8. THE CURRENT NASA METEOROLOGICAL SATELLITE PROGRAM

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Perhaps by way of introduction it would be well to pose the following question: Why is there a need for meteorological satellite data?

By its very nature, the atmosphere is a global phenomenon. It covers the entire earth, land areas and water areas alike, and extends upward with decreasing density. Moreover, the atmosphere is constantly in motion. This motion is produced and influenced by the complex interaction of many events: the unequal heating by the sun of the land and ocean areas, the latitudinal variation of this heating, the surface irregularity of the landmasses, the rotation of the earth, and others. Atmospheric motions are not simple in character, yet are extremely important because in the lower 10 to 15 miles of the atmosphere practically all the weather that affects man is produced.

The meteorologist recognizes the global character of the atmosphere and well realizes that he must observe, describe, and understand the behavior of the atmosphere over a large portion of the globe if he is to explain and predict with any degree of confidence the weather events that occur in any locality. The requirement for global data increases rapidly with the length of the forecast period.

Thus, over a period of years, there has evolved among meteorologists of all countries the realization that only with the assistance of cooperative international observations will it be possible for any country to fulfill its own national meteorological obligations. The World Meteorological Organization is the vehicle through which active international cooperation in meteorology is achieved. Many hundreds of observations are taken daily by many countries. These observations are made the common property of the entire meteorological community through established rapid international communications channels.

Despite this participation of men in many countries observing the atmosphere and sharing these observations for individual and mutual benefit, it is perforce necessary that these observations be restricted primarily to those regions regularly frequented by man. The atmospheric events in desert, polar, and oceanic areas for the most part remain undetected, and information on their contribution to the global atmospheric motion and to associated weather patterns has been unavailable to meteorologists on a regular basis. It is only when these events move out of the uninhabited areas that their presence becomes known. By this time it may be too late to issue the necessary kinds of warnings for the protection of life and property. For example, some of the most destructive storms are those of tropical origin which form near the equator in those oceanic areas that are practically devoid of weather information. Frequently, the first warning of such a storm is when it strikes an island, ship, or continental shoreline.

Figure 8–1 shows the distribution of observing stations in the world radiosonde network. Each dot represents a station. Note the absence of stations in the oceanic areas and in many land areas as well. Satellites can provide surveillance of these data-sparse ocean regions on a global basis, permitting early detection and accurate tracking of storm systems. Based on such observations, timely warnings can be issued to both populated areas and vessels at sea. In the same manner, accurate identification and tracking of storms in data-sparse regions at higher latitudes would aid in more accurate forecasting of these systems.

More generally, then, since the atmosphere is global in character, knowledge of its behavior in some of the more remote areas is frequently required if suitable prediction of weather for

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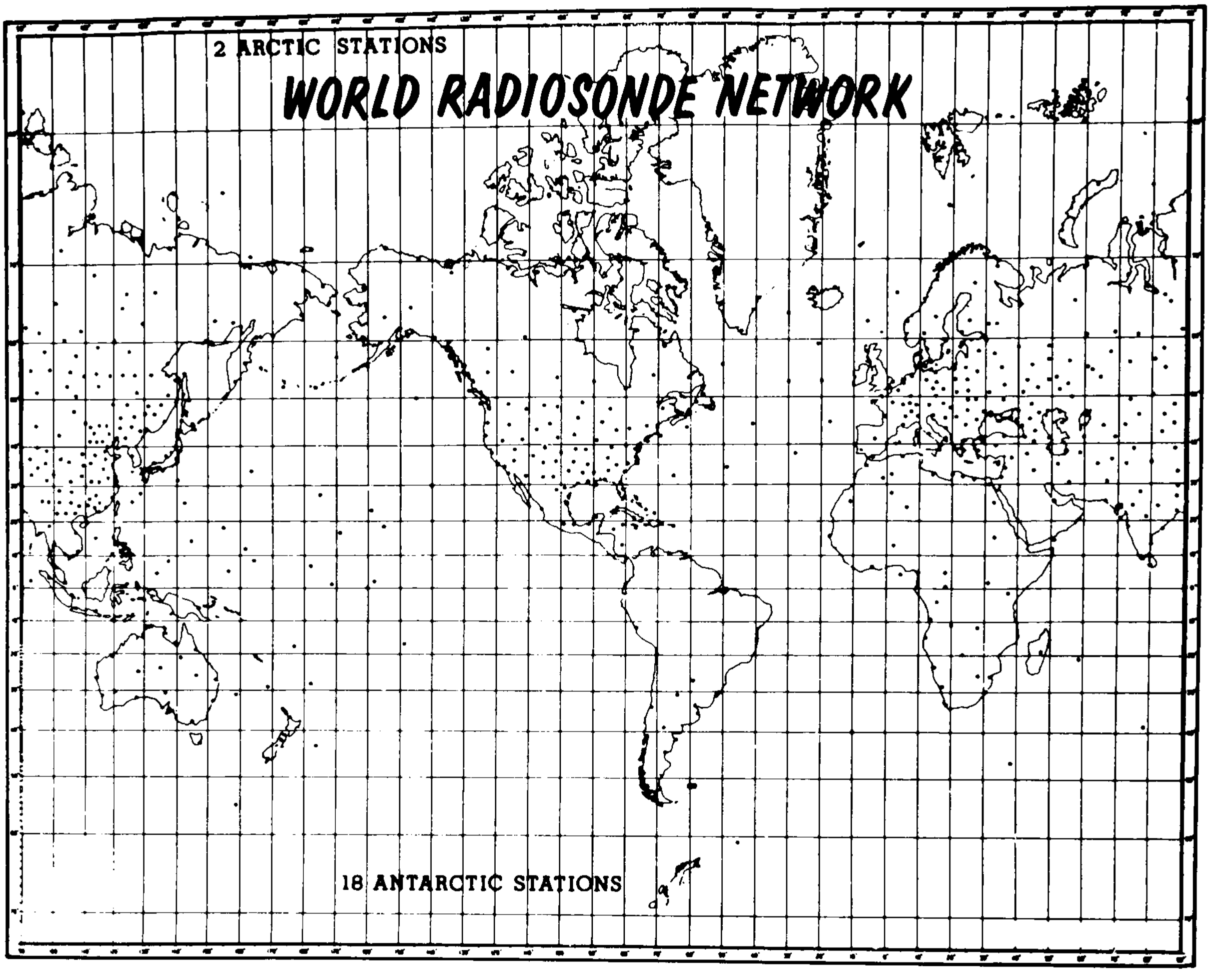


FIGURE 8–1.

a desired location is to be obtained. Even in continental regions where stations seem to be very dense, as shown in several areas of the globe (fig. 8–1), the network of stations is frequently still too coarse to catch the smaller scale weather events, such as local showers, thunderstorms, and severe local storms, including tornadoes. These storms are small in extent and have a relatively short duration. It is almost by chance that they are identified by the existing network.

A meteorological satellite having sensors with good resolution and a capability for continuous surveillance will be able to identify and track the smaller scale phenomena. Thus, it will be possible to give more explicit and detailed short-term forecasts of these severe weather events to the general public and to aviation interests. Furthermore, satellites can provide types of data not possible from other observing systems. Being situated outside the atmosphere of the earth, the satellite can view the sun directly without interference from the filtering action of the atmosphere which accompanies earth-bound observations. In the last analysis, the energy for atmospheric motions comes from the sun. With radiation sensors onboard, the satellite is in a position to measure the net balance between the solar input and the outgoing solar radiation. This net balance represents the energy available for driving the atmosphere. Moreover, this balance may be viewed from onboard a satellite either in a gross manner to acquire the global radiation budget or in detail to study local effects.

The TIROS series of meteorological satellites has demonstrated both the technical feasibility of obtaining the desired data and the practical utility of the data so obtained. TIROS consists of a series of experimental spin-stabilized meteorological satellites launched into orbit at an angle of about 50° at a distance of about 400 miles. TIROS I was launched April 1, 1960, and operated until mid-June 1960. TIROS II was launched on November 23, 1960, and was still providing useful television data 9 months later. TIROS III was launched on July 12, 1961, and has had a remarkable history of hurricane and typhoon surveillance. Figure 8–2 is a photograph of TIROS III and shows the outside of the satellite.

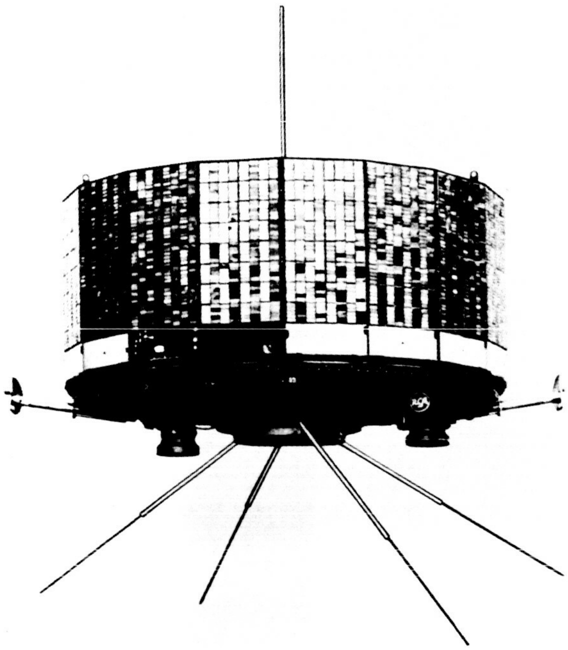


FIGURE 8–2. TIROS III.

Each TIROS satellite carried two television cameras to obtain pictures of cloud cover. TIROS II and TIROS III carry scanning-type five-channel radiometers and black- and white-body radiometers for observing parts of the field of view with a wide-angle camera. TIROS III, in addition, carries a wide-angle radiometer similar to the one carried on the Explorer VII satellite.

Figure 8–3 shows TIROS II situated on top of the Thor-Delta launch vehicle. Although the satellite is exposed in this photograph, it is usually covered before launch with a shroud, a protecting device to assist it in its launch through the atmosphere. The equipment on the right services the rocket and the satellite prior to launch. Of course, it is disengaged at launch time.

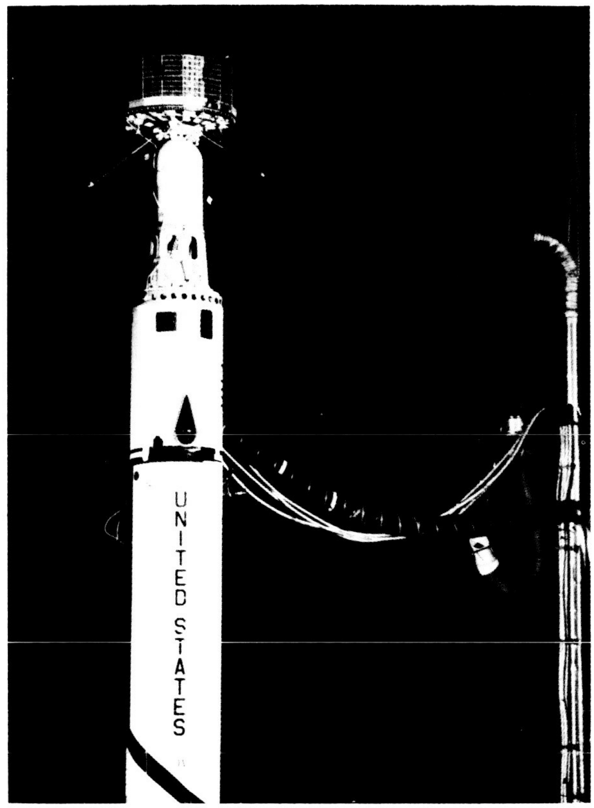


FIGURE 8–3. TIROS II and Thor-Delta launch vehicle (shroud removed).

Figure 8–4 shows TIROS I actually being launched. Here, the shroud is in place protecting the satellite on top of the rocket. The equipment on the right has been disengaged.

Figure 8–5 presents a cutaway view showing the interior of TIROS II.

Figure 8–6 shows the types of meteorological observations that can be deduced from the TIROS infrared radiation measurements. They are listed corresponding to the various channels existing in the TIROS II and III satellites. In paper 10 the components and functioning of the TIROS satellite are described in greater detail.

Following TIROS III it is expected that four additional TIROS spacecraft will be launched, at about 4-month intervals, to provide a continuity of operational meteorological satellites in orbit through the estimated date of the first Nimbus launch. Consideration is also being given to launching some of these last four TIROS spacecraft into higher inclination orbits.

TIROS *demonstrated that a spacecraft and supporting ground system could be developed around special sensors like the cameras and the*

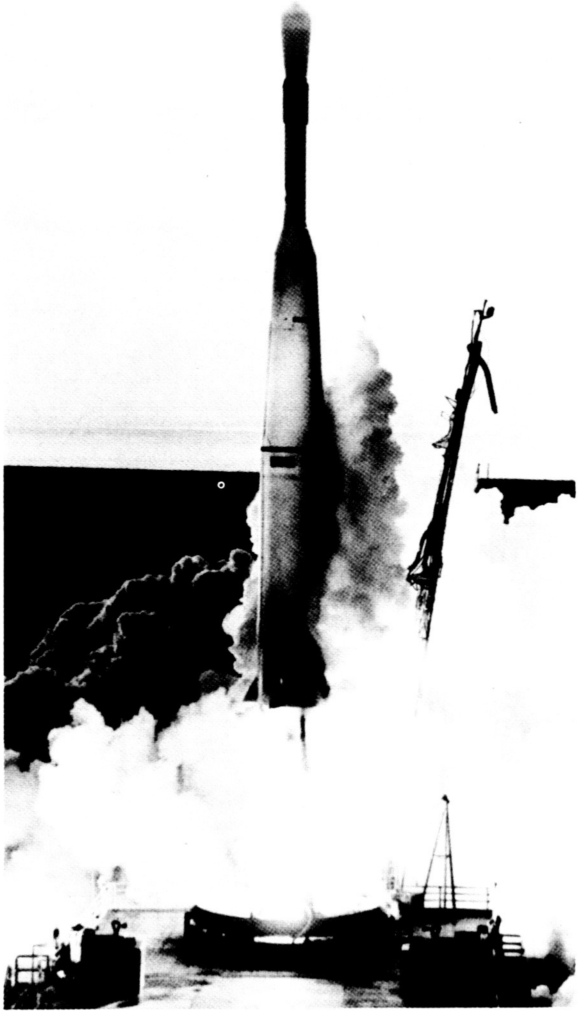


FIGURE 8-4. TIROS I being launched.

radiation detectors and could transmit the measurements of these sensors to the earth with satisfactory fidelity. The almost 23,000 pictures taken by TIROS I and the even greater number of pictures taken by TIROS II and TIROS III, as well as the considerable volume of infrared radiation data, all provide the most convincing testimonial of successful satellite system operation. The brilliance of this performance was only slightly dulled by the fact that the wide-angle camera in TIROS II was somehow defocused during launch and one of the TIROS III cameras failed about 12 days after launch. The resulting pictures from TIROS II, although not of the same quality as those from TIROS I and later from TIROS III, still show clearly the larger cloud and land areas and lack only detail.

Figure 8-7 shows pictures from TIROS I on the left and TIROS II on the right. The top two photographs are of the same land areas, the Gulf of Aden, and the Red Sea. The TIROS I picture is seen to be much clearer and shows considerably more detail, but the TIROS II pictures still show information on a gross scale. A similar degree of clarity exists with regard to the two storms in the Indian Ocean, one observed by TIROS I on the left and the other observed by TIROS II on the right. This remarkable performance of the satellites required the successful operation of many interdependent and delicate subsystems, components, and electronics. In several instances new previously untried technological advances were made. For example, spin rockets were fired on ground command after as much as 10 months in a space environment. There was a partial control of the attitude of the satellite, also on ground command. There was also the operation of lubricated ball bearings in a space environment.

The satellite measurements were found to contain useful meteorological information. With the receipt of the very first pictures from TIROS I, it became apparent that the satellite system was producing photographs of clouds, cloud formations, and cloud patterns. The meteorological research teams at the U.S. Weather Bureau, the Air Force Cambridge Research Laboratories, the Naval Weather Research facilities, and other institutions attacked the problem of interpreting the TIROS pictures in terms of weather information content. These studies indicated excellent correspondence between cloud formations and meteorological patterns, such as low-pressure areas and associated cyclonic storm systems, cold fronts, large areas of stratus cloudiness, convective areas having cellular-shaped clouds, local severe storms, jetstreams, and mountain clouds. As a matter of fact, these findings confirmed previous suggestions based on limited photographs from high-altitude rockets that Nature was drawing her own weather map by means of clouds.

Figure 8-8 shows a mosaic of photographs of cloud cover taken on May 20, 1960. On the top are the pictures taken by the TIROS I satellite. The picture below has superimposed upon it, and rectified according to geography, the location of these clouds, and also the meteorol-

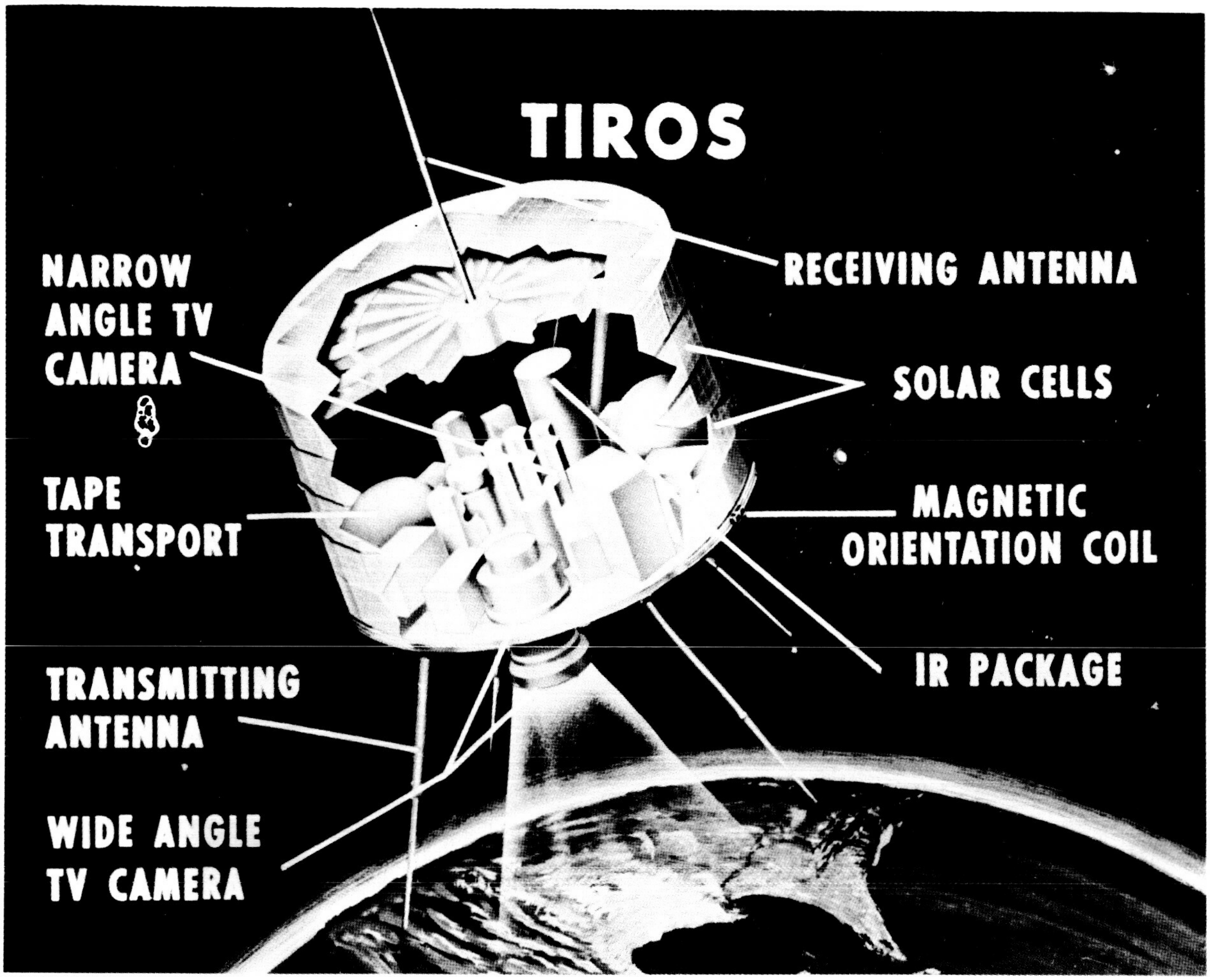


FIGURE 8–5. Cutaway view of TIROS II.

logical fronts, analysis, and pressure pattern of that day. The correspondence between these two is remarkable.

The extraction of meteorological information from TIROS II and TIROS III infrared measurements is proceeding at a slower rate. Signals from the satellite must be converted into meaningful physical measurements which must then be plotted on a map for proper study. Preliminary results have been very satisfying. Areas of satellite low-temperature measurements have been associated with cloudy zones and areas of high temperatures with cloud-free pressure regions.

The TIROS data have made it possible to increase the accuracy of weather analyses, have provided increased information both on the gross aspects of weather and on its detail, have assisted in the interpretation of cloud features and patterns, and have made it possible to infer weather patterns over areas where other data are nonexistent or insufficient. Ample illustrations of both the picture data results and the results of the infrared-radiation measurements are provided in subsequent papers.

It would have been significant enough had TIROS been successful only in providing new and detailed research data about atmospheric processes. This would undoubtedly have led to a more thorough understanding of the weather and the factors that produce it. However, TIROS was important in still another respect. In anticipation of the possible utilization of TIROS data for operational purposes, teams of meteorologists were stationed at the data-acquisition stations to study the incoming data in real time. *Within 60 hours after Tiros I was launched, picture data less than 6 hours old were being interpreted and the analyses forwarded by facsimile transmission to the Na-*

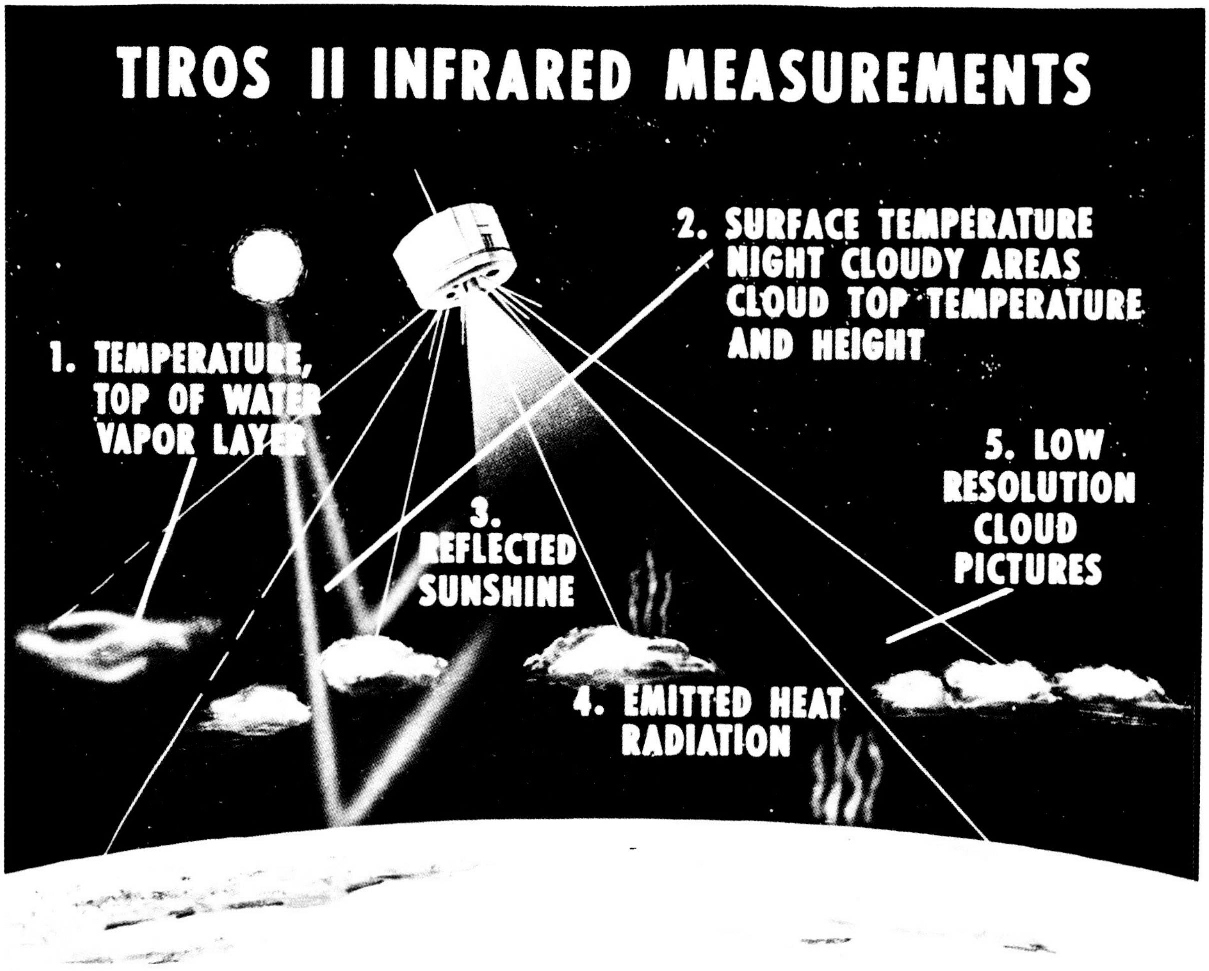


FIGURE 8–6.

tional Meteorological Center of the U.S. Weather Bureau at Suitland, Md. These transmissions were incorporated into the regular anaylses and forecasts of the Weather Bureau. Copies were also relayed to U.S. air and naval services, both in this country and overseas, where they proved to be very useful. In later periods these analyses have been made available to foreign weather services.

In their use of this information the U.S. weather services have indicated that these cloud analyses established, confirmed, or modified surface frontal positions, assisted in the briefing of pilots on accurate weather conditions, were used in direct support of overwater deployment and aerial refueling of aircraft, gave direct support to an Antarctic supply mission, confirmed the position of a Pacific typhoon, verified and amplified local analyses particularly over areas of few reports, and more. There is a full discussion of the utilization of TIROS data for current analyses in paper 15. Because the atmosphere is a global phenomenon and meteorology is an international science, it is well recognized in the U.S. meteorological satellite program that maximum benefits will be derived only through international cooperation and participation. Thus, the TIROS program has been developed to include international participation as follows:

1. The transmission of meteorological analysis to foreign countries.—As described previously, as satellite data are acquired at readout stations, they are analyzed directly by teams of meteorological experts, and their analyses of the data are furnished to the National Meteorological Center whence they are retransmitted to field users, both nationally and internationally.

2. The availability of basic data for foreign research groups.—Copies of the TIROS picture data

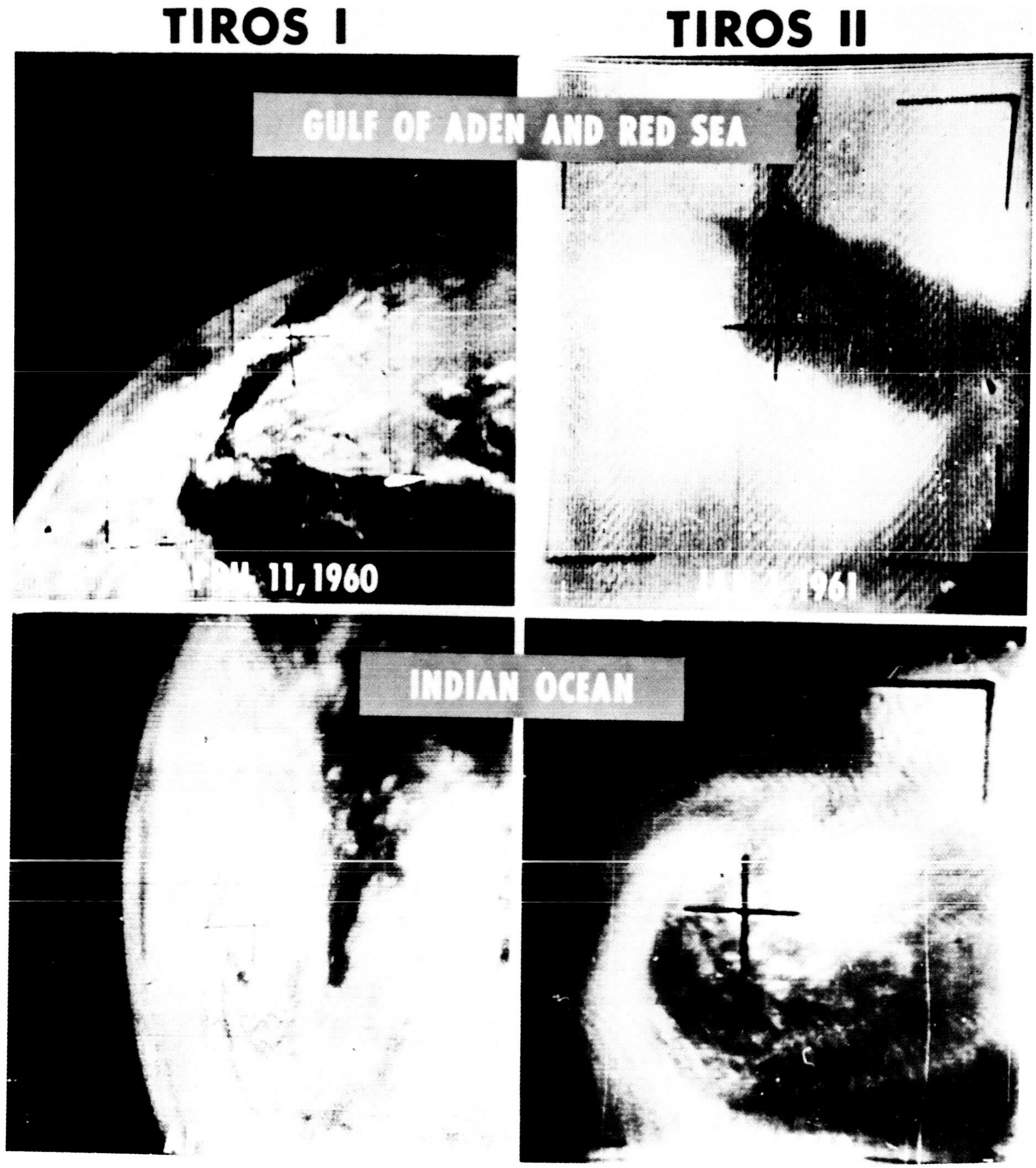


FIGURE 8–7. Comparison of TIROS I and II wide-angle-camera photographs.

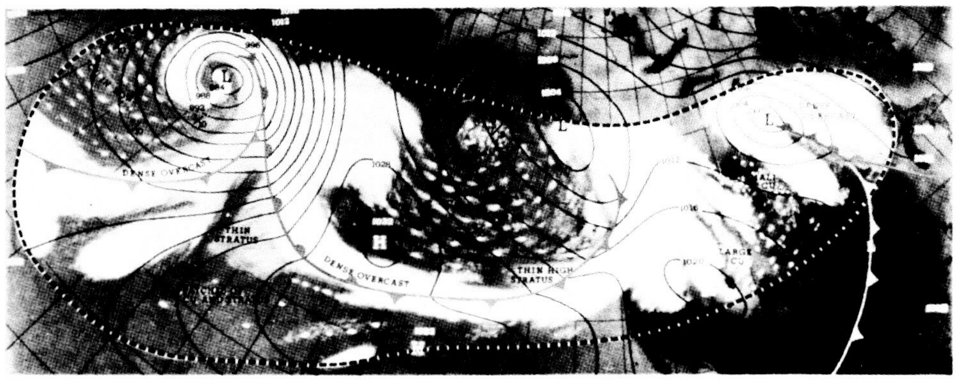
may be acquired by any country in the form of 35-millimeter positive transparencies for projection or 35-millimeter duplicate negatives from the National Weather Records Center at Asheville, N.C. A catalog, of which the TIROS I portion has been published (ref. 1), contains maps showing the approximate area viewed in each picture sequence and other useful information required for proper interpretation and analysis of the pictures.

3. Supporting meteorological observations.—Satellite information is more useful when combined with other meteorological observations, for example, special upper air soundings, aircraft observations, rocket observations, special radar coverage, and others.

STORMS AND FRONTS

A Family of Weather Systems

MOSAIC OF TIROS PHOTOGRAPHS



WEATHER MAP, MAY 20, 1960, WITH TIROS CLOUD DATA

FIGURE 8–8.

In connection with TIROS II, the national meteorological services of 21 countries adhering to COSPAR were contacted and were offered the necessary satellite orbital information in the event they wished to make special observations which could be correlated with the satellite observations over their locality. Seventeen countries indicated that they were anxious to participate in this program. This program never fully materialized in view of the degraded pictures of the TIROS II wide-angle camera. However, a similar program, expanded to include invitations to approximately a hundred of the countries adhering to WMO, was initiated in association with TIROS III. Over 30 countries have indicated their intentions to participate actively. It is anticipated that similar programs, probably on a more routine and continuous basis, will be operated in connection with future TIROS launches.

4. International Meteorological Satellite Workshop.—The objective of the Workshop is "to present directly to the foreign weather services the results of the U.S. meteorological satellite activity to date and the possibilities for the future so that the program may be more completely known and understood by the scientific world community, that the present activity may be put in its proper perspective relative to future operational programs; and, finally, that the foreign weather services may acquire a working knowledge of the TIROS data for assistance in their future analyses programs, both in research and in operations and guidance in their own national observational support efforts."

Reference

1. PYLE, ROBERT L., AND MERCER, DONALD M., compilers: *Catalogue of Meteorological Satellite Data—TIROS I Television Cloud Photography.* Key to Meteorological Records Documentation No. 5.31, U.S. Dept. of Commerce, Weather Bur., 1961.