Comments on "Cloud Heights and Nighttime Cloud Cover from TIROS Radiation Data"

JAY S. WINSTON

Meteorological Satellite Laboratory, U. S. Weather Bureau, Washington, D. C.

12 June 1964 and 2 November 1964

1. Introduction

It is obvious that observations from meteorological satellites are providing meteorologists with much information which is new and different from what could be obtained prior to the advent of the satellites. In some cases these results will be truly startling and indeed the results presented in the paper by Rasool (1964) are a case in point. In particular, his findings that cloud cover over parts of the Southern Hemisphere in July–September 1961 increased by as much as a factor of 2 from day to night are truly phenomenal. This is particularly so when one considers that conventional climatological data show diurnal variations over ocean regions to amount to about 5–15 per cent. Of course, if the reader cannot accustom himself to this severe jolt from his long-established ideas about diurnal cloud variations over oceans, the author does allow him the option of assuming that the cloud amounts do not vary, but that the cloud heights should be 2 to 4 km higher during nighttime as compared with daytime over the Southern Hemisphere. Similar arguments are applied, but in reverse fashion, to the diurnal variations shown for the Northern Hemisphere.

In view of the unusual nature of either or both of these interpretations of the satellite data, it is surprising that these results were not subjected to careful, critical examination prior to publication with respect to 1) previous findings regarding diurnal variations in cloudiness, 2) methods of procedure, and 3) the reliability and nature of the data sample. Since this has apparently not been done, I wish to discuss here some of the questions regarding Rasool's treatment of the data and to cite some evidence against the validity of the results presented in his paper.

2. Climatology of cloudiness

It seems pertinent first of all to present some climatological data with respect to diurnal variations in cloudiness. In Table 1, I have assembled some readily available existing data on percentage cloudiness (the parameter used by Rasool) from ocean and land stations in both hemispheres, mostly for the month of August. These data for night and day were obtained according to the same basic time definitions used by Rasool. Average values between 06 and 18 local time are considered to be daytime values; and between 18 and 06 to be nighttime values. As many stations as possible were selected for ocean areas, while only a limited selection has been included for continental regions. In view of the sparsity of ship data, February values for some of the Northern Hemisphere ships have been placed at corresponding latitudinal locations in the Southern Hemisphere, with the hope that they may possibly be representative of diurnal variations in wintertime cloudiness over the Southern Hemisphere oceans. A further selection of those data which could be conveniently plotted in one diagram is portrayed in Fig. 1, along with day and night cloudiness values presented by Arking (1964) and Rasool (1964).

No strong claims are being made for great reliability of surface observations nor for the latitudinal representativeness of each of the stations shown, but the predominant comparison that can be made between night and day is that the variations are relatively small (differences of no more than 15 per cent between night and day) and that virtually all oceanic stations show more cloudiness during the day than at night. This was essentially the conclusion of the study of subtropical ship data by Riehl (1947) who showed, even when only periods around full moon were considered (i.e., when presumably nighttime observations are more reliable), that the cloudiness averaged higher in daytime (Riehl's

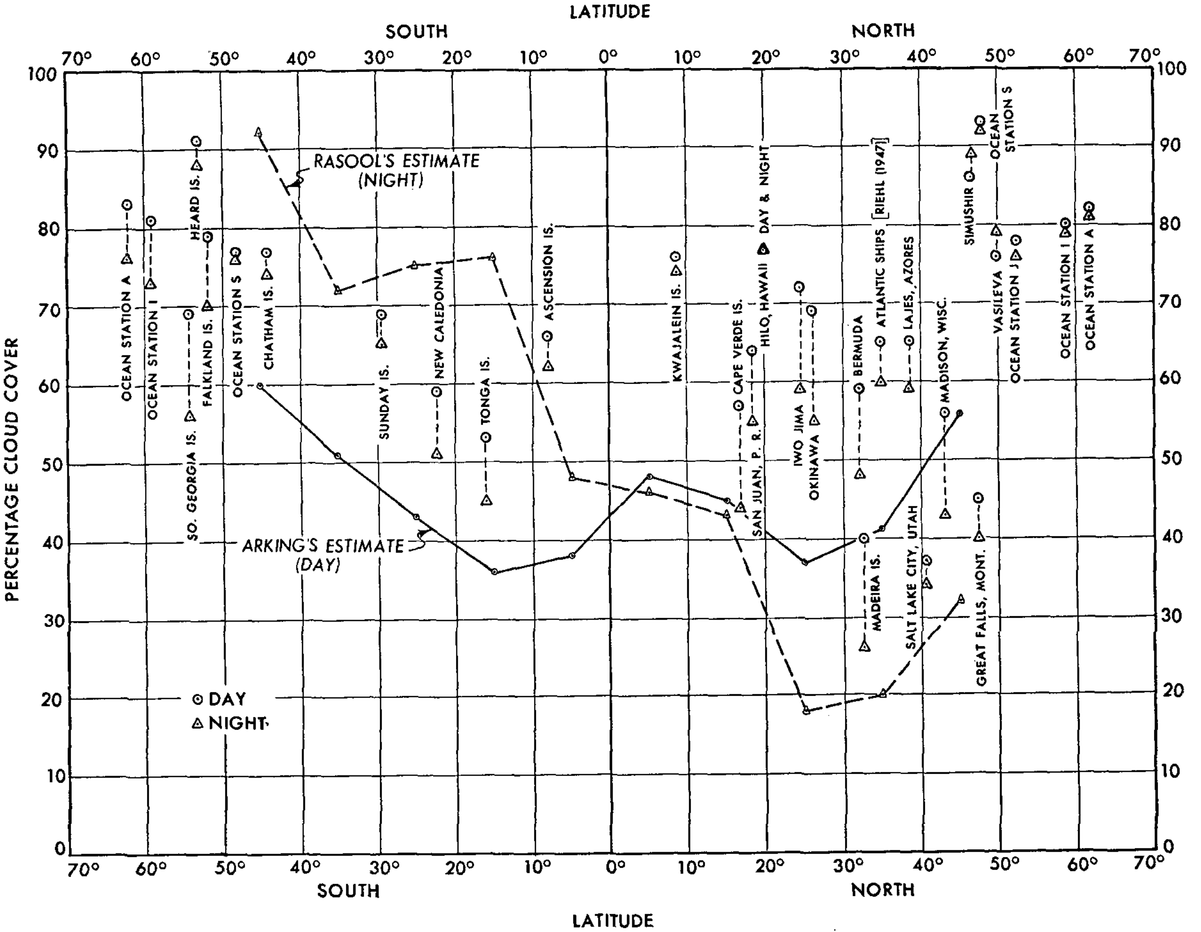

FIG. 1. Average percentage cloud cover in August for day and night for stations selected from the listing in Table 1. February values for ocean stations A, I, and S have been plotted at corresponding latitudes in the Southern Hemisphere to provide values which may possibly be representative of oceanic regions at those latitudes. Day and night estimates as obtained from TIROS III data by Arking (1964) and Rasool (1964) for July–September 1961 are also shown.

Table 1. Average percentages of cloud cover for day and night for August (except as noted).

Latitude zone	Station	Latitude	Longitude	Average percentage cloud cover		No. of years of record	Data source†
				Day	Night		
North of 50N	Ocean Station A	62°00′N	33°00′W	82	81	6	1
	Ocean Station A	62°00′N	33°00′W	86	86	1	1
	Ocean Station I	59°00′N	19°00′W	80	79	6	1
	Ocean Station J	52°30′N	20°00′W	78	76	6	1
	Vasileva	50°00′N	155°23′E	76	79	3	3
40° to 50N	Ocean Station S	48°00′N	162°00′E	93	92	3	4
	Seattle, Wash.	47°32′N	122°18′W	58	49	10	2
	Great Falls, Mont.	47°29′N	111°21′W	45	40	10	2
	Simushir	46°51′N	151°52′E	86	89	3	3
	Madison, Wisc.	43°08′N	89°20′W	56	43	10	2
	Boston, Mass.	42°22′N	71°01′W	56	50	10	2
	Salt Lake City	40°46′N	111°58′W	37	34	10	2
30° to 40N	Denver, Colo.	39°46′N	104°53′W	48	39	10	2
	Washington, D. C.	38°51′N	77°02′W	52	48	10	2
	Lajes, Azores	38°45′N	27°05′W	65	59	15	3
	Phoenix, Ariz.	33°26′N	112°01′W	36	41	10	2
	Dallas, Texas	32°51′W	96°51′W	37	26	10	2
	Madeira Isl.	32°38′N	16°54′W	40	26	5	3
	Bermuda	32°22′N	65°40′W	59	48	10	3
	Ships in Subtropical Atlantic	Centered at 35°N	40°W, 52–55W 70°W				
	All observations			61	53	2	6
	at full moon			65	61	2	6
20 to 30N	Okinawa	26°10′N	127°50′E	69	55	15	3
	Miami, Fla.	25°49′N	80°17′W	62	43	10	2
	Iwo Jima	24°47′N	141°20′E	72	59	15	3
	Honolulu, Hawaii	21°20′N	157°56′W	47	40	10	2
10 to 20N	Hilo, Hawaii	19°43′N	155°04′W	77	77	10	2
	Wake Island	19°17′N	166°39′W	53	47	10	2
	Aquadilla, P.R.	18°30′N	67°08′W	61	56	5	5
	San Juan, P.R.	18°28′N	66°07′W	64	55	4	5
	St. Thomas, V.I.	18°20′N	64°58′W	51	31	5	5
	Santa Isabel, P.R.	17°58′N	66°24′W	45	35	3	5
	St. Croix, V.I.	17°42′N	64°48′W	63	45	5	5
	Cape Verde Isl.	16°53′N	25°00′W	57	44	8	3
0 to 10N	Kwajalein Isl.	08°43′N	167°44′E	76	74	18	3
0 to 10S	Ascension Isl.	07°55′S	14°25′W	66	62	7	3
10 to 20S	Tonga Isl.	15°58′S	173°64′W	53	45	5	3
20 to 30S	New Caledonia	22°01′S	166°13′E	59	51	4	3
	Sunday Isl.	29°15′S	177°55′W	69	65	8–10	3
40 to 50S	Chatham Isl.	43°58′S	176°31′W	77	74	3	3
	*Ocean Station S	48°00′S	162°00′E	77	76	2	3
South of 50S	Falkland Islds	51°42′S	57°52′W	79	70	5	3
	*Ocean Station J	52°30′S	20°00′W	80	68	6	1
	Heard Isl.	53°01′S	73°23′E	91	88	6	3
	So. Georgia Isl.	54°16′S	36°30′W	69	56	5	3
	*Ocean Station I	59°00′S	19°00′W	81	73	6	1
	*Ocean Station A	62°00′S	33°00′W	76	75	1	1
	*Ocean Station A	62°00′S	33°00′W	83	76	6	1

* Data from Northern Hemisphere Ocean stations were included at corresponding Southern Hemisphere Latitudes. February data were used to reflect approximate August conditions in the Southern Hemisphere.

† Key to data sources:

1. Ocean weather ship meteorological summaries, Meteorological Office, Great Britain. (Years: 1955–1960; 1961 for the additional single year at Ship A.)
2. Climatography of the United States, Decennial Census of United States Climate—Summary of Hourly Observations, U. S. Weather Bureau. (Years: 1951–1960.)
3. Standard weather summaries, U. S. Air Force Climatic Center. (Various years.)
4. Special weather summary, U. S. Weather Bureau, National Meteorological Records Center. (Sept. 1950–May 1953.)
5. Special weather summaries, U. S. Weather Bureau, San Juan, Puerto Rico. (Various years between 1951 and 1960.)
6. Riehl, 1947 (see references). (June–October 1944, April–October, 1945.)

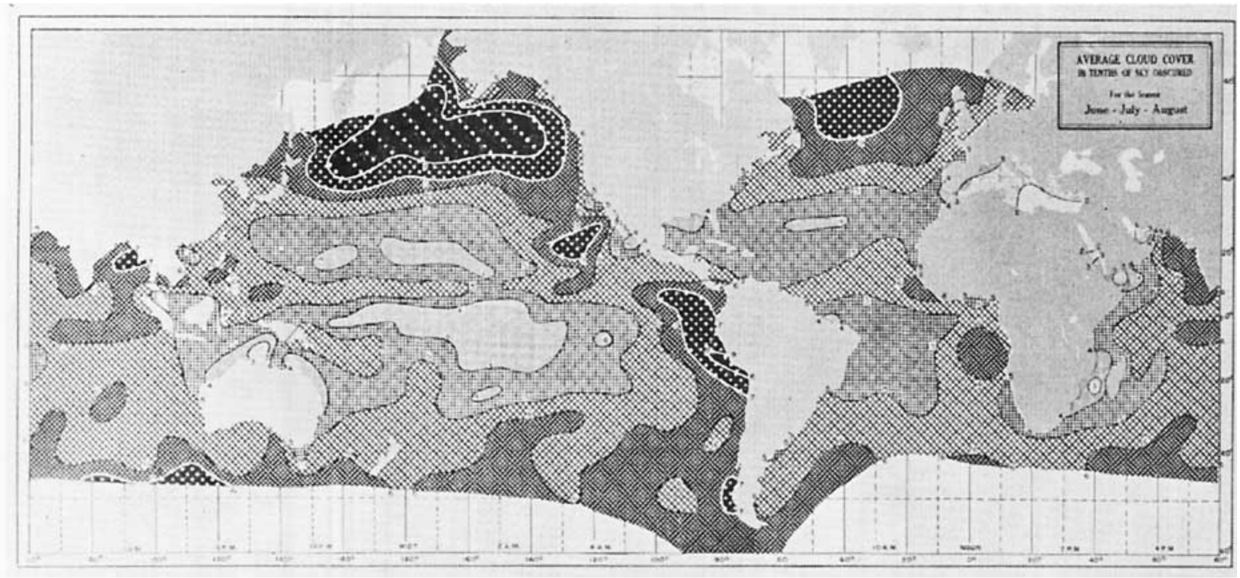

FIG. 2. Average cloud cover in tenths of sky obscured for the season, June, July, and August. Data are all for 1200 GCT. (Chart 69 of McDonald, 1938.)

values are included in Table 1 and Fig. 1). Even land stations over the Northern Hemisphere, which have relatively large diurnal variations, show much smaller diurnal differences, when averaged over 12-hour intervals, than Rasool's values for entire latitude belts in the Northern Hemisphere.

Further evidence of a general lack of difference between daytime and nighttime cloudiness over oceans may be found in Fig. 2 which shows average cloud cover for June, July and August based on many years of ship observations made at 1200 GCT (McDonald, 1938). In this collection of data, the values at each longitude have a different local time. Thus, one can compare daytime cloudiness in the Atlantic and Indian Oceans at the same latitudes with nighttime cloudiness in the Pacific Ocean. Naturally many of the differences in cloudiness are due to geographical differences in the synoptic climatology (e.g., more cloudiness in the temperate latitudes of the North Pacific as compared with the North Atlantic is associated with differences in storm tracks rather than diurnal influences). Nevertheless, on the average there are differences of only one or two tenths in cloudiness along almost any latitude circle; even smaller if all the data were averaged into the two twelve-hour day and night periods that we have been considering. Note particularly that the differences are very small over the Southern Hemisphere where Rasool shows such large differences between day and night.

When cloudiness data over ocean regions are examined in more detail relative to time of day there is some evidence of a maximum toward early morning, and usually a second maximum toward early evening (Sverdrup, 1945). This is found in the distributions of amounts of low cloudiness for the subtropical Atlantic ships by Riehl (1947) and for Eniwetok by Lavoie (1963).

The only evidence that may support Rasool's alternative suggestion that clouds may be higher in the Southern Hemisphere during the night than during the day is the indication that there is more precipitation at night over ocean regions as shown by Kraus (1963) and also by Lavoie (1963). However, it is a moot question as to how much higher the clouds would be. Certainly an average of 2 to 4 km higher, as suggested by Rasool, seems very excessive even if nighttime precipitation were much greater than daytime amounts. Also, if clouds were higher at night over Northern Hemisphere oceans in summer, then why wouldn't these oceanic effects either cancel or overshadow continental influences when averaging over latitude circles? Thus Rasool's differences for the Northern Hemisphere are subject to question on this basis too.

3. Inadequacies of TIROS radiation data for measuring diurnal variations

Rasool's differences between night and day may be strongly affected by synoptic and climatological changes over the period between 12 July and 10 September 1961. Over most areas of radiation data coverage the satellite views a location only once or up to two or three times a day; the multiple views are mainly obtained on consecutive orbits which may be only about two hours apart. Thus we have the situation, for example, that in July 1961 Southern Hemisphere data for the Atlantic Ocean, Africa, and the western Indian Ocean were mainly daytime data, whereas observations over the eastern Indian Ocean and the Pacific Ocean were made at night. During the month of August 1961 this situation was mainly reversed, with nighttime data in the former area and daytime data in the latter area. Thus, for the same synoptic periods one is comparing daytime values over the Atlantic, Africa and the western Indian Ocean with nighttime values over the Pacific Ocean. The diurnal comparisons for a given area involve examination of daytime data in one period of perhaps a few weeks with nighttime data in another period of similar length. For example, over the Atlantic Ocean, Africa and western Indian Ocean, daytime data occur in July and these are compared with nighttime values obtained in August; the opposite effect occurs in the Pacific Ocean. Obviously then this general inability to compare day and night data for the same regions day after day is damaging and could seriously affect these results. Certainly then this geographical and temporal bias of the data can have a profound influence on these so-called diurnal variations, especially when the total period of study is only two months.

In view of this problem it seems most desirable to try to investigate diurnal variations over particular geographical regions. There are some areas where radiation data have been obtained from two orbital passes approximately 12 hours apart. These are small areas over North and Central America and in the southern Indian Ocean [see Fig. 5 of Winston and Rao (1963) for an example of the areas that can be observed in this way]. In such areas it would be useful to look at the data from individual orbits 12 hours apart and to observe the average changes from day to night. So far as I know, this has not been done on a large scale basis as yet. Individual daily cases of diurnal change in satellite radiation values were reported on by Rao and Winston (1963) and by Fritz (1963), but mainly from the point of view of changes in cloudless regions. Extensive study of such areas, particularly where the results could be checked with information from conventional data, might enable us to arrive at more definite conclusions about diurnal variations in cloud amounts and/or heights.

4. Examination of possible diurnal variations in TIROS IV data

In studying the long-wave radiation data obtained from TIROS IV, our group in the Meteorological Satellite Laboratory has obtained composite daily maps of data from channel 2. Unfortunately, for purposes of investigating diurnal effects this compositing does not allow us to examine separately the data which are derived from two or more orbital passes. However, in most of the regions within about 20 degrees of latitude of the equator the data are obtained only during a single pass at one local time each day. We have been examining the data from some individual five degree latitude-longitude grid areas with respect to local time over the four month period of the TIROS IV record. Although the TIROS IV data are for a different period of the year than the TIROS III data (February–May 1962 as compared with July–September 1961) it is unlikely that physical processes involving diurnal changes would be appreciably different over oceans in the different seasons of the year. Examination of a few oceanic locations in the Southern Hemisphere (in the same latitudes where Rasool finds large differences) shows no apparent difference between nighttime and daytime observations.

As an example, daily values of outgoing long-wave radiation averaged for the area centered at 15S, 150W are arrayed with respect to local time in Fig. 3. When one considers the general range and average of values for daytime (06–18 local time) vs. nighttime (18–06 local time), it would be difficult to decide that there is any notable difference between them, even though seasonal changes would seem to appear like diurnal changes. There seems to be a relative lack of very low values between about 1400 and 2400, but such a lack can most readily be attributed to the lack of substantial cloudiness during the limited periods in which samples for these hours were obtained. It is obvious that even the sample of data available with TIROS IV, which is twice as large as the TIROS III

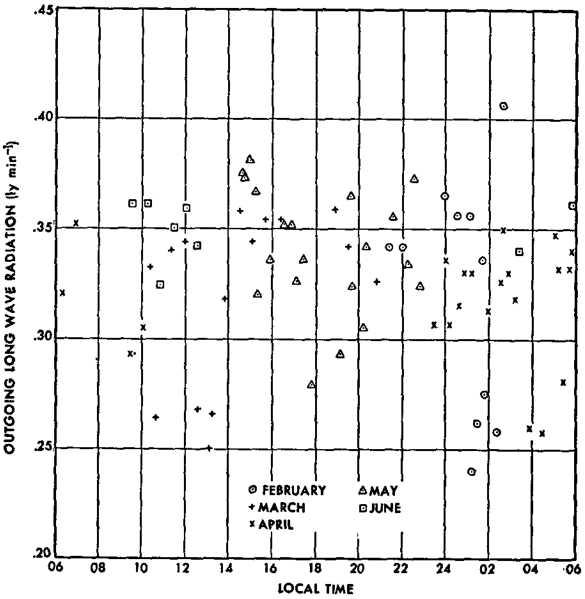

FIG. 3. Daily averaged outgoing long-wave radiation in the 5 deg latitude-longitude area centered at 15S, 150W as derived from TIROS IV data, arranged according to local time of observation. Values shown are for days when 20 or more radiation values were obtained within the area. Data in the various months are constrained within certain local time periods due to the nature of the TIROS orbit and the limited acquisition of TIROS data. Values shown are from the period between 11 February and 25 June 1962. Data were adjusted for empirical limb-darkening effects, but were not corrected for instrumental degradation.

sample used by Rasool, is inadequate to make a truly definitive judgment about the presence or absence of diurnal variations in the radiation data and hence the cloudiness.

5. Degradation problems

Substantial degradation in the channel 2 sensor occurred on the TIROS III satellite according to Bandeen *et al.* (1963). Rasool states that corrections for degradation were applied to the data. However, the corrections recommended by Bandeen are quite uncertain, are based on a number of assumptions, and may not account for all of the behavioral problems of the instrument. Corrections for channel 3 of TIROS III have been questioned, for example, by Fritz *et al.* (1964). Bandeen's recommended corrections vary with time (date), and it is possible that the routine application of these corrections to individual pieces of data for the sample used by Rasool could produce certain biases. These biases could even be responsible for some of the temperature differences between night and day that have been presented by Rasool. He should at least have attempted to estimate the possible influence of these degradation adjustments, particularly if the corrections are subject to some doubt.

6. Other questions concerning Rasool's methodology

There are many other gross assumptions made in Rasool's paper which could have produced spurious differences between his estimates of daytime and nighttime cloudiness and errors in the absolute magnitudes of cloud amounts. Particularly dangerous is the assumption of one model atmosphere for an entire 10° latitude belt. For example, the applicability of the hot and humid atmosphere shown in Rasool's Fig. 3 for the middle of the Sahara Desert is certainly open to question. Also inspection of his Figs. 3 and 4 indicates that rather small variations in the difference between the surface temperature and equivalent temperature measured by the satellite (ΔT) could result in significant differences in either percentage cloudiness or cloud height, which indicates a great deal of sensitivity in the whole method to small variations in the satellite measured equivalent temperatures. Such sensitivity leads to doubts about the significance of the differences obtained between night and day.

Other questions involving the absolute magnitudes of cloud amounts of course depend first of all on the accuracy of Arking's (1964) data, which in themselves are subject to many assumptions and questions about accuracy. Furthermore, since Arking's values for daytime cloud amounts were used, there is the further question of how well the daytime sample of radiation data matches the cloud picture sample. Examination of the location of cloud pictures used in Arking's study (Fig. 3 of Arking, 1964) and of the distribution of daytime radiation data used by Rasool shows that there are considerable differences in areal coverage and weighting of the observations. Such sampling differences could have an important influence too.

7. Conclusion

All things considered, Rasool's results can only be looked at very skeptically at the present time. I believe most meteorologists would like to have before them much firmer evidence before accepting the idea that diurnal variations in cloudiness are of such large magnitudes, or are even in the directions indicated by Rasool's results.

REFERENCES

Arking, A., 1964: The latitudinal distribution of cloud cover from TIROS photographs. *Science*, **143**, 569–572.

Bandeen, W. R., R. E. Samuelson and I. P. Strange, 1963: Correction models for instrumental response degradation. *TIROS III Radiation Data Users' Manual Supplement*, Goddard Space Flight Center, NASA, Greenbelt, Md., 59 pp.

Fritz, S., 1963: The diurnal variation of ground temperature as measured from TIROS II. *J. Appl. Meteor.*, **2**, 645–648.

——, P. K. Rao and M. Weinstein, 1964: Satellite measurements of reflected solar energy and the energy received at the ground. *J. Atmos. Sci.*, **21**, 141–151.

Kraus, E. B., 1963: The diurnal precipitation change over the sea. *J. Atmos. Sci.*, **20**, 551–556.

Lavoie, R. L., 1963: Some aspects of the meteorology of the tropical Pacific viewed from an atoll. *Atoll Research Bulletin*, No. 96, Pacific Science Board, Washington, D. C., 80 pp.

McDonald, W. F., 1938: *Atlas of Climatic Charts of the Oceans*. U. S. Weather Bureau, Washington, D. C., W.B. No. 1247.

Rao, P. K., and J. S. Winston, 1963: An investigation of some synoptic capabilities of atmospheric "window" measurements from satellite TIROS II. *J. Appl. Meteor.*, **2**, 12–23.

Rasool, S. I., 1964: Cloud heights and nighttime cloud cover from TIROS radiation data. *J. Atmos. Sci.*, **21**, 152–156.

Riehl, H., 1947: Diurnal variation of cloudiness over the subtropical Alantic Ocean. *Bull. Amer. Meteor. Soc.;* **28**, 37-40.

Sverdrup, H. U., 1945: Oceanography, Section XIV, 1030–1056. *Handbook of Meteorology*, New York, McGraw-Hill Book Co., Inc., 1068 pp.

Winston, J. S., and P. K. Rao, 1963: Temporal and spatial variations in the planetary-scale outgoing long-wave radiation as derived from TIROS II measurements. *Mon. Wea. Rev.*, **91**, 641–657.