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A Solar Activity Dependence of A Solar Wind Effect on Cosmic Ray Intensity Variations

H. KOJIMA[1], Y. HAYASHI[2], K. HAYASHI[2], N. ITO[2], S. KAWAKAMI[2], T. MATSUYAMA[2], M. MINAMINO[2], T. NONAKA[2], T. OKUDA[2], S. OGIO[2], A. OSHIMA[2], N.SHIMIZU[2], S. K. GUPTA[3], A. IYER[3], P. JAGADEESAN[3], A. JAIN[3], S. KARTHIKEYAN[3], P. K. MOHANTY[3], S. D. MORRIS[3], P. K. NAYAK[3], B. S. RAO[3], K. C. RAVINDRAN[3], K. SIVAPRASAD[3], H. TANAKA[3], S. C. TONWAR[3], S. SHIBATA[4], I. MORISHITA[5]
[1]*Nagoya Women's University*
[2]*Graduate School of Science, Osaka City University*
[3]*Tata Institute of Fundamental Research*
[4]*College of Engineering, Chubu University*
[5]*Department of Information Management, Asahi University*
hkojima@nagoya-wu.ac.jp

Abstract: We have investigated a solar activity dependence of a solar wind effect on cosmic ray intensity variations. The solar wind effect discussed here is concerned neither with transient origins such as Forbush decreases nor with known solar modulations. The effect is represented by the regression coefficient of cosmic ray intensity variations with solar wind velocities. For our analysis, cosmic ray intensity data recorded by the neutron monitor at Kiel and by the muon telescope at Nagoya during the period from 1963 to 2006 are used. The data recently observed by the muon telescopes (GRAPES) at Ooty in southern India are also used in the analysis. Solar wind velocities are referred to the OMNI 2 data set. To remove the transient effects, the days with more than 2% decrease of cosmic ray intensity compare to the average of the three preceding days and the days in the following recovery phase are rejected. Long term effects are also removed by taking differences from 27-day running average. For examining the solar activity dependence, we divide the corresponding period into 5 quiet terms and 4 active terms by referring the sunspot numbers. It is found that the regression coefficients of cosmic ray intensity variations with solar wind velocities are clearly dependent on the solar activity. They are large in active term and small in quiet term, and the ratio of coefficients is about 1.8.

Introduction

According to the diffusion-convection theory, it is expected that the cosmic ray intensities varies with the solar wind velocities. If their relation is quantitatively clarified, it will become observationally possible to obtain the diffusion coefficient for the propagation of cosmic rays; that is needed to describe the density of galactic cosmic rays flown into the heliosphere from inter stellar space.

Since the beginning of direct measurements of solar wind with satellites, there have been several reports [1, 2, 3] that describe the effect of solar wind on the variations of the cosmic ray intensities, so called the solar wind effect; i.e. the intensity of cosmic rays decreases as the velocity of solar wind increases. Despite these investigations, there are seldom quantitative analyses of the solar wind effect. The reason is as follows. Since the intensity of cosmic rays varies with several causes, it shows a very complicated time profile which is composed of many different variations with different time periods. For example, it contains a long term intensity variation of eleven-year period, a transient variation like a Forbush decrease, or a short term variation caused by the displacement of an active region on solar surface faced to the earth due to the solar rotation. Anisotropy of cosmic ray flow due to the earth's rotation or revolution around the sun also causes another intensity variation of cosmic rays. In our observation, the intensity variation of the cosmic rays is the mixture of these different phenomena. As for the solar wind velocity, it is also known that there exist several components of the variation such as a high speed flow accompanied by a solar flare, a recurrent variation with a period of around 27 days (13.5 days) corresponding to the solar rotation, or a long term variation with a period of several years. Thus for the both of variations of the cosmic ray intensity and the solar wind velocity, it is very difficult to separate each component of variation with different cause in a simple way. Then we are not always able to obtain an acceptable result from a simple correlation analysis between these data of the cosmic ray intensity and the solar wind velocity in an extended period. Needless to say, it is even more difficult to study the dependence of the solar wind effect on the solar activity.

The cosmic ray intensity has been observed for more than sixty years. Since IGY (1958), the world wide observational network of neutron monitor stations has been developed, and almost all the stations have still been continuing the observation. As for the muon observation at the surface of the earth, the observation using ionization chambers has started from sixty years ago and the high accuracy observation using the large scale telescope has started from late 1960's. A muon telescope with 36 m^2 at Nagoya has been continuing the observation from 1970 till now and recently muon telescopes with larger area of 560 m^2 and with more fine angular resolution, named GRAPES, have been working at Ooty in southern India. As for the direct observation of the solar wind in space, the continuous observation has also done by linking the data obtained by the number of satellites since 1963.

In this paper, relations between the observed cosmic ray data from Kiel neutron monitor which is one of WDC stations, from Nagoya muon telescope and from GRAPES and the solar wind velocities are investigated. A solar activity dependence of the obtained solar wind effect is also reported.

Analysis and Result

For our investigation, cosmic ray intensity data observed by the neutron monitor at Kiel for 44 years from 1963 to 2006 and by the muon telescope at Nagoya for 37 years from 1970 to 2006 are used. The data observed by the muon telescopes at Ooty for 6 years from 2000 to 2005 are also used in the analysis. Solar wind velocities and other plasma parameters of the interplanetary magnetic field in the corresponding period are referred to the OMNI 2 data set which is an archive of measurements obtained by various satellites.

Preprocessing

In order to reject some kinds of interference between several variations caused by the different origins described in the previous section, the data we used have been preprocessed as the following way.

At first, we have scanned all the daily values of the cosmic ray intensity. Then, all the day which has a value with more than 2% decrease compared to the average of the three preceding days has been rejected by regarding as an indication of transient phenomena like a Forbush decrease. The days in the following recovery phase beginning at the day rejected just before have also been rejected from our analysis. We have adopted about 70% as the threshold of the recovery.

After above preprocess, we have removed the effects of long term variations by using the 27-day numerical high pass filter; i.e. by taking differences from 27-day running average of daily values. Daily values and 27-day running averages of the cosmic ray intensity recorded by the neutron monitor at Kiel are plotted in Figure 1.

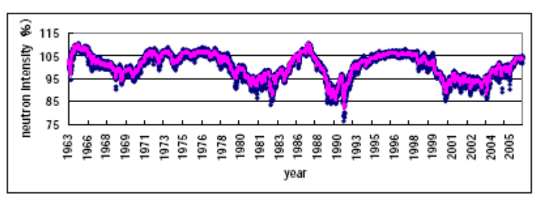

Figure 1: Time profile of daily values of the cosmic ray intensity (blue) and 27-day running averages (red).

For the corresponding data of the solar wind velocity, we have also applied the same numerical high pass filter. The same plots for the solar wind velocity are shown in Figure 2.

The preprocessed daily values of the cosmic ray intensities recorded by the neutron monitor at Kiel and by the muon telescope at Nagoya are

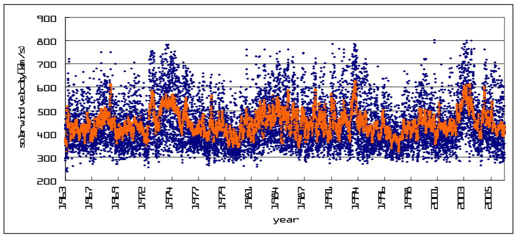

Figure 2: Time profile of daily values of the solar wind velocity (blue) and 27-day running averages (orange).

shown along with the solar wind velocity in the Figure 3 and Figure 4 respectively. It can be seen from these figures that the long term variations have clearly been removed from both the intensity of cosmic rays and the solar wind velocity.

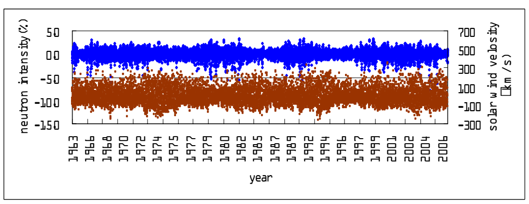

Figure 3: Time profile of the preprocessed daily values of the cosmic ray intensity recorded by the neutron monitor at Kiel (blue) and the solar wind velocity (brown).

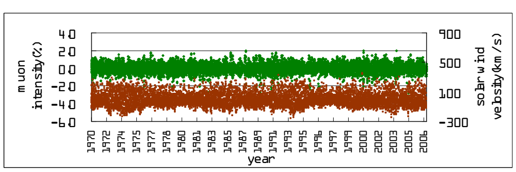

Figure 4: Time profile of the preprocessed daily values of the cosmic ray intensity recorded by the muon telescope at Nagoya (green) and the solar wind velocity (brown).

Division by the solar activity

To investigate the dependence of the solar wind effect on the solar activity, we have divided all the preprocessed data into 4 active and 5 quiet terms defined as follows. At first, the daily values of the sunspot numbers have smoothed by taking a 365-day and a 27-day running averages. And next, we have determined every boundary day between the active and the quite terms as the day when the smoothed value of the sunspot number is coincide with an average of the maximum and the minimum values at the nearest peak and trough respectively. Then, an active term is defined as a term including a peak and a quite term is defined as a term including a trough. The time profile of the smoothed sunspot numbers is shown in Figure 5. The active and quiet terms of the solar activity defined as above are indicated by colors in the same Figure; red and blue correspond to the active and quiet terms respectively

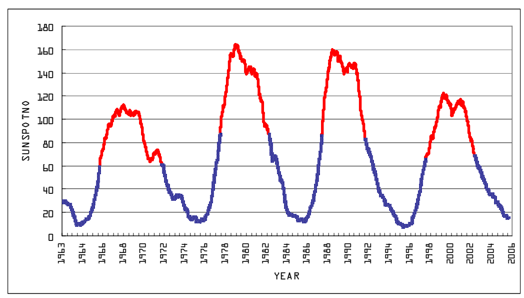

Figure 5: Time profile of the smoothed sunspot numbers after taking the 365-day and 27-day running averages and the definition of the active (red) and quiet (blue) terms of the solar activity.

Solar wind effect

All the data preprocessed as described before are divided into the terms thus defined to construct the data sets (9 sets for the neutron in 1963 to 2006 and 8 sets for the muon in 1970 to 2006). Then, for each data set, we have done the regression analyses separately to derive the regression coefficient in each solar activity term. The regression coefficients thus obtained are thought to represent the solar wind effect on cosmic ray intensity variations in the different solar activity terms. They are plotted along with the average values of the sunspot number in each term in Figure 6.

It is evident from Figure 6 that there is a clear difference between the regression coefficients, or the solar wind effects, in the active terms and in the quiet terms for both neutron and muon. From the regression analysis using all the data combined in the active terms, the regression coefficient is (-0.00360+/-0.00018) %/(km/s) for neutron and (-0.00140+/-0.00011) %/(km/s) for muon. From that in the quite terms, on the other hand, it is (-0.00200+/-0.00010) %/(km/s) for neutron and (-0.00080+/-0.00007) %/(km/s) for muon. Then it is found that the ratio (active/quiet) of coefficients is about 1.8 for both components of cosmic rays.

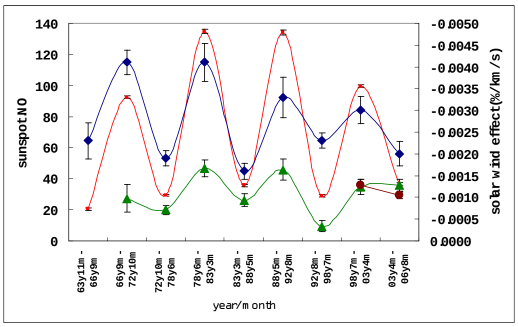

Figure 6: Variations of the regression coefficients between cosmic ray intensities and solar wind velocities (blue: neutron vs. velocity and green: Nagoya muon vs. velocity, brown: GRAPES muon vs. velocity) on the solar activities plotted along with the average of the sunspot numbers (red) in each term.

Conclusion

Although it was often pointed out that the intensity of cosmic rays varies with some transient variations of solar wind velocity such as the high speed flow associated with a solar flare, there have been seldom quantitative analyses of the solar wind effect on the intensity of cosmic rays. In this paper, as the result of the analysis of data observed in an extended period of 44 years or four solar cycles, it is clearly shown that there are rather steady negative correlation between the intensity of cosmic rays and the solar wind velocity, so called the solar wind effect, besides the transient variations described above.

By the examination of the solar activity dependences using the data divided into 4 active and 5 quiet terms by referring the sunspot numbers for 44 years, it is found that the regression coefficients of cosmic ray intensity variations with solar wind velocities are clearly dependent on the solar activity (see also [4]). They are large in active term and small in quiet term, and the ratio of coefficients is about 1.8.

Acknowledgements

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References

[1] Y. Munakata and K. Nagashima. Correlation Analysis between Cosmic Ray Intensity Variation and Interplanetary Plasma Parameters, 16th Int. Conf. Cosmic Rays, Kyoto, 3, 530, 1979

[2] K. Fujimoto, H. Kojima and K. Murakami. Cosmic Ray Intensity Variations and Solar Wind Velocity, 18th Int. Conf. Cosmic Rays, Bangalore, 3, 267, 1983

[3] K. Fujimoto, H. Kojima and K. Murakami. The Solar Wind Effect on Cosmic Rays and the Solar Activity, 19th Int. Conf. Cosmic Rays, San Diego, 3, 262, 1985

[4] H. Kojima et al. The Change in Cosmic Rays Intensity Variation with the Solar Wind Velocity, published in this conference