Quiet arc の成因

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Origin of the quiet arc

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By the global M-I coupling simulation named the REPPU (REProduce Plasma Universe) code, the quiet arc is reproduced during the growth phase of numerical substorm. Since the grid structure gives the most significant influence on the performance of the global simulation, the REPPU code uses a dense unstructured grid system having no apparent singularity. The generation of this grid is started from a dodecahedron. First, one pentagonal surface of dodecahedron is divided into 5 triangles, and then each triangle is divided into 4 smaller triangles. Similar process is continued and 122,886 grid points (245,760 triangles) are obtained after 7 times of division. The 3-D grid system is generated by radially stacking 360 spheres. Inner and outer boundaries are at 2.6 Re and 300 Re, respectively. For this grid system, spatial resolution is about 0.5° in the ionosphere.

Figure 1 shows the growth phase solution obtained by the REPPU. Four white lines in Figure 1 are drawn from the most high-latitude and most low-latitude points in the region 2 FAC area (proton auroral region) for two LTs. When the magnetic field lines are traced up from the region 2 FAC area in the pre-midnight, these magnetic field lines reach the high-pressure region in the equatorial plane (x=-7 - -12 Re) that is extending behind the inner boundary of the plasma sheet. Figure 2 is similar to Figure 1, but shows current lines instead of magnetic field lines. As shown by the white lines in Figure 2, the current lines that are traced up from the proton auroral region bend to the west after reaching some extent high-altitude and connect to the reverse ring current. It is not guaranteed that current lines from the ionospheric FAC coincide with the magnetic field lines up to the equatorial plane. That is, the current lines go deviated from the magnetic field lines when they reach the high-altitude region. When the magnetic field line is traced up from the quiet arc (exactly region 1 FAC area), its low-latitude edge is mapped to the midtail plasma sheet (around x=-15 Re) as shown by red lines in Figure 1. Similarly, its high-latitude edge is mapped to the lobe just outside the lobe-plasma sheet boundary (red lines in Figure 1). Namely, the region 1 FAC in the ionosphere distributes over both regions of closed and open magnetic field lines. Even the current lines are traced up from the same points, they do not coincide with the traces of the magnetic field lines. After extending beyond x = -10 Re, all current lines traced up from the region 1 FAC area reach the outside of lobe-plasma sheet boundary (red lines in Figure 2). All region 1 FACs finally reach the mantle and connect to the dynamo there. Magenta lines in Figure 7 show the cross-tail current.

From observations, it is generally believed that proton precipitation is from the outer radiation belt and the most low-latitude arc is connected to the near-earth plasma sheet within X=-10 Re. In the model estimated from observations, the current line is simply replaced by the magnetic field line, so that not only the origin of electron precipitation to the most low-latitude arc (=precursor of the onset) but also the formation of CW are assumed to be in the near-earth plasma sheet around x=-7 Re. This assumption has brought about a strong motivation for the theory that the substorm onset starts from the instability at the near-earth plasma sheet.

Thus, a fundamental contradiction occurs in the way of understanding the quiet arc and accompanying FAC, between the observational estimation and the simulation result. In the traditional interpretation, it is generally assumed that the configuration of magnetic field controls the particle precipitation and the particle precipitation further controls the FAC. However, it is misleading to understand the FAC as an another aspect of particle precipitation. In the simulation result, the FAC occurs to transmit the motion from the magnetosphere to the ionosphere. The FAC is more fundamental structure determined by the global dynamics. The current is a twist of magnetic field lines carried by convection, and has no direct relationship with the particle structure. In the resulting region 1 FAC area (upward FAC area) in the evening side, electron precipitation is promoted by the upward FAC. The flow shear in the y direction (fast inside slow outside) penetrates into the plasma sheet as far as x=-12 Re corresponding to the electron precipitation. Similarly, the proton precipitation on the evening side is determined by the distribution of region 2 FAC. The width of the proton precipitation zone becomes 2° both in the observation and simulation.

The quiet arc reproduced in the simulation contradicts with the onset caused by the CW. In the simulation result, the onset is generated by the near-earth dynamo. Thus, simulation results also require to abandon the traditional CW.

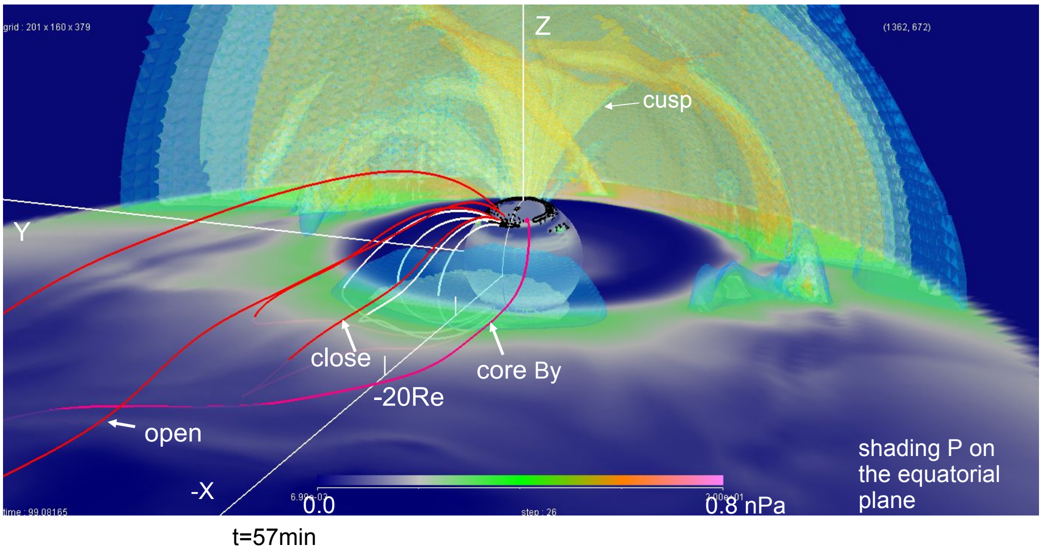

Figure 1. Magnetic field configuration and pressure distribution in the growth phase magnetosphere. In this figure, color shading illustrates pressure distribution on the equatorial plane and on the r=2.6 Re surface. Red and white lines illustrate the magnetic field lines extending from the region 1 and 2 FAC areas, respectively. Volume rendering shows the 3D distribution of pressure (3 transparent surfaces for 0.3 nPa, 0.5 nPa, and 0.7 nPa).

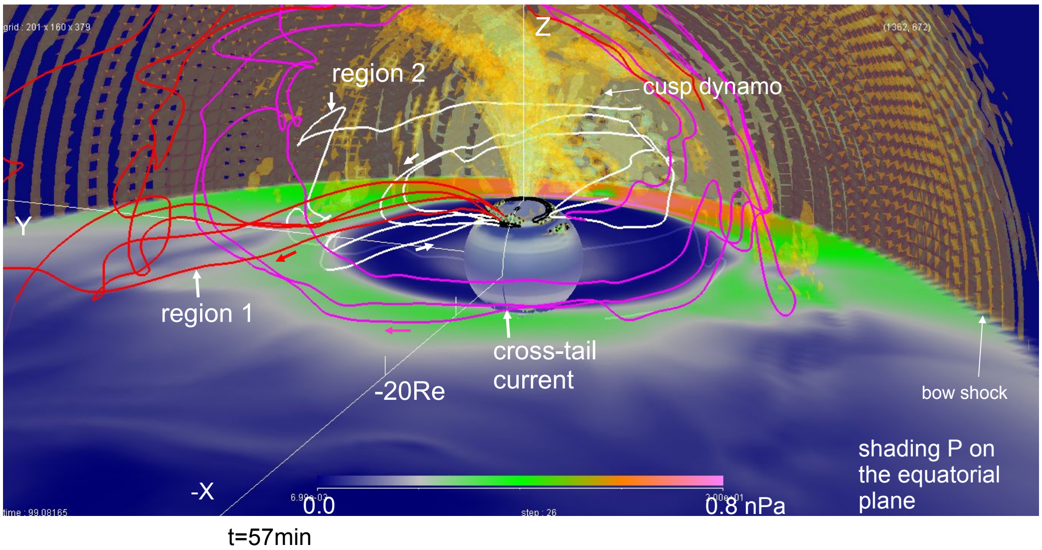

Figure 2. Current system during the growth phase. In this figure, color shading illustrates pressure distribution on the equatorial plane and on the r=2.6 Re surface. Red and white lines illustrate the magnetic field lines extending from the region 1 and 2 FAC areas, respectively. Magenta lines show the cross-tail current. Volume rendering shows the 3D distribution of dynamo (two transparent surfaces for 3.9 × 10-12 and -15.6 × 10-12 joule/sec/m3).