ABSTRACTS (PH D THESIS)

Simulation Study on Enhancements of Energetic Heavy Ions in the Magnetosphere

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Introduction

One of the dynamic phenomena emerging in the geospace is the substorm. During the substorm, reconfiguration of the magnetic field takes place in the magnetosphere and the energetic charged particles are enhanced. In particular, singly charged oxygen (O^+) ion is known as the most responsible ion species for the substorm. Many observations show that energetic O^+ ions (tens of keV) rapidly increase in the inner magnetosphere and contribute significantly to the ring current during substorms. In spite of many studies, the energization process of the O^+ ion in the inner magnetosphere is still a controversial issue. In the present study, we perform test particle simulations in a global MHD electromagnetic fields [1]. Using the test particle simulation result, we reproduce spatiotemporal variations of distribution function and flux of O^+ ion after the substorm-time acceleration based on the Liouville theorem [2]. Through the numerical studies, the global trajectories and accelerations of O^+ ions from their source regions and their contributions to the energetic O^+ ions in the inner magnetosphere are examined.

Oxygen Injection in the Plasmasheet during the Substorm

We focus on an acceleration of O^+ ion around the nightside magnetic reconnection region, which can be thought as the most dynamic region during the substorm. Mechanisms of the enhancement of the dawn to dusk electric field and of subsequent accelerations of O^+ ions due to the intensive electric field are investigated in detail. In the inner magnetosphere, our simulation reproduces a realistic flux enhancement with the O^+ ion such as the dispersion-less structure, the dispersed structure and the nose structure which are often observed by in-situ observations as shown in Fig. 1. In addition to the dispersion structures, our simulation shows that another type of structure named void structure in the inner magnetosphere (Fig. 2). The structure is observed by the Van Allen Probes HOPE instruments. We reveal that the generation mechanisms of the void structure consist of the formation of the strong equatorward flow in the low pressure region and tailward flow in the high pressure region and the intense non-adiabatic acceleration of O^+ ions.

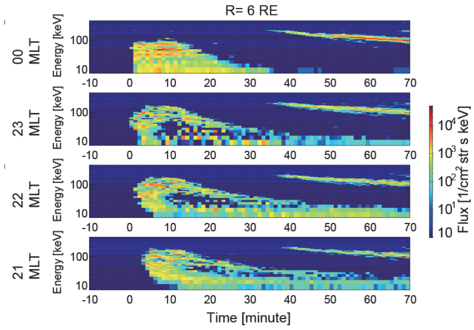

Fig. 1. Energy versus time spectrograms of the differential flux of the O+ ions at fixed positions

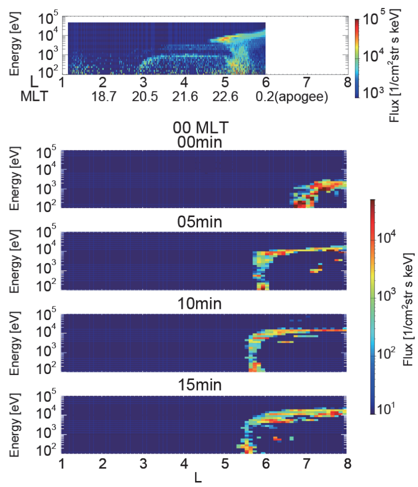

Fig. 2. Observation and Energy-L spectrograms of the simulated O^+ ions at 00 MLT in the equatorial plane.

Substorm-time O^+ outflow from the ionosphere

We also examine variations of O^+ outflow during the substorm and their impacts on the enhancement of energetic O^+ in the inner magnetosphere. We reveal that, during the substorm growth phase, O^+ ions at tens of eV are extracted from the dayside polar region due to the region 1, resulting in the enhancement of the warm O^+ ions (hundreds of eV) in the lobe (Fig. 3). This process works as a "pre-conditioning" of the O^+

ion. After the substorm onset, the enhanced warm O^+ ions are non-adiabatically accelerated to tens of keV and injected to the inner magnetosphere. A combination of the pre-conditioning and the non-adiabatic acceleration of the O^+ establishes a realistic O^+ ring current. At the same time, the initial brightening occurs in the midnight aurora region, then up to a few keV O^+ ions are extracted and directly supplied to the inner magnetosphere, developing a fraction of the O^+ ring current (Fig. 4).

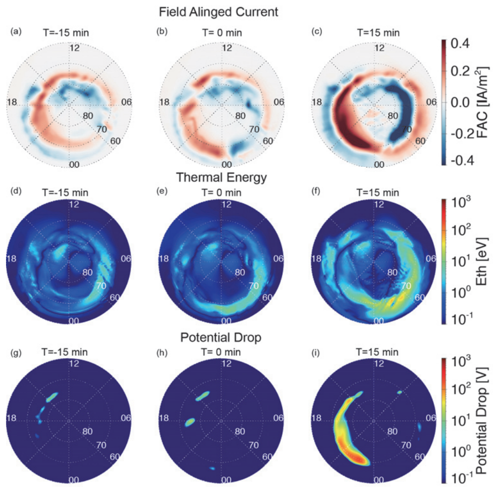

Fig. 3. MHD conditions and auroral outflow parameters at 1000 km altitude.

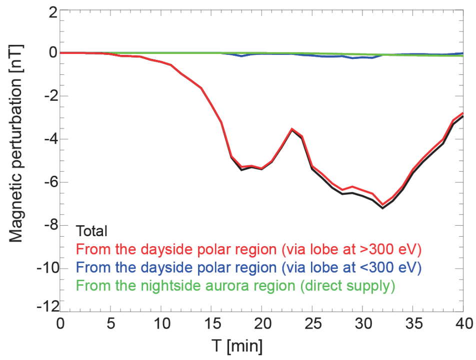

Fig. 4. Magnetic perturbation on the ground due to the several groups of O^+ ion.

Conclusion

This thesis addresses important issues and contributes to understand the big picture of the O^+ ion energization during substorms. Global paths of O^+ ions from the ionosphere to the inner magnetosphere have been tracked, and the realistic spatiotemporal flux has been reproduced by the large-scale computer simulations. During the growth phase of the substorm, the large scale region 1 FAC results in the extraction of warm O^+ ions from the dayside polar region. The O^+ ions transported to the lobe region with the adiabatic heating due to the convection electric field. The warm (hundreds of eV) O^+ ions are directed to the acceleration region in near-earth plasma sheet via the lobe region which is work as the "preconditioning". After the onset substorm expansion phase, the rich and warm O^+ ions are rapidly (within minutes) energized up to tens of keV under the effect of the large dawn-to-dusk electric field. This acceleration that occurs in the non-adiabatic manner, leading to the formation of the void structure in energy-L spectrograms. This is consistent with in-situ observations. The energetic O^+ ions via lobe significantly contribute to the O^+ ring current build up. At the same time, the auroral acceleration process thermalizes the ionospheric O^+ ions to hundreds of eV. Consequently, they are supplied to the inner magnetosphere and contributes to a fraction of the O^+ ring current. From the results, we have concluded that a combination between the pre-conditioning of the warm O^+ ion (hundreds of eV) in the lobe due to the enhancement of the midday part of the region 1 FAC and the non-adiabatic acceleration in the near-earth plasmasheet is the dominant energization process for the ring current O^+ ion during the substorm.

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