TABLE 5

COMPARISON OF WINDS AT LEVEL REPORTED IN ZONE 18-30N

Reporting Level (mb)	Cloud vs. Rawinsonde		Rawinsonde vs. Rawinsonde	
	u difference (m/sec)	v difference (m/sec)	u difference (m/sec)	v difference (m/sec)
1000			2.92	2.34
900	3.29	3.44		
850			3.13	2.93
800	3.45	2.90		
700	4.71	3.80	3.20	3.08
600	6.64	5.04		
500	7.21	5.16	3.82	3.63
400	6.79	4.96	3.92	3.83
300	8.56	6.93	5.26	5.63
200	10.58	8.08	6.36	6.02

TABLE 6

COMPARISON OF WINDS AT LEVEL REPORTED IN ZONE 18-30S

Reporting Level (mb)	Cloud vs. Rawinsonde		Rawinsonde vs. Rawinsonde	
	u difference (m/sec)	v difference (m/sec)	u difference (m/sec)	v difference (m/sec)
900	4.32	3.36		
850			7.83	4.24
800	4.59	7.30		
700	5.39	6.39	7.03	3.78
600	3.83	4.32		
500	6.10	5.32	3.77	6.08
400	4.72	6.37	6.59	6.71
300	5.25	8.51	5.59	7.91
200	7.41	8.25	8.22	10.37

for the scale of comparison used.

The detailed analysis of the data showed the Northern Hemisphere rawinsonde stations to have less variability than the Southern Hemisphere stations. The Northern Hemisphere rawinsonde stations measurements showed a slight accuracy superiority to the cloud tracked wind measurements especially in the upper atmosphere. The reverse was true in the Southern Hemisphere. The cloud winds appear to be slightly superior to the rawinsonde measurements in the Southern Hemisphere.

References

Arnold, A., 1965. "Representative Winds Aloft," Bul. of Amer. Met. Soc. 37(1), 27-30.

Great Britain Meteorological Office, 1940: (a) "Variations of Wind with Distance. (b) Variation of Wind with Time." Meteor. Office Monogr. 389, 8 pages.

Reiter, Elmer R., "Jet Stream Meteorology," University of Chicago Press, Chicago, 1961.

IV. A COMPARISON OF WINDCO CLOUD MOTION WINDS FROM INFRARED SMS IMAGES WITH REPORTED RADIOSONDE WINDS OVER NORTH AMERICA

by Kenneth G. Bauer

Introduction

The comparative utility of a cloud motion wind and a radiosonde wind in representing motion in the atmosphere must be established if they are to be used synergistically in the data base for numerical modeling on a global basis. A series of time and space coincident examinations over the most data-rich (in the more conventional sense) area viewed by the SMS geostationary meteorological satellite--the United States and its environs--is required to establish this comparative utility. Comparison methods must be developed and tested over an extensive data base if a true measure and appreciation of the comparative utility is to be found. This study is a beginning in the necessary development and testing stage addressing a horizontal and vertical intracomparison between adjacent radiosonde wind runs followed by horizontal and vertical inter-comparisons between cloud motion winds derived from SMS-A infrared images and radiosonde wind reports.

Data Base

Coinciding data in both time and space are essential to minimize, as much as possible, data extrapolation induced uncertainty in wind comparisons. Such data were available for three synoptic times during the last two days of October 1974. During this period SMS-A images archived by SSEC spanned the radiosonde observations for most of North America supplied by the

National Meteorological Center (NMC). The 30/1200Z, 31/0000Z, and 31/1200Z data periods were used in this study. With North America in almost total darkness at 0000Z and 1200Z only infrared images were used to obtain cloud motion winds at these times.

Radiosonde Wind Intracomparison

To measure the variation to be expected when comparing a wind report at one point in the atmosphere with wind reports in the surrounding atmosphere a radiosonde wind to radiosonde wind intracomparison was made using the NMC North America radiosonde set for each of the three data periods. Each radiosonde run available in the set was selected in turn as the base run for comparison with the three (minimum of two) radiosonde runs available within a 660 Km radius of the base location. Once the three comparison radiosonde runs were identified they were compared with the base run on a pressure level to pressure level and a height to height basis.

In the pressure level comparison the u and v components of the wind reported at a standard pressure at each of the comparison runs was extrapolated to the location of the base wind report by fitting a plane through the three comparison reports. The difference between the extrapolated u component and the base wind u component (u_{diff}) was then computed by subtracting the extrapolated u component from the base u component. v_{diff} was computed in a similar fashion.

The height to height comparison was made by using the reported height of a standard pressure level of the base radiosonde run as the target height. The u and v components of the wind at this target height were derived for

each of the comparison runs by matching the target height to the reported heights of the comparison radiosonde runs. Once the target height was bracketed between the two appropriate comparison heights the u and v components of the wind at that target height were linearly interpolated from the u and v components of the bracketing wind reports. The comparison procedures from this point then followed that just described in the previous paragraphs.

The results for the overall radiosonde wind intracomparison are summarized in Table 1. Both absolute values and algebraic values of u_{diff} and v_{diff} were used in the computations. The pressure level and height comparison methods show little difference. For the height comparison the average value for the three cases of the mean absolute difference between a radiosonde wind report and other radiosonde wind reports extrapolated to the location of the target wind was found to be 4.2 mps for the u_{diff} and 5.1 mps for the v_{diff} . The mean algebraic difference for the same comparison was found to be .0 mps for the u_{diff} and .2 mps for the v_{diff} .

The results summarized by latitude band are given in Table 2 for the height comparisons. Averaged mean absolute u_{diff} values range from 3.7 mps at 30°-35°N to 5.2 mps at 45°-50°N. v_{diff} values range from 4.3 mps at 30°-35°N to 6.1 mps at 50°-55°N.

The results for latitude/longitude bounded zones are summarized in Table 3. for the height comparison. The location of the zones is given in Figure 1. Figures 2 through 4 show the NMC 500 MB analysis for the periods considered. The considerable variation in averaged mean absolute u_{diff} from 2.9 mps to 6.2 mps and in v_{diff} from 3.5 mps to 7.7 mps when compared with the 500 MB analysis indicates the variability of the

comparison results is directly linked to the weather pattern present during the comparison period.

Cloud Wind/Radiosonde Wind Intercomparison

The McIDAS WINDCO program was used to obtain cloud motion winds and the height of the clouds. Clouds were present for tracking in the ^{the} infrared over most of central and eastern United States and southeast Canada at 1200Z on the 30th with fewer present at 0000Z on the 31st. The L(P) Norm correlation tracking matrix was used in conjunction with the velocity cursor. Height determination was automatic from the data present at the center of the tracking cursor. Image match surface quality control was employed. Quality control limits of 4 meters per second (mps) were set for the difference between both u and v components of the cloud motion wind pairs. WINDCO data massaging applying an operator optimized gray level enhancement was invoked.

Three image sequences of full resolution IR [(1130Z = T_1 , 1200Z = T_2 , 1230Z = T_3) or (2330Z = T_1 , 0000Z = T_2 , 0030Z = T_3)] bracketing the 0000Z or 1200Z radiosonde observation times were used. The change in position of a selected cloud from T_1 to T_2 produced the first cloud motion wind and the change in position from T_2 to T_3 of the same cloud produced a second cloud motion wind. The averaged u and v components of the two cloud motion winds (meeting the quality control criteria), positioned at the averaged latitude and longitude of the two cloud wind positions was the cloud motion wind compared with the radiosonde wind reports.

The intercomparison between a cloud wind and radiosonde wind reports from the surrounding atmosphere was carried out in the same manner as used for a height comparison of a radiosonde wind described previously. The

reported height of the cloud wind was the target height of the comparison. The difference between the u and v component of the cloud wind and the u and v component of the radiosonde interpolated/extrapolated wind was then computed in the form:

$$u_{diff} = u_{cloud} - u_{sonde}$$

$$v_{diff} = v_{cloud} - v_{sonde}$$

In this formulation a positive difference indicates a stronger easterly (less westerly) u_{cloud} component or a stronger northerly (less southerly) v_{cloud} component.

For the 30/1200Z comparison 223 cloud winds were measured from the SMS-A IR images (met quality control criteria). Only 61 cloud winds could be measured for the 31/0000Z comparison--the number of cloud winds measured being directly related to the number and distribution of target clouds.

The results for the overall cloud wind/radiosonde wind intercomparison are summarized in Table 4. For the 30/1200Z intercomparison period the mean absolute cloud wind u_{diff} was 4.3 mps compared to 4.3 mps for the radiosonde intracomparison for the same period. The mean absolute cloud wind v_{diff} was 4.1 mps compared to 5.1 mps for the radiosonde intracomparison.

The results summarized by latitude band are given in Table 5. For the 30/1200Z comparison period the mean absolute cloud wind u_{diff} ranged from 3.0 mps at 35°-40°N to 7.3 mps at 25°-30°N. The v_{diff} values ranged from 2.6 mps at 50°-55°N to 4.9 mps at 30°-35°N. These results are comparable to those from the radiosonde intracomparison for the same period.

The results for latitude/longitude bounded zones are summarized in Table 6. A comparison of the mean absolute differences found during the radiosonde intracomparison with those found during the cloud wind/radiosonde wind intercomparison for the 35°-45°N, 65°-85°W zone are given in Figure 5.

The variation with height of both comparison techniques is quite pronounced. The relatively uniform distribution in the vertical of observed cloud winds illustrates the effectiveness of the total WINDCO system in tracking low, middle, and high clouds.

Summary

Radiosonde winds were intracompared over North America for three synoptic times resulting in average mean absolute u_{diff} values of 4.2 mps and v_{diff} values of 5.1 mps. Cloud motion winds were intercompared with radiosonde winds for two of the three synoptic periods resulting in average mean absolute u_{diff} values of 4.3 mps and v_{diff} values of 4.0 mps. Similar comparisons by latitude band and latitude/longitude zone have been presented along with a vertical variation plot. In this study both techniques display similar variations in differences with latitude, longitude, height, and time. This behavior suggests that a cloud motion wind and a radiosonde wind have a similar capability to represent atmospheric motions.

Table 1. Radiosonde Wind Report Intracomparison.

Date/time of observation	30/1200Z	31/0000Z	31/1200Z	Average
Radiosonde runs intracompared	90	87	93	
" " rejected	34	27	35	
Comparison level	Pressure Height	Pressure Height	Pressure Height	Pressure Height
Total atmospheric levels compared	757 719	740 700	808 765	
" " rejected	143 114	130 99	122 91	
Mean absolute u_{diff} (mps)	4.2 4.3	4.1 4.2	4.1 4.2	4.1 4.2
" " v_{diff} (mps)	5.0 5.1	5.0 5.1	4.8 5.1	4.9 5.1
" " standard deviation (mps)	4.3 4.4	4.5 4.6	4.1 4.2	4.3 4.4
" " " "	5.5 5.8	6.1 6.1	5.9 6.5	5.8 6.1
Mean algebraic u_{diff} (mps)	0 0	-.2 -.2	.1 .1	0 0
" " v_{diff} (mps)	.4 .5	.6 .6	-.4 -.4	.2 .2
" " standard deviation (mps)	6.1 6.1	6.1 6.2	5.8 6.0	6.0 6.1
" " " "	7.4 7.7	7.8 7.9	7.6 8.2	7.6 7.9

Table 2. Radiosonde Wind Report Intracomparison - Latitude Band (height)

Date/time of observation	30/1200Z	31/0000Z	31/1200Z	Average
<u>25°-30°N</u>				
Radiosonde runs intracompared	10	9	11	
" " rejected	1	1	0	
Atmospheric levels compared	83	69	96	
" " rejected	14	18	10	
Mean absolute u_{diff} (mps)	5.9	4.3	3.8	4.7
Mean absolute v_{diff} (mps)	5.0	5.7	3.9	4.9
<u>30°-35°N</u>				
Radiosonde runs intracompared	15	14	16	
" " rejected	4	0	3	
Atmospheric levels compared	122	113	126	
" " " rejected	17	17	16	
Mean absolute u_{diff} (mps)	4.1	2.7	4.2	3.7
Mean absolute v_{diff} (mps)	6.0	3.6	3.4	4.3
<u>35°-40°N</u>				
Radiosonde runs intracompared	19	20	20	
" " rejected	2	0	2	
Atmospheric levels compared	153	162	161	
" " rejected	20	15	20	
Mean absolute u_{diff} (mps)	3.6	3.5	4.3	3.8
Mean absolute v_{diff} (mps)	4.8	4.7	5.1	4.9

Table 2. (continued)

Date/time of observation	30/1200Z	31/0000Z	31/1200Z	Average
<u>40°-45°N</u>				
Radiosonde runs intracompared	20	20	21	
" " rejected	1	0	1	
Atmospheric levels compared	159	151	175	
" " rejected	27	27	20	
Mean absolute u_{diff} (msp)	3.6	4.6	3.9	4.0
Mean absolute v_{diff} (mps)	4.2	4.6	5.0	4.6
<u>45°-50°N</u>				
Radiosonde runs intracompared	12	11	12	
" " rejected	1	1	1	
Atmospheric levels compared	93	91	94	
" " rejected	15	12	13	
Mean absolute u_{diff} (mps)	4.9	6.3	4.3	5.2
Mean absolute v_{diff} (mps)	5.1	6.5	6.5	6.0
<u>50°-55°N</u>				
Radiosonde runs intracompared	9	9	8	
" " rejected	1	1	2	
Atmospheric levels compared	73	79	68	
" " rejected	12	6	8	
Mean absolute u_{diff} (mps)	4.5	4.9	4.5	4.6
Mean absolute v_{diff} (mps)	6.2	5.9	6.1	6.1

Table 3. Radiosonde Wind Report Intracomparison - Latitude/Longitude Bounded Zones (height)

Time	12Z	00Z	12Z	Avg	12Z	00Z	12Z	Avg	12Z	00Z	12Z	Avg
Zone	25°-35°N	65°-85°W	105	97	105	25°-35°N	85°-105°W	43	45	69	25°-35°N	105°-125°W
Atmospheric levels compared	55	40	54	105	97	105	43	45	69	16	7	13
"	4	9	5	11	19	8	11	19	8	16	7	13
Mean absolute u _{diff} (mps)	4.7	2.5	3.3	3.5	3.1	3.1	3.1	3.1	3.5	9.2	4.5	4.1
Mean absolute v _{diff} (mps)	6.0	2.6	2.5	3.7	2.8	3.5	4.2	3.5	11.5	7.8	3.7	7.7
Zone	35°-45°N	65°-85°W	113	105	119	35°-45°N	85°-105°W	88	95	90	35°-45°N	105°-125°W
Atmospheric levels compared	113	105	119	118	105	119	88	95	90	160	112	116
"	22	14	14	9	17	17	9	17	17	16	11	16
Mean absolute u _{diff} (mps)	3.0	2.8	2.8	2.9	4.0	5.4	5.0	4.8	3.8	4.1	4.6	4.2
Mean absolute v _{diff} (mps)	3.4	3.8	4.1	3.8	4.3	5.6	4.9	4.9	6.3	4.7	6.6	5.9
Atmospheric levels compared	55	50	56	37	32	19	47	59	60	8	5	4
"	13	8	11	3	4	3	8	5	4	4.6	5.8	3.0
Mean absolute u _{diff} (mps)	3.7	7.3	5.6	5.5	5.8	4.8	8.1	6.2	4.6	5.8	3.0	4.5
Mean absolute v _{diff} (mps)	4.1	8.9	9.1	7.4	4.2	4.5	6.0	4.9	7.8	6.0	4.9	6.2

Table 4. Cloud Wind/Radiosonde Wind Intercomparison

Date/Time of observation		30/1200Z	31/0000Z
Total cloud winds	recompared	208	51
"	" " rejected	4	10
Mean absolute	u_{diff} (mps)	4.3	4.3
"	" v_{diff} (mps)	4.1	3.9
"	" u_{diff} standard deviation (mps)	4.3	3.9
"	" v_{diff} standard deviation (mps)	4.1	3.4
Mean algebraic	u_{diff} (mps)	- .4	- .5
"	" v_{diff} (mps)	-1.0	1.4
"	" u_{diff} standard deviation (mps)	6.1	5.8
"	" v_{diff} standard deviation (mps)	5.7	4.9

Table 5. Cloud Wind/Radiosonde Wind Intercomparison - Latitude Band

Date/time of observation	30/1200Z	31/0000Z
	<u>25°-30°N</u>	
Cloud winds compared	26	2
" " rejected	1	0
Mean absolute u_{diff} (mps)	7.3	4.2
Mean absolute v_{diff} (mps)	4.8	.7
	<u>30°-35°N</u>	
Cloud winds compared	31	10
" " rejected	2	1
Mean absolute u_{diff} (mps)	3.4	4.5
Mean absolute v_{diff} (mps)	4.9	2.2
	<u>35°-40°N</u>	
Cloud winds compared	47	11
" " rejected	1	0
Mean absolute u_{diff} (mps)	3.0	2.1
Mean absolute v_{diff} (mps)	3.1	3.3
	<u>40°-45°N</u>	
Cloud winds compared	44	11
" " rejected	0	2
Mean absolute u_{diff} (mps)	4.3	6.6
Mean absolute v_{diff} (mps)	4.6	4.9
	<u>45°-50°N</u>	
Cloud winds compared	44	10
" " rejected	0	0
Mean absolute u_{diff} (mps)	5.1	4.0
Mean absolute v_{diff} (mps)	4.1	6.0
	<u>50°-55°N</u>	
Cloud winds compared	10	0
" " rejected	0	
Mean absolute u_{diff} (mps)	4.1	
Mean absolute v_{diff} (mps)	2.6	

Table 6. Cloud Wind/Radiosonde Wind Intercomparison - Latitude/Longitude Bounded Zones

Time	1200Z 0000Z	1200Z 0000Z	1200Z 0000Z
Zone	25°-35°N	25°-35°N	25°-35°N
	65°-85°W	85°-105°W	105°-125°W
Cloud winds compared	21 5	26 6	10 1
" " rejected	2 1	1 0	0 0
Mean absolute u _{diff} (mps)	4.7 2.3	4.0 5.9	8.9 7.0
Mean absolute v _{diff} (mps)	3.9 1.6	2.9 1.7	12.1 6.0
Zone	35°-45°N	35°-45°N	35°-45°N
	65°-85°W	85°-105°W	105°-125°W
Cloud winds compared	68 6	16 14	4 2
" " rejected	1 0	0 2	0 0
Mean absolute u _{diff} (mps)	3.4 3.7	3.7 4.9	4.8 1.2
Mean absolute v _{diff} (mps)	3.3 4.1	5.9 4.0	6.8 4.5
Zone	45°-55°N	45°-55°N	45°-55°N
	65°-85°W	85°-105°W	105°-125°W
Cloud winds compared	22 9	31 1	1 0
" " rejected	0 0	0 0	0 0
Mean absolute u _{diff} (mps)	6.5 3.2	3.8 11.1	3.2
Mean absolute v _{diff} (mps)	4.1 6.1	3.7 5.5	1.3

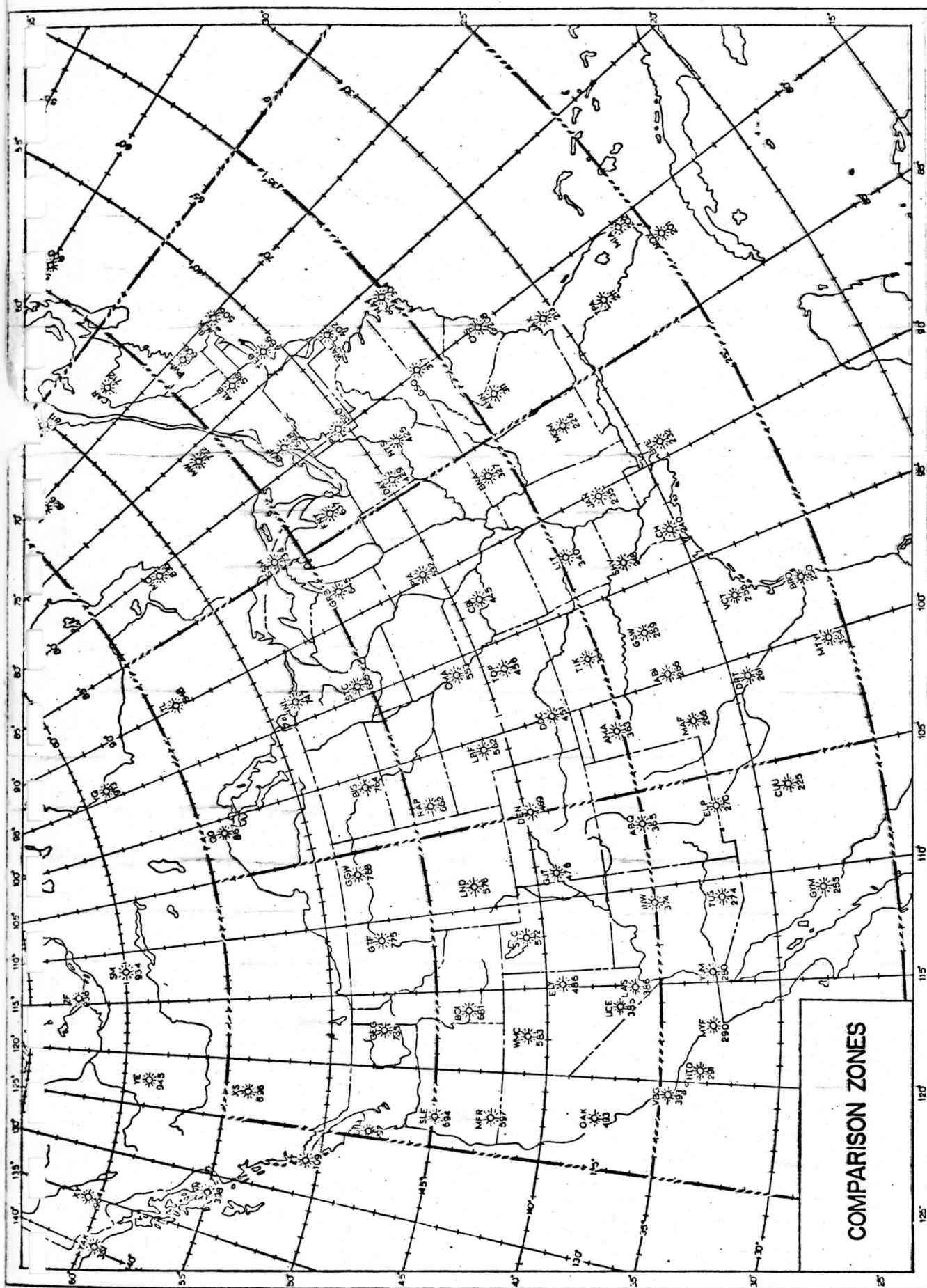
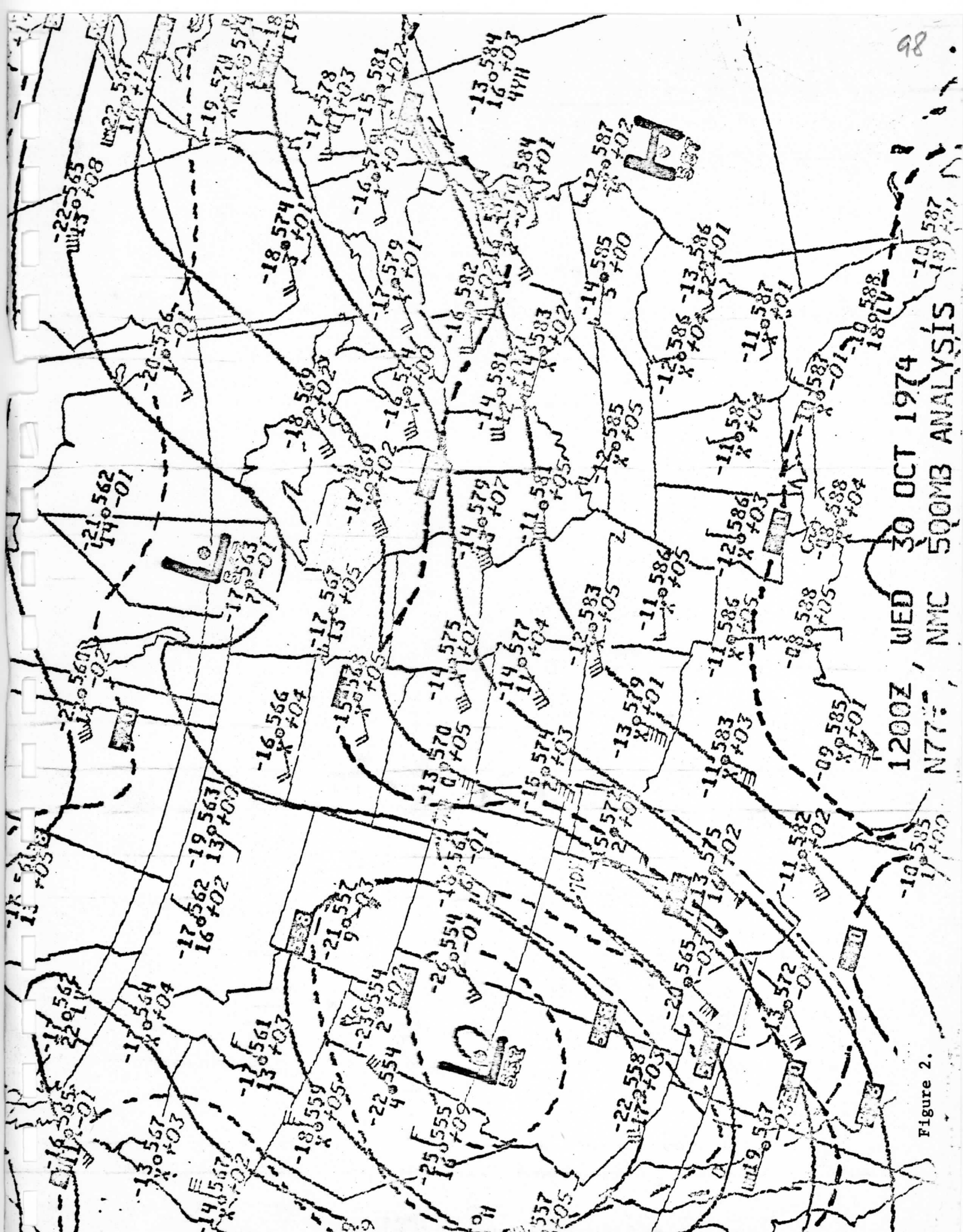


Figure 1



1200Z, WED 30 OCT 1974
N77° NMC 500MB ANALYSIS

Figure 2.

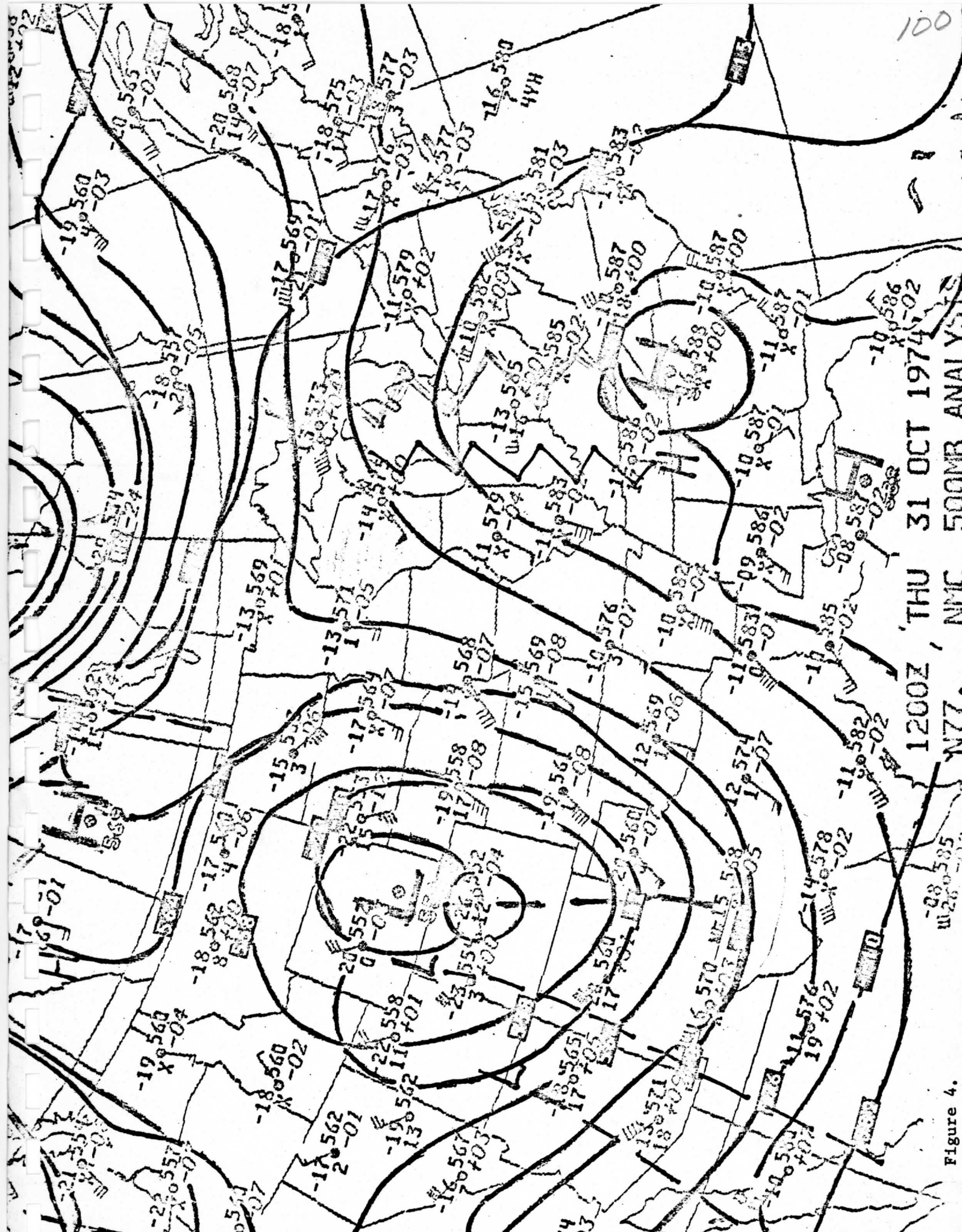


Figure 4.

1200Z, THU 31 OCT 1974, NMC 500MB ANALYSIS

100

VARIATION WITH HEIGHT ZONE 35°-45°N, 65°-85°W DAY 303/74 1200 Z

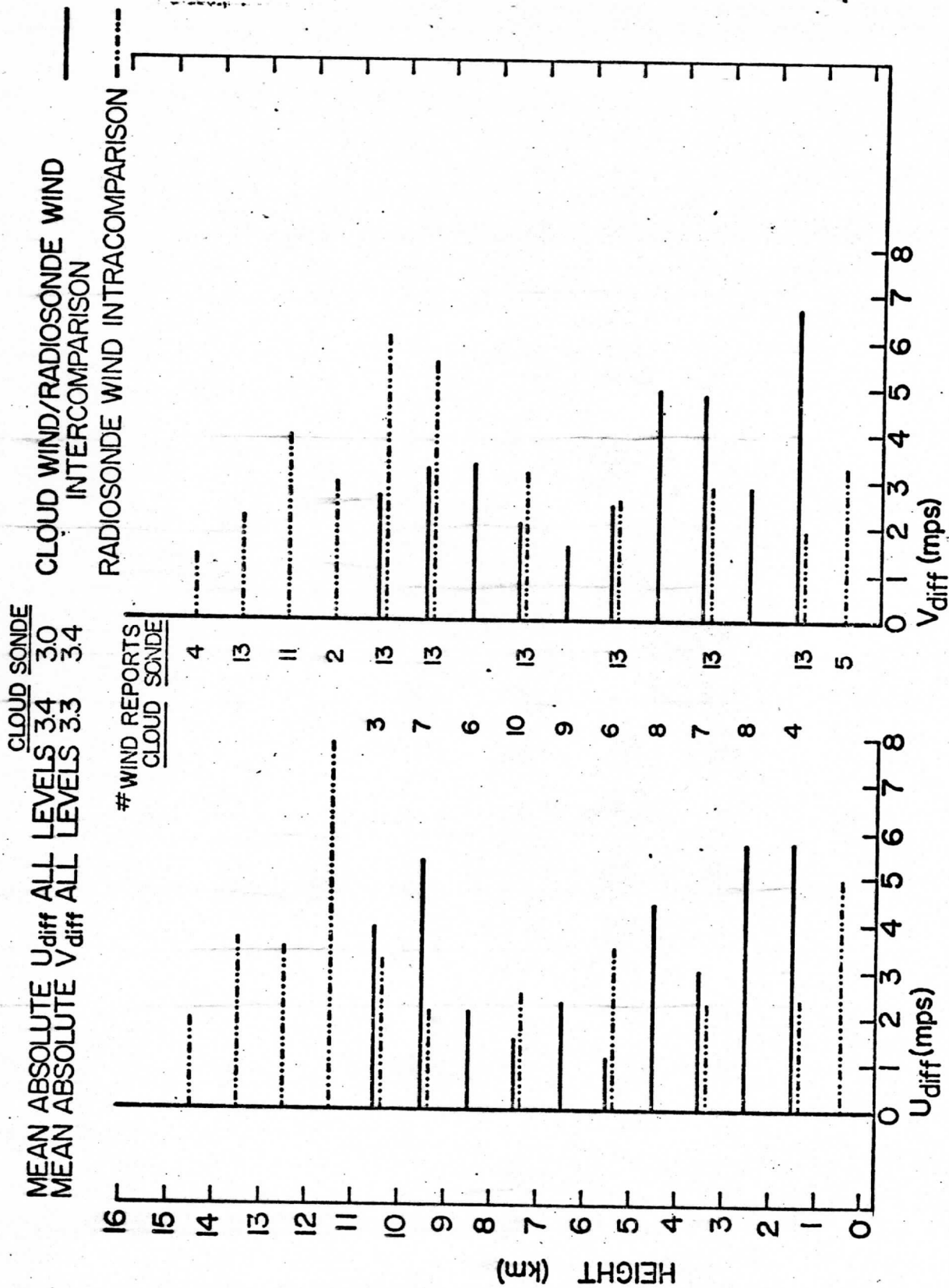


Figure 5

102

V. SUMMARY AND CONCLUSIONS

This report has demonstrated that the cloud tracking system developed at the University of Wisconsin for wind measurement purposes is comparable to conventional means of obtaining winds in terms of accuracy of measurement, and is complimentary to these conventional means in terms of horizontal coverage. The systematic errors due to misalignment of images in the tracking sequence was shown to be on the order of 10 cm/sec. The alignment of the images was shown to be consistently much better than one visible pixel. The other errors in the cloud tracking system are random in nature, and are caused primarily by errors in height determination, and growth and dissipation of the clouds being tracked.

This report contains three separate analyses of the cloud tracked winds produced at Wisconsin on the McIDAS system. The first dealt with the GATE wind sets. These wind sets have a high density of vectors. The sets were carefully produced for research purposes. Overlays of the cloud tracked winds on the radiosonde measured winds from the GATE ships showed a remarkably close agreement. In every case the dominant features defined by conventional measurements were present in the fields of the satellite winds. Differences between proximate satellite and ship winds were close to noise levels. In every case the satellite wind field showed more structure than the ship winds. The satellite winds clearly depicted the nature of the complex flow patterns around the tropical cloud clusters. Divergence and vorticity fields have been produced from the measured satellite winds. These fields showed consistency and matched the evolutionary stages of the cloud cluster. This is particularly encouraging since both divergence and vorticity have proven to be highly difficult to measure with any degree of certainty by conventional methods. The reproducibility tests showed that the cloud wind field produced do not depend upon the operator. A cloud field was measured by several different operators. An objective analysis

scheme was used to get grid point values. The mean difference between operators was 1.3 m/sec for low level winds and 2.0 m/sec for high level winds. The reproducibility of the vorticity and divergence fields showed a good agreement on the qualitative features and showed reasonable agreement of their quantitative aspects.

The second analysis in the report dealt with the comparison of satellite cloud tracked winds using visible images with conventional rawinsonde measured winds. The satellite wind sets were produced during the January DST and consist of quasi-operational quality wind measurements where the operator had a deadline to meet. The analysis was done using the global radiosonde network reports. A time and space interpolation program was used to estimate the conventional sounding at the time and location of the cloud being tracked. The differences between the conventional measurement at the satellite cloud measurement was recorded at the level assigned the cloud wind, at the temperature assigned the cloud, and at the level of best fit. A similar analysis was done comparing the radiosonde report closest to the cloud wind report with the other radiosondes around it. Both cloud-rawinsonde and rawinsonde-rawinsonde comparisons showed cumulative absolute differences of approximately 5 m/sec. Previous studies on atmospheric variability have shown similar results. Both comparisons showed the smallest differences in the lower equatorial atmosphere. Both showed an increase in the differences at higher latitudes and at higher elevations. The rawinsonde-rawinsonde comparison had smaller differences in the northern hemisphere than the cloud-rawinsonde comparison. In the southern hemisphere, the cloud-rawinsonde comparison had smaller differences.

The final analysis in this report dealt with the comparison of satellite

cloud tracked winds using only infrared images with conventional rawinsonde measurements over the United States. The cloud winds were measured at the same time as the rawinsonde flights so no time interpolation was necessary. By use of enhancement techniques, the lower clouds were tracked in addition to the higher clouds. An intracomparison of rawinsonde measurements similar to the previous section was performed and compared with the cloud-rawinsonde intercomparison. The cloud motion wind intercomparisons resulted in average u and v differences of 4.3 m/sec and 4.0 m/sec. The rawinsonde intracomparison resulted in average u and v differences of 4.2 m/sec and 5.1 m/sec. This study showed both techniques to display similar variations in differences with latitude, longitude, height, and synoptic situation. This behavior suggests that a cloud motion wind and a radiosonde wind have similar accuracy capabilities.