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AN EFFECT OF DISTURBED MAGNETOSPHERIC CONDITIONS ON THE MODELED GLE PARAMETERS

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Abstract. On the basis of up-to-date magnetosphere models of Tsyganenko-89 (T89) and Ostapenko-Maltsev-97 (OM-97) modeling of 7-8December, 1982 GLE, which occurred during magnetically disturbed period ($D_{st} \approx -90nT$) has been performed. Characteristics of the primary radiation field outside the magnetosphere have been obtained. To estimate the effect caused by magnetic disturbances the calculated responses and asymptotic cones of ground based neutron monitor stations have been compared with analogous ones obtained for quiet conditions. It is shown that calculated particle trajectories are influenced by the magnetospheric tail more than by the disturbances themselves.

Introduction

An importance of taking into account the magnetospheric disturbances for analysis of Ground Level Enhancements (GLE) caused by relativistic solar protons was noted by many authors. *Flueckiger et al.*, 1990 pointed out the significant changes in calculated asymptotic cones and geomagnetic cutoffs for a number of neutron monitor stations during the GLE of 7-8 December,1982 occurred on a disturbed geomagnetic background. The similar results were obtained by *Duldig et al.* (1993) for the GLE of October 22, 1989. *Danilova and Tyasto* (1997) using the T89 model studied the asymptotic cones of Moscow and Irkutsk stations and found their changes during magnetically disturbed conditions.

The asymptotic direction calculations are only a part of more general task of modeling the characteristics of primary solar protons outside the magnetosphere by fitting the calculated responses of different neutron monitors the experimentally observed ones. So, in frame of this work we have studied the effect of magnetospheric disturbances on the calculated characteristics of primary radiation.

On the other hand, by now there is no magnetospheric model adequately describing any kind of magnetic disturbances The widely used Tsyganenko 89 model (Tsyganenko 1989) utilizes as a parameter the K_p-index which is known as a measure of magnetic disturbances at relatively high latitudes and characteristic of changes in the outer parts of magnetosphere, i.e. in the tail and at the magnetopause. At the same time the disturbances often reach the inner magnetosphere manifesting in depression of the D_{st}-index as it was in the considered here GLE of 7-8 December, 1982. which occurred during a magnetic storm with the D_{st} depressed as low as -90nT We found the OM-97 model (*Ostapenko, Maltsev* 1997) to be suitable for this case. Besides the K_p-index, it uses as input parameters the D_{st}, dynamical pressure of the solar wind and B_z-component of IMF, which enables to describe the disturbed geomagnetic field up to distance 10 R_E.

So, in this work we compare the results of asymptotic cone computations and GLE modeling with the T89 and OM-97 models under disturbed and quiet geomagnetic conditions. It was also interesting to reveal the relative contribution of the magnetic disturbances and magnetospheric tail influence to shifting the computed asymptotic directions for different local times and particle rigidities.

Modeling

Asymptotic direction calculations were performed with the familiar technique of computation of the trajectory of negatively charged particle starting at the station location on the surface of earth (in reality, the starting point is at the height of 20 km). The task is reduced to the integration of the relativistic particle motion equation in the model magnetosphere.

$$\gamma m(\partial^2 \mathbf{r} / \partial t^2) = Ze(\partial \mathbf{r} / \partial t) \times \mathbf{B} \qquad (1)$$

where γ is the Lorentz-factor, r is the radius-vector of a particle, **B** is the magnetic induction vector, Ze is the charge of a particle. The integration was performed by the Runge-Kutta - Felberg method of the 4th-5th order. The magnetospheric field was represented by the T89 model with $K_p = 4$ and the OM-97 model with the following parameters: $K_p = 4$, $D_{st} = -85nT$, $B_z = -5nT$, $P_{dyn} = 3.433nPa$, where P_{dyn} is the dynamical pressure of the solar wind. The effect of the tail currents was estimated in the first approximation by limiting the trajectory integration region by radius of 10 R_E.

The characteristics of the primary field of radiation were calculated by solving the problem of finding optimal parameters of the function describing relative increase effects due to the SCR at different neutron monitors of the worldwide network by with methods of constrained optimization.

$$(\Delta N/N)_j = K \int_{Rcj}^{\infty} J_{\parallel} (R) F(\theta_j (R)) S (R) d R$$

where j is the station index, $(\Delta N/N)_j$ is the relative increase effect at the j-th station in per cent, K is the coefficient of proportionality; $J_{\parallel} (R)$ is the differential rigidity spectrum: $J_{\parallel} (R) = AR^{-\gamma}$ (particles/ (cm^2 s ster GV)), where γ is monotonously decreasing by $\Delta \gamma$ per 1 GV for R≥2 GV; S(R) is the specific yield function (*Debrunner et al.*, 1984). Pitch-angle distribution is supposed to have a form:

$$F (\theta) = \exp (- \theta^2/ C)$$

where the θ is the angle counted off the anisotropy axis (the last one is usually directed along the IMF vector).

Using the Legendre principle for a solution of the system of constrained equations we reduce them to the nonlinear least square problem:

$$SN = \sum ((\Delta N/ N)_{j\,CALC} - (\Delta N / N)_{j\,EXP})^2 \to min$$

A quality of the optimization results was estimated by a rest error defined by the formula:

$$\varepsilon = SN/ \sum (\Delta N/N)^2_{j\,EXP},$$

where indexes CALC and EXP mean calculated end experimentally measured values, respectively.

Data analysis and results

Data of 21 neutron monitor stations were used in the analysis. Fig.1 show asymptotic cones computed for the period of 01 UT 8.12.1982 for Inuvik trajectories traversing the day side of the magnetosphere, the evening side (Apatity) and the night side (Goose Bay). The calculated characteristics of solar relativistic protons outside the magnetosphere: namely the intensity and exponent of the rigidity spectrum, anisotropy axis direction and pitch-angle distribution width (C) are given in Table. The first two 5-min ranges of the considered interval have a relatively high rest error (~17-20%) indicating a poor truncation of the optimization algorithm. But starting already from 00.15 UT the truncation became satisfactory that may be explained either by a poor time resolution of the experimental data under strong variability of the field of radiation or by more complicated spatial and angle distributions than it was suggested. Unsatisfactory modeling results at early stage of the event were also reported by *Duldig et al.*, (1995).

Conclusions

1. Taking account of magnetospheric disturbances in the trajectory computation results in significant modifications of the computed asymptotic approach directions of primary protons (up to 15-20° for R=5GV and 40-45° for 1GV) and corresponding modifications in the asymptotic cones of the ground based stations. This affects the calculated characteristics of the primary field of radiation and first of all the anisotropy axes direction. The calculated parameters of the rigidity spectrum, i.e. γ, $\Delta\gamma$, J_0 and the parameter C in pitch-angle distribution (3) are less sensitive to the magnetosphere changes caused by disturbances.
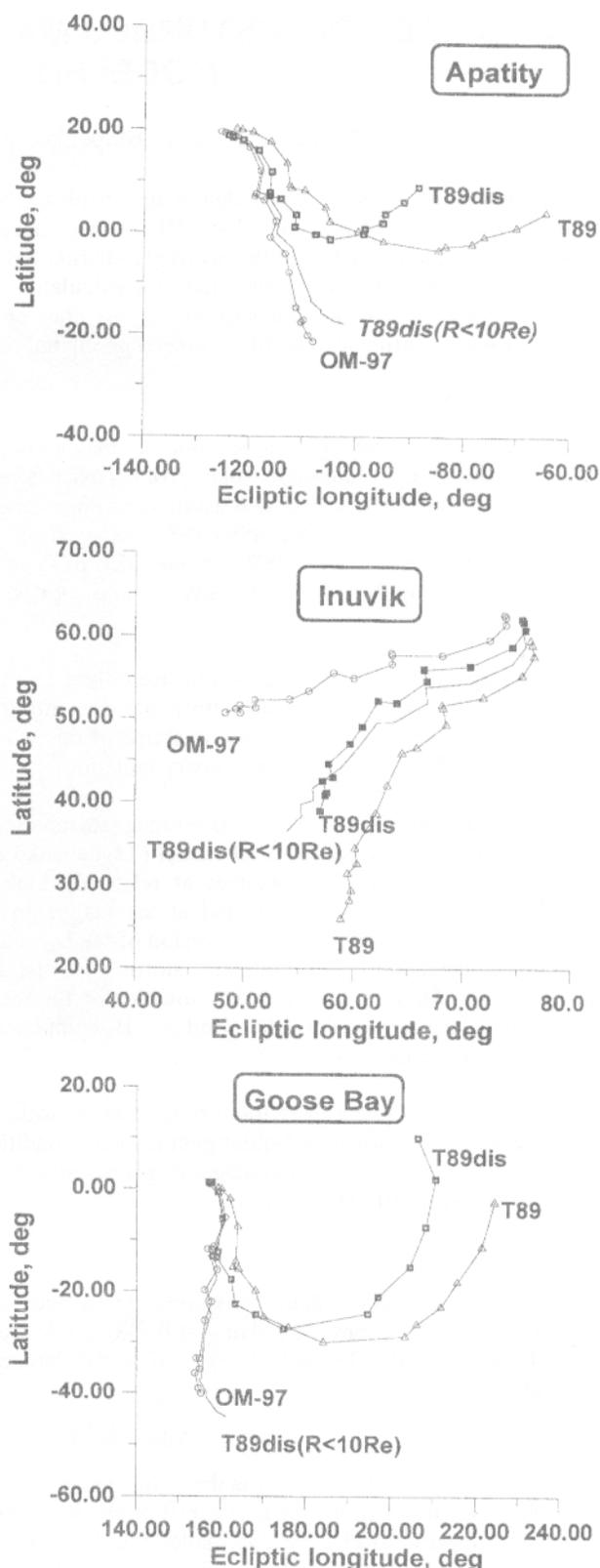

Fig.1. Neutron monitor asymptotic cones for 00:00 UT 8 December 1982 for quiet geomagnetic conditions and disturbed geomagnetic conditions.

Table. Derived Spectra and Apparent Source Direction

	MODEL	UT:00-05	05-10	10-15	15-20	20-25	25-30
J_0	OM-97	13.97	1.63	1.17	3.64	2.39	2.60
	T89dis	6.06	2.78	1.43	4.96	2.14	2.65
	T89	8.76	1.73	1.20	3.51	1.98	2.59
γ	OM-97	2.22	2.30	1.89	2.90	2.56	2.77
	T89dis	1.65	2.81	2.15	3.39	2.48	2.85
	T89	1.83	2.34	1.95	2.92	2.38	2.83
$\Delta\gamma$	OM-97	1.11	0.27	0.37	0.31	0.39	0.35
	T89dis	0.82	0.22	0.33	0.21	0.39	0.32
	T89	0.92	0.26	0.36	0.28	0.40	0.32
C	OM-97	0.55	4.11	5.29	4.45	8.07	10.22
	T89dis	0.52	3.43	5.05	4.46	8.06	9.92
	T89	0.56	3.86	5.17	4.45	8.04	10.22
Lat.,deg	OM-97	46.9	72.1	81.1	82.2	94.2	100.2
	T89dis	42.3	61.8	74.7	78.8	90.6	95.1
	T89	38.1	60.0	70.17	74.0	85.2	92.0
Lon.,deg	OM-97	251.5	241.5	235.0	236.1	227.0	214.3
	T89dis	265.7	254.5	246.7	249.4	236.8	226.2
	T89	267.4	254.7	248.9	252.3	242.2	229.4
ε	OM-97	21.52	19.13	5.34	2.82	2.04	1.23
	T89dis	15.9	18.51	5.21	3.07	1.97	1.13
	T89	19.27	19.25	5.51	3.00	2.1	1.25

2. Using the OM-97 and truncated T89 models gives close results in calculation of asymptotic directions on the night side and considerably different ones at the day side. The mean direction of the anisotropy axis obtained by calculations with the T89 model (Kp = 0 and Kp = 4) is closer to the mean IMF direction than that given by the OM-97 model, though it may be, first of all, due to the effect of the tail and currents flowing there considered in the T89 model. The OM-97 model in its current state is limited by radius of 10 R_E and does not include the tail, though it does not exclude the strong currents flowing in the near night side during disturbances (*Maltsev, Ostapenko*, 1998).

3. The comparison of asymptotic directions calculated with the truncated models (without the tail) shows that the effect of disturbance on the day side is greater than ones of the tail. The effect of disturbances decreases on the evening side, while on the night side the influence of the tail is dominating.
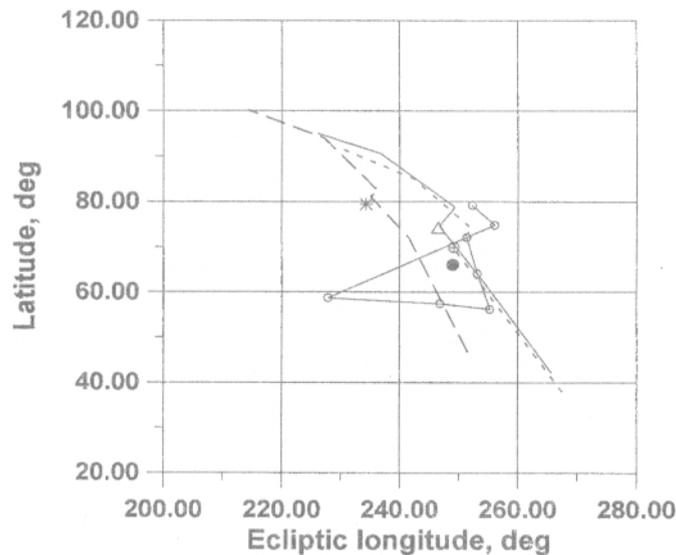

Fig.2. Derived apparent source direction: solid line-OM-97, dashed line - T89, dotted line -T89dis. Averaged direction: * - OM-97, Δ - T89dis, ⊕ - T89. ● - mean IMF direction (-180[0])

References

Cramp J.L., M. L. Duldig and J. E. Humble , The effect of Near-Earth IMF Structure on the Modeling of Ground Level Enhancements, *Proc.24 Int.Cosmic Ray Conf.*, Rome, Italy, 1995, V.4,.289.

Danilova O.A., M.I.Tyasto, Asymptotic directions of vertically incident cosmic rays for stations Moscow and Irkutsk, *Izv.RAN.*, ser.phys.,1997, V.61, N6, 1147.

Duldig M.L. Cramp J.L., Humble J.E., et al., The ground level enhancements of 1989 September 29 and October 22, *Proc. Astron.Soc.Aust.* 1993, V.10, P.211.

Flueckiger E.O., E.Kobel, D.F.Smart and M.A.Shea ,On the significance of the magnetospheric effects in the analysis of the ground - level solar cosmic ray event on 7 December 1982 , *Proc.21 Int.Cosmic Ray Conf. Adelaide*, Australia, 1990, V.4, 22.

Lockwood J.A., Webber W.R., Hsieh L. Solar flare proton rigidity spectra deduced from cosmic ray neutron observations. *J Geophys.Res.* 1974, V.79, No28 4149.

Maltsev Yu.I, Ostapenko A.A.. Substorm and storm effects in the bulk magnetic field of the magnetosphere. *Proc. 4 Int.Conf. on Substorms*, Lake Hamana, Japan, March 9-13, 1998, P1-36, 123.

Ostapenko A.A., Maltsev Yu.P., The magnetic field model in the inner magnetosphere of Earth, *Geomagnetism and Aeronomy*, 1996, V.36. No5, 35.

Palmeira, R.A. R., R.P. Bukata, and P.T. Gronstal, Determination of the solar-flare cosmic-ray rigidity spectrum using the wordwide neutron monitor network, *Can. J. Physics*, 1970, V48, 419.

Tsyganenko N.A., A magnetospheric magnetic field model with a warped tail current sheet, *Planet. Space Sci.*,1989, V. 37 , 5.