Significant decreases in the geomagnetic indices in the ascending phase of Solar Cycle 24

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Solar activity was quite low from January 2008 to February 2009, ever since the start of Solar Cycle 24. In 2008, the number of days in a year during which there were no sunspots was the fourth-largest since 1842. However, it is likely that the sunspot number would not have been able to reveal the solar inactivity in the beginning phase of cycle 24 because it hit the lower limit (zero) on more than two-thirds of the days of 2008. Geomagnetic data covers the longest span of time next to sunspot number, but its value has never reached that limit. The K-index, which is a geomagnetic index, from 2008 to the beginning of 2009, has been recorded at several observatories as being the smallest in the history of observation. The K_p-index, which characterizes the geomagnetic planetary activity, has also significantly decreased. Taking into account the relation between the K_p-index during the minimum phase of the solar cycle and sunspot numbers of the following maximum, it has been suggested that the peak solar activity in cycle 24 will be quite low. If solar activity in cycle 24 continues to be quiet, geomagnetic data are expected to be one of the key tools for monitoring space climate.

Key words: Solar activity, geomagnetic, K-index, K_p-index, solar cycle, sunspot number, space climate, KAKIOKA.

1. Introduction

The Solar Influences Data Analysis Center (SIDC) at the Royal Observatory of Belgium reported the start of Solar Cycle 24 on January 4, 2008 (SIDC, 2008). However, as the solar activity has been extremely low during the entire 2008, the start of cycle 24 has been the subject of further discussion. Sunspot numbers for the last 11 years are shown in Fig. 1. The number of spotless days in 2008 was 266, which is the fourth-largest number for 1 year since 1842 (Table 1).

Though sunspot number is a synthetic, rather than a physical index, it is a useful parameter for monitoring long-term variations in solar activity. Sunspots were nearly absent from 1645 to 1715, a period known as the "Maunder Minimum" (e.g. Chian and Kamide, 2007). It is said that the period coincided with an era of cold weather in North America and Europe.

However, it is important to mention that the lower limit of the sunspot number is zero by nature and that it reached the lower limit for more than two thirds of 2008. It is likely that the sunspot number of 2008 does not fully resolve the current solar inactivity.

Solar radio, ionosphere, solar wind, flares, and geomagnetic field variations are all observed for monitoring solar-terrestrial activity. In particular, geomagnetic data have been accumulated for more than 70 years, a period covering six solar cycles.

From the point of view of monitoring long-term variations of solar activity, geomagnetic data cover the longest time next to sunspot number, and geomagnetic data have never reached the limit zero.

This paper reports that some of the geomagnetic indices from 2008 to 2009 are the smallest in the history of geomagnetic observation.

2. *K*-Index

The K-index is a quasi-logarithmic local index of geomagnetic activity. The purpose of K-index is to measure the effects of the solar corpuscular radiation on the terrestrial magnetic field, as distinct from the wave radiation (Mayaud, 1967). It is based on a range of irregular variations observed over a 3-h interval in two components, horizontal force and declination. The K-index is ranked into one of ten range classes; $K = 0$ to 9.

The Kakioka Magnetic Observatory, Japan Meteorological Agency (36°13′56″N, 140°11′11″E) has observed geomagnetic field values since 1913, and K-indices at Kakioka have been provided ever since January 1932, except three years, 1934, 1935 and 1939. We use ΣK, which is the sum of the value of the K-index over 1 day, to indicate daily geomagnetic activity in this report. Figure 2 shows sunspot numbers and the monthly mean ΣK. Monthly mean ΣK has remained below 10.0 throughout the 10 months from May 2008 to February 2009. The monthly mean ΣK has never continuously been less than 10.0 for more than 2 months before 2007. Of the 890 months for which the K-index has been calculated at Kakioka, there are only 18 months with a monthly mean ΣK less than 10.0.

This significant decrease in the K-index has also been observed at two other branches of the Kakioka Magnetic Ob-

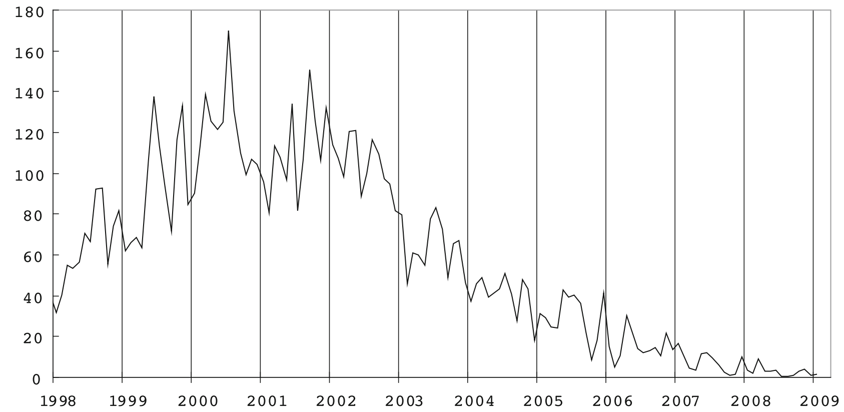

Fig. 1. Monthly mean sunspot number (January 1998–February 2009).

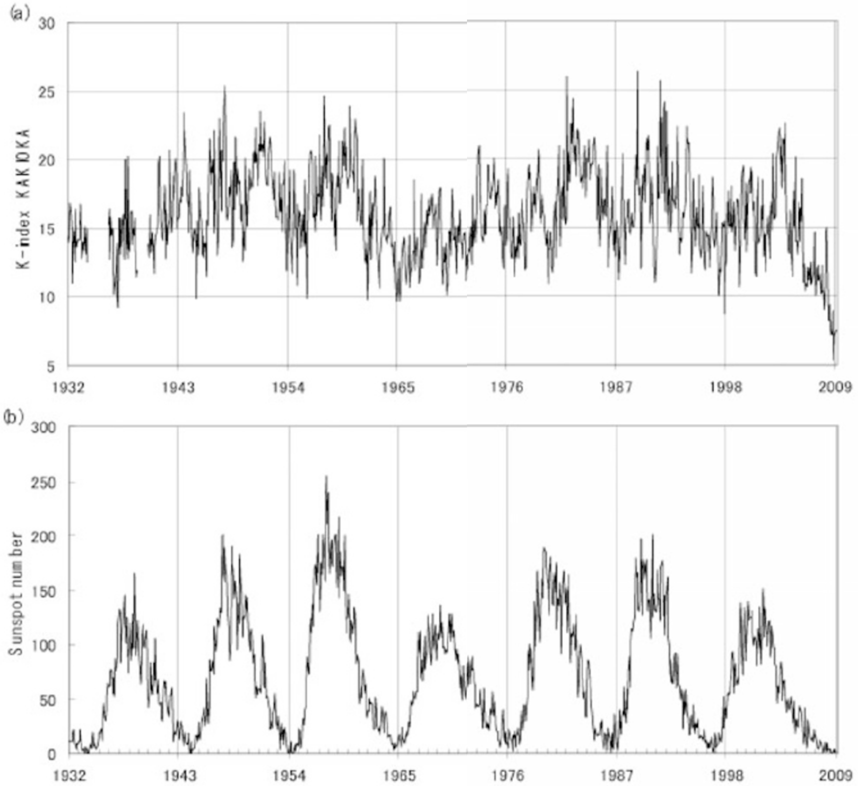

Fig. 2. Monthly mean ΣK at Kakioka (a) and sunspot number (b).

Table 1. Top five of years with most number of spotless days since 1849.

Year	Number of spotless days
1913	311
1901	287
1878	280
2008	**266**
1902	257

servatory; Memambetsu (43°54′36″N, 144°11′19″E) and Kanoya (31°25′27″N, 130°52′48″E). However, geomagnetic data at Showa Station (69°00′22″S, 39°35′24″E) which is in the polar region shows that the decrease in the K-index is not so significant.

3. K_p-Index and *Dst* Index

The K-index is an indicator representing local geomagnetic activity, while the K_p-index, which is derived from K-index at selected stations, is commonly used to characterize planetary geomagnetic activity. The number of "K_p stations" is currently 13. Kakioka, Memambetsu and Kanoya are not included in the K_p stations (Menvielle and Berthelier, 1991). K_p-index data are available since January 1932. Figure 3 shows the monthly mean ΣK_p, which is calculated the same way as ΣK.

Monthly mean ΣK_p were less than 10.0 for the 7 months from July to September in 2008 and from November 2008 to February 2009. Yet the monthly mean ΣK_p is less than 10.0 for only 18 of the 926 months for which K_p-index data are available.

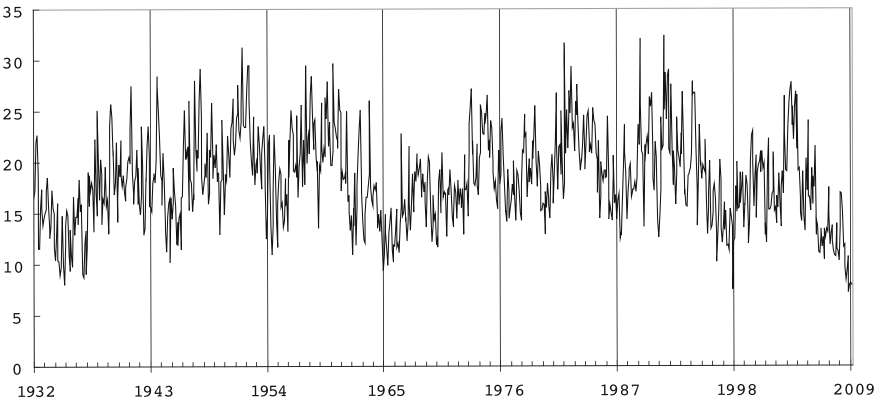

Fig. 3. Monthly mean ΣK_p.

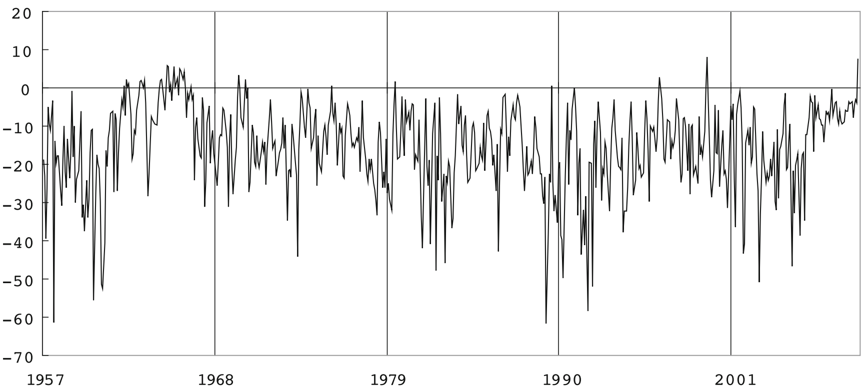

Fig. 4. Monthly mean *Dst*.

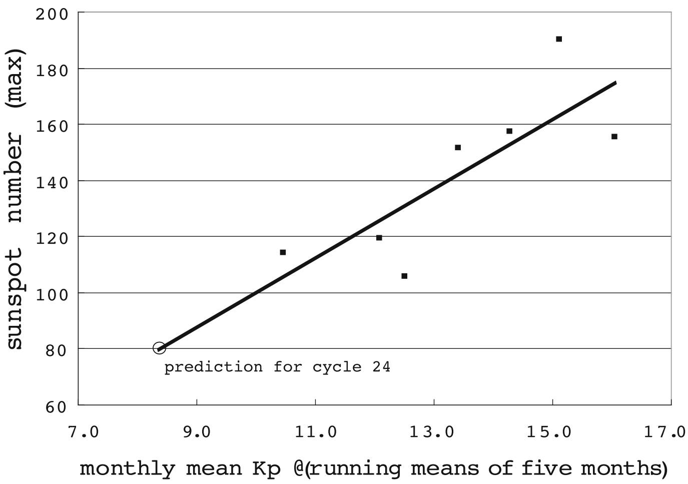

Fig. 5. Relation between the minimum K_p-index and the next maximum sunspot number. X-axis, minimum monthly mean ΣK_p, five-month running mean; Y-axis, following maximum monthly mean sunspot number. Line indicates relationship between minimum monthly mean ΣK_p, 5-month running mean and following maximum monthly mean sunspot number by fitting a linear equation. Open circle indicates prediction for cycle 24, which is derived from K_p-index values in 2008 and 2009.

Next we present another index, the *Dst* index, which is for monitoring equatorial ring current variations (Mayaud, 1980). It is derived from geomagnetic data at four near-equatorial geomagnetic observatories, including Kakioka. Low *Dst* index values indicate a strong equatorial ring current and high solar activity. *Dst* index values are provided from January 1957.

Figure 4 shows the monthly mean *Dst* index. Unlike the K or K_p indices, which have larger values for more solar activity, smaller *Dst* index values indicate a strong equatorial ring current with high solar activity.

Though *Dst* index values remained high from January 2008 to February 2009, they are not record-setting like the K- and K_p-indices. The *Dst* index is characterized by geomagnetic disturbances lasting several hours, while the K- and K_p-indices are dependent on disturbances of shorter periods. This may be the cause of the difference in variations among the indices.

4. Discussion

K-index peaks do not always correspond with sunspot number peaks. Vennerstrøm and Friis-Christensen (1996) suggest that geomagnetic activity during the solar cycle can be divided into several peaks. Echer *et al.* (2004) show that the correlation between geomagnetic and solar activity has decreased since the end of the 19th century and that the lag in their phase has increased.

A large number of techniques for predicting solar activity on a cycle timescale are tested with historical data. The K_p index is one of the data sets used for the prediction. Rangarajan and Barreto (1999) show that the frequency of occurrence of K_p indices with values 0–1 representing geomagnetic calm and values between 4 and 7 representing moderate geomagnetic disturbances in the declining phase of a solar cycle is linearly related to the sunspot maximum of the next cycle. Figure 5 indicates the correlation between the K_p-index in the minimum phase of a solar cycle and the next maximum sunspot number in solar cycle 17 to cycle 23. In order to avoid the effect by the local minimum, we use the ΣK_p 5-month running mean. Taking into account the lifetime of solar active phenomena (e.g. sunspots, coronal halls), the period 5-month was adopted.

The K_p-index in 2008 and 2009 suggests that solar activity in cycle 24 will be quite low. It is consistent with a prediction for maximum sunspot number 87.5±23.5 in cycle 24 using another geomagnetic index, *aa* (Duhau, 2003).

K-indices at several observatories and the K_p-index have been recorded to be the smallest in the history of observation, and values of these indices have never reached these limits. It is probable that these indices will reveal the quiet sun which sunspot numbers cannot fully resolve. In this study, we show that the K-index and K_p-index are sensitive indicators to monitor inactive solar. This is likely because these are quasi-logarithmic indices of geomagnetic activity.

The number of geomagnetic observations is more than 100. Geomagnetic data will be useful for attempting to describe spatial-time distributions of the solar-terrestrial environment.

It follows from these arguments that if there is not much solar activity in cycle 24, geomagnetic data are expected to be one of the key tools for monitoring space climate.

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