NOAA Technical Memorandum ERL PMEL-8

AN EVALUATION OF CLOUD FACTORS FOR ESTIMATING INSOLATION OVER THE OCEAN

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Seattle, Washington
September 1976

UNITED STATES
DEPARTMENT OF COMMERCE
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NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
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ABSTRACT. Observations at three coastal sites are used to derive a cloud factor for the computation of insolation at sea. The factor is $1 - 0.62C + 0.0019\alpha$, where C is cloud cover in tenths and α is noon solar altitude. This relation is also valid for 125 days of recent measurements over the eastern North Pacific Ocean. The relation above can be used to estimate monthly oceanic insolation with a random error less than ±10%.

Most previous cloud factors are inappropriate for a number of reasons: (1) relations derived at inland terrestrial locations are not valid at sea; (2) data have been grouped without regard to season (solar altitude); and (3) erroneous clear-sky formulas have been used. Lumb's (1964) formulas are valid, but their use places high demands on the quality of cloud observations. If cloud cover is estimated from satellite photographs, the amount should be increased by about 0.2 to give agreement with visual estimates on which the above cloud factor is based.

1. INTRODUCTION

The insolation (direct solar and diffuse sky radiation) reaching the sea surface is a large and variable term in the heat budget of the upper ocean. In order to determine the relevant processes (surface exchange, advection, and diffusion) affecting the heat content of the ocean (and its changes over periods of a few days to a few months), it is imperative that one be able to specify the insolation with reasonable reliability. Since measurements over oceanic areas are normally lacking, the radiation is usually computed with formulas.

Reed (1975) reviewed the various formulas for computing insolation under clear skies and concluded that the most satisfactory for oceanic applications was a formula derived by Seckel and Beaudry (1973) from data in the Smithsonian Meteorological Tables, using a transmission coefficient of 0.7, and a formula derived by Lumb (1964). Further, it was concluded that random errors in clear-sky estimates for periods of a few days or longer would not normally exceed ±5%. The major variable that alters insolation, however, is clouds; until cloud factors can be specified with confidence, estimates of insolation reaching the sea surface will remain uncertain.

This study deals with the reduction in radiation caused by clouds. The methods to be used are as follows: (1) various cloud factors that have been used are reviewed; (2) in order to obtain an adequate data base, observations at coastal sites in the National Weather Service network are used to derive a factor; (3) recent oceanic data are compared with the factor derived, and the relationship between visual and satellite-derived cloud estimates is investigated; and (4) various factors that have been suggested are intercompared and discussed.

2. REVIEW OF PREVIOUS FACTORS

Many cloud factors have been derived empirically from insolation data over land; these factors will not be discussed here, however, unless they have been widely used for oceanic studies. Numerous studies (e.g., Vonder Haar and Hanson, 1969; Holle and MacKay, 1975) show marked differences between the amount and thickness of terrestrial and oceanic clouds, and use of land-derived data should generally cause underestimates in the insolation received at sea. Most of the cloud factors proposed can be classed in three main groups: (1) linear functions of cloud amount; (2) nonlinear functions of cloud amount; and (3) functions of both cloud amount and solar altitude.

An early factor that was widely used was that derived by Kimball (1928):

$$Q_s/Q_o = 1 - 0.71C, \tag{1}$$

where Q_s is the insolation received on a horizontal surface, Q_o is the clear-sky insolation, and C is cloud amount in tenths. This relation was derived primarily from the land data available at the time, but it has been frequently used to estimate oceanic insolation (see e.g., Dietrich, 1963). In 1960 T. G. Berliand (Kondratyev, 1969) proposed use of the nonlinear relation

$$Q_s/Q_o = 1 - aC + 0.38C^2, \tag{2}$$

where a varies with latitude (between 0.36 and 0.40 from 0 to 60°). This relation was presumably derived entirely from data over land, but it has been used for oceanographic studies (Wyrtki, 1965; Dorman et al., 1974).

Laevastu (1960) used oceanic data from low and middle latitudes in the Atlantic to derive the cubic relation

$$Q_s/Q_o = 1 - 0.60C^3. \tag{3}$$

Tabata (1964) used a large group of data at ocean weather station P (50°N, 145°W) and found the relation

$$Q_s/Q_o = 1 - 0.716C + 0.00252\alpha, \tag{4}$$

where α is noon solar altitude. Thus his factor is a linear function of two variables, cloud amount and solar altitude. Lumb (1964) analyzed a large set of data at Atlantic Ocean weather stations north of 45°N. He considered cloud amount, type, and general weather conditions to obtain nine separate cloud categories for which nine separate formulas were developed. It is noteworthy that these relations also show a strong dependence of insolation on solar altitude.

3. NATIONAL WEATHER SERVICE DATA

In his study of insolation under clear skies, Reed (1975) used data from the network of solar radiation stations maintained for a number of years by the National Weather Service. The stations used were at coastal sites far removed from urban areas so that the atmosphere there should be generally typical of that over the ocean. In using such data to derive cloud factors, one should probably be even more cautious than for comparisons of clear-sky insolation because of the effects that land features, especially if there is significant orography, have on clouds (Holle and MacKay, 1975).

The National Weather Service data are of very uneven quality as originally archived (Michael Riches, personal communication). One problem is that after 1956 the pyranometer receivers were coated with Parson's black lacquer, which turned grey or green after several years of field use, and the sensitivity decreased as much as 20% in some instances. The errors were not significant, however, for short periods of use (2-3 years or less). Another source of error was caused by calibrating Parson's black instruments against lampblack standards; the lampblack instruments had equal sensitivities in the sun and the integrating sphere, but the Parson's black instruments had sensitivities about 7% too low in the sphere. Thus the field readings with the Parson's black instruments were 7% too high because of this crossmatching of sensor surfaces during calibration.

3.1. Methods of Data Analysis

Daily solar radiation (format 480) was obtained on magnetic tape from the National Climatic Center, Asheville, North Carolina. Average cloud cover during daylight hours (derived from hourly visual observations) is included in this format. The stations and periods used were some of those previously used by Reed (1975), except for Swan Island which did not have zero cloud cover for the period examined, where the insolation under clear skies closely matched the formula from the Smithsonian Meteorological Tables. Data were not used for a period longer than a year after installation of recently calibrated pyranometers to eliminate the possibility of sensor surface deterioration or large changes in the calibration constants. A 7% correction was applied to eliminate the effects of crossmatched sensor surfaces during calibration. The stations and periods chosen were: Swan Island (17°24'N, 83°56'W), January-November 1964; Cape Hatteras (35°16'N, 75°33'W), April-December 1962; and Astoria (46°09'N, 123°53'W), May 1962-February 1963 and July 1967-April 1968. These stations are less than 2 km inland and have elevations of 10 m or less.

Three stations that Reed (1975) used were purposely excluded. The clear-sky data at Apalachicola, Florida, suggested a rather pronounced seasonal land-sea breeze cycle; hence it is likely that the clouds would have significant land effects in winter. The site at Annette Island, Alaska, is amid mountainous terrain on this and nearby islands, and the clouds would probably be strongly influenced by orography. Santa Maria, California, is about 15 km inland at an elevation of 88 m. As a check on conditions there, the monthly mean factors Q_s/Q_o and cloud cover were computed for August 1973-June 1974; except in winter, the relation from these data give estimates of insolation 3-11% less than that from the cloud factor derived in this study, which suggests that the thickness or density of the clouds was greater there than at sea.

Although the data for the stations and periods used (except for Swan Island) had been examined by Reed (1975) and found to be in good agreement with the clear-sky formula derived from the Smithsonian Meteorological Tables, they were reexamined, and the results for cloud covers 0.2 and less are summarized in table 1. It is apparent that in the mean there are no very significant departures of clear-sky values from insolation computed with the formula, and it is also clear that the reduction of insolation by clouds of amount 0.1 and 0.2 is generally quite small. Two of the larger standard deviations from the means occurred at Astoria in 1962-63; as will be discussed later, this apparently results from small but significant departures of clear-sky insolation from that computed by the formula during 2 winter months. On the whole, however, these data reflect expected conditions, and on this basis appear to be quite suitable for an examination of the reduction in insolation caused by clouds.

On initially examining the data taken at Swan Island, quite anomalous relations between the daily factors Q_s/Q_o and cloud cover occasionally appeared. These days were typified by virtually no reduction in radiation even though cloud cover was 0.5-1.0. (As will be shown, the mean cloud factor at 0.5 cloud cover is roughly 0.8 and at complete overcast is roughly 0.5.) This would not appear to be the result of scattered or fair-weather cumulus clouds enhancing the radiation by reflection because these clouds, especially their daily means, are nearly always less in amount than 0.5 (see e.g., Kaiser and Hill, 1976). It was suspected that this condition was the result of cirrus cloudiness in the absence of significant amounts of other types. Such a situation frequently occurs over a portion of the tropical Pacific (Quinn and Burt, 1968), and the effects are very similar to those found in the Swan Island data. Hence it was decided to eliminate the effects of this suspected cirrus cloudiness because it is not generally typical of most of the world ocean where substantial amounts of low or middle clouds are usually present. The choice was made to eliminate daily data from the monthly means when $Q_s/Q_o > 0.95$ for $C = 0.5\text{-}0.7$ and when $Q_s/Q_o > 0.90$ for $C = 0.8\text{-}1.0$. The number of values omitted by this procedure for each station for each month are shown in table 2. (Also shown in table 2 are the number of obviously erroneous data, several of which appear to be decimal point errors.) The data omitted because of suspected cirrus cloudiness have very little effect on the results except at Swan Island. Inclusion of

Table 1. Comparison of the ratio of observed to computed insolation (Q_s/Q_o) at the stations used here for cloud cover (C) less than 0.3.

Station	Period	C = 0			C = 0.1			C = 0.2		
		# of Obs.	Q_s/Q_o	σ*(%)	# of Obs.	Q_s/Q_o	σ*(%)	# of Obs.	Q_s/Q_o	σ*(%)
Swan Island	Jan-Nov 1964	0	-	-	14	0.97	±2	24	0.97	±4
Cape Hatteras	Apr-Dec 1962	35	1.00	±5	16	0.99	±7	15	0.96	±5
Astoria	May 1962-Feb 1963	11	1.03	±8	5	0.99	±7	10	1.04	±5
Astoria	July 1967-Apr 1968	21	1.00	±4	9	1.00	±6	6	0.95	±2

* σ = standard deviation from the mean difference

Table 2. Statistics concerning the data used in forming the monthly means of insolation and cloud cover at the stations used here. (1) = total daily values of insolation and cloud cover available for the month; (2) = number of daily values rejected because of erroneous data; (3) = number of daily values not used in forming the means because of suspected cirrus cloudiness.

Station	January			February			March			April			May			June		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Swan Island (1964)	30	0	0	28	0	2	31	0	7	29	0	7	31	0	7	26	0	5
Cape Hatteras (1962)										22	0	2	30	0	4	30	1	1
Astoria (1962-63)	31	2	0	27	2	0							29	0	0	29	0	0
Astoria (1967-68)	31	1	2	28	0	0	31	0	2	29	1	4						

Station	July			August			September			October			November			December		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Swan Island (1964)	30	1	2	28	0	2	30	1	2	31	3	1	30	2	4			
Cape Hatteras (1962)	27	0	5	29	0	1	29	1	5	29	0	0	28	2	0	30	2	0
Astoria (1962-63)	31	0	0	31	0	0	30	0	0	28	0	0	30	2	0	31	2	0
Astoria (1967-68)	30	0	0	31	0	0	30	0	0	31	2	5	29	4	3	31	0	1

the data for 5 months when four or more values were omitted causes the monthly insolation to be 4 to 11% greater than it is when the data are omitted, but for other months there is no significant effect.

3.2. Presentation of Data

The monthly mean data were used to prepare plots of the factor Q_S/Q_O versus cloud amount in tenths, and the results are presented below for each station.

3.2.1. Swan Island

The Swan Island data are presented in figure 1. The data suggest that the reduction of insolation is a linear function of cloud amount (for cloud cover 0.3 to 0.8) with a significant dependence on season or solar altitude. Thus the two dashed lines were drawn to fit the data for the two groups of months with similar noon solar altitude. There is remarkably little scatter in the data, and the dashed lines shown fit the relation

$$Q_S/Q_O = 1 - 0.62C + 0.0019\alpha. \tag{5}$$

3.2.2. Cape Hatteras

The results for Cape Hatteras are shown in figure 2. The two dashed lines are those given by eq. (5) fitted to the means for two groups of months with similar noon solar altitude. Although the fits are somewhat less good than at Swan Island, the maximum deviation of a monthly factor from eq. (5) is only 0.05, and all the others are within 0.03 of the regression.

3.2.3. Astoria

Data for 1962-63 are shown in figure 3; the data have been fitted to eq. (5) as was done for Cape Hatteras. The fit is quite good except for December and January. Examination of individual values with cloud cover 0.2 and less reveals that the measured insolation was significantly greater (approximately 10%) than the computed insolation during these 2 months. This would produce the deviations shown in figure 3. It is suspected that this condition may have been caused by air that was drier and of more continental origin than the more typical marine atmosphere over this site.

The 1967-68 data at Astoria are presented in figure 4. Again the fit to eq. (5) is less good than at Swan Island, but the maximum deviation from eq. (5) is only 0.06.

3.3. Discussion of Results

It is of interest to evaluate the standard deviation of the monthly factors from the factors computed by eq. (5). Assuming a normal

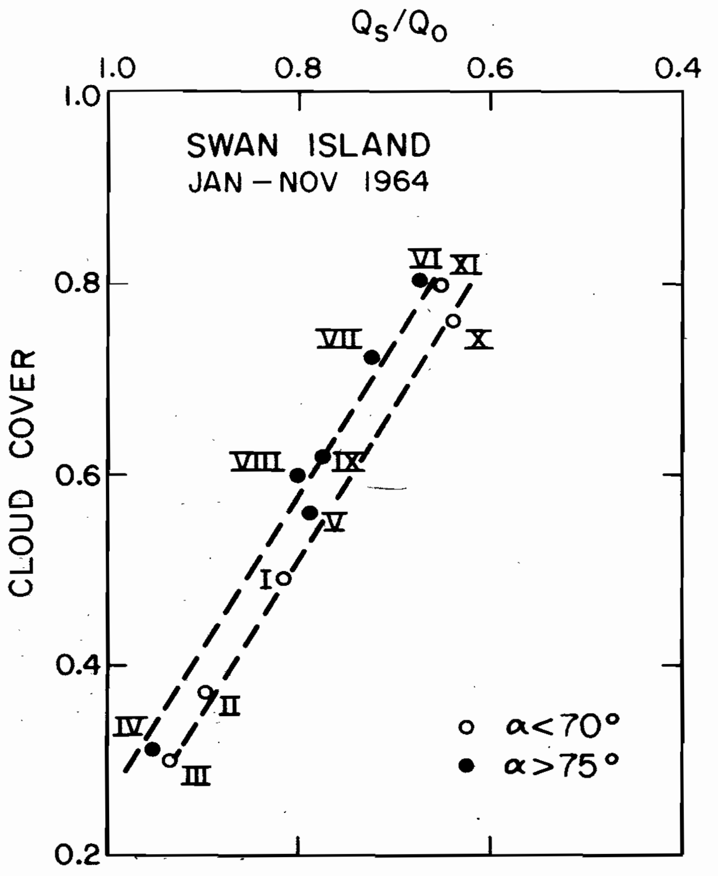

Figure 1. The relation between cloud cover (in tenths) and reduction in insolation Q_s/Q_o at Swan Island, January-November 1964.

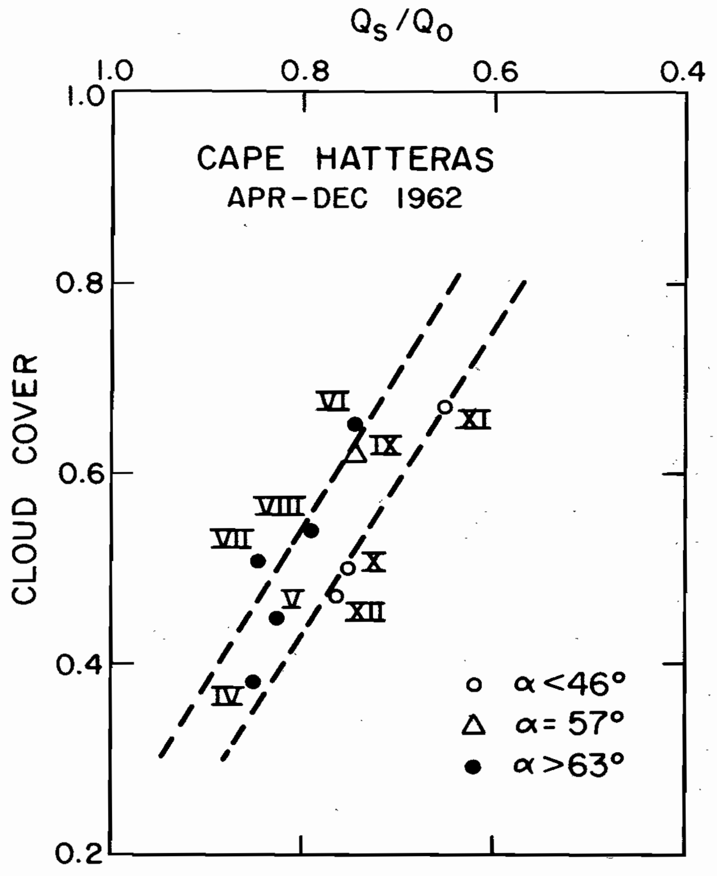

Figure 2. The relation between cloud cover (in tenths) and reduction in insolation Q_s/Q_o at Cape Hatteras, April-December 1962.

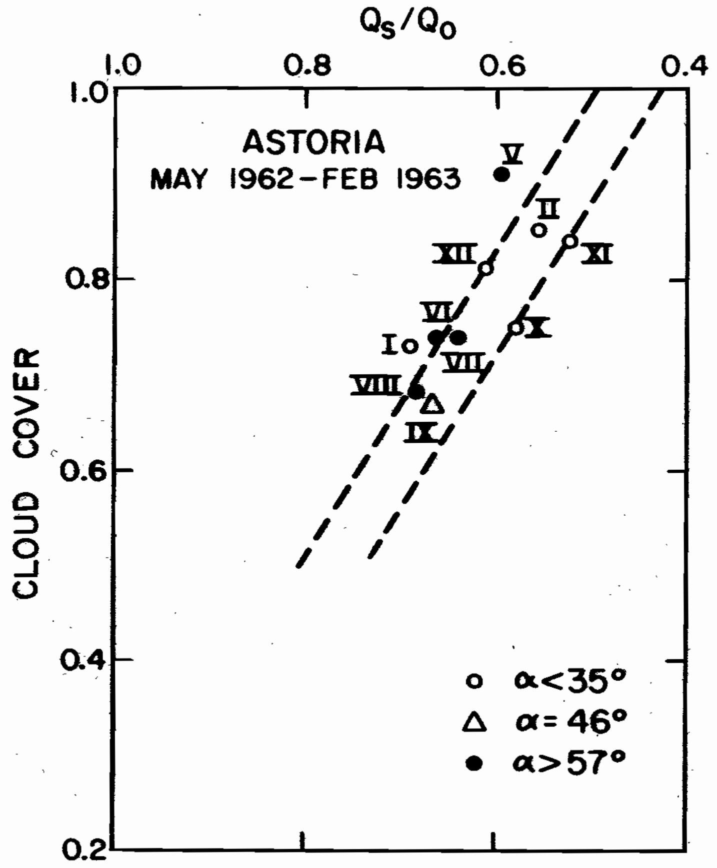

Figure 3. The relation between cloud cover (in tenths) and reduction in insolation Q_S/Q_O at Astoria, May 1962-February 1963.

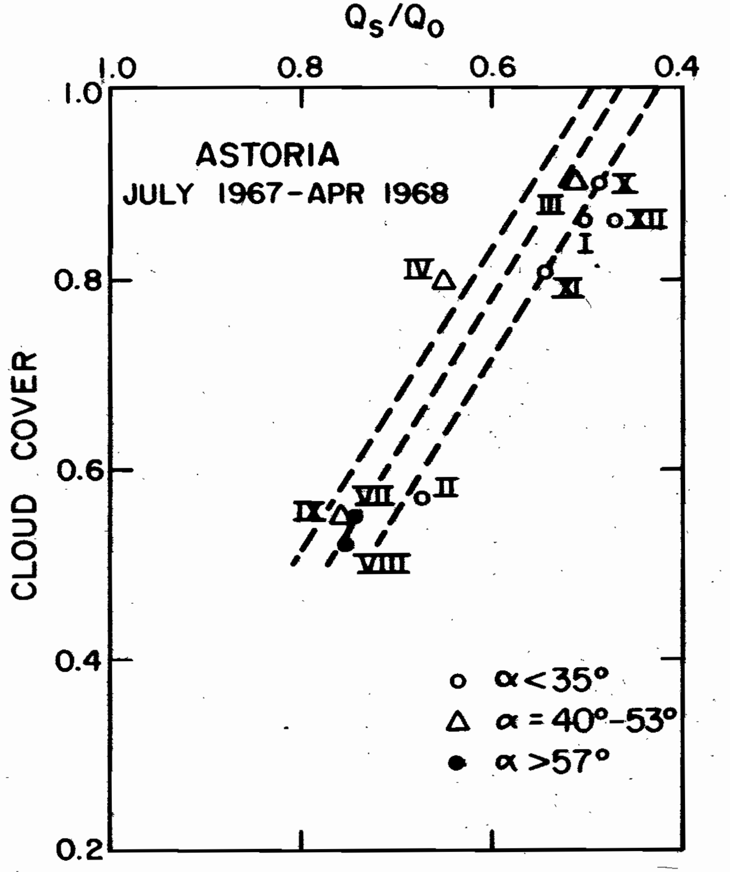

Figure 4. The relation between cloud cover (in tenths) and reduction in insolation Q_S/Q_O at Astoria, July 1967-April 1968.

distribution, 2σ (two standard deviations) should represent the random error of estimate (at 95% confidence limits) of a monthly mean value computed from eq. (5). At Swan Island, 2σ = ±6%, although the value is strongly influenced by one relatively large deviation (November). Cape Hatteras has a value of ±5%. In 1962-63 at Astoria, 2σ = ±15%; this large value results mainly from the deviations in December and January, which are believed to have been caused by anomalously high clear-sky insolation rather than natural variations in clouds. The last period at Astoria has a random error of estimate of ±8%. Ignoring the largest error estimate, which appears to be the result of systematic rather than random differences, one can conclude that a value of monthly mean insolation computed by eq. (5) should have a random error of less than ±10%.

4. RECENT OCEANIC MEASUREMENTS

Measurements of insolation at sea have been quite limited, and most of the recent measurements have not been published or analyzed. In 1975 a program was started to obtain radiation measurements during the cruises of the NOAA ship *Oceanographer*, which was to operate over a large area of the eastern Pacific. It was believed that these data would be very useful in evaluating empirical formulas in various oceanic regions.

An Eppley model 8-48 pyranometer was installed atop a leveled post on the forepeak of the ship. In 1975 a Bristol analog recorder with a disc integrator was used; the 1976 data were recorded on a Hewlett-Packard analog recorder with an integrating circuit designed and built in our laboratory. Daily totals of radiation were obtained by recording values from the integrator, whose output was frequently checked electronically and by comparison with digitized values from the analog traces. The same pyranometer has been used throughout this program; it was calibrated by the manufacturer in December 1974 and again in December 1975, and the two calibration constants differed by only 0.4%. Although it is difficult to quantify all possible sources of error, it is believed that random errors in daily values do not exceed 4-5% and that there are no systematic errors greater than 2-3%. In support of the measurements of insolation, weather observations were made every hour, and daily means of cloud type and amount during daylight hours were determined.

4.1. Comparison of Oceanic Data with Eq. (5)

The data observed aboard the *Oceanographer* have been grouped into various periods ranging in length from 5 to 17 days. Some of these groupings represent a single cruise; in other instances the data from a cruise have been subdivided either to prevent the area covered from being excessively large or when cloud types were quite different. The data during 1975 are given in table 3, and the data for 1976 are presented in table 4. (The lack of data in late 1975 is the result of a recorder not being generally available.) The observed insolation Q_S has been compared to Q_O (computed with the formula derived from the Smithsonian Meteorological Tables, using a transmission coefficient of 0.7, except during February 1-7 and July 8-23 when observed clear-sky values were somewhat

Table 3. Comparison of the ratio of observed to clear-sky insolation Q_s/Q_o with Q_s/Q_o computed from eq. (5). Data were observed aboard the NOAA ship *Oceanographer* during 1975.

Dates	Latitude (°N)	Longitude (°W)	Clouds		Q_s/Q_o Observed	Q_s/Q_o Computed
			Amount	Type		
Feb 1-7 (6 days)	59-60	142-146	0.28	Cu	0.87†	0.85
Feb 19-27 (9 days)	59-60	143-147	0.95	St,Sc*	0.31	0.45
Apr 22-May 2 (9 days)	14-16	126-127	0.95	Sc	0.51	0.57
May 16-28 (5 days)	14-16	125-127	0.90	Sc	0.58	0.60
May 17-29 (8 days)	14-16	125-127	0.73	Sc,Cu	0.74	0.70
July 8-23 (13 days)	43-47	124-127	0.88	Sc,St	0.58†	0.58
Aug 28-Sept 8 (12 days)	15-18	126-128	0.77	Cu,Ac, Cs	0.66	0.68
Sept 9-13 (5 days)	12	131-151	0.80	Cu, Ac, Cs	0.69	0.66
Oct 26-Nov 15 (9 days)	9-20	124-151	0.67	Cu, Ac, Ci	0.78	0.70

† Q_o adjusted to fit observed clear-sky values
* Rain or snow about half the time

Table 4. Comparison of the ratio of observed to clear-sky insolation Q_s/Q_o with Q_s/Q_o computed from eq. (5). Data were observed aboard the NOAA ship *Oceanographer* during 1976.

Dates	Latitude (°N)	Longitude (°W)	Clouds		Q_s/Q_o Observed	Q_s/Q_o Computed
			Amount	Type		
Feb 17- Mar 5 (17 days)	9-24	126-138	0.73	Cu,Sc, Ac	0.76	0.67
Mar 6-15 (10 days)	6-19	139-156	0.75	Cu,Sc, Ac	0.60	0.68
Mar 25-Apr 2 (9 days)	8-16	145-155	0.85	Cu,Sc, Ac,Cs	0.69	0.63
Apr 3-12 (10 days)	10-15	126-140	0.88	Cu,Sc	0.54	0.61
Apr 25-30 (6 days)	11-18	130-139	0.79	Sc,Ac	0.73	0.68
May 1-6 (6 days)	8-20	141-151	0.79	Cu,Ac	0.76	0.67

different than those computed), and the ratio Q_S/Q_0 was also computed from observed cloud amount and solar altitude by eq. (5).

The ratios derived by these two different methods are also plotted in figure 5. (The value in parentheses is for a period when precipitation was abnormally heavy, apparently causing insolation to be quite low (see Lumb, 1964), and it is omitted from the statistical properties to be discussed.) Of the 14 values in figure 5, five of the ratios based on observed values are less than those computed from eq. (5), and eight of the ratios based on observed values are greater than those computed with the equation. In the mean, the agreement is quite good with the mean observed ratios being 2% greater than those computed. The standard deviation from this mean difference is ±9%; hence the random measurement error (at 95% confidence limits) can be assumed to be 2σ or ±18%. The mean duration of these data groups was 9 days, and the random measurement error is two to three times that for monthly means based on the National Weather Service data. It should be noted also that cloud amount for the oceanic data are for a very limited range (0.67-0.95 except for one period), whereas monthly mean cloud cover at the Weather Service stations varied from about 0.3 to 0.9.

4.2. Comparison of Visual and Satellite-Derived Cloud Estimates

The observations aboard the *Oceanographer* provide an interesting set of data for comparing insolation and conventional cloud cover estimates, and they also provide an opportunity to compare these visual estimates with estimates from photographs derived from satellite sensors. It has been noted before (U.S. Department of Commerce and U.S. Air Force, 1971; Holle and MacKay, 1975) that satellite sensors (whether vidicon cameras or radiometers) yield cloud cover estimates that are systematically and substantially smaller than those obtained by observers. Hence if one is to use an empirical formula such as eq. (5) with satellite-derived cloud estimates, a correction should presumably be applied to produce approximate agreement with visual estimates on which the formula is based.

Visible and infrared satellite photographs were obtained for the data periods shown in tables 3 and 4, and mean cloud cover for the periods was derived from photographs once a day (0900 local time for NOAA-4 and about noon local time for the geostationary or SMS-2 satellite) based on the area that the ship operated in during daylight hours. For the first two periods in 1975, data from the very high resolution radiometers (VHRR, 1-km resolution) on NOAA-4 were used; during the rest of 1975 outputs from the standard scanning radiometers (about 4-km resolution in the visible and 8-km resolution in the infrared) aboard NOAA-4 were employed. In 1976 data were obtained from the SMS-2 satellite, whose radiometers have a resolution approximately the same as the standard radiometers on NOAA-4. A comparison of the mean satellite-derived and visual cloud estimates for the periods listed in tables 3 and 4 is presented in figure 6. The difference between the two types of estimates is striking, and the general lack of scatter is rather surprising considering the subjective nature of estimating cloud cover from photographs and the fact that

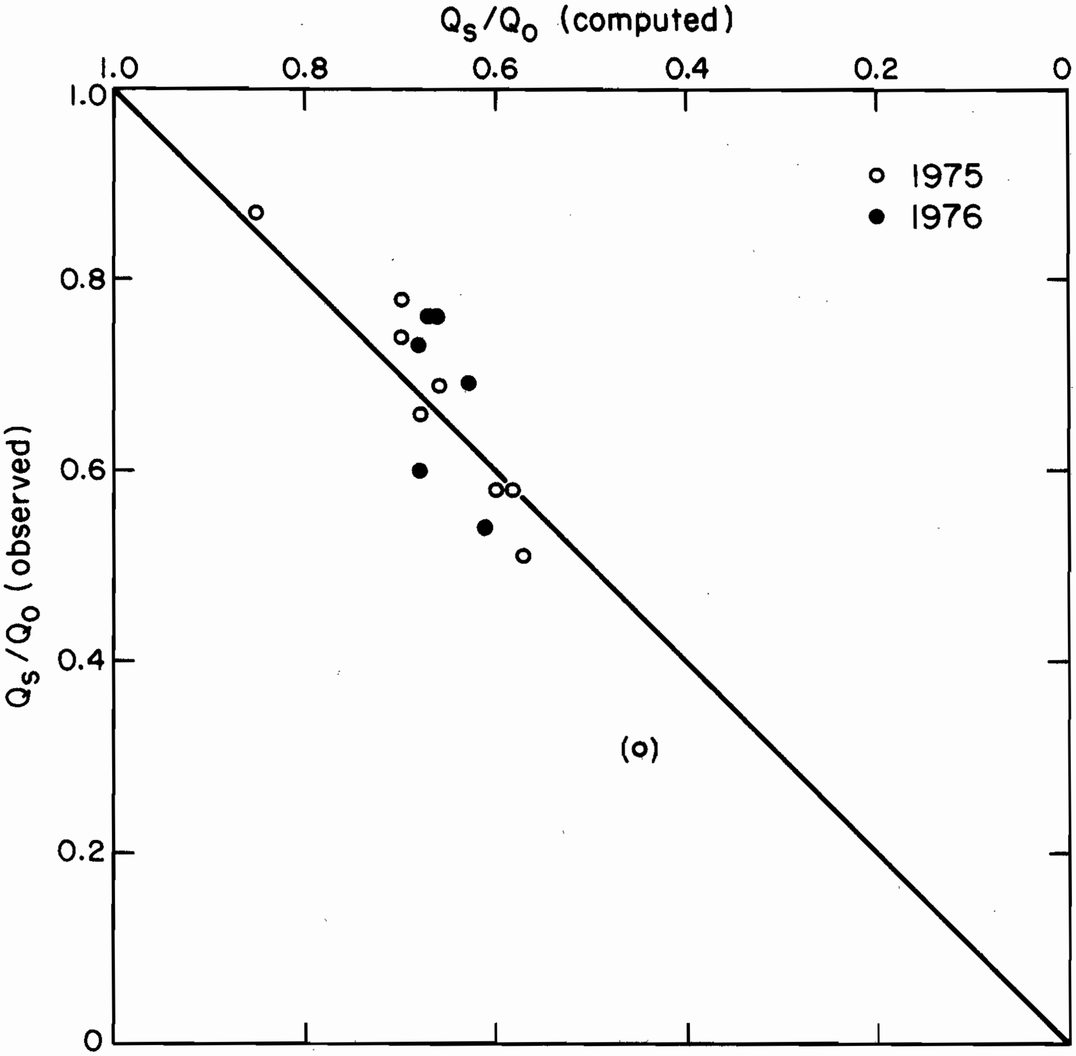

Figure 5. The observed reduction in insolation Q_s/Q_o versus the reduction in insolation computed by eq. (5) from data obtained by the NOAA ship *Oceanographer*, February 1975-May 1976. The data periods and locations are given in tables 3 and 4.

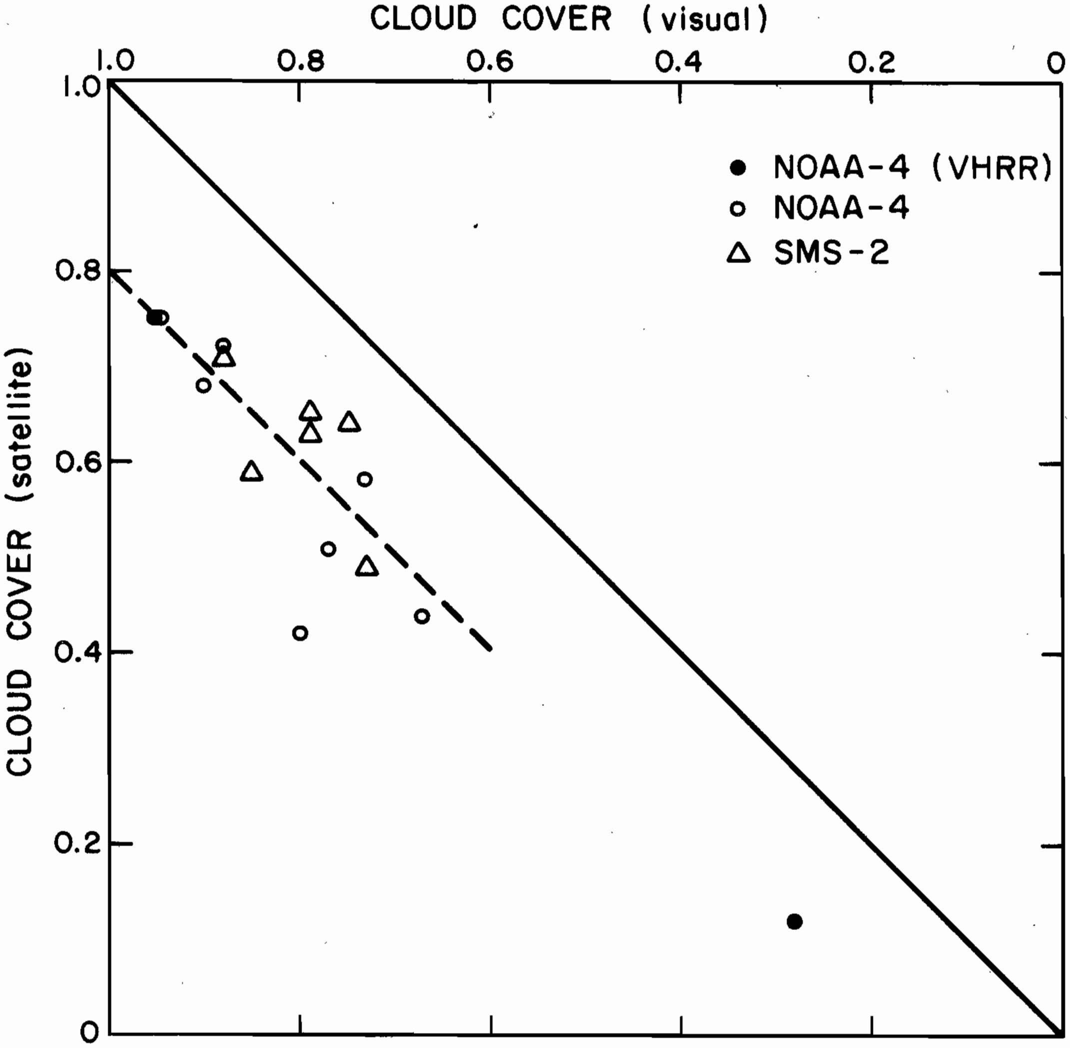

Figure 6. Mean cloud cover estimates (in tenths) by visual observations aboard the NOAA ship *Oceanographer* and from photographs obtained from satellite radiometers, February 1975-May 1976. The data periods and locations are given in tables 3 and 4.

each mean was based on the data in only 5 to 17 photographs. Thus this comparison suggests that cloud cover estimates derived from satellite sensors should be increased by about 0.20 to agree with visual estimates.

5. INTERCOMPARISON OF FACTORS

Figure 7 allows comparison of the various cloud factors discussed in section 2 plus eq. (5). The disagreement among them is quite pronounced; differences in computed insolation of over 50% could easily result. Why has it been so difficult to reach a consensus on the proper procedures for computing insolation in the presence of clouds? First, data derived from observations over inland terrestrial locations have been indiscriminantly applied to oceanic regions. It is apparent that the factors of Berliand and Kimball give much lower results than the others, presumably at least partially as a result of land effects on the clouds. Second, the general form of the proper relation (with insolation as a function of cloud amount and solar altitude) seems not to have been recognized until recently (Tabata, 1964; Lumb, 1964; eq. (5)). Laevastu (1960) did not consider solar altitude effects in deriving his factor, and the very high values at intermediate cloud amounts perhaps suggest the presence of cirrus cloudiness in the absence of other types. In comparison with eq. (5), at complete overcast Tabata's (1964) formula yields results about 8% lower at a solar altitude of 80° and about 15% lower at an altitude of 40°; at lesser cloud amounts the agreement becomes better. Tabata's (1964) factor appears to give results too low because of his use of clear-sky data that give higher values than the formula from the Smithsonian Meteorological Tables (Reed, 1975). Lumb's (1964) various formulas (not shown) generally gave good agreement with the *Oceanographer* data; their use, however, requires very detailed and reliable cloud observations, and it is doubtful if they are suitable for use with routine data.

6. CONCLUSIONS

For the computation of clear-sky insolation at sea, the formula derived by Seckel and Beaudry (1973) from the Smithsonian Meteorological Tables (with a transmission coefficient of 0.7) is recommended. Eq. (5), which is a linear function of cloud amount and solar altitude, appears to be suitable for computing insolation at sea in the tropics and at middle latitudes. When applied to monthly mean data, the random error of estimate (at 95% confidence limits) is better than ±10%, and for weekly data it is about ±20%. The formula appears to be valid for cloud cover from 0.3 to 1.0; cloud cover 0.2 and less causes no significant decrease in radiation, and the reduction of insolation by appreciable amounts of cirrus (in the absence of other types) appears to be about 5%. It is suggested that data on days when mainly cirrus (not cirrostratus) clouds are present (total low and middle cloud < 0.3) should be separated from the other data for computation of insolation. Use of only the lower cloud amount as a solution to the problem of cirrus clouds is not recommended; the *Oceanographer* data revealed numerous instances when low and middle cloud were in approximately equal amount so that use of only lower cloud amount would result in gross overestimates of insolation. Finally,

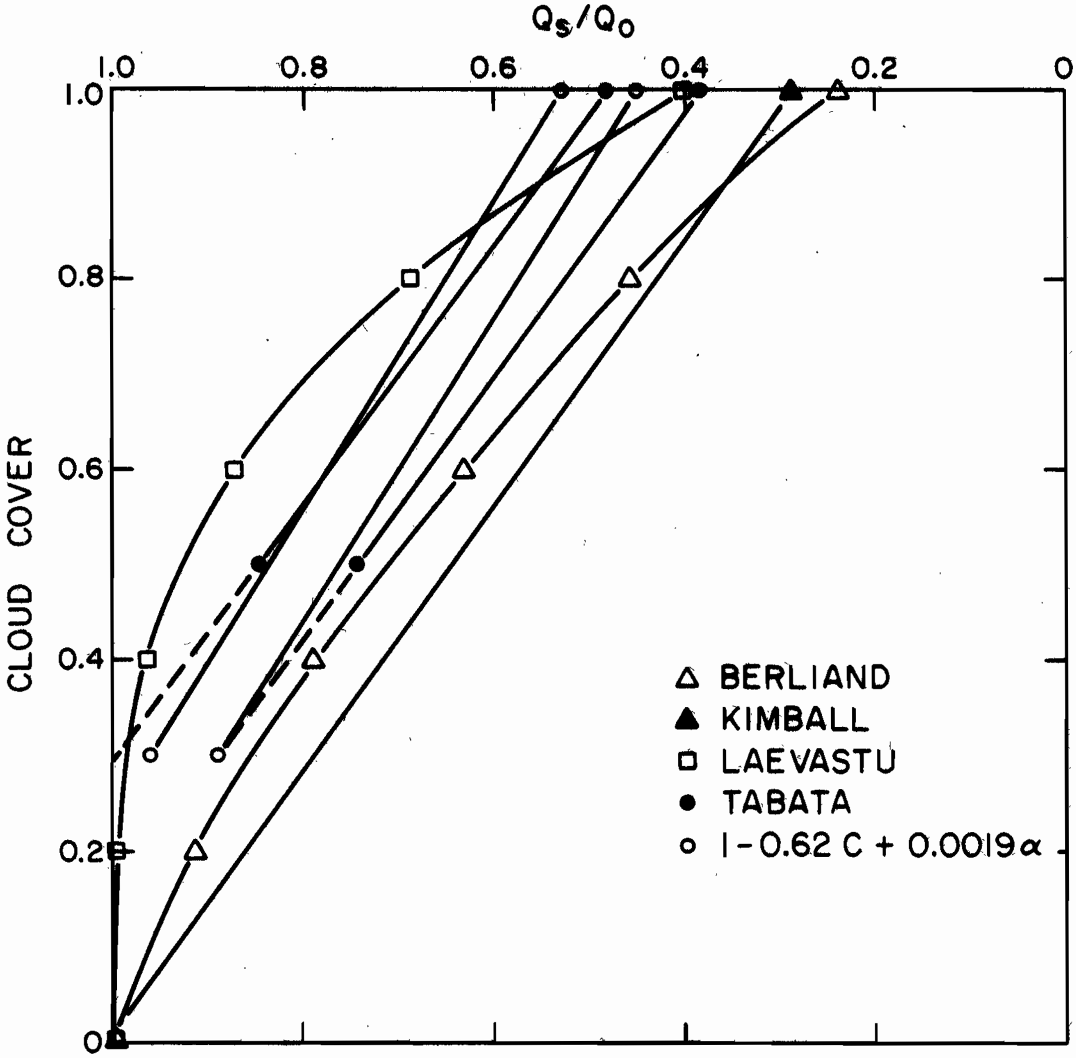

Figure 7. Comparison of the reduction in insolation Q_s/Q_0 and cloud cover (in tenths) computed by the formulas of Berliand, Kimball, Laevastu, Tabata, and eq. (5). Results from Tabata's formula and eq. (5) are shown for solar altitudes of 40° and 80°.

if clouds are estimated from satellite photographs, it is suggested that the amount be increased by 0.2 for better agreement with visual estimates on which eq. (5) is based.

7. ACKNOWLEDGMENTS

I thank Michael Riches, National Weather Service, for providing information on the instruments used in the National Weather Service network. CDR R. E. Newell and the survey technicians aboard the *Oceanographer* diligently maintained the instrument and recorder system, and the quartermasters provided very complete weather observations. J. D. Larrance of PMEL loaned me a recorder, and D. B. Spell, T. G. Jackson, and R. Newman provided much assistance in design, modification, and maintenance of equipment. Finally, I have benefitted appreciably from conversations and correspondence on numerous aspects of insolation with G. R. Seckel, National Marine Fisheries Service.

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