NOTE AND CORRESPONDENCE

In Situ Measurement of Solar Radiation over the Sea South of Japan

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Abstract

In situ measurement of the solar radiation was made during 166 days from August 1989 to January 1990 over the sea south of Japan, by using a small-sized pyranometer which was attached to the moored surface buoy system. In this prompt report, the daily mean values during 135 days from August to December 1989 were reported and the monthly mean values were compared with the available data which were mostly estimated by other authors using the various empirical formulae for the experimental area.

1. Introduction

In order to understand the air-sea interaction, it is important to estimate the fluxes through the ocean surface such as the wind stress, heat fluxes and the fresh water. Among the heat fluxes, in general, the solar radiation is a dominant component as well as the latent heat flux. So far, many empirical formulae for the estimation of solar radiation, *i.e.*, the indirect method, have been proposed (*e.g.*, Reed, 1977: Kondo and Miura, 1985). However, when we calculate the solar radiation using the different formulae, we obtain different values even if the same input data of marine meteorological elements are used; the differences are substantial (Iwasaka, 1989). Therefore, at the present stage, an *in situ* measurement for fluxes is highly desirable (*e.g.*, WOCE, 1989). Weller *et al.* (1990) made an *in situ* measurement of the solar radiation together with other marine meteorological elements by using the moored surface buoy system as a fixed platform during the period of FASINEX in the North Atlantic.

In the present paper, the result of the *in situ* measurement of the solar radiation, using a small-sized pyranometer attached to the surface buoy moored in the open ocean, will be described.

2. Apparatus and the experimental site

2.1 The pyranometer

The pyranometer, IKS-35 (Koito-Kogyo Co LTD.), is a small-sized silicon photodiode photometer of 15 mm in diameter and 27 mm in length. The recorder, KADEC-UP (Kona System Co LTD.), is a digital data recorder, in which the sensor output can be integrated over a predetermined interval and recorded in IC memories. The size is 175 mm in width, 80 mm in depth and 58 mm in height, and the weight is 800 g. This recorder can store 30, 720 data for about 3 years by battery backup. The integrating interval of 1 hour was selected in this experiment.

2.2 The moored surface buoy and the experimental site

The fixed platform for the pyranometer was the moored surface buoy which was designed and developed by the OMLET (Ocean Mixed Layer Experiment: Chairman Y. Toba, Tohoku University) members of Ocean Research Institute (ORI), University of Tokyo. The sensor and the recorder were directly attached to the upper part of the buoy without gimbals. The buoy system was deployed at 28°49′N, 135°02′E in August 12, 1989 in the testing cruise of the new R/V *Hakuho Maru*, belonging to ORI (Taira *et al.*, 1990). The sea depth is 4820 m. The position of the buoy system was continuously inspected by the Argos system. Although the buoy

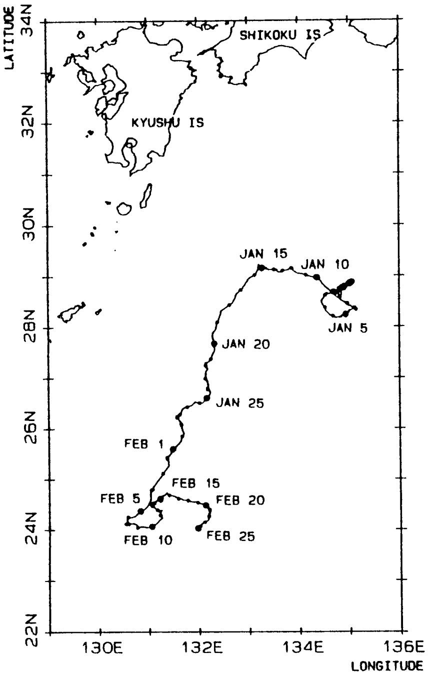

Fig. 1. Positions of the measuring site. The moored surface buoy used as a platform of the the pyranometer was originally settled at 28°49′N, 135°02′E. From late December, the surface buoy together with the mooring cable of about 100 m length began to drift and was recovered in February 26, 1990.

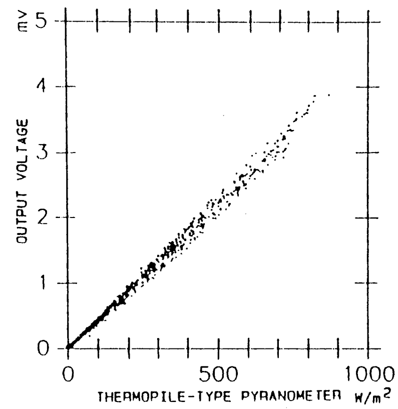

Fig. 2. Output voltage of the present sensor, IKS-35 (Koito Co LTD.) versus the insolation by the thermopile-type pyranometer, MS-34F (Eko-Seiki, Co LTD.). The data are 30-minute averages taken for 40 days under various sky conditions.

was located around the settled point until December 22, the surface buoy together with the mooring cable of about 100 m length began to drift, as shown in Fig. 1. Unfortunately, the cause was unclear. The buoy system was recovered by the new R/V *Hakuho Maru* on her way from the Around-the-World cruise, in February 26, 1990 at 23°56′N, 131°57′E (Taira *et al.*, 1990).

2.3 Calibration of the pyranometer

Since the sensitivity of the silicon photodiode photometer strongly depends on the wavelength, we made an intercomparison experiment between the system used and a thermopile-type pyranometer, MS-43F (Eko-Seiki Co LTD.), at our university campus in Sendai. The thermopile-type pyranometer has also been calibrated against the Ångström pyranometer (Eppley Co LTD.) by the members of the Meteorological Laboratory, Tohoku University. This calibration showed that the accuracy of the thermopile-type is within 2 %.

Figure 2 shows the relationship between the output voltage of the pyranometer used in this experiment and the radiative flux measured by the thermopile-type pyranometer for 30-minute averages during the period of 40 days. The conversion curve from the output voltage to the radiative flux was made, and it was found that the standard deviation of the differences between the values of our pyranometer and those of the thermopile-type pyranometer was 6 Wm^{-2} for the daily mean value.

In the field experiment over the ocean, troublesome errors may enter the measured data because of the rocking motion of the sensor due to wave motion and the mean (preferential) tilt of the buoy. Katsaros and DeVault (1986) tried to theoretically estimate these errors under idealized sky conditions, and they pointed out the possibility of substantial errors especially due to the mean tilt of the sensor. Since the surface buoy used in the present measurement was not tightly moored and so could freely move around its central position, it can be expected that there was no substantial mean tilt. However, it is hard to say at the present stage how much error is included in the present result.

3. Results

The data for 166 days from August 13, 1989 to January 25, 1990 were obtained. Subsequently, the integrating interval was found to have unexpectedly changed. This change may have been due to electric noise because of the intrusion of the sea water into the recorder. In this report, the daily mean values of 135 days from August 13 to December 25 are described. This period corresponds almost to the time that the surface buoy existed at the originally settled point. Figure 3 shows the variation of the daily mean insolation, in which the curves of the ratio to the theoretically expected insolation at the top of the atmosphere are superposed. Figure 4 shows the frequency distributions of the ratio between the observed values and theoretically expected insolations at the top of the atmosphere for each calendar month.

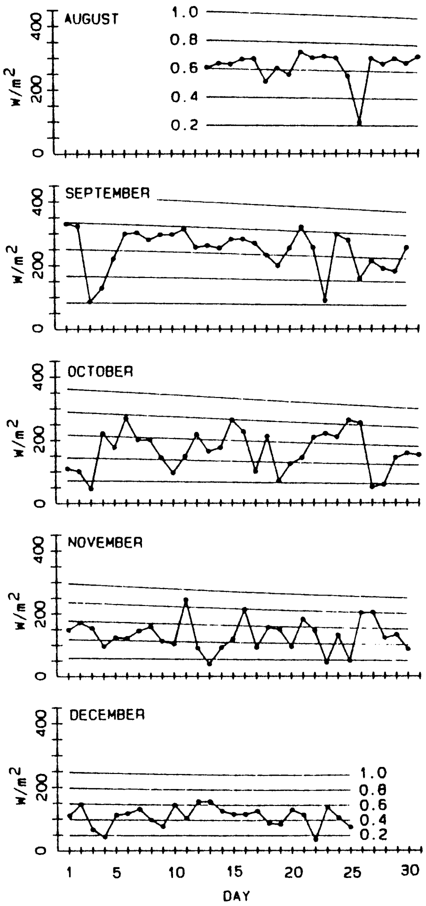

Fig. 3. Time series of the daily mean insolation from August 13 to December 25. The five curves in the figures denote the theoretically expected values at the top of the atmosphere multiplied by constants of 0.2, 0.4, 0.6, 0.8 and 1.0.

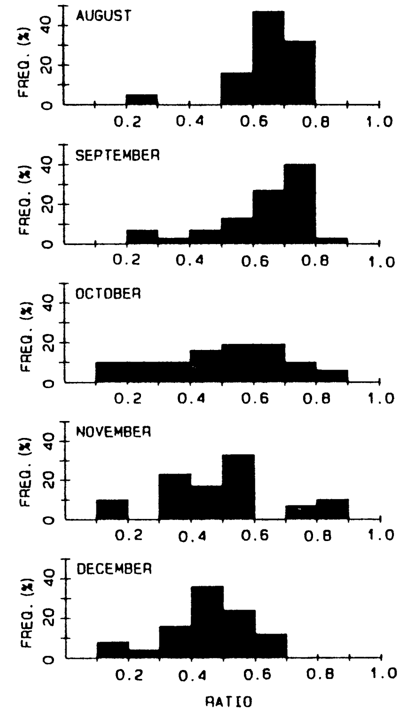

Fig. 4. Frequency distributions of the ratios between the observed daily mean values and those at the top of the atmosphere for each calendar month.

It is found that both the day-to-day variations and the distributions of the ratio to the insolation for each calendar month show a behavior consistent with the cloud climate in this sea area (*e.g.*, Kodama and Asai, 1988). That is, in August and September, since the sea area is covered by the subtropical high, the ratios are, in general, relatively high (monthly mean ratio of 0.63 for both months). From late September and October, since traveling cyclones and anticyclones pass over the experimental site alternately, the ratios are scattered ranging from 0.2 to 0.8 (monthly mean ratio of 0.50 for October). In the winter season, since the cold-air outbreak, so called *Kisetsuhu*, frequently occurs and the level of cloud top becomes lower, the ratios become small (monthly mean ratios of 0.48 and 0.44 for November and December, respectively).

The monthly mean values of measured insolation were calculated as 273 Wm^{-2}, 247 Wm^{-2}, 166 Wm^{-2}, 131 Wm^{-2} and 105 Wm^{-2} from August through December, respectively. It may be helpful to compare these values with the previous estimates for the experimental sea area. Koizumi (1956), Maeda (1965) and Kurasawa *et al.* (1983) estimated the insolations from the marine meteorological elements obtained at the former Ocean Weather Station "T" (29°N, 135°E). They used different empirical formulae and the estimation periods were also different from each other. Otobe (1989) summarized the results of direct measurement of the shortwave radiation made by himself, using the thermopile-type pyranometer on board of the R/V *Hakuho Maru.* The ship tracks are widely distributed in the sea area south of Honshu for each cruise. Nevertheless these data are very valuable. Figure 5 shows the summary for them. Here, the values of the present measurement were multiplied by constant of 0.94 under the assumption of the albedo of 0.06 at the sea surface (Payne, 1972: Otobe, 1989). It is seen that the values indirectly estimated from the marine meteorological elements are generally an underestimation compared with the directly observed values, especially in summer season. However, it may be premature to state this conclusion. To confirm this item, the accumulation of the data by *in situ* measurements is indispensable.

Finally, it may be also useful for us to compare the present result with the insolations measured by the pyranometers installed on the Ocean Data Buoy operated by the Japan Meteorological Agency (JMA). The buoy is located at 29°N, 135°E, *i.e.*, about 10 nautical miles away from our experimental site. Two

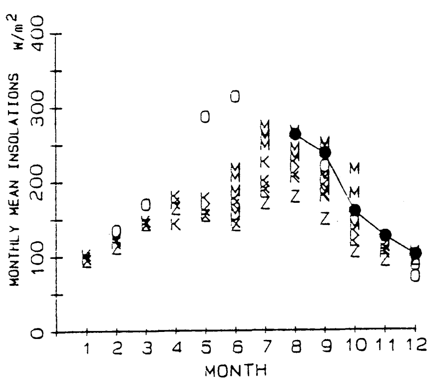

Fig. 5. Comparisons of monthly mean insolation of the present result (black circles with solid line) with the previous studies for the experimental sea area. Symbols denote the authors: Z-Koizumi (1956), M-Maeda (1965), K-Kurasawa *et al.* (1983) and O-Otobe (1989). Except for Otobe (1989), those were indirectly estimated by using the empirical formulae from the marine meteorological elements obtained at the former Ocean Weather Station "T" (29°N, 135°E). Note that the values of the present result are multiplied by constant of 0.94 under the assumption of the albedo of 0.06 at the sea surface.

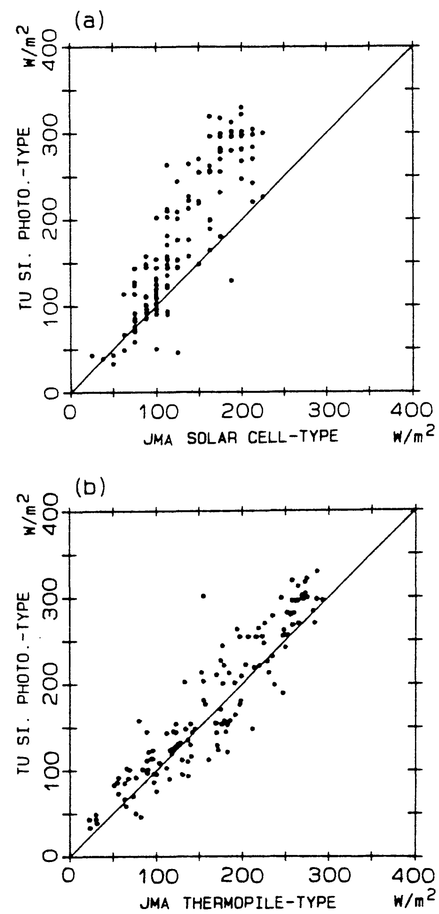

Fig. 6. Comparison between the daily mean insolations observed by two types of pyranometers attached to the JMA Ocean Data Buoy (abscissa) and those of the present result (ordinate). (a) Insolations measured by the solar cell-type pyranometer (SCP data). (b) Insolations measured by the thermopile-type pyranometer (TPP data).

types of pyranometer are installed on this buoy. One is a solar cell-type pyranometer (henceforth SCP data) and the other is the thermopile-type pyranometer which was experimentally installed on this buoy (TPP data).

Figures 6a and 6b show the scatter plot between daily mean insolations of SCP and those of the present study and that between those of TTP and ours, respectively, during the experimental period. The SCP and TPP data used were provided by the Oceanographic Division (JMA, 1990). The SCP data are a considerable underestimation of about 30 % compared with the present result. This tendency of underestimation has already been pointed out by Endoh *et al.* (1987), whose estimation is about 10 %. It is suggested that this too large an understimation is caused by a simple mistake in setting the pyranometer system (such as an amplifier magnification).

On the other hand, the TPP data are in relatively good agreement with our result. An average of the daily mean values of the TPP data during the experimental period is 168 Wm^{-2}, which is smaller by about 7 % than that of our result (180 Wm^{-2}). The root-mean-square of differences of daily mean values between the two data amounts to 34 Wm^{-2}. At the present stage, we can not say whether or not this scatter is caused by the actual difference of cloud conditions at the two experimental sites. To measure the insolations at plural sites closely arranged may be desired for the clarification of such spatial variability. On the other hand, the largely scattered distribution of the SCP data can be attributed to the fact that the SCP daily mean insolations are calculated from simultaneous values every three hours, since this scattered distribution is also seen in the relationship between the TPP and SCP data (not shown here). The monthly mean values of TPP data were calculated as 249 Wm^{-2}, 229 Wm^{-2}, 157 Wm^{-2}, 124 Wm^{-2} and 99 Wm^{-2} from August through December, respectively. The differences from the present result amount to -24 Wm^{-2}, -18 Wm^{-2}, -9 Wm^{-2}, -7 Wm^{-2} and -6 Wm^{-2} from August through December, respectively.

4. Concluding remarks

There is no doubt that solar radiation data obtained by *in situ* measurements in the open ocean are very valuable in themselves. They will be also used as the sea-truth data in the development of algorithms for the estimation of insolation from the satellite data. In addition, they can be used to improve the empirical formula applied to the marine meteorological elements. Although the use of the satellite data will be the primary means of estimation of insolation in the future, it is also important to archive the long-term time series of surface fluxes by using the historically accumulated marine meteorological data.

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日本南方海域における日射の現場観測

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日本南方海域に係留された表面ブイに小型の日射計を取り付け、日射の現場観測を行った。1989年8月から1990年1月まで166日間の観測に成功した。この速報では、1989年12月までの135日間の日平均日射量を示した。月平均値に対しては、これまで同海域で海上気象資料から経験式を用いて評価されている値と今回の結果を比較した。