Full-waveform analysis of core-mantle boundary seismic waves

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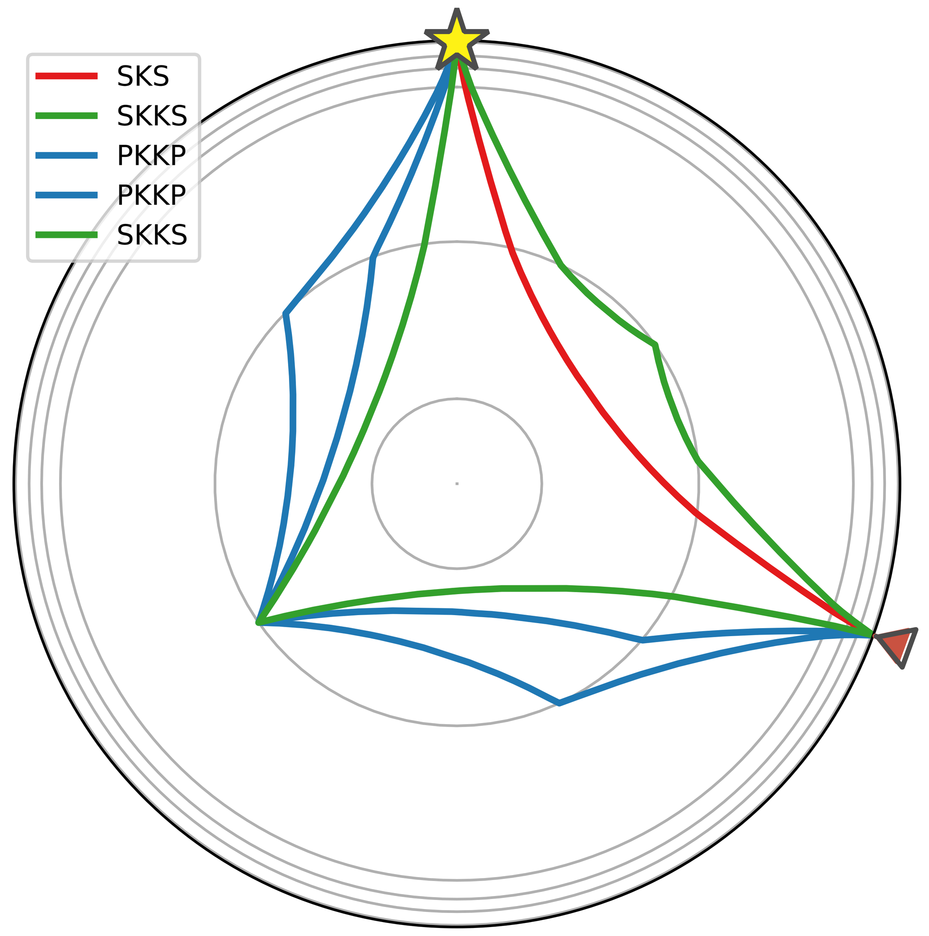
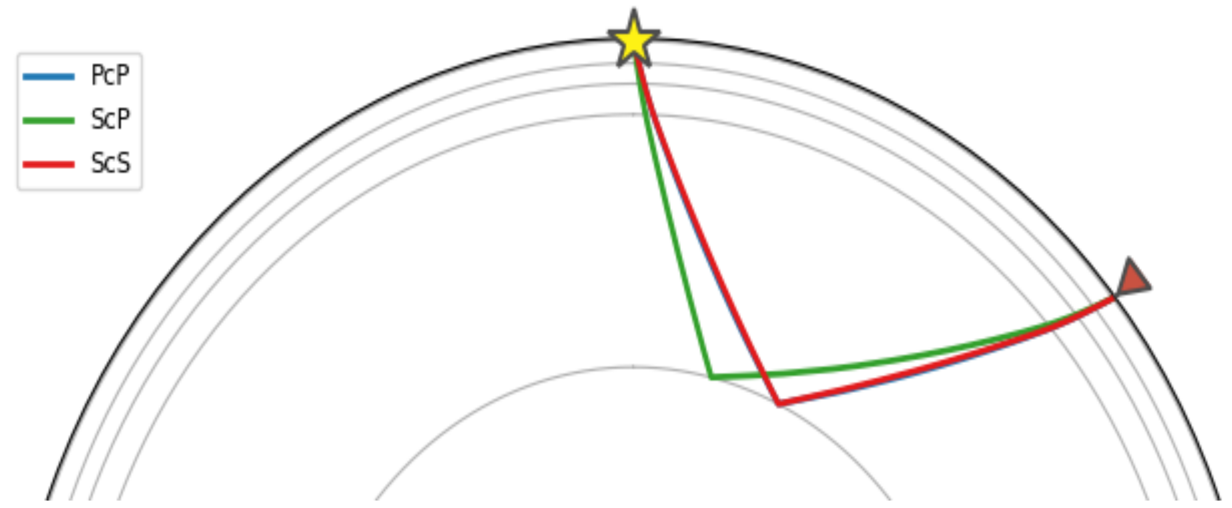
1. INTRODUCTION

The core-mantle boundary is perhaps the most important region of deep earth that helps us explain the dynamic evolution of our planet. Seismically, this region represents an area of major refractions and reflections of *P*- and *S*-waves which produce a plethora of information, but usually are difficult to observe and/or isolate the unique interactions with CMB. Knowledge about its seismic structure is usually limited by strong trade-offs between seismic properties, whose variations have complex effects on the waveform and traveltime of many seismic waves. The focus of our study is on the following commonly used phases:

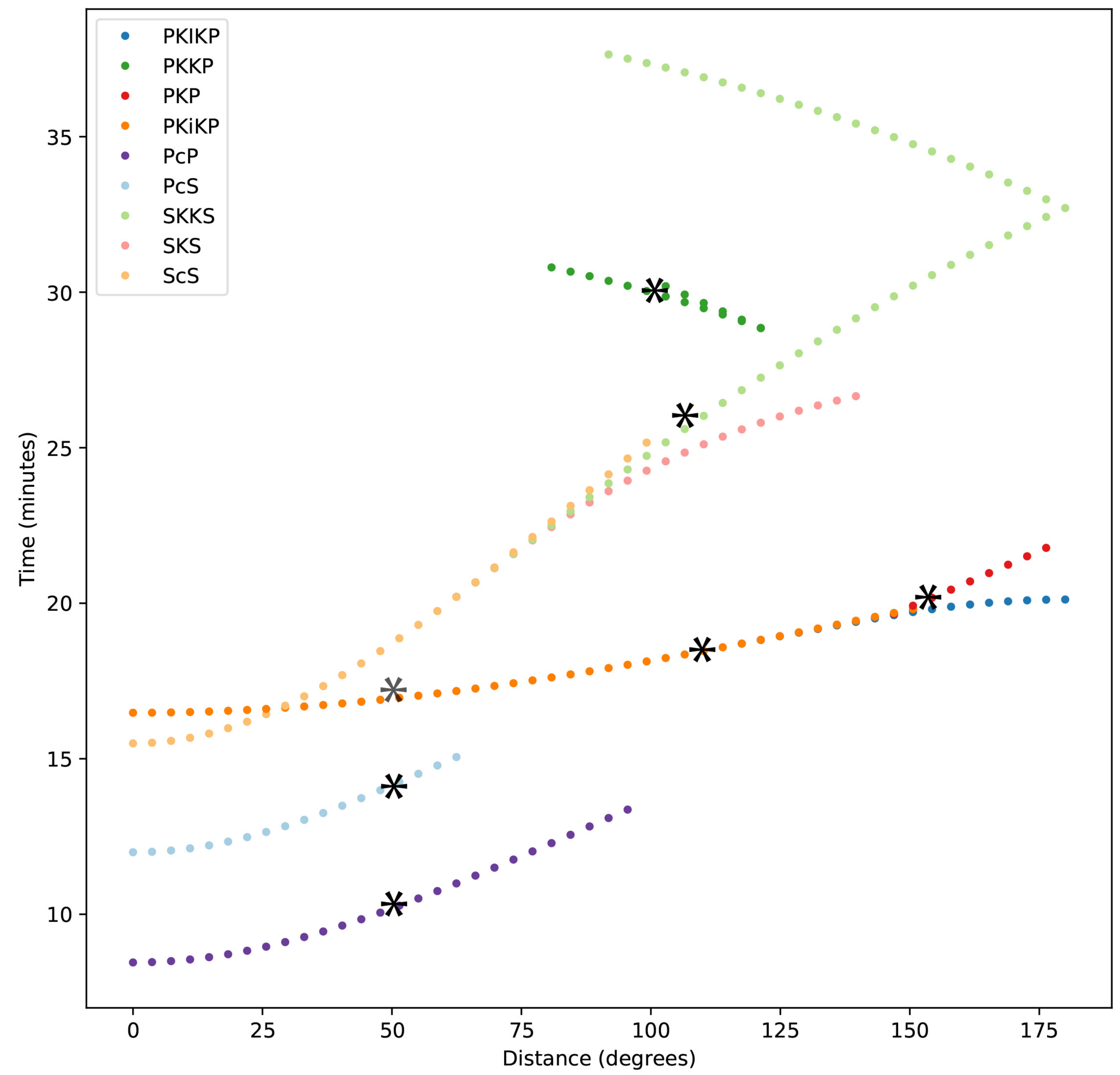
PcP, PKP, PcS, ScS, SKS and SKKS

- **Our study aims at adding new information about the usability of certain seismic phases frequently appearing in literature and analyse their full-waveform sensitivity, which so far hasn't been done before. This will guide to more efficient inversion for CMB structure. We seek feedback about which parts of waveforms would help mitigate the trade-off between velocity and topography.**





Left: Ray paths of PK- and SK-phases, which we investigate in terms of traveltimes.
Right: ScS, PcS, PcP, these are reflected phases

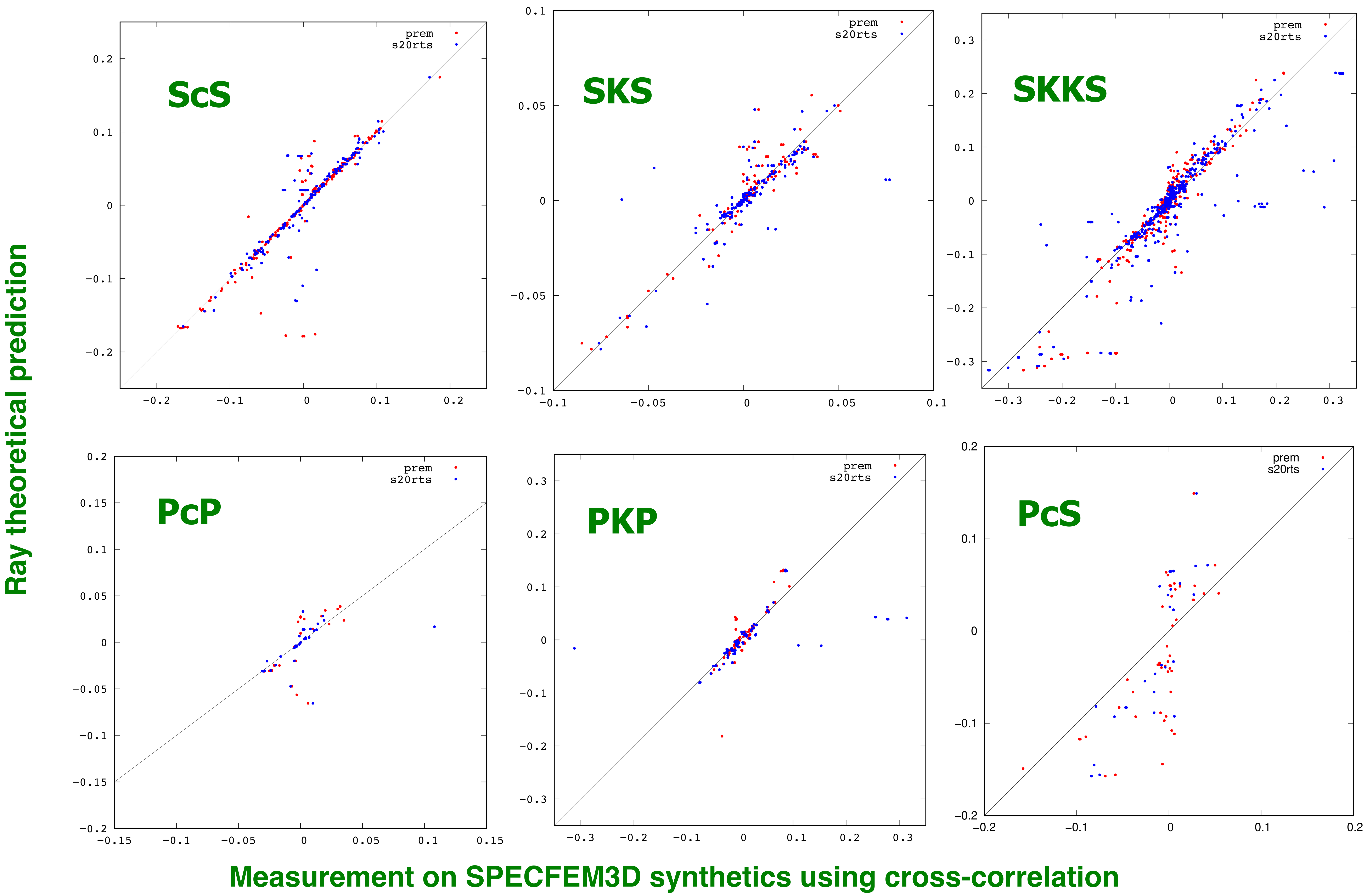


Traveltime curves computed for 1-D model reference for various of the phases we show. Stars indicate the epicentral distance and arrival time, characteristic of each phase for investigating each traveltime sensitivity.

Synthetic modelling and methods

Using SPECFEM3D_GLOBE (*Komatitsch & Tromp 2002a,b)* & adding long-wavelength CMB topography model *(Tanaka 2010*) in 1-D *(PREM*) & 3-D velocity mantle model *S20RTS, (Ritsema et al. 1999)*.

- Dominant period of seismograms is T~12 seconds.
- We band-pass filter between 0.01- 0.1 Hz.
- A shallow, fictitious earthquake at 20 km focal depth is used.



- The scatter plots show a comparison between traveltime anomaly predicted by ray theory given a known topographic variation vs. a time anomaly measured in SPECFEM3D synthetics by comparing synthetics w/ and wo/ topography in 1-D & 3-D background velocity models. Similar to <u>*Koroni & Trampert 2016.*</u>
- The line of slope 1 is supposed to be indicative of how well the two time anomalies agree for each seismic phase.
- The plots are for 1-D and 3-D background. Each dot represents a source-receiver pair where a traveltime anomaly measurement is made on.

Finite frequency sensitivity kernels with adjoints

- **Exact sensitivity kernels, based on banana-doughnut theory in order to understand finite-frequency effects & compare volumetric and boundary sensitivities.**

- **We run adjoint simulations on 1-D PREM background model since we want to investigate the finite frequency sensitivity of the selected phases. The interaction between the kernel and model variation to the traveltime window is going to indicate the contributing paths on the windows.**

○ Generic expressions relating the traveltime anomaly and the kernels of:

Boundary

$$dT = \int K_h \, \delta h(x) d^2 x$$

Shear velocity

$$dT = \int K_\beta \, \delta \ln \beta(x) d^3 x$$

Compressional velocity

$$dT = \int K_\alpha \, \delta \ln a(x) d^3 x$$

dT: traveltime in selected window

K_h: Boundary kernel
K_α : Compressional wavespeed kernel
K_β : Shearwavespeed kernel

δh : variation on the surface of CMB
δlnβ : relative variation of shear wavespeed wrt to background model
δlnα β: relative variation of compressional wavespeed wrt to background model

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3. TRAVELTIME ADJOINT SENSITIVITY KERNELS

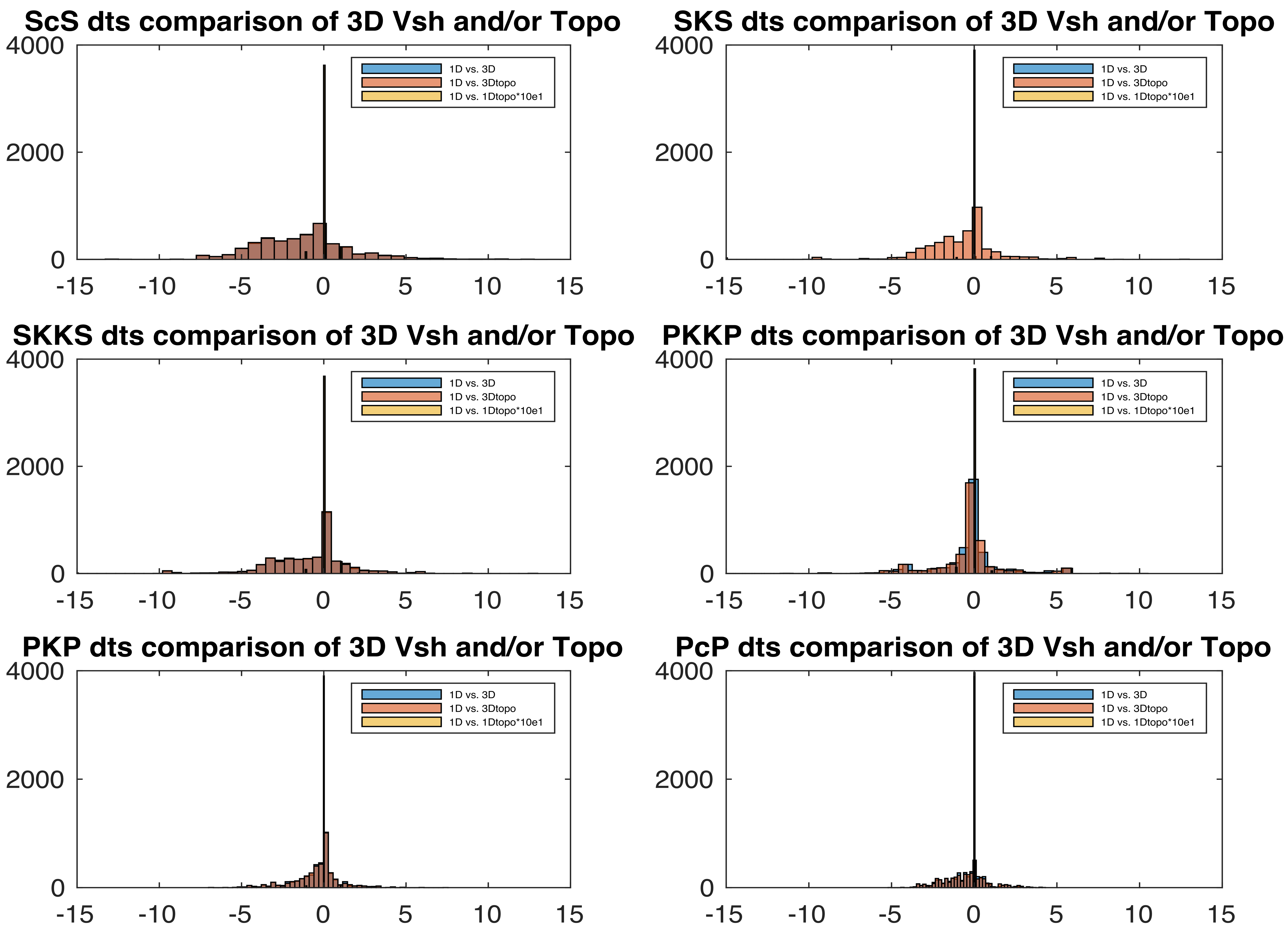
Seismic phases traveltime exhibit relatively larger sensitivity to velocity than CMB topography. Need to incorporate both derivatives to improve inversion & necessarily quantify the crosstalk.

Quantitative comparison of effects on traveltimes & Conclusions

4. SEPARABLE EFFECTS?

The measured dt's used for the scatter plots are now used to compare the separate effects of different models:

1D vs. 3D → 3D velocity
1D vs. 3Dtopo → 3D + CMB topo
1D vs. 1Dtopo → CMB topo



x axis: Measured traveltime anomaly in seconds

5. CONCLUSIONS & OUTLOOK

- Sensitivity kernels show that there is no particular phase that shows unique CMB sensitivity.
- Effect of CMB topography is an order of magnitude smaller than 3-D velocity variations; the latter has similar effect on time anomaly to when both parameters are present on exact waveforms.
- If CMB topography varies by only few kilometers, as suggested by most existing models, its effect is indistinguishable on traveltimes.
- For joint inversion, necessary to quantify the strong trade-off: New methodology for CMB imaging under way.