New estimates of shear-wave speeds in the Earth's inner core by coda-correlation wavefield

T.-S. Phạm, H. Tkalčić, T. Costa de Lima, and X. Ma

Research School of Earth Sciences, The Australian National University

Probing the Earth's inner core (IC), which accounts for just about 1% of the Earth's volume, is critical for understanding the planet's formation and evolution. However, geophysical inferences have been challenging due to the lack of seismological probes sensitive to the IC, including its shear properties. The discovery of spatial correlation in ambient noise and earthquake coda has made a profound breakthrough in structural seismology, supplying high-resolution images of the Earth's interior near its surface. More significantly, it has initiated a new theoretical and practical framework, the global correlation wavefield, to better understand the architecture of the late coda and place novel constraints on IC structures. The global correlation wavefield has robustly detected shear waves (i.e., *J* waves) propagating through the IC.

Here, we will present several new observations of correlation features, which have recently become possible thanks to the latest advancement in correlation wavefield theory. Interestingly, one new, clearly observed feature is exclusively sensitive to the IC shear wave speeds, which are minimally influenced by inevitable uncertainties in velocity models of the upper shells, such as the mantle and outer core. This feature suggests low J-wave speeds in the IC, i.e., a 3.4±0.5% reduction from PREM values, which is about 3.39±0.02 km/s at the inner-outer core boundary and 3.54±0.02 km/s at the Earth center. The new absolute estimate of J-wave speeds provides better constraints for future investigation of mineral physics examining the compositions and physical states of iron alloys in the Earth's inner core.

Sound velocities and thermo-elastic properties of iron and iron alloys at Earth's inner core conditions

Daniele Antonangeli

Sorbonne Université, Muséum National d'Histoire Naturelle, UMR CNRS 7590, Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, IMPMC, 75005 Paris, France

Seismic body waves propagation and normal modes are among the few direct observations we have to constrain the properties of the Earth's solid inner core. As such, the knowledge of compressional and shear sound velocities, and more in general thermo-elastic properties at high pressure and high temperature of iron and iron-alloys expected to comprise the inner core, are fundamental to interpret the seismic observations and to build compositional and elastic models. However, the experimental difficulties inherent in performing sound velocity measurements in the extreme conditions of the Earth's core, and in synthesizing well-characterized samples, have considerably limited the available data sets, which are currently largely dominated by results obtained by ab initio calculations which, for their part, are not systematically benchmarked against experiments.

In this talk I will review experimental determination of sound velocities of pure hcp iron at high pressure and high temperature and I will address the different effects that light elements might have on the sound velocities depending the substitutional (e.g. silicon) vs. the interstitial (e.g. carbon) character of the alloy. I will also compare results from ab initio calculations on iron and iron alloys over the pressure and temperature ranges for which experimental data are available, discussing observed agreements and disagreements. Finally I will highlight the current limitations and potential dangers of interpreting seismic models on the basis of as yet insufficient knowledge of material properties.

Session 6 Inner Core 04

Title: The Free Inner Core Nutation (FICN)

Author(s): Behnam Seyed-Mahmoud

Affiliation(s): University of Lethbridge, Lethbridge, Canada

Title: The Free Inner Core Nutation

Abstract

We study the inner core as an independent body subjected to the gravitational and pressure torques due to the mantle and the liquid core. We show that what would be the tilt-over mode (TOM) of a freely rotating inner core evolves into what is known as the free inner core nutation (FICN). We will also show that the period of this mode depends strongly on the gravitational coupling between the mantle and the inner core as well as, as it is well known, on the liquid core density. Further, we discuss the effects of liquid core's dynamical stability on the period of this mode.

If the liquid core were a freely rotating body then the conservation of the angular momentum would require that

$$-2\mathrm{i}(\omega - \Omega)(\omega + e_I\Omega)A_I\alpha_I = 0 \tag{1}$$

It is obvious that this would yield the frequency of the TOM, $\omega = \Omega$. and that of the Eulerian (Chandler) wobble (ICW) $\omega = -e_{IC}\Omega$.

We now assume that the Earth's three segments are: 1- the rigid mantle; the liquid core is assumed to be a cavity shell ($\rho = 0$); 3- the rigid inner core. The conservation of the Earth's angular momentum then requires that

$$-2\mathrm{i}(\omega - \Omega)\left[(\omega + e_I\Omega)A_I\alpha_I + (\omega + e_M\Omega)A_M\alpha_M\right] = 0 \tag{2}$$

Obviously, $\omega = \Omega$ is the frequency of the TOM. Therefore,

$$(\omega + e_I\Omega)A_I\alpha_I + (\omega + e_M\Omega)A_M\alpha_M = 0 \tag{3}$$

We need a second equation relating α_I and α_M to solve for ω. We use

$$-2\mathrm{i}(\omega - \Omega)(\omega + e_I\Omega)A_I\alpha_I = \Gamma_G \tag{4}$$

where Γ_G is the gravitational torque on the IC due to the Mantle.

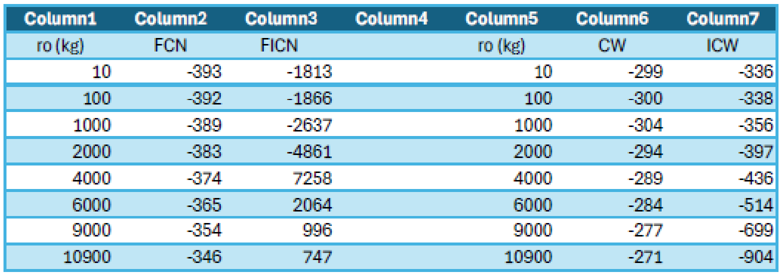
$$\Gamma_G = -i\frac{16\pi}{5}Ge_IA_IJ_3(\alpha_I - \alpha_M) \tag{5}$$

Using properties of PREM and solving these equations, the numerical solutions are

$$\omega_1 = -0.00335\Omega;\ \ \omega_2 = 1.00056\Omega;\ \text{and}\ \omega_3 = -0.003\Omega. \tag{6}$$

ω_1 is, of course, the frequency of the Chandler wobble of the right Earth $e = 0.000335$. ω_2 is that which would have been the frequency of the TOM of the IC from equation (1) above but is now modified because of Γ_G. It is a retrograde nutation, as seen in a rotating frame, $\sigma = (1 - 1.00056)\Omega = -0.00056\Omega$ (please read further; the period will be prograde as LC is added). ω_3 is the modified frequency of the ICW.

Next, we assume a three layer Earth model with a LC, increase the (constant) density of the LC from 10 kg to 10900 kg and solve equations (29) or Seyed-Mahmoud et al. (2017) for the periods of the Earth's rotational modes. These



Column1	Column2	Column3	Column4	Column5	Column6	Column7
ro (kg)	FCN	FICN		ro (kg)	CW	ICW
10	-393	-1813		10	-299	-336
100	-392	-1866		100	-300	-338
1000	-389	-2637		1000	-304	-356
2000	-383	-4861		2000	-294	-397
4000	-374	7258		4000	-289	-436
6000	-365	2064		6000	-284	-514
9000	-354	996		9000	-277	-699
10900	-346	747		10900	-271	-904

Figure 1: The periods of the Earth's rotational modes as the LC density increases from $\rho = 0$. Periods are in sd.

period are given in table (1). As you can see, FICN is initially retrograde but LC density of 4000 kg it turns prograde. The period goes to infinity ($\omega = \Omega$) when the density is somewhere between 2000 kg and 4000 kg. The 747 sd period for $\rho = 10900$ kg is what is known as the period of this mode for an Earth model with rigid inner core.

The effect of source-side subduction on inner-core anisotropy measurements

S. Russell[1], J. K. Magali[1], C. Thomas[1]
Institut für Geophysik, Universität Münster, Germany

When making measurements of inner core anisotropy, and of the seismic properties of the deep Earth more generally, seismologists utilise earthquakes and seismometers from many different geographic areas. The wide spatial distribution of sources and receivers means that these measurements are influenced by Earth's heterogeneous mantle and crust. Previous studies have investigated the effect of receiver-side subduction zones on specific measurements of inner core anisotropy observations, for example the effects of the Alaskan slab on the highly anomalous South Sandwich Islands to Alaska path. However, the effect of source-side subduction has not been examined, and events of this nature contribute large amounts of data to measurements of inner-core anisotropy.

Here we use AxiSEM3D to model the effect of source-side subduction on differential times used to constrain inner-core anisotropy. We build semi-realistic synthetic subduction zones from a simple plate cooling model, and convert temperature to velocity and density using Perple_X assuming a pyrolytic mantle. We optimise the AxiSEM3D inputs for our problem, allowing us to run global simulations at 3s period. Our initial simulations indicate that for certain paths the signature of source-side subduction can be significant and should be visible in the data; we also examine an existing dataset of measurements to look for this.

Interpreting Earth's inner core structure through ultrasonic scattering and wavespeed measurements

Ming Gong, Michael I Bergman (Simon's Rock College), and Neelesh Bhadwal (U. Toronto)

Abstract

Seismic waves provide two critical observations on the Earth's iron-alloy inner core:

- Large and variable inner core seismic attenuation[1][2], which could be attributed to
  - High viscoelasticity (intrinsic attenuation) and/or
  - Scattering from reflections due to impedance variations, such as might arise from differently oriented crystals.
- A low shear wave speed, which, along with possible high viscoelasticity, might suggest a low shear modulus[3].

We have conducted ultrasonic pulse-echo studies on hexagonal close-packed zinc-tin alloys with both textured, columnar dendritic and randomly oriented, fine-grained equiaxed microstructures. These serve as analogs for possible inner core iron alloy microstructures.

1. In one set of experiments, we used longitudinal waves at room temperature to quantify the ratio of the transmitted to scattered energy for different microstructures. We find that the ratio is highest in the growth direction of the columnar crystals, lowest in the transverse directions, and intermediate for fine-grained microstructures. However, as we decrease the wavelength λ of the ultrasonic pulse, the ratio for the fine-grained alloy decreases dramatically near the condition of maximum scattering $2\pi d = \lambda$[4], where d is the grain size, whereas we do not see such a sharp decrease in either direction for the columnar crystals. This condition for maximum scattering corresponds to a few hundred meters for a 1-10 Hz PKIKP wave. This suggests that observations of increased scattering in the deep inner core might be due to finer grains, consistent with rapid growth after nucleation from an undercooled liquid, and also that lateral variations of attenuation are due to scattering, as one would not expect intrinsic attenuation to vary laterally.

2. In a second set of experiments we refined and used a novel method to couple samples to a Li-Nb piezoelectric shear crystal at elevated temperatures, in order to calculate the shear modulus. The method uses foil as a dry couplant[5], which is easier to use and longer lasting than epoxies. Our results for aluminum and zinc alloys compare well with prior studies. We confirm that, as expected, the shear modulus decreases as a function of temperature, but the zinc alloys show no steep decrease of the shear modulus as high as .97 T_E[6], the eutectic temperature, where the echo became indiscernible from the noise.

[1] Cormier, V.F., Xu, L., Choy, G.L., Seismic attenuation of the inner core: Viscoelastic or stratigraphic?, Geophys. Res. Lett., doi.org/10.1029/1998GL900074, 1998.
[2] Pang, G., Koper, K.D., Wu, S.-M., Wang, W., Lasbleis, M., & Euler, G., Enhanced inner core fine-scale heterogeneity towards Earth's centre, Nature, 620(7974):570-575. doi:10.1038/s41586-023-06213-2, 2023.
[3] Tkalcic, H. and Pham, T.-S., Shear properties of Earth's inner core constrained by a detection of J waves in global correlation wavefield, Science, 362(6412):329-332, doi:10.1126/science.aau7649, 2018.
[4] Papadakis, E.P., Ultrasonic attenuation caused by scattering in polycrystalline media, in Physical Acoustics, ed. Mason, W.P., Academic Press, New York, 1968.
[5] Bhadwal, N., Milani, M.T., Coyle, T., & Sinclair, A., Dry coupling of ultrasonic transducer components for high temperature applications, Sensors, 5383, doi:10.3390/s19245383, 2019.
[6] Martorell, B. et al. Strong premelting effect in the elastic properties of hcp-Fe under inner-core conditions, Science 342, 466-468, DOI:10.1126/science.1243651, 2013.

Geodynamica: slinging Earth and (exo)planets' structure and dynamics into Diamond Open Access

Stefano Maffei[1], Maëlis Arnould[2], Mandy Bethkenhagen[3], Thibault Duretz[4], Mohamed Gouiza[5], Iris van Zelst[6]

[1]*ETH Zurich, Switzerland*

[2]*University Claude Bernard Lyon 1, France*

[3]*LULI, Palaiseau, France*

[4]*Goethe University, Frankfurt, Germany*

[5]*University of Leeds, United Kingdom*

[6]*DLR, Berlin, Germany*

The past decade has seen the consolidation of open access practices in scientific publishing, with funding bodies, international agencies and academic institutions requiring free access to not only scientific papers but also other output such as dataset and computer codes. While mostly embraced by the scientific community, the transition to open access practices have led multiple academic pushing companies to offer Gold Open Access schemes, under which scientific papers are free-to-read. Compared to the traditional publication schemes, Gold Open Access comes at a much higher cost for the submitting authors, normally of thousands of US Dollars for a single paper. These practices have had documented negative impact on the scientific publishing landscape, from the rise of predatory journal to broadening the economic divide between academic institutions.

Partly in response to the negative impact of Gold Open Access practices, different fields of Earth Sciences have recently seen the rise of several community-led, Diamond Open Access journals (e.g., Volcanica, Tektonika, Seismica). There journals are free-to-publish and free-to-read. The aim is to remove the paywall barriers by publishing peer-reviewed articles at no cost to both authors and readers, thus offering a platform for true open science. Diamond Open Access journals are created and maintained by the very same scientific community they aim to serve, thus removing economical and business considerations that drive a large fraction of the modern publishing landscape. Therefore, community-led journals offer a high-quality alternative to classical for-profit scientific journals.

We are pleased to announce the birth of a new Diamond Open Access journal initiative called **Geodynamica**, with the aim of publishing free-to-publish and free-to-read research in the fields the dynamics of dynamics of Earth and (exo)planets' interior. Geodynamica was born in 2023 thanks to the effort of six scientists, who form the core committee that coordinate the efforts of the various teams of the initiative. The target launch date for the journal is autumn 2024. Geodynamica aims at promoting academic discourse and disseminating research pertaining to the quantitative study of Earth and (exo-)planetary internal structure, dynamics, and evolution from observational to modeling perspectives.

Geodynamica enjoys the support of the University of California, and hugely benefits from the experience of existing community-led journals within the geosciences community, namely Volcanica, Tektonika and Seismica.

In this contribution, we will provide the vision behind this initiative, report on the structure of this journal, its scope, and the remarkable community effort that will make this new diamond open access journal a reality.

Uncertainty in Seismic Measurements Sensitive the Earth's Interior

Ringler, A. T.[1], Adourian, S.[2], and Lau, H. C. P.[2]

[1]U.S. Geological Survey, Albuquerque Seismological Laboratory

[2]Brown University, Department of Earth, Environmental, and Planetary Science

Abstract

Waveforms recorded at seismic stations provide a fundamental tool for probing the interior of the Earth. At short-periods (e.g., ≈1 s) recording phases like PKiKP at long running stations, from repeating earthquakes, provide information about potential changes of the inner-core. At slightly longer periods (e.g., 50 s to 250 s) it is possible to use surface waves to aid in our understanding of the anelastic structure of the Earth. Finally, at even longer periods (e.g., 300 s to 1000 s) it is possible to use the free oscillations and their splitting to estimate global properties of the Earth. Of particular interest is the fact that the latter part of the seismic spectrum holds significant sensitivity to lateral variations in density.

As with any observational measurement, there are associated uncertainties and errors in recording seismic waveforms that can limit our ability to use this data to estimate properties of the Earth. For seismic data this can arise from stations with high-noise levels, problems with the instrument response, as well as more subtle effects like the sensitivity of instruments to non-seismic sources (e.g., ambient variations in pressure and temperature).

In this work, we provide several examples of compromised seismic observations as well as methods to estimate and associated uncertainty. These include timing and phase response errors at short periods, problematic response problems around the corner period of the instrument, and finally changes in long-period spectra from station noise. The ultimate goal of our analyses is a catalog of seismic spectra, where each continuous spectrum is paired with its associated uncertainty as a function of frequency. Such a catalog may then be applied in studies to constrain Earth's interior structure.

Compaction-driven convection in the growing inner core

Kang Wei Lim[1,2], Renaud Deguen[2], David Cébron[2], Amelie Schulze[3], and Mioara Mandea[1]

[1]CNES – Centre National d'Études Spatiales, 2 place Maurice Quentin, 75039 Paris Cedex 01, France
[2]Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, UGE, ISTerre, 38000 Grenoble, France
[3]Heidelberg University, Heidelberg, Germany

The Earth's inner core (IC) is known to exhibit heterogeneous structures with their origins still unknown. From the onset of nucleation, the IC can grow via sedimentation and compaction of iron crystals freezing out from the fluid outer core. Previous studies of IC growth have shown entrapment of fluid within the solid matrix, and unstable density profiles in 1D can appear depending on the efficiency of fluid percolation. In this study, we perform simulations of IC growth via compaction and melt percolation in spherical geometries for the first time (assuming axisymmetry). We find that it is possible for the IC to develop large scale convective flows under certain conditions and, in some instances, produce small-scale heterogeneites close to the IC boundary. Assuming representative values for the physical properties of the Earth's IC, we show that it is possible for the IC to exhibit large-scale convective motions today. The resulting fluid distribution and flows can have potential implications on the IC seismic structure and outer core dynamics.

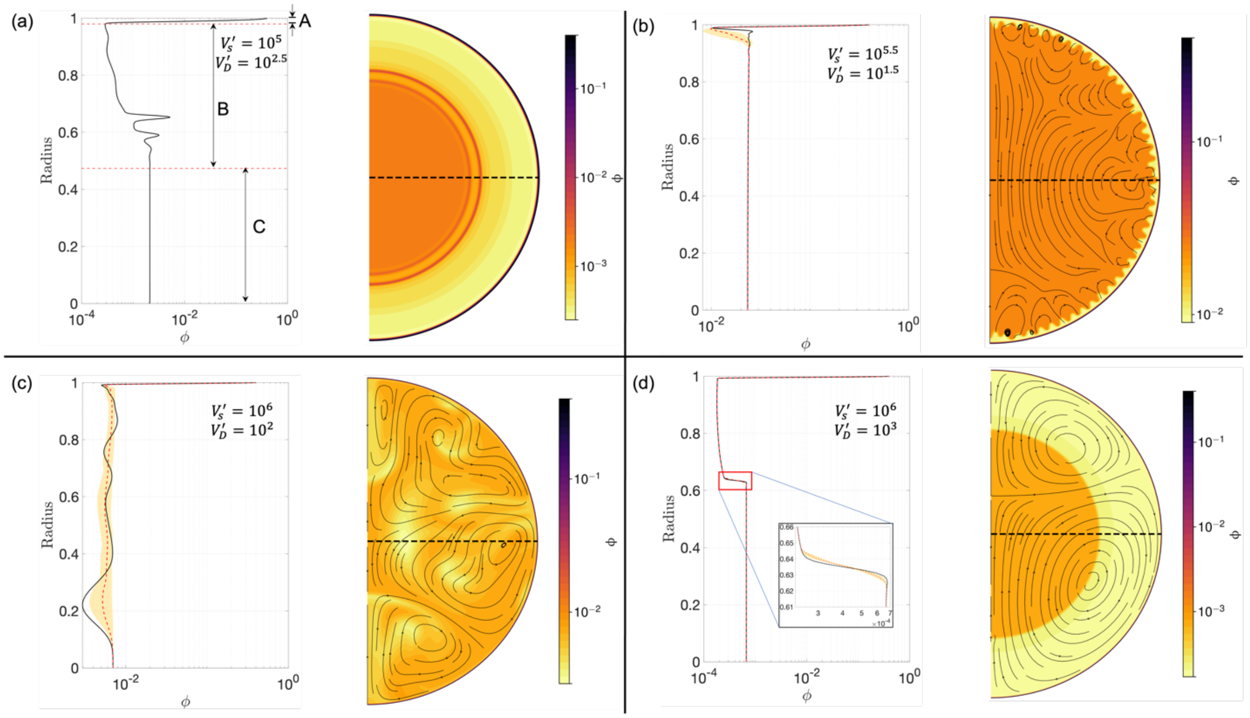


Figure: Porosity profiles from different regimes of our simulations. The two nondimensional parameters that govern the dynamics are V_S' and V_D'.

Globally Enhanced Inner-Core Fine-Scale Heterogeneity towards Earth's Center

Guanning Pang[1], Keith Koper[2], Sin-Mei Wu[3]

[1]Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY

[2]Department of Geology and Geophysics, University of Utah, Salt Lake City, UT

[3]Lawrence Berkeley National Laboratory, Berkeley, CA

Earth's inner core acquires texture as it solidifies within the fluid outer core. The size, shape, and orientation of the mostly iron grains comprising the texture record the growth of the inner core and may evolve over geologic time in response to geodynamical forces and torques. Seismic waves from earthquakes can be used to image the texture, or fabric, of the inner core and gain insight into the history and evolution of Earth's core. Here we observe and model seismic energy backscattered from the fine-scale (<10 km) heterogeneities that constitute inner core fabric at larger scales. We use a novel dataset created from a global array of small-aperture seismic arrays—designed to detect tiny signals from underground nuclear explosions—to create a 3D model of inner core fine-scale heterogeneity. Our model shows that inner core scattering is ubiquitous, existing across all sampled longitudes and latitudes, and that it substantially increases in strength 500–800 km beneath the inner core boundary. The enhanced scattering in the deeper inner core is compatible with an era of rapid growth following delayed nucleation.

Attenuation and Scattering in the Innermost Inner Core

Ravi Wickramathilake and Vernon F. Cormier
Department of Physics
University of Connecticut
Storrs, CT 06269-3046

The existence of an innermost inner core between 400 to 800 km radii has been proposed in a number of body wave studies[1,2], suggesting a change in composition or phase in the history of the inner core's solidification. Investigations of the deep inner core are few due to the lack of a reference wave to eliminate the effects of shallower structure on the travel time, attenuation, and scattered coda of the PKIKP wave. In this study we avoid the use of a reference wave to estimate the attenuation and scattering of PKIKP that sample the deep inner core by seeking an attenuation operator and scattered coda shape, which when convolved with an inverted source-time function and an average mantle attenuation operator, fit observed PKIKP waveforms. We extend an earlier study[3], which plotted $1/Q_P$ (1 Hz) measurements for individual PKIKP ray paths to find a best fitting two layered model of attenuation in the inner core between 200 km depth to its center. Best fits to PKIKP waveforms are found for a transition to an innermost inner core having a sharp increase in Q_P (decrease in $1/Q_P$) at radii between 800 to 400 km. A boundary near 600 km radius, below which Q_P approaches infinity ($1/Q_P$ approaches zero), predicts an average Q_P of 450 between radii 1000 to 600 km in inner core, which agrees with estimates using a reference PKP-C waveform[4]. Hypotheses for this transition include a change in the inner core's composition, including the percentage of light elements or its superionic state, a change in pre-melting, and/or a change in heterogeneity texture or crystalline lattice structure. Using the 2.5D AxiSEM[5] numerical code we determine upper bounds to two parameters describing the heterogeneity spectrum of the innermost inner core assuming an exponential spatial autocorrelation of P wave velocities. These are 2 to 6 km for the autocorrelation length and 1.2% to 2% for the rms perturbation to P wave velocities. The decrease in intrinsic attenuation near the transition to an innermost inner core may also explain observations of an increase in the power of back-scattered PKiKP coda in the deep inner core[6] even though an increase in forward scattered coda is not observed in PKIKP waves bottoming below 600 km radius. AxiSEM modeling predicts strong focusing of scattered PKIKP coda for seismic stations within 0.5 deg of 180°, consistent with the amplitude and complexity observed in the coda of waveforms recorded close to 180°. Increased observations of antipodal seismograms may enable further refinement of a depth-dependent model of inner core heterogeneity.

1. Niu, F., & Chen, Q-F., 2008. Seismic evidence for distinct anisotropy in the innermost inner core, *Nature Geoscience*, 1, 692-696, doi: 10.1038/ngeo314.
2. Tkalčić, H., Costa de Lima, T.P., Phạm, T.-S. and Tanaka, S. 2023. Inner core anisotropy from antipodal PKIKP traveltimes. In: *Core-Mantle Co-Evolution* (eds T. Nakagawa, T. Tsuchiya, M. Satish-Kumar and G. Helffrich), doi: 10.1002/9781110526919.ch10.
3. Li, X, and Cormier, V.F., 2002. Frequency dependent attenuation in the inner core: Part A viscoelastic interpretation, *J. Geophys. Res.*, 107(B12), doi: 10.1029/2002JB001795.
4. Iritani, R., Takeuchi, N., and Kawakatsu, H., 2010. Seismic attenuation structure of the top half of the inner core beneath the northeastern Pacific, 37(19), *Geophys. Res. Lett*, doi: 10.10292010Gl044053.
5. Nissen-Meyer, T., van Driel, M., Stahler, S.C., Hosseini, K., Hempel, S., Auer, L., Columbi, A., Fournier, A., 2014, AxiSEM: broadband 3-D seismic wavefields in axisymmetric media, *Solid Earth*, 5(1), 425-445.
6. Pang, G., Koper, K.D., Wu, S-M., Wang, W., Lasbleis, M., and Euler, G., 2023, *Nature*, doi: 10.1038/s441486-06213.

Inner Core Flow Inferred From the Presence Of Elastic Anisotropy

***Prajna Paramita Das**, University of California Berkeley, (prajnapdas@berkeley.edu);*
Bruce Buffett, University of California Berkeley, (bbuffett@berkeley.edu);
Daniel Frost, University of South Carolina, (dfrost@seoe.sc.edu)

Elastic anisotropy of the Earth's Inner Core (IC) with the fast axis parallel to the Earth's spin axis is now well established by many studies. Here we explore possible dynamic mechanisms of developing seismic anisotropy within the IC. Analysis of seismic body wave PKIKP differential travel-time residuals, reveal that the strength of seismic anisotropy increases with depth into the inner core and is stronger in the western hemisphere. The most favored explanation for this anisotropy is the lattice preferred orientation of intrinsically anisotropic hexagonal-close-packed (hcp) iron crystals, aligning the crystallographic c-axis with the rotation axis. A single crystal hcp iron is also thermally anisotropic with the thermal conductivity higher along the c-axis than along the a-axis. We explore the possibility that anisotropic thermal conductivity contributes to the development of elastic anisotropy.

A simple 3-dimensional IC seismic anisotropy model is approximated considering the first-order IC anisotropic characteristics, i.e., anisotropy linearly increases with depth and the maximum anisotropy is shifted ~200 km in the West. We use the seismic anisotropy as a proxy for thermal conductivity anisotropy. Using thermal models for the growth of the IC, the calculated temperature drop across the present-day radius of the IC is less than the predicted Adiabatic profile. This, along with the high values for the average thermal conductivity (>100 W/mK) promote conductive cooling of the IC and suppress deformation processes that rely on thermal convection. Large-scale deformation is still possible if anisotropy in thermal conductivity causes temperature perturbations as the IC conductively cools. We have computed the creeping flow resulting from thermal anomalies, for a quasi-steady state. This flow mechanism supports dynamic stresses as large as 2 MPa. The flow influences the temperature perturbations and so we aim to use ASPECT *(Advanced Solver for Planetary Evolution, Convection, and Tectonics)* to solve for the coupled flow and temperature field in the presence of anisotropic thermal conductivity. This flow mechanism can potentially produce further IC anisotropy without relying on external forcings.

Differential rotation of the Earth's inner core: A reflection

Xiaodong Song[1], Yi Yang[2], and Kaixin Wu[1]
1. School of Earth and Space Sciences, Peking University, Beijing, China
2. School of Earth Sciences and Engineering, Nanjing University, Nanjing, China

Geodynamo theory predicts that the inner core is likely to rotate relative to the mantle by electromagnetic coupling (Glatzmaier and Roberts, 1995). The first evidence for the differential inner core rotation was reported in 1996 (Song and Richards) from seismological observations of the temporal changes of seismic waves traversing the inner core. In the subsequent nearly three decades, we have been working steadily on the issue. Although the idea has gone through twists and turns, it has reached to the current incredible point that the differential rotation may be linked all the way to the sea level rise and the temperature at the surface of the Earth (Yang and Song, 2023). In this summary presentation, we will briefly review some of the major developments. The key questions are: (Q1) Are the temporal changes real or artifacts? (Q2) Where do the temporal changes come from? (Q3) What is the rotation rate? (Q4) Does the rotation vary with time and how? (Q5) What causes the (variable) rotation? (Q6) And finally, what are the implications for the dynamic earth system?

Some aspects seem certain. (Q1) Since the observations from earthquake doublets by Zhang-Song et al. (2005), there is little doubt that the temporal changes are real. (Q2) The temporal changes of inner core waves come mostly (if not all) from the body (interior) of the inner core, rather than the inner core surface, thus inner core rotation remains the best interpretation (Yang and Song, 2020). (Q4) The inner core rotation itself clearly changes with time and the inner core rotation paused around 2009 and seems to have changed from super-rotation to supra-rotation (Yang and Song 2023).

However, some other issues are still to be resolved. (Q3) The estimates of the inner core rotation rate have considerable uncertainties. The current best estimate around 0.05 to 0.15 degree/year average over the last few decades. (Vidale et al., 2000; Yang and Song, 2022). (Q4) The inner core seems in an oscillation with periods to be resolved (Wang and Vidale, 2022; Yang and Song, 2023; Tkalčić, 2024). (Q5-6) The inner core rotation seems to be regulated by electromagnetic as well as gravitational coupling between the inner core, outer core and the mantle (Creager and Buffett and Creager, 1999; Buffett and Glatzmaier, 2000). But the precise mechanisms and the implications for the solid earth systems need to be worked out.

References

Buffett, B. A., & Creager, K. C. (1999). A comparison of geodetic and seismic estimates of inner-core rotation. *Geophysical Research Letters*, *26*(10), 1509–1512. https://doi.org/10.1029/1999GL900271

Buffett, B. A., & Glatzmaier, G. A. (2000). Gravitational braking of inner-core rotation in geodynamo simulations. *Geophysical Research Letters*, *27*(19), 3125–3128. https://doi.org/10.1029/2000GL011705

Glatzmaier, G. A., & Roberts, P. H. (1995). A three-dimensional convective dynamo solution with rotating and finitely conducting inner core and mantle. *Physics of the Earth and Planetary Interiors*, *91*(1–3), 63–75. https://doi.org/10.1016/0031-9201(95)03049-3

Song, X., & Richards, P. G. (1996). Seismological evidence for differential rotation of the Earth's inner core. *Nature*, *382*(6588), 221–224. https://doi.org/10.1038/382221a0

Tkalčić, H. (2024). On the inner-core differential-rotation (un)resolvability from earthquake doublets: the traps of data selection. *Geophysical Research Letters*, *51*(6). https://doi.org/10.1029/2023GL107043

Vidale, J. E., Dodge, D. A., & Earle, P. S. (2000). Slow differential rotation of the Earth's inner core indicated by temporal changes in scattering. *Nature*, *405*(6785), 445–448. https://doi.org/10.1038/35013039

Wang, W., & Vidale, J. E. (2022). Seismological observation of Earth's oscillating inner core. *Science Advances*, *8*(23), 1–7. https://doi.org/10.1126/sciadv.abm9916

Yang, Y., & Song, X. (2020). Origin of temporal changes of inner-core seismic waves. *Earth and Planetary Science Letters*, *541*, 116267. https://doi.org/10.1016/j.epsl.2020.116267

Yang, Y., & Song, X. (2022). Inner core rotation captured by earthquake doublets and twin stations. *Geophysical Research Letters*, *49*(12). https://doi.org/10.1029/2022GL098393

Yang, Y., & Song, X. (2023). Multidecadal variation of the Earth's inner-core rotation. *Nature Geoscience*, *16*(2), 182–187. https://doi.org/10.1038/s41561-022-01112-z

Zhang, J., Song, X., Li, Y., Richards, P. G., Sun, X., & Waldhauser, F. (2005). Inner core differential motion confirmed by earthquake waveform doublets. *Science*, *309*(5739), 1357–1360. https://doi.org/10.1126/science.1113193

Titled transverse isotropy in the Earth's inner core

Arwen Deuss[1], Hen Brett[1], Jeroen Tromp[2],
[1] Utrecht University, the Netherlands
[2] Princeton University, US

SEDI, June 2024

The Earth's inner core is one of the most strongly anisotropic regions of our planet. On average, the anisotropy appears to be aligned with the Earth's rotation axis with a larger wave velocity in the polar (North-South) direction than in the equatorial (East-West) direction. Over de last few decades, seismic studies of inner core anisotropy have revealed regional variations with ever increasing detail, suggesting that the top 60-80 km of the inner core is isotropic, the western hemisphere is more strongly anisotropic than the eastern hemisphere and that the anisotropy in the innermost inner core has an anomalous slow direction. Most previous studies assumed that the symmetry axis of the anisotropy is aligned with the rotation axis and then attributed regional variations to variations in the magnitude of the anisotropy.

Here, we make a tomographic model of inner core anisotropy using seismic body waves observations using a different approach. We assume that the inner core is made of cylindrically symmetric anisotropy crystals that all have the same magnitude of anisotropy, and instead we allow the fast symmetry axis symmetry axis to vary in 3D, resulting in a model of tilted transverse isotropy. We find that our model fits the body wave data equally well as models in which the magnitude varies, with the advantage that our model requires fewer parameters. In our model, the anisotropy in the central part of the inner core is still mainly aligned with the rotation axis. In the upper part of the inner core we find two caps around South-East Asia and Central America with anisotropy tilted towards the equatorial plane. Inner core anisotropy is most likely due to alignment of hcp iron crystal formed either (i) during solidification at the inner core boundary or (ii) afterwards by deformation deeper in the inner core. Thus, our new model may be related to flow in the inner core or solidification processes at the inner core boundary and constrain geodynamic processes in the inner core.