HYPOTHETIC INTERPRETATION OF ATMOSPHERIC ELECTRIC FIELDS AND CURRENTS AT HIGH LATITUDES MEASURED DURING SEP

Peter Tonev

Space Research and Technology Institute, Bulgarian Academy of Sciences, e-mail: peterton@abv.bg

ABSTRACT*:* *The electric response in mesosphere, stratosphere and at ground level at high latitudes during major SEP events observed by experimental measurements during decades is characterized by systematically peculiar and extremely large variations of the electric fields and currents. The experimental case considered demonstrates vertical electric fields ~10 V/m in mesosphere at latitude 58.5°S during major SEP event began from 19 October 1989 and very strong geomagnetic storm (Kp reaches 8+) on 21 October (the experimental day). We show that the profile of vertical electric field indicates for severely reduced conductivity in the mesosphere and upper stratosphere, and for capability of generation of extra downward electric currents below the mesosphere during major SEP events. These last can give a key for explanation of the peculiar behavior of electric fields measured in the stratosphere at auroral latitudes during GLE69.*

Introduction. Atmospheric electric response at high latitudes to major SEP is studied on the base of two experimental measurements: I. rocket experiment in mesosphere and stratosphere; II. In Antarctic stratosphere, which show large peculiar variations. Common hypothetic interpretation is proposed in this work.

<u>**I**. Rocket-borne measurements of electric field in **mesosphere**</u> during major solar proton event (SPE) on 19-22 October 1989. Rocket-borne profile of the vertical electric field E_z has been obtained on 21.10.1989 at 19.31 UT at latitude 58.5°S (Zadorozhny and Tyutin, 1998). SEP accompanied by major geomagnetic storm on 20-21.10 (on 21.10 index Kp reached 8+; Kp=8 during rocket launch). Profile of E_z is shown in ***Fig.1a***. The peak values of E_z are:

$$E_z = +12.2 \text{ V/m at altitude z=58 km, and -9.7 V/m at z= 46 km}$$

<u>Unexplained peculiarities</u>: *i*) Too large peak E_z values in mesosphere; *ii*) Change of direction of E_z (and of related current J_z). For comparison, by usual conductivities 2-6x10^{-11} S/m (***Fig.4***) and fair-weather current Jz=~-2 pA/m^2 E_z should be <~-100 mV/m (at least two orders smaller); and well below that during SEP, as result of enlarged conductivity caused by strong impact ionization.

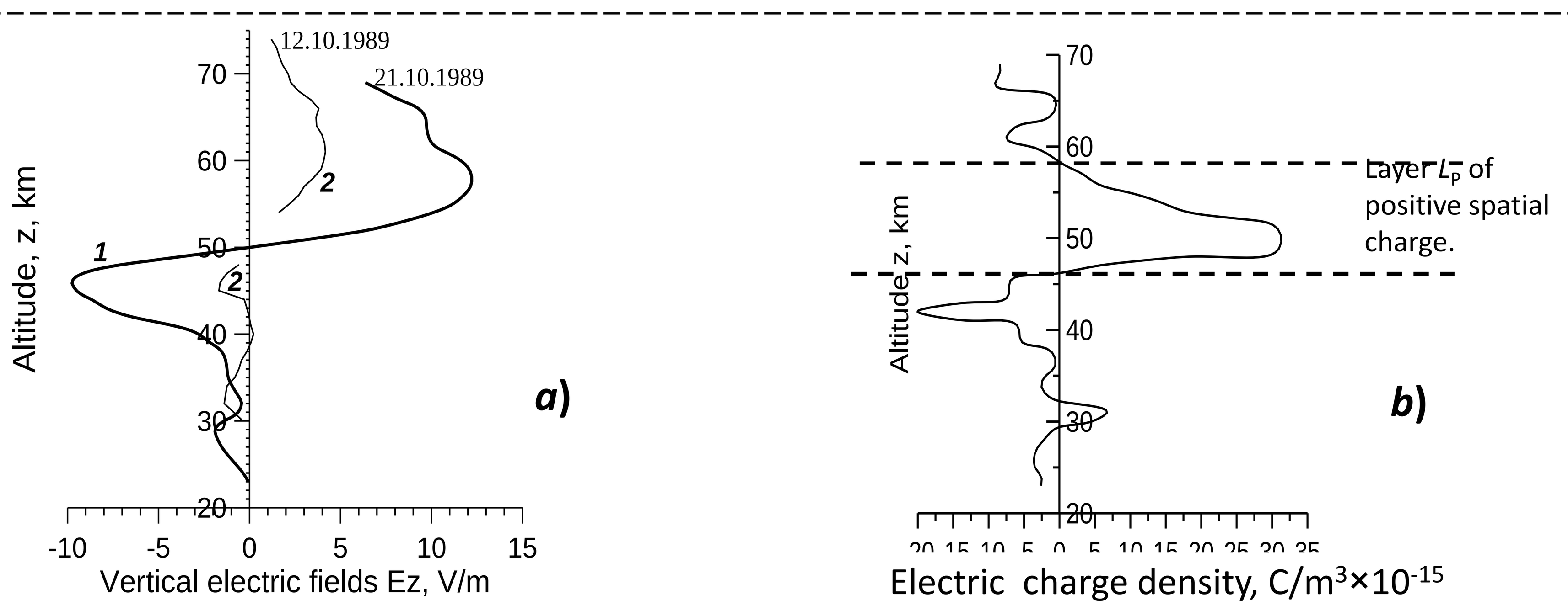


Fig.1. *(**a**) Profile of vertical electric field Ez from rocket-borne data at latitude 58.5° (Indian Ocean) on 21.10.1989, 19:31 UT during major SPE (GLE event) and major geomagnetic storm. Peak values of Ez are largest ever measured (they are compared with the second strongest fields on 12.10.1989 shown by thin line (Zadorozhny and Tyutin, 1998).*
*(**b**) profile of the electric charge density ρ (z) derived from Gauss's law:* $\operatorname{div} \mathbf{E} = \rho/\varepsilon_0$, or $dEz/dz = \rho/\varepsilon_0$

We estimate the main layer L_P of positive charge around 50 km (***Fig.1b***) and the total positive charge Q_{LP} in it. This layer is hypothetically fed by the uncompensated positive charges injected together with energetic protons during SPE. Precipitation of protons from magnetosphere have no significant contribution to layer L_P

- Layer L_P is in quasi-steady state at time of the experiment since the decay of proton flux is very slow (~7% per hour, as follows from ***Fig.2***), and no other sources affect it. The conductivity in L_P satisfies the equation:

$$Q_{LP} / t_P = J_P \qquad (1)$$

where $J_P(z) = F_P(z)q_e$ is the source current of newly injected uncompensated positive charges; $F_P(z)$ is the proton flux reaching altitude z), and t_P is the relaxation time, $t_P = \varepsilon_0 / \sigma$

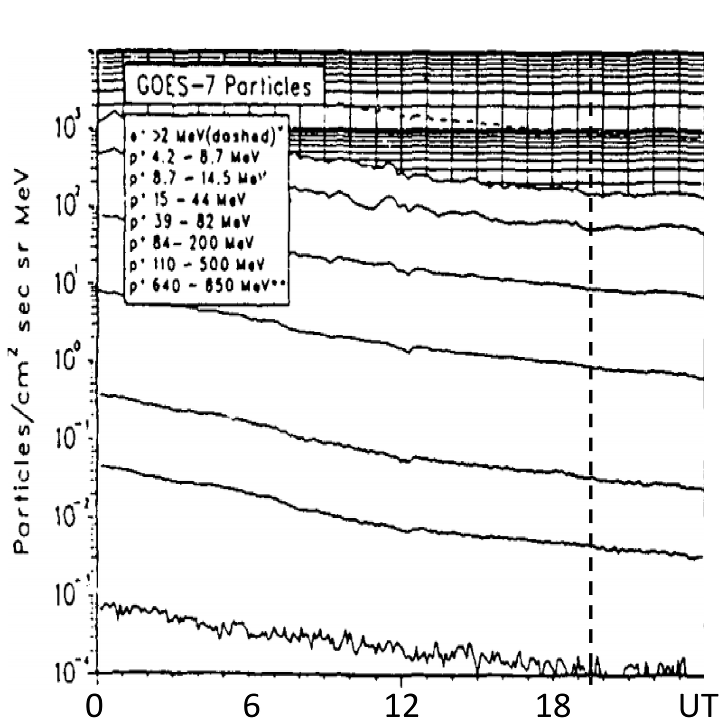


Fig.2. *GOES-7 data on 19-21.10.1989. Proton channels: 1) 4.2-8.7; 2) 8.7-14.5; 3) 15-44; 4) 39-82; 5) 84-200; 6) 110-500; 7) 640-850 MeV (Dashed curve is for electrons >2 MeV). Vertical line indicates launch time 19:31 UT.*

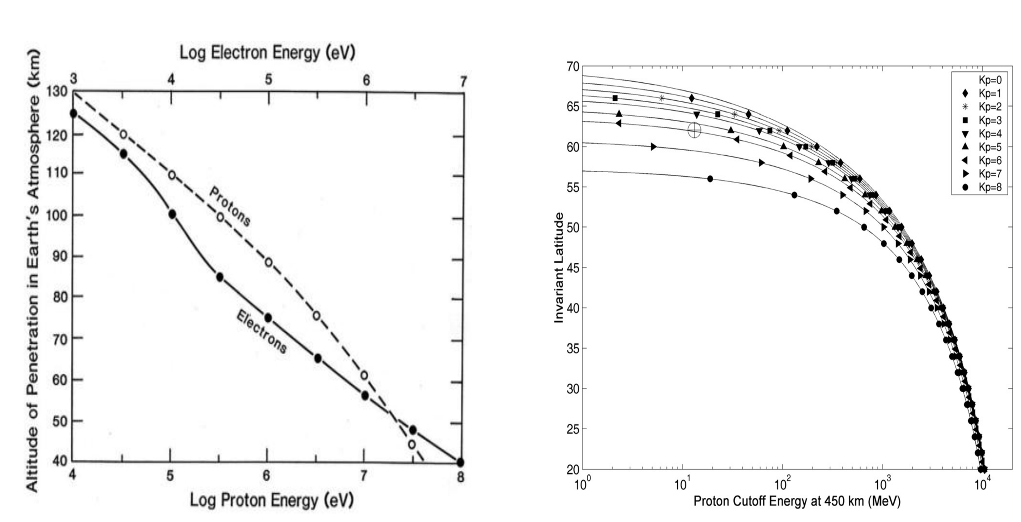


Fig.3. *Stopping altitudes of energetic protons (dashed line) and electrons (solid line) as function of their energy (left panel); Proton cutoff rigidity at 450 km by different values of Kp index, Rodgers et al. (2006) (right panel).*

<u>*Integral Fluence for 19-31.10 (cm^{-2}); & Total related positive charge Q_{PT} income*</u>

	>1 MeV	>5 MeV	>10 MeV	>30 MeV	>60 MeV	>100 MeV
	1.03×10^{11}	3.89×10^{10}	1.92×10^{10}	4.26×10^{9}	1.23×10^{9}	4.65×10^{8}
Q_{PT}, C/m^2	1.65×10^{-4}	6.24×10^{-5}	3.07×10^{-5}	6.82×10^{-6}	1.97×10^{-6}	7.44×10^{-7}

We assume that the positive electric charges injected by SPE proton flux is responsible for formation of quasi-steady-state layer L_P of positive spatial charge around ~50 km altitude which is consistent with large fluence. The source current J_P of the injected positive charges is derived from the spectrum of the proton flux (***Fig.2***) by assumption that at the top of atmosphere (~90 km) its spectrum is the same to that measured on GOES-7 (adopted also by another authors), and by the use of stopping altitudes and cutoff rigidity for energetic protons as functions of their initial energy (***Fig.3***). With columnar charge density in L_P Q_{LP}~10^{-10} C m^{-2} and J_P~10^{-14} Am^{-2} for the layer L_P, the roughly approximate conductivity σ_{LP} in the layer is close to:

$$\sigma_{LP} = J_P\varepsilon_0 / Q_{LP} \sim 10^{-15} \text{ S/m} \qquad (1)$$

which is needed in order to avoid fast relaxation of the quasi-steady-state charge layer L_P.

Such extremely low conductivity could take place only under key role of aerosol carriers of spatial charges. Such conclusion has been made previously by Zadorozhny (2001), Holzworth and Goldberg (2004), etc., which leads to severe modifications of conductivity profile ***(Fig.4)***. The conclusion of Holzworth and Goldberg (2004) about low conductivity in a noctilucent cloud in the summer mesopause at ~81 km altitude (σ ~ 4×10^{-13}) is derived from measurements of the vertical electric field Ez (***Fig.5***). Their estimation supports the ability of dramatic reduction of conductivity in an aerosol layer even in the absence of SEP .

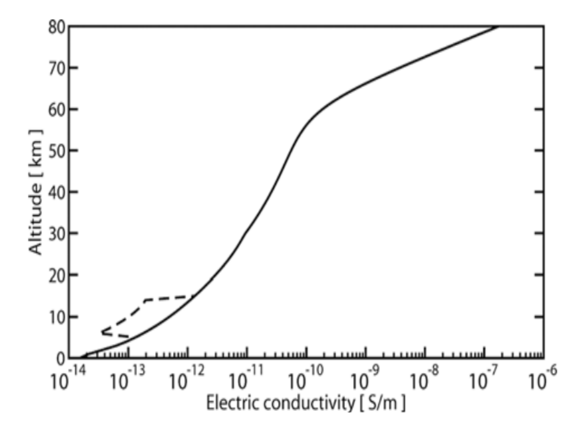


Fig.4. *Typical profile of atmospheric electrical conductivity σ under quiet conditions.*

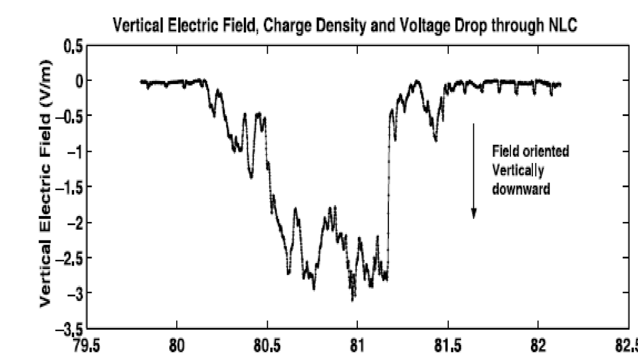
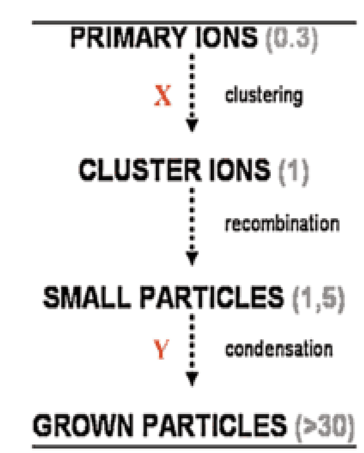


Fig.5. *Profile of vertical electric field Ez in noctilucent cloud in summer mesopause measured by Holzworth and Goldberg (1984).*

Formation and growth of aerosol particles (APs): they control conductivity modifications



Main phases of creation and growth of aerosol particle. We suppose that during major SPE aerosol particles (APs) are being created and grown to larger particles, and also charged much more intense than without SPE. The velocity of AP growth density of charges of both polarities they carry supposed to increase with time.

Expected:

- *Growth and charging of APs (accelerating in time);*
- *Grown APs are stable and relatively immobile;*
- *They become determinable for conductivity during SPE;*
- *It is supposed that development of APs leads to descending of significant portion of the main unsatisfied positive charge which forms current J_D*

Conductivity declines reciprocally with the increase of the average mass (AMU) of charge carriers.

Hypothetic structure of ionosphere-to-surface el. link at high latitudes during late SPE (in the case of Fig.1)

- In region Reg_L from surface up to high stratosphere, 0 - ~37 km, conductivity is relatively less affected by SPE. The respective columnar resistance r_L remains almost constant. Above Reg_L spatial el. charges are carried preliminary by APs.
- In upper regions Reg_{INC} (37-47 km), Reg_{PL} (47-50 km), Reg_{PU}(50-58 km), and Reg_N (above 58 km) conductivity strongly declines during SPE together with APs formation and growth. Respective columnar resistances r_{INC}, r_{PL}, r_{PU}, and r_N are negligible before SPE, and can become comparative to (or even larger than) r_L.
- Reg_{PL} and Reg_{PU} represent a layer L_P of positive spatial charge created due to injected unsatisfied charges of arrived protons.
- The charge in L_P relaxes via an upward current J_U (above 50 km) and a downward current J_D (below 50 km). Current J_D is significant if $r_{P2}+ r_N >\sim r_{HT}+ r_{P1}$.
- In Reg_{INC} and Reg_N negative spatial charge is induced consistently with currents J_D and J_U and due to conductivity gradient.
- The vertical current J_z in the link is superposition of fair-weather current J_{fw}, and currents J_D and J_U. Its orientation (and that of E_z) at an altitude depends on magnitude Q_P of the positive electric charge in L_P, and on interplay of resistances r_{INC}, r_{PL}, r_{PU}, and r_N.

<u>**II**. Balloon-borne measurements of electric characteristics in **Antarctic middle stratosphere**</u> (31-33 km altitude) during SPE on 20.01.2005 (GLE69), *Kokorowski et al. (2006*). Balloon coordinates: (70.9°S,10.9°W) - (71.4°S,21.5°W) *Geomagnetic conditions*: *i*) From SPE onset at 06:51 UT until 14:00 UT – quiet; *ii*) Increased geomagnetic activity from 14:00 UT on; *iii*) Strong geomagnetic substorm after 15:54 UT. Fig.6 demonstrates variations during the day 20.01.2005 of: ***a***) the conductivity σ (some data close after SPE onset are missing); ***b***) the vertical electric field E_z.

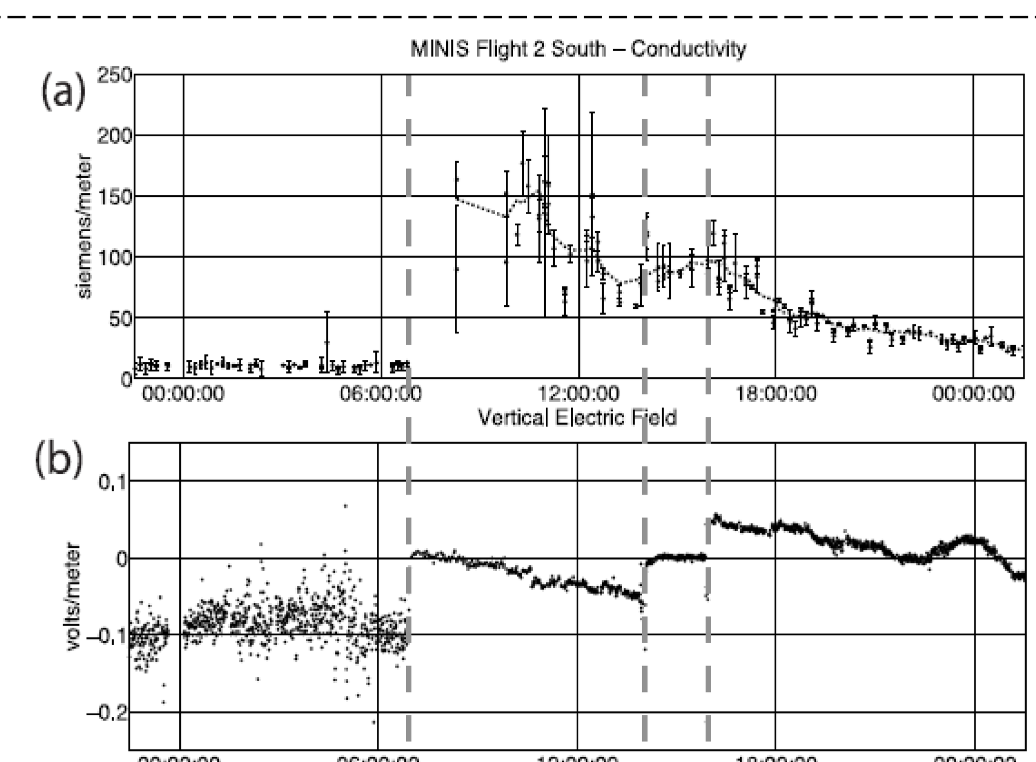


Fig.6. *Time variations of: a) σ ; b) Ez.*

<u>*Unexplained features:*</u>

i)Typical moderate variations of related current density J_z~ 2 pA/m^2 are strongly impaired (J_z=σ E_z).

ii) Too large integrated el. current flows across the balloon altitude for each of two time periods ~08:30-14:00 UT and from 16:00 UT on. The origin of related electric charge is unknown.

iii) Ez has non-transient reversals: several times it becomes upwards for hours, i.e. it is opposite to fair-weather current J_z.

iv) Ez has too well expressed jumps, at 14:00 and 15:56 UT, which coincide with changes in solar wind parameters, and with jumps in flux of protons with energies 1-5 MeV.

Electrical coupling is demonstrated between mesosphere & stratosphere during SEP and thus, consistency between electric field variations in different atmospheric regions.

Additional sources of electric charges to middle atmosphere at high latitudes during SEP can be by precipitations of: i) protons < 3 MeV (positive charges injected); or ii) electrons (EEP or REP) (loading negative charges) which can be triggered by geomagnetic storm accompanying SPE.

<u>Hypothetical interpretation of Fig.6</u>.

1) Initial reversal of Ez (for ~1.5 h) can be due to relaxation current by the unsatisfied positive charges injected by protons >~100 MeV below the balloon, while JD<<Jfw due to small resistances leading to (2) in this initial phase of SPE.
2) From 08:30 till 14:00 UT current J_z increases (more than twice) together with JD since (3) is satisfied.
3) In time period 14:00 - 16:00 UT E_z~ 0 possibly due to electron precipitation and negative charge neutralizing layer L_P.
4) At 16:00 UT stronger EEP injects much negative electric charge which descends to layer LP and reverses its polarity.

Conclusions:

- Extremely large electric fields (exceeding 10 V/m) observed in mesosphere at auroral latitudes during major SEP could be caused by development of aerosol layers and injection of uncompensated positive electric charge.
- Creation and growth of aerosol particles in mesosphere and upper stratosphere at high latitudes are driven by SEP; they cause dramatic decrease of conductivity and thus control the redistribution of uncompensated positive charges within the atmosphere.
- These processes determine effective electrical coupling between mesosphere and stratosphere at high latitudes which appears as consistency of electric field behavior in these regions.

References:

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