AN APPRECIATION OF THE METEOROLOGICAL
SATELLITE APPLICATIONS RESEARCH PROGRAMS
at
The Space Science and Engineering Center
University of Wisconsin

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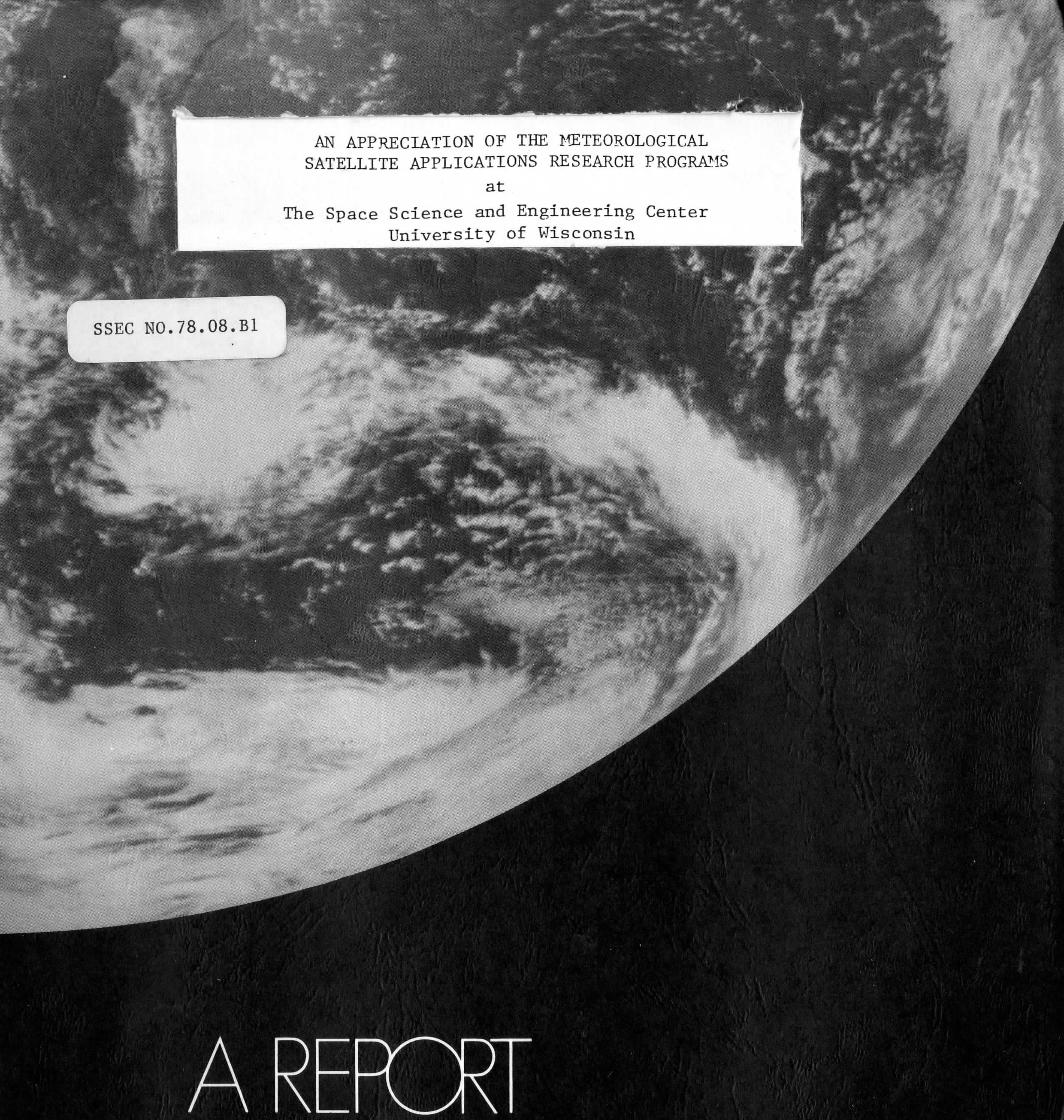

A REPORT

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

AN APPRECIATION OF THE METEOROLOGICAL SATELLITE APPLICATIONS RESEARCH PROGRAMS at The Space Science and Engineering Center

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CONTENTS

CHAPTER I. INTRODUCTION

It is difficult, and perhaps unrealistic, to summarize in a few pages the various meteorological research and instrumentation development programs that are currently pursued at the Space Science and Engineering Center. An attempt to do this will require one to write extensively on the research and development in the electronic sensors and probes for agricultural and space research; on the developments in computer hardware and software techniques; on the contributions in the meteorological uses of data from satellites; and on other scientific investigations that have direct bearing on man and his environment. All these have engaged the attention of researchers at the Center for over a decade. Research activities are performed at the state of the art, and there are plans to extend the scope and quality of research in the future. With such plans, it is doubly difficult to write a comprehensive report on the activities at the Center.

The purpose of this report, therefore, is to present to my colleagues in Nigeria and to the sponsors of my visit to the United States a qualitative appraisal of my exposure to the facilities and to a small fraction of the current research activities at the Center. The time spent at the Center was too short to digest most of the techniques and to participate effectively in some ongoing research work. However, I was around long enough to have the "flavor" of the various research endeavors at the Center. In the subsequent chapters, I shall attempt to summarize very briefly some of my impressions and my involvements in the activities at the Center.

A brief account of the applications of McIDAS (Man-computer Interactive Data Access System) is given in chapter two. Literature on this system abounds at the Center and no effort will be made to give a complete description (assuming that is possible) in this report. The system is being expanded to improve its capabilities and its efficiency, even at the time this report is being written. Many statements that may be true about the system now will be invalid in the next six months. The chapter about the McIDAS, therefore, will only state the salient points about the basic structure and capabilities of the system at the time of the report.

In chapter three, I shall discuss some results of my "encounter" with the McIDAS and my acquaintance with some of the ongoing scientific investigations at the Center. No calculative details will be given; in fact, extensive discussion of the various topics is impossible in a report of this kind. Such discussions will not only make the report unwieldy but also defeat its purpose. Pictures of graphic displays by the McIDAS of some quantities computed on the system are shown to demonstrate some capabilities of the system.

In chapter four, the possibilities for introducing this system or something like it for meteorological operations and research in Nigeria and perhaps other parts of Africa is explored.

Some concluding remarks to this report are given in chapter five. It is my hope that this will not conclude my association with the Center. For, after spending about ninety days at the Center, I have been able to identify several areas of meteorological and space research that call for cooperation between Nigerian scientists and the scientists at the Center. Such cooperation will not only involve visits by scientists at the Center to Nigeria but will also require that Nigerian scientists pay more visits to Madison.

I have avoided identifying references in the text of this report in the usual manner for two reasons. First, I have had the opportunity of talking directly with the people whose publications I will be referring to. As is usually the case, more ideas have been developed since the last time they put their thoughts down in writing. Although the time I had to talk to the scientists varies from a few minutes to one hour at a time, necessary words were said and important comments were made during these periods to help me in understanding the various aspects of the ongoing research at the Center.

Second, in the chapter on acknowledgements, specific names were mentioned in connection with specific ideas learned. I found it a particularly difficult task to list all the names of the people at SSEC who have helped directly or indirectly in making my stay at the Center very rewarding. If some names are omitted, it is not intentional and such omissions are regretted. Parts played by such people are equally appreciated.

CHAPTER II. THE McIDAS SYSTEM

The McIDAS is a computer controlled data processing device developed by the Space Science and Engineering Center (SSEC) of the University of Wisconsin. The device is a demonstration of how a large variety and a large amount of data can be accumulated, quality-controlled and used not only on a delayed time basis but also on a real time basis. The basic needs of weather forecasting are timely data in the necessary quantity and variety and the ability to process the data with speed and acceptable accuracy. Such requirements are within the demonstrated capabilities of the McIDAS system. Data collected and processed by the McIDAS have an objectivity that is advantageous. The software and hardware in the system have been designed to provide efficient processing of enormous quantities of data generated by satellite imaging with little or no loss of quality in spatial and brightness resolution. Conventional data are stored in the system and computations made from them and presented to the user of the system at his command. The computers in the system make calculations, subject many results to comparative analysis and draw most likely conclusions from the data more effectively than can be done otherwise.

Figures 2-6 show the McIDAS system functional block diagrams and flow charts. These illustrations have been adapted from the publications and other general information available at the Center. As a detailed description of this system cannot be accomodated in this rêport, readers who may be interested in learning more about the system are referred to publications by SSEC.

However, the following salient points about the McIDAS system can be made.

1. General Capabilities of the McIDAS

(i) The McIDAS can digest any set of data points and arrange them for picture format display. It can also display a set of images in any desired time sequence.

(ii) The system allows for its operator to make decisions on the kind of data he wishes to display and use. The ability of the users to control the quantity and the quality of the data he uses is an important feature of the system.

2. Application of McIDAS for the Analysis of Satellite and Conventional Meteorological Data

(i) The McIDAS system utilizes both the precision of digital data storage techniques for computational use and the wide bandwidth capabilities of analogue storage for image display. The device also has a data cataloguing system which aids the user in finding and using several thousands of satellite imagery that may be available for use.

The McIDAS at SSEC is connected by telephone lines to satellite ground stations, to a weather radar, and by teleprinters to the airways weather reporting stations network. The system then collects, decodes and stores these various data in parameter/time files by the weather data ingest and management group of modules.

The weather data analysis modules in the system are capable of computing streamlines, equivalent potential temperature, vorticity, divergence, stretch and shear deformations and other derived parameters which are then converted into graphics and displayed on the video screen. Line drawings and character plots of basic parameters like temperature, pressure, winds, etc. and derived parameters including upper air soundings, cross sections, advection plots and many others can be handled by the graphic modules in the system.

(ii) It is possible, on the McIDAS system, to combine into a single TV display images representing different spectral channels. This capability allows the user to view cloud patterns as seen both in the visible and the infrared channel simultaneously. The operator not only sees the cloud distribution but also has an idea of the temperature field accompanying it.

(iii) The enhancement of satellite image data is an operation which emphasizes selected portions of the linear curve relating radiance to signal strength. An enhanced imagery isolates deep convection from other clouds, and distinguishes between darker seas and vegetated land surfaces. The process thus makes it possible to delineate areas of strong convection and to identify cloud types and levels. The McIDAS has a digital enhancement capability so that the enhancement of satellite imagery can be accomplished in a matter of seconds.

(iv) The McIDAS system has a loop capability. This capability allows for a movie loop of a set of picture sequences to be made from original digital data from a geostationary satellite. The images are then displayed on a TV screen. Cloud tracking to estimate winds on such movie loops are done routinely at SSEC for research purposes. The system allows for double looping of infrared and visible images (by use of two independent heads on the analog disk). With a single key one can transfer from one image to the other.

The process by which winds are generated on the McIDAS cannot be fully described in this report. However, more will be said on this aspect of the use of McIDAS in the next chapter.

(v) Although the physical basis for the relationship between convective cloud brightness as observed from satellites and rainfall is not well established and experiments on this are still going on at the Center and elsewhere, considerable advances have been made at the Center to infer rainfall from images using basically this concept. Cloud areas and associated volumetric rainfall are measured with McIDAS at the Center. The procedure developed at the Center has been used to estimate rainfall from geostationary satellite images over the GATE area.

Essentially, the procedure involves measuring areas and thickness of individual clouds (this requires some amount of expertise) as a function of time, and then rainfall is estimated for each cloud using gauge calibrated rainfall data.

(vi) One of the many advantages of the McIDAS is the speed with which data can be processed and analysed on real time or near real time basis, thus providing prompt results. Examples of how current satellite pictures (GOES-2) and data from the conventional observation platforms can be amalgamated to give current weather information over most of the North American continent are shown elsewhere in this report.

(vii) Vertical temperature profiles of the atmosphere can be derived from satellite radiation measurements. Literature now abounds on the theories relating satellite radiance measurements to the temperatures in the atmosphere for both cloudless and cloudy conditions. Interpretation of radiance measurements from satellites, however, is still complex and difficult. Instrument calibration and instrumental noise remain a problem. Nevertheless, temperatures for different levels of the atmosphere are now inferred from satellite soundings in research centers (and operationally in a few places) with increasing accuracy. Experimental results from the McIDAS to test the capabilities of the device in this area of temperature retrieval have been good. Such capabilities will be further developed in preparation for the VAS (Visible Infrared Spin Scan Radiometer Atmospheric Sounder) program in which the Space Science and Engineering Center will be participating actively. The VAS will be the first radiometer to provide data from geosynchronous orbit for profiling temperature and humidity of the atmosphere.

3. Use of McIDAS for Analysis of Data from LANDSAT (ERTS)

In the earlier sections of this chapter, the utility of McIDAS for purely meteorological analysis and computation were considered. Data from ERTS (Environmental Resource Technological Satellite--launched in 1972 and renamed LANDSAT I in 1975) have been analysed successfully on the McIDAS. LANDSAT II has also been launched. As their names imply, these satellites receive (apart from making passive measurements on their own) and retransmit data about the earth's environment from collection platforms mounted on buoys (air and water temperature and motion), from ground based data collection points (weather, hydrological and seismic data) and from constant level balloons (temperature, pressure and winds). They are used for monitoring and identifying crops, soil and water surface conditions and other structural features of the earth's surface. The green and red visible channel and two near infrared channels on the satellites make these possible.

The McIDAS can be used to carry out complex analysis of the LANDSAT data. It can be used to separate urban from rural areas, identify particular crops, select best routes for the construction of roads, etc. The device can also analyse data from LANDSAT for land use and classification. The SSEC has evaluated and is still experimenting with several classification schemes on the McIDAS.

CHAPTER III. SOME RESULTS OF MY INTERACTION WITH THE McIDAS SYSTEM AND WITH SOME RESEARCH ACTIVITIES AT SSEC

Naturally I was interested in those research areas in which I have had experience, namely mesometeorological research, operational weather forecasting research, and research in the use of satellites in the atmospheric sciences. Since my stay at the SSEC was short, I was unable to engage in any particular research. However, my experience in these areas of meteorological research have been enriched and my horizons in the techniques for research have been extended considerably. My association with scientists at the Center has enabled me to initiate specific research efforts which will engage my attention in the next few years. These research efforts are tied in with the West African Monsoon Experiments (WAMEX). While the main WAMEX experiments will not take place until April next year, the preparations and anxieties about the program have already begun. The three areas of research in which I will be involved are:

(a) The structure of the southwesterly flow over the continental West Africa;

(b) The structure of convective systems over West Africa;

(c) The analysis of satellite data from Meteosat and other satellites.

Exposure to some research activities at SSEC has provided some leads as to how these research efforts should proceed. In particular, my acquaintance with the following activities at SSEC needs mention:

1. Research with Satellite-Derived Data

(i) I had the opportunity to make computations on the McIDAS of cloud drifts in an attempt to estimate winds from geostationary satellite data. The results of such computations are shown later in this chapter.

(ii) Methods of estimating precipitation from satellites and the underlying theories behind them were learned. There were, however, no opportunities to carry out specific computations on the McIDAS.

(iii) Problems of computing albedos, brightness from satellite data and cognate problems were discussed with scientists directly involved in this research effort. I was made aware of the current techniques and applications of the results of research. The application of results of albedo studies to the problems of the Sahelian drought was of much interest. Unfortunately, apart from a few demonstrations of how information on albedo and brightness could be extracted from satellite data on the McIDAS, there was no time to get more involved in the ongoing research.

(iv) Discussion sessions on the retrieval of temperature profiles of the atmosphere and the related problems of determining cloud heights from satellite data were also held with people active in this area of research. Possibilities of applying new techniques developed by these scientists to some research effort that I have attempted in the past are good, and prospects of cooperative efforts in that direction are being discussed. Definite proposals on such cooperative efforts will be written in due course.

(v) In the search for organizing concepts in the understanding of the atmospheric processes in the tropics, several international experiments have been mounted over different regions of the northern Atlantic Ocean. The most recent and the most intensive (in terms of equipment, frequency of observation, number of participating countries, etc.) was the GATE (GARP Atlantic Tropical Experiments) which was organized off the coast of West Africa, west of Dakar in 1974. The SSEC is an important Center for the analysis of the enormous data collected during the Experiment. The Experiment has provided the facts; the process of explaining the facts has engaged the attention of several research groups at SSEC.

Mesoanalysis of cloud clusters and related convective systems over the GATE area has been done by scientists at the Center using satellite-derived windsets, computed on the McIDAS. Documents on some initial results obtained have been made available to me. I have also had the opportunity to go through tapes (save tapes) of some of the processed data collected during this experiment. I was exposed to the methods of the processing of these data on the McIDAS and to some of the procedures for making computations from the data. The various problems involved in the analysis of the data were also explained.

The information provided by the scientists involved in the GATE data analysis and interpretation will serve as a guide in the execution of some aspects of the West African Monsoon Experiment (WAMEX).

(vi) The WAMEX program is part of the extensive global monsoon experiment of GARP. Scientists at SSEC have been actively involved in the recent monsoon experiments over India and in East Africa. Some preliminary analysis of the monsoon as observed in the Ocean adjacent to the continent of West Africa is also being carried out. The useful discussions with those who are engaged in this research effort will no doubt give a lead in the interpretation of the data that will be collected during the WAMEX program.

During WAMEX, attention will be focused on the continental West Africa and the Gulf of Guinea. The various scales of atmospheric motion over the region, the upwelling in the Gulf and its effects on weather processes over land, and other phenomena will be the subject of intensive research during the Experiment. Explanations of observations from WAMEX will extend some of the results from GATE (Oceanic) to cover the land areas of West Africa. Such phenomena as the West African squall lines, monsoon rains, dust laden Harmattan winds, flood producing convective systems will be studied from better organized and well-coordinated data sets. Some preliminary analysis of the squall line made from satellite data has been carried out at SSEC by a graduate student.

(vii) Information about the procedure used for navigating imageries from geostationary satellites at SSEC was also obtained. Navigation is the process by which transformations from satellite image coordinate systems to an earth coordinate system are made from the knowledge of the position of the satellite in space. At SSEC the approach to the navigation of the imageries is to model the orbit and motion of the spacecraft. The system uses an initial orbit measured by NASA tracking, refines the orbit to the accuracy required for image processing and then propagates the orbit in time with a simple elliptical orbit model. The necessity for navigating the imageries from geostationary spacecraft systems arises from the fact that images taken by the satellites tend to move. This apparent motion of the images can be attributed to three things. First, the orbits of the spacecraft are not perfectly circular as theories require. Secondly, the orbits are usually inclined relative to the earth's equatorial plane. Thirdly, the spin axis of the satellite is usually not parallel to the spin axis of the earth. The net effect of these is to cause the satellite images to make a figure eight pattern.

I did not have the opportunity to navigate images on the McIDAS, but I was acquainted with some of the procedures used at the Center for doing this.

(viii) The METEOSAT is the geostationary satellite owned and managed by the European Space Agency. The satellite was launched in December 1977 with a subpoint near the Greenwich meridian and the equator. This launching of the METEOSAT presages a new era for meteorology over the West African continent. With the ATS/SMS generation of satellites part of the region is too close to the terminator and most of the region is completely outside the field of view of the satellites. The data from these satellites, as far as this region was concerned, were only useful in the western edge of the region. The METEOSAT is located right over the region. This makes for better resolution of data and better coverage of the region for the WAMEX experiments. The METEOSAT also has three channels -- the visible (0.4-0.7 μ), the water vapor (6.7 μ), and the infrared (11.2 μ). The water vapor channel is of special interest since it will allow for the tracking of moisture over the region. The information about moisture distribution over the region is very important to the study of the monsoon over West Africa.

The process of storing the METEOSAT data obtained from the European Space Agency on the McIDAS had just begun during my stay at SSEC. However, I had the opportunity of looking at some of the data from the water vapor channel on the McIDAS. I was also acquainted with some of the problems involved with the use of data from the METEOSAT. I hope to become better acquainted with this satellite during my short visit to Darmstadt, Germany.

In the meantime, I have gone through some relevant data from the Defense Meteorological Satellite Program (DMSP) satellites of the United States Air Force in preparation for the WAMEX program. The DMSP satellites are in sun synchronous circular orbit about 450 nautical miles above the earth. Two types of data are obtainable from these satellites -- visible data, which is a measure of reflected solar radiation, and infrared data which is a measure of emitted earth and cloud radiation. The resolution of the satellite is 2.0 nautical miles in the visible data and 2.4 nautical miles in the infrared data at the subpoint. Better resolution is available in both the visible and in the infrared with some of the DMSP satellites.

Data from the DMSP are available at SSEC and I have made copies of the data that will be of research value to the WAMEX program.

2. Research with Conventional Data

I had an opportunity to go through some of the conventional data collected during GATE and to be familiar with how the data was integrated with the satellite data to analyse synoptic and mesosynoptic systems over the area of the experiments. However, an equally exciting experience was the use of the conventional weather information brought into the McIDAS for synoptic analysis of the current weather on the system. Only those who have undergone the ordeal of analysing the synoptic charts manually can appreciate the amount of labor that has been removed by the process of analysing charts on the McIDAS. General information on the kinematics of the atmosphere can be obtained promptly. Up-to-date weather information for airline operations and for the general public can, therefore, be provided.

For research purposes, the capabilities of McIDAS can be used to analyse a large amount of data to start with, and to select the more important data for thorough analysis. Figures 7-15 illustrate some of the operations that can be accomplished on the McIDAS.

3. Computation of Cloud Drift Winds from Geostationary Satellite Imageries on the McIDAS

An example of winds generated on the McIDAS is shown in Figures 16-24. The data used was chosen from the numerous data from the geostationary satellite, GOES-2, archived at SSEC. The data was for June 22, 1978 (1000-1200Z). The area over which the computation was made was centered at about latitude 10°N and longitude 30°W.

The philosophy behind estimating winds from the cloud motion observed from geostationary satellites is predicated on the assumption that if cloud tracers are properly chosen and tracked their motion will reflect the speed of the air in which they are imbedded. The knowledge to achieve this runs through the gamut of many recognized disciplines -- celestial mechanics, radiative transfer, spherical geometry, algebra, microphysics of clouds, etc. Most of the computations which a few years ago had to be done manually and sometimes with the help of computers can now be done quickly and with great efficiency on the McIDAS. There are many problems attending the estimation of winds from cloud drifts observed from satellite platforms. Some of these problems are discussed in subsequent paragraphs.

(i) Some problems involved in estimating winds from geostationary satellites.

(a) Problems of Navigation: Navigation is the process by which satellite motion is removed from the cloud motion computations. To have confidence in the use of satellite imagery used for cloud motion computation, one needs to know the earth location of cloud tracers of interest. Due to orbital effects, the earth moves around within the image plane of the satellite. The knowledge of where the position of the satellite is and how it is oriented in space vis-a-vis the earth is required. The navigation process therefore calls for knowing the satellite attitude and to use the information to make a transformation from the satellite image coordinate system to an earth coordinate system. At SSEC, the scientists have developed a good technique to accomplish the navigation process on the McIDAS

(b) Problems of determining cloud heights: From experience, meteorologists know that the variation of winds with height can be quite large. This makes the precision with which the level at which the cloud tracers are being tracked rather poor. The scientists at SSEC have employed several methods based on the infrared data and are experimenting with other techniques. The techniques now used at SSEC, and which have been incorporated into the McIDAS, have met with some success. The cloud height system developed at Wisconsin uses the visible channel data to determine the optical thickness of the cloud tracer of interest. The optical thickness is then used to determine the infrared emissivity and this measurement, in conjunction with fractional cloud measurement, is then used to correct blackbody temperature. This infrared cloud temperature thus obtained is then equated to the actual cloud temperature, and the height is determined through comparison with temperature and height in standard atmosphere sounding.

(c) Problems of clouds not moving with the speed of winds in which they are embedded: In nature this situation probably obtains more often than not. However, good judgment in selecting a suitable cloud tracer by a competent meteorologist can reduce errors due to this problem considerably. The McIDAS permits its users to make decisions of cloud selection of this wind.

(d) Resolution errors: The accuracy with which cloud drift winds can be estimated from satellite imagery also depends on the temporal and spatial resolution of the imageries used. Data obtained near the subpoint of the satellite and at 5-10 minute intervals are bound to produce better results than imageries obtained near the terminator and with longer time intervals. Effects of these parameters on cloud tracked winds have been taken into account on the McIDAS. Pixel sizes are matched to image timing by averaging data. For the examples shown in Figures 16-24, images at about a 30 minute interval from GOES-2 have been used.

(e) Operational errors: Magnitude of this kind of error depends largely on the operator of the McIDAS. The greater the competence of the operator and the longer his experience, the smaller the error. My three months experience with the McIDAS can hardly be regarded as adequate to reduce errors of this kind to the minimum. However, from the computations made from the wind set shown in the examples the expected magnitudes of quantities are obtained. Therefore, errors arising from limited experience have not manifested themselves appreciably.

(ii) Procedure to compute satellite-derived winds: In this section the procedure used for obtaining winds for this report is outlined without elaboration and without filling in the technical steps.

(a) The first thing to do is to obtain a series of satellite images (three or more pictures already navigated and properly stored), with good geometric fidelity, which are then made into a loop. This is accomplised on the McIDAS.

(b) Suitable clouds for tracking are then identified on the McIDAS video system. This requires experience, and a qualified meteorologist is needed to do this. The operator then commands the computer through a keyboard using a special language requiring no knowledge of programming. Only dexterity is required for this aspect.

(c) Tracking of clouds can then be commenced. Three methods of tracking clouds are available at present on the McIDAS.

In the first case, the operator uses the cursor (which is manipulated by one of two joysticks which are part of the keyboard ensemble) to indicate the cloud position in line and element on two successive pictures. The navigation transform converts line and element to longitude and latitude, and the computer computes the cloud velocity.

The second method involves single pixel tracking. Here the operator positions a cursor on the cloud tracer to be tracked. The velocity cursor function then automatically displaces the cursor from one picture to the next according to the position of the second joystick. This displacement is linear within the display television set. The computer then computes the distance covered within the time interval and produces the speed.

The third method is called "correlation tracking." This method of tracking is more accurate than the single pixel tracking system, even though that method has its own utility. In the example shown here the winds have been computed by correlation tracking. With this method, the operator uses a square box cursor ('manipulated' by a joystick) which he places over the cloud of interest. The computer is then commanded to perform a correlation analysis on the original digital data within the box cursor for successive pictures. The correlation computation measures the cloud displacement to less than a picture element.

(iii) Computation of cloud heights: The heights of cloud elements whose velocities have been calculated can now be estimated using both the visible and infrared data. The first step is to use the visible imagery to determine the emissivity of the cloud. The infrared blackbody temperature data is then corrected for emissivity to determine the cloud top temperature. Finally, standard atmosphere soundings corrected for latitude are then used to determine the height of clouds.

Both height in geopotential meters and in pressure coordinates (mb's) are computed. In the example reported in this manuscript the cloud drift motions computed were grouped into three levels -- low levels (from 900mb to 700 mb), middle levels (600 mb to 400 mb), and upper levels (300 mb to 100 mb).

(iv) Quality control. There is no doubt that some cloud vectors computed will be of dubious quality for a variety of reasons. Cloud elements do change in shape and size every minute and the structure of cloud elements being tracked may change appreciably from one picture to another.

To control the quality of cloud motion computed on the McIDAS two procedures are adopted.

(a) Cloud measurements are made twice using three images. The measurements that do not agree with a residual criteria set by the operator are flagged to be in error. The same quality control procedure could be applied to height determination.

(b) If during correlation, the best match of two images occurs on the boundary of the data matrix, the data is flagged.

There are several other quality control measures under development at SSEC.

(v) Results from computations.

(a) Table 1 shows a sample from the 618 vectors computed from the GOES-2 data of June 22, 1978 over the east Atlantic off the coast of West Africa. The data was automatically produced and printed out as each vector is computed on the McIDAS.

Column five gives an estimation of the level of the cloud tracer in hundreds of millibars. Columns six and seven give the longitude and latitude of the computed vector and columns eight and nine give the easterly (x) and northerly (y) components of the vector. Columns ten and eleven give the speed and direction of the vector. The last two columns give the estimates of the cloud thickness and blackbody temperature of the cloud top. The first five columns indicate respectively the identifying number for each vector, the day, and the times T_1 and T_2 at which the positions of the cloud element were determined (the speed was determined using the time interval T_2-T_1). The vectors were sorted out and grouped into three levels -- lower level (900-700 mb), middle level (600-400 mb), upper level (300-100 mb). Some averaging process was used to smooth the vectors for each level and the resultant vectors were plotted by the computer as shown in Figs.

(b) Derived quantities of the cloud motion fields: Table 2a-j, 3a-j, and 4a-j show derived quantities from the cloud motion fields. The grid is a 5° by 5° grid. It must be noted that these computations were made solely to illustrate the possible analysis that can be made with the cloud motion fields and not for making conclusions about the state of the atmosphere over the area where the data was taken. To do this a more careful analysis of the data will have to be made. This will be done in the future.

Tables 2c-2d, 3c-3d, 4c-4d give the field of relative vorticity and divergence. The tables 2e-2g, 3e-3g, and 4e-4g give the stream functions and the non-divergent wind values, respectively. The velocity potential and the divergent values for the u and v components are shown in Tables 2h-2j; 3h-3j, and 4h-4j.

CHAPTER IV. POSSIBLE IMPACTS OF THE McIDAS SYSTEM ON METEOROLOGICAL OPERATIONS AND RESEARCH IN NIGERIA

The examples of the application of the McIDAS systems for the analysis of meteorological data at SSEC given in previous chapters bear out the promise that the McIDAS system or systems based on the McIDAS idea will become common features in meteorological research centers, and airline operation centers in the foreseeable future. Whether African countries should take advantage of this kind of technological advancement at this stage of their development is a subject that often provoked heated debates; and for good reasons. Certain questions are usually asked when decisions about introducing results of modern technology into many African countries are made. First, can the country provide the monetary outlay to acquire such technology? Secondly, does the country have enough human resources - (qualified personnel) to mount an effective scientific program to justify the investment? Thirdly, are there complementary facilities (reliable power supply, technical staff to maintain the equipments) to make the importation of the results of modern technology (or the technology itself) into the country? Fourthly, do the priorities of the country warrant the investment? Fifthly, how would the new technology help in the development of the country? Sixthly, can the country improve on the technology it is importing? These and similar questions are usually asked by African governments before they make decisions on introducing products of new technology into their countries. Some countries ponder answers to these questions carefully before they take decisions. Some do not even ask the questions (let alone find answers) before they acquire new products of modern technology. The results in such cases are disastrous.

In the case of Nigeria the following can be said:

First, there is a growing awareness of the usefulness of remotely sensed data for land use analysis, water resources, etc., within the country. There is also an awareness that the data involved could be enormous. The task of learning how to use this data in Nigeria has already begun. A system like the McIDAS may make the task easier.

Second, Nigeria has produced some scientists (even though the community is still small) in the Earth, Space and Computer Sciences to appreciate the utility of a system like the McIDAS.

Third, with the present stage of the development in the country some complementary facilities can be provided to support such a system.

Fourth, there is a plan (part of which is under execution) to build or expand the existing facilities for weather forecasting and analysis in the nineteen states of the country. There is also a plan by the government to expand research in atmospheric sciences in Nigeria. More meteorological data will be generated as a result of these expansions. The McIDAS type of equipment may be the answer to the effective management of such data.

Fifth, Nigerians are receiving training and participating in research in every sphere of scientific endeavor around the world. As these people return to Nigeria, local expertise in various areas of science and technology are developed. Currently a colleague, Dr. F. B. A. Giwa (from Nigeria), with interest and experience in instrument design, computer programming and meteorology is spending his sabbatical year at SSEC. There are Nigerian scientists at the Jet Propulsion Laboratory and at the Agency of the United Nations dealing with the peaceful uses of outer space. Several Nigerians have also undergone the United Nations (FAO) training in the use of satellite derived data for application in forestry and water resources.

Nigeria is an active participant in the WAMEX program, and Nigerian scientists will be very much involved in the collation and analysis of the data obtained during the experiment. The McIDAS system is the ideal for archiving and retrieving such data.

The apparent cost of the McIDAS system can be deceiving. There are many examples of routine use of systems and techniques, once considered too expensive, that have actually sometimes proven to be economical. The acquisition of the McIDAS type of equipment for use in atmospheric and space research in Nigeria may turn out to be a wise investment.

CHAPTER V. CONCLUDING REMARKS

In the preceeding chapters I have attempted to summarize my experience at the Space Science and Engineering Center of the University of Wisconsin-Madison. There were many activities in which I was unable to participate because of the limited time available to me. However, it was possible for me to discuss in general terms some areas of future cooperation with the scientists at the Center. The two areas of cooperation in the immediate future are:

1. Study of the structure and the propagation of tropical cyclones using data (visible, infrared, water vapor) from satellites. In this study, advanced methods currently being developed at SSEC will be used to investigate the tropical storms along the general lines in which I have worked in the past.

2. Study of convective systems over the land areas of West Africa. Possibilities of a joint investigation of the convective systems over West Africa (with some data collected during the WAMEX program) by myself and some scientists at SSEC have been discussed in general terms. There is no doubt that this investigation will benefit from the experience gained from the analysis of GATE data by scientists at SSEC, and by myself. Details of such a joint program will be drawn up in due course.

If plans to carry out these joint programs materialize and are carried out successfully, then they will open new areas of further cooperation.

ACKNOWLEDGEMENTS

An organization like the Space Science and Engineering Center (SSEC) runs because all the members perform to create an atmosphere which permits anybody interested in research to work and develop himself and his area of research. Therefore, everyone at the Center has contributed directly or indirectly to making my stay a rewarding one. I wish to express my appreciation to Professor V. E. Suomi for making it possible for me to be at SSEC.

For navigation problems connected with satellite imageries I have benefited greatly from the discussions with Messrs. J. T. Young and F. Mosher. Some results of the analysis of GATE data and the problems associated with the estimation of precipitation from satellite data were explained by Dr. D. Martin. The advances made in the effort to estimate the temperature profile of the earth's atmosphere from satellites, and the problems associated with these attempts were discussed with Dr. P. Menzel and Mr. F. Mosher. Dr. W. Smith directed my attention to some of the current problems and publications in this field. I appreciated the patience of Messrs. F. Mosher and H. Virji in explaining the processes of computation of cloud motion field and cloud height determination and the underlying principles on the McIDAS system. The problems of Sahelian drought and the general circulation of the atmosphere over West Africa were discussed with Dr. C. Norton. Some aspects of the METEOSAT data were discussed with Mr. G. Chatters.

My visit to SSEC also gave me the opportunity to use the facilities of the Department of Meteorology and the Institute for Environmental Studies of the University of Wisconsin. Fruitful discussions were held with Professors H. Lettau, R. Bryson, S. Hastenrath and J. A. Young on problems of tropical meteorology and climatic change. Mr. H. Virji was very helpful in drawing my attention to the rainfall data available at the Institute for Environmental Studies and the Department of Meteorology. He also assisted with the computer work to retrieve this data and also to make computations from data obtained on the McIDAS.

I also appreciated the cooperation of Ms. L. Parker, the Administrator of Services at SSEC; Ms. K. Shervis, SSEC Librarian; Ms. C. Zielinski of the DMSP Library; and Ms. D. Cavallo, Computer Operator.

I am grateful to Mr. T. Haig, the Executive Director of SSEC, and to his secretary, Ms. J. Edwards for their interest in my well-being during my stay in Madison.

This list of people is perforce selective and probably omits many equally important staff at SSEC who have contributed to the success of my stay in Madison. This I consider necessary to save space.

Lastly, I wish to thank Ms. K. Paprocki for typing the draft of this manuscript.

GENERAL REFERENCES AND SELECTED PUBLICATIONS OF SSEC

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Suchman, D., D. W. Martin, F. R. Mosher, B. Sawyer and K. G. Baur, 1975: Preliminary assessment of the cloud tracking system developed at the University of Wisconsin. SSEC Publication.

ILLUSTRATIONS

TABLES

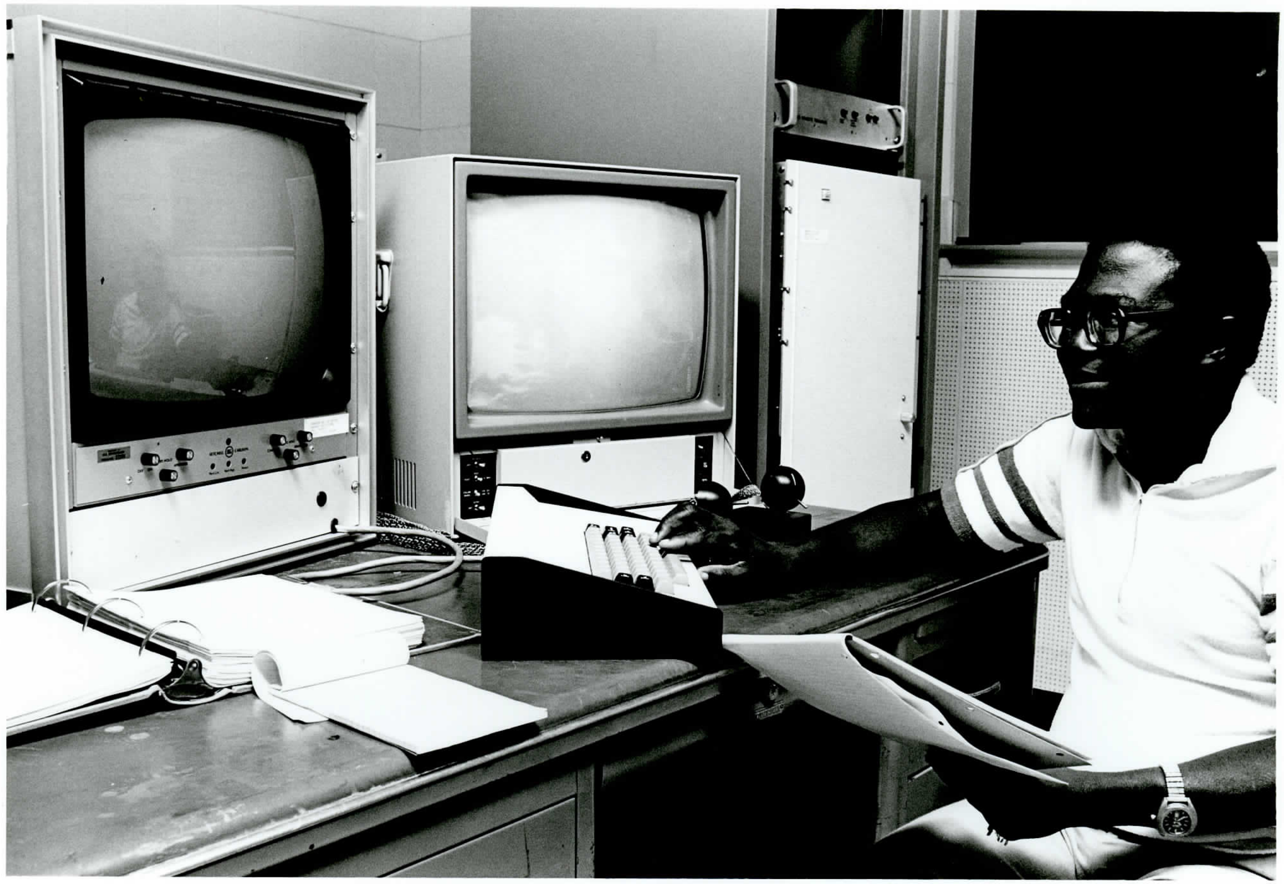


FIGURE 1. Author at Terminal 2b of the McIDAS System

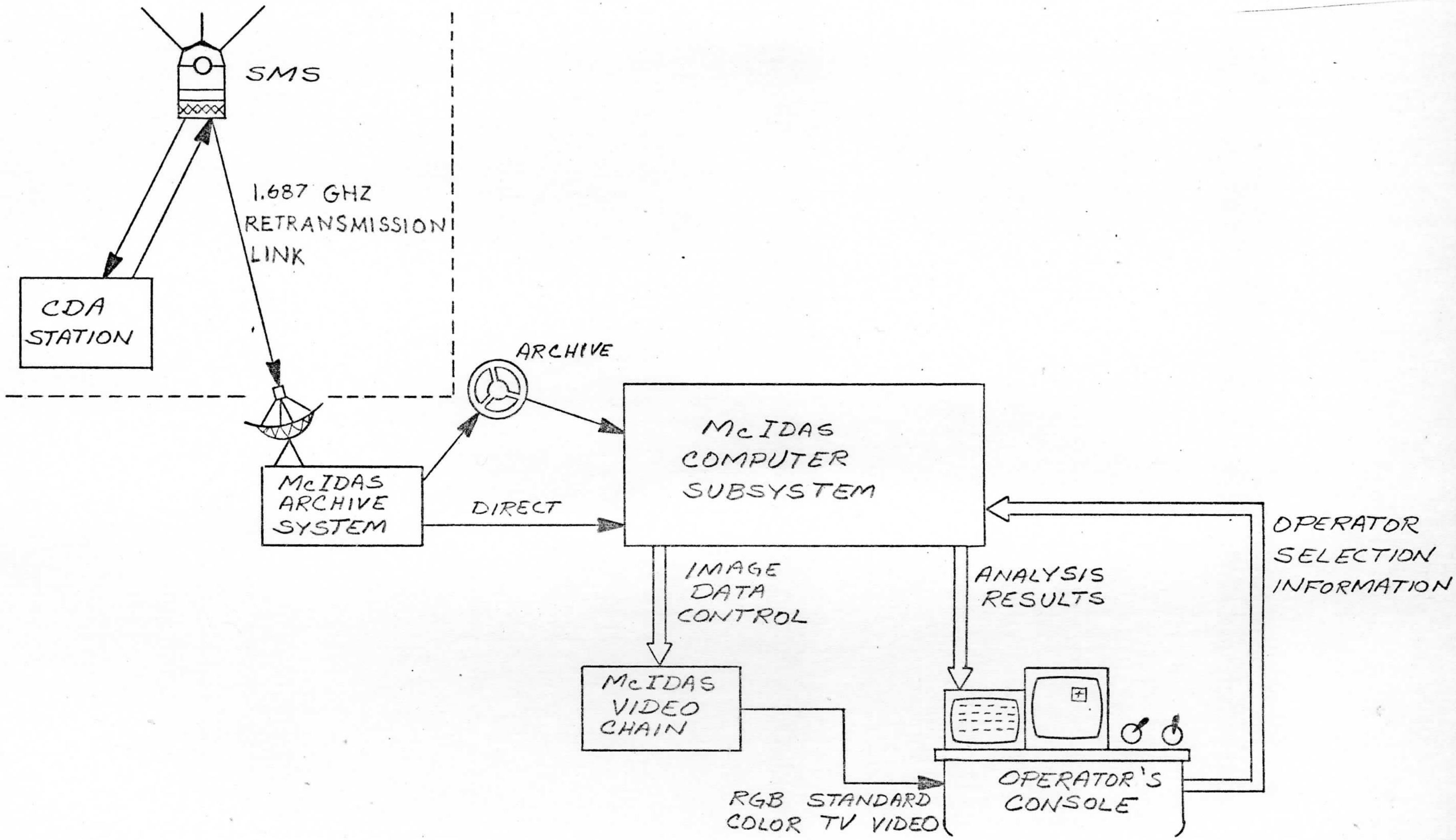


FIGURE 2: McIDAS SYSTEM FUNCTIONAL BLOCK DIAGRAM

McIDAS CONTROL SOFTWARE

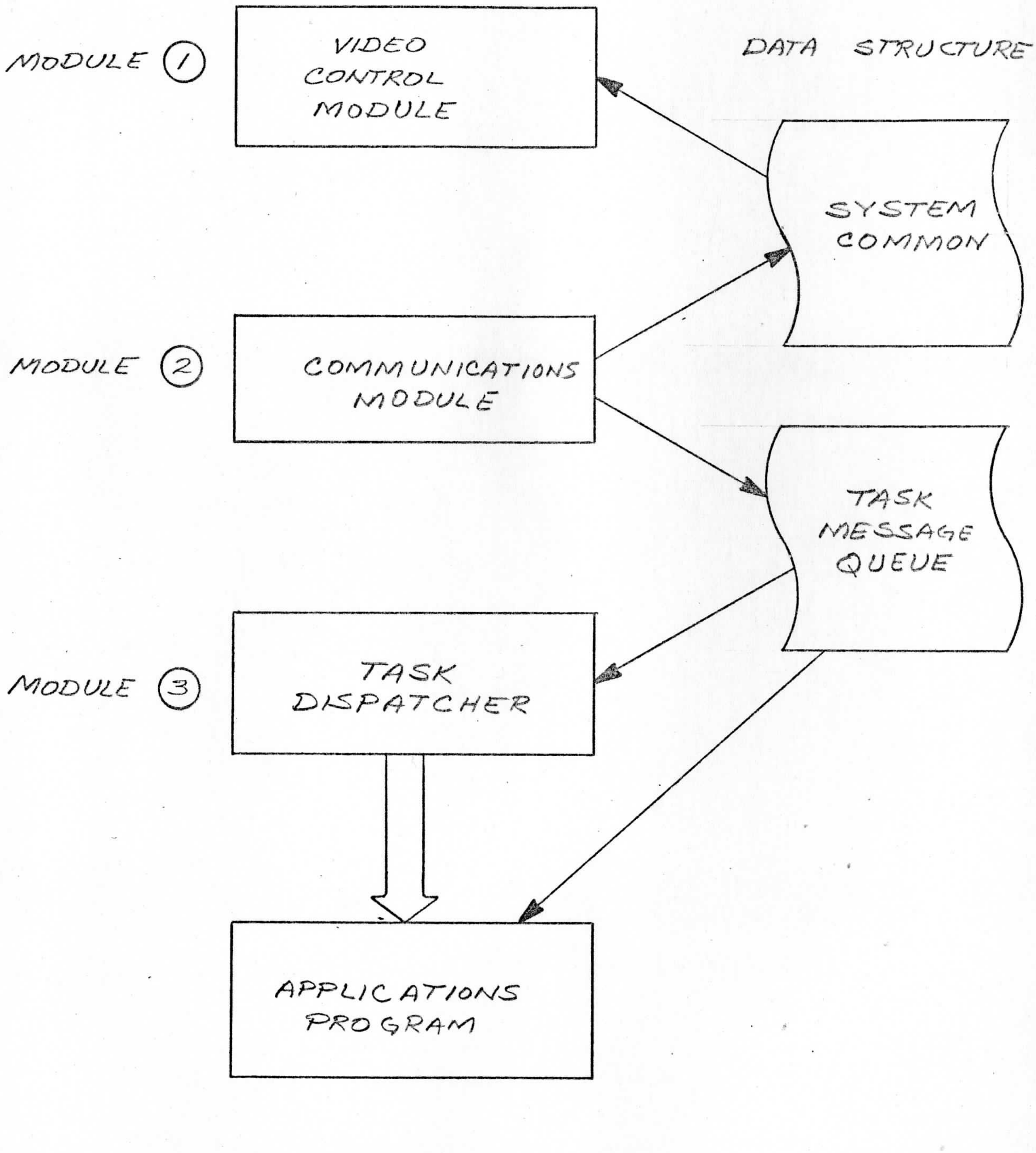


FIGURE 3

APPLICATIONS SOFTWARE SUB-SYSTEMS

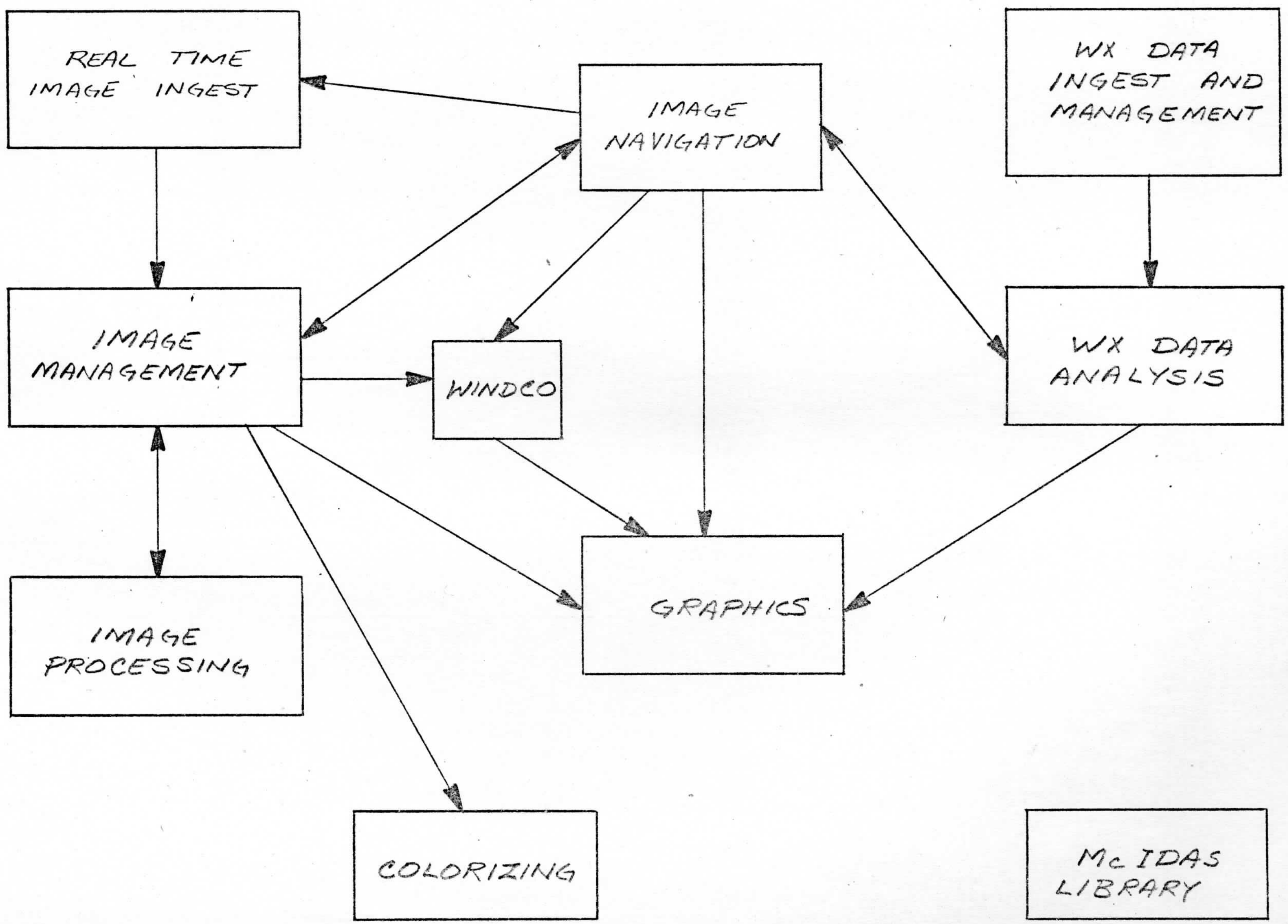
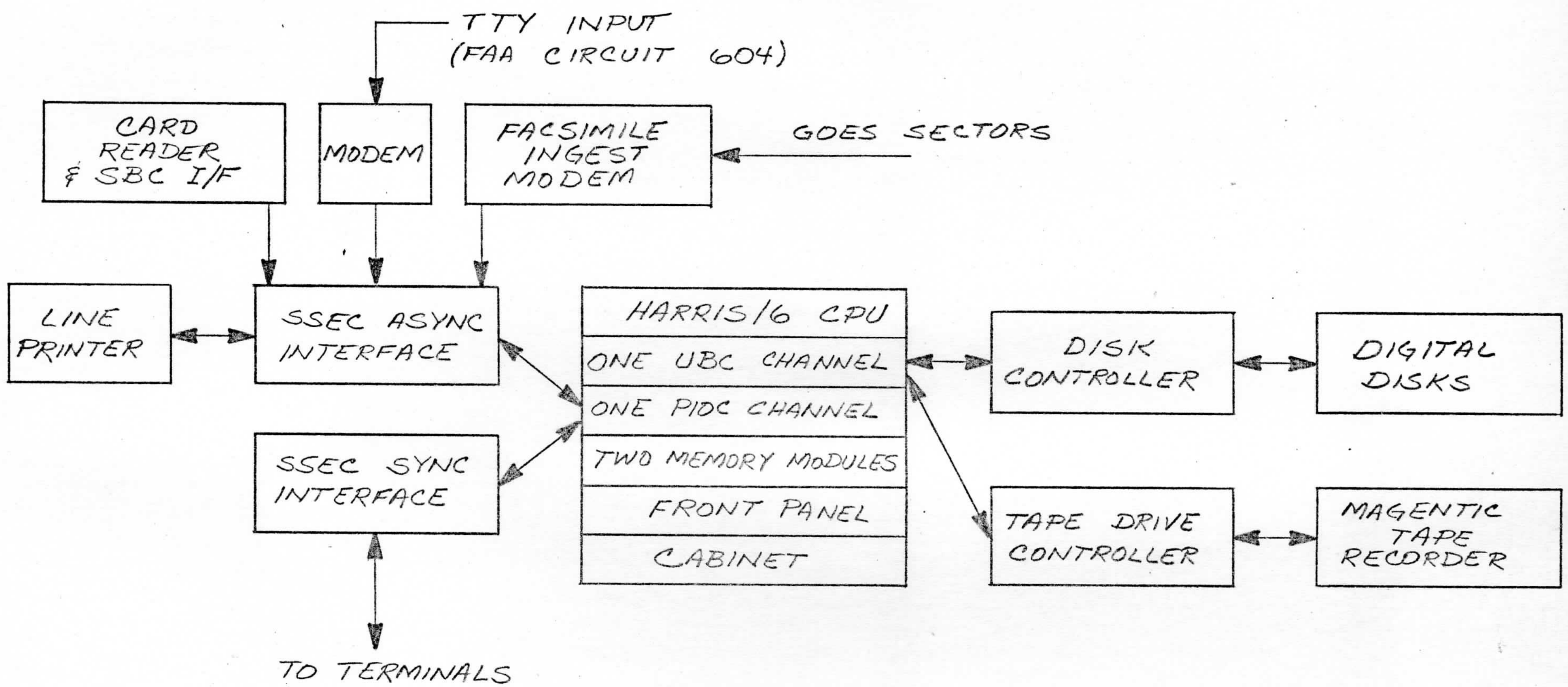
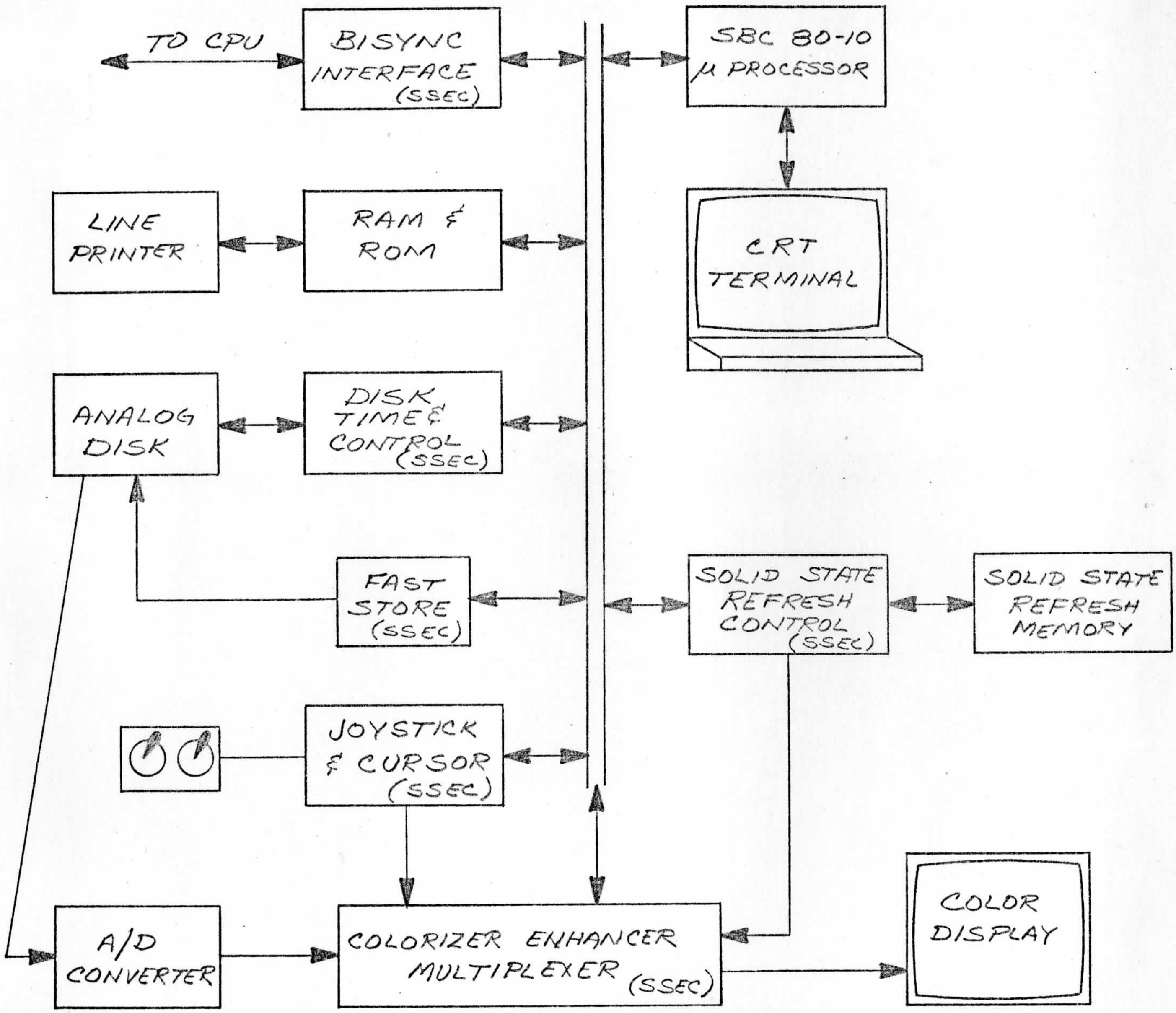


FIGURE 4



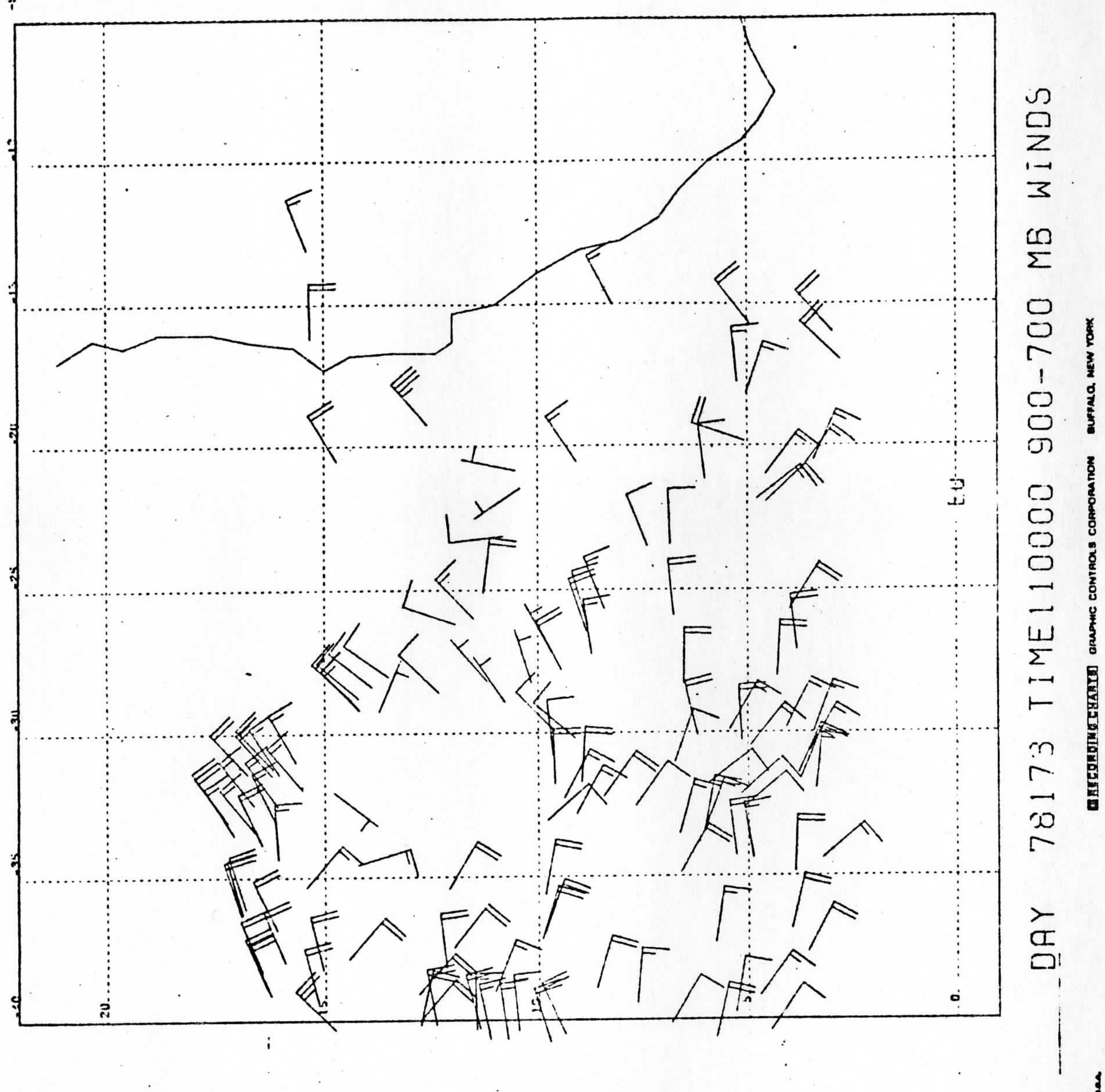
TYPICAL McIDAS-2 PROCESSOR SECTION

FIGURE 5



TYPICAL McIDAS-2 TERMINAL

FIGURE 6



A09965,0525,9000132689 GSP MAY 78

DATE. TIME: 08/03/78: 14:59:21

FIGURE 22. Processed data from Figure 21 for 900–700 mb winds

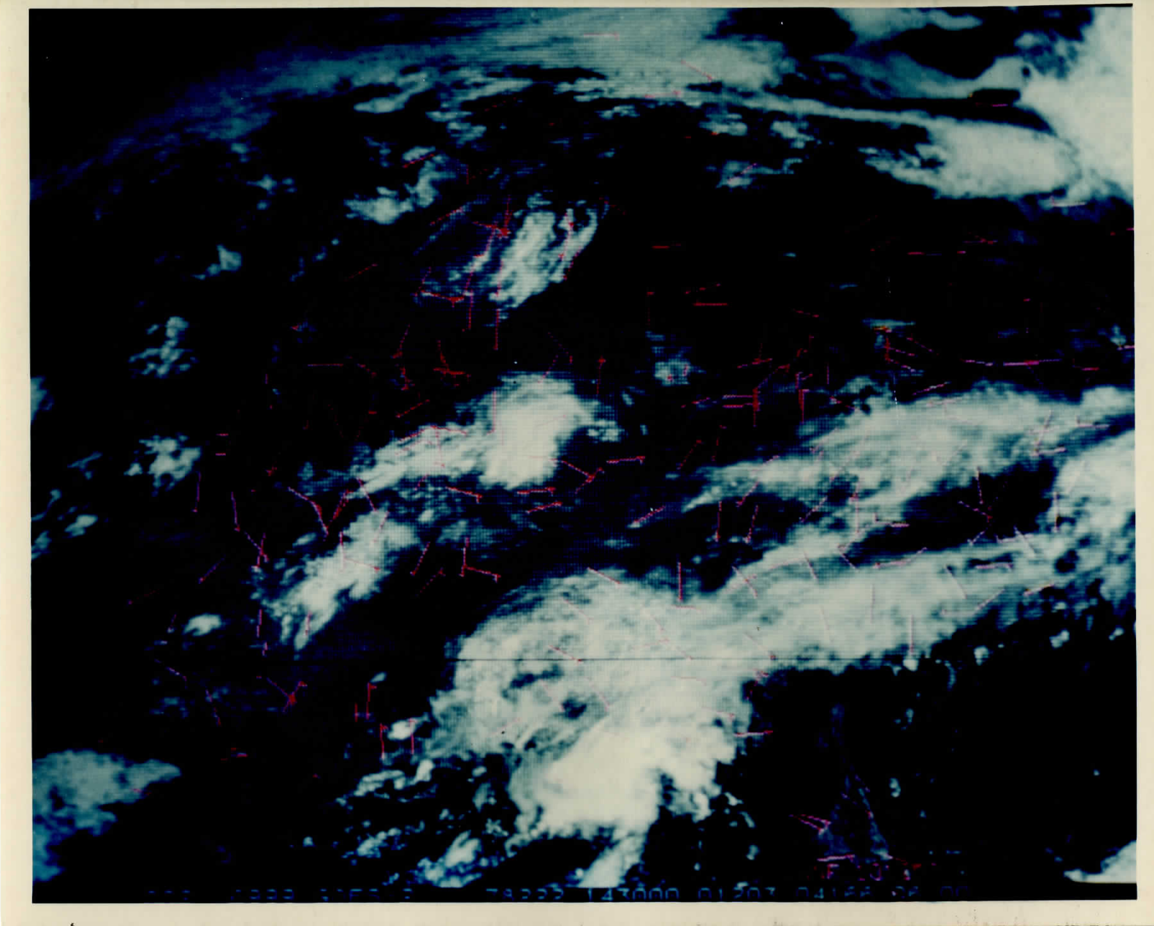


FIGURE 7. Surface winds for 1200Z, 10 August 1978 over North America plotted over GOES-2 satellite imagery, 1430Z, 10 August 1978.

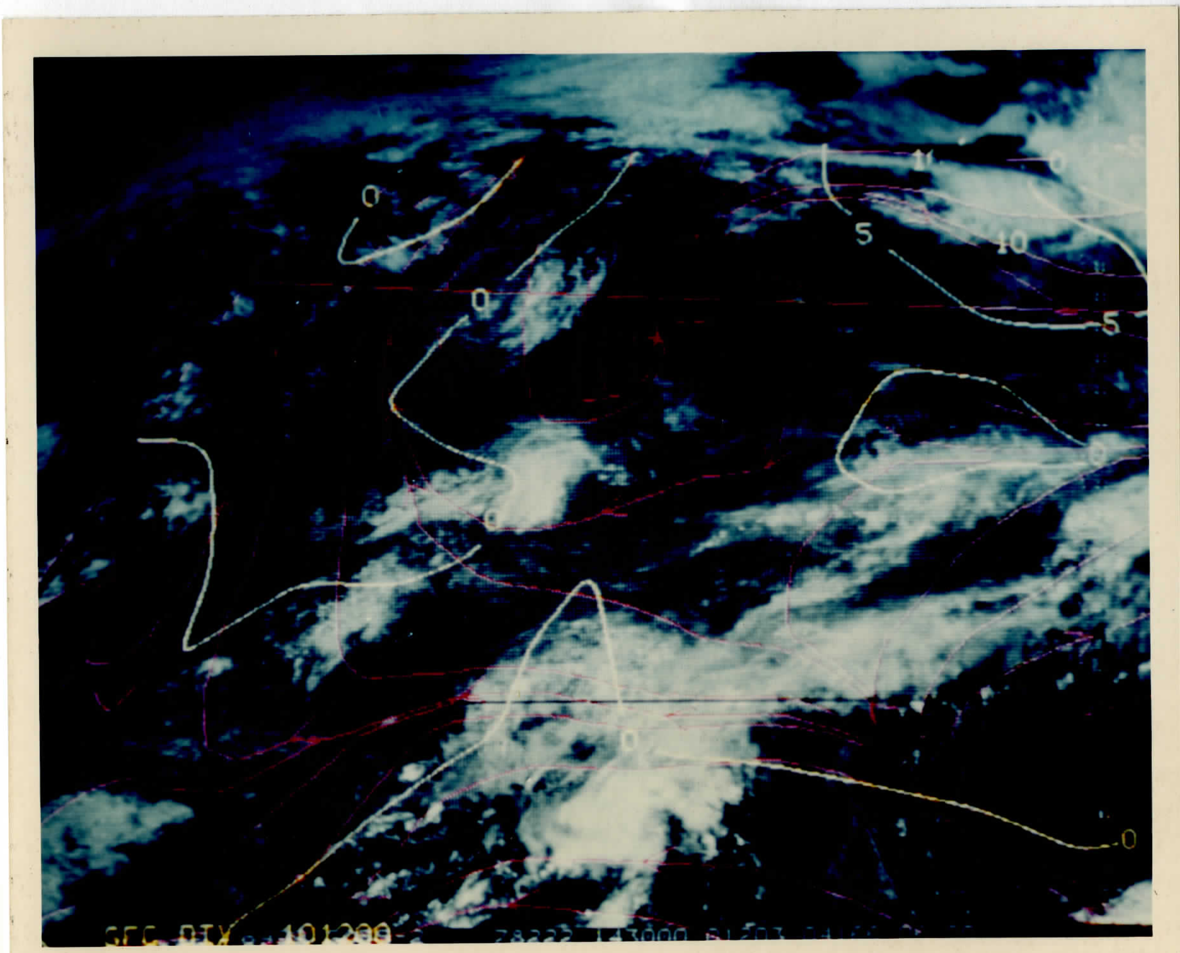


FIGURE 8. Surface streamlines and divergence 10^{-6} sec^{-1} for same situation as in Figure 7

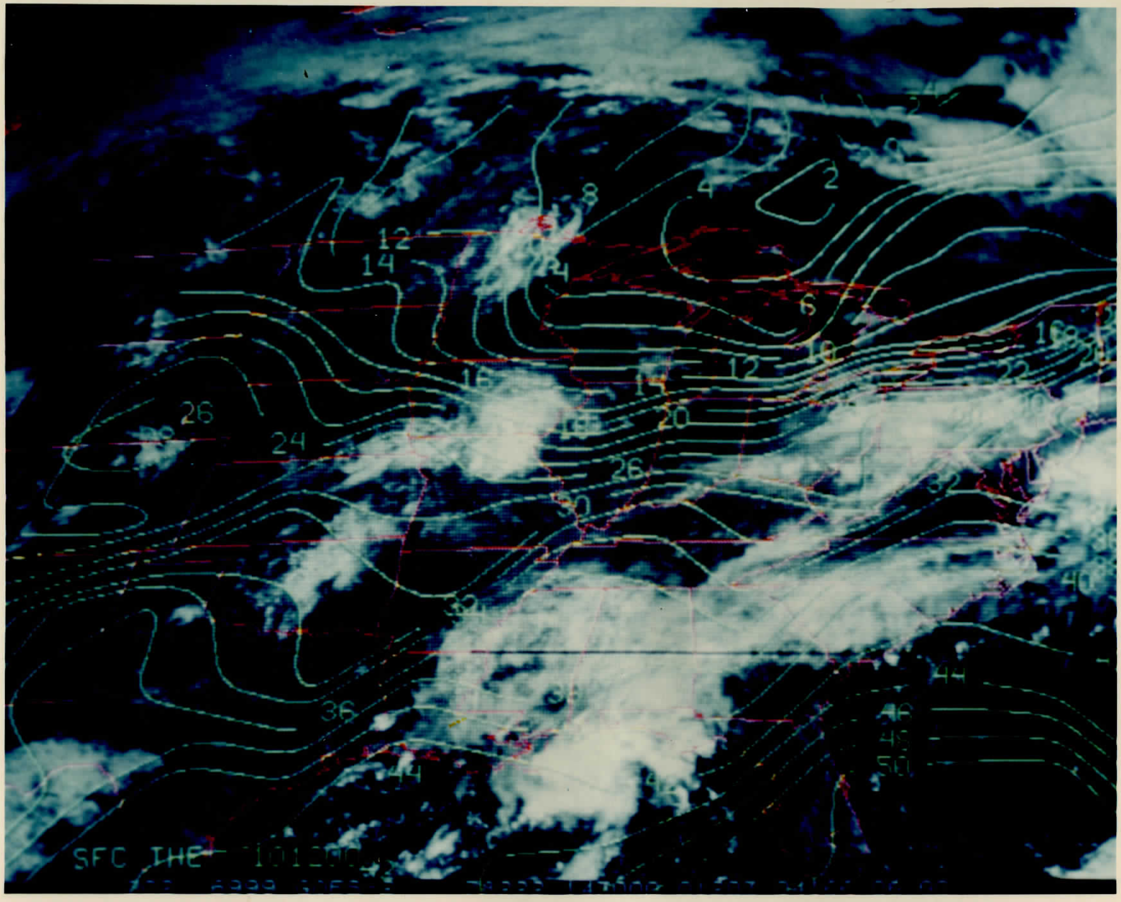


FIGURE 9a. Surface equivalent potential temperature θ_E (situation same as in Fig. 7)

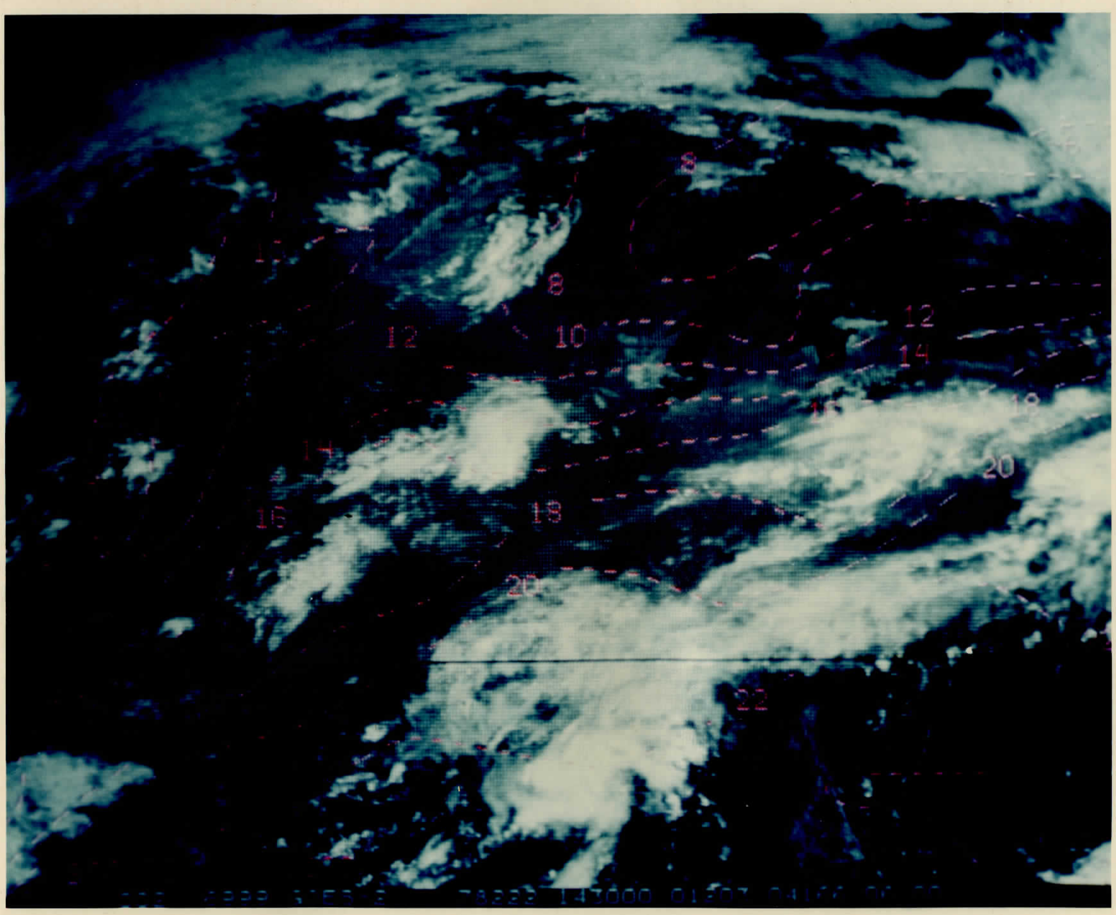


FIGURE 9b. Dew point temperatures

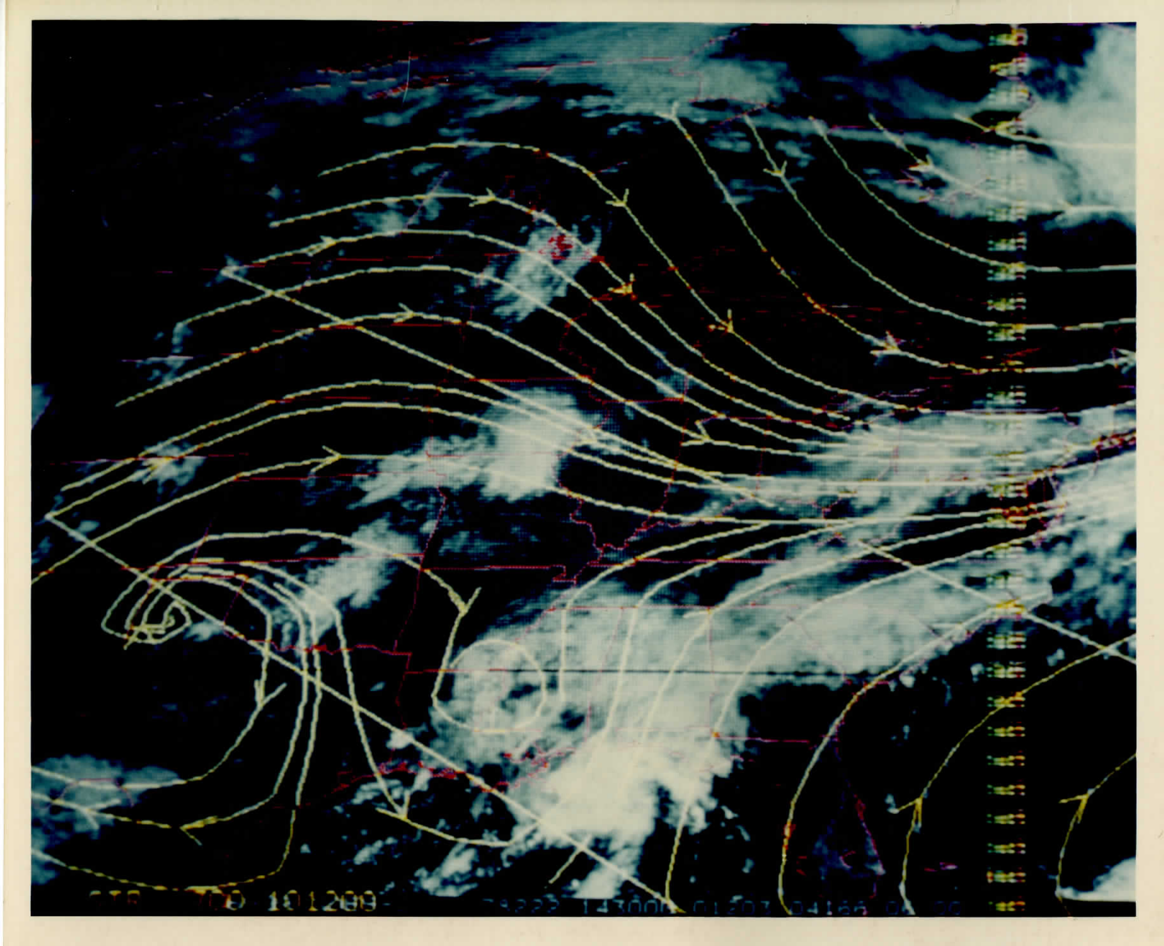


FIGURE 10. Streamlines for 700 mb surface, 1200Z, 10 August 1978

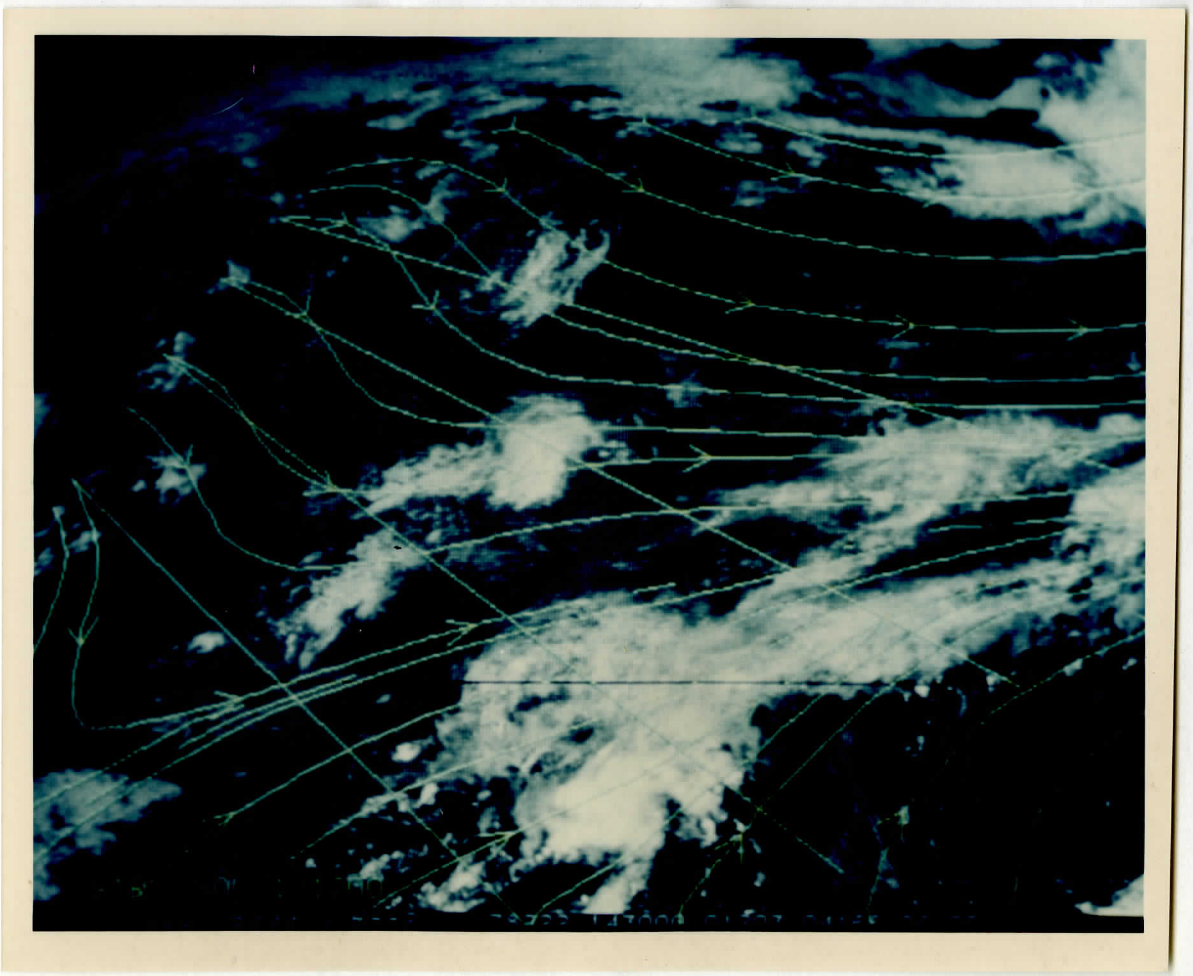


FIGURE 11. Streamlines for 500 mb surface (situation same as in Fig. 10)

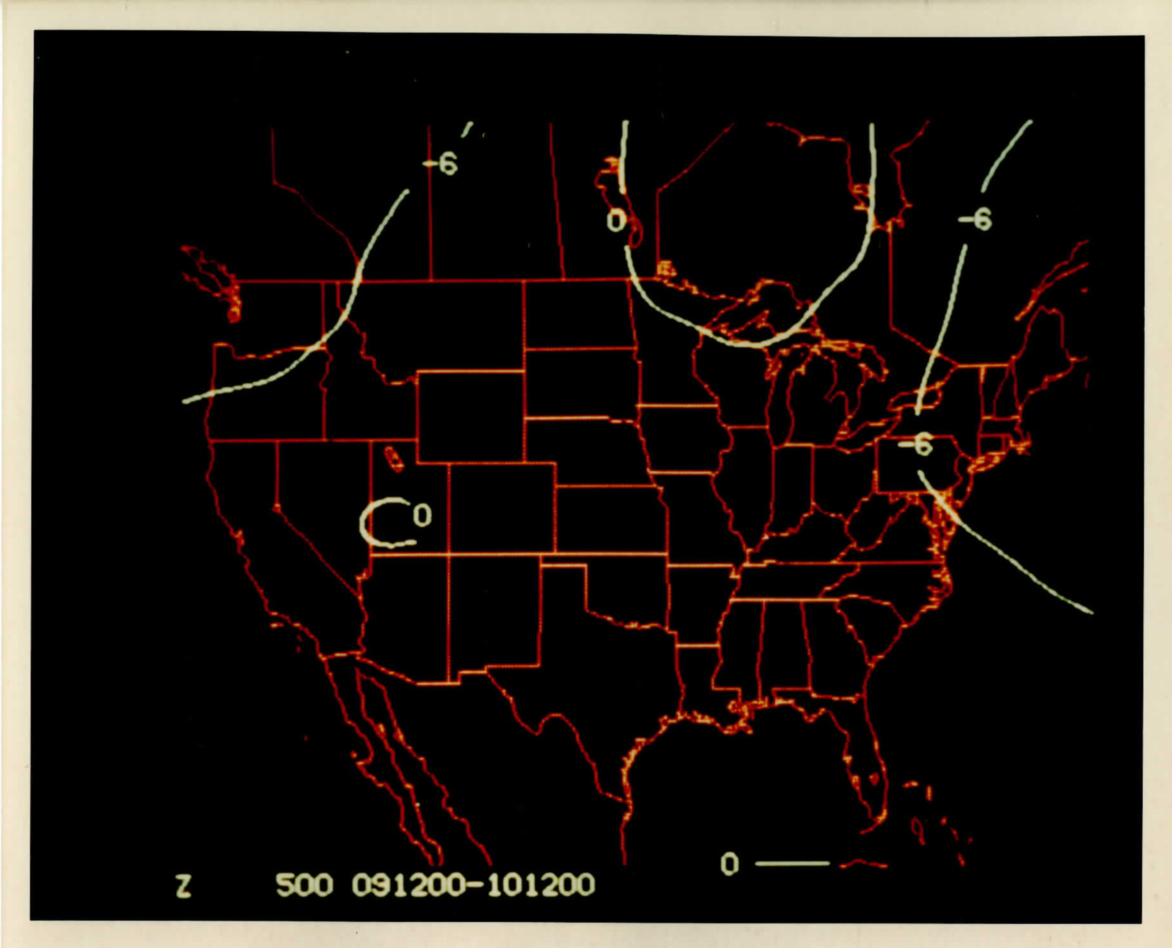


FIGURE 12. 24 Hour height change for 500 mb surface 1200Z, 10 August 1978

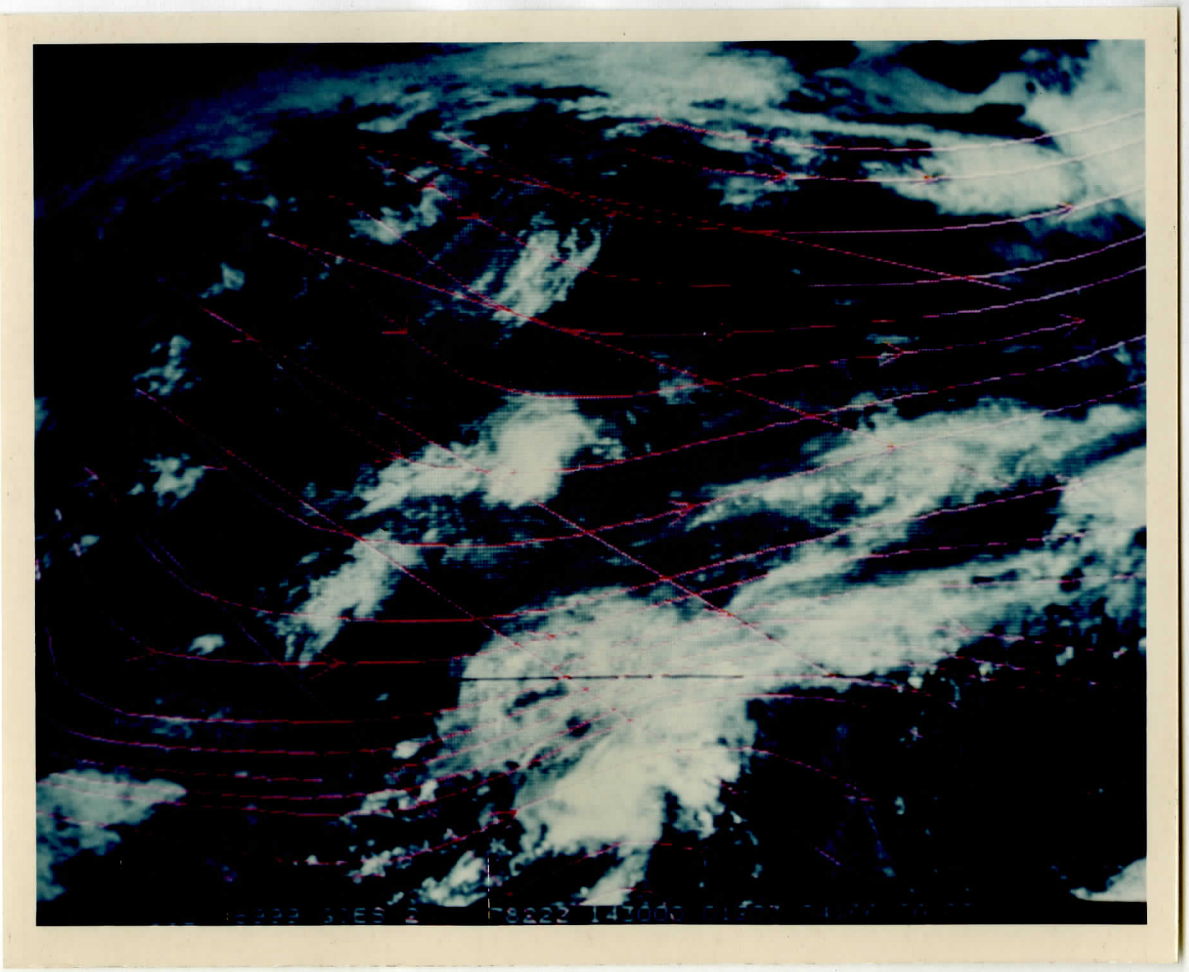


FIGURE 13. Streamlines for 200 mb surface (situation same as Fig. 10)

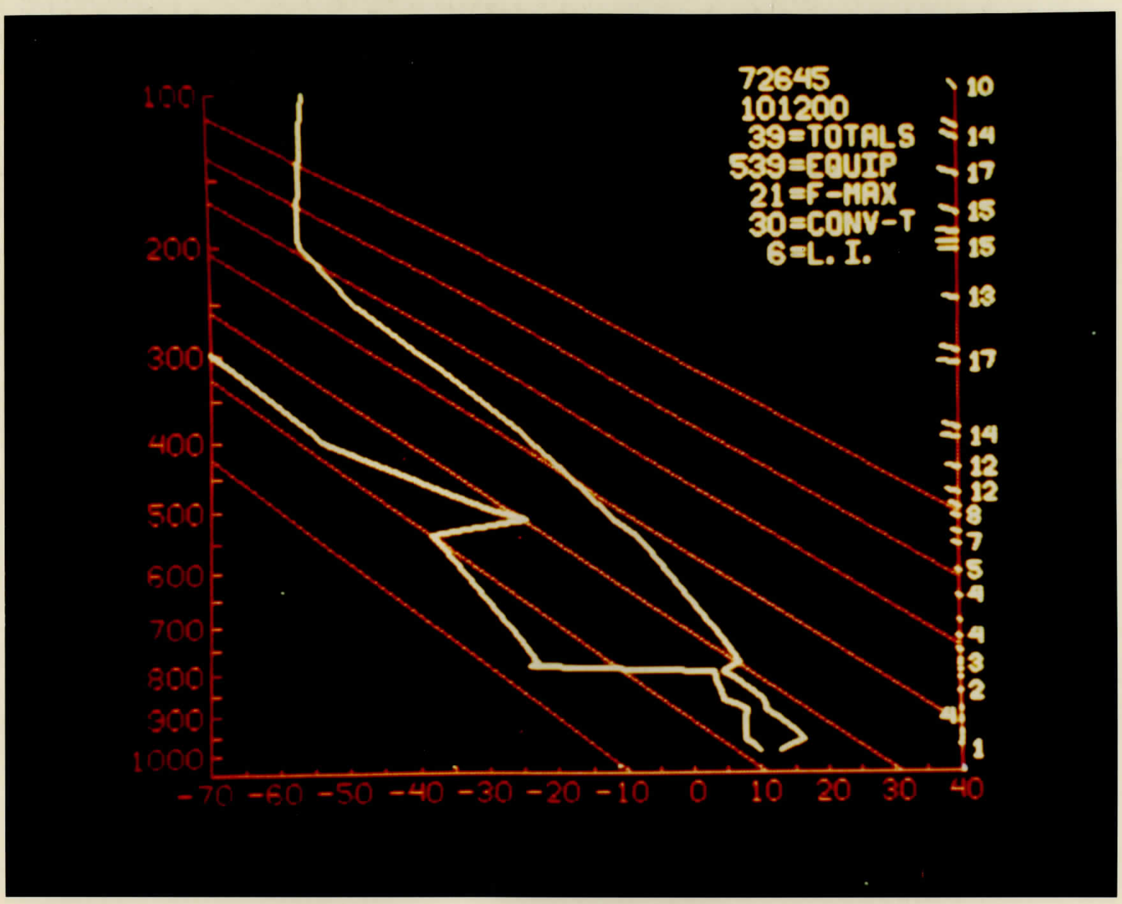


FIGURE 14. Upper air sounding for station 72465, 1200Z, 10 August 1978

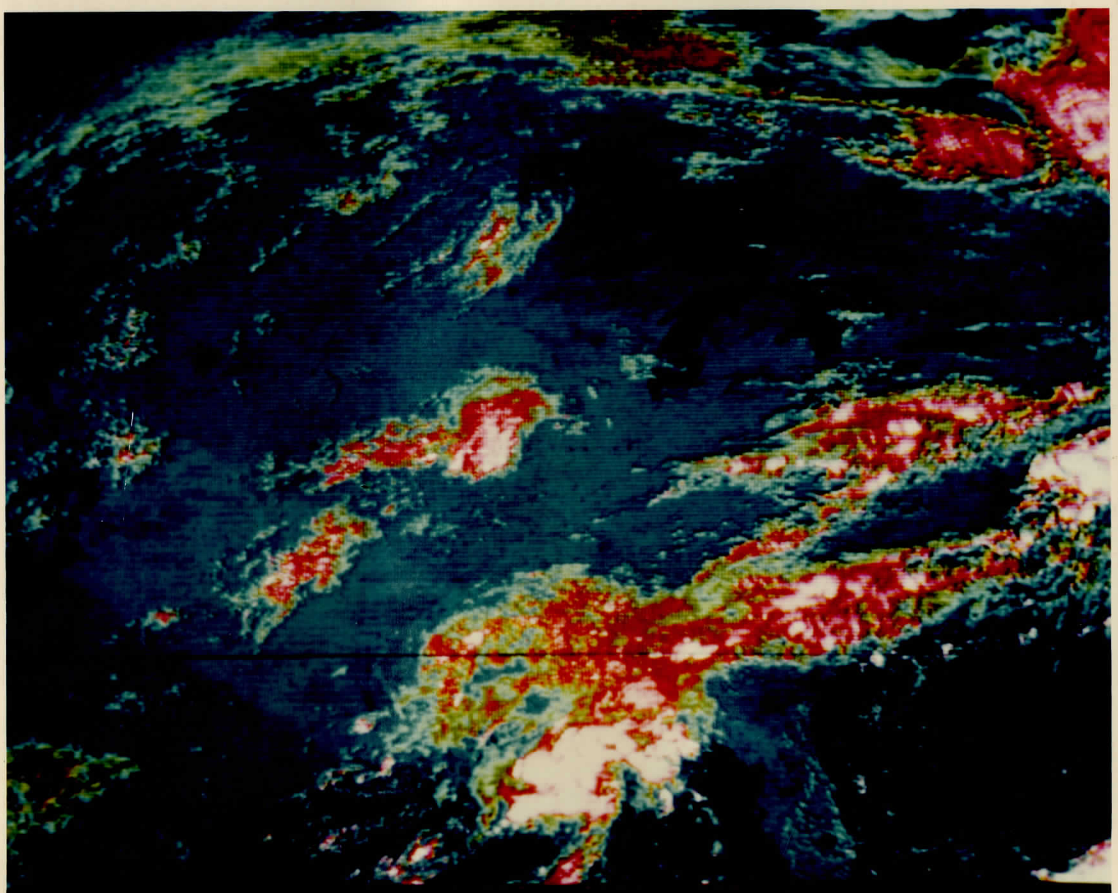


FIGURE 15. Enhanced satellite picture from GOES-2, 1430, 10 August 1978

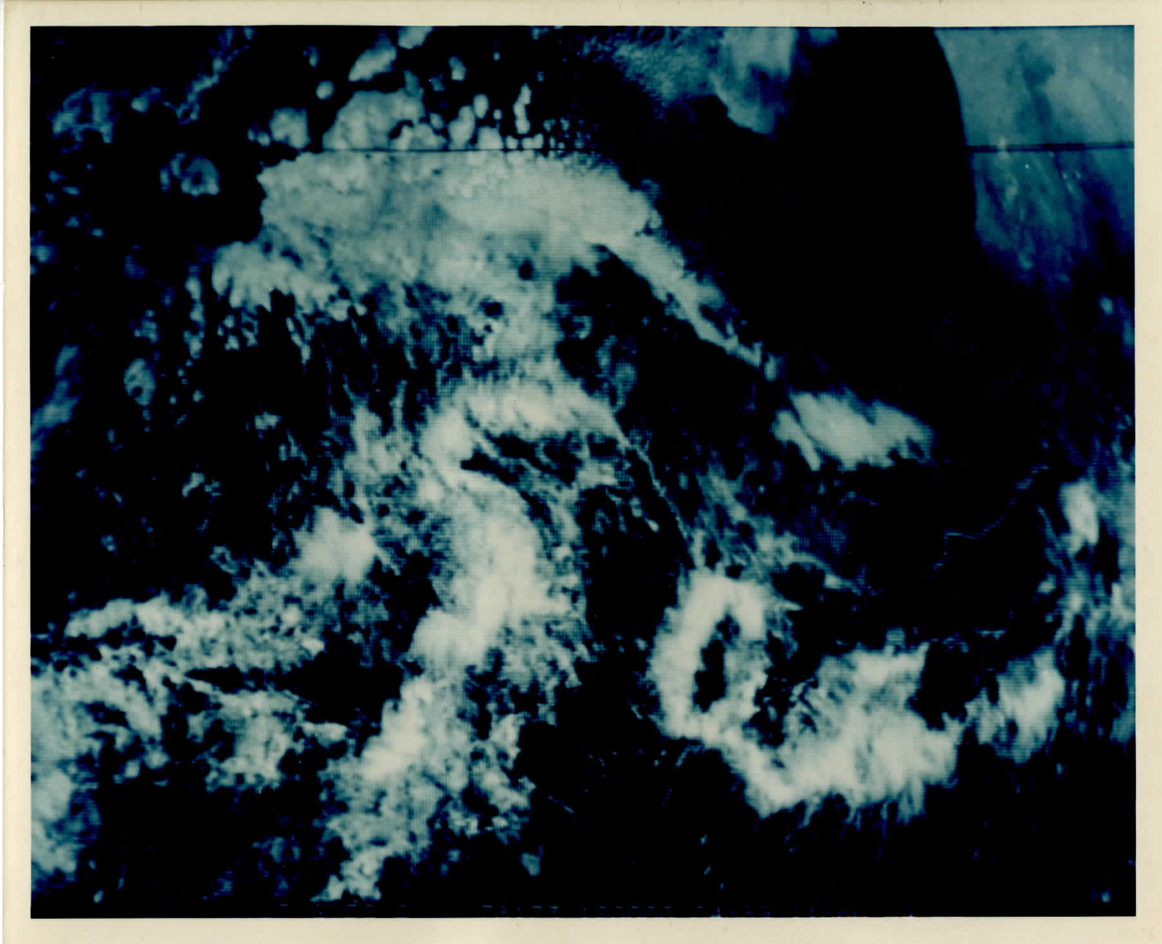


FIGURE 16. GOES-2 satellite picture for 10 August 1978 of coast of West Africa. Center of picture 10°N latitude, 30°W longitude.

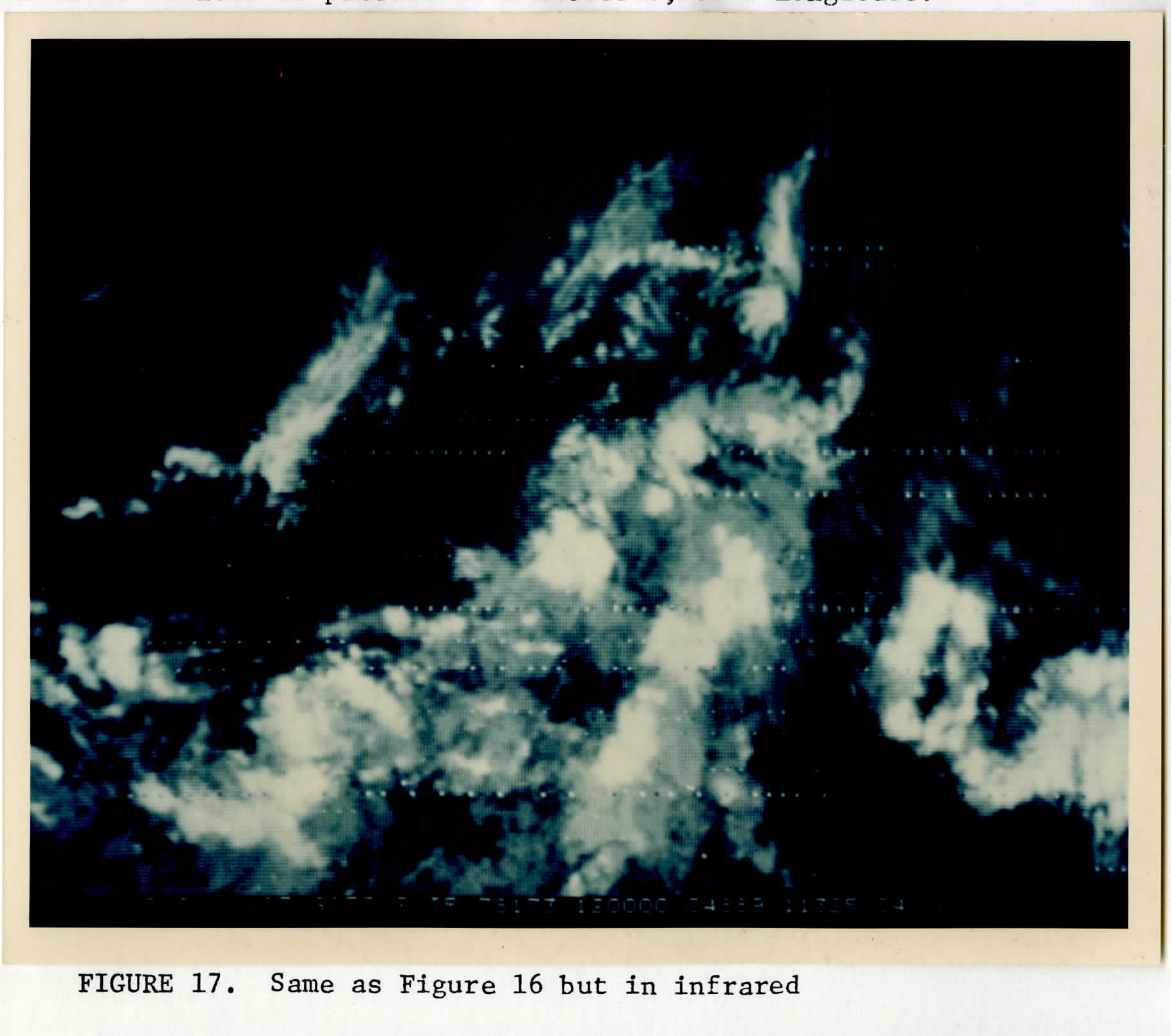


FIGURE 17. Same as Figure 16 but in infrared

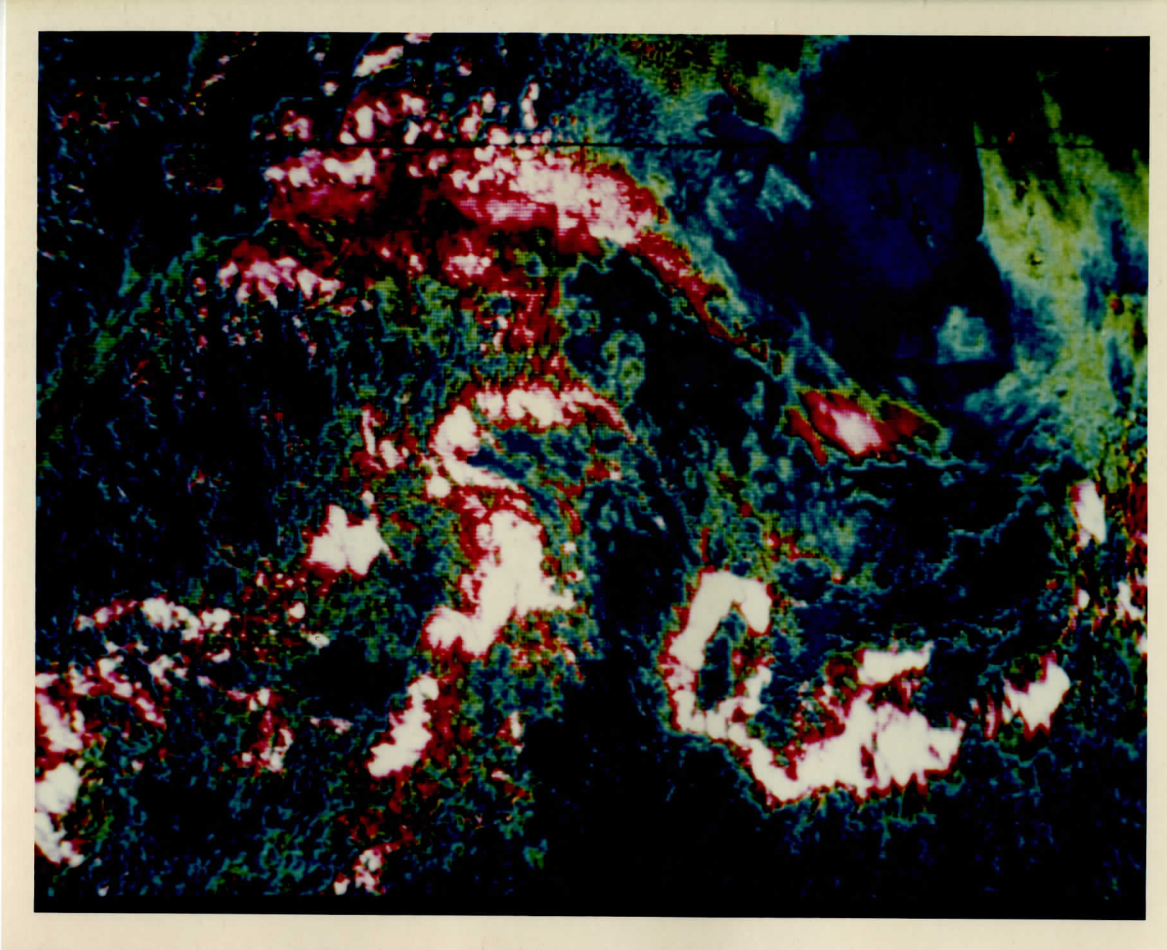


FIGURE 18. Enhanced version of Figure 17

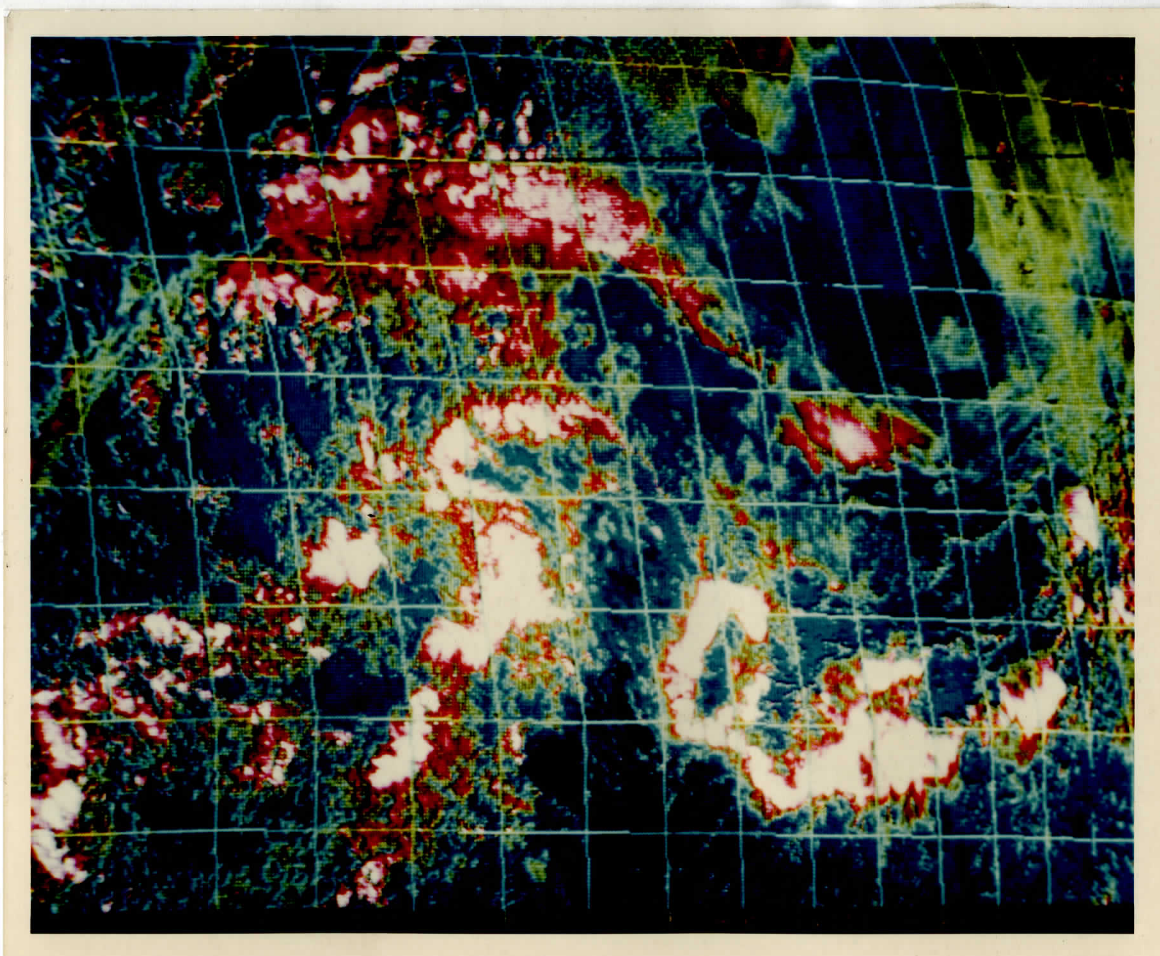


FIGURE 19. Gridded version of Figure 18

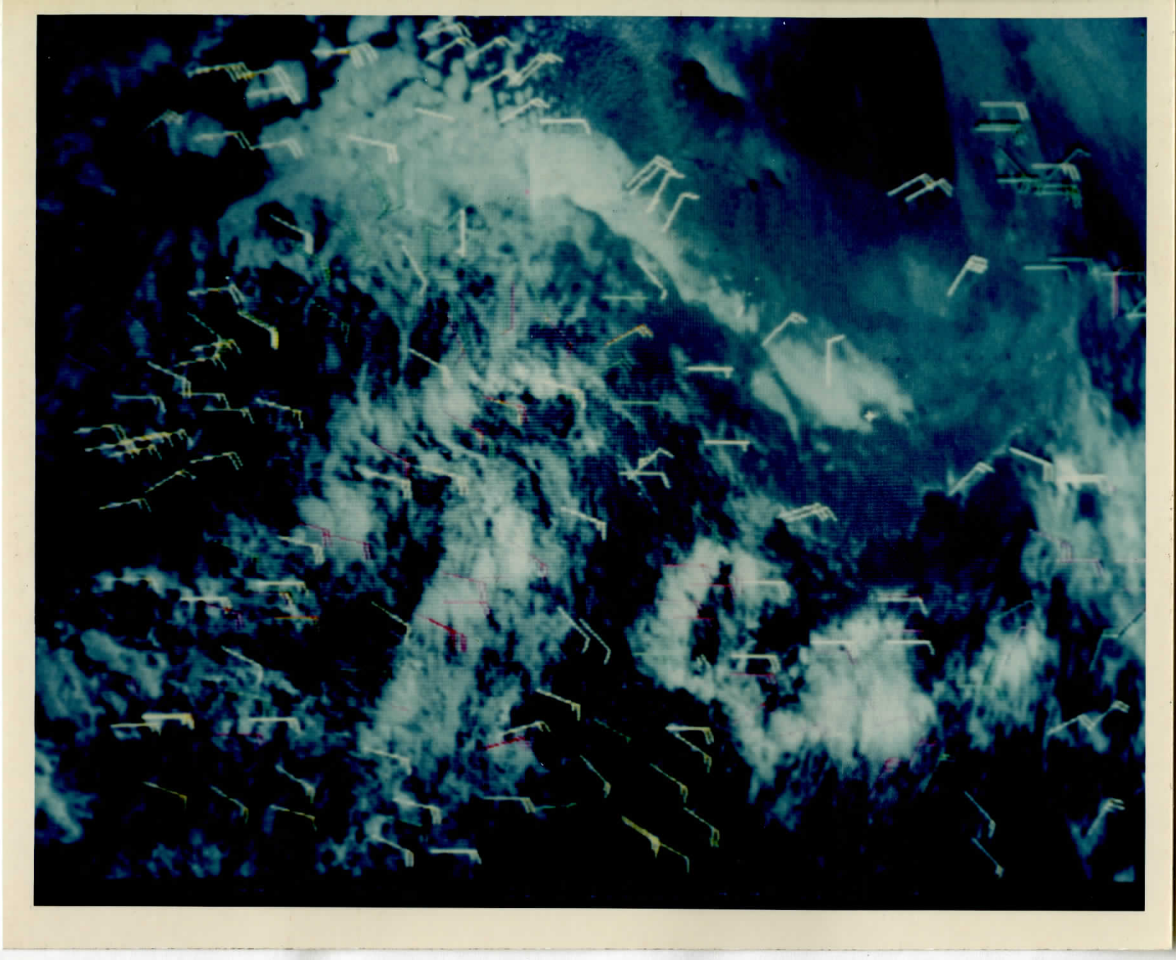


FIGURE 20. Computed cloud motion vectors from satellite data in Fig. 17

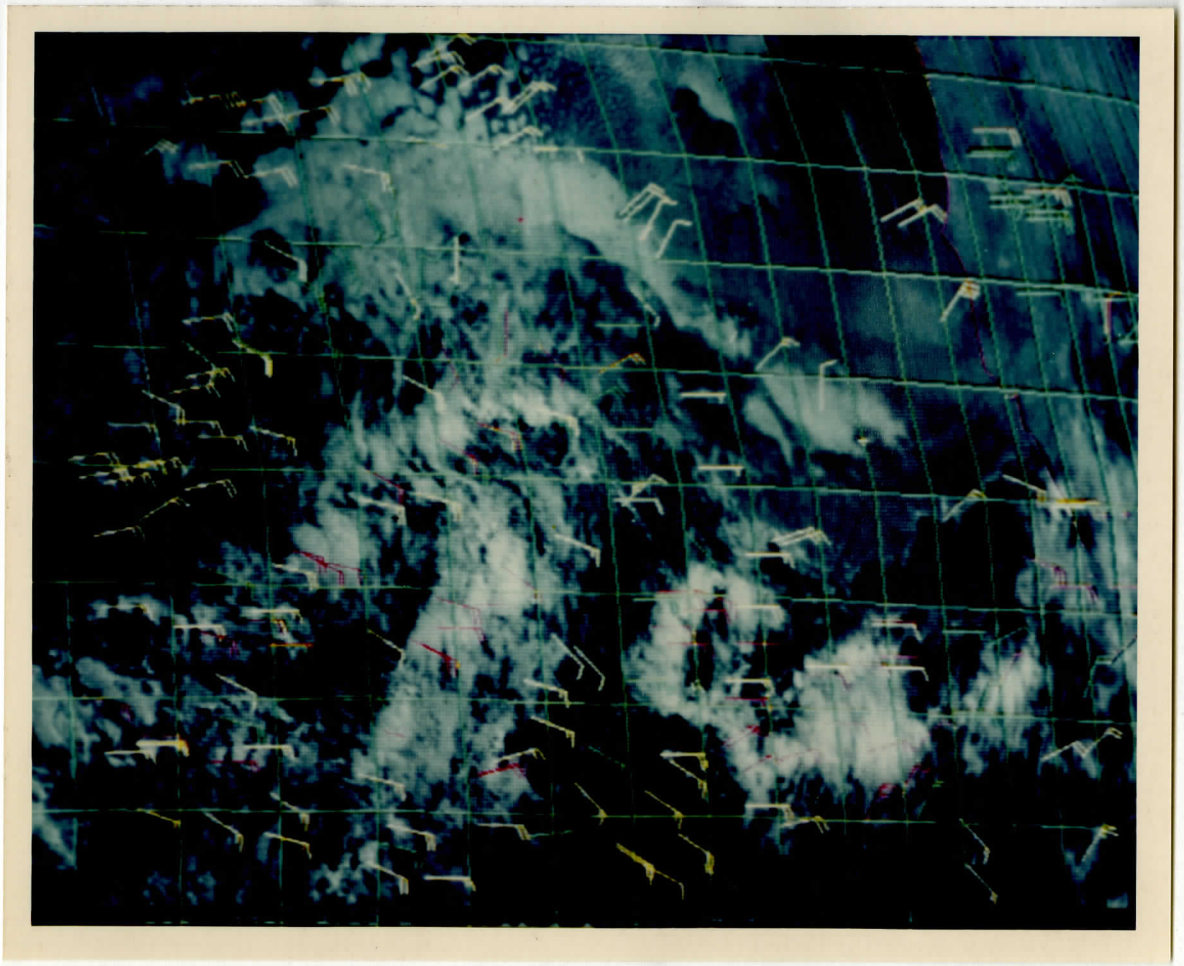


FIGURE 21. Gridded version (2° x 2°) of Figure 20

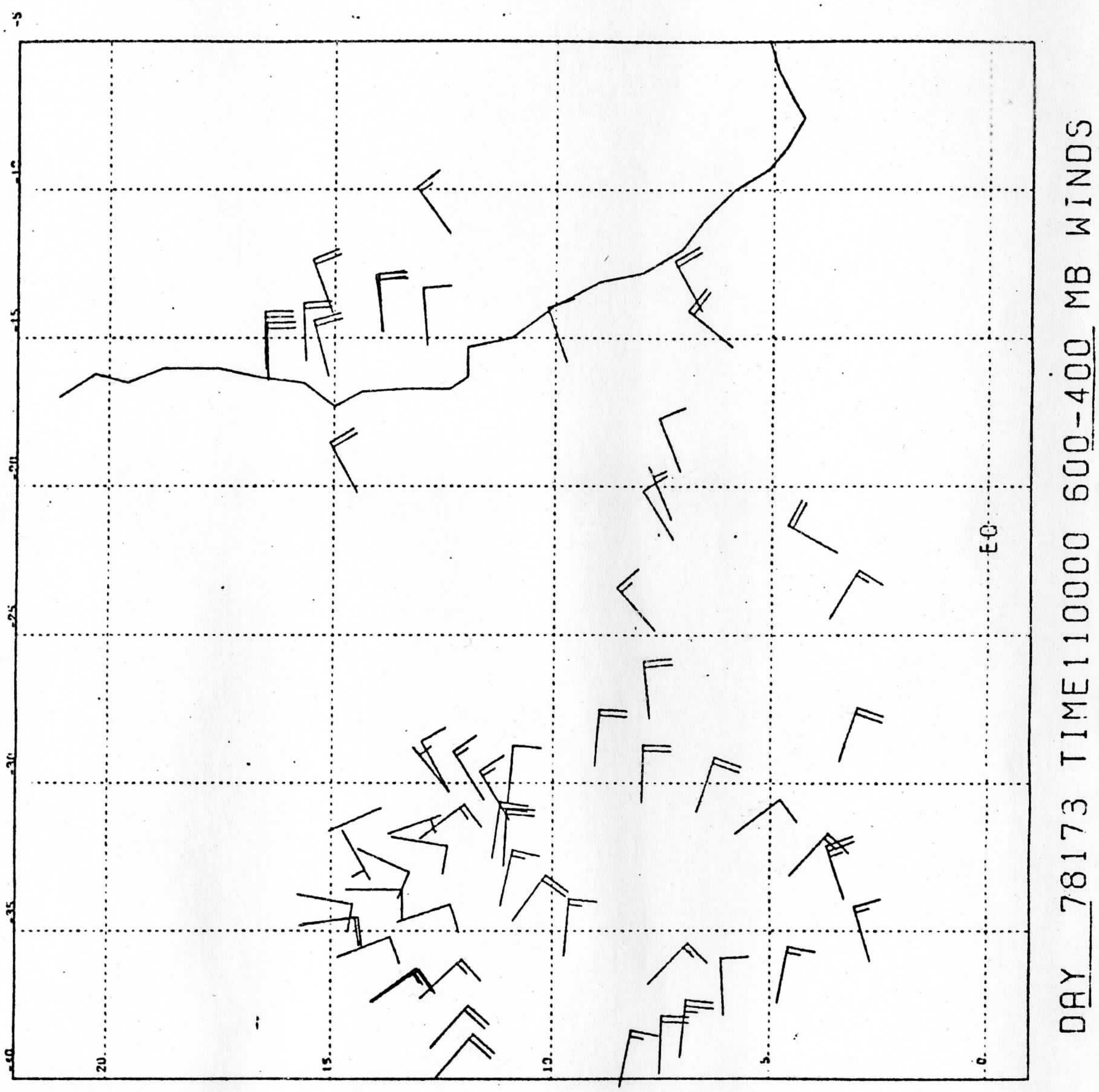
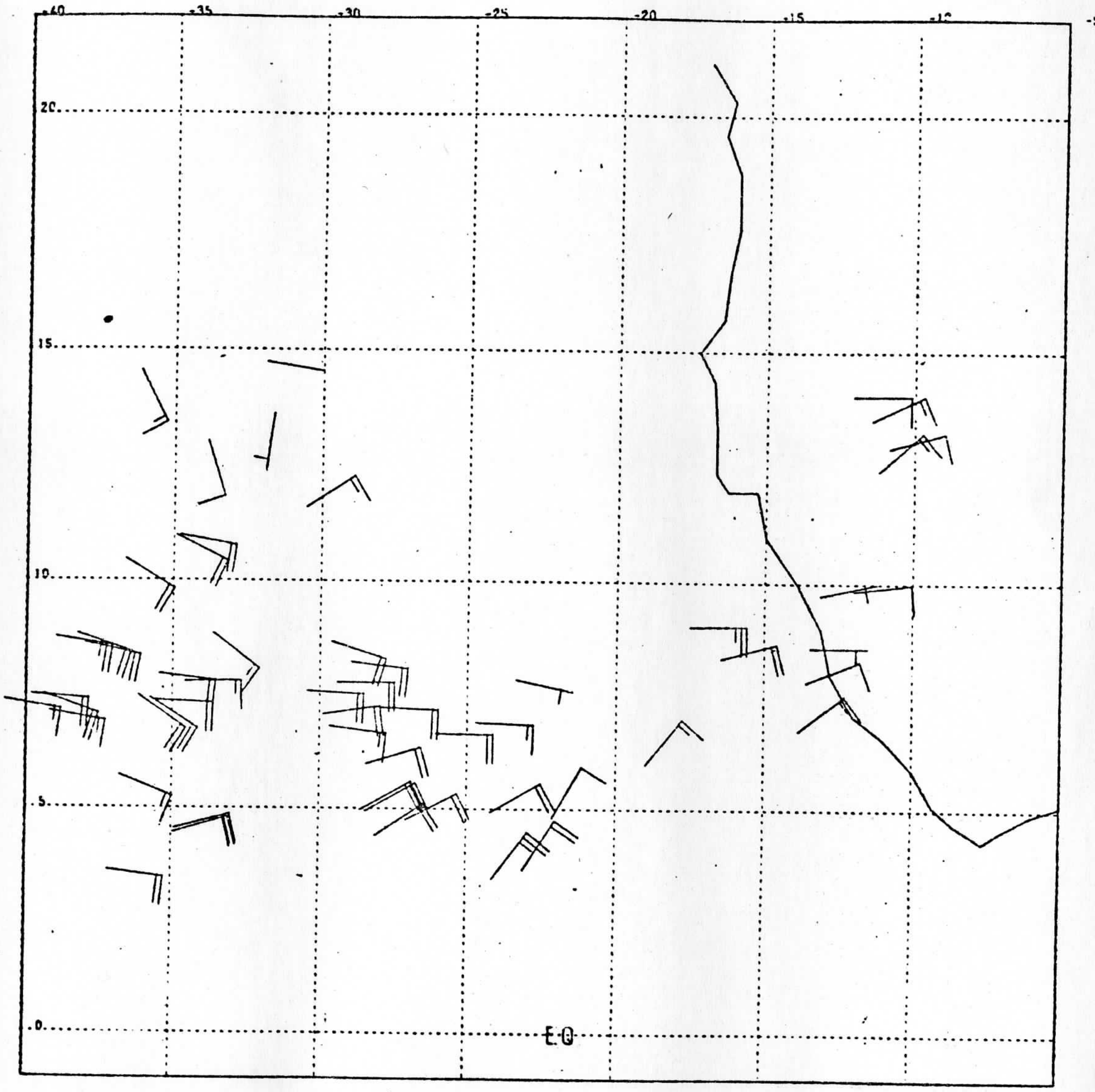


FIGURE 23. Same as Figure 22, but for 600-400 mb winds.



DAY 78173 TIME110000 300-100 MB WINDS

FIGURE 24. Same as Figure 23, but for 300-100 mb winds

TABLE 1.

*** S S E C M C I D A S *** PROGRAM: WINDIO TERMINAL: 026 PROJECT: 5910 DATE:

131	2278173	110000	113000	9	113443	-363847	-7. 29	4. 61	8. 63	122. 31	52. 8	286. 0
132	2278173	113000	120000	9	113718	-364642	-9. 21	4. 48	10. 24	115. 94	46. 1	288. 0
133	2278173	110000	113000	9	121323	-371003	-9. 29	-. 80	9. 32	85. 08	99. 1	282. 0
134	2278173	113000	120000	9	121601	-371709	-9. 64	-. 83	9. 68	85. 08	99. 9	284. 0
135	2278173	110000	113000	9	123724	-390955	-8. 94	1. 37	9. 04	98. 71	88. 2	283. 0
136	2278173	113000	120000	9	124010	-391704	-10. 09	1. 49	10. 20	98. 40	99. 5	283. 0
137	2278173	110000	113000	9	133357	-412617	-10. 09	-2. 78	10. 47	74. 60	52. 0	290. 0
138	2278173	113000	120000	9	133642	-413330	-11. 91	-2. 85	12. 25	76. 54	45. 4	288. 0
139	2278173	110000	113000	6	123751	-412245	-11. 39	-2. 60	11. 68	77. 14	41. 4	268. 0
140	2278173	113000	120000	6	124055	-412758	-9. 12	-1. 99	9. 33	77. 69	39. 7	268. 0
141	2278173	110000	113000	9	61616	-340113	-7. 44	4. 01	8. 45	118. 32	60. 8	277. 0
142	2278173	113000	120000	9	61828	-340232	-9. 97	2. 99	10. 41	106. 69	46. 7	279. 0
143	2278173	110000	113000	9	24252	-334800	-7. 40	5. 10	8. 99	124. 57	15. 7	289. 0
144	2278173	113000	120000	9	24526	-334710	-4. 74	4. 82	6. 76	135. 48	21. 5	290. 0
145	2378173	103000	110000	6	135943	-333655	. 40	4. 11	4. 13	185. 56	99. 9	258. 0
146	2378173	110000	113000	6	140432	-333547	-. 40	4. 47	4. 49	174. 89	99. 9	260. 0
147	2378173	103000	110000	5	125939	-315849	1. 55	4. 44	4. 70	199. 24	99. 9	243. 0
148	2378173	110000	113000	5	130410	-315511	. 49	4. 09	4. 12	186. 83	99. 9	244. 0
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152	2378173	103000	110000	4	150352	-344144	-1. 40	5. 15	5. 34	164. 79	99. 9	263. 0
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159	2378173	110000	113000	4	133436	-365200	-4. 81	5. 23	7. 11	137. 40	. 1	230. 0
160	2378173	103000	110000	4	141421	-353016	-2. 55	4. 21	4. 92	148. 80	. 1	230. 0
161	2378173	110000	113000	4	141903	-353342	-2. 35	4. 52	5. 09	152. 53	. 1	230. 0
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176	2378173	103000	110000	4	94038	-344848	-9. 03	. 52	9. 04	93. 30	. 1	230. 0

TABLE 2a
Lower Level Data, 900-700 mbs

U WIND COMPONENT (M SEC-1)

ANALYZED VALUES

-11.	-9.	-8.	0.	0.	0.	0.	0.
-11.	-6.	-4.	-4.	-8.	-11.	0.	0.
-9.	-10.	-6.	-8.	-6.	-8.	0.	0.
-7.	-8.	-6.	-9.	-6.	-8.	-8.	0.
-7.	-8.	-7.	-10.	-7.	-9.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 2b
Lower Level Data, 900-700 mbs

V WIND COMPONENT (M SEC-1)

ANALYZED VALUES

-4.	-3.	-4.	0.	0.	0.	0.	0.
-5.	3.	-2.	-4.	-4.	-2.	0.	0.
-2.	2.	-1.	-2.	-3.	-4.	0.	0.
1.	1.	2.	1.	-2.	-5.	-5.	0.
3.	3.	2.	1.	4.	-6.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 2c

Lower Level Data, 900-700 mbs

RELATIVE VORTICITY (10-6 SEC-1)

ANALYZED VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	2.	-4.	-9.	-4.	-4.	2.	0.
0.	-2.	-5.	-7.	0.	5.	-4.	0.
0.	2.	-1.	-5.	-6.	-4.	4.	0.
0.	7.	4.	10.	0.	4.	12.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 2d

Lower Level Data, 900-700 mbs

DIVERGENCE (10-6 SEC-1)

0.	0.	0.	0.	0.	0.	0.	0.
0.	2.	-1.	-2.	-3.	12.	10.	0.
0.	5.	-3.	-5.	-2.	8.	12.	0.
0.	-0.	-4.	-2.	-6.	-0.	8.	0.
0.	1.	1.	1.	-1.	2.	4.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 2e

Lower Level Data, 900-700 mbs

STREAM FUNCTION (10 M)

RELATIVE HEIGHT VALUES

2.2	1.9	1.6	1.4	1.4	1.3	.9	.7
1.2	1.1	1.1	1.1	.9	.8	.5	.4
.4	.4	.5	.5	.3	.1	.0	-.0
-.4	-.4	-.3	-.3	-.3	-.4	-.6	-.5
-1.2	-1.2	-1.2	-1.2	-1.1	-1.1	-1.2	-.9
-1.7	-1.7	-1.7	-1.8	-1.6	-1.6	-1.5	-1.3

TABLE 2f

Lower Level Data, 900-700 mbs

U WIND COMPONENT (M SEC-1)

NONDIVERGENT VALUES

-11.	-9.	-8.	-0.	0.	0.	-0.	0.
-11.	-7.	-5.	-4.	-6.	-7.	-4.	-3.
-7.	-11.	-7.	-8.	-4.	-5.	-3.	-4.
-7.	-10.	-7.	-10.	-5.	-5.	-9.	-3.
-6.	-9.	-7.	-10.	-7.	-8.	-2.	-2.
0.	0.	0.	-0.	1.	-0.	0.	0.

TABLE 2g

Lower Level Data, 900-700 mbs

V WIND COMPONENT (M SEC-1)

NONDIVERGENT VALUES

-4.	-3.	-4.	-0.	1.	-3.	-3.	0.
-5.	1.	-2.	-4.	-4.	-5.	-4.	0.
-2.	2.	-0.	-1.	-2.	-1.	1.	0.
1.	1.	1.	0.	-2.	-4.	-3.	0.
3.	3.	0.	1.	2.	-5.	2.	0.
0.	1.	0.	1.	0.	1.	2.	0.

TABLE 2h

Lower Level Data, 900-700 mbs

VELOCITY POTENTIAL (10 M)

RELATIVE HEIGHT VALUES

2.2	1.9	1.6	1.5	1.4	1.3	.9	.7
1.2	1.1	1.1	1.1	.9	.8	.5	.4
.4	.4	.5	.5	.3	.1	.0	-.0
-.4	-.4	-.3	-.3	-.3	-.4	-.6	-.5
-1.2	-1.2	-1.2	-1.2	-1.1	-1.1	-1.2	-.9
-1.7	-1.7	-1.6	-1.7	-1.6	-1.6	-1.4	-1.3

TABLE 2i
Lower Level Data, 900-700 mbs

U WIND COMPONENT (M SEC-1)

DIVERGENT VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	1.	1.	0.	-3.	-4.	4.	0.
0.	1.	2.	-1.	-2.	-3.	3.	0.
0.	2.	1.	0.	-0.	-4.	1.	0.
0.	0.	0.	0.	-0.	-1.	2.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 2j
Lower Level Data, 900-700 mbs

V WIND COMPONENT (M SEC-1)

DIVERGENT VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	1.	-1.	-0.	0.	2.	4.	0.
0.	-0.	-1.	-1.	-1.	-3.	-1.	0.
0.	-1.	1.	1.	0.	-1.	-2.	0.
0.	0.	2.	1.	2.	-1.	-2.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 3a

Middle Level Data, 600-400 mbs

U WIND COMPONENT (M SEC-1)

ANALYZED VALUES

0.	-0.	0.	0.	0.	-11.	0.	0.
-7.	-1.	-1.	-3.	-10.	-11.	-9.	0.
-9.	-8.	-7.	-7.	-5.	-6.	-8.	0.
-8.	-8.	-7.	-7.	-6.	-9.	0.	0.
0.	-10.	-9.	-9.	-7.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 3b

Middle Level Data, 600-400 mbs

V WIND COMPONENT (M SEC-1)

ANALYZED VALUES

0.	5.	0.	0.	0.	-1.	0.	0.
3.	5.	0.	-2.	-3.	-1.	-2.	0.
1.	2.	-1.	-1.	-2.	-1.	-3.	0.
1.	1.	2.	1.	-5.	-3.	0.	0.
0.	-1.	1.	3.	-0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 3c
Middle Level Data, 600-400 mbs

RELATIVE VORTICITY (10-6 SEC-1)

ANALYZED VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	-10.	-13.	-10.	-5.	5.	-6.	0.
0.	-8.	-8.	-5.	3.	0.	9.	0.
0.	-1.	-1.	-7.	-6.	9.	10.	0.
0.	8.	9.	5.	3.	8.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 3d
Middle Level Data, 600-400 mbs

DIVERGENCE (10-6 SEC-1)

0.	0.	0.	0.	0.	0.	0.	0.
0.	8.	-1.	-7.	-5.	1.	13.	0.
0.	6.	-0.	-0.	3.	-1.	3.	0.
0.	3.	-2.	-2.	-2.	4.	5.	0.
0.	-7.	2.	2.	3.	4.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 3e

Middle Level Data, 600-400 mbs

STREAM FUNCTION (10 M)

RELATIVE HEIGHT VALUES

.9	1.0	1.2	1.3	1.5	1.8	1.9	1.6
.4	.8	1.0	1.1	1.0	1.0	1.2	1.2
-.3	.2	.4	.4	.3	.3	.3	.7
-1.1	-.7	-.5	-.2	-.3	-.5	-.3	.3
-1.5	-1.5	-1.3	-1.1	-1.0	-1.0	-.7	-.3
-1.6	-1.8	-1.7	-1.6	-1.4	-1.4	-1.3	-1.1

TABLE 3f

Middle Level Data, 600-400 mbs

U WIND COMPONENT (M SEC-1)

NONDIVERGENT VALUES

0.	-0.	-0.	-0.	0.	-11.	0.	0.
-5.	-1.	-4.	-3.	-11.	-10.	-6.	-0.
-9.	-7.	-6.	-7.	-8.	-9.	-5.	2.
-7.	-7.	-8.	-7.	-5.	-10.	-0.	0.
-2.	-9.	-6.	-8.	-7.	-3.	0.	1.
0.	-0.	0.	0.	0.	0.	-0.	0.

TABLE 3g
Middle Level Data, 600-400 mbs

V WIND COMPONENT (M SEC-1)

NONDIVERGENT VALUES

0.	3.	0.	2.	0.	2.	-0.	0.
3.	5.	-1.	-2.	-4.	1.	0.	-0.
1.	2.	-2.	-2.	-3.	-5.	-2.	-0.
1.	3.	2.	2.	-5.	-5.	-1.	-0.
0.	1.	2.	3.	1.	1.	-0.	-0.
0.	-2.	1.	0.	2.	0.	-1.	0.

TABLE 3h
Middle Level Data, 600-400 mgs

VELOCITY POTENTIAL (10 M)

RELATIVE HEIGHT VALUES

.9	1.0	1.2	1.3	1.5	1.8	1.9	1.6
.4	.8	1.0	1.1	1.0	1.0	1.2	1.2
-.3	.2	.4	.4	.3	.3	.3	.7
-1.1	-.7	-.5	-.2	-.3	-.5	-.3	.3
-1.5	-1.5	-1.3	-1.1	-1.0	-1.0	-.7	-.3
-1.6	-1.8	-1.7	-1.6	-1.4	-1.4	-1.3	-1.1

TABLE 3i
Middle Level Data, 600-400 mbs

U WIND COMPONENT (M SEC-1)

DIVERGENT VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	-0.	3.	-0.	1.	-1.	-3.	0.
0.	-1.	-1.	-0.	3.	4.	-2.	0.
0.	-1.	1.	-1.	-1.	1.	0.	0.
0.	-1.	-2.	-1.	-0.	3.	-0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 3j
Middle Level Data, 600-400 mbs

V WIND COMPONENT (M SEC-1)

DIVERGENT VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	-0.	1.	1.	1.	-2.	-2.	0.
0.	-0.	1.	2.	1.	4.	-1.	0.
0.	-2.	-0.	-1.	0.	2.	1.	0.
0.	-2.	-1.	-0.	-1.	-1.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4a

Upper Level Data, 300-100 mbs

U WIND COMPONENT (M SEC-1)

ANALYZED VALUES

0.	0.	0.	0.	0.	0.	0.	0.
-7.	-3.	-1.	0.	0.	-7.	-6.	0.
-10.	-10.	-8.	-7.	-9.	-7.	-4.	0.
-9.	-9.	-10.	-9.	-6.	-7.	-6.	0.
0.	-10.	0.	-9.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4b

Upper Level Data, 300-100 mbs

V WIND COMPONENT (M SEC-1)

ANALYZED VALUES

0.	0.	0.	0.	0.	0.	0.	0.
5.	4.	0.	0.	0.	-1.	-1.	0.
3.	3.	1.	0.	-1.	-0.	-0.	0.
0.	0.	-2.	-4.	-5.	-3.	-2.	0.
0.	-1.	0.	-8.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4c
Upper Level Data, 300-100 mbs

RELATIVE VORTICITY (10-6 SEC-1)

ANALYZED VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	-14.	-11.	-7.	-9.	-8.	-3.	0.
0.	-8.	-10.	-10.	-6.	-1.	1.	0.
0.	-3.	3.	-4.	9.	9.	6.	0.
0.	8.	2.	8.	13.	7.	5.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4d
Upper Level Data, 300-100 mbs

DIVERGENCE (10-6 SEC-1)

0.	0.	0.	0.	0.	0.	0.	0.
0.	3.	2.	1.	-6.	-6.	7.	0.
0.	5.	4.	3.	4.	6.	7.	0.
0.	3.	1.	11.	1.	-0.	6.	0.
0.	0.	-1.	-3.	3.	-3.	-2.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4e

Upper Level Data, 300-100 mbs

STREAM FUNCTION (10 M)

RELATIVE HEIGHT VALUES

1.2	1.1	1.0	1.0	1.0	1.1	1.0	.8
.9	1.1	1.1	1.0	.9	.8	.7	.6
.1	.5	.6	.6	.3	.2	.1	.1
-.5	-.2	-.2	-.3	-.6	-.6	-.6	-.4
-.7	-.9	-.8	-1.0	-1.2	-1.1	-.9	-.7
-.9	-1.2	-1.0	-1.3	-1.2	-1.2	-1.1	-1.0

TABLE 4f

Upper Level Data, 300-100 mbs

U WIND COMPONENT (M SEC-1)

NONDIVERGENT VALUES

0.	-0.	-0.	-0.	-0.	0.	0.	0.
-6.	-2.	-2.	-1.	-2.	-4.	-6.	-2.
-8.	-8.	-8.	-7.	-8.	-8.	-6.	-3.
-7.	-9.	-8.	-9.	-9.	-6.	-6.	-3.
0.	-9.	-1.	-7.	0.	-1.	0.	-1.
0.	-0.	0.	-0.	0.	-0.	0.	0.

TABLE 4g
Upper Level Data, 300-100 mbs

V WIND COMPONENT (M SEC-1)

NONDIVERGENT VALUES

0.	-2.	-0.	-1.	1.	1.	-2.	0.
5.	2.	-2.	-2.	-3.	-3.	-4.	-0.
3.	2.	1.	-2.	-2.	-2.	-1.	0.
0.	2.	-1.	-2.	-4.	-1.	0.	0.
0.	2.	0.	-4.	1.	1.	2.	0.
0.	0.	1.	-1.	2.	-0.	1.	0.

TABLE 4h
Upper Level Data, 300-100 mbs

VELOCITY POTENTIAL (10 M)

RELATIVE HEIGHT VALUES

1.3	1.2	1.0	1.0	1.0	1.1	1.1	.9
.9	1.1	1.1	1.0	.9	.8	.7	.6
.1	.5	.6	.6	.3	.2	.1	.1
-.5	-.2	-.2	-.3	-.6	-.6	-.5	-.3
-.7	-.9	-.8	-1.0	-1.1	-1.1	-.9	-.7
-.9	-1.2	-1.0	-1.3	-1.2	-1.2	-1.1	-1.0

TABLE 4i
Upper Level Data, 300-100 mbs

U WIND COMPONENT (M SEC-1)

DIVERGENT VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	-0.	0.	1.	2.	-3.	-1.	0.
0.	-2.	0.	-1.	-0.	0.	2.	0.
0.	-0.	-2.	-0.	4.	-2.	1.	0.
0.	-1.	1.	-1.	-0.	1.	-0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

TABLE 4j
Upper Level Data, 300-100 mbs

V WIND COMPONENT (M SEC-1)

DIVERGENT VALUES

0.	0.	0.	0.	0.	0.	0.	0.
0.	2.	2.	2.	3.	2.	3.	0.
0.	0.	0.	3.	2.	2.	0.	0.
0.	-1.	-1.	-2.	-1.	-2.	-2.	0.
0.	-2.	-0.	-4.	-1.	-1.	-2.	0.
0.	0.	0.	0.	0.	0.	0.	0.