Non Linear Analysis of Differential Travel Times of PKP Phases and D” Structure

Raphaël Garcia[1], Hrvoje Tkalčić[2] and Sébastien Chevrot[3]

contact e-mail : garcia@ipgp.jussieu.fr

[1] Département de Géophysique Spatiale et Planétaire, Institut de Physique du Globe de Paris, 4, Ave de Neptune, 94107 Saint Maur des Fossés, France
[2] Lawrence Livermore National Laboratory, P.O. Box 808, L-206, Livermore, CA 94568
[3] Laboratoire de Dynamique Terrestre et Planétaire, Observatoire Midi-Pyrénées, 14, Ave E. Belin 31400 Toulouse, France

ABSTRACT

ne triplication of PKP core phases has been dely used to extract information on the ructure of both the inner core and the base the mantle. We present a new method perrming a non linear inversion of the 3 main re phases waveforms (PKP(DF), PKP(BC) d PKP(AB)). The differential travel times tween these body waves are computed with gh accuracy even when they interfere on e records, or when pPKP depth phases are esent. This property allows us to investite the epicentral distance range 146-149 dees previously hidden by the interference tween the 3 core phases, and new ray paths associated to shallow events. The inversion of PKP data of the temporary EIFEL experiment in central europe reveals strong variations of the AB-BC differential travel time residuals which could be related to short wavelength heterogeneities at the base of the mantle. A global inversion of a large data set of AB-BC and BC-DF differential travel time residuals explains the anomalous AB-BC travel time residuals by a sharp D” structure below scandinavia, which is consistent with other global D” models. Our new BC-DF data set does not favour an hemispherical pattern of the inner core anisotropy.

METHOD

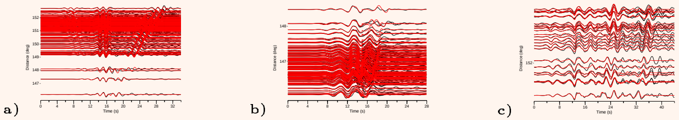
on linear waveform inversion with Simulated annealing

nthetic PKP phases are computed following the formula :

$$(t) = \mathrm{PKP(DF)}(t) + \mathrm{PKP(BC)}(t) + \mathrm{PKP(AB)}(t) \quad S_i(t) = R_{DF} A(t_i^*) * W(t+\tau_i^{DF}) +$$
$$(t+\tau_i^{BC}) + R_{AB} H * W(t+\tau_i^{AB})$$

ne ouput parameters are : $W(t)$ the waveform of the PKP(BC) phase taken as ference ; τ_i^{DF}, τ_i^{BC} and τ_i^{AB} the time shifts of the PKP(DF), PKP(BC) d PKP(AB) phases respectively ; t_i^* the differential attenuation between KP(DF) and PKP(BC) ; and R_{DF} and R_{AB} standing for amplitude corrections.

Examples of data fit



a) b) c)

gure 1 : Examples of core phases data fit for (a) well separated phases, (b) interfering ases, and (c) strong interference due to the presence of depth phases.

dvantages of the method :

- automatic measurement of differential travel times and attenuations in a fully non linear analysis.
- retreival of the parameters even in case of interference of the 3 phases (146°-149° epicentral distance, or shallow earthquake (PKP+pPKP))
- two independent estimates of error bars by statistical analysis and cross-correlation methods

cknowledgments

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eferences

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Chevrot, S., 2002. Optimal waveform and delay time analysis by simulated annealing, *Geophys. J. Int.*, **151**, 164-171.
Tkalčić H., B. Romanowicz, N. Houy, 2002. Constraints on D” structure using PKP(AB-DF), PKP(BC-DF) and PcP-P travel times data from broad-band records, *Geophys. J. Int.*, **148**, 599-616.
Garcia, R., 2002. Constraints on upper inner core stucture from waveform inversion of core phases, *Geophys. J. Int.*, **150**, 651-664.

INVERSION AND D” STRUCTURE

Data set

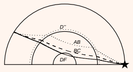


Figure 2 : Ray paths of the three PKP branches in the Earth : PKP(DF) (full line), PKP(BC) (dashed line) and PKP(AB) (dotted line). The event (black star) and the D” layer at the base of the mantle are also indicated.

The inversion of broad band records has allowed to constitute a large data set of 3416 BC-DF and AB-BC differential travel times. Then, data presenting statistical error bars larger than 0.7 s have been excluded leading to 2483 BC-DF and 2475 AB-BC differential travel times.

D” and inner core model

The global AB-BC and BC-DF differential travel times have been inverted by damped least squares for a simple Earth’s model composed of

– an inner core separated in two hemispheres with homogeneous axysimetric anisotropy.
– a 200 km thick D” layer composed of equal area blocks of 5x5° at the equator (see figure 3).

The results are then averaged for 18 different D” grid positions.

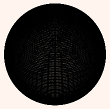


Figure 3 : D” model grids

The inner core anisotropy is parametrized in each hemisphere by the formula :

$$\frac{\delta v(r,\xi)}{v_0(r)} = a + \epsilon \cos^2\xi + \gamma \sin^2 2\xi$$

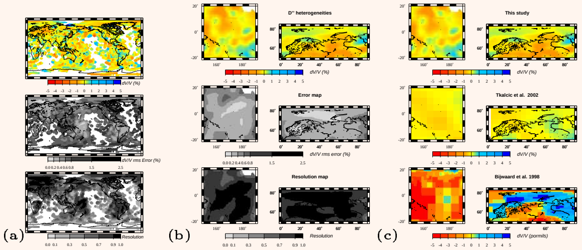
A priori rms error is set to 0.2, 3% and 1.5% respectively for the parameters a, ϵ (anisotropy level) and γ.

The inversion minimize the misfit function

$$f(\mathbf{d},\mathbf{m}) = (\mathbf{d}-\mathbf{g}(m))^T C_d (\mathbf{d}-\mathbf{g}(m)) + \mathbf{m}^T C_m \mathbf{m}$$

with C_d the data covariance matrix obtained from cross correlation errors, and $C_m = \sigma^2 I$ a diagonal model covariance matrix with $\sigma = 1\%$

D” Structure



(a) (b) (c)

Figure 4 : (a) global D” results and (b) focusing on the best resolved regions. From top to bottom, D” P-velocity perturbation, rms error and resolution after inversion. (c) Comparison with other D” P-velocity models.

Our D” model presents a lot of short wavelength heterogeneities due to the fact that differential travel times are sensitive to short wavelengths, and because at the global scale many regions presents a low resolution. The best resolved regions (Figures 4.b and 4.c) presents also short wavelength structures. These structures are compared to a D” model obtained from differential PKP travel times at larger epicentral distances (Tkalcic et al., 2002) and to a D” model obtained from ISC absolute travel times (Bijwaard et al., 1998). The differences between the models could be ascribed to the different data sets. However, the discontinuity below the north of scandinavia in our model is also seen in the Bijwaard’s model, and it is responsible of short wavelength PKP(AB) travel time anomalies observed on the EIFEL experiment data set (see figure 5).

Anomalous PKP(AB) data

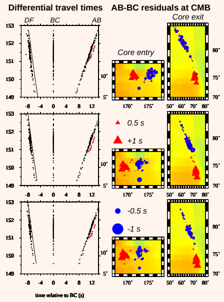
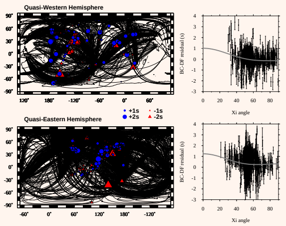


Figure 5 : Anomalous AB-BC residuals from the EIFEL experiment data set plotted at the core entry and exit points of the PKP(AB) ray paths over our D” model.

Inner core structure



Western Hemisphere :
$a = -0.12\% \pm 0.06\%$
$\epsilon = 1.22\% \pm 0.34\%$
$\gamma = -0.36\% \pm 0.17\%$

Eastern Hemisphere :
$a = 0.21\% \pm 0.09\%$
$\epsilon = 0.85\% \pm 0.23\%$
$\gamma = -0.27\% \pm 0.17\%$

Figure 6 : On the left, ray paths of PKP(DF) rays with symbols representing the BC-DF residuals relative to the ak135 model at the PKP(DF) ray turning points. On the right, BC-DF residuals as a function of the angle ξ between the PKP(DF) ray at its turning point and the Earth’s spin axis. The grey line represents the prediction by the inverted inner core anisotropy model for an average ray path. Fron top to bottom, quasi-western data set (PKP(DF) turning point longitude in between -180° and 40°) and quasi-eastern data set (PKP(DF) turning point longitude in between 40° and 180°)

The inner core anisotropy model obtained after inversion presents about 1% inner core anisotropy in both hemispheres, and so, it does not favour an inner core hemispherical pattern.

Discussion

The data set collected from broad band records has been processed by our simulated annealing algorithm in order to extract differential travel times of core phases. This large data set has been inverted for a simple Earth’s model including only a 300 km thick D” layer and a hemispherical inner core anisotropic model. Despite it’s very simple form, our model reduces by 45% the variance of the data. In the regions properly resolved by the inversion, our model presents short wavelength heterogeneities. In particular, it reveals a sharp heterogeneity at the base of the mantle below the north of Scandinavia and Siberia well sampled by the data of the EIFEL experiment. This result is not consistent with the interpretation by Luo et al. (2001) of PKP(AB) anomalous travel times, with approximately the same ray paths, in terms of an anomalous structure in the pacific.

Our inner core model presents low anisotropy levels (≈1%) in both hemispheres, which is not consistent with an hemispherical pattern of inner core anisotropy in the 100 to 300 km depth range. The absence of inner core hemispherical pattern could be due to the lack of PKP(DF) rays perfectly aligned along the spin axis of the Earth, but also to the effect of D” heterogeneities taken into acount in our model.

The next steps in this study will be the enlargement of the data set, the extraction and analysis of the differential amplitudes and attenuations of the core phases, and the improvement of the forward modelling and inversion process.