[S5-P01] Magnetic instability, slow-wave propagation, and dynamo saturation

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Abstract

Magnetic instability of an axisymmetric toroidal field in a rotating, magnetostrophic, and finitely conducting fluid sphere is studied by means of linear eigenvalue analysis. The model is similar to the one that Phillips and Ivers (PEPI 153, 83-100, 2005) studied, but we assumed a toroidal field that is proportional to s^k (1-z^2)^(k-1) (1-r^2) (k=1,3,5,..; equatorially symmetric field) or to s^(k-1) z (1-z^2)^(k-2) (1-r^2) (k=2,4,6,..; equatorially antisymmetric field) in order to examine instability of equatorially concentrated toroidal fields, where (s,z) are the cylindrically radial and axial coordinates and r^2=s^2+z^2. We successfully obtained the complex angular frequency of the most rapidly growing (or most slowly decaying) mode for different parities with respect to the equatorial plane, different azimuthal wavenumbers, and the Elsasser number and the index, k, of the basic toroidal field.

The results are summarized as follows: (1) There is a general tendency that a magnetic field perturbation of the same parity as the basic toroidal field grows fast; that is, when k is even, for example, a magnetic field of dipole parity grows as a result of magnetic instability. (2) The resulting field perturbation propagates eastward (prograde) at a phase speed that is not very different to the slow-wave velocity scale. The wave speed becomes high with increasing k. (3) The critical azimuthal wavenumber is roughly equal to k. The wavelength becomes shorter, as the basic field is concentrated around the core equator. (4) The critical Elsasser number lies in the range from 6 to 15 as far as we studied (k< 16). (5) We defined the maximal growth rate, where the dimensionless growth rate (the imaginary part of the eigen frequency) is scaled by the slow-wave timescale. We obtained a good approximation that the maximal growth rate is proportional to k^2.

As was written in Introduction of Roberts and Loper (JFM 90, 641-668, 1979), studies on magnetic instability have two meanings: explanation for the geomagnetic westward drift and its workings on the geodynamo. We surmise that the westward drift reflects a westward zonal flow but is slightly modified by eastward wave propagation. We propose an idea that strength of a naturally generated axisymmetric toroidal field can be explained by considering the balance between the energy transfer rates of magnetic instability loss and dynamo creation. The discussion will be given in the poster presentation.

*Speaker

[S5-P02] Planar convection-driven dynamos yield magnetically-guided jets and large-amplitude cycles

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Abstract

Understanding the dynamics of the Earth's outer core remains challenging due to the inability of conventional numerical models to access core-like parameter regimes. We simulate numerically a convection-driven dynamo model in a plane layer geometry that is valid in the asymptotic limits of small Ekman and magnetic Prandtl numbers. Previous investigations of the hydrodynamic version of this model have found an inverse-cascade-generated large-scale vortex that passively advects the underlying convective structures. The presence of the magnetic field fundamentally alters this process by saturating the depth-averaged flow at a length scale that is comparable to that of the convection. For strongly-driven flows, depth-averaged jets form in a direction that minimizes ohmic dissipation; the jets then become shear unstable and lead to large-amplitude dynamo cycles. The jets organize and shear the underlying small-scale convection, leading to an increase in ohmic and viscous dissipation and therefore a net increase in the heat transfer.

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†Speaker

[S5-P03] Spontaneous Transitions of the Magnetic Field Morphology within Long-time Evolution Simulations

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Abstract

We present the results of convection-driven spherical dynamo simulations that are evolved up to 30 large-scale magnetic diffusion times. Periods of strongly-stable dipolar magnetic fields lasting up to 6 magnetic diffusion times, and periods of chaotic magnetic polarity reversals lasting up to 9 magnetic diffusion times, are both observed during the same simulation. The transition from stable dipole to chaotic reversals is preceded by an instability at the tangent cylinder, which generally acts as a transport barrier during periods of stable dipolarity. The instability is marked by the radiation of high frequency inertial waves and leads to a net transfer of magnetic energy from the dipole to higher poles; the result of this process is a growth of magnetic energy that eventually exceeds the kinetic energy during the chaotic reversal period. The thermal evolution rate of the system, as characterized by the Nusselt number, increases during the chaotic reversal period when the ohmic dissipation exceeds the viscous dissipation.

*Speaker

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[S5-P04] Thermal Convection with a Strong Vertical Magnetic Field

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Abstract

The fluid outer core of the earth and many other planetary interiors generate large-scale magnetic fields. Though these magnetic fields are thought to change the dynamics of the flow significantly, the details of their influence on the dynamics of planetary interiors remain poorly understood. We utilize direct numerical simulation in a Cartesian plane layer geometry to study the physics of convection in the presence of a strong, imposed vertical magnetic field. We consider the geophysically-relevant limit of asymptotically-small magnetic Prandtl number. Three dynamical regimes are observed as the Rayleigh number Ra is increased for each fixed value of the Chandrasekhar number Q. Each regime is characterized by distinct flow characteristics and heat transfer (Nusselt number, Nu) scaling. In the first regime, the boundary layer is not well-formed and a finite mean temperature gradient exists in the fluid interior. In the second regime, the interior of the flow becomes nearly isothermal, and the Nu-Ra is suggestive of dynamics that are largely controlled by a marginally-stable thermal boundary layer. At even higher values of Ra, inertia becomes dominant over the Lorenz force, resulting in a Nu-Ra that resembles that of the non-magnetic case. The changes of the dominant terms in the governing equations, and the contribution of ohmic and viscous dissipation are analyzed. A reversed (stable) temperature profile occurs in the second regime, which is associated with a stable thermal plume structure, suggesting an efficient way of heat transfer. The results of this work help to illustrate the complex role that magnetic fields might play in the dynamics and thermal evolution of natural dynamos.

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[S5-P05] Scaling behaviour of spherical shell rotating convection

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Abstract

Convection-driven flows under the influence of rotation exist in many natural systems such as the liquid iron cores of terrestrial planets. The dominant role of rotational forces on core dynamics prevents state of the art numerical models from being run with Earth-like parameters. In order to establish a connection between numerical models and the geophysical motivation, we turn to scaling laws.
We undertake a systematic investigation of non-magnetic convection in a rotating spherical shell which uses a radius ratio of 0.35 and heat flux boundary conditions as to best match the Earth's core. The dynamics are determined by the Ekman number (E), a measure of the strength of the Coriolis force, the Rayleigh number (Ra), measuring the vigour of the thermal driving, and the Prandtl number (Pr), the ratio of the viscous and thermal diffusion. We consider a suite of _~ 100
numerical models with Ekman numbers spanning 1e-6 - 1e-3 , Pr = 1 and Ra up to 800 times the critical value for the onset of convection, Rac.

In agreement with recent findings, we identify different dynamical regimes through observed changes in the scaling behaviour of the heat transfer and flow properties. Close to the onset of convection the heat transfer, characterised by the Nusselt number (total heat transfer/conductive heat transfer), is described by the nonlinear perturbation analysis. For increased supercriticalities, at low Ekman number (E < 10^{−5}) a steep heat transfer scaling is exhibited in the rapidly rotating regime. When the thermal forcing is sufficiently high, the rotational constraint on the flow is gradually lost until the weakly rotating behaviour is recovered Nu _~ Ra^{2/7} .
In this poster we will describe the scaling behaviour for the heat transfer (Nusselt number, thermal boundary layers) and the flow properties (typical length scales, flow speeds, mechanical boundary layers) in the different dynamical regimes.

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[S5-P06] Precessional-convectional instabilities in a spherical system

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Abstract

Generally, the Earth's dynamo is attributed to thermo-compositional convection, which is supported by numerical simulations in a range of parameters far from core conditions. Meanwhile, numerical studies (Tilgner, 2005; Wu and Roberts, 2009; Lin et al., 2016) have shown that precession alone is also a plausible forcing mechanism to drive a dynamo. In particular, Lin et al. (2016) have observed that large scale vortices (LSV) can favor the generation of large scale magnetic fields in the conducting region. Similar observations have been reported in thermal convection simulations (Guervilly et al., 2015) suggesting that LSV may play an important role in the dynamo process. In different geometries, tidal forcing can be inhibited or enhanced by the temperature profile (Le Bars and Le Dizès, 2006; Cébron et al., 2010), and numerical simulations suggest that the coupled precession-convection forcing can enhance magnetic induction (Wei, 2016). In the present study, we investigate numerically in a full sphere the coupled precession-convection dynamo starting with the purely hydrodynamical regime.

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[S5-P07] Core flow driven by nutation of the Inner Core

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Abstract

In planetary bodies with a fluid core, gyroscopic motions of the rotation axis, such as precession, produce flow structures that can store and exchange angular momentum with other planetary layers. Such flow can then develop instabilities, lead to large-scale vortices and ultimately sustain a dynamo effect (Lin et al., 2016).
In Earth's case, we note that the axis of rotation not only experiences precession, but also secondary motions such as nutation and wobble (Mathews et al., 2002).
In the present study, we focus on the flow driven by nutations of the Inner Core, in particular the so-called Free Inner Core Nutation. To that aim, we employ the QuICC simulation framework (Marti et al., 2016) to numerically study the flow driven in a rapidly rotating spherical shell by the forced nutation of the Inner Core alone.
Varying the nutation frequency at low amplitude shows that the laminar response exhibits "resonance" with inertial modes. This behavior reduces to the single spin-over mode as E tends towards planetary settings. For the spin-over mode, we employ a torque balance approach (following Busse, 1968; Noir et al., 2003) which allows us to estimate the uniform vorticity flow. We further demonstrate that forced nutations can trigger parametric instabilities in a spherical shell similarly to precession.

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[S5-P08] The effect of topography on magnetic waves in planetary cores

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Abstract

Nowadays, the main Earth's magnetic field is accurately monitored from satellites placed on a low orbit. Together with records of the Earth's rate of rotation,the magnetic field observations give precious information about magnetohydrodynamic waves in the Earth's fluid core. The propagation of these waves is sensitive to the properties of the core-mantle boundary: height of the interface with respect to a mean sphere; electrical conductivity of the solid mantle adjacent to the fluid core. The aim of the study is to develop a 2-D reduced model of the fluid dynamics that would account for the non-spherical core-mantle boundary. The simplification of such a quasi-geostrophic model rests on the invariance of the fluid velocity parallel to the rotation axis. This type of model has already been applied to investigate thermal convection without a magnetic field or to investigate the propagation of magnetic waves in a perfectly spherical cavity. Here, we combine these approaches and give a model description in newly developed curvilinear coordinates for arbitrary ellipsoids, which give an interesting case for the study of topography.

*Speaker

[S5-P09] Taylor state axisymmetric mean field dynamos

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Abstract

Earth's magnetic field is generated in its fluid metallic core through motional induction in a process termed the geodynamo. Fluid flow is heavily influenced by a combination of rapid rotation, Lorentz forces and buoyancy; it is believed that the inertial force and the viscous force are negligible. In such a system, the velocity and magnetic field organise themselves in a special manner, such that magnetic field B satisfies a solvability condition, known as Taylor's constraint. In this work, we solve this system using methods of optimal control to ensure that the required condition is satisfied all the time. We confine ourselves to axisymmetric case, and $\alpha effectisintroducedtosidestepCowling'santi - dynamotheorem.Wealsocompareourresultstoamodelretaininganinertialterm, whichintroducestorsionaloscillations.$

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[S5-P10] Trio of simple optimised axisymmetric kinematic dynamos in a sphere

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Abstract

In 1989, Dudley and James proposed three simple axisymmetric flows within a sphere which produce growing magnetic field solutions in the kinematic dynamo approximation. These flows, which contain only one toroidal and one poloidal mode, remain some of the simplest known functioning dynamos. In this study, we present optimised versions of the Dudley-James flows. Using the Lagrangian optimisation for steady flows in a sphere developed by Chen et al. (J. Fluid Mech, 839: 1-32, 2018), we found the smallest critical magnetic Reynolds number (Rmc) for each flow type when Rm is measured using a shear or enstrophy-based norm. A Galerkin method was used, in which the spectral coefficients of the fluid flow and magnetic field expansions were updated in order to minimise the target functional. The optimised flows display Rmcs that are up to four times smaller than the original Dudley-James flows. Furthermore, all Rmcs are quite similar, suggesting that there is only a weak preference for a flow dominated by particular modes. Similarly to Chen et al., two of the three flows diplay an alignment of the velocity and vorticity in the inner region of the sphere, resulting in significant helicity. The flows have Rmc roughly 26 times larger than the Backus bound.

*Speaker

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[S5-P11] Quasi-analytic inviscid geodynamo solutions

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Abstract

The geodynamo is driven by the motion of fluid within the Earth's outer core. In this motion, which is governed by the MHD equations, rotational forces are dominant over inertial and viscous forces, which means the Ekman and Rossby numbers are very small. Numerical models are used to simulate the geodynamo and have had some success, but are only possible in parameter regimes vastly different to that of the Earth, of Ekman and Rossby numbers being far too large. There is an alternative approach proposed by Taylor in 1963, of an inertia-free and viscous-free model as the asymptotic limit of Earth's dynamo. In this theoretical limit of a magnetostrophic balance, a certain necessary condition, now well known as Taylor's constraint, must hold.

The geostrophic flow is the component of the flow that evolves in such a manner as to ensure this constraint on the magnetic field is continuously satisfied through time.

We propose a method for determining the instantaneous geostrophic flow in a fully 3D geometry; amending Taylor's original analysis to consider a generalised magnetic state. We present a variety of examples implementing this method.

This work now facilitates the development of a time-stepping method to find 3D solutions of the magnetostrophic equations.

*Speaker

[S5-P12] How long do reversals take?

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Abstract

A pure GAD field that reverses by a monotonic change in moment from +1 to -1 produces an instantaneous directional flip. At all locations, a paleomagnetist would observe a sudden 180 degree jump in inclination and declination. Higher-order terms will modify the outcome, and the duration of the directional reversal will be site-specific. Dynamo models have shown that the octupole component may or may not reverse in synchronicity with the dipole component (Heimpel and Evans, 2013). A model based on CALS7K.2 yields some 'sub-decadal' cases (Brown et al., 2007), but the vast majority of locations yield durations between 200 and 2000 years. A recent report claims that the Matuyama-Brunhes transition 'lasted less than 13±6 years' at the Sulmona site in central Italy (Sagnotti et al., 2016). However, a detailed investigation of the relevant magnetic properties indicates that the sediments involved are prone to later remagnetization, and leads to the conclusion that 'this section does not carry a reliable high-resolution record of the geomagnetic field' (Evans and Muxworthy, 2018). As far as palaeomagnetic observations are concerned, the best global summary is still that of Clement (2004) who obtained a mean directional reversal duration of 7±1 kyr. We have carried out numerical dynamo calculations for fields consisting of dipole, quadrupole, and octupole components. In particular, we simulate intensity and inclination patterns as a function of site latitude. We find that the time scale of intensity and dipole component reversal is roughly 15 to 25 kyr, whereas inclination reversal requires roughly 0.5 – 1.5 kyr, and varies with location.

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[S5-P13] A comparison between a full three dimensional and a quasi-geostrophic model of thermally-driven convection in a spherical shell

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Abstract

Two dimensional quasi-geostrophic (QG) models of thermally-driven convection are an important tool in the study of the convective dynamics found in planetary interiors. Existing QG models, in which flows perpendicular to the rotation axis are assumed rigid and buoyancy is limited to non-axial component, are designed to study convection outside the tangent cylinder (TC). Furthermore, their application has been limited to this region in part because the β parameter, which captures the geometrical effect of the spherical boundaries on the flow, is discontinuous and diverges to infinity at the TC. In this work, we present a QG model in which the geometry near the TC is slightly modified such that the β parameter remains finite and continuous across the TC. We further show how Ekman pumping terms in the no-slip and free-slip regimes can be incorporated into the model. These modifications allow us to apply our QG model to the full spherical shell geometry and compare the results with that from a full three dimensional (3D) model. The QG model captures very inadequately the dynamics inside the TC. This is because axial buoyancy, absent in the QG model, dominates the dynamics of this region. Outside the TC, the QG model is better at capturing the salient dynamics, but the energy budget remains weaker than in the 3D model, likely also a consequence of neglecting axial buoyancy. In the no-slip case, a good analogy to the 3D model is achieved outside the TC if the temperature of the TC surface is assumed to be equal to that of the inner core boundary and the model's Rayleigh number is boosted accordingly; this is what is usually done in existing QG models limited to the region outside the TC. However, we show that differences remain in the free-slip case, notably that the QG model tends to remain in a vacillating convection regime when the 3D model is in a chaotic equilibrium balance.

*Speaker

[S5-P14] Convectively driven decadal zonal accelerations in Earth's fluid core

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Abstract

Azimuthal accelerations of cylindrical surfaces co-axial with the rotation axis have been inferred to exist in Earth's fluid core on the basis of magnetic field observations and changes in the length-of-day. However, the physical mechanism causing these decadal-timescale accelerations is not well understood. Scaling arguments suggest that the leading order torque averaged over cylindrical surfaces should arise from the Lorentz force. In this regime, decadal fluctuations in the magnetic field inside the core, driven by convective flows, could force decadal changes in the Lorentz torque and generate zonal accelerations. We test this hypothesis by constructing a quasi-geostrophic model of magnetoconvection, with thermally driven flows perturbing an imposed, single-valued background magnetic field. By choosing an Alfvén number similar to that in Earth's core, and by allowing the model's convective flow to stretch and shear the magnetic field on convective timescales, Lorentz forces dominate and we are able to reproduce both fast, free Alfvén waves and slow, forced accelerations. Furthermore, the ratios of relative strength and relative timescale between the free and forced accelerations are similar to those inferred for the Earth's core. We then extend our model by prescribing a more realistic background magnetic field which, while still steady, varies with radius, and characterize the consequent change in the behaviour of the free and forced waves. Our results support the hypothesis that convectively-induced changes in the magnetic field deep inside Earth's fluid core drive the observed decadal zonal accelerations of cylindrical surfaces through the Lorentz torque.

*Speaker

[S5-P15] On the formation of the axial dipole in rapidly rotating dynamos

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Abstract

The dominant polarity of the magnetic field in rapidly rotating spherical dynamos is the axial dipole. Studies of the onset of magnetoconvection in the limit of vanishing Ekman number have proposed that the dipole is favored over other polarities because its equatorial symmetry generates kinetic helicity that would be otherwise absent in non-magnetic convection. This study explores the effect of the magnetic field in the selection of the axial dipole in rapidly rotating, supercritical dynamos. The strength of convection is chosen such that the axial dipole grows from a starting seed field in the nonlinear dynamo, but fails to grow in the kinematic dynamo at the same parameters. The magnetic field is shown to excite convection over a range of length scales, and at the same time extract energy from smaller scales through the Lorentz force in order to feed itself. This leads to substantial helicity generation in a range of length scales and helicity loss in smaller scales, both relative to non-magnetic convection. The time scale for the increase in convection intensity relative to the non-magnetic state approximately coincides with the time scale for the formation of the axial dipole, which indicates that the Lorentz force has an important role in polarity selection.
Crucially, the dipole forms from a chaotic state well before the saturation of the dynamo, implying that planetary dynamos choose their polarity during their nonlinear growth phase.

*Speaker

[S5-P16] Polarity reversals in numerical dynamos of moderate viscosity

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Abstract

Polarity reversals are one of the most intriguing features of the geodynamo.Their sporadic nature does not lend itself to a detailed paleomagnetic description of the state of the geodynamo shortly prior, during, and after it reverses polarity. Numerical simulations can offer some insight into the nature of the transitional field, yet they are hampered by their computational cost, as reversal studies require integration times at least larger than a few magnetic diffusion times. To overcome this limitation, one can either resort to low-resolution, highly diffusive (or hyperdiffusive) models, or decide to impose some questionable azimuthal symmetry on the dynamo.

Here we report results obtained for a set of moderately viscous (Ekman number of $10ˆ{-4]$ and 3_˜$10ˆ{-5}$, magnetic Prandtl number Pm between 0.2 and 5.0) direct numerical simulations of chemical dynamos comprising 40 members. All simulations are subject to no-slip boundary conditions, and have a conducting inner core. We find that the transition between dipole-dominated and multipolar dynamos occurs for local Rossby numbers spanning a range from 0.08 to 0.15 (for sufficiently large values of Pm).

*Speaker

[S5-P17] Force balance in numerical geodynamo simulations: a systematic study

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Abstract

It is assumed that the geomagnetic field is generated as a result of convection of liquid metal in the Earth's outer core. To study this process commonly numerical dynamo simulations are used. However, limited computational resources require the use of parameters remote from the conditions of the Earth, which has put the physical relevance of such simulations in question. By performing a systematic parameter space survey at Ekman numbers $E = 10\text{-}4$ and $E = 10\text{-}5$, we show variations of the force balance when changing the forcing (Rayleigh number, Ra) and the ratio between viscous and magnetic diffusivities (magnetic Prandtl number, Pm). For dipole-dominated dynamos, we observe that the force balance is structurally very robust throughout the investigated parameter space, exhibiting a geostrophic balance (balance between Coriolis and pressure forces) at zeroth order, followed by a first-order MAC balance between the ageostrophic Coriolis, buoyancy and Lorentz forces. At second order this balance is disturbed by contributions from inertia and viscous forces. To assess the agreement of the model force balance with that expected in Earth's core, we introduce a parameter quantifying the distance between the first- and second-order forces. Analysis of this parameter shows that strong-field dynamos can be obtained in regions of the parameter space where the influence of inertia can be minimised by reducing Ra and increasing Pm. Additionally, close to the onset of dynamo action exceptional cases can be found where the dynamo is controlled by either a first-order VAC (Viscosity-Buoyancy-Coriolis) or CIA (Coriolis-Inertia-Buoyancy) balance. Our study illustrates that most classical numerical dynamos reproduce the zeroth- and first-order force balances expected for the Earth, while cases where viscosity and inertia play a dominant role are the exception rather than the norm.

*Speaker

[S5-P18] Linear model of subgrid induction at the core surface in geodynamo simulation: impact for core flow reconstructions

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Abstract

Unresolved magnetic and velocity fields are a source of substantial magnetic induction at the core surface. They are at most considered as an extra source of uncertainty in the core flow inverse problem. Here we show that such subgrid induction in geodynamo simulations is accurately modeled as a linear combination of the magnetic and velocity fields at large length-scales. We next consider the linear operators involved above to modify the observation operator that enters the core flow inverse problem. Through twin experiments on geodynamo snapshots, we show that this procedure significantly improves the recovery of the reference state, reducing the impact of spurious core motions towards small length-scales. We discuss how the applications of this algorithm to geophysical observations modifies the picture we derive for the core surface dynamics.

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[S5-P19] Geomagnetic jerks and rapid hydromagnetic waves focusing at Earth's core surface

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Abstract

Geomagnetic jerks are abrupt changes in the secular acceleration of Earth's magnetic field that punctuate ground observatory records. Recent jerks have been linked to short-lived, temporally alternating and equatorially localised pulses of secular acceleration observed in satellite data, associated with rapidly alternating flows at Earth's core surface. The dynamical origin of jerks has been unclear but can now be investigated in numerical models of the geodynamo that realistically simulate the interaction between slow core convection and rapid hydromagnetic waves. Using one such model, we show that the observed jerk patterns can be explained by the arrival of localised Alfvén wave packets radiated from sudden buoyancy releases inside the core. As they reach the core surface, the waves focus their energy towards the equatorial plane and along lines of strong magnetic flux, creating sharp interannual changes in core flow and producing geomagnetic jerks through the induced variations in field acceleration. The ability to numerically reproduce jerks offers a new way to probe the physical properties of Earth's deep interior.

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[S5-P20] Geomagnetic acceleration and rapid hydromagnetic wave dynamics in advanced numerical simulations of the geodynamo

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Abstract

Geomagnetic secular acceleration is a unique window on the dynamics taking place in Earth's core. In this study, the behaviours of the secular acceleration and underlying core dynamics are examined in new numerical simulations of the geodynamo that reside on a theoretical path in parameter space connecting the region where most classical models are found to the natural conditions. The typical time scale for geomagnetic acceleration is found to be invariant along this path, at a value close to 10 years that matches Earth's core estimates. Despite this invariance, the spatio-temporal properties of secular acceleration show significant variability along the path, with an asymptotic regime of rapid rotation reached after 30% of this path (corresponding to a model Ekman number E=3e-7). In this regime, the energy of secular acceleration is entirely found at periods longer than that of planetary rotation, and the underlying flow acceleration patterns acquire a two-dimensional columnar structure representative of the rapid rotation limit. The spatial pattern of the secular acceleration at the core-mantle boundary shows significant localisation of energy within an equatorial belt. Rapid hydromagnetic wave dynamics is absent at the start of the path but can be clearly exhibited in the asymptotic regime. This study reports on ubiquitous axisymmetric geostrophic torsional waves of weak amplitude relatively to convective transport, and also stronger, laterally limited, quasi-geostrophic Alfvén waves propagating in the cylindrical radial direction from the tip of convective plumes towards the core-mantle boundary. Quasi-geostrophic Alfvén waves are shown to be an important carrier of flow acceleration to the core surface that links with the generation of strong, short-lived and intermittent equatorial pulses in the secular acceleration energy.

*Speaker

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[S5-P21] Convective lengthscale in planetary cores

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Abstract

Convection in planetary cores is thought to be turbulent and constrained by rotation. A major unknown in the study of the core dynamics is the dominant lengthscale of the convective flows. In the absence of magnetic fields, the convection takes the form of tall and narrow columns aligned with the rotation axis. Near the linear onset of convection, the short lengthscale of the convection columns depends on the fluid viscosity and is thus expected to be very small in core conditions (_˜10m). Using numerical simulations of rapidly-rotating convection, we show that the convective lengthscale increases with the flow speed (i.e. with the thermal forcing) and becomes independent of viscosity for high Reynolds numbers (Re> 10,000). Extrapolation of the convective lengthscale obtained in our results to Earth's core conditions gives an estimate of about 30km.

*Speaker

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[S5-P22] Subcritical thermal convection in a 2D quasigeostrophic spherical flow at low Prandtl number

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Abstract

We study rapidly-rotating thermal Boussinesq convection driven by internal heating in a full sphere. We use a numerical model based on the quasi-geostrophic approximation for both the velocity and the temperature fields.
This simplified approximation allows us to perform simulations for Ekman numbers Ek down to 10^{-11} for a fixed Prandtl number (Pr=0.01). The Reynolds numbers obtained are up to 10 000.
The subcriticality of rapidly-rotating thermal convection observed in Guervilly et al (JFM, 2016) and Kaplan et al (PRL, 2017) is confirmed at these lower values of Ekman numbers. This behaviour is the consequence of the presence of a nonlinear dynamical branch, called inertial or strong branch, where the inertial term is the main nonlinearity. At Ekman numbers larger than 10^{-6}, the saturation is obtained on the well-know supercritical branch, called thermal or weak branch, which is mainly controlled by the nonlinear advection of temperature. We observe an asymptotic behaviour at very low Ekman numbers ($Ek < 10^{-9.5}$) where the subcritical range (Rayleigh number normalised by its critical value at the linear onset) remains unchanged.

*Speaker

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[S5-P23] Magnetostrophy, Where Art Thou?

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Abstract

Global scale magnetostrophic balance, in which Lorentz and Coriolis forces comprise the leading-order force balance, has long been thought to describe the natural state of planetary dynamo systems. However, we will argue here that dynamo modelling results are not typically in the global magnetostrophic state. Further, we will show via simple scaling arguments for what we call the magnetostrophic cross-over scale, only below which magnetostrophic balance may tend to arise in dynamo systems. Based on our cross-over scale estimates, the suggestion will be tendered that magnetostrophic convection dynamics exists in planetary cores on small scales, well below those that can be characterized by external magnetic field observations.

*Speaker

[S5-P24] A transition from laminar to a turbulent dynamo

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Abstract

Many numerical geodynamo models are laminar although the outer Earth's core occurs in the state of high developed convection. This is mainly due to numerical reasons. We present transitions from laminar to turbulent dynamos, with focus on the way these transitions are influenced by viscous and thermal diffusive processes. In all the cases, the dynamos are driven by the temperature gradient between upper and lower boundaries, as is typical for many geodynamo models. As expected, transitions from dipolar to quadrupolar and multipolar dynamos are observed as well as transitions from the large-scale columnar to the small-scale velocity flows. For laminar dynamos at low Prandtl numbers, toroidal components of velocity and magnetic fields dominate over the poloidal ones, while the situation is reversed for turbulent dynamos, i.e. the poloidal components of velocity and magnetic fields dominate over the toroidal ones. When the Prandtl number equals unity, toroidal flows dominate over poloidal ones for both laminar and turbulent dynamos, while toroidal and poloidal components of the magnetic field are comparable for both laminar and turbulent dynamos. For laminar dynamos, Ohmic dissipation dominates over the viscous dissipation, while for the turbulent dynamos viscous dissipation dominates over the ohmic dissipation. One could wonder why our magnetic Reynolds numbers and Elsasser numbers are large. This is due to small magnetic diffusion used in our computations.

*Speaker

[S5-P25] A Boussinesq slurry model of the F-layer at the base of Earth's outer core

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Abstract

Seismic observations suggest that a stably-stratified layer, known as the F-layer, 150–300 km thick exists at the bottom of Earth's liquid outer core. These observations contrast with the density inferred from the Preliminary Reference Earth Model (PREM), which assumes an outer core that is well-mixed and adiabatic throughout. The liquid core is composed primarily of iron alloyed with a light component. Purely thermal variations within the F-layer produce unstable stratfication, and in thermochemical models the direct freezing of heavy iron at the inner core boundary leads to release of light element that would disturb a stably stratified layer.

We therefore propose that the layer can be explained by a slurry on the liquidus, whereby solid particles of iron crystallise from the liquid alloy throughout the layer. A key feature of the slurry model is that it provides a dynamical explanation of how light element can be transported across the layer whilst maintaining stable stratification. We assume fast-melting, where the timescale of freezing is considered short compared to other processes. We also assume the light element is composed of oxygen, which is expelled entirely into the liquid during freezing.

We present a steady state 1D box model of a slurry formulated in a reference frame moving at the speed of inner core growth. We ascertain temperature, light element concentration and solid flux profiles for various layer thicknesses, inner core heat fluxes and values of the core thermal conductivity. Our solutions show that the steady state slurry can satisfy the geophysical constraints on the density jump across the layer and the core-mantle boundary heat flux.

*Speaker

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[S5-P26] Impact of inner-core size on the dipole field behaviour of numerical dynamo simulations

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Abstract

We investigate 56 chemically-driven dynamo simulations with aspect ratio χ (inner to outer core radii) ranging from 0.10 to 0.44. We show that the growth of the inner core leads to a transition between a "small inner-core" regime ($\chi \leq 0.18$), when the field produced is inter- mediately strong and dipolar, and a "large inner-core" regime ($\chi > 0.26$), when the field is stronger and more dipolar. During that transition the field is weaker and slightly less dipolar. For aspect ratios $0.20 \leq \chi \leq 0.22$, reversal frequencies appear to be much more sensitive to changes in the vigour of the convection, allowing high frequencies to be reached much more easily. The occurrence of such a transition for the Earth's core between the end of the Precam- brian and the end of the Devonian could account for the occurrence of episodes of reversal hyperactivity and complex low intensity fields during that still poorly documented period of time.

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†Speaker

[S5-P27] Estimation of temperature perturbation at ICB induced by CMB heat flux variation by numerical dynamos

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Abstract

Recent seismic tomographies suggest that seismic velocity variation at the bottom of mantle is dominated by degree 2 component of the spherical harmonics. It is widely considered that this variation corresponds to the heat flux variation at the core mantle boundary (CMB), and that convection of iron alloy and geodynamo are also under the influence on this heat flux variations. Furthermore, seismic observation also suggests that inner core has seismic velocity anomaly with degree 1 of the spherical harmonics. These seismic heterogeneities are generated by the thermal or compositional heterogeneities at the CMB and inner core, and convection in the outer core is under the influence of these heterogeneities. In the present study, we investigate how much thermal heterogeneity at CMB can generate the thermal heterogeneity at the ICB by using a numerical dynamo model.

In the present study, we perform dynamo simulations with changing amplitude of the heat flux variation at CMB with fixing dimensionless numbers. We apply the sectorial (*Y2,2* component of the spherical harmonics) mode of the heat flux variation as a thermal boundary condition at CMB, and change the relative amplitude of the perturbation $q*$ to the average heat flux over the CMB. We also apply the homogeneous heat flux condition at the ICB and compare the sectorial mode of the temperature variation to the axisymmetric mode (*Y2,0* component of the spherical harmonics) of the temperature variation at the ICB.

The results suggest that the temperature perturbation of the sectorial mode at ICB is generated by looking at the time average. However, the amplitude of the sectorial mode is less than 40% of the axisymmetric mode which is generated by the convection of the outer core. We also find that the sectorial temperature perturbation at ICB shift from that on CMB approximately 30 degree to west in the cases with $q*> 1.0$, because the phase of the sectorial temperature perturbation changes in the stratification due to the inward heat flux near CMB. By exploration of the results with sustaining the magnetic field, the sectorial mode of the temperature perturbation will exceed the axisymmetric component at ICB in $q*> 104$. Based on the *ab initio* simulation, the horizontal variation of the heat flux is estimated to be $Q* = 0.75$. By assuming the ohmic dissipation and total heat flux at CMB to be 0.5TW and 14TW, respectively, the relative heat flux variation at CMB for the dynamo model is $q* = 21$. From the present dynamo simulations, the sectorial temperature variation which is induced by the given heat flux variation from CMB is approximately 0.6 times of the axisymmetric temperature variation at ICB. Consequently, Earth's present ICB thermal heterogeneities are almost decoupled from the current CMB thermal heterogeneities.

*Speaker

[S5-P28] Coupled inertio-rotational modes of the Earth.

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Abstract

The non-uniform rotation of a planet can influence the flow pattern inside its fluid parts. Conversely, inertial modes of the fluid are known to be responsible for the disturbance of the rotational dynamics. (Free Core Nutation (FCN) and Chandler Wobble (CW)). We present the first high-resolution treatment of this coupled problem based on the joint (numerical) resolution of the equations for rotational and fluid dynamics. We clarify the relation between the FCN (and CW) and the spin-over mode and we examine the influence of the Core-Mantle Boundary topography on the frequencies and damping of the coupled modes.

*Speaker

[S5-P29] Geodynamo Models With a Stable Layer and Heterogeneous CMB Heat Flow

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Abstract

The mean heat flow at the CMB may be less than the heat that can be transported by conduction along a core adiabat, which may render the top few hundred kilometers of the core to be stably stratified. The CMB heat flow is likely very heterogeneous and locally the thermal gradient below the CMB could be unstable. The way in which lateral heat flux differences are accommodated and the consequences for the dynamics of a stable layer are not clear apriori. Numerical dynamo and magnetoconvection simulations with a strongly stabilizing average density gradient and large lateral heat flux differences suggest that a circulation in a thin layer immediately below the CMB balances the differences in heat flow by lateral advection. Deeper parts of the stable layer and the convecting region itself remain unaffected by the thermal heterogeneity at the CMB. A simple scaling theory for the shallow circulation layer is developed and is found to be in rough agreement with the numerical results. It predicts for Earth that the thickness of the layer is a few hundred meters, the horizontal velocity reaches values around 1 mm/s, and lateral temperature differences at the CMB are slightly less than 1 K. The morphology of the magnetic field is only marginally compatible with characteristics properties of the geomagnetic field when the stable layer thickness is 400 km and is incompatible for a thicker layer. If a sufficiently stable layer exists at the top of the core, thermal heterogeneity at the CMB would not influence the flow pattern in deeper parts of the core or affect heterogeneous growth of the inner core. Likewise, proposed mechanisms for the dipole offset from the center of Mercury based on heterogenous CMB heat flow are unlikely to work if the upper part of Mercury's core is thermally stable.

*Speaker

[S5-P30] On the dynamics of a stably stratified layer at the top of the core

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Abstract

A growing amount of evidence, coming from the latest investigations in mineral physics (e.g. Hirose et al. 2013) as well as from the latest interpretations of the geomagnetic field fluctuations (Buffet 2014), suggests the presence of a stratified fluid layer at the top of the Earth's liquid core. Taking into account the uncertainties in all parameters (e.g. the core-mantle boundary heat flux), the depth of this stratified layer is still largely unknown, with estimates ranging from tens to hundreds of kilometers. But no matter what the effective size of this layer is, it obviously has a non-negligible effect on the underlying convective flow that must be damped by this thermal and momentum blanket, and on the magnetic field. Besides, following studies on the dynamics of other systems where such a two-layer organization is naturally present (i.e. troposphere/stratosphere in planetary atmospheres, convective/radiative zones of stars), the stratified layer also has its own dynamics: underlying turbulence patterns excite internal-inertial waves sustained by stratification and rotation (e.g. Ansong and Sutherland 2010, Alvan et al. 2014), and the non-linear interactions of those waves generate large-scale flows, responsible for instance for the so-called Quasi-Biennial Oscillations of the equatorial zonal wind in the Earth's tropical stratosphere (Lindzen and Holton 1968), and possibly for the misalignment of hot Jupiters around hot stars, one of the many "observational mysteries" of these exotic systems (Rogers et al. 2012).
Here we present a series of simulations of a Boussinesq fluid with a nonlinear equation of state, which in thermal equilibrium is convective in the bottom part of the domain, but stably stratified in the upper part of the domain: the two-layer dynamics is thus reproduced in a self-consistent way. The various regimes of convection as a function of the stiffness of the interface, as well as mean flow generation by waves non-linear interactions, are described in details. Possible consequences for the Earth's core are discussed.

Refs.:

Couston, L. A., Lecoanet, D., Favier, B., & Le Bars, M. (2017). Dynamics of mixed convective–stably-stratified fluids. *Physical Review Fluids*, *2*(9), 094804.
Couston, L. A., Lecoanet, D., Favier, B., & Le Bars, M. (2018). Order out of chaos: slowly reversing mean flows emerge from turbulently generated internal waves. *Physical Review Letters*.

*Speaker

[S5-P31] Sensitivity of the geomagnetic octupole to a stably stratified layer in the Earth's core

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Abstract

Current "Earth-like" numerical dynamo simulations are able to reproduce many characteristics of the observed geomagnetic field, except for the geomagnetic octupolar component. Here we investigate whether a stably stratified layer at the top of the core, a missing ingredient in the dynamo simulations, can explain the observed geomagnetic octupole. Through numerical simulations, we find that the existence of a stable layer has significant influence on the octupolar component of the magnetic field. Particularly, we find that a 60 km stable layer with relatively strong stability or a 130 km layer with relatively weak stability are compatible with the observations, but a 350 km stable lalyer, as suggested by recent seismological evidence, is not compatible with Earth's octupole field over the past 10,000 years.

*Speaker

[S5-P32] Instabilities in Earths outer core due to Thermohaline rotating convection in a sparsely packed porous medium

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Abstract

The linear and nonlinear stability of convection due to Thermohaline rotating convection in a sparsely packed porous medium in Earth's outer core has been investigated. We have obtained the values of Takens–Bogdanov bifurcation points by plotting
graphs of neutral curves corresponding to stationary and oscillatory convection for different values of
physical parameters. We have derived a non-linear two-dimensional Landau–Ginzburg equation with
real coefficients near the onset of stationary convection at a supercritical pitchfork bifurcation and two
non-linear one-dimensional coupled Landau–Ginzburg type equations with complex coefficients near
the onset of oscillatory convection at a supercritical Hopf bifurcation. We have studied Nusselt number
contribution from a Landau–Ginzburg equation at the onset of stationary convection. We have
discussed the stability regions of standing and travelling waves. We have also discussed the occurrence
of secondary instabilities such as Eckhaus, zigzag and Benjamin–Feir instabilities.

*Speaker
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[S5-P33] Inertial modes of the liquid core of an Earth model with elastic mantle and inner core

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Abstract

We investigate the effects of mantle and inner core elasticity on the frequencies and displacement eigenfunctions of some of the inertial modes of a liquid core model with elastic boundaries. Traditionally, the rigid boundaries of a liquid core are considered to study these modes. We consider a rotating spherical Earth model consists of an elastic inner core, a one layer elastic mantle, and a compressible, stratified, inviscid liquid core. A Galerkin method is applied to solve the momentum and the Poisson's equations, which describe the dynamics of the Earth's layers, with the boundary conditions using the spherical harmonics. We show that the computed frequencies and displacement eigenfunctions of these modes may be significantly affected by the elasticity of an inner core and mantle. For example, the frequencies of the (2,1,1), (4,1,1), (4,2,1) and (4,3,1) modes are changed from 0.500, -0.410, 0.306 and 0.854 for a Poincaré model to 0.4998, -0.4205, 0.3087 and 0.8486, respectively.

*Speaker

[S5-P34] The free-core nutation, the free-inner-core nutation and the spin-over mode of the Earth

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Abstract

We study the tilt-over mode (TOM), the spin-over mode (SOM), the free core nutation (FCN), and their relationships to each other using a simple Earth model with a homogeneous and incompressible liquid core and a rigid mantle. Using analytical solutions we show that the FCN is the generalization of the SOM when the Earth is allowed to wobble. The equations representing mass and momentum conservation reduce to the well-known Poincare equation, a scalar second-order ODE with reduced pressure as the dependent variable. Analytical solutions are then found for the displacement eigenfunctions in a meridional plane of the liquid core for the aforementioned modes. Finally, we include an inner core which is free to wobble as a rigid body, and use successive approximations to the reduced pressure eigenfunction in order to represent the free inner core nutation (FICN).We discuss three aspects of the FICN: its relation to the SOM, the slow convergence of the eigenperiod, and the characteristic surfaces of the Poincare equation exhibited by the eigenfunction

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[S5-P35] Magneto-convection scaling inside the Terrestrial planets

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Abstract

Previously two-decade promising numerical planetary MHD dynamo-like first principal modeling has troubles nowadays in its' parameter space. It is been very far from realistic also gives doubtful access to the true physical scales and values via the known scaling laws. Here I have analytically reintroduced/supplemented those laws and suggested hopefully correct and new ones. Under viscosity control, I outline suitable parameter space and supplement simple magnetic laws with magnetic energy exiting kinetic one. In the opposite – inviscid limit I have comparable energies in the frame of such one-scale balances. The one-scale viscous and my two-scale balances are compatible with the Christensen-Aubert (2006) magnetic law up to moderate magnetic domination. Further, on the way to the powerful fast rotating and diffusion-free planetary-type dynamos, I've got scaling laws with strong magnetic dominations those should as well obey to the known after (Rhines, 1975) pure hydrodynamic scaling. Thus, contrasting to the mainstream I advocate sufficient influence of the inertia and isolate it integrating the radial component of the curl of the momentum equation. In inviscid limit this 2D integral-condition gives balance between magnetic and inertia terms in contrast to the zeroing 1D Taylor (1963) condition. Similarly, I manipulated with 0-1-2-3D two-three term balances in the dynamo-equations for correct analytical scaling. On this way, I introduced a variety of typical values those have clear physical and prognostic meaning matching well to the previously observed/estimated magnetic and hydrodynamic values inside the Earth, planets and moons of the Terrestrial type.

*Speaker

[S5-P36] Chemical convection and stratification at the top of the Earth's outer core

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Abstract

Convection in the Earth's outer core is presently driven by the combination of two sources of buoyancy. The latter originate from fluctuations of temperature, characterized by a Prandtl number close to 1 or smaller, and from anomalies in the chemical composition, associated with a large Prandtl (or Schmidt) number.

The vast majority of dynamo simulations to date have used a simplified approach where thermal and compositional density differences are described by only one variable, the so-called codensity. This is a gross simplification that amounts to modelling only thermal convection and ignores the rich dynamics only arising in so-called double diffusive systems when the diffusivities are sufficiently different. In addition, this approach is probably incorrect inside stratified layers.

Using a recently developed version of the code PARODY (J. Aubert, E. Dormy) including a particle-in-cell (PIC) method, we conducted a first exploration of the properties of pure chemical convection at infinite chemical Prandtl number (neglecting the chemical diffusivity) in a rotating spherical shell where light elements are injected within a thin layer above the bottom boundary. Convection is characterized by thin chemical plumes that eventually break-up to form chemical blobs, due to secondary instabilities of different nature inside and outside the tangent cylinder. Owing to their very weak chemical diffusivity, these parcels of buoyant material are able to reach the top of the shell and accumulate to form a chemically stratified layer, the existence of which has been inferred by seismic and magnetic observations. The extrapolation of these results to the Earth requires more detailed studies including the destabilizing effect of thermal convection, more realistic modeling of mushy layer processes and more turbulent flows that will be conducted in the future.

*Speaker

[S5-P37] Erosion of a chemically stratified layer at the top of the Earth's core

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Abstract

Seismic and geomagnetic observations suggest the presence of a stratified layer at the top of the Earth's core. This has important consequences for the dynamics and evolution of the core. However, the origin of this layer remains enigmatic. Previous models proposed that the layer built up over geological time by accumulation of light elements emanating from the inner-core boundary, barodiffusion or chemical interactions with the mantle. Alternatively, the layer could be primordial. A recent study showed that each giant impact of Earth formation produced a chemically stratified layer by incomplete mixing between the terrestrial core and that of the impactor. However, it is unclear whether such a primordial layer can be preserved up to the present-day or whether it will be eroded by turbulent convection in the core.

To answer this question, we study the erosion of a chemically stratified layer by thermal convection in a rotating sphere representing the Earth's core. Previous studies of rotating convection underneath a stratified layer do not consider the spherical geometry of the Earth's core or the weak diffusivity of chemical elements. To account for these effects, we use the code PARODY with a particle-in-cell method that properly solves the evolution of both the temperature and the compositional field. We characterize the flow regime and the erosion rate of the stratified layer as a function of the strength of convection relative to that of stratification.

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