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Heat flux boundary anomalies and thermal winds

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Several studies have shown strong effects of outer boundary heat flux patterns on the dynamo mechanism in planets. For example, the hemispherical field of the ancient Martian dynamo can be explained by a large scale sinusoidal anomaly of the core mantle boundary heat flux triggered by large scale mantle convection or giant impacts. The magnetic fields show typically the desired effect – though dynamo action is locally stronger where the underneath heat flux is higher. However, it remains an open question if these effects still apply for more realistic planetary parameters, such as vigor of the convection (Rayleigh number) or the rotation rate (Ekman).

The sinusoidal variation of the CMB heat flux along the colatitude with larger heat flux in the southern and smaller in the northern hemisphere as used for Mars can lead to a concentration of magnetic field in the south. The shape of such a hemispherical dynamo matches the crustal magnetization pattern at the surface and seems therefore an admissible mode for the ancient Martian dynamo. As the consequence of the emerging latitudinal temperature gradients convection and induction are dominated by thermal winds. These zonal flows were found to be equatorial antisymmetric, axisymmetric, ageostrophic, of strong amplitude and have therefore a severe effect on core convection and especially the induction process. We measure the underlying thermal anomalies as a function of Rayleigh and Ekman number and show that they are responsible for the thermal winds.

Our results suggest that temperature anomalies decrease clearly with the supercriticality of the convection due to faster stirring and mixing, but show no additional dependence on the Ekman number. Interestingly, the decline of the latitudinal temperature anomaly follows a recently suggested scaling law for the thickness of thermal boundary layers. Even though the convective supercriticality of planetary cores is rather large and therefore only a minor effect of thermal boundary disturbances is expected, we suggest thermal winds can still significantly contribute to the total kinetic energy in real planetary core.