Solar Radiation and Energy Flux Change on Manus Island,
Papua New Guinea

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Abstract

We observed global solar radiation changes through two months during the IOP of TOGA-COARE from 19 November 1992 to 19 January 1993 on Manus Island, Papua New Guinea, in the western tropical Pacific. The whole observation period was divided into four stages through consideration of the daily variations of solar radiation. Significant features of each period were also presented in terms of the activity of cloud convection derived from TBB data of GMS and zonal wind changes observed by a wind profiler. Surface winds were changeable throughout the observation period; however, an episodic strong westerly wind was observed from the end of December to early January. The most active stage of cloud convection, which was characterized by a decrease of solar radiation in the afternoon, was observed before the westerly wind episode. Morning convection was, however, prominent during the period of the strong westerly wind. A diurnal change of solar radiation was also compared with the change of latent and sensible heat fluxes obtained using the eddy correlation method. Energy fluxes on a ground surface indicated a quick response within about 30 minutes to solar radiation change. Latent and sensible heat fluxes were almost zero at nighttime, but the maximum value of latent and sensible heat fluxes in the daytime were about 270 and 200 Wm$^{-2}$, respectively.

1. Introduction

Solar radiation has two aspects in cloud convection. One is that the solar radiation absorbed at the earth's surface is a major source of energy for maintaining atmospheric convection. The other is that the solar radiation is strongly affected by the amount of cloud which results from active convection. Organization of cloud convection around equatorial region is related to the development of tropical cloud clusters, which play an important role in the atmospheric circulation. Therefore, it is important to have information on the solar radiation change around the equatorial region and to investigate the effect of solar radiation on tropical cloud formations. The energy flux change on the ground surface corresponding to the fluctuation of the solar radiation is also helpful to reveal the generating mechanism of a topographic cloud that would trigger the development of cloud clusters.

Since solar radiation is a dominant component in describing the surface heat fluxes, an in situ observation of the solar radiation is required to estimate an accurate value of the input energy to the surface. Continuous observations on the solar radiation in a tropical region will provide valuable results to estimate surface energy fluxes. On the other hand, solar radiation is strongly affected by the type and amount of clouds. Cloud characteristics observed by satellites are often used for meteorological researches in the tropical region (e.g., Nakazawa, 1988; Takayabu and Murakami, 1991). The comparison of solar radiation with cloud data by satellites is useful to clarify the relationship between the input energy and cloud activity of tropical convection.

The relationship between cloud activity and a westerly wind burst is also discussed by many re-
searchers (e.g., Nitta and Motoki, 1987; Lau et al., 1989). The westerly wind signature is a good indicator of tropical convection. Gage et al. (1991) is concerned with the application of wind profiling technology on tropical atmospheric research. A continuous and short-interval observation by a wind profiler is useful to detect wind changes in the lower troposphere.

To understand the mechanism of cloud system and air-sea interactions in the tropical region, several synthetic observations were carried out around the western tropical Pacific in the TOP (Intensive Observation Period) of TOGA-COARE (Tropical Ocean and Global Atmosphere program, Coupled Ocean Atmosphere Research Experiment). One of the purposes of this study is to describe equatorial synoptic situations around Manus Island, Papua New Guinea, through the two month observation period by dual-Doppler radar. The radar observations found several kinds of convection around Manus Island such as squall-line type or topographic convection and stratiform rainfall from cloud clusters (e.g., Takahashi and Uyeda, 1995; Satoh et al., 1995; in this issue). The convective activity and the cycle for the development of clouds throughout the observation period were changeable. Therefore, we classified the whole period into four short stages by considering the daily change of solar radiation.

Another purpose is to describe the differences in the features of solar radiation and cloud activity in each short period. The cloud activity was confirmed from GMS and radar data around Manus Island. Zonal wind structures obtained by a wind profiler on Manus Island corresponded to the cloud activity in each period. The diurnal change of solar radiation indicated that the irradiation had a different signature in each period.

Energy flux observations on the tropical ocean were carried out among the main projects of TOGA-COARE. To describe the effect of islands on the formation mechanism of cloud clusters, we will mention energy flux changes on the ground surface obtained by the eddy correlation method.

2. Observations and data sources

On Manus Island, Papua New Guinea, dual-Doppler radar and several meteorological observations were carried out about two months from November 1992 to January 1993 during the IOP of TOGA-COARE (Uyeda et al., 1995; in this issue). Manus Island is about 100 km in length and about 30 km in width; the highest mountain is 702 m in height. To understand the features of irradiative energy in the tropical region, observations of solar radiation were conducted from 19 November to 19 January at Momote airport (2.0°S, 147.4°E), which is located on the eastern edge of Manus Island, in correspondence with the radar observation. Air temperature and rainfall amount were observed at Momote by the National Weather Service of Papua New Guinea.

A wind profiler at Momote was continuously operated by NOAA in the IOP of TOGA-COARE. In this study, we used 91 m and 1519 m height horizontal wind data every 30 minutes. The GMS data of 0.1 degree longitude-latitude gridded TBB around
the COARE region every hour through the observation period were utilized from TOGA-COARE GMS CD-ROM. Solar radiation is strongly affected by clouds locating just over the observation point. We used only one grid data (about 10 x 10 km area) over Momote, since typical topographic convections often observed on Manus Island were small in horizontal scale (about 10 km) and showed slow movement (Takahashi and Uyeda, 1995; in this issue).

Latent and sensible heat flux measurements by the eddy correlation method using an ultrasonic anemometer and an infrared gas analyzer were carried out a few times through the observation period when the surface wind was calm. The ultrasonic anemometer and the infrared gas analyzer were mounted at 1.8 m in height on open grassland near a landing strip of Momote airport. The ground was coral covered with grass less than 10 cm in height. In a series of observations, the horizontal and vertical wind, air temperature, and water vapor data of 10 Hz frequencies were recorded on the hard disk of a personal computer for 10 minutes in every 30 minutes throughout the 24-hour measurements. Diurnal changes of latent and sensible heat fluxes were evaluated from the data every 30 minutes.

3. Classification of the observation period

We classified the whole observation period into four stages as Periods A to D. The four periods were split as follows; Period A was from 19 November to 9 December, Period B was from 10 to 23 December, Period C was from 24 December to 4 January, and Period D was from 5 to 19 January. Each period was determined from the daily variation of solar radiation. The characteristics of each period are shown in the following.

a) Solar radiation

Open circles and the solid line of Fig. 1 show the daily change of the global solar radiation amount in the observation period. Throughout the observation period, the daily amount of solar radiation over 22 MJ m\(^{-2}\)day\(^{-1}\) corresponded to a clear day. During Period B, solar radiation below 10 MJ m\(^{-2}\)day\(^{-1}\) was often observed and there was no clear day. This means that Period B was an active phase of cloud convection, since decreases of solar radiation reflect large amount of clouds.

b) GMS T\(_{BB}\)

Cloud activity was also confirmed by using the GMS T\(_{BB}\) data. Open squares and the dashed line of Fig. 1 show the daytime average of 0.1 degree gridded T\(_{BB}\) just over Momote. The daily change of solar radiation and the averaged T\(_{BB}\) correspond well with each other.

Small open squares of Fig. 2 show hourly T\(_{BB}\) changes over the observation point. The averaged T\(_{BB}\) of around 250 K in Period B indicated strong activity of cloud convection. Several lower peaks indicated that a high activity of deep convection often occurred in Period B. The cloud convection in Period C was less active than Period B, but more intense than in Periods A and D. The averaged T\(_{BB}\) of over 290 K, which indicated no or less cloud, was often indicated in Periods A and D, but rarely obtained in Periods B and C.

It is shown that about a 2-day-cycle fluctuation was present throughout Period B, and about a 3-
day-cycle fluctuation present throughout Period C. These cycles are consistent with the wind features described in the next section. On the other hand, a 5-day or longer interval of TBB decreases, which related to the cloud clusters, was apparent in Periods A and D.

c) Zonal wind

The change in the zonal wind at 91 m height, which is the lowest available height of the wind profiler data, is shown in Fig. 3. A strong westerly wind of over 5 m s$^{-1}$ in zonal component was continuously observed throughout Period C; therefore, Period C was identified as an episodic strong-wind period.

It is readily apparent that a 2-day-period fluctuation of zonal wind related to cloud signatures was present in a thick line throughout Period B. Daily fluctuation of wind features (e.g., land-sea breeze) was removed by the use of a 24-hour running mean; therefore, the clear wind shift of the 2-day period corresponded to the development cycle of convective clouds. From analyses of the radar data around Manus Island, it was considered that the wind shift
near the surface was strongly affected by the outflow from topographic cumulonimbus storms generated over Manus Island.

Figure 4 shows the change in zonal wind at 1519 m (corresponds to about 850 hPa) in height. Strong westerly winds were also observed throughout Period C. Contrary to the near-surface wind, about 3-day-period fluctuations were present throughout Period C. These 2- or 3-day-cycle fluctuations of winds are consistent with the TBB features in Periods B and C; however, the reference height of the cycle is different from the surface to 850 hPa.

Fig. 5. Diurnal change of global solar radiation from 06 to 18 LST. The thick solid line indicates the averaged solar radiation for the whole observation period from 19 November to 19 January. The dashed line indicates the averaged solar radiation for Period A from 19 November to 8 December. The open circle and thin line indicate a typical case of solar radiation in 1-minute intervals for Period A on 23 November 1992.

Fig. 6. The same as Fig. 5, but for a typical case for Period B on 14 December 1992 and averaged from 10 to 23 December.
4. Diurnal variation of solar radiation

The diurnal variation of solar radiation shows different features in each period. During Period A, the daily amount of solar radiation sometimes decreased corresponding to the activity of cloud clusters. Zonal wind was changeable through the period but a strong westerly wind was observed before the passage of a cloud cluster on 24 November. Figure 5 shows a typical diurnal change of solar radiation in Period A. The averaged feature of this period resembled the solar radiation change through the whole observation period. The fluctuations of solar radiation indicated that small cumulus clouds obstructed and reflected the direct solar radiation throughout the daytime.

Period B was the most active stage for convec-
tion before the episodic westerly wind. Convective clouds were often observed around Manus Island by GMS cloud pictures, and the wind direction at Momote was changeable through the period. Figure 6 indicates that the morning solar radiation of Period B was not much diminished; however, the afternoon solar radiation showed a large decrease. This means that strong cloud convection occurred in the afternoon. This was confirmed by the radar observation's showing that a storm was generated on the mountain area of Manus Island and moved toward the observation site in the afternoon.

Contrary to Period B, morning convection was dominant in Period C. The smooth change of solar radiation in the afternoon on 28 December (Fig. 7) indicates that there was no cumulous cloud that could obstruct and reflect the direct solar radiation. The high-frequency fluctuations in the morning mean that some cumulus clouds existed which affected the direct solar radiation. The averaged solar radiation in the morning was relatively lower than the afternoon irradiance. It is considered from analyses of radar data that the decrease was caused by the convection which developed over the ocean in the night or early morning.

Figure 8 shows the averaged solar radiation and a typical case of Period D. Although Period D corresponded to the aftermath stage of the westerly wind episode and the wind signature resembled in Period A, the diurnal change of averaged solar radiation in Period D was similar to that of Period C. The morning convection and large solar radiation on the afternoon of Period D resembled those in Period C; however, the TBB features in Period D were similar to these of Period A.

5. Energy flux change on the grassland of Manus Island

We present a case of flux observation on 5 December, when we observed little rainfall (none counted on the raingauge) at around 1000 LST and heavy rainfall (about 20 mm in 20 minutes) at around 1320 LST. Figure 9 shows the global solar radiation change on 5 December. Figure 10 shows the latent and sensible heat fluxes every 30 minutes. The maximum value of latent and sensible heat fluxes was about 270 Wm$^{-2}$ and 200 Wm$^{-2}$, respectively. Due to the heavy rainfall, latent heat flux data between 1300 and 2130 LST were not obtained.

The changes in the sensible and latent heat flux corresponded well to the 30-minute running mean of solar radiation. Sensible heat flux decreased, corresponding to large decreases of solar radiation around 1000 and 1400 LST. Small decreases of solar radiation around 1200 and 1530 LST also corresponded to the heat flux change. Throughout the observation period, the quick response of the vertical energy flux to solar radiation within about 30 minutes was generally obtained by the observations in the daytime; however, the sensible and latent heat fluxes on the island were nearly zero in the night.
6. Concluding remarks

In this study, we used several kinds of data, such as solar radiation, GMS TBB, and wind profile around Manus Island. The simultaneous observations in the tropical region were useful to reveal the development cycle and occasion of cloud clusters.

An episodic strong westerly wind at the end of December 1992 was the most significant event throughout the observation period. The amount of solar radiation had decreased about 15 days before the westerly wind episode, and morning convection was more dominant than afternoon convection during the strong westerly wind period.

Tanaka (1994) shows that the onset dates of the summer monsoon determined by the clouds were 10 to 30 days earlier than the onset dates of the monsoon winds over the land areas in interior New Guinea. Although Manus Island is located on the northern Ocean of New Guinea, the cloud activity corresponding to the wind features resembled that of the land areas. Chu and Frederick (1990) shows that deep convective clouds are sometimes found east of strong westerly winds. The cloud characteristics in their studies had similarities with the features of clouds on Manus Island.

Godfrey et al. (1991) said that the diurnal change of latent and sensible heat fluxes from the ocean around the COARE region is small but the energy flux is strongly affected by the surface wind speed. The energy flux change on the island presented noticeable diurnal change in the daytime. The quick response of solar radiation and energy flux was conductive to the generation of convection on the island in the afternoon. It is considered that the morning convection over the ocean in the strong wind period corresponded to the relatively large heat and moisture fluxes over the ocean at night.

Cloud signature showed that a 2-day cycle fluctuation, which was consistent with the characteristics of surface zonal wind, was present throughout Period B, and a cycle fluctuation of about 3 days, which was consistent with the changes of the 850 hPa zonal wind, was present throughout Period C. The diurnal pattern of the cloud formation was also different in Periods B and C; one was developed in the morning and the other was developed in the afternoon. This means that the cloud formation in Periods B and C were dominated by different mechanisms. Therefore, the differences in the equatorial synoptic situations have to be considered to understand the mechanism of diurnal change and the development cycle of convective clouds in the tropics.

It is considered that the change of the wind signature and cloud activity throughout the observation period indicated one aspect of the 30–60 day oscillation in the tropics. The equatorial synoptic condition around Manus Island affected the place, the occasion, and the cycle of storm development. It is important to consider what type of tropical synoptic situation dominates the storm generation while investigating the developing mechanism of each storm.

Fig. 10. Diurnal change of latent (open triangle and dashed line: IE) and sensible (open square and solid line: H) heat fluxes on 5 December 1992.
In this preliminary study, we presented an index to classify the storms developing around Manus Island. The characteristics of clouds and winds in each 10- to 20-day period were well identified. The upper air sounding data, the other island's wind profiler data, and regional GMS data were, however, not used in the present study. To understand the detailed synoptic situation in the tropical region, more intensive research is required around the COARE region.

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References


バブアニューギニア、マヌス島における日射量とエネルギーフラックスの変動

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TOGA-COAREの集中観測期間中、西部熱帯太平洋上のバブアニューギニア、マヌス島において1992年11月19日から1993年1月19日までの2ヶ月間、全天日射量の観測を行なった。日射量の変化の特徴から観測期間を4つに分割した。GMSのTBBからみた対流の活発度やウインドプロファイラーから得られた東西風にも各期間の特徴がみられた。観測期間を通して地上風の変動は激しかったが、12月下旬から1月上旬にかけて強い西風が観測された。最も対流活動が活発であった期間は午後の日射量の低下で特徴付けられ、西風強化の前に行っていた。一方、西風が強化された期間では午前中の対流活動が支配的であった。日射量の日変化を渦相関法によって求められた顕熱や潜熱のフラックスと比較すると、陸上におけるエネルギーフラックスの変化は日射量の変動に30分程度すばやく対応していた。潜熱と顕熱のフラックスは、夜間はほとんど零であり、昼間の最大値は顕熱で約270 W/m²、顕熱で200 W/m²であった。