Plasmaspause Dynamics and Plasmaspheric Outflows

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Abstract

A three dimensional dynamic model of the plasmasphere coupled with the ionosphere model has been developed to determine the number density and temperatures of the different particles in the ionosphere, the plasmasphere, the plasmapause boundary layer and the plasmatrough. This is crucial because the plasmasphere plays a central role in magnetosphere-ionosphere dynamics and has also influence on the radiation belt populations. The position of the plasmapause, the limit of the plasmasphere, is highly dynamics with the geomagnetic activity. The model of the plasmasphere has been extended to give temperatures and composition and is provided as nowcasting and forecasting tool on the space weather portal.

1. Introduction

The plasmasphere is a characteristic region of the magnetosphere filled by ionospheric particles trapped in the magnetic field of the Earth. Its outer surface is the plasmapause where the number density sharply decreases. The thin region immediately outside the plasmapause is called the Plasmapause Boundary Layer (PBL). The shape and extend of these regions depend strongly on (i) the level of geomagnetic activity, (ii) on magnetic local time (MLT) and (iii) on universal time (UT).

In the kinetic model developed at BISA [1], the plasmasphere is filled with thermal electrons, protons, and other charged particles of ionospheric origin whose energies are less than 1-2 eV. They spiral along the geomagnetic field lines, and revolve around the Earth with the angular velocity almost equal to that of the Earth. These charged particles are trapped within the gravitational and the magnetospheric electric fields. Inside the plasmasphere, the electron and ion densities decrease smoothly along geomagnetic field lines and with radial distance up to the plasmapause where a sharp 'knee' is generally observed in the radial electron density profile. Beyond the plasmapause, the plasma density drops from about 300 cm^{-3} to less than 10 cm^{-3} over radial distances sometimes as short as 0.1 R_E. This sharp density gradient has been consistently observed by in space probes since the earliest missions, as well as from whistler wave analysis. Detailed analyses of whistler waves propagating along geomagnetic field lines from one hemisphere to the other enabled to determine characteristic variations of the plasmapause surface as a function of MLT and UT during geomagnetic variations. An updated compilation of the plasmaspheric discoveries obtained with the Cluster and IMAGE missions has been published in [2].

The physical mechanism used for peeling off the plasmasphere in the kinetic model is based on plasma interchange motion becoming convectively unstable from time to time. Indeed, during magnetospheric substorm onsets the plasma in the post-midnight outermost layers of the plasmasphere is accelerated eastwardly due to sudden enhancements of the convection velocity. The stronger the eastward acceleration, the steeper the density gradient will be in the midnight-to-dawn PBL. This is precisely what has been found from OGO-5 in-situ observations. Both satellite and ground based whistler observations definitely support the interchange theory for the formation of the plasmapause. In our numerical simulations, the initial equatorial cross-section of the plasmapause and its subsequent evolution depend on the history of Kp-index variations. The time dependence of the plasmapause is inferred from whistler data and confirmed by many other studies based on satellite measurements. As in our simulations, all these observations indicate that the plasmapause is closer to the Earth surface in the post-midnight region than at other magnetic local times; these observations indicate also that sometimes a bulge is forming in the plasmapause surface in the afternoon or dusk sectors at high altitudes. Morever, a plasmaspheric wind, i.e., a continuous expansion of the plasmasphere, rather similar to that of the solar corona has been inferred from the equatorial density profile of a corotating exosphere in hydrostatic equilibrium.. Recent Cluster observations confirm a slow but continuous hydrodynamic expansion of the plasmasphere.

The plasmasphere and plasmapause region also host the waves which are responsible for the acceleration, decay and transport of radiation belt particles [3]. The plasmasphere plays an important role in spacecraft charging effects, and it is a significant contributor to TEC (Total Electron Content) which contributes to GPS (Global Positioning System) inaccuracies and communications problems. Therefore the dynamics of the plasmasphere requires monitoring, modeling and forecasting, as contributed by our kinetic model.

2. Dynamical simulations of the plasmapause formation and deformation

Time dependent simulations of plasmasphere erosion based on the interchange mechanism were developed using different electric and magnetic field models [4]. They were confronted to actual plasmapause positions obtained from satellite and whistler observations during substorms and geomagnetically quiet periods. These comparisons show that most of the time simulations based on the interchange instability fit qualitatively in-situ observations. BISA's dynamical simulations have also been compared to EUV/IMAGE observations. These observations support satisfactorily time dependent simulations based on E5D magnetospheric electric field models, and on the peeling off mechanism of the plasmasphere by interchange instability.

3. Dynamical model with formation of plasmatails, plumes, shoulders or ripples

The three dimensional dynamical model of the plasmasphere developed at BISA can be used to forecast and nowcast the plasma density in the plasmasphere and in the plasmatrough. It is continuously running on Space Weather web site portal. It has also been imported at the Community Coordinated Modeling Center (CCMC) of NASA. This plasmaspheric model has recently been coupled to an ionospheric model [5] and require only time inputs (date and hour) to determine the level of geomagnetic activity, the convection electric field and the plasmaspheric characteristics in the geomagnetic equatorial plane, as well as in the meridian plane. An example is provided on Figure 1 illustrating the plasmapause position (in pink) and proton density obtained with the model in the plasmasphere during Halloween's event on 31 October 2003.

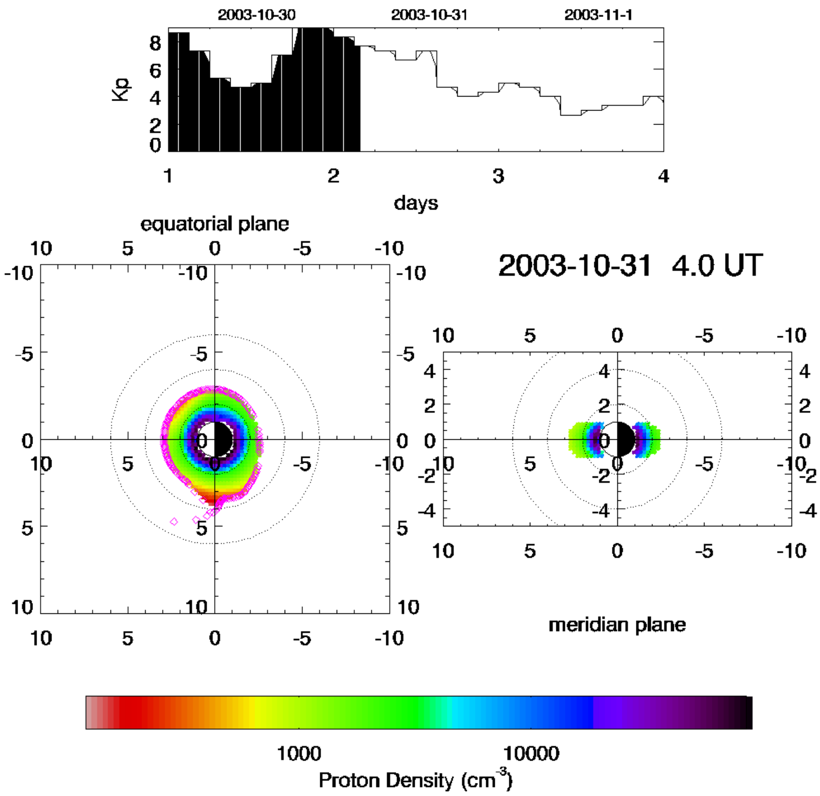

Figure 1: Plasmapause position and proton density obtained in the plasmasphere during Halloween's event on 31 October 2003. Due to this strong magnetic storm associated to a very high Kp index, the plasmapause is located very close to the Earth and a plume appears in the dusk sector.

This strong magnetic storm was associated to a Kp index larger than 8. A sharp plasmapause is then generated at a distance of the center of the earth lower than 3 Re. A plume is formed in the dusk sector.

Multiple plasmapauses have often been reported from whistler measurements as well as from in-situ satellite observations. The formation of an intermediate region between an old vestigial plasmapause and a new one that is formed at larger distances during a subsequent less severe substorm event has been simulated with the model. A kinetic description for the refilling of magnetic flux tubes, which had been emptied during a substorm has also been developed at BISA. At the plasmapause, large and small scale plasma irregularities have been observed by whistler and satellite observations. They are interpreted as diamagnetic plasma elements produced by the mechanism of plasma interchange instability. In addition to the electron number density, the plasmaspheric model is also completed with temperature profiles and ion composition.

4. Conclusions

The plasmasphere is a dynamic region being permanently influenced by the ionosphere and the outer magnetosphere. It is controlled by the relative intensities of the solar wind-imposed convection electric field and the co-rotation electric field. At the simplest level the plasmasphere is controlled by three factors: a global convection electric field, outflow/inflow from/to the ionosphere, and diffusive equilibrium. Fundamental parameters of the plasmasphere like the plasma distribution, density and composition and its dynamics with space weather events are provided by the plasmaspheric model. The formation of the plasmapause, the generation of shoulders and plumes, the plasmaspheric wind and the refilling process of plasmatrough flux tubes are important topics that are studied with the model to advance the understanding of magnetospheric physics. The model can be run on the space weather portal (www.spaceweather.eu) .

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7. References

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