EPSC Abstracts
Vol. 10, EPSC2015-677, 2015
European Planetary Science Congress 2015

Flows and magnetic fields in the convective interiors of tidally locked exoplanets

W. Dietrich (1), K. Hori (1), J. Wicht (2) and C.A. Jones (1)
(1) Department of Applied Mathematics, University of Leeds, Leeds, UK (2) Max Planck Institute for Solar System Research, Göttingen, Germany (w.dietrich@leeds.ac.uk)

Abstract

A large fraction of exoplanets orbit their host in synchronous rotation, hence the front side of the planet is strongly irradiated. We aim to understand the dynamic consequences for the convective flows and the dynamo process induced in the convective interiors subject to heterogeneous cooling. For exoplanetary gas giants the convective interior is part of the thick gaseous atmosphere, whereas for terrestrial planets we model the liquid part of the iron core. It is not understood, how such an outer boundary thermal anomaly is affecting the interior. Global, threedimensional dynamic models of convection and magnetic field induction might help to further develop a physical understanding of the interior properties and dynamics of exoplanets. As a first step, incompressible systems with and without competing radial convection should set a basis of more complex models taking various other characteristics, such as compressibility or inflation into account.

1. Introduction

We numerically investigate the convective interior as an incompressible, electrical conducting and rapidly rotating fluid contained in a spherical shell which is subject to internal heating and which outer boundary heat flux is varied along azimuth (see figure 1). The strong hemispherical temperature difference between front and back drives two strong azimuthal flow cells converging into a persistent and strong downwelling on the far side of the planet. Earlier analytical models suggested that the downwelling is phase shifted by 90 degrees eastwards to the terminator ([1], [2]). Our 3D fully nonlinear results confirm that prediction, but also characterise different regimes of the phase shift and the jet-like downwelling for sub- and supercritical convection. It is found, that for supercritical convection the position of the downwelling depends on various model parameters, such as the amplitude of the outer boundary heat flux anomaly. Further we discuss the interior flow and temperature structure and give an overview of the morphology of the induced dynamo fields.

2. Results

The combination of radial and horizontal temperature gradients will lead to a complex superposition of various flows. The heat flux anomaly is positioned such that, the hot mantle feature (and hence the host star) is on the right at $\phi = 0$, where then also the smallest amount of heat is extracted from the core as indicated by the small red arrows in the figure. Thus the largest CMB heat flux is at the opposite point (at $\phi = \pi$). Expectably, the boundary anomaly should drive a flow consisting of two cells, a (eastern) cold cyclone and a western hot anticyclone. The cells merge into an upwelling (downwelling) where the CMB heat flux is small (large).

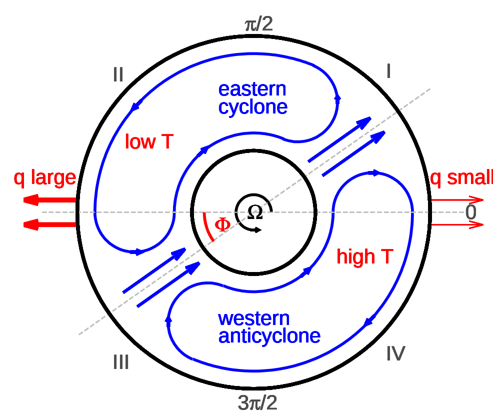

Figure 1: The horizontally varying outer boundary heat flux is mininal (maximal) at $\phi = 0$ ($\phi = \pi$).

A larger, but still subcritical Rayleigh number focusses the downwelling and smeares out the upwelling by temperature advection. Whereas a further enhanced Rayleigh number close to onset of convection allows for buoyancy to take part, and the persistent downwelling migrates slightly backwards. We report methods to isolate and characterise the downwelling in time variable flows, overview the azimuthal distribution and 3D structure of mean flows, convection, temperature. Further we propose a scaling law for the amplitude of the downward jet. Finally, we investigate the structure of the emerging magnetic fields and how they alter the leading order force balance.

3. Summary and Conclusions

Our numerical results confirm the analytical predictions ([1], [2]), but show clearly that there are various further flow regimes depending on the unstable stratification [3]. For a realistic planet with a strong boundary anomaly the time-persistent jet-like downwelling might be phase shifted by ca. 30 degrees eastwards from the antistellar point seperating the hot western and cold eastern hemisphere. Hence the radial convection is much stronger at smaller azimuthal angles then the jet location, but almost suppressed eastward of it. This might have consequences for the magnetic field induction process as it relies on small scale, buoyant flows. When the heat flux variation is significantly smaller than the mean heat flux, the jet can move to much larger phase shifts. Further a scaling prediction suggest, that amplitude of the inward jet is at least on the order the global kinetic energy.

References

[1] Zhang, K., and Gubbins, D.M.: On convection in the earth's core driven by lateral temperature variations on the lower mantle, Geophys. J. Int., Vol. 108, 1992

[2] Yoshida, S. and Hamano, Y.: Fluid Motion of the Outer Core in Response to a Temperature Heterogeneity at the Core-Mantle Boundary and Its Dynamo Action, J. Geomag. Geoelctr., Vol. 45, 1993

[3] Dietrich, W., Wicht, J. and Hori, K.: Jet-like flows in the liquid cores of tidally locked terrestrial exoplanets, submitted to Astrophysical Journal, 2015