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Geomagnetic Activity and Lower Atmosphere Processes

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Abstract

During substorms and storms, the ionosphere was subjected to rather a significant Joule heating, and the power of precipitating energetic particles was also great. If there is a mechanism for the magnetospheric disturbance effect on meteorological processes in the atmosphere, it supposes a more complicated series of many intermediates, and is not associated directly with the energy flux that arrives into the ionosphere during storms. In this study, I have briefly reviewed our present understanding of how these events play a key role in energy transfer from the solar wind into the magnetosphere and ionosphere, which ultimately results in the Earth's ionosphere-atmosphere coupling.

1 Introduction

A magnetospheric storm is a 1-3 day long phenomenon spanning all the magnetosphere regions, and it features sharp depressions in the magnetic field. During storms and substorms, the ionosphere undergoes rather significant Joule heating with a great power of precipitating energetic particles. Huge energy increases the ionosphere temperature, causes large-scale ion drifts, and neutral winds.

The issue of the reality and the physical mechanism for solar-terrestrial couplings has rather a long history. Many geophysicists were most decisive in rejecting the idea about a solar activity effect on the lower atmosphere condition as absolutely unacceptable. And, first of all, the matter was that the power of atmospheric processes exceeds the solar-wind input energy flux into the near-Earth space enormously. Due to this, it seems most unlikely that solar activity could significantly affect the lower atmosphere condition. However, the research done over the last years allowed us to find a clue to overcoming this inconsistency. The main objection to a possibility of the solar activity effective influence on the condition of the lower atmosphere and weather, based on insufficient power of the solar wind, appears quite surmountable; see e.g. [2]. Also, like the computations in [2] show, the energy necessary to create the atmospheric optical screen (shield) is incomparably lower than the amplitude of the variation in the screen-induced solar energy flux arriving in the lower atmosphere.

According to [8], the interplanetary electric field influence is realized through acceleration of the air masses, descending into the lower atmosphere from the troposphere, and formation of cloudiness above the Antarctic Ridge, where the descending air masses enter the surface layer. The cloudiness results in the sudden warming in the surface atmosphere, because the cloud layer efficiently backscatters the long wavelength radiation going from ice sheet, but does not affect the process of adiabatic warming of the descending air masses. Influence of the interplanetary electric field on cloudiness has been revealed for epochs of the solar activity minimum, when Forbush decreases effect is absent. The acceleration of the descending air masses is followed by a sharp increase of the atmospheric pressure in the near-pole region, which gives rise to the katabatic wind strengthening above the entire Antarctica. As a result, the circumpolar vortex around the periphery of the Antarctic continent decays and the surface easterlies, typical of the coast stations during the winter season, are replaced by southerlies. It is suggested that the resulting invasion of the cold air masses into the Southern ocean leads to destruction the regular relationships between the sea level pressure fluctuations in the Southeast Pacific High and the North Australian – Indonesian Low, since development the El-Nino event strongly follows anomalous atmospheric processes in the winter Antarctica.

In [1] author examined the possible connection between atmospheric parameters measured at low and middle altitudes and geomagnetic storms occurred in 2000 and 2003. The results presented in [1] may show evidence to support that atmospheric parameters at heights of the troposphere and lower stratosphere could be possibly related to geomagnetic storms.

The objective of this paper is to investigate the global electrical processes coupling the solar wind and magnetosphere, the magnetosphere and ionosphere, and the ionosphere and lower atmosphere.

2 Solar wind-geomagnetosphere-ionosphere-atmosphere interaction

When the CME velocity relative to the velocity of the unperturbed solar wind exceeds the local magnetosonic speed, which is approximately equal to the Alfven speed in the solar corona, a piston shock forms in the leading portion of the perturbed zone. Earth's bow shock (BS) is a piston shock. The front of the Bow Shock (BS) is the region where the parameters of the Solar Wind (SW) undergo strong changes, especially in the "nose" part. The particle number density and the intensity of the tangential component of the magnetic field increase approximately by a factor of 4 behind the front, the normal velocity component decreases by the same factor (according to data of well-known satellite missions – GEOTAIL, CLUSTER-II, THEMIS). If almost all SW energy before the front is concentrated in the progressive motion, then behind the front it is concentrated in the energy of compressed gas and magnetic field. The bow shock front is the main converter of solar wind kinetic energy into electromagnetic energy [4]. When passing through the bow shock front, the intensity of the tangential component of the SW magnetic field and the plasma density increase several fold. Therefore, among other things, the BS front is a current sheet. This current is diverging in this layer, that is the front is the generator of the current. Since plasma with magnetic field passes through the front, electric field arises in the front reference system. Thus, the BS front is a source of electric power. There is a potential difference between the BS front and the magnetosphere, unequivocally (since the Transition Layer (TL) magnetic field is determined by the SW magnetic field) associated with the velocity of the transition layer plasma flow. Thus, the magnetopause potential is functionally related to SW parameters [5-7]. The solar wind energy also feeds the ion acceleration process, the generation of waves in the region of bow shock, and the energy necessary to build up the foreshock. It is clear that the primary energy source for magnetospheric processes is the solar wind, but the process of energy transfer from the solar wind into the magnetosphere, or rather, to convecting magnetospheric plasma, appears to be rather complicated.

The power consumed by the magnetosphere is spent on the compressor work and consists of active and reactive power. The active part covers losses in the ionosphere (ohmic, primarily), the reactive part returns to the magnetospheric compressor [5-7].

The equations of the two-fluid or one-fluid magnetohydrodynamics with isotropic or anisotropic pressure are as a rule applied to describe collisionless magnetospheric plasma. In this case any dissipative processes in the system are considered inessential. This statement is usually valid for ohmic loss and loss by radiation. However, particles (and energy) also escape from the magnetospheric plasma into the atmosphere through open ends of flux tubes. This type of loss can be very substantial and should be taken into account. Combined action of plasma convection and pitch-angle diffusion of electrons and protons lead to the formation of plasma pressure distribution in the magnetosphere. Specifying the initial pressure at the boundary, we can find the resultant pressure at any point on the flux line. In such a way, the field of plasma pressures in the entire magnetosphere is calculated [5-7]. The projection (mapping) of the plasma pressure relief onto the ionosphere corresponds to the form and position of the auroral oval. This projection, like the real oval, executes a motion with a change of the convection electric field, and expands with an enhancement of the field. Steady bulk currents are connected to distribution of plasma pressure. The divergence of these bulk currents brings about a spatial distribution of field-aligned currents, i.e. magnetospheric sources of ionospheric current systems [5, 7]. The source region of electrojets in the magnetosphere is on the earthward slope of the gas pressure peak. The transversal current in the magnetosphere near the equatorial plane has two components: $j_R \sim -\nabla_\lambda p_g$ and $j_\lambda \sim \nabla_R p_g$, where R, λ, φ are spherical coordinates. The latitude φ is calculated from the magnetic equator; the longitude λ, from the midday meridian counter-clockwise. The presence of the positive gas pressure gradient on the earthward slope of the gas pressure peak p_g is associated with particle losses by precipitation. This gradient $\nabla_R p_g$ produces the counter-clockwise current j_λ. Its possible competitor is a drift current of clockwise energetic protons. The current j_λ is closed in remote parts of the magnetosphere through the current segments (radial). The $j_\lambda E_\lambda$ product and $j_R E_R$ are negative. This suggests that both j_λ and j_R can work when branch off to the ionosphere. There is a component of the Poynting vector directed into the ionosphere: $S_\varphi = -(J_R E_R + J_\lambda E_\lambda)$, where J_R and J_λ are j_λ and j_R currents integrated with respect to the current-carrying layer thickness. It is known that auroral electrojets are dominantly Hall currents flowing between two 'curtains' of field-aligned currents, which flow into the ionosphere to the south of the electrojet at dusk, to the north of the electrojet at dawn and flow out to the north of the electrojet at dusk and to the south at dawn (for the northern hemisphere). Besides, as is seen from fig. 1b, the westward current can also be closed through the ionosphere. The proton DR-current has $j^{DR}{}_\lambda E_\lambda > 0$, therefore it is a power consumer and cannot do work upon the ionosphere. It takes away a portion of the j_λ current for itself. This suggests that the gas pressure of fast protons in the DR-current favours a decrease in $\nabla_R p_g$.

The situation changes radically when the boundary conditions are time dependent. Knowing the distribution of the plasma pressure, we can determine the places of MHD-compressor and MHD-generators location in the geomagnetosphere. Consider a situation arising in the region of the dusk electrojet, using a circuit. For simplicity, in this figure the current systems supplying electrojets are divided. The radial current along with the radial electric-field component supplies the 'curtain' structure of field-aligned currents. It is evident that $j_R E_R < 0$ in the magnetosphere, i.e. there is a source of electric power, whereas in the ionosphere $j^I{}_R E^I{}_R > 0$, i.e. there is a consumer of electric power. The Poynting vector is directed everywhere to the ionosphere. The work upon electric forces in the magnetosphere is done by the gas pressure falling in the direction of convection velocity, therefore $\mathbf{V}\nabla\mathbf{P_g} < 0$.

Auroral electrojets are supplied by four magnetospheric generators comprising a fairly complex power system. The generators feed the current systems of Birkeland-Bostrom (BB) of the first and second types. Three of them, referred to as secondary, work due to the pressure gradient of compressed plasma. The MHD-compressor is powered partly by the primary generator and partly by the back electric current of secondary generators. The value of the back electric current depends on the load intensity largely determined by resistance of the ionosphere in the auroral zone. Intensification of auroral electrojets produces changes in currents of the magnetotail (see in details [6]. Since the sign of the p_g gradient changed and that of the p_B gradient remained unchanged, the double "curtain" of field-aligned currents is formed, which is a characteristic feature of auroral electrojet feeding. The corridor is shown in a way, in which it is stretched along the lines B=const under the small corner, that’s why the time of plasma tube devastation τ can be considered the constant quantity. The plasma flow in a corridor also happens under a small angle to its axis. Field-aligned currents (FACs) connect the magnetosphere and the ionosphere into a uniform electric circuit.

The atmospheric process power incomparably exceeds energy flux from the solar wind into the geomagnetosphere, and the power of extremely strong magnetospheric disturbances. The energy flux from the magnetosphere into the atmosphere during the strong storm was about 1.5×10^{19} (erg/s) $\times24\times3600=1.2\times10^{24}$ ergs/day, which is by 2-3 orders of magnitude less than the atmospheric process power whose values are in [2].

In the frame of the global electric circuit concept, thunderstorms act as a "meteorological" generator and create a potential drop of $U_{int} \approx 270$ kV between the ionosphere and the Earth's surface. It is considered that this potential is identical at all points of the ionospheric shell. In the high-latitude ionosphere, U_{int} is superposed by the potential from the magnetospheric source (U_{ext}). Distribution of U_{ext} corresponds to the ionospheric plasma convection, which is directly related to plasma convection in the geomagnetosphere. Therefore, how the electric field is transferred from the solar wind to the geomagnetosphere, and magnetospheric plasma convection generation, are very important issues.

There is no simple global electric circuit via which a sharp increase in the solar wind electric field during magnetospheric disturbances would be possible. The solar wind electric field penetration process is complex and non-linear. The atmospheric conductivity sharply declines between the polar ionosphere and the layer at h~10 km.

A realistic model of equivalent circuit with capacitors, resistors, and switches is presented and is shown in [3]. The electrodynamic coupling between the Earth’s atmosphere and the ionosphere is very complex and may be described by the global electric circuit [3].

3 Discussion and conclusions

The global atmospheric electric circuit is connected through a high-altitude ionosphere, and magnetospheric disturbances can effect on the stationary and changes of an atmospheric electric field. Process of electric field penetration from the solar wind is complicated; this phenomenon is nonlinear. Plasma convection generation in the geomagnetosphere is associated with processes at the bow shock front. A combined action of plasma convection and pitch-angle diffusion of electrons and protons lead to the formation of plasma pressure distribution in the magnetosphere. As it is known, bulk currents are associated to plasma pressure distribution in the magnetosphere. Divergent of these bulk currents gives a spatial distribution of FACs, i.e. magnetospheric sources of ionospheric current systems. Field-aligned currents (FACs) connect the magnetosphere and the ionosphere into a uniform electric circuit.

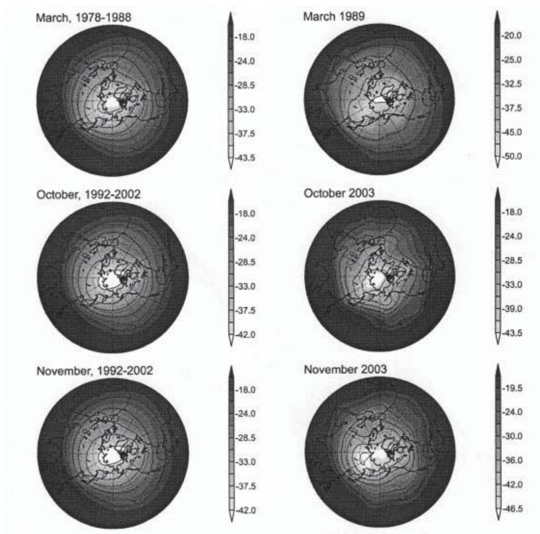

Figure 1. Comparison of the NCEP/NCAR reanalysis results for the average temperature at the level of 400 hPa for different periods and days.

The geomagnetospheric disturbance effect on the troposphere is weak compared with a multitude of other factors affecting it (see fig. 1-2). However, the existing works on a high correlation between tropical cyclones and magnetic storms may evidence either the existence of another mechanism for the effect (that was not addressed in this study), or a random coincidence rather than a physical essence. Thus, now we can note that, probably, there is some connection between processes at the bow shock front region and meteorological processes at the lower atmosphere, because the magnetospheric plasma convection generation is associated with processes at the bow shock front.

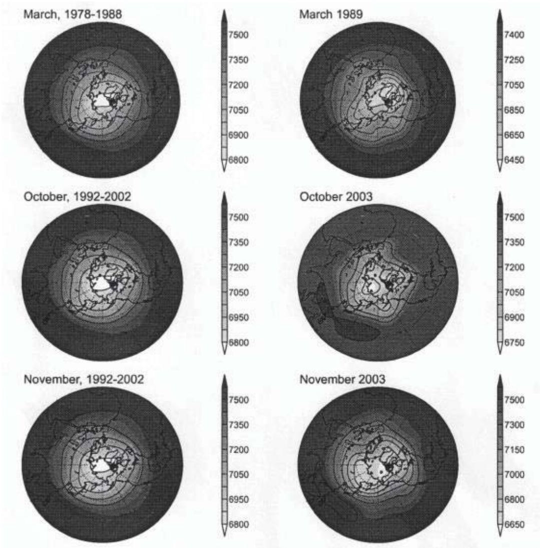

Figure 2. Comparison of the NCEP/NCAR reanalysis results for the average geopotential heights at the level of 400 hPa for different periods and days.

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