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LONG-TERM VARIATIONS OF THE ATMOSPHERIC AND OCEANIC CONDITIONS[1]

By

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Abstract

Much discussion on the causes of the long-term variations of the atmospheric and oceanic conditions has been made by many students. But because of the complexities of the phenomena, the general theories on the causes and effects or on the variation mechanism have not yet been established.

To find out the actual conditions of these phenomena, the speaker presents a physical model of the variation mechanism, and then comparing it with the observation data, examines whether this model is useful or not.

1. A physical model of the variation mechanism

We assume that the motive power generating long-term variations in the atmospheric and oceanic conditions is the fluctuation of the solar radiation. As this fluctuation quantity which affects the earth is estimated about 1% in the normal state for the duration of about 100 years, it affects the atmospheric and oceanic conditions very little. It is necessary, therefore, to know the physical mechanism in the normal state, and for that purpose, we adopt the present accepted model concerning atmospheric and oceanic general circulations.

Now, in case the solar radiation increases, the internal and potential energy of the earth atmosphere and ocean increases compared with the normal state, and temperature gradient of north-south direction becomes large, and accordingly the net energy trasport to the pole increases. So, in the atmosphere the general flow (zonal wind) is intensified corresponding to the increase of transport. Vertical sheer of the wind increases corresponding to the intensity of general flow, and the baroclinic atmosphere becomes unstable and stimulates the cyclone and anticyclone to grow with the influence of general flow. Accompanied by this flow pattern, wind system, atmospheric temperature, evaporation and precipitation

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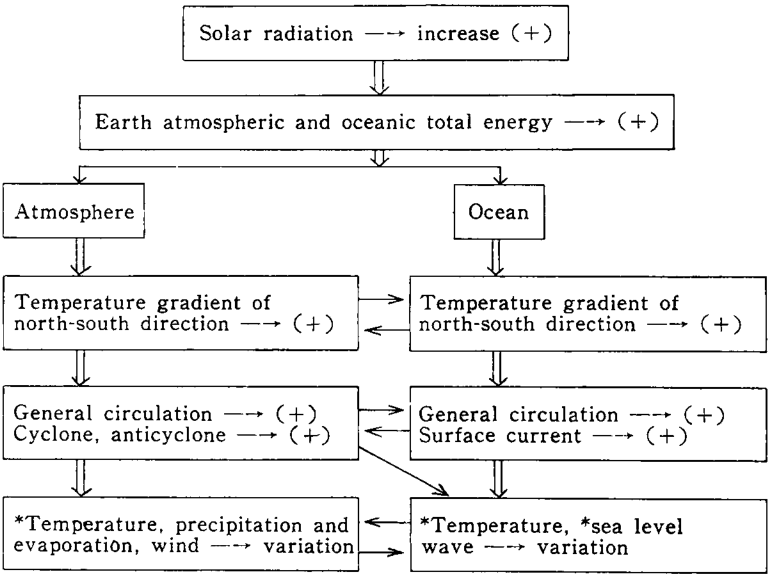
change in their distributions and quantities, and heat quantity and momentum are redistributed. In the ocean, corresponding to the increase of water temperature gradient of north-south direction and atmospheric general circulation, wind increases and ocean circulation and surface current also increase, and disturbing surface wave and vortex are stimulated to generate. On the other hand, the variations of wind system and ocean current generate the variations of sea level and water temperature, and their energy is redistributed according to the latitude, geographical environment, atmospheric condition, and so forth. In case the solar radiation decreases the phenomena in the air and sea are expected to be reverse.

The model mentioned above is shown in the block diagram as follows : From this diagram, we cannot judge the increse of the solar radiation always indicates the increase of the variation of the atmospheric and oceanic phenomena.



Notes: (1) Symbol (+) denotes 'increase'.
(2) In the case of decrease, put (−) in place of (+) to denote 'decrease'.
(3) Symbol (*) denotes the existence of retardation effect.

2. Examining the physical model using some observation data

To examine the above-mentioned physical model, we must know how the atmospheric and oceanic conditions react to the variation of the solar radiation.

Now, as the index of the long-term variation of solar radiation, we take sunsport relative number which is generally accepted, though with some questions. But as this is not sufficient index to examine the model, we take atmospheric pressure gradient which indicates the atmospheric general circulation, and also take the observation data of sea level, atmospheric temperature and water temperature to see in influence of the variation of solar radiation.

We use atmospheric pressure gradient calculated from monthly mean values of sea level pressure at the three stations ((Yamagata (38°15′N, 140°21′E), Tokyo (35°41′N, 139°49′E), Taipei (25°02′N, 121°31′E)) from the end of last century up to the present. The Far East region including these three stations is a most characteristic meteorologic region in the world as shown in the charts by Dzerdzeevskii [1963]. In his charts, he classified the atmospheric circulation types in the northern hemisphere into 4 groups, and in every group this region appears as a passing route of cyclone. Namely, this is a most effective route to transport the solar radiation energy received on the earth from south to north by horizontal mixing, and at the same time it is the route to exchange the warm air mass for cold one. Accordingly the pressure gradient in this region must be a good indication of the reaction of atmospheric general circulation and solar radiation variations.

The comparison of the original values of annual average sunspot number (denoted by 0_s) with that of the meridional component of atmospheric pressure gradient (denoted by $0_{p\varphi}$) in winter is shown in Fig. 1 (a). The positive direction of $0_{p\varphi}$ is northward, so, assuming the geostrophic wind, the positive values denote west wind and the negative values denote east wind. In this figure, most of the variation periods of the pressure gradient $0_{p\varphi}$ are 3-year period and 2-year period comes next in number.

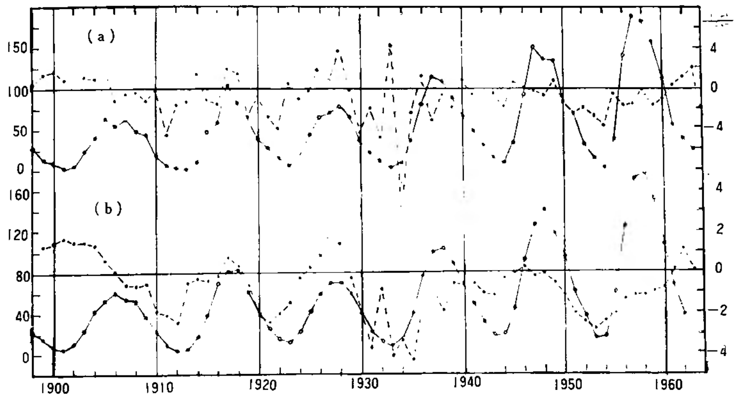


Fig. 1. Comparison between sunspot number, and meridional component of atmospheric pressure gradient calculated among 3 stations (Yamagata, Tokyo, Taipei), in winter.
Full line : Sunspot number. (a) 0_s, (b) 3-year movening average of 0_s
Broken line · Meridional component. (a) $0_{p\varphi}$, (b) 3-year movening average of $0_{p\varphi}$

These curves show that when sunspot number is large, west wind is strong, but sunspot cycle of $0_{p\varphi}$ is not shown so clearly because sunspot variation is 11-year period while these variations are 2-or 3-year period. So, 3-year moving

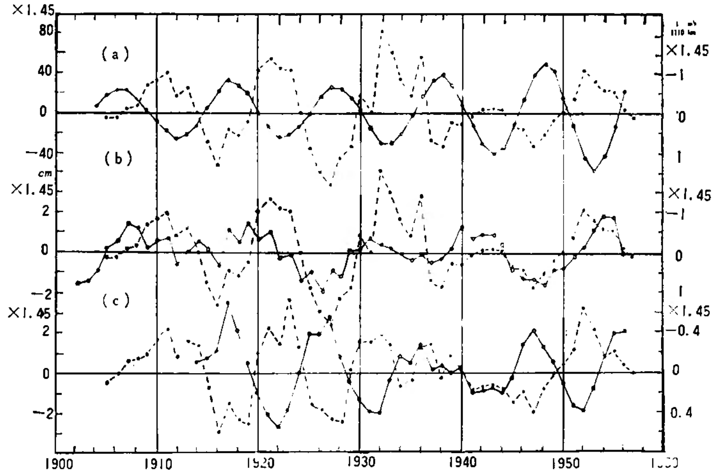


Fig. 2. Comparison between sunsport number and meridional and zonal component of pressure gradient and sea level in winter.
Full line : (a) Sunsport number $[1_s-2_s]$
(b~c) Sea level, (b) Aburatsubo, (c) Oshoro
Broken line : (a~b) Meridional component $[1_{p\varphi}-2_{p\varphi}]$
(c) Zonal component $[1_{p\lambda}-2_{p\lambda}]$

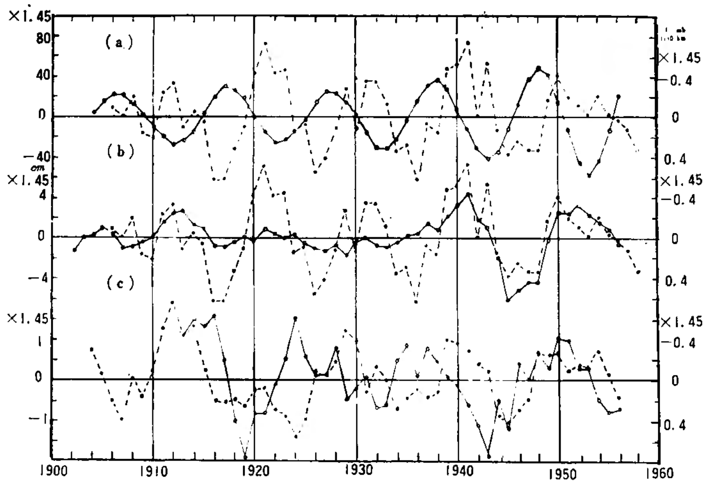


Fig. 3. Comparison between sunspot number and meridional and zonal component of pressure gradient in summer.
Full line : (a) Sunspot number $[1_s-2_s]$
(b~c) Sea level, (b) Aburatsubo, (c) Oshoro
Broken line : (a~b) Zonal component $[1_{p\lambda}-2_{p\lambda}]$
(c) Meridional component $[1_{p\varphi}-2_{p\varphi}]$

average of $0_{p\varphi}$ and that of 0_s are taken respectively.

The comparison of these two curves is shown in Fig. 1 (b), and they run in parallel and show clearer correspondence though it is not perfect. In order to select 11-year period, 5-year moving average of $0_{p\varphi}$ is taken and denoted by $1_{p\varphi}$, then 11-year moving average of $1_{p\varphi}$ is taken and denoted by $2_{p\varphi}$. Series $[1_{p\varphi}-2_{p\varphi}]$ has nearly 11-year period. The same operation for sunspot number is taken, and 1_s, 2_s and $[1_s-2_s]$ are obtained.

The comparison between the sunsport number $[1_s-2_s]$ and pressure gradient $[1_{p\varphi}-2_{p\varphi}]$ is shown in Fig. 2 (a). This figure shows that the correspondence of these two is surprisingly good and perfect through the whole term. Namely, when sunspot number is large, west wind is strong and when sunspot number is small, east wind blows. Comparison between sunspot number $[1_s-2_s]$ and the

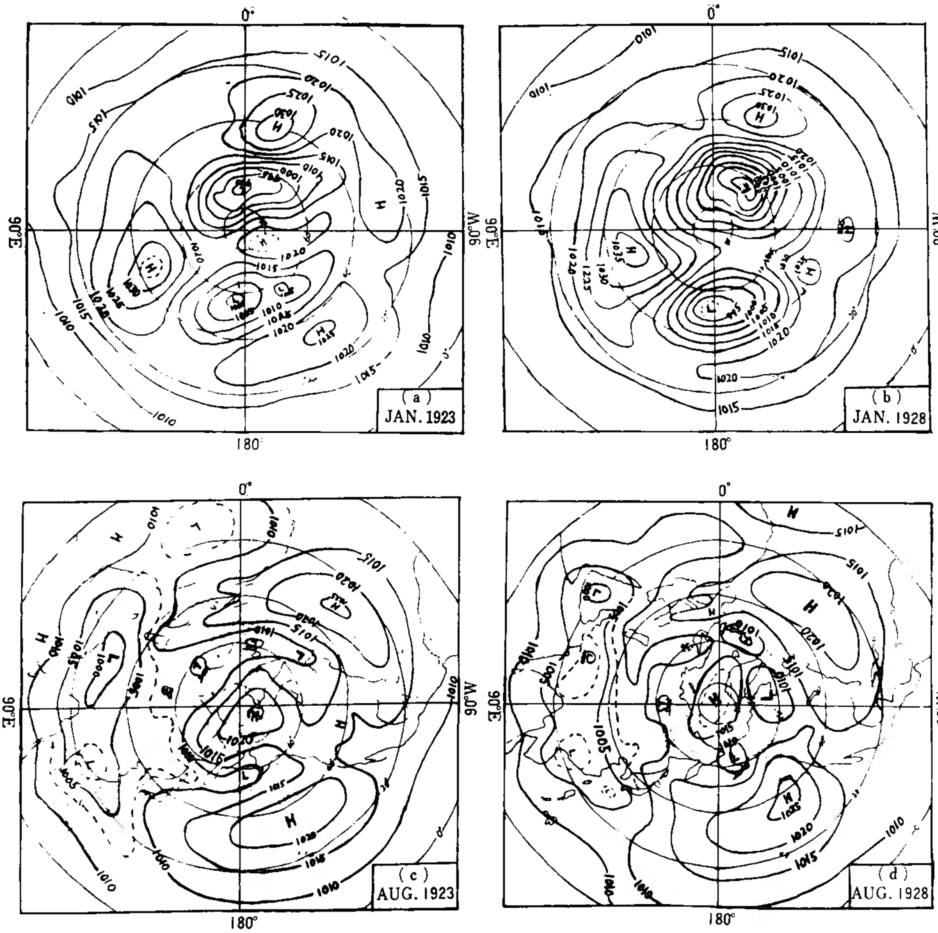


Fig. 4. Monthly mean weather plotting chart at sea level (after U. S. W. B).
(a)—Jan. 1923 (b)—Jan. 1928 (c)—Aug. 1923 (d)—Aug. 1928

same moving average zonal component of pressure gradient [$1_{p\lambda}-2_{p\lambda}$] is shown in Fig. 2 (a, c). The positive direction of [$1_{p\lambda}-2_{p\lambda}$] is eastward. The correspondence of these curves is good, too, and when sunspot number is large, north wind is strong, and when sunspot number is small, south wind blows. These relations hold true in the case of summer period shown in Fig. 3 (a). But the correlation between sunspot number and meridional component of pressure gradient is not so good in summer as in winter.

The northern hemispheric weather plotting charts of January and August in 1923 when sunspot number is minimum, and those in 1928 when sunspot number is maximum are shown in Fig. 4. These charts show clearly that when the solar activity is at its height, cyclone and anticyclone increase. This relation is held true in the northern hemispheric weather charts (Japan Meteorological Agency [1961]) at 500mb from 1946 to 1960 (figures are omitted).

Here is an example to show that long-term variations of sea level have no direct relation with the solar activity but are subject to the wind action. The data used here are those of sea level for about 70 years observed at Aburatsubo (35°09′N, 139°37′E) on the Pacific coast and at Oshoro (43°13′N, 140°52′E) on the Japan Sea coast. The influence of monsoon at Aburatsubo is the very reverse of that at Oshoro according to the distribution of sea and land. From this original data the series of [1_t-2_t]—the variation of a period of approximately 11 years—is calculated after the same method of obtaining pressure gradient [$1_{p\varphi}-2_{p\varphi}$]. The two curves of [$1_t-2_t$] and [$1_{p\varphi}-2_{p\varphi}$] are shown in Fig. 2 and Fig. 3. From the curves shown in Fig. 2., we can see the variation of sea level at Aburatsubo is perfectly reverse of that at Oshoro in winter according to the tidal condition influenced by the wind action. Accordingly the relation between sunspot number and sea level at Aburatsubo is reverse in phase as shown in sea level of Atlantic Ocean given by Fairbridge [1963], while the variations of sunspot number and sea level at Oshoro are parallel in phase. In summer as shown in Fig. 3. the above-mentioned relation is not so clearly seen as in winter. But using anual mean value, the relation between sunspot number and sea level seems to be nearly the same as it is in winter. These results show that there is no direct relation between sunsport number and sea level.

Next, we compare sunspot number [1_s-2_s] with the corresponding atmospheric temperature [$1_\theta-2_\theta$] and water temperature [$1_\theta-2_\theta$] and show the comparison in Fig. 5.

The data of atmospheric and water temperature are gained through the observation at 5 meteorological stations (Nemuro, Yamagata, Tokyo, Kyoto and Fukuoka) and 4 coast stations (Todogasaki, Shioyasaki, Nojimazaki and Yakushima) in Japan. From the anual mean values of these data at each station [1_θ

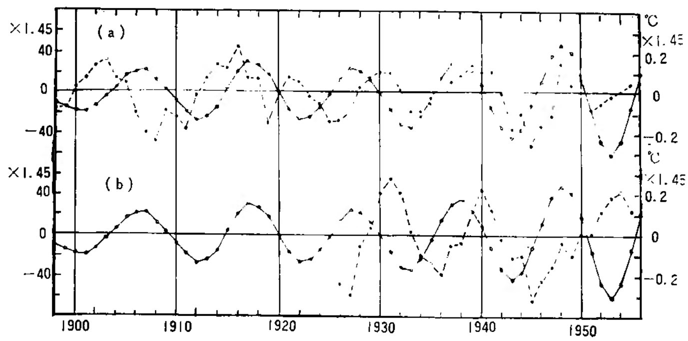


Fig. 5. Comparision between sunspot number and annual mean atmospheric temperature (5 stations' mean in Japan) and annual mean water temperature (4 stations' mean in Japanese waters).
Full line : (a~b) Sunspot number [1_s-2_s]
Broken line : (a) Atmospheric temperature [$1_\theta-2_\theta$]
(b) Water temperature [$1_\theta-2_\theta$]

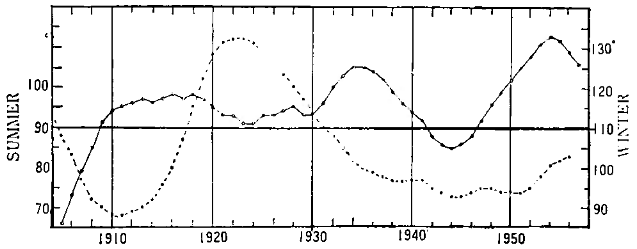


Fig. 6. Variation curves of the direction of the atmospheric pressure gradient [2_{pd}], calculated among 3 stations (Yamagata, Tokyo, Taipei) in winter (full line) and summer (broken line).

-2_θ] is calculated after the same method of obtaining sunspot number [1_s-2_s].

These curves seem that when sunspot number is large, atmospheric temperature is high and sea water temperature is low. But there is no clear correspondence between sunspot number and atmospheric and water temperature.

In the natural world the variations of approximatety 20-year period (Hale period) are not rare, but in order to select such variations, it is necessary to obtain long-term observation data. Now, for convenience we take series 2_{pd} from the data of the direction of atmospheric pressure gradient at the 3 stations mentioned above, and it is shown in Fig. 6. The direction of pressure gradient takes 0° at south in summer and at north in winter and counts clockwise. This shows some 20-year periodic variation though it is not perfectly selected. It is interesting that forms of these curves show a remarkable change at about 1930. In summer after 1930 the direction is below 90°, that is, assuming geostrophic wind, south-south-east wind blows, and south-south-west wind does not blow as in 1920s. And its variations are not remarkable. On the other hand, in winter

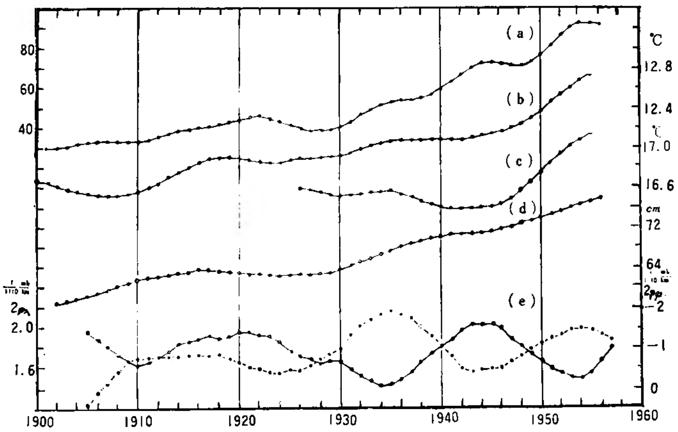


Fig. 7. Secular trend of sunspot number, annual mean atmospheric and water temperature, sea level and zonal and meridonal component of winter mean atmospheric pressure gradient near Japan.
(a) sunspot number, 2_s (b) atmospheric temperature, 2_θ
(c) water temperature, 2_θ (d) sea level, 2_t, (at Aburatsubo)
(e) Zonal component [$2_{p\lambda}$] (full line) and meridional component [$2_{p\varphi}$] (broken line) of pressure gradient

from 1910 to 1930 we scarcely find any variation, but from 1930 up to the present, the amplitude of variations is large. This might show that 1930 is a turning point of the atmospheric general circulation.

To see the trend of long-term variations of the atmospheric and oceanic conditions reacting to long term solar activity, the comparison of sunspot number 2_s and the above mentioned annual mean atmospheric temperature 2_θ, sea water temperature 2_θ, sea level at Aburatsubo 2_t and winter mean atmospheric pressure gradient $2_{p\varphi}$, $2_{p\lambda}$ are shown in Fig. 7. From this figure, the trend of atmospheric and sea water temperature and sea level correspond to sunspot number and continue to rise gradually from the beginning of this century up to the present. But the magnitude of pressure gradient $2_{p\varphi}$ and $2_{p\lambda}$ do not have such a trend. The trend of sea level variation at Aburatsubo does not show the general trend of sea level variation near the coast of Japan, which shows that it is under the influence of the moving of the land mass, and requires further study.

From these results, we may conclude as follows :

The variations of sunspot of 11-year period and those of solar activity of Hale period give rise to the variations of atmospheric pressure gradient of approximately 10-and 20-year period. These variations appear as the variations of kinetic energy in baroclinic atmosphere.

On the other hand, the long-term variations of solar activity indicated by sunspot number give rise to the variations of temperature and sea level of 50-

year or longer period. These variations appear as the variations of total potential energy or heat energy, and this energy has accumulated effect much longer than the kinetic energy in the atmosphere and ocean, and also retardation effect.

3. The other examples which seem to have some relation with solar activities and a problem for future discussion

Now, the other examples of the long-term variations which seem to have some relation with the solar activities are briefly stated. Many studies on the climatic change of Japan related to sunspot activities are made, and generally speaking, when sunspot number is large, atmospheric pressure and temperature rise, and precipitation is little (Takahashi [1955], Yamamoto [1956]).

Of the whole northern hemisphere, in high latitudes, atmospheric temperature has negative correlation with precipitation, and when sunspot number is large, atmospheric temperature is high, and precipitation is little (Willett [1951]).

There is an opinion that the variations of some 10-year average meteorological elements in Japan and that of the world meteological phenomena have some relation with the long-term variation of the jet stream (Yamamoto [1958]).

In the long-term variations of the Pacific Ocean near Japan, sea level, water temperature and the Kuroshio are studied. Continuous observation of sea level and water temperature has been made, and they are reported to have 11-year periodic variations (Miyazaki [1953], Fukuoka [1959]).

We have not enough data to make the long-term variations of the Kuroshio and its characteristics clear, but there are not a few studies on the Kuroshio (Uda [1964], Shoji [1963], Yoshida [1961], Masuzawa [1961], Kawai [1955]).

Judging from these studies, it seems that the great variations of the current velocity and the axis of the Kuroshio occur around the period of the minimum and maximum of sunspot number. It is also pointed out that the volume transport and the velocity of the Kuroshio are closely connected with the North Pacific high (Hayami & Matsukawa [1966]). Judging from the above-mentioned results, the long-term variations in the atmospheric and oceanic conditions are subject to the direct influence of solar activities or to the indirect one by the agency of the atmospheric general circulation. This casual relation can be applied to the world-wide variations.

But it is difficult to verify it, because the transformation of the energy is carried out relatively fast in the form of momentum in the short-term variation, while in the long-term variations, the variation quantity is small, and masked by the larger short-term variations and retardation effect.

The problem for future studies is to make the relation between short-term variations and long-term ones clear through the energy balance, and also make the relation between local and larger regional variations in space clear. It seems that the amplitude of short-term variation is large when that of the long-term variation is large. For example, the meteorologically abnormal years of 1933-4 and 1963-4 were about at the minimum of 11-year sunspot cycle, but these phenomena are affected not only by sunspot number but also by the motive energy of long-term variations accumulated gradually in the form of the total potential energy according to the baroclinic state.

We hope to make the variation mechanism much clearer by using other data in future.

Acknowledgment

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