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BALLOON AND GROUND LEVEL OBSERVATIONS DURING GIANT SPE OF JANUARY 20, 2005

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Abstract. The results of balloon measurements, which were performed at the high latitude point Apatity (N 67.3°, E33.3°) during the great solar proton event (SPE) on 20 January, 2005 have been considered. Balloon measurements enable accurate determination of the spectrum of solar protons in the energy range from 80-100 up to 350-400 MeV. In the SPE of 20 January, 2005, the energy spectra of the solar protons measured in the stratosphere had a power-law form, with the integral power of ~5. They agreed well with the spectra, obtained in adjacent energy ranges: at GOES-11 spacecraft and from neutron monitor observations at the isotropy phase of GLE. Before that, the spectra measured at the ground level had exponential dependence on energy. Possible reasons of energetic spectra difference at the initial and late phases of SPE are discussed.

1. Introduction

This paper considers the balloon measurements of solar protons during the large SPE on 20 January, 2005. This SPE was characterized by the greatest since 23.02.1956 ground-level effect of solar cosmic rays. The parent flare 2B/X7.1 had helio coordinates N14, W61. The type II radio onset signaling the energetic proton acceleration was reported at 06:44 UT. The flare caused the worldwide GLE registered by the neutron monitors over the globe. Balloon measurements enable accurate measurement of spectrum of solar protons in the energy range from 80-100 up to 350-400 MeV (Bazilevskaya and Svirzhevskaya, 1998). The solar protons spectrum is determined from the relation between a detector count rate and air thickness above the balloon measured during the balloon ascent. The cylindrical G-M tube and a vertical telescope of two such tubes with aluminum absorber between them are used as detectors. During the January 20, 2005 SPE, the balloon measurements of solar protons were carried out at the launching point in Apatity (joint Lebedev Physical Institute and Polar Geophysical Institute PGI) balloon experiment.

2. Observations

The first balloon measurement was made in the time interval from 7:20-to 8:00 UT, the mean time 7:40 UT, about 50 min after the first relativistic solar protons were registered on the Earth. Since then during the following 25 hours 7 solar proton spectra were measured in consecutive moments of time. These spectra are shown in Fig.1. The indicated moments correspond to the middle of the measurement time interval which is, on the average, 30-60 min. All the spectra have the power-law form with an integral power of about 5, with a tendency to flattening at energies < 200 MeV. It is noticeable that the spectral form did not change significantly during the whole period of observations, which continued for more than a day.
In Fig. 2 the intensity time profiles of integral fluxes of solar protons measured in the stratosphere are shown in combination with the analogues profiles obtained by the GOES-11 spacecraft in the energy range from 10 to 100 MeV. The estimated measurement errors of the points in Fig.2 are of the order of the size of the symbols. One can see a common character of solar proton intensity behavior with time from >30 to >400 MeV.

2. Comparison with ground based observations

In Fig.3a the ground level effect of relativistic solar protons (RSP) is shown based on the data of neutron monitor stations McMurdo, Antarctic and Apatity. The vertical arrow indicates the onset time of II type radio emission, shifted back by 8 min. (the suggested moment of relativistic particle generation on the Sun (Cliver et al., 1982)).
The numbered arrows correspond to the moments of time, when in the RSP flux dominate: (1) the prompt component (PC) and (2), the delayed component (DC) (Vashenyuk et al., 2005). Figures 3 b,c show the derived by modeling technique (Vashenyuk et al., 2003) spectra of PC (1) and DC (2) in double logarithmic and semi-logarithmic scale, respectively. In Fig.3 b, c the data of direct solar protons measured by GOES11 spacecraft (blackened dots) and balloon measurements in Apatity at 07:40 UT (crosses) are also presented.

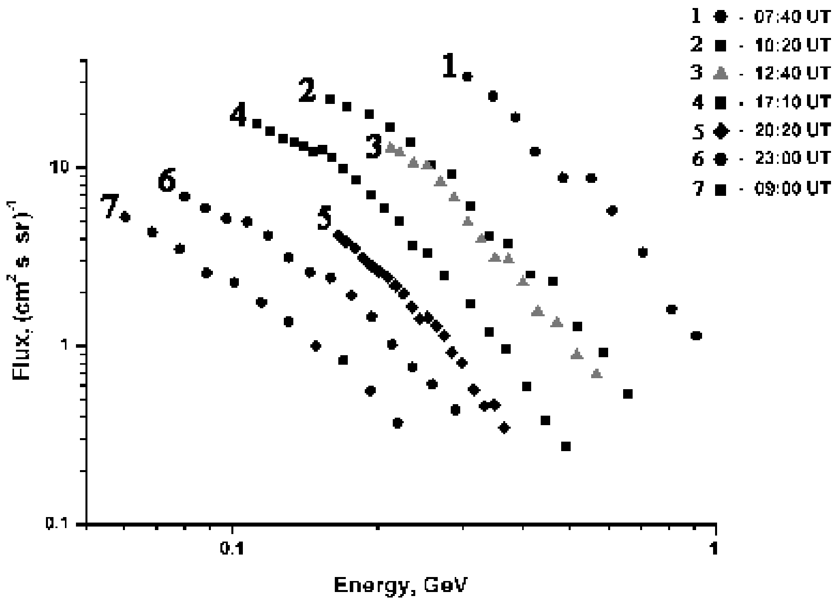

Figure 1. Solar proton spectra obtained in balloon measurements on January 20 and 21, 2005.

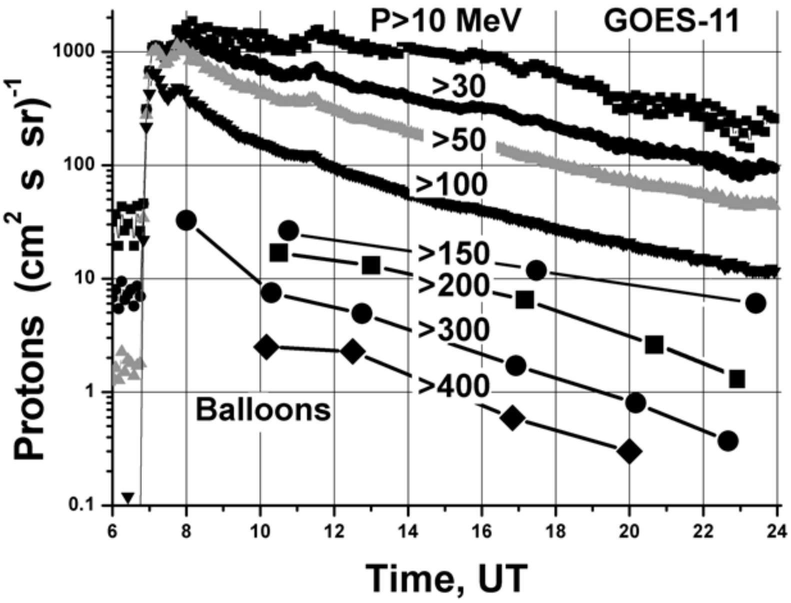

Figure 2. The intensity-time profiles of solar proton integral fluxes measured in the stratosphere at energies from >150 to >400 MeV combined with analogues profiles obtained by the GOES-11 spacecraft at energies from >10 to >100 MeV.

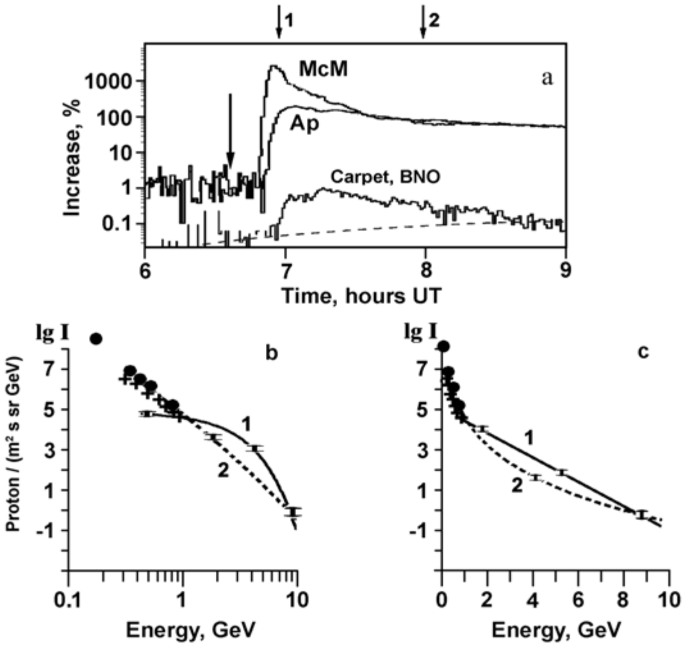

Figure 3. (***a***) Intensity-time profiles at the NM stations McMurdo (McM), Apatity (Ap); and EAS array "Carpet" The vertical arrow indicates the suggested moment of relativistic particle generation on the Sun. (***b, c***) derived energy spectra at moment 1 (solid line) and 2 (dashed line). Direct solar proton data are crosses (balloons) and blackened dots (GOES-11 spacecraft)

3. Discussion and conclusions

A strong anisotropy existed at the initial stage of the event, with the increase in McMurdo exceeding that in Apatity by more than 20 times. The anisotropy disappeared after about 7.30 UT. As can be seen from Figures 3b, c, the PC spectrum has nearly an exponential dependence on energy (straight line in semi-logarithmic scale) and within the limits of shown error bars can be described by the expression: $J = 1.5\times10^5\exp(-E/0.72)$. The DC spectrum (2) depends on energy according to the power law $J = 7.5\times10^4E^{-6.2}$, and within the limits of error bars is a straight line in double logarithmic scale (Vashenyuk et al., 2005b). There is a good consistence between the spectrum of DC obtained from the NM data and intensities of direct solar protons in adjacent range of energy measured on balloons and GOES-11 spacecraft. Moreover, the spectrum of direct solar protons also depends on energy according to the power law and appears to be an extension of DC spectrum of relativistic solar protons into the energy range from 700 to 100 MeV. Thus, the mechanism of DC generation is effective enough in a wide energy range. As suggested by Vashenyuk et al. (2005b), an appropriate mechanism for DC generation could be, for instance, acceleration by MHD turbulence during explosive energy release in a flare (Gallegos and Perez-Peraza, 1995). As far as the PC spectrum is concerned, it proved to have exponential form in energy, and this may be an evidence of acceleration by electric fields arising in the reconnecting coronal sheets (e.g., (Vashenyuk et al., 2003, Balabin et al., 2005)). At impulsive magnetic reconnection in a current sheet, an electric field arises, which is directed along a null magnetic field line. The particles of surrounding plasma move along this electric field and gain energy, which is proportional to a path traveled in the electric field. At the same time, the number of particles traveled a given path in the reconnection region falls exponentially with increase of this path. This is because of the losses owing to particle leaving the acceleration volume due to the drifts. Thus the spectrum of particles accelerated by the electric field inside the volume where reconnection proceeds, should have exponential dependence on energy. The extrapolated intensity of the prompt component (spectrum 1) at energy 100 MeV, however, is about 3 orders of magnitude lower than that for DC(spectrum 2) , being near the background level and inaccessible to direct measurements. The features of solar proton spectra obtained in the balloon and ground level observations and addressed in the present study may be explained within high-energy solar proton generation and release scenario recently suggested in (Vashenyuk et al., 2005 b). The prompt component of RSP is produced during initial energy release in a low-corona magnetic null point. This process is related to the H-alpha eruption, CME and type II radio emission onset (Manoharan and Kundu, 2003). The accelerated particles of PC leave the corona along the open field lines with diverging geometry that results in high anisotropy due to strong focusing of a particle bunch. The DC particles are originally trapped in magnetic arcs in the low corona. As the disturbance grows, DC particles are accelerated by a stochastic mechanism at the MHD turbulence in expanding flare plasma. The accelerated particles can be then carried to the outer corona by an expanding (lifting) CME. They are released into interplanetary space after the magnetic trap is destroyed giving rise to an extended in time and azimuth particle source.

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References

Balabin Yu.V., Vashenyuk E.V., Mingalev O.V., Podgorny A.I., Podgorny I.M. The spectrum of solar cosmic rays: Observational data and model computations, Astron. J. (rus), 2005, V. 82, No 10, P.940-949.

Bazilevskaya G.A., Svirzhevskaya A.K. On the stratospheric measurements of cosmic rays. Space Sci.Rev. V.85, 431-521, 1998

Cliver E.W., Kahler S.W., Shea M.A., and Smart D.F. Injection onsets of ~2 GeV protons and ~1 MeV electrons and ~100 keV electrons in solar cosmic ray flares. Astrophys. J., V. 260. p.362-370, 1982.

Gallegos-Cruz A., Perez-Peraza J. Derivation of analytical particle spectra from the solution of the transport equation by the WKBJ method. Astrophys.J. V. 446, p. 400-420, 1995.

Manoharan P.K., Kundu M.R. Coronal structure of a flaring region and associated coronal mass ejection. Astrophys.J. 2003, V.592, P.597-606.

Perez-Peraza J., Galegos-Cruz A., Vashenyuk E.V., and Miroshnichenko L.I. Efficiency for RSP acceleration in the 14.07.2000 and 15.04.2001 events. Proc. 28th Int. Cosmic Ray Conf., Japan, Tsukuba. V.6. p.3327-3330, 2003.

Vashenyuk E.V., Balabin Yu.V., Gvozdevsky B.B. (2003) Relativistic solar proton dynamics in large GLE of 23-rd solar cycle. Proc. 28th Int. Cosmic Ray Conf. Japan, Tsukuba, 2003.V.6, p.3401-3404.

Vashenyuk E.V., Balabin Yu.V., Gvozdevsky B.B., Karpov S.N. Super GLE 20 January, 2005 (2005a), this issue.

Vashenyuk E.V, Balabin Yu.V., Perez-Peraza J., Gallegos-Cruz A., Miroshnichenko L.I. (2005b), Some Features of the Sources of Relativistic Particles at the Sun in the Solar Cycles 21-23. J. Adv. Space Res.., doi:10.1016/j.asr2005.05.012.