16. PHYSICAL MEASUREMENTS AND DATA PROCESSING

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Of main concern in this discussion are the radiation experiments, in general, on the Tiros satellites. There are three aspects to the radiation experiments. The first one is the instrumentation used on the Tiros satellites. Since the instrumentation has already been discussed, in part, in paper 10, only a brief discussion will be given herein. The second aspect of the radiation experiments is the calibration of the instruments. Work is still being done to try to calibrate these instruments more precisely, which means to relate the input into these instruments more precisely to the output telemetered to the ground stations. The third aspect of the radiation experiments is the problem of data reception, processing, analyzing, and interpretation. There is much work to be done on this phase of the experiments.

It may be worth while to summarize briefly the various publications and the work done by researchers in the field of radiation experiments.

Reference 1 is a basic paper in which the instruments and some of the preliminary data received from Tiros II are described. The electronic aspects of the Tiros radiation experiments are discussed in reference 2. Charts or maps of the Tiros radiation data are available (ref. 3) and these will be described briefly herein. Some initial efforts to interpret the data from Tiros III in terms of various situations which have been reviewed are given in reference 4.

Figure 16–1 is a photograph of the Tiros II satellite. This figure is presented to show the viewing ports of the radiation sensors onboard the satellite. There are two radiation instruments onboard. One is a so-called five-channel scanning radiometer, sometimes referred to as a high-resolution or medium-resolution radiometer. The radiometer, as used in these experiments, measures both reflected and infrared radiation from the earth, reflected in visible regions and emitted in infrared regions. These radiations have been observed in five more or less spectrally defined regions; thus, the instrument is called the five-channel radiometer.

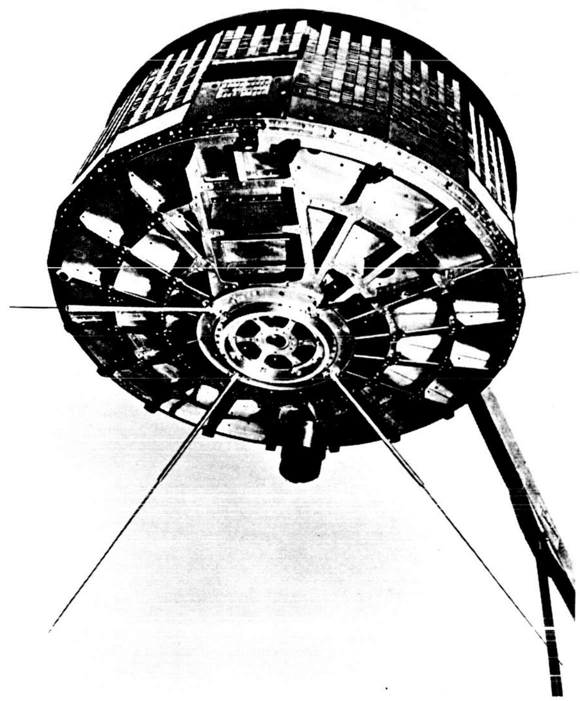

Figure 16–1. Tiros II meteorological satellite launched November 23, 1960. The medium-resolution scanning radiometer looks through rectangular apertures in the side and base plate. The low-resolution radiometer looks through the round aperture in the base plate almost diametrically opposed to the protruding wide-angle television lens.

It is mounted in the pillbox-shaped satellite on the side so that one viewing port looks out toward the bottom of the satellite (usually referred to as the floor side), whereas the other looks out toward the side (usually referred to as the wall side). The distinction between the sides is important because one serves as the reference side, and the other, as the signal side. Sometimes, the floor side looks at the earth; then, *it* is the signal side. Sometimes, the wall side looks at the earth; then *it* is the signal side. The reference side looks constantly into outer space and compares the outer space signal which is obviously zero or which has very little radiation in it against the one that it receives from the surface of the earth.

The other radiation instrument onboard is a wide-field radiometer, shown in figure 16–2. It

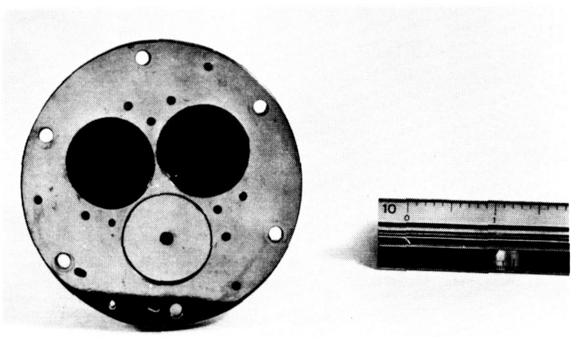

FIGURE 16–2. Exterior view of the low-resolution radiometer showing the black detector (left) and the white detector (right).

has a much lower resolution than the five-channel radiometer. The five-channel instrument is able to resolve a square of about 60 kilometers on the earth. The wide-field radiometer sees the whole disk of the earth underneath the satellite; it consists of two cones, one with a detector painted white, which is sensitive only to infrared radiation and which reflects visible radiation, and one with a detector painted black. This latter one is sensitive to the total radiation received. The exact workings of this instrument will be discussed subsequently.

The five-channel or scanning high-resolution radiometer is shown in detail in figure 16–3. The viewing ports for the individual five spectral regions of the wall side can be seen on the bottom.

Figures 16–4 and 16–5 define and describe the spectral regions in which the five-channel instrument is sensitive. Figure 16–4 shows the sensitivity of channels 3 and 5 to reflected radiation from the earth. Channel 3 is sensitive from about 0.2 micron to about 6 microns. Channel 5 is sensitive from about 0.5 micron to about 0.8 micron. The reason why these two

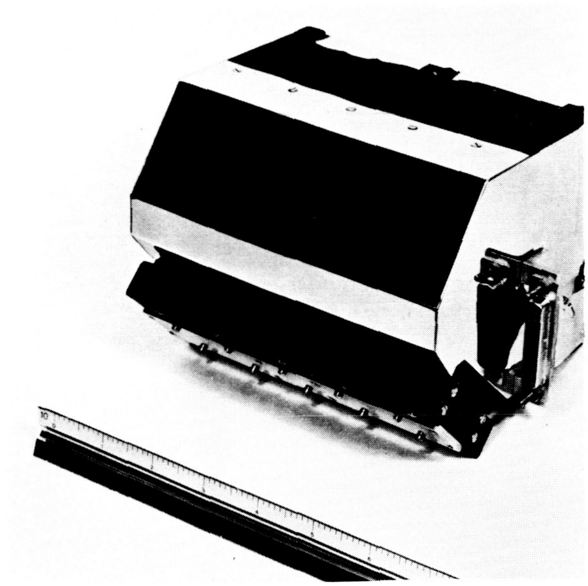

FIGURE 16–3. Exterior view of the medium-resolution radiometer showing the view apertures in one direction of the five channels. The prismatic cross section of the reflector is seen on the right of the line of appertures.

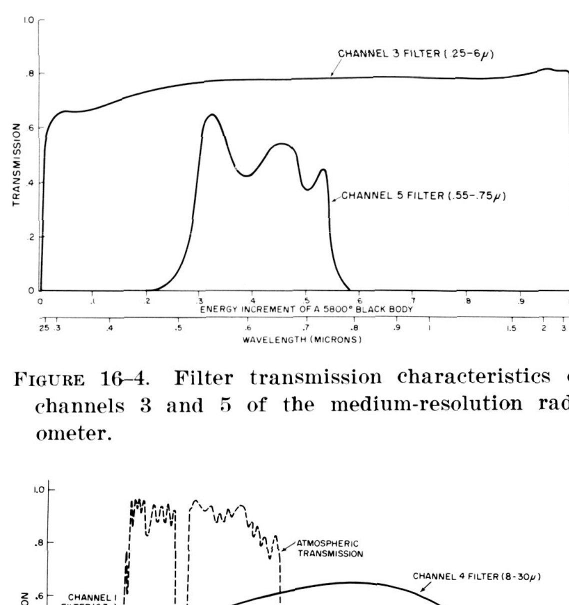

FIGURE 16–4. Filter transmission characteristics of channels 3 and 5 of the medium-resolution radiometer.

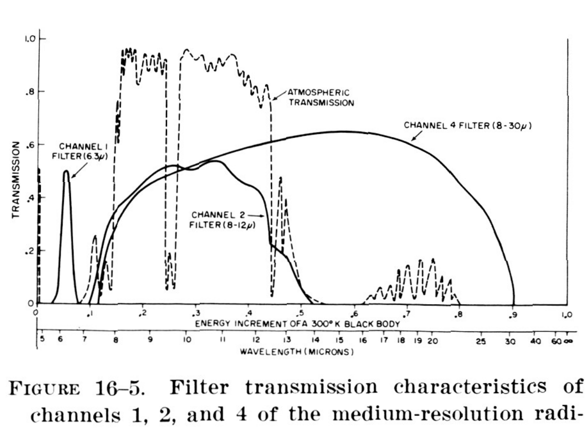

FIGURE 16–5. Filter transmission characteristics of channels 1, 2, and 4 of the medium-resolution radiometer. The dashed line is the approximate transmission characteristic of 1 atmosphere.

regions were chosen is the following. Channel 3 was intended to encompass the total reflected sunlight from the earth. Channel 5 was intended to be sensitive near the actual maximum spectral intensity of sunlight. There is also a more practical reason for selecting this narrow spectral region; the spectral sensitivity of this channel is very close to the spectral sensitivity of the television cameras onboard the same satellite. The spectral curves (figs. 16–4 and 16–5) are somewhat stylized in the sense that they do not show some of the erratic response occurring outside these bands. The reason is that the curves were drawn before an exact and precise knowledge of the spectral response of this instrument was obtained. This erratic response was detected only after rigorously calibrating these instruments in the laboratory. Channel 5, which already has a complicated response curve in the 0.5- to 0.8-micron range, also has a small but noticeable response farther out in the 1-micron region. This makes the processing and analyzing of the data accordingly more complicated.

Figure 16–5 shows the infrared channels or the three channels sensitive to emitted radiation from the earth. Channel 1 has a very narrow peak in the 6.3-micron region. The dashed lines show the transmission characteristic of the atmosphere. In the 6.3-micron region there is practically no transmission; this is due to the absorption by water vapor in the atmosphere. Maximum atmospheric transmission occurs in the spectral region in which channel 2 is sensitive except for the dip at approximately 9.5 or 9.6 microns, which is due to the absorption of ozone in the upper atmosphere. However, the total energy in this atmospheric transmission dip is rather small compared with the total energy in the spectral region for which this filter is sensitive. This region starts at about 8 microns and extends to about 13 microns. After these curves were drawn, more precise calibration indicated that there is a slight response of this channel at about 16 microns. It was hoped that this channel would be a perfect "window" channel; however, as the spectral calibration has shown, there is some response outside this window. There is, then, a minimum transmission through the atmosphere in the channel 1 region and a maximum transmission in the channel 2 region.

In the third remaining infrared channel, channel 4, a spectral range as broad as possible, extending from about 7 microns to about 30 microns, is chosen; here, it is intended, to receive the total thermal energy emitted from the earth.

With the complicated spectral responses described it is a difficult task to obtain a measure of radiation from the electrical energy measured at the output of each channel. A relationship between received radiation and measured output voltages must therefore be established experimentally. This is done in the following ways. The infrared channels of the instrument are exposed to black-body targets whose radiation temperatures are known precisely. The output of the radiometer is recorded with varying target temperatures. This means that a 1-to-1 correlation between the total energy emitted from the target and the output of the instrument can be established. When the satellite is in orbit the earth takes the place of the black-body target, and the electrical output from the instrument after demodulation can be expressed in terms of black-body target temperatures which in turn can be converted to radiation energy received from the earth. This approach, however, does not render a satisfactory picture of the radiation emitted from the surface of the earth or the atmosphere because the radiation measured within the highly nonuniform spectral response of the instrument (fig. 16–5) must be correlated with the total radiation emitted from a given altiude region of the atmosphere of the earth in a given direction. A method to obtain such a correlation is described in paper 17.

Figure 16–6 shows the installation in the laboratory for experimentally calibrating the visible channels. In the visible channels, the reflected-light channels, the problem is somewhat different from the thermal-calibration problem. A 1-to-1 correspondence between the radiation from the target and the output of the instrument cannot be obtained as simply as in the case of the infrared channels. A well-calibrated source which illuminates a diffusing screen, simulating a reflecting cloud surface (fig. 16–6), must be used. The distance of the screen can be varied and, therefore, the intensity of the diffuse emitter or diffuse reflector, which is a special type of paper, can be varied. This

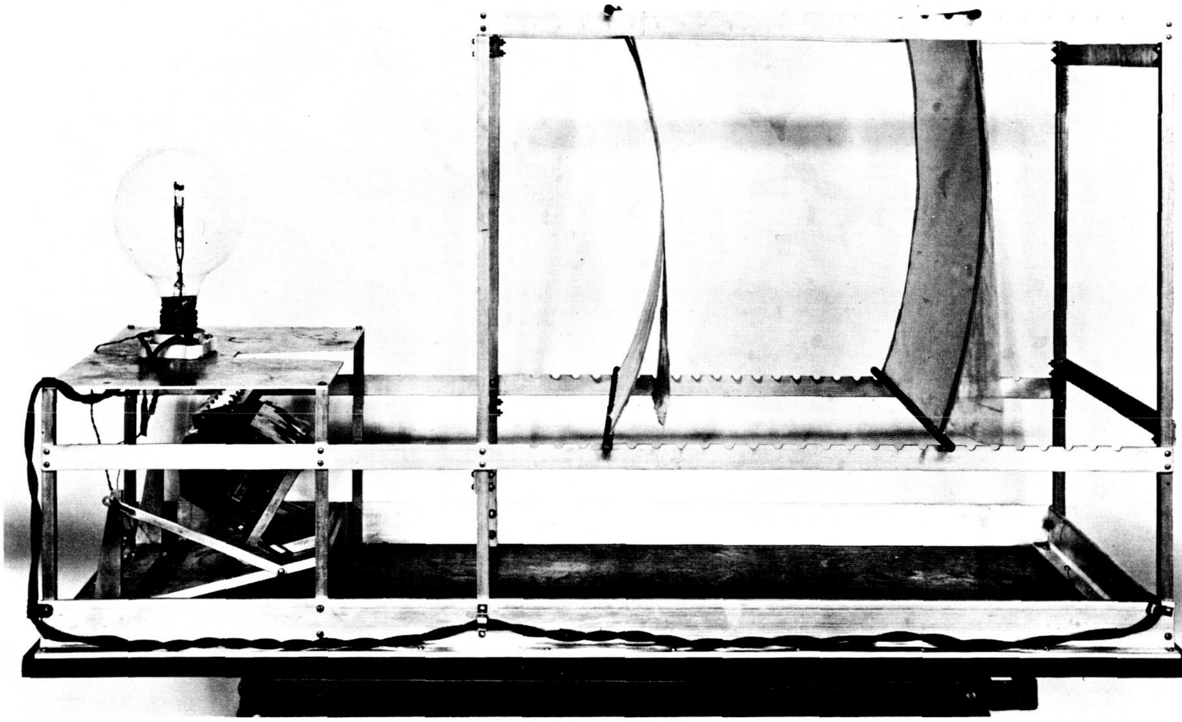

FIGURE 16–6. Calibration installation for the two visible-light channels of the TIROS five-channel radiometer. A 1.5-kilowatt calibrated tungsten bulb shown in the left side of the light stand illuminates a diffuse paper target mounted in the right side of the stand. The radiometer is mounted underneath the tungsten bulb and shielded from direct light.

diffuse reflector then illuminates the radiometer and the output of the two visible channels is monitored as a function of the distance of the screen from the bulb; namely, as a function of the total intensity or brightness of the screen. Again, a 1-to-1 correspondence could be obtained if the paper screen truly simulated reflected solar radiation. However, this is not the case. This source used in the laboratory at its brightest has a color temperature of about 3,000° K. The sun has a temperature almost twice this value. The spectral characteristics of the laboratory source and the sun are therefore vastly different.

In order to convert the output to the albedo seen by the instrument, the exact spectral characteristic of the source, the exact spectral response of the instrument, and the exact spectral characteristic of the sun must be known. For the latter a black-body radiator of 5,800° K is assumed for channel 3; a black-body radiator of 6,000° K is assumed for channel 5. These assumptions may be made confidently. The exact spectral response of the instrument and of the source are very difficult to obtain. As a source a carefully calibrated bulb is used as a "primary standard." The spectral response of the instrument is measured by comparing it with the response of detectors of uniform spectral sensitivity.

In TIROS II these calibration problems had not been solved as completely as in TIROS III, and most of the data received, particularly most of the visible energy data, were only relative measurements. In TIROS III the calibration has been perfected and there is more certainty about the absolute measurement of energies reflected from the earth in the visible part of the spectrum. Measurement, of say, the transmission of a filter or of any optical component in the five-channel radiometer by just using the various monochrometers and spectrophotometers available is not very simple. The problem is not only to produce monochromatic radiation and have the radiometer respond to it but also the calibration must be performed with a detector of greater precision than the one contained in the radiometer; such detectors are very difficult to find because of the required uniformity of response over the broad spectral regions over which the instrument must be calibrated. This, again, is particularly true for the infrared channels.

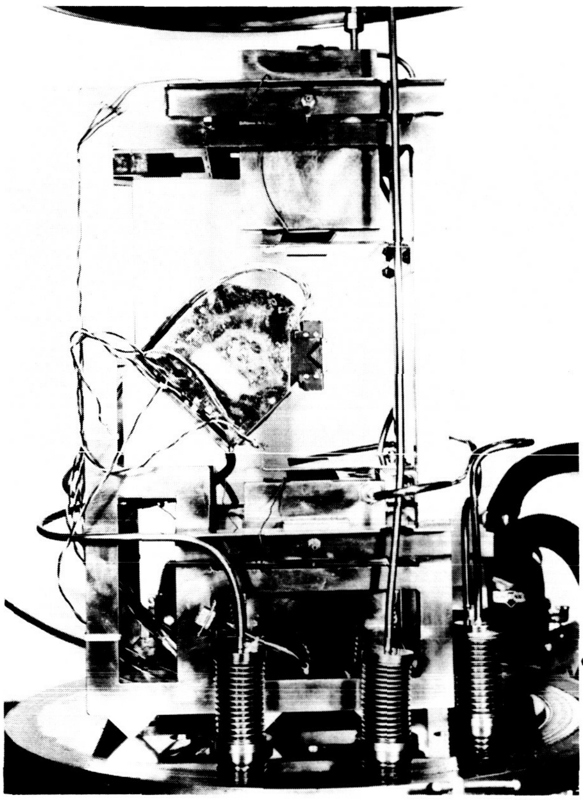

FIGURE 16–7. Laboratory installation used for calibrating infrared portion of the TIROS five-channel radiometer. The radiometer is mounted in the center. Identical black-body targets are mounted on top and bottom. All the equipment shown fits inside a Bell jar which is evacuated to a maximum pressure of 10^{-6} mm Hg.

Figure 16–7 shows the facility used in the calibration of the thermal channels, the infrared channels. The radiometer is mounted in the center of the apparatus with one viewing port looking up and the other viewing port looking down. There are two black-body targets, one above the radiometer and one below. The slots visible in the two targets are actually the conical black bodies into which the instrument looks. If both of these targets are embedded, say, in liquid nitrogen, then the three infrared channels see practically no radiation through both viewing ports. This simulates the situation the satellite encounters in outer space when neither wall nor floor side are looking at the earth. The output of the instrument should then be zero. When the temperature of one of these black-body targets, for instance the top, is increased to a range which is comparable to the equivalent black-body temperatures of the earth, the output of the instrument will increase; the increasing voltage can then be measured as a function of the increasing black-body temperature of this target. Then, the process is reversed; the top target is kept at liquid nitrogen temperatures and the bottom one is heated. The response of the instrument is not exactly the same, although theoretically it should be. This difference in response between the "wall" and the "floor" sides is an important part of the calibration and very cumbersome to handle in the data reduction.

Figure 16–8 gives a picture of the results. The black-body temperatures are plotted on the abscissa; these temperatures range from liquid nitrogen temperatures (−196° C) up to about 40° C. If the floor side is chosen to be the scanning side and looks at a target of variable temperature, the wall side will constantly look at a liquid nitrogen target. As the temperature is increased, the voltage increases from zero up to a saturation level of approximately 12 volts. Thus, a curve of voltage against black-body temperature of the target is obtained; the temperature of the satellite is an additional parameter in obtaining these curves. Two different temperatures for the instrument are shown in this figure, 25° C and 45° C. As the temperature of the instrument varies, nearly parallel curves will result. After the output has been obtained as a function of these two parameters, namely, the temperatures of the instrument and the target, the energy which is available under the filter function curves (fig. 16–5) may be computed for a given black-body temperature.

Figure 16–9 shows this relation. This curve is obtained by using Planck's law for a given black-body temperature and integrating it over the filter function of the instrument. This is where the complication occurs. If this filter function were perfectly rectangular, it would be elementary to compute the relationship between the black-body temperature and the energy received by the radiometer. The complex nature of the filter function not only complicates the computational process of this in-

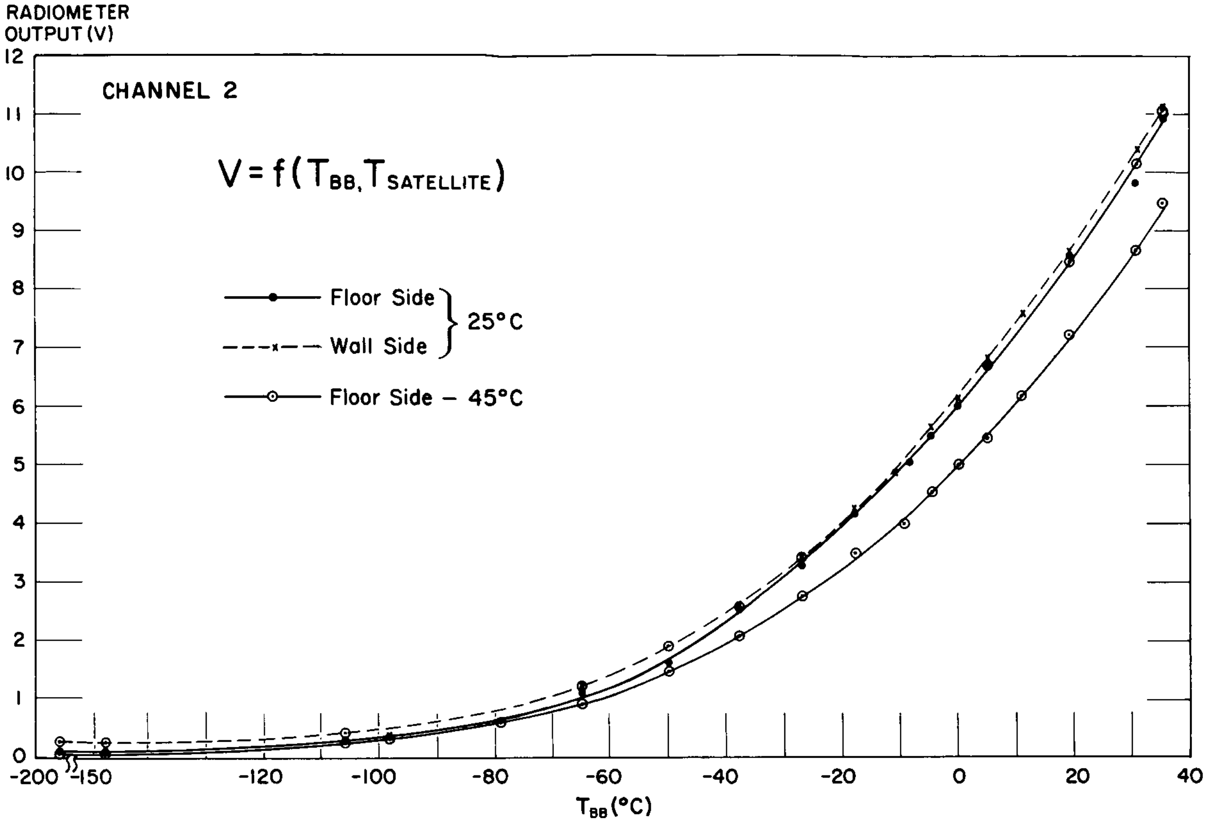

Figure 16–8. Typical curve showing the relationship between the voltage output of channel 2 of the scanning radiometer and the temperature of a black-body target viewed by the scanning beam of the radiometer. The reference beam at the same time is looking at a black-body target at liquid nitrogen temperatures.

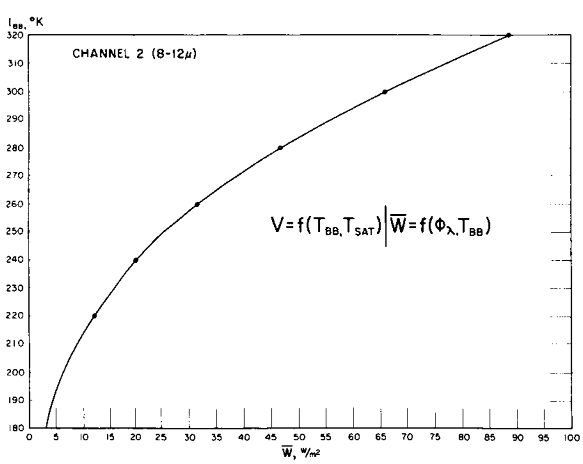

Figure 16–9. Curve showing the relationship between black-body temperature T_{BB} and energy W received by the radiometer. This relationship is obtained by integrating the theoretical black-body energy curve over the spectral range to which the radiometer is sensitive.

tegration but also makes it necessary to find a mathematical correlation between the energy received under the filter function and the energy emitted by the earth within the spectral range of interest. As mentioned previously, such a correlation will be discussed in paper 17

Figure 16–10 presents a group of equations showing the functioning of the wide-field radiometer. The temperatures of the black and white sensors are proportional to the energies radiated to the sensors by the target, which will be the earth, and by the housing of the sensor itself, as well to the heat conduction from the housing to the sensor. This energy relation is simply a proportionality expressing the balance of incoming and outgoing energies at each dètector. In these equations there are four constants of proportionality for each the black and the white cone which must be determined in the laboratory. First, each cone is calibrated with thermal radiation in the infrared only

NETWORK RESISTANCE → T_{SENSOR}

$$T^4_{\substack{SENSOR\\BLACK}} = B_1 T^4_{TARGET} + B_2 T^4_{SATELLITE} + B_3(T_{\substack{SENSOR\\BLACK}} - T_{SATELLITE}) + B_4 I_{ALBEDO} \rightarrow B(T_{TARGET}, I_{ALBEDO})$$

$$T^4_{\substack{SENSOR\\WHITE}} = W_1 T^4_{TARGET} + W_2 T^4_{SATELLITE} + W_3(T_{\substack{SENSOR\\WHITE}} - T_{SATELLITE}) + W_4 I_{ALBEDO} \rightarrow W(T_{TARGET}, I_{ALBEDO})$$

→ THERMAL CALIBRATION: $I_{ALBEDO} = 0$ (WHITE): W_1, W_2, W_3 MAY BE DETERMINED FROM VARIATION OF $T_{\substack{SENSOR,\\BLACK}}$ T_{TARGET} AND $T_{SATELLITE}$

$$\rightarrow W_4 = \frac{T^4_{\substack{SENSOR\\WHITE}} - W_1 T^4_{TARGET} - W_2 T^4_{SATELLITE} - W_3(T_{\substack{SENSOR\\WHITE}} - T_{SATELLITE})}{I_{ALBEDO}}$$

→ THERMAL CALIBRATION: $I_{ALBEDO} = 0$ (BLACK): B_1, B_2, B_3 MAY BE DETERMINED FROM VARIATION OF $T_{\substack{SENSOR,\\WHITE}}$ T_{TARGET} AND $T_{SATELLITE}$

$$\rightarrow B_4 = \frac{T^4_{\substack{SENSOR\\BLACK}} - B_1 T^4_{TARGET} - B_2 T^4_{SATELLITE} - B_3(T_{\substack{SENSOR\\BLACK}} - T_{SATELLITE})}{I_{ALBEDO}}$$

FIGURE 16–10. Equations showing the functioning of the wide-field radiometer.

which affects the first three terms on the right-hand side of the two equations at the top of figure 16–10. Since all lights are turned off, there is no energy from the visible targets which means that I_{ALBEDO}, the intensity of albedo, is zero. The three constants, B_1, B_2, and B_3 for the black sensor, or W_1, W_2, and W_3 for the white sensor, are determined by putting the instrument through a range of various sensor temperatures, target temperatures, and satellite temperatures. By a least-squares solution these constants are determined.

After B_1, B_2, B_3 and W_1, W_2, W_3 have been determined, the lights are turned on. The brightness of the light targets corresponds to a given albedo intensity I_{ALBEDO}. The temperatures of both the black and white sensors, the satellite, and the thermal target are measured. The constants B_4 and W_4 are then obtained by the arithmetic process shown in figure 16–10.

In the satellite the temperatures of the black and white sensors of the satellite itself are measured and telemetered to the ground. With the knowledge of constants B_i and W_i (i=1 . . . 4), the two unknowns, namely, the temperature of the equivalent black-body temperature of the earth T_{TARGET} and the intensity of the albedo I_{ALBEDO} can be determined.

Figure 16–11 is a record of the signals received from the satellite. It shows seven channels. The bottom channel is simply a timing channel. It shows sun pulses which the satellite picks up by scanning the sun, and as the satellite moves into the shadow of the earth these sun pulses disappear. This record is very close to either sunrise or sunset and, therefore, the visible channels receive no light. The top five traces show the signals obtained from the high-resolution radiometer, traces 3 and 5 being the visible channels. The infrared channels (traces 1, 2, and 4 from the top of the figure), however, receive very strong signals; one of these channels will be shown subsequently on an enlarged record. The signals from the wide-field radiometer (trace 6) are of interest here. They are seen in a commutated fashion. In the groups of three dots the outside ones represent the temperature of the black sensor and the center one represents the temperature of the white sensor. These two temperatures are at different levels, naturally, because of their different spectral sensitivity. The voltages for each of these dots are measured and then the equations presented in figure 16–10 are solved for albedo intensity and for equivalent black-body temperature of an area of the earth viewed underneath the satellite. This area is several hundred miles in radius.

Figure 16–12 gives an idea of the typical geometry. In one position (top of picture) the

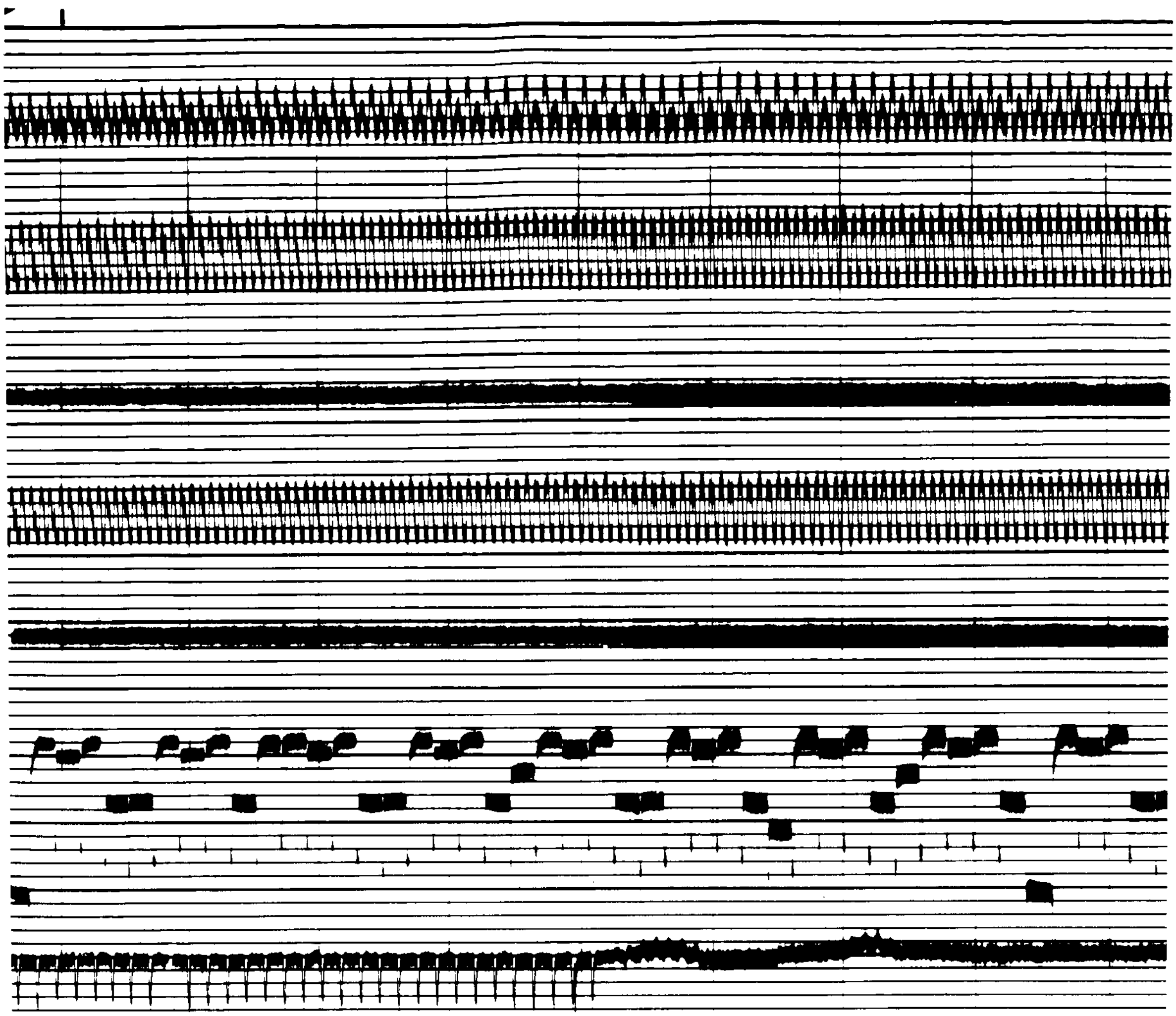

FIGURE 16-11. A typical record of data transmitted from the TIROS radiation experiments. The top five traces show the responses of the five-channel radiometer. Traces 1, 2, and 4 from the top correspond to the three infrared channels; traces 3 and 5 correspond to the visible channels. The bottom channel is a timing reference. The second channel from the bottom is commutated into various segments and contains the information transmitted from the wide-field radiometer as well as "housekeeping" parameters of the satellite, such as temperature and pressure.

bottom of the satellite, the floor side, looks straight down upon the earth; therefore, the wide-field or low-resolution radiometer views an area directly under the satellite. The five-channel or medium-resolution radiometer, which in this case scans through the floor side, describes a circle as the satellite spins; the traces scanned may be seen in the figure. The other beam looking out through the wall side of the satellite will see outer space. Since no radiation is received in this beam, this is the reference side. Then, as the satellite progresses in orbit, about halfway around the earth it will come to a position where not the floor or the bottom but the side of the satellite looks down on earth, whereas the spin axis of the satellite is parallel to a tangent to the surface of the earth. At this point the wide-field radiometer ceases to view the earth (the bottom case in fig. 16-12). It sees outer space and the signal is useless except for reference because there is no radiation. The five-channel radiometer, however, continues to scan as the satellite spins. The floor beam which looks out through the floor of the satellite at 45° to the spin axis will scan the earth over one portion of the spin

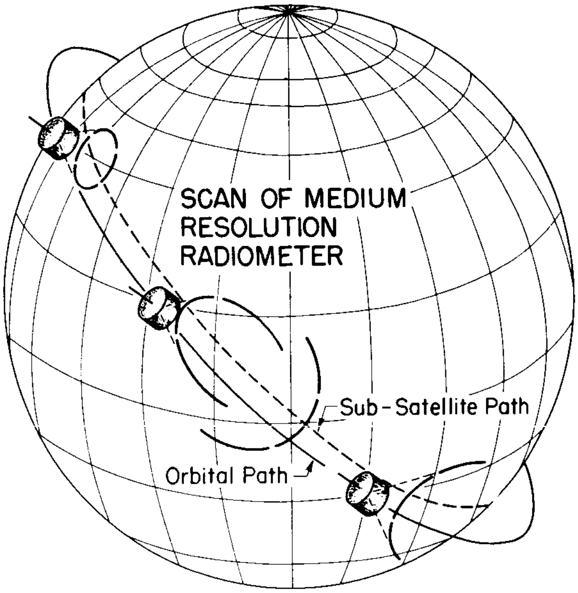

FIGURE 16–12.—Geometry of the scanning motion of the five-channel radiometer.

cycle, and over the other portion it will look into outer space. After this beam has turned to scan outer space, the other beam which looks out through the wall will start to scan the earth. There are, then, alternative sweeps between the wall side and the floor side during one satellite revolution.

Figure 16–13 shows a typical pattern. This pattern was derived from the 8- to 12-micron channel. It was taken under the condition where the satellite was "sideways;" in other words, the earth was being viewed alternately by the floor beam and the wall beam. The lowest signal level in figure 16–13 results when both beams are looking into outer space. As one side starts to see the earth the signal rises suddenly to a fairly high level. The steep transients at the beginning of the scan and at the end occur as the horizon is scanned. Between horizons the beam scans the earth and considerable detail can be seen. The variation of the signal amplitude is due to changes in the emission from the earth.

In terms of the black body, the minimum temperatures would correspond to about 250° K to 260° K. It is approximately 4 to 5 volts in terms of output of the instrument. The maximum temperatures correspond to very warm spots. Apparently, the instrument is viewing areas of clear skies and senses equivalent black-body temperatures very close to the surface of the earth of the order of 280° K to 290° K, or about 10 volts.

These data can be reduced by converting the signal traces point by point from voltages shown in figure 16–13 to black-body temperatures by means of applying all the knowledge obtained from the calibration curves; then, a map may be plotted by going back to the orientation of the satellite which can be determined from various data provided by the tracking stations. This procedure would be very lengthy. If points were read at reasonable intervals, say, if a scan were divided into 50 points or so for each of the six channels, one orbit would yield several hundred thousand data points. TIROS II has radiated data during a thousand or so orbits. TIROS III is now in its 1,700th orbit. If all the data points from TIROS II and III were combined, there would be approximately a billion data points. Thus, the problem of reducing these data is staggering.

A more sophisticated method of reading, scaling, and presenting the data must be used. This is what is called data reduction. It will be demonstrated that by using high-speed computers, this problem can be solved. The next step is to analyze the data. As a result of the data-reduction process the data are presented to the world meteorologists in various forms ranging from plotted maps to magnetic tapes since various applications in the analysis will call for different forms of presentation. It will apparently take many scientists to exhaust all the material presented in the TIROS radiation maps.

Figures 16–14 and 16–15 give an idea of the data reduction and presentation. The focal point in the diagram shown in figure 16–14 is the radiation data program. Various types of information are fed into this program which is placed in a 7090 electronic data processing machine at the Goddard Space Flight Center at Greenbelt. Included are the radiation data stored on tape in the satellite and transmitted on command playback; these data are recorded at a ground station at the Goddard Space Flight Center and then demodulated. The data are converted into voltage signals and then into actual digital signals on tape. This procedure, thus far, requires the preparation of about three magnetic tapes. The analog signals

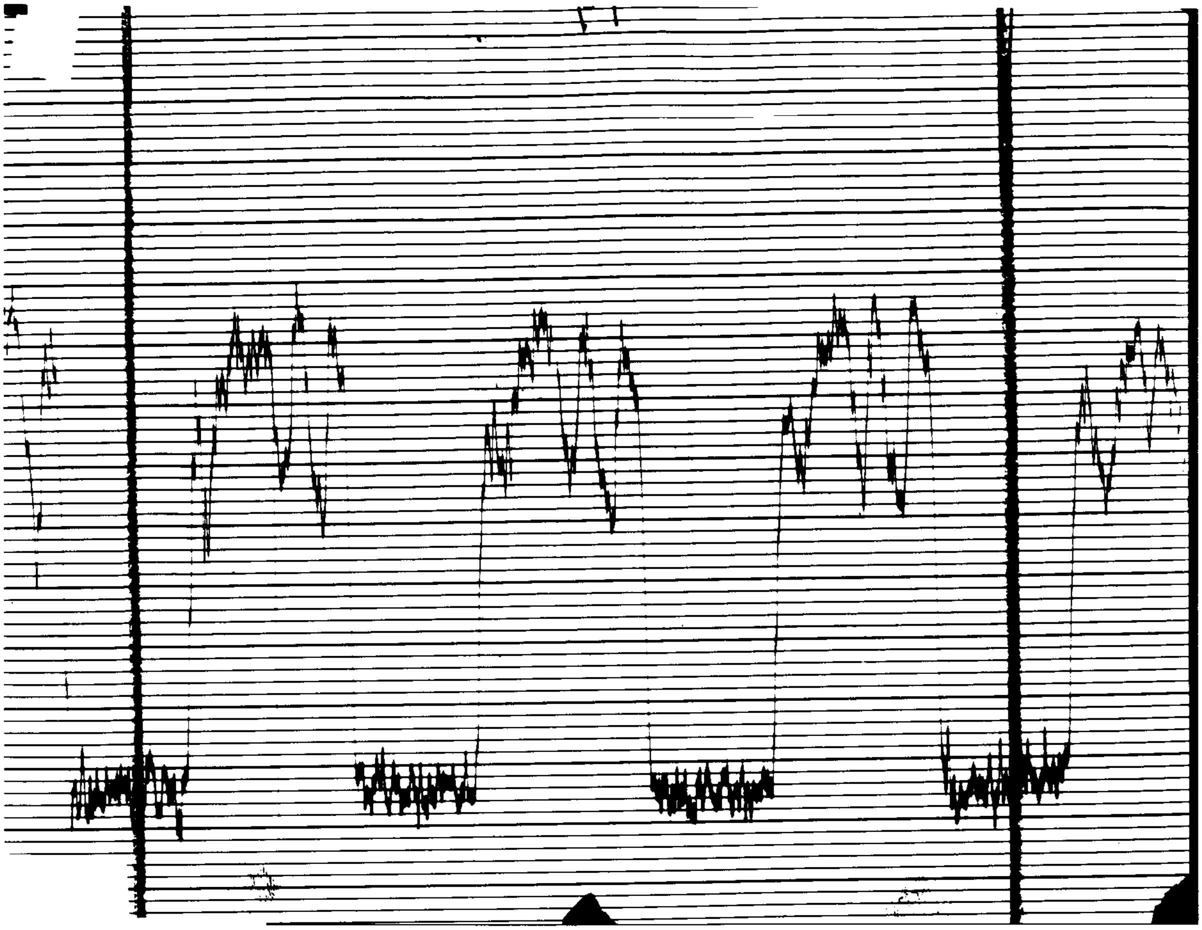

Figure 16–13. Oscillogram showing three consecutive sky-earth scans of channel 2 of the medium-resolution radiometer. The amplitude is approximately proportional to the radiant energy received.

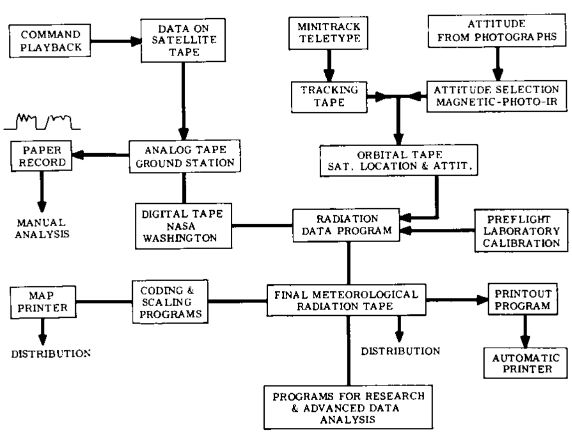

Figure 16–14.—Schematic diagram of the flow of radiation data during its course of processing.

can be tapped off before the digital tape is prepared and just for checking purposes one or two scans can be studied every day to see that the satellite is still working properly and to conduct a manual data analysis.

Then, the digital tape is fed into the radiation program. At the same time the tracking information which goes through an orbital program is obtained from the minitrack stations. The 7090 computer also prepares these magnetic tapes and feeds them into this program. In addition, attitude information of the satellite or the orientation of the satellite, which can be obtained by various methods, is fed in. A brief introduction to the methods of attitude information is given in paper 10 in which it is shown, how the magnetic field and gravitational effects on the orientation of the spin axis of the satellite are used to determine the attitude of the satellite. These effects can be calculated and, therefore, the attitude of the satellite can be predicted or calculated if the

ORBIT 4

Channel 2

8–12 Microns

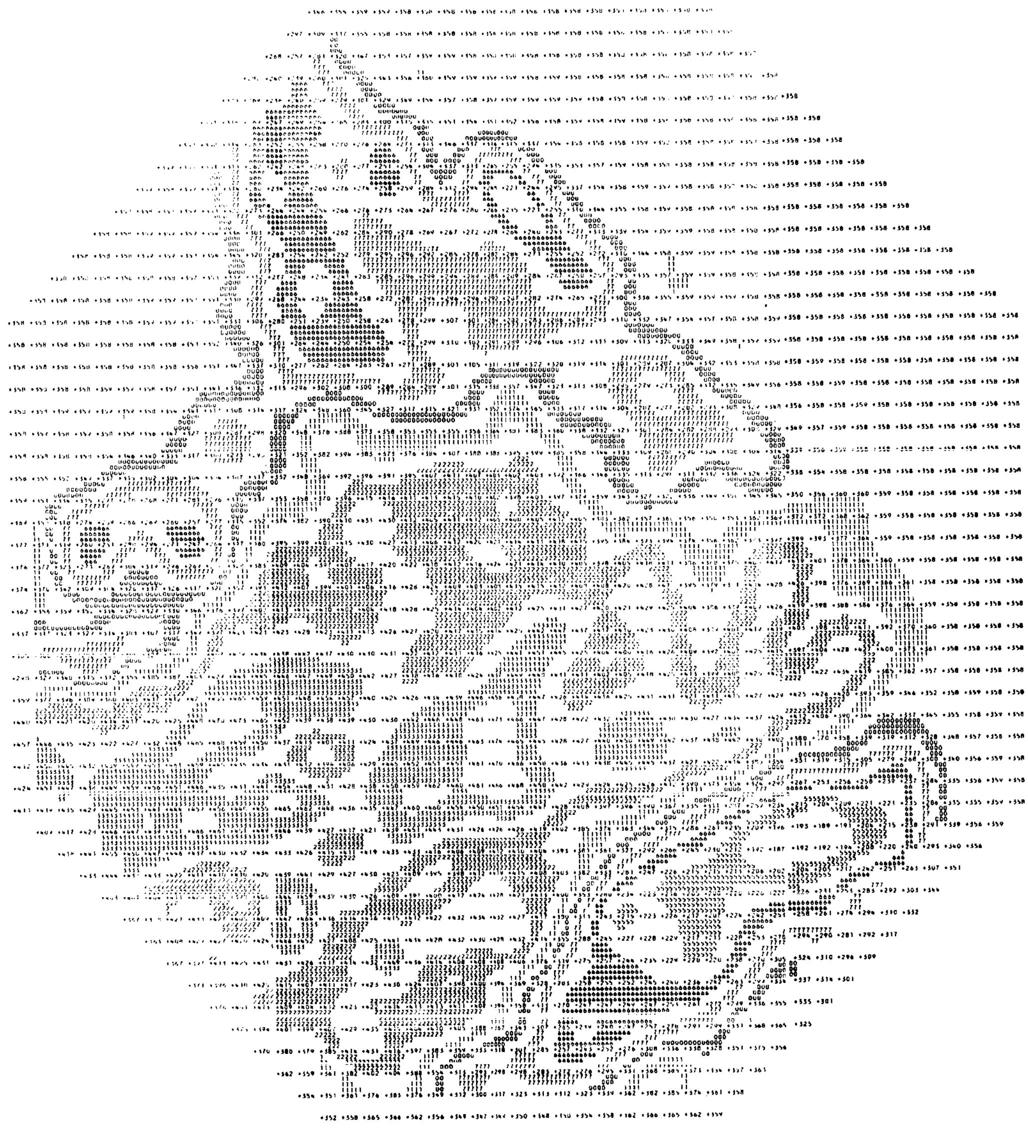

FIGURE 16–15. Typical map produced by automatic printer through processing shown in figure 16–14. The numbers accompanied by a plus prefix indicate the radiated emittance of the surface of the earth in watts per square meter in a wavelength region viewed by infrared channel 2. A grid overlay must be used to determine the geographic coordinates.

necessary auxiliary information is available. The infrared sensors, as they scan the horizon, can provide attitude information independently. The television photographs can also aid in providing the orientation of the satellite if they show landmarks.

All this orientation information feeds into an attitude program, which in turn, provides an imput to the radiation data program, which then combines all this information and puts out a final magnetic tape. All these stages go through magnetic tapes. Nobody has to punch cards or perform any similar manual chore. Actual patterns of radiation can be obtained from the final meteorological radiation tape by playing it back through a digital computer. The computer is needed in order to print a list of the radiation data as a function of time, location, and angular relationships. A computer program called the printout program performs this listing. At the same time maps may be plotted with another program which performs the scaling and coding necessary to print the data in a geographic grid pattern.

The final meteorological radiation tapes, rather than just being printed or mapped, can also be used for more advanced studies. The radiation maps need not be printed out if interest centers on the total heat budget of the earth. In that case, for instance, the data would be retained on tape and calculations would be programed and performed in the computer on the energy available in the various spectral regions, the radiative transfer of this energy through various model atmospheres, all the complex integrations, and so forth. Only the final data need to be printed. How many programs there could be in order to digest the data presented in this so-called final tape is left to the imagination.

Figure 16–15 shows one sample of the maps plotted from the first 50 usable orbits of TIROS II. The numbers indicate radiation emitted in channel 2, which is the 8- to 12-micron channel, for a given orbit over a certain area of the earth. The radiant emittances from the surface of the earth are expressed in watts per square meter. The geographic location can be established by using an overlay which shows the geographic features of the particular area and then by determining the locations where these points fall. These data are presented and described in reference 3. The particular pattern shown in figure 16–15 was taken with Lake Michigan roughly in the center of the picture. In that area radiation emitted from the earth was about 40 watts per square meter. A photograph taken during this same orbit and pass by the satellite shows that there was a frontal passage over the eastern United States accompanied by an overcast, which was apparently very high with dense clouds because they are bright. This decreases the total radiation emitted over that area of the United States (far right portion of fig. 16–15) by about half of what it is over the cloudless areas to the west.

Many of these maps have been studied. It has been found, for instance (ref. 3), that the infrared radiation emitted from the earth in all channels depends above all on the cloud cover and the water-vapor content of the atmosphere. Clouds and water vapor control in a very remarkable way the total energy leaving the earth and also, naturally, the total energy reflected from the earth.

A very interesting study of three particular cases has been made and is presented in reference 3. The area chosen was over the tropical ocean, off the shore of South America. The sky over this area was cloudless, or as cloudless as can be found. Simultaneous television pictures were available with the data received from the five-channel radiometer and the wide-field radiometer. It was found that the wide-field radiometer agreed very well with the five-channel radiometer in the sense that it showed albedo values comparable to those of the two visible channels. The observed albedo over this ocean area ranges from 5 to 7 percent. This observation was at local noon over a cloudless ocean; the reflected radiation obviously was very low.

The total energy received in the 7- to 30-micron channel, about 80 percent of which is infrared radiation from the earth, shows blackbody temperatures ranging from 250° K to 260° K. This agrees, again, very well with the energies measured by the wide-field radiometer. Thus, the experiment appears to be consistent. However, it is interesting that, even over this clear area, the "window" channel in the 8- to 12-micron region shows temperatures which are about 20° below what is assumed to be the water temperature in that region. Temperatures are about 275° K, definitely under 280° K. This would indicate a great sink of energy. It appears to be somewhat significant since this measurement was taken near an area where just a few days before hurricane Anna had developed.

A more interesting case was found over the desert regions. The area from the Mediterranean into the Indian Ocean was studied for orbit 46 of TIROS III. This case is interesting for the following reason: First, the satellite passes over the Mediterranean Sea, a clear area in a very warm region. Then, it scans the desert, which has very high surface temperatures and low water-vapor content. Over the desert the 8- to 12-micron window channel yields temperatures very close to surface temperatures, around 310° K. This temperature indicates that radiation comes from very near the surface of the earth.

As the satellite traverses the 15th parallel into the tropics, the window-channel temperature drops by about 20° to 25°. It could be that the surface temperature is somewhat lower in this area. However, a more reasonable explanation is that the water-vapor content increased tremendously in the tropics. This may be determined by looking at the 6.3-micron channel; there, also, the temperature drops by about 30° as the satellite crosses the 15th parallel and passes over tropical Africa. The 7- to 30-micron channel, as well as the wide-field radiometer, shows a very similar behavior. These record about 280° K to 290° K over the African desert and about 260° K over tropical Africa. The albedos in this case show that the desert reflects about 30 percent of the incident sunlight, whereas the vegetated area farther south in Africa reflects about 15 percent of the incident sunlight.

The same values were measured in the first case where the satellite passed over the coastline of South America (albedos of about 15 percent) and in another case studied over the United States (orbit 4, TIROS III). Over Michigan, Indiana, and Illinois with clear skies, about 15 to 16 percent of sunlight reflected. On the same pass farther south, near Kentucky, over dense clouds, as much as 50 to 55 percent of sunlight is reflected. That was one of the brightest large-area clouds found in the TIROS pictures. The maximum albedo values occasionally measured over smaller clouds have been near 65 percent. Albedo values over 70 percent have never been observed.

The radiation data presented here were intended only to give an understanding of the experiment. The meaning of these data in terms of a better understanding of the atmosphere and of an application to large-scale meteorological observation is given in subsequent papers. The potential contained in the TIROS radiation measurements will probably not be exhausted for many years.

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Question Period

MCCULLOCH, Canada: I would like to ask whether there are any plans for investigating the ultraviolet and X-ray ranges with a view toward determining any information on, for example, solar variability and perhaps its relationship to terrestrial weather?

NORDBERG: This question has been posed to us by many people. Particularly, suggestions have been made to monitor continuously the solar intensity in various bands in the ultraviolet and visible portion of the spectrum. We have never considered X-rays. But in the visible and ultraviolet, particularly in those spectral regions that are responsible for creating ozone and for destroying it, we have thought that it would be interesting, for instance, to look at the Hertzberg bands which are responsible for creating ozone, and then, say, at the Hartley or some of the other bands instrumental in destroying ozone. The change in ratio between these bands could cause changes in the ozone distribution and therefore influence the heat budget of the earth. At the moment we are not considering such experiments for meteorological satellites because, for instrumental reasons, they are better suited for the astronomical observatory types of satellites that NASA is planning.

At this time there is a plan to monitor the radiation of the sun over almost the whole spectrum, from very far in the ultraviolet into the visible, on one of the NASA astronomical observatories. If these results show any interesting avenues, it will certainly be worth while to consider the inclusion of such experiments on meteorological and geophysical satellites which are generally designed to look at the earth and are not the best suited vehicles to carry sensors to observe the sun; the solar observatory and astronomical satellites, of course, are designed for that purpose. Maybe there will be good reason to combine the measurements from the two programs.

JAMES, United Kingdom: I would like to ask Dr. Nordberg about the equations he wrote for determining the parameters when calibrating the radiation instruments. Are they satisfactory for a satellite?

NORDBERG: I can give a quick answer to your question. The equations that were written down are for steady state. They do not use a time variation. The time constant of the instrument was measured in the laboratory, and this is another one of these extraneous calibration procedures that we have to go through. It turns out that this instrument, the wide-field radiometer, has a time constant of up to 1 to 1½ minutes. This is not very good if you want to get a fairly high resolution. But, on the other hand, this instrument has not been designed for high resolution. In comparing this instrument with the very fast responding five-channel instrument, the data still agree very well when we consider time and space averages.

If the satellite passes over an area of rapidly changing radiation features, such as in the African case I mentioned, in which the satellite starts out over the Mediterranean Sea, then passes over the desert, and finally passes over tropical areas, the time constant of the wide-field radiometer produces a time lag with respect to the faster responding five-channel instrument.

So it is true; one cannot get a high resolution in time with this instrument just as one cannot get a high resolution in space with this instrument. This is a very crude instrument. Even though it is so crude, it yields a good deal of useful data over the time that it sees the earth.