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Systematic Errors in Estimation of Insolation by Empirical Formulas

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Systematic errors in the estimation of surface insolation, Q, by two popular empirical formulas are investigated statistically by using coincident measurements of the global solar radiation and the total cloud cover at JMA observatories over Japan. The results show that Reed's (1977) widely-accepted formula remarkably overestimates Q under overcast conditions. The overestimation is particularly evident in the summer months. The formula also overestimates Q in cloud-free conditions, which may be due to an overestimation of the clear-sky transmittance by Seckel and Beaudry (1973). By contrast, Kondo and Miura's (1985) formula underestimates Q under overcast conditions, whereas it slightly overestimates in partially cloudy conditions. It is shown that these systematic errors can explain some of the published differences between the estimation of Q by the two formulas. The users of these formulas should be careful since these cloudiness-dependent errors can contaminate not only the absolute values but also the temporal anomalies or the spatial variability of the insolation predicted by them. In particular, it can be serious in regions of dense cloud cover such as the northern North Pacific, the northern North Atlantic and the Southern Ocean. It is also shown that the ratio of Q to the insolation at the top of the atmosphere, Q_{TOA}, takes on a range of values, particularly under dense cloud cover. This implies an inherent difficulty in estimation of Q by a simple empirical formula utilizing only readily-available observables such as cloudiness.

Keywords:
- Surface insolation,
- empirical formula,
- surface heat budget,
- bulk formula,
- cloudiness,
- cloud amount.

1. Introduction

The precise estimation of the solar radiation incident on the sea surface (insolation) is a key to a quantitative understanding of the surface heat budget. However, it is hardly possible to obtain sufficient spatial and temporal coverage solely from the in situ radiometric measurements over the vast oceans. Therefore, many oceanographers have empirically deduced and used relationships between insolation and more commonly available marine observables, such as cloud cover, solar altitude, humidity and others. Since the 1980s, satellite imagery data have been used for preference to estimate the surface insolation (e.g. Gautier *et al.*, 1980). The satellite method can estimate insolation globally with an RMS error of 10% for monthly values (Schmetz, 1989). However, since we must rely on empirical formulas to calculate the flux variation during the pre-satellite period or in the cases for which such a technique is unavailable, it is still important to know the characteristics of the empirical formula to be used. In fact, it is known that different empirical formulas give very different results, even when applied to an identical cloud cover data set (Talley, 1984; Chou, 1985; Iwasaka and Hanawa, 1990). Which is the most accurate is not generally known.

There are roughly 100 formulas for estimating the surface insolation (Kondo and Miura, 1983). They could be categorized according to the time scale of the estimated insolation (i.e. hourly, daily, weekly and monthly) and also to the information required as inputs. Among such numerous formulas, Reed's (1977) empirical formula:

$$Q = Q_0(1 - 0.62C + 0.0019\alpha_n) \tag{1}$$

has been almost exclusively used in the oceanographic community (Weare *et al.*, 1981; Talley, 1984; Reed, 1985; Hsiung, 1986; Oberhuber, 1988; Iwasaka and Hanawa, 1990). In Eq. (1), Q represents the daily surface insolation to be estimated, Q_0 is the daily clear-sky surface insolation given by Seckel and Beaudry (1973), C is the daytime-averaged total cloud cover in tenths, and α_n is the noon solar altitude in degrees. The formula was initially determined from colocated measurements of insolation and cloud cover at three US coastal sites and later validated in the tropical to subarctic eastern Pacific Ocean (Reed, 1977, 1982). The performance was reported to be equally good both for land and sea.