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A mechanism of a jet-like flow in rotating spherical magnetoconvection

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We made a high-resolution numerical simulation of magnetoconvection and found a characteristic flow pattern like a narrow jet. We describe the structure of the jet-like flow in detail and present the possible generation and sustaining mechanism.

Magnetoconvection occurs in a rotating self-gravitating spherical shell. A uniform axial magnetic field is applied so that the Elsasser number (a presumable ratio of the Lorentz to the Coriolis forces) is unity. A temperature difference between the inner core and the mantle drives thermal convection. A westward (retrograde) zonal flow is prominent in most of the fluid outer core, though there are rather stationary vortices beneath the equatorial part of the core-mantle boundary (CMB). A hot plume rises from the equatorial part of the inner core surface, capturing an axial magnetic field at the western (downstream) side. On the other hand, a cold plume occurs from bottom of the mantle, capturing the magnetic field at the eastern (upstream) side. These plumes in the presence of the westward zonal flow form a wavy flow pattern circulating around the inner core. The location of the plume drifts westward at almost the same phase velocity as that of the zonal flow. However, it fluctuates due to the presence of rather stationary vortices beneath the CMB. When the drift of the cold plume decelerates, the axial magnetic field at the eastern side becomes dammed up, creating a steep gradient of the magnetic field intensity at the plume. This magnetic field structure might be designated as a magnetic front. There forms an electric current sheet along the magnetic front and the resulting westward Lorentz force can be balanced by the Coriolis force due to the velocity component of the plume down from the CMB. As a result, there forms a thin jet-like flow starting from the CMB and ending to nearly the inner core surface, just parallel or antiparallel to the thin current sheet to sustain a force balance. There exist axial (poleward or equatorward) electric currents perpendicular to the equatorial plane because zonal (toroidal) magnetic fields in the mid-latitudes are forced to be wound up by the thin jet. There also coexist poleward axial flows away from the equatorial plane so as to compensate the Lorentz force by the Coriolis force. The poleward flows stretch and intensify the axial magnetic field around the equatorial plane, sustaining the magnetic frontal structure in a natural manner.

Magnetoconvection in the presence of an ambient field is chosen so that a coupling between flows and magnetic fields can be seen in the condition of a moderate Reynolds number. Although this is not a self-exciting dynamo, the general structure and process found in this simulation would be applicable to rapidly rotating magnetohydrodynamic problems including the geodynamo.