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PRELIMINARY STUDY OF PLANETARY-SCALE OUTGOING LONG-WAVE RADIATION AS DERIVED FROM TIROS II MEASUREMENTS

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ABSTRACT

Daily composite Northern Hemisphere charts of outgoing long-wave radiation were derived from TIROS II measurements for about 25 days in late November and December 1960. Although data coverage was incomplete and variable each day, both latitudinal and overall daily averages of long-wave radiation were obtained. Large-scale temporal variations in the long-wave radiation are observed and are found to be generally related to temporal variations in kinetic and available potential energy over the Northern Hemisphere. Examination of the radiation latitudinally for various stages of an energy cycle that occurred at this time shows that the outgoing radiation, particularly at lower latitudes, decreased as westerly flow increased at lower latitudes. An average latitudinal profile of the TIROS long-wave data for all days studied shows rather good agreement with previous estimates made by investigators of the atmospheric heat budget.

One of the primary purposes of the radiation experiments on meteorological satellites is to observe for the first time on a global basis the heat budget of the earth-atmosphere system. Two of the five channels of the TIROS II radiometer [1] were designed to provide measurements which could be used for this purpose. These are channel 3, which was designed to measure reflected solar radiation so that albedo and net incoming solar radiation could be derived, and channel 4, which was designed to measure the total outgoing long-wave radiation to space. Unfortunately, the channel 3 data from TIROS II are of questionable use because of difficulties in calibration. On the other hand, preliminary evaluations seem to indicate that the channel 4 data, at least during certain observational modes on each orbital pass [2], are generally reliable.

The channel 4 radiometer measures intensity of radiation in the range of 7–33 microns at a given zenith angle, which varies over each scan and each orbital pass, and the spectral sensitivity of its filter is not flat. These characteristics offer limitations which must be overcome to derive the total outgoing radiative flux. Methods of adjusting these data so that radiative flux can be obtained from any given channel 4 measurement have been derived by Wark et al. [3] and their procedures were applied to the data we have used in our investigation.

Broad-scale study of the overall long-wave radiation derived from the channel 4 measurements has been attempted through use of daily composite radiation charts for the Northern Hemisphere. These charts, for which the data in overlapping portions of the orbital passes during a given day were simply averaged together, were prepared for about 25 days in late November and in December 1960 (only for those days when usable infrared data were available from at least three orbital passes). A sample of one of these daily composite radiation charts is shown in figure 1, where the radiation data are superimposed on the 500-mb. contours for the beginning of the day. The radiation data are not for one synoptic time, but generally cover a substantial portion of the 24-hour period. At any given latitude (except north of about 40° N.) the measurements are taken at either one or two specific local times during the day. Data on these charts are limited by the basic maximum number of orbital passes that can be interrogated by the two acquisition

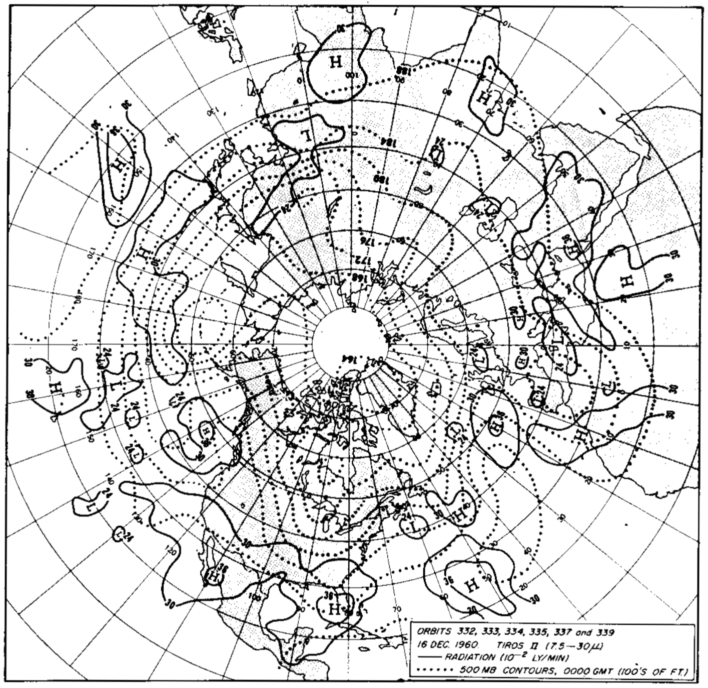

FIGURE 1.—Composite chart of overall infrared radiation for a 24-hour period derived from channel 4 data through use of procedure given by Wark et al. [3]. At grid points with overlapping observations from two or more orbital passes averages of all available data for the day were obtained. H and L refer to maxima and minima of long-wave radiation, respectively. Superimposed 500-mb. contours (dotted lines) are for the beginning of the day (0000 GMT). Radiation data north of about 55° N. are nonexistent because of TIROS orbit. Substantial gaps in the data also exist over all latitudes south of 55° N.

stations, the variation in the number of passes interrogated because of technical problems, and the inability of the TIROS II satellite to take observations north of about 55° N.

Since these infrared data from channel 4 are highly correlated with the values in the "window" region (channel 2), most of the variations in the field of radiation data in figure 1 are related to the distributions of cloudiness: low values where there are middle or high clouds and high values where there are low, scattered or no clouds (cf. [4], [5]). It can be seen that this radiation pattern shows a general relationship to the flow pattern, but the relationship between the ridge and trough systems and the high and low values of radiation is by no means a simple one. Much detailed synoptic study can be made of these patterns relative to the flow and the cloudiness, but this will not be attempted here. The main purpose for showing this chart is to exemplify the type of data coverage which was used to derive the broad-scale summations of the radiation data which will be shown in the following figures. From each of these daily maps, radiation values were tabulated for each 5° latitude-longitude intersection where data were available. Furthermore, some of the analyzed data in figure 1 and in other composite charts were not used because only a relatively small number (less than 10) of the original digital data from the channel 4

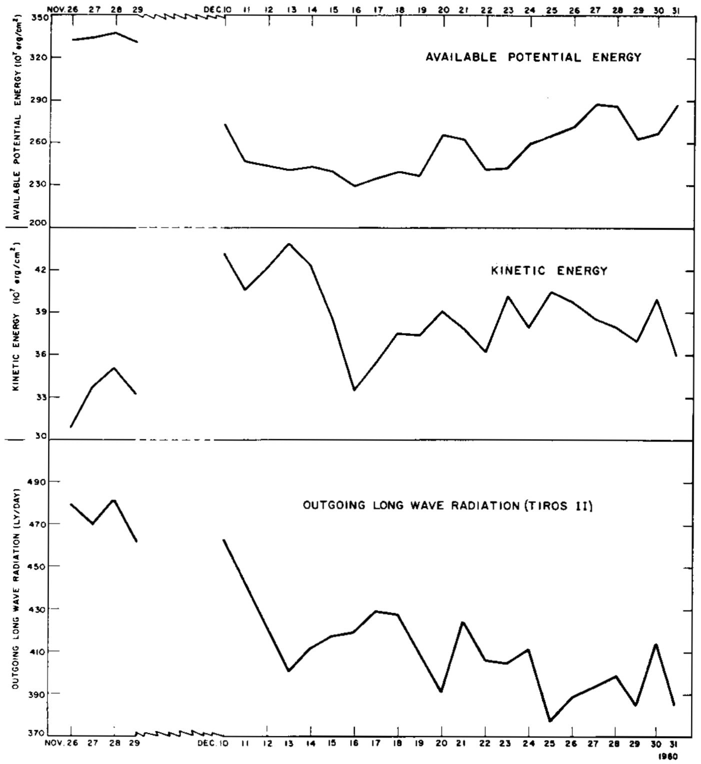

FIGURE 2.—Time variations of average long-wave radiation from TIROS II over all latitudes (20°–55° N.) for each day (lower), and of kinetic energy (middle) and available potential energy (upper) for the layer 850–500 mb. for the entire Northern Hemisphere (approximately 20°–90° N.).

radiometer were available for grid points near such intersections. Thus, from the more numerous portions of the data, daily average values at each latitude circle between 20° and 55° N. were obtained. The latitudinal averages were not adjusted in any way to take care of missing longitudinal intersections within the latitude circle, but were simple averages of all data available each day. In addition, one overall average value of radiation for all latitudes was obtained each day.

The variation of this overall average value with time is shown in the lower part of figure 2. In view of the many variations in the areas of data coverage from one day to the next, it is unwise to dwell on the day-to-day changes in the radiation, but the large-scale differences in the overall level of the infrared radiation between the four days in late November and most of the December period seem noteworthy. (Unfortunately, insufficient data were available for preparation of composite maps for the period November 30 through December 9.) Certainly the changes in the radiation, from relatively high values at the end of November to considerably lower values in the middle of December and then apparently to even slightly lower values in the last 10 days of the month, appear to be quite significant. Inspection of temporal variations in energy parameters that were computed for the Northern Hemisphere (northward of 20° N. and for the layer 850 to 500 mb.) (cf. [6]) show that the kinetic energy and the available potential energy (shown in fig. 2) were going through some marked variations at this time too. In particular, the available potential energy had dropped from rather large values at the end of November to considerably lower values in December with some sign of a rise toward the end of that month. On the other hand, kinetic energy was at a rather low value in late November and had risen to somewhat higher values through the month of December. This represents a large-scale energy cycle during which a large supply of available potential energy (strong thermal gradients over the hemisphere) built up in late November and then decreased rapidly in the first part of December with an accompanying increase in the kinetic energy. The latter increase is attributable to a transformation of a portion of the available potential energy into kinetic energy. It is interesting to note then that the variations in the infrared radiation during this period at least bear a gross relationship to these variations in the large-scale energy parameters for the Northern Hemisphere.[1]

To examine this relationship further the data were averaged for three periods and examined more closely relative to their latitudinal distributions. These are shown in the lower part of figure 3, where the four November days are seen to have greater outgoing radiation at all latitudes than the other two periods in December. As could be anticipated from the variations in figure 2, the radiation for all latitudes reached its lowest value by the last part of December, but the largest overall drop occurred at the lower latitudes. It is interesting to compare these latitudinal profiles of the radiation with latitudinal profiles of zonal kinetic energy (essentially the square of the mean zonal wind in each latitude) for the same periods, as shown in the upper part of figure 3. Note that in the initial period the westerlies were strongest between 40° and 45° N. and generally weaker in the lower latitudes. As the energy cycle progressed, the zonal kinetic energy (or the zonal westerlies) increased at all latitudes south of 40° N. Toward the end of December some further increase in the westerlies took place south of about 32° N., but there was some decrease to the north. Thus, in the large-scale hemispheric flow, there was an increase of westerlies in the subtropics and in lower portions of temperate latitudes between the end of November and approximately the last 20 days of December.

These stronger westerlies at lower latitudes were accompanied by increased cyclonic activity and more middle and high cloudiness relative to the preceding regime of weak westerlies when strong subtropical anticyclones were dominant at these latitudes. Increased cloudiness at middle and high levels would, of course, tend to decrease the net outgoing long-wave radiation as observed by the

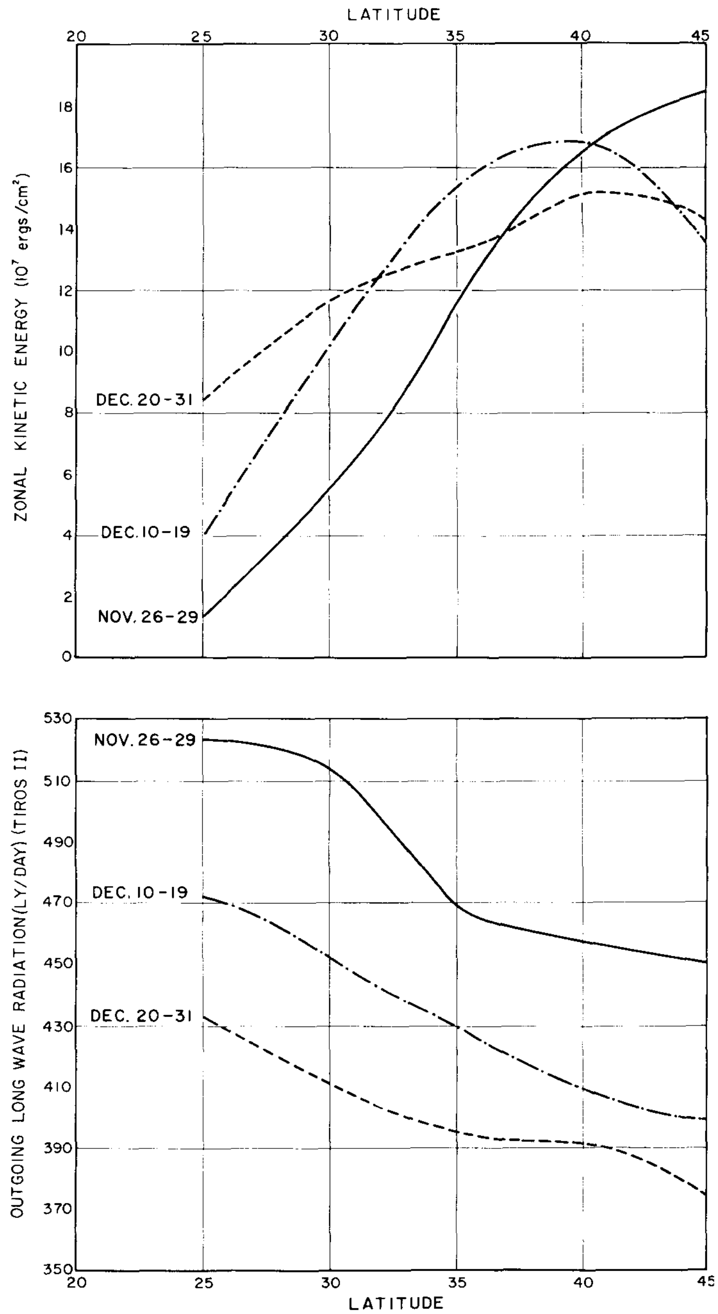

Figure 3.—Latitudinal variation of long-wave radiation (lower) and of zonal kinetic energy (upper) for three time periods during November–December 1960.

satellite. Another factor contributing to this decreased long-wave radiation in December, even at middle latitudes where the westerlies decreased, would be the large-scale decrease in temperatures in the troposphere as the available potential energy decreased and the westerlies expanded southward. Indeed, cursory examination of temperature falls from late November to December 1960 (which were generally markedly in excess of normal decreases) showed that much of the decrease in outgoing radiation north of about 35° N. could be attributed to the basic lowering of temperatures without any changes in middle or high cloudiness. At lower latitudes, however,

[1] The relationship of radiational heating to these energy parameters is best expressed physically through considerations of the generation of available potential energy (cf. [7], [8]), but the lack of satellite measurements of long-wave radiation north of 55° N. and of solar radiation hampers the calculation of energy generation from these data. Nevertheless, some efforts at estimating energy generation for this period are presently being made by our colleague, Mr. A. F. Krueger, but results thus far are too tentative to be discussed here.

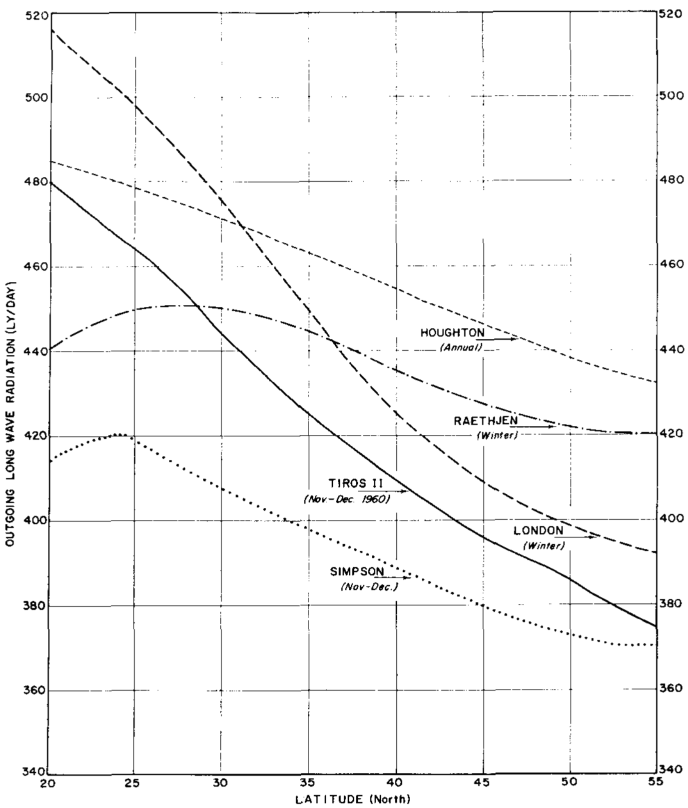

FIGURE 4.—Average latitudinal variation of long-wave radiation from TIROS II for all available days in November–December 1960 in comparison with estimates made by several investigators of the heat budget.

the temperature changes were too small to account for the marked drop in radiation, and increased middle and high cloudiness would appear to be the principal cause of the sharp falls in outgoing radiation observed there. Essentially then the increase in westerlies (or zonal kinetic energy) in the lower latitudes was accompanied by a decrease in the north-south contrast in outgoing radiation, which had been much stronger at the start of this cycle of available potential energy. In summary there seems to be physical reality to these time variations in the TIROS II radiation data, which is very gratifying at this early stage in their evaluation on a large-scale basis.

One final summation of the data is shown in figure 4, where the overall latitudinal averages of the outgoing infrared radiation for all days of the period are given. This curve is shown relative to several estimates made in heat budget studies over the years by various investigators. It will be noted that the general slope of the latitudinal distribution of outgoing radiation agrees most closely with the study of London [9], although the differences from Raethjen's [10] and Simpson's [11] are also not very great. Even Houghton's [12] curve for the average annual variation of outgoing radiation does not differ by an unexpected amount. It is possible that the TIROS II data, which are dominated by the lower values accompanying the pronounced energy cycle, may actually be lower than the "normal" radiation for this time of year. On the other hand, all previous studies are based on estimates of the distribution of meteorological parameters such as temperature, humidity, and clouds to obtain a broad-scale computation of the outgoing radiation. As many more satellite radiation data accumulate, the true outgoing long-wave radiation to space should become known with much more precision than any estimates could possibly achieve. For the present, however, figure 4 provides the very interesting information that TIROS II has made radiation measurements which agree well with some of the best previous estimates based on theory and empiricism.

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