Large thermal anomalies in the lower mantle and implications for Earth's magnetic field

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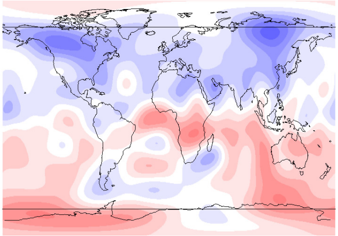
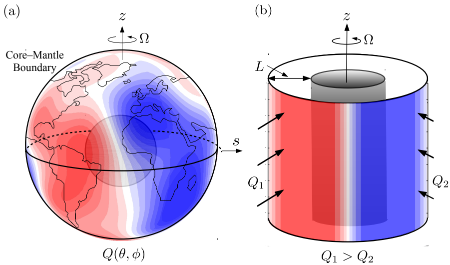
Earth's magnetic field



(Willis, Sreenivasan & Gubbins, 2007).

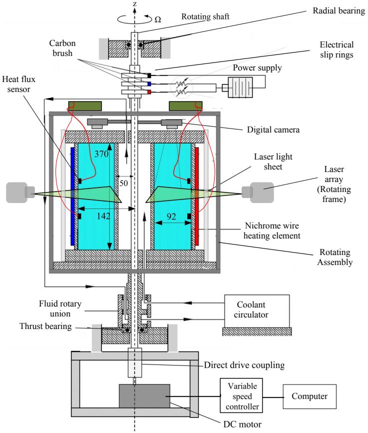
- The high-latitude magnetic flux lobes suggest inhomogeneity of core convection. The Canadian pair is relatively unstable; the Canadian lobe split in half in the mid-19th century (Jackson et al., 2000; Gubbins et al., 2007).
- Identifying the differences in flow pattern beneath West and East can help constrain the regime of core convection.

Lower mantle heterogeneity



- The seismic shear wave velocity variation in the lower mantle is nearly symmetric about the equator.
- Interaction between lateral buoyancy and gravity peaks approximately at the equator.
- Identifying the differences in flow pattern beneath Canada and Siberia can help constrain the regime of core convection.

Experimental set-up

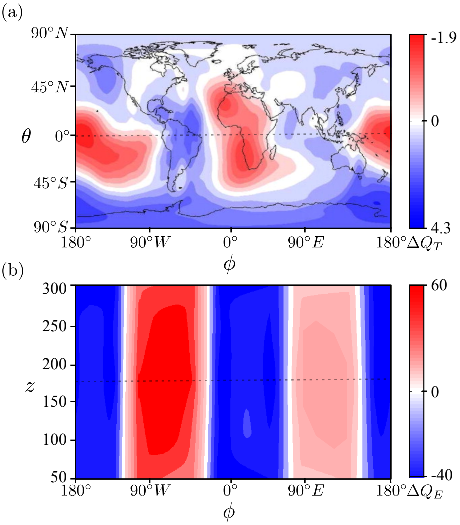


$r_i/r_o = 0.36$, $\Omega = 300$ rpm, flow measurement by PIV.

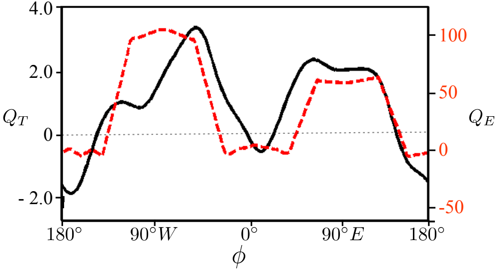
The experiment

- Uses centrifugal acceleration and a reversed temperature gradient. Rotational Froude number $\Omega^2 L/g = 9.26$.
- Inner cylinder is isothermal, outer cylinder has constant heat flux imposed on it.
- The experiment examines the response of rotating convection to a large-scale variation in outer boundary heat flux.
- q^*, the ratio of maximum azimuthal variation in boundary heat flux to the mean value, varies in the range 0–2. Provides unstable and neutrally stable stratification. Value of q^* for the core is not well constrained.

Applied boundary heat flux variation

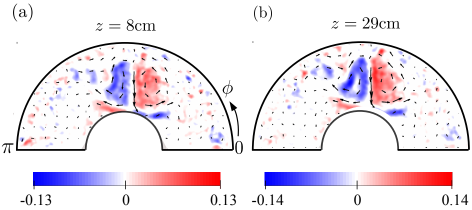


Applied vs equatorial heat flux



- Ratio of equatorial heat fluxes beneath regions of high seismic shear wave velocity are scaled to the experiment. $q^* = 2.4$.
- Highest heat flux anomaly beneath South America.
- Heat fluxes beneath Pacific and Central Africa are kept equal for simplicity. (These regions may be stratified beneath CMB).

Quasi-geostrophy



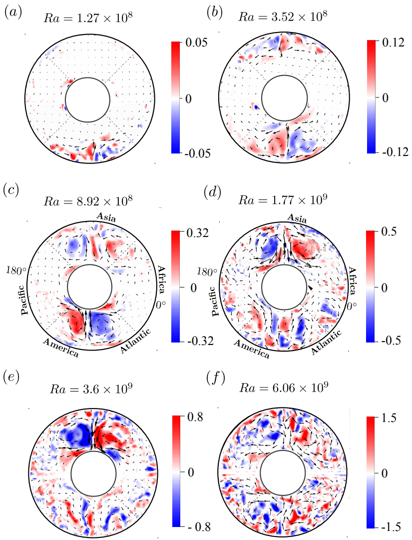
For $Ra = \Omega^2 \alpha \beta L^5 / \nu \kappa \sim 10^{10} \sim 50 Ra_c$,

$$\frac{\overline{\omega_1 \omega_2}}{\sqrt{\overline{\omega_1^2}\ \overline{\omega_2^2}}} > 0.8.$$

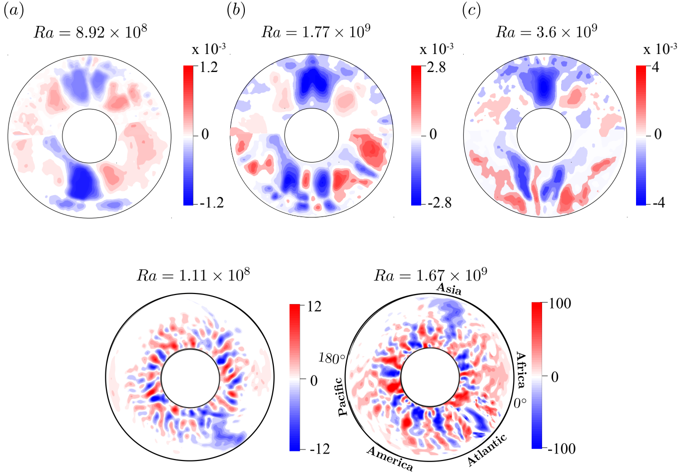
$$\frac{\partial \omega_z}{\partial z} = \frac{Ra\ E}{Fr}\ \nabla_H^2 T + Ra\ E\ \left[2 \frac{\partial T}{\partial z} + r \frac{\partial^2 T}{\partial r \partial z} \right] + E\ \nabla^4 u_z,$$

where ∇_H^2 is the horizontal Laplacian. $\partial T / \partial z \approx 0$.

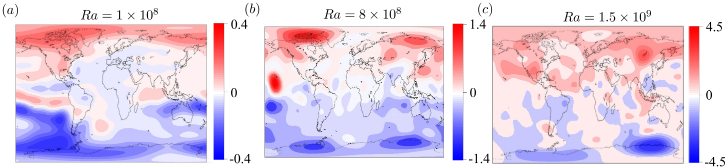
Convection patterns



Experiment and simulation – radial velocity



Spherical shell dynamo – radial magnetic field



- The migration of coherent convection from West to East is reflected in the migration of the high-latitude magnetic flux lobes.
- Strongly driven convection with large lower mantle heterogeneity produces the eastward preference for the magnetic North pole.
- This regime is obtained in approximately geostrophic states, which requires strong rotation in models.