Galactic cosmic ray modulation along with geomagnetic activity, interplanetary magnetic field and solar wind

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Abstract: The modulation consists of two discrete states (high and low intensities), corresponding respectively to those of the polarity of the polar magnetic field of the Sun. This can be interpreted on the basis of the following hypothesis; when the polar magnetic field of the Sun is nearly parallel to the galactic magnetic field, they could easily connect with each other, so that galactic cosmic rays could intrude more easily into the heliomagnetosphere along the magnetic line of force, as compared with those in the anti-parallel state of the magnetic fields. Galactic cosmic rays are modulated in the heliosphere by four different mechanisms: inward diffusion and energy loss due to the scattering of cosmic rays of magnetic irregularities, outward convection due to radial flow of solar wind and the effect of gradient, curvature and neutral sheet drifts. Geomagnetic activity is generated by the interaction of the solar wind with the magnetosphere in connection with energy and mass transfer. In this study we tried to find out the correlation between the solar plasma parameters and the modulations of both galactic cosmic diurnal variation and geomagnetic activity on quiet days. Our analysis reveals that the enhancement in the cosmic ray diurnal anisotropy results from the corresponding enhancement in the magnitude of the solar wind speed and the interplanetary magnetic field strength (V x B). This reflects that both the solar wind speed and interplanetary magnetic field contribute significantly in cosmic ray modulation. The geomagnetic activity is found to well correlate with the magnitude of VB rather than with the magnitude of the interplanetary magnetic field itself. Thus we can say that the product VB is more important for the modulation of galactic cosmic rays and geomagnetic activity rather than the interplanetary magnetic field alone.

Keywords: cosmic ray, geomagnetic activity, solar wind, interplanetary magnetic field.

1 Introduction

Long-term variations of galactic cosmic rays were compared with the behavior of various solar-activity indices and heliospheric parameters many times by different authors. In doing so, special importance was attached to the solar magnetic field calculated on the solar wind source surface (Hoeksema and Scherrer, 1986). The coronal magnetic field is calculated from photospheric field observations under potential approximation, i.e., in terms of a source surface (SSMF) model. Under this assumption and within the Parker model, the field is radial at some height above the photosphere. This sphere is called the source surface and, for better agreement with real measurements near the Earth, is placed at a distance of 2.5 solar radii (see, for example, Hoeksema and Scherrer, 1986). The complex field structure in the photosphere simplifies with increasing height in the corona until a single line is left separating the two polarities at about 2.5 solar radii. Cosmic ray as measured in the vicinity of the Earth undergoes variations in different time scales. The least studied are short-time quasi-periodic variations with periods from minutes to several hours, the so-called cosmic ray fluctuations. The magnitude of fluctuations is comparable to the noise level of real data leading to the low signal-to-noise ratio. Accordingly, when studying the cosmic ray fluctuations one meets a problem of signal extraction from the high background noise which can be solved by special methods of time series spectral analysis. The power spectrum of CR fluctuations is highly variable, varying both in power and in the frequency depending on the momentary state of the interplanetary magnetic field and solar wind. Therefore, such spectra contain a large amount of different kinds of information, and their analysis is not straightforward especially on long-time scales. Accordingly, it is common to introduce various indices of CR fluctuations that characterize the time behaviour of the cosmic ray power spectrum [1-3].
Sun has a complex magnetic field, the dipole term nearly always dominates the magnetic field of the solar wind. The projection of this dipole on the solar rotation axis (A) can be either positive, which we refer to as the A1 state, or negative, which we refer to as the A2 state. Near each sunspot maximum the di-pole reverses direction, leading to alternating mag-netic polari-ty in successive solar cycles. Babcock [4] was the first to observe a change in the polarity state when he observed the northern (southern) polar region change to positive (negative) polarity, that is, a transition to the A1 state. Many modulation phenomena have different patterns in solar cycles of opposite polarity. Possibly, the most striking of these is the change in the flux of electrons relative to that of protons and helium when the solar polarity reverses [5-7].

Cosmic ray modulation is closely associated with the evolution of the solar magnetic field [8-9 and references therein]. Wibberenz et al. [10] emphasised that the modulation is composed of a gradual com-ponent and “medium-term events”.

These events lasting about a year, have previously been called “steps” and considered to be caused by merging processes beyond about 10 AU [11]. How-ever, Cane et al. [8] showed that they were related to episodes of new open magnetic flux at the Sun.

Advances in our understanding of the evolution of the solar open magnetic flux and the interplanetary magnetic field (IMF) over time scales of months and years have been made by Wang and colleagues (e.g., Wang et al. [12 and references therein]. They con-clude that “the large-scale magnetic field of the Sun, including the open flux that extends into the inter-planetary medium, originates in active regions but is redistributed over the photosphere by differential ro-tation, super granular convection, and poleward me-ridional flow.” In their studies, the photospheric field observations are combined with a potential field model, to determine open field regions and their field strength. A flux transport model [13] is used to show how the emergent flux decays and is transported to the polar regions, changing the solar polarity. They are able to show how the radial component of the IMF at 1 AU varies throughout the solar cycle, although the predictions are not very satisfactory near solar minimum, partially related to the difficulty in measuring the solar polar fields.

2 Data Analysis

The hourly data observed by the five neutron monitors are collected from LS (http://neutron-monitor.ta3.sk/), Oulu (http://cosmicrays.oulu.fi/), Moscow (http://helios.izmiran.troit-sk.ru/cosray/m-ain.htm), Kiel (http://134.245.132.179/kiel/ main.htm) and Rome (http://cr0.izmiran.rssi.ru/rome/mai-n.htm) respectively. The daily data of solar parameters and Dst indices such as IMF, SW density, SW speed, SW temperature and Dst are taken from OMNI of NASA (http://omniweb.gsfc.nasa.gov/). (Datawere normal-ized when necessary and extracted to clean data for the linear regression.

3 Results and Discussion

The first unambiguous detection of the out-flowing solar plasma was made in 1961 by Explorer 10. Continuous recording of the near-Earth solar wind speed (Vsw) and its embedded magnetic field (B) only started in 1963, therefore, any continuous estimates of Vsw or B before 1963 are necessarily indirect (Lockwood et al., 1999). Svalgaard and Cliver (submitted for publication) and Rouillard et al. (2007) have shown, using geomagnetic indices, that the eleven-year running means of yearly solar wind speed values have changed by as much as $14.4 \pm 0.7\%$ between 1900 and 1950. Rouillard et al. (2007) show that the eleven-year running means of yearly averages of the total open solar magnetic flux have also changed in the same period by $73 \pm 5\%$ leading to a $45.1 \pm 4.5\%$ change in the strength of the interplanetary magnetic field at Earth. Similar estimated changes in B and Vsw are obtained using three different combinations of geomagnetic indices [For details of the method, the reader is referred to Rouillard et al. (2007)].

Further evidence for secular change in the heliosphere comes from direct measurements of Galactic Cosmic Ray (GCR) fluxes and the abundances of cosmogenic isotopes produced by GCR bombardment and stored in terrestrial reservoirs, such as ice sheets, tree trunks and ocean sediments. The Dye-3 ice core from Greenland shows century-scale drift in the 10Be cosmogenic isotope, whereas much smaller changes are seen in an Antarctic core. In general, the Dye-3 data are the more reliable because local precipitation rates are much greater. In addition, Dye-3 agrees more closely with 14C found in tree trunks all over the world up until about 1940, after which increased release of carbon from fossil fuel burning and nuclear bomb explosions render the 14C record unusable. Lockwood (2001, 2003) investigated the relationship between GCR changes and the secular change in the open solar flux using regression and response function analysis.

The annual diurnal anisotropy vectors, A1 (%) obtained on 60 QD for five different neutron monitors have been resolved into two components (not shown here). One is along the 12-Hr direction i.e., the radial anisotropy component, A1R (%); and the other is along the 18-Hr direction i.e., the radial anisotropy component, A1 (%) and references therein. Svalgaard and Cliver (submitted for publication) and therefore, any continuous estimates of Vsw or B before 1963 are necessarily indirect (Lockwood et al., 1999). Svalgaard and Cliver (submitted for publication) and Rouillard et al. (2007) have shown, using geomagnetic indices, that the eleven-year running means of yearly solar wind speed values have changed by as much as $14.4 \pm 0.7\%$ between 1900 and 1950. Rouillard et al. (2007) show that the eleven-year running means of yearly averages of the total open solar magnetic flux have also changed in the same period by $73 \pm 5\%$ leading to a $45.1 \pm 4.5\%$ change in the strength of the interplanetary magnetic field at Earth. Similar estimated changes in B and Vsw are obtained using three different combinations of geomagnetic indices [For details of the method, the reader is referred to Rouillard et al. (2007)].

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depicted in Figure 2, it is found that the magnitude of the 3-Hr component is larger than the 6-Hr component during the positive polarity epoch, which results in shifting the anisotropy vector towards earlier hours; but the same does not hold good for the negative polarity epoch, i.e. the magnitude of the 6-Hr component is not always found to be greater than the 3-Hr component.

The amplitude of the radial anisotropy is zero till 1970 and increases sharply after polar field reversal of 1971. This analysis has been extended to diurnal and semi-diurnal anisotropy for the period 1964–95. The semi-diurnal anisotropy has been resolved along the two perpendicular components in the 3-Hr and 6-Hr directions.

4 Conclusion

We observed that two phenomena for bush decrease and geomagnetic storms can be used to predict the space weather forecast. The use of cosmic ray intensity records has practical application for space weather predictions.

5 References