NASA Conference Publication 2257

The Conception, Growth, Accomplishments, and Future of Meteorological Satellites

Proceedings of the session on Meteorological Satellites at the American Meteorological Society's 62nd Annual Meeting San Antonio, Texas January 11-15, 1982

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NASA

National Aeronautics
and Space Administration

Scientific and Technical Information Branch

1982

PREFACE

Meteorological satellites have developed to where they are now considered to be an integral part of the nation's routine meteorological observation system. Since the initial thoughts and plans were developed during the 1950's, significant progress has been made in the application of space technology for meteorological uses. New understanding of our atmosphere and useful applications of imagery at both global and local scales have resulted from the program. The papers provided in this report were prepared not only to provide an opportunity to reflect on the accomplishments, but to provide a basis from which the future potentials might be envisioned. The authors and their respective organizations have played very important roles in the meteorological satellite system development and application activities.

The papers presented in this report were prepared for presentation at the American Meteorological Society's 62nd Annual Meeting held January 11-15, 1982, in San Antonio, Texas. They comprised the session on Meteorological Satellites - Their Conception, Growth, Accomplishments and Future. The papers are published with the approval of the authors and the American Meteorological Society.

A companion session entitled Meteorological Satellites - Past, Present and Future was organized for the American Institute of Aeronautics and Astronautics' 20th Aerospace Sciences Meeting held January 11-14, 1982, in Orlando, Florida. The session contained papers more orientated toward the various meteorological satellite sensor systems. The papers have been published in NASA Conference Publication #2227.

Dr. Thomas Vonder Haar, Colorado State University, Session Chairman;
Dr. William W. Vaughan, NASA, Marshall Space Flight Center, Session Organizer;
Dr. M. H. Davis, Universities Space Research Association, Session Recorder and Editor;
Melanie A. Cook, Universities Space Research Association, Assistant Editor.

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EARLY SATELLITE PROGRAM DEVELOPMENTS

William W. Kellogg, NCAR, Boulder, Colorado

After a youth filled with enthusiasm for Buck Rogers and a fascination with the possibility of spaceflight, it was a thrill for me to represent the U.S. Air Force on the Upper Atmosphere V-2 Research Panel in 1945. The first V-2's fired from White Sands carried concrete in the nose cone as ballast, but it was obvious that better uses could be found for the payload-carrying capacity. The scientists on the panel suggested instrument payloads. (This panel later became the Upper Atmosphere Rocket Research Panel, and continued for many years.)

Several years later, while I was still a graduate student at UCLA, I joined the Rand Corporation. RAND was already at that time (1947) working on the concept of satellites, though it would be more than a decade before the first satellite would actually be launched. The idea that satellites could be used as weather reconnaissance vehicles seemed fairly obvious. I began to work on the problem, and found RAND with its many resources the ideal place. I was joined by Stan Greenfield, newly graduated from NYU. What we needed was evidence that observations from a satellite would be useful in meteorology.

In January, 1949, Delbert Crowson, then a Major in the Air Force, published a short paper in the Bulletin of the AMS with the title "Cloud Observations from Rockets." In it he showed for the first time a photograph taken looking down on clouds from a rocket, and he included a short analysis. However, he did not take the next step to point out the possibilities of observations from satellites.

My favorite professor at UCLA, Joc Bjerknes, had great enthusiasm for the idea of doing a detailed analysis of rocket pictures. The case-study by Bjerknes, in which he interpreted several sets of photographs taken high above New Mexico, was published as an appendix to a short report by Greenfield and myself, which was classified SECRET in 1951 when it first came out. Now there is a version that was declassified in order that it appear in the archives. Bjerknes wrote "...it may be said that the rocket pictures add a considerable amount of interesting information to the ordinary weather map analysis and, in addition, that the accumulated knowledge from the maps help us in the new problem of interpreting what we see from high-level rocket pictures. It may be added that although in the present report the ordinary surface and upper wind maps had to be used to a great extent to arrive at the total picture, accumulated experience from several analyses from joint rocket and conventional methods would make it possible to arrive at the right analysis by rocket pictures only." We will see in the subsequent discussions this morning whether Bjerknes' feeling was borne out or not.

There were many other activities in those days - projects that eventually led to the meteorological satellite. Most meteorologists were hard to convince that rocket and satellite data would really be useful to them. It was another group of scientists, our cousins you might say, who coined the word "aeronomy" and who were most active in this area. They were the people who studied charged particles and magnetic fields and the composition of the upper atmosphere. I considered myself to be a meteorologist, but, in effect, I straddled the two fields of meteorology and aeronomy. The general attitude of meteorologists working on problems of the lower atmosphere was: "I could use all this space money in better ways." Some still have this point of view. For example, the AMS Upper Atmosphere Research Committee, which was chaired by Bernhard Haurwitz, prepared - with my help - a statement that said that there should be more emphasis put on the development of meteorological satellites. (This was in about 1956.) It seemed obvious to us that this would be a good idea, and meteorological satellites were already being planned at that time. To our surprise, the Council of the AMS decided not to approve the statement. Bernhard Haurwitz was furious, not so much because of the turn-down by the Council, but because of the reasons given. The Council said that they could not approve the resolution because they did not have an expert on meteorological satellites(!).

In July, 1955, Professor Joe Kaplan who was chairman of the US-IGY Committee announced at a meeting of the Committee Speciale de l'Annee Geophisique Internationale (CSAGI) in Brussels that the President of the United States had agreed that the US would launch a satellite as a contribution to the IGY for geophysical research. Kaplan liked to call it a "long-playing rocket", since these were the early days of long-playing microgroove phonograph records, and the name was popular for a while.

A panel was created under the National Academy of Sciences to guide the U.S. Scientific Earth Satellite Program. I was the meteorological member. It was chaired by Richard Porter, whom many of you remember; he became the long-time President of COSPAR. I remember that the panel constantly worried about whether we would actually get a satellite into orbit, since the Vanguard Program depended upon the Viking Rocket. The Viking had been developed by Martin for the Navy. It was the most advanced rocket of its time, particularly in its guidance and control systems. But unfortunately it was unstable in the early stages of its flight. (It was long like a pencil and developed vibrational modes of oscillation that caused the instability.) It was capable of only putting about 45 kg into orbit, which put serious restrictions on possible instrumentation and power sources.

Due to the delays of the Vanguard and Viking programs, the first US satellite with a scientific payload was actually put up after a crash program that involved the Army's Redstone Arsenal and the Jet Propulsion Laboratory of CalTech. William Pickering, James Van Allen, and Werner Von Braun did manage to get it up in short order -- but that's another story, since it didn't involve meteorology. (It did lead to the discovery of the radiation belts.) Still, relatively few meteorologists were interested in the potential of satellite observations at that time. Notable exceptions were members of the Army's Evans Signal Lab group led by Bill Stroud, Bill Nordberg, and Verner Suomi at the University of Wisconsin. (I wish Vern had been able to make it to this meeting to help me reminisce about the early days of satellite meteorology.) The experiments proposed by the Evans Signal Lab group and the University of Wisconsin were backed up by ground-based work sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Laboratory. Such people as Chan Touart, William Widger, Arnold Glaser, and others took rocket pictures and began to get experience analyzing them. This experience paid off when the first satellite pictures began to come in.

The first satellite that could be called "meteorological" was Vanguard II, a 45 kg satellite launched on 17 February, 1959. The instrumentation was developed by the Evans Signal Lab group, Stroud and Nordberg. It involved a very simple concept similar to the scanning radiometers we have now, with a photocell that would scan the Earth and build up a picture one line at a time. Scanning was to be done by rotation of the satellite as it went along its path, and it had a tape recorder that would record the output of this one cell. However, uneven separation from the launch vehicle and the fact that it apparently was not properly balanced meant that instead of rotating smoothly, it wobbled so that the scan on the ground made a complicated pattern that never could be unravelled. Therefore, we never actually got a picture from the Vanguard II.

The second meteorological experiment was entirely different. It was Suomi's proposal for the First Earth Radiation Experiment. As is characteristic of Suomi's ideas, it was beautifully simple and it worked. It consisted of ping-pong balls, in effect, on the ends of transmission antennas; some of them black and some white. They measured the omnidirectional flux of solar and infrared radiation. The first satellite with Vern's ping-pong balls went "into the drink" shortly after launch, but the second one was launched on 13 October, 1959 and became Explorer 6. It worked, and it got the first measurements of the radiation balance from the Earth; something that I think Tom Vonder Harr is going to tell us more about later.

While the Vanguard Program was struggling for success, there were many other things happening. One was that the Upper Atmosphere Rocket Research Panel changed its name to the Rocket and Satellite Research Panel. I had been a member all this time, and some other "big guns" joined it at this time. People like James Van Allen, Homer Newell, Werner Von Braun, William Pickering, John Townsend, and several others, encouraged by Joe Kaplan, worked very hard to sell the idea of a civilian space agency. They felt there were two things a civilian agency could provide that the military, which had, after all, supported the rocket and satellite program very well, could not do. One was that, if civilian, the program could be unclassified. Security classification had always been a nagging problem in this program. And secondly, it would show to the world that the US space program, which would eventually have to be very large, was in the service of mankind and was entirely for peaceful objectives.

In March of 1958, President Eisenhower announced that he had decided to go ahead with the creation of NASA, the National Aeronautics and Space Agency. That was in the spring. It was clear that it would take a while for NASA to get into high gear, so as a holding operation, the Department of Defense set up the Advanced Research Projects Agency (ARPA) and they decided early in the game that a meteorological satellite would be one of its projects. Roger Warner was in charge of ARPA's meteorological satellite development. He called a historic meeting at the Pentagon with Gordon Vaeth, Michael Ference, F.W. Reichelderfer, Sigmund Fritz, and Harry Wexler (who up until his death was one of the great supporters of the program). Also, several people from the Military were there: Ernst Stuhlinger, Charles Bates, Arthur Bostick, William Widger, plus Edgar Cortright from NACA, which was later to become NASA. One of the first things they did was to set up a committee to oversee the development of a meteorological satellite.

I was chairman of that committee. We had the problem of designing the first satellite, although the general decision had been made to go with RCA's newly developed Vidicon television tube as the basic sensor. It was ideally suited to this application for a number of reasons, but we had some interesting problems; one of them being how to mount this Vidicon on the satellite so that it could get a picture. We did not have any way of stabilizing the satellite as we do now -- it was a rotating satellite. We decided to put the Vidicon looking along the spin axis. For this configuration you would know the direction of the picture, but you would not know its orientation. Originally, we wanted to have three cameras: a wide-angle, a medium-angle and a narrow-angle with about 100 meters resolution. The third camera was dropped, because in those days such a detailed picture was considered to be too militarily sensitive. (This attitude may seem peculiar nowadays, since the LANDSAT pictures now have nearly an order of magnitude better resolution than this.)

TIROS-I was turned over to NASA, to a division under Morris Tepper and Ed Cortright, in the Spring of 1959. It was launched on April Fools' Day, 1960. The satellite we turned over to NASA was fairly well along in its development, and it worked very well after the launch. In the years since that famous launch in April 1960, we have seen enormous advances in the science and technology of satellite meteorology. I was personally a bit disappointed in those early days that applications of this new technique did not happen faster. But we will learn from the rest of the talks this morning what did happen in the years that followed.

Dave Johnson:

It may be interesting to point out that in the audience this morning is George Ludwig, who built the sensors and the tape recorder for Van Allen's satellite. He was listed as co-author of the radiation belt paper and also built the tape recorder that was on Vern Suomi's experiment. Tape recorders were very important in those days because there weren't that many readout stations.

Unidentified Speaker:

As a little historical note, Dr. C.F. Brooks, founder of our society, was very interested in the years before the satellites ever went up. I took a course by correspondence right after high school at Clark University, where he was a professor. In that correspondence course, we heard a lot about Goddard (and his rocket experiments). Brooks expressed a lot of interest in rockets and told us that rockets would cast light on cloud structure. So he really should go down in the history of meteorological satellites.

EARLY PROGRAM DEVELOPMENT AND IMPLEMENTATION

Morris Tepper, NASA (retired), Silver Spring, Maryland*

The U.S. meteorological satellite program had its earliest beginnings in the Department of Defense, in its Army Ballistic Missile Agency (ABMA). It was there that studies were undertaken with the Radio Corporation of America (RCA) for the utilization of television cameras in reconnaissance. The project was called Janus II.

Then came Sputnik I on October 4, 1957. The shock of that flight provided the necessary impetus to this country, forcing it to reorganize its space activity so as to be in a better position to respond to this Soviet challenge. Among the many actions taken at that time was the consolidation of all space reconnaissance activities into the Air Force. It was then decided to reconfigure the ABMA's Janus II project as a meteorological satellite effort, to have its sponsorship taken over by the Advanced Research Projects Agency (ARPA), and its named changed to TIROS. (Television and Infrared Observational Satellite.)

It was also then that the national civilian space agency was born. By mid-1958, the expressed direction which our country took was to separate the purely civilian space efforts from the military efforts and to incorporate them in a civilian controlled agency whose actions would be totally unclassified and whose direction was to pursue space activity for the benefit of man. In this way NASA was established on Oct. 1, 1958.(Fig. 1)

In the ensuing months a number of programs and projects under the direction of the DOD were transferred to the new agency, among these TIROS. On April 13, 1959, NASA assumed responsibility for the existing TIROS effort and with it the national responsibility for meteorological satellite research and development. In order to insure proper and continued coordination with the two agencies having the greatest involvement in weather activity, NASA immediately took two important steps:

First, in anticipation of acquiring the responsibility for weather satellite R & D, NASA transferred funds to the Weather Bureau for the purpose of organizing within the Weather Bureau an entity for the meteorological processing and analysis of the expected data. In subsequent years, the support for this entity was undertaken by the Department of Commerce. This entity has grown to its current mature state and is known today as the National Earth Satellite Service (NESS).

On a purely personal note, I might mention that the Weather Bureau, in turn, transferred me to NASA Headquarters where I was given the responsibility for the planning, direction and the implementation of the program. My critics might cynically observe that the Weather Bureau came out ahead on both of these transfers.

Upon receiving management responsibility for the TIROS program, the second coordinating action which NASA took immediately, was to establish the Joint Meteorological Satellite Advisory Committee (JMSAC). This committee included representation from every branch of the DOD having weather responsibilities, as well as from the Weather Bureau. In JMSAC, which existed for five years until the establishment of a new format under the National Operational Satellite System (NOMSS), the smallest details of satellite development, including progress and future plans, were reported on by NASA. The DOD and WB representatives reviewed, critiqued and contributed to these plans in the context of their agency requirements; and they actively participated in the trade-off decisions that were necessary as we moved towards an operational system.

Now, the events to which I have been referring transpired more than 20 years ago. It is quite natural that one's memory about events, sequences and

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dates would grow fuzzy after such a long period of time. Fortunately, I have not as yet disposed of my personal correspondence files and papers which I took with me upon retirement from NASA. Most of the material I am presenting to you today comes from that personal source.

Although I was a principal participant in the events about which I read in these files, I became completely engrossed, and my time became completely saturated with this reading for days and, I might add, nights on end. As I continued to pour over this rather old material, my recall of many of the details improved, and I found myself experiencing anew the enthusiasm, the pace, the excitement, even the actual joy and exhilaration which we all felt during that period.

For the purpose of this talk I will concern myself almost entirely with the first decade -- that is, through the 1960's.

First, let me remind you of the satellite launch achievements during that period. (Fig. 2)

Until 1965 there were nine successful TIROS launches, followed by 10 in the operational satellite series -- for a total of 19 successive successful TIROS launches. During this same ten-year period there was one Nimbus launch failure out of four attempts. Not shown here are the launches of the communication satellites, Application Technology Satellites (ATS). On ATS-1, and again on ATS-3, the spin scan camera was flown and showed that useful cloud cover picture information could be retrieved from geostationary orbits (over 20,000 mi away from the Earth) from which winds could be derived using the cloud motion. This was the precursor of the Synchronous Meteorological Satellite (SMS) series which would be implemented in the 1970's.

Let me give you some of the highlights of these early satellite launches:

- TIROS 1 proved the general concept of retrieving useful meteorological information from space;
- TIROS 2 extended the imaging capability to the scanning of upwelling infrared radiation;
- TIROS 3 and 5 were specifically launched so as to be useful during the hurricane season and more generally in tropical weather reconnaissance;
- TIROS 4 proved highly applicable to the problems of ice formation and its breakup in the spring;
- TIROS 6 launched to overlap TIROS 5 gave us experience with operating two satellites in orbit at once;
- TIROS 7 was used primarily to insure continuity of observation (it dutifully survived more than 30 months);
- TIROS 8 carried the Automatic Picture Transmission System (APT) which I will mention again later;
- TIROS 9 changed the orientation of the satellite to the "cartwheel" configuration permitting vertical viewing of the Earth and its atmosphere from space.

The Nimbus satellite series was that of a truly three-dimensional Earth-stabilized meteorological observatory, on which it was possible to check out the numerous remote sensing instruments for measuring different components of the Earth, atmosphere and solar radiation. Using ingeniously developed conversion algorithms, scientists were able to extract useful meteorological parameters from the radiation information. A sometimes overlooked product of this Nimbus series was the check out and use in space of one of the first, if not the first, space nuclear power supplies. With this information on the successes of the program, let us pause a moment to review our expectations prior to the launch of TIROS 1.

In March, 1947, a camera system was launched on a captured German V-2 rocket which, I believe, provided us our first look at cloud structure as seen from space altitude. (Fig. 3) You will note that fine structure in the cloud systems is well discernible. These pictures and others acquired through subsequent sub-orbital flights fired the imagination of early planners to think in terms of developing imaging systems to fly onboard space satellites.

Our first orbital attempts, however, were far from encouraging. In 1959, Explorer VI was put into space carrying a photocell which responded to the reflected radiation from cloud tops. Fig. 4 shows one of the very few (if not the only) reconstructed photos (April 15, 1959). One could not get very enthusiastic about the future of space data such as this.

Thus, at the time of the TIROS 1 launch, our hopes were in the direction of the earlier results from the rocket system. But, I must confess, our expectations were not so optimistic in view of the Explorer results.

How well I recall that eventful day -- April 1, 1960 -- the launch of TIROS 1. (Fig. 5)

We had been up all morning, starting well before 4 AM, monitoring the events at Cape Canaveral, from a special briefing and communications room in NASA Headquarters. The countdown, my very first, was just as exciting and possibly even more exciting than those which I experienced in subsequent years for manned flight. Finally there was the launch. My attention then turned to our Command and Data Acquisition Stations (CDA Stations), which would be contacting the "bird" -- the satellite -- interrogating it and acquiring data from it. One CDA Station was located at Kaena Pt., Hawaii, and Dave Johnson was sent there to safeguard the program's interests. The other was at Ft. Monmouth, N.J. and our man there was Sigmund Fritz.

I had had a special telephone facsimile machine installed in my office, courtesy of the U.S. Signal Corps. The telephone permitted me to stay in voice contact with Sig Fritz at the Ft. Monmouth CDA Station and hopefully the facsimile element would be used when the first pictures from TIROS 1 would be received at the station.

At long last, the critical data-taking overpass took place over Ft. Monmouth. I believe it was on the second orbit. The "bird" was acquired, interrogated and data was received. The meticulously prepared system for demodulating the signal, extracting the data, and converting it to a hard copy worked flawlessly. Finally Sig was the phone.

"OK, Morris, we have pictures."

"What do they show? Can you see a horizon? Are geographic features noticeable? Can you see clouds? Can you differentiate cloud types? --- "

Sig interrupted my flood of questions.

"Wait a second" he said calmly, "If you will just get off the phone, I'll transmit the pictures to you and you will be able to see for yourself."

Since the system could not work on both modes simultaneously, I had to hang up and wait impatiently while the machine slowly painted out the transmitted pictures line by line.

And finally I had them. (Fig. 6)

Yes, it was all there, the viewed Earth, the horizon, the Gulf of St. Lawrence and the cloud pattern over the Northeastern U.S. and Southeastern Canada.

By now we were all excited. The NASA Administrator, Dr. Keith Glennan, called the White House, and we were requested to come right over. President Eisenhower interrupted a cabinet meeting in order to view the pictures which we had brought over and he genuinely shared in our excitement. We all felt that a breakthrough had taken place and that we had ushered in a new era. And, of course, we had.

As you know, progress was rapid in improving the quality of the space derived pictures. Although the early TIROS products (Fig. 7) revealed magnificent, important and usable pictures, they were still pale in comparison to what we were able to achieve later (Fig. 8) in accuracy and clarity.

So far I have spoken only of the cloud pictures. What about the other meteorological elements?

I found an interesting report in my files. On June 22, 1959, I appeared before NAS/NRC Committee on Atmospheric Sciences to brief that Committee on our plans and aspirations for meteorological satellites. Remember this was almost one year before the launch of TIROS 1. I said: (Fig. 9)

"To improve our scientific understanding of the atmosphere, to provide proper initial conditions for forecasting, and to detect existing storms, are all among the objectives of the national meteorological and rocket programs. So far as the meteorological satellite program is concerned, it is planned to observe and measure the global and local distribution of the following by means of photocells, television cameras, infrared and short-wave radiation detectors, radar onboard orbiting satellites, and by telemetering the observations to the selected readout stations:

- clouds - amount and type (perhaps motion of identifiable cloud elements to determine winds);
- precipitation - distribution and intensity;
- thunderstorm distribution;
- water vapor;
- ozone;
- carbon dioxide;
- temperature of the stratosphere, tropopause, cloud tops and the Earth's surface (some of the theoretical work of Dr. Lewis Kaplan suggests a more continuous vertical profile of temperature might also be possible;
- incoming solar radiation;
- reflected solar radiation;
- radiation from Earth and the atmosphere."

Also in this report, I spoke about our plans for satellite systems of the future. Since we hadn't as yet considered the possibility of nonsynoptic data assimilation, our thinking was heavily based by the then regular synoptic time data analysis procedures. Therefore, with regard to satellite systems of the future, I reported to the Committee on Atmospheric Sciences:

"Our ultimate plans envisage a system consisting of a group of six or so, pole-to-pole orbiting low-level satellites spaced longitudinally to yield a more or less synoptic surveillance of the entire globe, and another system of three or four equator-orbiting satellites to view local events continuously."

It is remarkable how little changed have been these objectives and plans with the passage of time. During the years that followed, every one of the parameters, about which I speculated to the Committee on Atmospheric Sciences--every one, and more, I might add, have been retrieved to one extent or another by means of remote sensing from space. Some of these which are proven to be applicable to climate research programs are given in Fig. 10.

With respect to our visions of the future meteorological satellite systems, here too our plans proved to be prophetic. The plans for the Global Experiment conducted just two years ago (Fig. 11) called for an array of satellites very similar to our earliest concept: two U.S. satellites (TIROS-N and NOAA-1), two USSR satellites (Meteor series) and the U.S. Seasat satellite in pole-to-pole orbit and five equatorial satellites (although since the USSR satellite was not ready, a third U.S. satellite was used).

As I continued to read through these dust-gathering files, it became clear that while we engaged in reports, program reviews, presentations, travel, meetings, coordination conferences, and seminars, we were in fact pursuing several important objectives. The objectives which emerge clearly from the intricate matrix of feverish activity are given in Fig. 12. Each one of these objectives has its own fascinating story of plans, approaches, personalities, compromises, agreements, disappointments, developments, progress and results, and yet in each the U.S. meteorological satellite program has proven to be remarkably successful.

Unfortunately, it will be impossible to give proper treatment to each of these subjects in the time allotted to me. Rather, I will simply describe briefly what was involved in each and leave the comprehensive treatment for other occasions and other formats. However, in view of my personal interest and particularly active personal involvement in the international aspects of the program, I have added some extended remarks on that phase in an Appendix.

1. To develop and maintain support for the program.

Here, we were engaged with the entire gamut of external relations -- with developing programmatic support within our individual agencies; with acquiring financial support from the administration, from the Executive Office of the President, and from Congress; with the developing interest and participation of academia and the scientific community in general; and in providing the public with general information on what we were doing, what we had accomplished, and what we were planning to do -- and most important, the significance of each of these.

I recall, for example, after the launch of TIROS-2, we were asked to come to the White House immediately and to bring a model of the satellite with us. Two of us grabbed the model which must have been about 35 inches in diameter and about 20 inches high, with antennas sticking out the bottom and top, and raced with it across Lafayette Square to the White House. We arrived just as President Kennedy and President Ayub Khan of Pakistan were leaving the Oval Office where they had been conferring. They stopped, and still breathless from our hectic run, I explained briefly what it was we had.

"Tell President Khan how this satellite will help Pakistan" Kennedy said as he turned to me.

I can only say that in situations such as that one we were fortunate that we said the proper things, to the proper people in the proper way -- because during that decade we did develop and maintain a rather enthusiastic support for the program on many fronts.

2. To solve critical technological problems.

Here, we were confronted at almost one and the same time with urgent needs to solve critical technology problems in such diverse fields as mechanics, thermodynamics, electronics, telecommunications, optics and data processing. Examples of the problems to be solved in some of the specific areas were:

   a. In satellite systems -- power supply, stabilization and control, heat transfer, command devices, clocks, tracking beacons, tape recorders.

b. In satellite sensors -- television cameras, low-light viewing devices, and in general the development of sensors that are sensitive to different portions of the spectrum from which atmospheric parameter information could be inferred.

   Fig. 13 shows this idea schematically. Towards the origin, in a clock-wise rotation, the electromagnetic spectrum is depicted, ranging from long wavelengths to short wavelengths. On the outside are listed various sensors particularly effective in the corresponding wavelengths. In between are the various meteorological elements that might be retrieved from the measurements taken by the indicated instruments for the indicated wavelengths.

c. In data handling and processing -- telecommunications, demodulation of signals, gridding, analogue to digital conversion, cataloging, and all sorts of data manipulation techniques.

In the solution of all of these important technical problems, expertise had to be found in industry or government or developed within government field centers. The program was particularly fortunate that at the Goddard Space Flight Center (GSFC), there was a particularly strong technical team, the Aeronomy and Meteorology Division, headed by William Stroud, that gave extraordinary leadership and attention to the solution of many of these problems.

3. To establish an operating system.

Immediately after the success of TIROS 1, there was strong pressure for pushing on towards an operational system and as indicated in Fig. 1, on October 10, 1960, an interagency Panel on Operational Meteorological Satellites (POMS) was established to plan for such a system. During the following three and a half years, until the National Operational Meteorological Satellite System (NOMSS) was established in January 1964, delicate negotiations were held at several levels of the government and in the public sector:

- o to define the operational system;
- o to clarify the role of the operational system relative to the ongoing satellite research and development program;
- o to assure the continuity of both;
- o to delineate agency responsibilities in the operational program and in the R & D program;
- o to insure the needed coordination at all levels of the program;
- o to incorporate, as much as possible and was feasible, the military requirements within the civilian program.

The health and vitality of the National Earth Satellite Service (NESS) and the manner in which meteorological data is currently being included in routine meteorological analysis and forecasting attests to the success of the early efforts in establishing a viable operational system.

4. To provide the technological base for the Global Experiment and for the Climate Program.

I have already referred to the remote sensing instruments that were developed, sensitive to various portions of the electromagnetic spectrum, and to some of the meteorological products that have been derived from these measurements. As the requirements for the Global Experiment were clarified, an active dialogue had to be established between the scientists who were seeking particular data and the technologists who were able to guide them in terms of what was technologically possible. The resulting compromises provided the basis for proceeding with the R & D.

As a result, most of the elements that are depicted in Fig. 14 are being made available through the use of satellite systems. The derivation of information such as this by remote sensing from space carefully conducted research programs for:

- o Combining raw telemetry tapes containing sensor data, ephemeris data, and spacecraft operating condition data.
- o Converting telemetry information into physical units.
- o Developing and applying an algorithm for interpreting the physical units in terms of geophysical parameters.
- o Validating the data using ground truth; and establishing error levels.
- o Applying the data to specific scientific problems.

This is the long and tedious process characteristic of research in the interpretation and utilization of remote sensing, and we can indeed be proud that the record is so full of valuable results.

5. To share developments with other countries and give them a sense of participation in it.

The national civilian space effort was established with the objectives of pursuing the "peaceful uses of outer space" and "to share the benefits of space activity with the other countries of the world." Nowhere were these objectives more enthusiastically adopted and more successfully achieved than in the U.S. Meteorological Satellite Program. Actions in the direction of these objectives were undertaken almost immediately after the successful launch of TIROS 1.

Fig. 15 shows a list of international activities which were important elements of the Meteorological Satellite Program. A more complete description of each is given in the Appendix to this paper.

This then is an overview of those early years -- those exciting years -- those highly successful years.

One could question how it was possible, in a mere decade of time . . .

- to establish and execute such a viable program plan for the development of meteorological satellites;
- to develop the necessary confidence in sister government agencies so that they would work in a mutually supportive mode;
- to stimulate U.S. industry to respond enthusiastically and in a timely manner;
- to achieve the incredible record of so many successful launches;
- to overcome the initial inertia of the scientific community so that space meteorology was included, both in its research and in its operations;
- to maintain the momentum in technology development so that various instrument and systems improvements were on the drawing board even before the original version was launched;
- to enlist the cooperation and the support of the Administration and Congress so that resources were available when needed;
- to recruit the participation and interest of scientists in other countries into the program, thus permitting a meaningful Global Atmospheric Research Program (GARP);

- to overcome the limited image of weather and weather forecasting as it existed before the 60's, to its role in big science in the 70's and today.

As I look back, I believe that two unique features were at work:

First: In addition to the availability of technical competence, there was exceptionally high morale and widespread informality among participants; high professional integrity; there was personal commitment -- personal identification with the program, its objectives and its successes. All of this brought out the best in effort, the best in creativity, the best in production, the best in results on the part of everyone.

Second: There was quite a bit of naivité on the part of the participants. Any experienced bureaucrat would have known when we started that it simply was not possible to lay out a program plan such as this, much less to implement it in the short period of ten years.

But very few of us were experienced bureaucrats, at that time. We simply didn't know that it could not be done. So we went ahead and did it!

APPENDIX

EFFORTS MADE TO SHARE DEVELOPMENTS WITH OTHER COUNTRIES AND TO GIVE THEM A SENSE OF PARTICIPATION IN THE PROGRAM

a. Transmission of nephanalyses and other summaries on facsimile circuits in order to make information operationally useful at the earliest possible time.

Fig. 16 contains two such nephanalyses. Note that the one for 1829Z contains information from hitherto data sparse areas.

b. Arrangements were made with interested foreign countries to provide them with accurate information on satellite overpass over their territory. In this way, they could mount programs of ad hoc ground-based observations for the study of special situations.

c. On request, the provision was made of specific satellite data to foreign research groups studying particular weather situations. This sharing of data familiarized foreign scientists with satellite data, its utilization and potential for the future. This familiarity was indispensable in the future planning for GARP.

The execution of the first three activities was handled almost exclusively by the U.S. Weather Bureau working through its representation in the World Meteorological Organization (WMO).

d. By the summer of 1961, three TIROS satellites had been successfully launched and their data was being incorporated by the Weather Bureau in the daily analysis. NASA and the Weather Bureau organized an international workshop inviting participation by countries adhering to the WMO to come and learn (through actual laboratory exercises) how to handle the satellite data and incorporate it into their operations. 37 representatives from 28 countries attended this first satellite workshop. Fig. 17 shows the participants in a laboratory exercise session.

This workshop was the precursor of numerous workshops on varied meteorological satellite topics sponsored by both the WMO and individual countries.

e. The initial TIROS camera system operated in both a direct and storage mode. The direct mode provided only the local scenes and the storage mode provided scenes taken during orbits since the last passage over a CDA station. As was mentioned earlier, nephanalyses of cloud patterns as analyzed by the Weather Bureau were transmitted to foreign weather services.

This arrangement served well in the analysis of large extratropical storms that persist for several days and influence the weather over large areas. However, for rapidly developing systems, systems of shorter duration and lesser geographic extent, the elapsed time between satellite passage and receipt of nephanalyses by local authorities proved to be too great.

The Automatic Picture Transmission (APT) Subsystem initially developed under the Nimbus program overcame this difficulty. Using a special slow scan vidicon, this system transmitted continuously and reception of its signal was possible by any properly equipped rather inexpensive local station within its line of sight.

On July 1, 1976, we had information that APT stations existed in about 120 countries.(Fig. 18) The amount of coverage possible at a given station is clearly illustrated here. However, since specifications for an APT station have been widely distributed and construction is rather straightforward with readily available parts, there is really no way of knowing where and how many APT stations exist.

f. By the middle of the 60's, the U.S. had organized a Meteorological Rocket Network (MRN) for the purpose of making vertical soundings of the stratosphere and mesosphere. Other countries recognized that the rocketsonde technology and launching procedures were in a small way a stepping stone to the space activity that might follow. Consequently, as a result of a suggestion by Argentina, a special rocketsonde observational program was set up in the Western Hemisphere -- the Experimental Inter-American Meteorological Rocket Network (EXAMETNET). The participating stations are shown to the left of Fig. 19. Their north-south orientation was for the purpose of measuring the variations in the stratosphere along a longitudinal transect. Countries participating directly in EXAMETNET were: Argentina, Brazil, France and the U.S. Other countries having rocket launching capabilities were attracted by the scientific and technological advantages of EXAMETNET and became adjunct members of the program. These included: Mexico, Japan, Spain, India, Pakistan and Australia. A major feature of this cooperative effort was the exchange of measurements and resulting analyses among the participants and periodic meetings for the purpose of discussing these measurements and results.

g. In view of the demonstrated capability of both the U.S. and the Soviet Union in conducting space activity, it was recognized early by both sides that it would be to their mutual advantage to conduct bilateral discussions leading to joint space efforts. In March of 1963, the first such discussions were held in Rome. In the area of space meteorology, we established a data link between Moscow and Washington across which operational meteorological data was exchanged between the USSR Hydrometeorological Service and the U.S. Weather Bureau. Later, a cooperative program in rocket observations was established. The USSR set up a line of meridional stations in the Eastern Hemisphere (Fig. 19) in parallel to the EXAMETNET line in the Western Hemisphere. In addition to periodic exchange of observations and results, another important feature of this cooperative effort was a program for co-located measurements for the purpose of instrument data processing intercomparison. This was followed by a program of co-located measurements by airborne remote microwave instruments in a special Bering Sea observation exercise in order to intercompare these instruments before they were committed to space flight.

h. Other countries were also making rapid strides in space activity. France embarked on the development of an ambitious space system for the interrogration and location of instrumented platforms. At the same time they developed a sophisticated constant level balloon system capable of supporting a number of instruments for making in situ measurements. Both of these developments were then incorporated in their first space venture, EOLE. We cooperated very closely with the French in these developments. Then finally the French system for interrogating and locating remotely located instrumented platforms was incorporated into the U.S. Operational Meteorological Satellite System. Also, the UK sounder of the upper atmosphere - the Mesospheric Sounding Unit (MSU), was developed with U.S. cooperation and support and is now a feature of our operational system.

i. The reality of meteorological satellite systems which permitted the viewing of the Earth and its atmosphere globally and continuously, made possible the planning and execution of the Global Experiments under GARP. The U.S. Meteorological Satellite Program provided a good deal of the leadership as well as the technological base and the satellite technology essential to the implementation of the operational phase of this program.

j. The Committee on the Peaceful Uses of Outer Space was the focus within the U.N. for international discussion, negotiation and agreement on international space activity. Again in view of its successful execution, the U.S. Program details of progress was continuously made available to the Committee.

SOME CAUSES AND EFFECTS

October 4, 1957	:	Sputnik I
October 1, 1958	:	NASA established
April 13, 1959	:	TIROS transferred from ARPA to NASA
April 1, 1960	:	TIROS I launched
October 10, 1960	:	POMS established
January, 1964	:	National Operational Meteorological Satellite System (NOMSS) established

FIGURE 1

METEOROLOGICAL SATELLITE LAUNCHES
(1960 - 1969)

TIROS 1	-	April 1	,1960
TIROS 2	-	November 23	,1960
TIROS 3	-	July 12	,1961
TIROS 4	-	February 8	,1962
TIROS 5	-	June 19	,1962
TIROS 6	-	September 18	,1962
TIROS 7	-	June 19	,1963
TIROS 8	-	December 21	,1963
TIROS 9	-	January 22	,1965
Nimbus 1	-	August 28	,1964
Nimbus 2	-	May 15	,1966
Nimbus B	-	May 18 -failed-	,1968
Nimbus 3	-	April 14	,1969

OPERATIONAL SATELLITES

OT-1	-	July 2	,1965
ESSA 1	-	February 3	,1966
ESSA 2	-	February 28	,1966
ESSA 3	-	October 2	,1966
ESSA 4	-	January 26	,1967
ESSA 5	-	April 20	,1967
ESSA 6	-	November 10	,1967
ESSA 7	-	August 16	,1968
ESSA 8	-	December 15	,1968
ESSA 9	-	February 16	,1969

FIGURE 2

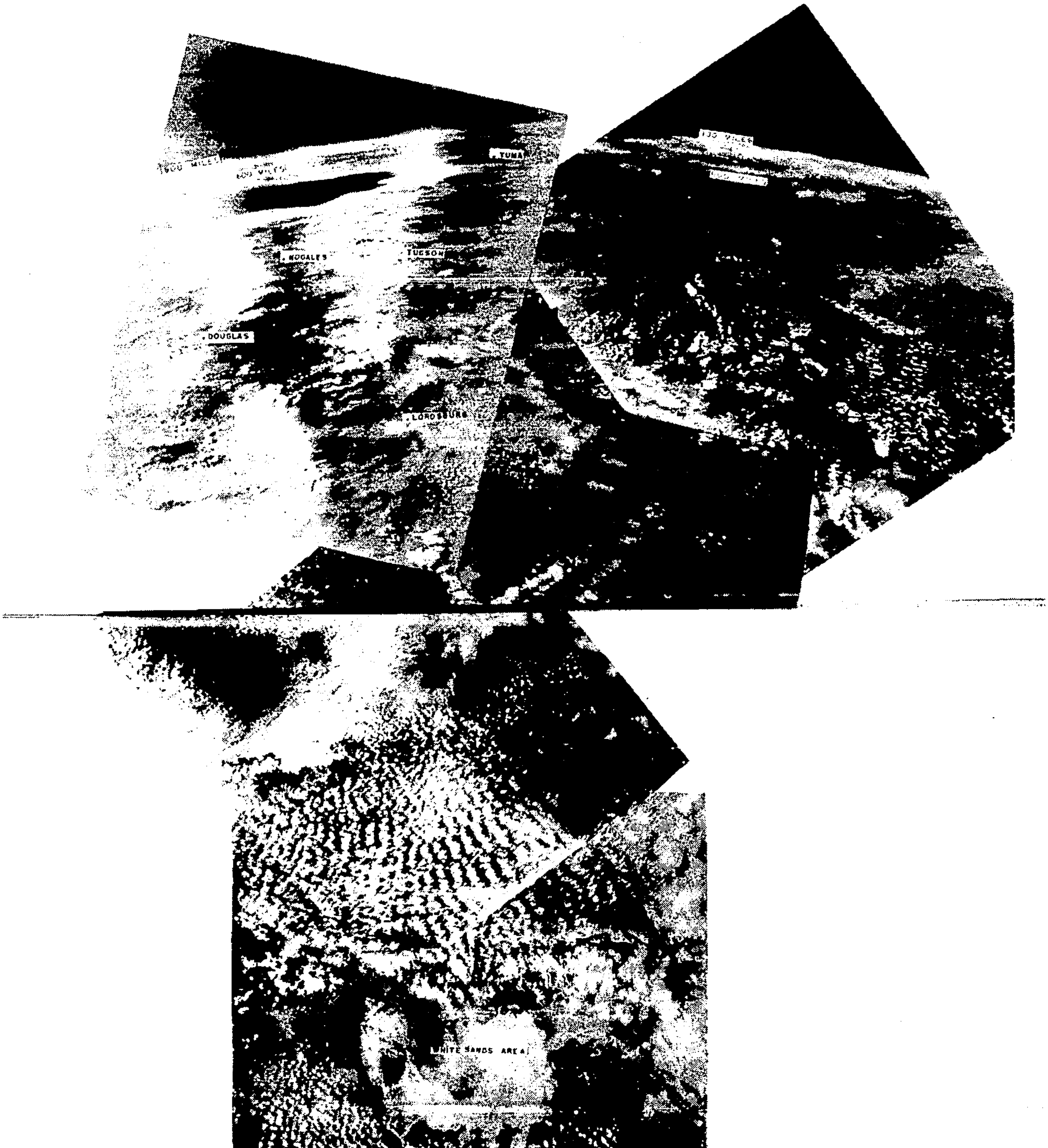


Fig. 3. Composite photograph obtained from rocket while at altitudes between 80 and 101 miles. The pictures do not match exactly owing to varying angles of direction of the camera. (Courtesy U.S. Navy Dept.)

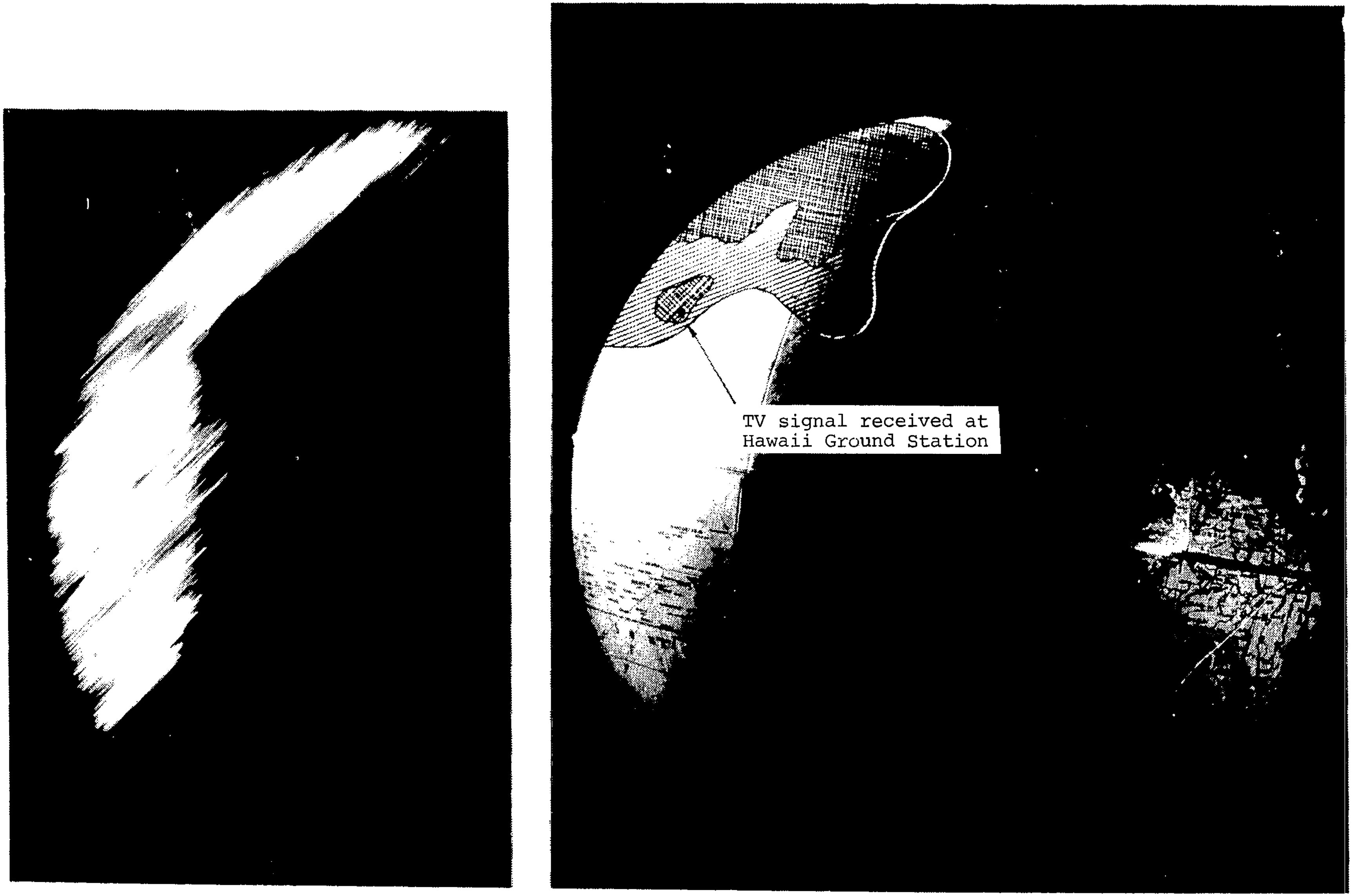


Fig. 4. Explorer VI photocell results - radiation reflected from cloud tops (April 15, 1959).

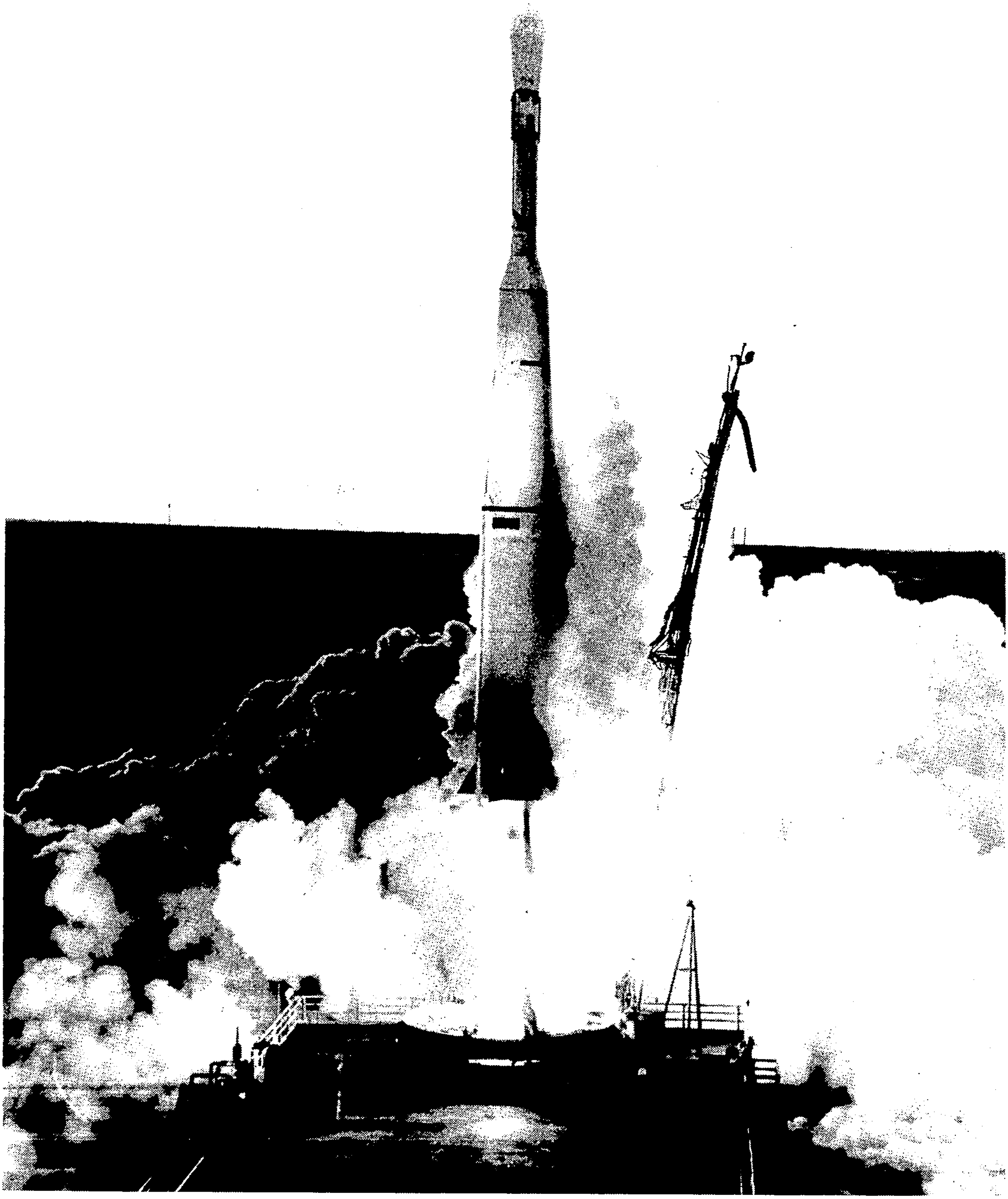


Fig. 5. Launch of TIROS 1 (April 1, 1960)

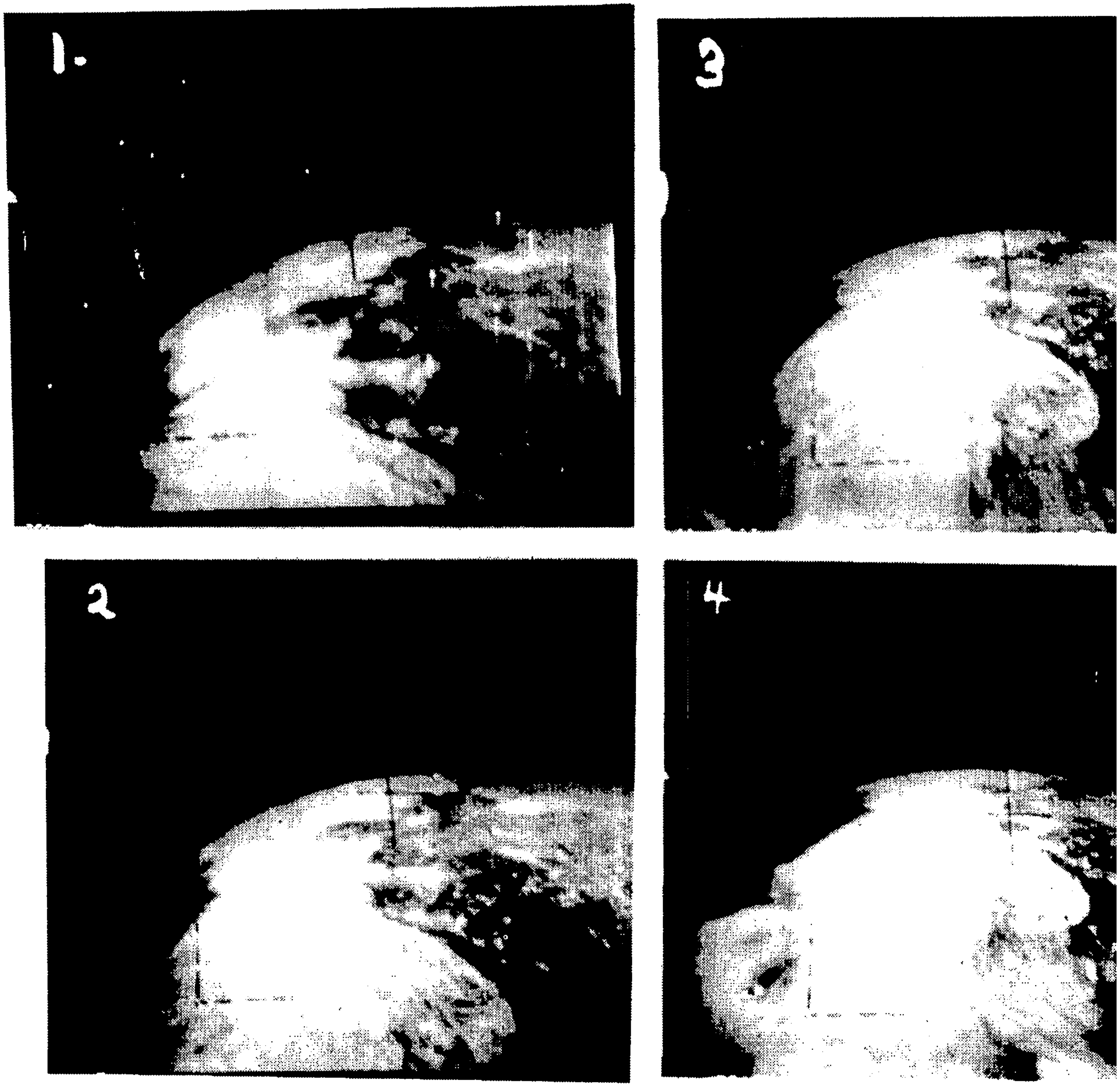


Fig. 6. First TIROS 1 photographs, cloud cover over Northeastern U.S. and Ca

TIROS CLOUD PATTERNS

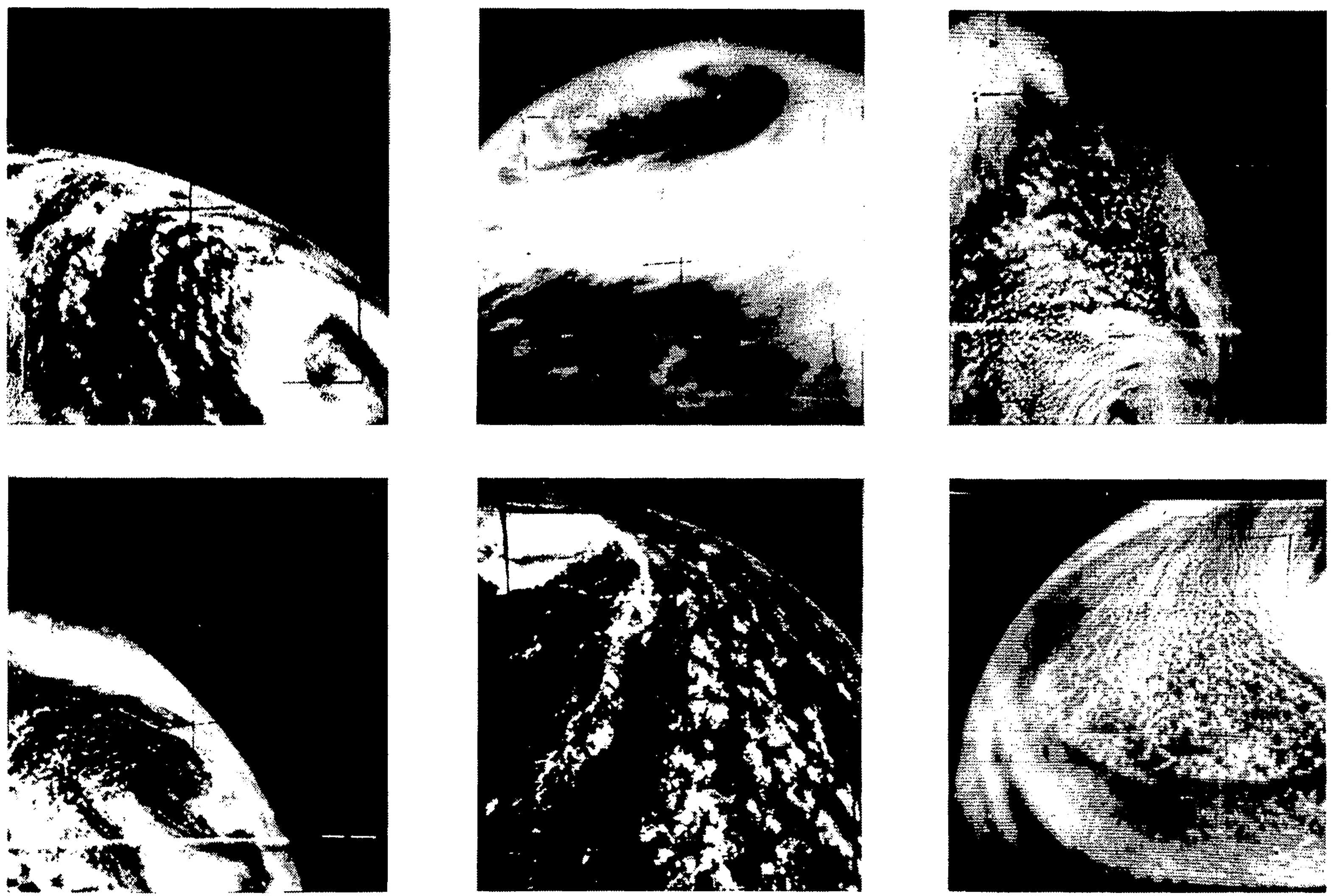
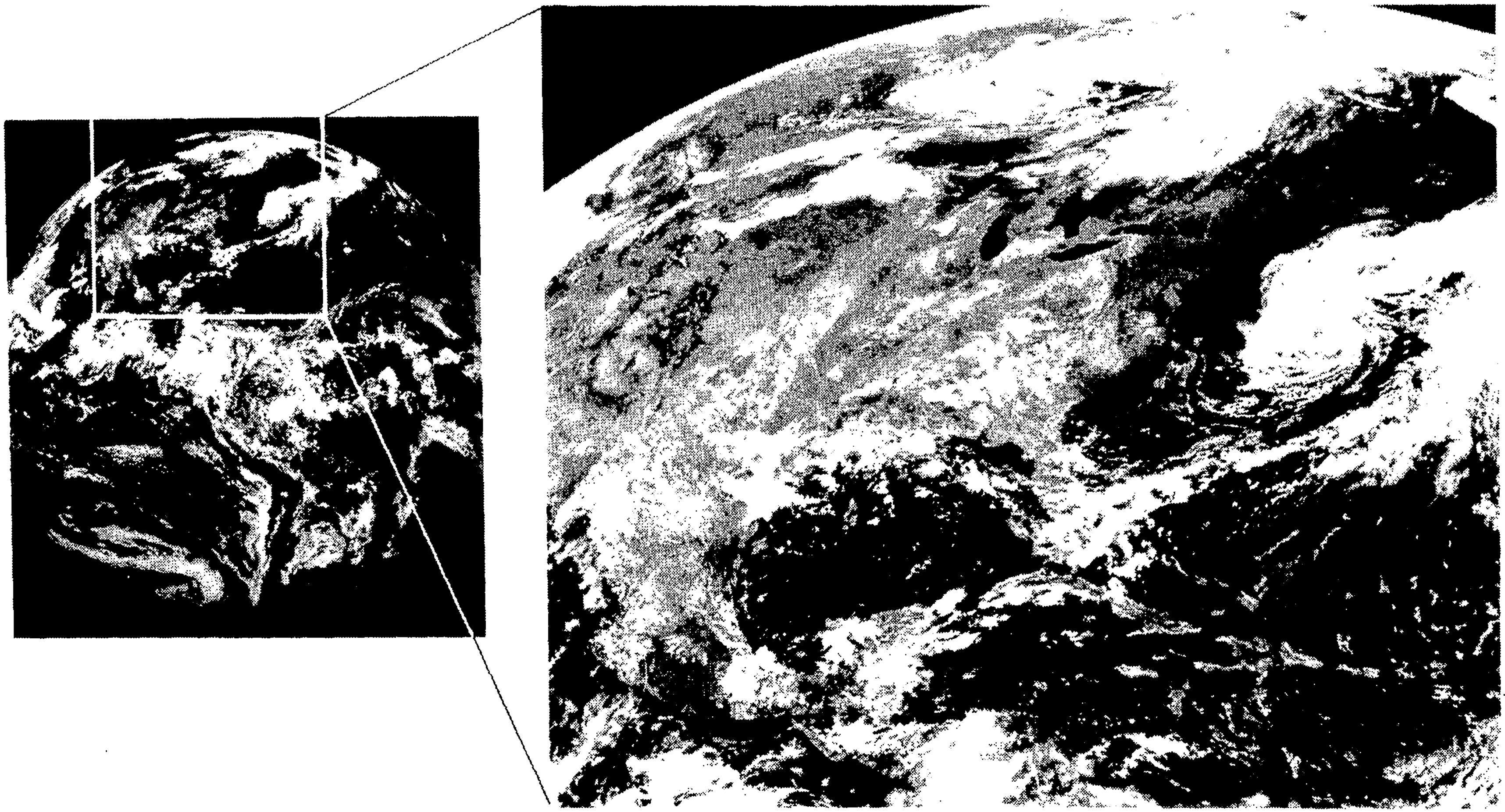


FIGURE 7.



SMS–1 Visible image, June 30, 1975 (hurricane Amy (1 N. Mi. resolution)

FIGURE 8.

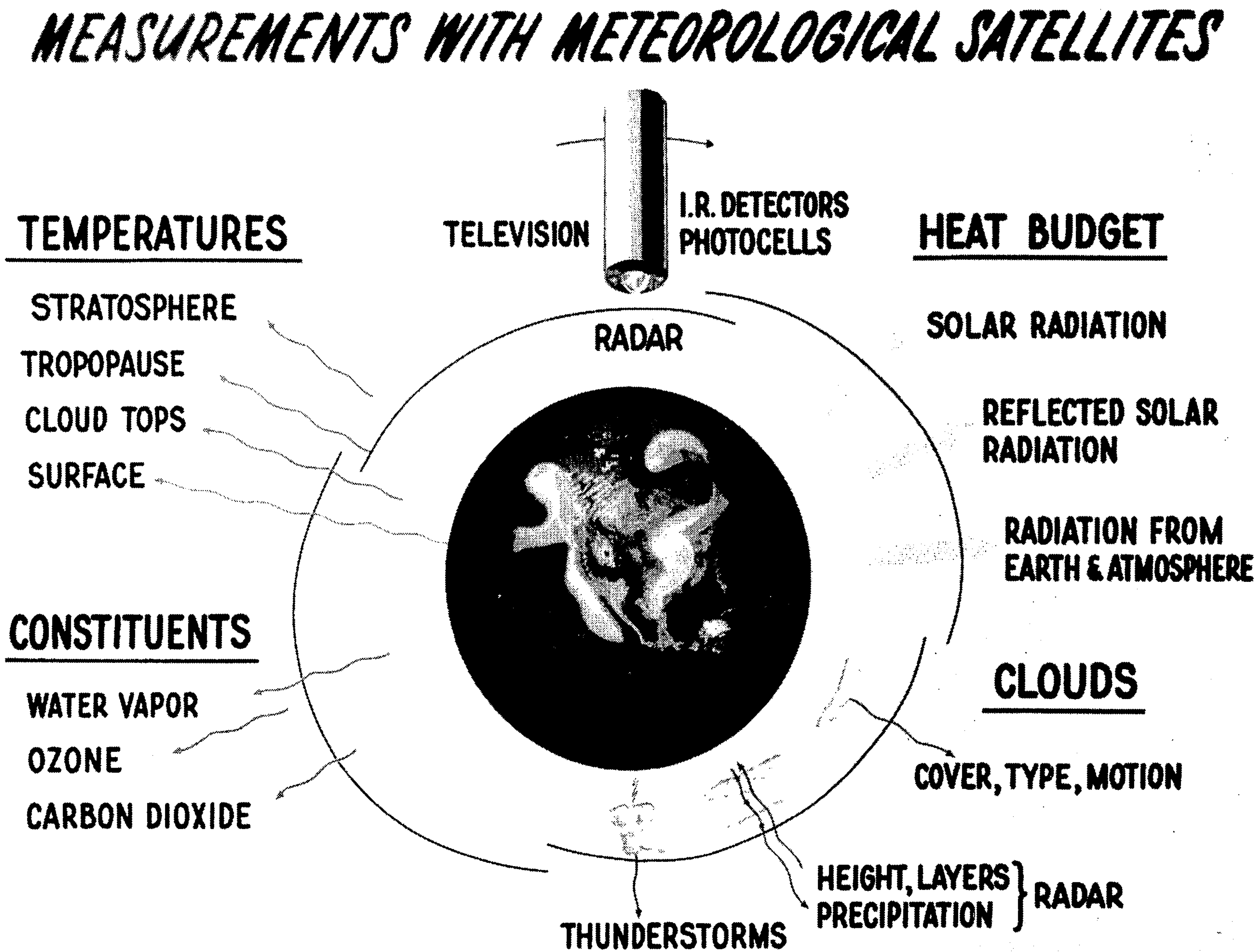

MEASUREMENTS WITH METEOROLOGICAL SATELLITES
TEMPERATURES
STRATOSPHERE
TROPOPAUSE
CLOUD TOPS
SURFACE
TELEVISION
I.R. DETECTORS
PHOTOCELLS
RADAR
HEAT BUDGET
SOLAR RADIATION
REFLECTED SOLAR RADIATION
RADIATION FROM EARTH & ATMOSPHERE
CONSTITUENTS
WATER VAPOR
OZONE
CARBON DIOXIDE
CLOUDS
COVER, TYPE, MOTION
HEIGHT, LAYERS
PRECIPITATION
RADAR
THUNDERSTORMS

FIGURE 9.

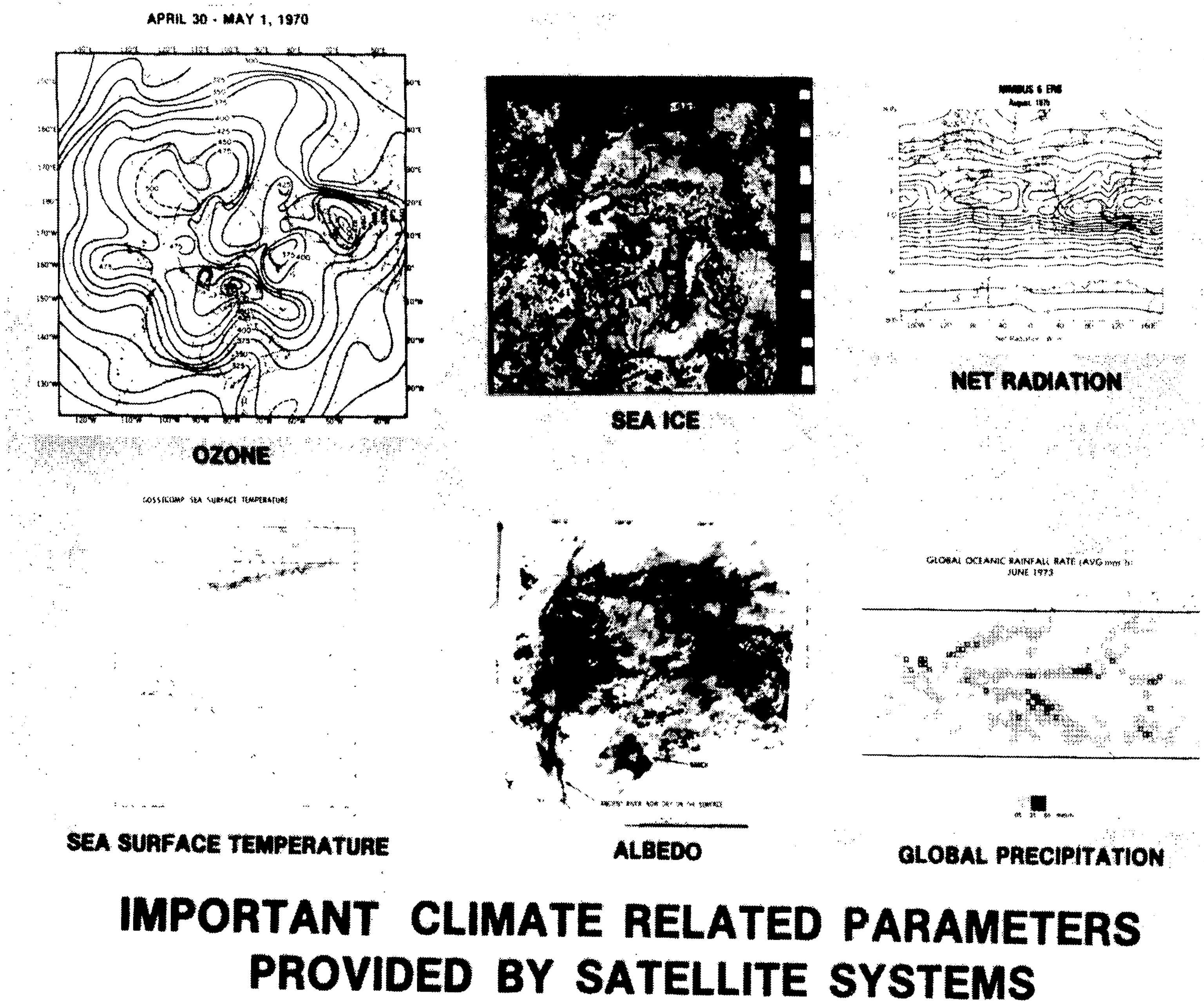


FIGURE 10. (Transferred from color to B&W)

NASA HQ ER77-2634 (3)
Rev. 9-22-77

GLOBAL ATMOSPHERIC RESEARCH PROGRAM
THE FIRST GARP GLOBAL EXPERIMENT
1978 - 1979

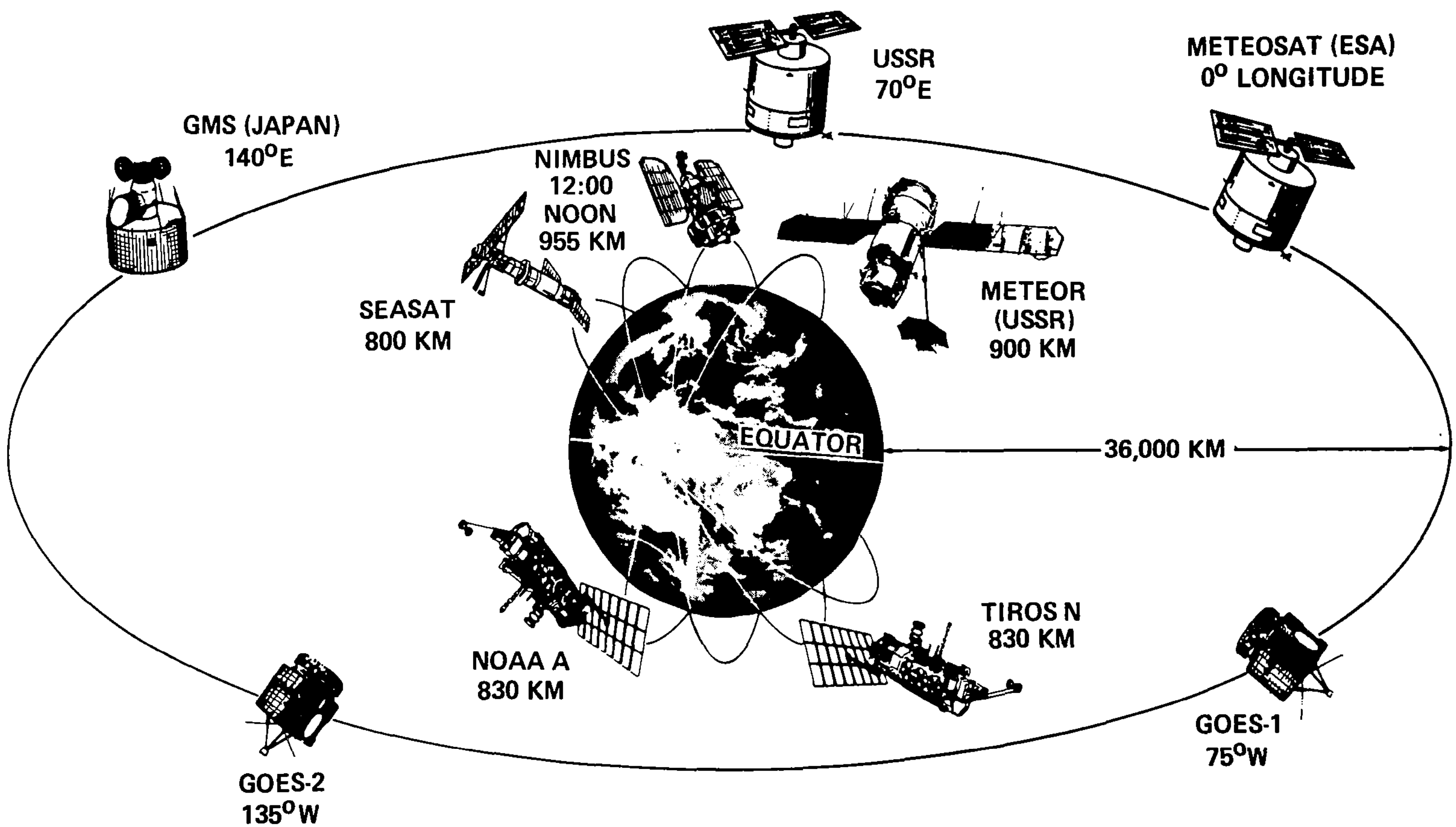


FIGURE 11.

U.S. METEOROLOGICAL SATELLITE PROGRAM OBJECTIVES
(1959 - 1969)

1. To develop and maintain support for the program

2. To solve difficult technological problems

3. To establish an operational system

4. To provide the space technology base for GARP

5. To share space developments and results with other countries, and to give them a sense of participation in the U.S. program

FIGURE 12.

METEOROLOGICAL INSTRUMENTATION IS BASED ON ATMOSPHERIC PROPERTIES & CHARACTERISTICS IN THE VARIOUS SPECTRAL REGIONS

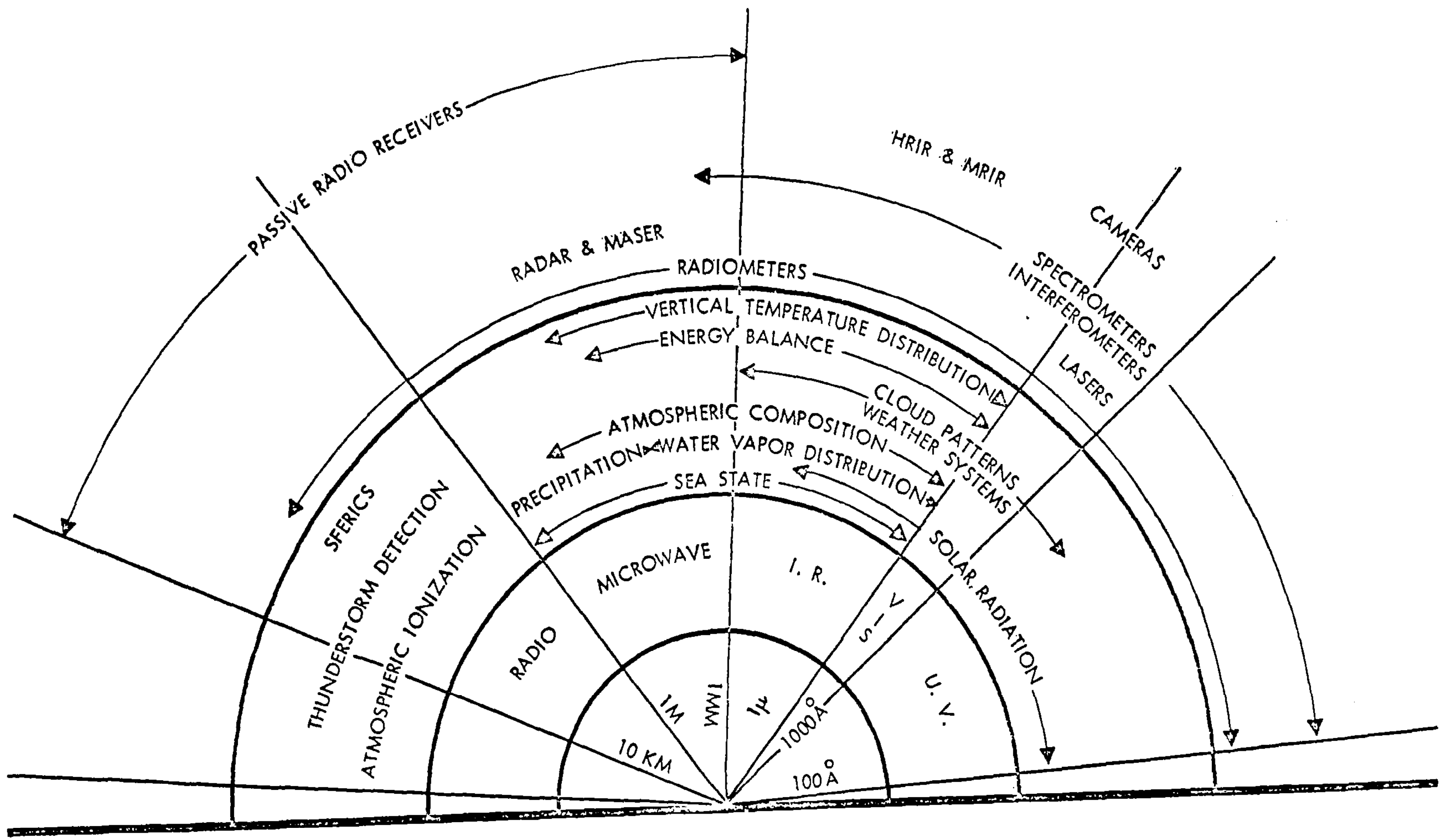


FIGURE 13.

NASA SF 65-1716
10-26-65

COMPONENTS OF THE CLIMATIC SYSTEM

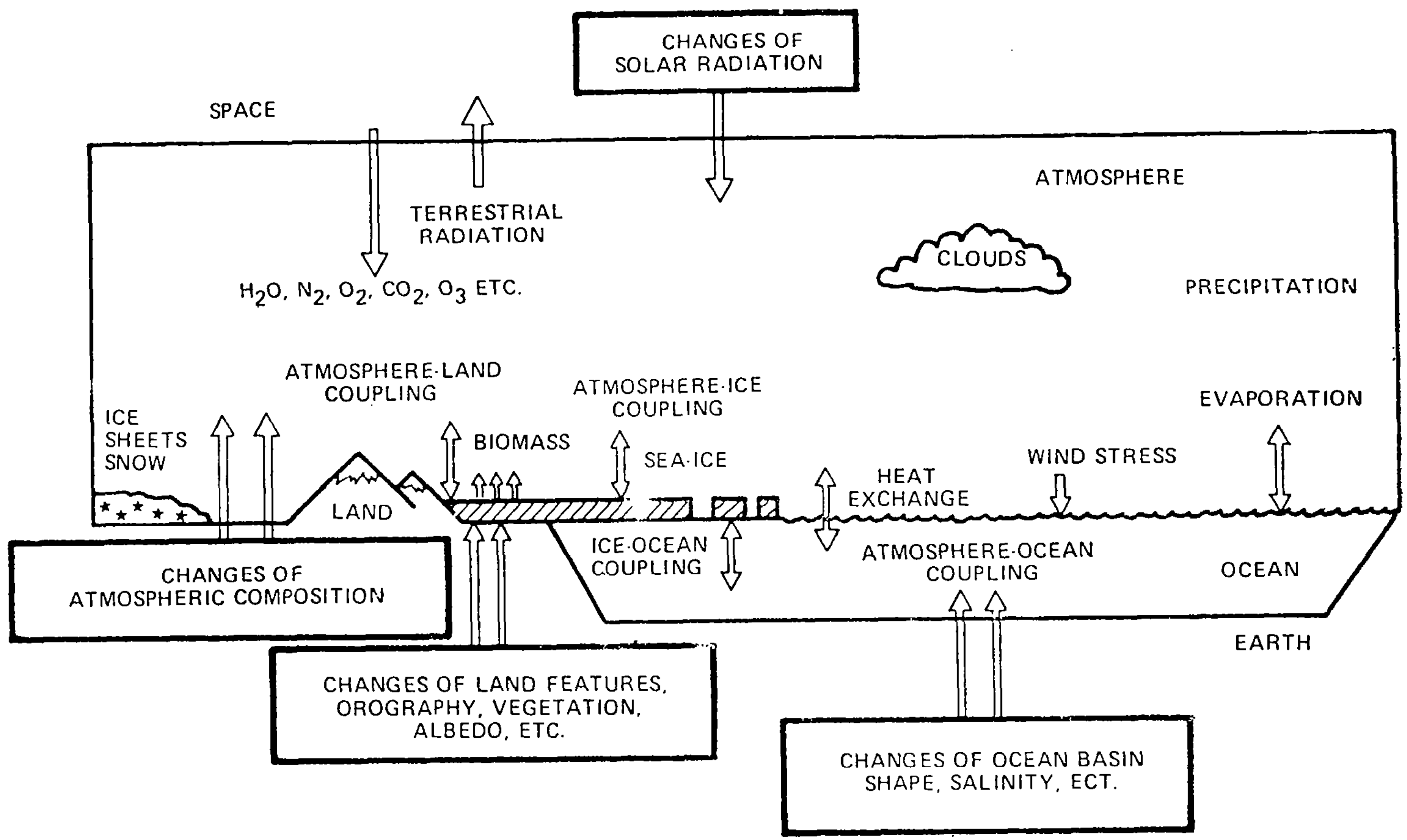


FIGURE 14.

NASA HQ ER77-1378 (1)
1-13-77

To share space developments and results with other countries, and to give them a sense of participation in the U.S. program

- Transmission of nephanalyses and other summaries
- Notification of periods of satellite overfly
- Provision of satellite data
- International Meteorological Satellite Workshop (November 1961)
- Automatic Picture Transmission System (APT)
- Meteorological rocket sounding (EXAMETNET)
- U.S./U.S.S.R. bilateral activities
- Foreign technology on board U.S. satellites
- Support of GARP
- Support of U.N. Committee on Peaceful Uses of Outer Space

FIGURE 15.

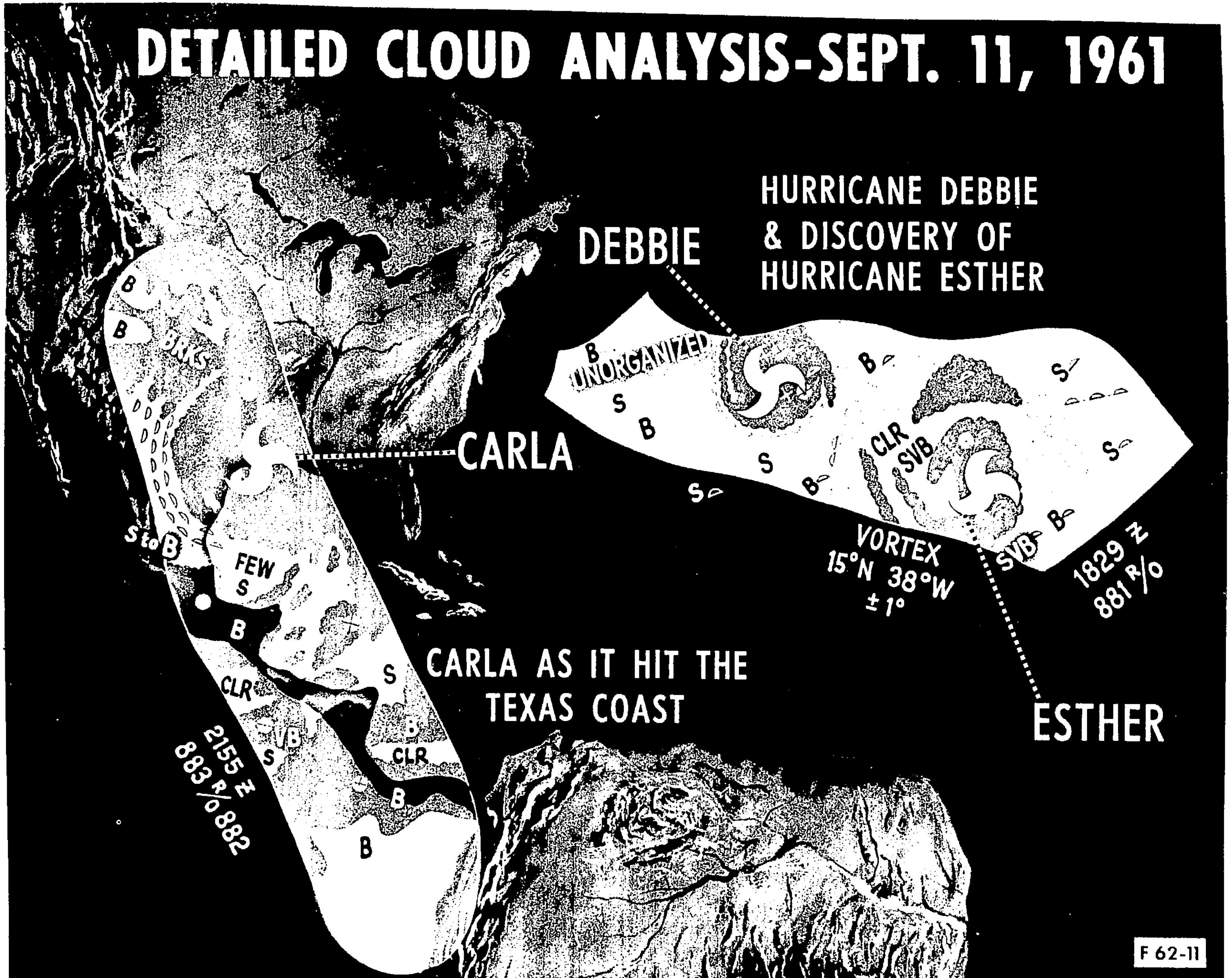

DETAILED CLOUD ANALYSIS-SEPT. 11, 1961
HURRICANE DEBBIE
& DISCOVERY OF
HURRICANE ESTHER
DEBBIE
CARLA
UNORGANIZED
CLR
SVB
VORTEX
15°N 38°W
±1°
1829 Z
881 R/O
ESTHER
CARLA AS IT HIT THE
TEXAS COAST
FEW
S
S to B
BRKS
CLR
2155 Z
883 R/O 882
F 62-11

FIGURE 16.

INTERNATIONAL METEOROLOGICAL SATELLITE WORKSHOP
WASHINGTON, D.C., NOV. 13-22, 1961

FIGURE 17.

AUTOMATIC PICTURE TRANSMISSION (APT) SITES LOCATED IN ABOUT 120 COUNTRIES

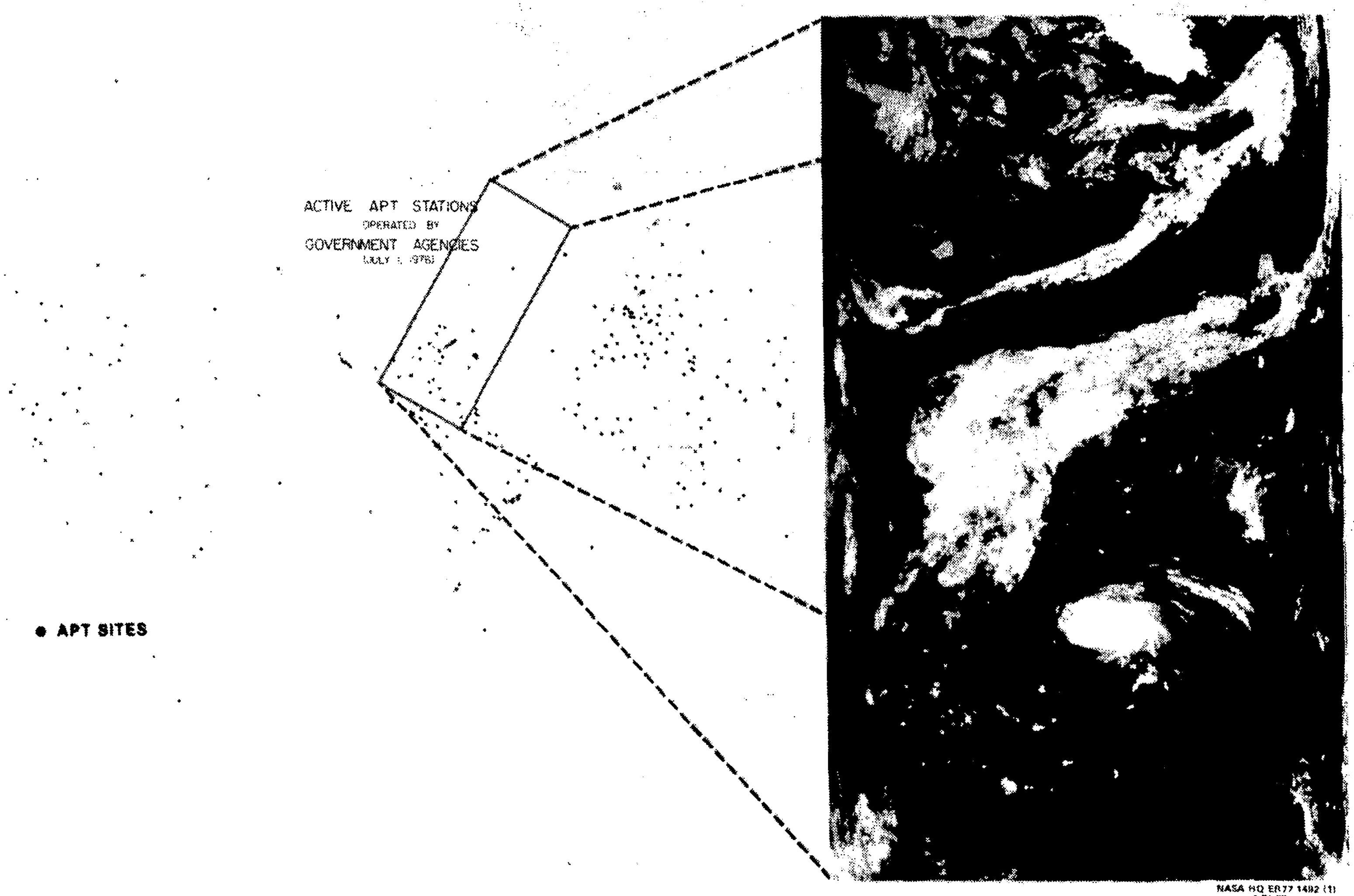


FIGURE 18.

USA - USSR EASTERN - WESTERN HEMISPHERE NETWORK

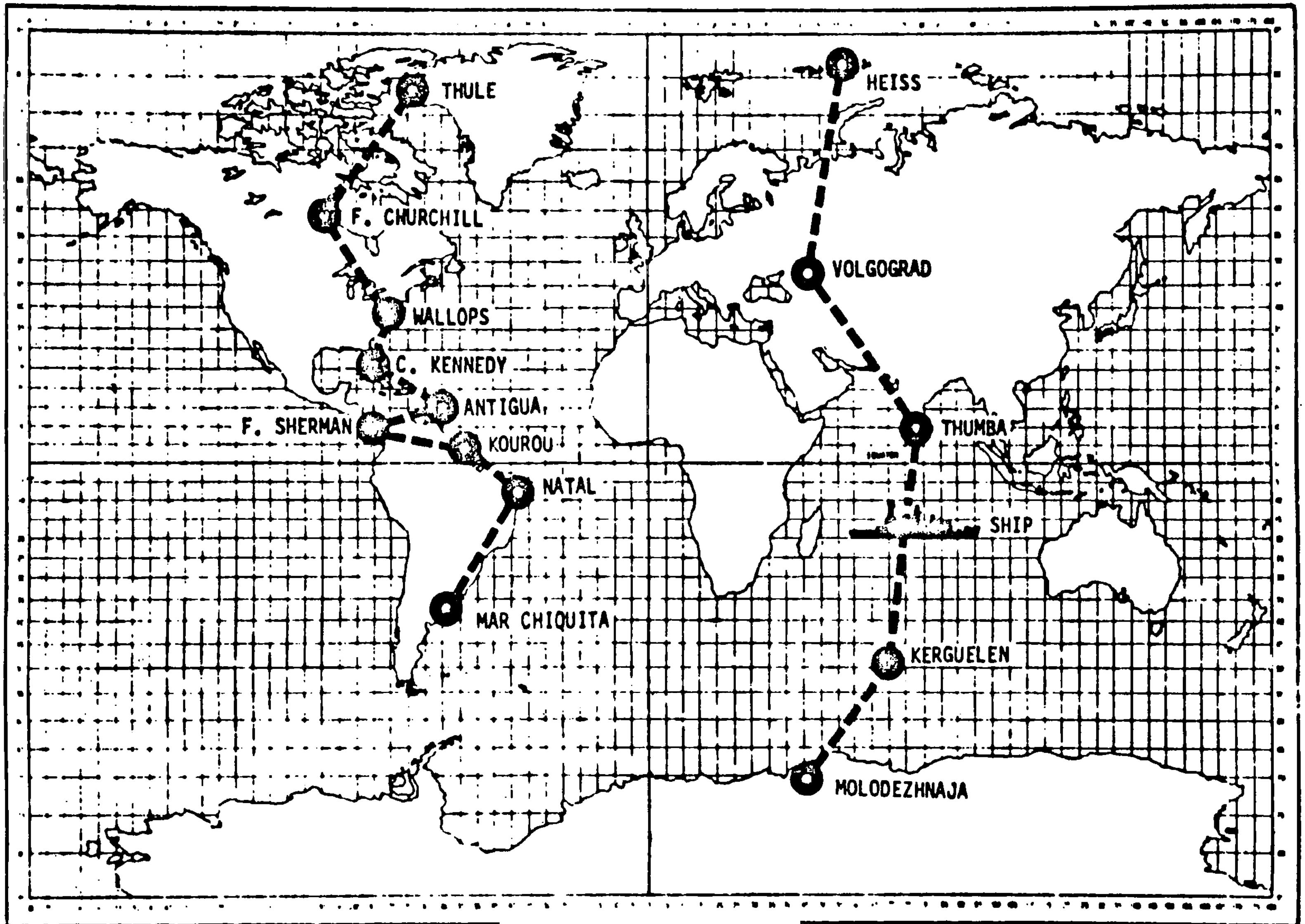


FIGURE 19.

DEVELOPMENT OF THE OPERATIONAL PROGRAM FOR SATELLITE METEOROLOGY

David S. Johnson, Former Assistant Administrator for Satellites, National Oceanic and Atmospheric Admin.*

The current operational system is the complementary sum of two kinds of satellites; the geostationary satellites which provide a nearly continuous view of the middle and tropical latitudes of the Earth, and the polar satellites which give a view of the entire Earth.

There are systems contributed by several countries. The only gap in geostationary satellite coverage at the present time is over the Indian Ocean. India is, however, planning to launch INSAT in 1982, which will fill this gap. INSAT will be the only one of the five geostationary meteorological satellites not compatible with respect to some of the services that the others provide. It will be a multi-purpose satellite, since meteorology isn't its main objective. It is primarily for television broadcast and telecommunications, but an imager will be included onboard. It is being built by Ford, and will be launched by NASA. We have indeed come a long way in achieving a system of such great complexity through informal international agreement, without treaties. It was done with the same kind of cooperative effort that Morris Tepper described, by people who really wanted to see something happen and then made it happen.

The geostationary satellites and the polar satellites complement each other. The polar satellites cover the entire Earth a few times a day. Each satellite passes over the poles twice a day, and, because of their closer proximity to the Earth, have provided more precise measurements of radiation parameters than were possible from the geostationary satellites. We are now, however, moving to the ability to obtain atmospheric soundings from geostationary satellites; this new capability may change our thinking about satellite systems in the future. Geostationary satellites have the tremendous advantage of continuously monitoring a major portion of the Earth's surface for tracking mesoscale features, severe storms, etc.

Fig. 1 shows the coverage of the network of geostationary satellites in existence now (when INSAT becomes operational). The solid circles are the imaging coverage and the dashed circles represent the communications coverage.

The advanced TIROS-N spacecraft in polar orbit, the first of which may be launched later this year, is similar to the TIROS N series which has been flying since 1979. However, the body has been stretched to enable NASA to fly scientific experiments in addition to the operational sensors that NOAA uses. NOAA also is adding an operational satellite instrument for measuring ozone profiles, based on the one which was developed in the NIMBUS program. NASA will fly the Earth-Radiation Budget Experiment, and a search and rescue experiment in cooperation with a number of other countries. Thus, the one spacecraft will have the capability to support operations and at the same time to carry on experimental work. This is

*Mr. Johnson's colleagues at the National Earth Satellite Service of NOAA provided much of the technical information upon which this paper is based.

very necessary in years of austerity. There is a wide variety of applications of the environmental satellite data in the civil sector; some examples follow.

Images produced from the data acquired by the Advanced Very High Resolution Radiometer (AVHRR) on the TIROS N series are used to produce ice analyses for the Arctic and the Antarctic. In the absence of clouds, the infrared channels of the AVHRR are used to look at the sea-surface. The images can be enhanced by a minicomputer to provide higher temperature contrast of the sea-surface being analyzed, for example, in the Gulf Stream. The very large eddies that develop along the shear zone of the Gulf Stream are clearly visible. Routine analyses of these images are now produced and transmitted by facsimile or in coded messages to marine interests. This information is of considerable importance to shipping; also fishing; I am sure that it has military applications as well.

Quantitative values of sea-surface temperature for the entire globe are also derived by objective techniques from the AVHRR data. A new computational system was introduced operationally in November, 1981 which has resulted in a significant improvement in the quality of the sea-surface temperature derivations. Comparison of the new satellite temperatures with 74 observations from buoys and research ships showed a bias of 0.02° and an r.m.s. deviation of 0.58. The December results are equally good, including a few comparisons with buoy data in the Southern Hemisphere. The reduction in bias is a major step forward.

There has been a continuous improvement in quantitative data derived from satellite observations -- nothing particularly dramatic -- but a stepwise progression to the point where there is a real impact on the quality of numerical weather predictions. For example, a new algorithm for correcting for cloud cover contamination in the infrared temperature sounder data introduced in 1980 has resulted in significant improvement in the temperature accuracy in the lower layers of the atmosphere. More improvement is required to reduce the bias and the r.m.s. error, especially in the lower layers of the atmosphere where it is most important. Use of improved microwave temperature sensors appears to hold the greatest promise at this time.

On the current TIROS N series, there is an instrument called ARGOS, provided by the French government, which relays data from and locates platforms. During the First GARP Global Experiment (FGGE), this system was used to track several hundred buoys that were drifting in the Southern Hemisphere. Sensor data were relayed via the satellite for central processing and distribution. This system has been working fine since the first launch of TIROS-N in 1979, and locates platforms with an r.m.s. error of less than 1 km.

Let us turn now to the geostationary satellites, the U.S. version of which is called the Geostationary Operational Environmental Satellite (GOES). The satellite contains a large aperture telescope (40 cm) for imaging; and the latest versions also have infrared sounding capability. The rotation of the satellite around its spin-axis generates the East-West scan, while a tilting mirror provides the North-South scan. Under normal operation, the Earth is viewed once every thirty minutes in both the visible and the infrared. The frequency of observations can be increased to every three minutes (the fastest we have been using) but then the extent of North-South scan must be sacrificed.

Fig. 2 is a particularly dramatic image illustrating the primary function of GOES -- monitoring severe weather events. This image of severe thunderstorms conveys the quality of today's images in terms of dynamic range and resolution. As Morris Tepper mentioned, it is hard now to imagine why we were so ecstatic about that first picture from TIROS 1. But that was the beginning; we have come a long way in a short time.

I'd like to stress something that we tend to forget. All this technology isn't worth much unless the information gets to somebody who can use it. The operational character of the current system must be stressed; it has led to the response that has developed in the last twenty years in the acceptance of many of these data by the operational meteorologist, as well as the research worker. Part of this acceptance has resulted from a major effort to improve the dissemination of information. But there is a long way to go and major improvements will be expensive. For example, let's say it costs $100,000 for an interactive display device, which obviously every weather office should have. The National Weather Service has 52 forecast offices and around 250 weather service offices. Multiplying $100,000 each by about 300 locations, gives $30,000,000, a very large capital investment; which must be followed by significant sums for maintenance and operation.

A major concern is to get the end product of the satellite system out to the user. NESS now uses a "sectorizer" system, as it's called, located at Suitland, to process images and transmit them to the 52 forecast offices every half an hour. Within 20 minutes after each satellite image is received by NESS, selected images (more than twenty can be selected by dial-up telephone) go out from Suitland to the forecast office through the Satellite Field Service Stations. The latter are advisory-consultant units of NESS at seven locations which assist the forecasters in the field. There is a long way to go, but the steps already taken toward immediate dissemination of satellite information have accomplished more than anything else to make this new technology useful to the forecasters.

As Morris predicted, geostationary satellite images can be used to track clouds from which the winds at cloud altitude can be inferred. This is something Professor Verner Suomi and his colleagues developed. This kind of information is produced for two levels: essentially 850 millibars and upper levels, generally 200-300 millibars. The question, of course, is: How good are they? Fig. 3 is a plot for winds, derived by NESS, showing the vector difference between observations derived from the cloud motions and radio wind observations.

Notice the larger difference in the high cloud winds. This is primarily due to the inability to determine the altitude of the clouds accurately; any vertical shear will be reflected in an error in the derived winds. Those who use winds derived from data from geostationary satellites of different nations should realize that different procedures result in different error characteristics. For example, the Japanese technique is different from that of Europe and the U.S. The Japanese results indicate much larger errors in the upper level winds. Even so, the winds have become a very useful input to numerical predictions, and are now used in a very routine manner.

Sequences of images from the geostationary satellite in the thermal infrared also can be used to estimate the amount of convective precipitation. Flash flooding is a very major problem. Because of early success with this technique, NESS now is supporting the Weather Service by making this kind of precipitation estimate whenever flash flooding potential is high. With the introduction of a new interactive processing system, it is planned to expand this service by the end of 1982.

Another application in Florida uses geostationary satellite infrared images on clear nights when there is strong radiative cooling, to improve frost warnings. Computer processing emphasizes the 0°C line so that pockets of surface air -- warmer and colder than freezing -- can be readily identified by the Weather Service office near Tampa to assist the agricultural industry in protecting citrus crops.

There is a problem with the polar orbiting satellite data in filtering out cloudy areas to determine sea-surface temperatures by infrared techniques. However, with the GOES, a new infrared image is obtained every thirty minutes, 24 hours a day. Unless there is a very persistent, solid overcast area, the movement of breaks in the cloud cover will enable the sea-surface temperature to be determined at some time during each 24 hour period. An automated process has been introduced by NESS for the U.S. continental shelf areas, in which the sea-surface temperature is updated frequently and stored on a computer disk file in Suitland, which is available for output on a remote terminal by a dial-up system.

Now there is a new instrument in space on GOES called the "VAS", or VISSR Atmospheric Sounder, which again comes from Professor Suomi's fertile mind.

There are three basic modes of operation of the VAS. There is the normal operational imaging mode, in use since 1974, which has a visible channel with 1 km resolution, and a thermal infrared window (11 μm) channel with 8 km resolution. The multispectral imaging mode provides the full resolution visible channel plus any three of the 11 infrared channels (IR windows, plus CO_2 and water vapor bands). The third mode is the sounding mode, in which all of the infrared channels are used. To obtain the signal-to-noise ratio needed to derive quality soundings, repetitive scanning of the same area is used in the sounding mode, compared to the single scan of each area used in the two imaging modes. This limits the north-south area from which soundings can be derived, or the frequency of observation. If soundings are desired once an hour, coverage is limited to about a twenty degree latitude zone. Flexibility in modes, frequency, and extent of coverage is available by ground command.

Most dramatic are images showing moisture patterns as observed in the 6.7 μm band. These now are being produced on an operational basis twice a day. In the sounding mode, temperature changes over a period of a few hours can be monitored. One can operate through breaks in the clouds, because of the very high resolution of the sensor. The combination of high spatial and temporal resolution provides soundings not otherwise obtainable with the polar satellite or the radiosonde network. This new tool may prove to be extremely important in studying and forecasting mesoscale phenomena.

Comment:

The VAS data is available every three hours each Thursday on the East Satellite, and every Tuesday on the West Satellite, starting at 0230Z Thursdays, all the way up to 1130Z, and that program has been extended up to the 31st of January, 1982.

Johnson:

There will be another program starting during 1982 to make more VAS data available for research. It's having to be done on a non-conflict basis. NESS is installing some additional equipment that will allow a fair amount of VAS data to flow. This is not an operational program, but it will allow for more experimental development.

Dutton:

Would you say something about the distribution of errors in the winds?

Is it skewed? Peaked?

What do we know about it?

Johnson:

I don't know, but the data are available from NESS.

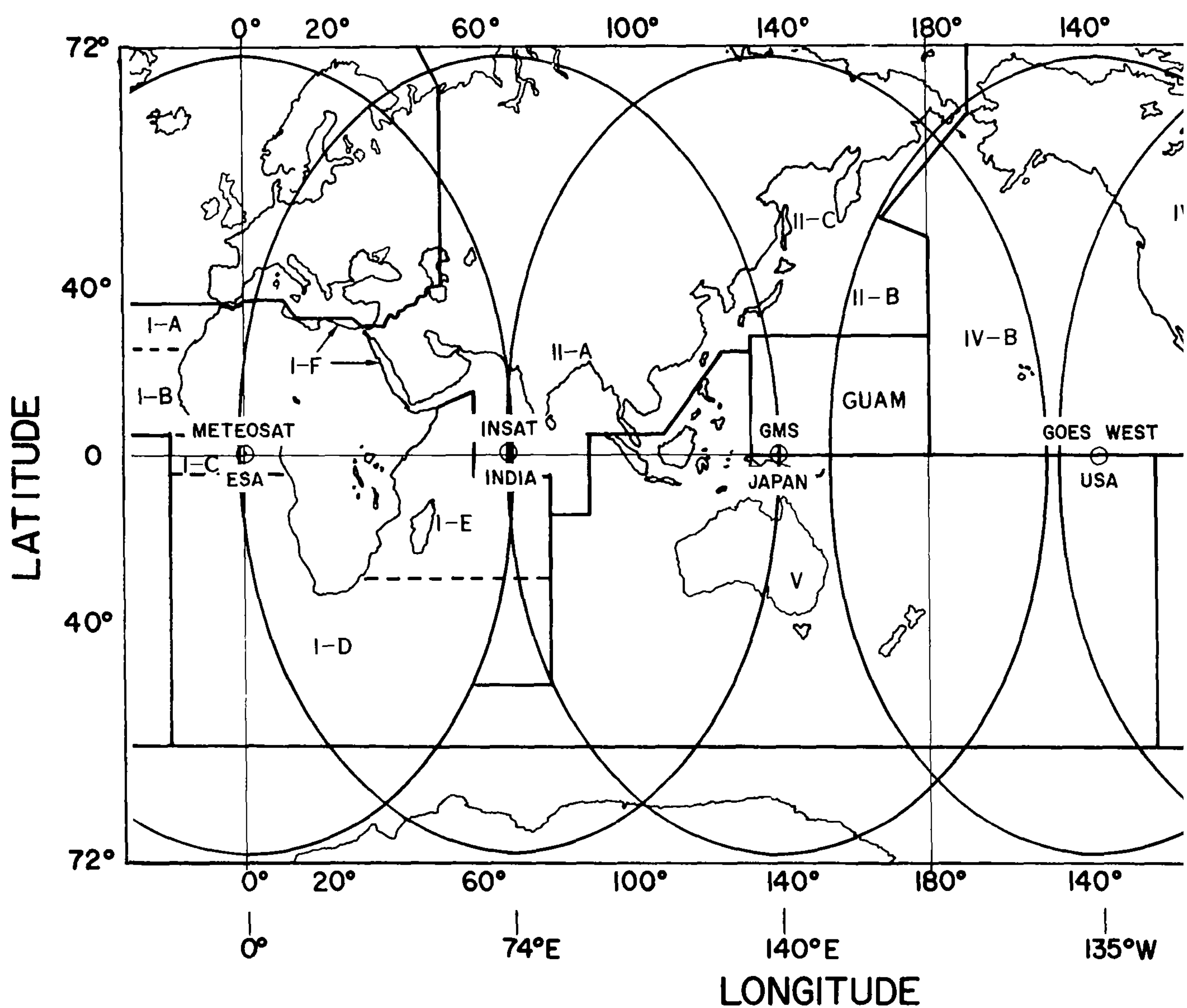


Figure 1. Imaging and communications coverage of the global network of meteorological satellites as of early 1982.

Figure 2. Full resolution visible image from a Geostationary Operational Environmental Satellite showing several severe thunderstorms over the midwestern United States on 31 May 1976. Note shadows of penetrating convective towers which are cast on the surrounding cirrus shields.

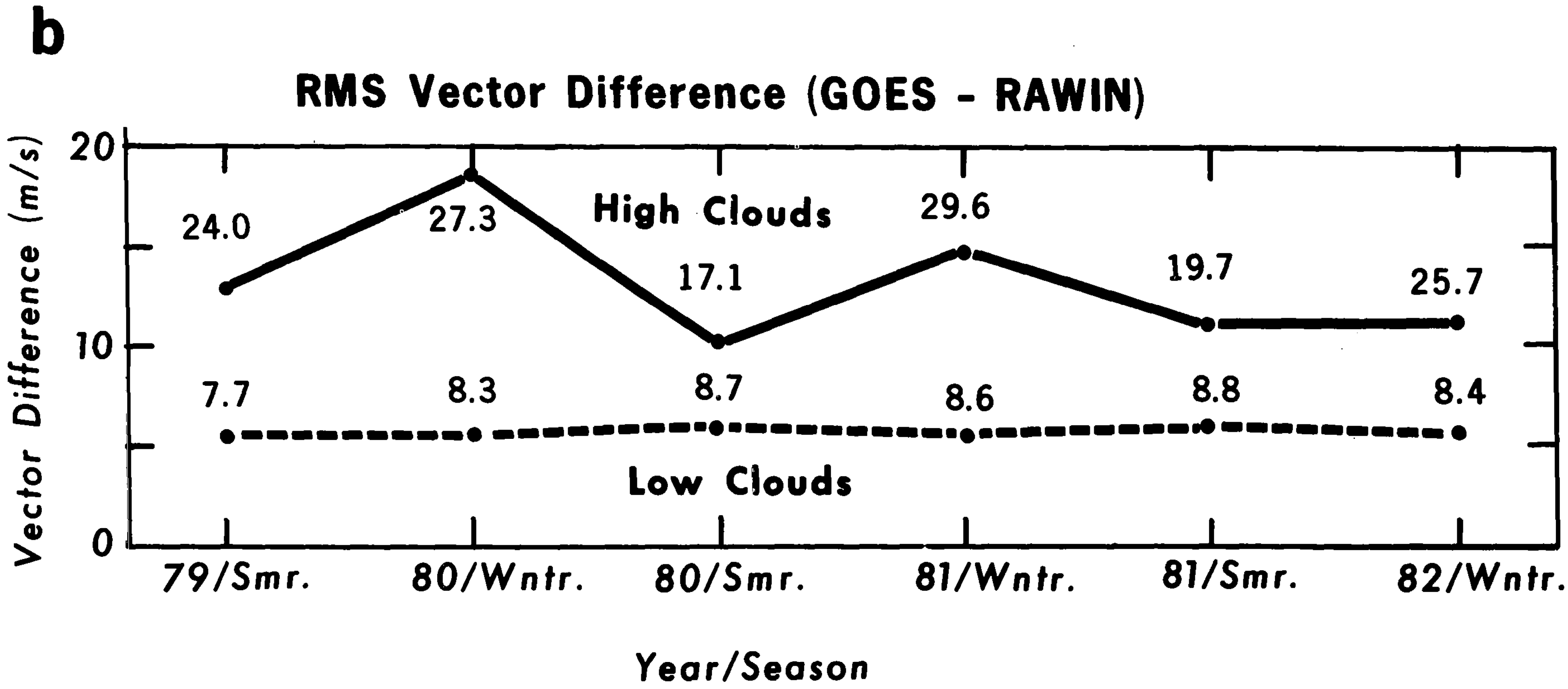


Figure 3. RMS vector difference between winds measured by radio-wind techniques and those inferred from cloud displacements measured in sequences of images acquired by the Geostationary Operational Environmental Satellites (GOES).

MILITARY APPLICATIONS EVOLUTION AND FUTURE

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Air Weather Service, Scott AFB, Illinois

In this presentation I would like to give you some of my thoughts on the military applications of METSAT data and, in particular, on the evolution of AWS's use of the Department of Defense METSAT, the polar-orbiting Defense Meteorological Satellite Program (DMSP), originally known as Data Acquisition and Processing Program (DAPP).

I will focus on our METSAT use at Air Force Global Weather Central (AFGWC), our centralized facility, and by our field units deployed around the world. In addition, I'll point out some examples of the DOD mission payoffs the DMSP has provided in the past, and some of our ideas for future DMSP enhancements.

The primary mission of AWS is to support Air Force and Army combat operations. Important keys to successful combat operations include target detection, identification, tracking, and destruction. In modern warfare, the presence or absence of clouds directly impacts the ability to successfully and economically perform these missions, and with the recent development of extremely expensive cloud-sensitive weapons systems (such as TV, IR and laser-guided bombs and missiles), the accuracy of cloud information assumes an even greater role.

AWS uses all available data to satisfy mission requirements. Peacetime cloud data sources include the Defense Meteorological Satellite Program, NOAA Polar and Geostationary Satellites, Worldwide Surface and Upper Air Data, and conflict, global environment data to support worldwide DOD operations. This mission demands at least two operational spacecraft in orbit at all times, with the sensor complement and orbit times selected to provide the maximum environmental support to military decisionmakers.

The DMSP history has been one of constant evolution. The system was originally conceived and designed in the 1960's to satisfy important, scientific military requirements. The early vehicles carried videcon cameras providing only IR and visual cloud imagery. Since its inception, a cornerstone DMSP requirement was to put data in the hands of the military decisionmakers as soon as possible. Therefore, DMSP was configured to provide data in two ways: the recorded and direct readout data modes.

In the recorded data mode, data are recorded aboard the spacecraft and downlinked to readout sites at Loring AFB, Maine, and Fairchild AFB, Washington. In the earlier days, the data were passed to the Air Force Global Weather Central (AFGWC) at Offutt AFB, Nebraska, by landlines. Today, they are passed by a communications satellite. In recent years, the system has included a comsat downlink to Fleet Numerical Oceanography Center in Monterey, California, and an additional readout site at Kaena Point, Hawaii.

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That vehicle carried a tropospheric temperature sounder and a precipitating electron spectrometer. The first Operational Linescan System (OLS), a vastly improved system for cloud sensing, was flown in September of 1976.

The initial transportable terminals, using the direct readout data, supported Air Force and Army commanders around the world. The Navy came on board with their requirement for direct readout data in 1971, installing their first shipboard capability on the USS Constellation.

The DMSP antennas were located midship below and on either side of the flight deck. In two separate incidents ('72 and early '73), aircraft (an A-7 and an F-4) broke the arresting cable on landing. The cable wrapped around the DMSP antenna, destroying it in each case, and the barrier held. Therefore, DMSP (Weather) could be considered to have saved two aircraft.

Today, direct readout data continue to provide direct cloud imagery support to Army and Air Force field commanders and Navy operations afloat. DMSP continues to grow and change to meet DOD requirements. Unique capabilities are: DOD command and control unconstrained by external agreements, the capability of encrypted communications into combat zones, orbits and sensors specifically selected to satisfy DOD requirements, flexibility to alter coverage to respond to rapidly changing DOD support needs, and a system designed to minimize delay in readout of critical recorded data.

In addition, today's DMSP possesses other characteristics extremely valuable to AWS: Its constant cross-scan high resolution imaging is valuable for snow/cloud discrimination and "black stratus" analysis. Its low light nighttime capability is valuable in determining the magnitude and extent of the auroral oval. Finally, it has a full complement of ionospheric sensors critical to many DOD systems operating in or through the near-Earth environment.

In the next few minutes, I will amplify on the use of recorded and direct readout DMSP data by the Air Force. Recorded DMSP data received at AFGWC results in documented savings of hundreds of millions of dollars per year. Recorded data are used to support worldwide operations such as the Rapid Deployment Joint Task Force, hurricane/typhoon positioning, aerial refueling and the Strategic Air Command aircraft reconnaissance missions. Direct readout data are used by meteorologists in forward areas to support battlefield commanders conducting combat operations. Critical to the effectiveness of both capabilities, especially recorded data, is spacecraft command and control.

To meet rigid operational support timelines, command and control must be responsive. Therefore, the spacecraft ground command and control system is co-located with the AFGWC. If we need DMSP data that are not normally collected to satisfy a short-notice requirement, new software commands can be generated and implemented within 6 hours through the control readout sites.

Military requirements for forecasts of icing, turbulence, severe weather, fields of small cell cumulus and snow/cloud discrimination, demand immediate manual application of high-quality 0.3 and 1.5 nm resolution visual and IR imagery data. These data are displayed on "hard copy" transparencies for use by forecasters at AFGWC. (After the data are no longer operationally useful the transparencies are archived at the University of Wisconsin for public use.) At the same time, the data flow into a completely automated processing system.

The telemetry data are split off for command and control purposes. Atmospheric and space environmental data are stripped out and processed by sensor-unique software. Temperature sounder data are currently used globally in the stratosphere as well as in the troposphere; both in the Southern Hemisphere and data-sparse ocean areas in the Northern Hemisphere.

Unique space environmental data are provided by the precipitating electron spectrometer, the plasma monitor, and the visual cloud sensor. The visual data and the electron spectrometer locate the auroral oval -- important to forecasts for high frequency radio communications in polar regions, and to the high latitude early warning and tracking radar network in North America and Europe. The plasma monitor provides in situ electron densities -- essential to space system ephemeris calculations and anomaly investigations as well as transionospheric propagation for the Space Detection and Tracking System.

Visual and IR imagery are mapped into a satellite global data base, a digital data base with a 3 nm resolution. This data base is constantly updated by continuous on-line processing of the imagery and is available in visual and IR display for both hemispheres.

Under the shared METSAT data concept, the satellite global data base is planned to be provided to NOAA, NESS and FNOC. We apply the automated data base in three ways:

1. High quality displays are sent by digital facsimile to Air Force command and control centers. The data are also relayed to a myriad of other government agencies.

2. Displays are used as large overlays for forecast applications within AFGWC.

3. The third application is unique to AWS. AFGWC is a pioneer in using computers to blend satellite data with other data and build automated cloud analyses which, in turn, are used to initialize automated cloud forecasts.

The automated cloud analysis model integrates the visual and IR imagery, remote sensed temperature soundings and conventional observations, to create a 25 nm resolution three-dimensional cloud analysis. Data covering high priority areas are analyzed immediately upon receipt, while the normal global analysis is accomplished every three hours. The process is totally automated with the exception that analysis in high priority areas can be manually modified if needed. We have now begun work to develop a real-time cloud analysis model that will analyze all satellite data immediately upon receipt. Thus the real-time analysis will always include the most current satellite data.

The cloud analysis initializes the final step in the process -- the automated cloud forecast model. It is processed every three hours and forecasts cloud cover and precipitation out to 48 hours in the Northern Hemisphere and 24 hours in the Southern Hemisphere.

As you can see, recorded data are used today at AFGWC in a complex system relying on a considerable amount of computer hardware and software. Yet, the system is extremely reliable. Over 95% of the DMSP data are routinely processed through the system and are used in the forecast models. Not only do units in the field receive analysis and forecast products from AFGWC to support tactical requirements, but they also have access to DMSP direct readout data.

The DMSP direct readout data capability satisfies DOD requirements for worldwide, responsive, secure, high resolution METSAT information. The system is complete and self-sufficient, and the transportable terminals have their own power supply and data processing capability. In this mode, DMSP provides timely visual and infrared imagery directly to transportable terminals co-located with battlefield commanders.

Through these few examples: the support of critical decisions in Vietnam; support to U.S. forces in data-denied areas such as Israel; the support to Europe where weather data will be used as a weapons multiplier; support of U.S. readiness forces such as REDCOM and TAC; and support of U.S. resource protection efforts in the Pacific... I plan to show how we've used the DMSP in the past and how we're currently using it.

General Momyer, AF Commander in Vietnam, relating his experience with the DMSP system said, "As far as I'm concerned, this (DMSP) weather picture is probably the greatest innovation of the war." In his book, while discussing the scheduling, targeting and launching of strike missions against North Vietnam, he went on to say that, "Without them (meaning the DMSP photos)... many missions would not have been launched."

The responsiveness of the DMSP to military requirements was first demonstrated during the early stages of Vietnam when a satellite was launched to support our bombing missions. AF commanders in Vietnam making go/no-go decisions affecting strike missions used DMSP because it is a complete system with a tactical readout capability. The tactical, or direct readout terminal, located in Saigon, provided processed, analyzed pictures of the weather in the various target areas in a matter of minutes after being observed. This information was used to update and adjust strike targets and the life sustaining refueling areas based on the current weather observed by the DMSP.

In late 1970, very specific weather was required to support the mission to extract U.S. prisoners of war from a North Vietnamese prison camp. This mission, the Son Tay Prison Raid, was scheduled to coincide with the break in weather between two tropical storms. Conventional weather data were denied and an aerial weather reconnaissance flight might tip off the operation. The need for secrecy and for limiting the number of people who knew of our interest in the weather near Son Tay was satisfied by the operational secrecy available with the DMSP. The DMSP data provided to the 7th AF planners from the DMSP tactical terminal at Saigon were crucial in identifying the best weather window possible to achieve the precision timing necessary for this mission, while maintaining the secrecy necessary in such a sensitive military operation.

Global war is not necessary to affect the free exchange of meteorological data among nations. Increased local tensions between two or more nations can cut the flow of necessary weather data. During the Yom Kippur War all nations in the area of conflict stopped transmission of standard meteorological data over civil communications circuits -- despite international agreements to the contrary -- because weather data could possibly aid the opposition commanders in making military decisions. Early in the U.S. resupply effort of Israel, Lod Airport at Tel Aviv was closed due to heavy fog and stratus and our resupply flow was disrupted. Weather data from the DMSP enabled us to determine that the weather pattern was frontal in nature and to accurately predict clearing, ensuring earliest possible completion of the vital airlift during the initial phases of the war. During a European war, our enemies will almost certainly stop transmitting weather data. In addition, our allies may stop transmitting weather data because of its usefulness to Warsaw Pact countries, and the encrypted DMSP data available at tactical terminals in Europe may be the only weather data our European forces have to use. During August of 1979, we used DMSP to support operations in Nicaragua from the tactical terminal at Howard AFB, in Panama, when conventional data were not available in Nicaragua during the overthrow of the Somoza Regime.

The U.S. Readiness Command's mission requires short notice deployment of a joint task force to virtually any area of the world. High resolution satellite data, responsive to the deployed military commander, are often the sole source of weather data in a contingency area where data are either sparse or denied. In support of U.S. commitments to NATO, the U.S. regularly deploys tactical fighter squadrons from U.S. bases to designated allied airfields in Europe. Decisions to launch, delay or change refueling areas, not only for the fighter aircraft but also for the tanker aircraft needed for refueling, are often made based solely on the high resolution data available from the DMSP.

A DMSP tactical terminal, as well as recorded data from AFGWC, provides coverage necessary for the Air Force weather satellite support to the Joint Typhoon Warning Center (JTWC) located at Guam in the Pacific. JTWC provides typhoon warnings and accurate fixes of storm positions, and also provides DOD with resource-protection warnings necessary in this predominantly data-sparse area. In 1978 and 1979, more than half of the JTWC's warnings in the Western Pacific were based on satellite positions of tropical cyclones. In the Indian Ocean, where aircraft and land-based radar were not available, over 95% of the JTWC's warnings were based on satellite fixes. This information, required by military commanders throughout the Pacific, is also made available to civil and international agencies.

The examples I've just discussed highlight the extensive use of DMSP by Air Weather Service. Limited military resources and continued tensions worldwide call for increased responsiveness of the DMSP system. In addition, commanders using more complex, sophisticated weapons systems which are highly sensitive to environmental factors dictate the further exploitation and expansion of the DMSP. To meet these growing operational support requirements during the 1980's, we have programmed additional capabilities for the DMSP.

The space environment mission will be strengthened with the addition of both a topside ionosonde and a refined plasma density monitor for detailed profiles of electron density. The microwave imager will allow us to recover aerial extent and rates of precipitation over the globe. We envision that these data will give us an improved cloud analysis capability, and over data-denied areas, will, when combined with knowledge of the terrain, provide improved trafficability forecasts for army commanders. This will allow commanders to more effectively employ their heavy tanks, trucks, and artillery pieces in their overall strategy. Finally, increased system survivability and reliability will increase the DMSP utility at the Air Force Global Weather Central. We plan to improve the automated imagery-processing system by installing interactive and softcopy display consoles to increase data base accessibility and reduce critical processing timeliness. Also, the cloud analysis model is being improved so that incoming data will update the analysis continuously. Therefore, cloud forecasts can be run at any time using the latest data available.

AF is currently deploying an improved direct readout terminal for tactical use. The Mark IV is a totally self-sufficient tactical terminal, transportable on C-130 type aircraft, as opposed to the larger C-5 sized aircraft needed to airlift our current tactical terminal.

In the future, multiple sensor data, such as microwave imagery and atmospheric sounder data, are planned to be included in the direct readout mode. These data will increase the capability of the battlefield meteorologist to provide the tactical commander with critical support information when conventional weather data are denied. In addition, we plan to include a data processing capability in the future tactical van. This system will be able to provide instantaneous updates on the weather to the tactical commanders' automated systems. The commanders will then be able to make immediate changes to targets or tactics, maximizing the potential of their automated command and control systems.

The DMSP, a system responsive to military requirements, has grown considerably during the past decade. The close interaction among the weatherman at the tactical readout terminal directly supporting the tactical commander, the Air Force Global Weather Central, building and applying its worldwide data base, and dedicated command and control of the on-orbit DMSP satellites has provided a finely tuned military system capable of responding to national security requirements. In short, military METSAT applications have proven to be a vital source of data for AWS's support to national defense, and will continue to evolve to meet the changing needs of military decisionmakers.

Atlas:

We keep hearing about measuring precipitation from space, and I still have my doubts about the use of the SSMI or any other microwave radiometer to do this. What do you think?

Kaehn:

Well, I do think that it offers a way with some potential. There is a problem, but there appears to be potential. This appears to offer one of the most promising ways to obtain the information. If you ask me to forecast the degree of success -- I would be presumptuous if I attempted a definite prediction. But we're working on the problem as hard as we can. It is data that we have got to have.

Ludwig:

In the context of the first half the morning's discussion, I notice a hole in the early history of the DOD Meteorological Satellite Program. Is there some prospect that this rich early history might be filled out by including the DOD portion at some time?

Kaehn:

In the Air Force we have a rather extensive historical program. If we knew exactly how far you wanted to go back, we could find the people and the right information for you.

Kellogg:

I want to first remind the audience of the cover of the Bulletin of the AMS that showed a nighttime picture of the U.S. from the Air Weather Service that was taken by the very sensitive camera that was mentioned. You mentioned that the Defense Meteorological Satellite Program shares its data with our own Weather Service. Do you also share this data with other countries -- Japan, Europe, elsewhere? Is it fed into the Global Meteorological Network which is a WMO function?

Kaehn:

It is made available at the University of Wisconsin and anybody who wants it can get it from there. We don't feed it to the network.

Kellogg:

The Global Telecommunications Network carries meteorological satellite information as well as conventional meteorological information for other countries, and I wondered if DMSP data is included.

Kaehn:

No.

Phillips:

Why don't you do that?

Kaehn:

It is just a question of cost. Who would pay for it? We do make use of the data provided by the civilian meteorological satellite network, and conversely, we provide data in cases where it is needed. There is a close cooperation. There is a shared METSAT data initiative that we are doing now, where we analyze the clouds, NESS will do the temperature soundings, and the Navy will look at the sea-surface temperatures. We will show the federal community that we can share the data and do these three analyses separately -- but it all takes money.

Johnson:

With respect to the Global Telecommunications System (GTS), practically no image data is sent. The capacity just isn't there. Emphasis is on quantitative data -- winds and temperatures. Those are produced by NESS and are available on the GTS. There have been arrangements made with respect to some of the tactical sites to meet certain specialized data requirements as mutually agreed to between the Air Weather Service and NESS. Data is made available in certain circumstances where it makes a very significant contribution beyond those data that would otherwise be available through the civil systems. It is done on a special case-by-case basis, however, not routinely.

Kaehn:

Another point is that we need to look at different parts of the world on different days.

KEY SCIENTIFIC QUESTIONS AND THE ROLE OF SATELLITES

Eugene W. Bierly, Director, Division of Atmospheric Sciences, National Science Foundation

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 International 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: <u>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</u>. 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 1

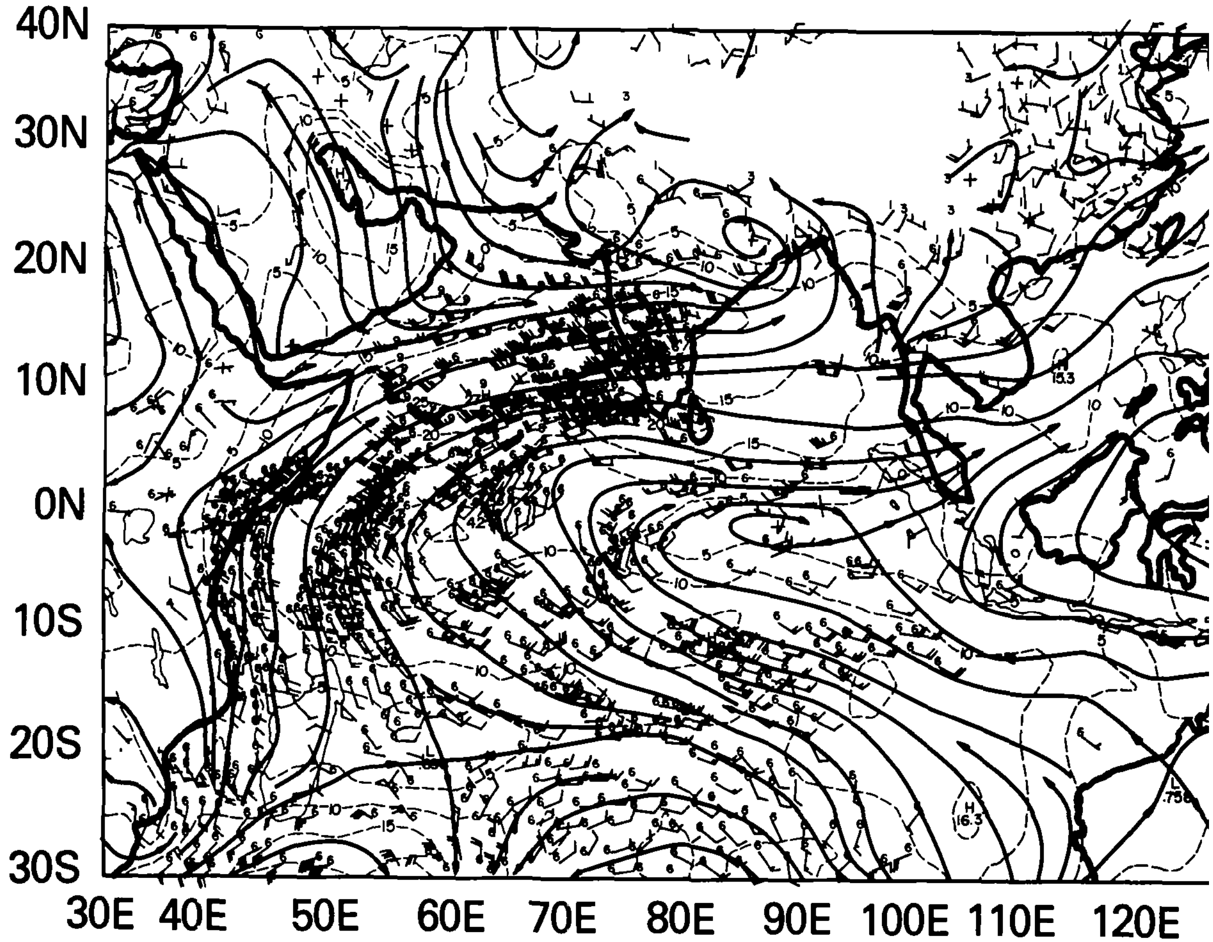


Fig. 1. (Taken from T.N. Krishnaumurti's 1979 Atlas

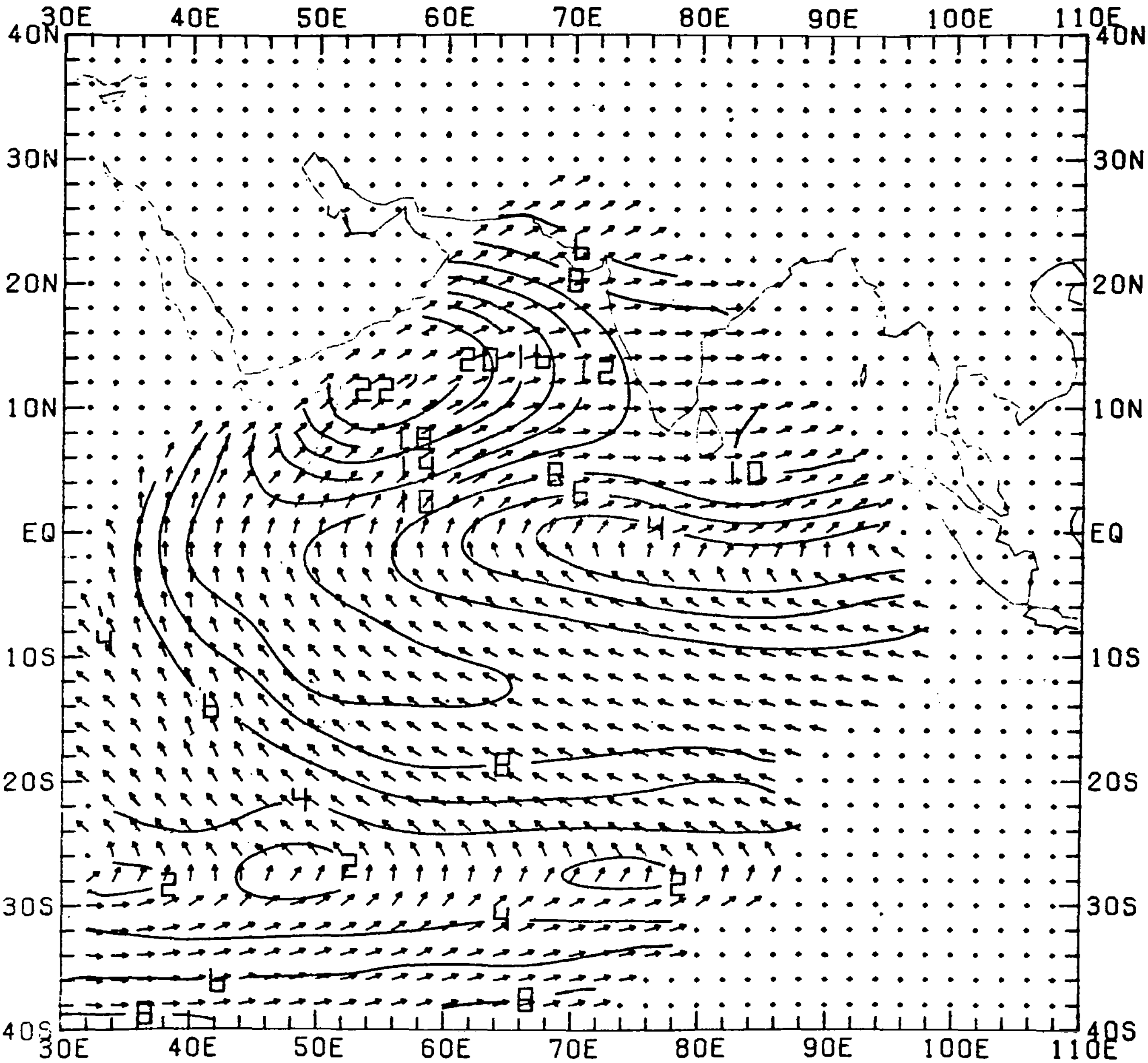


Fig. 2. Cloud-derived wind fields, July 1979 average.
(after J. Young)

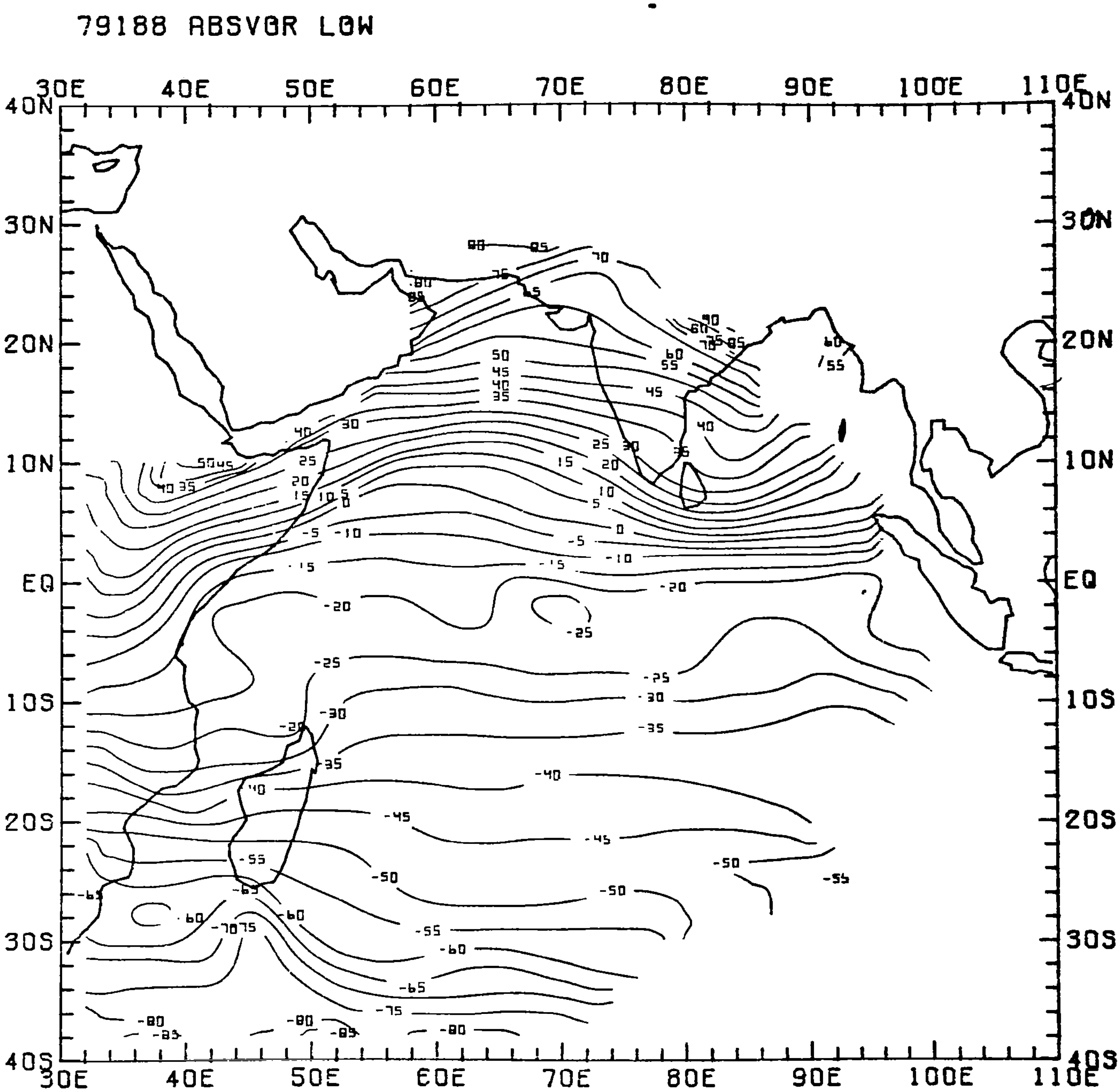


Fig. 3a. Absolute vorticity - calculated from the wind fields of Fig. 2.

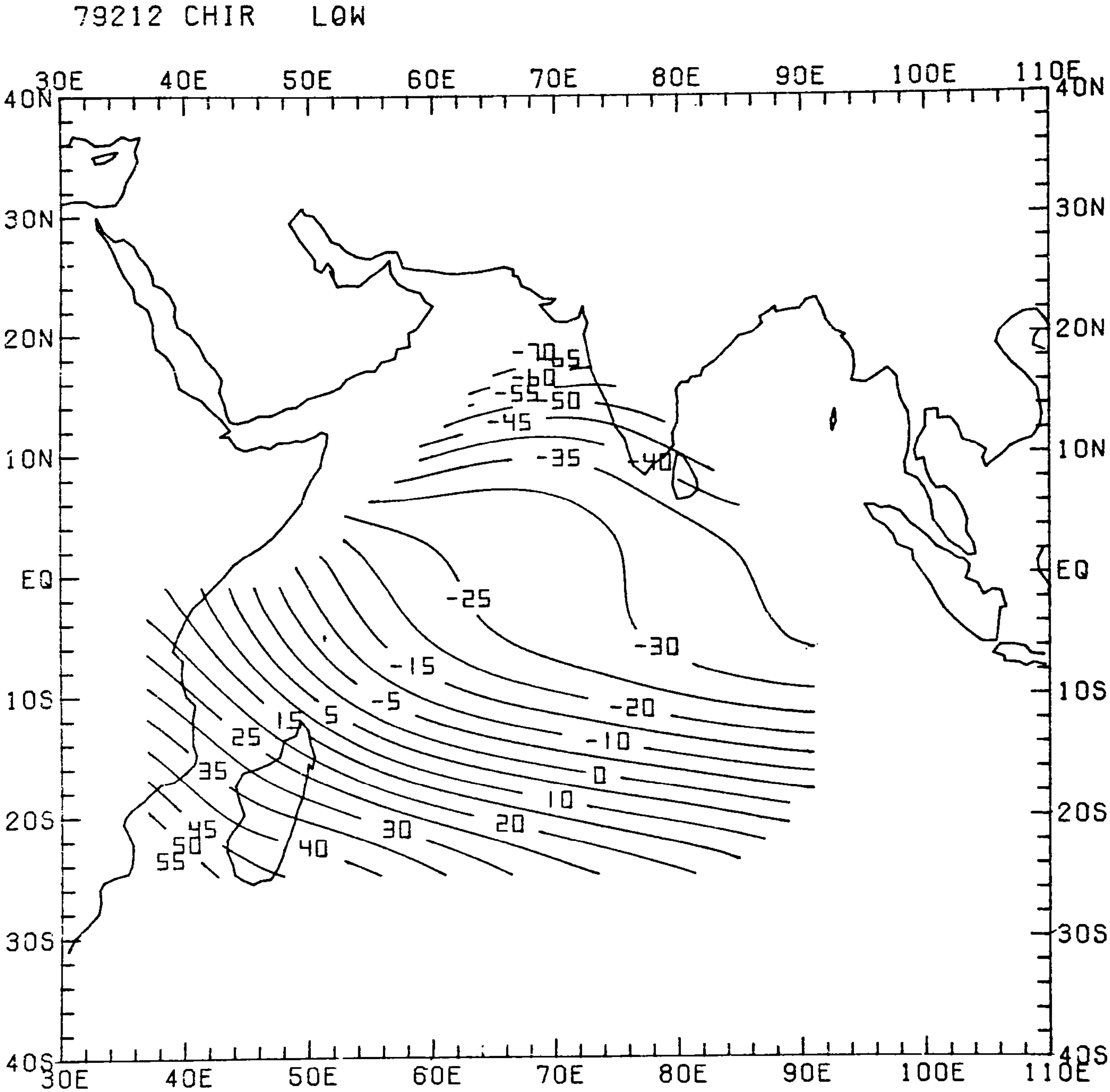


Fig. 3b. Geopotential field - calculated from the wind fields of Fig. 2.

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

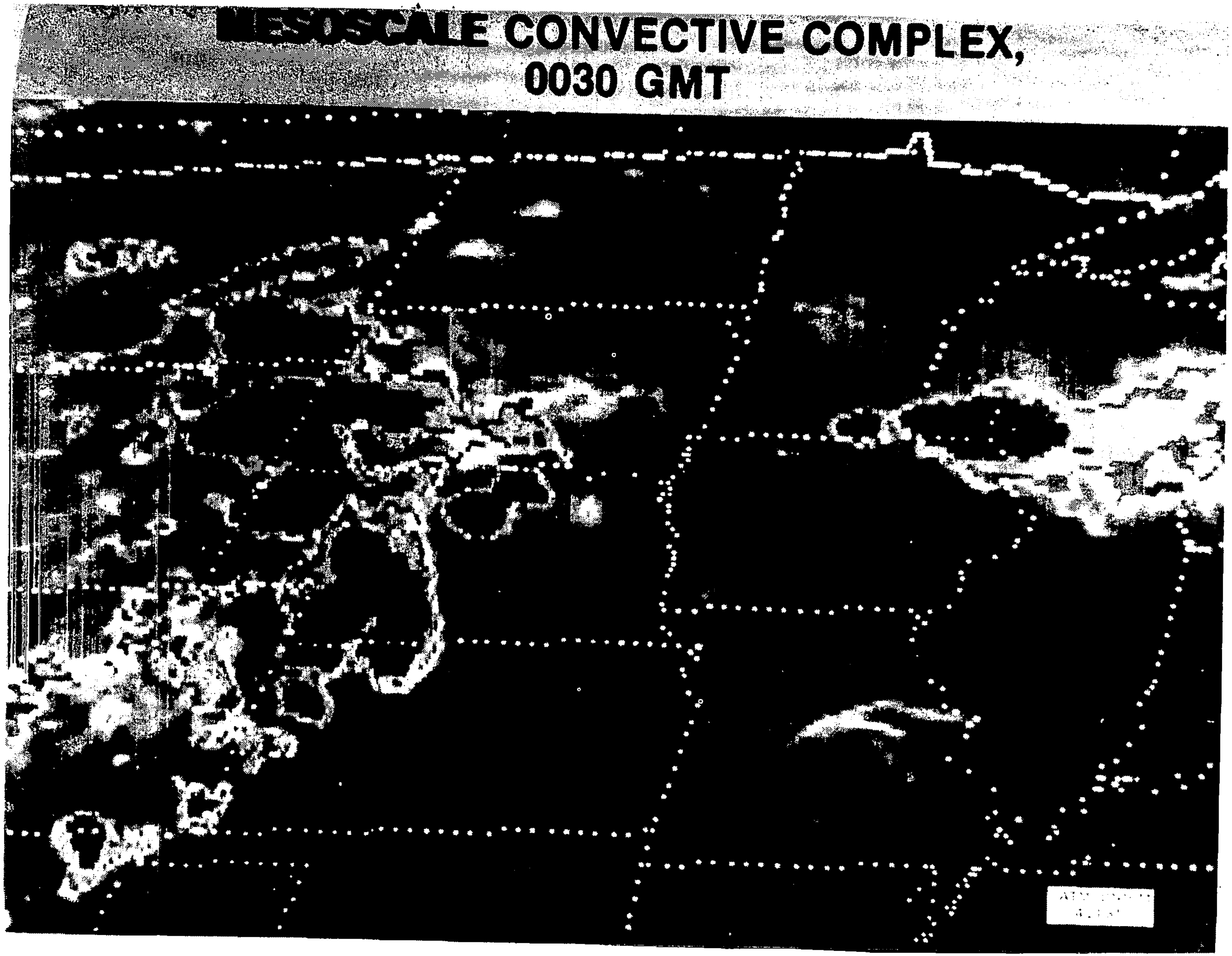


Fig. 5a.

MESOSCALE CONVECTIVE COMPLEX, 0400 GMT

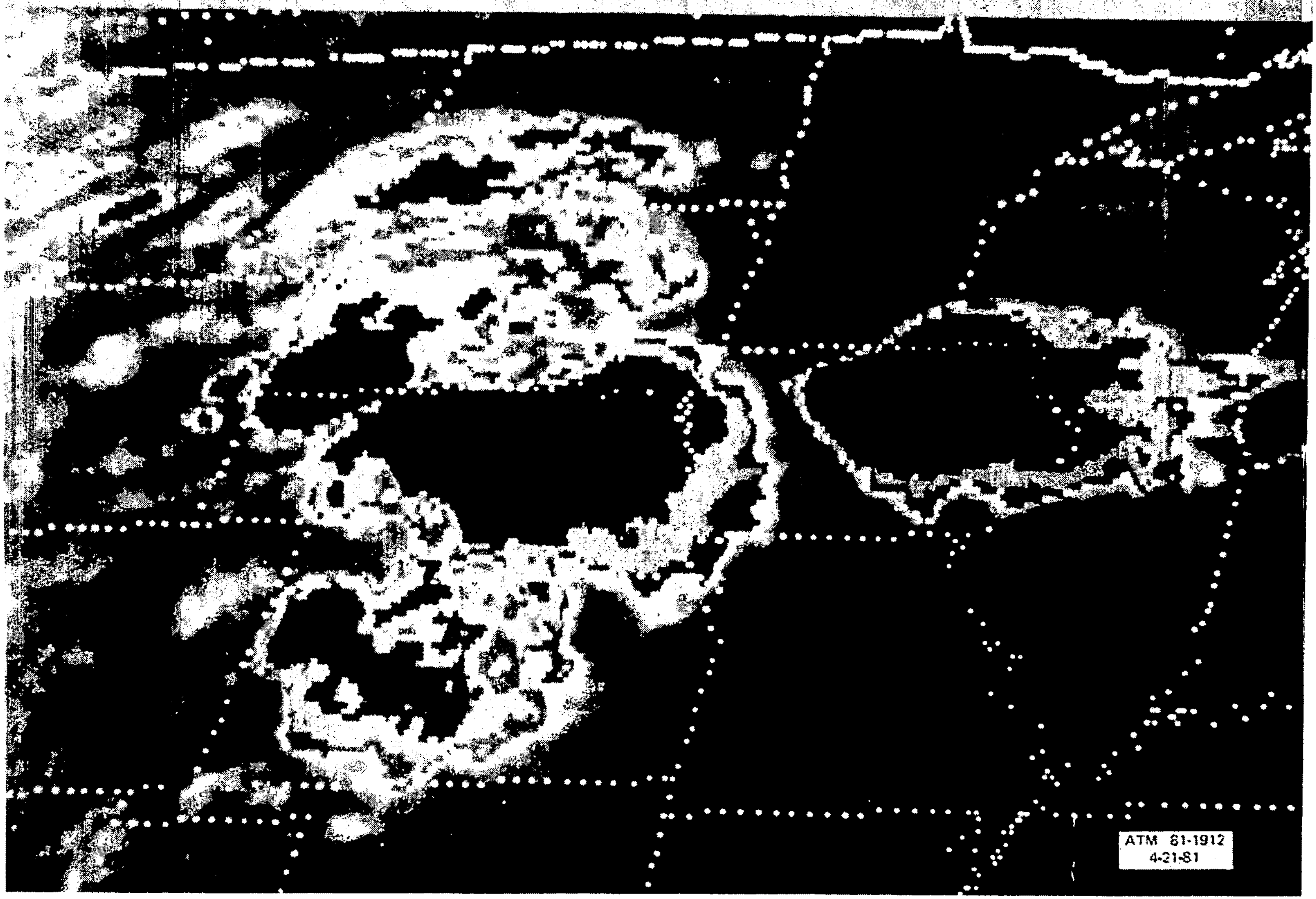


Fig. 5b.

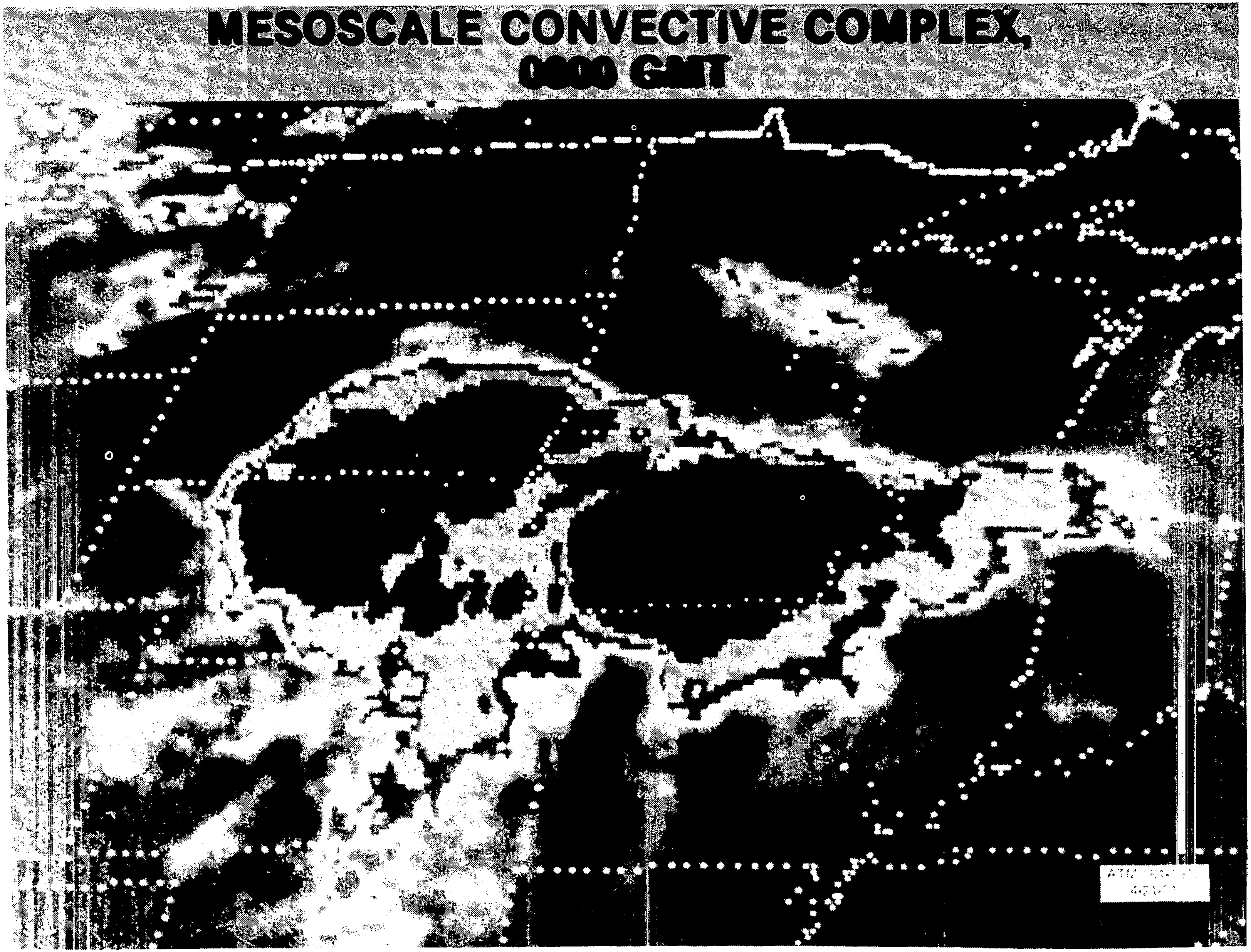


Fig. 5c.

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)

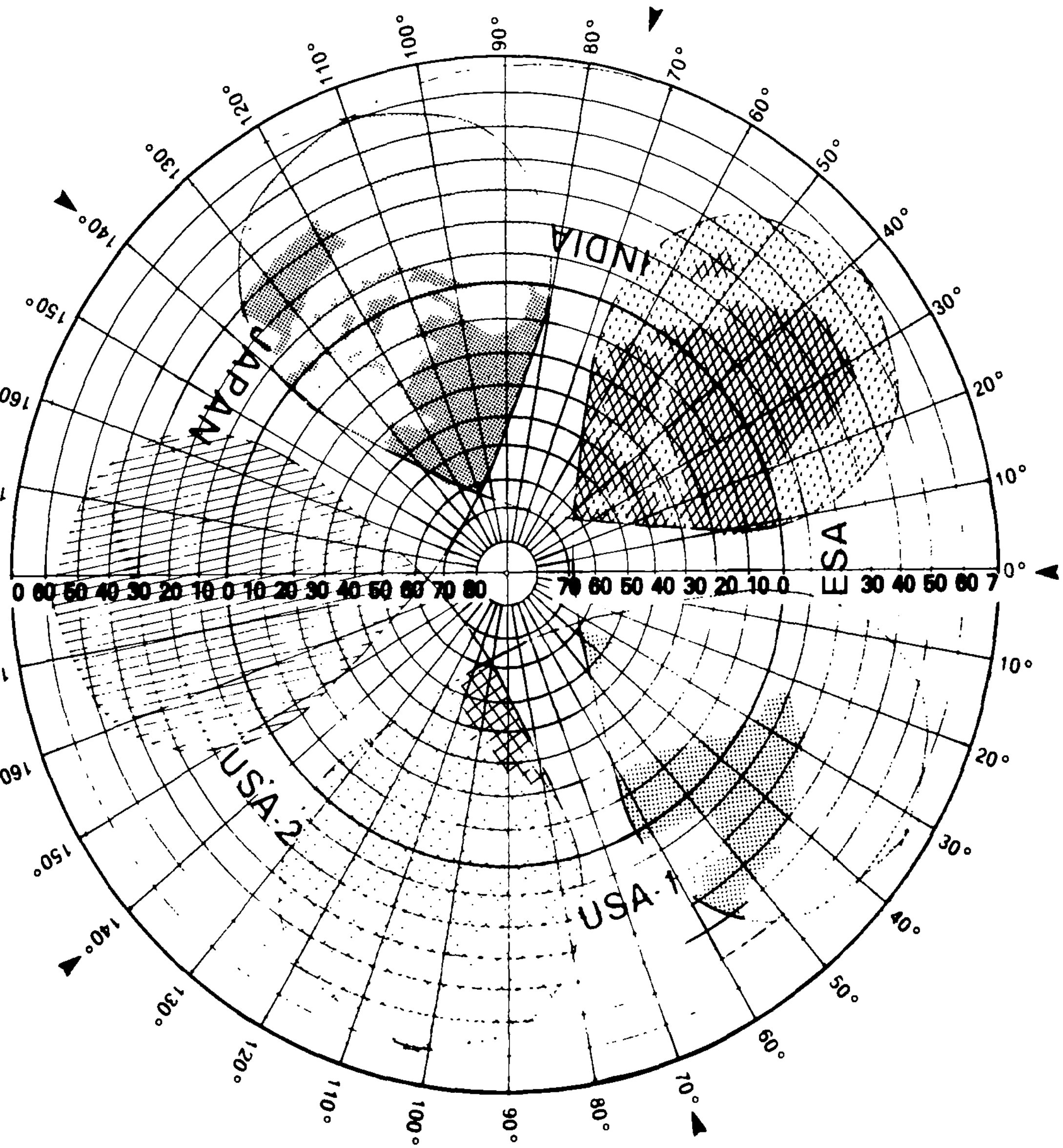


Fig. 9.

ISCCP: STATUS OF SATELLITES, 1980-84

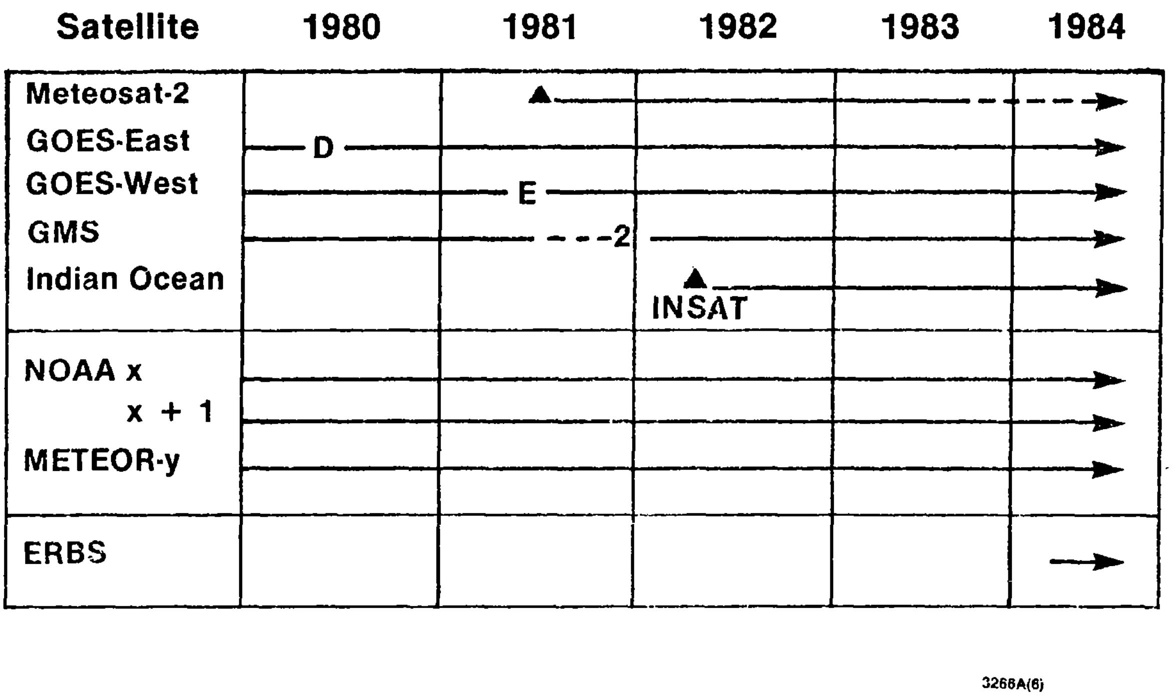


Fig. 10.

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

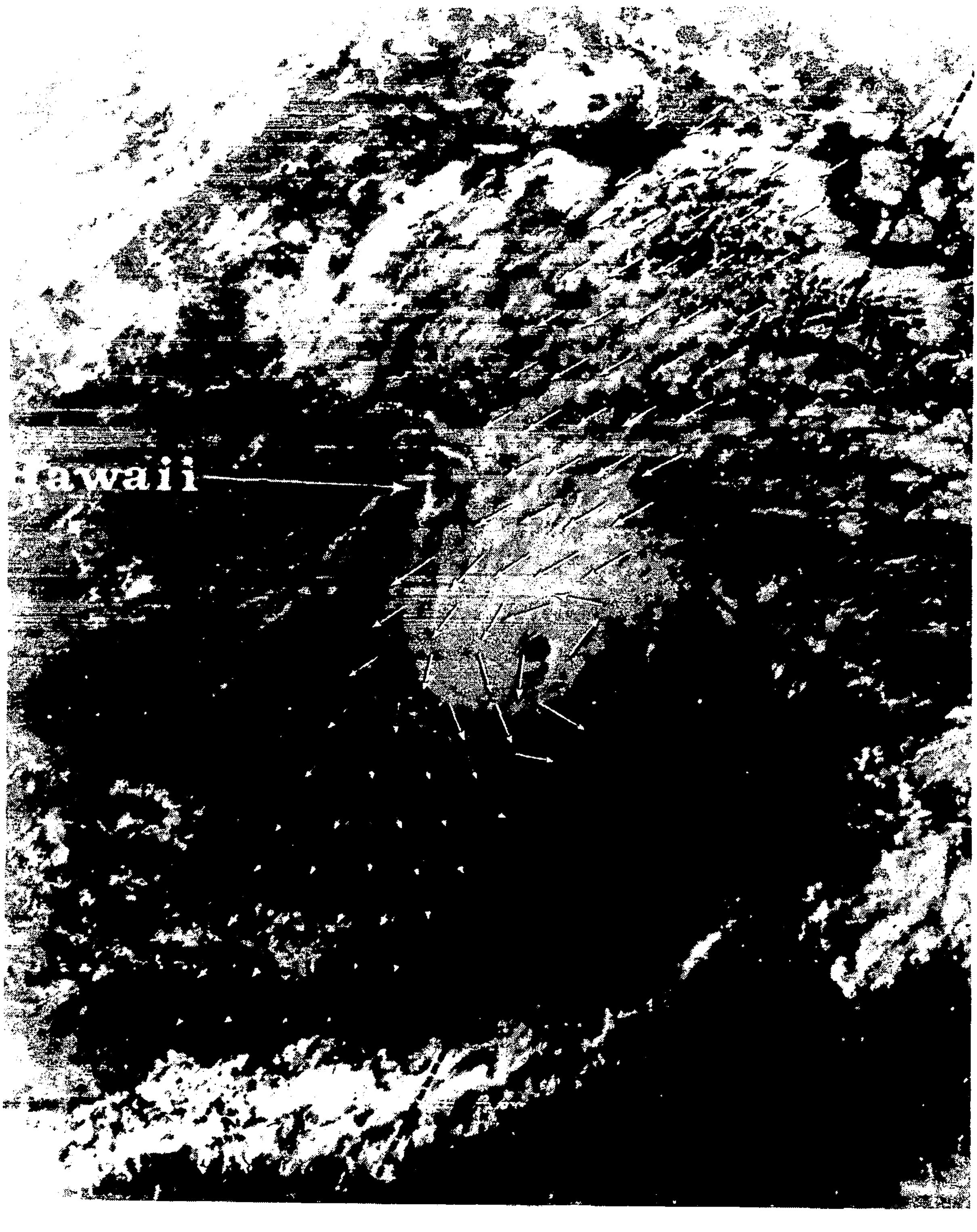


Fig. 15. Wind vectors from SEASAT scatterometer data. July 20, 1979.

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.

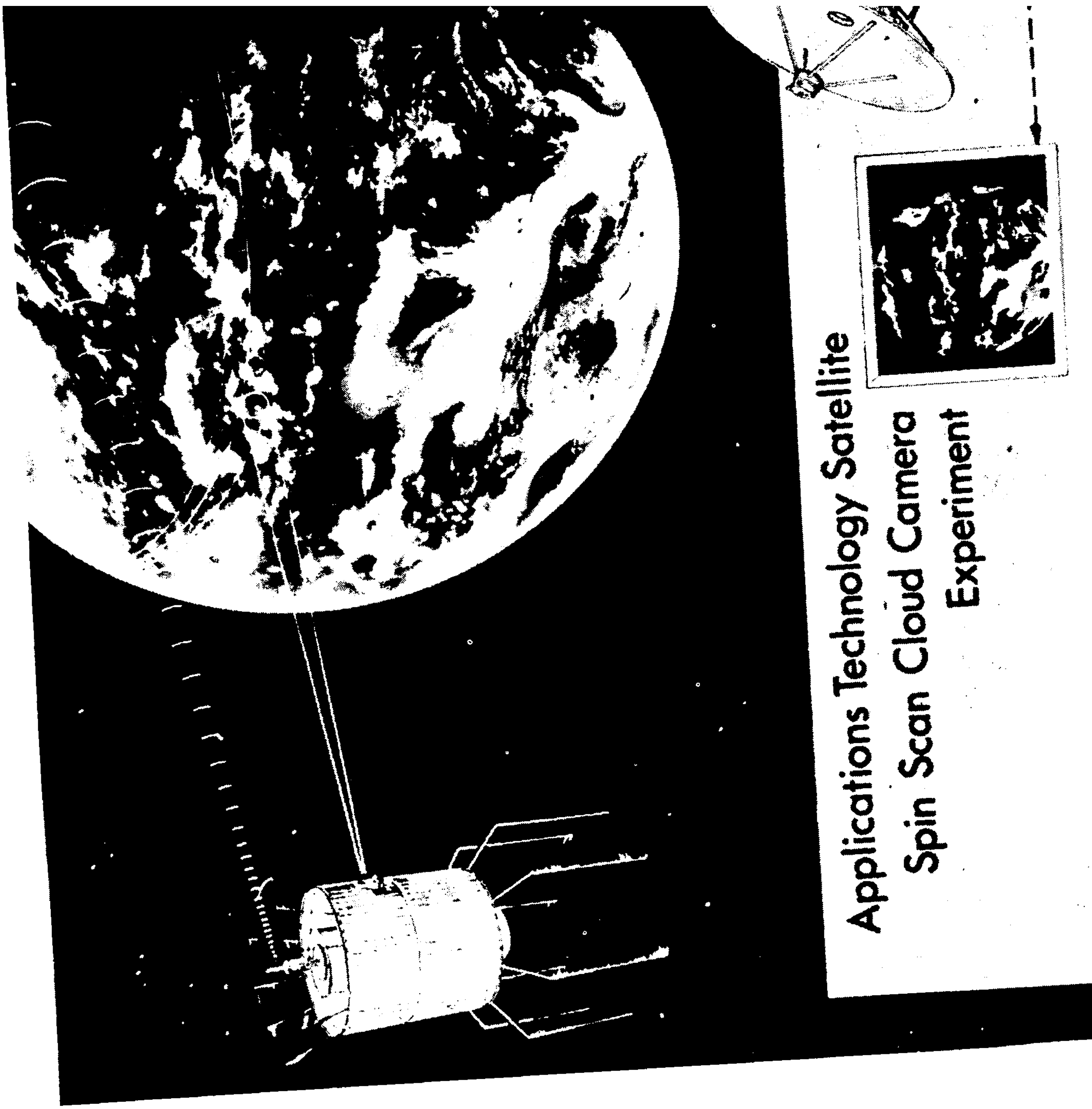

Applications Technology Satellite
Spin Scan Cloud Camera
Experiment

Figure 1.

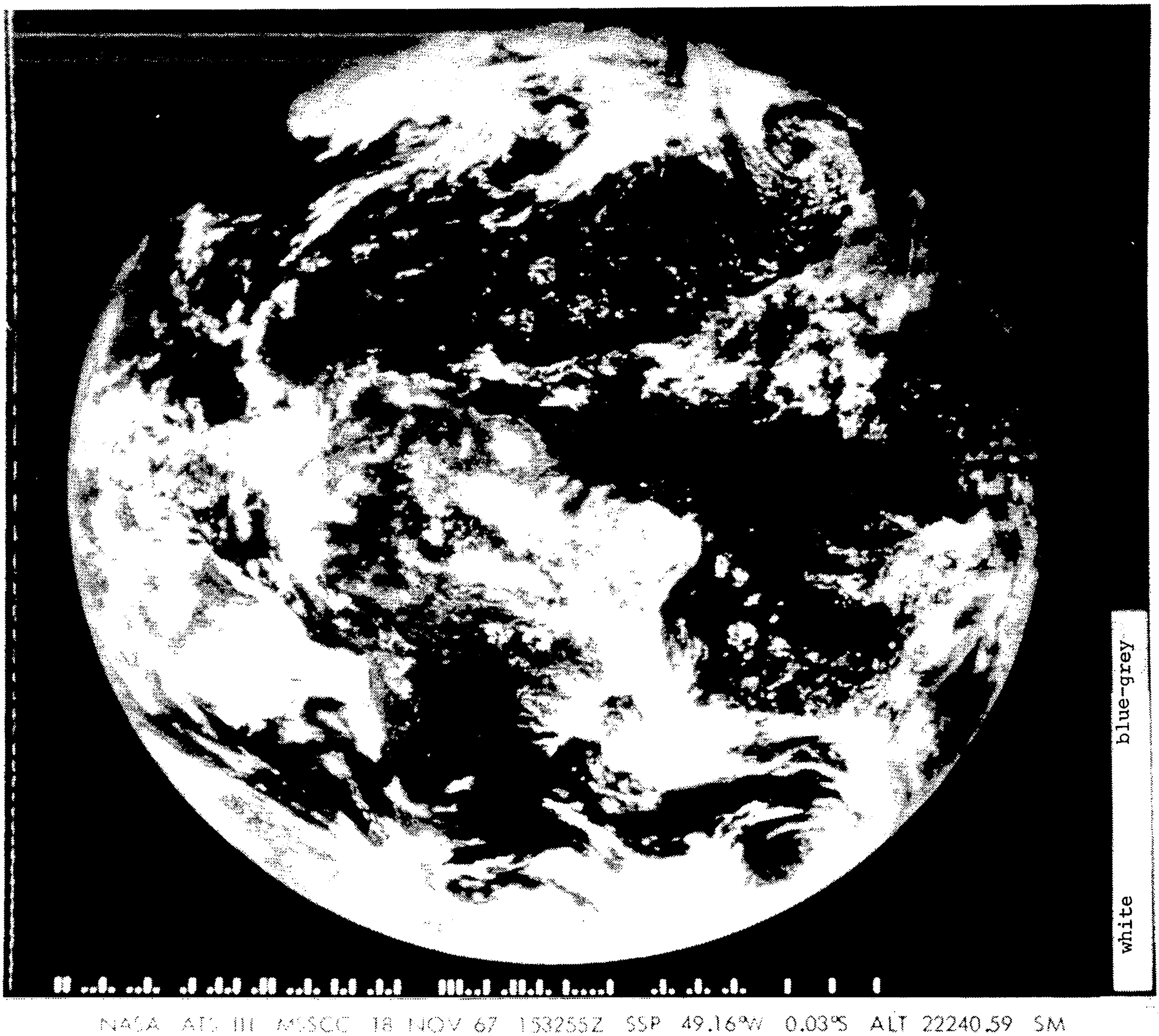


Fig. 2. First satellite color picture of Earth. (for the purposes of this report, transferred from color to B & W - for approximate color, see graph on figure)

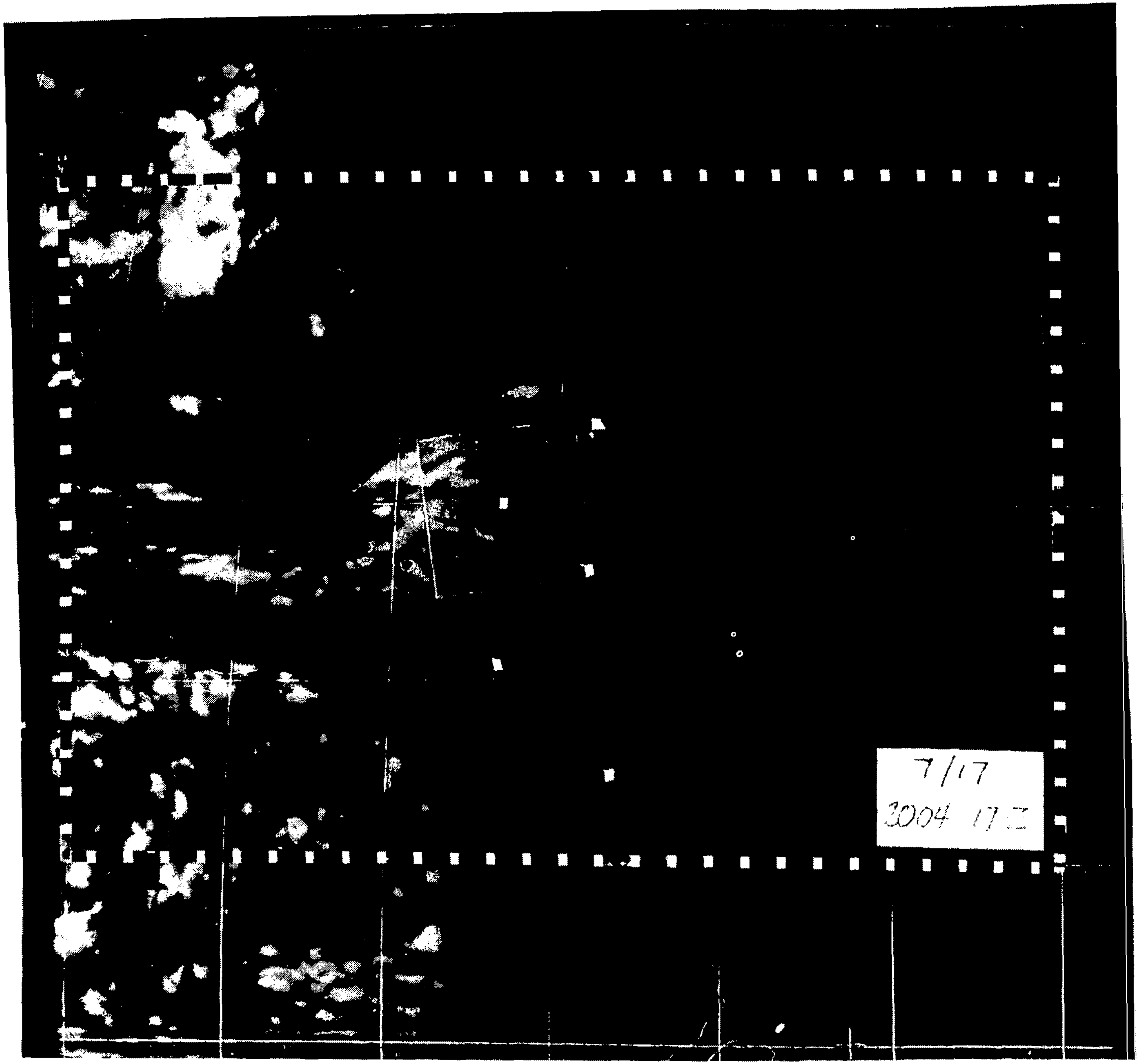
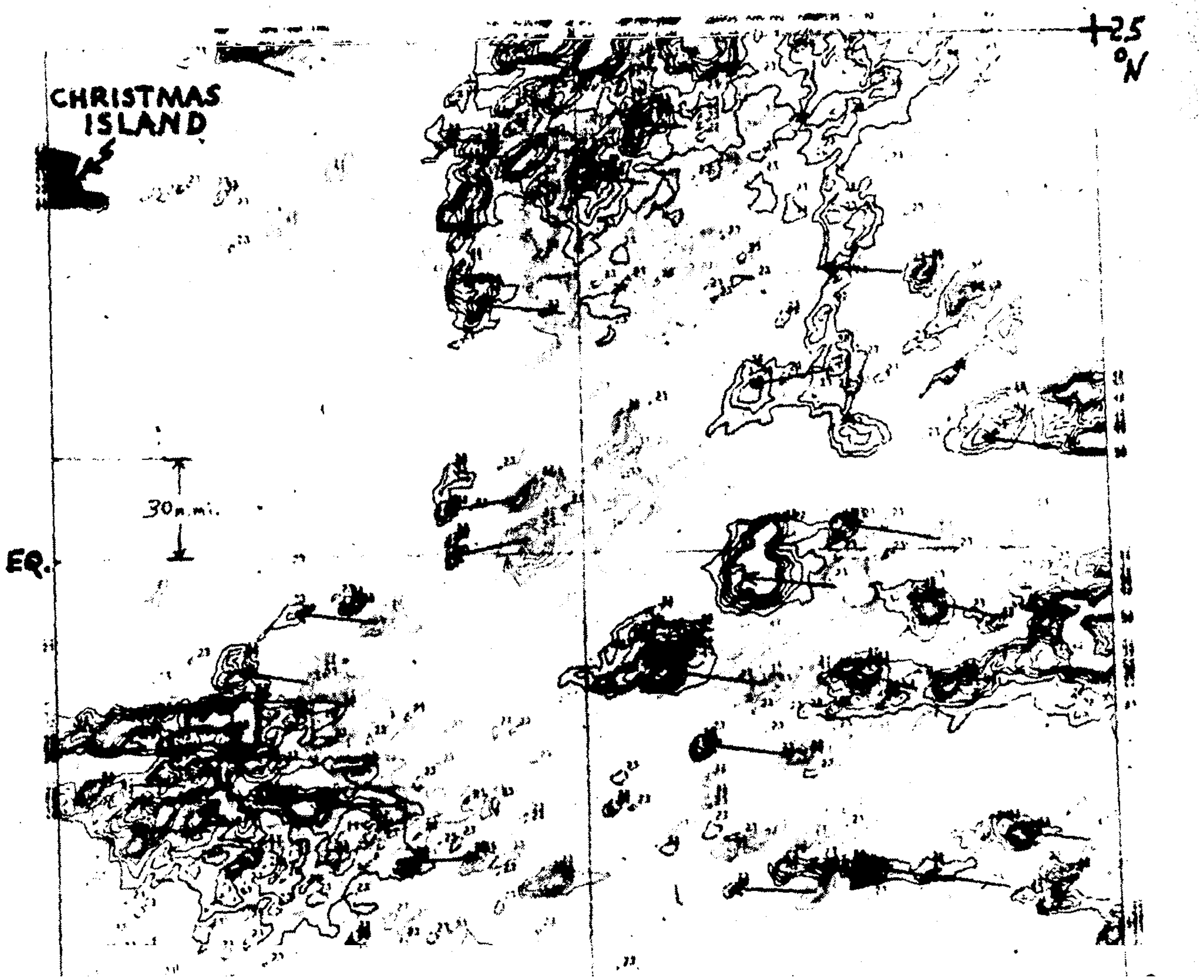


Fig. 3. Picture taken during 1969 BOMEX.



CHRISTMAS ISLAND
30 n.mi.
EQ.
2.5 °N

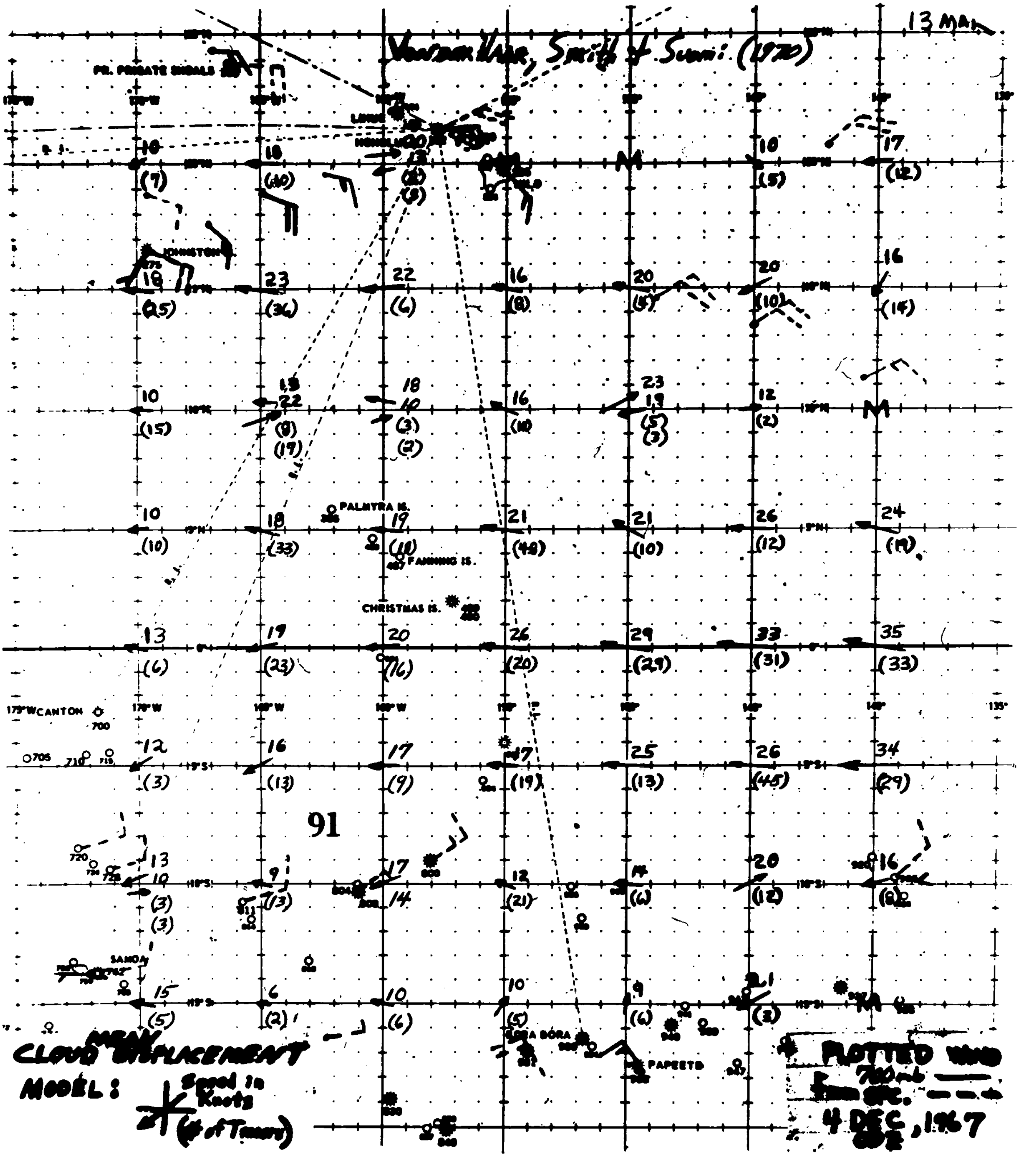


Fig. 5. Wind fields derived from data shown in Fig. 4.

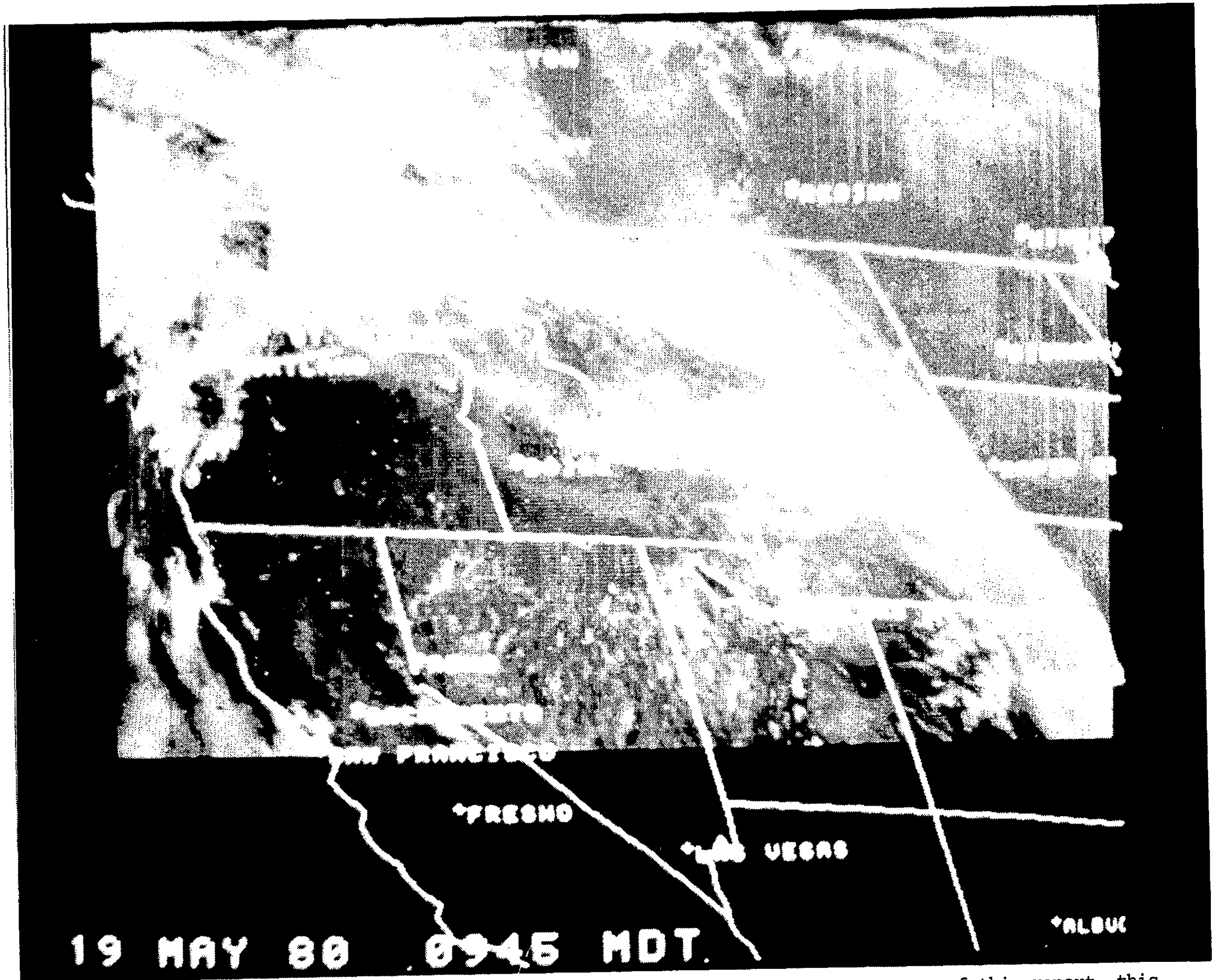


Fig. 6. Example of present geostationary satellite imaging. (For the purposes of this report, this picture was transferred from color to B & W. Color range from lightest-white to darkest-dark blue.)

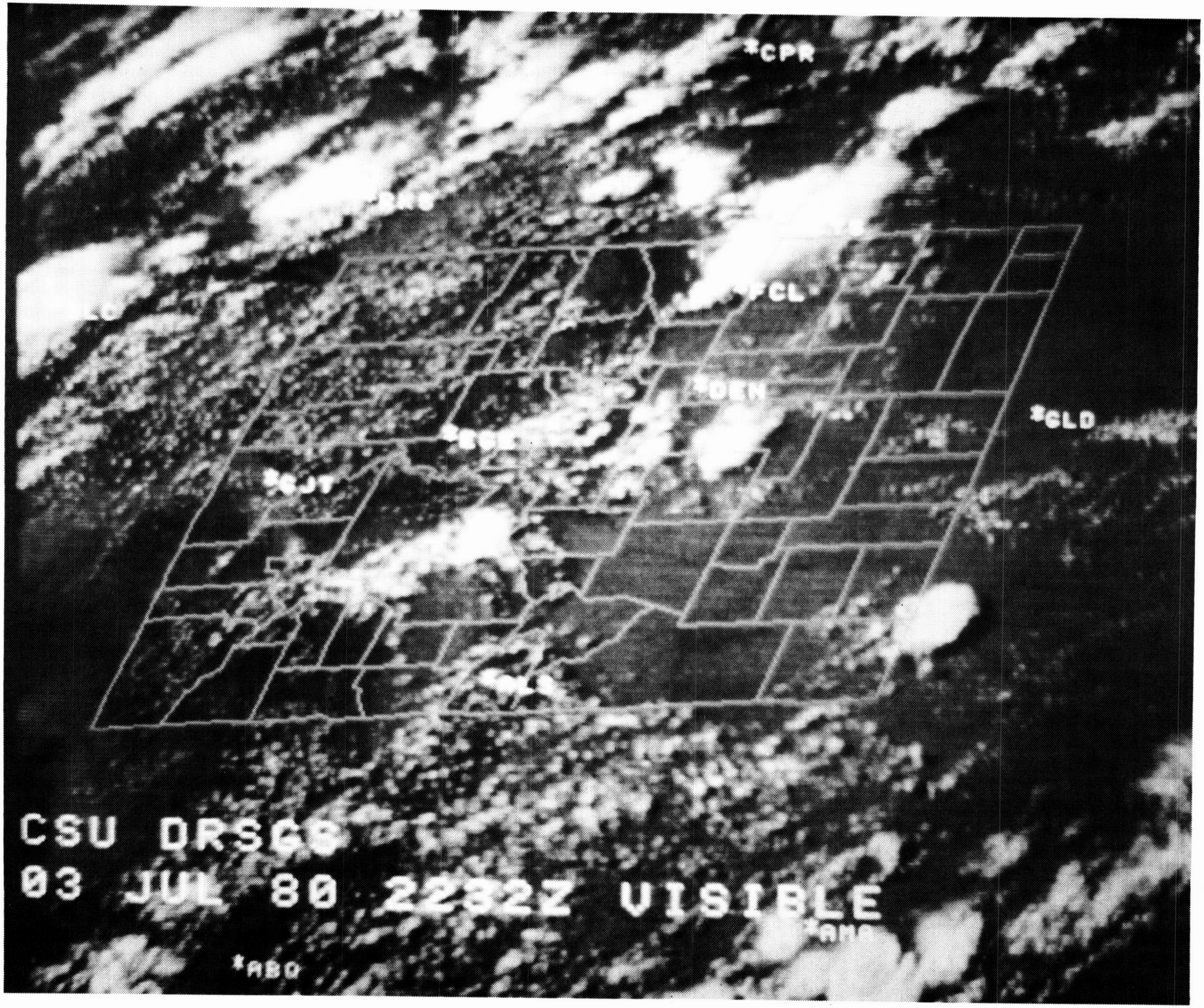


Fig. 7. Example of image data from GOES showing Colorado. (For the purposes of this report, the picture was transferred from color to B & W. Color range is the same as Fig. 6.)

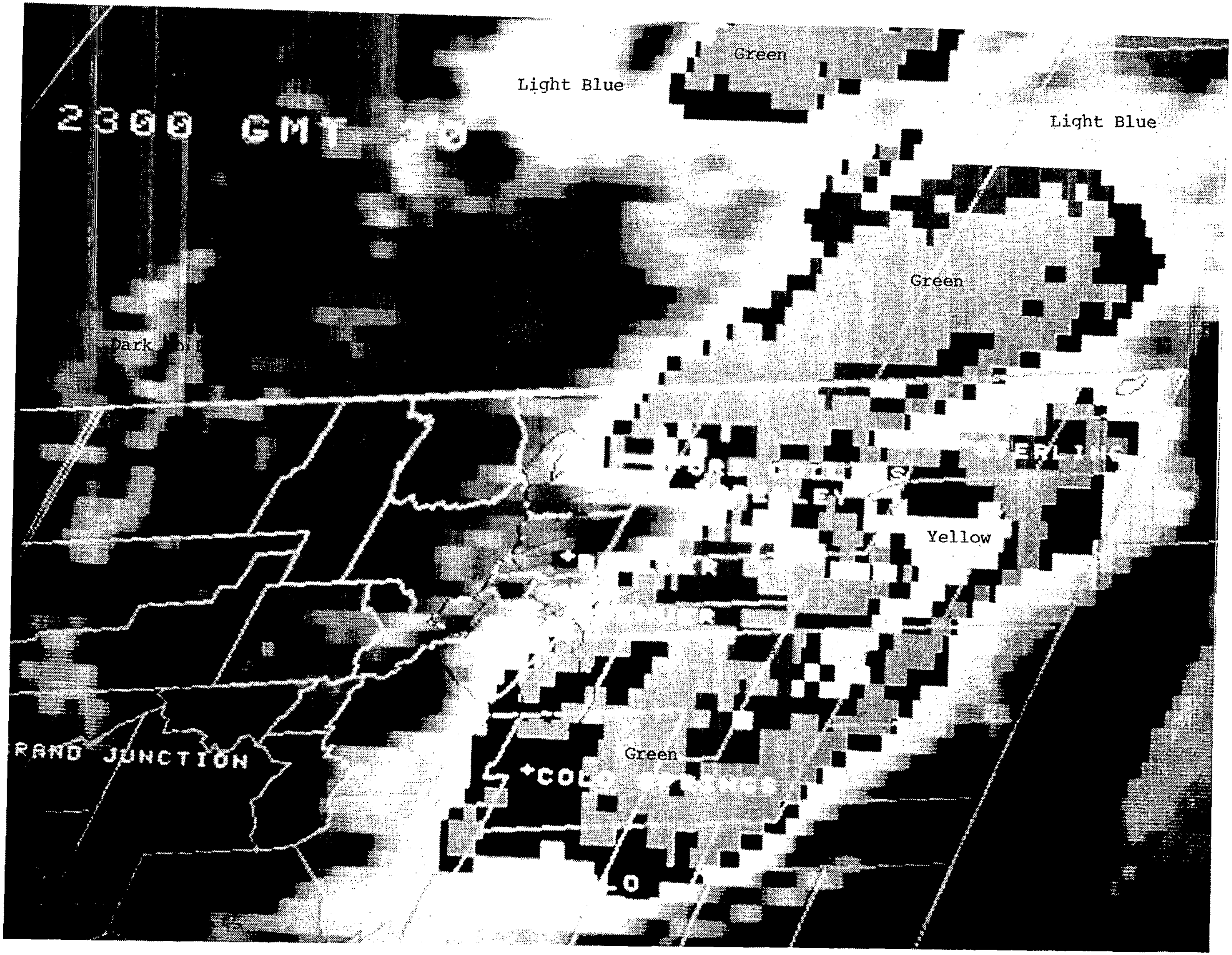


Fig. 8. Computer-generated false-color image showing a severe hail storm together with political boundaries. (For this report, transferred from color to B & W, colors noted where possible.)

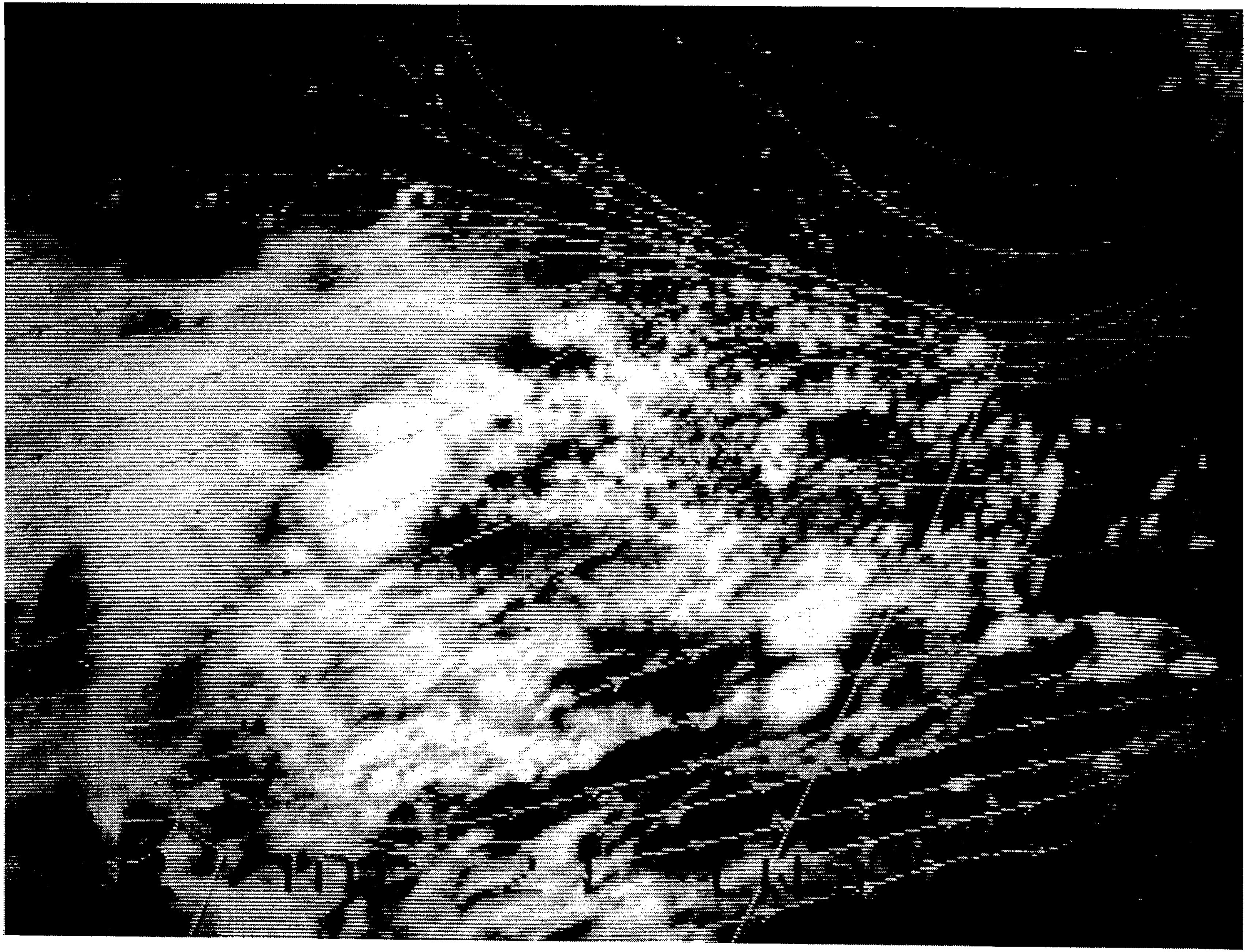


Fig. 9. Example of computer superposition of streamline fields. (For this report, picture transferred from color to B & W. Arrow lines-green, range from white to dark blue.)

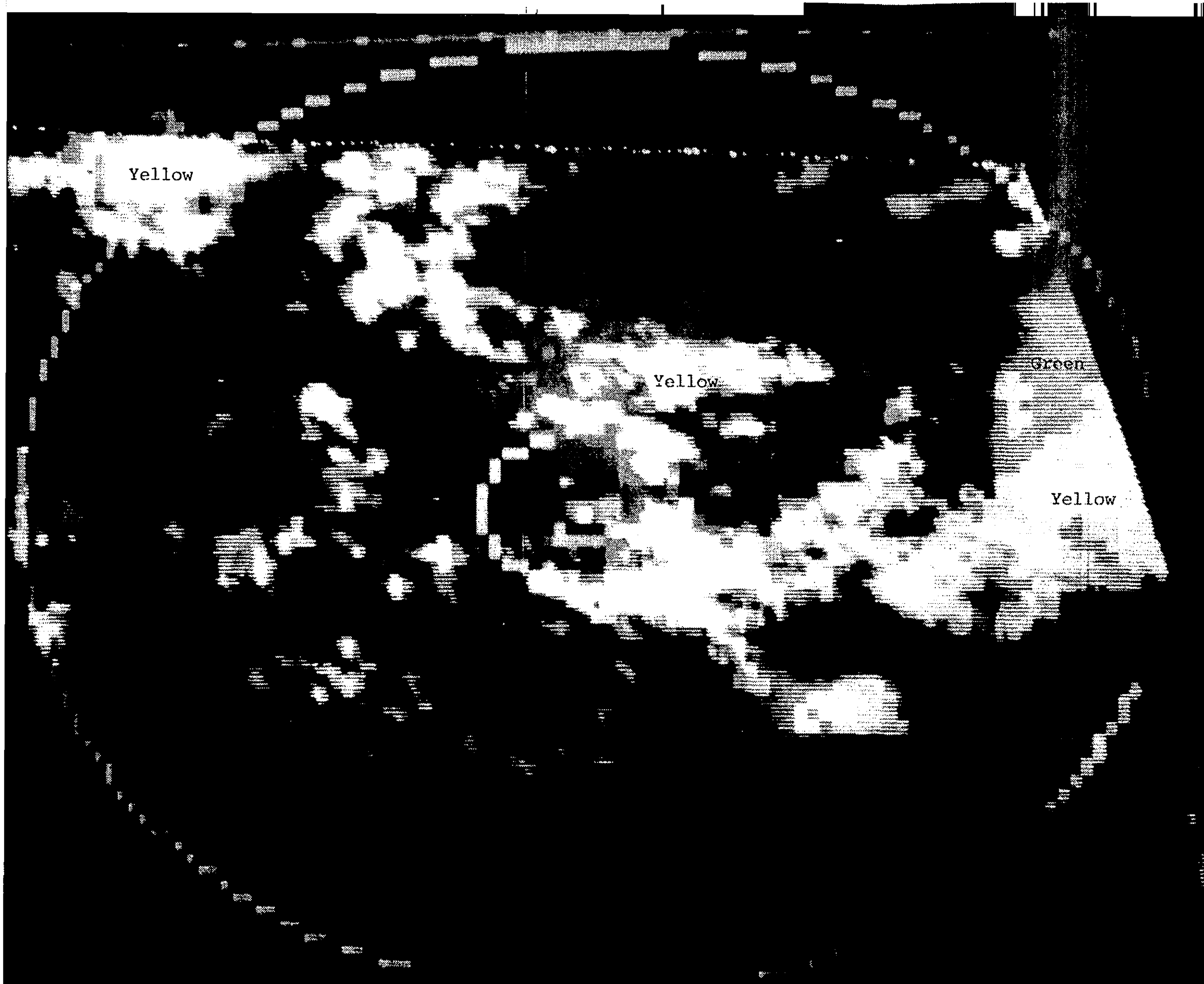


Fig. 10. Combined radar and satellite data. (For the purposes of this report, this picture was transferred from color to B & W. Color range, as indicated shows lightest areas yellow, to green, to red.)

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.

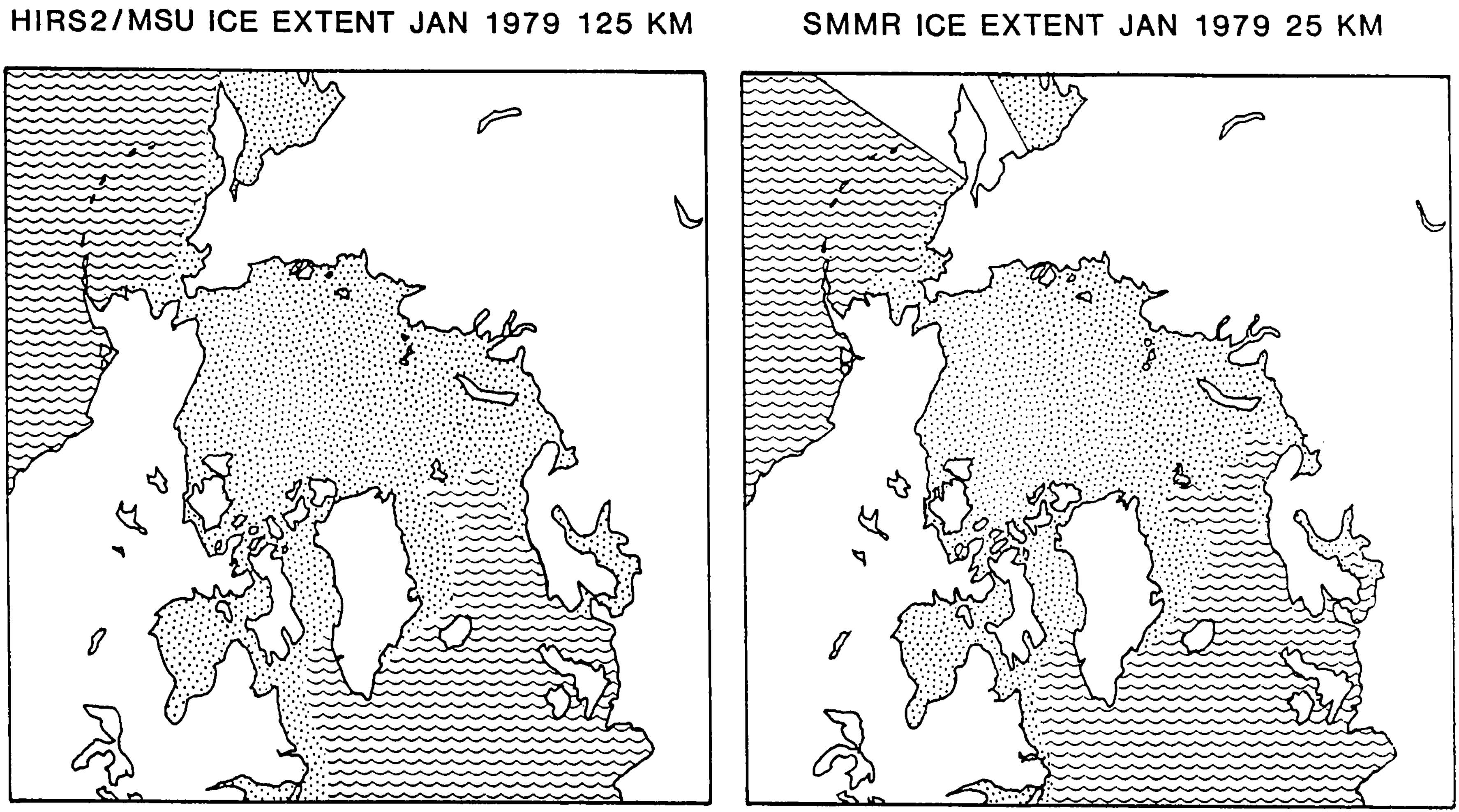


Fig. 1. Sea-ice mapping from HIRS-2 on TIROS-N (January 1979).

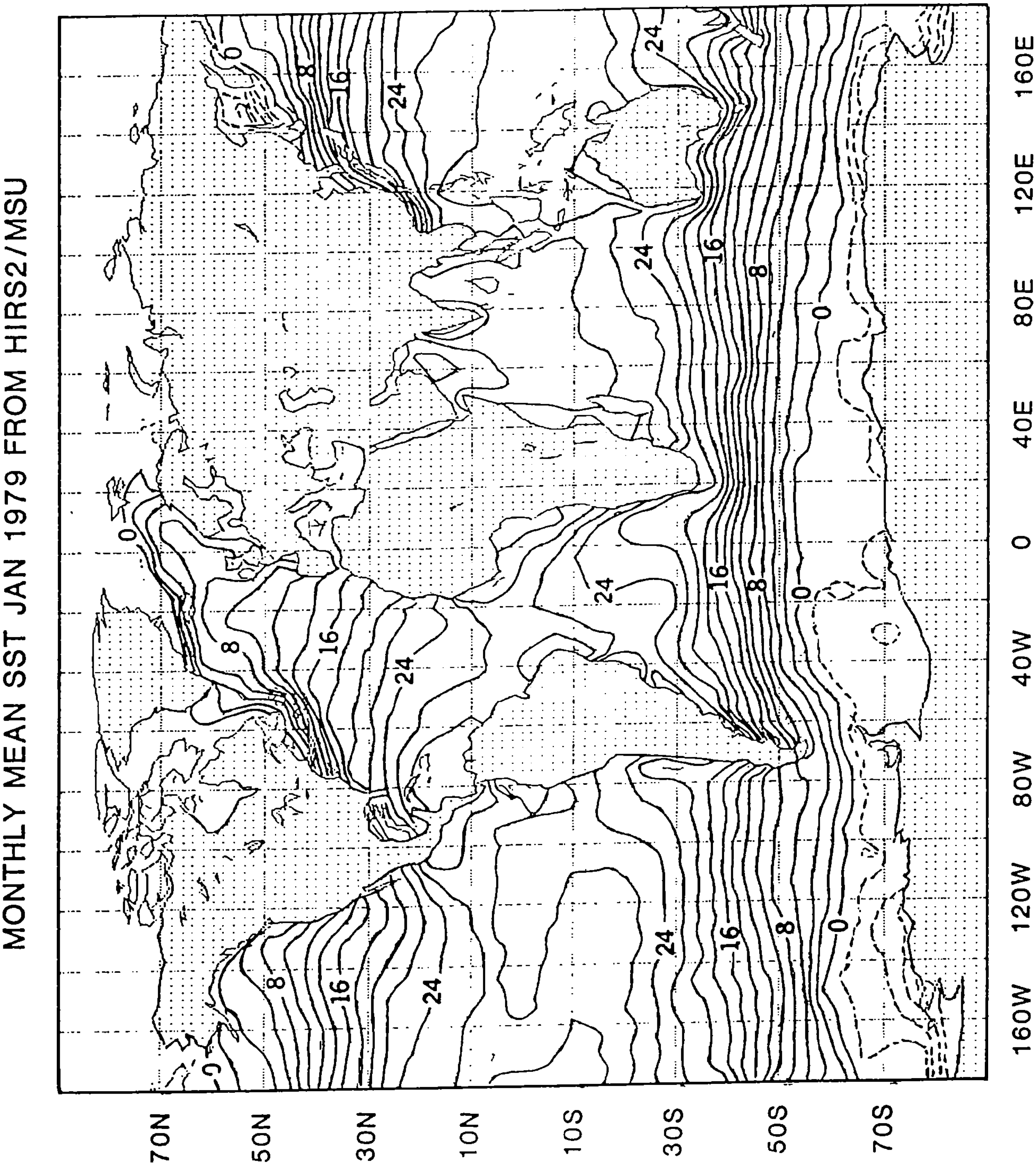


Fig. 2. Sea-surface temperatures from HIRS-2/MSU on TIROS-N (Jan. 1979).

SEA SURFACE TEMPERATURE ANOMALY
(JAN. 1979) - (20 YEAR JAN. AVERAGE)

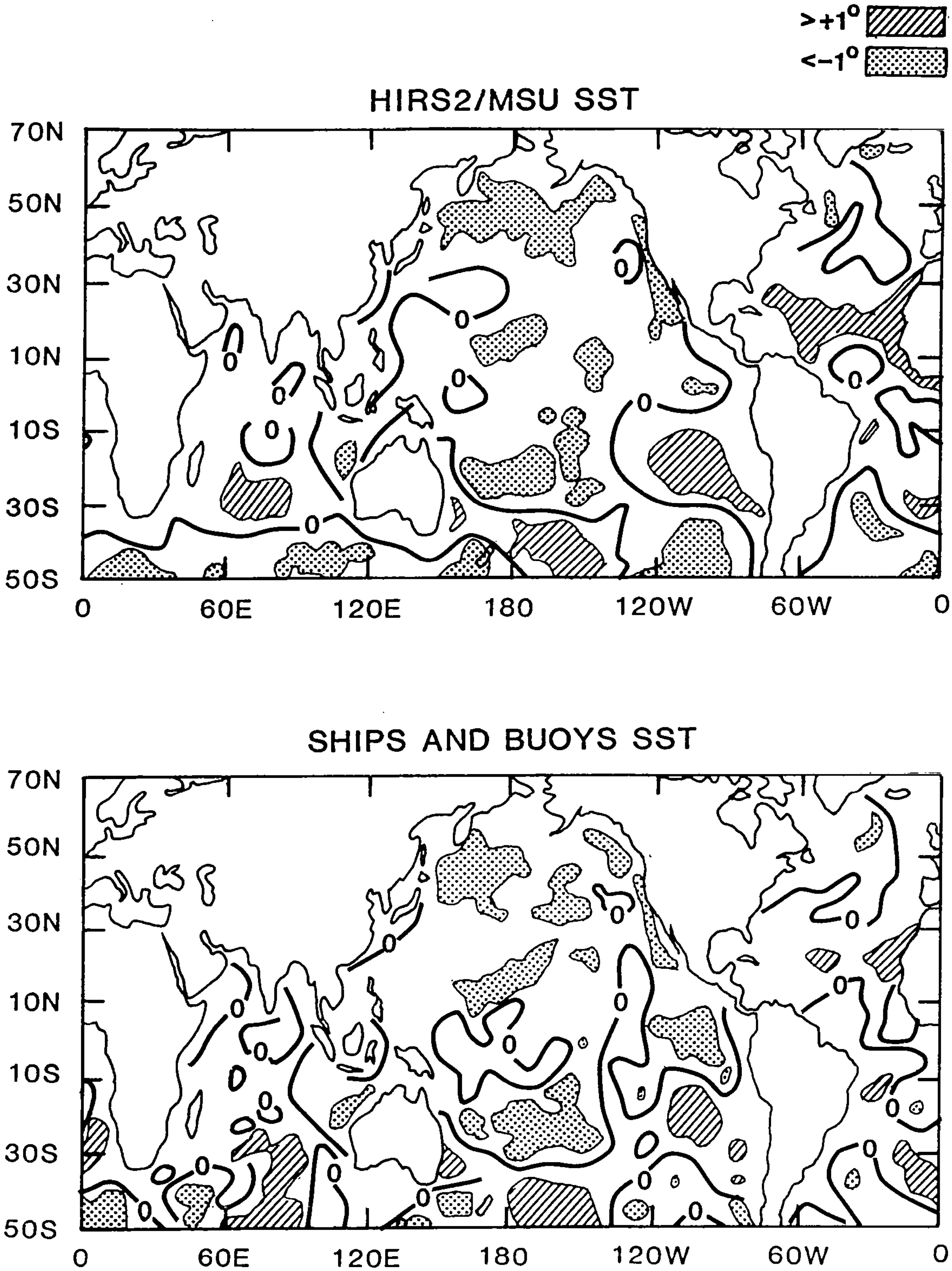


Fig. 3. Sea-surface temperature anomaly - present data minus 20-yr. average.

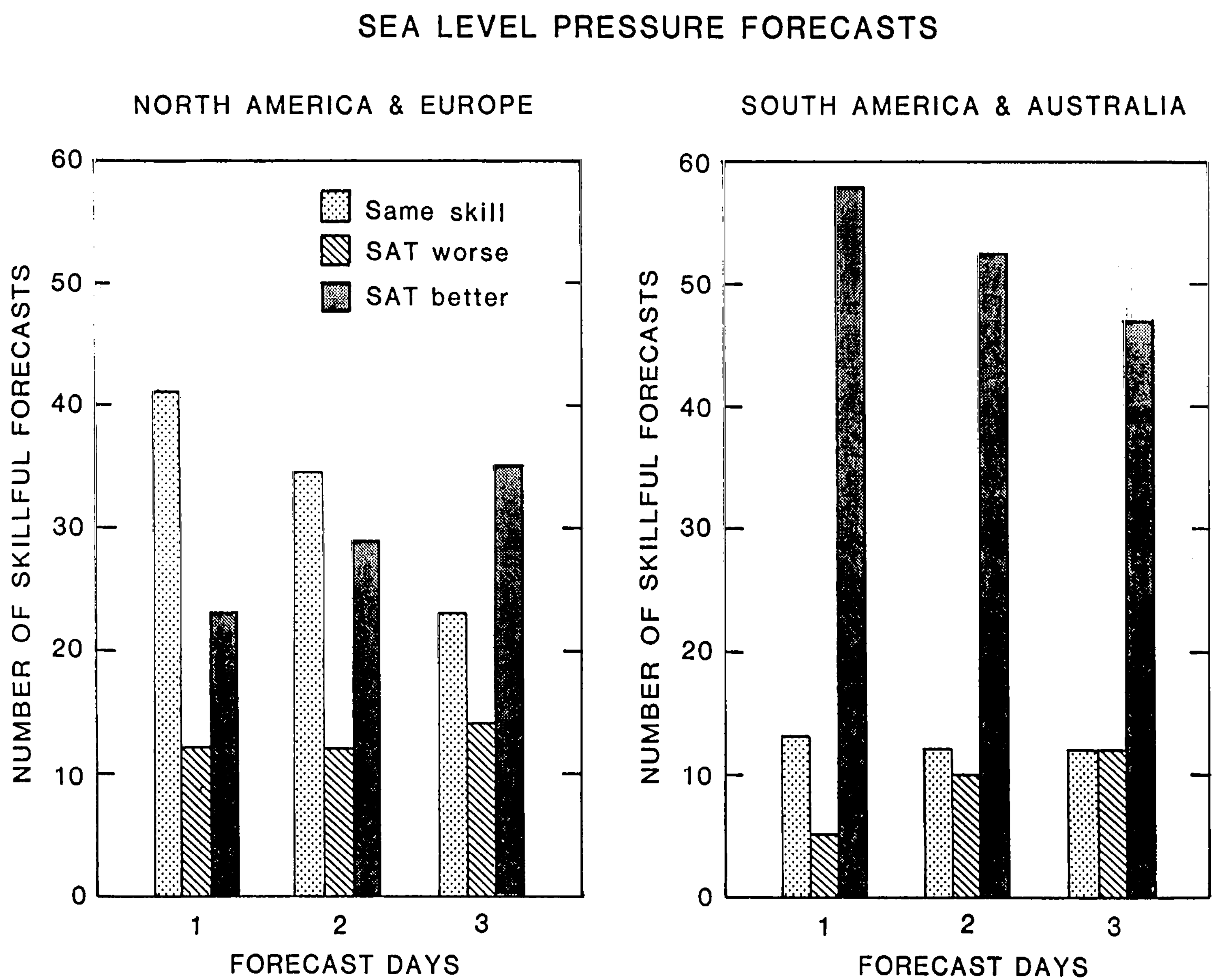


Fig. 4. Satellite data impact on forecast skill.

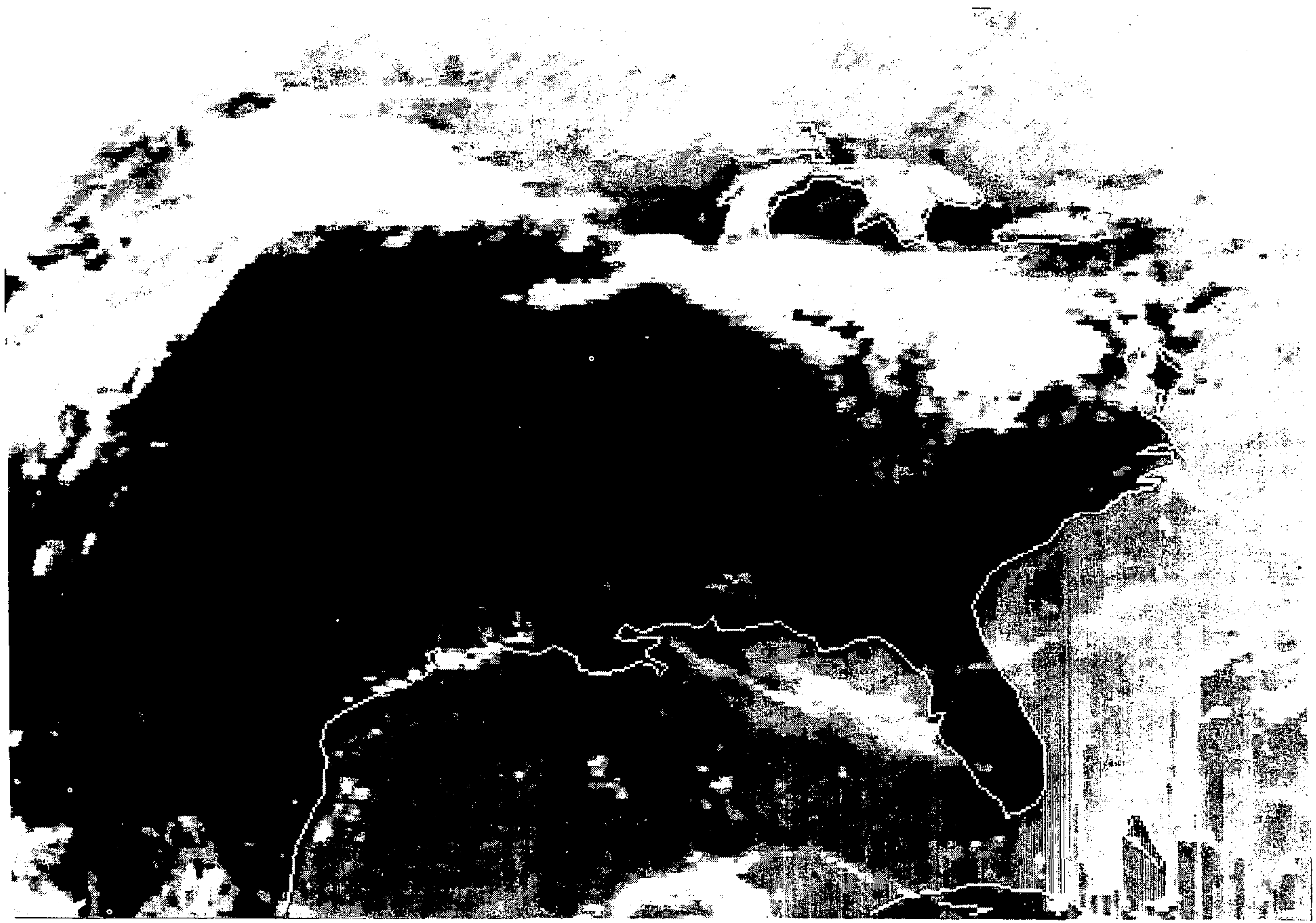


Fig. 5. VAS data.

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

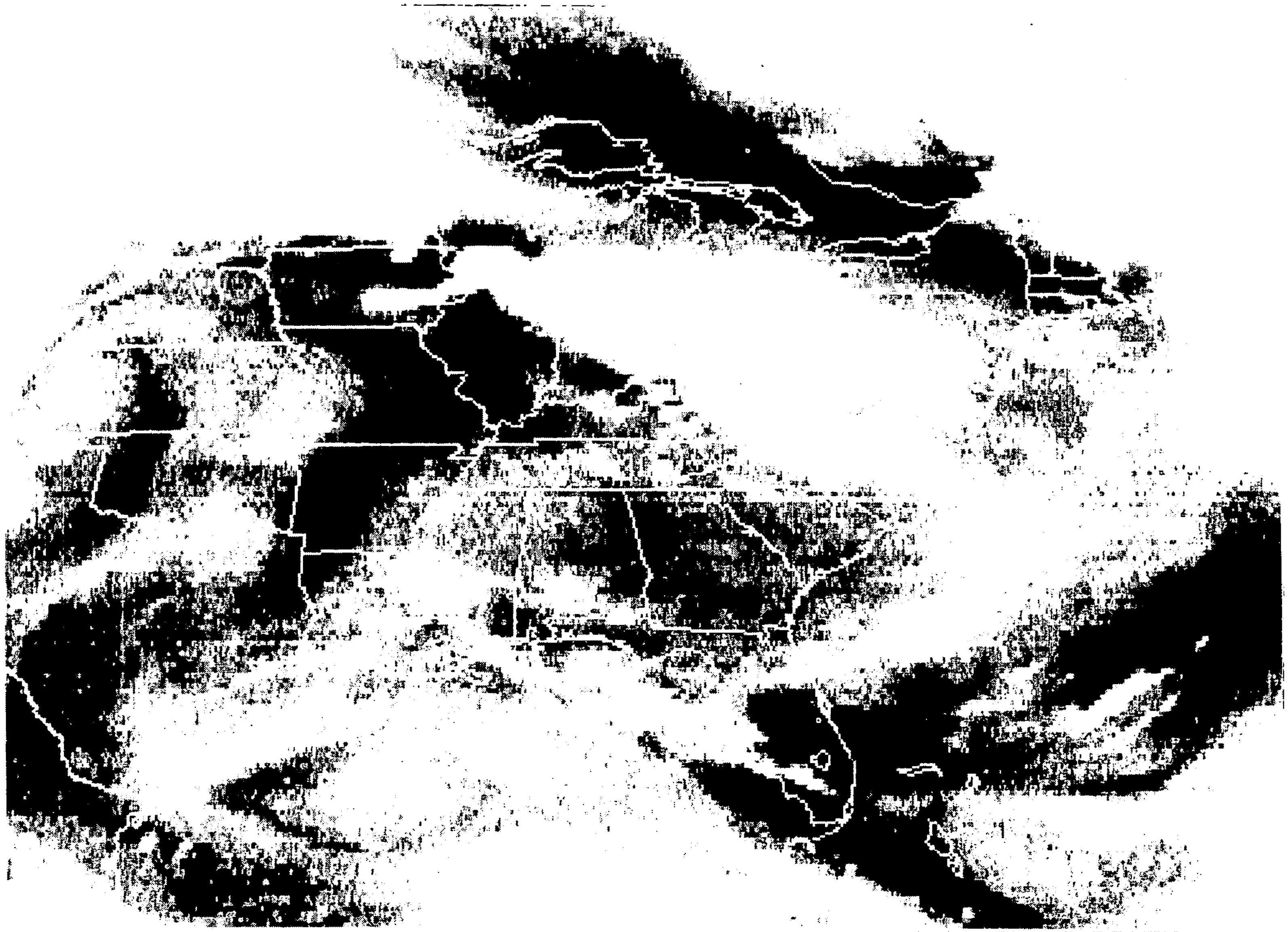


Fig. 6. VAS data.

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

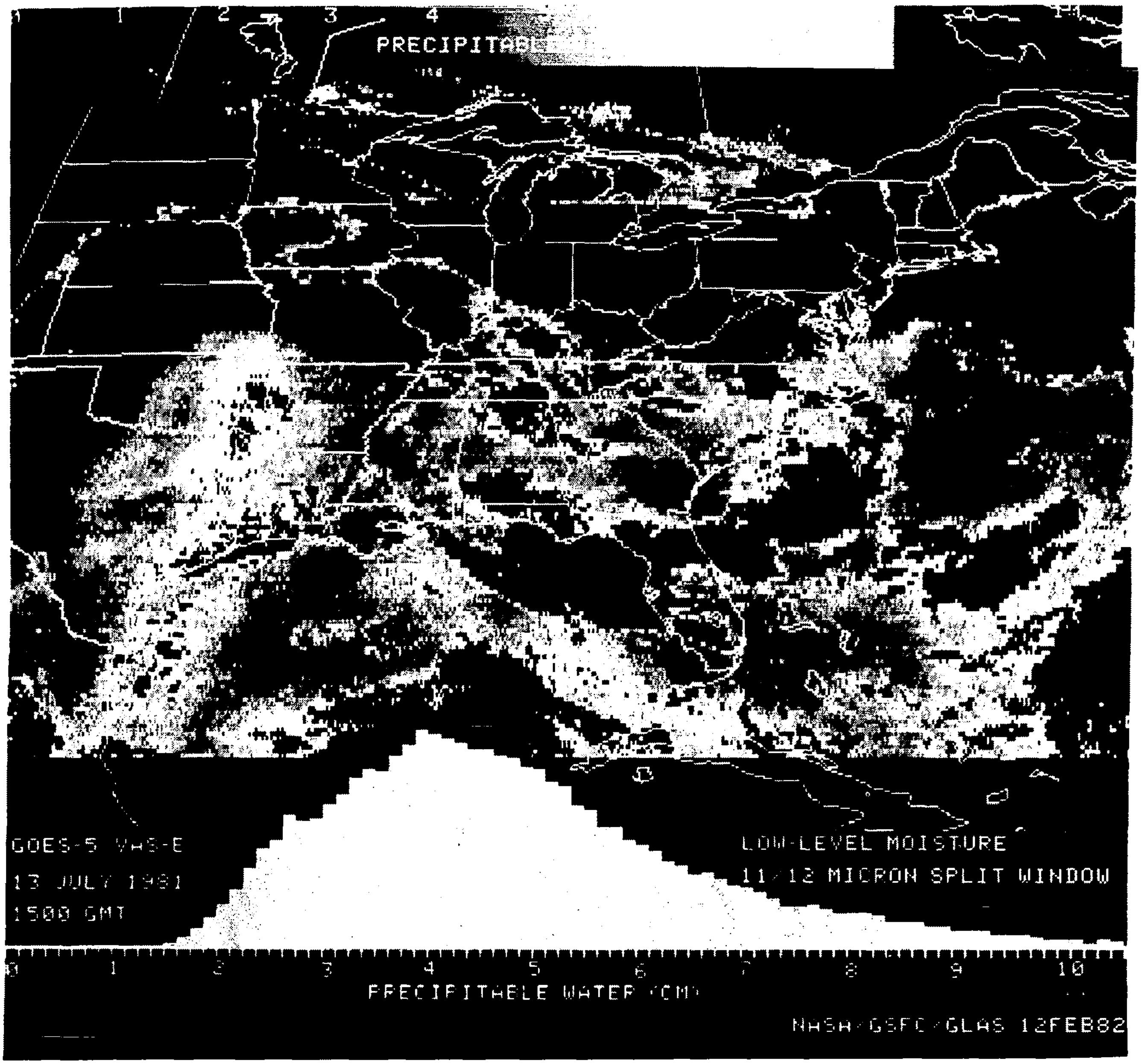


Fig. 7. VAS split window moisture data.

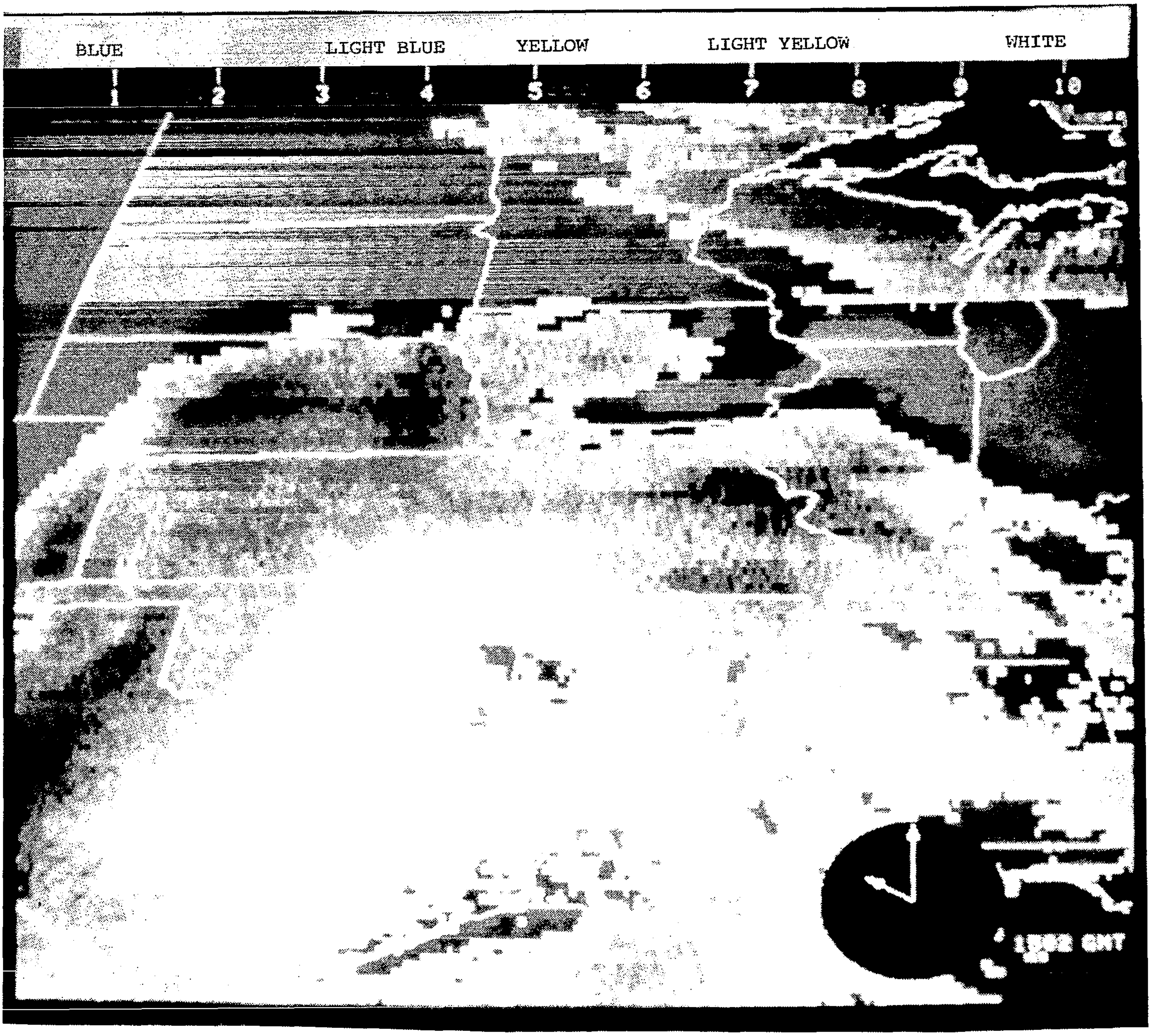


Fig. 8. Moisture (yellow) from the split window, dryness aloft from 6.7 μm channel. (For the purposes of this report, this picture was transferred from color to B & W. Color range, as noted on the graph above, shows darkest areas dark blue to lightest areas going from yellow to white.)

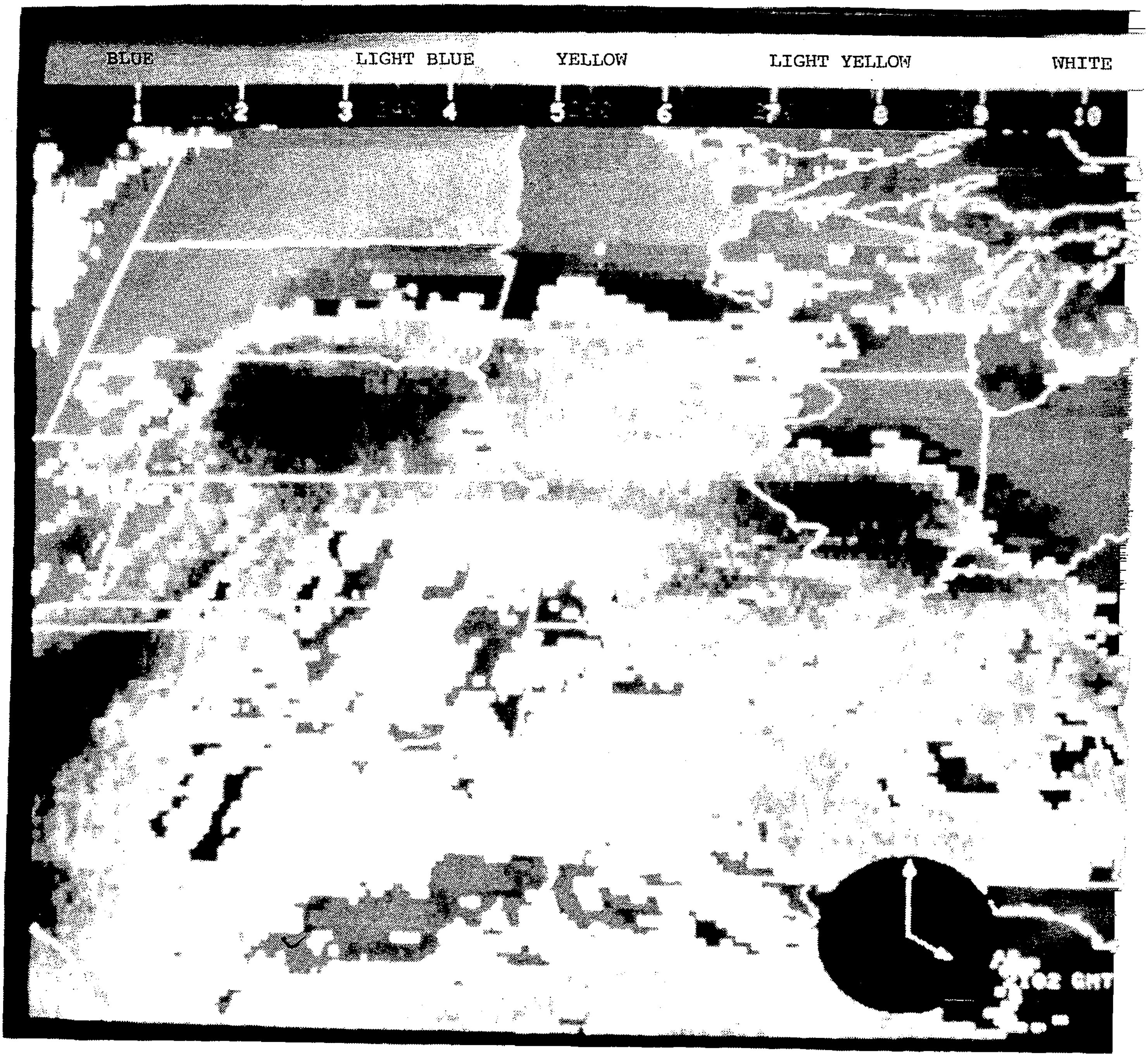


Fig. 9. Same as Fig. 8, six hours later.
(For the purposes of this report, this picture transferred from color to B & W. Color range is same as Fig. 8.)

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.

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA CP-2257		

4. TITLE AND SUBTITLE	5. REPORT DATE
The Conception, Growth, Accomplishments, and Future of Meteorological Satellites	November 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR William W. Vaughan, Organizer	8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	10. WORK UNIT NO. M-391
	11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 25046	13. TYPE OF REPORT & PERIOD COVERED Conference Publication
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This report was prepared under the sponsorship of the Atmospheric Sciences Division, George C. Marshall Space Flight Center.

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.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Meteorology Meteorological satellites - history Satellite instrumentation Spacecraft	Unclassified - Unlimited Subject Category 47

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	101	A06

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1982