A new full-waveform model of the North Atlantic region

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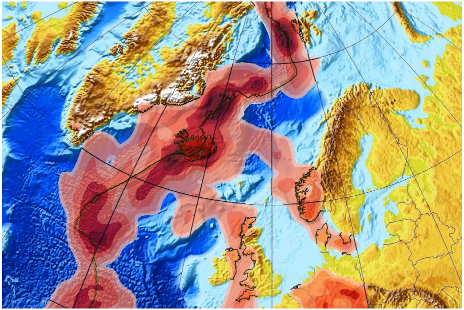


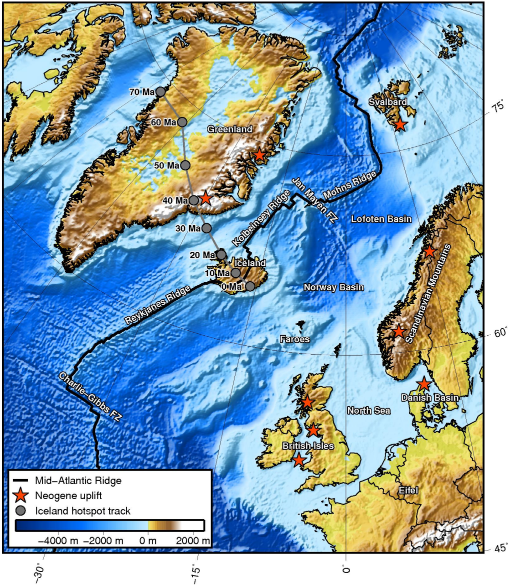
- 4th QUEST Workshop in Benodet (France), May 2013 -

Overview

1. The North Atlantic region
2. Adjoint tomography and instantaneous phase misfit
3. Dataset and Inversion
4. Features of the model
5. Conclusions

The North Atlantic region

Bathymetry/Topography



- Iceland/Jan Mayen: Deep mantle plume or shallower source?
- Are Iceland and Jan Mayen separate hotspots / plumes?
- What is the lateral extent of the 'plume head' beneath the lithosphere?
- Is the post-breakup uplift (< 30 Ma) at the continental margins related to the plume?

Adjoint Tomography

1. Computation of the **forward wavefield** using the spectral element method (SEM)
   $\rightarrow$Accurate seismograms in 3-D reference model

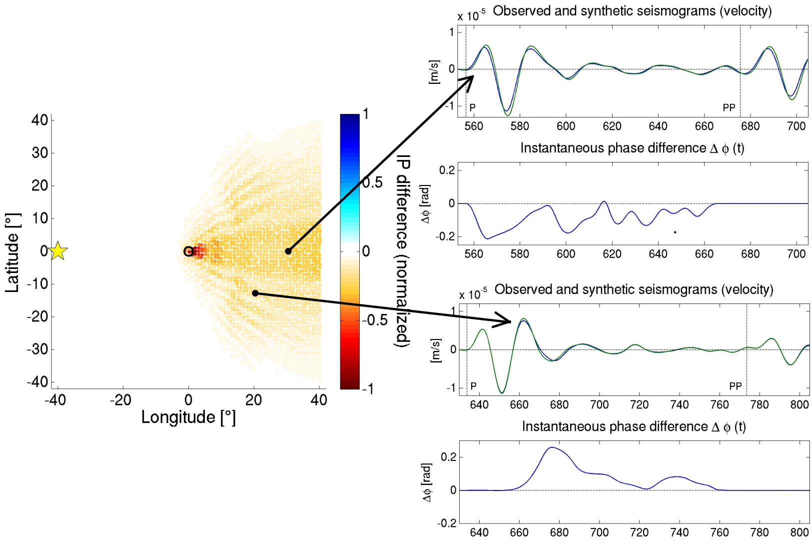
2. Evaluation of **misfit** between data and synthetics, computation of adjoint sources

3. Computation of the **adjoint wavefield** by time-reverse propagation of adjoint sources (again using SEM)

4. **Gradients** (sensitivity kernels) are constructed from interaction of forward and adjoint wavefields

5. Iterative model update using a **conjugate gradient scheme**

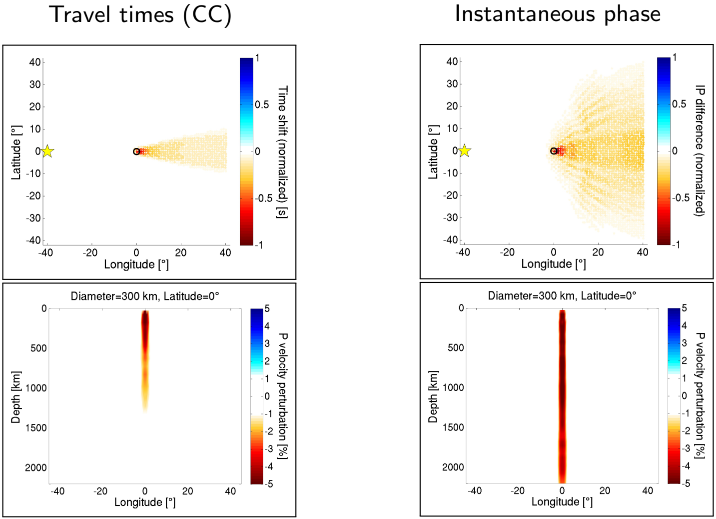
$\Rightarrow$ Fully 3-D non-linear inversion based on arbitrary misfit
Potential to exploit the full seismogram



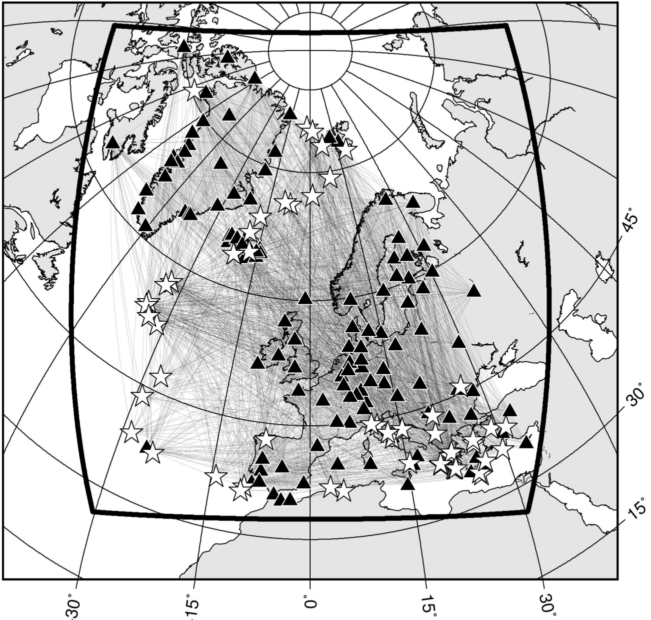
Time-continuous, amplitude-independent phase difference

⇒ Diffracted waves in the coda can be measured and included in the inversion

Instantaneous phase

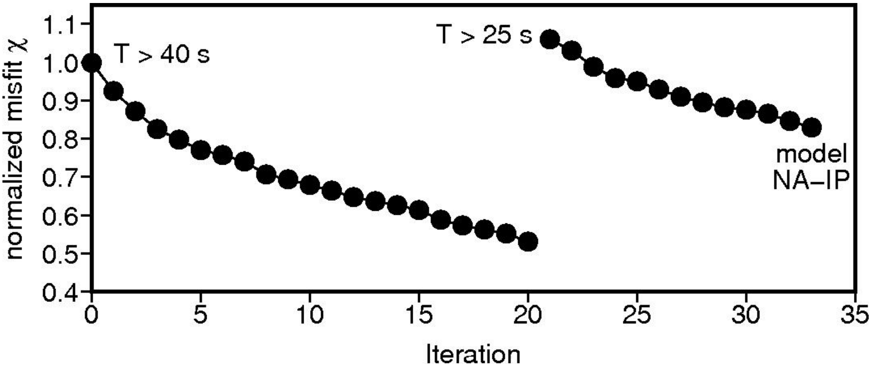


⇒ Plumes in the deep mantle can be imaged if diffracted waves are considered



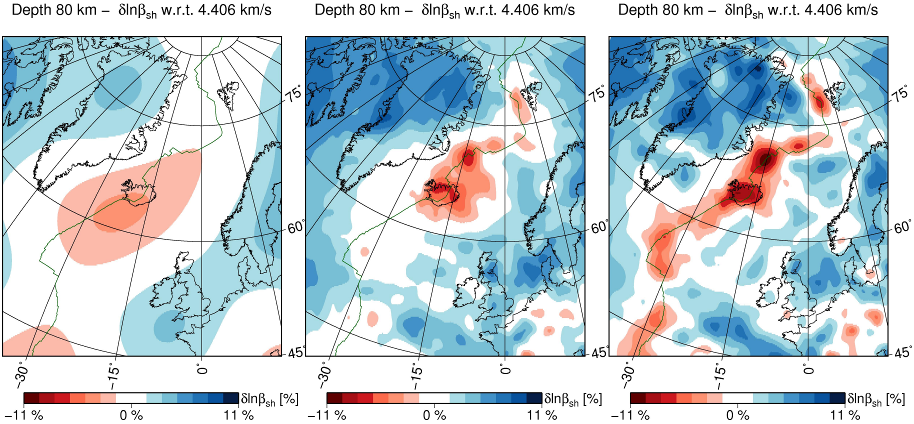
- Depth: 1500 km
- 60 events
- ca. 4500 seismograms
- Full-waveform starting model (Fichtner et al., 2011)
- Inversion for v_{sh} and v_{sv} (but only v_{sh} presented)

Inversion: Reduction of the total misfit



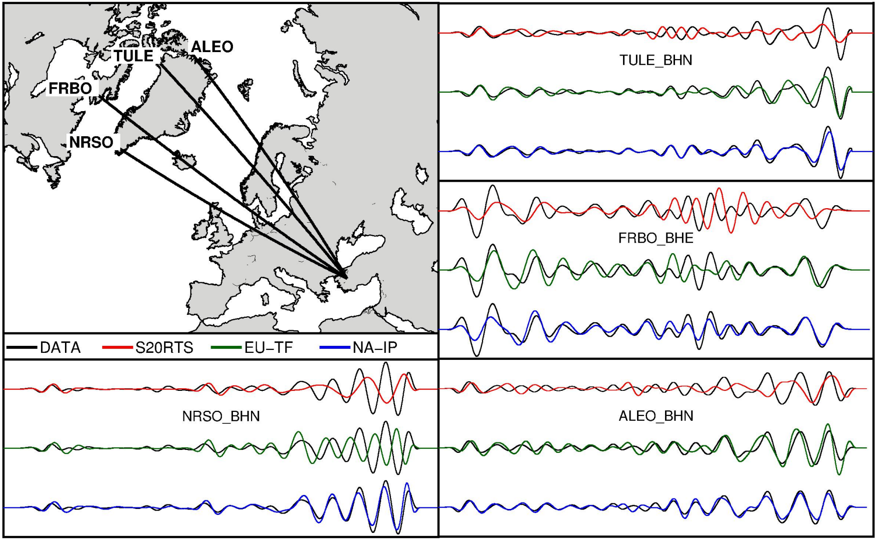
- ≈ 2.5 million CPU hours

S20RTS (Ritsema et al., 1999) ⇒ **EU-TF** (Fichtner et al., 2011) ⇒ **NA-IP**

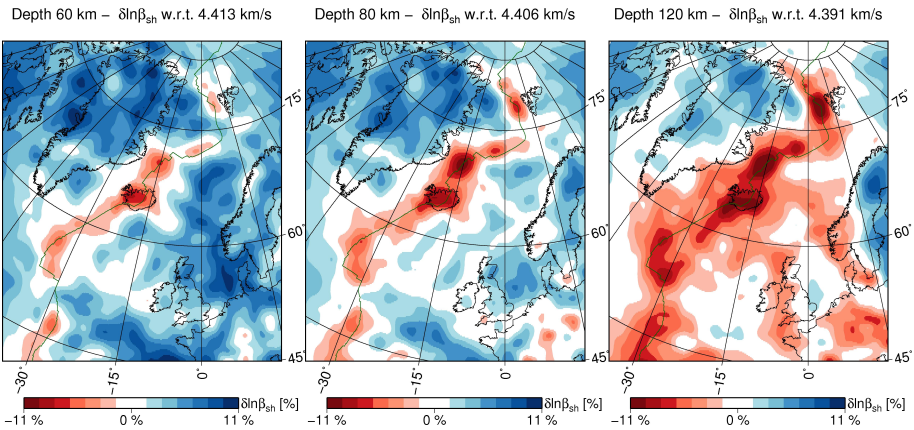


- correlation with tectonic and geologic features

Validation: Waveform fits compared to S20RTS and EU-TF



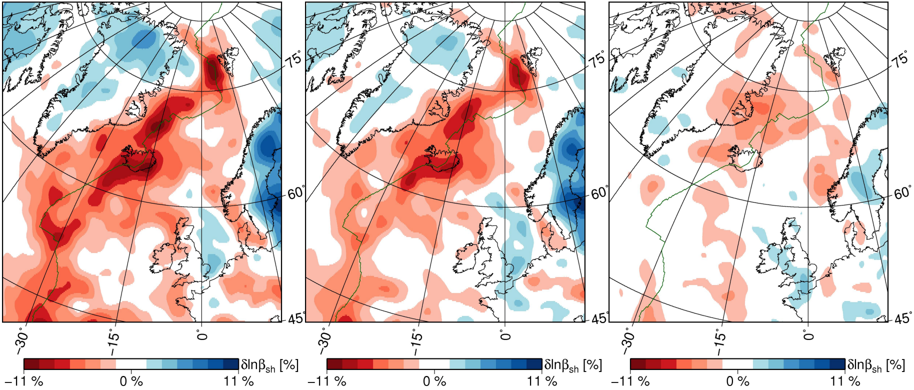
Model NA-IP: Horizontal slices 60, 80, 120 km



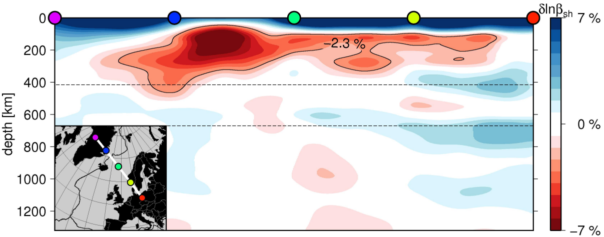
- separate hotspots beneath Iceland and Jan Mayen
- deep cratons Greenland + Baltic shield
- low-velocity layer beneath oceanic lithosphere
- 'fingers' extend beneath continental lithosphere

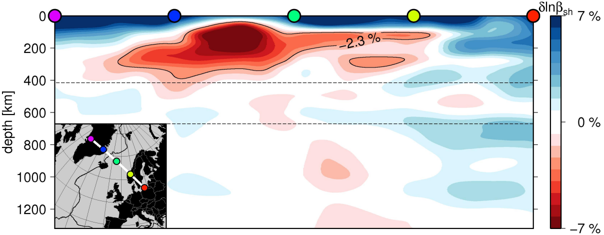
Model NA-IP: Horizontal slices 160, 200, 300 km

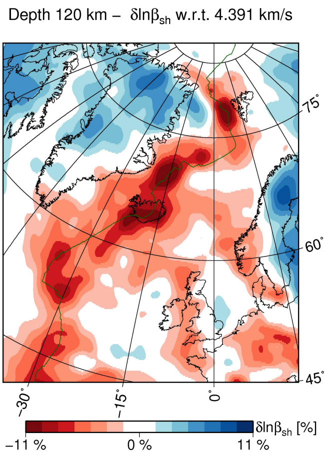
Depth 160 km – $\delta\ln\beta_{sh}$ w.r.t. 4.376 km/s   Depth 200 km – $\delta\ln\beta_{sh}$ w.r.t. 4.409 km/s   Depth 300 km – $\delta\ln\beta_{sh}$ w.r.t. 4.609 km/s



Model NA-IP: Cross-sections along Scandinavian low-velocity 'finger'

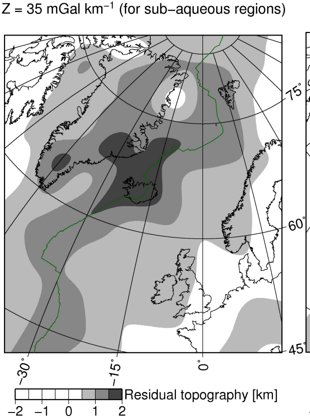




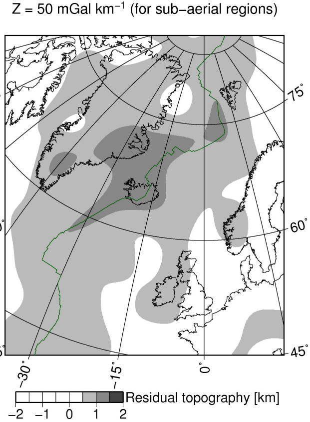


Dynamic topography estimated from gravity

(oceanic)



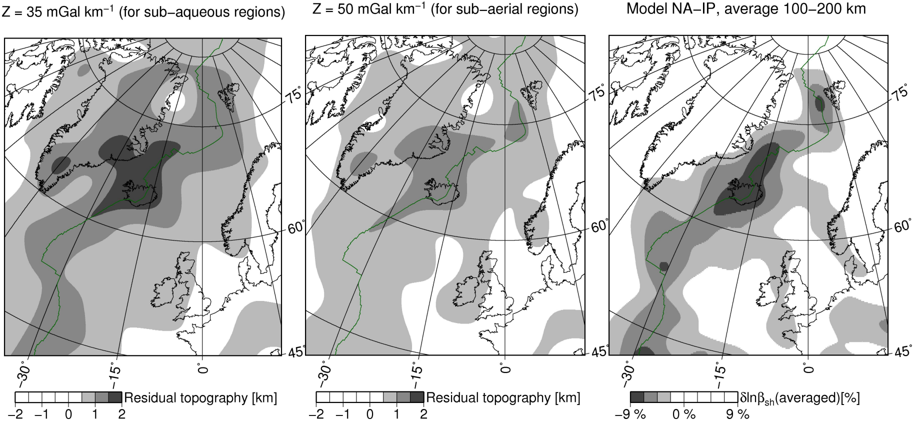
(continental)



(after Jones et al., 2002)

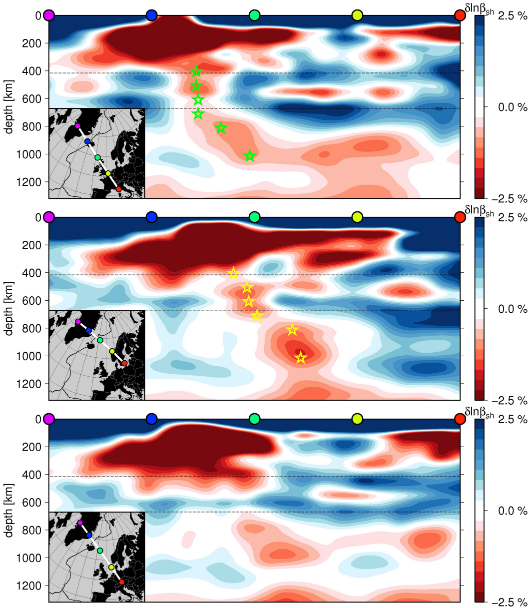
Dynamic topography estimated from gravity | S-velocity

(oceanic) | (continental) | (average 100-200 km)



(after Jones et al., 2002)

Model NA-IP: Cross-sections of plume conduits



Iceland

Jan Mayen / Kolbeinsey Ridge

In-between Iceland and Jan Mayen

Conclusions

- We successfully improved the tomographic resolution of the North Atlantic region using adjoint tomography with the instantaneous phase misfit.
- Iceland and Jan Mayen are separate hotspots, caused by deep plumes that are clearly separated in the upper mantle.
- A widespread low-velocity layer is found beneath much of the oceanic lithosphere of the North Atlantic.
- Fingers of the layer extend beneath the continental lithosphere of southern Scandinavia and Britain, supporting the uplift of these regions.
- Excellent agreement with independent, gravity-based estimates of dynamic topography.

- Rickers, F., Fichtner, A. and Trampert, J., 2013. **The Iceland - Jan Mayen plume system and its impact on mantle dynamics in the North Atlantic region: Evidence from full-waveform inversion.** Earth Planetary Science Letters 367, 39–51

- Rickers, F., Fichtner, A. and Trampert, J., 2012. **Imaging mantle plumes with instantaneous phase measurements of diffracted waves.** Geophysical Journal International 190, 650–664