Comparison of Measured and Estimated Insolation over the Eastern Pacific Ocean[1]

R. K. REED

Pacific Marine Environmental Laboratory, NOAA, ERL, Seattle, WA 98105

(Manuscript received 28 August 1981, in final form 11 December 1981)

ABSTRACT

Measurements of insolation at sea are reported and used to compare with a recent empirical formula for computing insolation. The measured and computed results are in good general agreement over a vast region of the eastern Pacific between 7°S and 66°N. Measurements and computations differ by a few percent in the mean over some regions, apparently because of atypical cloud cover.

1. Introduction

In 1975 our laboratory started a program to routinely measure insolation at sea aboard the NOAA ship *Oceanographer*, and these measurements were continued for six years. Prompted by the need for insolation estimates for oceanic heat budget work, Reed (1977) used observations at six coastal nonurban sites in the National Weather Service network to verify a clear-sky formula derived by Seckel and Beaudry (1973) from data in the *Smithsonian Meteorological Tables* (List, 1958) and to develop an appropriate cloud factor with inputs of cloud amount and solar altitude. The first 125 days of data from the *Oceanographer* were compared with the cloud factor, and the mean difference was only 2%. Reed (1978) also used the initial two years of data to examine regional differences in radiation caused by variable clouds in the tropical Pacific. The entire six years of data from the *Oceanographer* have not been published but have been archived as individual daily totals, with supporting meteorological data, at NOAA's National Climatic Center in Asheville, North Carolina. The data set is used here primarily for comparison with the cloud factor developed previously.

2. Data and methods

An Eppley model 8-48 pyranometer was mounted atop a leveled post on the forepeak of the *Oceanographer*; the output of the pyranometer was recorded on an analog recorder, and the signals were accumulated by an electronic integrator that was used to derive daily total insolation. Technicians aboard the ship annotated the records and inspected and cleaned the pyranometer dome. In support of these measurements, *hourly* (rather than three- or six-h) weather observations were made to allow determination of cloud cover.

Details on calibration of the pyranometers are contained in Table 1. Pyranometer number 12299 was used from the start of the program until it became inoperative in March 1979; number 12536 was used for the remainder of the cruises. The instrument calibrations performed by Eppley Laboratory were referred to the International Pyroheliometric Scale (IPS 56), but those conducted by NOAA's Environmental Research Laboratories (ERL) at their facility in Boulder, Colorado were based on the Absolute Scale as maintained by an absolute, cavity radiometer at the World Radiation Center in Davos, Switzerland (E. Flowers, pers. commun., 1981). The Absolute Scale has recently been adopted by the World Meteorological Organization (WMO) as the international reference scale, and it gives radiation values 2.5% greater than the IPS 56 scale. Discounting the difference in the Absolute and IPS scales, the greatest change in calibration factor for an instrument was 1.2% for number 12299 from December 1975 to January 1978.

Conversion of the *Oceanographer* data to a common scale was considered, but it was decided not to do this. If the entire data set were referred to the Absolute Scale, mean insolation would be only ~1% greater than used below. Errors in individual calibrations, instrument response, electronic signal processing, etc. may reach this magnitude. The National Weather Service data used to verify the clear-sky formula and derive the cloud factor (Reed, 1977) were nominally on the IPS 56 scale, which was the scale approved by the WMO at the time, but the primary pyranometer standard, to which field in-

---

[1] Contribution No. 534 from the Pacific Marine Environmental Laboratory.

Unauthenticated | Downloaded 01/27/22 12:50 AM UTC

TABLE 1. Information on Eppley model 8-48 pyranometers used aboard the NOAA ship *Oceanographer*, February 1975–November 1981.

Serial number	Calibration date	Source of calibration and scale	Calibration factor ($\times10^{-6}$ VW^{-1} m^2)
12299	Dec 74	Eppley (IPS 56)	10.93
	Dec 75	Eppley (IPS 56)	10.97
	Jan 78	ERL (Absolute)	10.56
12536*	Dec 74	Eppley (IPS 56)	10.57
	Dec 79	ERL (Absolute)	10.30

* Used Mar 79–Nov 81.

strument calibrations were linked, was in fact closer to the Absolute Scale (Hanson, 1976). Although the National Weather Service data were carefully examined and various corrections were made (Reed, 1977), uncertainties of 1–2% probably exist for some instruments. Hence any further adjustments to this data base or the *Oceanographer* data seem pointless.

3. Comparison

The *Oceanographer* data set does not provide any very conclusive *direct* evidence for additional verification of the clear-sky formula given by Seckel and Beaudry (1973). (Nine daily values in the region 3°S–46°N and 106–125°W, with mean cloud cover < 0.2 and characteristic clear-sky traces, had mean insolation 3.0% less than the computed value and a standard deviation from the mean of ±4%.) Since ratios of measured to clear-sky insolation are compared with computations from the cloud factor, the results below are not independent of the procedure for determining clear-sky radiation; we must rely on previous verification of the clear-sky procedures (Reed, 1977), however.

The reduction of insolation under clouds was computed with the cloud factor (Reed, 1977)

$$Q_s/Q_0 = 1 - 0.62C + 0.0019\alpha, \qquad (1)$$

where Q_s is the insolation under cloudy skies, Q_0 is the insolation under clear skies (Seckel and Beaudry, 1973), C is cloud cover in tenths, and α is noon solar altitude. A comparison of computations with Eq. (1) and the ratio of measured to clear-sky insolation is shown in Fig. 1. The periods over which the data groups shown were averaged varied from 5 to 27 days, and mean cloud cover varied from 0.28 to 1.00. The data shown in Fig. 1 are also roughly segregated into "mid-latitude" (23–66°N) and "tropical" (7°S–31°N) regions because, as will be shown, certain characteristics of insolation in these general regions appear to be slightly different.

It is, of course, possible to segregate the data in other ways, such as a function of noon solar attitude (α). This was done explicitly for four groups of α, with the result that intermediate angles had the greatest departures of observed from computed ratios. The data shown in Fig. 1 may also be influenced by the type of dominant clouds. The observations indicated that middle or high clouds were more prevalent in the tropical regions than in mid-latitudes; attempts at a more refined treatment were not very convincing though, perhaps because the cloud-type estimates are imperfect and subjective. There is also an apparent tendency in Fig. 1, especially in the tropical data, for the higher observed ratios to be greater than the computed values and vice versa for the lower observed ratios. While all the factors causing the variability apparent in Fig. 1 have not been resolved, the focus of the following analysis will be on the means and standard deviations in these large data sets.

The results of comparison of observed ratios and those computed by Eq. (1) are summarized in Table 2 along with certain statistical data. The *Oceanographer* obtained 607 days of observations that appear to be reliable and that were supported by hourly observations of cloud cover. These data were then used to form 54 groups with a mean duration of 11 days. In separating the data into these groups, the size of the area covered, similarity of meteorological conditions, and synopticity of the data were mainly considered; the choices were, of course, somewhat subjective. The data were also separated into sets of tropical and mid-latitude observations as shown in Table 2.

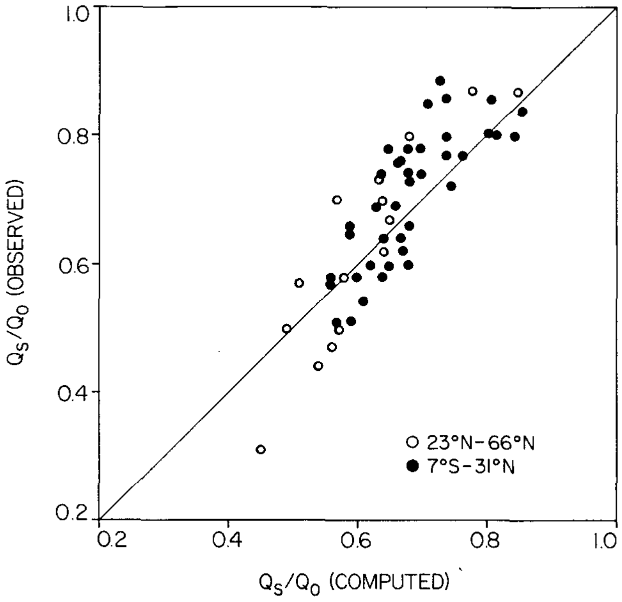

FIG. 1. The observed reduction of insolation Q_s/Q_0 versus the reduction computed by Eq. (1) from data on cruises of the NOAA ship *Oceanographer*, February 1975–November 1981.

Unauthenticated | Downloaded 01/27/22 12:50 AM UTC

TABLE 2. Statistics from comparison of insolation ratios observed aboard the NOAA ship *Oceanographer* and those computed from Eq. (1). The data were obtained from February 1975 to November 1981 in the area bounded by 7°S–66°N and 104°W–180°.

		Insolation ratios: Computed minus observed		
Sample	Groups	Mean difference of ratios (%)	Standard deviation from mean (%)	95% confidence interval of mean (%)
All data, 7°S–66°N	54	−2.6	11	3.0
Tropical, 7°S–31°N	39	−3.4	10	3.0
Mid-latitude, 23–66°N	15	−0.7	15	8.3

The groups of data were then treated as individual values without weighting for duration, which makes no significant difference to the values below, to form means and standard deviations. The mean difference between computed and observed ratios for all data in Table 2 is −2.6% (observed values are greater than those computed); the tropical set has a mean difference of −3.4%, but the difference is −0.7% for the midlatitude data. The standard deviation for the entire data set was used to estimate the standard error in an estimate of insolation by Eq. (1); thus a *monthly* mean should be reliable to ±13% at 95% confidence limits. This value is larger than that (<10%) estimated from the deviations at individual sites (Reed, 1977) but is similar to the estimates (13 and 17%) based on the tropical and midlatitude sets. The relatively large scatter in the data sets here probably results from the heterogeneous meteorological conditions over these large regions.

It would be useful to know if the means given in Table 2 actually reflect real differences between the observed insolation and that computed by the cloud factor or if the means of the *samples* and the *population* are somewhat different. Using Student's *t*-distribution (Freund, 1979), the 95% confidence interval for each mean difference was computed and is given in Table 2. For the combined and midlatitude data sets, the mean differences were not significantly different (at the 95% level) from zero, indicating that Eq. (1) is consistent with these observations. For the tropical data set, however, the null hypothesis was rejected at the 5% level, suggesting that significant, albeit slight, differences do exist between Eq. (1) and the tropical observations.

Thus we might summarize these results as suggesting that Eq. (1) is applicable over this entire region but that it probably produces slight underestimates in the tropics. Such a result was indicated in the comparison by Reed (1978), where it appeared that the computed values are more deficient in the central and western Pacific than to the east. This was attributed to the prevalence of cirrus clouds in the absence of significant amounts of other types as had earlier been suggested by Quinn and Burt (1968). The areas where these effects predominate do not comprise a large part of the tropical Pacific, however, and Eq. (1) should be appropriate for regional estimates as recently given by Weare and others (1980). The *Oceanographer* data demonstrate the utility of a single empirical formula over a vast region.

Acknowledgment. I thank James R. Holbrook for discussions about statistics and other comments. Two anonymous reviewers also made helpful suggestions. Thomas G. Jackson of our laboratory performed most of the vital work of maintaining the shipboard equipment.

REFERENCES

Freund, J. E., 1979: *Modern Elementary Statistics.* Prentice-Hall, 510 pp.

Hanson, K. J., 1976: A new estimate of solar irradiance at the earth's surface on zonal and global scales. *J. Geophys. Res.*, **81,** 4435–4443.

List, R. J., 1958: *Smithsonian Meteorological Tables*, 6th rev. ed. Smithsonian Institution, 527 pp.

Quinn, W. H., and W. V. Burt, 1968: Incoming solar radiation over the tropical Pacific. *Nature*, **217,** 149–150.

Reed, R. K., 1977: On estimating insolation over the ocean. *J. Phys. Oceanogr.*, **7,** 482–485.

——, 1978: Cloud effects on insolation over the tropical Pacific Ocean. *J. Appl. Meteor.*, **17,** 401–404.

Seckel, G. R., and F. H. Beaudy, 1973: The radiation from sun and sky over the North Pacific Ocean (abstract). *Trans. Amer. Geophys. Union*, **54,** 1114.

Weare, B. C., P. T. Strub and M. D. Samuel, 1980: *Marine Climatic Atlas of the Tropical Pacific Ocean. Contrib. Atmos. Sci.,* No. 20, University of California, Davis, 147 pp.

Unauthenticated | Downloaded 01/27/22 12:50 AM UTC