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Influence of Mercury's laterally varying surface temperature on its mantle convection, geoid, lithospheric stress distribution and dynamo action

P. J. Tackley (1), J. M. Aurnou (2), and J. Aubert (3)

(1) Institut für Geophysik, ETH Zürich, Switzerland (ptackley@ethz.ch), (2) Department of Earth and Space Sciences, University of California Los Angeles, USA, (3) Dynamiques des Fluides Geologiques, Institut de Physique du Globe de Paris, 4 place Jussieu, 75231 Paris cedex 5, France

Due to the absence of an atmosphere and proximity to the Sun, Mercury's surface temperature varies laterally by several 100s K, even when averaged over long time periods. The dominant variation in time-averaged surface T occurs from pole to equator ($\tilde{2}25$ K) [1]. The resonant relationship between Mercury's orbit and rotation results in a smaller longitudinal variation ($\tilde{1}00$ K) [1]. Here we demonstrate, using models of mantle convection in a 3-D spherical shell, that this stationary lateral variation in surface temperature has a small but significant influence on mantle convection and on the lateral variation of heat flux across the core-mantle boundary (CMB). We evaluate the possible observational signature of this laterally-varying convection in terms of boundary topography, stress distribution, gravity and moment of inertia tensor. We furthermore test whether the lateral variation in CMB flux is capable of driving a thermal wind dynamo, i.e., weak dynamo action with no internally-driven core convective motions.

For Mercury's mantle we assume a dry olivine rheology including both diffusion creep and disclocation creep with rheological parameters such as activation energy and volume taken from the synthesis of [2]. We assume decaying radiogenic heat sources with the same concentration as in the bulk silicate Earth, and a parameterised model of core cooling. The models are run for 4.5 Ga from a relatively hot initial state with random initial perturbations. We use the code StagYY, which uses a finite-volume discretization on a spherical yin-yang grid and a multigrid solver [3].

Results in spherical axisymmetric geometry, compare a case with constant surface temperature to one with a latitude-dependent surface temperature. The system forms about 3 convection cells from pole to equator. Although the results look similar to first order, in the latitude-dependent case the convection is noticably more sluggish and colder towards the pole. In CMB flux, both cases display large oscillations due to convection cells. A pole-to-equator trend is superimposed on this for the case with laterally-varying surface temperature. Although the amplitude of this long-wavelength variation is smaller than that of the within-cell variation, its long-wavelength nature might be effective in driving thermal winds in the core.

Results in a full 3-D spherical shell indicate that convection adopts a cellular structure with a polygonal network of downwellings and plume-like upwellings, as is usually obtained for stagnant lid convection, for example, in the recent 3-D spherical Mercury models of [4]. This is in notable contrast to the models of [5], in which linear upwellings were obtained. This difference could be because the initial perturbations used by [5] used a small number of low-order spherical harmonics, i.e., a long-wavelength pattern with particular symmetries, whereas our initial perturbations are random white noise. The origin of this difference requires further investigation.

The pattern of CMB heat flux shows a strong l=2, m=0 pattern, again with superimposed small-scale variations due to convection cells. The surface geoid displays an very dominant (2,0) pattern, which would be a strong diagnostic of this behaviour. These models are being further analysed for boundary topography and stress distribution.

Models of planetary dynamos have traditionally depended upon the concept that secular cooling and internal radioactive decay are responsible for genererating convective fluid motions within the core [e.g. 6]. Some models, of Earth's dynamo in particular, also include thermal winds –shear flows driven by heat flux variations along the core-mantle boundary – that modify the dynamo process [e.g. 7]. We have now shown, following the work of [8], that thermal winds themselves are capable of driving dynamo action in planetary cores (Fig. 4). In fully self-consistent, three-dimensional models, we find that thermal wind dynamos do not require a net heat flux to emanate from the core and can operate even when the core fluid is neutrally stratified. In these models, the dynamo is powered externally by thermal energy stored in the mantle. This dynamo mechanism can occur on planetary bodies, such as Mercury, which are likely to have weak net heat fluxes from their cores but possess significant core-mantle boundary heat flux variations (Figures 1 - 3). We plan to use the pattern of CMB heat flux from the mantle models as a boundary condition for core models, in order to determine the feasibility of thermal wind dynamo action occurring in Mercury's core.

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