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SOME FEATURES OF INJECTION OF RELATIVISTIC ELECTRONS INTO THE INNER MAGNETOSPHERE DURING A MAGNETIC STORM

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Abstract. We analyze a bunch of storms occurred in 2000-2001 trying to find out what the condition parameters are most relevant to the output of storm-generated relativistic electrons. Most of the analysis is made for the geosynchronous orbit (GOES) although the deeper L-shells (L~4) are concerned too with involving the Polar data. It is shown that neither storm amplitude (|Dst|max) nor solar wind speed do not separately determine the storm-relevant output of relativistic electrons at the geosynchronous altitudes, while for the highest manifestation of this effect (intensity of 2 MeV electrons is >10^4 1/cm2_s_sr) two factors are found to be a must: the high level of substorm activity at the recovery phase and the high-speed solar wind. It is also shown that the storm-time relativistic electrons intensity may grow in the inner magnetosphere on the storm recovery phase while their intensity at geostationary orbit remains under the prestorm level. This reveals that the mechanisms of a relativistic electron generation in the inner and outer L-shells may differ somehow. All the complexity of the discussed phenomena underlines the importance of the few known magnetospheric laws such as the empirical formula binding the strength of a storm |Dst|max with an L-position of the peak of storm-injected relativistic electrons. Application of this relation to the predicting the storm-time ring-current ion pressure, made under certain assumptions, is illustrated.

Introduction

Last years, relativistic electrons became an issue of high interests of spacephysicists (Baker et al., 1997; Reeves, 1998; Tverskaya, 1998; Li et al., 1999; Ivanova et al, 2000; Blake et al, 2001; Tverskaya et al., 2002); in most it is because of the pronounced impact of the effect onto space weather.

One earliest idea on the storm-time appearance of the MeV electrons in the inner magnetosphere is a betatron acceleration of the plasmasheet electrons during the dipolarisation process on the main phase of a storm (Tverskoy, 1969) with additional adiabatic acceleration on the recovery phase (Vakulov et al., 1975).

Next approach was inferred by a series of intensive measurements in the geosynchronous orbit: relativistic electron enhancements there develop during several days and well correlate with the solar wind velocity (Paulikas and Blake, 1979). Basing on this Baker et al. (1979) concluded the recirculation mechanism (Nishida, 1976) to be essentially responsible for the strong electron acceleration.

However recently has been found an appearance of high-energy electrons at the inner L-shells (L=3-4) just on a one-hour time scale during the storm maximum (Tverskaya, 1998, 2000; Li et al., 1999). Just within this period the westward electrojet moves to its lowest L-position at which a peak of the storm injected belt of relativistic electrons finally occurs. Such results were accompanied with the development of new theories explaining the electron acceleration on the base of wave-particle interactions (Kropotkin, 1996; Summers and Ma, 2000; Bakhareva and Dmitriev, 2002; and refs. therein all).

Below we try to judge what factors: the magnetospheric or the outer space (i.e. of solar wind) ones are most effective for the controlling the storm-time electron acceleration.

Observations

We analyze the public-domain data from GOES, IMP, Wind, ACE, the previously published data from Polar, and the indices Dst, AE, AU, AL.

Figure 1, compiled from (Tverskaya et al., 2002, in press), shows such a different behavior of the 2 MeV electrons in the inner (Polar) and outer (GOES) L-shells as a depressed intensity on GOES and an increased intensity on Polar, seen soon after a storm maximized on 1 October; intensities at L-peak along Polar orbit (Max. flux) are the focus. Note the abrupt turning of Bz northward on 1 October with its further remaining at about +10 nT for a day. An almost complete absence of substorm activity in this period is more a noticeable feature.

Figure 2 shows the event of the same Dst-scale yielding a pronounced enhancement of relativistic electrons on GOES (Polar data is unavailable here and forth). The conditions differ in that the substorm activity while the storm recovery is high and Bz correspondingly flutters.

Figure 3 and 4 present two superstorms with the similar peak-Dst magnitude and with the similar-scale high-speed solar wind (at the recovery phase at least). Although the relativistic electron outputs on GOES very differ from each other in these cases: 06 November is followed by a strong electron enhancement and 24 November is followed by a prolonged relativistic electron depression. Noticeable difference is again in the substorm activity on the recovery phase: it is high in Figure 3 and extremely low in Figure 4.

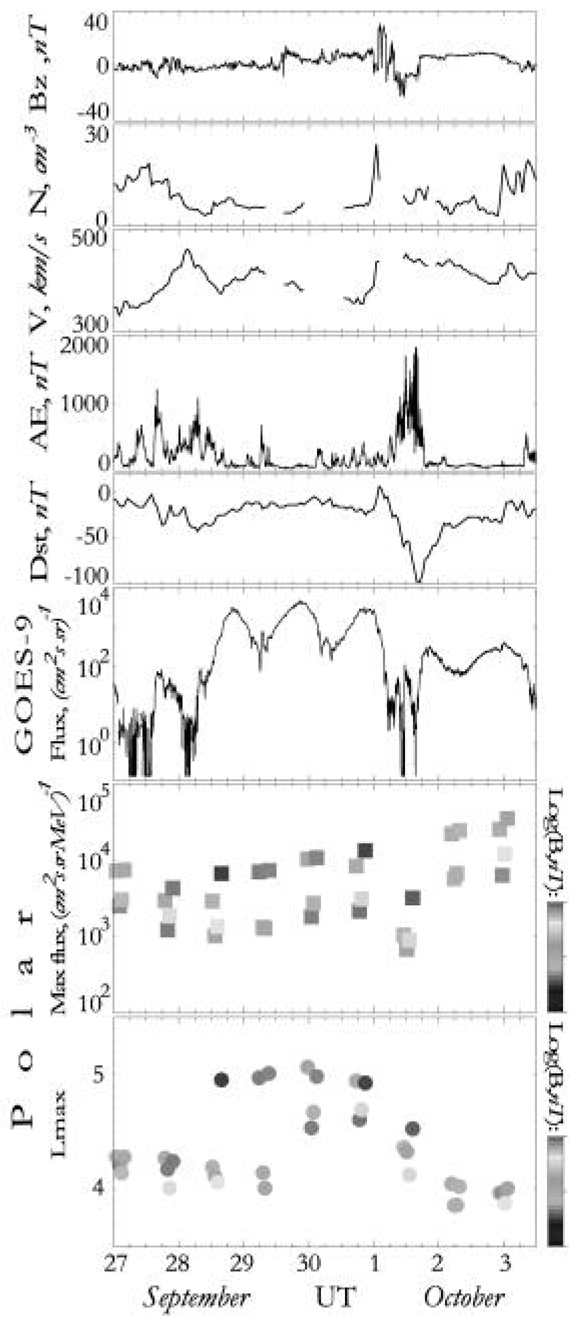

Fig. 1. An example of an injection of electrons Ee~2 MeV during a moderate storm of |Dst|max= 98 nT as measured on POLAR and GOES. From the top: Z-component of the interplanetary magnetic field; solar wind density and bulk speed (WIND and IMP); AE; Dst; GOES-9: intensity of 2 MeV electrons; POLAR: peak countrate and L-position of an electron peak, B is shadow coded.

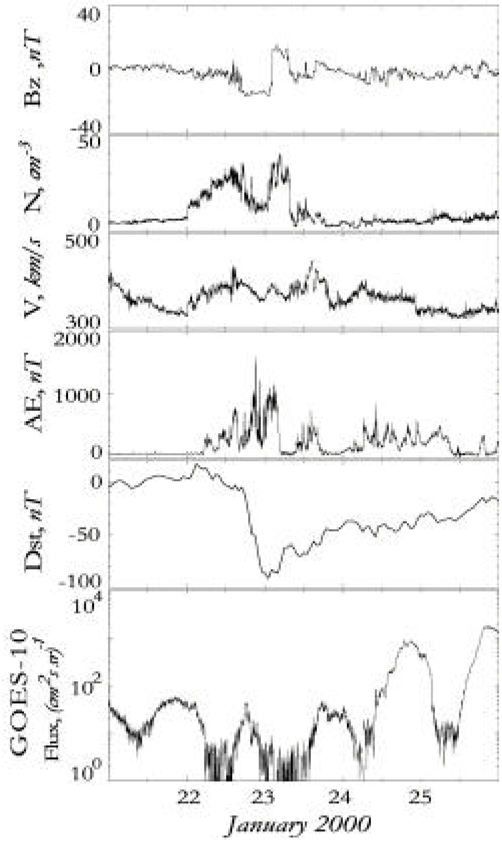

Fig. 2. The same as in Figure 1 but without Polar data; for January 2000. GOES-10 is used instead of GOES-9.

Discussion and Conclusions

Given figures present only a part of the analyzed cases; actually whole period 2000-2001 has been covered. More results (of the GOES data analysis) are as follows.

A view against solar wind speed:

- 11 events with high-speed solar wind (Vsw>500 km/s) and no after-storm enhancement of relativistic electrons are observed. All these cases were with low substorm activity during the recovery phase. These storms occur to represent the range |Dst|max=65-237 nT;
- 4 storms with Vsw<450 km/s, within the range |Dst|max=30-100 nT, occur to happen with large (one order of magnitude and more) enhancement of relativistic electron intensity after a storm. All these events exhibited high substorm activity on the recovery phase.

Resume: solar wind speed is not the sole factor determining an expected electron intensity level after a storm.

A view on the strongest storms (|Dst|max>200 nT):

- 6 strong storms are found in total;
- 2 cases of overall 6 showed depression of the relativistic electron intensity after a storm;

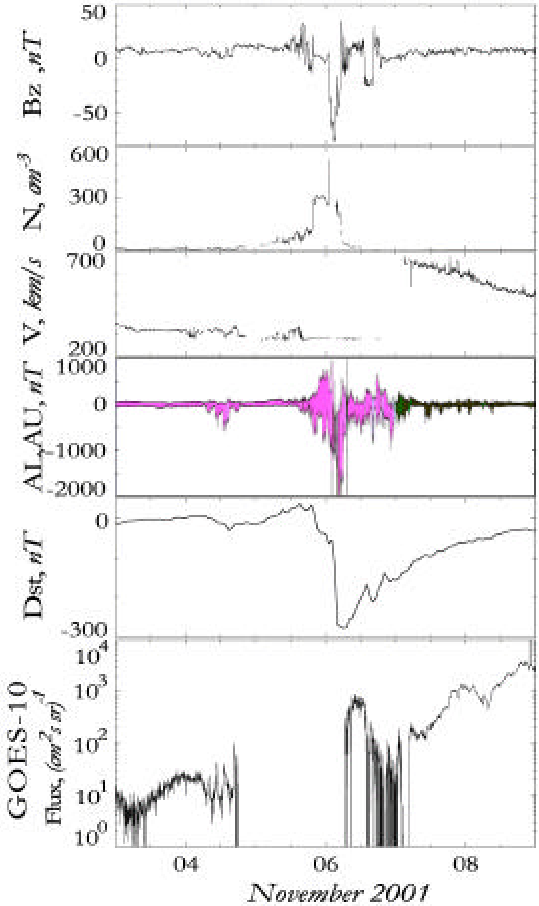

Fig. 3. The same as in Figure 2 but AU, AL are given instead of AE. Storm of 5th November 2001. A gap in GOES data with the following peak are an instrumental effect of solar proton contamination. The flat-low solar-wind speed near the storm maximum is probably an instrumental effect too.

- 1 case showed a high-amplitude (>10^4 1/cm2_s_sr) enhancement;
- other strong storms showed intermediate cases.

Resume: storm amplitude does not solely determine a value of the output of relativistic electrons after a storm. This is consistent with the result reported in (Reeves, 1998).

A view on the strongest outputs of relativistic electrons:

- 9 event with relativistic electron intensity >10^4 1/cm2_s_sr are found in total; |Dst|max range is 27-256 nT;
- in all these cases solar wind velocity was high, i.e. Vsw>600 km/s;
- in all these cases high level of substorm activity during the recovery phase was observed.

Resume: high substorm activity on storm recovery phase is a demanded attribute of the high intensity

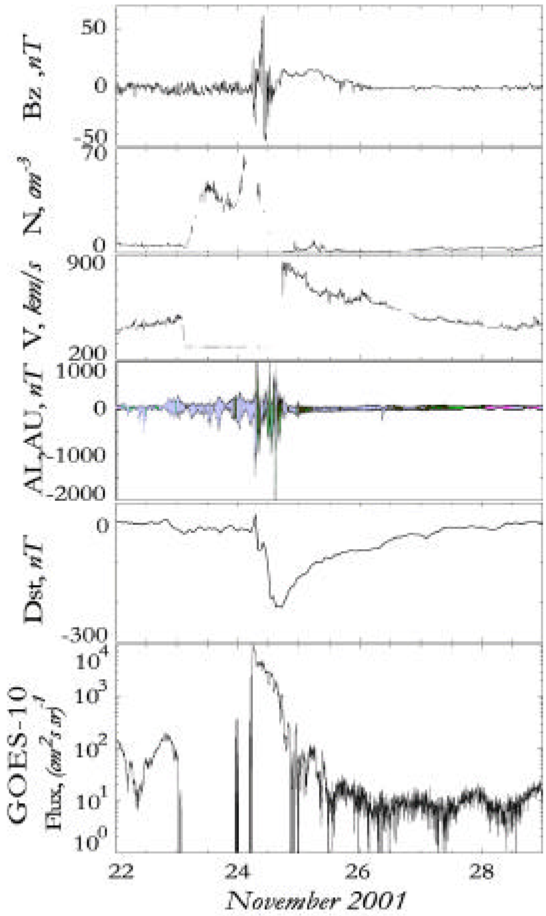

Fig. 4. The same as in Figure 3, including the notes on the instrumental effect suspected. Storm of 24th November 2001.

of relativistic electrons after a storm, and high solar wind velocity is a necessary factor for the strongest storm-output of relativistic electrons.

Figure 1 reveals that relativistic electrons may appear on the inner L-shells (L_{max} = 4) without an accompaniment on the outer L-shells. What mechanism may supply this “inner” appearance? Is this mechanism the same as acts for the outer L-shells? Probably is not.

The above discussion shows how complicated could be the parametrisation of the relativistic electron output generated in a storm. Several players participate in this phenomenon. For a successful analyses it is important to find out some basic relationships, like a formula established in (Tverskaya, 1986):

$$|Dst|_{max}=2.75 \cdot 10^4/L^4_{max}$$

This formula binds the strength of a storm |Dst|max and an L-position of the peak of storm-injected relativistic electrons. The formula may be used to derive some quantitative characteristics of the inner magnetospheric domain such as the lowest-latitude storm-time position of the westward electrojet (Tverskaya, 1986, 1998; Khorosheva, 1987) and the ion pressure of a symmetrised ring-current (Tverskoy, 1997); the latter is illustrated in Figure 5.

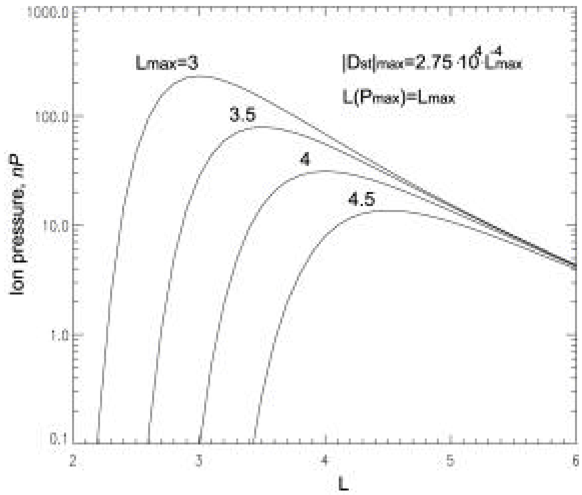

Fig. 5. Ion pressure distributions along L are plotted for a ring current convectively driven into the inner magnetosphere during a storm. The symmetric current is assumed. The formula is used under an assumption L(Pmax)=Lmax, i.e. an L-position of the maximum pressure at the storm maximum is stated to be equal to the L-position of a peak of the storm-injected belt of relativistic electrons. Lmax of 3 through 4.5 present four storm magnitudes: |Dst|max of 300 through 70 nT.

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References

Baker, D.N., P.R., Higbie, R.D., Belian, E.W., Hones, Jr., Do Jovian electrons influence the terrestrial outer radiation zone? *Geophys. Res. Lett.*, **6,** 531, 1979.

Baker, D.N., X., Li, N., Turner, J., Allen, L., Bargatze, J., Blake, R., Scheldon, H., Spence, R., Belian, G., Reeves, S., Kannekal, Recurrent geomagnetic storms and relativistic electron enchancements in the outer magnetosphere: ISTP coordinated measurements. *J. Geophys. Res.*, **102**, 14141, 1997.

Bakhareva, M.F., and A.V., Dmitriev, Statistical Alfvenic acceleration of electrons in outer magnetosphere, *Geomagn. i Aeron.*, **42**, No. 1, 21, 2002.

Blake, J.B., R.S., Selesnick, D.N., Baker, S., Kanekal, Studies of relativistic electron injections events in 1997 and 1998, *J. Geophys. Res.*, **106**, 19157, 2001.

Ivanova, T.A., N.N., Pavlov, S.Ya., Reizman, I.A., Rubinstein, E.N., Sosnovets and L.V., Tverskaya, Dynamics of the outer radiation belt of relativistic electrons in the solar activity minimum, *Geomagn. i Aeron.*, **40**, No. 1, 13, 2000.

Khorosheva, O.V., Magnetospheric disturbance and dynamics of ionospheric electrojets, polar auroras and plasmapause, *Geomagn. i Aeron.*, **27**, 804, 1987.

Kropotkin, A.P., Relativistic electron transport processes associated with magnetospheric substorms, *Radiation Measurements*, **26**, 343, 1996.

Li, X., D.N. Baker, M., Temerin, T.E., Cayton, G.D., Reeves, R.S., Selesnick, J.B., Blake, G., Lu, S.G., Kanekal, and H.J., Singer, Rapid Enhancements of Relativistic Electrons Deep in the Magnetosphere During the May 15, 1997 Magnetic Storm, *J. Geophys. Res.*, **104**, No. A3, 4467, 1999.

Nishida, A., Outward diffusion of energetic particles from the Jovian radiation belt, *J. Geophys. Res.*, **81**, 1771, 1976.

Paulikas, G.A., J.B., Blake, Effects of the solar wind on magnetospheric dynamics: Energetic electrons at the synchronous orbit, In: *Olson, W. (Ed.), Quantitative Modeling of the Magnetospheric Processes.* Vol. 21 of Geophys. Monogr. Ser. AGU, Washington D.C., pp. 180, 1979.

Reeves, G.D., Relativistic electrons and magnetic storms: 1992-1995. *Geophys. Res. Lett.*, **25,** 1817, 1998.

Summers, D. and C. Ma, A Model for Generating Relativistic Electrons in the Earth's Inner Magnetosphere Based on Gyroresonant Wave-Particle Interactions, *J. Geophys. Res.*, **105**, No. A2, 2625, 2000.

Tverskaya, L.V., On the Boundary of Electron Injection into the Magnetosphere, *Geomagn. i Aeron.*, **26**, No. 5, 864, 1986.

Tverskaya, L.V., Diagnosing the Magnetospheric Processes Using Relativistic Electron Data, *Geomagn. and Aeron.*, **38**, No. 5, 22, 1998.

Tverskaya, L.V., The main phase substorms and related phenomena in charged particle population, Proc. 5th International Conference on Substorms, ICS-5, ESA SP-443, 459, 2000.

Tverskaya, L.V., N.N., Pavlov, J.B., Blake, R.S., Selesnick, and J.F., Fennell, Predicting the L-position of the storm-injected relativistic electron belt, *Adv. Space Res.*, 2002 (in press).

Tverskoy, B.A., Main Mechanisms in the Formation of the Earth's Radiation Belts, *Rev. Geophys.*, **7**, No. 1-2, 219, 1969.

Tverskoy, B.A., Formation Mechanism for the Structure of the Magnetic-Storm Ring Current, *Geomagn. and Aeron.*, **37**, No. 5, 555, 1997.

Vakulov, P.V., L.M. Kovrygina, Yu.V.Mineev, and L.V. Tverskaya, Dynamics of outer belt energetic electrons during moderate magnetic disturbances, *Geomagn. i Aeron.*, **15**, 1028, 1975