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Semi-convective planetary cores

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The recent Juno and Cassini space missions delivered a wealth of observations of Jupiter and Saturn.
Constraints from gravity data and ring seismology suggest that these planets host a dilute core of substantial size, in which the concentration of heavy material increases with depth.
This stabilising compositional gradient coexists with a destabilising thermal gradient induced by the secular cooling of these planets.
As thermal anomalies diffuse on time scales much shorter than compositional anomalies, this configuration is prone to fluid instabilities termed semi-convective instabilities.
Semi-convection has been studied in the context of oceanography and astrophysics.
Results from local models in Cartesian geometry show that semi-convection can take the form of internal gravity waves or layered convection, in which sharp interfaces separate well-mixed regions that can eventually merge.
In order to check to which extent these results can be applied to the interior of giant planets, we have conducted a parametric study of semi-convective dynamics in a non-rotating, non-magnetised sphere, using the MagIC code.

A linear stability analysis shows that the instability takes the form of internal gravity modes, whose morphology and eigenfrequency can be adequately explained by an analytical solution derived in the ideal (diffusion-free) limit.
In particular, we find that the onset mode corresponds to the fundamental mode of the diffusion-free problem.

Past the onset, we identify three distinct regimes of semi-convection from our catalogue of 93 simulations.
In the first regime, close to onset, internal gravity modes emerge, with a large-scale azimuthal structure near the centre of sphere, and finer-scale structure near the surface (Fig.1a).
The fluid remains stably stratified, and the transport of composition and temperature across the domain is weak.
Triadic interactions between small-scale, unstable gravity modes and large-scale, stable gravity modes explain the overall stability of this regime.

The second regime is reached upon further increase of the thermal driving: internal gravity modes initially emerge but a convective core eventually develops at the centre (Fig.1b).
This core grows with time and finally occupies the whole fluid volume, which makes the transport of composition and heat more efficient than in the first regime.
Lastly, for the most driven simulations, convective layering occurs (Fig.~1c). In this third regime, the number of layer increases with the level of thermal driving.
These layers have a finite lifetime and they ultimately merge to yield a state of global overturning convection.

We discuss the application of our findings to the interior of Jupiter, that could operate either in the second or third regime, based on a tentative extrapolation of our results.

Speaker information

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