KEY SCIENTIFIC QUESTIONS AND THE ROLE OF SATELLITES

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Traditionally, NSF has not strongly supported activities in the satellite area. In fact, when I first came to NSF some fifteen years ago, we purposely did not support research that dealt with satellites. We transferred those proposals to NASA and what is now NOAA/NESS. Then GARP, the Global Atmospheric Research Program, came along, and the situation changed. It is still true, though, that much of the expertise resides in NASA and NOAA and scientists which they support.

I have chosen to look at some of the research opportunities that are currently available from geostationary satellite data, especially from MONEX during the Global Weather Experiment; to look at the cloud configurations that are now known as Mesoscale Convective Complexes; to say something about the International Cloud Climatology Program; and finally to look at some of the data that oceanographers need that are derived from satellite data on ocean winds.

During the Global Weather Experiment, the U.S. moved a geostationary satellite over the Indian Ocean to fill the position that the Russian satellite did not occupy. You have already seen several diagrams of the coverage. Fig. 1, taken from T.N. Krishnamurti's 1979 Atlas, shows a fully developed monsoon circulation on 27 June 1979 at 850 mbars. Data on this map come from various sources: dropwindsondes, constant level balloons, ships and rawinsondes, but over the Indian Ocean and the Arabian Sea, almost all of the data are from satellite derived winds. About 99% are from that source.

I will not have time to show a film that I have on the development of the 1979 monsoon, but I will describe it. On the 14th of June, a vortex began to develop in the eastern part of the Arabian Sea and then moved off to the west. At the same time, the flow intensified. That was the onset of the monsoon of 1979. The film shows the whole evolution of this flow, and, of course, the onset of rains around the 18th of June over central India is very important. The circulation just prior to this period was characterized by an explosive development of this tropical storm called the onset vortex. The storm moved westward, bringing in, to the north and to the west, strong moist westerlies with it and thus the monsoon began.

In most years the Indian monsoon is accompanied by the formation of an intense vortex like this one of 1979. Detailed examination of the onset vortex and the commencement of heavy monsoon rains over central India has revealed that the kinetic energy of the winds over the Arabian Sea increases ten-fold about one week prior to the occurrence of the rains. Krishnamurti calculated the day-by-day changes of atmospheric kinetic energy, which is a measure of the wind speed. It was expected that the winds would increase over the Arabian Sea prior to the rains, but the sharp and intense increase that occurred one week before the rains began was unexpected. Remember that was for 1979. Now we may have an element that could be used as a predictor for the monsoon onset about a week in advance. That would be quite important to the people in that part of the world.

Satellite cloud vectors are also used to initialize and verify model

simulations. These same data provided the inspiration for an attempt to predict the life-cycle of the Arabian Sea cyclone and its impact on monsoon onset and the attendant rainfall. Again, predictions were based on a model designed by T. N. Krishnamurti. The work was accomplished by Dr. Ramanathan, a visiting scientist from India. The rainfall predicted up to five days in advance bore a close resemblance to the actual distribution of rain along the west coast of India. The potential societal and economic impact on India of useful rain predictions is staggering.

That these wind fields are now being used to study the monsoon in some detail is gratifying. I am sure we are going to see a great deal more work done in this area. After all, the data have just become available from MONEX. The next five years will see an explosive development of research associated with this work.

Another result that comes from these cloud-derived wind fields is shown in Fig. 2. It is the average of the July 1979 satellite winds averaged from daily values at 900 mb. It was done by John Young and his group from the University of Wisconsin. These data compare favorably with those of Findlater. Wind fields, such as the one shown in the first figure, can be used to calculate other fields such as vorticity, shown in Fig. 3a, and also the geopotential field, shown in Fig. 3b. The geopotential field has been computed using the equations of motion with parameterized friction. The results compare favorably with Hastenrath's 70-year climatology of mean surface pressure in the region. Thus, the satellite wind fields become the grist for research in several important areas.

The next area that I would like to say a few words about is that of Mesoscale Convective Complexes. This is the work basically of Maddox and Frisch of NOAA's Environmental Research Laboratories (ERL). It is based on Maddox's dissertation from CSU. There is a common tendency for clouds in all parts of the world to organize on the mesoscale and yet there is a serious deficiency in understanding the fundamental factors that govern this organization. With the availability of detailed infrared imagery from geostationary satellites, studies have been made, this being one of them, where a previously unrecognized large organized mesoscale convective weather system has been identified. These are now called Mesoscale Convective Complexes. (See Fig. 4.) These systems seem to be generated when a number of individual thunderstorms are formed in a region which is favorable for convection. Regional modification of the environment takes place, which subsequently allows the organization of large mesoscale systems. This is shown in the next series of Figures. Fig. 5a at 0030Z, shows the beginning of some convective activity. Fig. 5b, 3½ hours later, indicates the broadening of this activity. Finally, another 4 hours later, Fig. 5c, the coming together of very large systems, has been identified from the satellite images. The MCC is important because it is the dominant weather system that produces precipitation and severe weather (tornadoes, floods, and so forth) during the growing season over the central U.S. Since they are organized in a distinctly nonrandum manner, on scales that are definitely not subgrid in nature, they really had not been seen until satellite observation made them apparent. Now it is very important that we begin to utilize this information and get it into the operational forecast system. That is the work that is being done at ERL. It is very important that we understand the system, that we understand the physics of the system. Once we understand the life cycle, the meteorological characteristics -- the up and down scale environmental interactions -- we may be able to parameterize them into large scale models. As mesoscale processes are studied more and more, we will continue to hear more about these things.

The third area I would like to touch on briefly is called the Interna-

tional Satellite Cloud Climatology Project. (See Fig. 6 for details.) In 1974, the Joint Organizing Committee for GARP (JOC) study pointed out two major stumbling blocks likely to limit progress in climate modeling. One is an understanding of cloud radiation and the other is an understanding of ocean processes. When the World Climate Research Program was developed, these two areas -- the effect of clouds on radiation budget of the climate and on ocean processes -- were again identified as major stumbling blocks. In 1980, at the first session of the Joint Scientific Committee (JSC), which is the overall guiding committee for the World Climate Research Program, the importance of cloudiness and radiation related to the World Climate Research Program were restated. These include: the sensitivity of climate to cloud radiation feedback, the prediction problem of cloud generation in climate models, empirical studies of the influence of clouds on climate, and the establishment of an adequate cloud climatology. The major questions concerning clouds and climate are simply stated: ..."Will changes in cloudiness cause changes in climate?" and "Will changes in climate cause changes in cloudiness?" People have ideas, but the answers to these questions are not in.

An International Satellite Cloud Climatology Project (ISCCP) has been proposed for the period 1983 to 1987, whose goal is to acquire a global data set of reduced radiances and cloudiness parameters of manageable proportions for a period of about five years. The quantity of data is potentially staggering, but that problem is being worked on and, hopefully, will be under control. Figs. 7a and 7b describe the program. In 1983, we intend to begin to collect satellite radiance data from U.S. satellites and to accelerate our national research. Tests using the FGGE data that already exists will be run to determine methods to get cloud information from radiances and to develop data handling schemes. The required global cloud climatology data will involve an understanding of the interdependence of clouds and climate. We will have to upgrade our climate models. We will have to do a lot of analyses, monitoring and making use of the data we already have for testing purposes. Fig. 8 indicates what the data requirements are. Fig. 9 shows the coverage of the five geostationary satellites. Fig. 10 is a time table. Note that India expects to launch its satellite in May or April of 1982. When that satellite goes up, there will be coverage from five geostationary satellites. The Chinese also have plans to launch a satellite over the Indian Ocean.

The data processing is a tremendously large job. Fig. 11 gives some idea of who the interested parties are that would be involved in such an activity. You can see that there is a good distribution of countries and of institutions around the world that are interested. The types of data needed for this project are summarized in Fig. 12.

Fig. 13 is the summary of the importance of clouds to climate prediction - why we really need this information. Let me just emphasize: the understanding of the role of clouds in climate and the proper representation of cloud radiation feedback in models is of primary importance in climate prediction. That is really why we are involved. Fig. 14 asks, "Why wait 9 years and why now?" It turns out that we did have some global coverage during the Global Weather Experiment, but it has lapsed. Because of some new computers and other hardware, now is a good time. The interest of the community is beginning to peak again in this particular area. Another important consideration is that a mechanism, the World Climate Research Program, now exists and is the vehicle by which such a project can be carried out.

The last area that I want to discuss is one that deals more with oceanography than with meteorology. We must keep in mind that meteorological satellites provide the data. In the summer of 1978, NASA launched SEASAT, which was equipped with several experimental

instruments. This satellite operated for one hundred days over fifteen hundred orbits. One of the major instruments on board was a scatterometer -- a radar instrument capable of producing estimates of wind speed and direction in an ocean patch about 50 km on a side. Some of the data from SEASAT have been examined carefully by oceanographers and meteorologists. There is cautious agreement that the scatterometer is capable of measuring wind speeds in many weather situations to within 2 meters per sec (approximately 5 miles per hour). This scatterometer, mounted on an orbiting spacecraft, is capable of providing surface wind speed and direction below its path as it moves around the Earth. If the orbit were adjusted to altitudes of about 2400 km, the satellite could cover the entire globe within a few days. This would be the first time in our history that we would have global coverage of the oceans, with new wind estimates over the oceans every week or so. Such information could be used in a variety of ocean models to determine ocean surface currents on many space and time scales. Oceanographers would then be able to estimate the distribution of ocean currents over the entire ocean area on a day-to-day basis, something they never had before.

Fig. 15 shows one of the results from SEASAT. Data from the scatterometer wind measurements give us the wind vectors that you see around the hurricane. This is Hurricane FICO, just before SEASAT passed over it on July 20, 1979. From data such as these, oceanographers feel they really could make great progress. Unfortunately, the satellite failed, but there will be others in the future. In the meantime, that small data base has been utilized quite well. We anticipate that ocean surface currents will be determined from other orbiting instrument platforms in the future. They will be as informative and instructive to the oceanographers as the early cloud pictures were to meteorologists.

Using quality data on wind fields, oceanographers can make new and interesting calculations. It has been observed that the strength and the position of currents such as the Gulf Stream vary throughout the year. The Gulf Stream meanders; it creates rings and eddies, and we do not know what all that means. We are trying to model the Atlantic Ocean. To do so, we have to know what is going on physically before we can ever be successful. There is no doubt that data such as was obtained by SEASAT will be very useful in modeling and understanding the physical mechanisms.

The El Niño is another area of interest to many people in this room, and especially to many oceanographers. If our present ideas are correct, we should be able to make predictions of an El Niño from scatterometer-type instruments by measuring winds over the Western Pacific along the equator. The appearance of strong westerly winds in the trigger region may allow us to forecast an impending El Niño.

Using infrared sea-surface temperature measurements, we should be able to measure from space the development of warm anomalies along the coast. Meteorologists and oceanographers believe that the Indian Ocean heat content may be a factor in the behavior of the monsoon. Furthermore, the distribution of the heat in the Indian Ocean is determined by sea-air interaction in the general ocean circulation. The ability to measure the winds in that area and the ability to calculate the ocean circulation will greatly enhance our understanding of the monsoon. Hinton and Wally at Wisconsin estimated monthly average sea-surface wind stress over the Indian Ocean using empirical relations from in situ measurements made by the geostationary satellite over the Indian Ocean during FGGE and from some of the FGGE ships. Wind stress is the kind of information oceanographers really want, and this kind of information will be very valuable in the development of air-sea interaction models.

There is a tremendous amount of satellite-related activity going on and I have only scratched the surface. There just is not time to do the subject justice, or to mention all the groups that are doing important, exciting things. I will stop at this point.

Question:

What is NSF's position on the possibility of studying the cryosphere?

Bierly:

One of the vu-graphs that I have, but did not show, was from Dave Atlas' group at NASA/GLAS. It shows the monitoring of areas of ice in the Northern and Southern Hemispheres. I am sure that the Canadians and the DOD are working in this area too. NSF certainly would be interested in funding research in this area, provided a good proposal was submitted.

Vonder Haar:

The cryosphere has been identified as of great importance in regional and global climate. We got a good start on the microwave sensing of ice with the NIMBUS satellites and we are worried about a gap in that program.

850 MB WINDS 12 GMT 27 JUNE 1979

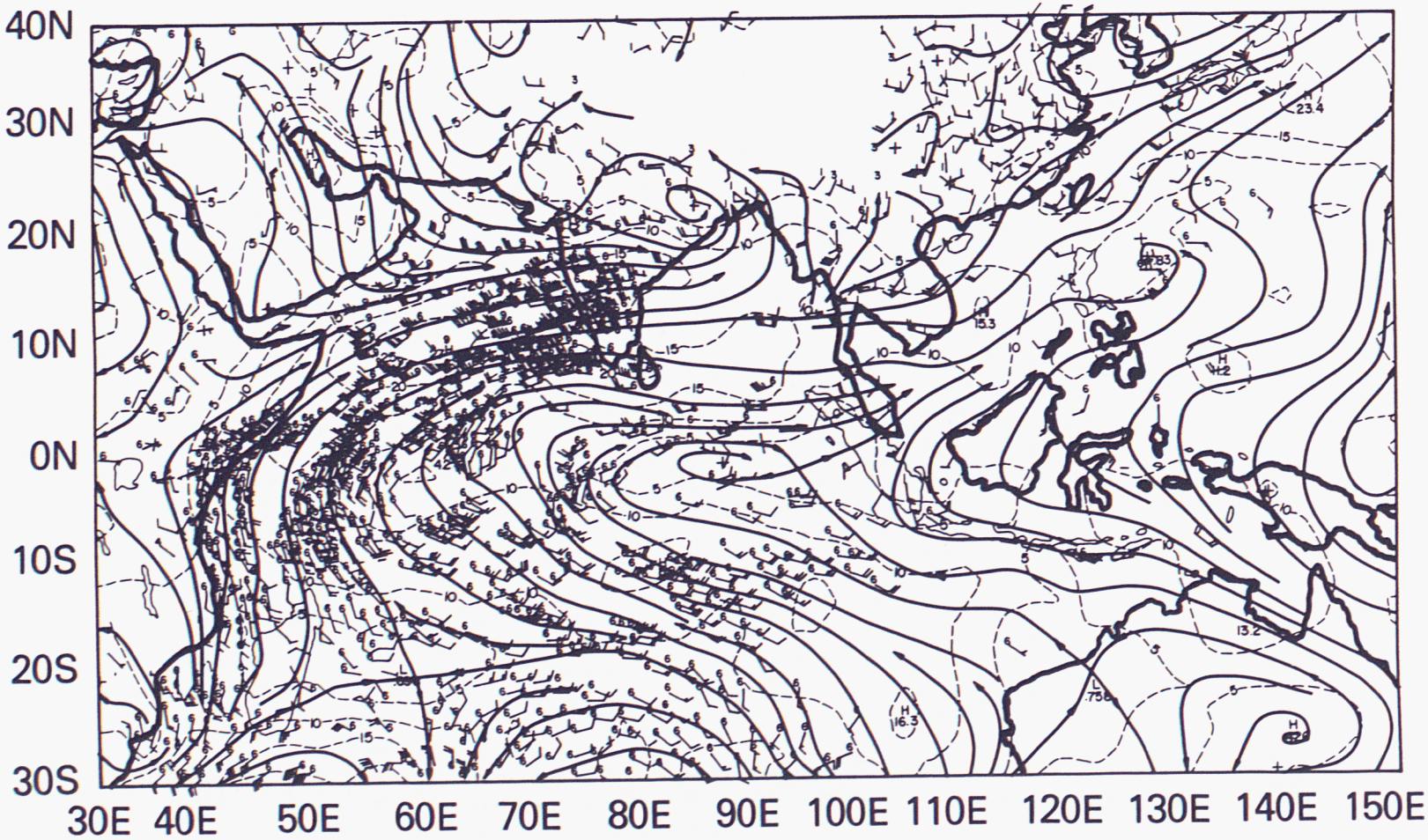


Fig. 1. (Taken from T.N. Krishnaumurti's 1979 Atlas.)

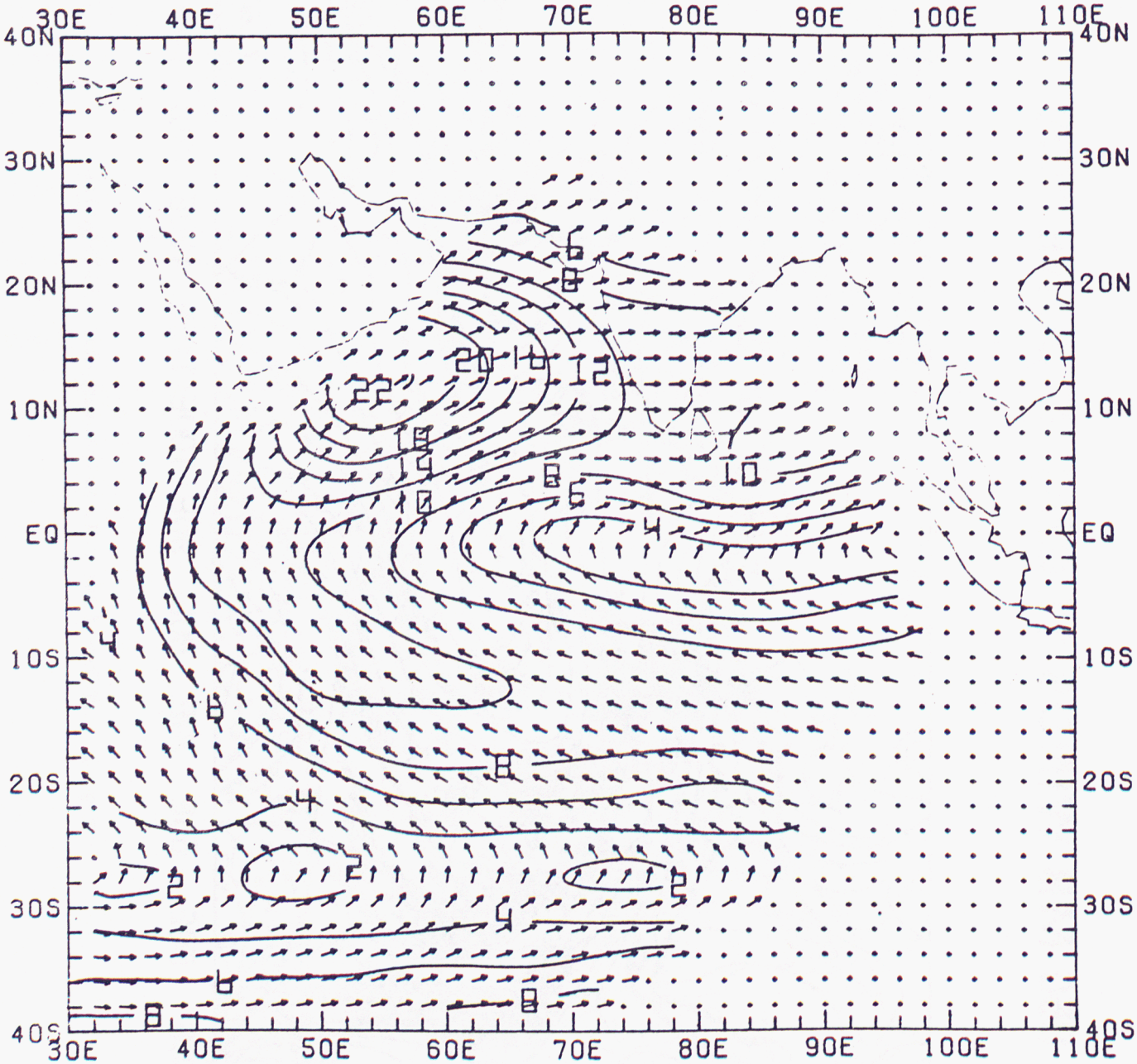


Fig. 2. Cloud-derived wind fields, July 1979 average.
(after J. Young)

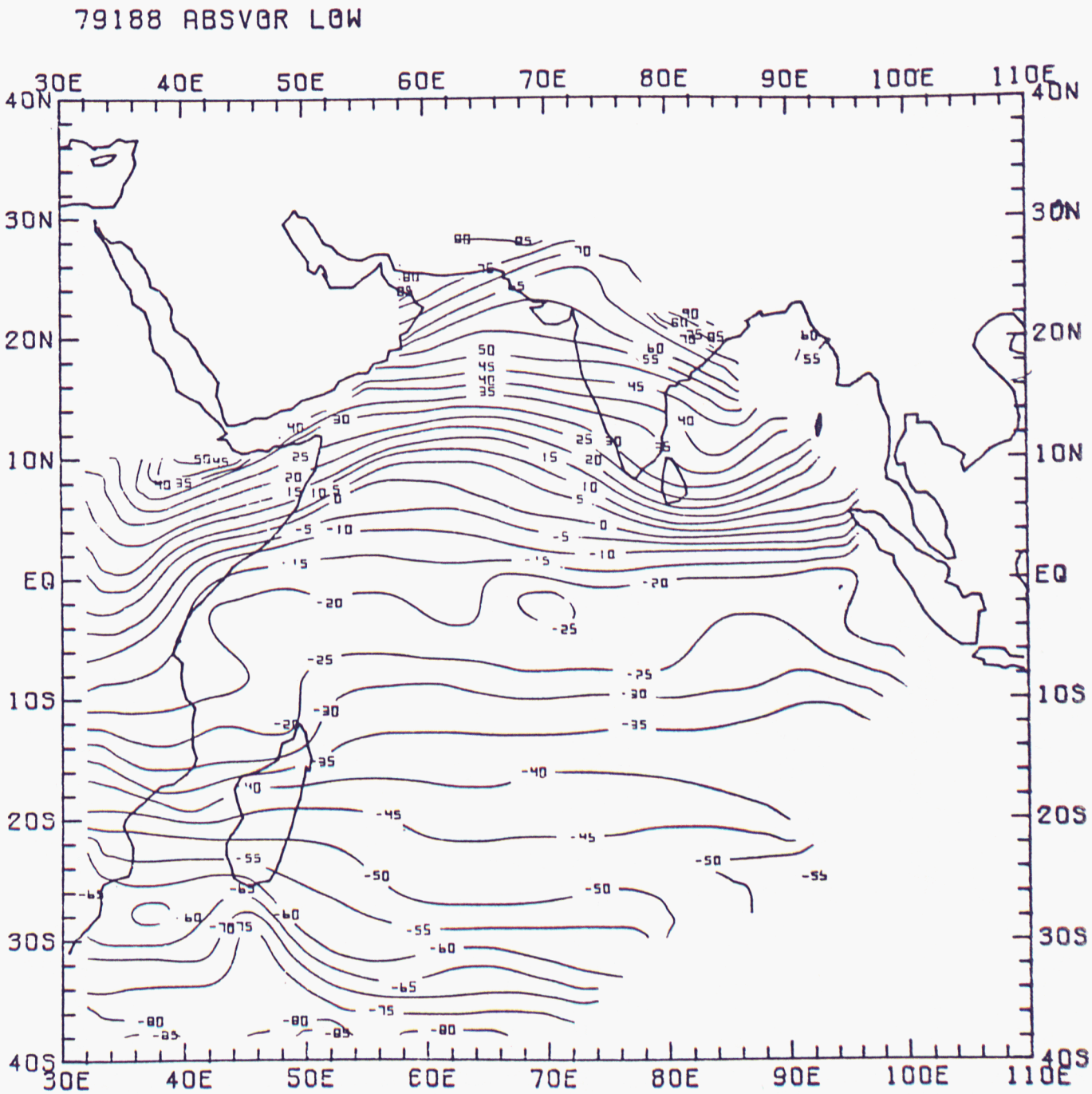


Fig. 3a. Absolute vorticity - calculated from the wind fields of Fig. 2.

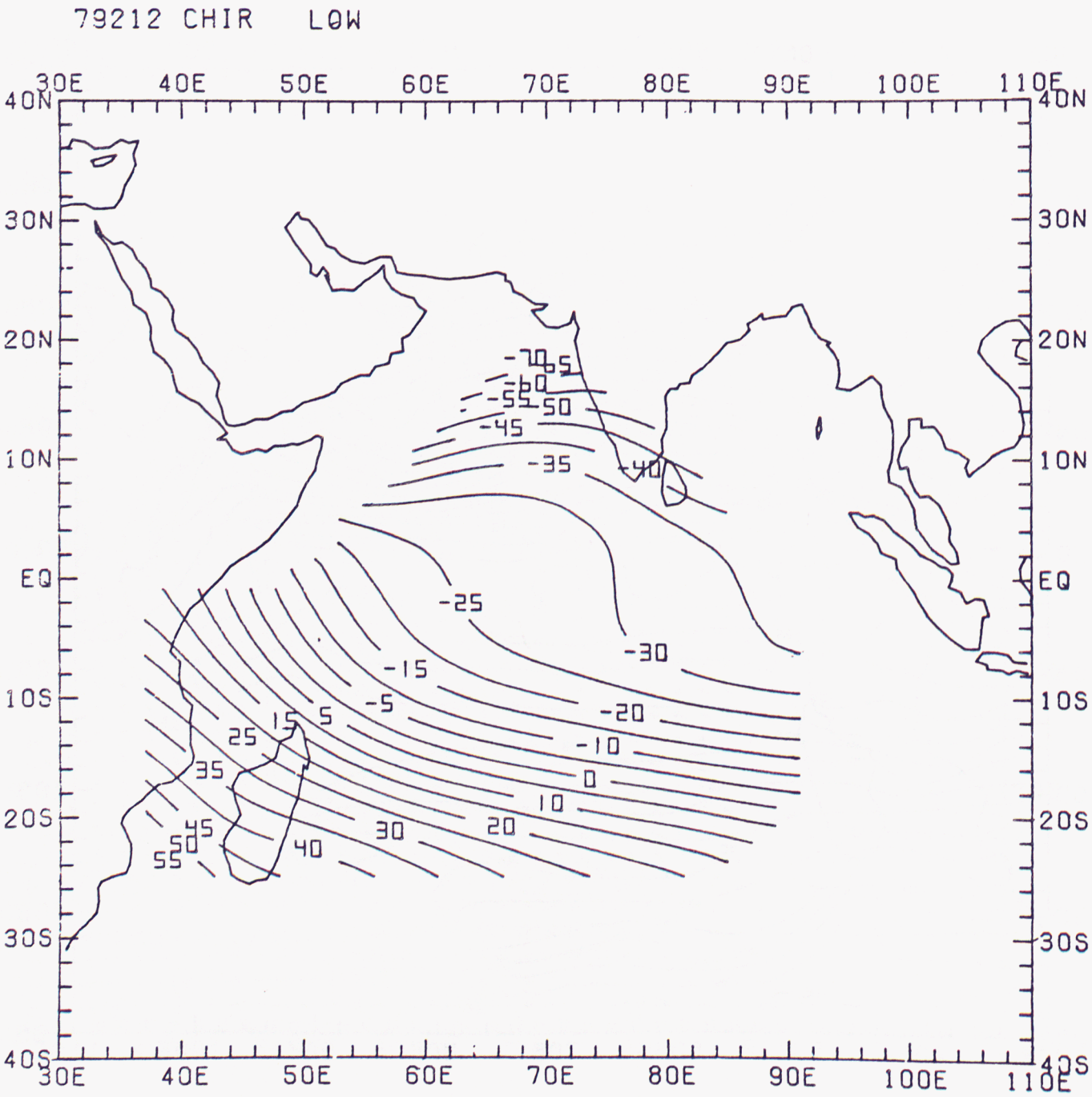


Fig. 3b. Geopotential field - calculated from the wind fields of Fig. 2.

MESOSCALE CONVECTIVE COMPLEX (MCC)
(BASED UPON ANALYSES OF ENHANCED IR SATELLITE IMAGERY)

PHYSICAL CHARACTERISTICS

- SIZE:

  A—CLOUD SHIELD WITH CONTINUOUSLY LOW IR TEMPERATURE $\leqslant -32^{\circ}C$ AND AN AREA $\geqslant 100{,}000\ KM^2$

  B—INTERIOR COLD CLOUD REGION WITH TEMPERATURE $\leqslant -52^{\circ}C$ AND AN AREA $\geqslant 50{,}000\ KM^2$

- DURATION:

  SIZE DEFINITIONS MET FOR A PERIOD $\geq$ 6 HR

Fig. 4.

ATM81-2078
4-21-81

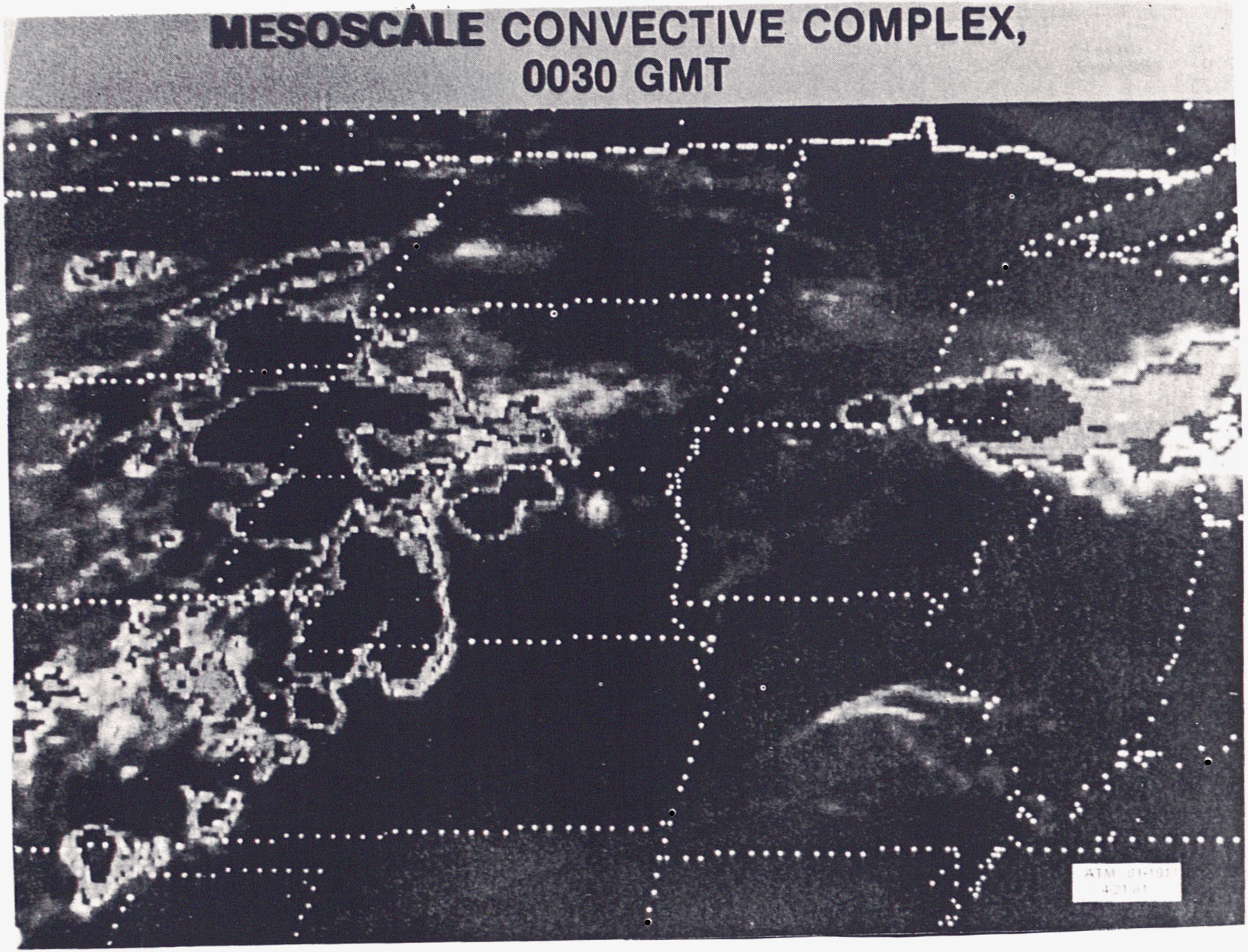


Fig. 5a.

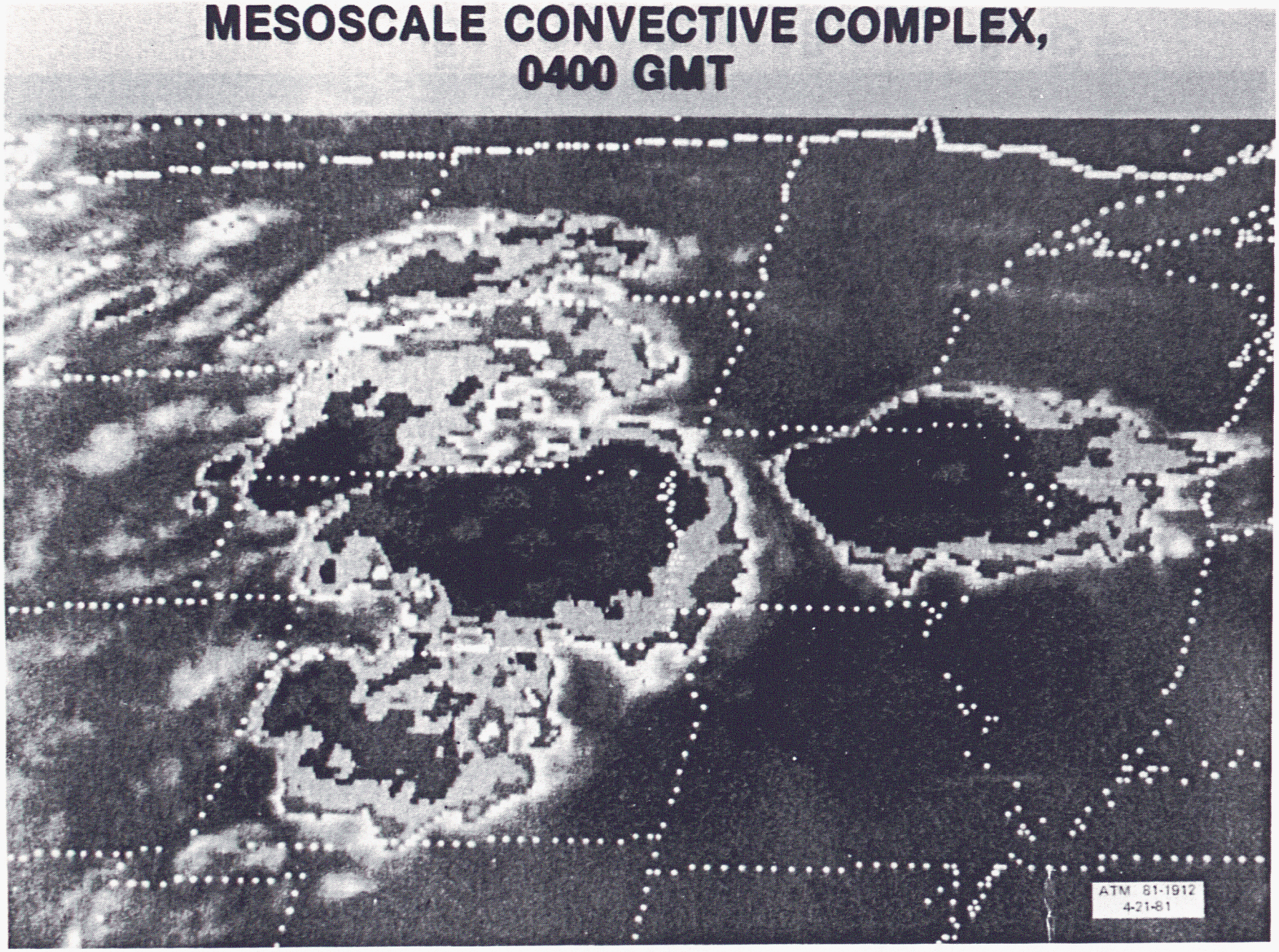


Fig. 5b.

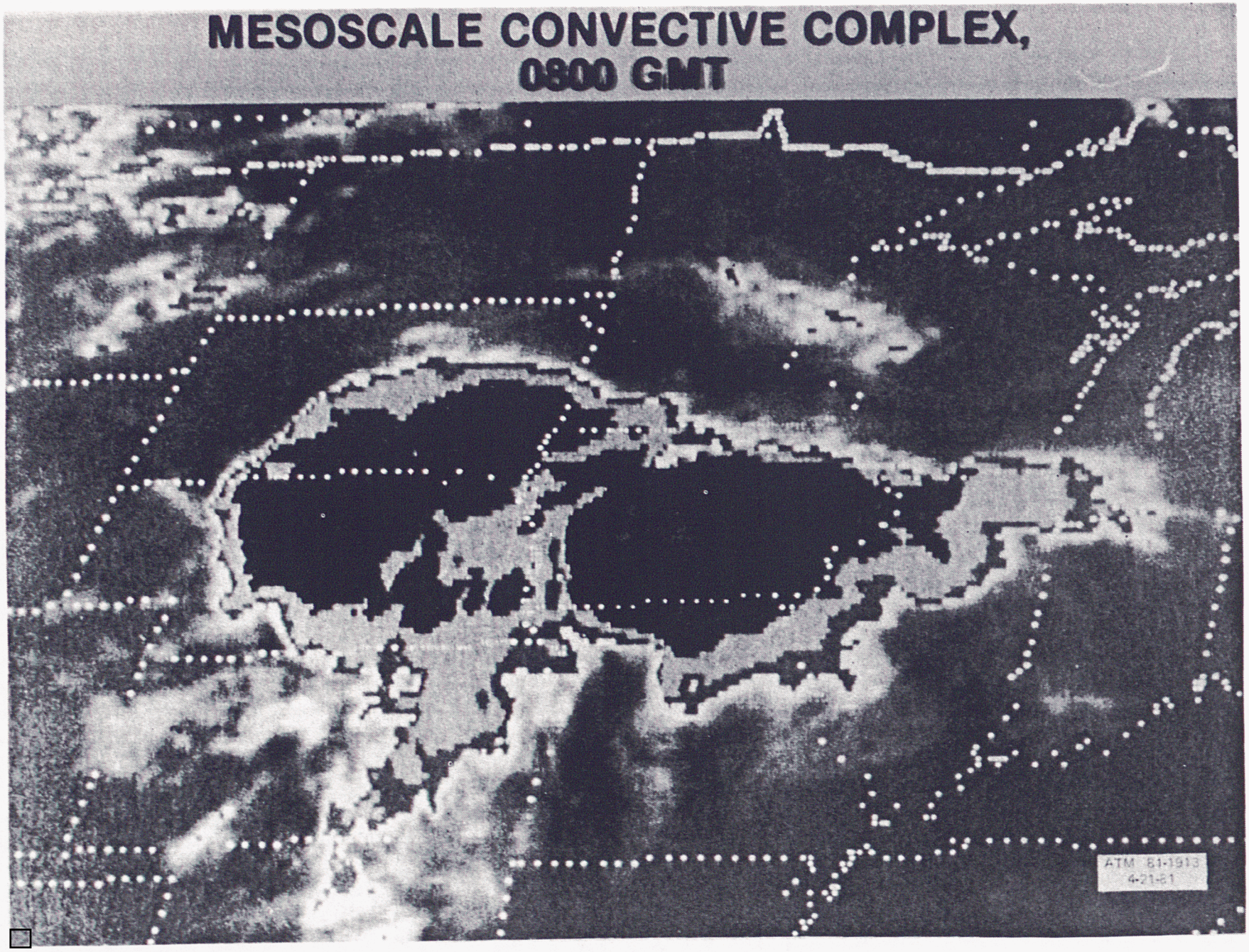


Fig. 5c.

INTERNATIONAL SATELLITE CLOUD CLIMATOLOGY PROJECT 1983-1987

- **Goal:**

  Acquire a Global Data Set of Reduced Radiances and Cloudiness Parameters of Manageable Proportions, for a Period of About Five Years

- **Data Source:**

  Radiance Data from 4 or 5 Geostationary Satellites Plus Polar Orbiting Satellites

- **Target Data Set:**

  Reduce Multi-Channel Radiance Information From Original Volume of Order 500,000 Tapes/Year to Compressed Radiances of Order 500 Tapes/Year Eventually Cloud Information of Order 5 Tapes/Year

- **Data Processors:**

  A World-Wide Community of Scientific Institutions (Government and Academic)

Fig. 6.

ISCCP

GLOBAL CLOUD CLIMATOLOGY DATA REQUIRED FOR:

- UNDERSTANDING INTERDEPENDENCE OF CLOUDS AND CLIMATE
- UPGRADING CLIMATE MODELS
- ANALYZING CLIMATE CHANGE
- MONITORING WORLD FOOD PRODUCTION AND WATER USE
- MAKING MAXIMUM USE OF SOLAR ENERGY

Fig. 7a.

INTERNATIONAL SATELLITE CLOUD CLIMATOLOGY PROJECT

U.S.A. PARTICIPATION

- BEGIN A 5-YEAR PROJECT IN 1983 TO COLLECT SATELLITE RADIANCE DATA IN INTERNATIONAL FORMAT FROM U.S. SATELLITES.
- ACCELERATE NATIONAL RESEARCH IMMEDIATELY
  - TO USE FGGE DATA TO RUN TESTS
  - TO DETERMINE METHODS TO GET CLOUDS FROM RADIANCES
  - TO DEVELOP DATA HANDLING SCHEMES

Fig. 7b.

ISCCP: DATA REQUIREMENTS (PRELIMINARY)

AVERAGING

1. Horizontal Averaging — 250 x 250 Km boxes
2. Time Sampling — 3-hourly samples
3. Time Averaging — 30-day averages (of 8 daily samples)
4. Parameters — For each parameter, box averages and variances are required (or comparable statistical measure of the shape of temporal distribution)

Fig. 8.

GLOBAL GEOSTATIONARY SATELLITE COVERAGE (EXPECTED FOR THE ISCCP)

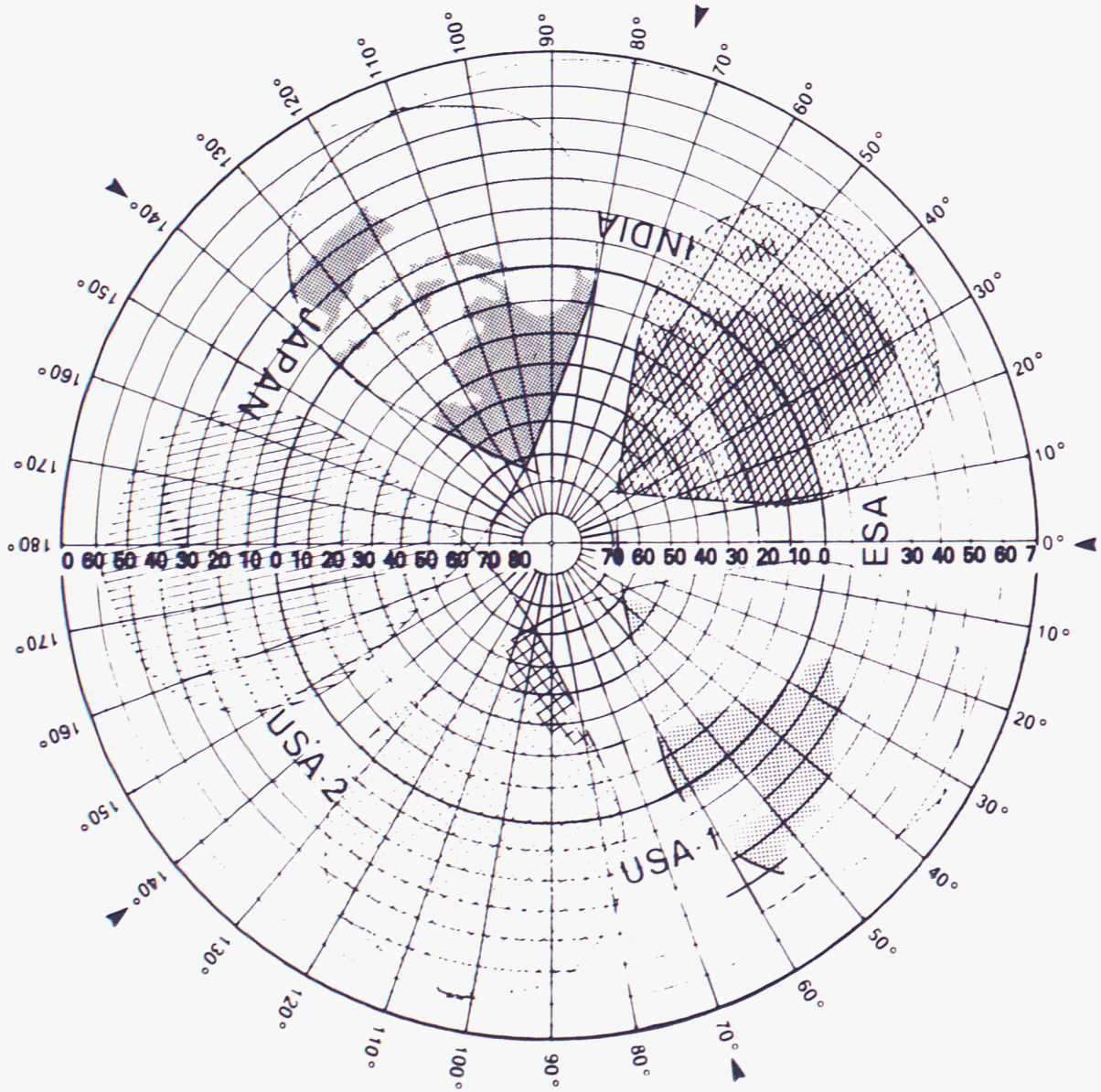
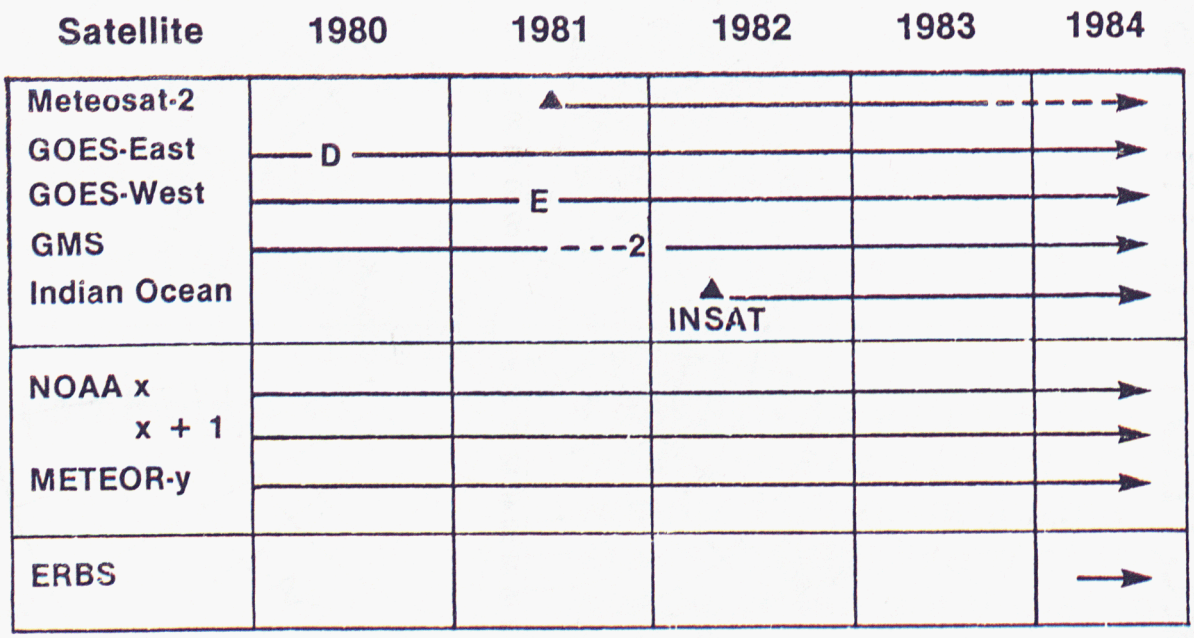


Fig. 9.

ISCCP: STATUS OF SATELLITES, 1980-84



3266A(6)

Fig. 10.

INTERNATIONAL PARTICIPANTS IN DATA PROCESSING FOR ISCCP

METEOSAT
ESOC (DARMSTADT), CMS (LANNION), OTHERS

GOES-EAST
U.S.A., CANADA, CMS (LANNION)

GOES-WEST
U.S.A., CANADA

GMS (SUNFLOWER)
JAPAN, AUSTRALIA

INDIAN OCEAN SATELLITE
INDIA, USSR, CMS (LANNION)

ARCTIC REGIONS
U.S.A. (NESS), USSR

ANTARCTIC REGION
U.S.A. (NESS), AUSTRALIA, SOUTHERN AFRICA

Fig. 11

ISCCP DATA TYPES

DATA	PURPOSE	SOURCE
1) 11 μm Radiances (Primary ISCPP Data)	Day and Night Non-Cirrus Cloudiness	All Satellites
2) 0.5 μm Radiances (Primary ISCPP Data)	Daytime Non-Cirrus	All Satellites
3) 6.7 μm	Cirrus	METEOSAT, Possibly GOES-D,E,F
4) 3.7 μm	Cirrus Phase (Ice/Water) Low Level Cloudiness at Night	NOAA-6,7
5) CO_2 Sounding Radiance (2 or 3 Channels; Peak Near Tropopause, e.g. 750 & 715 cm^{-1})	Cirrus	NOAA-6,7, Meteor
6) Clear Column Radiance	Cirrus	NOAA-6,7
7) 1.55 and/or 0.8 cm	Precipitating Cumulus	NOAA-6,7, Meteor
8) Microwave	Multiple Layers	Polar Orbiters

Fig. 12

SUMMARY POINTS ON IMPORTANCE OF CLOUDS TO CLIMATE PREDICTION

1. World Climate Program's Primary Goal is to Predict Climate Through the Use of Climate Models

2. Earth's Climate is Sensitive to Small Changes in Global Energy Balance

3. Clouds Represent one of the Largest Sources of Uncertainty in Models.

Therefore,

4. Understanding the Role of Clouds in Climate and Proper Representation of Cloud-Radiation Feedback in Models is of Primary Importance to Climate Prediction.

Fig. 13

ISCCP: WHY WAIT 9 YEARS (1974-83) AND WHY NOW?

(1) Global Satellite Coverage First Achieved in FGGE (1979); Expected Again in 1982

(2) Now Possible Because of Hardware: Relatively Inexpensive Direct Read-Out Station, Antenna, Powerful Midi-Computers

(3) Growing Nucleus of Cloud Physicists, Climate Modelers, Radiation Experts Who Are Interested in the Cloud-Radiation Problem

(4) International Resources and a Mechanism Exists (GARP/WCRP) to Make it Happen

Fig. 14

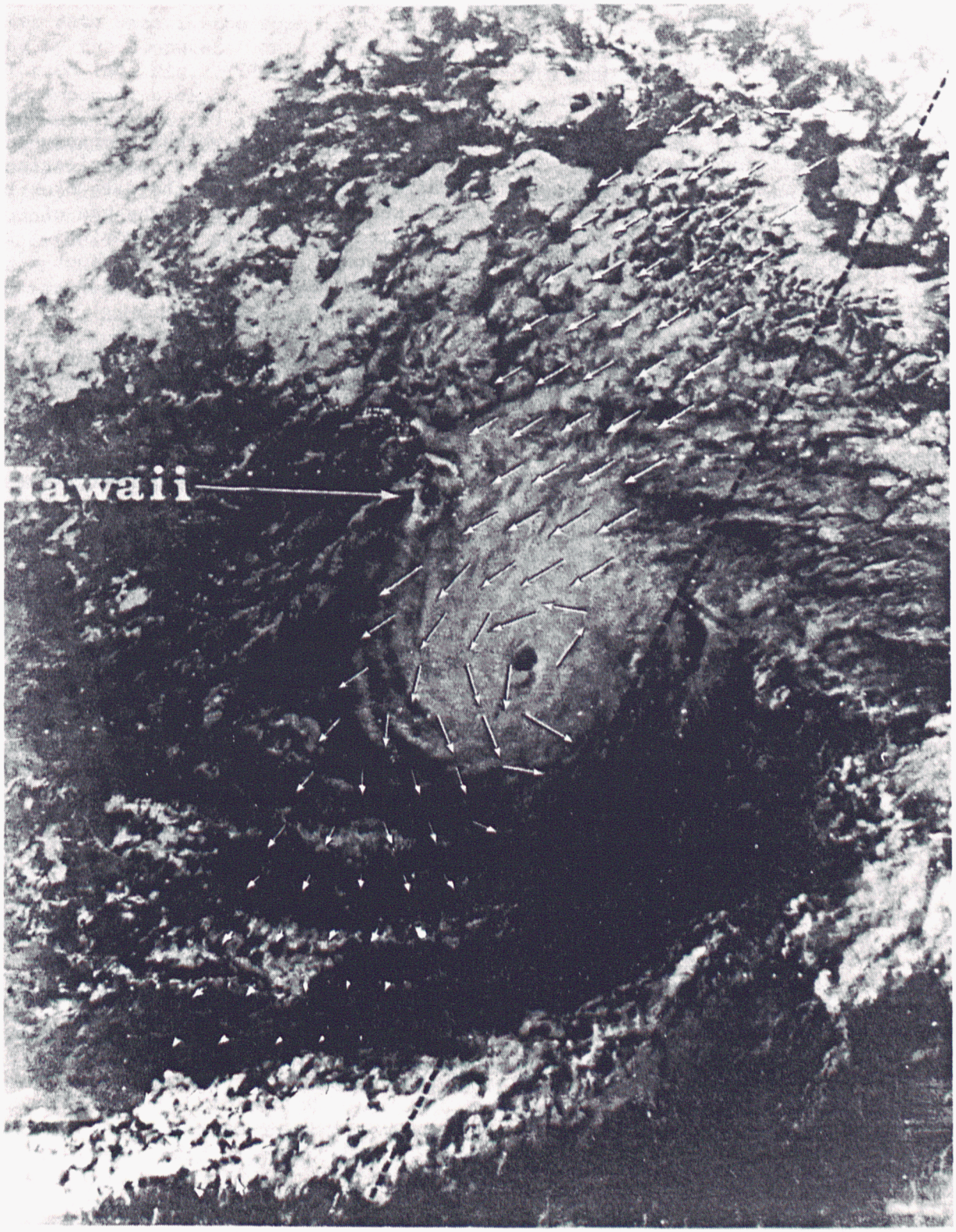


Fig. 15. Wind vectors from SEASAT scatterometer data. July 20, 1979.

COMMENTS ON SATELLITE METEOROLOGY

FROM GEOSTATIONARY SATELLITES

Thomas Vonder Haar, Colorado State University

We were to hear from Vern Suomi on geostationary satellites, but as you know, Vern was unable to come today, so Dave Atlas and I will attempt to fill in. Then Dave Johnson will come back to the podium and help us think about the future.

Fig. 1 is the Spin Scan Cloud Camera Experiment which Vern Suomi and Bob Parent (together with a lot of help from their friends) put together in the late 1960's. It was flown in 1967 on NASA's ATS-1 Satellite. Waiting for this sequence of photographs to come back from 40,000 km was probably as thrilling and exciting as watching that first photograph come in from TIROS 1. We began to explore the time-domain of our weather satellites.

The ATS-3 satellite, as many of you remember, actually had three photomultipliers that measured in the red, green, and blue wavelengths. Suomi, Parent and crew were able to put together the first color picture of the Planet Earth (Fig. 2). Color helped us differentiate clouds before we were able to obtain infrared pictures from that far away. These data were used in the late '60's and early '70's and we obtained the cloud view that is now familiar to everyone through TV weather programs. When you watch the TV programs of weather forecasters, you often see pictures of weather patterns on the Earth from the geostationary satellites. Many of the operational meteorologists also use the geostationary satellite data -- receiving it from NESS as Dave Johnson described. Back in the late 1960's, these were quite exciting developments that the group at the University of Wisconsin pioneered.

In 1968 we began to study the time rate-of-change of cumulus clouds and cloud systems. These new platforms essentially hung in space and served not only as places from which to observe the weather, but also as communications platforms to broadcast the data back to many weather observers. The use of satellite information in studying severe storms will be talked about a lot in the AMS Conference on Severe Storms.

Fig. 3 was taken in 1969 during the Barbados Oceanographic and Meteorological Experiment. The locations of some of NOAA's research ships are indicated in a fan pattern with the island of Barbados at the apex. This experiment in 1969 was one in which we were able to use satellite data perhaps for the first time in an integrated manner in a high frequency domain to study systems -- in this case a tropical wave moving through a network. And as we plan future field experiments, we almost take for granted the availability of geostationary satellite data. Back in 1969 we began an experiment on the joint use of satellites, aircraft, radars, and ships, since satellite data had entered the time domain. We were tracking clouds to obtain wind from cloud motion. This was something that Vern Suomi himself worked on. Figs. 4 and 5 are two computer plots taken near the equator in the Central Pacific from ATS-1, late in 1967. The experiment was simply to track the clouds from t_1 to t_2. The time interval here was 46 minutes and Suomi and some of us were able to obtain estimates of wind from the cloud motion. We are still trying to use these to the best advantage.

Fig. 6 is an example of a present use of geostationary satellites. It is an example of one of the sectors that Dave talked about, which was selected in a computer and developed for research purposes on a new minicomputer digital imaging system which many groups are now beginning to use.

The Air Weather Service will be displaying satellite data out of their computer data base in the form of pictures made by the computer. Here's my state, Colorado (see Fig. 7), with the counties superimposed, because in the summer of 1980 we were running an informal experiment with the National Weather Service Forecast Office in Denver. These digital images, actually special weather data products derived from satellite data, were transmitted to the forecast office in Denver in less than 15 minutes after reception processing at Colorado State University. Such high-resolution visible pictures are very useful for forecasting severe weather, and in our mountains of the West are extremely valuable for providing warning of possible flooding.

Fig. 8 was taken during the time of a very severe hail storm in Ft. Collins, where I live, and, again, it's one more example of how imagery is now coming out of the computer where it is mated with political boundaries, watersheds, and the like. Many of you remember the tragedy, the flood we had in the Big Thompson Canyon several years ago. We are hoping that with the aid of satellite information and other systems, we can be more alert to this kind of situation.

Fig. 9 is to remind you that we can put the streamline fields on top of the satellite pictures -- and it's the bringing together of various kinds of data such as radar and satellite data (see Fig. 10) that is the new challenge for the 1980's. Although we are using this type of display just for research purposes now, by using the minicomputer systems and data sets that are being produced by NESS, as well as research being done at NASA, this integrated data will be commonly available to the operational meteorologist in the 1980's. I should mention that there is a program under way at NOAA-ERL that is really going to move this technology into the National Weather Service forecasting area: the so-called PROFS -- (Prototype Regional Operational Forecast System) program.

I'd like to summarize with the comment that the geostationary satellites that began in the 1960's are going into the 1980's with yet-to-be-realized potential, both for observing the weather and for communicating that information. We have a great deal of work to do yet, so we've got to keep good international programs of the kind that Morris Tepper mentioned going. We should work in our own country and in the international forum to make satellite potential come to be realized for forecasters and operational meteorologists.

Now, I'd like to call on Dave Atlas.

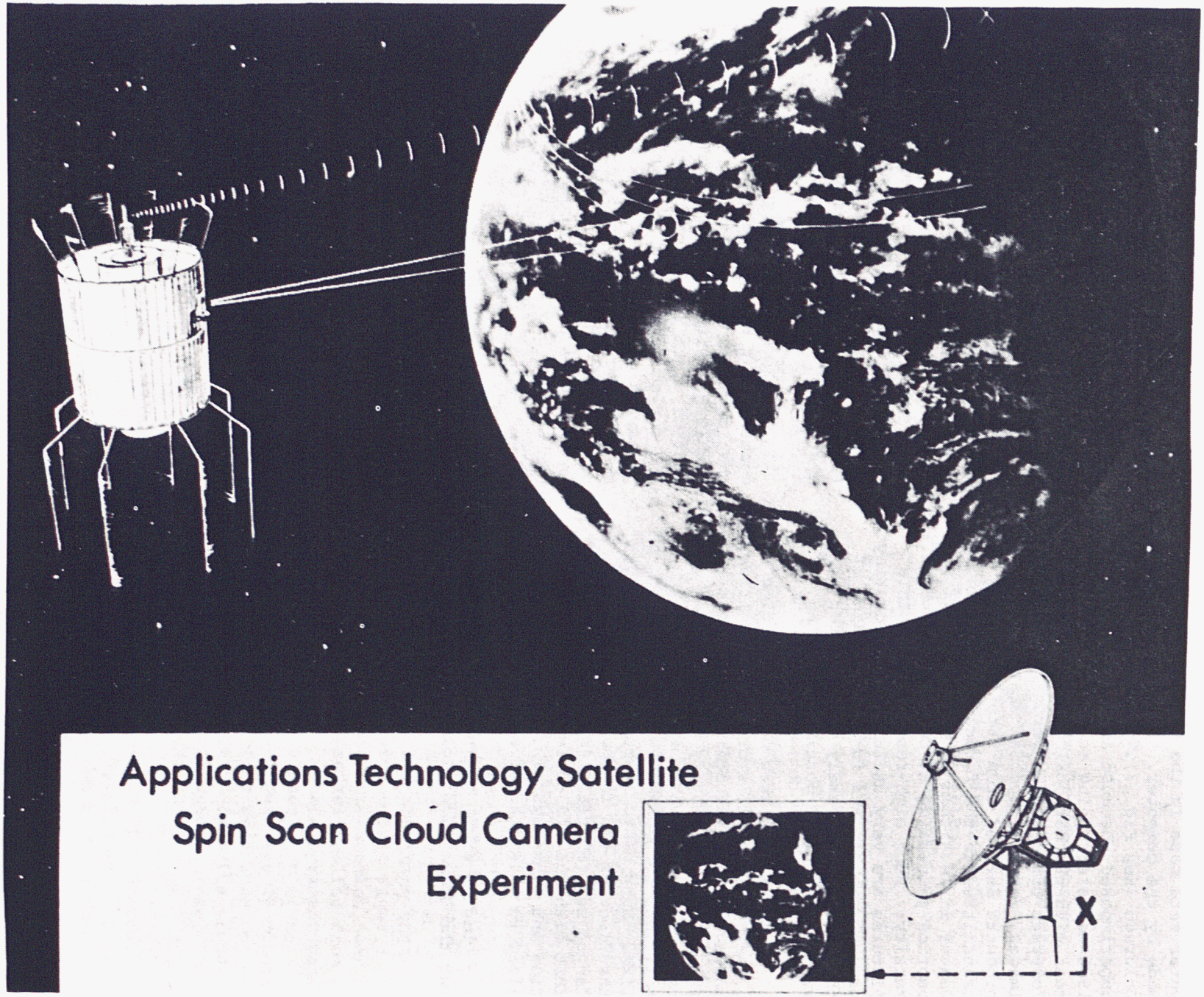

Applications Technology Satellite
Spin Scan Cloud Camera
Experiment
X

Figure 1.

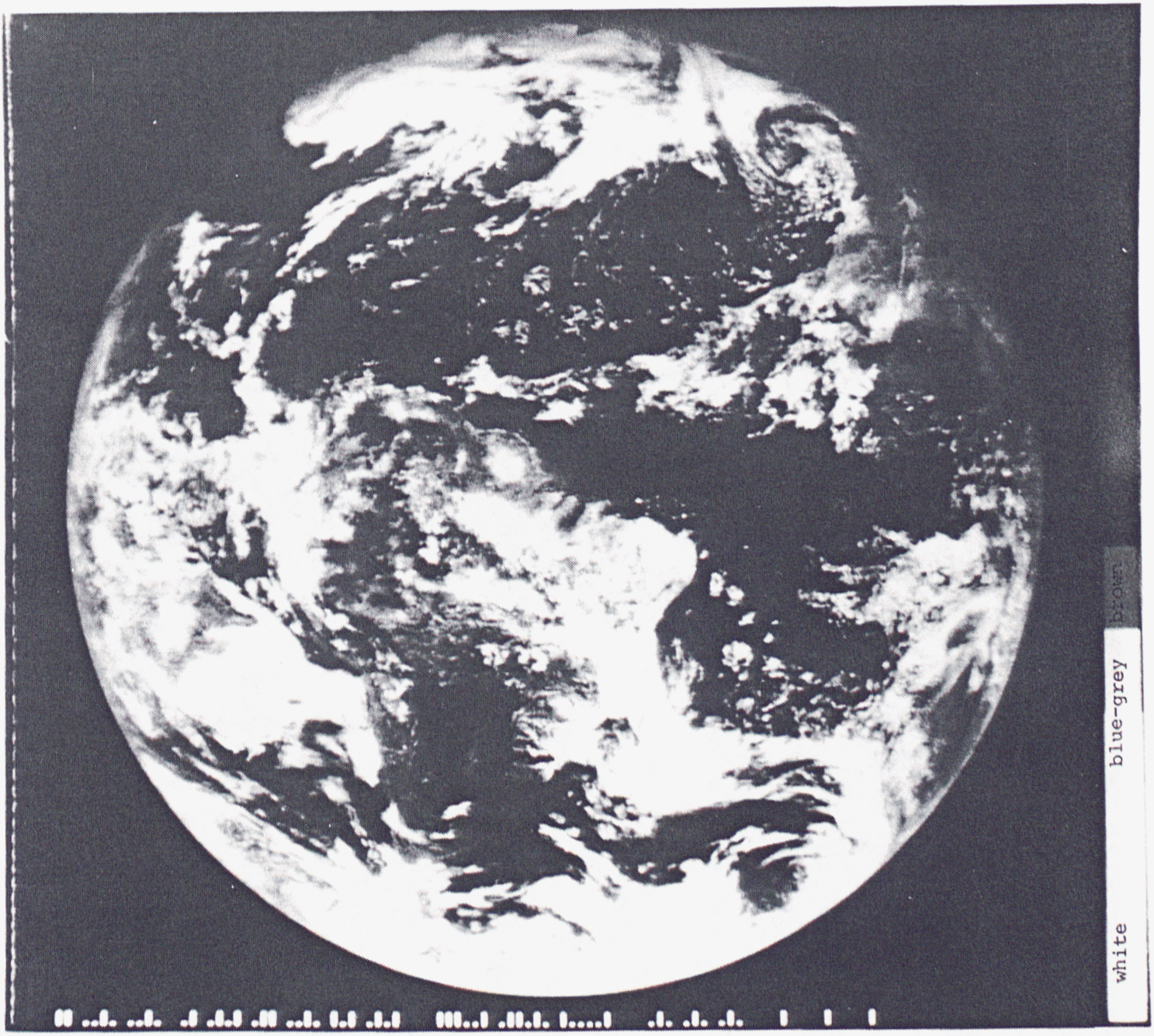


Fig. 2. First satellite color picture of Earth.
(for the purposes of this report, transferred from color to B & W - for approximate color, see graph on figure)

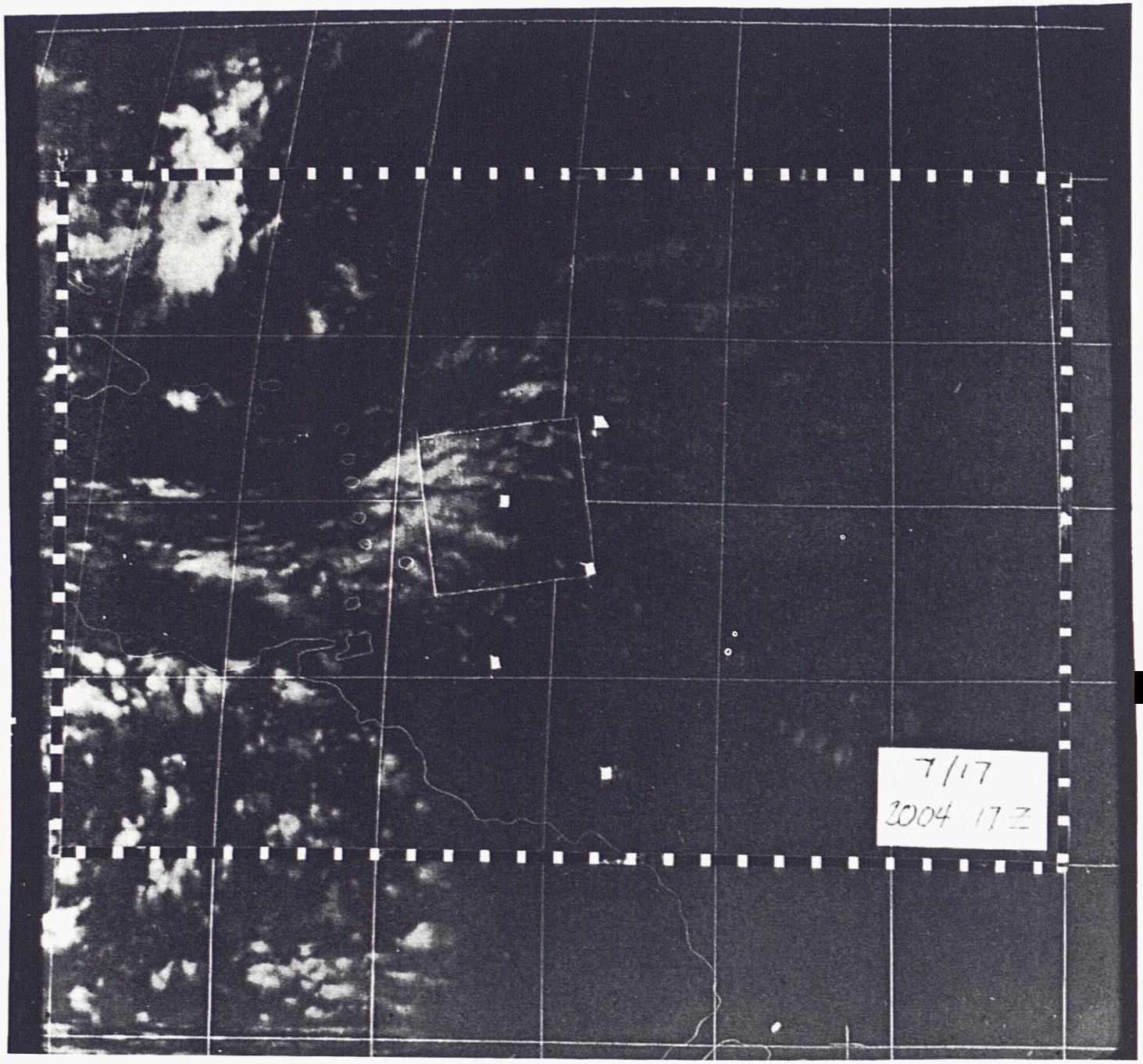


Fig. 3. Picture taken during 1969 BOMEX.

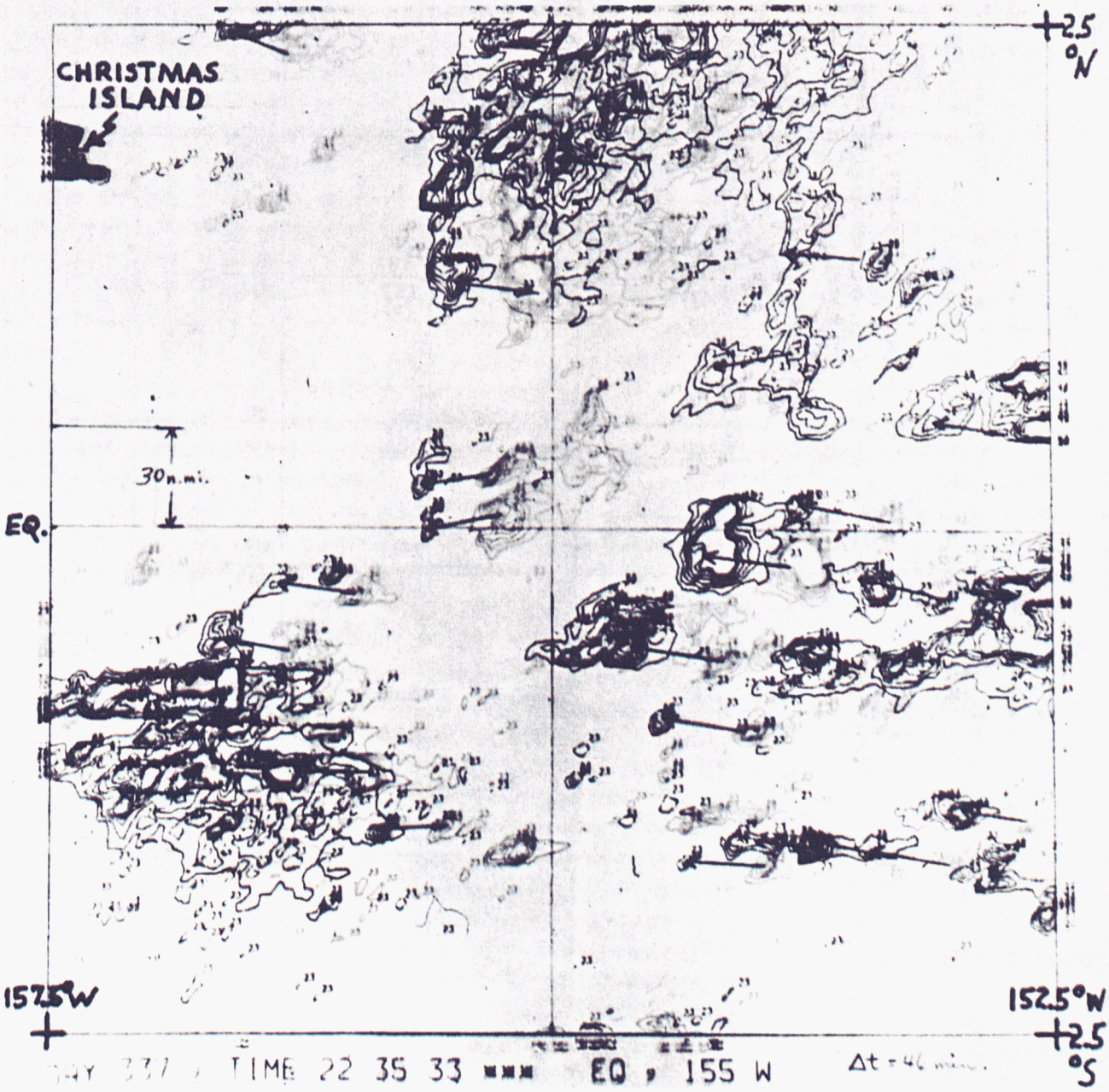


Fig. 4. Computer-generated cloud patterns at two times, 46 minutes apart (from ATS-1, late 1967).

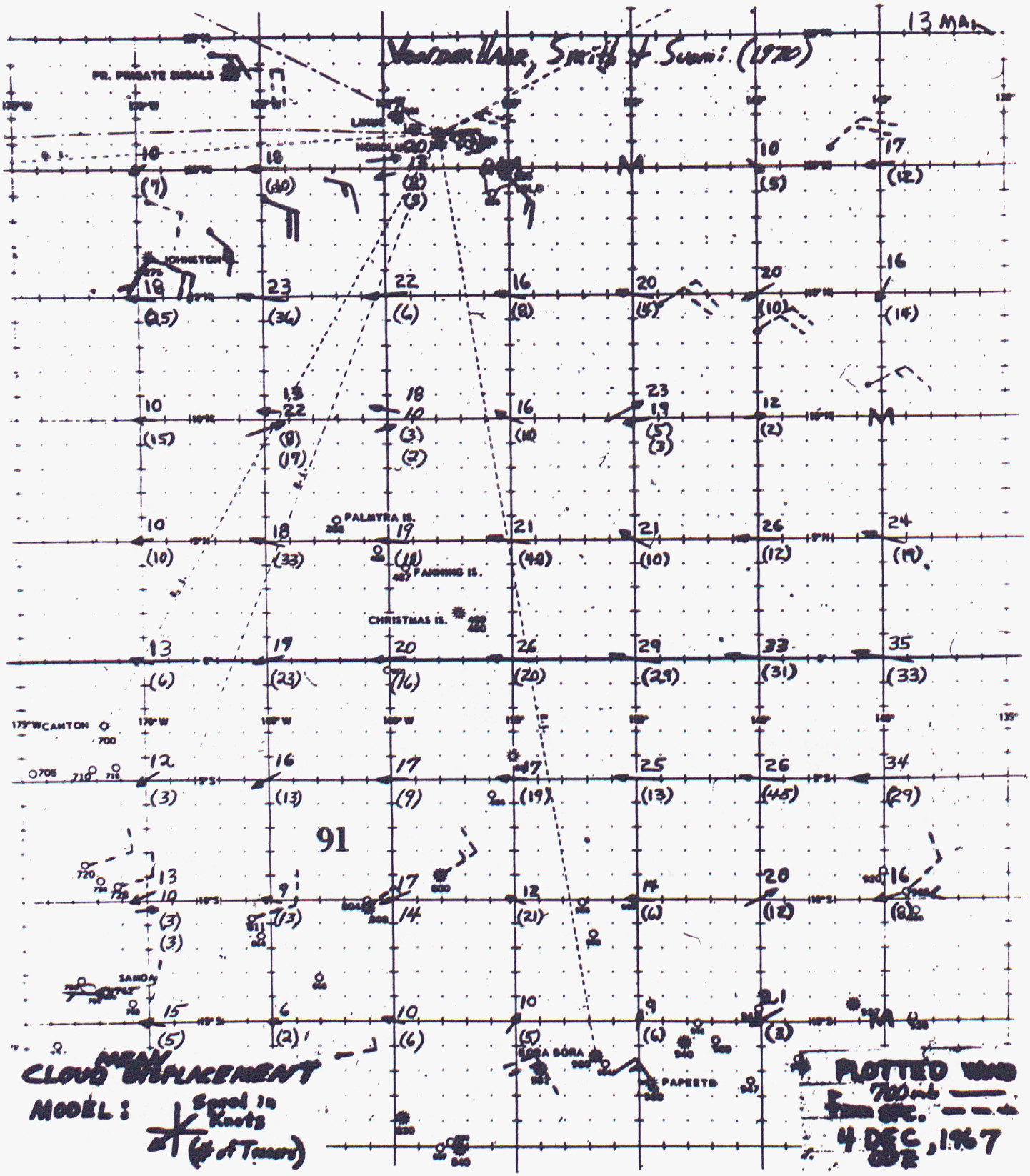


Fig. 5. Wind fields derived from data shown in Fig. 4.

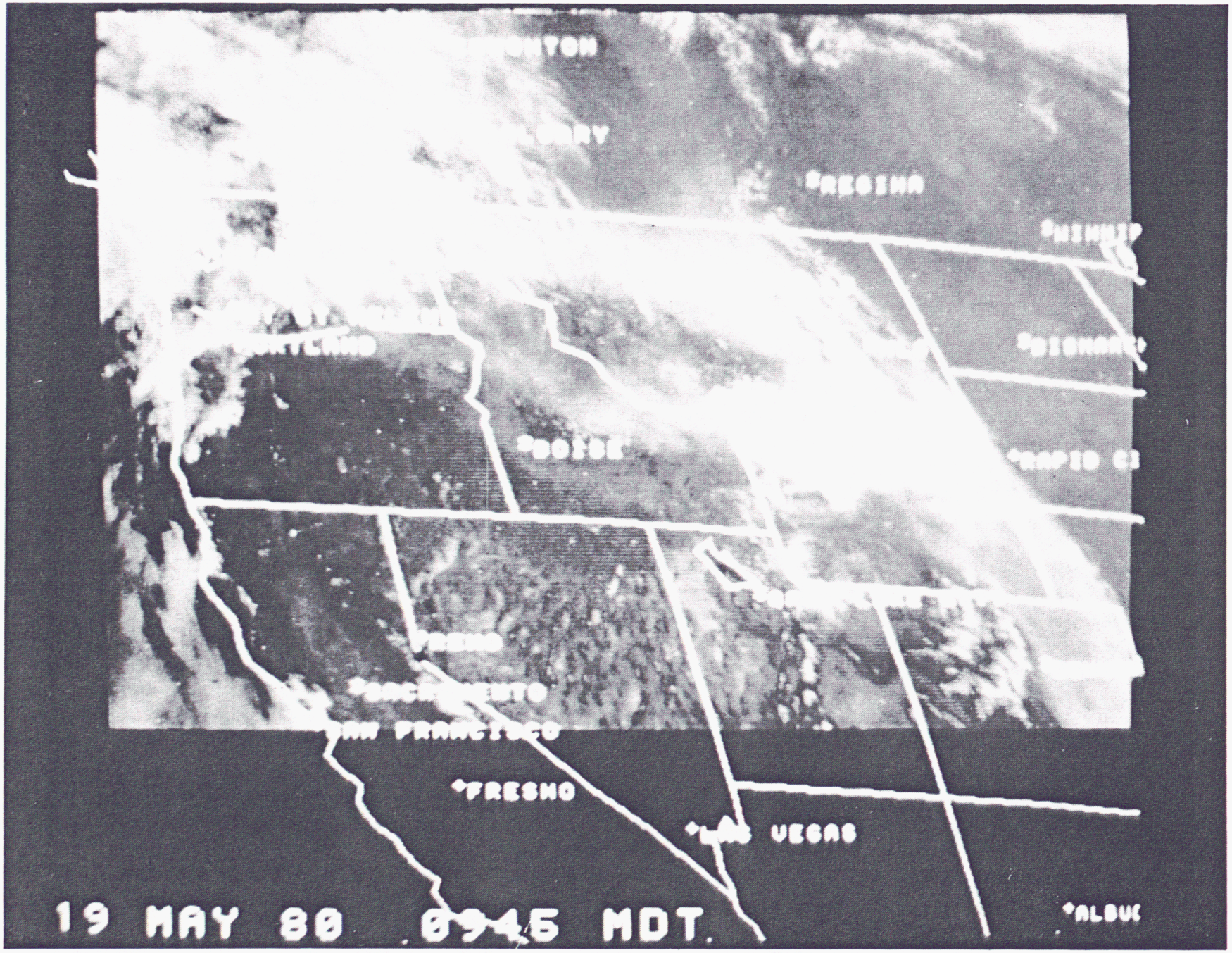


Fig. 6. Example of present geostationary satellite imaging. (For the purposes of this report, this picture was transferred from color to B & W. Color range from lightest-white to darkest-dark blue.)

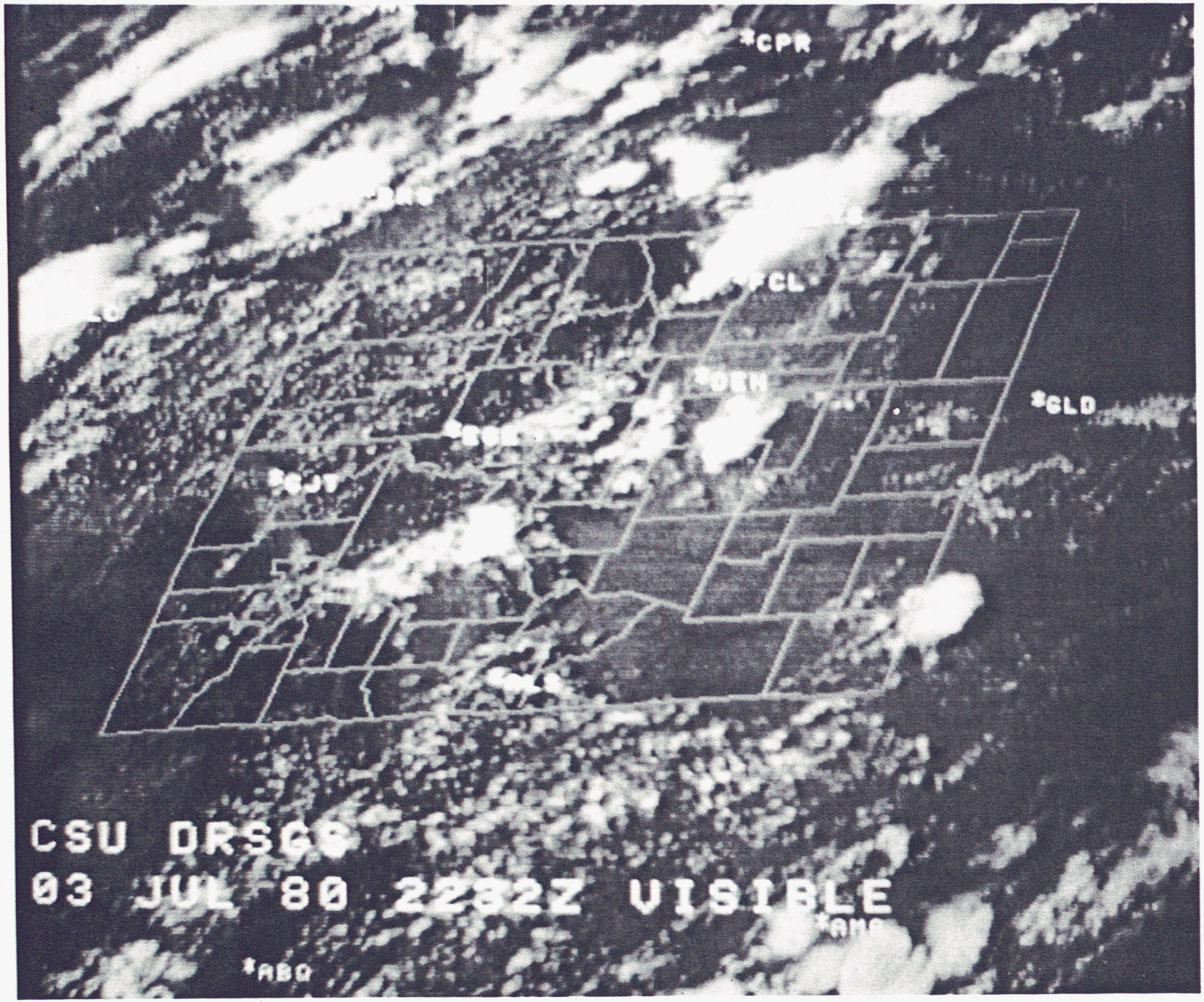


Fig. 7. Example of image data from GOES showing Colorado. (For the purposes of this report, the picture was transferred from color to B & W. Color range is the same as Fig. 6.)

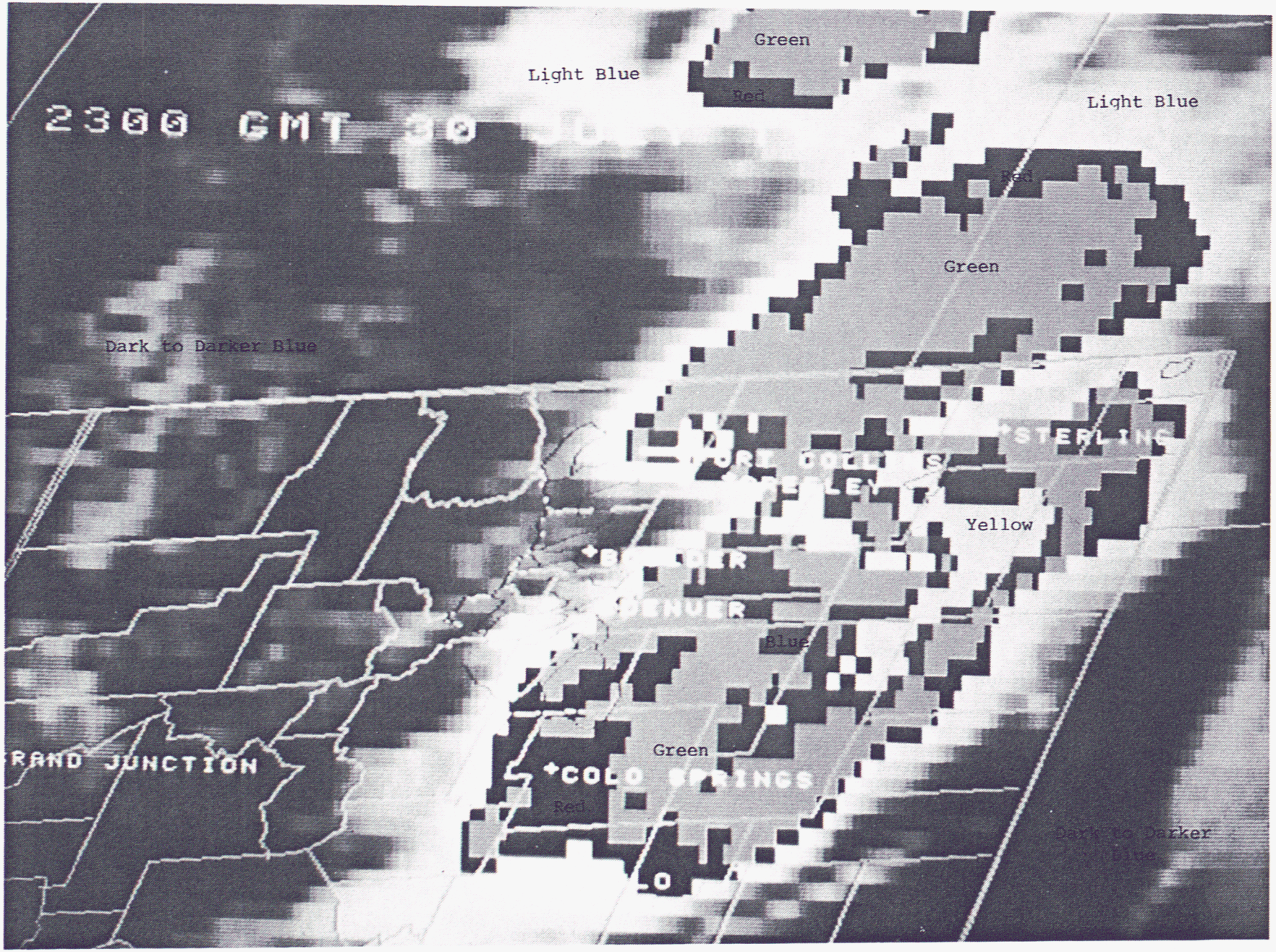


Fig. 8. Computer-generated false-color image showing a severe hail storm together with political boundaries. (For this report, transferred from color to B & W, colors noted where possible.)

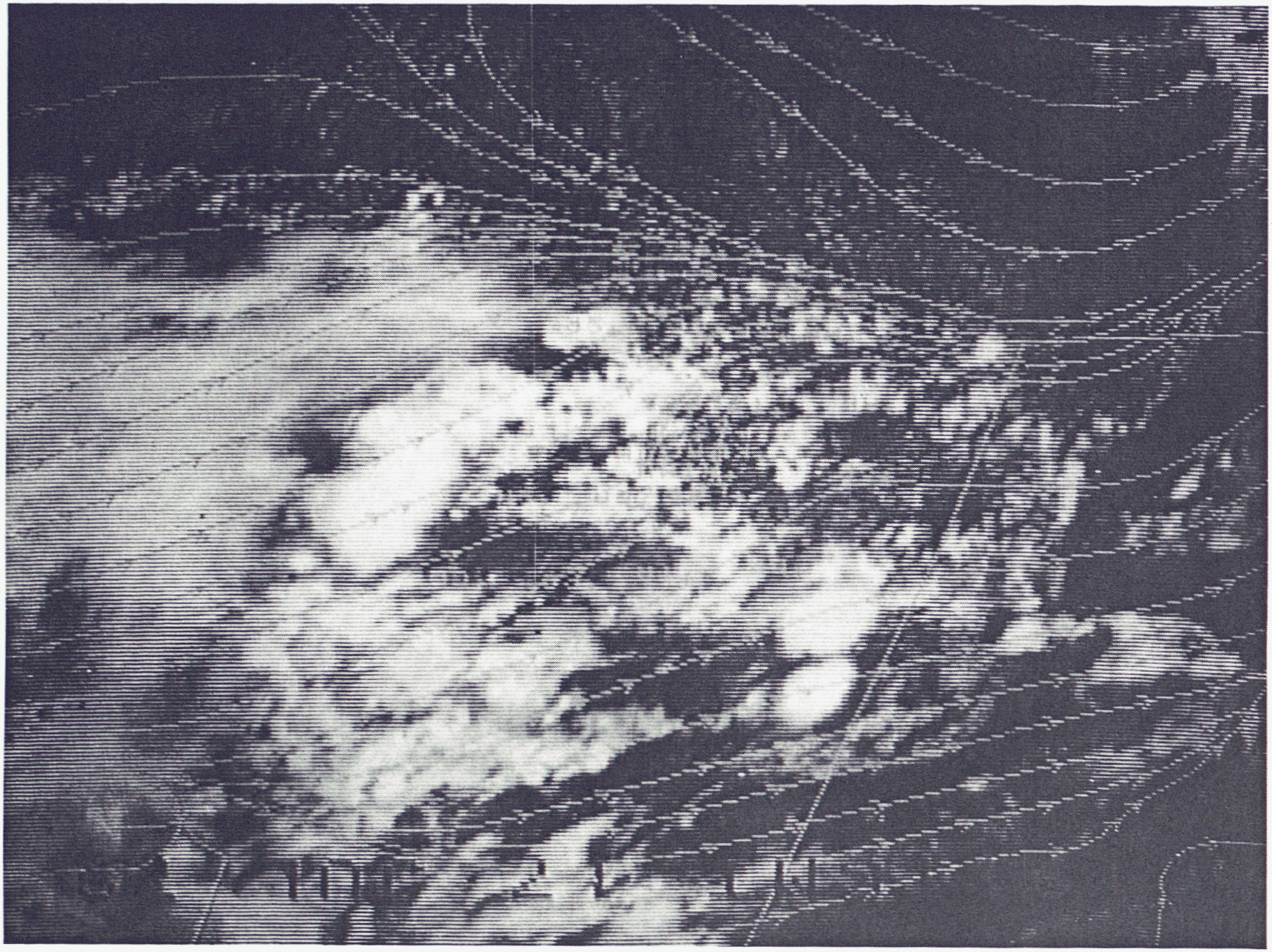


Fig. 9. Example of computer superposition of streamline fields. (For this report, picture transferred from color to B & W. Arrow lines-green, range from white to dark blue.)

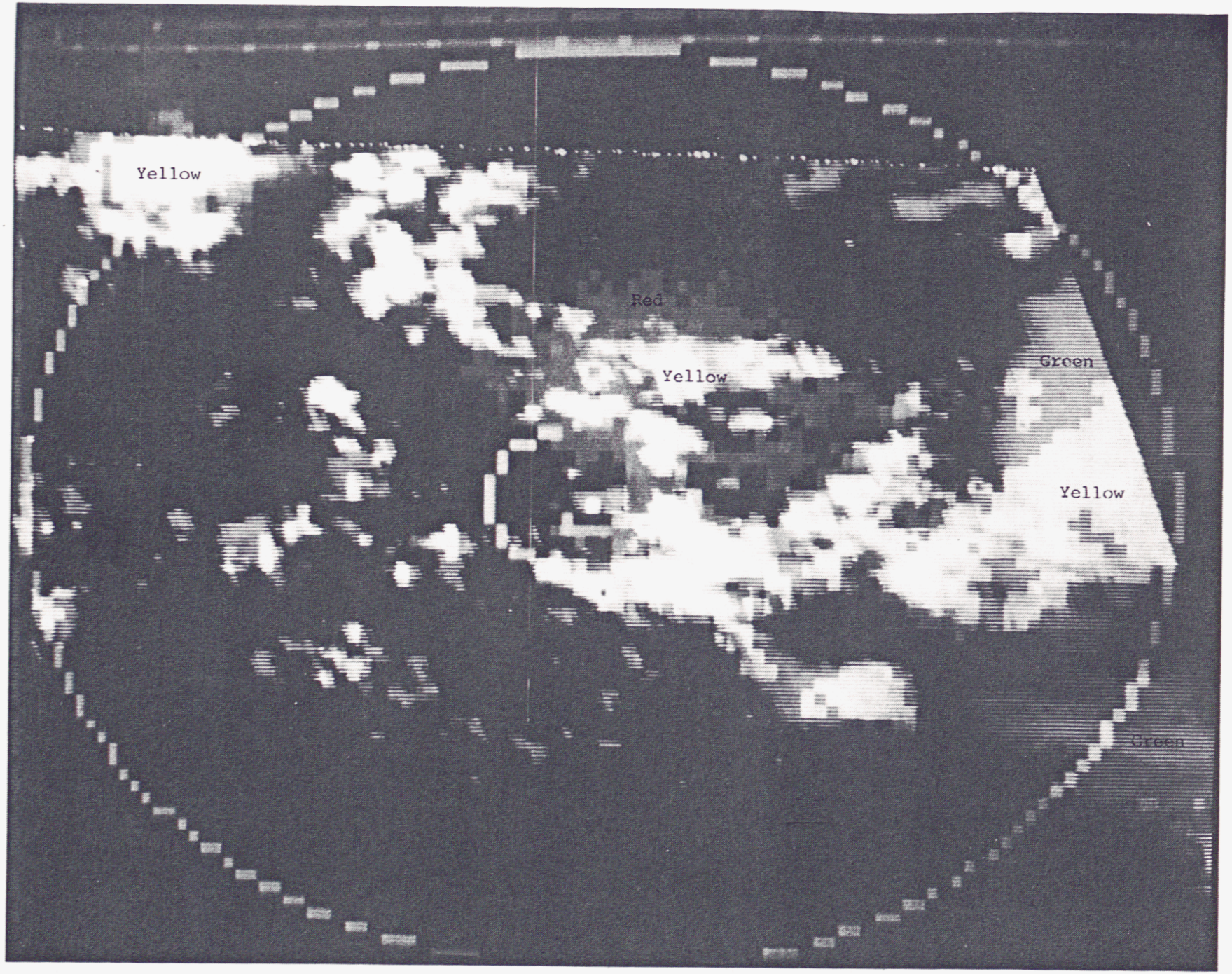


Fig. 10. Combined radar and satellite data. (For the purposes of this report, this picture was transferred from color to B & W. Color range, as indicated shows lightest areas yellow, to green, to red.)

PROSPECTS FOR THE FUTURE

David Atlas, Chief

NASA/Goddard Laboratory for Atmospheric Sciences

Thank you, Tom, good morning. I'm sorry that Vern Suomi, to whom we owe tremendous credit for the entire development of this field, couldn't be with us; but I thank him for the opportunity of squeezing in a little time on our own.

By the way, in Gene Bierly's presentation, he left out a number of important contributors to the weather and climate business in NASA. I'd particularly like to mention our friend Bill Vaughan from Marshall Space Flight Center, and our friends at Langley Research Center, and Ames and JPL.

In some respects the future is here now. I'm going to show you some of the results which have just come out of the computer at Goddard/GLAS and I want to credit a few of the people who are responsible for this; particularly Joel Susskind, GLAS, and Moustafa Chahine from JPL. The other part of the work is credited to Dennis Chesters and Louis Uccellini. By the way, the work I'm going to talk to you about with respect to the Global Weather Program and inference of new parameters from the existing system, comes from an effort at GLAS to get as much coordinated information as possible during the FGGE SOP-1, the Special Observing Period in January, 1979. The idea was to squeeze as much information as possible out of that data set. It turns out that, particularly in these times of stringent budgets, we find that we can do a great many things for which we thought we would have had to design new satellites.

The HIRS-2/MSU operational sounding data on TIROS-N has been analyzed at GLAS by direct physical inversion of the multispectral radiative transfer equation to produce a number of atmospheric and surface fields for the period January to February 1979. First, let us look at the sea-ice mapping. This field of sea-ice extent for January 1979 (Fig. 1) is derived from the emissivity of the surface as determined primarily from observations in the 50.3 GHZ MSU channel, using ground temperatures obtained primarily from the 3.7 μm and 4.0 μm channels on HIRS-2. Oceanic areas in which the emissivity, averaged for the month, is greater than 0.7 are indicated as ice-covered. For comparison, we have a field of sea-ice concentration greater than 25% as derived from SMMR (NIMBUS 7) observations with 25 km resolution, for the last 5 days in January. The agreement between the two fields is quite remarkable.

The next slide (Fig. 2) shows sea-surface temperatures. A couple of years ago the problem of measuring sea-surface temperatures accurately was one of the major ones we all faced in oceanography and climate. Suddenly we now have three methods, all of which seem to be giving sea-surface temperatures to useful accuracy. This is again from the HIRS/MSU system. The algorithms are complicated but you can see that climatology of the monthly temperatures from this system is really beautiful. You can see all the proper currents here: the Gulf Stream, the Humbolt and in the Pacific, the cold Eastern Pacific Region.

The next slide (Fig. 3) shows the anomalies in the Northern Hemisphere. This is the sea-surface temperature anomaly field for January 1979 obtained by differencing the observed temperatures from the 20-year average, averaged over 4° latitude by 5° longitude. We have a very cold anomaly in the Northern Hemisphere, the agreement with ships and buoys is very good. In the Southern

Hemisphere it is less good, but that is due, we think, to the paucity of ship and buoy coverage. The fact is that in the North Atlantic, we find that the r.m.s. difference between the temperatures from ships and buoys and the satellite is running about 0.4°C, and in the North Pacific about 0.6°C.

While the HIRS/MSU system was designed for temperature profiles, we also get sea-surface temperatures, cloud height and cloud amount, microwave surface emissivity, sea-ice and snow cover. We are currently working on schemes to get humidity profiles and cloud and surface albedo. In the future, we think we can get a handle on soil moisture by monitoring the day-night differences of land surface temperature. Research is under way to see if it is possible to determine air-sea temperature differences by incorporation of boundary layer theory into the retrieval algorithm. However, I'm very skeptical about obtaining the boundary layer wind speed over the ocean and rainfall over the ocean.

In the Global Weather Experiment during the SOP, we made 76 test forecasts to determine the impact of satellite observations on forecast skill. The solid bars in Fig. 4 represent the number of forecasts in which the satellite provided an increased skill, the dashed bars are those in which the no-sat forecast provided increased skill, and the dotted are those in which there was no change in skill (Halem, M., E. Kalnay, W. E. Baker, and R. Atlas, 1982: An assessment of the FGGE Satellite Observing System during SOP-1. BAMS, April, 1982). You can see that in the Southern Hemisphere the impact was just overwhelming. It decreases slightly with the number of days of the forecast. In the Northern Hemisphere, where we are data-rich, the skill is better with satellite observations and the difference increases with time out to about the fifth day.

Now I switch to the VAS system. I'm stealing Louis Uccellini's thunder from the severe storms conference, but I want to show you that the future is indeed here.

Fig. 5 shows the 3.9 μm channel, the best and cleanest window, and represents the surface temperatures plus a little reflection from the sun. You can see the surface temperature gradients from about Arkansas to Kansas.

Fig. 6 shows the 6.7 μm water vapor channel representative of the water vapor in about a 200 mb layer, nominally centered near the 400 mb level. The actual level sampled is variable, being lower where there is less water vapor, and higher where there is more water vapor. The water vapor itself is a determinant in controlling the level at which the observations are relevant. There is a vortex in the Kansas and Colorado region at roughly the 400 mb level which was well confirmed in the radiosonde observations themselves, but would not have been seen without the water vapor image. The dark region in the northeast is a jet of about 100 knots showing drying.

Vonder Haar:

This situation happened to be July 13, 1981, at the same time that the CCOPE experiments were going on in Southeast Montana. This will probably be one of the most studied cases of CCOPE, one of the many good cases they captured this summer. You can see the alternating moist and dry bands, moving into that system.

Atlas:

We thought originally that with VAS we would not be able to get the lower level moisture. But Dennis Chesters has very recently come up with a very interesting scheme to do this.

Fig. 7 shows you a combination of two channels that are used. What we do is to use a split window approach where the difference in the radiative signal in the 11.2 and 12.7 μm channels are used to determine the low level water vapor. The three pieces of information upon which those data are dependent are the surface skin temperature, air temperature, and the transmission of

the air, which is moisture-dependent. By taking the ratio of the two moisture channels and estimating the air temperature for a 300 mb layer (700 - 1000 mb) we can reduce the problem to two equations and two unknowns. The two unknowns which appear as radiative transmission "signals" are the surface skin temperature and the low level moisture. This estimate represents the moisture in the lowest 300 mb, roughly between 1000 and 700 mb, and is depicted on the figure in a color code representing precipitable water with a scale that runs from 1 gm to about 9 gm. In the region of East Oklahoma and Northeast Texas, there is about 5 gm of precipitable water, going to a significantly dry region in Kansas and Nebraska.

Now, we develop another picture by taking the 6.7 μm moisture band and overlaying it. Fig. 8 then shows yellow streaks, which represent contrast between the low level moisture from the split window and dryness aloft from the 6.7 μm channel at the 400 mb level, showing the potential for convective instability. This figure and the next (Fig. 9) show the clouds breaking out 6 hours later and we have very good convective activity in two streaks in Oklahoma. These results are very exciting in terms of the future of utilizing the VAS in a very effective way.

Needless to say my enthusiasm demonstrates that I have been converted to satellite meteorology. It is really quite remarkable what has been done and what the future portends.

Now I want to take a quick look into the future. The concepts I am about to discuss are due to a combination of brainstorming by Vern Suomi and my colleagues at Goddard, Hughes, and RCA. In the area of geosynchronous satellites we are going to see three-axis stabilized systems with pointing capability. Available now are two-dimensional multilinear arrays in which you can pack millions of detectors in a few square centimeters, so that you can take an entire image instantaneously, in any band that you select. The infrared arrays are in a more developmental stage than the others. There are incredible new optics that allow you to image the entire Earth with resolution of one-third of a kilometer, or better if you want, in the visible, and 1 km in the IR.

That's terribly important. One of the things that we note is that we are currently using 10 km IR resolution. When we track cells, we forget that the system is biased toward those large cells, which fill an IR pixel. These are the long-lived cells and, by definition, they aren't the ones that move with the winds. It is the small-short-lived ones that are the better tracers, and that's one of the reasons we have to go to higher resolution in the visible and in the IR. We also have to go to higher resolution in time because if a storm lives a half-hour, we can't trust it as a tracer. We think we can image the entire globe in 5 to 10 minutes, rather than 20 or more, and that's going to leave time to cover the local and regional "hotspot" areas in seconds to minutes. One can then develop time-lapse movies of the development of individual storms and fit them into the local and regional forecast system on call using some queuing system.

Soundings will be available, as will onboard processing. Coming out of previously classified defense work there will be onboard processing systems that will obtain cloud track winds very simply. We will then transmit the winds down to the ground. Spectral imaging will be done on board, and the ratioing of 2 or more channels will also be done on board to save bandwidth. And, of course, soundings will be done on board as well. Climatologically there will be some problems, because you may want to save some raw data in the hope of using them later in some unanticipated way.

Finally, I want to finish up by mentioning a spinning radiometer under development that will view the entire

globe for sea-surface temperature, for precipitation and storms, quantitatively over the oceans, and qualitatively over the land. Dual satellite stereography is coming along at a rapid pace. The work on oceanography is also remarkable. We hope TOPEX will fly in the late 1980's, depending upon the budget situation. But certainly ESA will be launching the ERS-1 and the Japanese will be launching the MOS. And, of course, there will be active radars in space looking at precipitation and lidars looking at a host of other things.

In short, technologically, the future is very bright; if the budgetary outlook were better, my optimism would be unbounded. In any case, the years ahead will be very exciting ones.

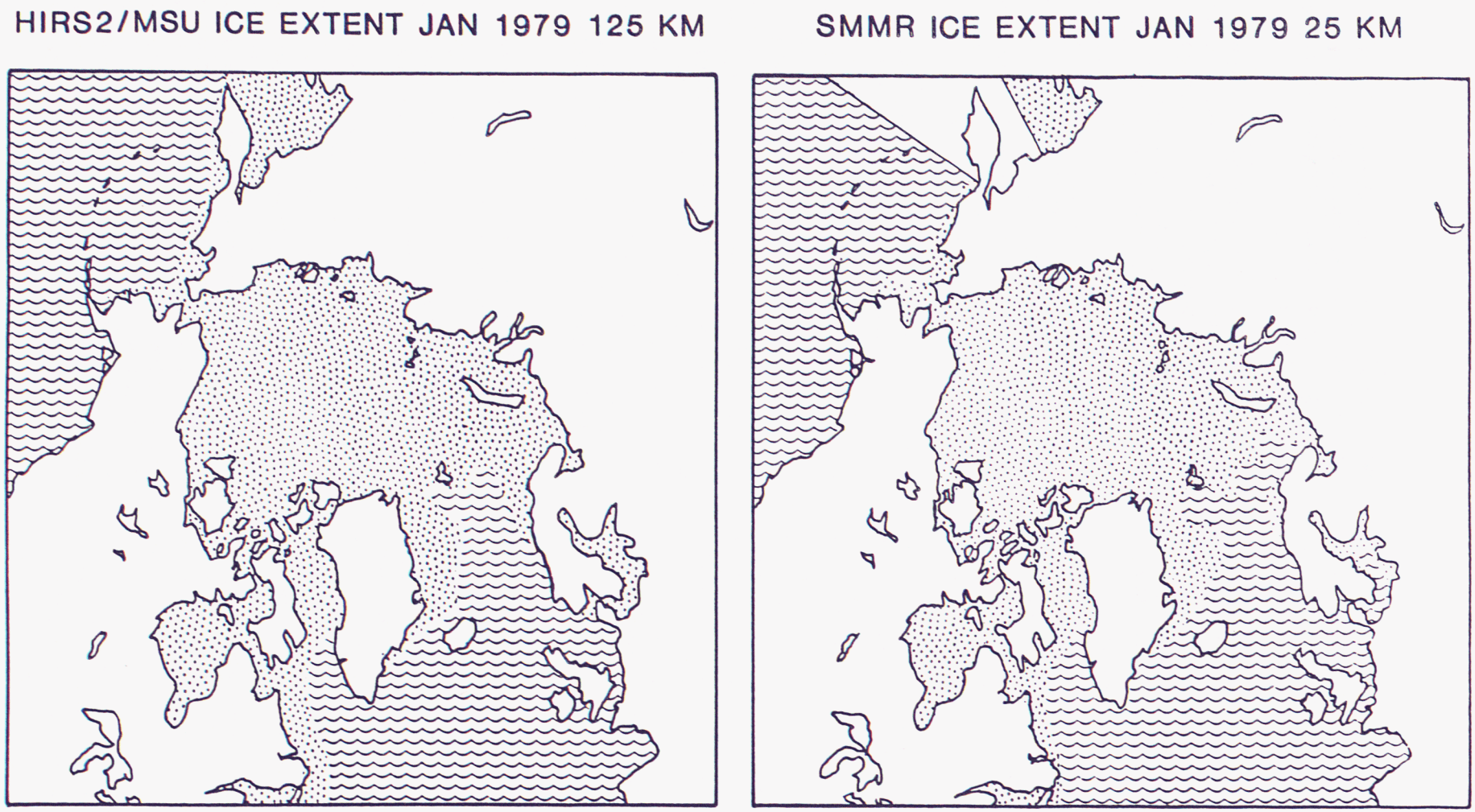


Fig. 1. Sea-ice mapping from HIRS-2 on TIROS-N (January 1979).

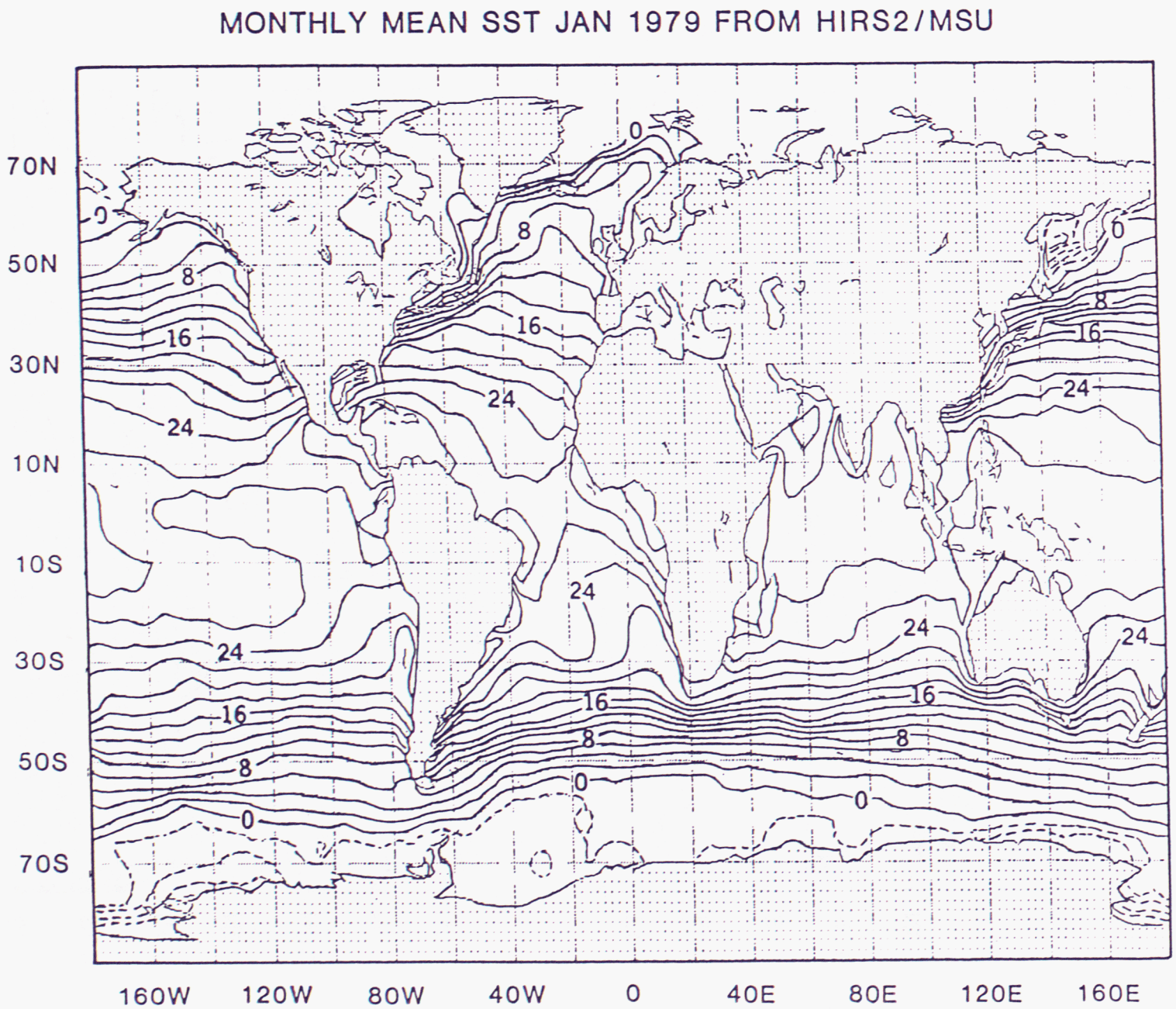


Fig. 2. Sea-surface temperatures from HIRS-2/MSU on TIROS-N (Jan. 1979).

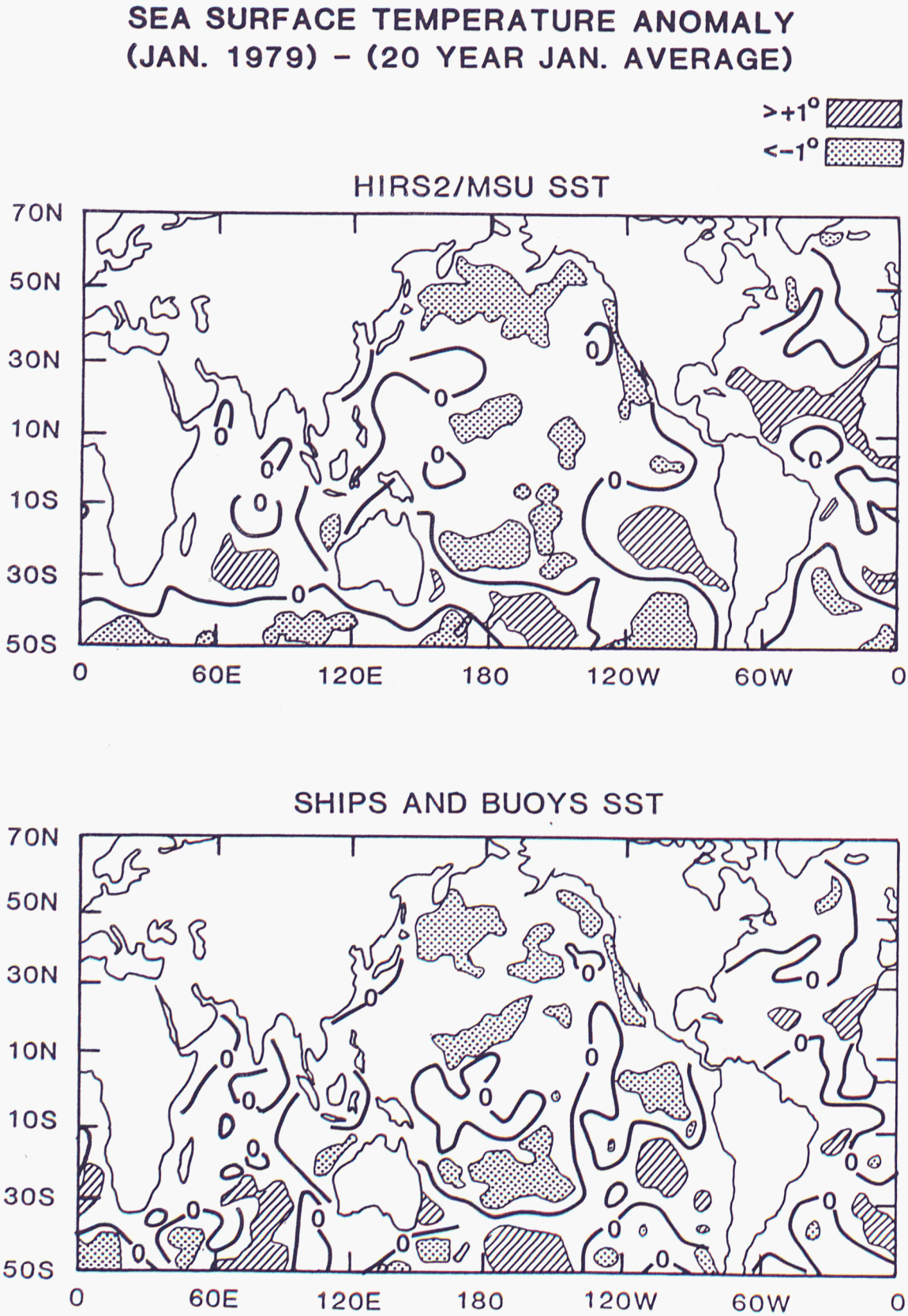


Fig. 3. Sea-surface temperature anomaly - present data minus 20-yr. average.

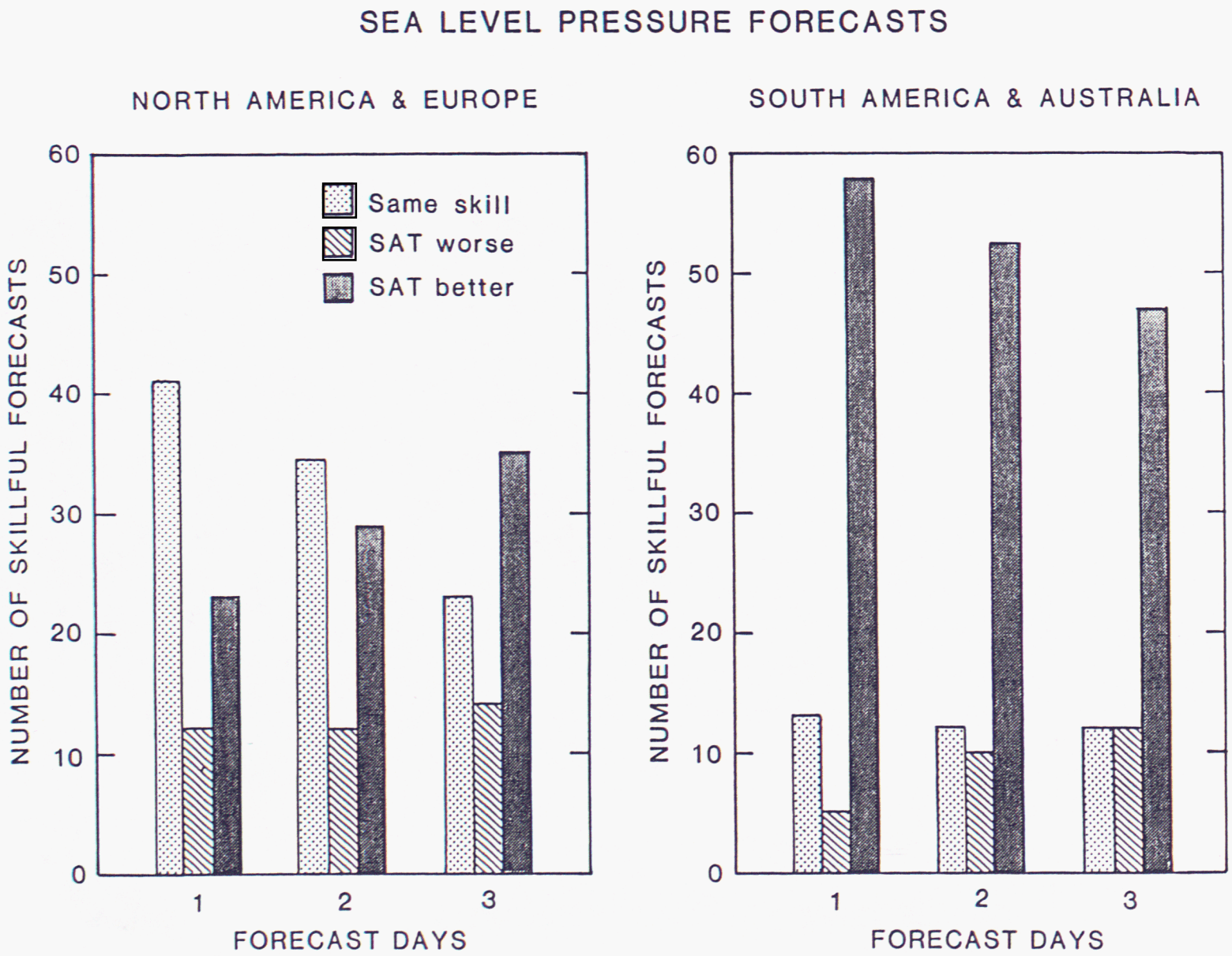


Fig. 4. Satellite data impact on forecast skill.

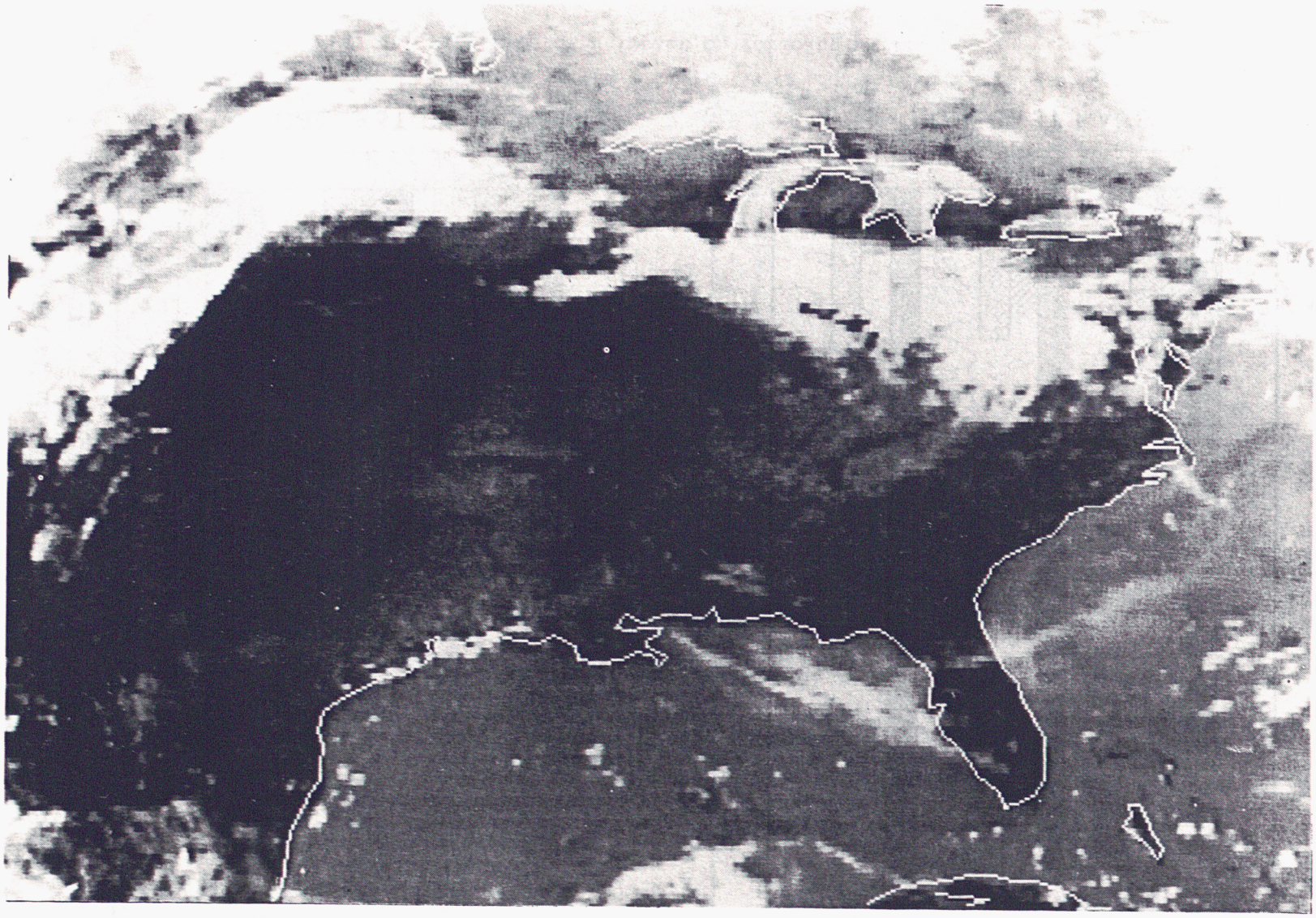


Fig. 5. VAS data.

GOES 5 - JULY 13,'81 - 1502 Z - CHANNEL 12 (WINDOW+SUN;4.3 MICRON)

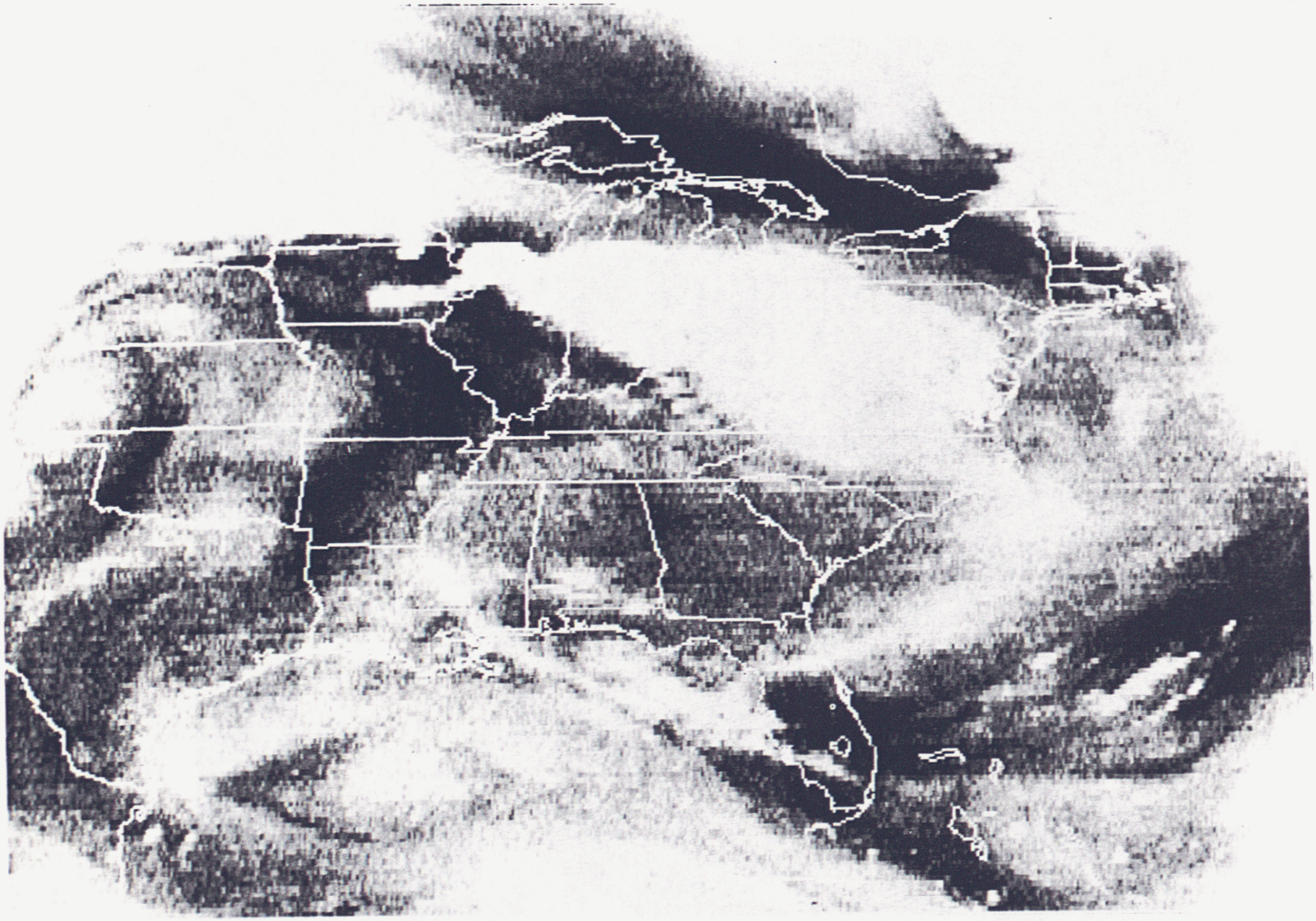


Fig. 6. VAS data.

GOES5 - VAS JULY 13, 1981 1500 GMT CHANNEL 10, 6.8 MICRON (MOISTURE)

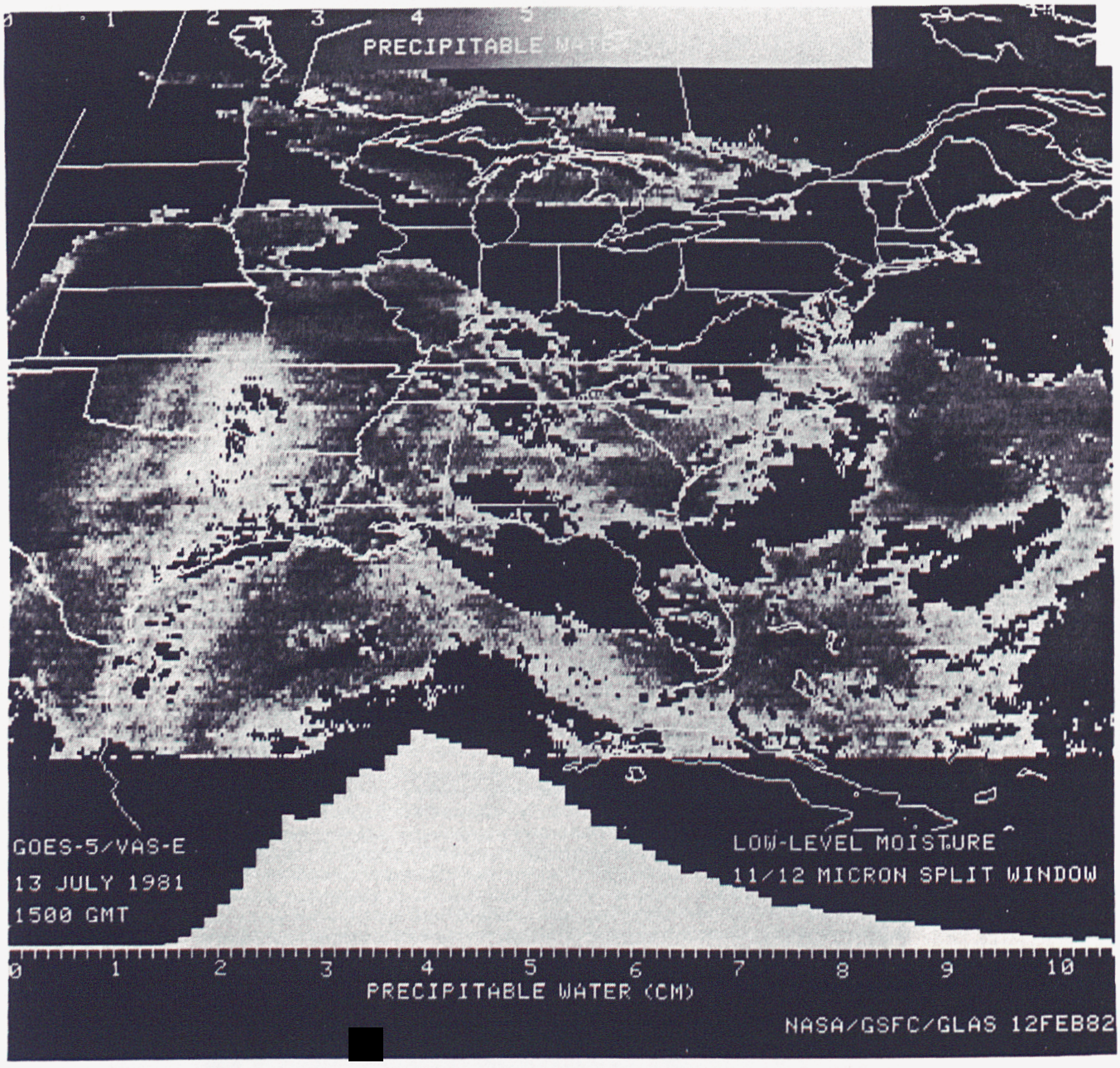


Fig. 7. VAS split window moisture data.

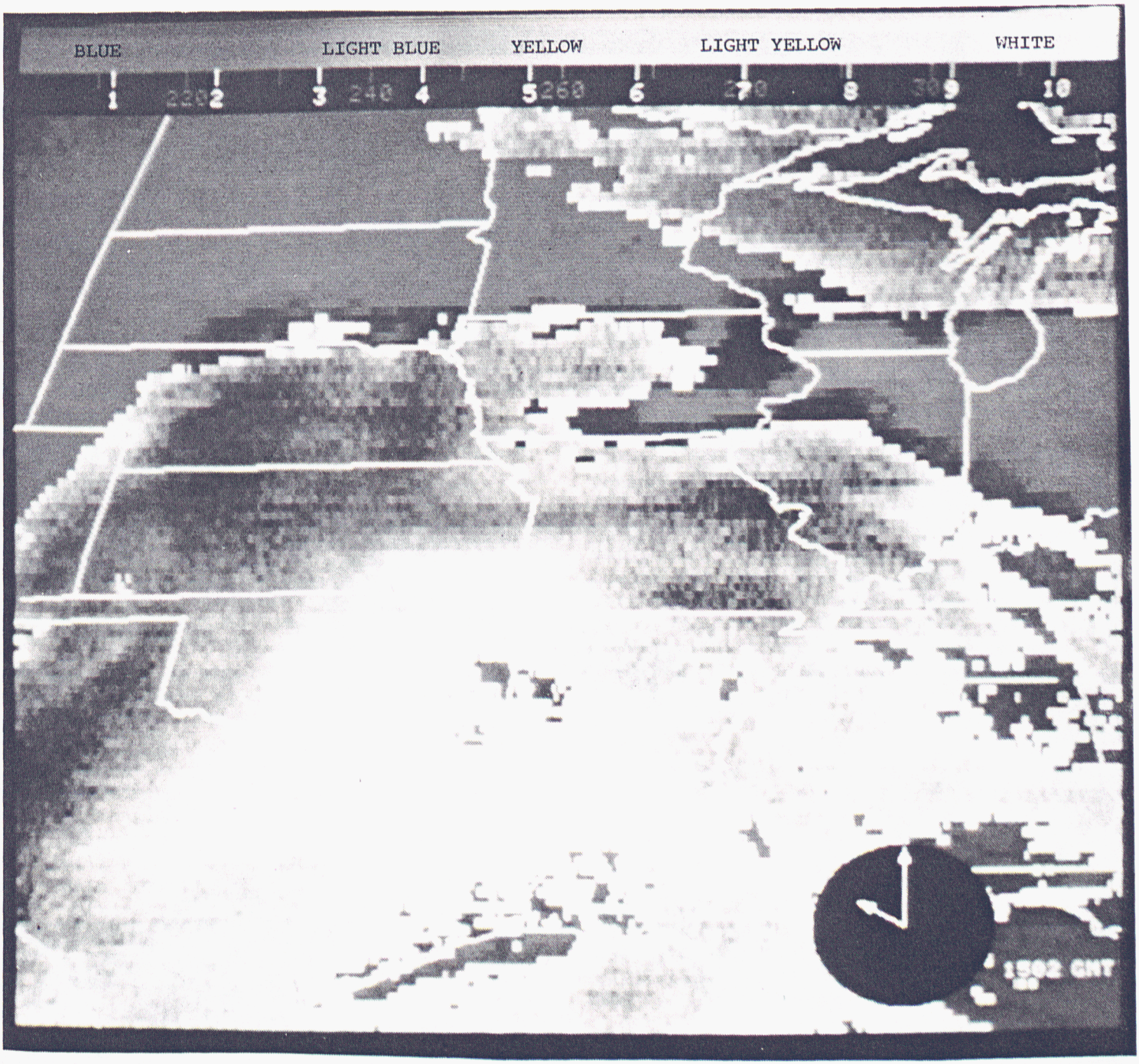


Fig. 8. Moisture (yellow) from the split window, dryness aloft from 6.7 μm channel. (For the purposes of this report, this picture was transferred from color to B & W. Color range, as noted on the graph above, shows darkest areas dark blue to lightest areas going from yellow to white.)

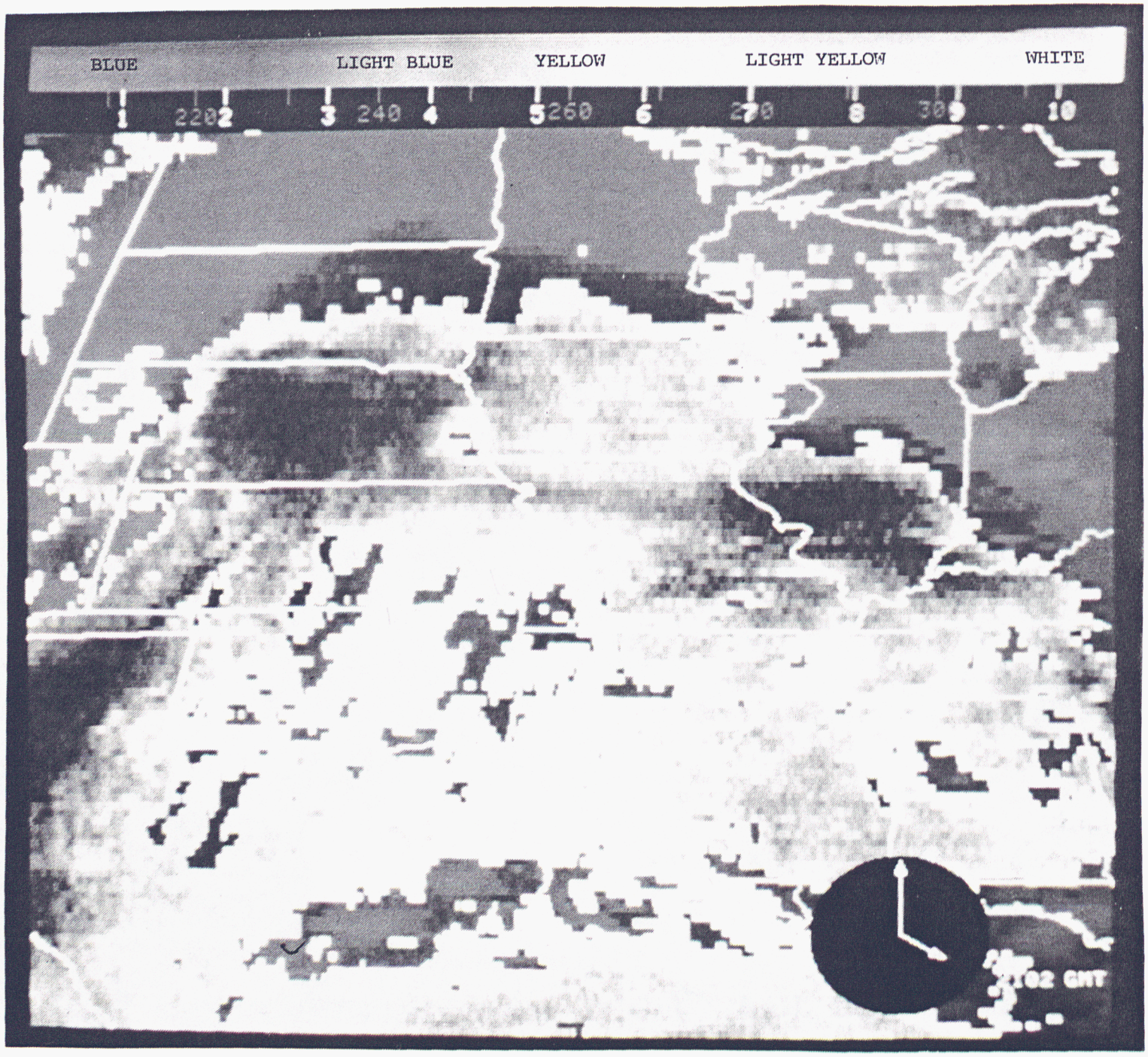


Fig. 9. Same as Fig. 8, six hours later.
(For the purposes of this report, this picture transferred from color to B & W. Color range is same as Fig. 8.)

REMARKS ON FUTURE DEVELOPMENTS

David Johnson

That's quite a plan Dave Atlas has suggested. Reminds me of one incident from history that might be worth noting. I'm going to be a skeptic now, and that may be surprising to many of you. I recall in late 1958, just about the time NASA opened its doors, everyone was scurrying around trying to figure out how to spend intelligently all the space development money that was flowing out of a concerned Congress, like water from a huge faucet. A group of us went to see the top decision-makers and within 48 hours, approval was granted to spend millions and millions of dollars on developing a promising new satellite system, which was launched in about 3½ years.

Well, that isn't the way it is today. Somebody has their hand on the faucet -- and someone is trying to pull the plug in the bathtub. If you're lucky today, it will be between 8 and 10 years from the time one knows exactly what is wanted and needed, to the time when it is launched -- and that does not include unusual delays in budget approval. It means that we can't think that everything's going to be solved tomorrow. How will we decide which of all those needed data outputs Dave listed are going to be obtained from a single satellite? Right now, to give you an example, NESS has real difficulty controlling the GOES satellites to satisfy the diverse research needs as well as operational requirements. It's not that the NESS people are against research. But everything can't be done simultaneously. The satellite itself has tremendous capabilities, but it can only do a few things at a time.

With those cautionary notes, I'd like to indicate what may still be feasible, in spite of my pessimism. I want to underscore what Dave has said, that this new way of looking at the world, like using a spacecraft bus for both operations and research, saves a lot of money. One has to make some compromises, but they're not all that great when you really come down to it. And there are a lot of strengths. For example, the data are pumped through in almost real time, regardless of whether it's for operations or research, and this helps everyone. I would hope that with the bigger Advanced TIROS-N polar orbiting spacecraft, it will be possible to start squeezing in some ocean observations, even beyond those contemplated for TOPEX. TOPEX must be a dedicated mission, and I hope it gets funded. Potentially, a scatterometer could be flown on the Advanced TIROS-N satellite. My feeling is that scatterometer observations for surface winds over the oceans are near the top of the list for both meteorology and oceanography. Microwaves are the way to go for ocean observations to get around clouds, but I am not a strong believer in microwave observations of the sea-surface alone. I think it's got to be microwaves and infrared.

I believe that we need and will have operational soundings from geostationary orbit. I think that the pressure in a year or two, when the research results now being developed are available, will clearly show the payoff of this capability, even in austere budget times. It will present real operational management challenges, requiring decisions between imaging and soundings. I'm very pleased with what our colleagues in NASA and NOAA have been doing in arranging for the forthcoming experimental period where accommodation has been made by both operational and research people. One would hope that the sounding versus imaging conflict problems can be resolved. However, care must be taken not to put a lot of other things onto the satellite, if they would lead again to a serious conflict between operations and research. In other words, there

must be a balance in the needs of the two communities.

Turning briefly to the polar orbiting satellites, the next step forward must be the highest quality microwave sounding that can be obtained. We know how to do it now. It is expensive, probably on the order of 30 to 50 million dollars to develop the first instrument, just the sensor. The cost for each subsequent operational instrument would be perhaps 10 million dollars. But this is cheap compared to the price tag on Dave's dream.

Now to discuss problems and issues. First is the question of research and development, and operations. What is the program going to be, from a policy and management point of view? No one can answer this question today. It is being debated now in the Administration, but what the outcome is going to be, no one knows. I'm sure that you've heard of the proposals to transfer the weather satellite program to the private sector. Questions are also being raised with respect to the entire National Weather Service in this regard. Where this is all going to lead, I don't know. Regardless of the policy decisions, I hope funds will be provided for the near-term improvements that I have touched upon, as well as sufficient funding to provide some new technology for the future. I personally don't think the rate of progress in the first two decades of the space age will be maintained, but I don't think that should discourage us. A lot can be done without needing the enormous sums of money that are required for the development and launch of entirely new space systems.

Vonder Haar:

This idea of sharing a satellite between operational and research purposes gives a lot of economies, just as you have been sharing facilities with the Air Weather Service. What would you think of dedicating every 4th or 5th in the series of satellites more towards research and thereby avoiding some of the conflicts that are inevitably there with two different groups with hands on the trigger.

Johnson:

It would be more expensive, it's that simple. If you put research sensors on an operational spacecraft, then the research budget does not have to fund the launch costs or basic spacecraft costs, telemetry, etc. Funds are required only for the add-on cost of the sensor itself, its integration into the spacecraft and then whatever data processing is required.

Vonder Haar:

Without a NIMBUS program to carry these experiments, we're eating our seedcorn if we don't continue to fly experiments that lead to the future operational systems.

Johnson:

We need to recognize that when we piggy-back on operational spacecraft, we have a very finite limitation on the kinds of sensors that can be tested. There are very serious limitations. But I was answering from the cost point of view.

Tepper:

One of the things that we all anticipated back in the early days was that these systems would be producing a lot of data, a lot of new data. I am reminded of some visits I made to NCAR and other places where I tried to involve people in utilizing the data, and almost every time we talked about the development of a system we said the major problem would be utilization. I'm glad to see Dave Atlas has referred to the utilization of the data that exists. One of the looks at the future that I would like to strongly encourage to the younger people who are coming along is not to "abandon the data cemeteries," as one of my friends has said. There is a lot of good stuff buried there, and one should get it out and use it

before we worry too much about developing new systems to give us more things to bury in data repositories.

The second comment I would like to make is with reference to the open faucet that was gushing millions of dollars into our pockets in the 1960's, and the notion that all we had to do was take the money and spend it. We were in a period of growing science at that time, and any growth situation is characterized by an exponential growth curve. Thus, the things we were doing were in big leaps and it was easier to convince people that satellite meteorology was a great thing. One of the first things we did when we faced budget people was to explain to them why meteorological satellite development was necessary. They didn't pour money into our pockets until they heard our story -- until we told them what the system could produce. Yes, it was easier to do then. We would show them a picture of a hurricane and this they understood.

Things are tougher now, not because we have a Dave Stockman and other such hard-nosed people at the faucet, but because it's really tougher convincing people that what we're going to get out of new systems will be that much of an increment over the past. So, in summary, I want to plan events in perspective. One reason the money was there in the early days was because it was easier to explain why satellite meteorology was a great thing. It's not so easy anymore. It is more difficult to explain why getting another tenth of a degree of accuracy out of a system is worth all that money. I think future support will depend upon the successful utilization of the data that we already have, the extraction of more information which will make predictions a little bit more accurate and useful.

Fleagle:

In Dave Atlas' talk, I don't think I heard anything about soil moisture and ice depth.

Atlas:

There is a great deal of work going on at Goddard on soil moisture by microwave methods. It requires 20 to 50 cm microwave wavelengths. You can get qualitative information about soil moisture fairly well, but it is affected by roughness and vegetation and what-have-you. I personally am doing a little research on this now with a colleague at GLAS and we find we can get soil moisture out of the daily trend of IR temperature. When you walk on the beach at the water line, the sun doesn't heat it up, and you're quite comfortable; while on dry sand, it's hot. We're using that sort of signal. But we normalize it in an interesting way. This is squeezing new and important information out of existing data. As far as ice depth is concerned, there are some concepts for it but I don't know them well enough to discuss them. I might note, however, that the community must make the decision as to whether they want to fly lidars for monitoring the icecap. It is a very important climatological problem. You don't have to do the measurement more often than once every decade or so. But it is an exceedingly important thing and nobody can visualize a better way of doing it than with a lidar system.

Freeman:

I would like to emphasize and even formalize Dave's statement about the scatterometer and the insistance that it be a weather measurement. This is a measurement prospect that is similar to the one of seeing the clouds, since you can now get the surface winds over the ocean areas. The ocean has been the place that has been the least observed in the past, and now it suddenly becomes the most observed. The surface wind is really just as important as the cloud height and the existence of clouds in studying meteorology. We can formalize this and say that it is the duty of the weather establishment to obtain the surface winds over the oceans. It is

possible to do it, so let's marshall the resources in spite of the political situation. It is very important scientifically.

Atlas:

I feel that a great deal of the progress that has been made has been the result of our close association with the academic community. They deserve tremendous credit. Unfortunately, there are only three university departments in the United States that have the resources to do an in-depth job in satellite meteorology. Not to mention that if you look in the literature, you will find that if you count the number of publications, you'll find that satellite observations are part and parcel of the vast majority of papers. But most cannot utilize satellite data in depth. I appeal to you in a time when budgets are tight, that the university community really should be supported intensively. UCAR should get into this satellite business and make it more accessible to the universities.

Dodge:

I would like to try to put Dave Atlas' and Morris Tepper's comments together here. I liked the picture of the growth of meteorology, especially the concept of an exponential growth, like a capacitor with the voltage going up. But unfortunately, when you reach the full charge, the voltage levels off, and that is where we are now. It is costing a lot to maintain the systems, to do all the research that Dave spoke about. NASA's programs alone are annually somewhere between 20 and 25 million dollars for data interpretation. We are not putting up very many new space systems right now, nor are we developing very many new sensors. It is costing us a great deal just to maintain the extensive research effort with all of its interactive systems, such as computers, along with massive organized collective data interpretation schemes. It's a good effort. I manage the Severe Storms Program, and we've supported 27 papers that will appear in the conference that follows this one. The applications are coming rapidly now, but it is costing the country a lot to maintain that flow of papers and research. I don't see an exponential growth of funding anywhere and that is the dilemma. Even if we get constant funding, if we want new sensors and new systems, what will we do? You can't have them while it's costing so much to maintain the present system.

Vonder Haar:

The base of users has increased tremendously. In the early days, all those dollars were spent by a small number of people, for a small number of experiments in universities and NASA. Now the base of users is much broader. The dollars in the satellite business are spread much wider, and therefore, the impact per person, per professional, is much greater. We are in the age of using new tools, not the least of which are the mini-computers. There would be a lot of benefit if we could give each Air Weather Service Officer or each university man an interactive system. I don't think we need to increase the amount of data. Rather, we should increase the output that comes from that pile of bits.

Wilson:

For daily meteorology and for climate studies, a lot of us are depending upon the satellites to give us records of many things, like the snow cover, the sea-surface temperatures, radiation budget estimates. In view of the signs of the budget cuts, do you think we will be able to defend the operational integrity of the system that we have built up over all these years -- geostationary and polar-orbiting satellites -- not worrying about the research questions or the new concepts. Are we going to be able to retain all this?

Johnson:

All I can say is that I hope so.

Ludwig:

Just to stimulate your thinking further; on the other end of the spectrum, away from reality, the technology now appears to be approaching where it should be possible to measure the three-dimensional wind field on a global basis, several times a day in the absence of clouds, by the use of lidar techniques -- scattering off atmospheric aerosols. This is a technology which is growing out of the military development of high-powered lasers. It is not outside the possibility that in ten years time, it might be possible, given the infusion of quite large sums of money, to make that an operational reality -- a three-dimensional wind field. Again, comparing it with the microwave imaging that Dave talked about, it certainly is something that is possible. It is just a matter of money at this point. I think that one of the things that has to be done is that there has to be a process gone through by the use of data that we have now, and perhaps some more intermediate experiments, to find out the relative values of these various things. We are probably not going to be able to obtain everything that is technologically possible. Sorting out the relative importance of research questions in terms of their end objectives -- forecasting the weather -- or whatever they may be -- is extremely important.

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16. ABSTRACT

The papers contained in this conference proceedings are those presented in the session on Meteorological Satellites during the San Antonio, Texas, American Meteorological Society's 62nd Annual Meeting held January 11-15, 1982. They provide reviews of past activities and assessments of the current and projected role of meteorological satellites, with emphasis on the program's development and achievements.

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