Deep Zonal Flow and Time Variation of Jupiter's Magnetic Field

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All four giant planets in the Solar System feature zonal flows on the order of 100 m/s in the cloud deck, and large-scale intrinsic magnetic fields on the order of 1 Gauss near the surface. The vertical structure of the zonal flows remains obscure. The end-member scenarios are shallow flows confined in the radiative atmosphere and deep flows throughout the entire planet. The electrical conductivity increases rapidly yet smoothly as a function of depth inside Jupiter and Saturn. Deep zonal flows will advect the non-axisymmetric component of the magnetic field, at depth with even modest electrical conductivity, and create time variations in the magnetic field.

The observed time variations of the geomagnetic field has been used to derive surface flows of the Earth's outer core. The same principle applies to Jupiter, however, the connection between the time variation of the magnetic field (dB/dt) and deep zonal flow (U_phi) at Jupiter is not well understood due to strong radial variation of electrical conductivity. Here we perform a quantitative analysis of the connection between dB/dt and U_phi adopting Jupiter's interior electrical conductivity profile. This provides a tool to translate expected measurement of the time variation of Jupiter's magnetic field to deep zonal flows. We show that the current upper limit on the dipole drift rate of Jupiter (3 degrees per 20 years) is compatible with 10 m/s zonal flows with < 500 km vertical scale height below 0.972 Rj. We further demonstrate that fast drift of resolved magnetic features (e.g. magnetic spots) at Jupiter is a possibility.

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