Mapping the Topography of Earth’s Core: Relationships Between Topography Variations and Seismic Waveforms

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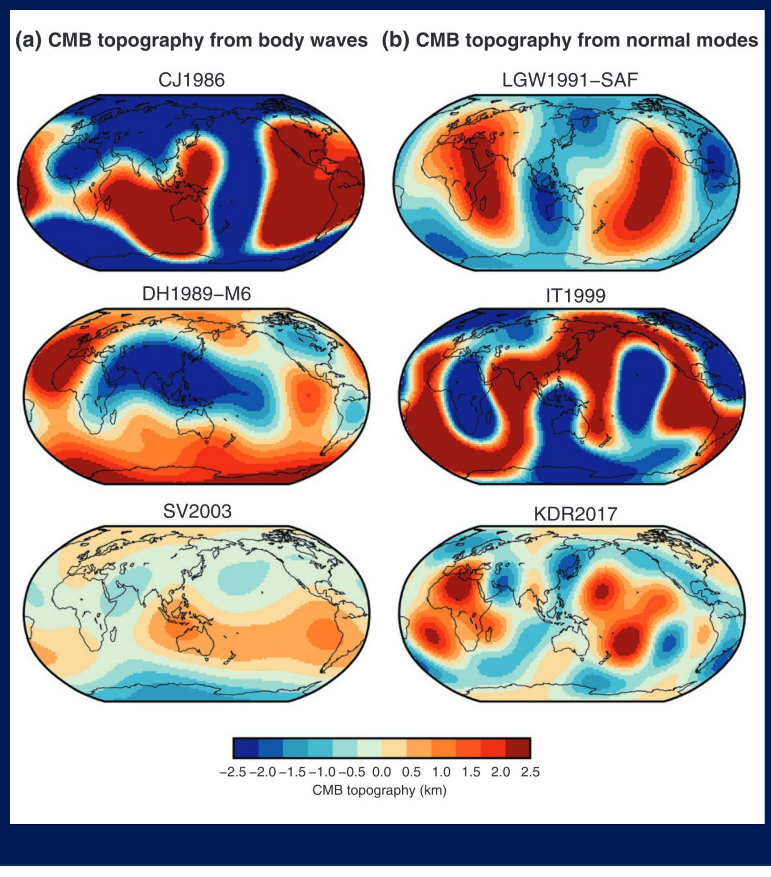
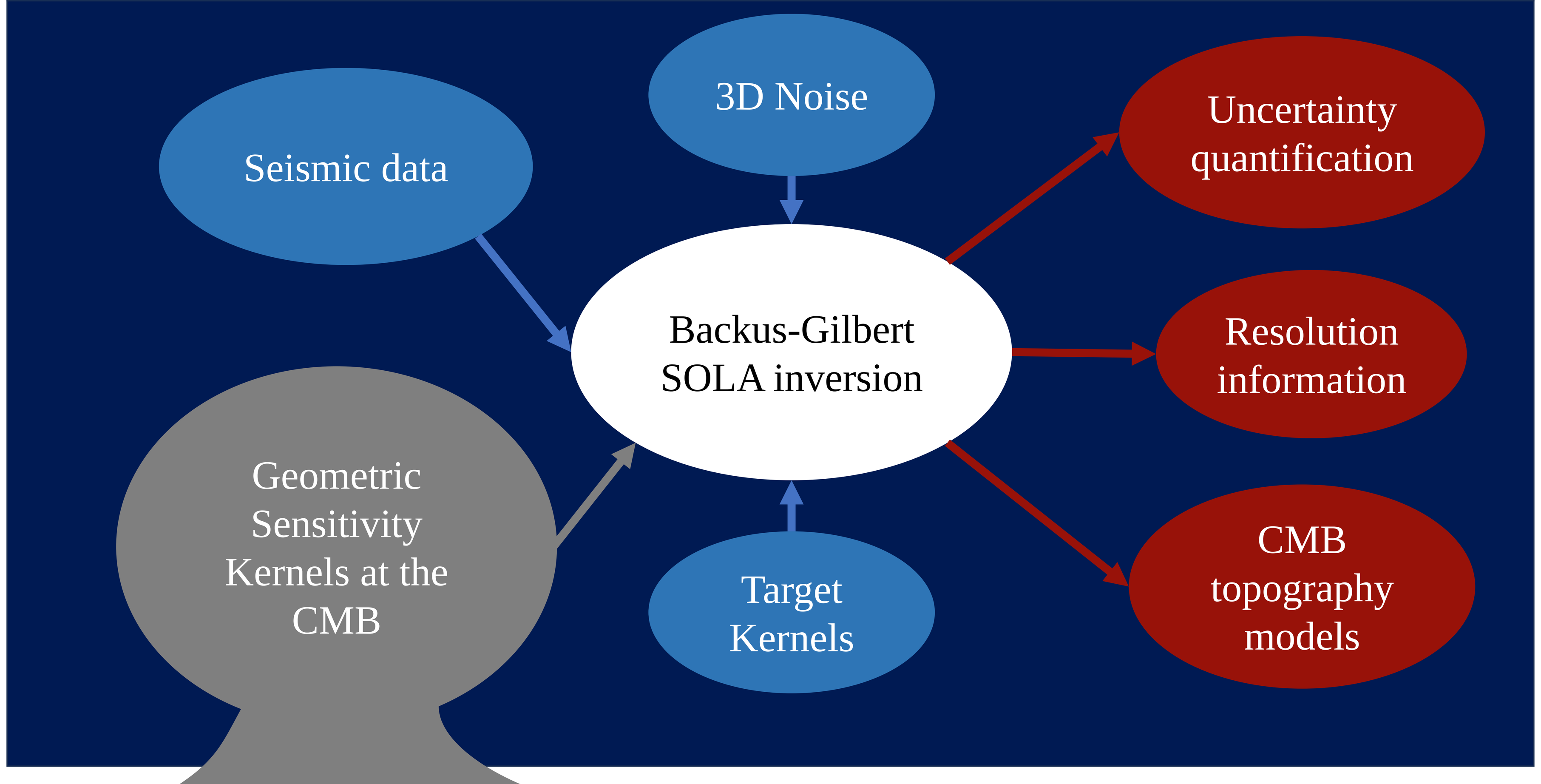
Motivation and Aim

- The Core-Mantle Boundary (CMB) is the most drastic discontinuity inside the Earth.
- Its shape affects the mantle dynamics and evolution.
- Even though its topography has been studied for more than 40 years, models still don’t converge[1].
- ➢ We aim to produce a robust, multi-scale model of the CMB topography.



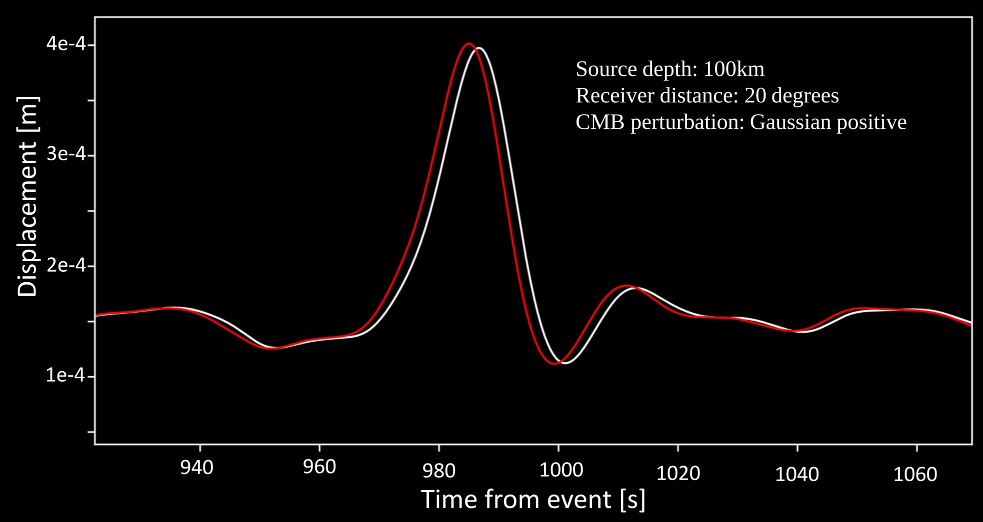
A collection of 6 published CMB topography models. (Koelemeijer, 2020)

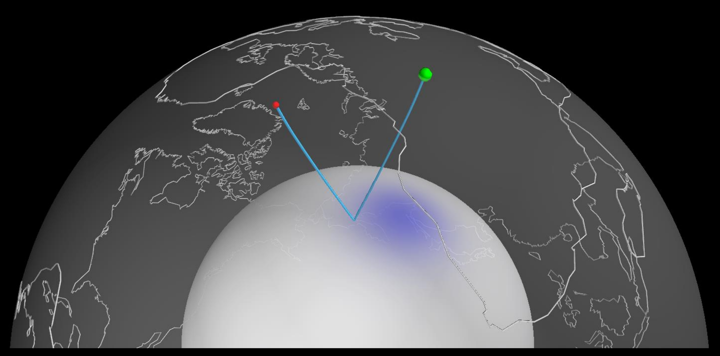
Ingredients for Inversion



CMB topography effect on waveforms

- Small perturbations in the topography of the CMB lead to waveform perturbations well approximated by time-domain shifts.





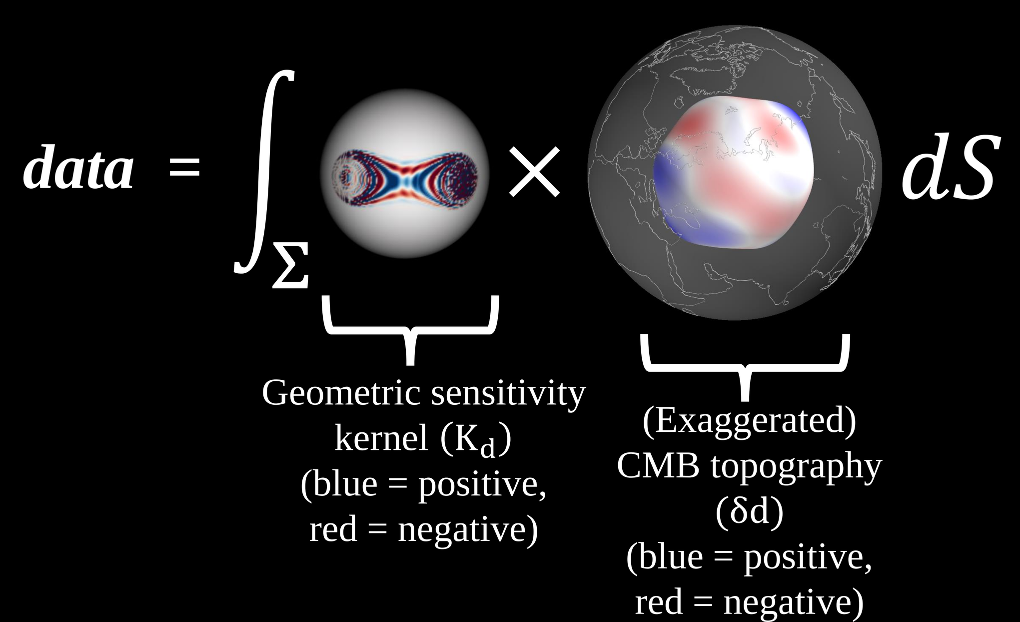
Ray paths of ScS phase. CMB topography is color-coded: blue>0, white = 0.

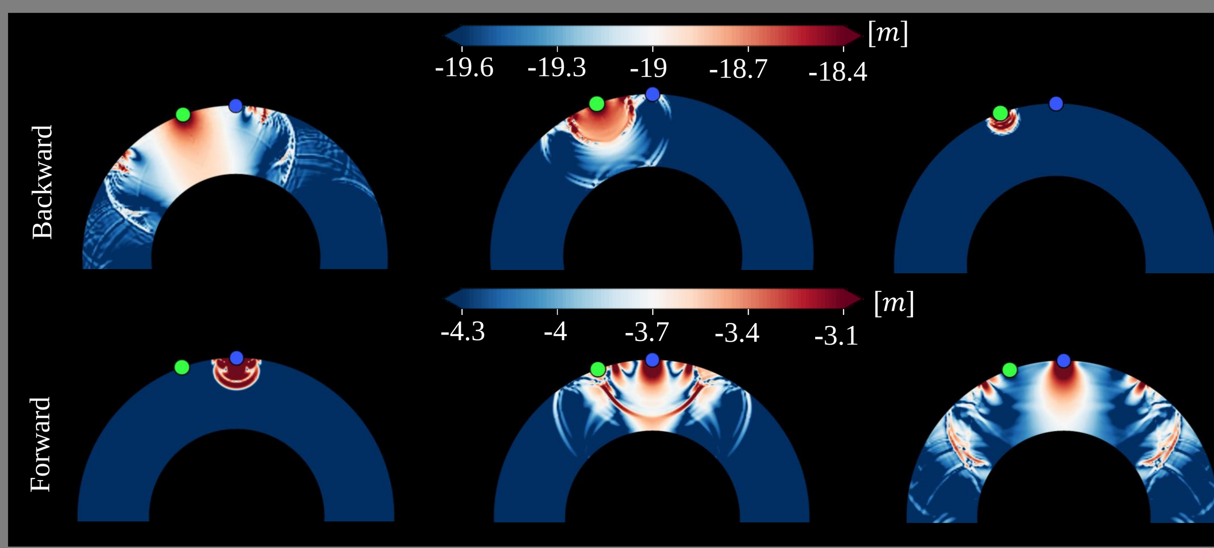
- Backus-Gilbert SOLA[2,3,4] inversion requires a linear relationship between the data and the model.
- Relation between waveforms (data) and CMB topography (model) can be linearized and used for BG-SOLA inversion.

Linearizing the relation between topography and waveforms

- The relation between waveform phase shifts and CMB topography perturbation in the linearized form is given by the following integral:

- Computation of geometric kernels is done via the adjoint method[5,6]
- Forward and backward wavefields are computed using the powerful yet efficient wave solver AxiSEM3D[7,8]





Left: diagram showing the interaction between forward and backward fields for ScS phase at 20 degrees distance between station and event. Below: Shear wave volumetric sensitivity kernel

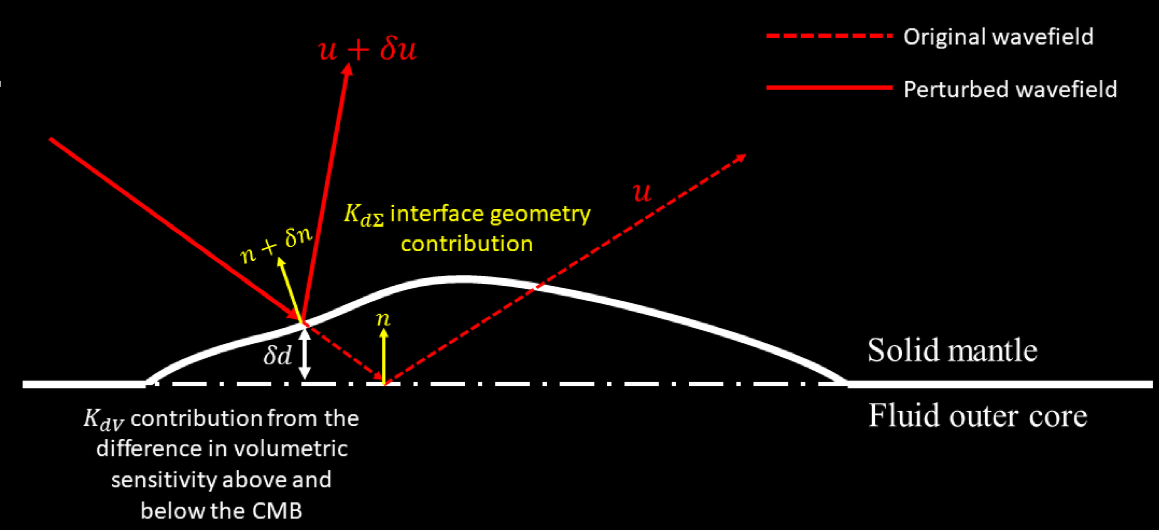
Geometric Sensitivity kernels

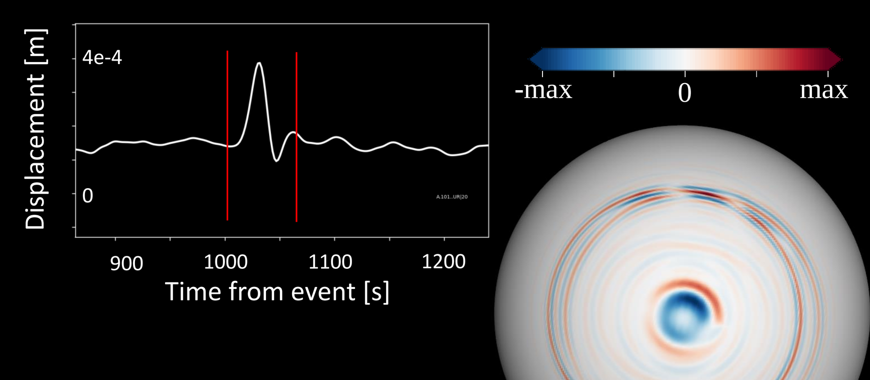
- The geometric sensitivity kernel can be split in 3 components:

$$K_d = K_{dv} + K_{d\Sigma_n} + K_{d\Sigma_t}$$

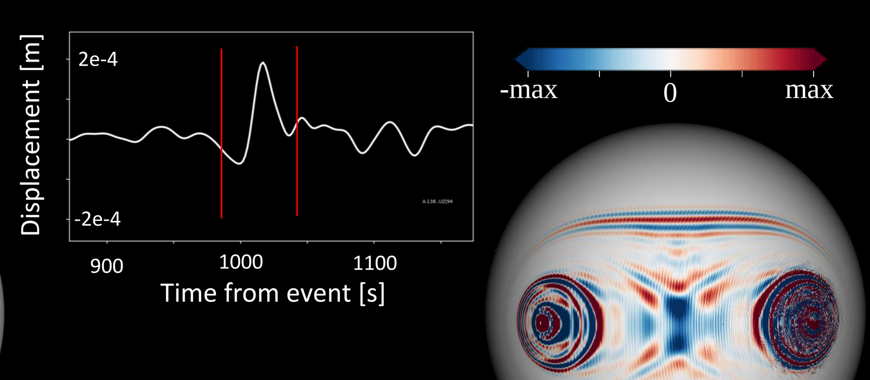
- $K_{d\Sigma_t}$ vanishes on solid-solid boundaries due to the tighter boundary conditions present there.
- K_{dv} is formed purely from volumetric sensitivities (density and elastic):

$$K_{dv} = \rho K_\rho + C :: K_C$$





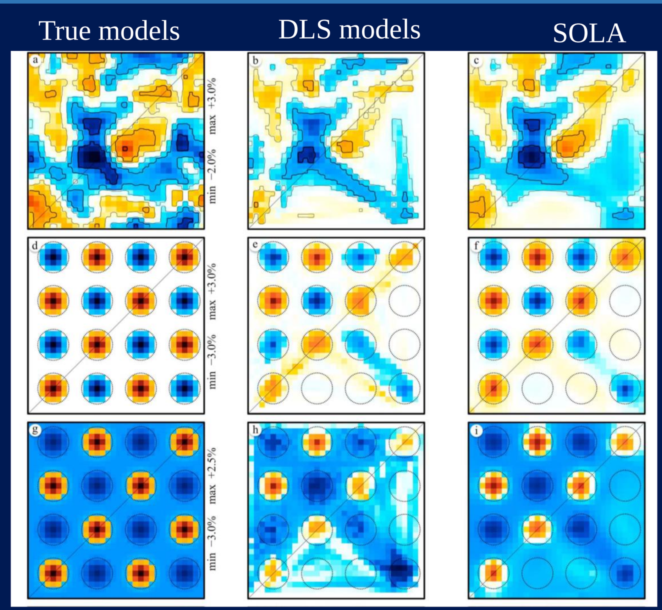
K_{dv} for ScS at 20° and 30s main period evaluated at the CMB



K_d for PP at 94° and 30s main period evaluated at the 670km discontinuity

BG-SOLA Inversion

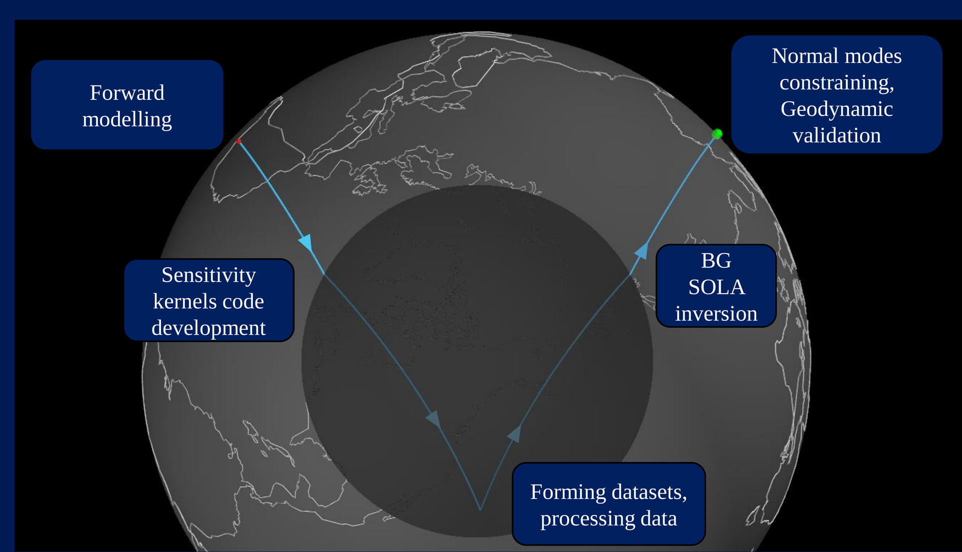
- The linearized relationship will be inverted using the Backus-Gilbert SOLA method (BG-SOLA)
- This method computes averages of possible models and provides a unique set of advantages:
  - Provides un-biased averages
  - Can invert locally
  - Easily parallelizable
  - Full uncertainty and resolution quantification



Comparison of inversion between SOLA and Damped Least Squared (DLS) methods (Zaroli, C., Koelemeijer, P. and Lambotte, S., 2017).

Future Work

- ➢ Finish kernel code framework
- ➢ Create framework for BG-SOLA
- ➢ Gather and process data
- ➢ Run BG-SOLA inversion
- ➢ Apply further constraints on model from independent normal modes data
- ➢ Compare with models from geodynamics simulations



Visual representation of the main steps of the Ph.D. project

References

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Acknowledgments

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