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27-day variation in cloud amount and relationship to the solar cycle

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15327

Abstract

Linkages between solar activity and the earth's climate have been suggested in previous studies. The 11-year cycle in solar activity evident in sunspot numbers is the most examined example of periodicity, and it is clearly recognized in variations in the thermal structure and dynamical motion of the stratospheric atmosphere. Also the variations in the stratosphere related to the period of apparent solar rotation have also been suggested; however, for such a short period, no quantitative evidence indicating a relationship to the tropospheric phenomena. We clearly demonstrate a 27-day variation in the cloud amount in the region of the Western Pacific warm pool, which is only seen in the solar maximum years of the 11-year cycle. The average spectrum in solar maximum years also shows an enhancement in the range of MJO period. Long-term variations in the tropospheric phenomena, including the 11-year cycle, are generally investigated based on monthly or even yearly averaged data, but the present results may suggest an alternative possibility: short-period variations could modulate longer periodic phenomena.

1 Introduction

Linkages between solar activity and the earth's climate have been suggested in previous studies. The 11-year cycle in solar activity evident in sunspot numbers is the most examined example of periodicity, and it is clearly recognized in variations in the thermal structure and dynamical motion of the stratospheric atmosphere (Haigh, 1994; Kodera, 1995; Shindell et al., 1999). Synchronization between the flux of galactic cosmic rays and cloud amount has also been reported in terms of the solar cycle (Svensmark, 1998) and in the longer time scale (Miyahara, 2008). Variations in the stratosphere related to the period of apparent solar rotation have also been suggested (Nastrom and Belmont, 1978; Hood, 1984); however, for such a short period, no quantitative evidence exists to indicate a relationship between solar activity and tropospheric phenomena. Here

15328

we focus cloud amount variation with ~one month periodicity using Outgoing Long-wave Radiation (OLR) and examine the modulation of the periodicity, paying attention to 11-year solar cycle.

2 Analysis and results

5 We used OLR data as a proxy for the cloud amount (Liebmann and Smith, 1996). The OLR is the total amount of thermal radiation emitted from the earth to interplanetary space. Low values of OLR at low latitudes are associated with cloud, as radiation from the low-temperature cloud top is weaker than that from the surface. That is, OLR is an indicator of the cloud amount. Figure 1 shows the map of the spectral power of OLR in the period of 25–29 day, that is about the cycle of solar rotation (27 days), for the low latitude region. Apparently two regions, that is, the eastern part of the Indian Ocean and the central part of the Western Pacific Warm Pool (WPWP) centred at 140° E, 10° N, show significant enhancement. The WPWP, which shows the broader enhanced area in the power spectrum, is known to show the highest sea surface temperature in any ocean and strong atmospheric convective activity. In the present study, as the first step, we conducted a spectral analysis for WPWP area to investigate this periodicity in detail for the OLR variation.

The OLR was spatially integrated over the longitudes 130° to 150° and the latitudes 0° to 10° (2.5°-square grid). The period of analysis is from 1980 to 2003, covering almost two and a half 11-year solar cycles. After removing long-term variations using a high-pass filter (cut-off period of 180 days), we calculated the power spectra of individual yearly data using the Fourier transform method with a Hanning filter. The yearly power spectra are smoothed with a running mean of 3 data points. The amplitude of solar parameters with 27-day period depends on the phase of the 11-year solar cycle and is generally larger at the solar maximum. If 27-day fluctuations of solar activity affect cloud amount, we would expect the response of cloud amount to vary with the phase of the 11-year solar cycle. We then categorized the analysis period into solar maximum and minimum periods using a 1-year unit. We used the 10.7 cm solar radio flux (F10.7)

15329

as a proxy of the degree of solar activity. Figure 2 shows variations in F10.7 for the period from 1980 to 2003. For the first two peaks, we define those years with smoothed F10.7 values of more than 180 (red lines) as solar maximum years (Max1 and Max2). For the third peak, the threshold is lowered to 160 (Max3). Those years with smoothed F10.7 values of less than 100 are defined as solar minimum years (Min1 and Min2). Consequently, five periods are determined according to the above procedure.

Figure 3a–e shows the yearly power spectra of OLR for each solar activity period. The yearly spectra for solar maximum years (black lines in Fig. 3a, c, and e) are characterized by two peaks with ranges of 24–30 days (vertical red bars) and 40–60 days, except for 1991. Consequently, the two peaks are clearly evident in the average spectra (red lines). One possible reason for the lack of clear periodicity in 1991 is that incoming solar radiation in 1991 was reduced following the eruption of Mt. Pinatubo during June of that year. Therefore, the spectrum for 1991 is excluded from the average spectrum. During the solar minimum years, the range of 24–30 days is devoid of remarkable peaks (black lines in Fig. 3b and d) and the spectrum features for periods of greater than ~30-day show large yearly variations, especially in terms of period.

A red (blue) line in Fig. 4a shows the power spectrum obtained by averaging all of the spectra for the maximum (minimum) years. The spectrum for 1991 is excluded, as described above. Figure 4b shows averaged spectra for F10.7 that were calculated in the same manner as those for OLR. It is evident from Fig. 4b that the amplitude of solar 27-day periodicity during maximum years (red line) is clearly greater than that during minimum years (blue line) by about 30 times. The shapes of the two average spectra in Fig. 4a are clearly different. Periodicities of ~27 and ~50 days are prominent in the solar maximum years (red lines), while no clear peaks appear in the range of 24–30 days in the solar minimum years (blue lines).

The above results can be summarized in terms of the following two new findings. First, the behaviour of variations in cloud amount depends on the phase of the 11-year solar cycle. Second, one of the two periodicities in solar maximum years has the almost same value as the cycle of solar rotation: 27 days. This suggests that the 27-day cycle

15330

in variations in solar activity controls variations in the cloud amount.

3 Discussion

We performed the same spectral analysis for other equatorial areas (results not shown) and found that the area in which the OLR always shows 27-day periodicity in solar maximum years is most prominent in the WPWP. This area may therefore be a kind of “accepting region” for solar activity with 27-day periodicity. Considering this fact as well as the large amplitude of 27-day periodicity, an investigation of the characteristics of WPWP may provide the key to understand the mechanism that generates the observed 27-day periodicity in cloud amount and world climate variation, as well as those of Indian Ocean.

Identification of the physical mechanisms for 27-periodicity is not easy work since the most solar parameters, including total solar irradiance, solar UV, and galactic cosmic ray (GCR) intensity, vary with the period of solar rotation and modulated by the 11-year solar cycle. Therefore, we think that the mechanism determination is beyond the scope of this paper and would insist on the importance of this paper as the first fact report on 27-day periodicity in OLR. However, here, we can mention some possible thin edges of the wedge for the explanation. Increase of GCR induced by lower solar activity could cause the increase of cloud condensation nuclei (CCN) (reviewed by Kirkby, 2007). Longer time period phenomena is sometimes successfully explained by GCR (ex. Miyahara, 2008). WPWP is one of the special places where the sea surface emits large amounts of water vapor and DMS (Dimethyl Sulfate), due to its high temperature, which will be changed to CCN via some processes with GCR. Marsh and Svensmark (2003) indicated the high correlation between GCR and low cloud amount in WPWP for long period data. Another possible explanation for the relationship between the solar parameter and cloud amount would be the mechanism related to the global circuit model, which could be modulated both by GCR and geomagnetic activities originated by solar wind variation. Modulation of the global electric circuit currents changes the distribution of highly charged aerosols, which may strongly influence cloud

15331

precipitation. This process is named as “electroscavenging” (Tinsley, 2000). WPWP is one of the most cloudy section of the sea in the world, meaning the most sensitive to the electroscavenging. At this stage we cannot exclude effect of UV radiation via heating of the stratosphere, effect of slight change of total solar irradiance (TSI) and other ideas for physical connections between solar activity and cloud amount. Note again that these hypotheses should be examined quantitatively based on the detail and careful analysis, which is beyond the scope of this paper.

Though the apparent periodicity in the averaged spectrum for solar minimum years (Fig. 4a) is 35 days, the periodicity shows some yearly variations in the range of 20 and 35 days. If the 27-day periodicity in cloud amount during solar maximum years is caused by solar activity, the periodicities during solar minimum years can be regarded as the internal periodicity of the Earth’s atmosphere. It could be possible that the internal periodicities are synchronized with 27-day period by the weak but persistent external force caused by solar activity. It is also found that the phase relationship between the solar parameters and the OLR is not constant through out a year, namely, in a certain period of consecutive months they oscillate in the same phase while in other few months they oscillate in opposite phase, although the yearly-averaged periods are almost same: ~27 days. This fact seems to support the idea that the internal periodicity is synchronized with weak external force.

A periodicity of 40–60 days is also prominent and relatively stable in solar maximum years compared to minimum years. This periodicity lies within the range of the Madden-Julian Oscillation (MJO) (Madden and Julian, 1971, 1972). This result implies some direct or indirect interaction between the occurrences of the 27-day and stable MJO periodicities. However, the detail and careful analyses, paying attention to the regional and temporal variations, are required to examine this possibility.

Long-term variations in the tropospheric phenomena, including the 11-year cycle, have been generally discussed based on monthly or even yearly averaged data. In such ways, we could not find 27-day periodicity, which has much larger amplitude, up to few tens of percent, than 11-year variation of only few percent in cloud amount. The

15332

present results here suggest that we should investigate the cause of longer periodic phenomena, taking into account two possibilities: One is that the averaged solar parameter directly induces it, as has been discussed. Another is that the short-period variations of solar parameter such as 27-day periodicity could modulate the period of climate parameter variation such as about one month variation of OLR, which has much larger amplitude in a short period, and then this modulation of period in climate parameter induces the longer period variation, as a structure of the time hierarchy.

4 Conclusions

We made simple frequency analysis for cloud amount based on OLR data of 25 years, focusing the relationship between short-term (~one month) change and 11-year solar cycle. It was found that the ~27-day variation of OLR is prominent in WPWP in solar maximum years. This fact suggests a possibility that the solar rotation influences the variations of the cloud amount in that area. Taking into account the fact that the apparent periodicity of cloud amount in the averaged spectrum for solar minimum years exists at ~35 days, which is clearly longer than 27 days, the possibility of synchronization with weak external source should be examined. The averaged spectrum of OLR variation in solar maximum years also shows a significant enhancement in the period range of 40–60 days, which corresponds to MJO periods, indicating some possible connection between them. Though some physical mechanisms to explain the solar activity effect on cloud amount variation could be proposed, careful and multidirectional approaches are strongly desired in the near future.

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15333

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15334

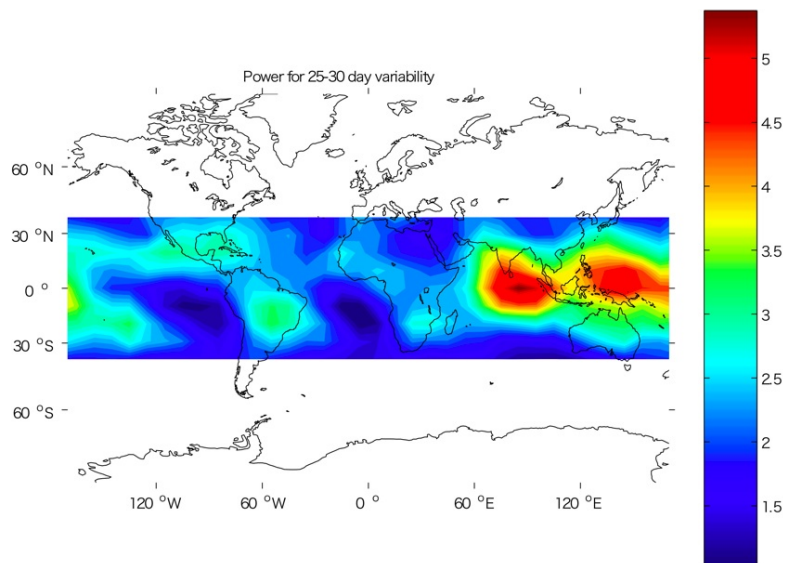


Fig. 1. Map of the spectral power of OLR in the period of 25–29 day.

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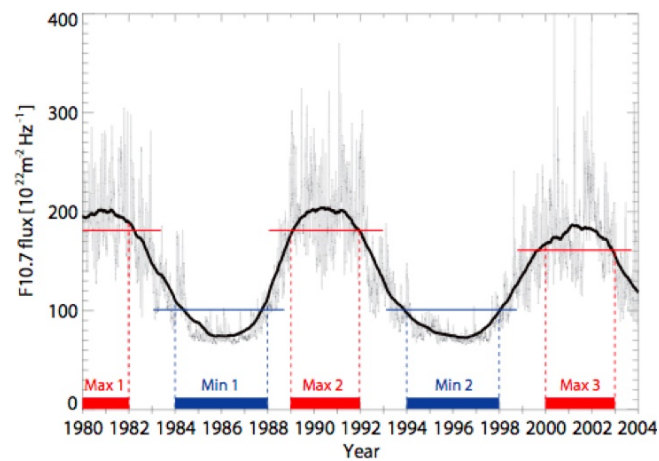


Fig. 2. Variations in F10.7 for the period from 1980 to 2003. Grey and black lines denote daily mean and 2-year running average values, respectively. Horizontal red and blue bars at the base of the figure indicate the solar maximum and minimum years categorized in this study, respectively. Five periods are labeled like as “Max 1”. The labels are indicated on the horizontal bars.

15336

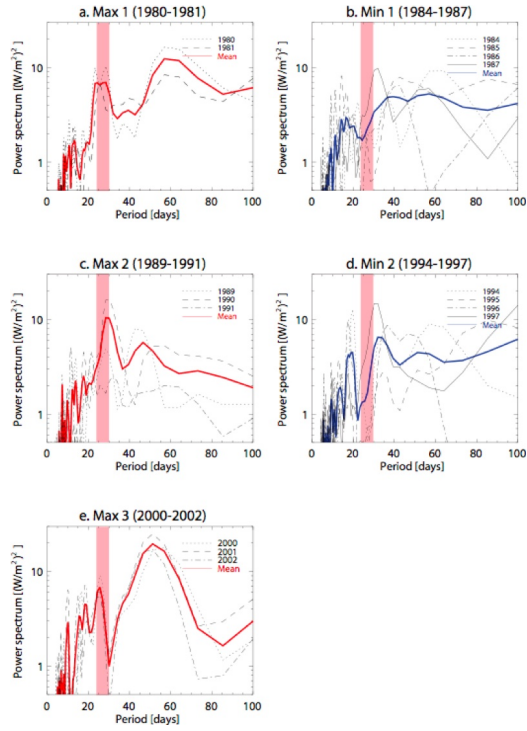


Fig. 3. Power spectra of OLR for each of the periods of solar activity. Black lines show yearly spectra. Red and blue lines represent the average spectra for the maximum and minimum periods, respectively (the spectrum for 1991 is excluded). The vertical red bars denote the period between 24 and 30 days (the solar rotation period is ~ 27 days).

15337

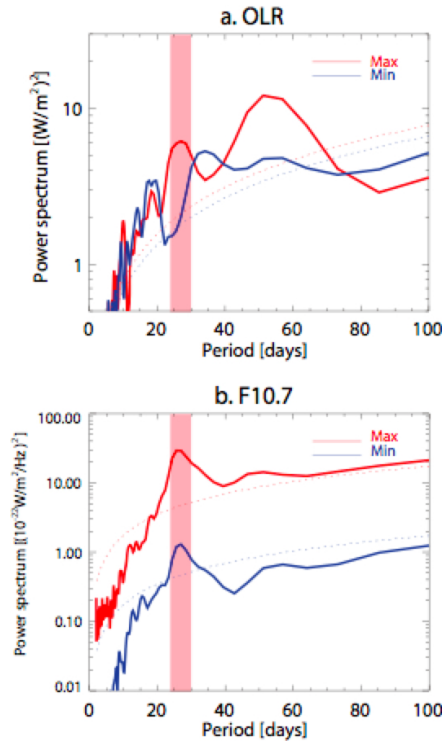


Fig. 4. (a) Averaged power spectra of OLR for the maximum (red) and minimum (blue) years. Dotted lines represent 1-s significance levels for the two averaged spectra calculated from the standard deviation of the data. The vertical red bar represents the period between 24 and 30 days. **(b)** As for (a), but for F10.7.

15338