# 3D surface-wave tomography with full resolution and robust model uncertainties using finite-frequency and SOLA-Backus-Gilbert inversion

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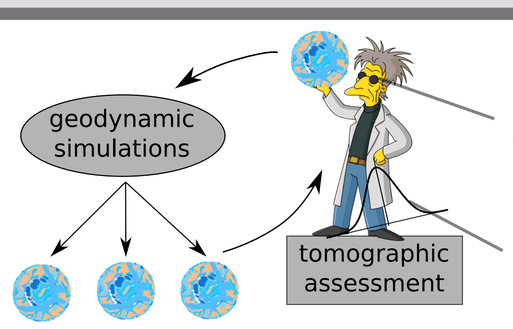
## Motivations

Mapping upper-mantle structure (Vs) with uncertainty quantification

for robust interpretation and meaningful statistical testing of geodynamical predictions




## Challenges

Tomographic **3D resolution**
- Lateral (poor ray coverage)
- Vertical (complex depth sensitivity)

Tomographic **uncertainties**
- Measurement
- Theoretical

## Key points

- ✓ Surface-wave tomography with control on 3D resolution & uncertainty: proof of concept
- ✓ An approach for theoretical uncertainty estimates
- ✓ Lateral & vertical smearing: quantitative observation
- ✓ Model uncertainty dominated by theoretical errors
- ✓ Real application: preliminary results

## Finite-frequency: 3D sensitivity[(a)]

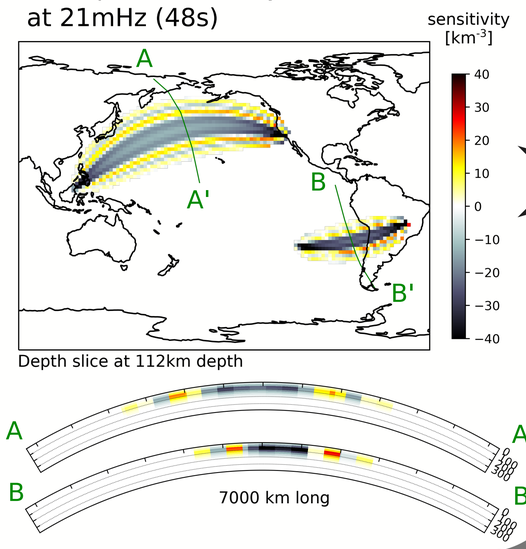
phase-delay / sensitivity kernel

$$\delta\phi_l(\omega) = \iiint_{\oplus} K_l(\omega;\boldsymbol{x})\delta \ln V_{SV}(\boldsymbol{x}) d^3\boldsymbol{x}$$

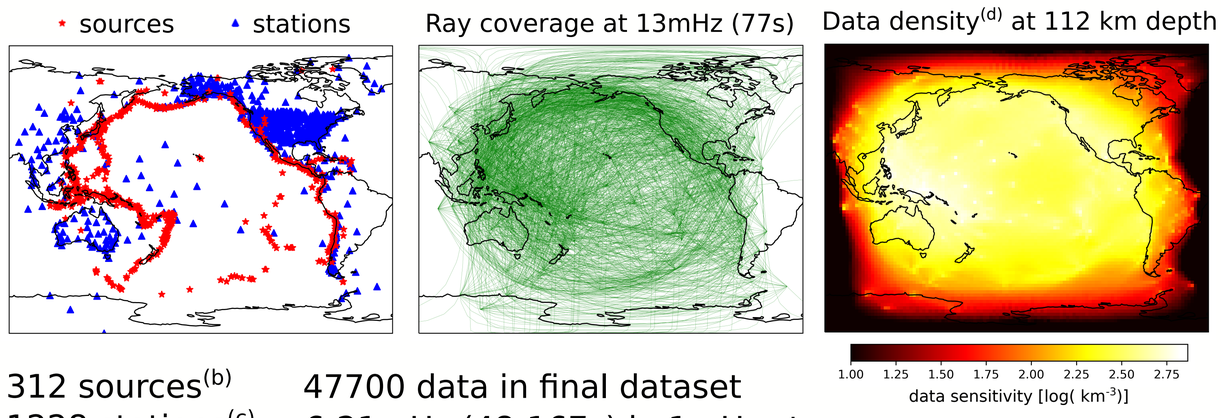
3D upper-mantle / perturbation Vsv

Fundamental mode vertical component Rayleigh-wave

Examples sensitivity kernels at 21mHz (48s)




## Data Geometry $G$

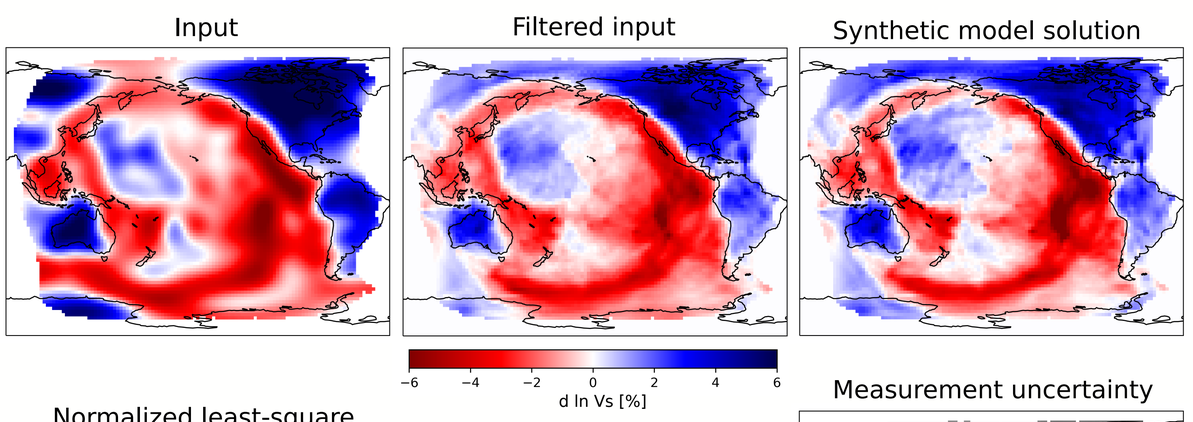



312 sources[(b)]
1228 stations[(c)]

47700 data in final dataset
6-21mHz (48-167s) in 1mHz steps

## Proof of Concept & Estimation of theoretical uncertainty

Measurement on synthetic SEM seismograms[(g)] computed in 3D model S362ANI[(h)] (with CRUST2.0[(f)] on top)

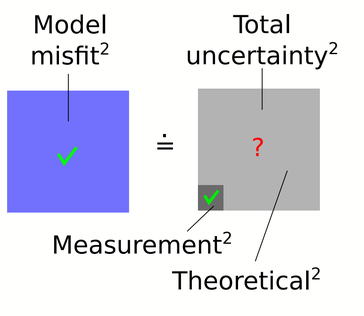


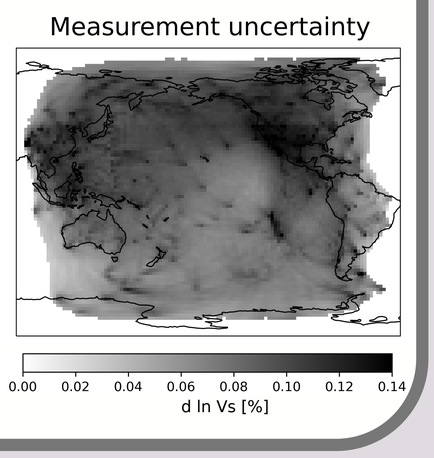

Normalized least-square model misfit

$$\chi_m \doteq \sqrt{\frac{1}{\#\mathcal{P}} \sum_{k\in\mathcal{P}} \frac{[(\boldsymbol{m^{out}})_k - (\boldsymbol{R}\boldsymbol{m^{in}})_k]^2}{(\boldsymbol{\sigma_m})_k^2}}$$

Model uncertainty

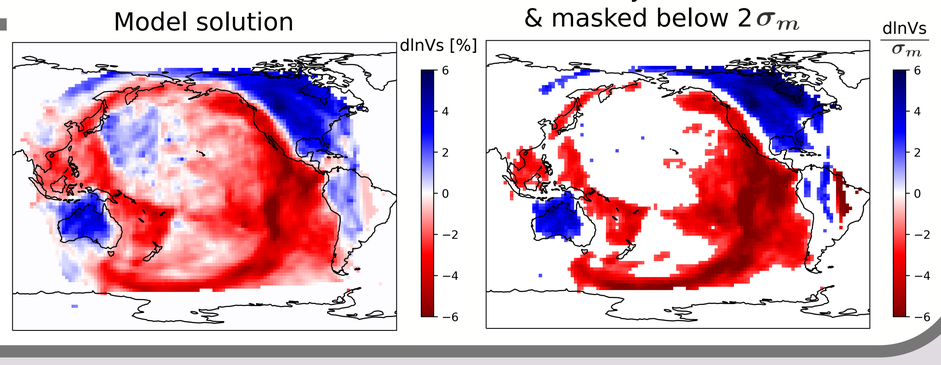
| Type | Mean |
|---|---|
| Measurement | 0.0852 |
| Theoretical | 0.5283 |
| **Total** | 0.5352 |




## Real case

Measurement on real seismograms



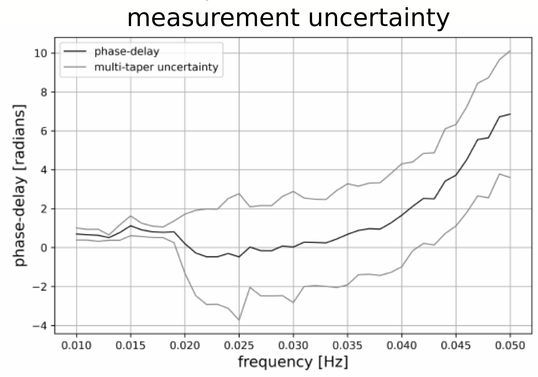

$G^\dagger$ $G$

$d +/- \sigma_d$

## Measurement & uncertainty

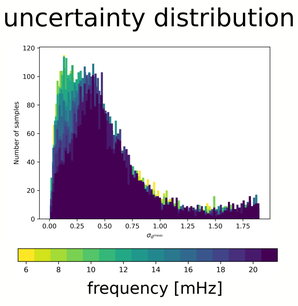
Multi-taper technique using 5 first Slepians

A dispersion curve with measurement uncertainty

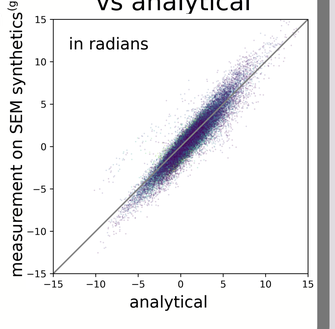



Data in synthetic 3D input model

Data measurement uncertainty distribution




Measurement vs analytical




Crustal correction[(f)]

## SOLA[(e)]

Given $G$, find $G^\dagger$ optimizing
- fit to target resolution
- uncertainty propagation

$$\arg\min_{\boldsymbol{G}^{\dagger k}} \sum_j [R_j^k - T_j^k]^2 \mathcal{V}_j + \eta^2 \sigma^2_{\widetilde{m}_k},$$

$$\sum_j R_j^k = 1$$

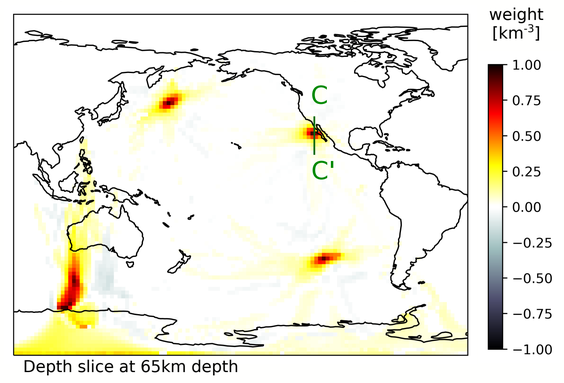
uncertainty propagation

resolution

$G^\dagger$

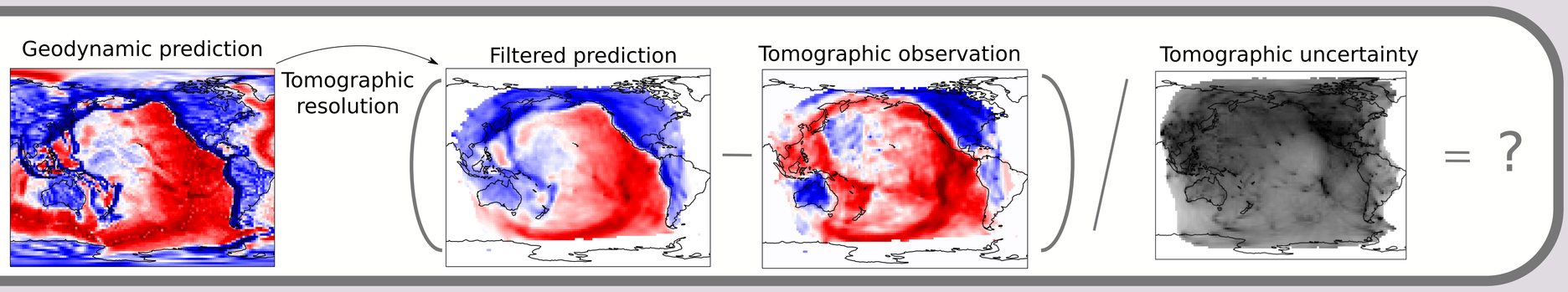
## Resolution

Resolution kernels of 4 model parameters at 65km depth




## Next[(i)]

Assessment of geodynamical predictions using tomographic observation, with full account for 3D resolution and uncertainty




(a) Zhou et al. 2008
(b) Source solution from GCMT
(c) Station data from IRIS
(d) Sum of sensitivity kernels in each cell
(e) Zaroli, 2016

(f) CRUST1.0 Laske et al., 2013 or CRUST2.0 Basin et al., 2000
(g) Synthetics from Global Shake Movie
(h) Kustowski et al., 2008
(i) Geodynamic models from J. Panton & Huw Davies (University of Cardiff)

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