Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 163–166

ID 819

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Magnetic Storm Associated with Energetic Particle Event of January 21, 2005

S.N. KUZNETSOV[1][1], YU.I. DENISOV[1], B.YU. YUSHKOV[1], N. HASEBE[2], M. HAREYAMA[2], S. KODAIRA[2], K. SAKURAI[2], N. MASUYAMA[2], M. AKIYAMA[3] AND K. HAMA[3]
[1]*D.V.Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow 119899, Russia*
[2]*Research Institute for Science and Engineering, Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan*
[3]*Institute for Unmanned Space Experiment Free Flyer, Shinko building 2-12, Kanda-Ogawamachi Chiyoda-ku,Tokyo 101-0052, Japan*
m-hare@waseda.jp

Abstract: A strong magnetic storm occurred in January 21st, 2005. During this magnetic storm, the fluxes of electrons trapped in the radiation belt were observed simultaneously with two low altitude orbital satellites, CORONAS-F and SERVIS-1 and some geostationary satellites, LANLs. The data obtained from these satellites indicated the shrinkage and recovery of magnetopause depending on local time and of the radiation belts depending on the energy of trapped electrons during the storm.

Introduction

Several large flares classfied as the X-class successively occurred on the sun between 15th and 20th January 2005. Solar energetic particles so-called SEPs and coronal mass ejections so-called CMEs were released in association with these flares, in particular, a CME associated with an X-class flare on 20th January is interesting because this CME caused a strong magnetic storm on the earth a day later on the 21st. According to many authors (e.g. [1, 2]), this storm and SEPs were remarkable in its morphological development.

The variation of the physical quantities as observed in the interplanetary space and at the magnetospheric boundary are shown in Fig.1. Clearcut two stepped increases were observed for the velocity (V) and the density (N) of the solar wind (SW) : these increases were associated with consecutive arrivals of two shock waves released from the flare site. They were observed at 17 h and 18 h on January 21st, as shown on the top panel. The second panel shows a sudden increase of the northward component (B_Z) of the interplanetary magnetic field (IMF), which were varied even after the arrival of the second shock. Due to the action of the first shock, the radius of the magnetosphere, $X(0)$, at the sunlit side shrank to 5 to 6 R_E, as estimated from the SW parameters as N, V and others (see the third panel). Until the second shock arrived, the radius, $X(0)$, remained as before. After the arrival of the second shock, this radius was recovered to 7 R_E or so and then remained in a stable observed at 24 h before that on January 21st, since it seemed that the density of SW decreased to the stable in a quiet time. The variations of the two parameters, H_{sym} and AE, for the geomagnetic disturbance are shown in the bottom panel. A storm sudden commencement (SSC) was observed at 17 h 11 m of January 21st, which was coincident with the arrival of the first shock. Immediately after this shock arrival, a magnetic storm was developed while the density of SW tended to increase. However, the value of H_{sym} was kept stably to be almost equal to -100 nT for about 10 hours during the main phase of the storm.

During the period between 15 and 20 January 2005, two satellites, Russian CORONAS-F[3] and Japanese SERVIS-1[4], were both orbiting to observe energetic electrons being trapped in the radiation belt. Their orbiting heights are, respec-

---

[1] Prof. Kuznetsov passed away on 17 May 2007 by an accident.

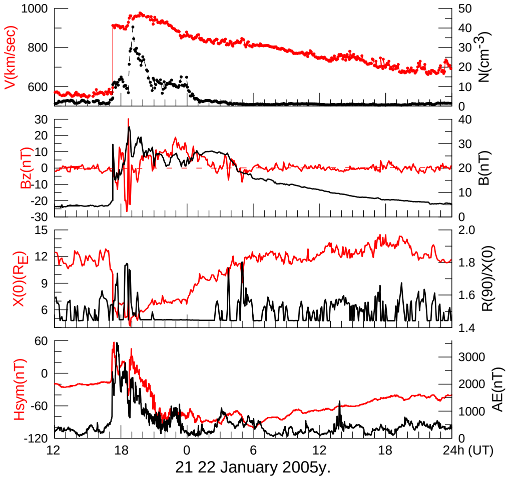

Figure 1: Time variation of space and geomagnetic conditions during the period from January 21st to 22nd, 2005. The first panel indicates those of the solar wind : V (red line) and N (black line) indicate the velocity and the density of the solar wind, respectively. The index $B_{\rm Z}$ (red) and B (black) is the Z-component and total intensity of the interplanetary magnetic field in the second panel. In the third panel, the calculated position of the nose of the magnetopause is given by $X(0)$. The bottom panel indicates the geomagnetic disturbances as $H_{\rm sym}$ and AE index.

tively, at 500 km for the former and at 1,000 km for the latter. Furthermore, the observed data on these electrons were available from many of US satellites for LANL series, whose heights were at 36,000 km in the geostationary orbit. Using the observed data on these electrons obtained from those satellites, the behavior of energetic electrons trapped in the radiation belt will be discussed here during magnetic disturbances during the period as cited before.

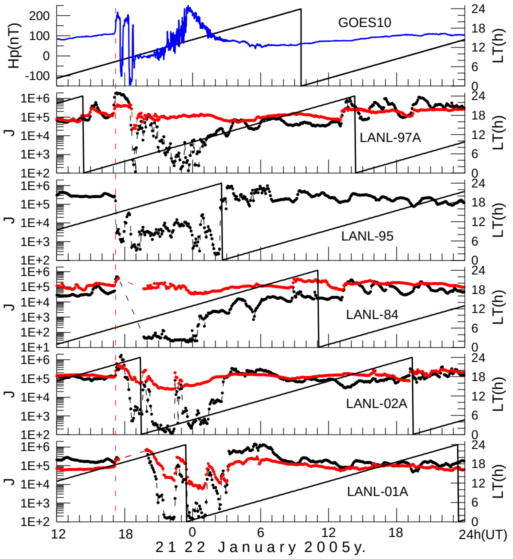

Figure 2: Time variation of the geomagnetic field component $H_{\rm p}$ (blue line) for the top panel and electron (black points) and proton fluxes (red points) in the energy 50 - 75 keV for the second to the bottom panels as observed in geostationary orbit by GOES10 and LANL satellites between 21st and 22nd January 2005. The black line in each panel indicates observation position of satellites as local time.

Behavior of trapped particles during the storm

The geomagnetic field observed by GOES10 satellite and the fluxes of energetic electrons observed by LANL satellites are shown in Fig.2. After the onset of SSC, the intensity of magnetic field (H_p) (see the top panel of Fig.2), which indicates the parallel component of geomagnetic field, alternately changed between positive and negative during the first shock and then was kept at 0 nT during the second shock. After the second shock, while the density of SW was almost the same as 10 cm^{-3}, H_p increased and then decreased to ordinary intensity at 24 h of 21st when the density of SW began to decrease to ordinary value. During this period, abnormally low fluxes of low energy electrons with 50 – 70 keV were observed by several LANL satellites in geostationary orbit, as shown in the second to bottom panels in Fig.2. The fluxes of electrons drastically decreased in dayside. After the SSC started, the electron flux observed by LANL-95 in dayside immediately decreased by order of 2, but the fluxes observed by the other LANLs in the other local time (LT) sectors rather increased. During the main phase, the intensity of electrons was quite stable and low as observed by LANL-84 in dayside after the second shock. The observed data from the other LANL satellites indicate that the electron fluxes remaind low, but unstable. Moreoever, when the density of SW recovered to the value before the SSC onset as that for 24 h of 21st (see Fig.1), the electron

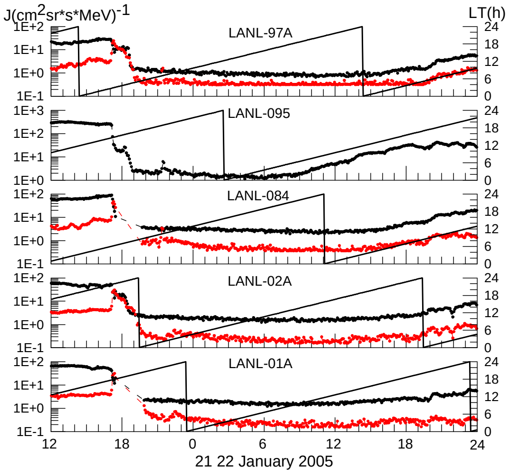

Figure 3: Time variations of electron flux ($E_e > 1.5$ MeV, black points) and proton one ($E_p = 1.2 \sim 1.9$ MeV, red points) as observed by LANL satellites. The data on relativistic electrons ($E_e = 1.1$ - 1.5 MeV) available from LANL-095 observation are also shown.

flux observed by LANL-84 at noon in LT increased rapidly and then gradually recovered to the one for quiet period. The similar variations were seen in the observed result of LANL-97A in dayside. The electron fluxes observed by the others in midnight or morning sector recovered to stable ones at later hours as about 3 h of 22nd when intensity of IMF as B shown in Fig.1 turned to decrease.

Let us consider the behavior of electrons with MeV energy observed by various satellites in different altitudes. As clearly seen in Fig.3, the electron fluxes with MeV energy observed by LANL satellites in geostationary orbit decreased rapidly at the onset of SSC indicating the arrival of the first shock and then further decreased rapidly together with the arrival of second shock. After the intensities of electrons began to decrease, they were being kept to be low and stable intensities for long hours during and after the storm. These situations seem to be independent of the observation point as LT.

The spatial distributions of electron flux as a function of L-value obtained by SERVIS-1 at 1000 km and CORONAS-F at 500 km are shown in Fig.4. As clearly seen in Fig.4, the structure of radiation belts observed by these two satellites was enforced to drastically and similarly change as dependent on the phase of the magnetic storm. On January 20th before the onset of the magnetic storm, the two maxima of relativistic electron fluxes were observed at $L \sim 2.5$ and $L \sim 3.5$, which respectively correspond to the inner and outer belts. The outer boundary of the outer belt was around $L = 6 \sim 7$ before the storm as shown in the top panel. During the main phase after the second shock, the boundary was observed at $L \sim 2.5$ and the inner radiation belt disappeared (the second panel). The intensities beyond the outer boundary during the main phase were smaller than those before the storm. As shown in the third and bottom panels, the recovery of the radiation belts to its stable state for quiet time was very slow temporally as compared with the shrinkage speed. However the recovery speed seems to depend on the energy of electrons. At the beginning of the decrease of IMF intensity, B, as shown in Fig.1, the outer boundary of trapped electrons with 1.5 MeV and more was in $L \sim 4$ and $L \sim 2.5$, respectively, while those with sub-MeV electrons were almost recovered to

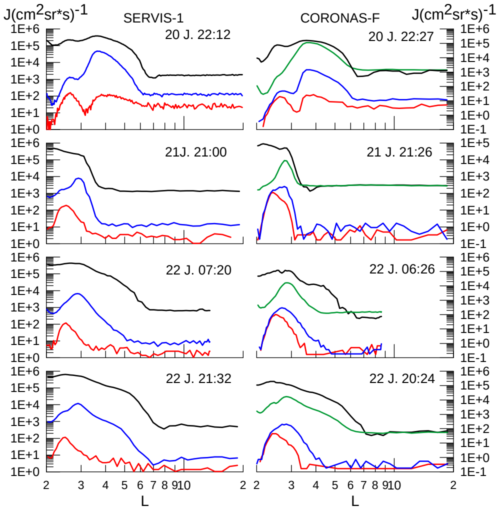

Figure 4: Changes in the particle fluxes in radiation belt during the period between 20 and 21 January 2005. Black lines indicate the fluxes of electrons (0.3 - 1.7 MeV)as observed by SERVIS-1 and electrons (0.3 - 0.6 MeV) as observed CORONAS-F. Green lines for the fluxes of electrons (0.6 - 1.5 MeV) as observed by CORONAS-F, blue lines for the fluxes by electrons (1.7 - 3.4 MeV) as observed by SERVIS-1 and electrons (1.5 - 3 MeV) from CORONAS-F and red lines for the fluxes of electrons (3.4 - 6.8 MeV) as observed by SERVIS-1 and electrons (3 - 6 MeV) by CORONAS-F.

the stable position (the third panel). On January 22nd after the storm, as shown in the bottom panel, the outer boundary further moved to outward as $L \sim 7$ for lower energy electrons and $3 < L < 7$ for higher energy electrons. However, the intensities of MeV electrons beyond the outer boundaries were still lower than those before the storm. These behavior of the outer boundary for sub-MeV electrons are consistent with the behavior of magnetopause as shown in Fig.1.

Concluding Remarks

The magnetic storm on January 21st, 2005 was in progress via two steps introduced by two discrete shocks arrived consecutively within two hours, which were associated with CMEs. The magnetopause estimated from the SW parameters was forced to shrink from 12 $\mathrm{R_E}$ to 6 or 7 $\mathrm{R_E}$ immediately after the arrival of the first shock. This shrinkage was maintained for 10 hours until the physical state of SW was recovered to that before the onset of the magnetic storm.

During the same period, the flux of energetic electrons with 50 – 70 KeV observed by LANLs in geostationary orbit decreased at only dayside. Furthermore, H_p observed by GOES10 became almost 0 nT during the main phase of the storm. These variations suggested that the magnetopause in dayside must have actually shrunken to 5.6 $\mathrm{R_E}$ as geostationary orbit during the magnetic storm. And, in the other sides as morning, evening or midnight, the timings of shrinkage or recovering of the magnetopause may be different from those in dayside. By carefully examining the results in Fig.2, it follows that the timings of decrease and increase of electron flux in the other side seem to delay from that in dayside. In the sides except for dayside, the electron fluxes in the beginning of the storm have bumps after the first shock and then began to decrease at the arrival of the second shock. Though those in recovery phase recovered immediately stable for quiet period, the beginning of recovery to stable state delayed as compared with that in dayside. These differences of behavior of low energy electrons may be related to the behavior of the magnetosphere depending on the local time sector.

The structure of radiation belts of sub-MeV or MeV electrons shrank rapidly in association with the shrinkage of the magnetopause. On the other hand, the recovery of radiation belts was slow and dependent on the electron energy. These behaviors of MeV electrons may be dependent on the structure of magnetosphere and its behavior. And, though being not displayed here, the flux of MeV electrons obtained by SERVIS-1 increased in the radiation belts only after the fisrt shock, while those obtained by LANLs indicated that their flux began to decrease at the arrival of shocks. As shown in Fig.2, in which a large fluctuation of keV electrons in midnight sector was seen during the storm, electrons with MeV energy may have been accelerated in the equatorial plane near the earth by betatron acceleration associated with the shrinkage of magnetosphere.

In order to explain the relation of the behavior of the radiation belts generated by trapped electrons with that of magnetosphere sructure associated with the disturbance of interplanetary space, further detailed analysis must be done in future. However, the present analysis indicates that the behavior of electrons with the energy from several ten keV to MeV trapped in the radiation belts obtained by several satellites in different altitudes may give some clue to understand howthe earth's magnetosphere behaves during magnetic storm.

Acknowledgments

Our thanks should go to the institutes and the agencies which permitted for us to use the observed records available from the satellites, CORONAS-F, SERVIS-1 and LANLs. During the course of this study, our friend and colleague, Prof. Kuznetsov passed away. We all wish to send our sympathy to him and his family left.

References

[1] Clilverd, M.A., C.J. Rodger and U. Thomas, *Geophys. Res. Lett.* **33**, L01102, 2006.

[2] Kuznetsov, S.N., V.G. Kurt, B.Yu. Yushkov et al., *Contributions of the Astronomical Observatory Skalnate Pleso* **36**, 85–92, 2006.

[3] Kuznetsov, S.N., B.Yu. Yushkov, K. Kudela et al., *Adv. Space Res.* **36**, 1997–2002, 2005

[4] Hareyama M., M. Asaeda M.. Fujii et al., *Proc. 29th Int. Cosmic Ray Conf.* (Pune, India) **1**, 257–260, 2005.