On the connection between the 27-day variations in the heliospheric characteristics and the GCR intensity

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Introduction

The 27-day variation in the galactic cosmic ray (GCR) characteristics in the heliosphere have been studied for many years. Due to the overall anticorrelation between the GCR intensity and solar wind (SW) velocity a majority of researchers consider the longitudinal variation of the SW velocity as the main factor explaining the 27-day cycle in the GCR intensity. However, beside the SW velocity, there are the heliospheric magnetic field (HMF) parameters which may also affect the GCR intensity. Moreover, it looks difficult to reconcile the above point of view with the notion (based on the numerical modeling) that the contribution of the SW convection into the long-tern variation of the GCR intensity is very small when compared with those of diffusion, adiabatic cooling and drifts.

In this talk we consider two episodes of the 27-day GCR

intensity variations, in 2007-2008 and 2014-2015, using the PAMELA proton data and comparing both these episodes and the PAMELA and neutron monitor (NM) data.

The data used and general picture

We use the sunspot area (solarscience.msfc.nasa.gov/greenwch.shtml), the solar magnetic field characteristic, the quasi-tilt of the heliospheric current sheet (HCS; wso.stanford.edu/) and the heliospheric characteristics near the Earth (OMNI2 database).

The PAMELA data on the proton 1 day averaged intensity in different energy ranges ($0.095 < T_n < 18$ GeV), described in more details in the talk by I. Borkut (this conference), are used. As an integrated high energy GCR intensity we use the neutron monitor data (Moscow), the effective energy $T_{eff}^{high} \approx 15$ GeV, helios.izmiran.rssi.ru/cosray/days.htm.

In Fig. 1 the time profiles of all related characteristics are shown since 2006. It is important that two periods studied in this talk - the first in 2007-2008 and the second in 2014-2015 - are quite different not only by the dominant HMF polarity A but also by their position in the solar cycle. The first one belongs to the phase of very low solar activity, especially in the N-hemisphere, and very stable quasi-tilt. The second period starts just after the end of sunspot maximum phase and the HMF reversal, when all the regular characteristics, including the sunspot area and quasi-tilt, are varying rather fast. As to the 27-d variation - the relative difference between the 1d- and 27d-averaged data - it is also rather stable, especially in the SW velocity, in 2007-2008 and looks less stable and less prominent in 2014-2015. With some reserve, the same can be said about the HMF strength. For the time being we note that the most prominent feature in the 27-d variation in the GCR intensity in the period under consideration is its rather high amplitude in 2014-2015. The other features will be discussed and illustrated below.

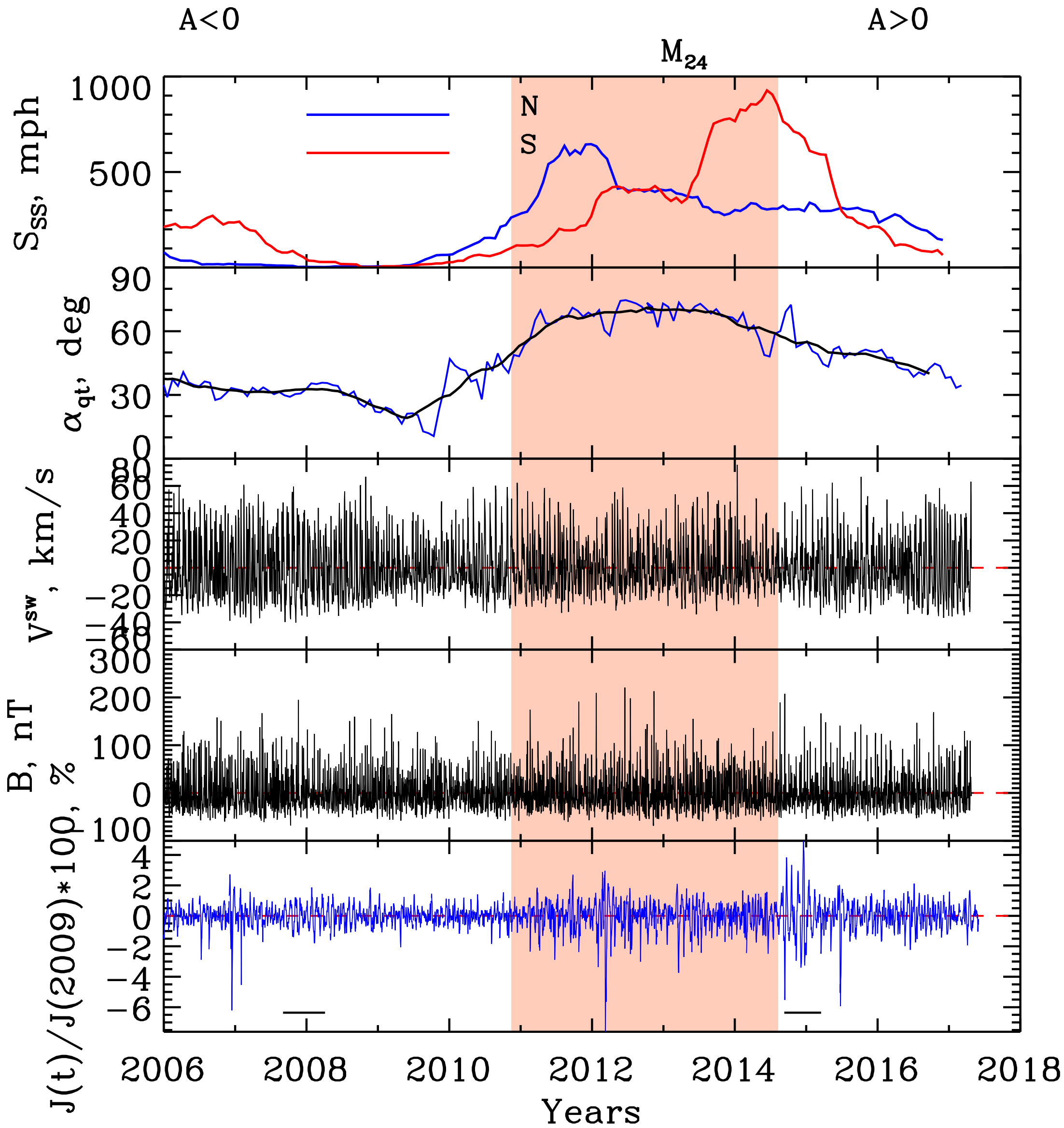

Figure 1. The solar activity, heliospheric parameters and GCR intensity in 2006-2017. The period of the HMF inversion and of the sunspot maximum phase in the solar cycle 24 is shaded and the moment of the sunspot maximum and the HMF polarity A for the periods with the "dipole" HMF polarity distributions are indicated above the panels. In the panels from the top: the yearly smoothed sunspot area in both solar hemispheres; the HCS quasi-tilt (black - for yearly smoothed data); the 27d variations for the SW velocity, the HMF strength and NM (Moscow) count rate. The periods considered in this talk are indicated by the horizontal black lines near the time axis.

Conclusions

1. **The properties of the 27d variations in the GCR intensity for two period under investigation are very different both by the amplitude and by the position of the maximum phase with respect to the specific phases of the heliospheric characteristics. During 8 Bartels rotations in 2007-2008, when the Sun was approaching its very low sunspot minimum and the heliospheric characteristics demonstrated the well-known longitude distribution of corotating interacting SW streams, both the NM and PAMELA data also show the qualitatively self-consistent and familiar picture, inherent to this phase of the solar cycle. In contrast, during 7 Bartels rotations in 2014-2015, just after the HMF reversal and sunspot maximum, when the heliospheric characteristics (except HMF sector structure) demonstrated the less steady longitude distributions, the position of the maxima in the NM and PAMELA data look slightly different, although both show very high amplitude of the 27-day variation.**

2. **The comparison of the properties of the 27d variations in the GCR intensity obtained from the neutron monitor (Moscow) and PAMELA (protons) data revealed both the similarity (especially for the first of the periods considered) and difference (especially for 2014-2015 case). However, what gives us some concern is the fact that in the PAMELA GCR proton data we see the distinct 27d variation at significantly lower energies than traditionally ascribed to the primary GCR intensity responsible for the NM data.**

3. **We hope that the noted distinctive features will help to make more clear the observational properties of the 27d variations in the GCR intensity and better understand the physics of this phenomenon.**

4. **We see the significant potential in the PAMELA (and AMS-2) data for the help in extracting the data on the primary cosmic rays from the data received in the long-term experiments recording the secondary cosmic rays in the Earth's stratosphere (regular balloon monitoring) and on the ground (neutron monitors).**

Period 03.09.2007-05.04.2008

The upper panels of Figs. 2-4 show the distribution of the relative 27d variation the relative difference between the 1d- and 27d-averaged characteristics in the GCR proton intensity of the three energies (in the increasing order) over the days of the average rotation for 8 Bartels rotations in 2007-2008. In these panels the 27d distribution is also shown (by the red histogram, multiplied by 5) for the NM (Moscow) count rate. In the second and fourth (from the top) panels the distribution of the relative 27d variation in the SW velocity and the HMF strength are shown, while the third panel shows the distribution of the average value of the radial HMF component. Note that all three above panels are the same for all Figs. 2-4.

Let us first discuss the distributions of the heliospheric characteristics. They are rather steady, as one can see from the small errors, and show a self-consistent and well-known picture. One can see two high-speed SW streams inside the unipolar HMF sectors and two low-speed streams at the boundary between sectors, i.e., at the HCS. Two peaks in the HMF strength are in the compression regions, where the high-speed streams overtake the low-speed ones. The low HMF strength is in the rarefaction regions where the high-speed streams run away from the low-speed ones.

Now we turn to the 27d variation in the GCR intensity. The NM data show rather sharply defined variation with one global maximum (approximately in the days of SW minimum and HCS crossing) and one minimum (near the days of SW maximum and inside the HMF sector) and small nonsignificant local extremes. The PAMELA data are consistent with this picture in general, although with greater amplitudes. If for NM the amplitude is around 1 percent, those from PAMELA data are about 3-5 percents for different energies. Rather large errors are also evident from PAMELA data.

It should be noted that the above picture for the 27d variations from the PAMELA data could be clearly seen only in the proton energy range $200 < T < 2500$ GeV. At the low and higher energies the peaks and gaps become multiple and their amplitudes comparable with the errors. Probably it corresponds to the decreasing amplitudes for the low energy particles, found in the talk by I. Borkut et al.

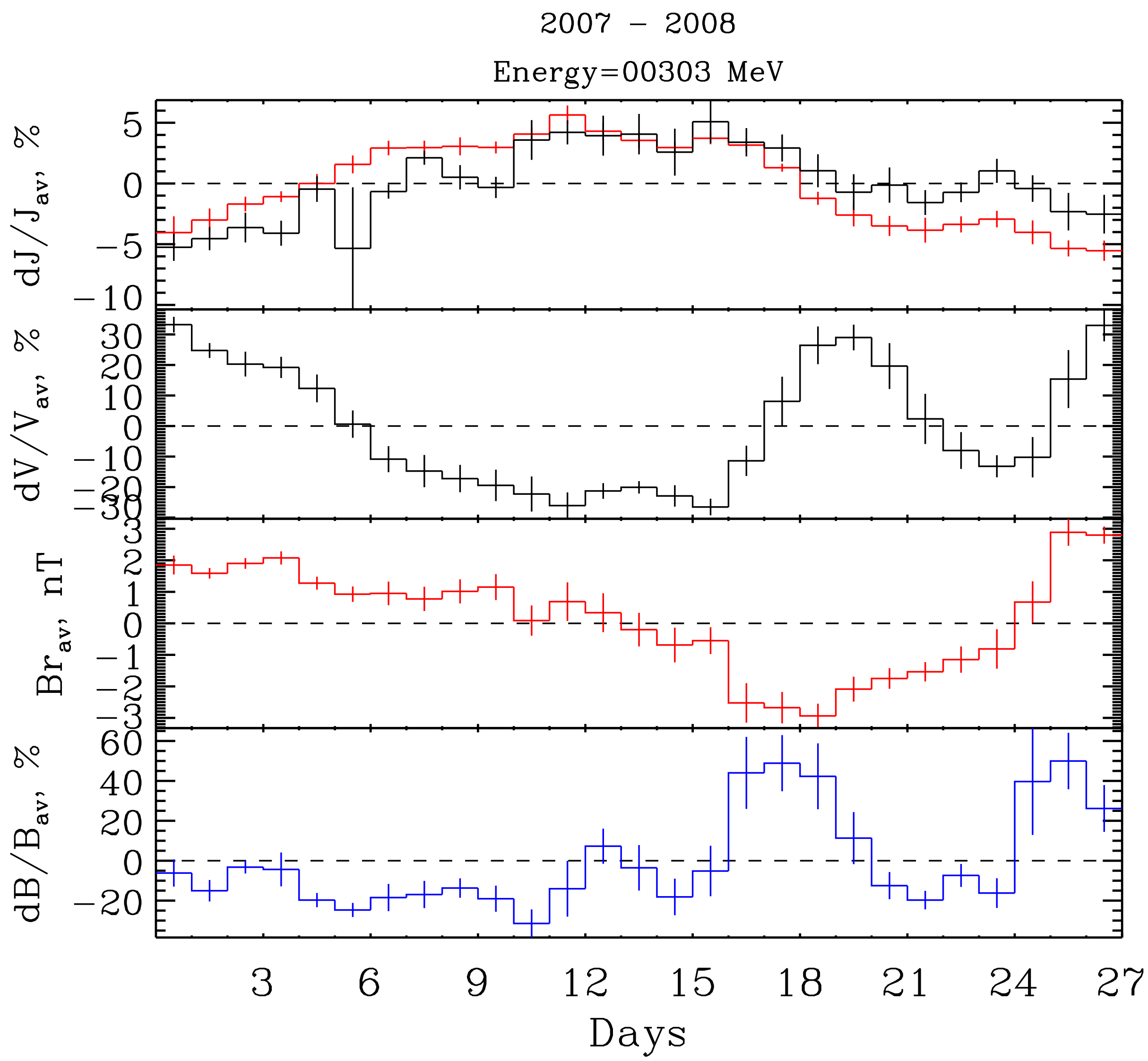

Figure 2

The distribution over the days of the average Bartols rotation of the relative 27d variations in the GCR intensity of protons with $T = 300$ MeV (upper panel) in comparison with those in the heliospheric characteristics for 2007-2008. From the top: second panel - the relative 27d variation in the SW velocity; third panel - the 27d variation in the average value of the radial HMF component; fourth panel - the relative 27d variation in the HMF strength.

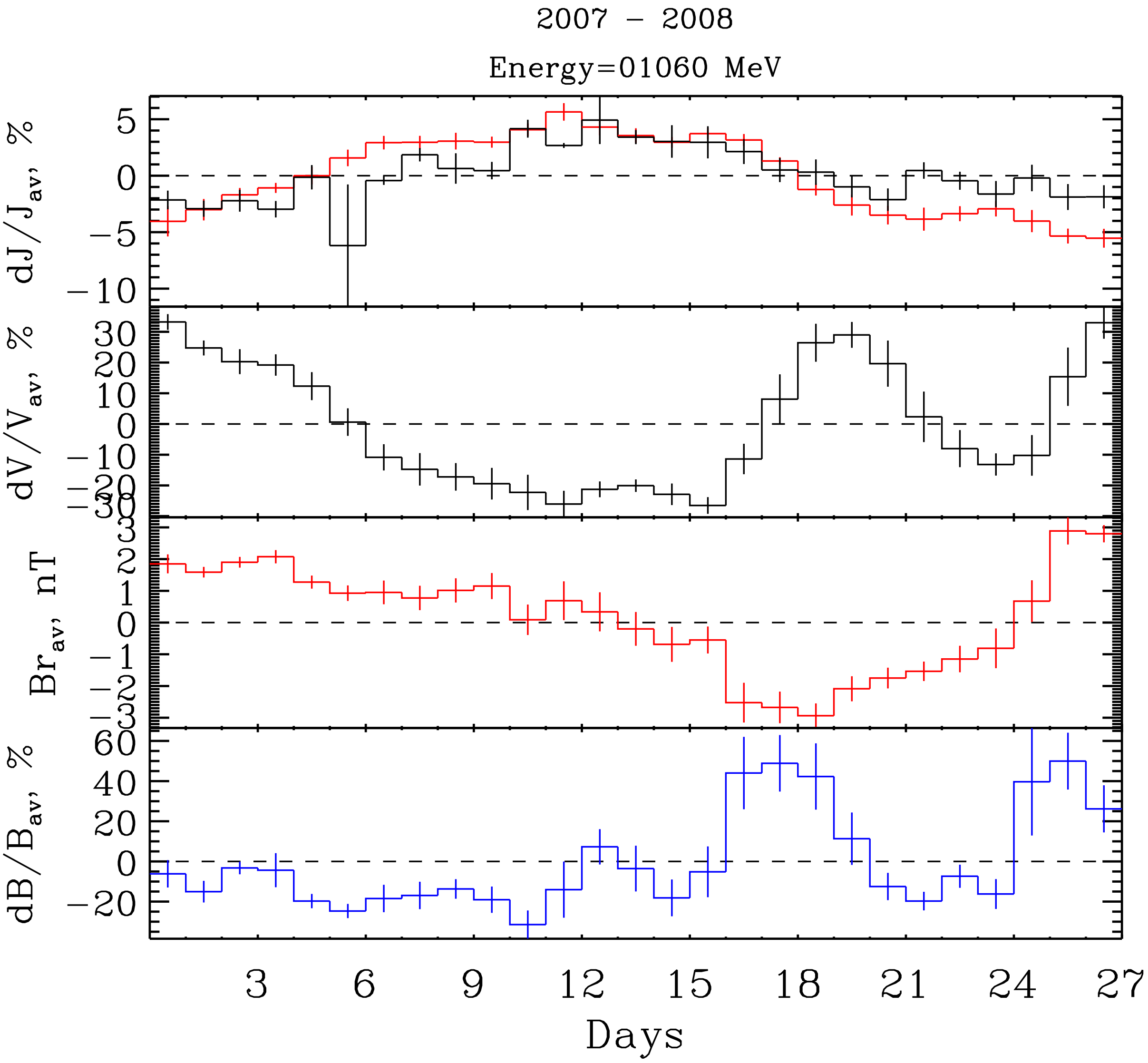

Figure 3

The same as in Fig. 2 but for the GCR protons with $T \approx 1000$ MeV.

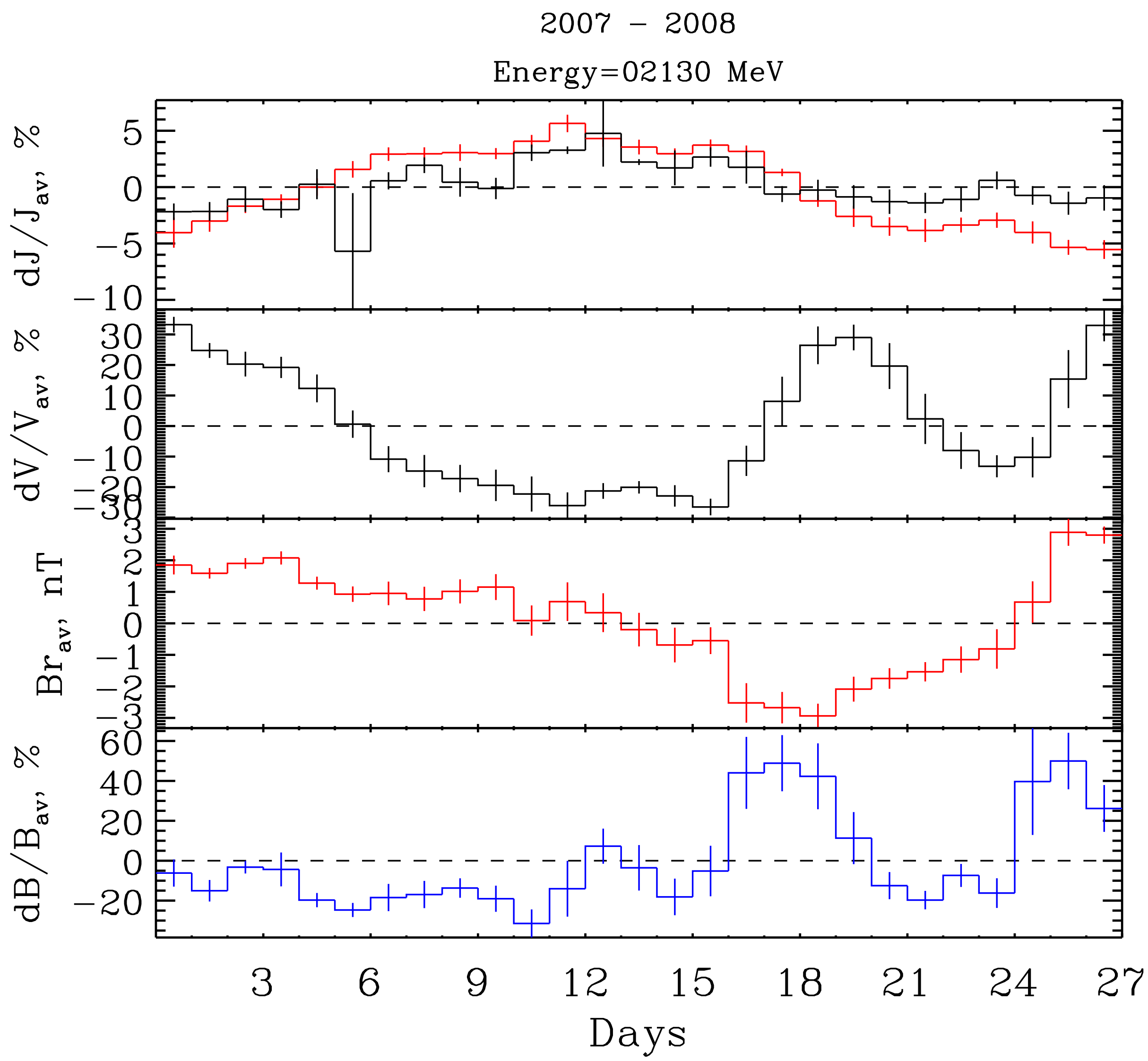

Figure 4

The same as in Fig. 2 but for the GCR protons with $T \approx 2100$ MeV.

Period 11.09.2014-18.03.2015

The upper panels of Figs. 5-7 show the distribution of the relative 27d variation the relative difference between the 1d- and 27d-averaged characteristics in the GCR proton intensity of the three energies (in the increasing order) over the days of the average rotation for 7 Bartels rotations in 2014-2015. In the second and fourth (from the top) panels the distribution of the relative 27d variation in the SW velocity and the HMF strength are shown, while the third panel shows the distribution of the average value of the radial HMF component. Note that all three above panels are the same for all Figs. 5-7.

Now it is rather difficult to isolate the high-speed and low-speed SW streams. Only one peak in the HMF strength is significant in small compression region, while the other peaks and gaps are comparable to the errors. However, the two-sector HMF sector zone, undistorted by the interaction between the SW streams, is clearly seen.

The NM data again show rather definite one-peak-one-gap structure, the two-percent peak being in the positive HMF sector. The PAMELA data demonstrate the same peak, although of much greater amplitude (8-10 percents). Besides, there is a smaller peak (with amplitude for higher energies comparable to the errors) in the negative HMF sector.

Again it should be noted that the above picture for the 27d variations from the PAMELA data could be clearly seen only for the proton energy range $200 < T < 2500$ GeV. At the low and higher energies the peaks and gaps become multiple and their amplitudes comparable with the errors.

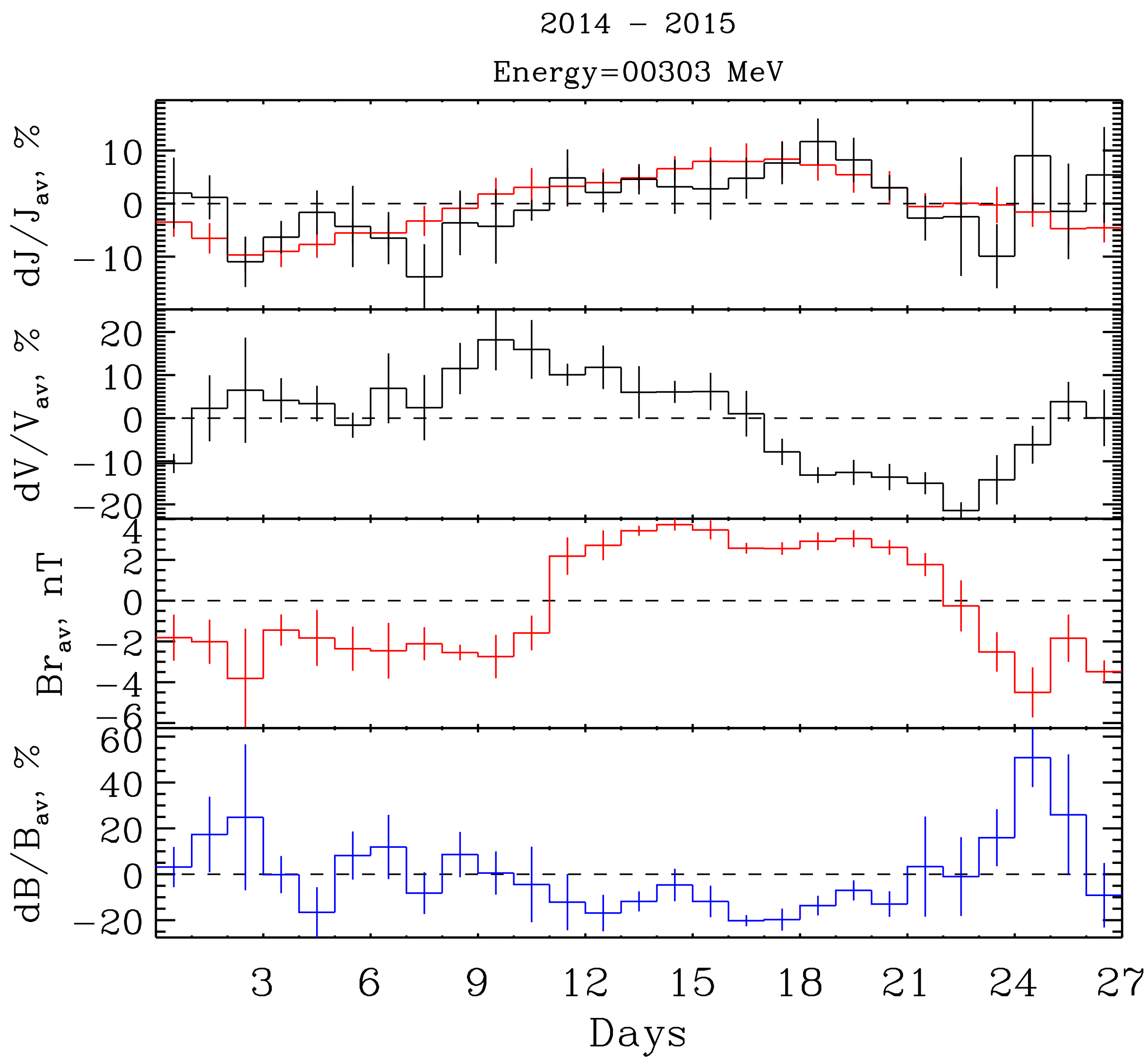

Figure 5

The distribution over the days of the average Bartols rotation of the relative 27d variations in the GCR intensity of protons with $T = 300$ MeV (upper panel) in comparison with those in the heliospheric characteristics for 2014-2015. From the top: second panel - the relative 27d variation in the SW velocity; third panel - the 27d variation in the average value of the radial HMF component; fourth panel - the relative 27d variation in the HMF strength.

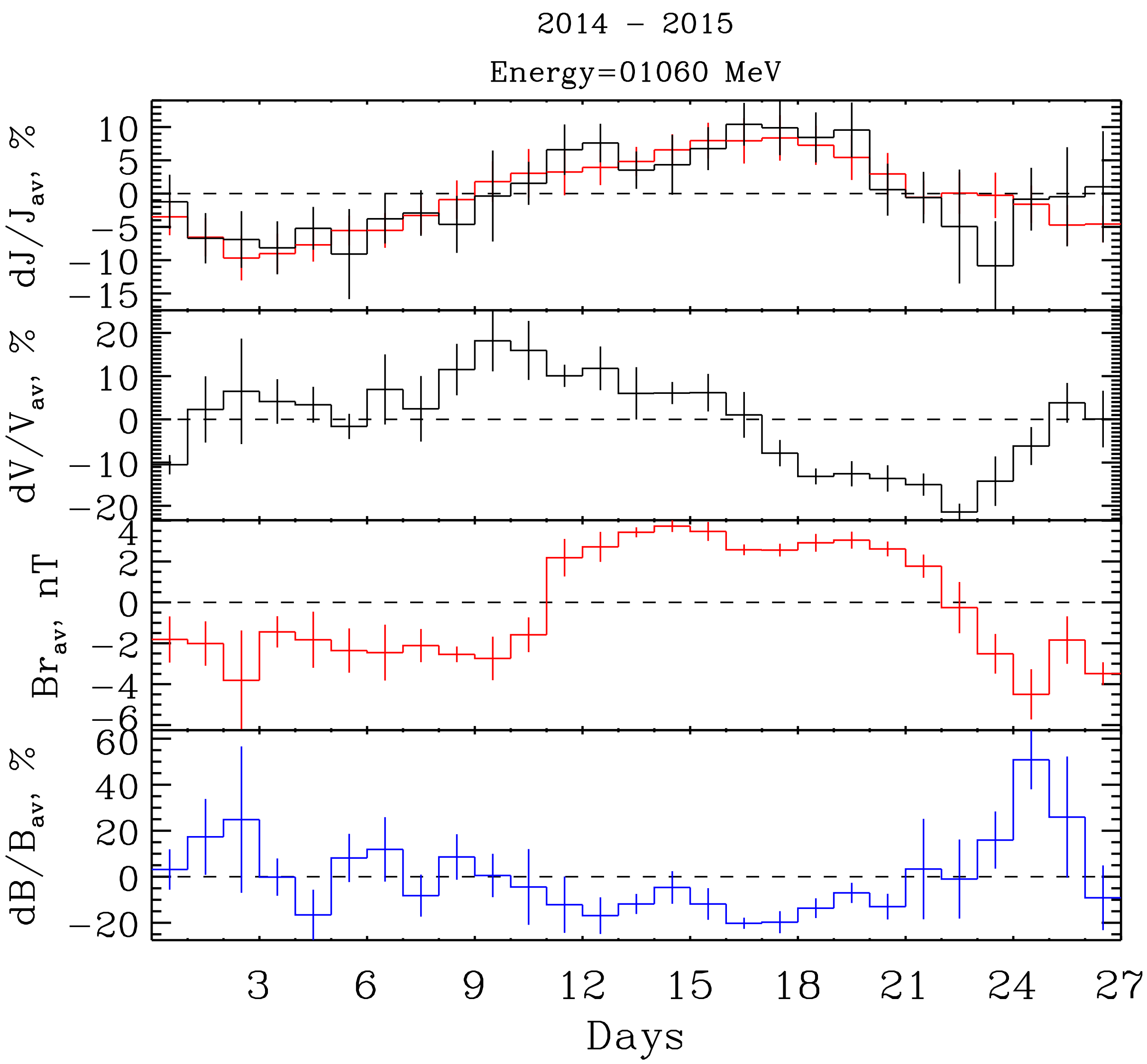

Figure 6

The same as in Fig. 5 but for the GCR protons with $T \approx 1000$ MeV.

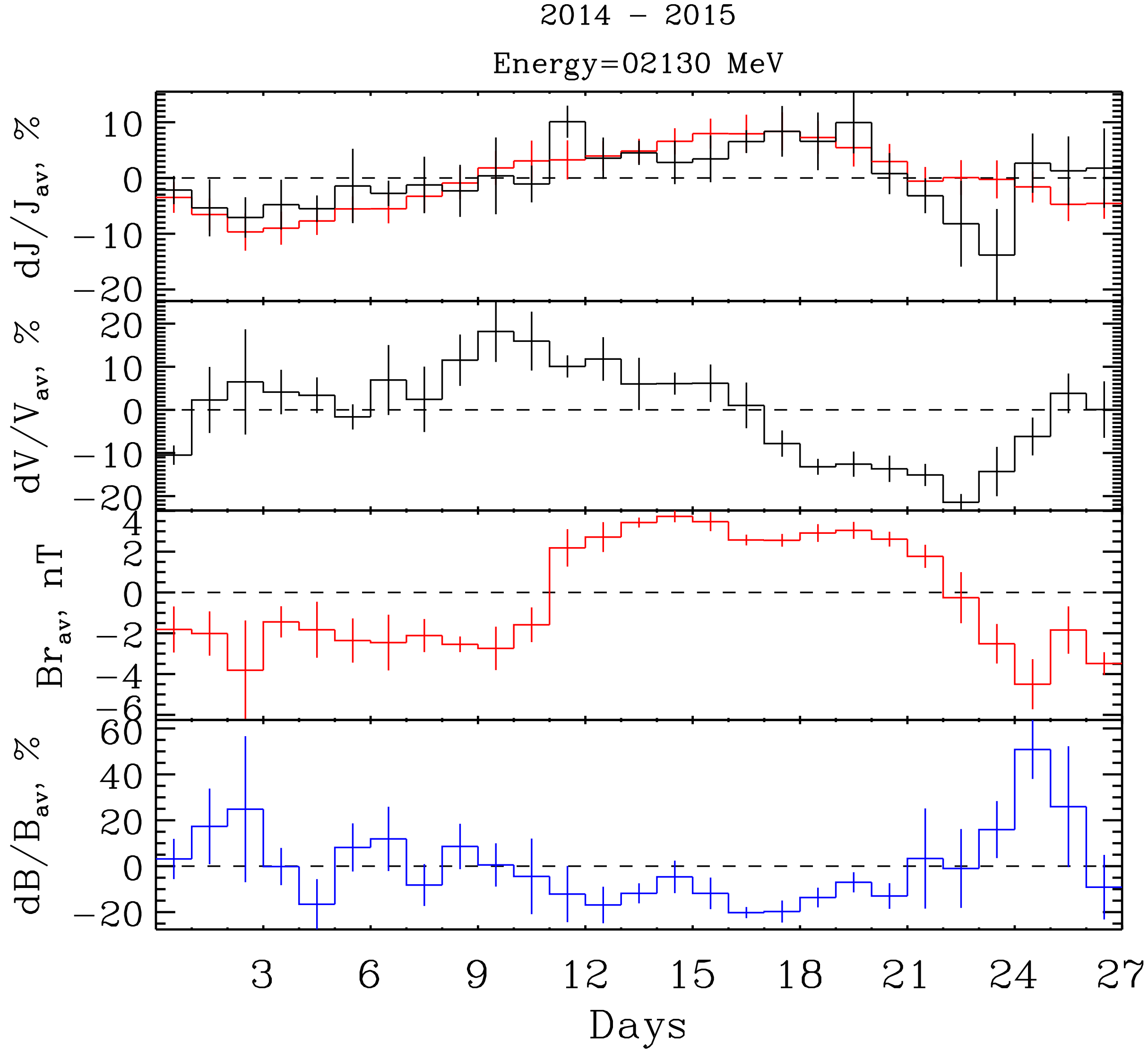

Figure 7

The same as in Fig. 5 but for the GCR protons with $T \approx 2100$ MeV.