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Long-term periodic variations (1.8 year) of cosmic rays in the outer Heliosphere

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Abstract. The Voyager 1 & 2 have been observed continuously for about 20 years. Using of those data, we investigate long-term variation of cosmic ray particles with energy of $>$ 70 MeV by wavelet transform technique.
We found ~ 1.8 year periodic variation. The period 1982 - 1990 is almost one solar cycle, with large amplitude compare to the other cycle. 1.4 years variations have been observed at Ulysses in early 1990's. These observational results may be showing difference of modulation effect due to the solar magnetic polarity and dependences on radial distance. We also analysed neutron monitor data for comparison. We report preliminary results for two solar cycle.

1 Introduction

Most of the analysis of long-term variation of cosmic rays have been carried out with data observed on the Earth. Now, it is also possible to use Voyager or Ulysses data for that purpose. These satellites have been operating more than 20 and 10 years, respectively. Actually, ∼1.4 year variation has been observed in early 1990's at the Ulysses. It makes it possible to derive spacial information of cosmic ray transport in the heliosphere.

We investigate long-term cosmic ray intensity variation with 20 years data from the Voyager spacecraft. We found the ∼1.8 year variation on cosmic ray intensity.

2 Results

The orbits of Voyager-1 and -2 are shown in figure 1. Voyager spacecrafts have been at distant as greater than 50 AU during the end of 1999. Voyager-1 made observation mostly at 30 degrees north. Voyager-2 observed at heliospheric equator until 1990 and had been moved toward the south.

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The counting rate of cosmic rays $>$ 70 MeV/n observed at Voyager-1 and -2 are shown in figure 2. Well known 11 years intensity variation are clearly seen in figure 2. After 1995, intensity is increasing gently because of the position of Voyager spacecrafts.

In this study, data are filtered by 800 days running average to focus on the intensity variation with wavelength of several years. Figure 3 shows deviation from 800 days running average for Voyager-1 and -2. It is evident that about 2 years variation is observed during the period of 1982 - 1990 at both spacecraft. But, there is no significant variation of ∼2 years periodicity after 1993.

We applied a continuous wavelet transform technique to determine wavelength and term of this component. The "Gopher wavelet",

$$\varphi(x) = \exp(-\frac{x^2}{8^2})\exp(ix) \quad (1)$$

is selected as the mother wavelet.

The result for Voyager-1 data is showing in figure 4. The wave components with wavelength of 600 - 800 days are shown. Light gray corresponds with large amplitude. It can be seen that 640 days ($\sim$ 1.8 year) wave component is dominant during 1980 to 1992.

It seems that enhancements followed by large decrease in 1982 and 1992 are corresponding to reversal period of solar magnetic polarities (Belov, 2000). Thus, during the period of negative polarity ($qA < 0$), the ∼1.8 year variation is exist.

Calibration or inverse wavelet transform are necessary to derive the amplitude of each wavele components by transfer from the wavelet module. But here, we estimate the amplitude of the ∼1.8 year variation directly from the figure 3.

During the period, in which the $\sim$ 1.8 year variation is dominant, rough estimation of amplitude is ∼20 On the contrary, there is no significant variation in scale of ∼1.8 year after 1993.

It should note that the radial distance have been increasing from 1 AU to 60 - 70 AU for those 20 years observations. It

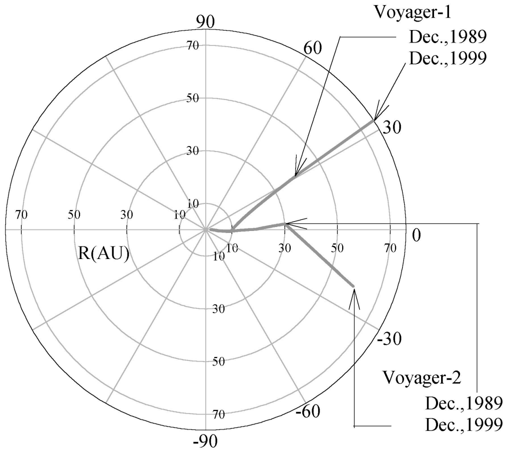

Fig. 1. Orbits of Voyager-1 and 2 from 1978 to 1999.

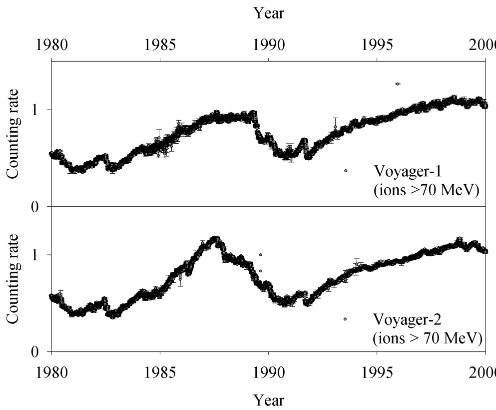

Fig. 2. Counting rate of ions (> 70 MeV) observed at Voyager-1 and 2. 11 years variation can be seen.

is necessary to check the dependences on the radial distance by comparing with long-term observation at 1 AU.

We analyzed neutron monitor data for comparison. Figure 5 shows filtered data observed at Climax, Hermanus and Rome. Median rigidity of these observatory are 11.1 GV, 19.8 GV and 21.6 GV, respectively.

The ∼1.8 year variation is observed in the same period and disappearing or weakening after 1995. Amplitude of the ∼1.8 year variation is roughly estimated as ∼5-7 in peak to peak value.

The ∼1.8 year variation is seemed to be existing longer than expected from the Voyager data. But amplitude of those components are significantly smaller than that in the period of negative polarity.

It is supposed that this phenomenon is suppressed quickly after reversing of magnetic polarity from negative to positive in 1990. While, it is remaining after reversing positive to negative in 1980.

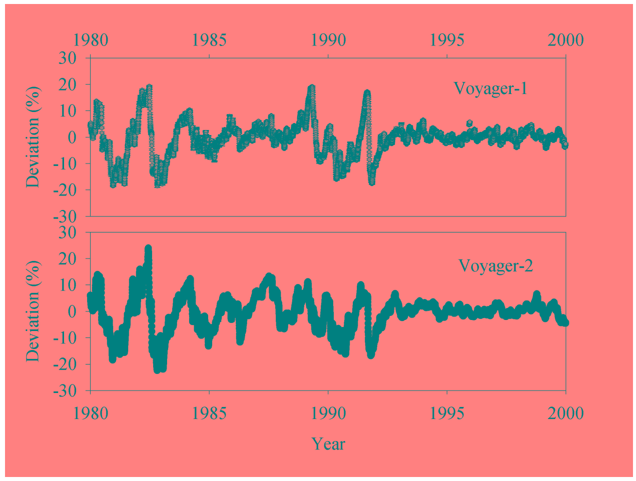

Fig. 3. Counting rate filtered by 800 days running average. The ∼2 year variation exist in the period of 1982-1992.

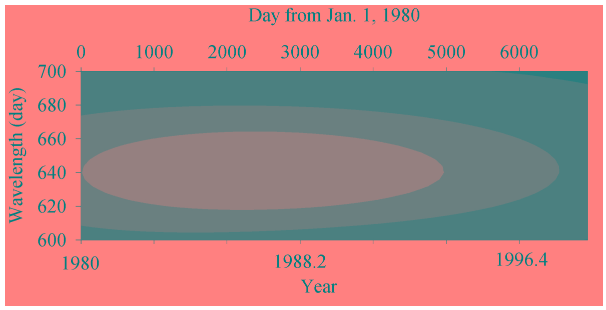

Fig. 4. Gray scale contour map of wavelet module for Voyager-1 data. The component, which has wavelength of ∼ 640 days, is dominant in 1980 - 1992. Similar contour maps are derived with data of Voyager-2 and neutron monitors.

3 summary

We investigated cosmic ray intensity for 23 years observed at Voyager spacecrafts and found ∼1.8year variation during the period of negative polarity. In the period of positive polarity, these phenomena are not significant or do not exist. The same type of variation has been found at 1 AU in neutron monitor data.

Qualitatively, these phenomena may be reflecting the different effect of modulation between two solar magnetic polarity. The heliospheric current sheet (HCS) tilt is one of the candidate to create this variation by considering the radial transport of cosmic rays. When $qA < 0$, the field is directed inward at the north pole, and positively charged particles drift in along the current sheet. Kóta and Jokipii (1991) showed that high intensity of cosmic rays is located along the current sheet for $qA < 0$ in their simulation. If the tile angle of HCS were changing with ∼1.8 year along the radial direction, the cosmic ray intensity could deviate with similar wavelength.

The data in the period 1990 - 2000 should be compared

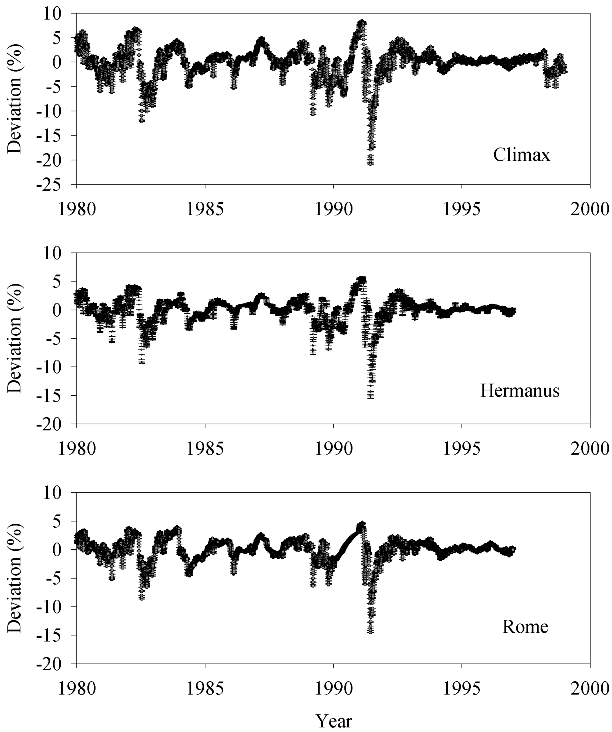

Fig. 5. Counting rate of neutron monitor at Climax (top), Hermanus(middle) and Rome(bottom). Data is filtered by 800 days running average. ∼ 1.8 year variation can be seen in 1982 - 1991.

with Ulysses data and it is also important to investigate the period 1970 - 1980 unsing NM data. Detailed analysis and comparisons with theoretical models are required as next step.

References

Kóta, J. and Jokipii, J.R., The role of corotating interaction regions in cosmic ray modulation, GRL, 18, 10, 1979-, 1991.

Belov, A., Large scale modulation: view from the Earth, Space Sci. Rev., 93, 79-105, 2000.