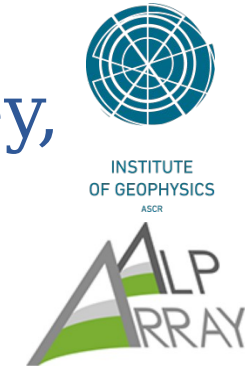
Surface Wave Tomography of the Bohemian Massif Crust

J. Kvapil, J. Plomerová, L. Vecsey,
V. Babuška and AlpArray WG



Workshop CzechGeo/EPOS
Prague 4th Dec 2019

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

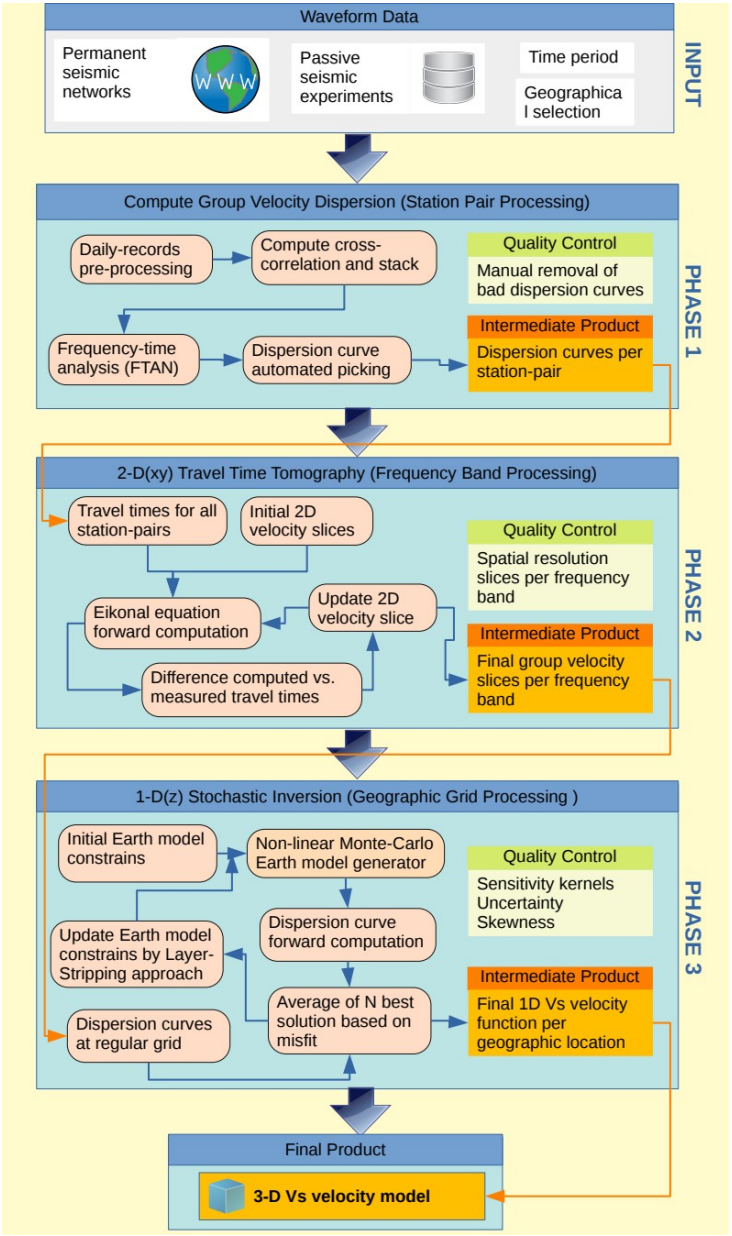
MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Introduction

- We are using ambient noise tomography to build crustal Vs velocity model of the Bohemian Massif

- We processed continuous waveform data from 404 permanent stations and passive seismic experiments from time period 2002 to 2016.

Ambient Noise Tomography



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  - Instrumental Response Removal
- Station-Pair Processing
  - Cross-correlation (MSNOISE package, Lecocq et al., 2014)
  - Stacking of traces (MSNOISE package)
    - Threshold of 60 days (minimum)
  - Frequency Time Analyses FTAN (PYTHON packages)
    - period (frequency) sampling: third octave bands
  - Dispersion Curve picking
    - Automated picking
    - Progressive max-amplitude picker with fundamental mode priority
    - Dispersion curve length (maximum period) set according to inter-station distance
  - Visual checking of dispersion curve to eliminate outliers
    - Total number of accepted dispersion curves: 21 066
- Common Period Processing
  - 2-D Fast Marching Surface Wave Tomography (FMST package, Rawlinson 2005)
    - Surface sampling 22 x 22 km (processing grid)
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    - Reconstruction of dispersion curves at regular grid
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  - 1D Non-linear Monte Carlo (GEOPSY package, Wathelet 2008)
    - 360 iteration, 280 initial models => 100 000 resulting models
    - 7-layered model based on IASP91 constrains
    - 4 passes of Layer-Stripping

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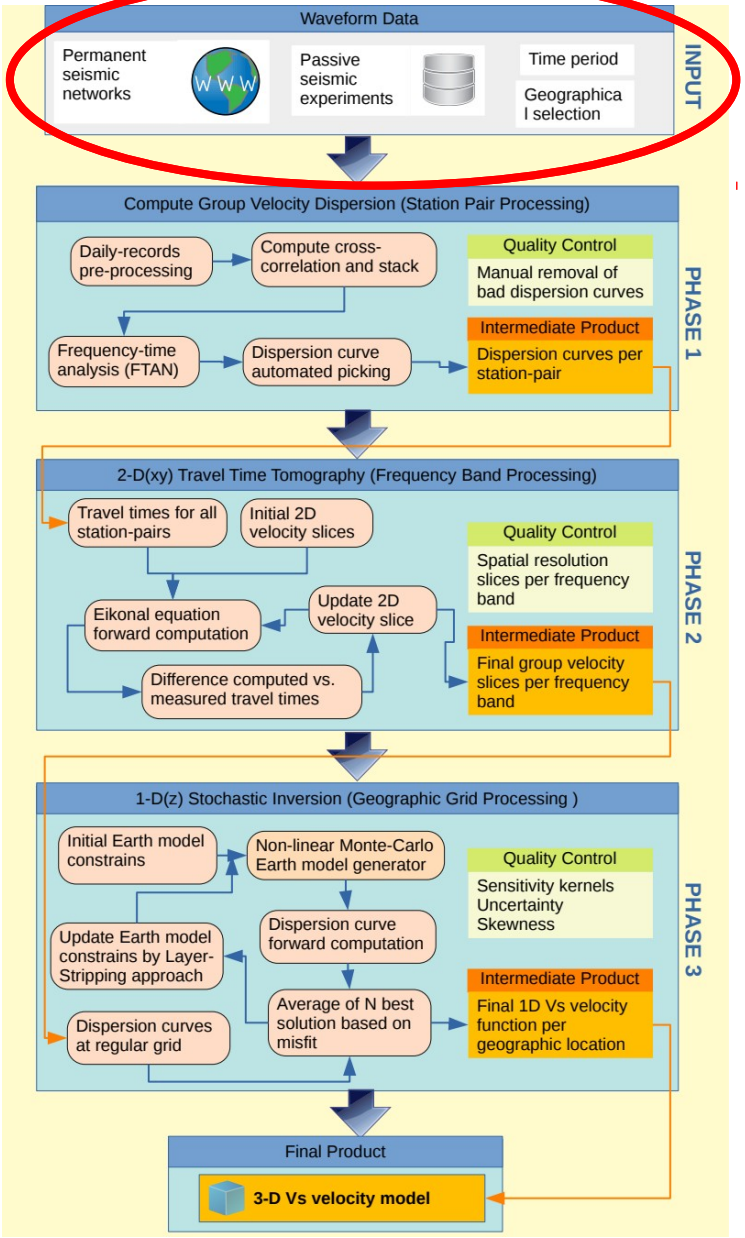

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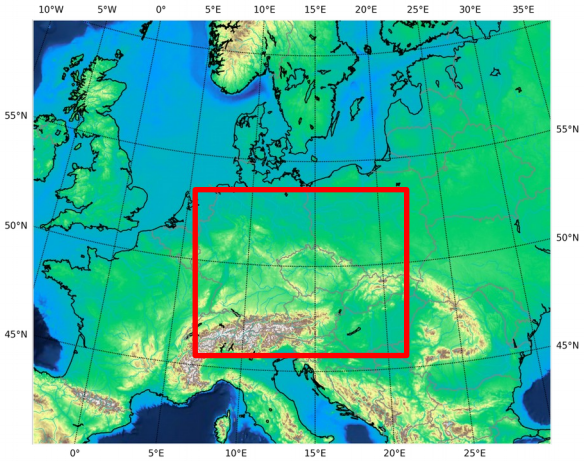
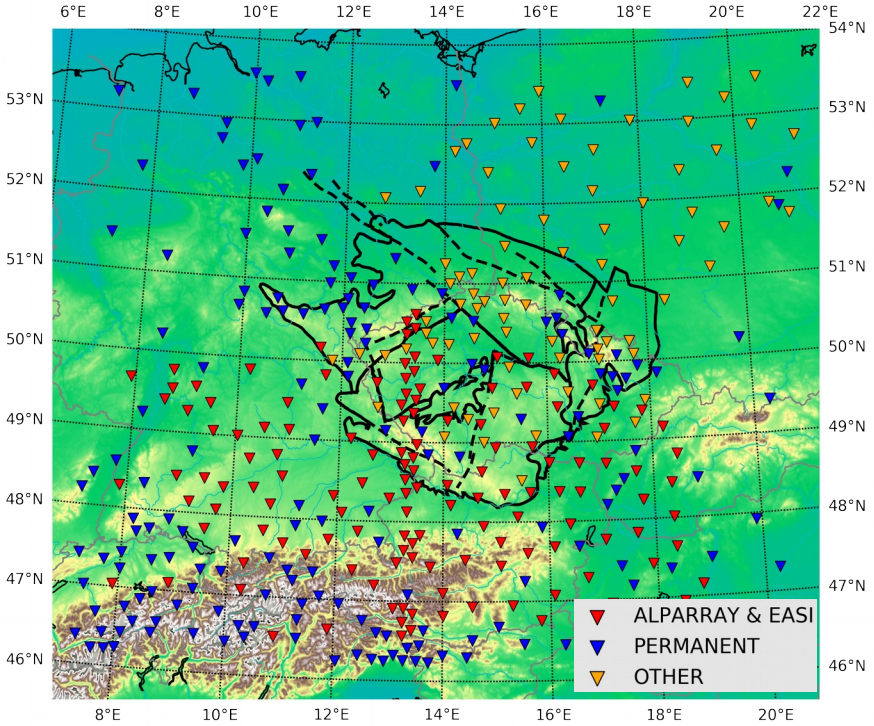
Seismic stations used in the study

- The target of this study is Bohemian Massif
- We use continuous vertical-component broadband recordings





Total Number of stations: 404

(About 160.000 hypothetical Source-Receiver pairs)

Permanent stations

- Czech Regional Seismic Network (CRSN including MONET & WEBNET)
- Stations from neighbouring networks (SXNET, GRSN and PLSN)

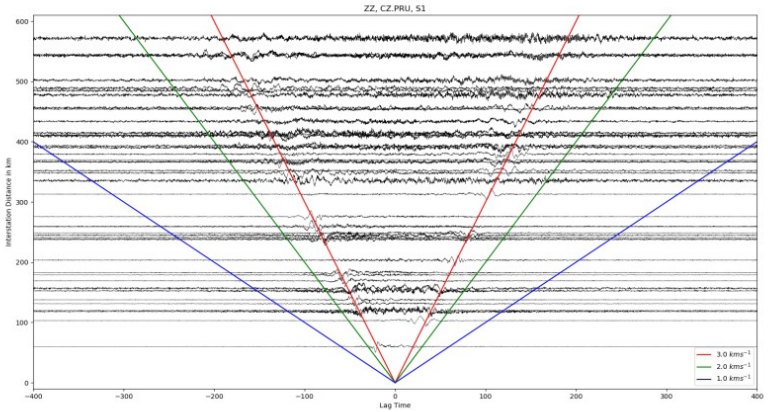
Temporary stations from passive experiments

- MOBNET IG (BOHEMA I-IV, PASSEQ, EGER-RIFT)
- ALPARRAY EASI & AASN

Analysis of Noise Sources

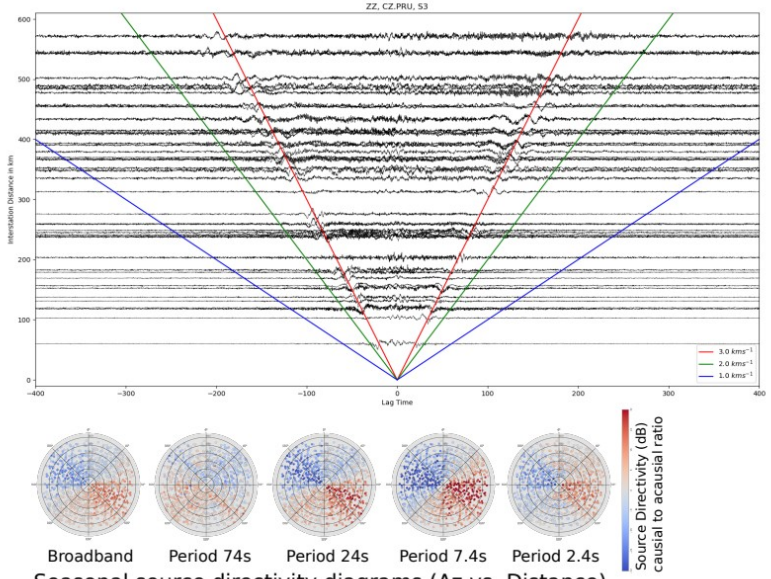
Seasonal variations

CCF - Winter stack (Dec,Jan,Feb)



Seasonal source directivity diagrams (Az vs. Distance)

CCF - Summer stack (Jun,Jul,Aug)

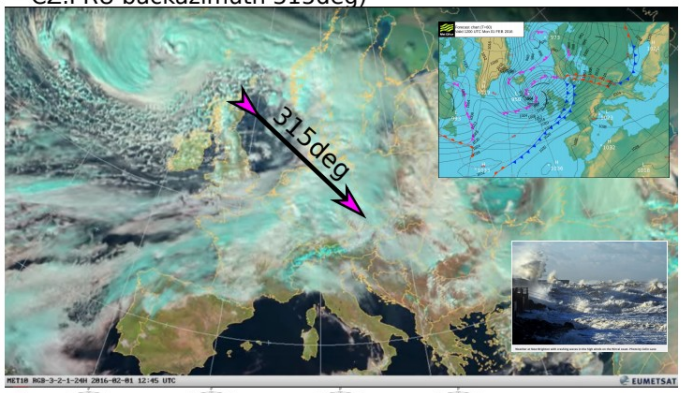


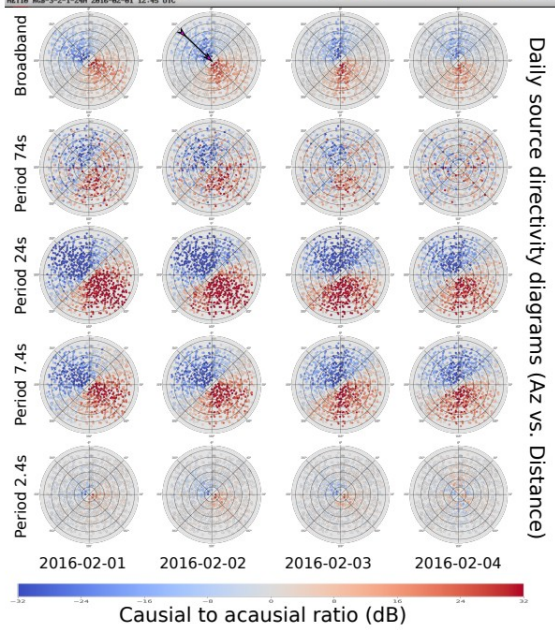
Seasonal source directivity diagrams (Az vs. Distance)

Analysis of Noise Sources

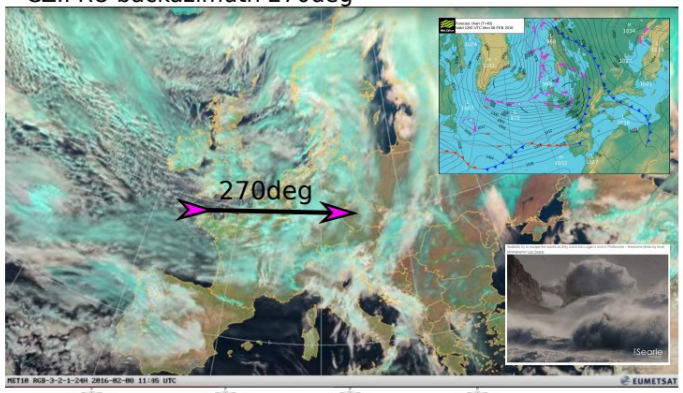
Atlantic storms

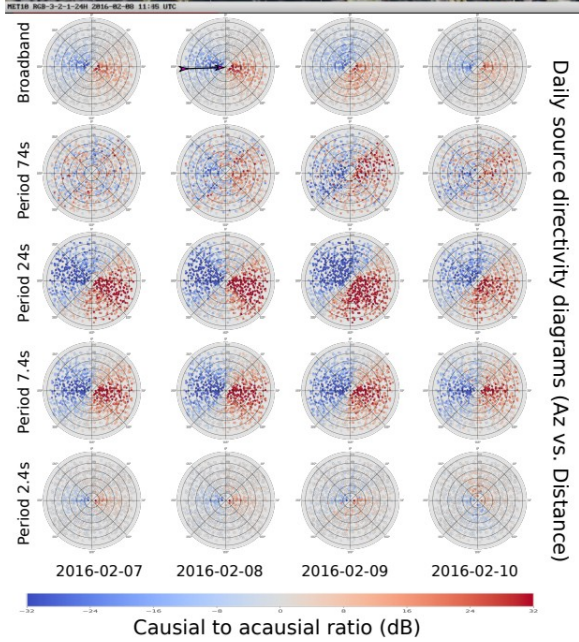
Storm Henry, gust of 90 mph in Outer Hebrides on 2016-02-02
 * strong winds to the NE of England
 * CZ.PRU backazimuth 315deg)





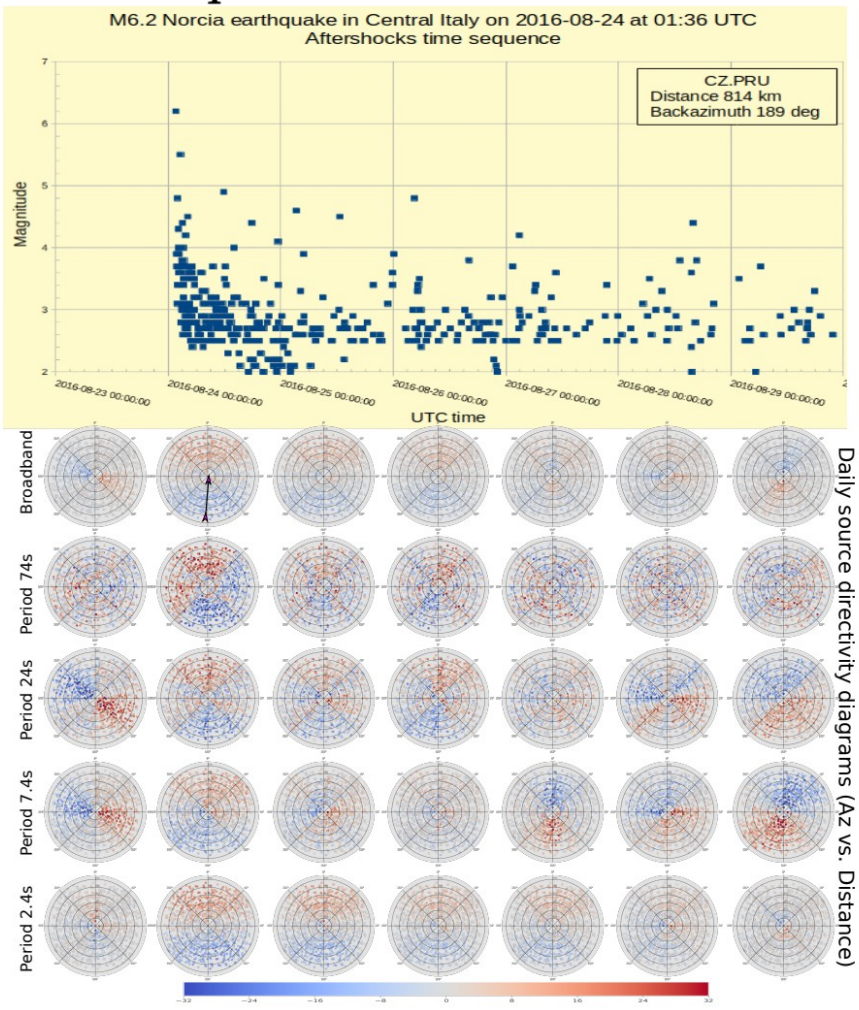
Storm Imogen, gust of 96 mph in Isle of Wight on 2016-02-08
 * strong winds across S Wales and S England
 * CZ.PRU backazimuth 270deg

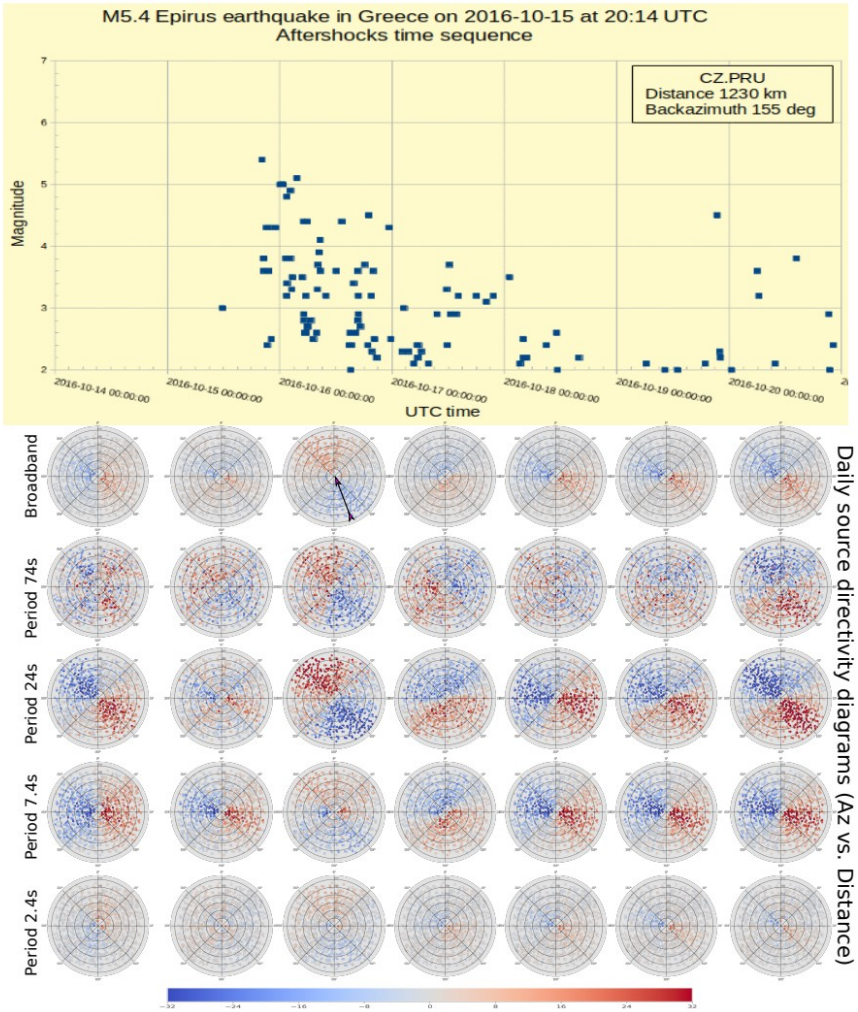




Analysis of Noise Sources

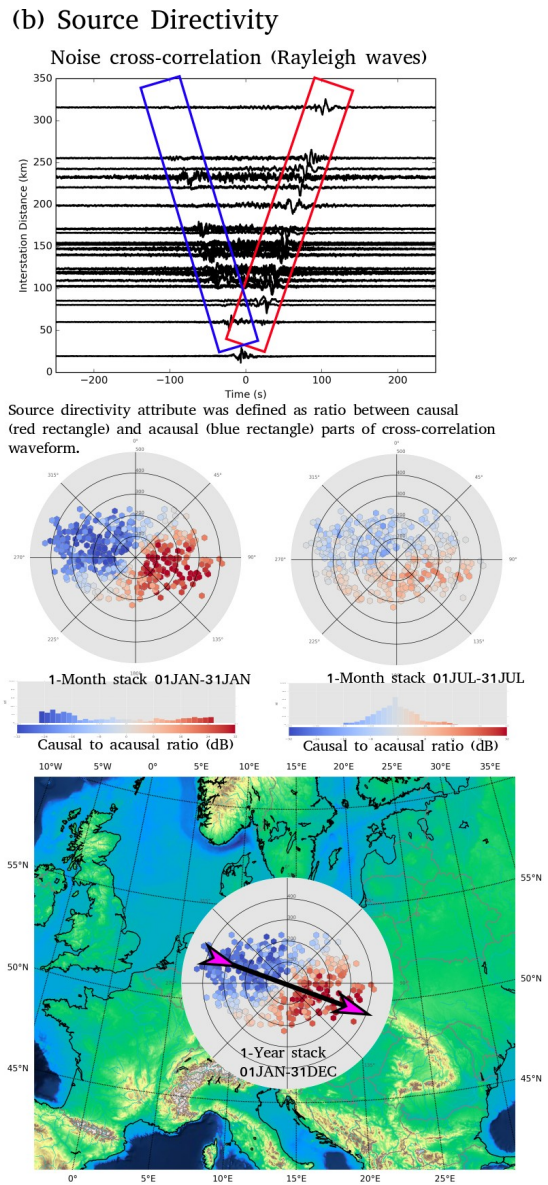
Earthquakes





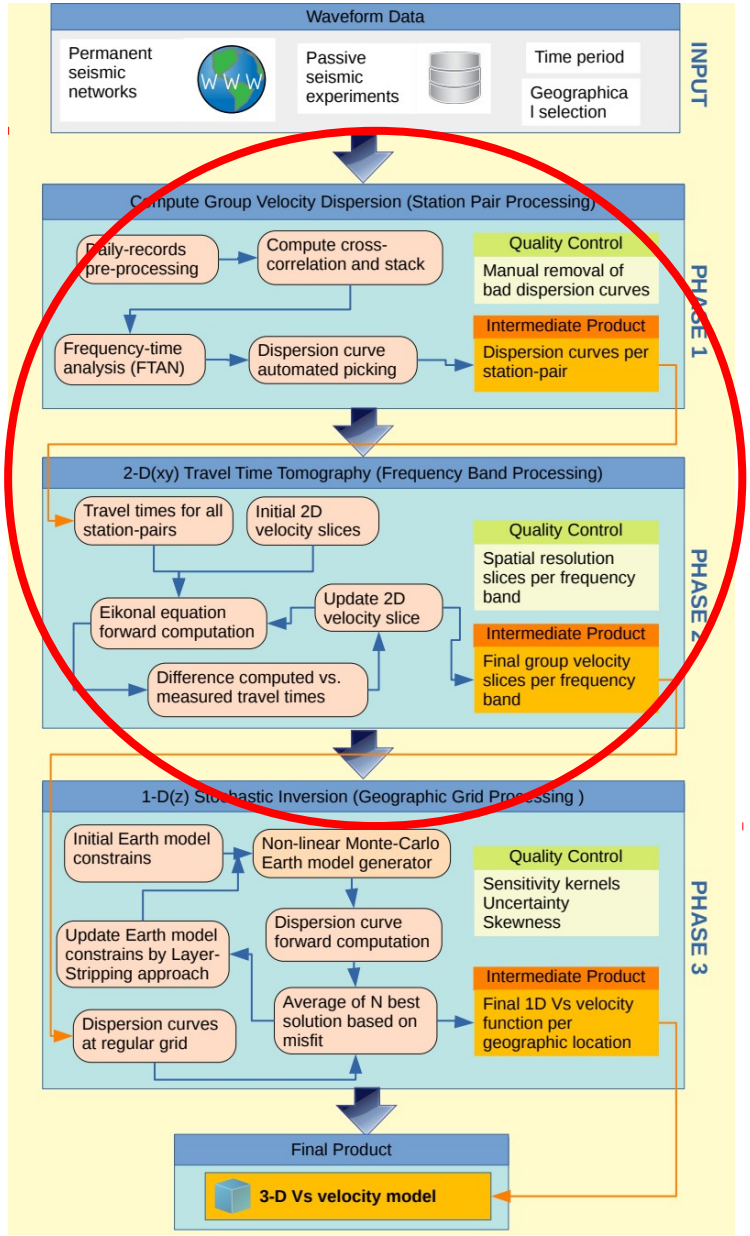
Data Selection

- Selection of quiet noise season
- Summer time June to August
- Isotropic ambient noise generators



Total Number of stations: 404
Processing Time Period: June-August
Station Pair Overlap: >60 Days
Total Number of Station-Pairs: **21 066**

Ambient Noise Tomography



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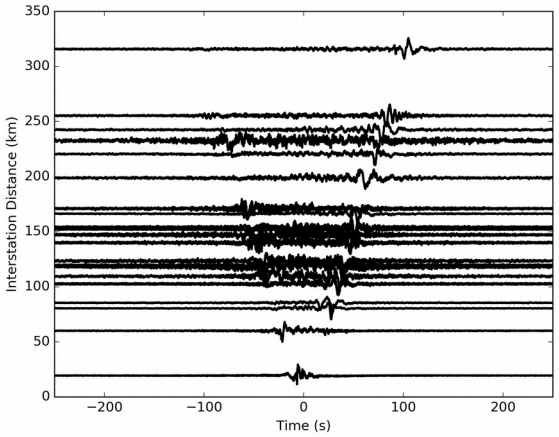
From noise Cross-correlations to surface wave velocity maps

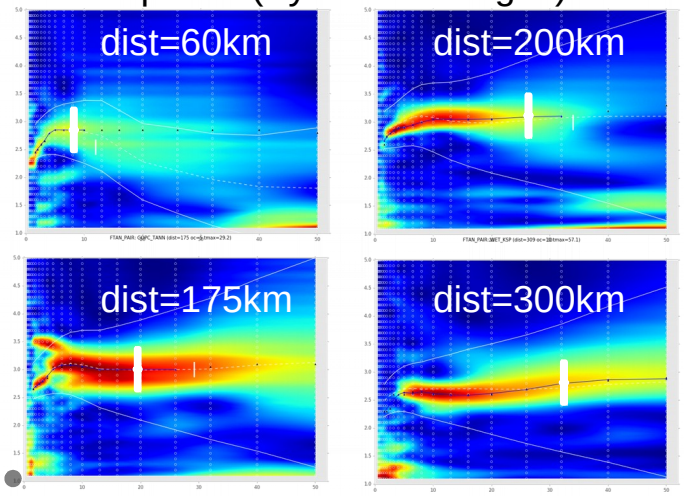
Cross-correlation functions

- MSNOISE package, Lecocq et al., 2014

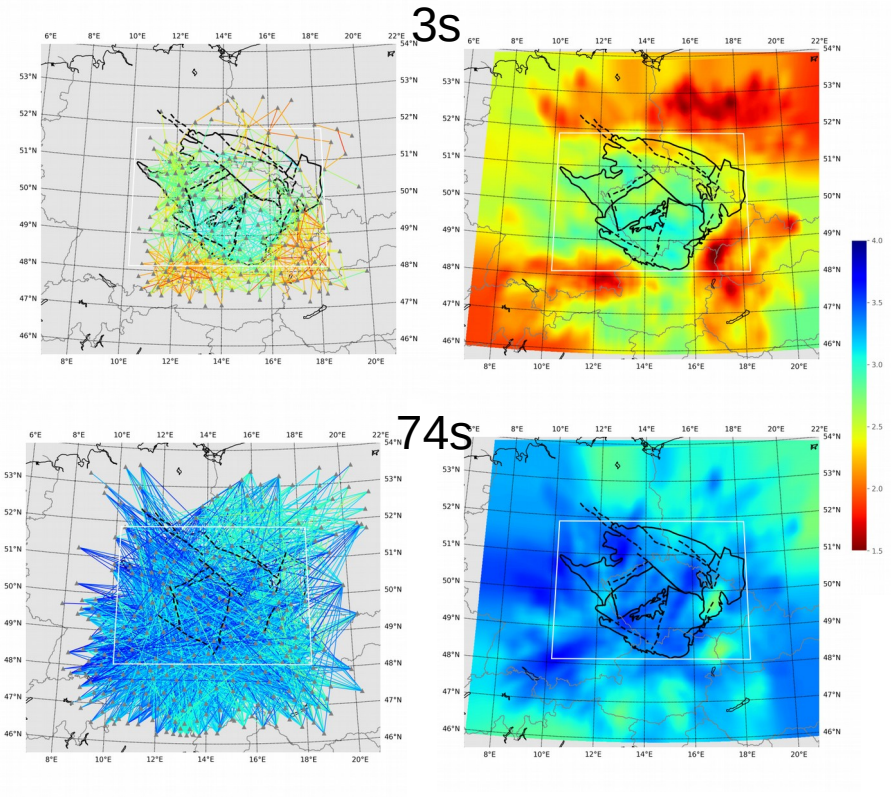


FTAN Analysis and dispersion curve picking

- Automated picker (Python Packages)



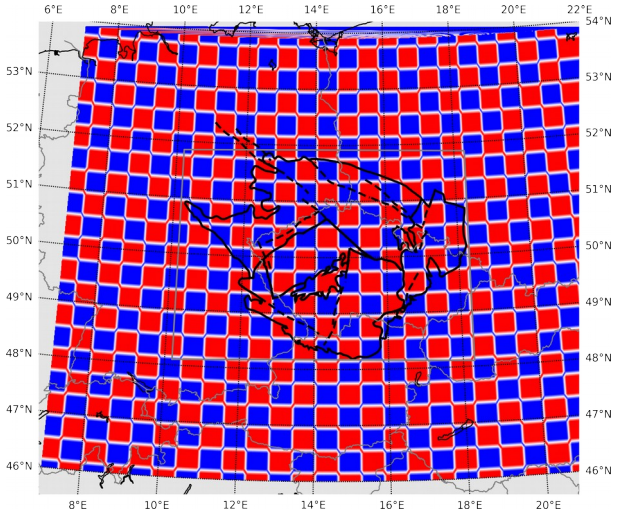
- **2D Fast Marching Surface Wave Tomography**
- FMST Package (Rowlinson 2005)
- Surface sampling 22 x 22 km (processing grid)
- 6 iterations (velocity search per period)
- Reconstruction of dispersion curves at regular grid

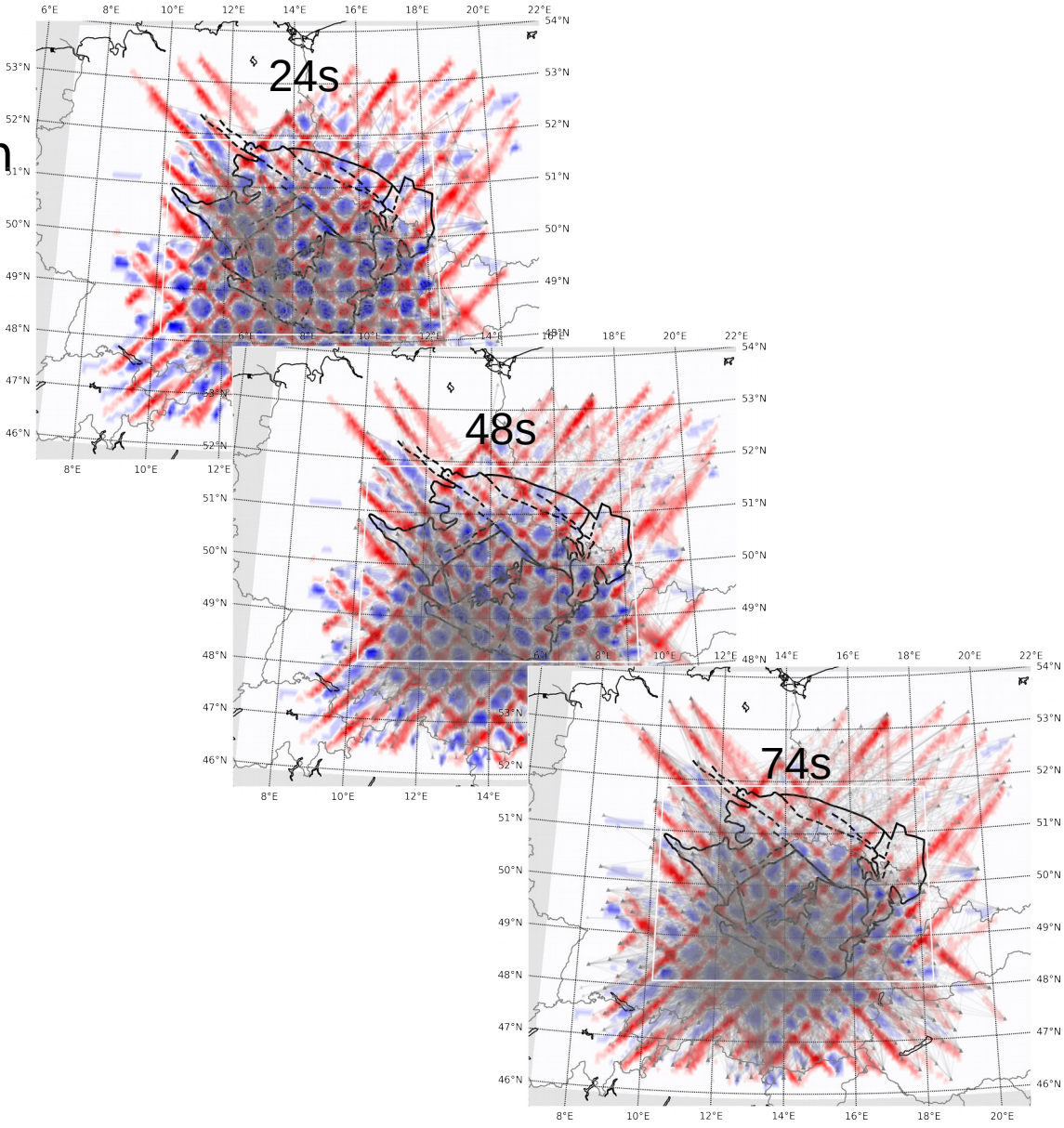


Spatial Resolution

- Checkergboard Test
- Checker size 44x44km

- Input (21066 pairs)





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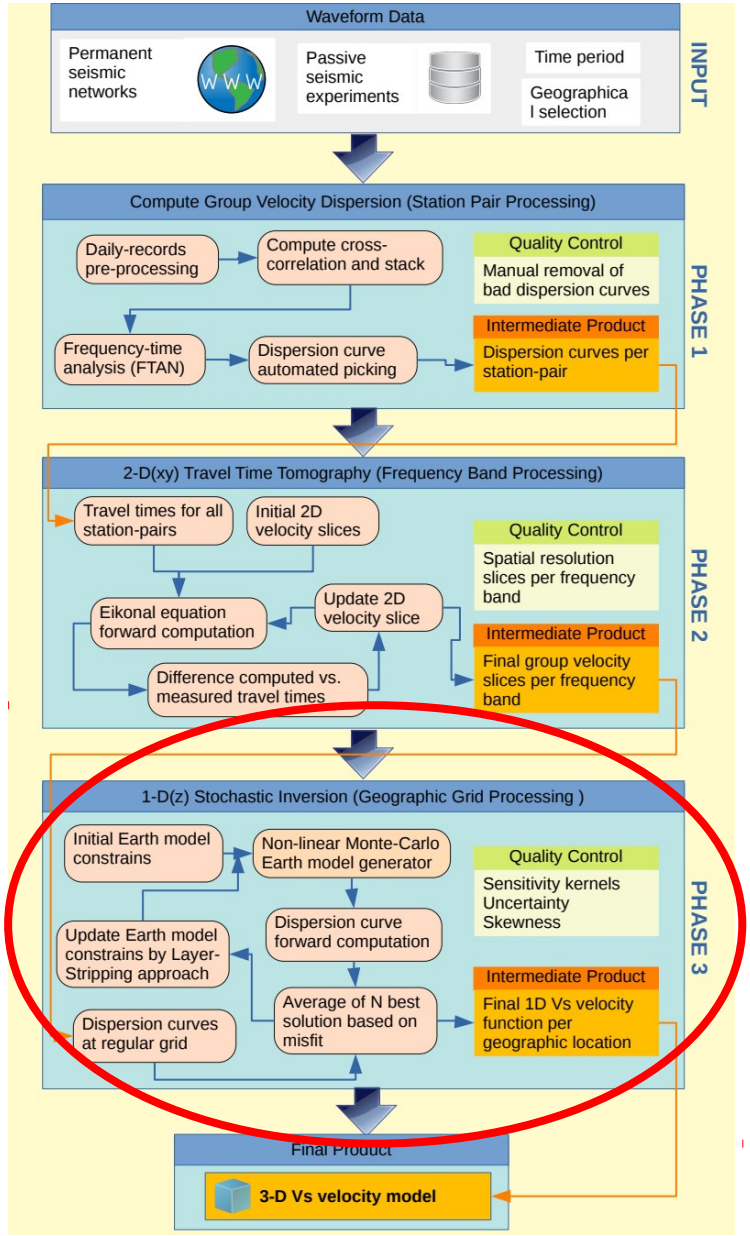

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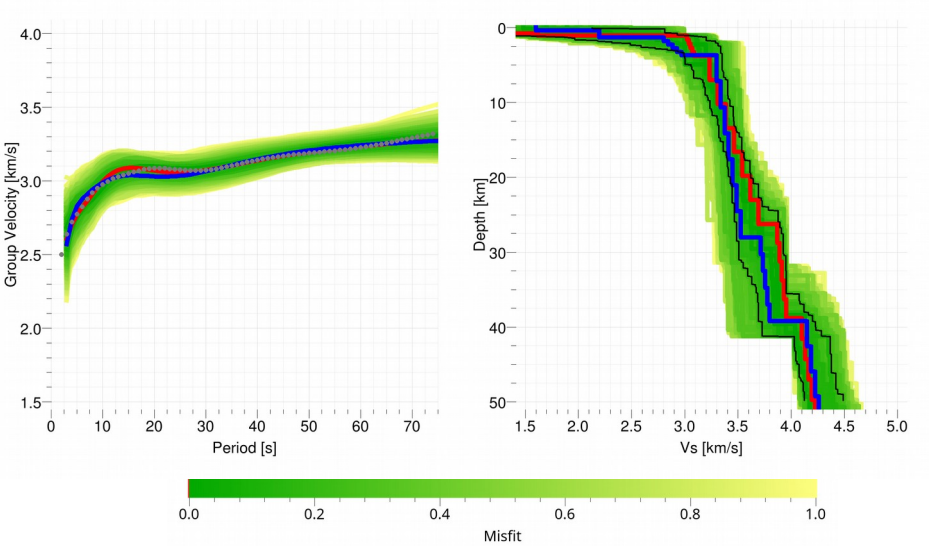
Surface Wave Depth Sensitivity

Plots of 10.000 best models scaled acc. to their misfit



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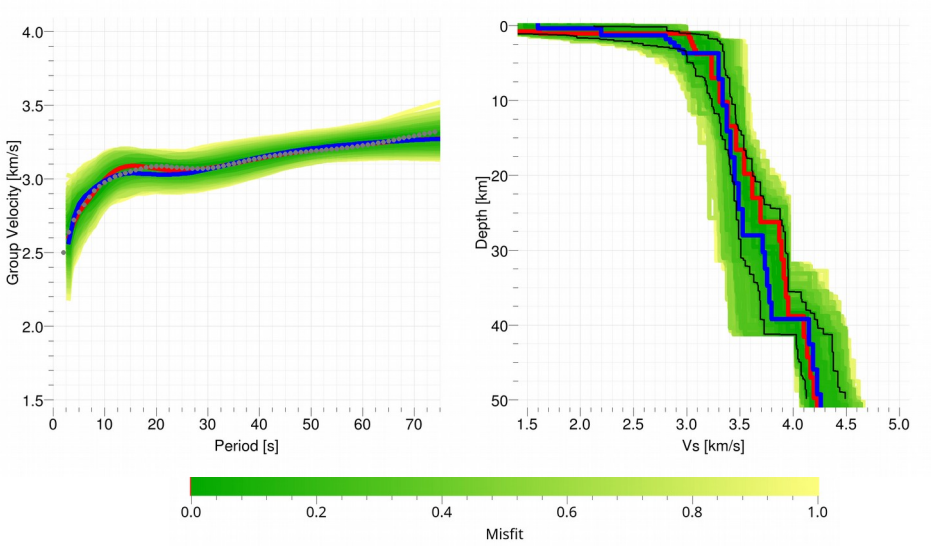
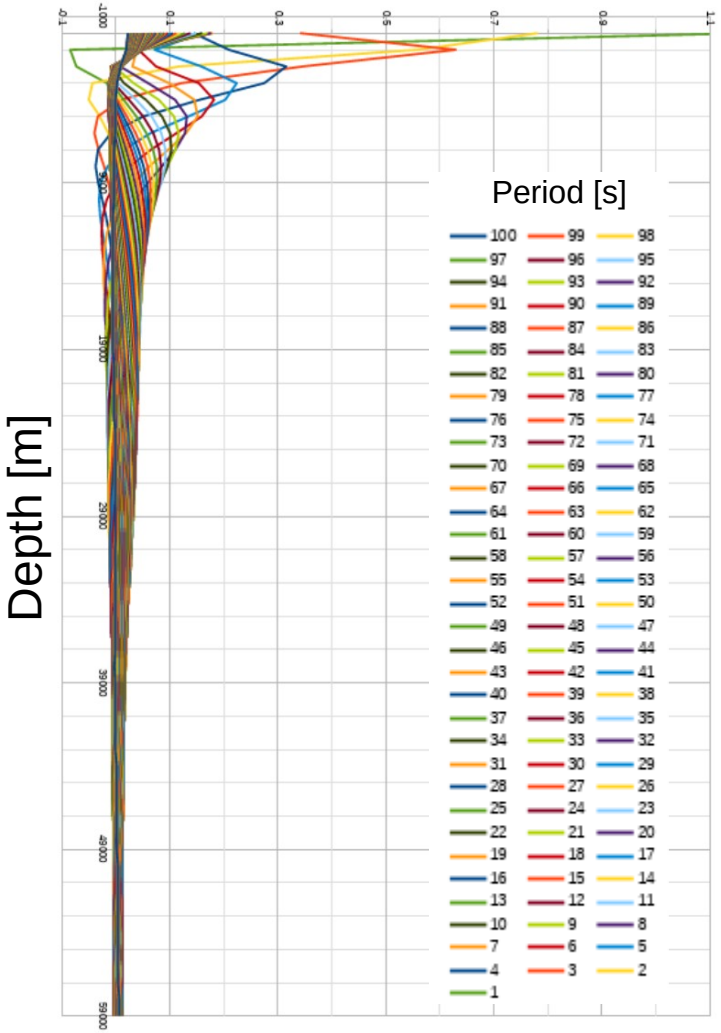


Sensitivity [δc/δβ]



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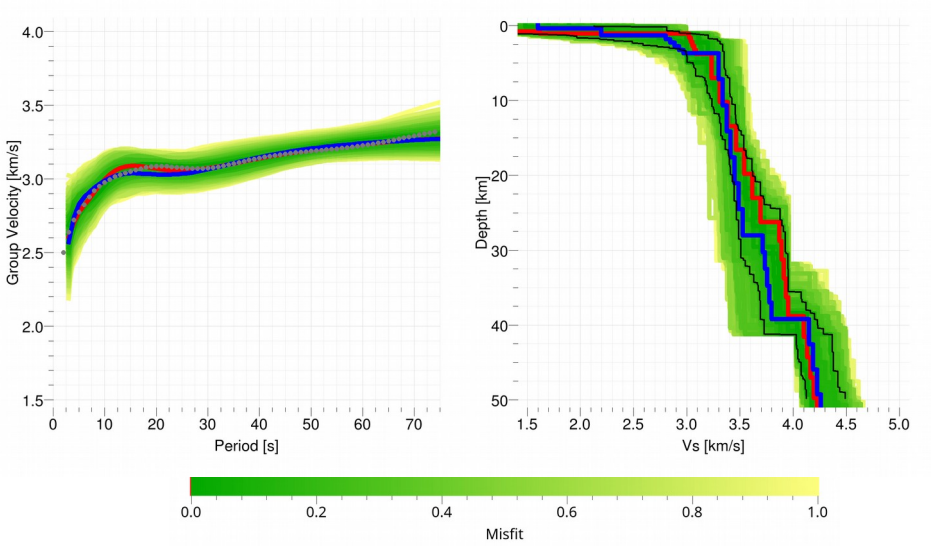

$$\delta c_i(\omega) = \sum_{j=1}^{M_0} \frac{\partial c_i(\omega)}{\partial \alpha_j}\delta\alpha_j + \frac{\partial c_i(\omega)}{\partial \beta_j}\delta\beta_j + \frac{\partial c_i(\omega)}{\partial \rho_j}\delta\rho_j$$

Usually 80-90% importance

$\frac{\partial c_i(\omega)}{\partial m_j}$ **is the 1-D depth sensitivity kernel, j is for the layer index**

$m_j = \alpha_j, \beta_j,$ or ρ_j

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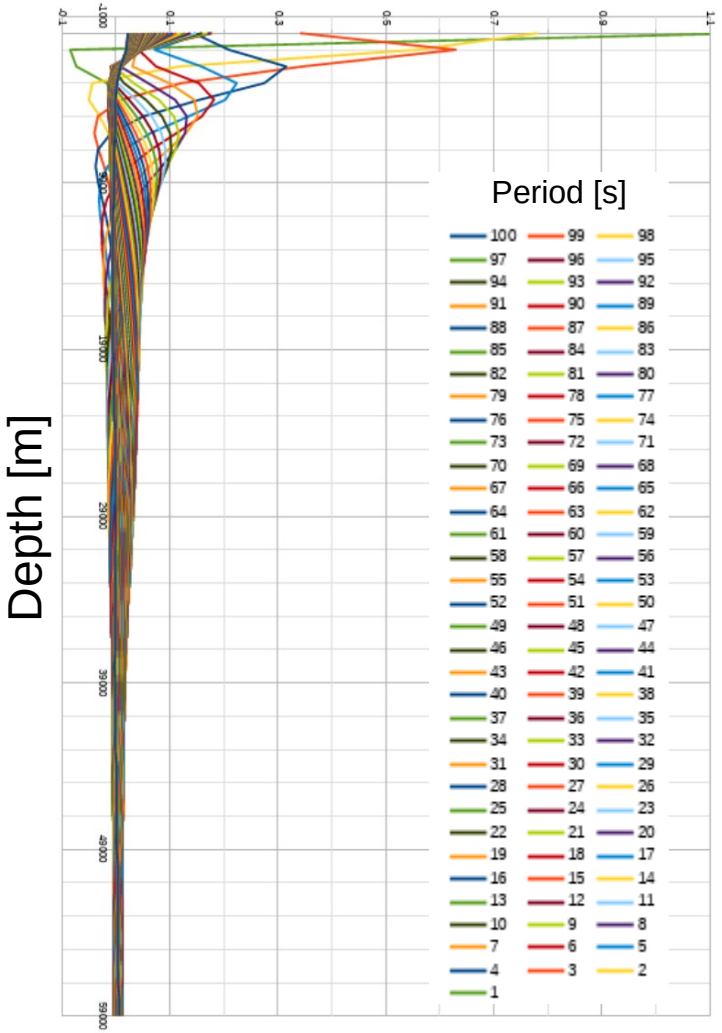
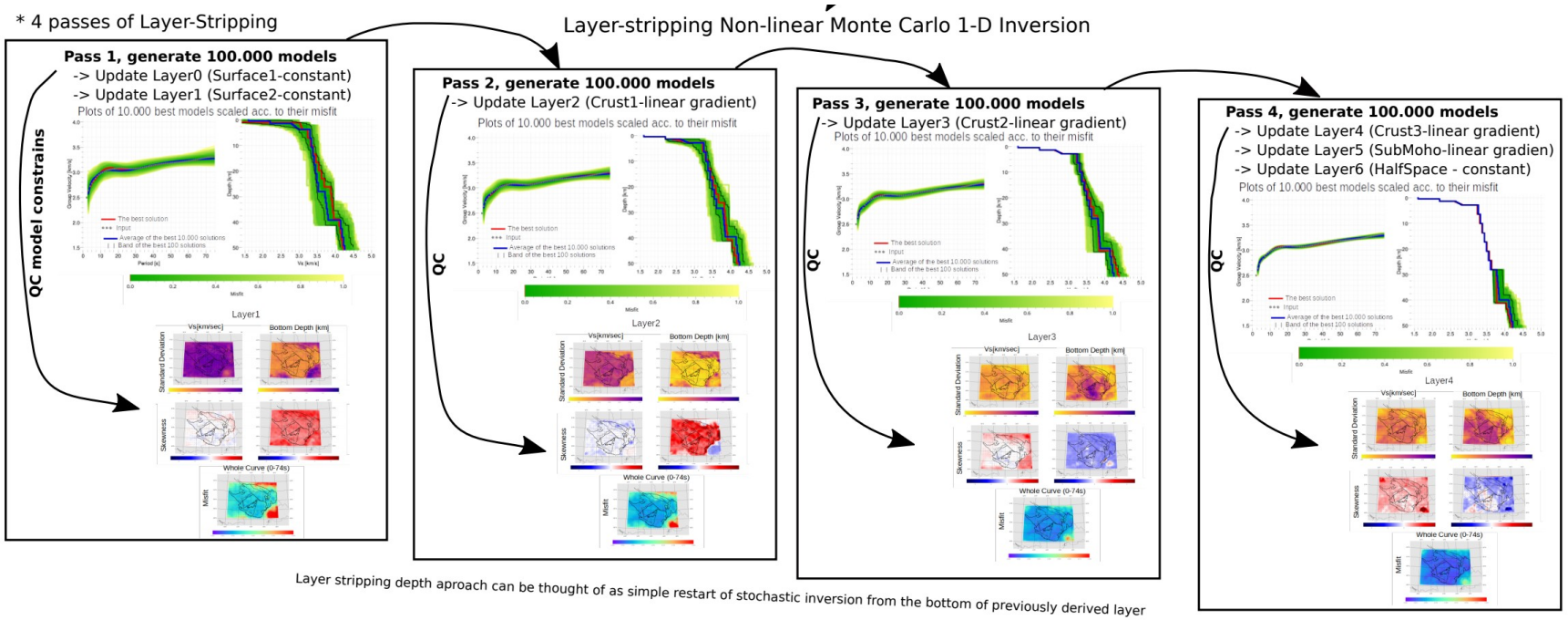


Layer Stripping



Layer stripping depth aproach can be thought of as simple restart of stochastic inversion from the bottom of previously derived layer

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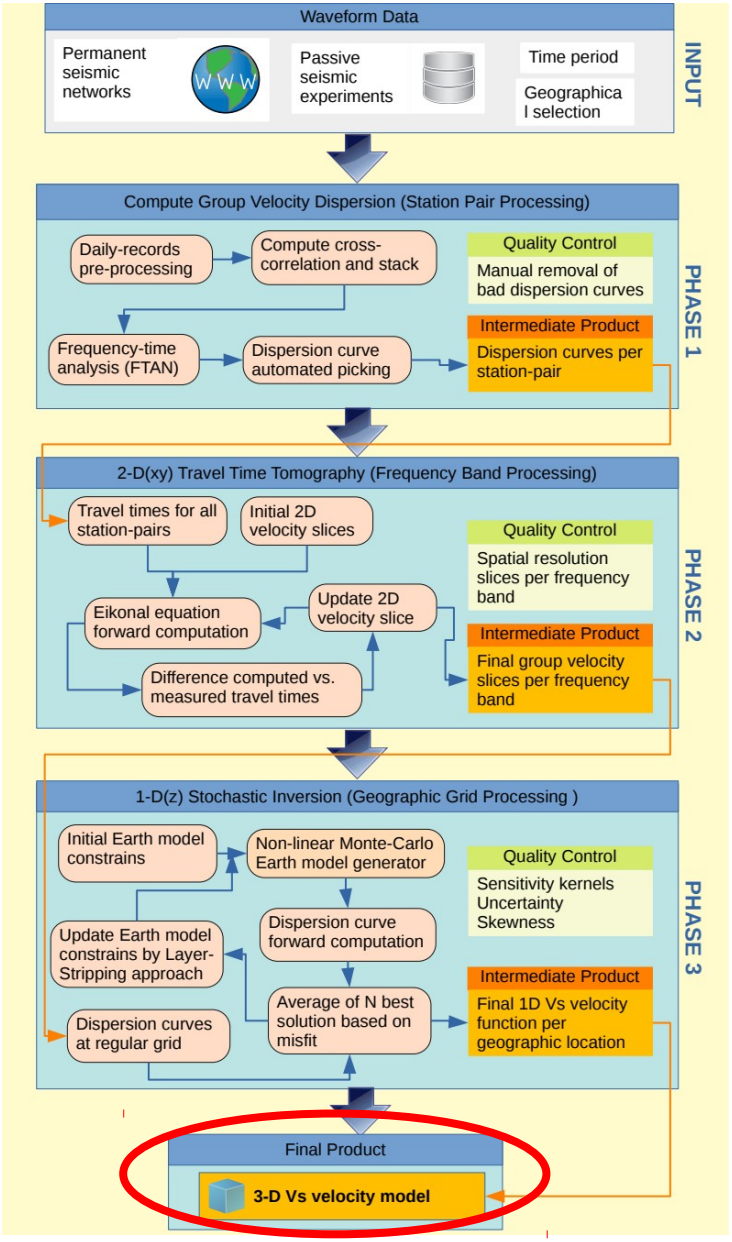

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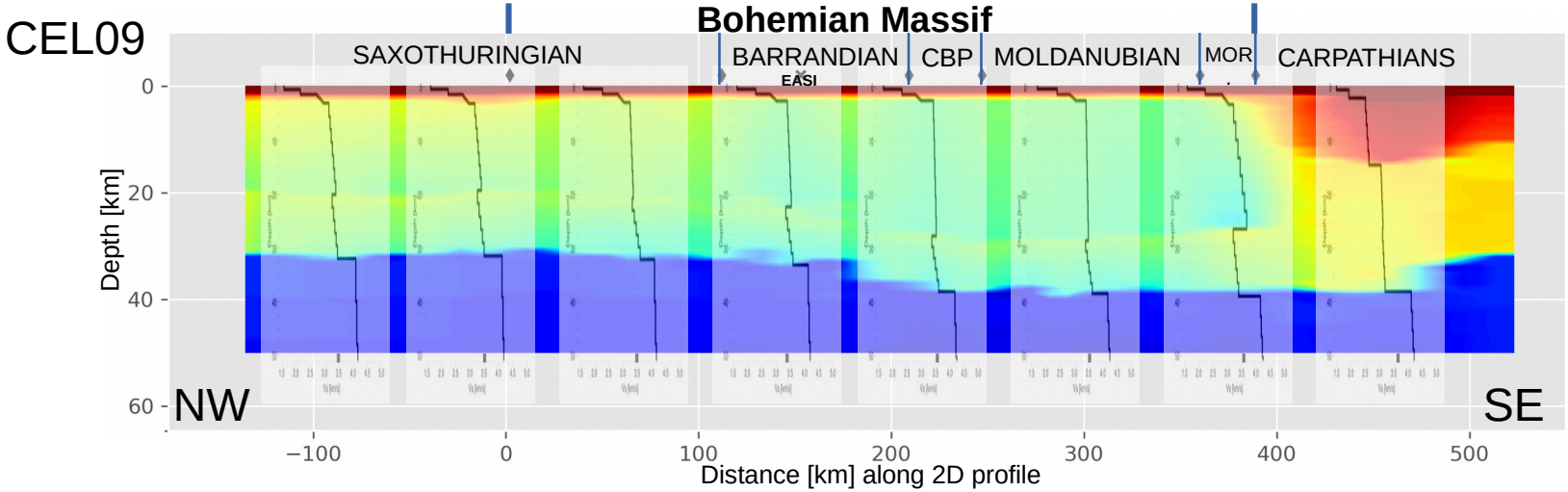
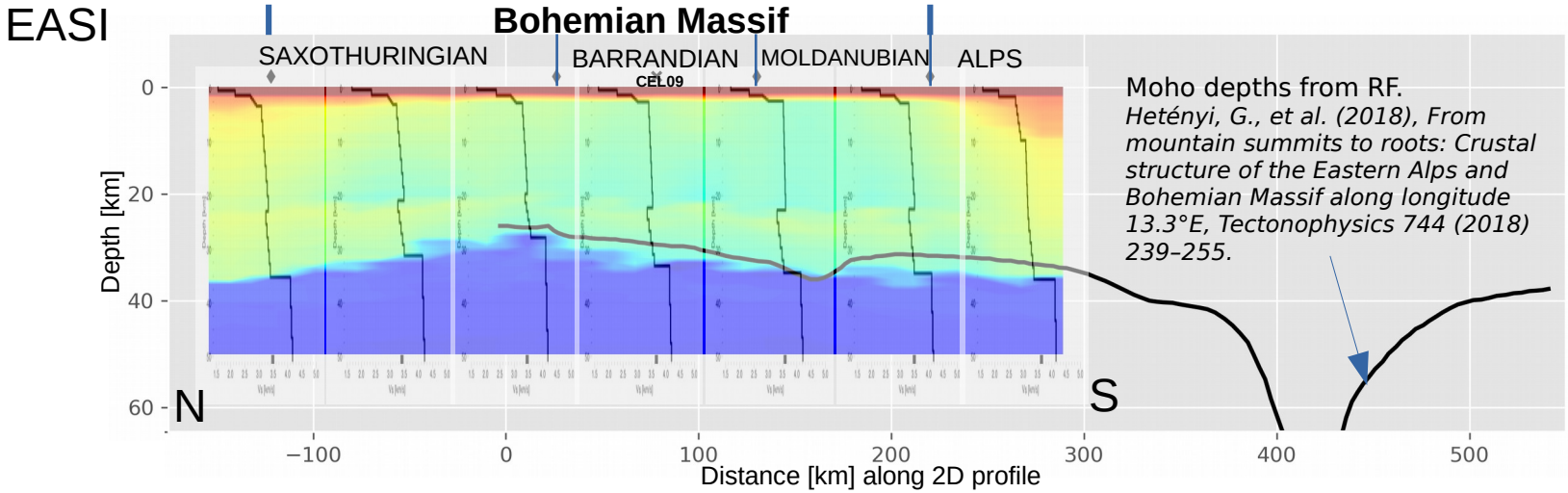
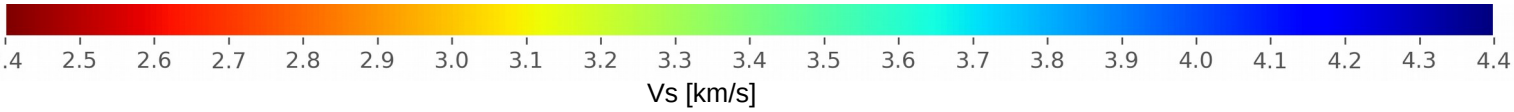
3D Velocity Model of Bohemian Massif Crust







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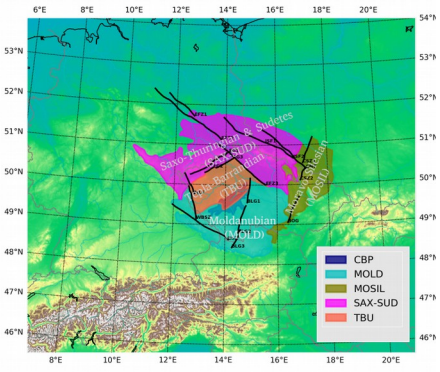
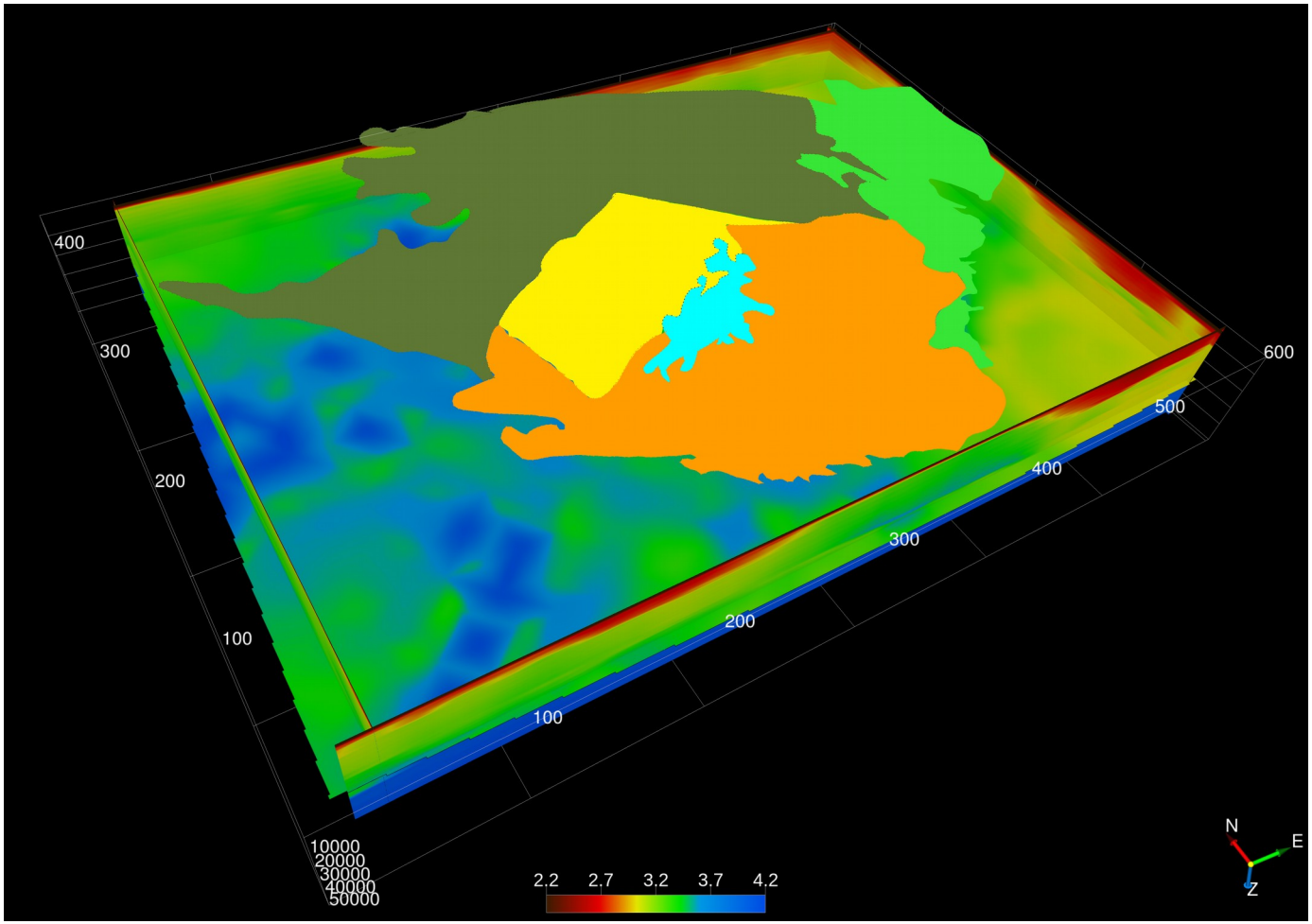
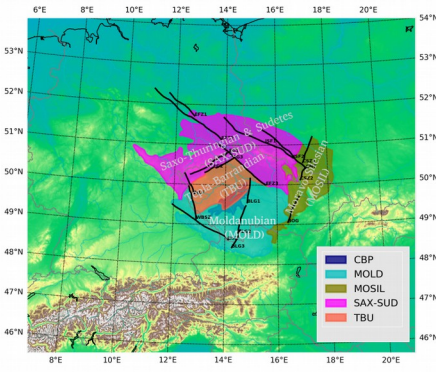


Tectonic map of the Bohemian Massif



Tectonic Units

3D Velocity Model of Bohemian Massif Crust



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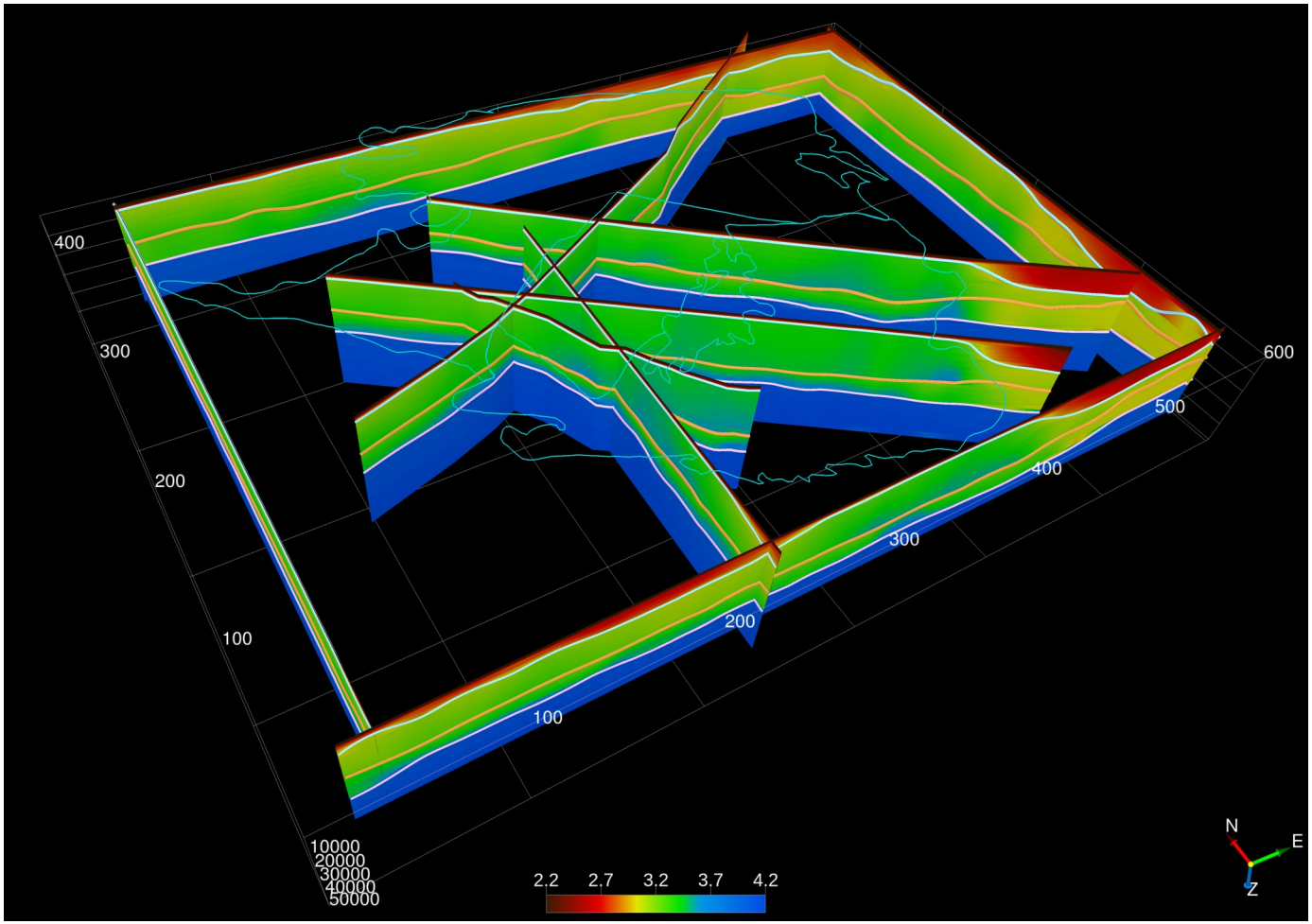
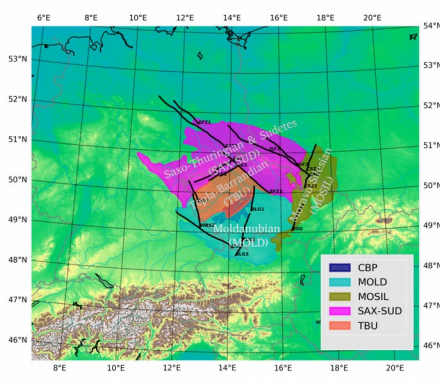


Vs

3D Velocity Model of Bohemian Massif Crust



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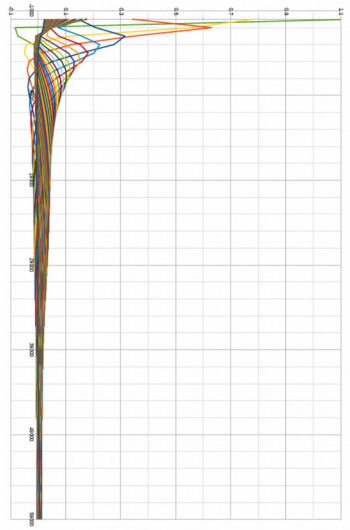

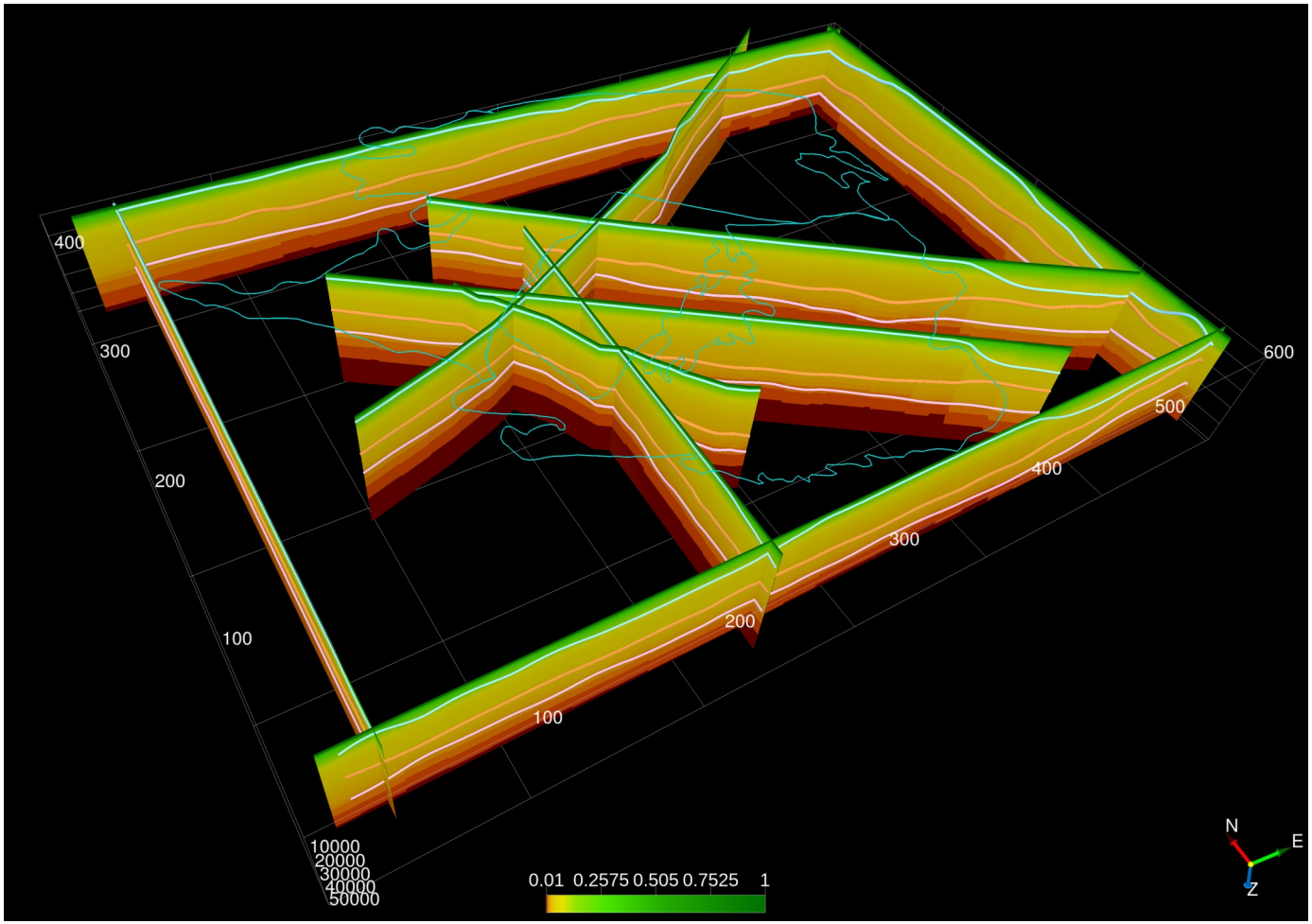

Sensitivity [δc/δβ]

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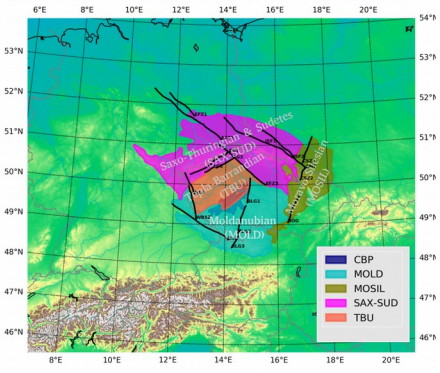

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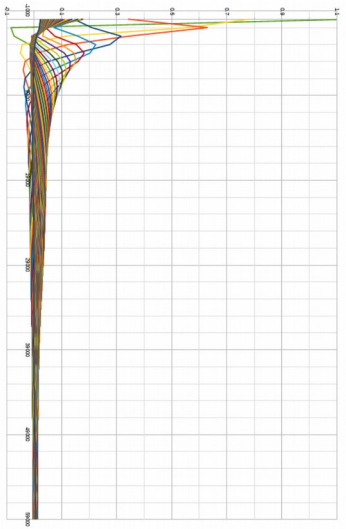
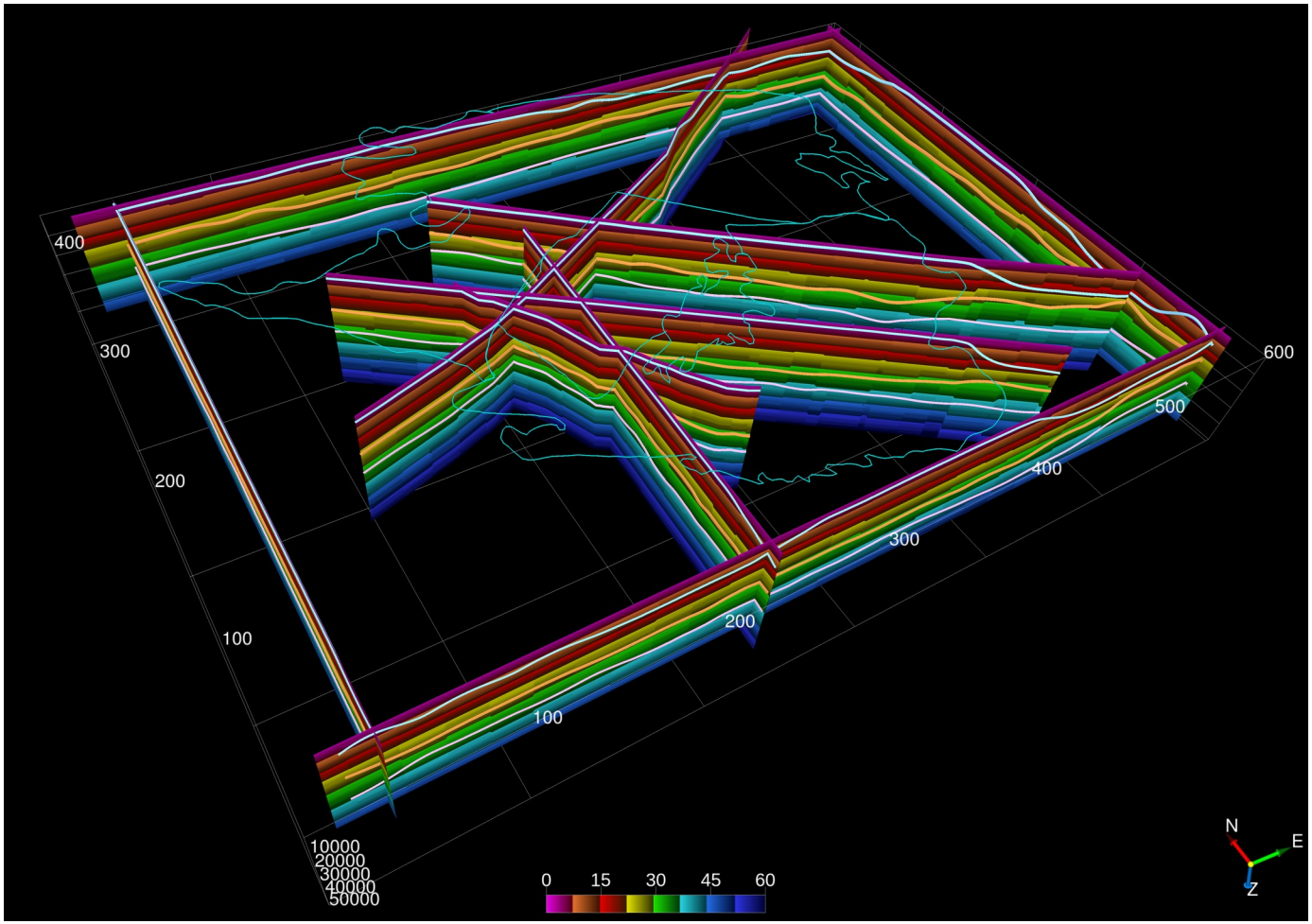
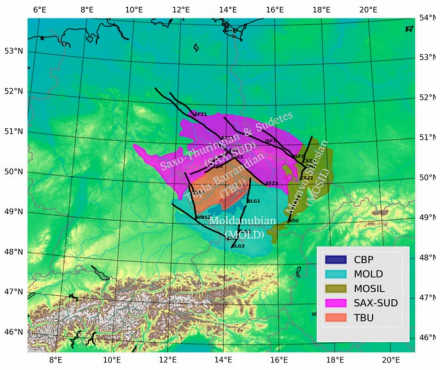


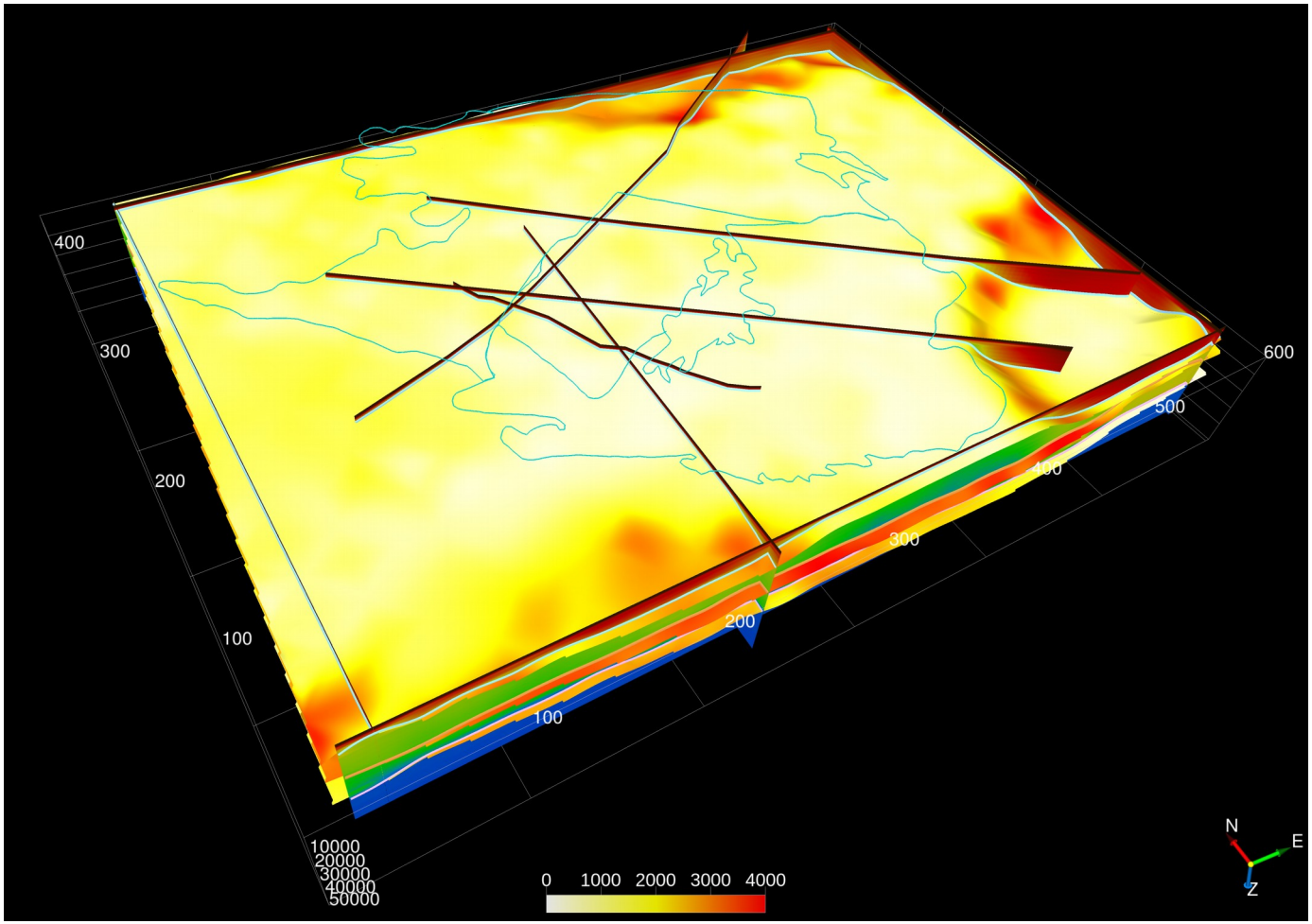


Sensitivity Envelope – Period [s]

3D Velocity Model of Bohemian Massif Crust

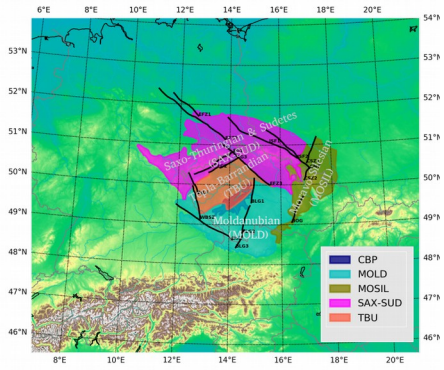


Tectonic map of the Bohemian Massif

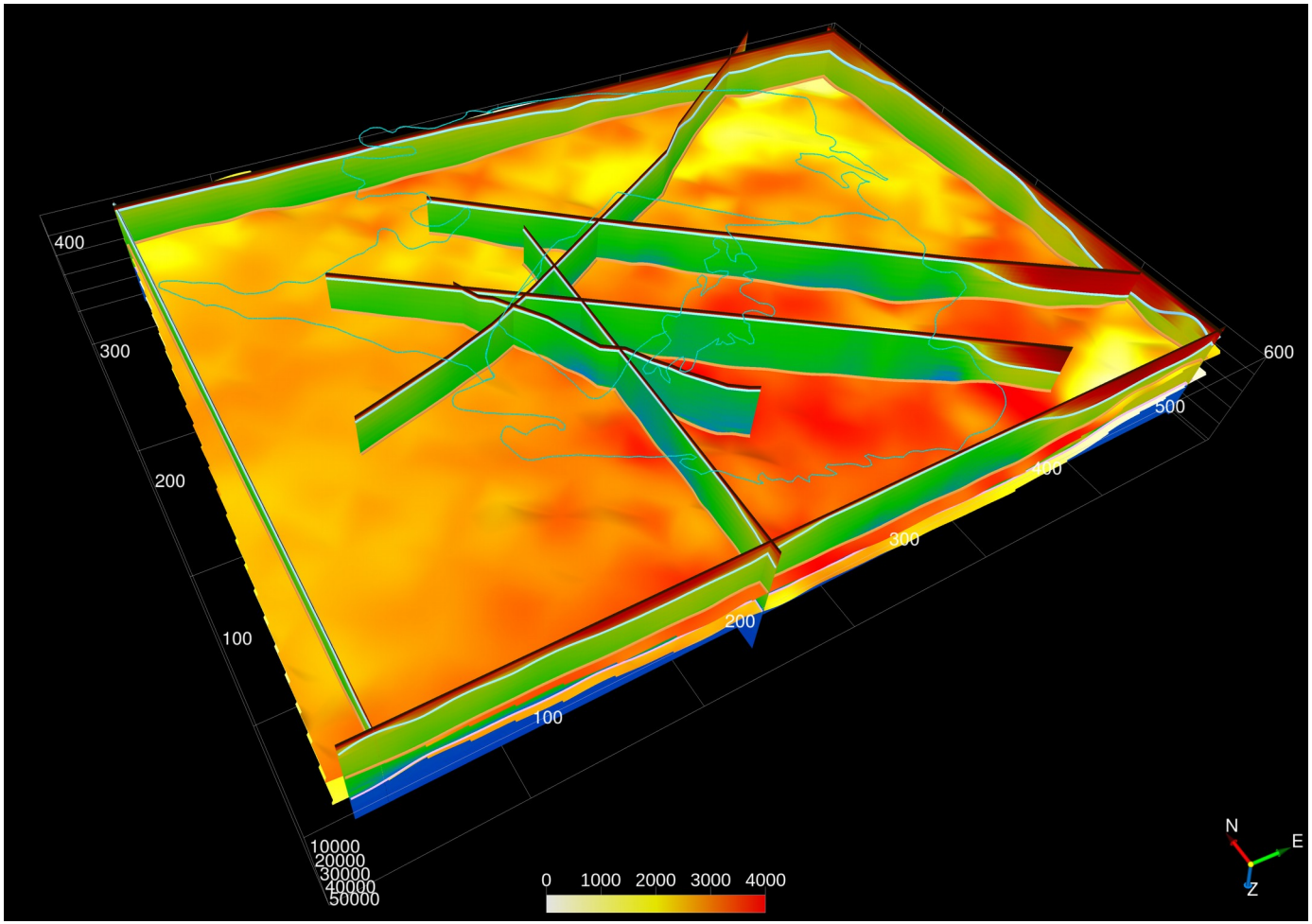


Top Crust – Depth STD [m]

3D Velocity Model of Bohemian Massif Crust

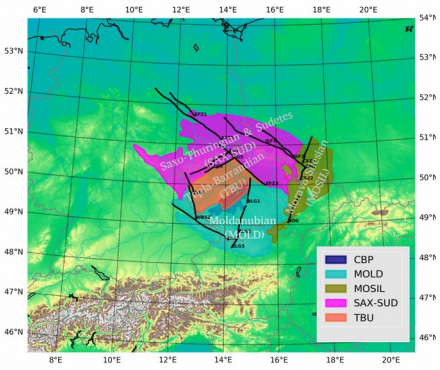


Tectonic map of the Bohemian Massif

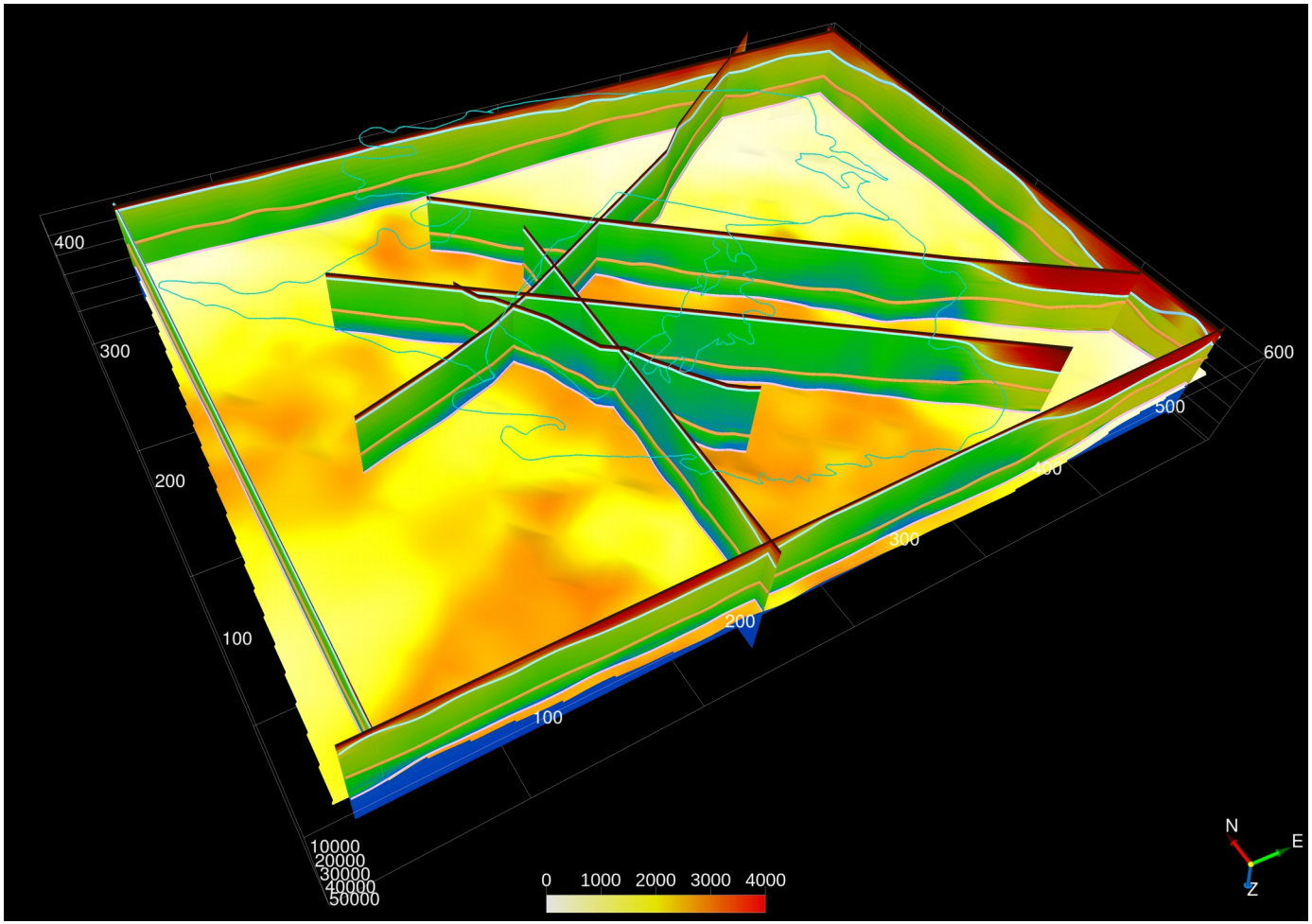


Mid Crust – Depth STD [m]

3D Velocity Model of Bohemian Massif Crust

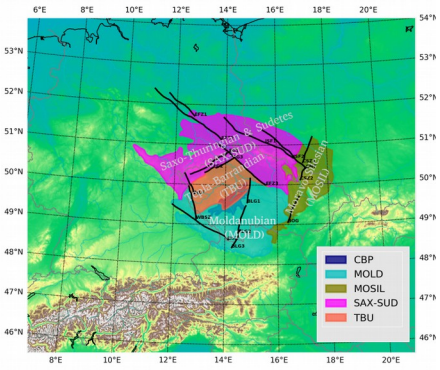


Tectonic map of the Bohemian Massif

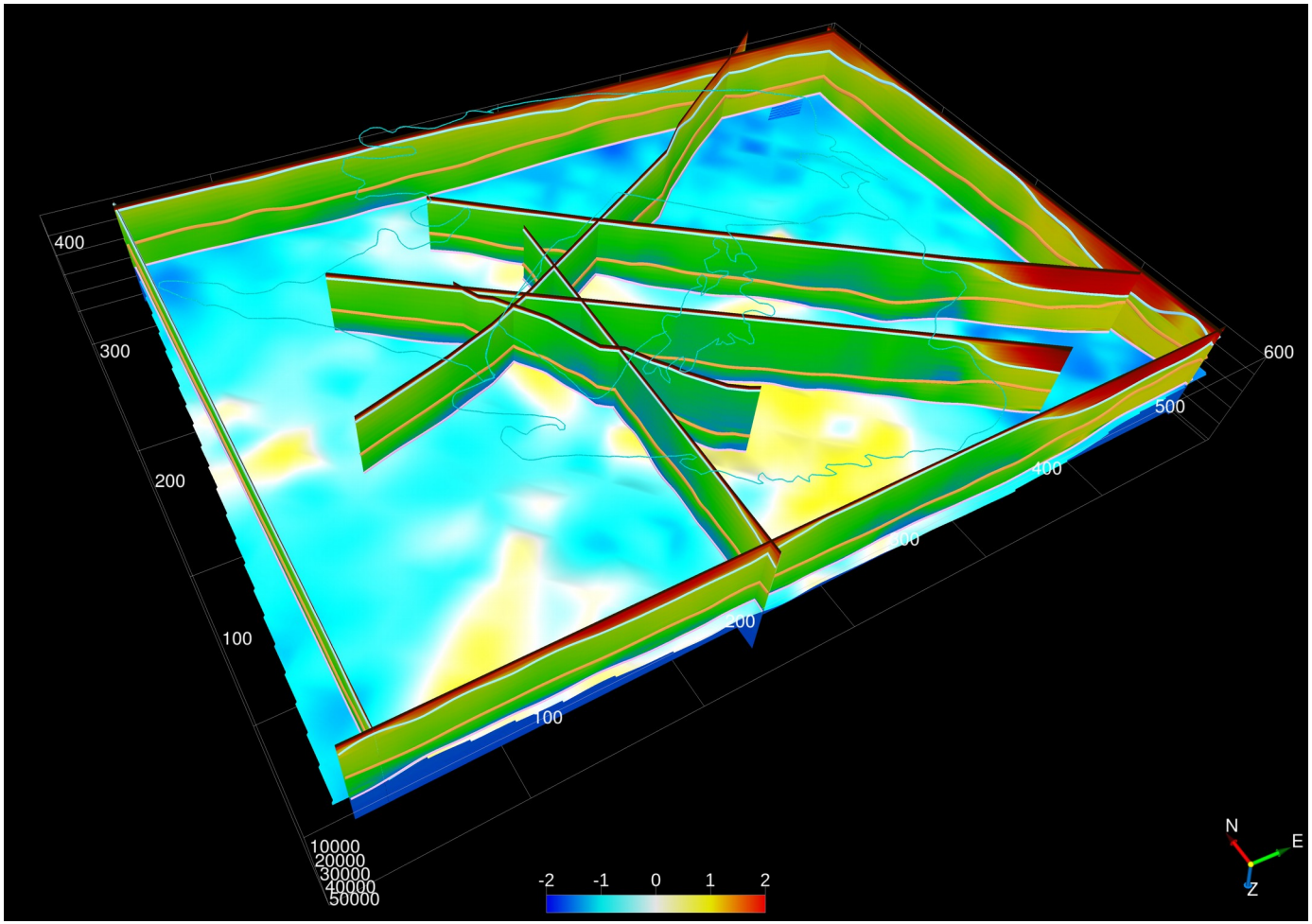


Base Crust – Depth STD [m]

3D Velocity Model of Bohemian Massif Crust

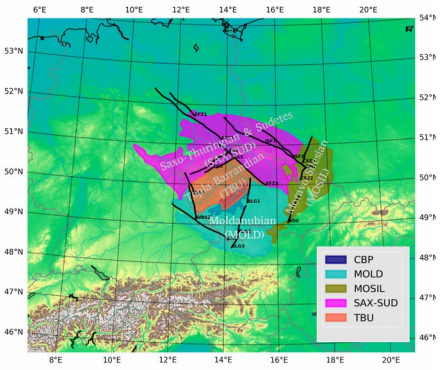


Tectonic map of the Bohemian Massif

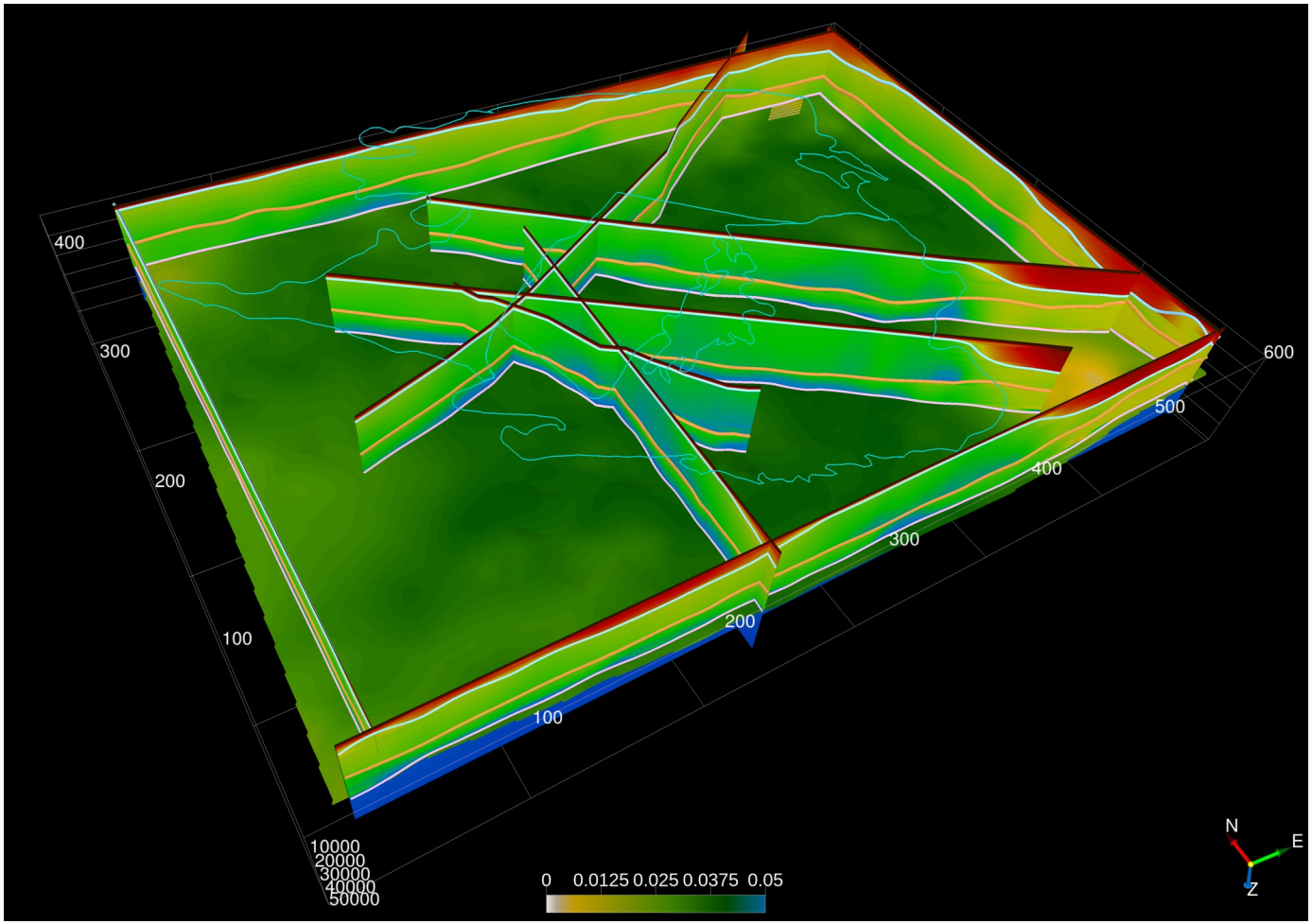


Base Crust – Depth Skewness

3D Velocity Model of Bohemian Massif Crust



Tectonic map of the Bohemian Massif



Base Crust - Misfit

Conclusions

* Continuous waveform data from all available permanent stations in the region complemented by recordings from temporary stations of passive experiments BOHEMA I-IV, PASSEQ, EGER RIFT, ALPARRAYEASI and ALPARRAY-AASN provide sufficient spatial resolution to expected scale of tectonic units of the Bohemian Massif.

* The source directivity analysis and seasonal variarion tests showed that the Bohemian Massif area is predominantly affected by weather conditions along the Atlantic coast as well as by Earthquakes with longer period of aftershock sequence.

* Layer-Stripping approach improves depth uncertainty of resulting velocity model and keeps total number of generated models on reasonable level. This approach also benefits from independent misfit measure for each layer.