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THE ROLE OF ION DIFFUSION IN FORMATION OF 3-D SPATIAL STRUCTURE OF THE PLASMASPHERE

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Abstract. The influence of various factors on formation of 3D spatial structure of the Earth's ionosphere and plasmasphere has been studying. In this work the role of ambipolar field-aligned diffusion in the process has been examined.

1. Introduction

The ionosphere and plasmasphere refilling was studied in many of theoretical and experimental works (e. g.[1,2,3]). But we don't know researches which examined this process in 3D statement and reviewed details of spatial structure of resulting plasmasphere. Our work is intended to fill this gap.

Our study was conducted by a computer simulation method using the global numerical model of the Earth's upper atmosphere UAM [4,5]. In order to select exclusively the role of the diffusion all other factors were eliminated in this calculation. Convection drift and neutral wind were set completely absent. In addition, the geographic and magnetic axes were superposed; the Sun was located exactly above the equator. The neutral temperature and composition distributions were stated as stationary in Solar-magnetic frame and ionospheric and plasmaspheric plasma rotated with the Earth, passing from day to night and back.

In the initial state the ionosphere and plasmasphere were uniformly filled with plasma of very low density. Then the ionization started and the plasma began field-aligned motion into upper parts of the field tubes. In order to smooth the sharp changes the calculation started in pre-midnight hours for each longitude (night-time ionization by scattered radiation), and to the sunrise time the ion distribution became more natural.

2. Model result

The overall picture after 5 days of simulation time is fairly realistic: the repetitive diurnal variation in the ionosphere and the plasmasphere which is virtually uniform in the longitudinal direction (Fig.1, 2). Thus, we can assume that the model with all above listed simplifications is still physically appropriate, and smaller structural features of the ionosphere-plasmasphere system can also be considered as physically meaningful.

At the ionosphere level these structural details of plasma density and ion composition are most evident in the night sector. There are 3 latitudinal areas (symmetrical in both hemispheres) with increased plasma density (Fig.3, 4): sub-auroral (latitudes 60-65º), near-equatorial (near 10º) and mid-latitudinal (30-40º). Physical mechanisms of their formation will be discussed below.

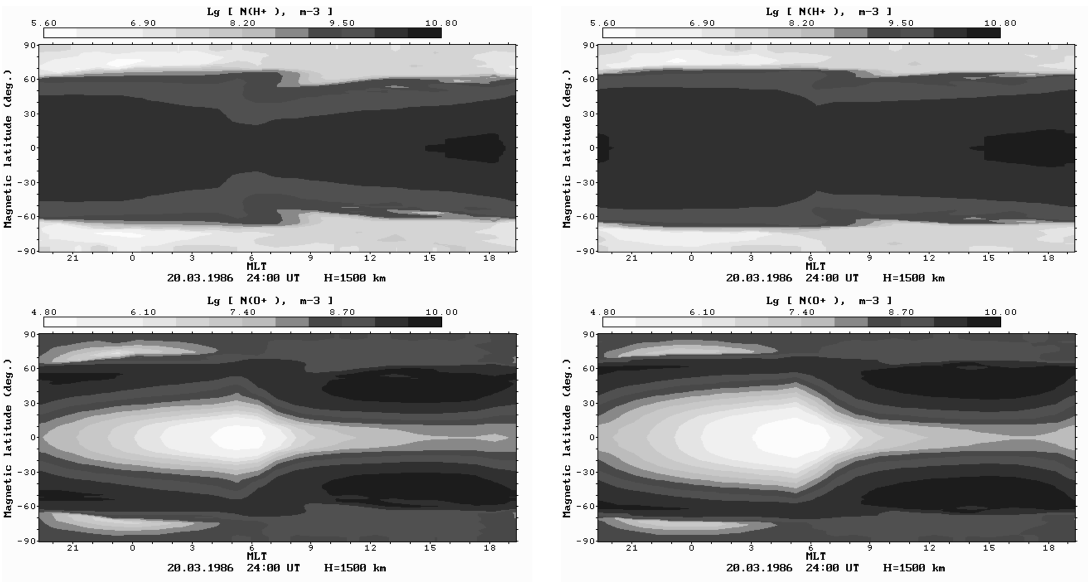

Figure 1. The horizontal cut of the ion density at the base of plasmasphere after 1 and 5 days of modeling time

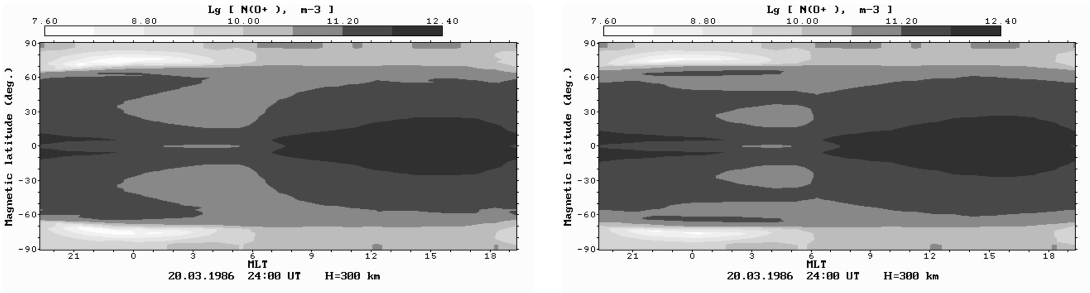

Figure 2. The horizontal cut of the ionosphere after 1 (left panel) and 5 (right panel) days of modeling time

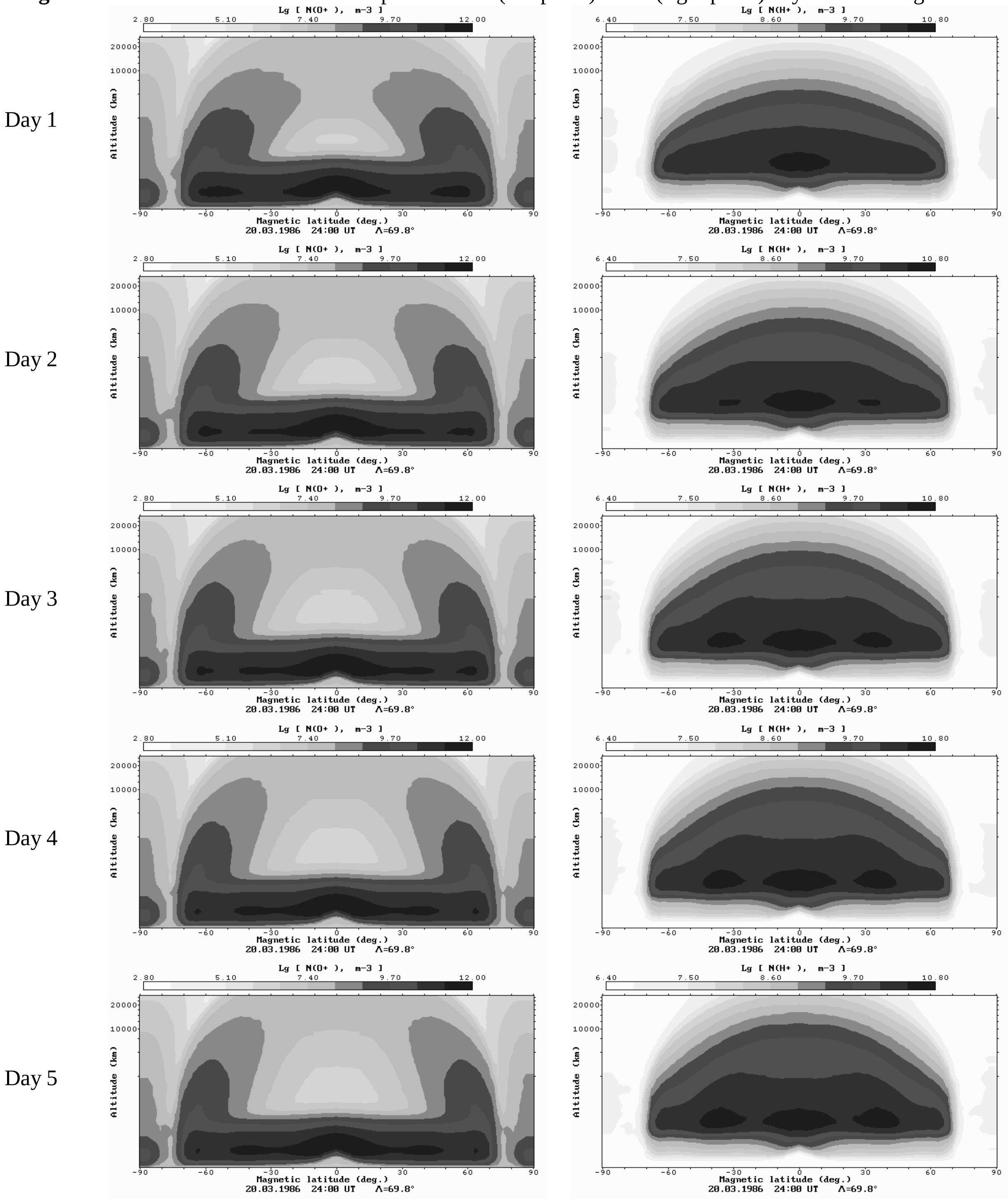

Figure 3. The ion density vertical cross-sections along the midnight meridian.
The altitude axe is in logarithmic scale

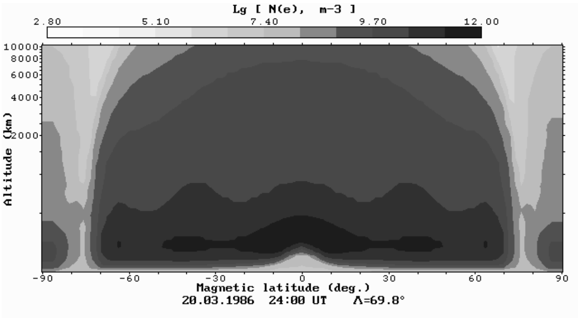

Figure 4. The n(e) vertical cross-section along the midnight meridian after 5 days of modeling time

2.1. Near-equatorial maximum

An arched area of high O^+ density appears during the first modeling day in the near-equatorial region and practically does not change further (Fig.3). On the horizontal section of the ionosphere (Fig.2) it looks similar to the equatorial anomaly, with peaks near latitude 10º and trough between them. But it was formed here exclusively by field-aligned diffusion process, without any participation of the electromagnetic drift and fountain effect.

We explain the formation of this maximum as follows. The tubes, in which it is formed, have a small length and small cross-section in the near-equatorial part. On the other hand, the "productivity" of the ionosphere source which "fills" this "reservoir" is greater than on other tubes, because big part of this near-horizontal tube is located in the active ionization area. Therefore, during the day a significant number of ions O^+ produces here and accumulates in the upper part of tubes where the recombination is almost absent. The gravity force in this area does not "drag" the ions back to the dense atmosphere (and to the fast recombination) because tubes are horizontal. Efficiency of O^+ losses in the charge exchange reaction is also lesser than in the longer tubes: H^+ ions can not leave these tubes and recycled back to the O^+.

As a result, a significant concentration of O^+ ions is formed here and remains through all the night. Shorter tubes are entirely in the more dense neutral atmosphere, and longer ones inclined stronger and the ions "roll" to the dense atmosphere under the force of gravity. Therefore in the both shorter and longer tubes the night recombination goes faster, and the maximum appears between them.

2.2. Sub-auroral maximum

Another noticeable feature of the forming structure is the sub-auroral night maximum and the "horns" of increased O^+ concentration above it (Fig.3). It appears in the first modeling day and later "melts" gradually from the low-latitude side as the "constant reserve" of H^+ accumulates in the upper part of corresponding tubes.

Due to huge volume of near-auroral tubes the plasma density remains very low even after several days of filling, and daytime outward flow of O^+ doesn't meet any obstacles. Large quantities of O^+ still penetrate far into upper parts of the tubes even after 3-5 days, when at lower latitudes the accumulated H^+ stops O^+ flows. As a result, the ion composition in the near-auroral tubes differs significantly. The H^+ density is very low (the light-ion trough), but O^+ concentration is significantly increased as compared to the same heights on shorter tubes – the above described "horns". After sunset these heavy O^+ ions drop back into ionosphere and support increased plasma density in ionosphere (Fig.5). Downstream flow lasts whole night with weakening only before sunrise. The smaller tubes become empty faster (Fig.2).

The efficiency of O^+ returning into ionosphere from high-altitude "store" is more then for H^+ ions: because of their mass they penetrate into dense atmosphere more easy. It results that thinner O^+ high-altitude plasma supports higher night F2-level density than more dense H^+ gas on shorter tubes of inner plasmasphere.

In the real ionosphere this maximum maps on the area of convection, which erodes it and doesn't allow to reveal it. May be it's possible only in very quiet conditions, after severe storms. But the areas of high $n(O^+)$ at the outer edge of the plasmasphere which are genetically related with it are known.

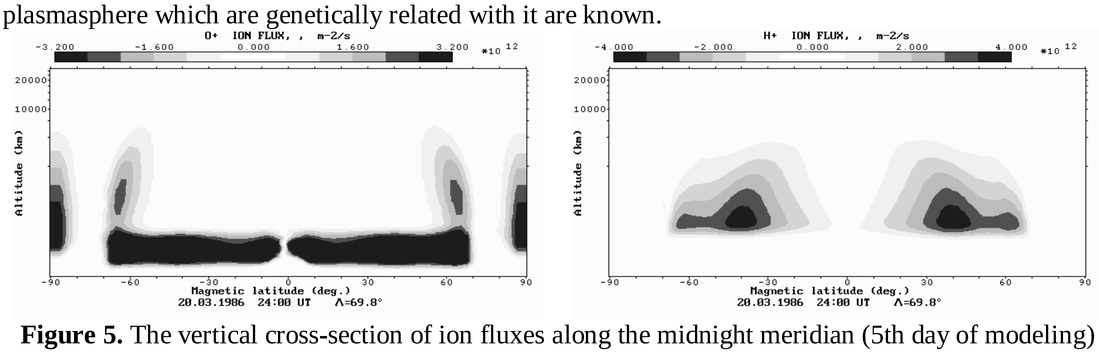

Figure 5. The vertical cross-section of ion fluxes along the midnight meridian (5th day of modeling)

2.3. Mid-latitudinal maximum

Instead of disappearing near-auroral maximum another one forms during 3rd-5th days of modeling time at the middle latitudes of night ionosphere. It clearly corresponds with accumulation of H^+ ions in upper parts of these tubes (Fig.3).

Such night mid-latitude areas of high electron content were observed in the experiments. Their existence was explained by Knyazeva [6,7] as the influence of neutral wind. But our simulation shows that this structure can be generated by diffusion process only.

In order to discover physical mechanism of its formation we ran another simulation, in which the ion temperature was set constant in whole space. In this modeling mid-latitudinal maximum did not appear. Therefore spatial inhomogeneity of T_i plays determining role in its generation.

The formation of this maximum results from coincidence of the two factors. Diffusional ion flux velocity increases with increasing T_i. On the other hand, the tube volume grows very rapidly with latitude (Fig.6). At the latitudes of 30-40° the diffusional fluxes are strong enough in order to fill relatively small volume of tubes during the daytime and to return big part of accumulated ions back to ionosphere in the night (Fig.5, right panel). As a result the night maximum appears here. At shorter tubes the ion temperature and diffusion rate are too low, and longer ones have too big volume to fill it.

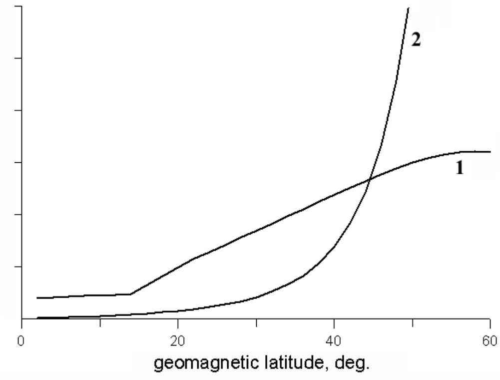

Figure 6. The latitudinal dependence of:
1 – ion temperature in the tube upper part
2 – tube volume

3. Conclusions

Thus, in our 3D simulation we have reproduced the formation of the plasmasphere under the influence solely of ionization / recombination and charge exchange reactions and field-aligned diffusion of O^+ and H^+ ions for fully symmetrical statement or problem. We have got physically plausible picture of plasmasphere-ionosphere with a few large-scale structural features of plasma density and ion composition. In the ionosphere they appear as 3 night-time maxima at some latitudinal areas: sub-auroral, near-equatorial and mid-latitudinal. We have explained physical mechanisms of generation of each of these maxima which complete previously known mechanisms.

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