§26. Reduced MHD Simulation of Magnetosphere-Ionosphere Feedback Interactions

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Theory of magnetic confinement fusion plasma has strong potential to provide us deeper understandings of unresolved problems in space and astrophysics. Auroral arc formation is one of the central questions in space physics, and is an example to which the theory of magnetic fusion plasmas can well be applied.

Spontaneous excitation of quiet auroral arcs has been discussed in terms of feedback interactions of the magnetosphere and the ionosphere. The magnetosphere-ionosphere (M-I) coupling system is destabilized, when the **E**x**B** convection flow exceeds a threshold[1]. The feedback instability grows with the ionospheric density and field-aligned current perturbations that would be associated with visible auroras. In previous studies of the feedback instability, the linear response of shear Alfven waves[2] (or its two-fluid extensions) was often employed for describing the cross-field dynamics of the magnetospheric plasma. Three-dimensional global simulations of the feedback instability involved the nonlinear magnetohydrodynamic (MHD) effects[3), 4)], while the coarse resolution employed made detailed studies of the nonlinear dynamics of auroral arcs quite difficult.

In our recent study[5], the reduced MHD equations are applied to the magnetosphere for construction of the M-I coupling system. The ionospheric behaviors are modeled by two-fluid equations. The new M-I coupling model enables us to explore nonlinear evolutions of the feedback instability. The reduced MHD simulation for a slab configuration manifests nonlinear saturation of the feedback instability growth. It is also found that the Kelvin-Helmholtz-like mode grows in the saturation phase, where role-up of thin vortex sheets is clearly observed. Simultaneously, one finds splitting of arc-like structures of the ionospheric density perturbation.

The theoretical and numerical model of the M-I coupling systems has recently been extended by means of the magnetic coordinates with the flux tube geometry for the dipole magnetic field configuration. Here, we introduced a similar idea to that used in the flux tube model for the turbulent transport simulation in toroidal confinement systems[6]. The new M-I coupling model greatly simplifying the theory and numerical implementation is a natural extension of the slab model. The simulation domain for the magnetosphere is shown in Fig.1 where the shear Alfven waves excited by the feedback instability propagates along the dipole field line. The magnetospheric dynamics is coupled with the ionosphere where the density and current continuity equations are solved in the same way as that for the slab case.

Snapshots of the ionospheric density and the vorticity on the magnetospheric equatorial plane are shown in Fig.2. The square box of 70km each in the left panel represents the two-dimensional ionosphere. The cross-section of the flux tube in the magnetosphere is a rectangular with 1,800km in the east-west and 3,300 km in the north-south directions, respectively. The simulation results shown in the figure demonstrate that the feedback instability growing in the dipole configuration causes nonlinear deformation of the vorticity pattern in the magnetosphere, as seen in the slab geometry. Correspondingly, after a short time delay, the ionospheric density and current patterns are also modified, and enter into a turbulent phase. This is the first simulation that can explain spontaneous growth of auroral arcs and their nonlinear deformation in the realistic (dipole) configuration of the M-I coupling.

Further extensions of the M-I coupling with application of more recent theoretical models for fusion plasmas are currently in progress, and will be reported elsewhere.

Fig.1. Simulation domain for the magnetosphere with the dipole configuration

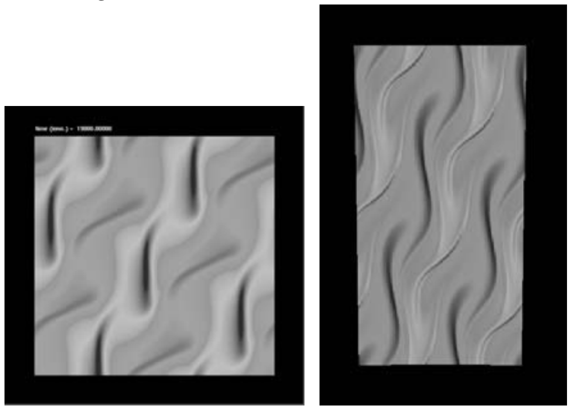

Fig.2. Snapshots of the ionospheric density (left) and the vorticity on the magnetospheric equatorial plane (right).

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