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TIROS EXPERIMENT RESULTS

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H. WEXLER
U. S. Weather Bureau Washington, D.C.

(Received February 10, 1962)

Meteorological satellites TIROS I, II and III were launched by the National Aeronautics and Space Administration on April 1, 1960, November 23, 1960 and July 12, 1961 into nearly circular orbits, 700 to 800 kilometers high, extending from 48° N to 48° S latitude. Descriptions of the spacecraft and its television cameras and radiation sensors are given elsewhere (STERNBERG *et al.*, 1960; BANDEEN *et al.*, 1961).

The two television cameras on TIROS I were "broad" angle and "narrow" angle, respectively, with aperture openings 104° and 12.7°, which, looking downward, took pictures 1200 km and 120 km square with resolutions of approximately 5 km and 0.5 km, respectively. A yellow filter and the vidicon itself confined the observed spectrum to between about 0.45 and 0.8 μ, with peak sensitivity between 0.5 μ and 0.7 μ. This increased the contrast of the clouds against the background of the earth's surface by reducing the light scattered upward by the atmosphere. Thus the recorded image corresponds closely to visible light.

During its 78 days of operation, 14,000 good pictures of the earth and its cloud

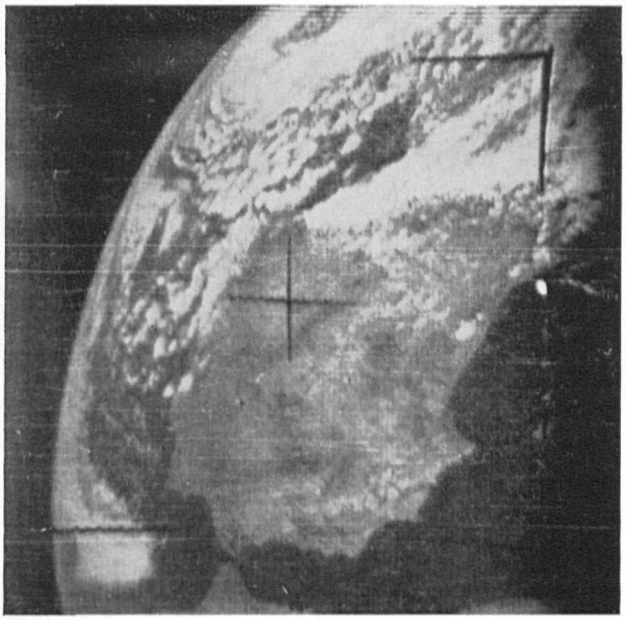

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Fig. 1. Spain and the Straits of Gibraltar, 15 July 1961, 1409UT, observed by TIROS III. Cyclonic storm clouds over the Bay of Biscay and orographic clouds over the Pyrenees Mountains.

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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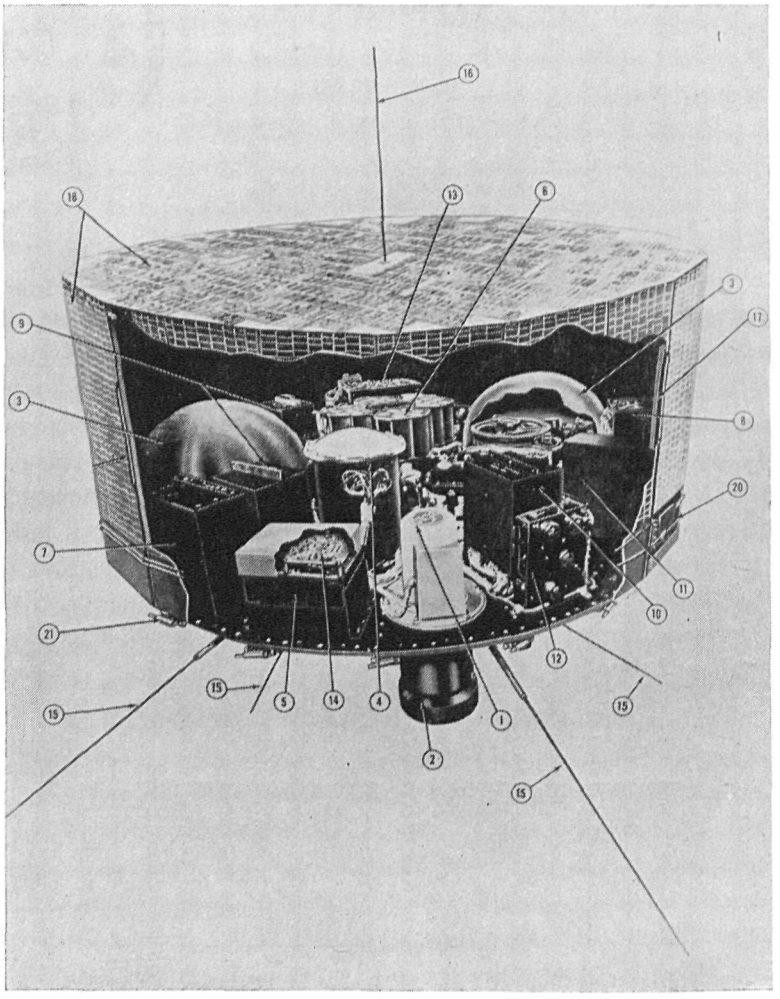

Cutaway of TIROS I showing components.

1. One of the two half-inch Vidicon TV cameras; 2. Wide-angle camera lens; 3. Tape recorders; 4. Electronic timer for operational sequencing; 5. TV transmitter; 6. Chemical batteries; 7. Camera electronics; 8. Tape recorder electronics; 9. Control circuits; 10. Auxiliary controls; 11. Power converter for tape motor; 12. Voltage regulator; 13. Battery charging regulator; 14. Auxiliary synchronizing generator for TV; 15. Transmitting antennas; 16. Receiving antenna; 17. Solar sensor to measure position of satellite with respect to sun; 18. Solar cells; 20. De-spin mechanism; 21. Spin-up rockets.

cover were obtained from TIROS I. These revealed a pattern of brightness clearly visible against the darker oceans and land areas. These bright areas were mostly clouds which normally cover about 50 percent of the earth's surface. Their higher reflectivity of light (generally 30% or higher) distinguishes them from land (albedo 3 to 30%) and water (albedo usually less than 10%).

When clouds were absent the differences in albedo between water, land, ice and snow permitted detection of coastlines (fig. 1), snow-covered mountains (fig. 2), valleys, lakes (frozen and open), deserts, sand dunes, darker rock and forested areas (FRITZ *et al.*, 1961) and pack-ice over the oceans (fig. 3), (WARK *et al.*, 1960). The observations of the snow fields will someday be utilized routinely in assessing mountain water resources and the ice field pictures will assist in navigation through ice filled waterways and oceans. Future snow and ice observations will also be used in determining the horizontal extent and perhaps thicknesses of transient snow and ice fields

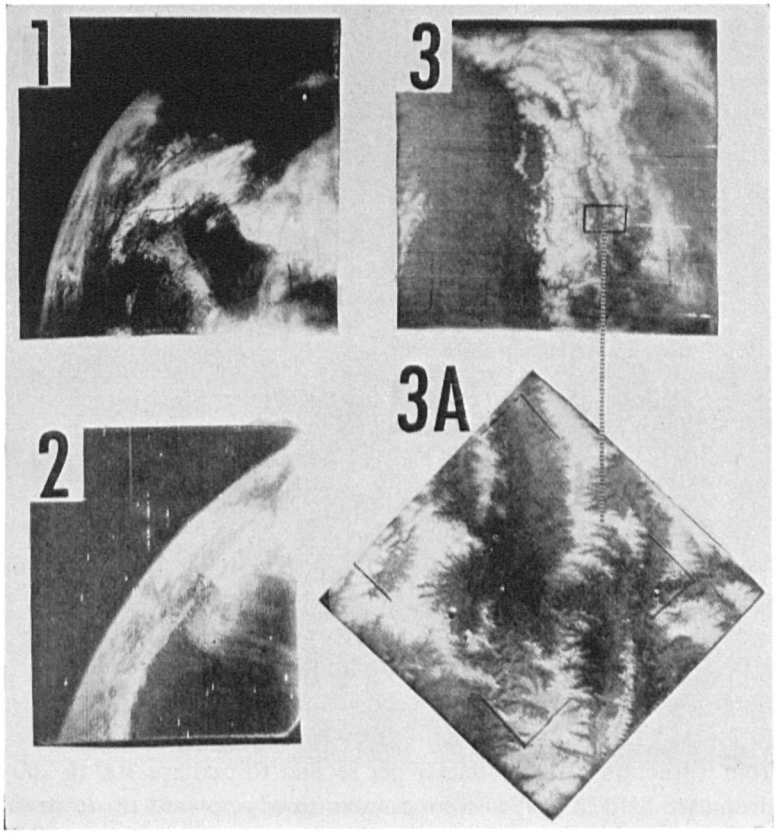

Fig. 2. Mountain areas appear prominently in TIROS I photographs. *Picture 1:* Snow and a few clouds over the Alps (April 2, 1960). Italy extends southward from the Alps to the lower center of the picture. *Picture 2:* Clouds streaming off South American Andes (April 29, 1960). *Picture 3:* The snowy Himalayas capped by a few clouds (May 13, 1960). *Picture 3A:* A high-resolution camera view of the area outlined in Picture 3.

which may then serve as natural indicators of seasonal and year-to-year changes in global weather and climate.

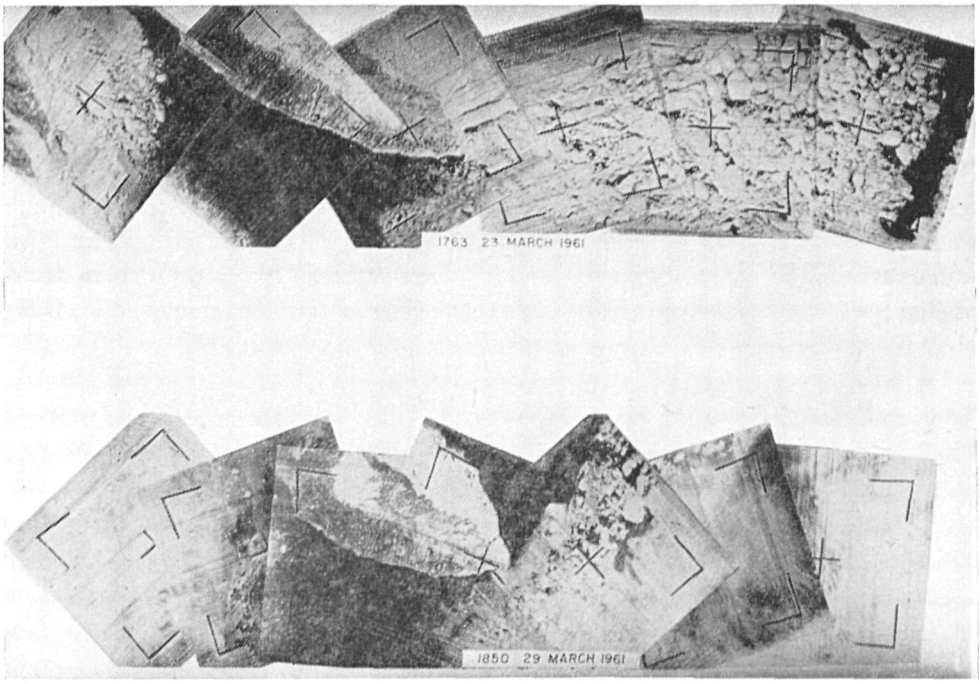

Fig. 3. Sea-ice over the Gulf of St. Lawrence, March 23 and 29, 1961. Fast ice, cracks, leads, medium and giant ice floes are visible in the two mosaics. Note the large ice-free area northeast of Anticosti Island on March 29, a region which six days before was covered by a heavy ice pack.

Meteorological Background

The majority of the pictures revealed clouds of many different scales and patterns. Clouds usually result from condensation of the captive water vapor by expansion and adiabatic cooling of air rising in response to orography, heating of the earth's surface or horizontal convergence of the winds. The condensation process causes formation of small water drops of diameter 10 to 50 μ, with concentrations of 100 to 500 cm^{-3} and liquid water density of the order of 1 gm m^{-3}. Their fall velocity is so small, ranging from a fraction of a centimeter per second to perhaps 100 to 200 cm sec^{-1} that the drops are held in suspension or move slowly upward or downward in the same upward air currents that caused their formation. Thus, the cloud drops, like smoke, are carried along horizontally by the winds and are made visible because of their collective high reflectivity of sunlight, as much as 90% in the case of dense, thick clouds composed of very small drops, but 50 to 60% for average clouds. Such clouds can exist as water at temperatures well below freezing but at low temperatures, usually

below $-20°$ C, more tenuous ice clouds form which normally are not as bright as water clouds.

Because of the uneven global distribution of absorbed solar radiation, the tropics are warmer than the polar regions. The atmosphere, in its endless quest to equalize its energy imbalances, creates wind and weather, performing countless experiments of interrelated phenomena of every size from global to microscopic. The large-scale circulation of the atmosphere arises from the attempt of the atmosphere to transport heat from the equatorial to the polar regions, while at the same time the Earth, with its complicated surface properties, is spinning about its axis. Because of this combination of factors, a predominantly west-to-east current forms in mid-latitudes, where the temperature gradient is largest and where the "polar front" is

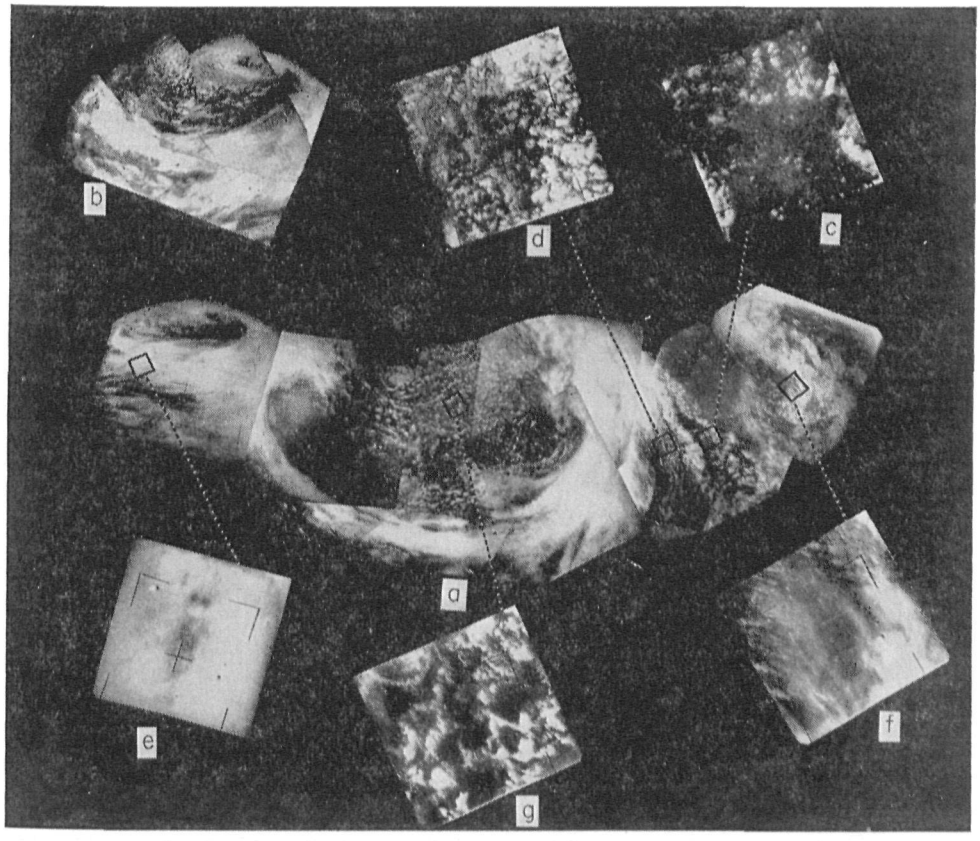

Fig. 4a. Mosaic made from TIROS I pictures taken near 0000 UT, May 20, 1960, shows a storm "family" composed of three cyclonic storms extending from the central Pacific Ocean eastward to central North America. The vortex on the extreme left (also shown in *b*) is an intensifying cyclone (central pressure 984 mbs) south of the Aleutian Islands. A polar front marked by a band of clouds extends eastward from this storm (*a*). North of this front (near the center of the mosaic) the cooler air is filled with cellular cumuliform clouds which are shown in greater detail in (*g*). The cloud system to the right is associated with a low pressure area near Lake Winnepeg. High resolution pictures (*c*) through (*g*) are for the areas indicated.

usually located. Eventually these currents, or the "westerlies", as they are called, become dynamically unstable, form large planetary waves which grow in amplitude and break down into large vortices, both of the anticyclonic (clockwise rotation in the Northern Hemisphere) and cyclonic type (counterclockwise rotation), 1500 km or more in diameter. The planetary waves and their anticyclonic and cyclonic descendants propel large masses of cold air toward the tropics and warm air toward the poles. During this process (in the northern hemisphere) the cold air generally sinks as it moves southward and clockwise about the anticyclonic vortices while the warmer air mainly rises as it moves northward and counterclockwise about the cyclonic vortices. The rising warm air, usually moist, cools by expansion and produces clouds, often covering areas of several million square kilometers.

Thus, in viewing the Earth from space, one would expect that large-scale cloudiness, perhaps circling around cyclone centers, would be commonly seen. In the subsiding cold air, especially over dry continents, relatively cloud-free areas would be found. However, as cold air flows over warmer, moister ground or ocean surfaces, cloud elements smaller than those found in cyclones would usually develop because of convective patterns produced by thermal instability. Other types of convective clouds would form from other processes. For example, heating of land areas during the day often produces cumuliform clouds; in the tropics, convergence of wind currents

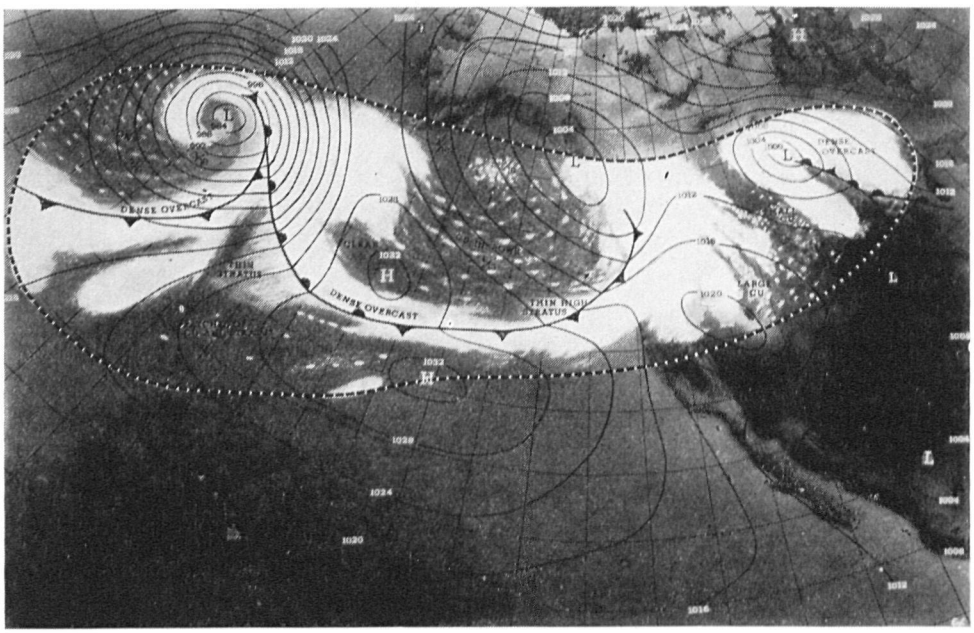

Fig. 4b. Cloud information from the previous mosaic is superimposed on a surface weather map. Such cloud mosaics extending several thousand miles along the orbit will have many important uses. They furnish, for example, detailed cloud information along the transoceanic airline routes. (After OLIVER, 1960).

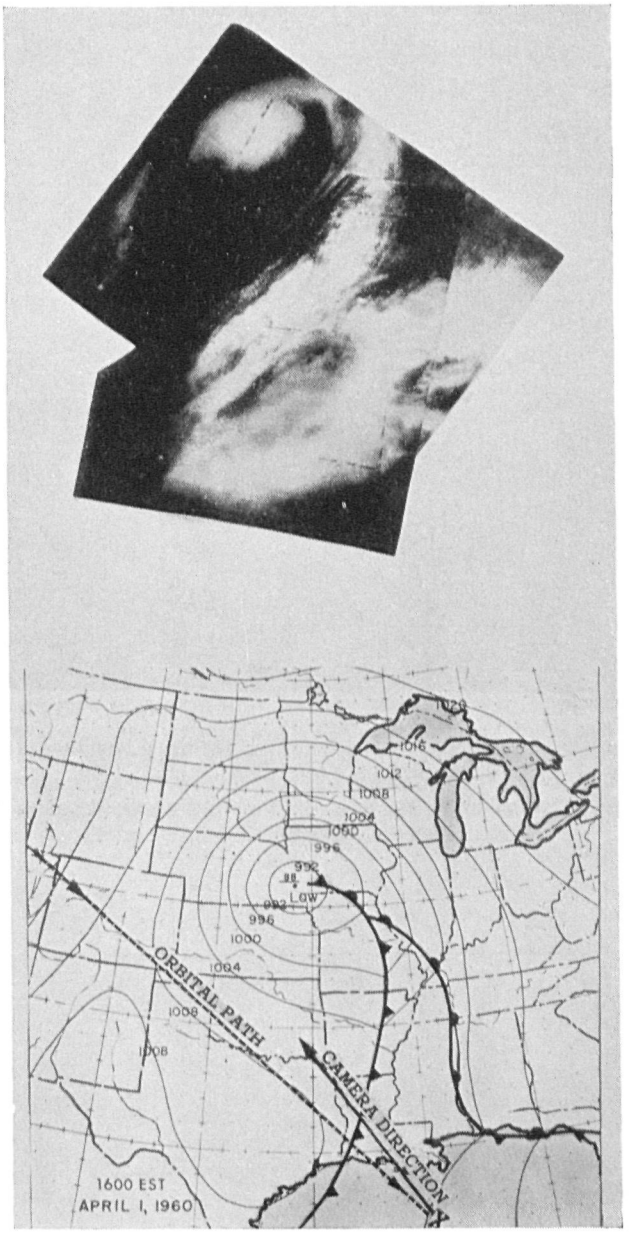

Fig. 5a. A well developed occluding cyclonic storm photographed over the midwestern United States on April 1, 1960. The corresponding surface weather map is shown below. Clear, cold, dry air moving in behind a cold front extending southward from the storm center appears black in the picture to the left of the cloud line associated with the cold front. The large cloud mass in the foreground was located near the Gulf coast of Louisiana and Mississippi. (After BRISTOR *et al.*, 1960).

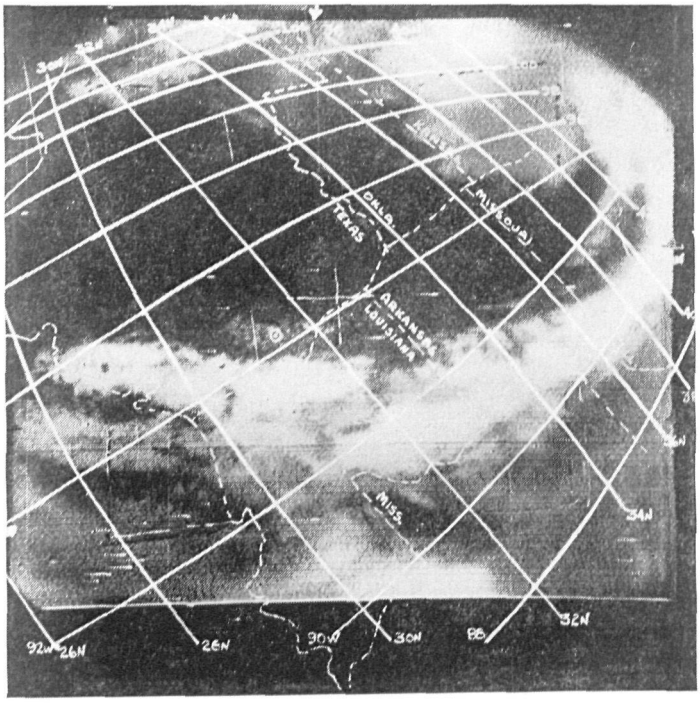

Fig. 5b. Same storm as shown on previous page with latitude and longitude grid superimposed to locate cloud elements. (After BRISTOR *et al.*, 1960).

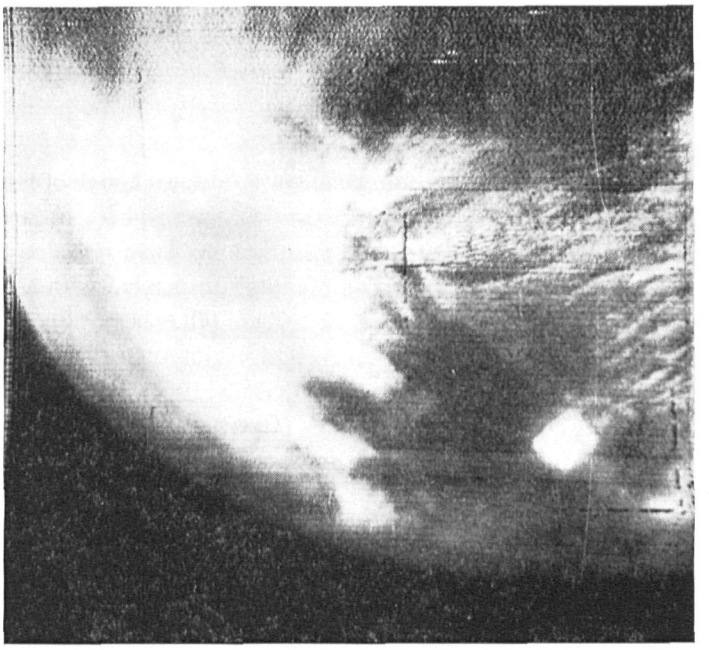

Fig. 6a. TIROS I was over southeastern Iowa with the camera pointing toward the southwest when this photograph was taken at 2000 UT on May 19, 1960. Much of the Central and Southern Plains is cloud covered. The bright square area in the lower right of the picture, about 160 km across, is an isolated conglomeration of about 100 cumulonimbus (thunderstorm) clouds. A few hours later this area expanded and moved northward (toward the upper left) spawning hailstorms and tornadoes in central Oklahoma. (After WHITNEY *et al.*, 1961).

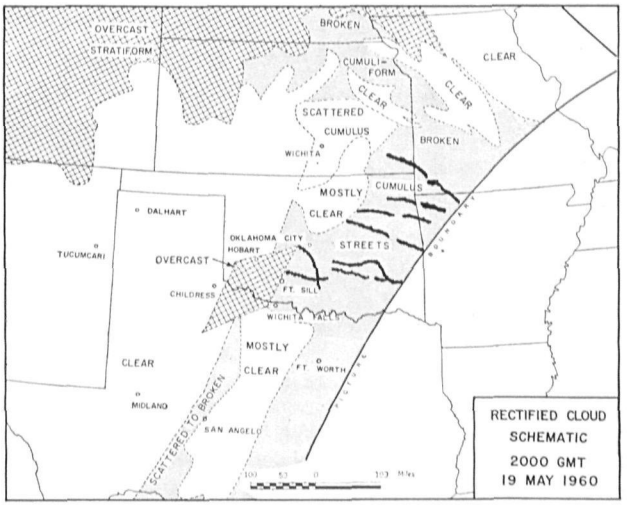

Fig. 6b. Rectified Cloud Chart, 2000 UT, 19 May 1960. (After WHITNEY *et. al.*, 1961).

sometimes coming from opposite sides of the equator, often produces massive cloud systems. Moreover, stratiform clouds may form in stable, moist air by radiative cooling.

Cloud Pictures

Clouds are thus the visible manifestations of a continuous exchange of heat, moisture, and momentum between the earth's surface and the atmosphere occurring in both large- and small-scale processes. The TIROS photographs have revealed clouds associated with many of these scales: a cyclone "family" associated with a thousands of kilometers long planetary wave in the westerlies, fig. 4 (OLIVER, 1960), 1500 kilometer wide spiraling vortices associated with individual cyclonic storms, fig. 5, (BRISTOR *et al.*, 1960; WINSTON, 1960; WINSTON *et al.*, TOURVILLE, 1960; FRITZ, 1961; TIMCHALK *et al.*, 1961; JONES, 1961); a tropical hurricane (FRITZ *et al.*, 1960); a 500 kilometer wide complex tropical cloud system, three thousand kilometers long in the Southwest Pacific (HUBERT, 1961a); an isolated tornado-producing cloud, 150 kilometers across, fig. 6, (WHITNEY *et al.*, 1961; WHITNEY, 1961); 50 to 80 kilometer wide cloud cells, fig. 7, (KRUEGER *et al.*, 1961); long cloud "streets", composed of individual cumulus clouds, a few kilometers wide and scores of kilometers long and aligned within 30° of the wind direction, fig. 8, (SCHUETZ *et al.*, 1961); a sharp-edged cirrus cloud deck associated with a "jet stream", the high-speed core of the westerlies crossing the west coast of South America, fig. 9, (HUBERT, 1961b); and the extraordinary system of cloud "waves", showing complicated interference-like wave patterns, apparently generated by passage of air over the Andes and extending nearly to the east coast of South America (fig. 10).

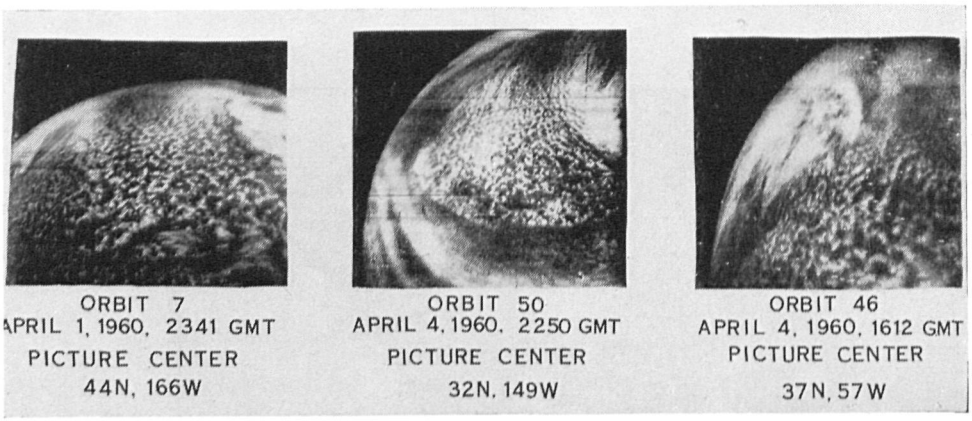

Fig. 7. Cellular convection patterns are illustrated in these three TIROS I photographs. The clouds in the central part of the left picture are in a northwesterly current of air located in the southwestern quadrant of a low pressure area in the Gulf of Alaska. Similarly, the clouds in the center picture are in the western portion of a low pressure area located northeast of Hawaii. The cellular type clouds in the picture on right are located in an easterly flow south of the center of a high pressure area located northeast of Bermuda. The cloud deck in the background indicates a moist current moving northeastward up a warm front about 1000 km west of the high pressure center. (After KRUEGER *et al.*, 1961)

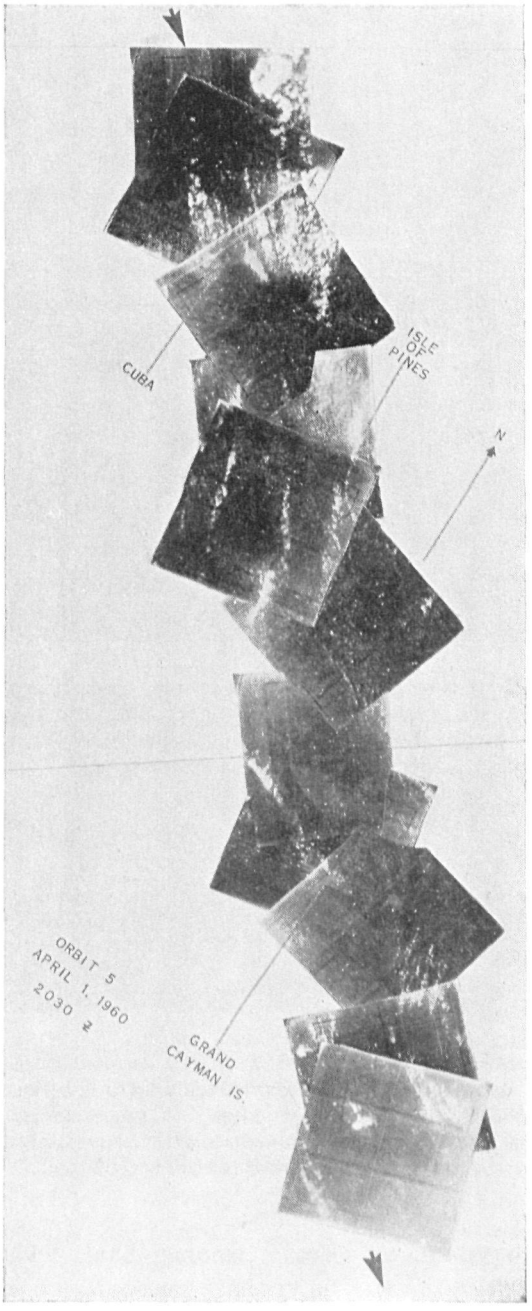

Fig. 8. This composite of high resolution photographs (120 km × 120 km) shows "cloud streets" which are long, narrow lines of clouds. Over Cuba and the Isle of Pines, where daytime surface heating is greater than elsewhere, the clouds are more numerous. The wind direction or wind shear may be indicated by the orientation of the cloud streets south or southeast of the Isle of Pines, 1 April 1960, 2030 UT. (After SCHUETZ *et al.*, 1961).

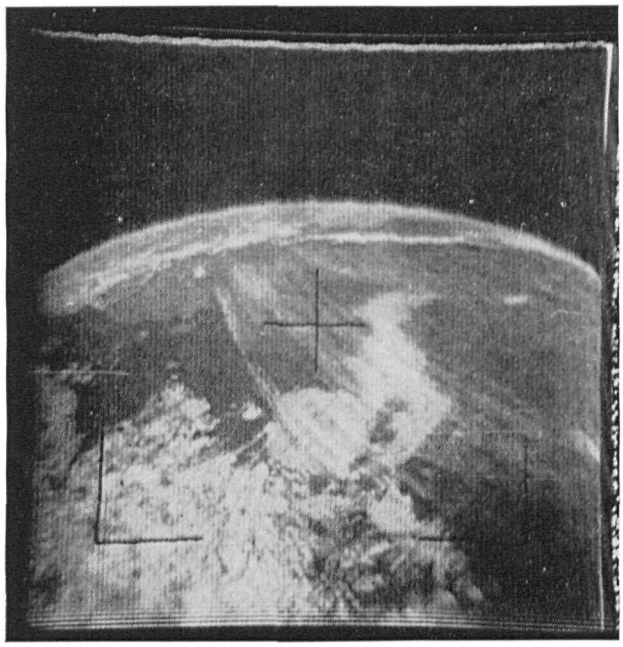

Fig. 9. Looking west, cirrus cloud streamers are seen crossing the east coast of South America north of the Gulf of San Matias and flowing above a large bright cloud system over the ocean. These cirrus streamers are probably associated with the jet-stream crossing the Andes, whose divide is indicated by the sharp cloud edge near the horizon. Picture taken on 3 August 1961, 1408 UT.

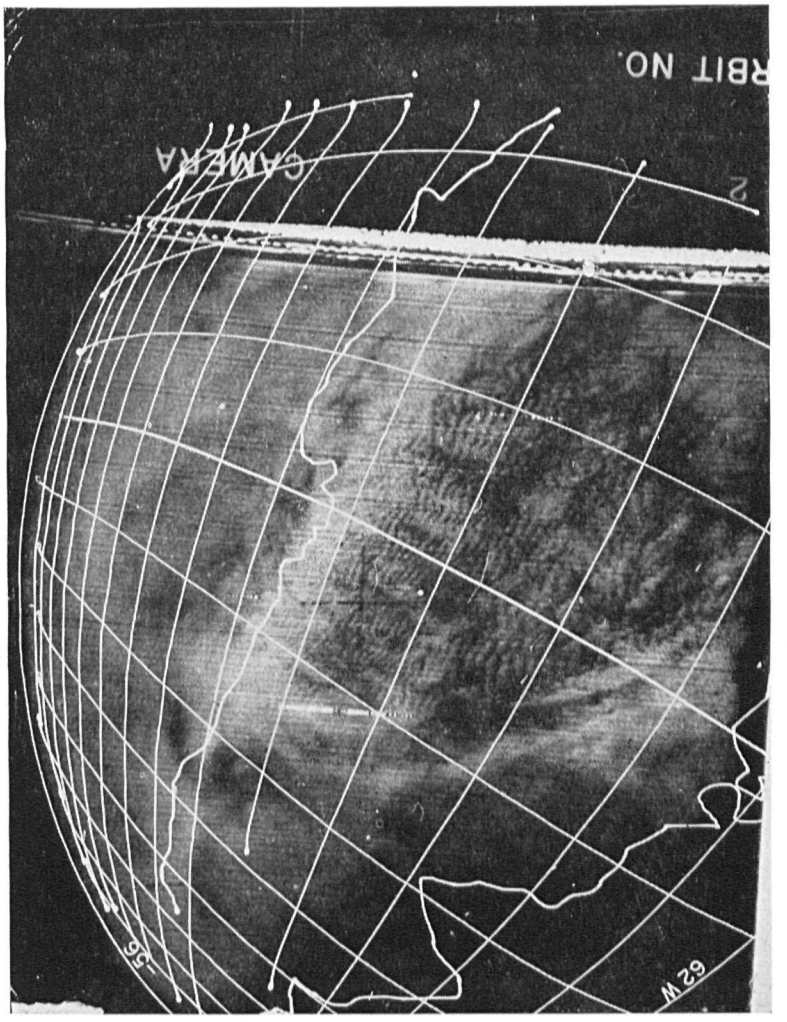

Fig. 10. Cloud waves east of the Andes, 18 April 1960, 1700 UT. These waves, of wave-length about 10 km, are probably generated at an interface between denser, moister air and lighter, drier air above, as the winds move over the mountains from west to east (from left to right). Another wave system, of wave-length about five times larger, seems to be superimposed on the smaller wave system. The latitude-longitude grid lines are drawn for each 2 degrees.

In general the satellite cloud pictures revealed an unexpectedly high degree of cloud organization and unsuspected scales of air motions (such as the 50 to 80 kilometer wide cloud cells referred to above, having an unusual width-to-height ratio of 30 or greater). As with fingerprints, no two cloud patterns are exactly alike although quite similar structures are often found. Even the cloud "vortex" associated with the same cyclonic storm can vary radically in appearance over a period of a day or less (WINSTON, 1960).

The earth-orbiting satellite, by its ability to photograph the cloud cover and measure the outgoing radiation patterns, takes advantage of the synthesis of observations that Nature herself has already performed in arranging clouds and air masses in certain orderly patterns, large and small, which meteorologists can interpret in terms of storms, fronts, and other atmospheric entities. A fuller interpretation of these "natural" weather maps derived from the cloud pictures will be aided by further comparison with conventional meteorological data and other pictures of the same clouds taken from the ground or airplanes. Even then, it is anticipated that much further research must be done, experimentally and theoretically, into the dynamics of convective and vortex flow before the complex cloud patterns can be better interpreted in terms of air motions, temperature gradients and other atmospheric properties. There may be a misleading tendency to interpret the large-scale cloud patterns observed by satellites in terms of known processes merely because they resemble familiar cloud patterns one or two orders of magnitude smaller (SCORER, 1961).

Cloud observations from satellites, particularly from the downward-looking, polar-orbiting NIMBUS satellites (expected to be launched in 1963), will also be used in climatic research, for example, to establish for the first time a truly global cloud census, to draw charts of world cloud cover averaged over months or other periods, and to note long-time variations in cloud amount and distribution. The world cloud cover is the most important component in the Earth's albedo and serves as a natural thermostat in keeping the world temperature within narrow limits. A larger than average cloud cover can reflect more radiation and cool the Earth, thus reducing the conventional currents and cloud cover. A smaller cloud cover will enable more solar radiation to heat the Earth's surface and thus cause more clouds to form.

Practical Uses of the Cloud Pictures

Despite the inability of meteorologists to interpret more than a fraction of the information contained in the satellite cloud pictures, these have proved to be quite useful in large-scale synoptic weather analysis and prediction. This is true particularly over oceans, deserts, polar regions and other uninhabited regions where current meteorological observations are so sparse or missing altogether that large storms can reside undetected for days. In these cases, the cloud patterns revealed by satellites may be the only evidence showing the existence of important weather phenomena. For example, TIROS III, launched purposely during the 1961 Northern Hemisphere tropical storm season, photographed six hurricanes in the Atlantic Ocean, three hurricanes in the Eastern Pacific, and nine typhoons (local name for hurricanes) in the central and western Pacific Ocean. In the first ten weeks of its existence, TIROS III photographed tropical storms on more than fifty separate occasions and the information was sent to weather forecasters in the affected areas. The existence of most of these storms was known or suspected from conventional surface, ship and aircraft reports but their estimated positions were sometimes in error, by as much as 400 km, as the satellite showed. But on one historic occasion, September 10, 1961, TIROS III photo-

graphed a suspicious cloud area near 11° N, 30° W, which proved to be Hurricane *Esther*, whose existence was confirmed two days later by conventional means and recognized officially. This storm was connected by a cloud band to another hurricane, *Debbie*, (fig. 11).

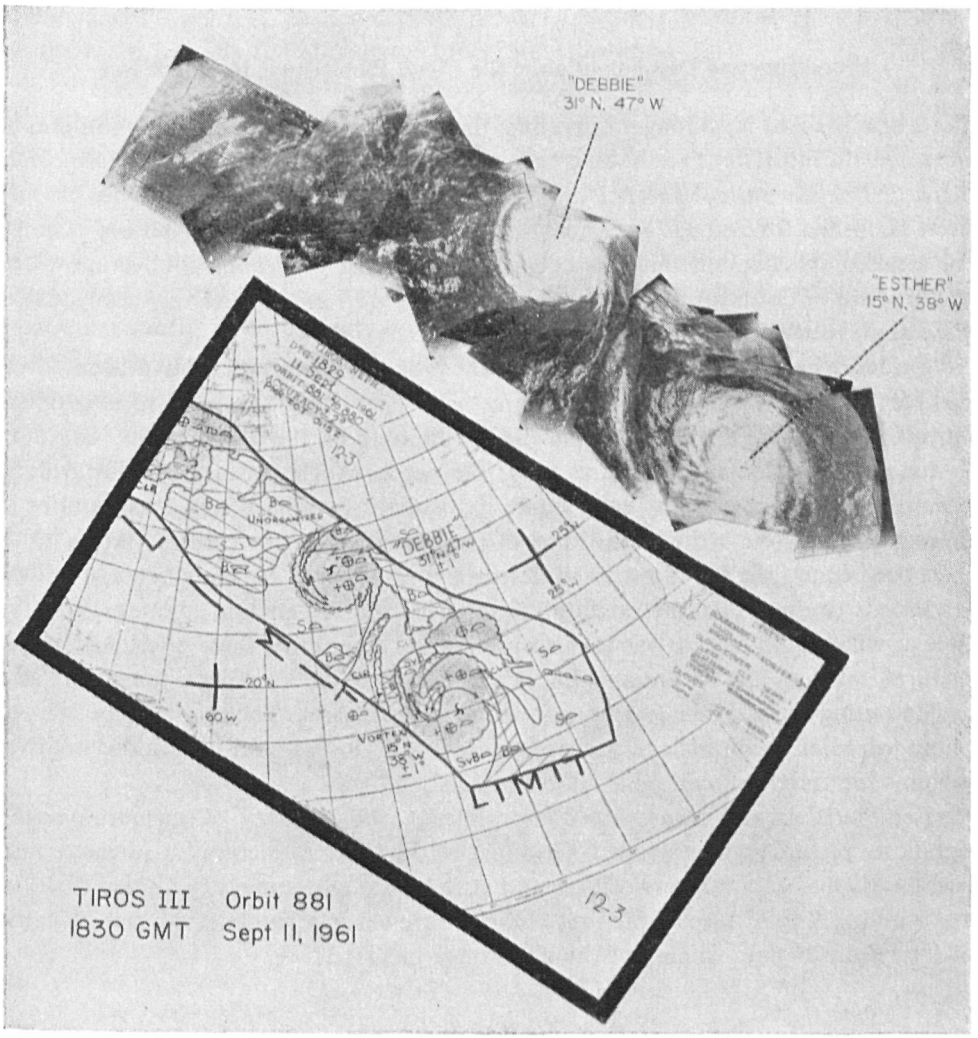

Fig. 11. A composite of TIROS III pictures showing Hurricanes *Debbie* and *Esther* together with a "nephanalysis" or a schematic cloud chart. (After WINSTON, 1962).

The satellite cloud information received daily is synthesized into cloud distribution charts, called "nephanalyses", which are transmitted to many forecast offices in both the northern and southern hemispheres by facsimile or coded messages. Pilots of trans-Atlantic and -Pacific aircraft have on many occasions received in their briefing

folders cloud information detected by TIROS a few hours before their departure and which they would encounter in flight a few hours later. This almost immediate operational usefulness of information from so-called "research and development" satellites has been a constant source of amazement to those who expect that a decently respectable time interval should normally separate research from its practical application.

Processing and Dissemination of the Cloud Pictures for Research Use

For a satellite that is no longer operating, the listings and maps of cloud photographs obtained during its entire lifetime will be published in the *Key to Meteorological Records Documentation Series* (U.S. Weather Bureau). Such a catalogue has already been published for TIROS I (PYLE and MERCER, 1961). Similar catalogues are planned for succeeding satellites, but will not include showing geographical coverage when pictures are of doubtful value for intensive study, such as the relatively poor quality wide-angle camera pictures from TIROS II.

Gridding programs, using electronic data processing machines, have been developed to further document the wide-angle pictures. These programs are used to produce latitude and longitude grids which are super-imposed on the photographs. Gridding is done on the wide-angle pictures only; the narrow-angle pictures are not gridded because the area covered by each frame is so small. In spite of the uncertainties in determining satellite attitude and time of picture taking in the case of TIROS I, grids have been computed for about 800 different TIROS I pictures. Measurements of known landmarks to determine the satellite attitude for certain "anchor" pictures, and the time at which each picture was taken, were used in computing these grids. Additional pictures, taken at known times within two hours of an anchor picture time, were also gridded using the attitude determined for the anchor frame. The grids will be merged photographically with their respective pictures for archiving, and the gridded archival pictures for TIROS I should be available in 1962.

For TIROS III and future TIROS experiments, the majority of meteorologically significant pictures can be gridded. Gridding of the TIROS III pictures is an easier task because the basic parameters of time and attitude are more precisely known than for TIROS I. Gridding of TIROS II pictures will be restricted to a few selected cases because of the relatively poor quality of the wide-angle pictures.

Radiation Measurements

In addition to television cameras, TIROS II and III carry three sets of radiometers (BANDEEN *et al.*, 1961). One is a cluster of five sensors, the optical axes of which are inclined 45° to the spin axis of the satellite. Each sensor has a 5-degree field of view, covering an area of about 50 km by 50 km; the spin and movement of TIROS II along its orbit provide the scanning motion. The sensors respond to the following bands of wavelengths: (i) 0.2 to 5 microns, a broad band that measures the energy of reflected solar radiation; (ii) 0.55 to 0.75 microns, a narrow band in the visible region that

provides data that can be correlated with television images; (iii) 8 to 12 microns, a band indicating the approximate temperature of either the earth's surface or the tops of clouds, whichever happens to be beneath the satellite; (iv) 7 to 30 microns, a very broad band bracketing most of the terrestrial infrared radiation; and (v) 5.6 to 7 microns, a narrow water-vapor emission band that provides the average temperature of the highest layer of the atmosphere in which there is an appreciable amount of water vapor (usually found near the top of the troposphere).

By April 1, 1961 more than 1000 100-minute orbits of radiation data had been obtained from TIROS II. This amounts to about 2,000,000 individual observations a day. For each orbit, about 18 minutes of IBM 7090 computer time are required to combine the orbital and radiometer calibration data with the digitalized raw radiation data to produce a binary output tape. This binary tape – the archival record – contains information that locates each radiation datum point in latitude and longitude, and in time, and the intensity of the radiation in watts per square meter for each response in a particular swath. To date twenty-one reels of meteorological radiation tapes have been processed in final format. These tapes contain data from the first 102 TIROS II orbital passes from which radiation data were received and will be available at the U.S. Weather Bureau's National Weather Records Center (World Data Center A, Asheville, North Carolina) (LEHR, 1962).

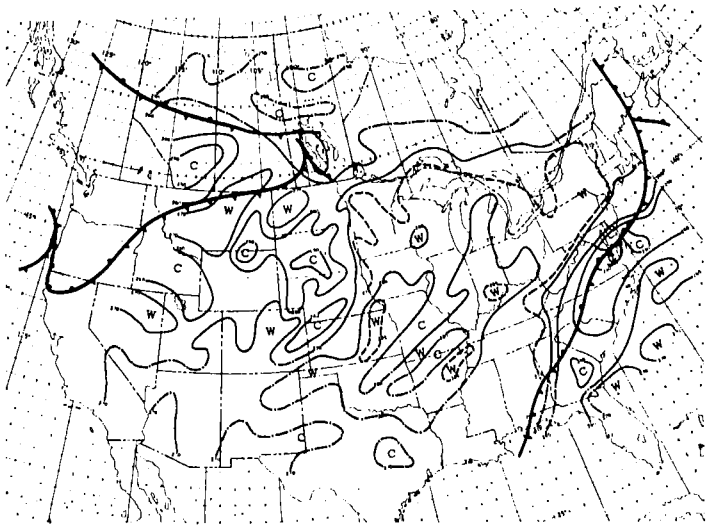

Fig. 12. Equivalent black body temperatures computed from 8–12 μ radiation observed by TIROS II on orbital pass 4, 23 November 1960, 1805–1815 UT. The path of the satellite on this pass was from the northwest corner of the country east-southeastward across southern Lake Michigan and across the east coast over Virginia. The broad northeast-southwest oriented band of low temperature (lowest about 240° K) is associated with a cloud system associated with the front (heavy line) extending from New England to southern Alabama. The central United States has a broad region of fairly uniform high temperatures ranging from about 280° to 285° K, indicating a much warmer equivalent radiating surface than in the east. (After FRITZ *et al.*, 1962).

Selected data from all five channels of the scanning radiometer on TIROS II have been mapped by computer and plotted mechanically on north hemisphere and south hemisphere charts (Staff Members, NASA/GSFL and USWB/MSL, 1961). The most useful data are of radiation in the 8–12 micron band, the water vapor "window", which show the "effective" temperatures of the radiating surfaces below the satellite (fig. 12) (HANEL *et al.*, 1961; FRITZ *et al.*, 1962). For dry, non-tropical atmospheres these radiating surfaces are the top layers of clouds in overcast area, and in cloud-free areas, the Earth's surface; for other atmospheres there will be a contribution to the 8–12 μ radiation from the moist layer above the Earth's surface or cloud top. In areas of scattered or partial cloud cover, these temperatures become ambiguous. Contours on these "temperature" maps in middle and low latitudes separate, in a gross manner, the cold cloud tops from the usually warmer Earth's surface, so these maps can be used as cloud maps. Since the radiation data are available over both daylight and night areas, maps of these data can be used as indicators of the gross pattern of cloudiness on the night side of the Earth where television pictures are not available. In addition to this use, the cloud top temperatures permit an approximate determination of the height of the tops of these overcast clouds (fig. 13) (FRITZ *et al.*, 1962).

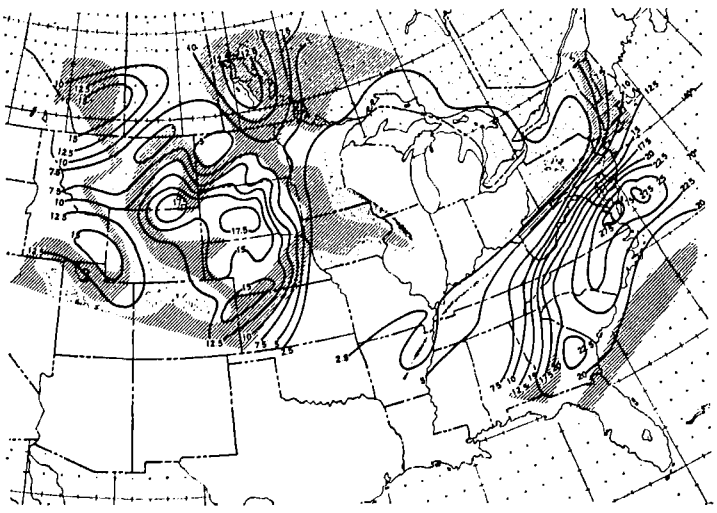

Fig. 13. Heights of cloud tops in thousands of feet from 1800 UT, 23 November 1960, estimated from TIROS II measurements of equivalent black body temperatures (shown in fig. 12) and from the observed temperature-height profiles. The shaded areas refer to partial cloud cover; these encircle the white areas of complete cloud cover which are located at or near te maximum cloud height contours. (After FRITZ *et al.*, 1962).

In the second radiation experiment, two black and white wide-cover sensors, having a 35° field of view (800 km resolution), observe a portion of the earth in the center of the area depicted by the wide angle television camera (BANDEEN *et al.*, 1961). One sensor responds to the terrestrial radiation emitted by the earth and atmosphere

while the other measures this radiation as well as the reflected and scattered solar radiation, thus enabling separation and measurement of the two radiation fluxes.

The third and related experiment (on TIROS III only) contains radiation sensors which are black and white hemispheres enabling measurement of the terrestrial radiation and reflected solar radiation from the intercepted disk of Planet Earth (WEINSTEIN *et al.*, 1961). This latter radiation experiment represents a continuation and extension of the low resolution solar and terrestrial radiation measurements made from EXPLORER VII satellite, launched on October 13, 1959. Charts of the outgoing radiation from the earth to space show a pattern composed of sizes and motions similar to those of anticyclones and cyclones (WEINSTEIN *et al.*, 1961). This is because the characteristic clear and cloudy areas of these atmospheric features determine the temperatures of the black-body radiating surfaces responsible for most of the outgoing infrared radiation.

A Summary and a Perspective

In the 20 months that TIROS cloud pictures have been available, much has been accomplished in developing and applying rapid and reasonably precise read-out procedures to the construction of cloud distribution charts, in applying these charts to practical problems in real time, and in interpreting the cloud patterns in terms of storms, fronts and other atmospheric phenomena. Much more remains to be done – empirically, experimentally and theoretically – before their information content can be exploited significantly beyond the preliminary stage now underway. Even so, these "primitive" TIROS data have clearly shown their great usefulness not only in supplementing conventional observations by filling in unknown gaps but also in showing over-all patterns and details to a degree not discernible even over the densest conventional observing networks.

The contribution of satellite cloud observations will be particularly significant in the Southern Hemisphere whose 80% ocean coverage makes difficult the obtaining of adequate meteorological data through conventional means. Also in the tropics, cloud patterns may become the principal working tool of forecasters, since the vigorous fronts and other weather changes of higher latitudes, so easily detected by barometric pressures, temperature and wind fields, are lacking.

As for radiation data from satellites, application or interpretation has been much slower because of formidable calibration and data processing problems. Exceptions have been (1) the 8–12 μ water vapor "window" data which have revealed clouds and cloud-top temperatures (and thus cloud top heights) with useful accuracy and (2) the outgoing infrared radiation fluxes from the earth and its atmosphere. However, the solar and infrared radiation data may, in the long run, exert as much influence on understanding longer range weather and climatic changes as do cloud pictures on the shorter period processes. The data will not only permit mapping of the geographical and temporal patterns of the net radiative energy that provides the basic fuel driving the atmospheric heat engine but may also, as more refined spectral measurements are made in the ultra-violet and in the infrared, enable profiles to be obtained of air

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temperature (KAPLAN, 1959 a & b; WARK, 1961; WARK *et al.*, 1962, to be published), concentrations and rough vertical profiles in cloudless air layers of water vapor, carbon dioxide and ozone (SINGER *et al.*, 1957; SEKERA *et al.*, 1961; TWOMEY, 1961; FRITH, 1961; VENKATESWARAN *et al.*, 1961).

Other techniques, employing radar installed on satellites, could map out the precipitating cloud layers, their tops and bases and even the height of their freezing isotherms. Wind velocities and trajectories over meteorologically unknown areas could be determined by locating and tracking with aid of satellites, hundreds of balloons set to float at predetermined heights. Sea-level barometric pressure and other meteorological and oceanographic data could be obtained from thousands of automatic stations on sea and on land transmitting their observations to dual purpose meteorological and communications satellites for storage and transmission to forecast offices and data centers.

By 1963 the first of a new family of meteorological satellites is expected to be launched – the downward-looking, polar-orbiting NIMBUS satellite – equipped with more refined television cameras and radiation equipment. Each NIMBUS will scan the entire earth twice daily – once by night and once by day. This will represent a vast improvement over the sporadic coverage now obtained by TIROS satellites and should mark the beginning of the next great period of advance in use of meteorological satellites in global weather prediction and in the better understanding of the ways of the atmosphere.

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