BOBMEX-98 Pilot: Measurement and analysis of incoming shortwave radiation data

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Empirical formulae for estimation of hourly incoming shortwave radiation over the Indian Ocean under different cloud amounts have been developed by using the pyranometer measurements of the incoming solar radiation and the cloud observations during BOBMEX Pilot (October – November 1998) cruise.

1. Introduction

Incoming shortwave radiation at the ocean surface is one of the major components affecting land and ocean surface heating. It plays a vital role in understanding the ocean–atmosphere interactions. Although the incoming shortwave radiation is a very important component in oceanic studies, it is seldom measured over the oceans. This has resulted primarily from the difficulty of making radiation measurements at the ocean surface. Until very recently our only knowledge of the incoming shortwave radiation in large oceanic regions came from sparse cloud observations used in empirical formulae. After the advent of satellite technology, the incoming shortwave radiation at the ocean surface has been estimated using satellite measurements. However, the development of satellite techniques for estimating the incoming shortwave radiation will depend crucially on the capability of calibrating the satellite estimates with *in situ* measurements in the region of study (Gautier 1986, 1988).

Empirical formulae for estimating the incoming shortwave radiation are developed in terms of the atmospheric transmission factor, defined as the ratio of the incoming shortwave radiation at the sea surface to the radiation incident on a horizontal surface at the top of the atmosphere. The most commonly used empirical formulae for estimating the incoming shortwave radiation over the Indian Ocean are those developed by Wyrski (1971); Seckel and Beaudry (1973); Budyko (1974); Reed (1977); Simpson and Paulson (1979); Atwater and Ball (1981) and

Mohanty and Mohan Kumar (1998). Most of these widely used formulae were developed using the data over the Atlantic and Pacific Oceans in the extra tropics. A problem with such empirical coefficients is that they may not be suitable for other climatic regimes and latitudes. Their validity and accuracy remain undemonstrated for the tropics in general, and for the Indian Ocean in particular.

Even though there have been numerous formulae, significant disagreement exists currently between the standard measurements and estimates from the formulae even for clear sky conditions (Reed 1977; Simpson and Paulson 1979; Dobson et al 1982). For example, Reed (1977) found that his measurements of clear-sky insolation differed by an average of -10% with that of the 'Berliand' formulae used by Budyko (1974). The use of a single cloudiness (without cloud type) parameter is not sufficient in general, since, low, middle and high clouds have very different effects on radiation. However, no systematic validations are available between empirical estimates and *in situ* measurements of this region. Weare (1989) has considered all sources of error associated with empirical formulae and concluded the random and systematic uncertainties to be around $\pm 72 \text{ Wm}^{-2}$ and $\pm 5 \text{ Wm}^{-2}$ respectively. Further, Bradley *et al.* (1990) have found the RMS difference of 30 Wm^{-2} between empirical estimates and *in situ* data.

The empirical formulae will be helpful to estimate the incoming shortwave radiation simply by knowing the cloud factor. IMD, IITM have developed empirical formulae for estimating the incoming shortwave

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radiation over the Indian continent (Ganesan 1970; Das and Pujari 1993). The formulae developed over land may not be suitable for use at sea, since the sea surface generates cloud regimes different from those generated over land (Dobson and Smith 1988). Secondly, the aerosols in the atmosphere reduce the total radiation on land when compared with that at sea in the same latitude. Also, there is a great need to develop parameterization on shorter time scales for the marine conditions, since the estimates of daily averages are of greater necessity as air-sea interaction studies focus more on diurnal time scales. In the hourly formulae (Lumb 1964; Lind *et al.* 1984; Gopala Reddy 1987; Dobson and Smith 1988) the cloud factor is directly incorporated. However, similar studies for the Indian Ocean are missing. Therefore, in the present study an attempt has been made for developing empirical formulae to estimate hourly incoming

shortwave radiation over the Indian Ocean under different cloud amounts.

2. Data and methodology

Hourly incoming shortwave radiation over Bay of Bengal and Arabian Sea has been measured by using a pyranometer on board INS Sagar Kanya for 17 days (161 samples) during the BOBMEX Pilot cruise (October – November, 1998). Along with the incoming shortwave radiation, the hourly cloud amount has also been observed during the same period.

Lumb (1964) developed regression equations for estimating solar radiation from hourly cloud observations, which can be fitted into one of nine categories, based on cloud amount and type. This method cannot be directly applied since it does not specify for the

Figure 1. (a) to (d) Graph showing the relation between solar radiation and the cloud amount for four selected days.

cloud observations which do not fit into one of the nine categories. Lind (1981) and Lind and Katsaros (1982) have extended Lumb's approach to include all cloud observations. Gopala Reddy (1987) and Dobson and Smith (1988) have revised the Lind model by incorporating the distance correction for calculating the solar radiation at the top of the atmosphere as follows:

$$Q_T = (\bar{d}/d)^2 \times S_0 \times \sin h \quad (1)$$

where $(\bar{d}/d)^2$ is distance correction for revolution of earth, which accounts for a variation of about $\pm 3.3\%$ in the incoming shortwave radiation at the top of the atmosphere, S_0 is solar constant (Wm^{-2}) and $\sin h$ is sine of the solar altitude.

Empirical formulae are developed for determining the incoming shortwave radiation at the ocean surface on hourly basis from a knowledge of total cloud amount reported, in terms of the atmospheric transmission factor (TF), the incoming shortwave radiation observed at the ocean surface ($Q_{SW\downarrow}$) and the radiation incident at the top of the atmosphere (Q_T) as:

$$\text{T.F.} = Q_{SW\downarrow}(\text{observed})/Q_T \quad (2)$$

where Q_T is calculated from equation (1). Gopala Reddy (1987) and Dobson and Smith (1988) have found a relation between T.F. and sine of the solar altitude as:

$$\text{T.F.} = A_i + B_i \sin h \quad (3)$$

with $i = 0$ to 8 oktas, A_i and B_i are regression coefficients for different total cloud amounts.

Using different values of T.F. and $\sin h$, the regression coefficients A and B of equation (3) were found for different amounts of cloud.

3. Results and discussion

It is well known that cloud feedback strongly regulates the solar radiation. The graphs between the observed hourly incoming shortwave radiation and cloud amount on four selected days, presented in figure 1 show a clear inverse relationship between the two. Figure 1(c) shows a maximum radiation of 1065 Wm^{-2} on 3.11.98 and figure 1(d) shows a secondary maximum of 1057 Wm^{-2} on 6.11.98 at noon under nearly clear sky conditions. On 31.10.98 (figure 1b) it can be seen that under overcast sky with cloud amount 7 to 8 oktas, the solar radiation is almost negligible.

The relationship between the Transmission Factor (T.F.) and sine of the solar altitude for different cloud amounts has been presented in figure 2. This shows that T.F. increases linearly with the sine of the solar altitude. Similarly, it can be observed from figure 3 that the hourly incoming shortwave radiation under different cloud amounts also increases linearly with

Figure 2. The relation between T.F. and $\sin h$ for different cloud amounts.

Figure 3. Graph showing the relation between hourly solar radiation and $\sin h$ for different cloud amounts.

the sine of the solar altitude. The relationship between the measured values and those estimated by using other models (Lind *et al* 1984; Gopala Reddy 1987; Dobson and Smith 1988) of T.F. and the sine of the solar altitude are given in figure 4 for comparison. Similar graphs showing the estimated incoming radiation and $\sin h$ are given in figure 5.

In the present study, the distance correction is also incorporated while calculating the T.F. The distance correction accounts for about $\pm 3.3\%$ of variation in the solar radiation at the top of the atmosphere. Thus, the present model is a slightly improved model than that of Lumb (1964). Due to data limitations, 4 categories of regression coefficients are obtained for estimating T.F. from cloud amount, which are given in table 1.

Figure 4. (a) to (d) Graph showing the relation between T.F. and $\sin h$ for different cloud amounts using different methods.

Figure 5. (a) to (d) Graph showing the relation between incoming solar radiation and $\sin h$ for different cloud amounts using different methods.

Table 1. Regression coefficients for estimation of T.F.

Cloud amount in oktas	Regression Coefficient			
	A	B	SD	RMS
1	0.502	0.187	0.048	0.038
4	0.491	0.138	0.082	0.507
5	0.412	0.179	0.093	0.492
6	0.261	0.336	0.096	0.393

Table 2. Comparison of the present model with other okta models.

Cloud amount in oktas	Present model (1998)		Lind <i>et al.</i> (1984)		Gopala Reddy (1987)		Dobson and Smith (1988)	
	SD	RMS	SD	RMS	SD	RMS	SD	RMS
1	0.048	0.038	0.046	0.272	0.087	0.222	0.036	0.331
4	0.082	0.507	0.118	0.404	0.113	0.334	0.121	0.451
5	0.093	0.492	0.095	0.229	0.083	0.146	0.117	0.350
6	0.096	0.393	0.057	0.237	0.085	0.184	0.068	0.296

Similar formulae were obtained by Lind *et al.* (1984) from JASIN data set, Gopala Reddy (1987) from Kiel Bay (lat. 54.5°) data set and Dobson and Smith (1988) from Pacific Ocean data set between 44° N and 62° N. The SD and RMS errors of these formulae are given in table 2 along with those of the formulae obtained in the present study for comparison. It can be seen that the RMS error for cloud amount 4 is higher, which is higher in the other models too. Further it can be seen from the table that the accuracy of the present formulae is in good agreement with those of the others.

4. Summary and conclusion

Empirical formulae for estimating hourly incoming shortwave radiation over the Indian Ocean under different cloud amounts (1, 4, 5, 6 oktas) were obtained by using the pyranometer measurements of the incoming shortwave radiation and the observed cloud amounts. These formulae have been developed by using the *in situ* observations taken over the Indian Ocean and can be used for estimating the hourly incoming shortwave radiation from cloud observations. The RMS error of these formulae varies between 0.038 and 0.507.

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