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The regular measurements of the GCR intensity in the stratosphere in comparison with the measurements by the neutron monitors and aboard the IMP8 spacecraft

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Abstract: We estimate to what extent the neutron monitor, spacecraft, and stratospheric GCR data can be used for getting and improving information on the intensity of the GCRs in a so called medium energy range (100-500 MeV/n), very important for studying the GCR modulation in the heliosphere.

Introduction

In the course of the regular balloon monitoring (RBM) of the cosmic rays in the Earth's atmosphere the variations of the GCR intensity are studied for the particles' energy from the hundred MeV to a few tens of GeV depending on the latitude and atmospheric depth $\boldsymbol{x}$. If one is interested in the low energy part of the spectra, one can use the omnidirectional counter count rate difference ΔN_{max} in the Pfoetzer maxima measured at the high (Murmansk; the geomagnetic cut-off rigidity $\boldsymbol{R_c} = 0.6$ GV) and middle (Moscow; $\boldsymbol{R_c} = 2.3$ GV) latitudes. In [1] we showed that the analysis of the differential stratospheric data ΔN_{max} can be an effective indirect means to study the so called medium energy (ME) GCR intensities, $100 < T < 500$ MeV/n, from 1957 to the present time. This range is of special interest for the studies of the GCR modulation in the heliosphere. It was shown in [2] that because of the atmosphere absorbing the low and medium energy cosmic rays, the ground level neutron monitor data are not as useful as the stratospheric differential data to get the proxy for the ME GCR intensity**.**

Here we estimate to what extent the neutron monitor and spacecraft data can be used for improving the stratospheric time series related to the medium energy GCR intensity. The hourly data of the neutron monitors Apatity (since 1969) and Moscow (since 1958) are used as well as the standard set of the IMP8/GME "quiet time" daily medium energy GCR intensities (p, 121-229.5 MeV; He, 168.8-455.5 MeV/n) and the integral count rate for GCR nuclei with $\boldsymbol{T} > 80$ MeV/n, kindly put at our disposal by the IMP8/GME team (PI Dr. McGuire).

Long-term behavior of the NM, stratospheric and the ME GCR intensity

Figure 1 shows the behavior in 1957-2006 of the half-year smoothed monthly count rate of different CR detectors normalized to 100% in February 1997. The thickness of the curves grow with the effective energy of the series.

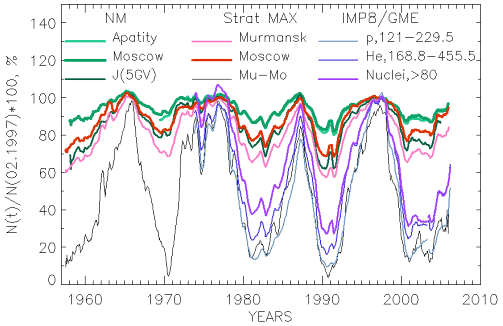

Figure 1

The lowest and thinnest (black) curve corresponds to the differential stratospheric data ΔN_{max}. It can be seen that the depth of modulation of the primary CR, determining this characteristic, practically coincides with that for the medium energy GCR protons and is somewhat greater than the modulation depth of the medium energy GCR helium and the integral intensity of the GCR nuclei with ***T*** > 80 MeV/n (next three lines from the bottom). Three intermediate curves illustrate the modulation of the GCR intensity with R=5 GV (related to the lowest energy determined reliably from the neutron monitor data, see [3], as well as the intensities fixing the maximum count rates in the stratosphere above Moscow and Murmansk. Two upper curves are for the NM Moscow and Apatity. It was noted in [1] that there were different trends in ME GCR intensities and stratatospheric ME time series. To take into account a possible energy dependence of the trends in Fig. 2 we show the linear trends of the 11-year smoothed data (for 11/1973-02/2006 for all series shown in Figure 1) as function of their minimum normalized count rate in 1990-1991. In this paper we use this characteristic as a proxy for the effective energy for different time series and call it quasienergy.

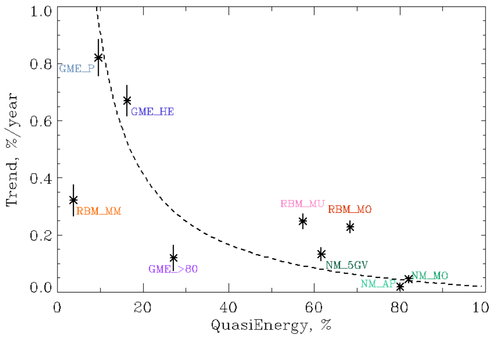

Figure 2

It is clearly seen that the trend for the stratospheric ME time series (marked RBM_MM) is much lower than those for both ME GCR intensities. Evidently, it is just the consequence of approximately equal (and rather high) trends in the maximum count rates in the stratosphere above Moscow and Murmansk. Note also rather low trend in IMP8/GME ***T*** > 80 nuclei count rate. The dashed line shows the inverse quasienergy dependence of the trends for the rest of time series.

On Correction of the RBM data

The differential data such as the difference between the cosmic ray fluxes at the high and middle latitudes, are very susceptible to the errors as they can strongly depend on many factors, which only weakly influence the data at each latitude separately. However, we hope that taking into account the neutron monitor data with high statistical accuracy and the IMP8/GME daily data we can improve the quality of balloon time series, both initial ones and those related to the medium energy GCR intensity. Below we, using the simultaneous results of the stratospheric and neutron monitoring above the Kola Peninsula and Moscow region, and also the daily IMP8/GME data, discuss the influence of one such factor - how the small duration of each balloon flight and small (and variable) number of flights per month can influence the monthly means, calculated as an average of the values obtained in the individual flights. By analogy with the solar flare monitoring we call the sought-for correction for the stratospheric monthly means the “patrol” correction. As shown in [2], even in the “best” times (1970-1985, Murmansk) the percentage of time, when the maximum count rate in the stratosphere is estimated, never exceeded 2.5 percents (less than 20 minutes in a flight, flights twice a day) and it is only ≈ 0.5 % since 1998 (14-15 flights a month) for each location. However, the days of the RBM measurements are evenly distributed over the month and there is no solar cycle dependence in the patrol time. On the other hand the great gaps are present in the daily IMP8/GME quiet time data set, especially during the high solar activity periods. There are no daily data at all for some months. It is easy to show that the criterion of the quietness used removes from the "quiet time" daily data set not only the data with solar particle contribution but also those without it when the solar particles contaminated only low energy channels. However, there is no sudden growth of the gaps in the daily IMP8/GME data in the end of 2001. As we noted in [2], if one’s task is to estimate the behavior of the monthly average (and not the daily, 27-day or Forbush decrease changes) and if the RBM results had the same accuracy and the same ratio of the within-the-month to monthly changes as the neutron monitor data, even very short RBM patrol time would allow to estimate the monthly means with the accuracy better than 0.5 % in each location. However, for the stratospheric data the relative amplitude of the within-the-month variations $Var_{d/M}$ - the ratio to the monthly average of the mean square root of the detailed data (the hourly for the neutron monitors, the daily for IMP8/GME, and the maximum count rates for individual RBM flights) to the monthly average - is about 2-3 times as great as that for the neutron monitors (see Fig. 3, where the relative amplitudes of the within-the-month variations smoothed with 0.5 year are shown). So much more significant patrol correction can be expected for the RBM than for NM measurements.

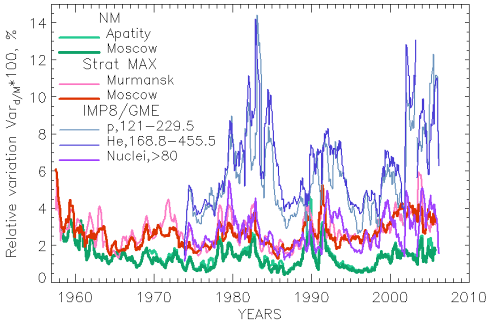

Figure 3

Note that the relative amplitude of the within-the-month variations for the integral count rate of the GCR nuclei with ***T*** > 80 MeV/n is approximately equal to those for the stratospheric data and for the medium energy GCR intensities it is few times greater. In Fig. 3 one can also notice the sudden growth of the relative amplitude of the within-the-month variations in the daily IMP8/GME data in the end of 2001, when the status of the IMP8 spacecraft changed.

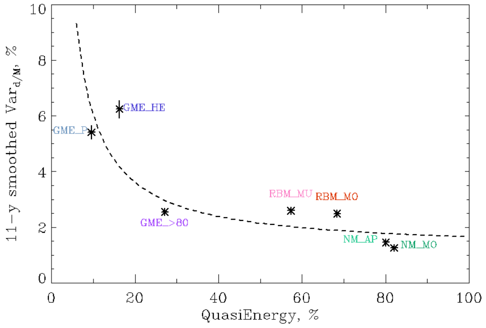

Figure 4

To take into account a possible energy dependence of the within-the-month variations in Figure 4 we show the average of the 11-year smoothed relative amplitude of the within-the-month variations (for 11/1973-09/2001 for all series shown in Figure 3) as a function of their quasienergies. The dashed line shows the inverse quasienergy dependence for all time series. One can see that the relative amplitude of the within-the-month variations for the stratospheric and ME He time series is somewhat greater than expected from the smooth energy dependence. A corrected for patrol monthly stratospheric count rate $N_M^{\max}$ can be estimated as a weighted mean, [2]:

$$N_M^{\max} = \sum_{j=1}^{K} N_j^{\max} \cdot W_j^{\max} \Big/ \sum_{j=1}^{K} W_j^{\max} , \qquad (1)$$

where K is the number of flights per month when we could estimate the count rate at the transition maximum and $N_j^{\max}$ is this count rate in the j-th flight. The weight $W_j^{\max}$ can be estimated as

$$W_j^{\max} = \frac{N_M^{\max}}{N_j^{\max}} \approx \frac{N_M^{nm}}{N_j^{nm}} \cdot \frac{Var_{j/M}^{\max}}{Var_{h/M}^{nm}} , \qquad (2)$$

where N_j^{nm} and N_M^{nm} are the neutron monitor count rate taken at the same moment as $N_j^{\max}$ and monthly mean, respectively.

Discussion

Instead of calculating $N_M^{\max}$ according to (1-2) for Murmansk and Moscow and then forming the difference between these corrected values for the ME series we prefer here to discuss the validity of the assumptions implied in (2). First, for the neutron monitor data the calculated variation $Var_{h/M}^{nm}$ actually combines different variations (diurnal, 27-day, transients) with, probably, different energy dependences. Second, for the balloon monitoring the meaning of the calculated variation $Var_{j/M}^{\max}$ is not clear: it very poorly accounts for the diurnal wave and usually poorly reflects the transients. To use (1-2) effectively one should interpolate the energy dependence of the variation between the energy range specific for the neutron monitors and that of the IMP8/GME in order to estimate the characteristics of the variation for the high altitude cosmic ray fluxes. Besides, the use of the monthly IMP8/GME data would make much more reliable the correction of the high altitude balloon data for the long-term trends in the efficiency by the model method (see [3]). The last and very important point is that the expression (2) implies that the recorded stratospheric count rate $N_j^{\max}$ for the individual flights is correlated with the neutron monitor count rate N_j^{nm} measured at the same time. To illustrate the real situation we show in Figure 5 the time behavior in 1958-2006 of the 0.5-year smoothed correlation coefficient between the NM Moscow and the count rate in Pfoetzer maximum in stratosphere (in the upper panel) and the daily IMP8/GME data (in the lower panel).

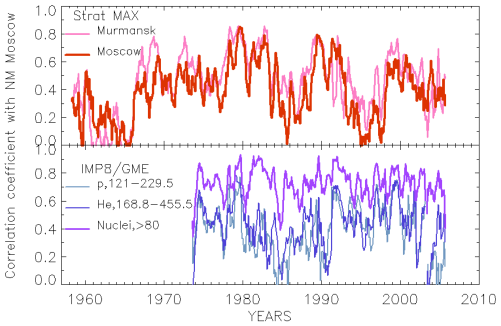

Figure 5

The smoothed correlation coefficient is positive and for the stratospheric data it demonstrates the solar cycle dependence, especially in 1977-2005 (the solar cycle 21-23), being 0.6-0.9 during solar cycle maximum phase and 0-0.3 during periods of low solar activity. It demonstrates that the relative uncertainty in the determination of $N_j^{\max}$ is of the order or greater than its relative variation within the month for the low activity periods. The mentioned in the previous section fact, that the relative amplitude of the within-the-month variation for the stratospheric time series is too great, also indicates that the contribution to $Var_{j/M}^{\max}$ of the errors of the determination of maximum count rates is significant. It means that the accuracy of the method of estimating the count rate in the transition maximum in stratosphere is too low now for using the expressions (1-2) to make the patrol correction for monthly averages during the periods of the low solar activity and we should try to improve this accuracy. Note that the IMP8/GME integral count rate of the GCR nuclei with T > 80 MeV/n demonstrates the highest correlation with the NM count rate, significantly greater than the ME GCR intensity and, especially during low solar activity periods, the stratospheric data. This fact makes the NM count rate and the IMP8/GME nuclear integral count rate the most perspective pair for improving the stratospheric data set related to the medium energy GCR intensity.

Conclusions

1. The comparison of the balloon high altitude data for the individual flights with the hourly and daily neutron monitor and IMP8/GME data can help in improving the balloon time series related to the medium energy GCR intensity.
2. To achieve the above purpose some methodical efforts with both the balloon and IMP8/GME data are needed. For the balloon data (1) the accuracy of the method of estimating the count rate in the transition maximum in stratosphere should be improved and (2) the cause of rather high long-term trend in stratospheric data should be understood and accounted for. For the IMP8/GME data (1) the different (less rigid) criterion should be used in forming the daily data set and (2) the cause of too small long-term trend in the integral count rate should be understood and accounted for.

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