

Sensible choices for adjoint tomography: Misfits, model parameterization, preconditioning, smoothing & iterating

Jeroen Tromp

Hejun Zhu, Ebru Bozdag & Daniel Peter

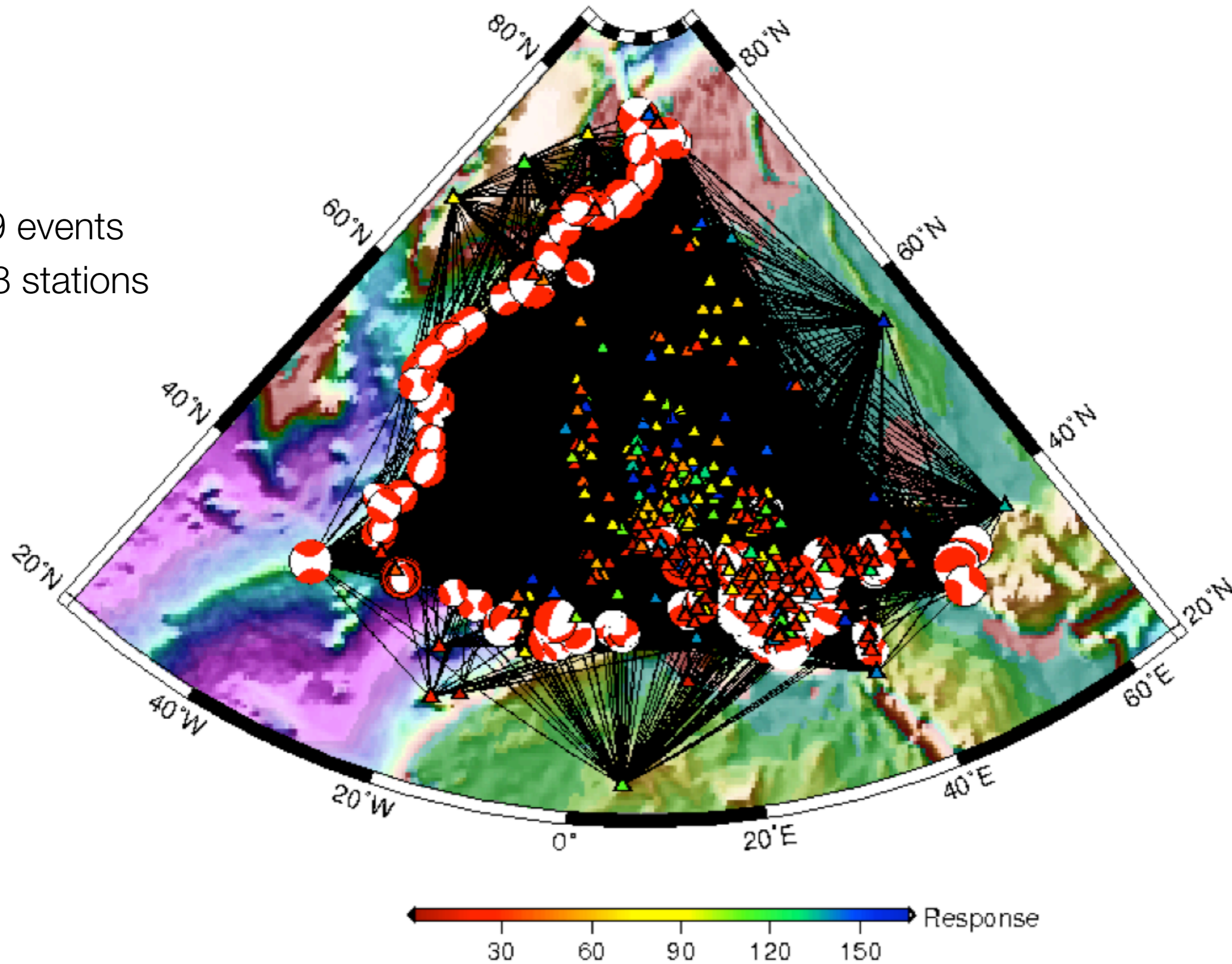
QUEST 2011



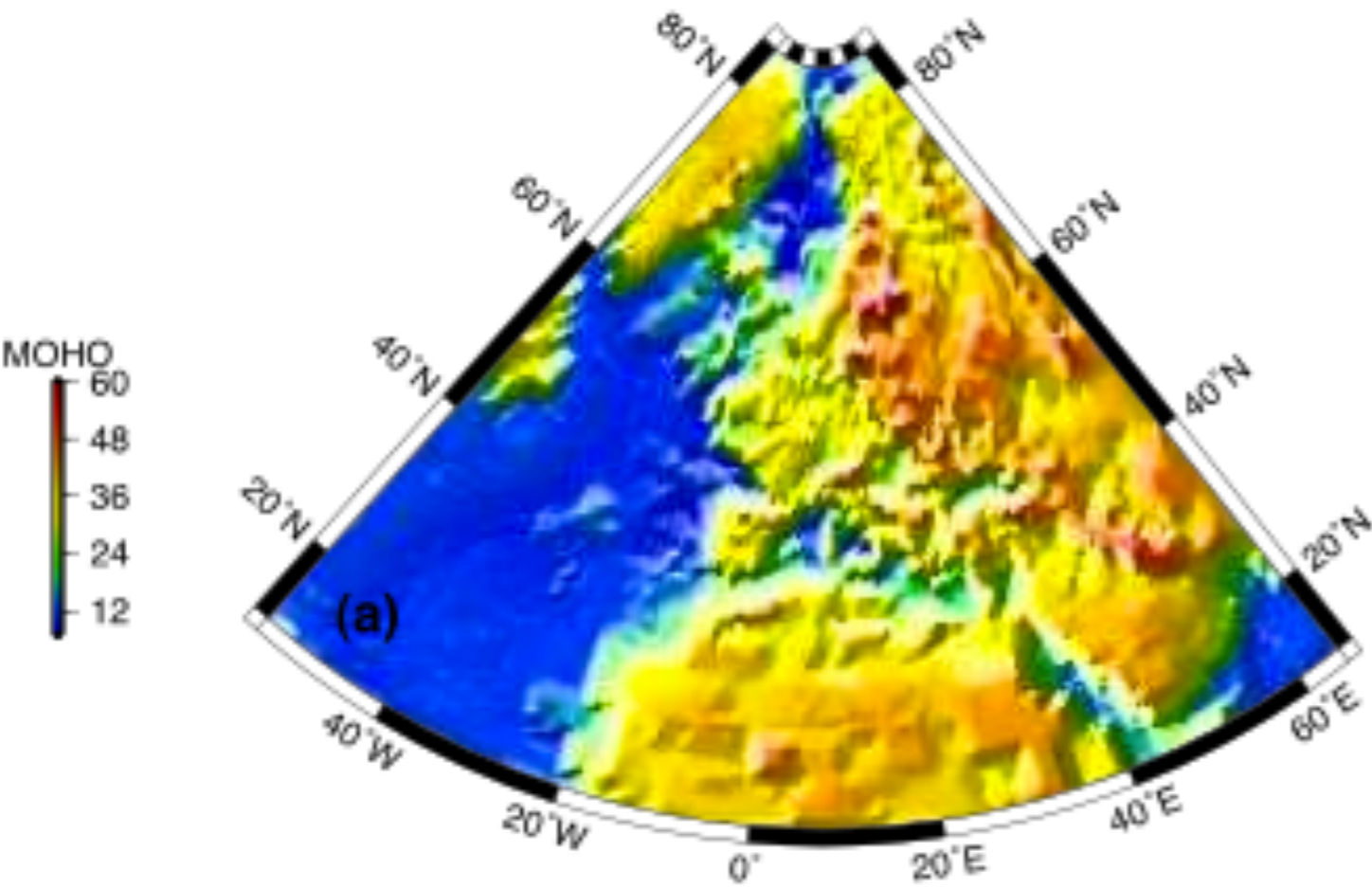
Adjoint Tomography of Europe: Progress Report

Ray Coverage

159 events
338 stations

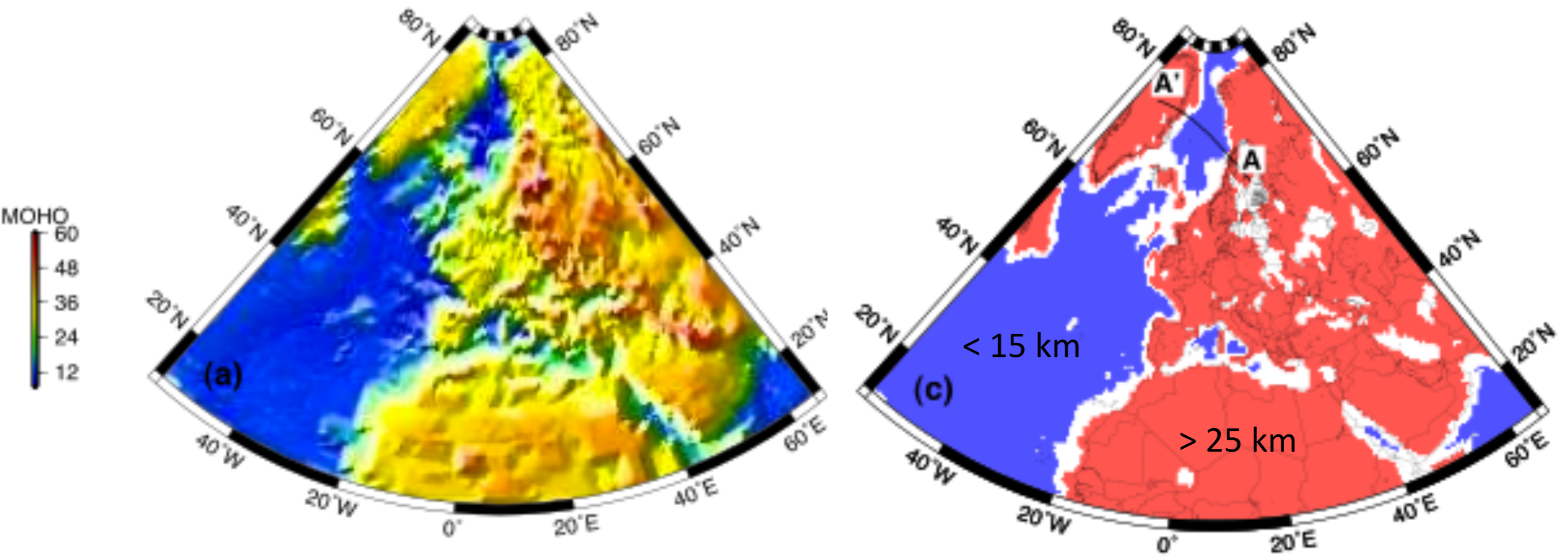


Starting 3D Crustal Model: EPCrust

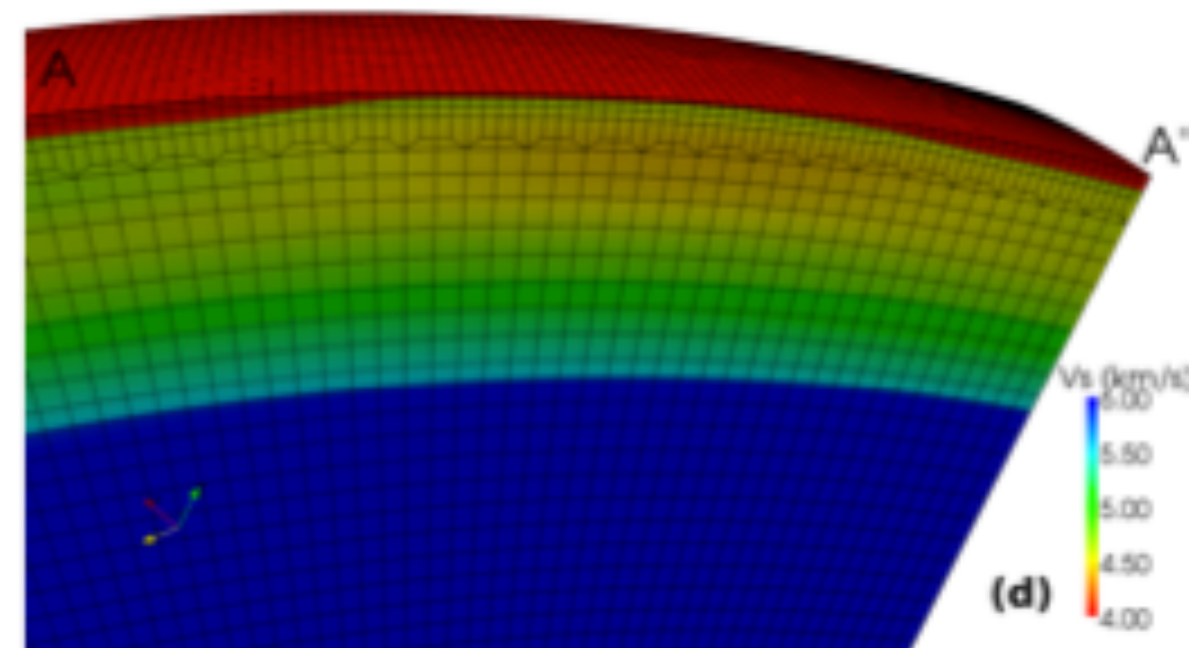


QUEST collaboration:
Irene Molinari

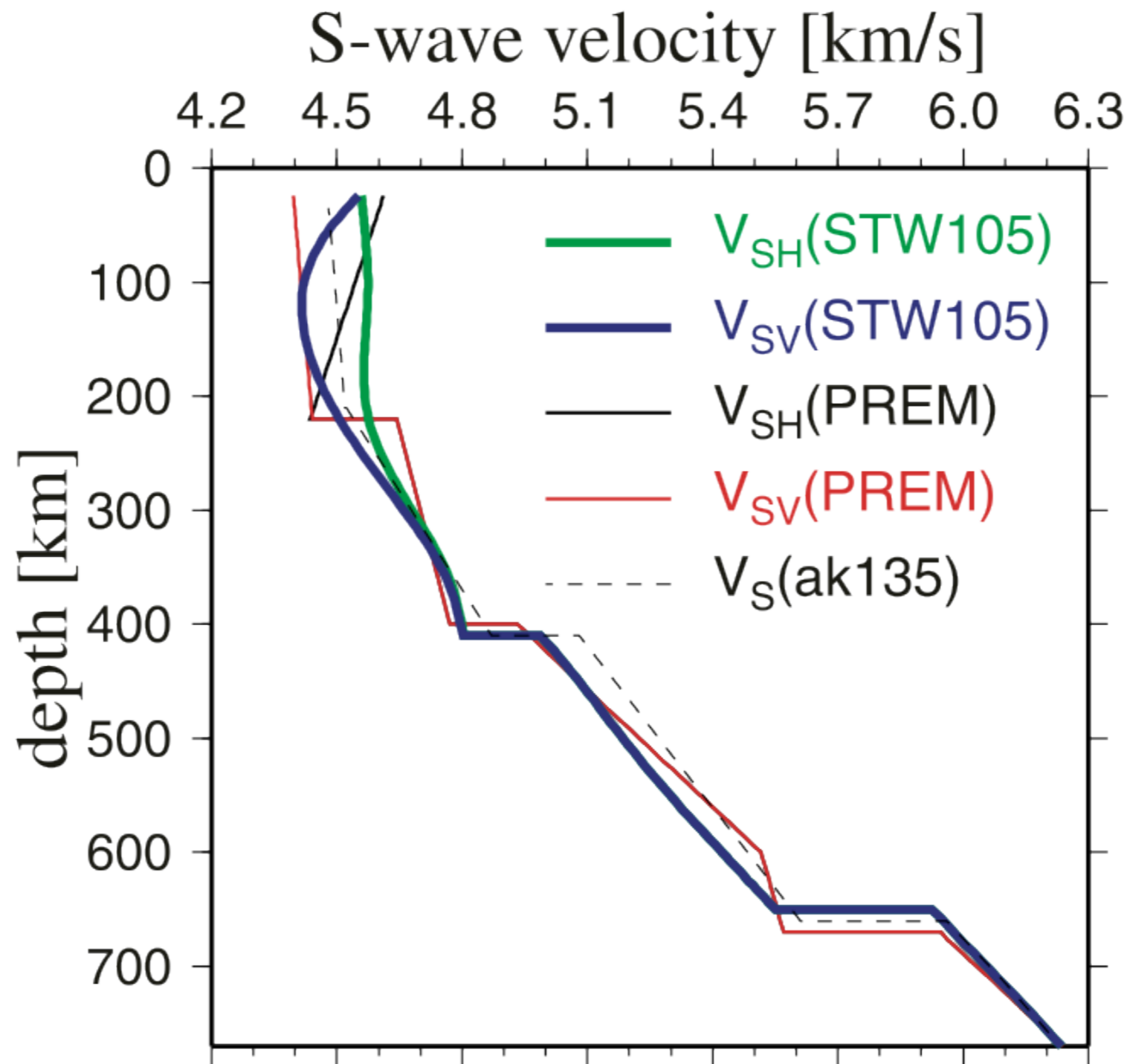
Starting 3D Crustal Model: EPCrust



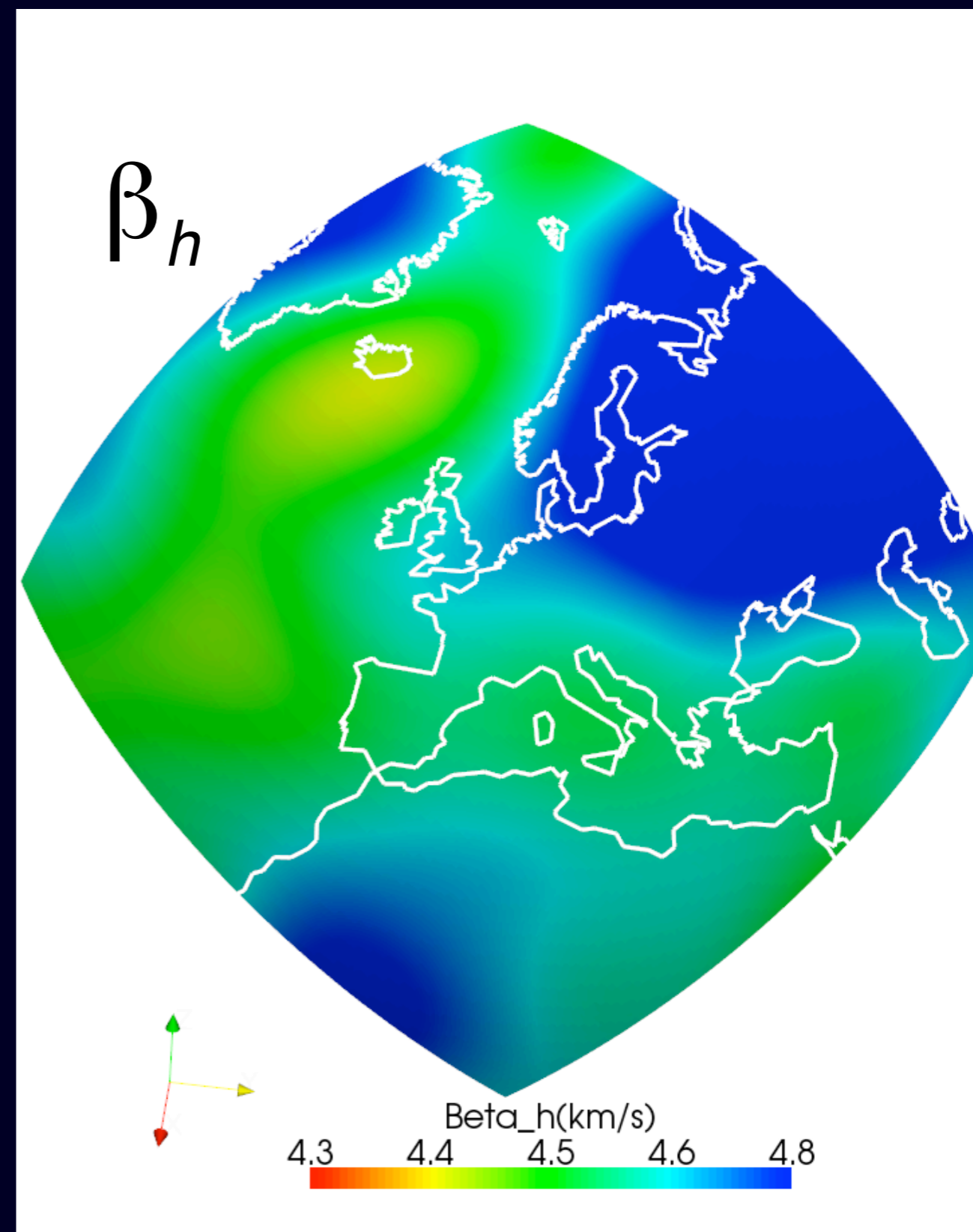
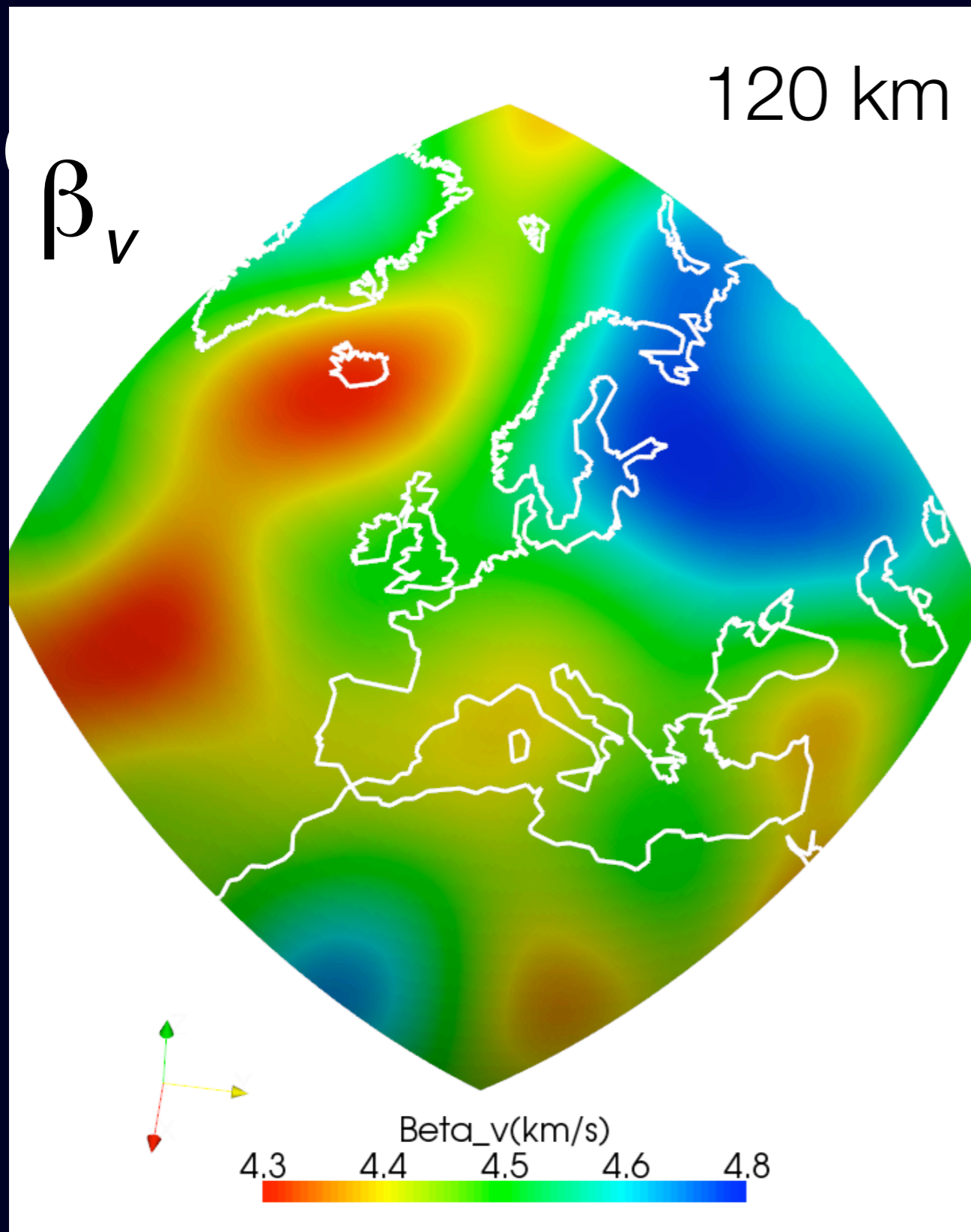
QUEST collaboration:
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1D Reference Model STW105

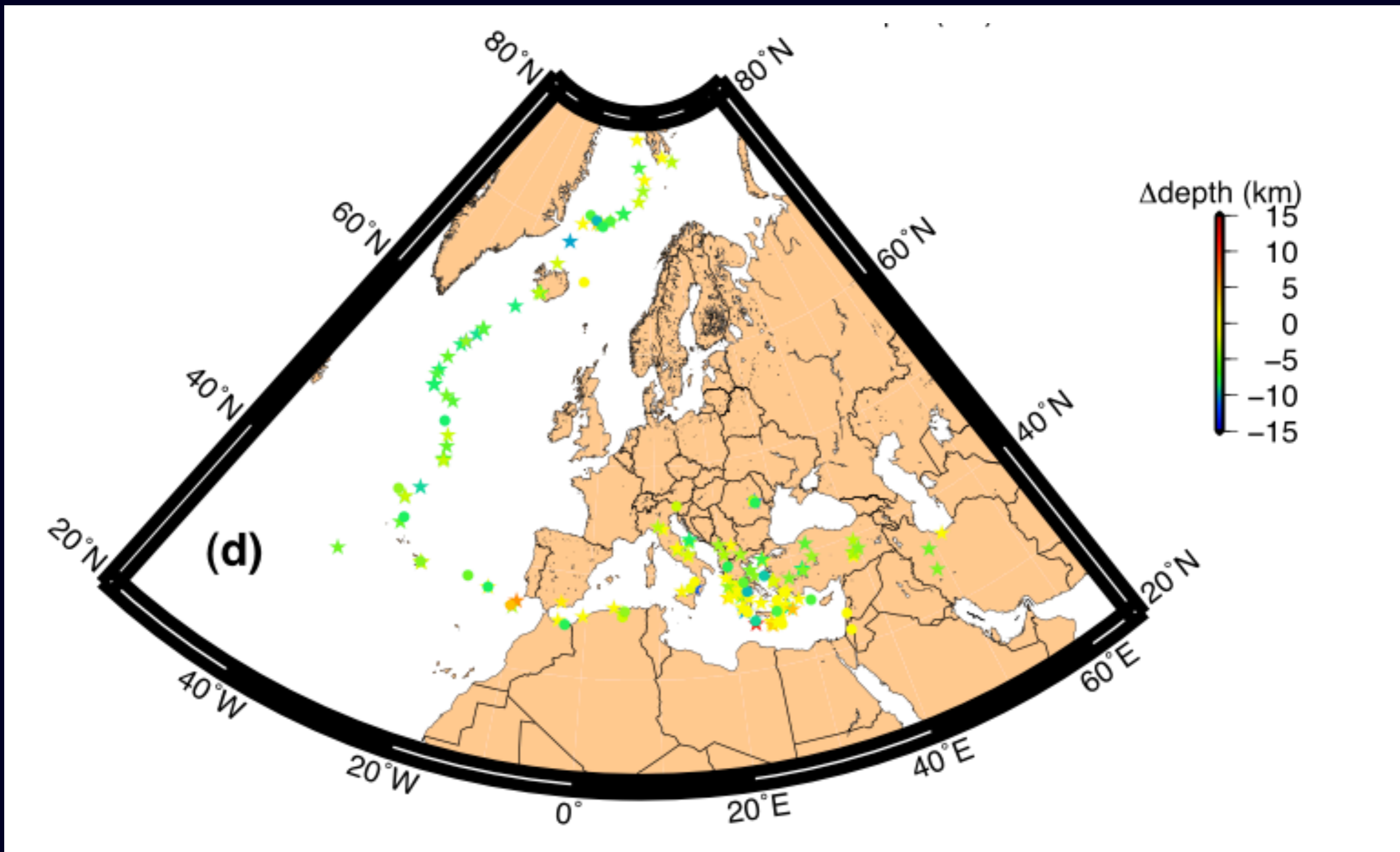


Starting 3D Mantle Model: S362ANI



Initial Source Inversion

Change in Depth



Current & Future Research

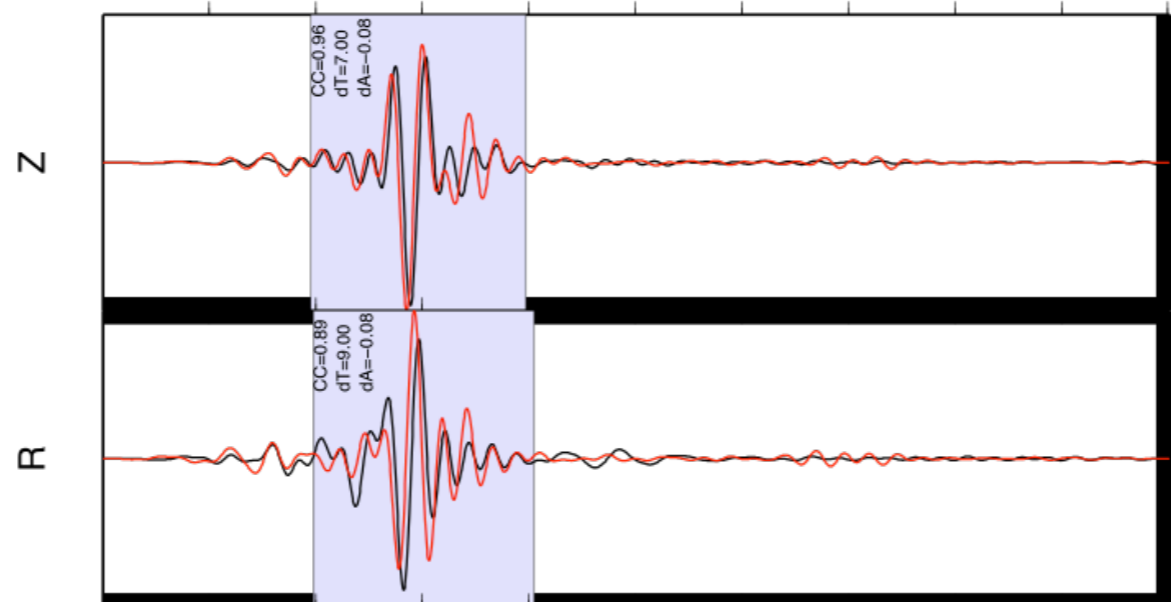
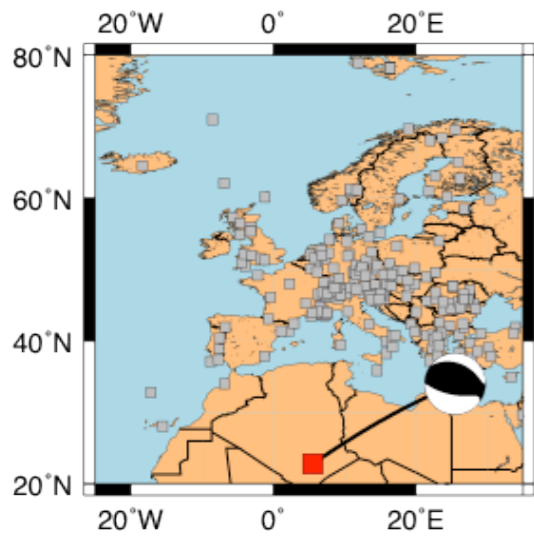
(Choices that need to be made in adjoint tomography)

- Model parameterization (transverse isotropy, Q, more general anisotropy)
 - Misfit
 - Measurement type (cross-correlation traveltimes, frequency-dependent phase & amplitude)
 - Window selection (steadily increase number of windows; FLEXWIN, Maggi et al.)
 - Band pass filtering (steadily increase frequency content)
 - Model basis
 - Regularization/smoothing
 - Preconditioning
 - Conjugate-gradient algorithm
 - Sampling the posterior model distribution (square-root variable metric algorithm; Tarantola)
 - Validation (e.g., separate earthquake data set, Tape et al. 2009, 2010; resolution tests, Chen et al. 2007, Fichtner et al. 2009)
-

Choice of Model Parameterization: Radial Anisotropy (Transverse Isotropy)

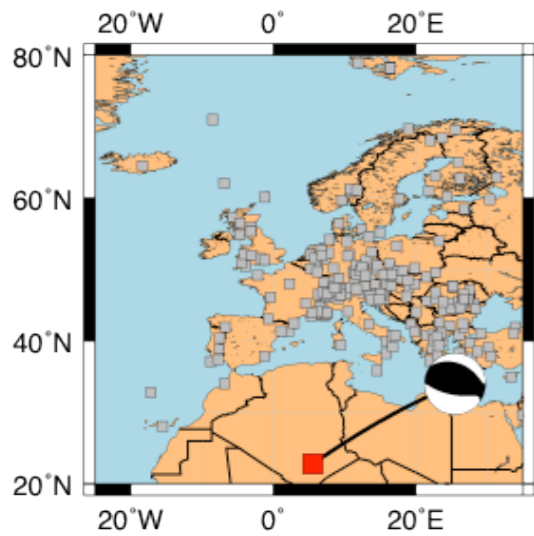
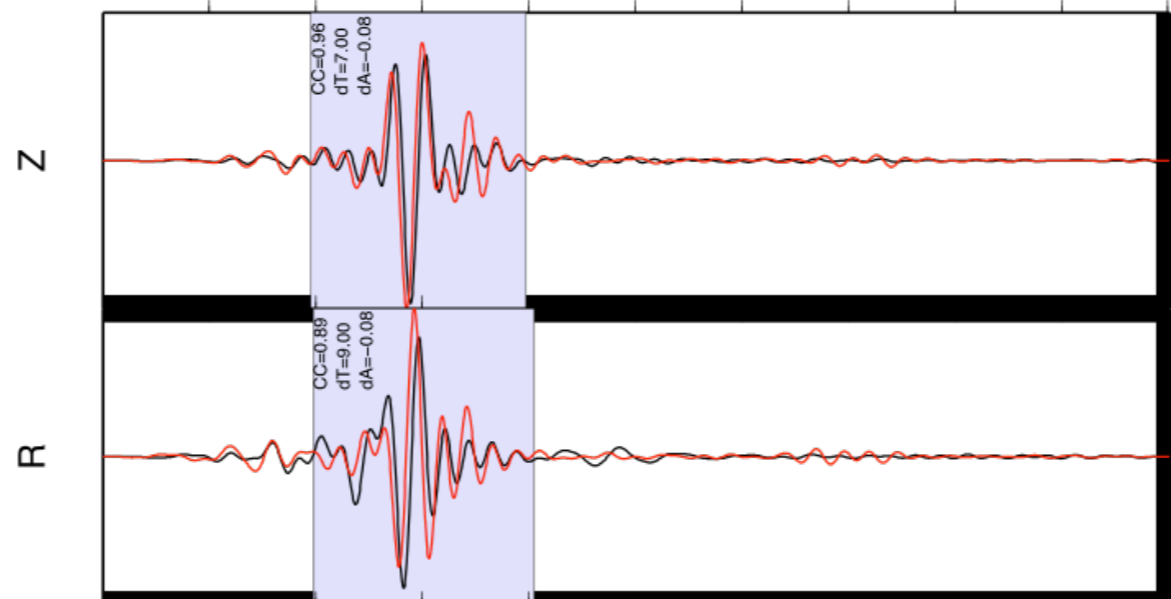
TAM.G

DIST: 20.77
BCAZ: 53.14
EVDP: 13.66
EVLO: 25.49
EVLA: 33.99
STLO: 5.53
STLA: 22.79

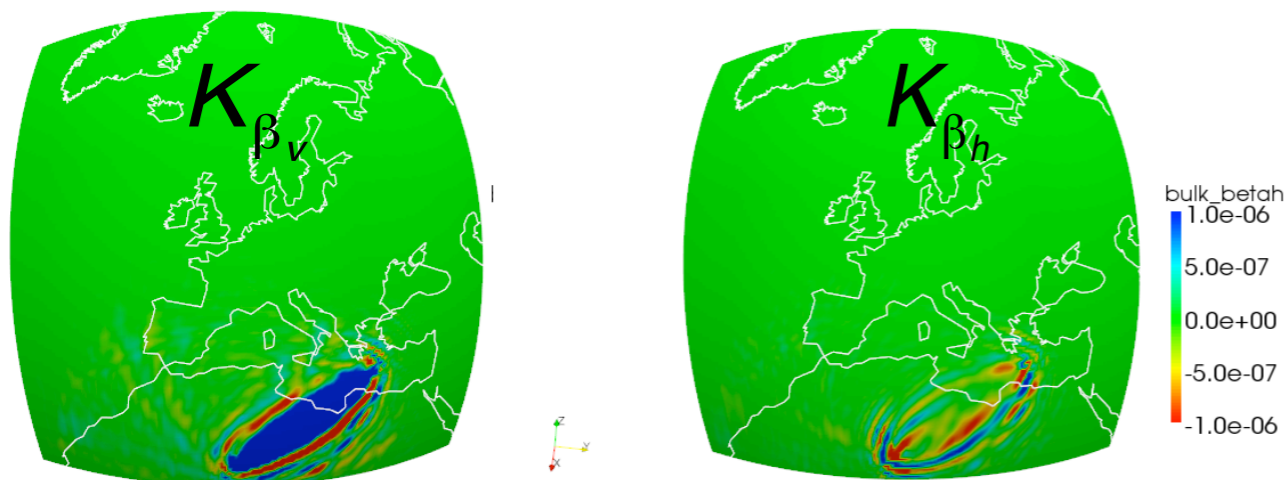


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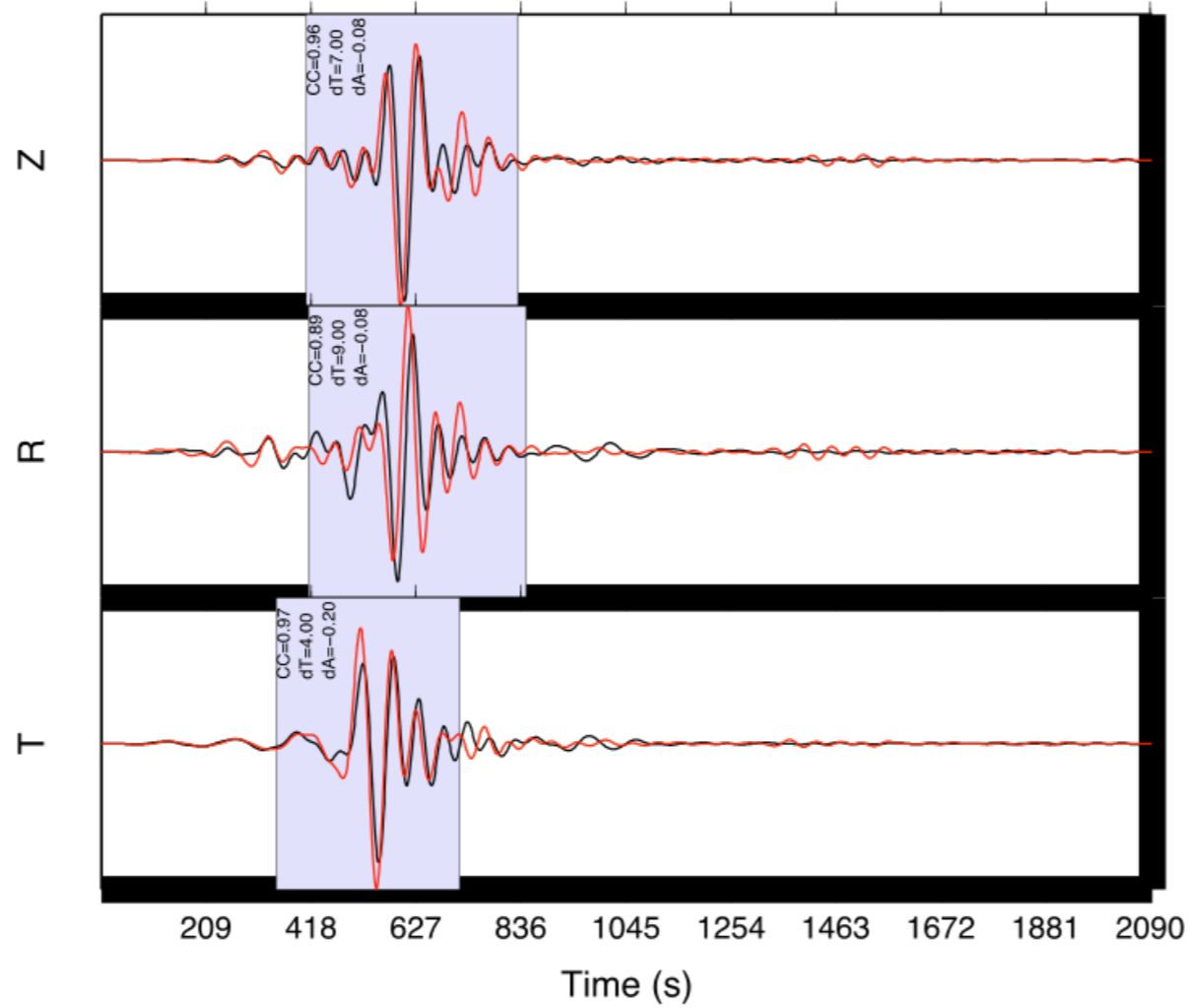
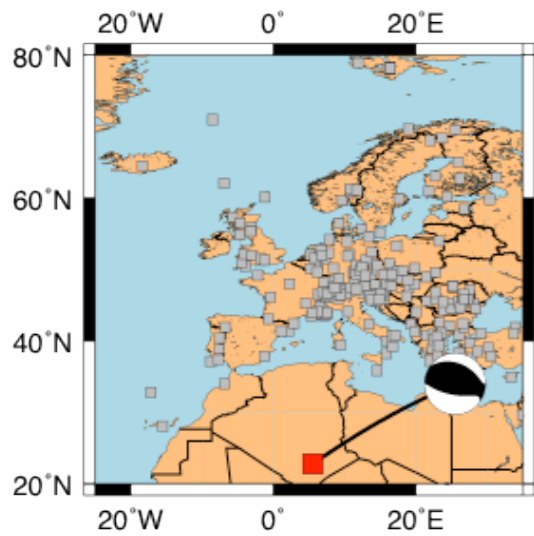


Rayleigh wave

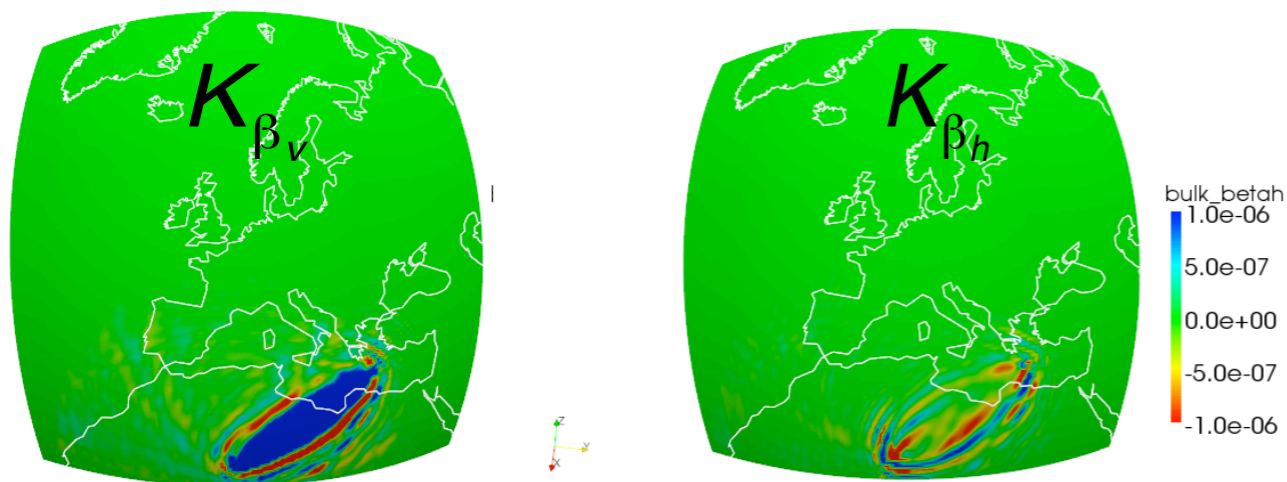


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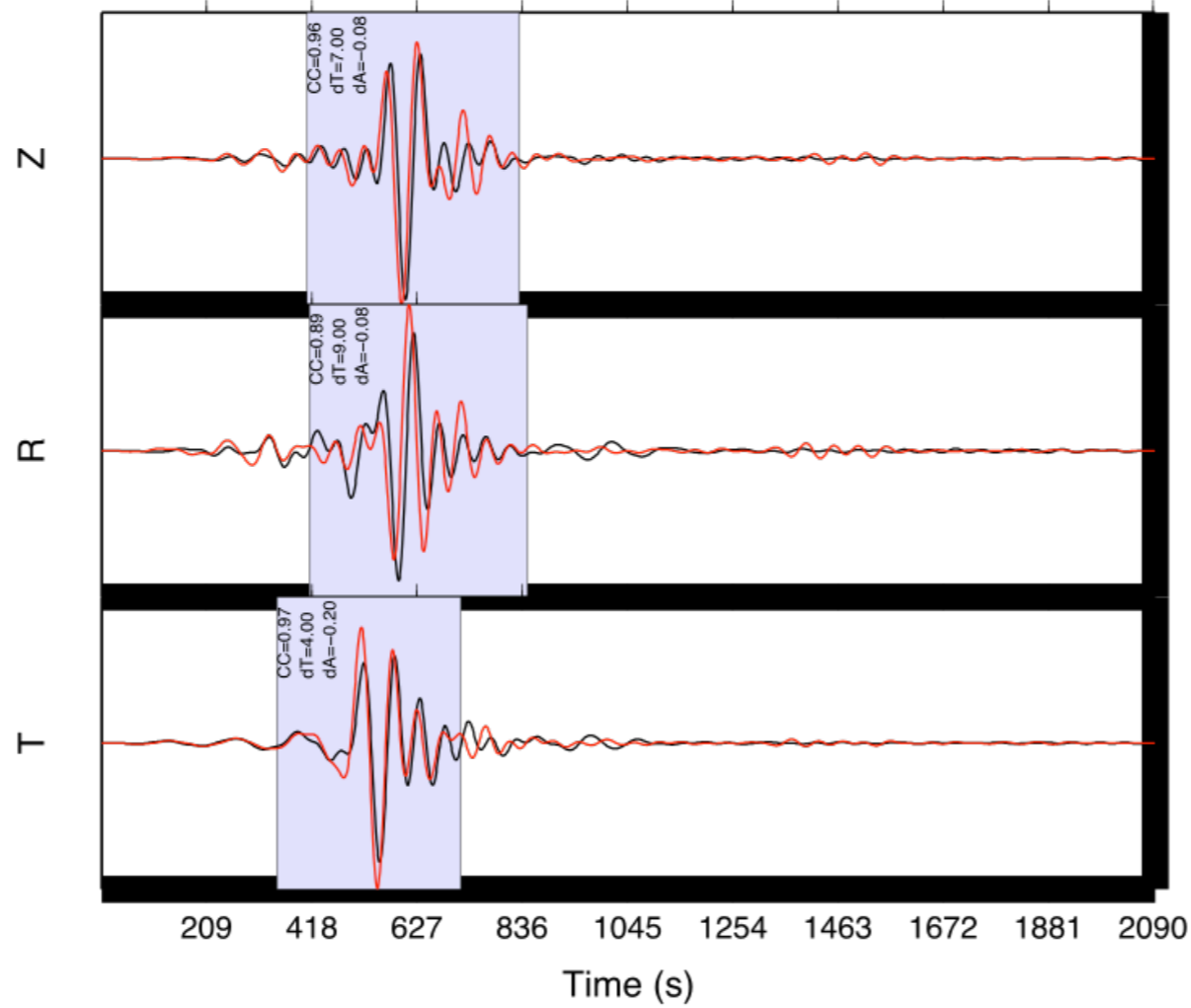
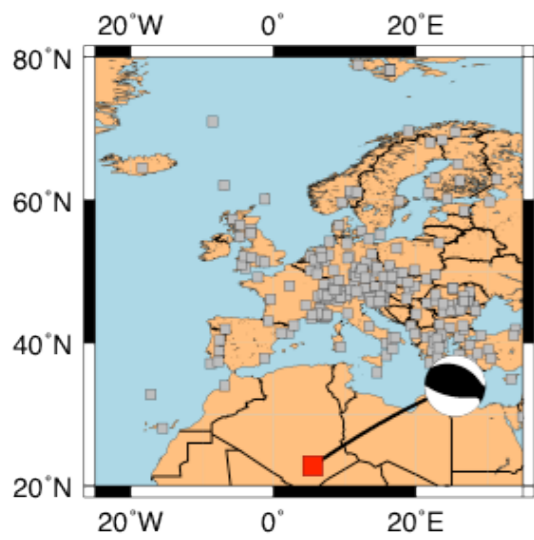
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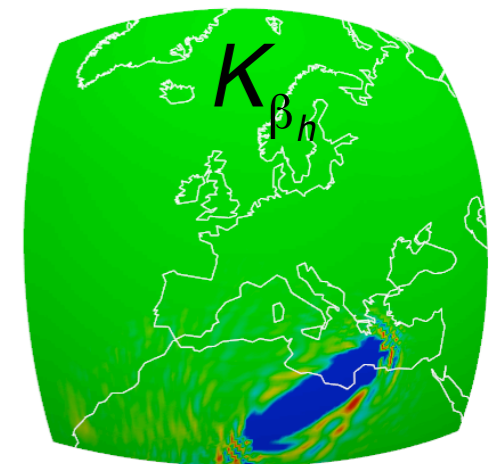
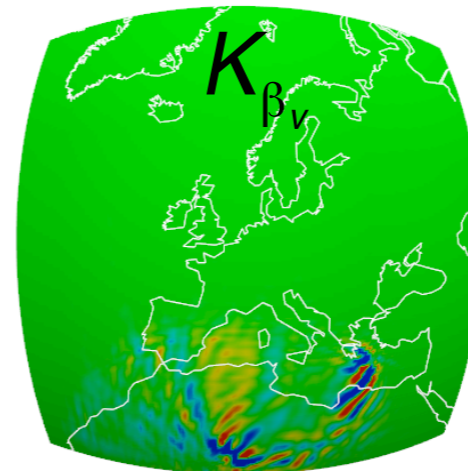
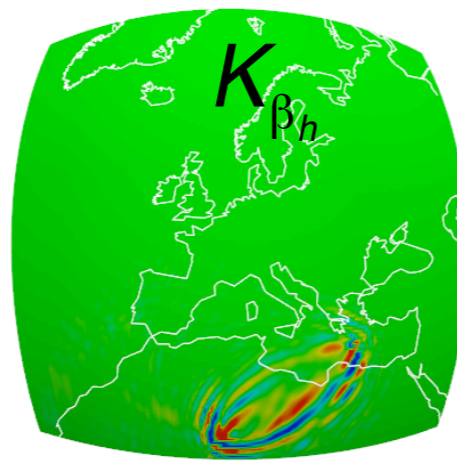
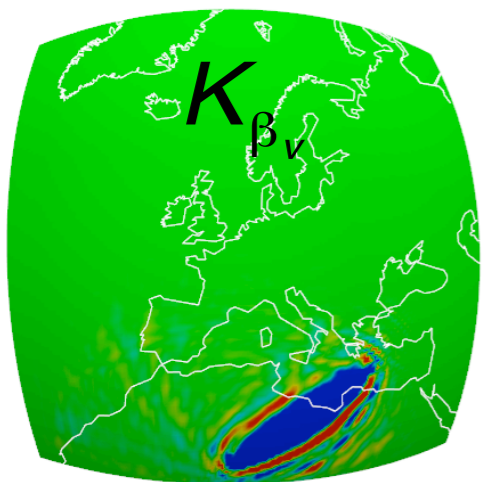
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Rayleigh wave

Love wave



bulk_be
 1.0e-0
 5.0e-0
 0.0e+0
 -5.0e-0
 -1.0e-0

Choice of Misfit

$$\chi(\mathbf{m}) = \frac{1}{6} \sum_{Z,R,T} \frac{1}{N_s} \sum_s \frac{1}{N_p} \sum_{i=1}^p \left(\frac{\Delta T_i}{\sigma_i} \right)^2 + \frac{1}{6} \sum_{Z,R,T} \frac{1}{N_s} \sum_s \frac{1}{N_p} \sum_{i=1}^p \int W_i \left[\frac{\Delta \tau(\omega)_i}{\sigma(\omega)_i} \right]^2 d\omega$$

Body-wave cross correlation/multitaper
15-40 s band pass
(1) P-SV (Vertical)
(2) P-SV(Radial)
(3) SH (Transverse)

Surface-wave multitaper
30-150 s band pass
(4) Rayleigh (Vertical)
(5) Rayleigh (Radial)
(6) Love (Transverse)

Adjoint source = SP(body-wave measurement) + LP (surface-wave measurement)

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Ultimate goal: 20 s surface waves

Choice of Misfit

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Adjoint source = SP(body-wave measurement) + LP (surface-wave measurement)

Ultimate goal: 20 s surface waves

$$\delta \chi^{TI} = \int K_c \delta \ln c + K_{\beta_v} \delta \ln \beta_v + K_{\beta_h} \delta \ln \beta_h + K_{\eta} \delta \ln \eta + K_{\rho} \delta \ln \rho dV$$

Optimization

Given a model $m = \{m_k\}$, we seek to minimize the misfit function

$$\chi(m)$$

Its gradient is

$$g_k(m) = \frac{\partial \chi}{\partial m_k}(m)$$

Find a new model $m + \Delta m$ such that

$$g_k(m + \Delta m) = \frac{\partial \chi}{\partial m_k}(m + \Delta m) = 0$$

which is the condition for stationarity of χ . We have

$$\frac{\partial \chi}{\partial m_k}(m + \Delta m) \approx \frac{\partial \chi}{\partial m_k}(m) + \frac{\partial^2 \chi}{\partial m_k \partial m_{k'}}(m) \Delta m_{k'}$$

Define the Hessian

$$H_{kk'} = \frac{\partial^2 \chi}{\partial m_k \partial m_{k'}}$$

Then we seek model update Δm such that

$$H_{kk'} \Delta m_{k'} = -g_k$$

In matrix notation we obtain the Newton method

$$H \Delta m = -g$$

and naively

$$\Delta m = -H^{-1} g$$

Steepest descent:

$$\Delta m \approx -\alpha g$$

for some positive step length α .

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and naively

$$\Delta m = -H^{-1}g \quad (\text{Fichtner's talk})$$

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(Preconditioned) Conjugate Gradient Method

Let i denote the iteration.

- Nondimensionalize the model parameters with the symmetric, positive-definite model covariance matrix:

$$\hat{m}^i = C_m^{-1/2} m^i$$

Use nondimensional, logarithmic model parameters, ideally with minimal cross-covariance.

- Calculate the value of the misfit function $\chi(m^i)$
- Compute the gradient $g^i = \partial\chi/\partial m^i$ based on the adjoint method
- Nondimensionalize the gradient:

$$\hat{g}^i = C_m^{1/2} g^i$$

- (Preconditioning:

$$\hat{g}^i \Rightarrow P^i \hat{g}^i = P^i C_m^{1/2} g^i$$

for some symmetric, positive-definite preconditioner P^i .)

- Determine the current descent direction:

$$\hat{p}^i = -\hat{g}^i + \beta^i \hat{p}^{i-1}$$

For the first iteration, $i = 0$, set $\beta^0 = 0$ and $\hat{p}^0 = -\hat{g}^0$; otherwise calculate β^i based on the Fletcher-Reeves, Pola-Ribiere, or the Hestenes-Stiefel formula.

- Model update

$$\Delta \hat{m}^i = \alpha^i \hat{p}^i$$

for some positive step length α^i .

Choice of Basis & Smoothing

One can choose to expand the model in a known basis:

$$m(\mathbf{x}) = \sum_k m_k B_k(\mathbf{x})$$

The corresponding Frechet derivative is

$$\frac{\partial \chi}{\partial m_k} = \int K_m(\mathbf{x}) B_k(\mathbf{x}) d^3 \mathbf{x}$$

One can damp the model, e.g., by adding a norm, gradient or second derivative term to the misfit

Instead, we ‘polish’ the gradient based on the shortest vertical and horizontal wavelengths of the waves in the dataset

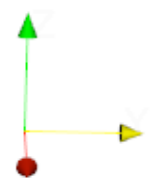
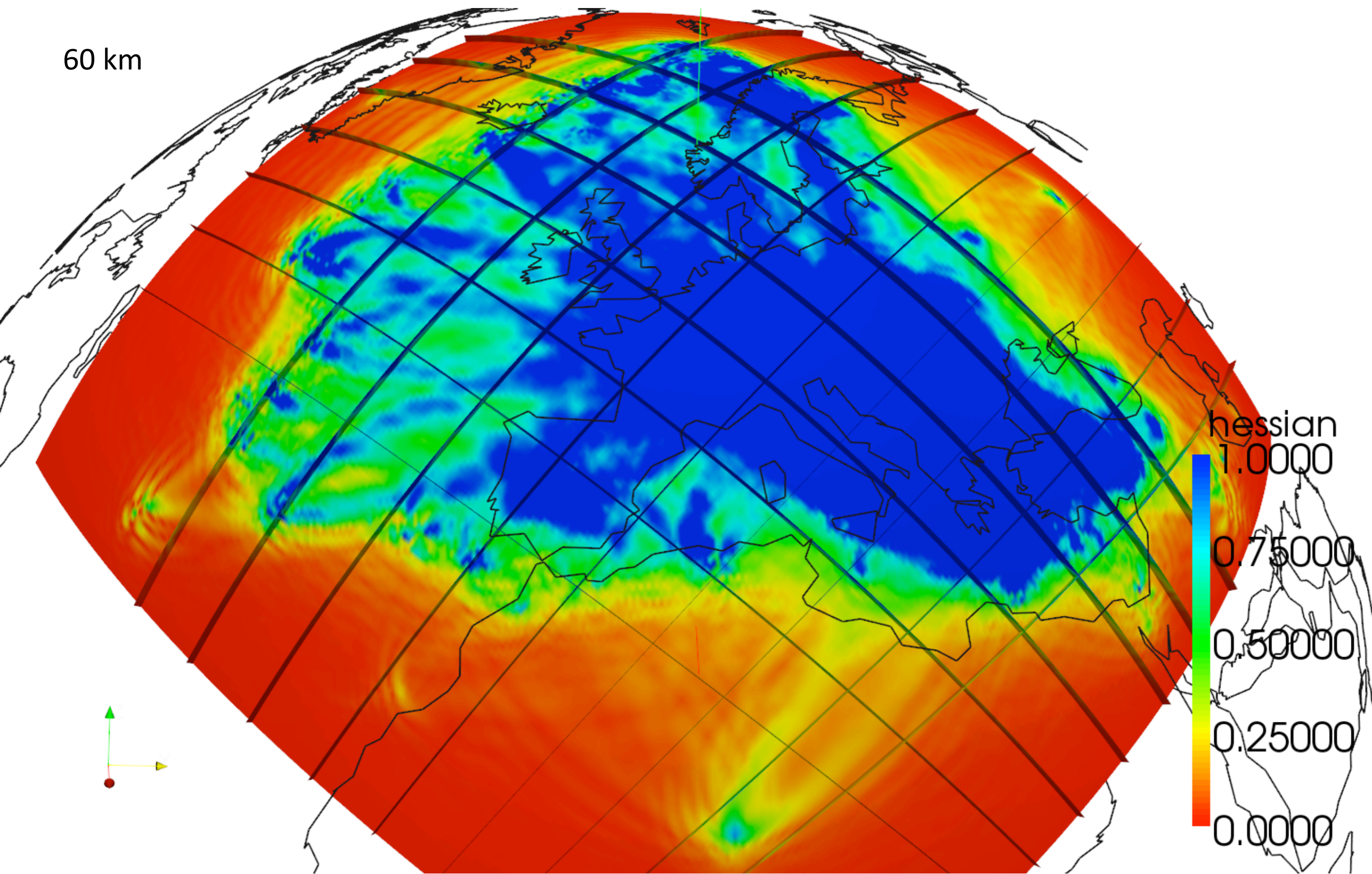
Choice of Preconditioning

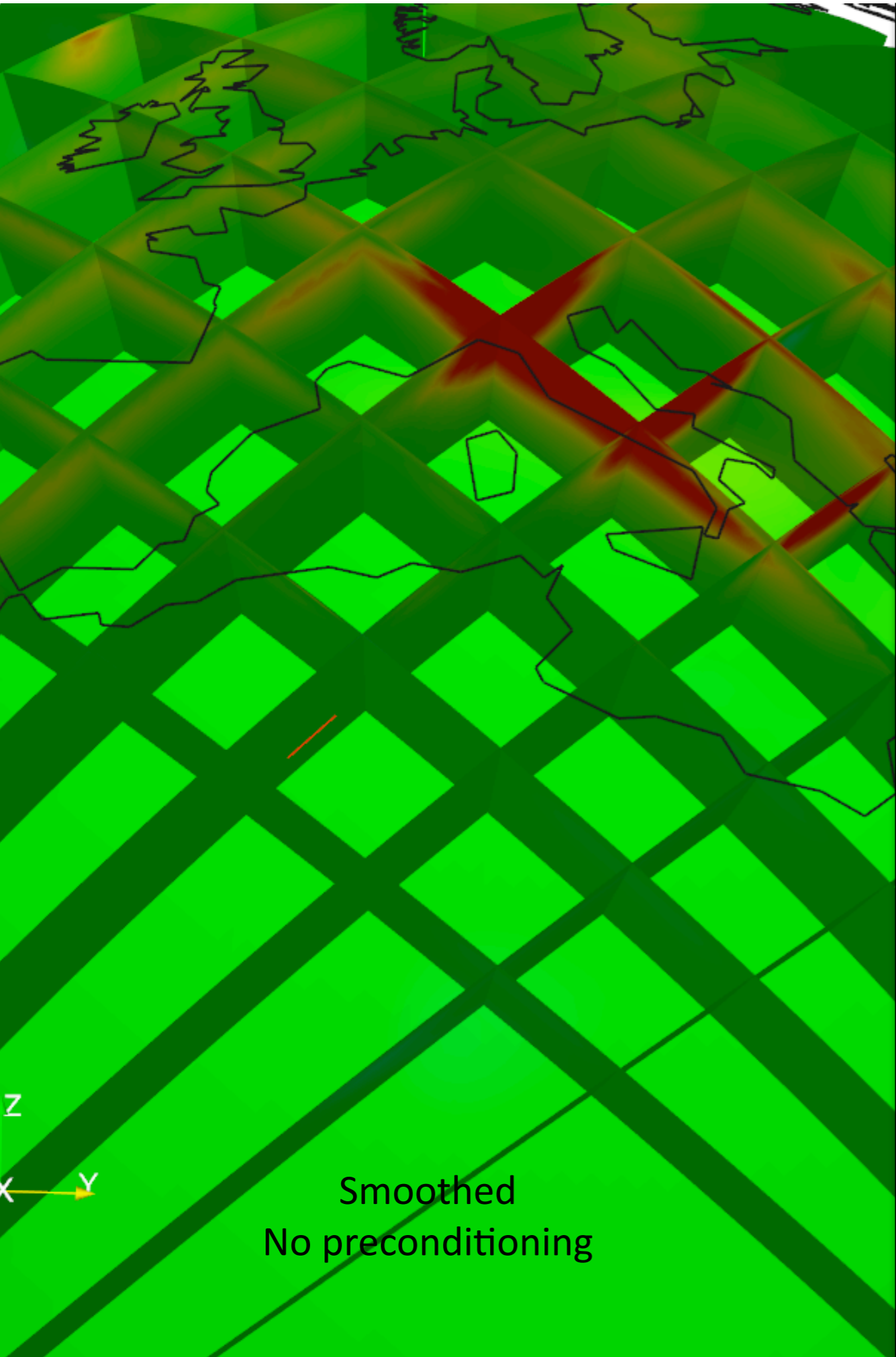
For all source-receiver combinations, calculate

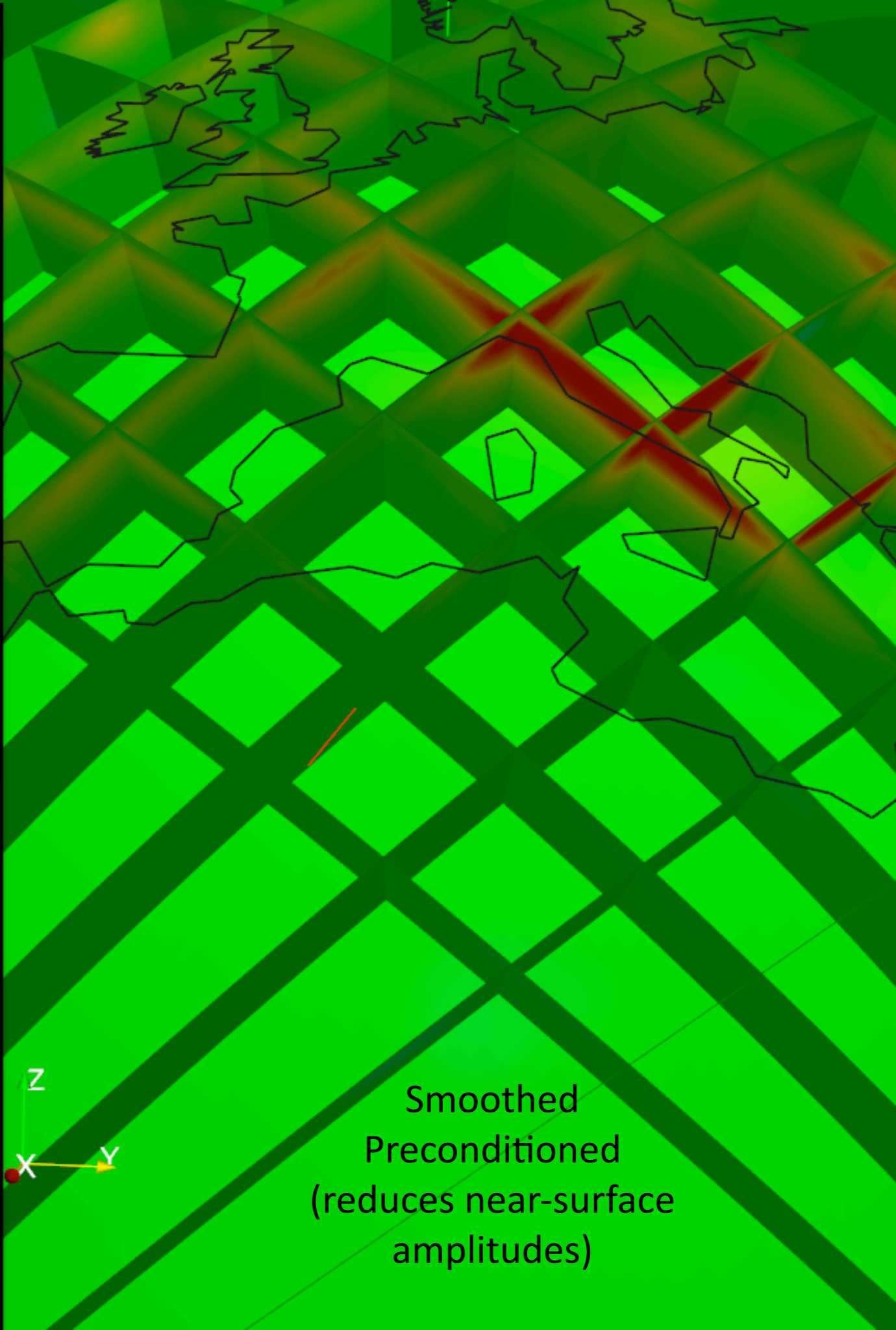
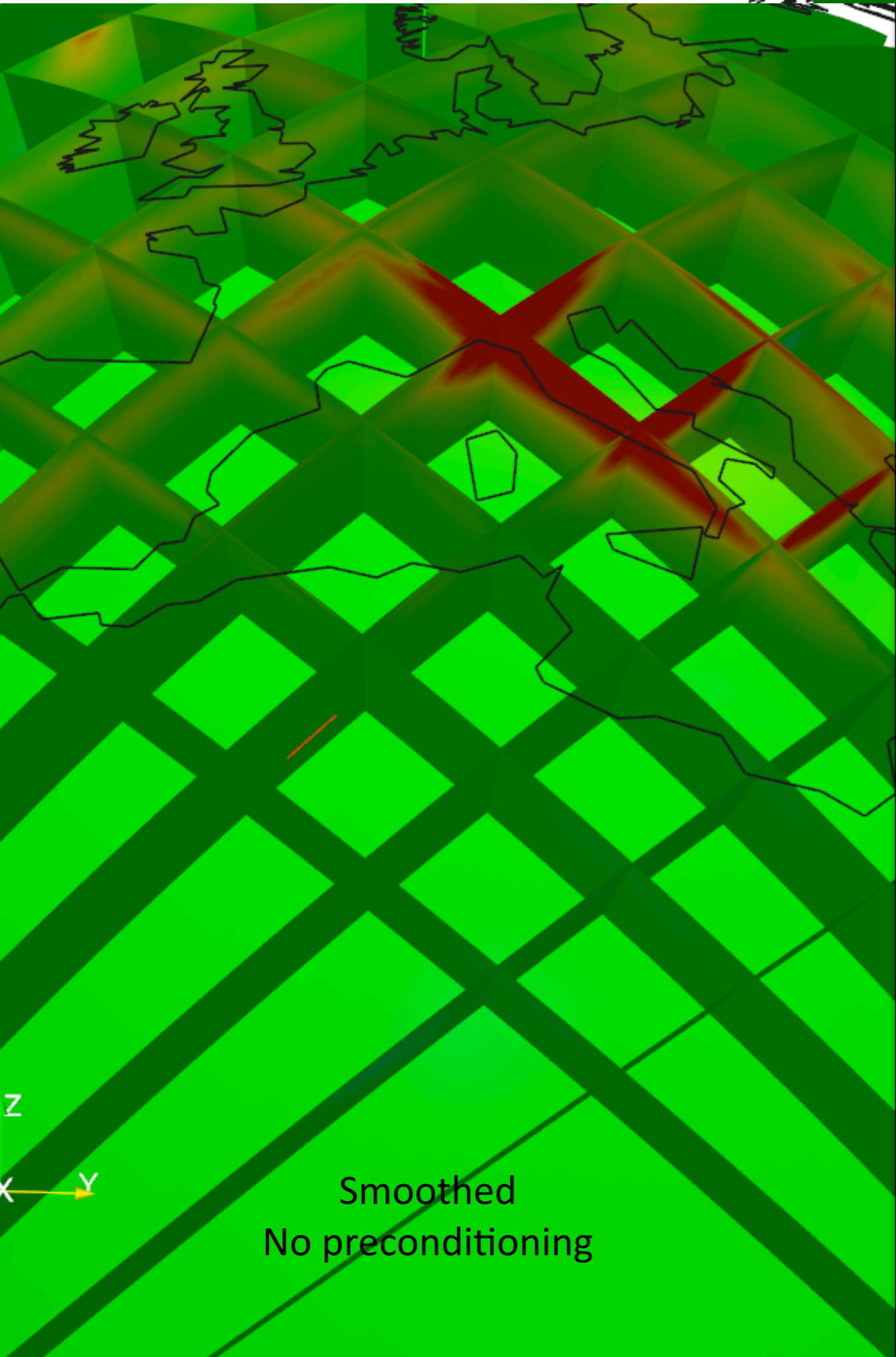
$$P(\mathbf{x}) = \int_0^T \partial_t^2 \mathbf{s}(\mathbf{x}, t) \partial_t^2 \mathbf{s}^+(\mathbf{x}, T - t) dt$$

Effectively, this yields a ‘ray density’ map which is used to precondition the gradient, thereby ‘undoing’ some of the geometrical spreading

60 km



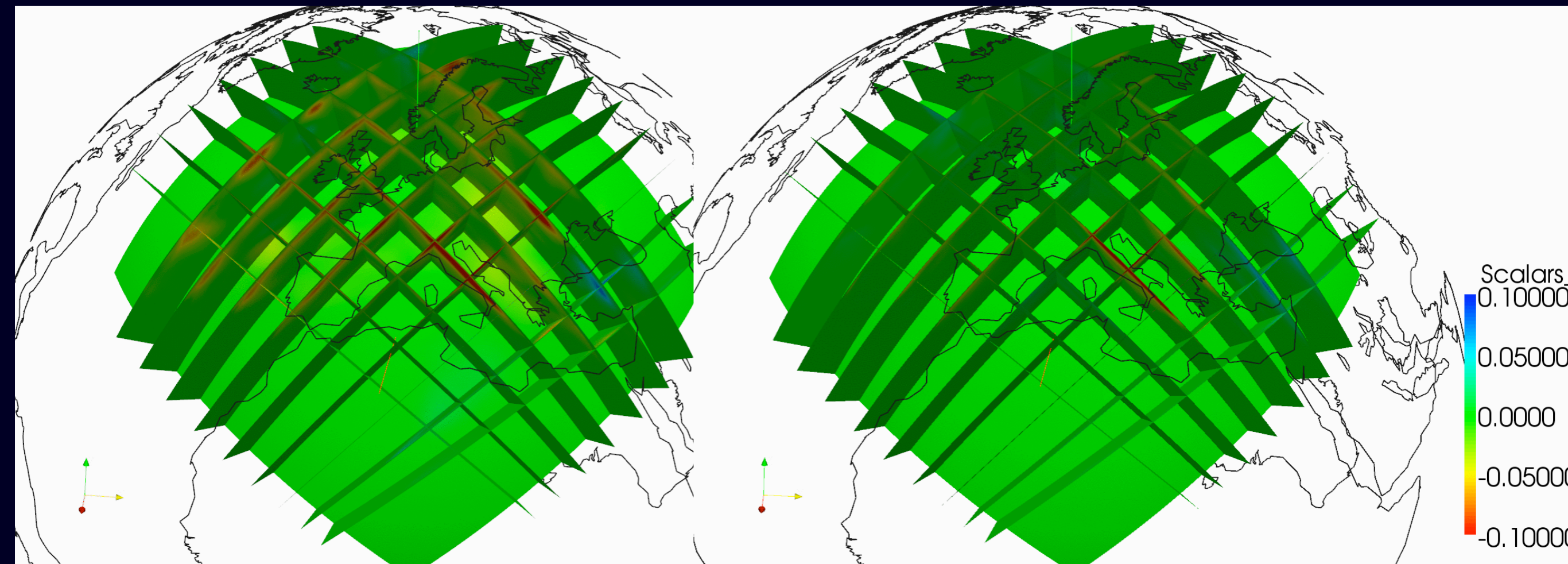




Misfit Gradient

Without preconditioning

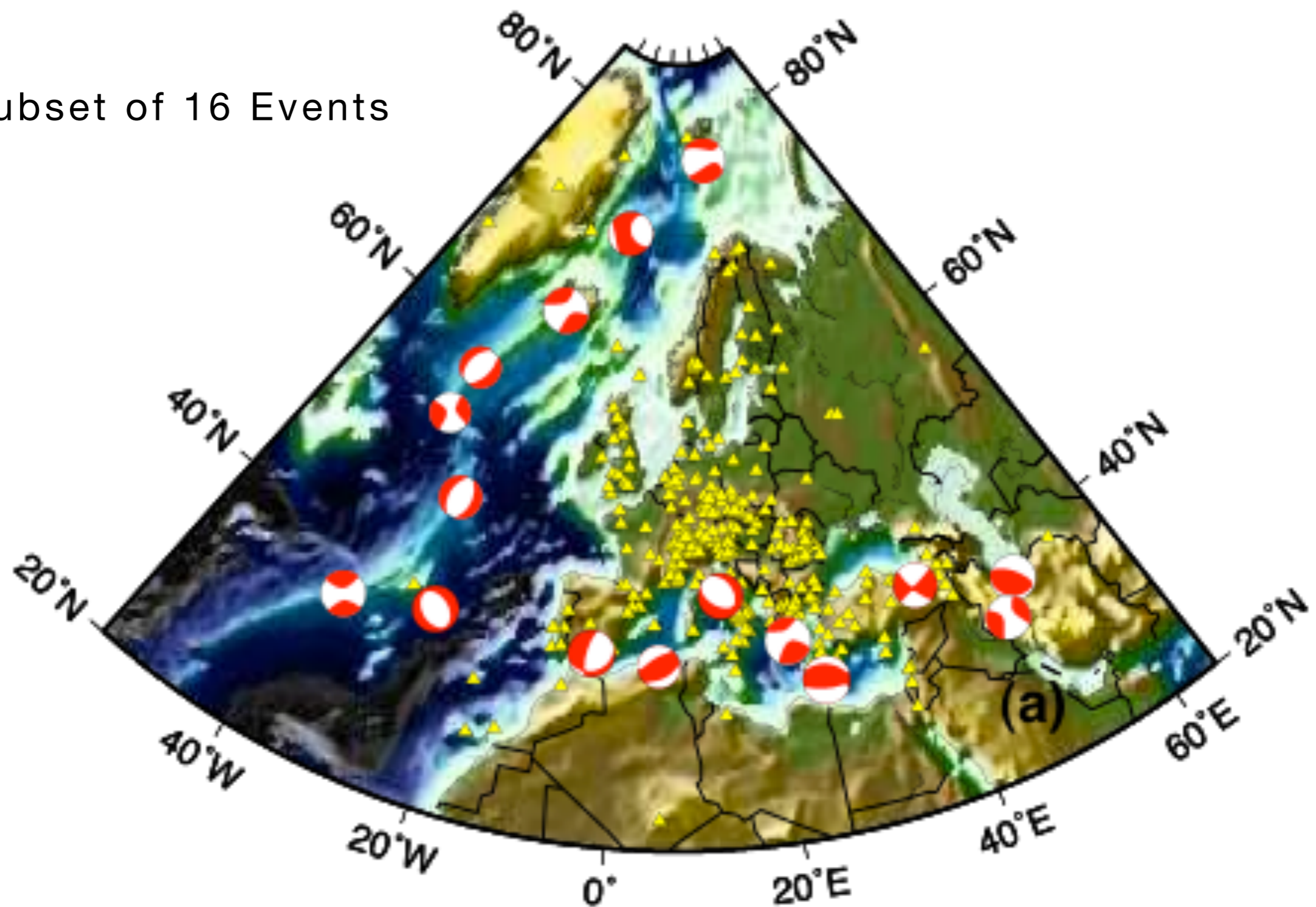
With preconditioning



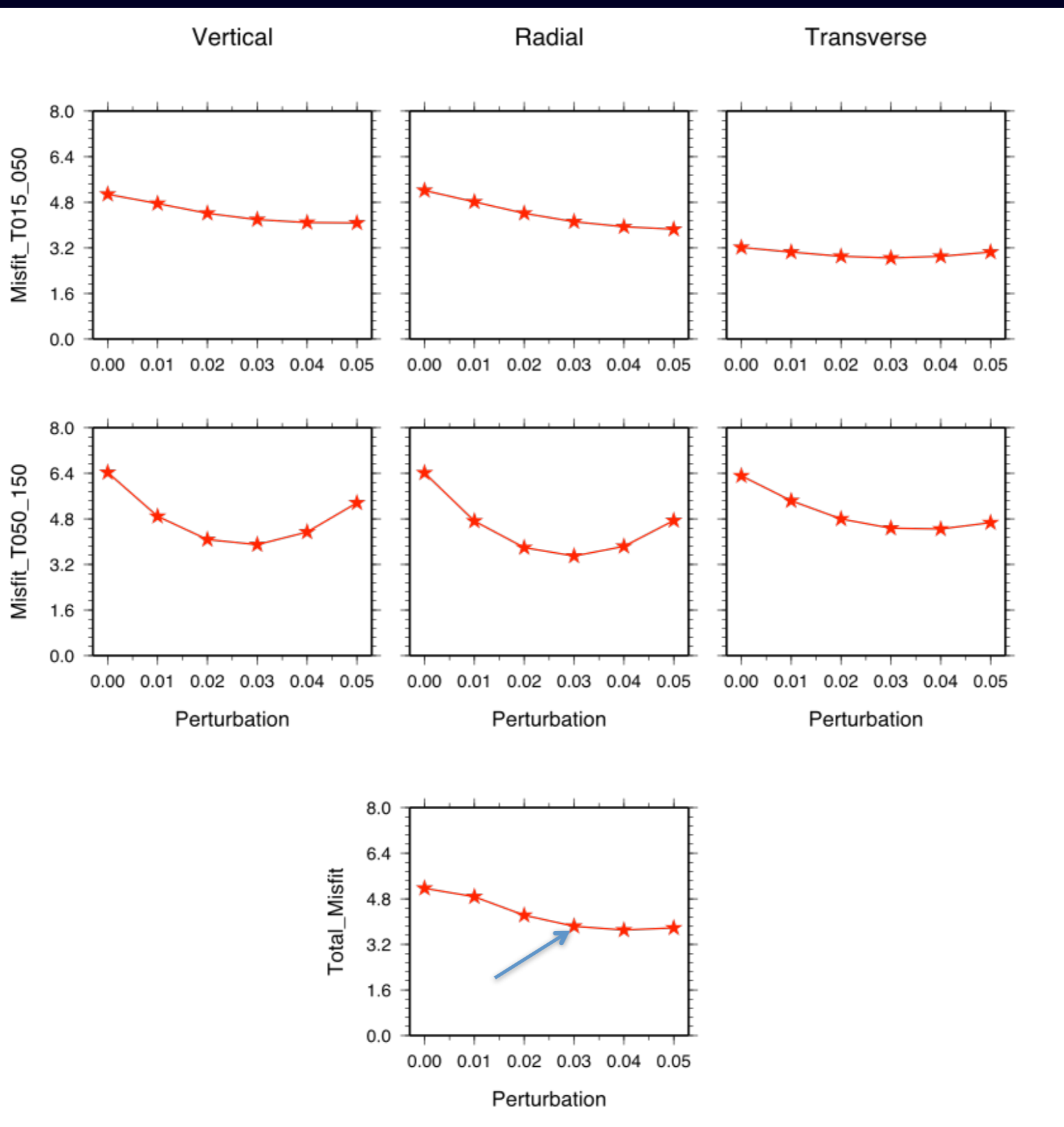
Red: speed up
Blue: slow down

Choice of Step Length: Line search

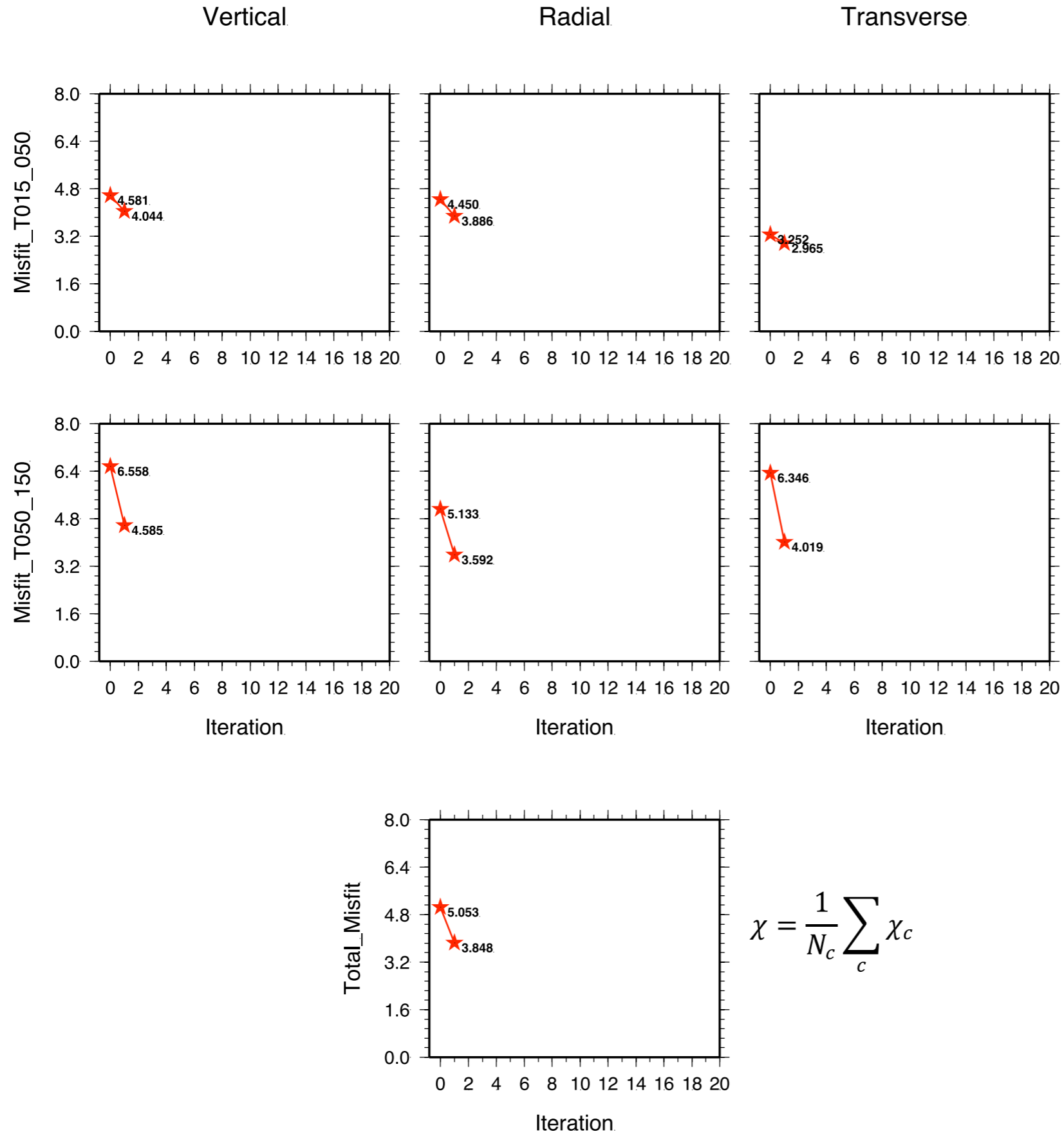
Subset of 16 Events



Choice of Step Length: Line search



Reduction in Misfit: First Iteration

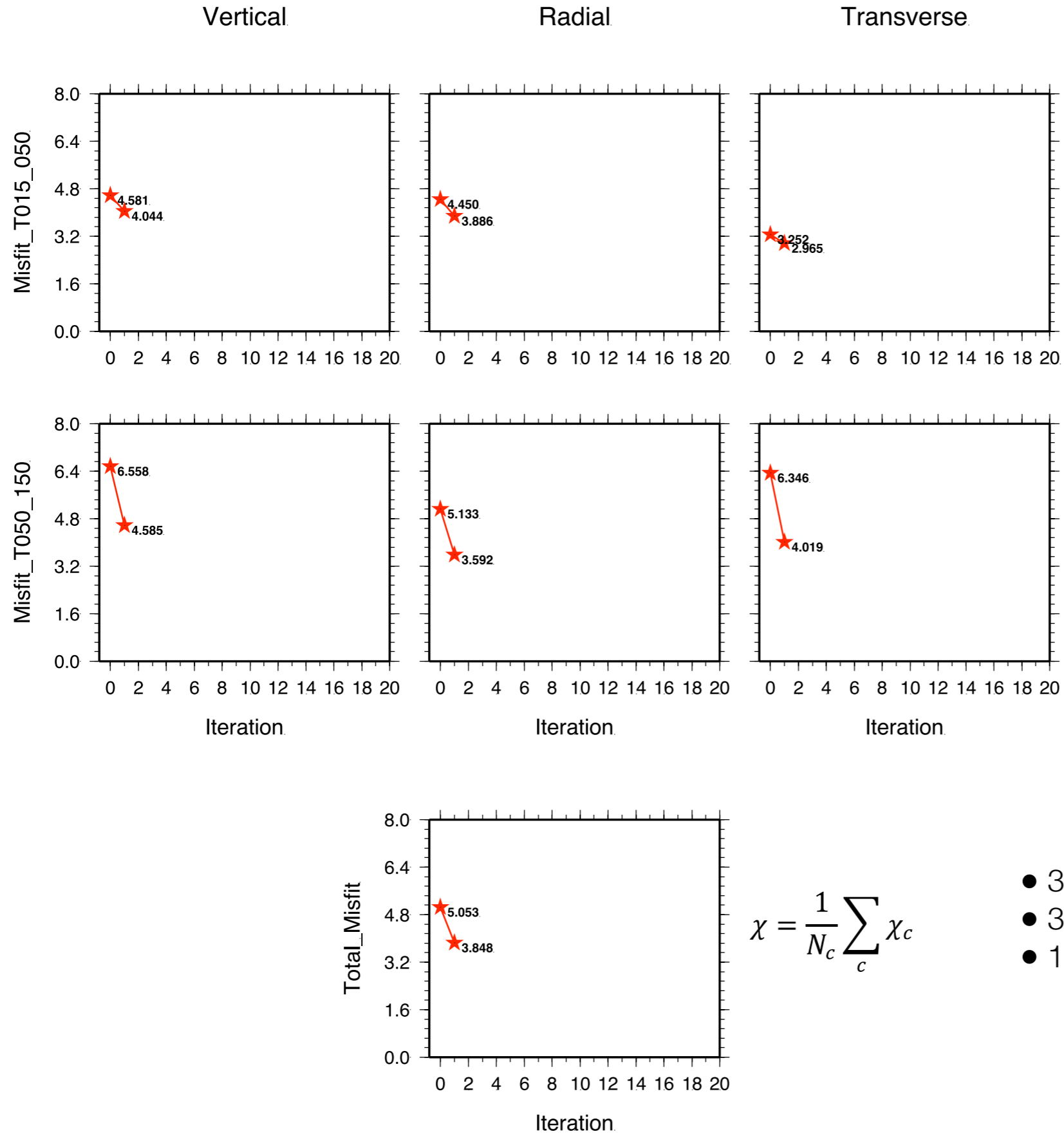


$$\chi_c = \frac{1}{N_s} \sum_s \frac{1}{N_p} \sum_p \left(\frac{\Delta T_p}{\sigma_p} \right)^2$$

$$\chi_c = \frac{1}{N_s} \sum_s \frac{1}{N_p} \sum_p \int W_p \left(\frac{\Delta \tau_p(\omega)}{\sigma_p(\omega)} \right)^2 d\omega$$

$$\chi = \frac{1}{N_c} \sum_c \chi_c$$

Reduction in Misfit: First Iteration



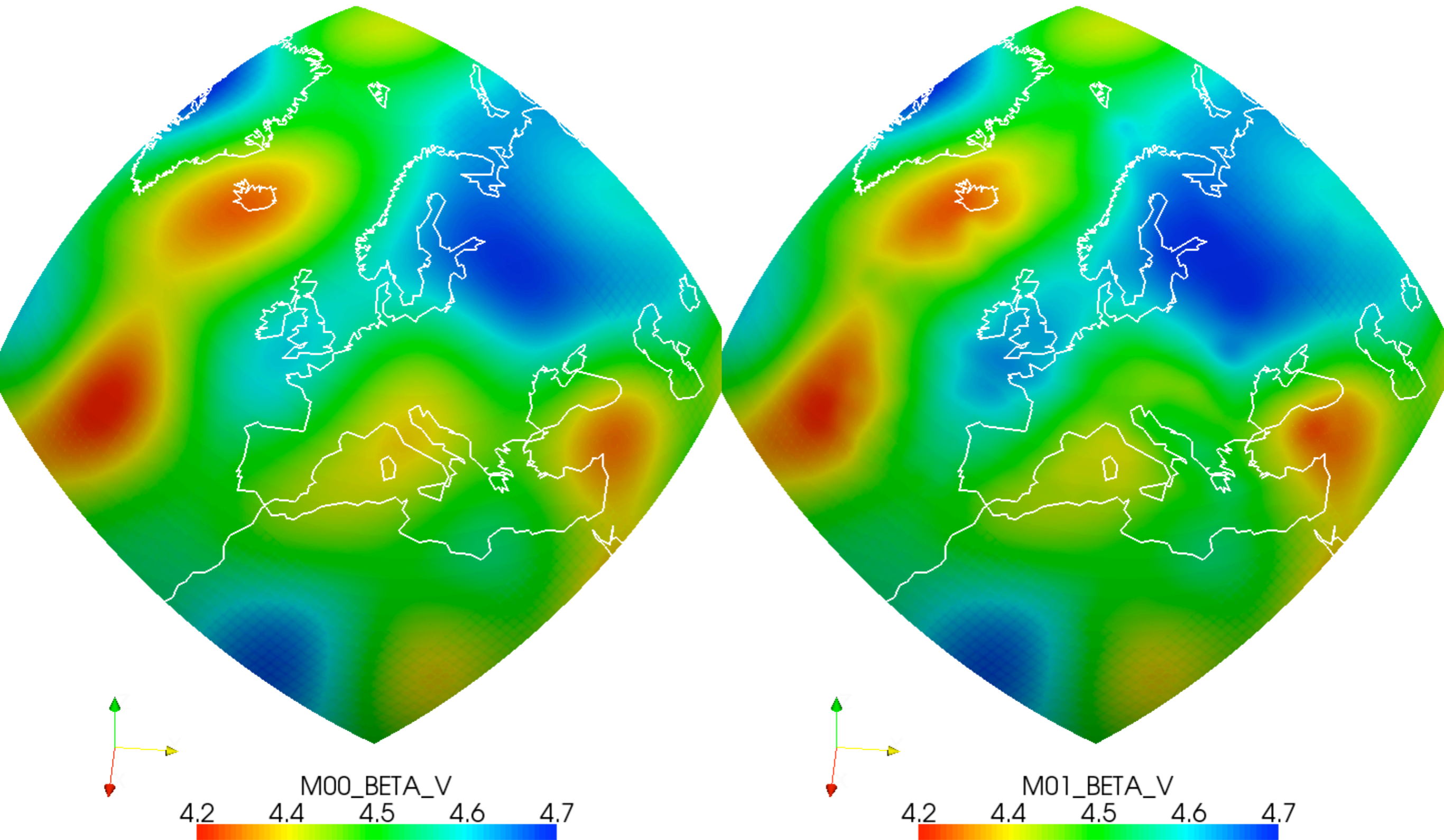
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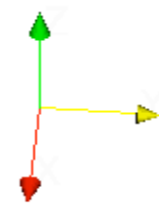
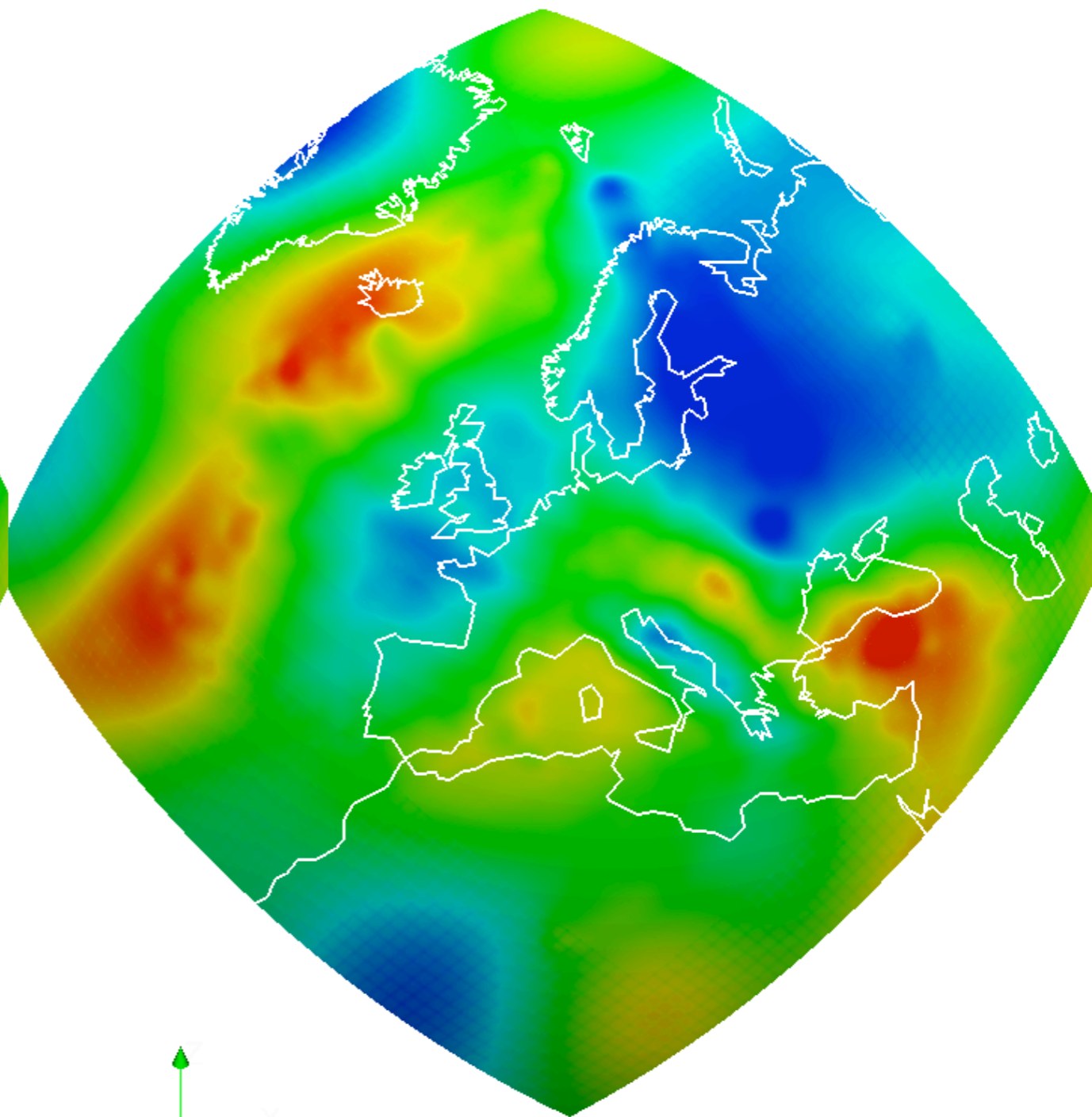
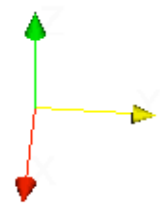
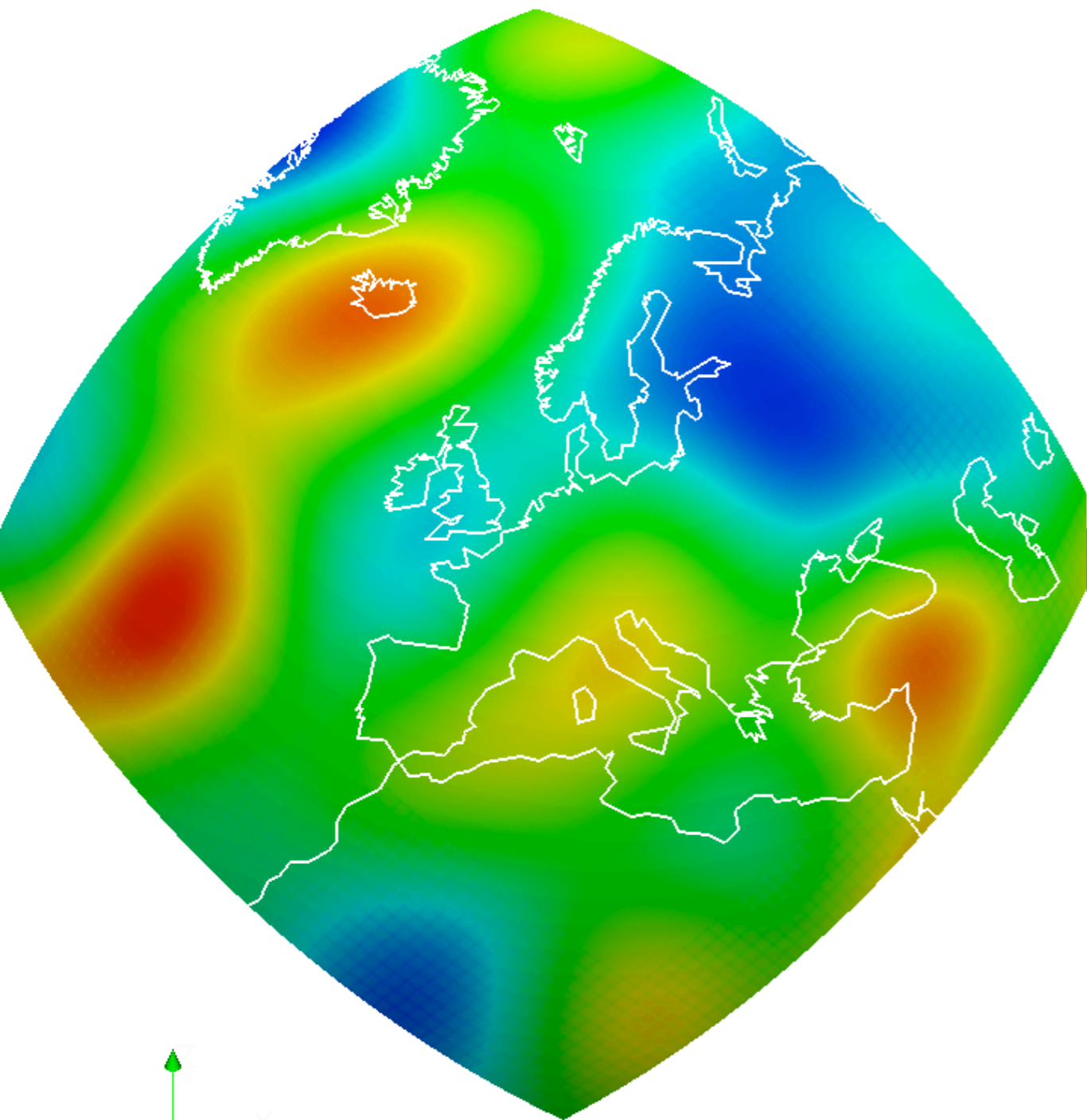
$$\chi = \frac{1}{N_c} \sum_c \chi_c$$

- 30 minutes per simulation (144 cores)
- 3 simulations per event per iteration
- 1 iteration ~ 1 day

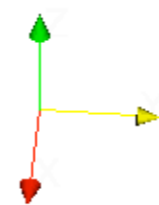
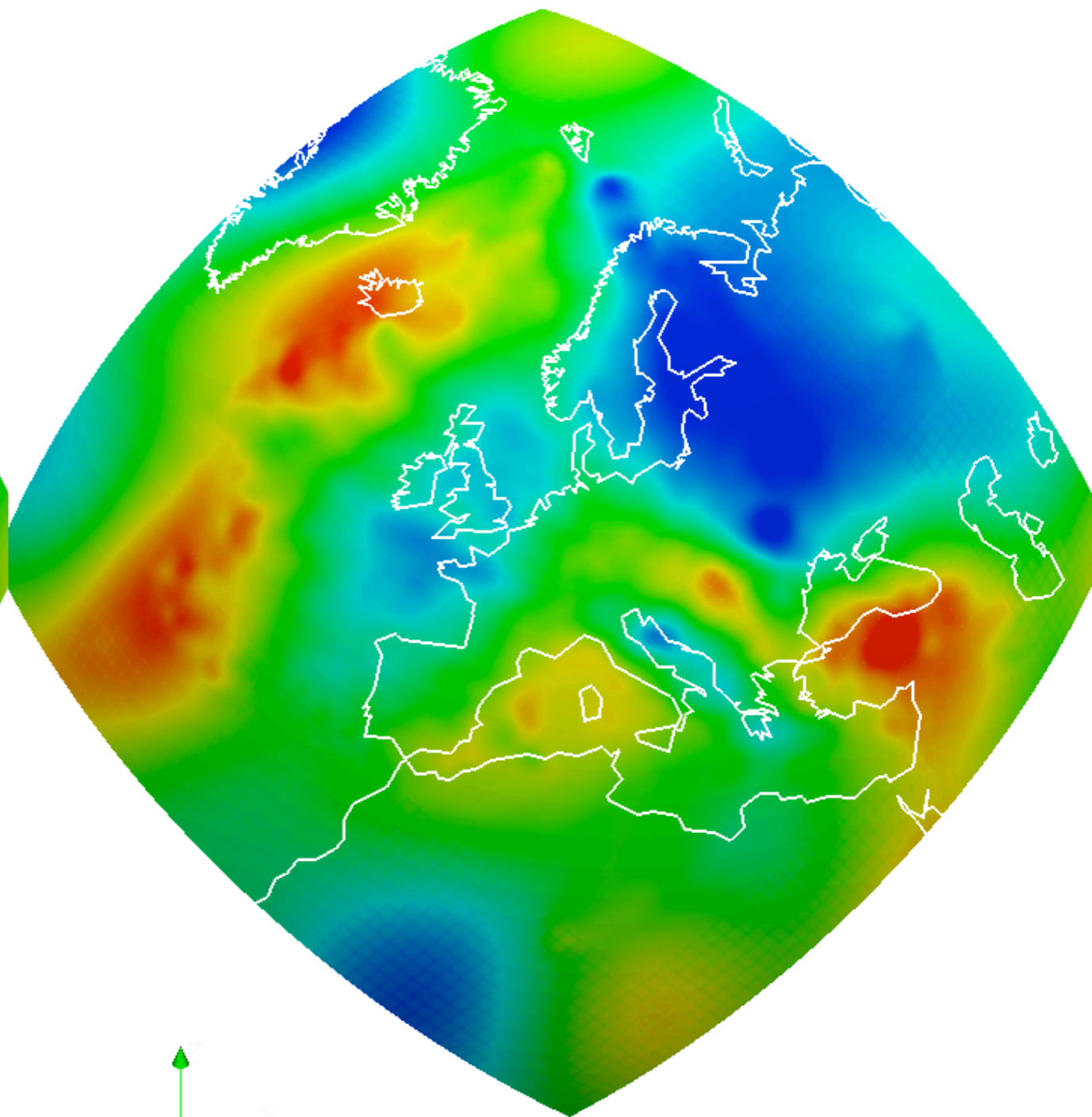
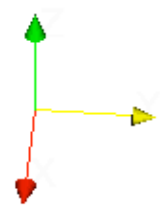
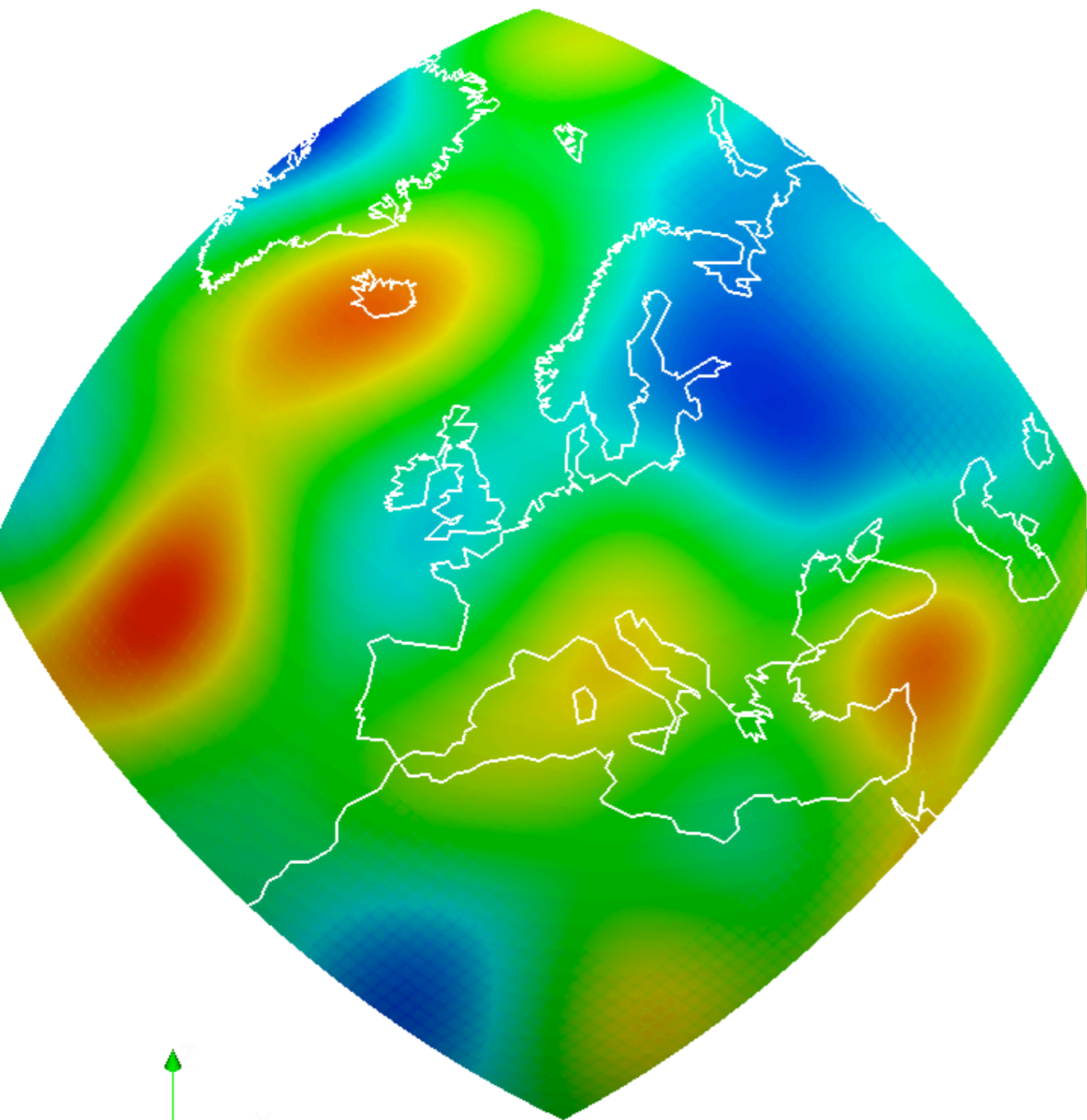
Depth 75 km



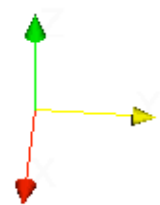
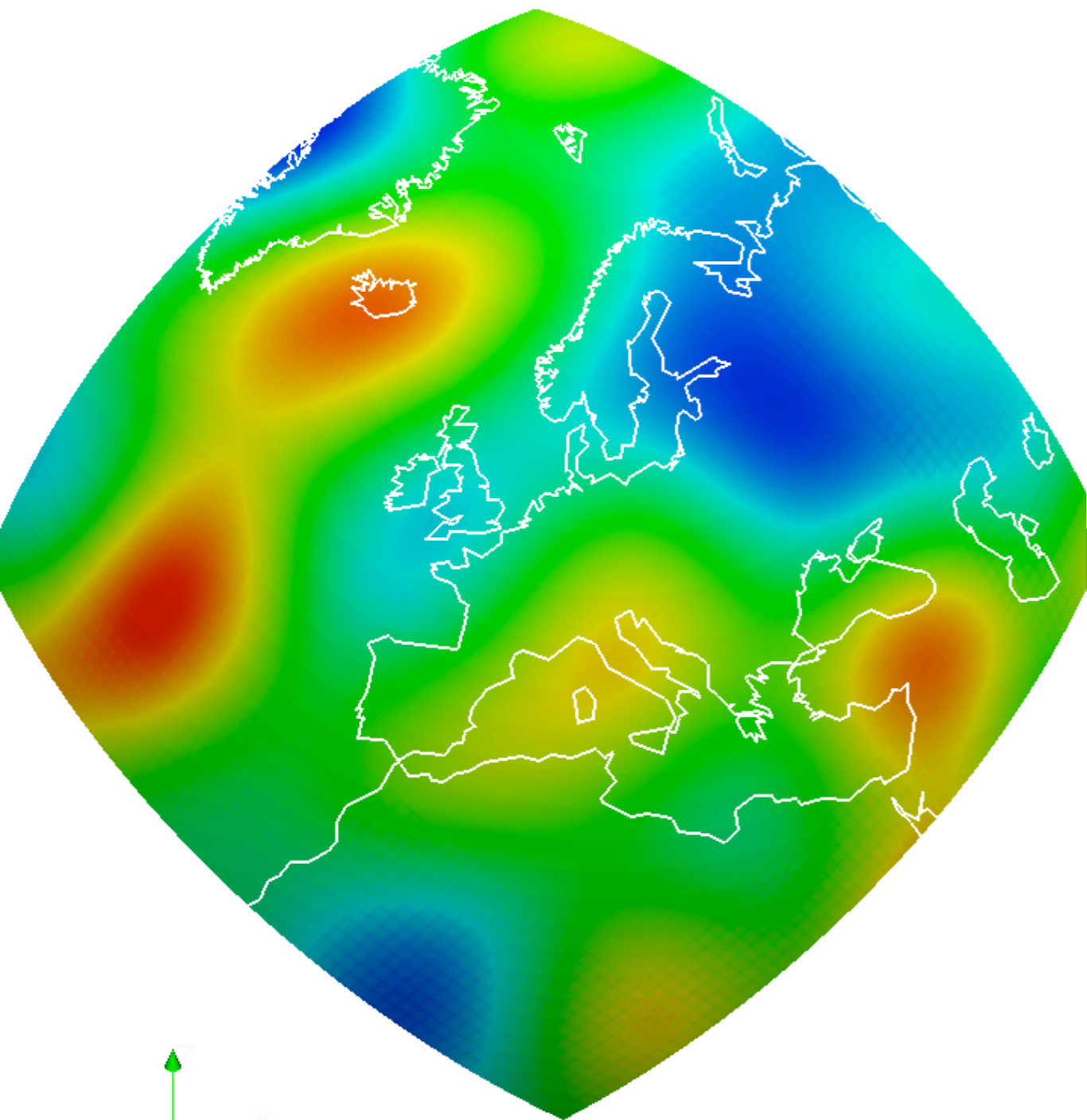
Depth 75 km



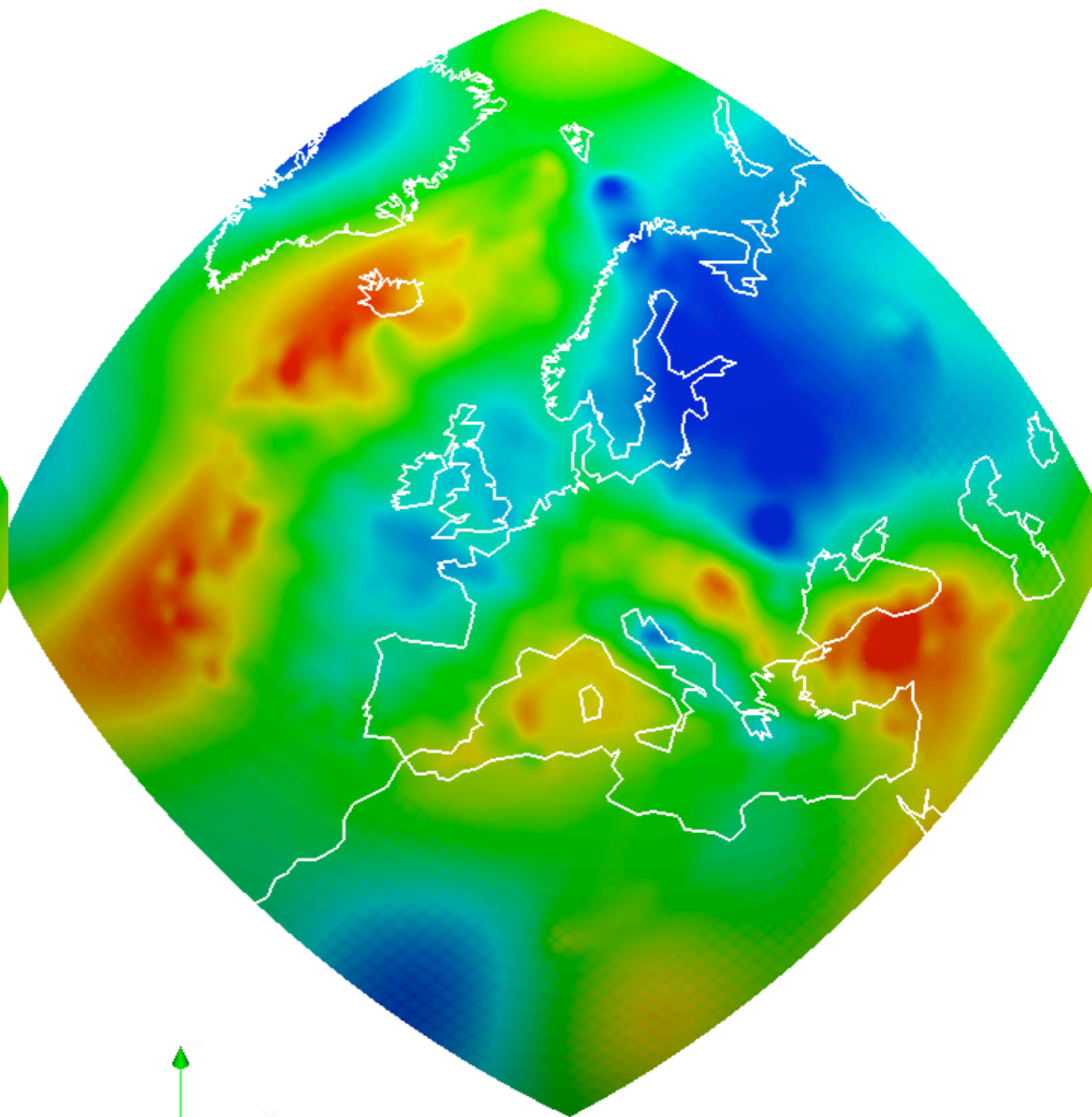
Depth 75 km



Depth 75 km

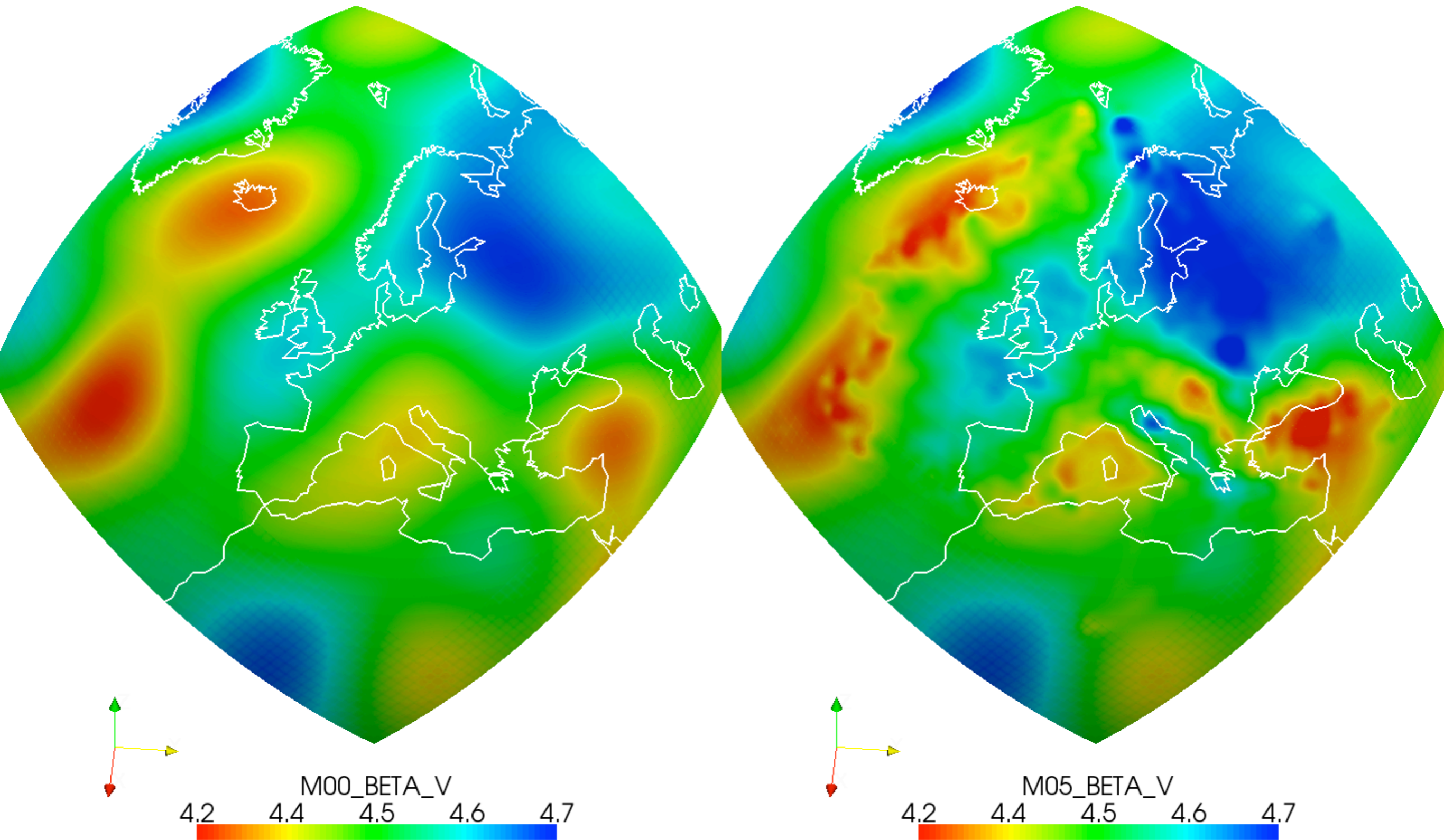


M00_BETA_V
4.2 4.4 4.5 4.6 4.7

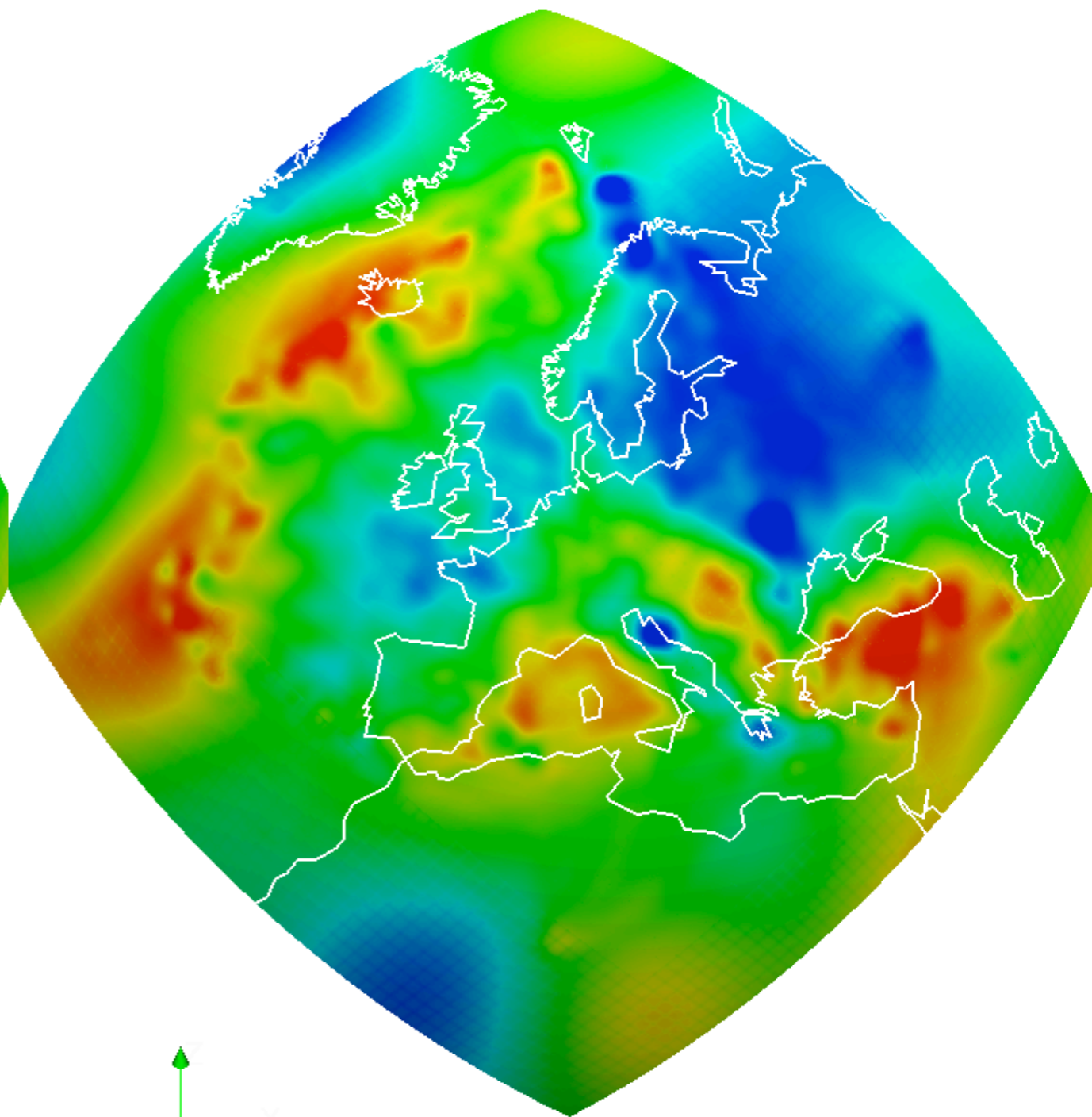
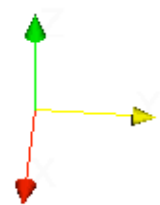
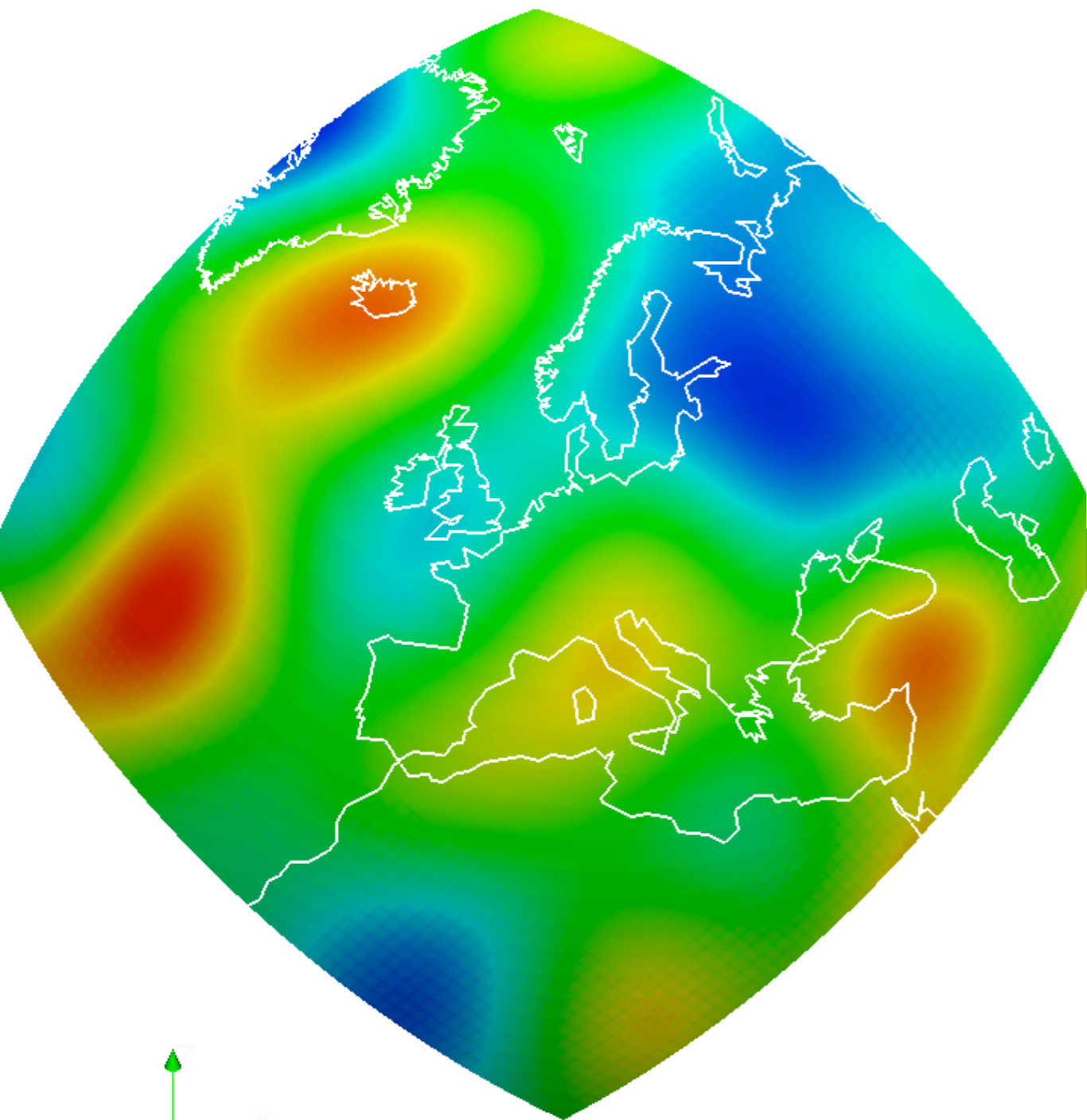


M04_BETA_V
4.2 4.4 4.5 4.6 4.7

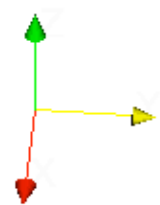
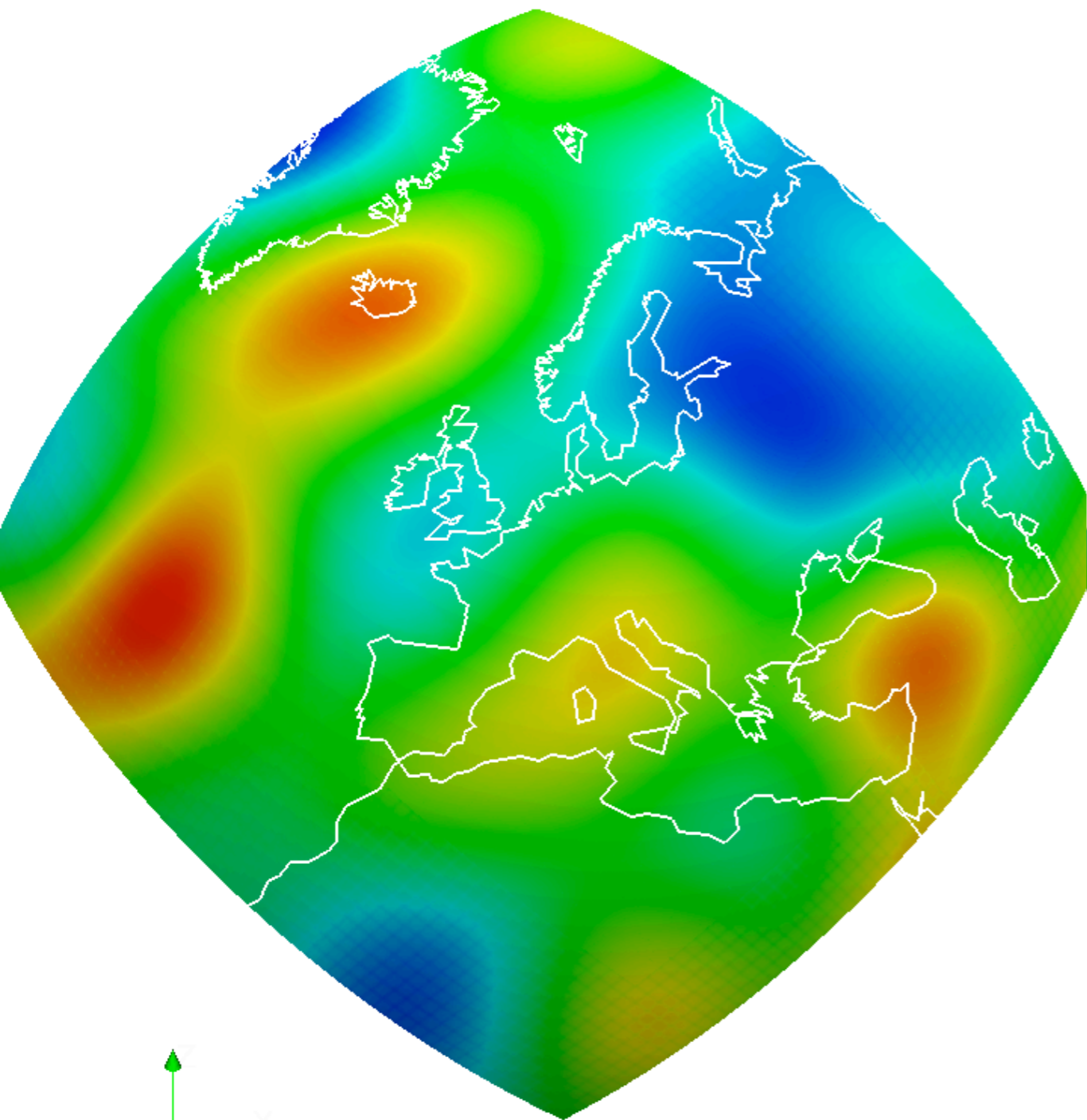
Depth 75 km



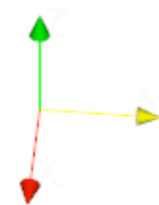
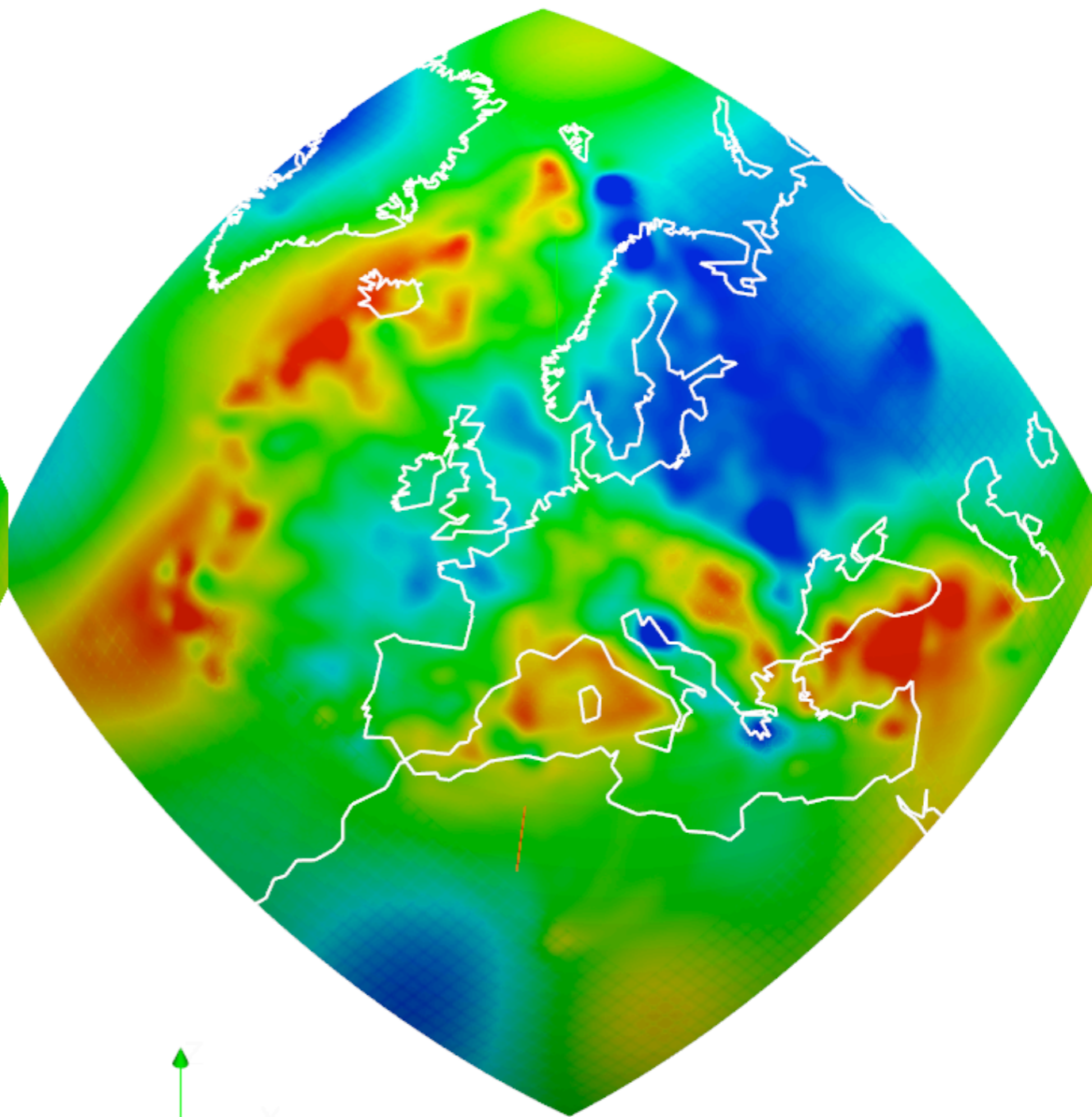
Depth 75 km



Depth 75 km

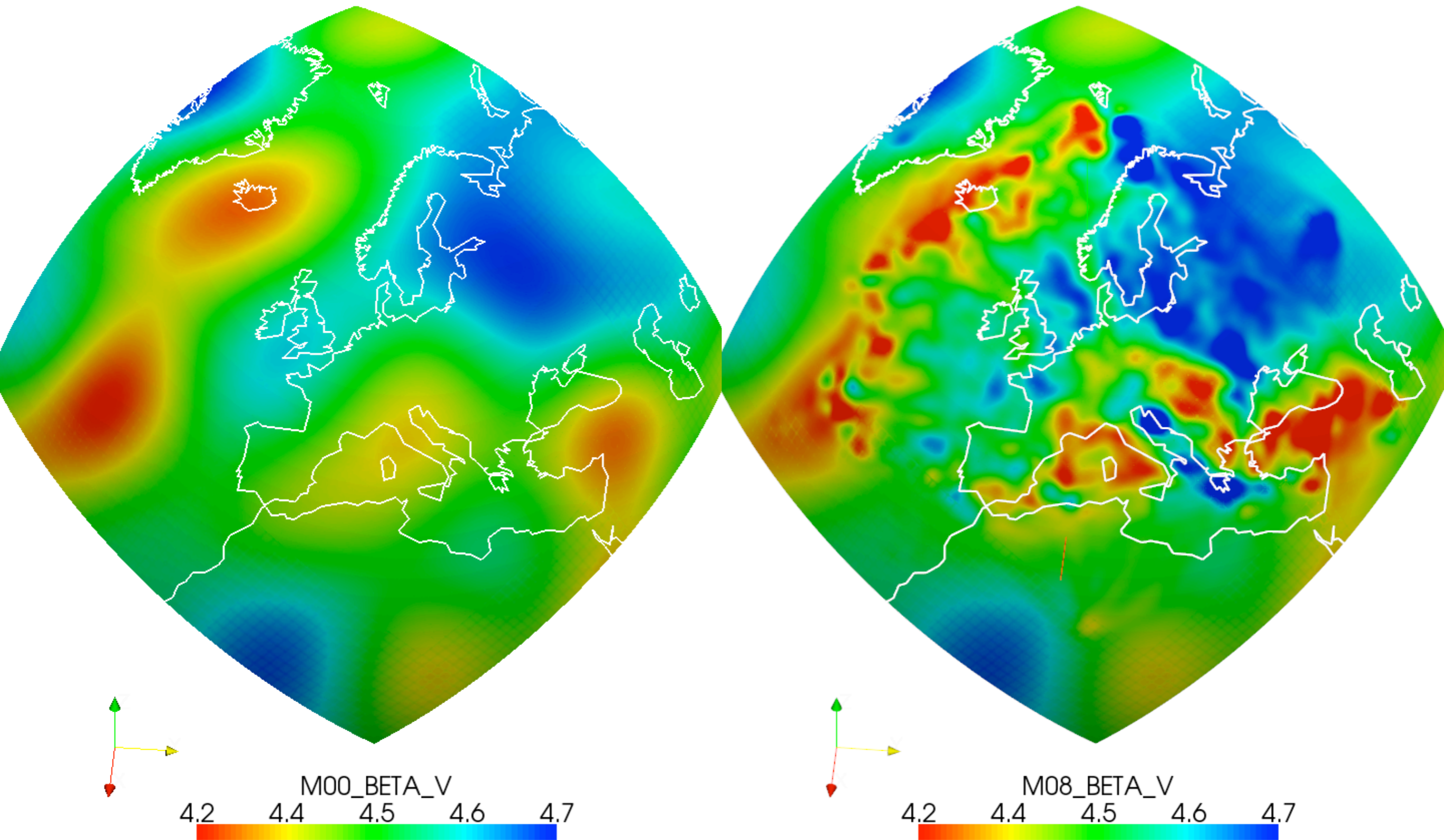


MOO_BETA_V
4.2 4.4 4.5 4.6 4.7

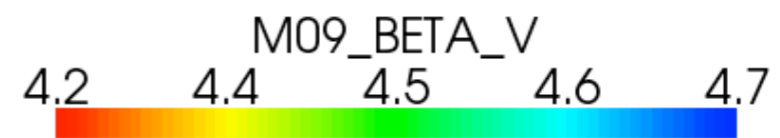
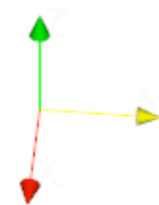
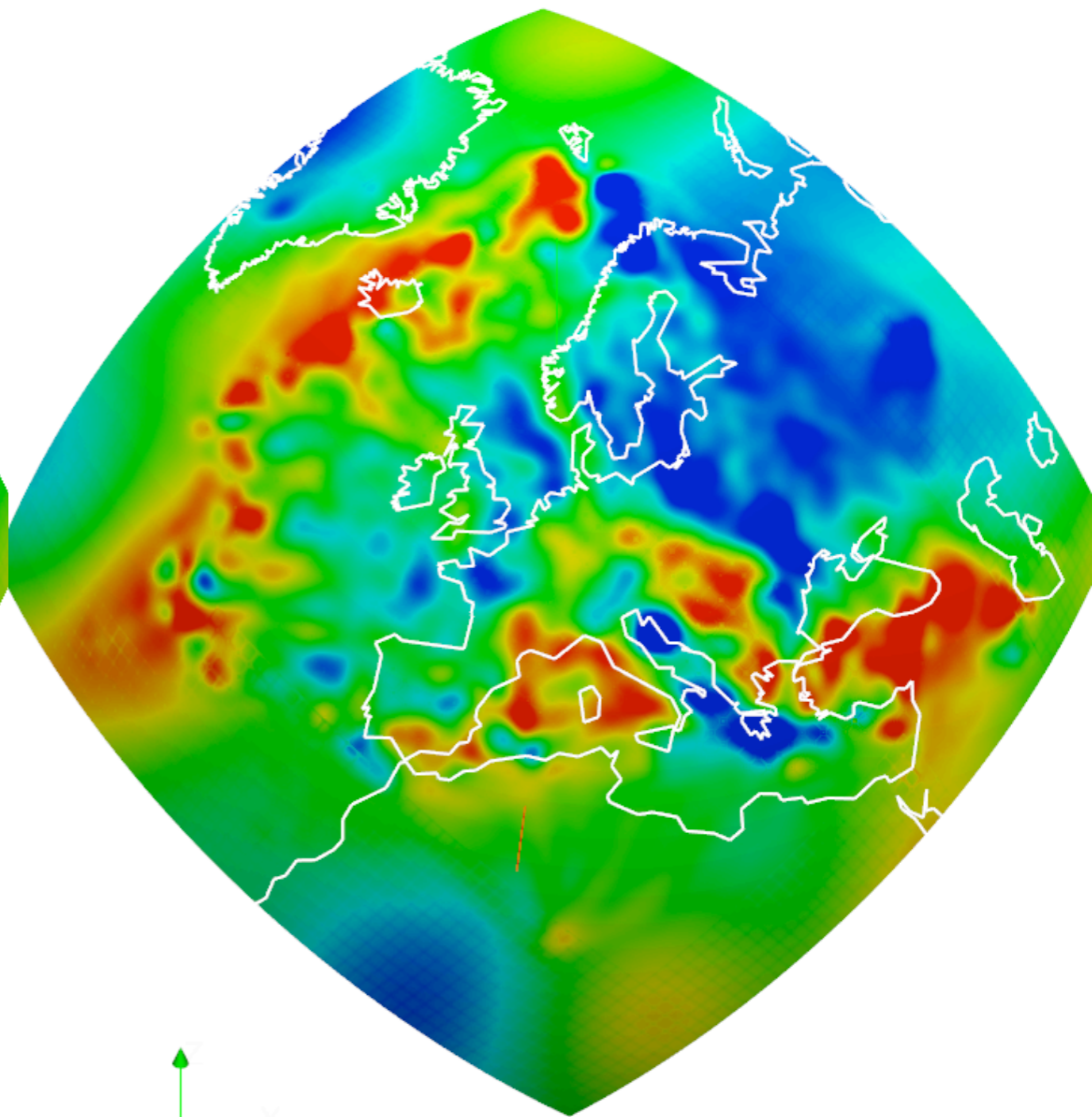
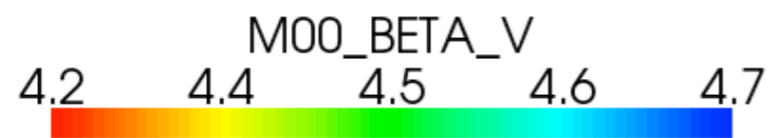
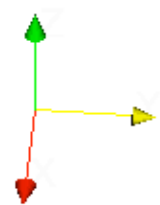
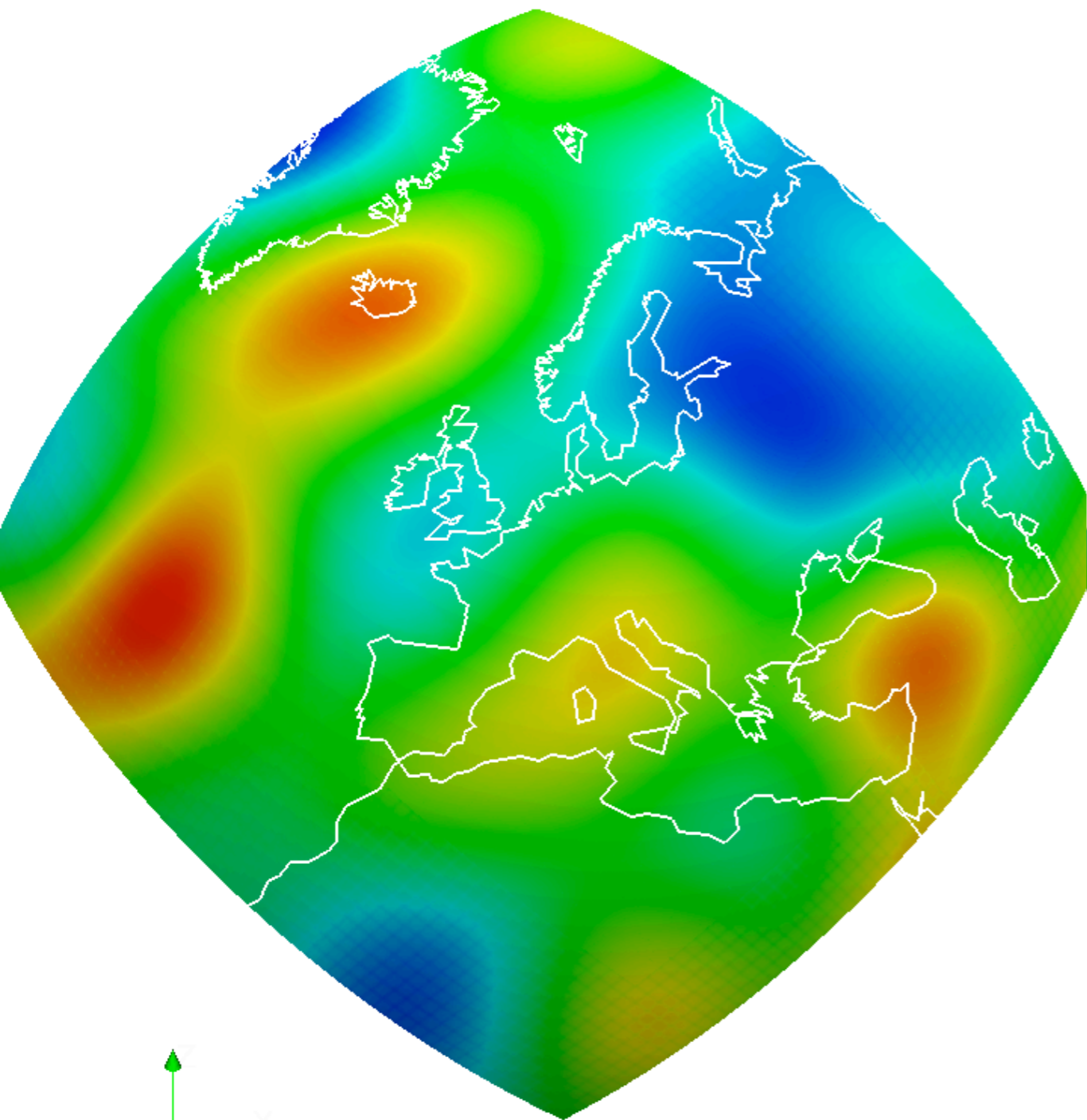


M07_BETA_V
4.2 4.4 4.5 4.6 4.7

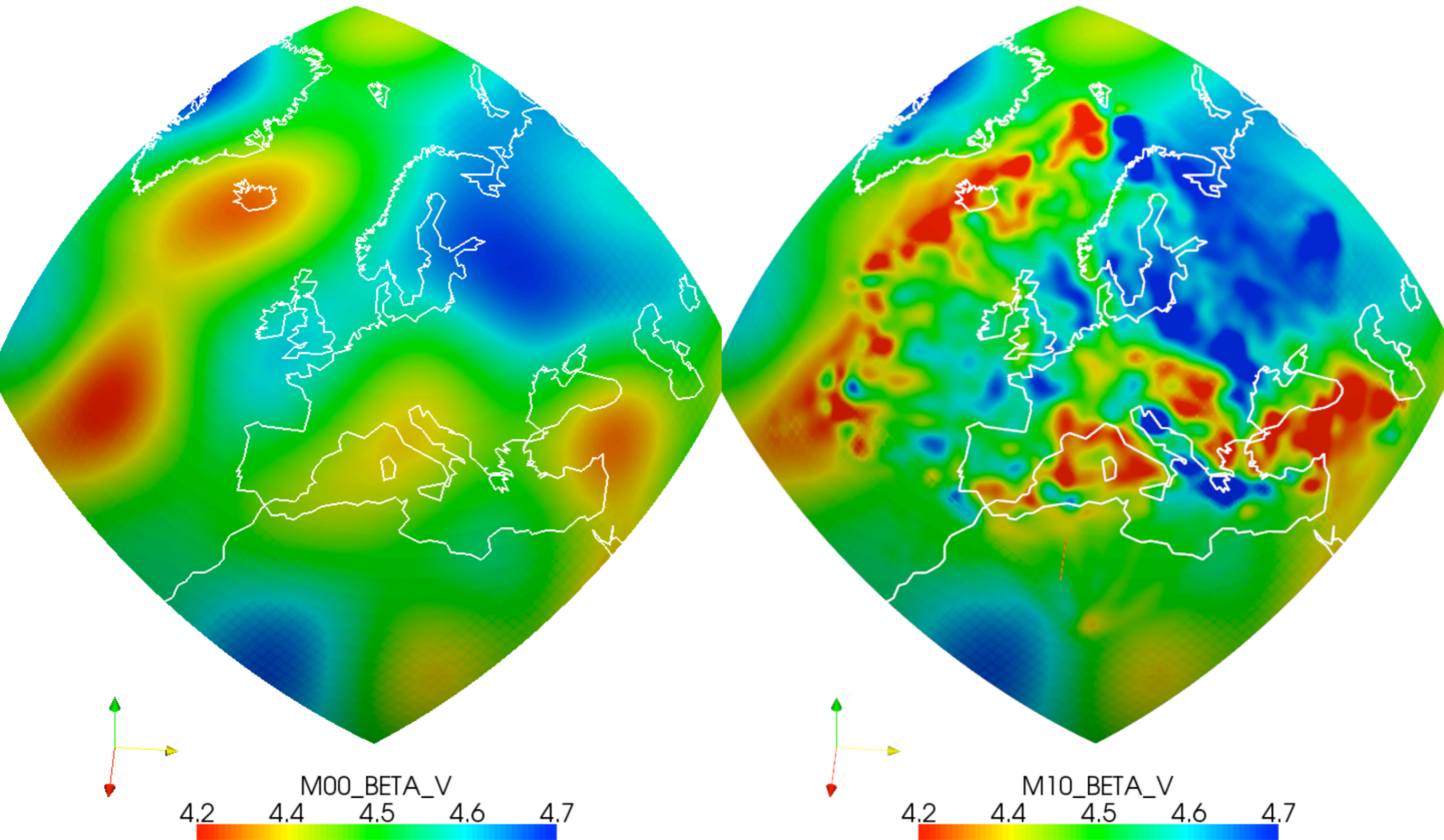
Depth 75 km



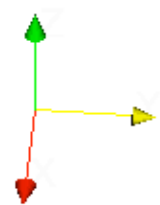
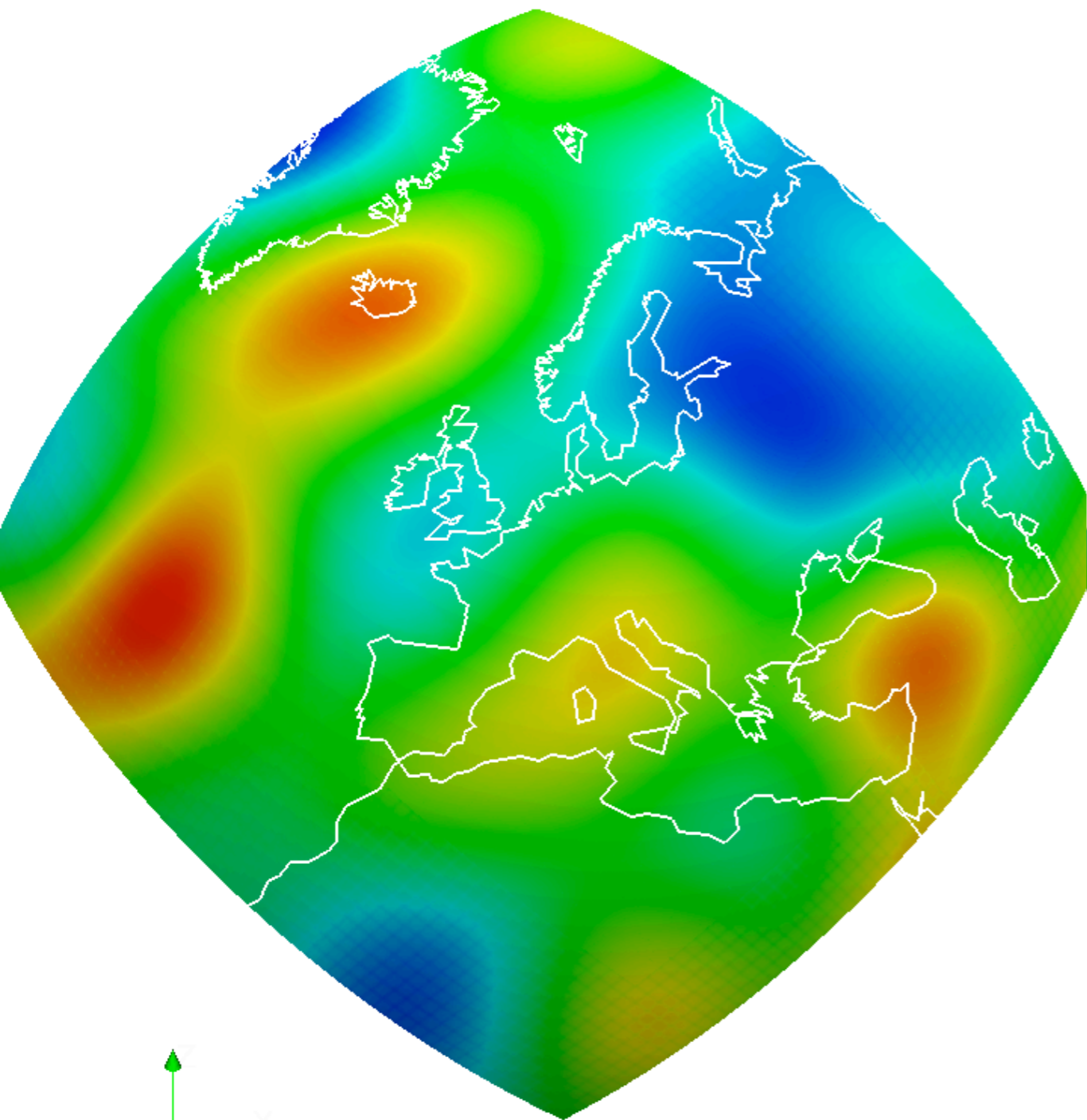
Depth 75 km



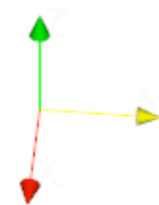
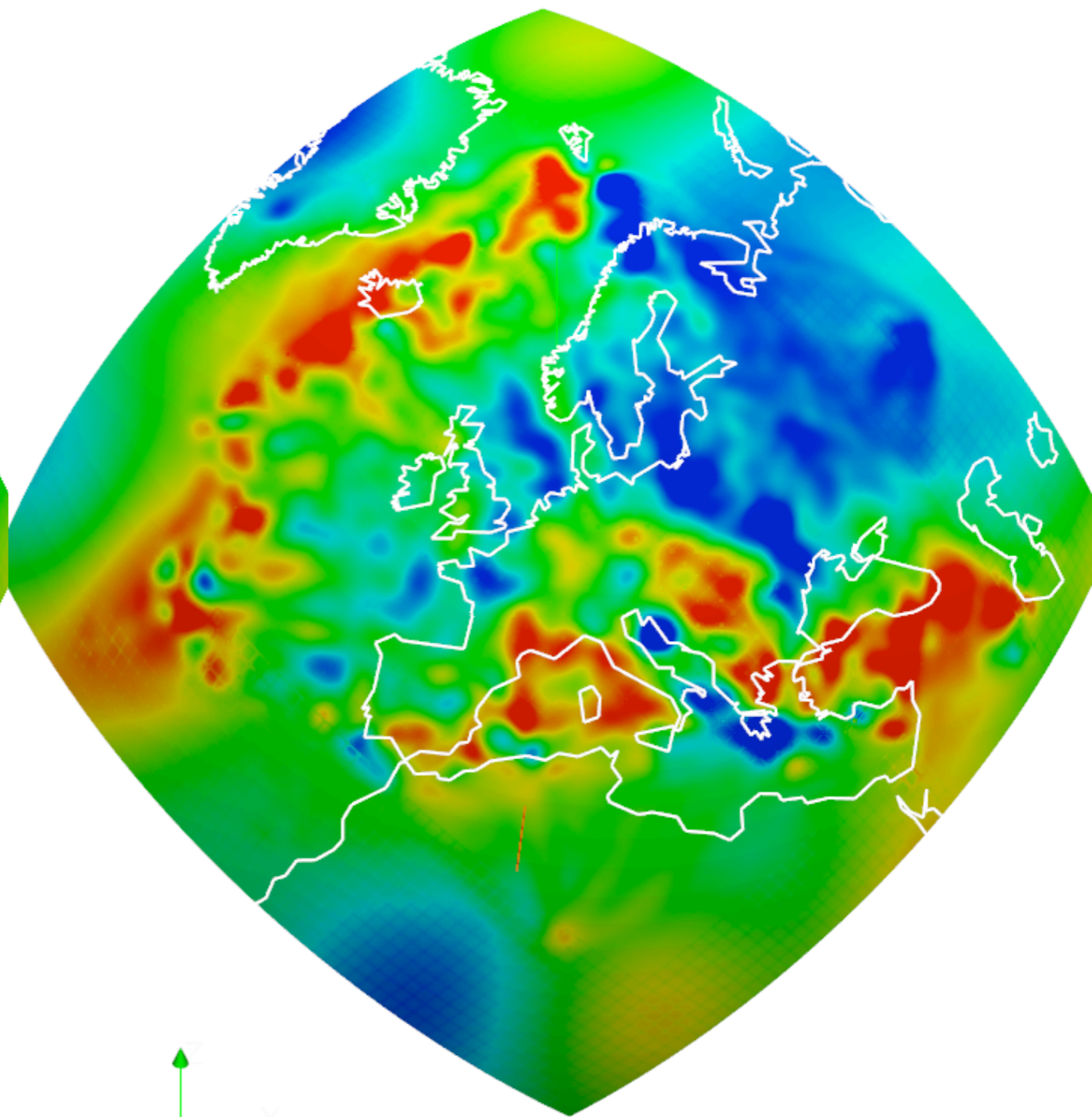
Depth 75 km



Depth 75 km

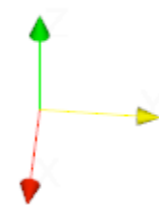
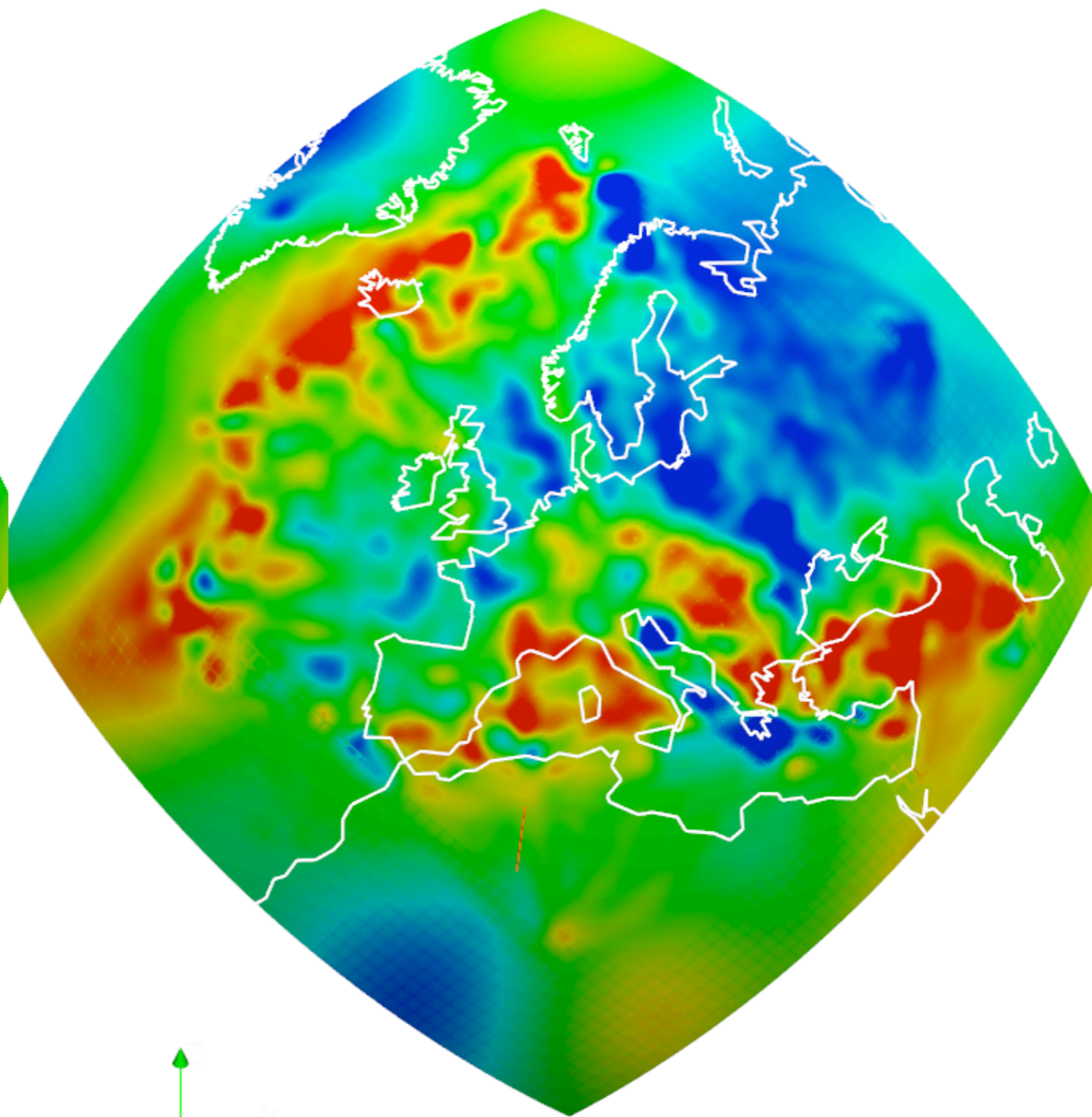
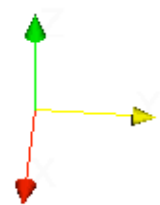
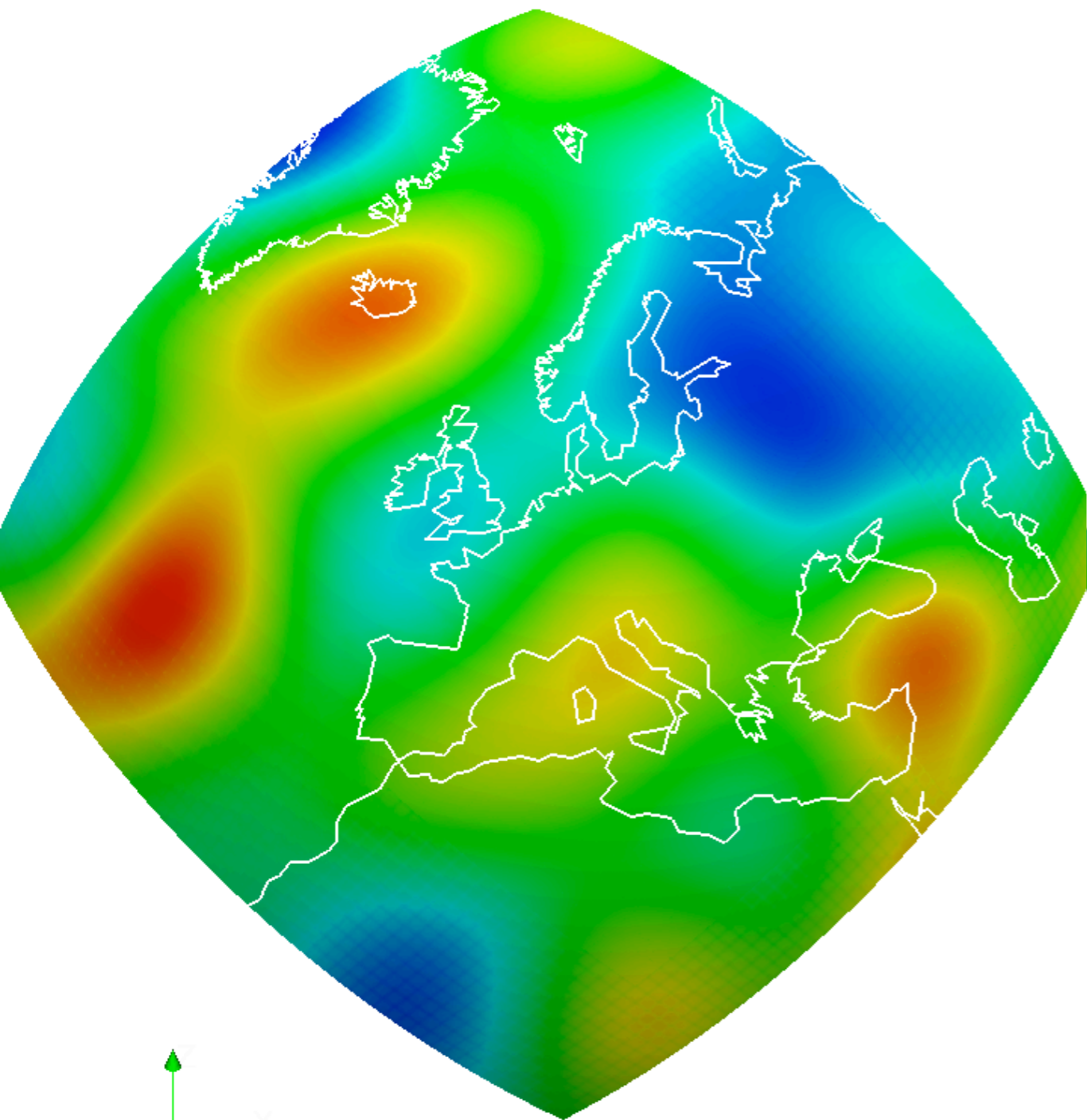


MOO_BETA_V
4.2 4.4 4.5 4.6 4.7

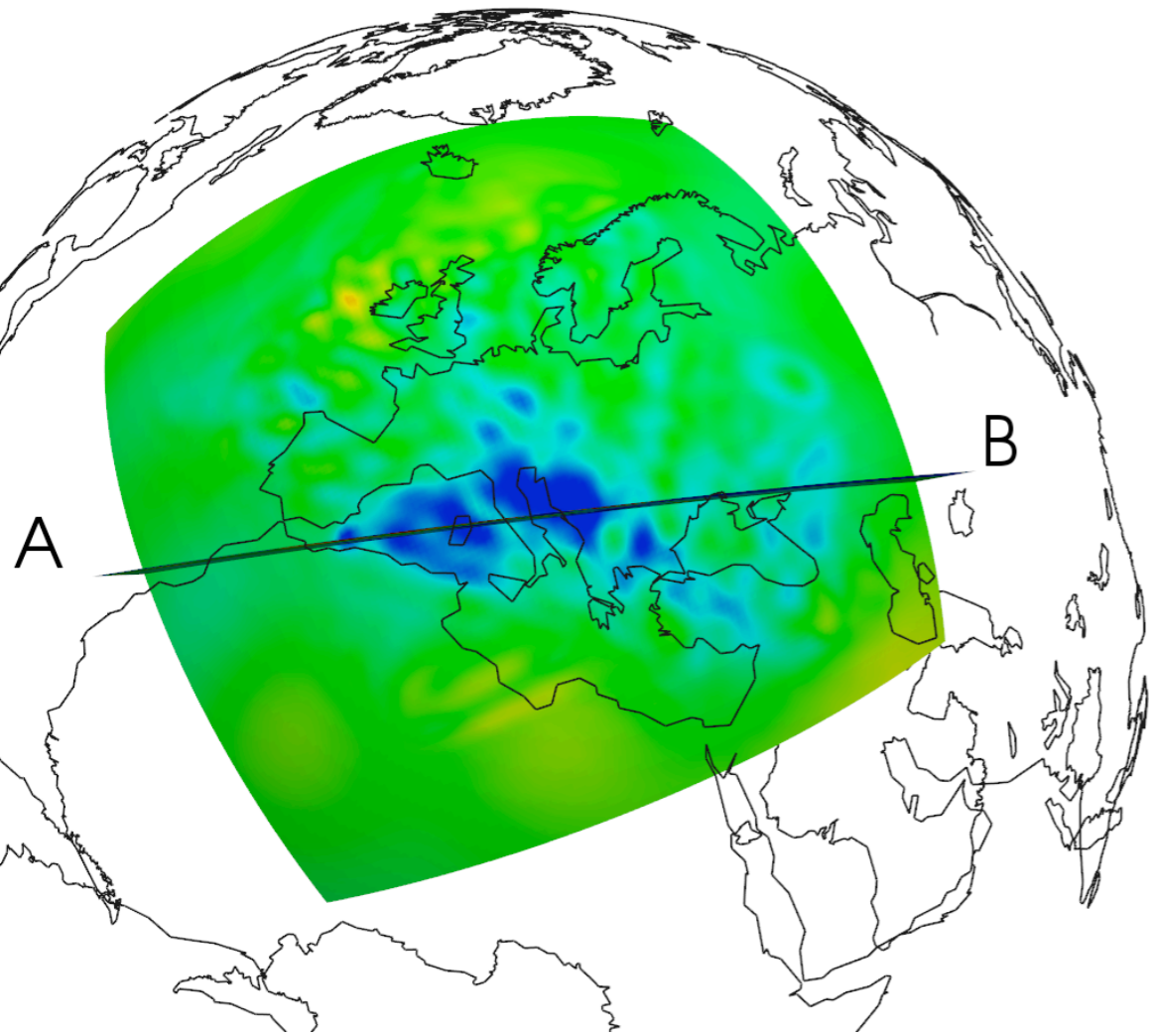


M11_BETA_V
4.2 4.4 4.5 4.6 4.7

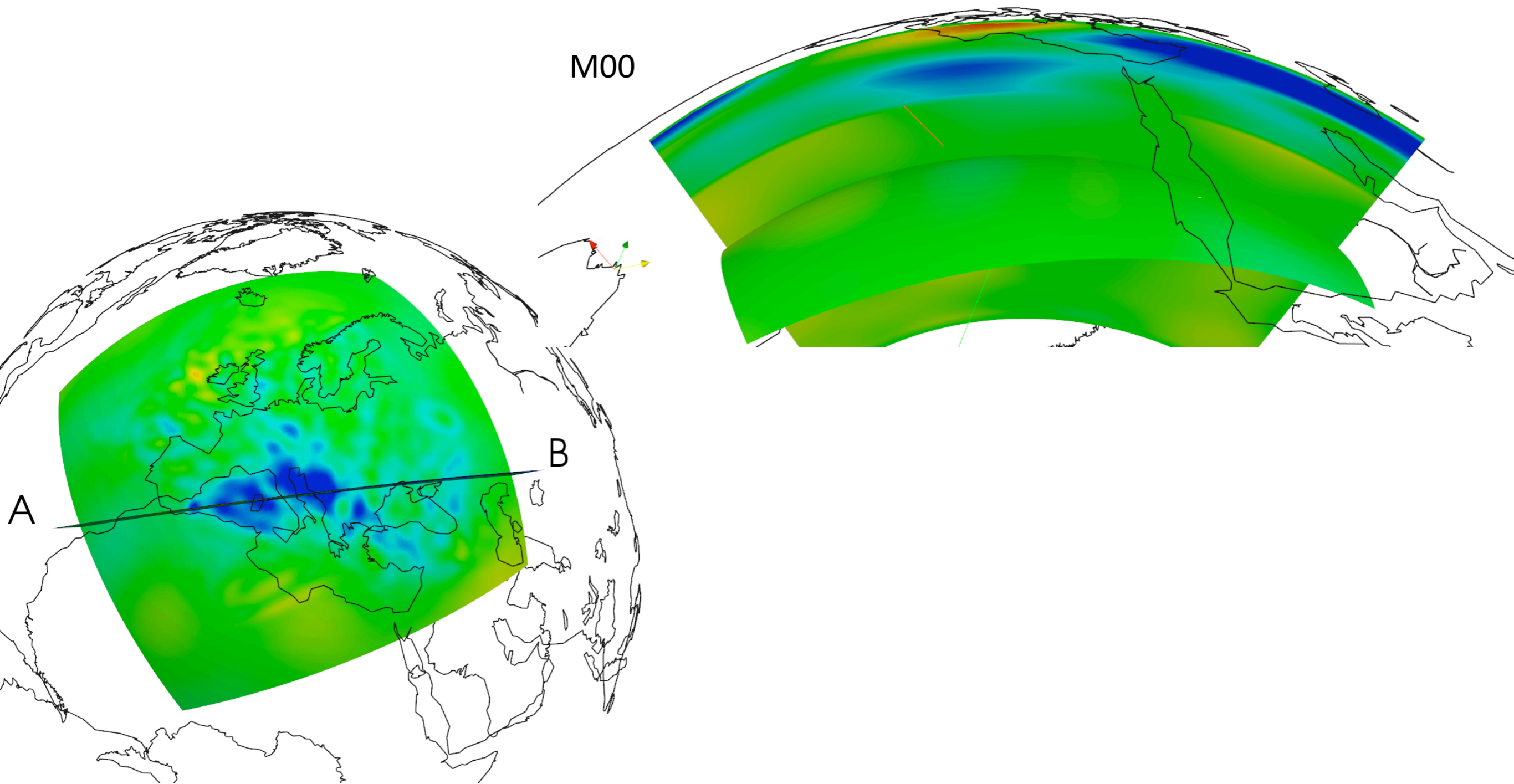
Depth 75 km



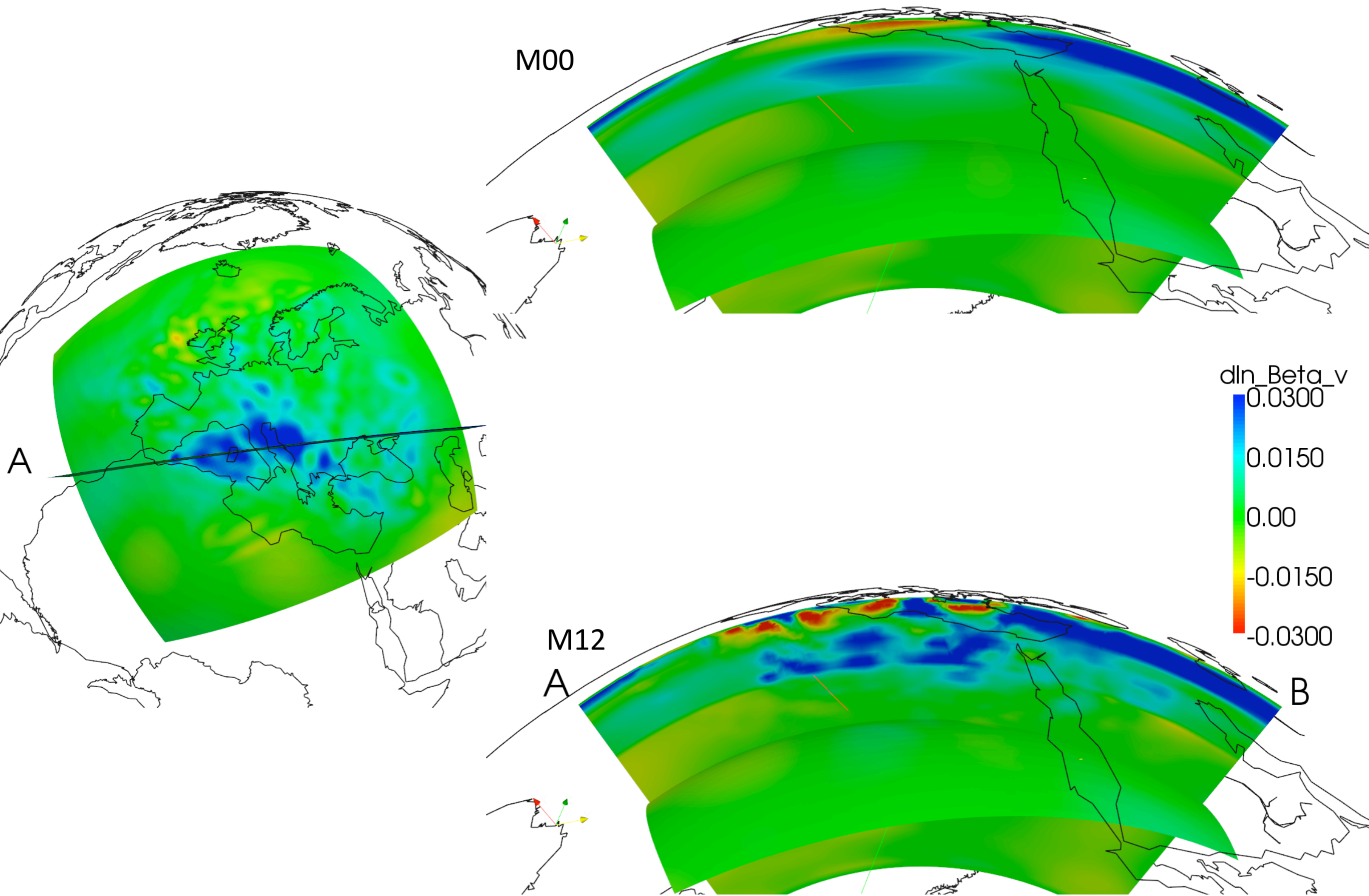
Carpathian-Vrancea Arc



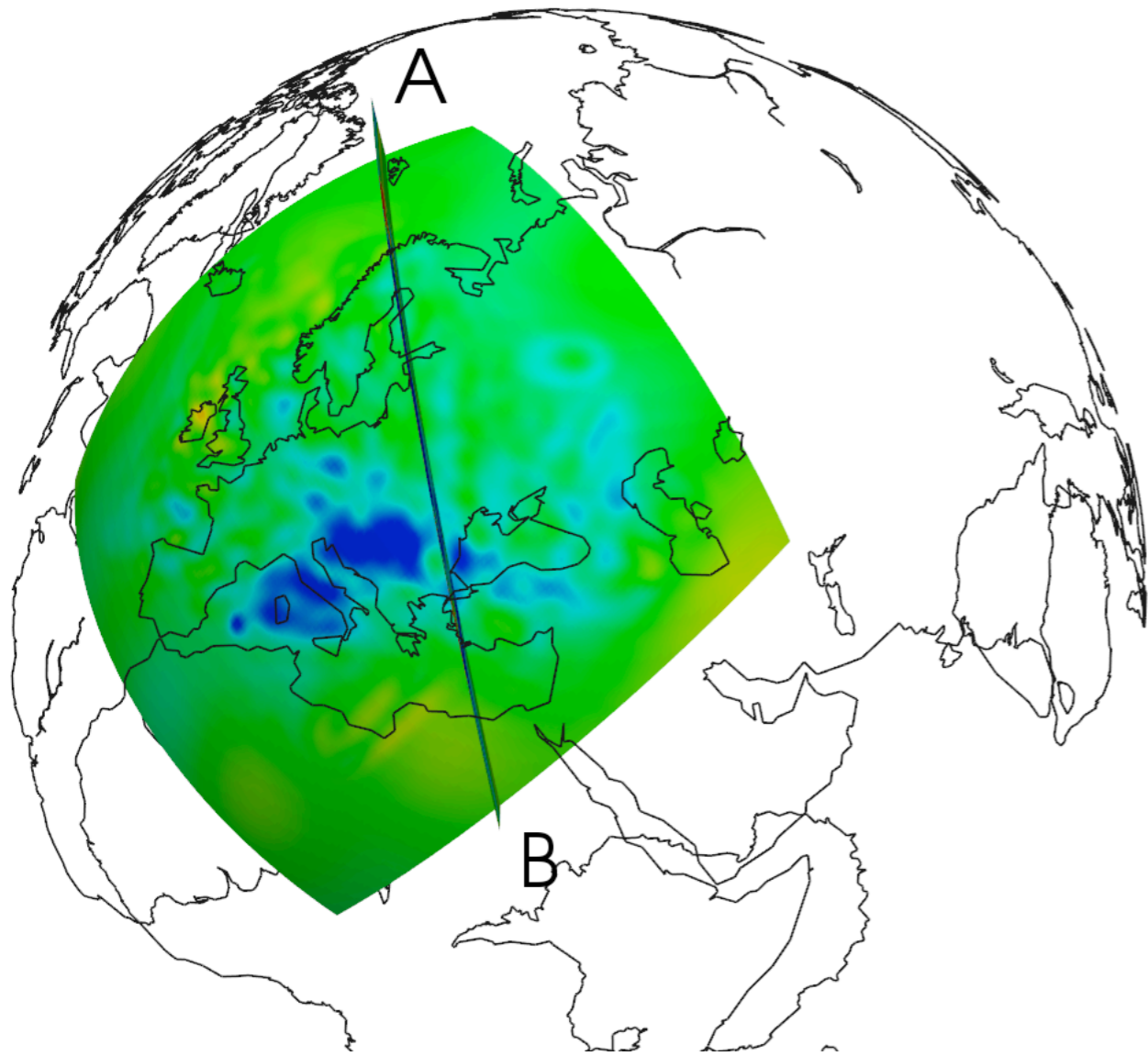
Carpathian-Vrancea Arc



Carpathian-Vrancea Arc

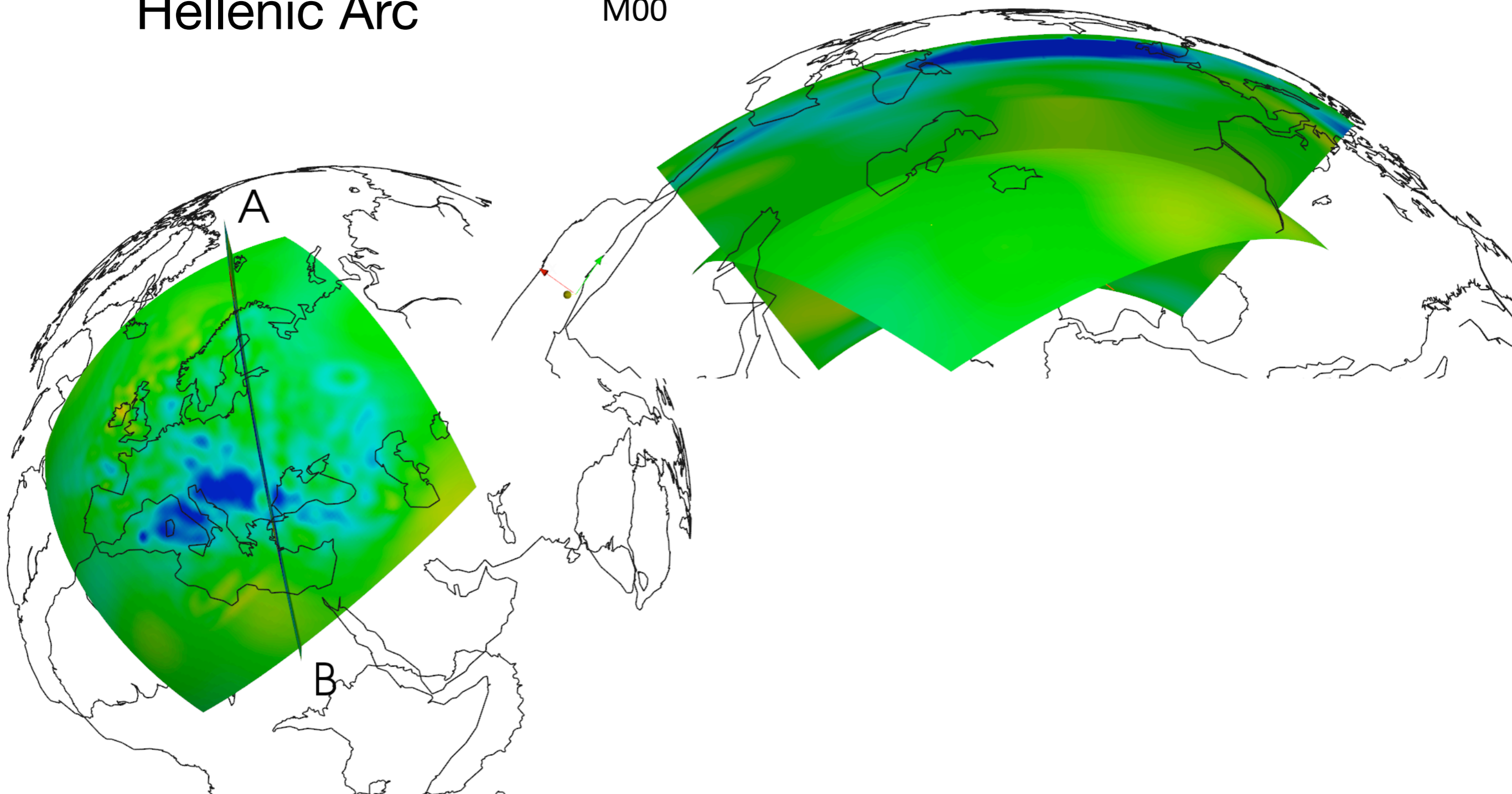


Hellenic Arc



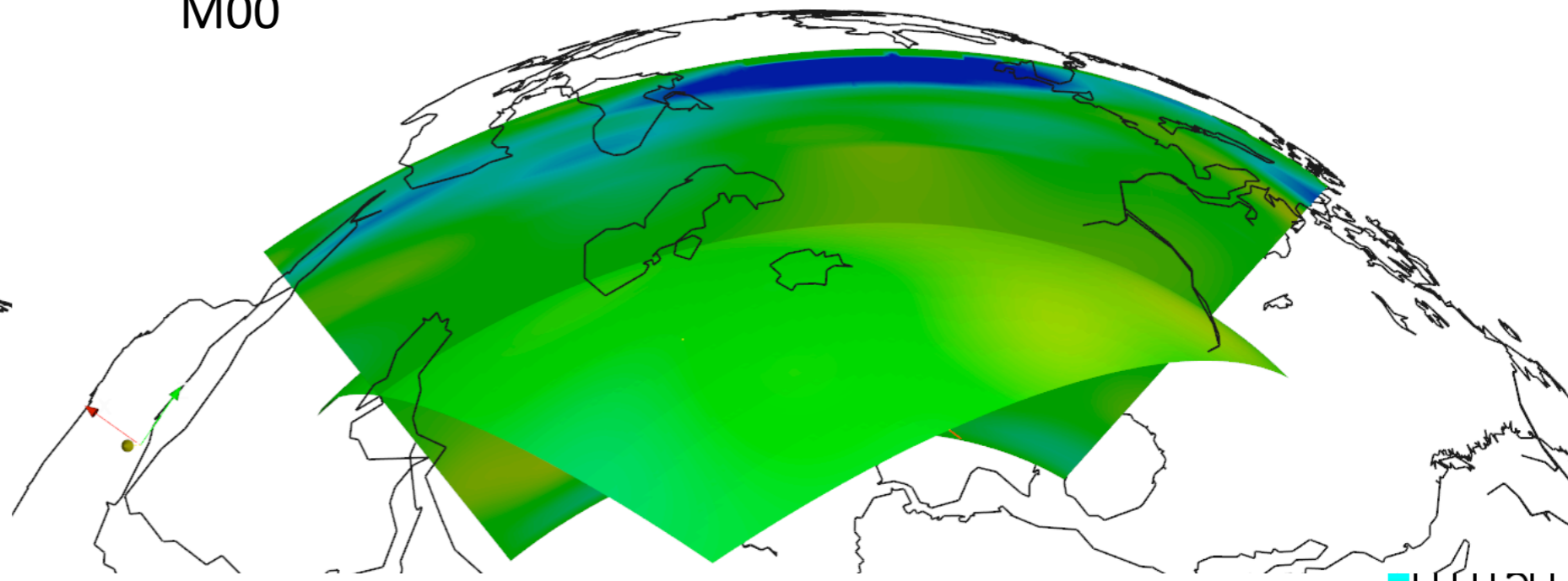
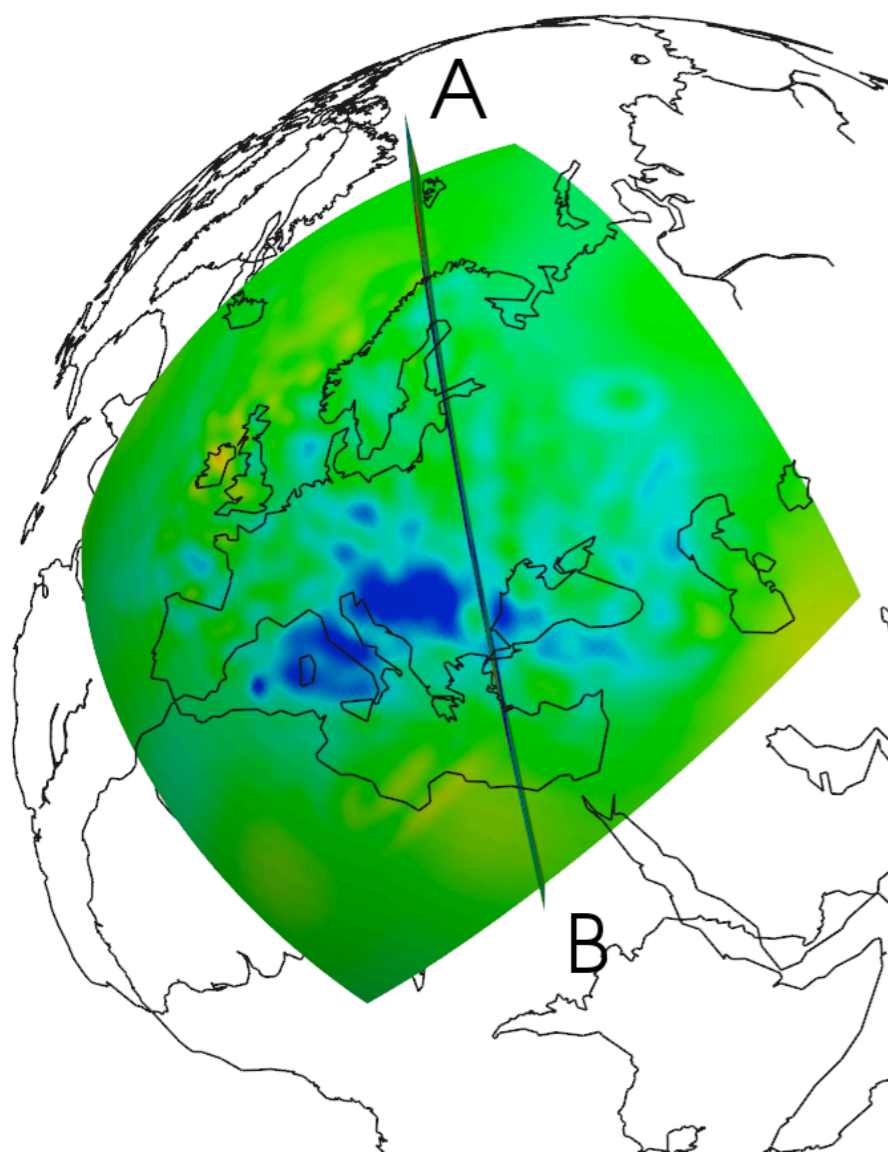
Hellenic Arc

M00

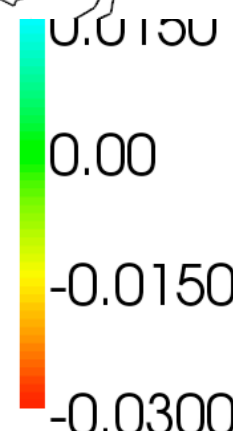
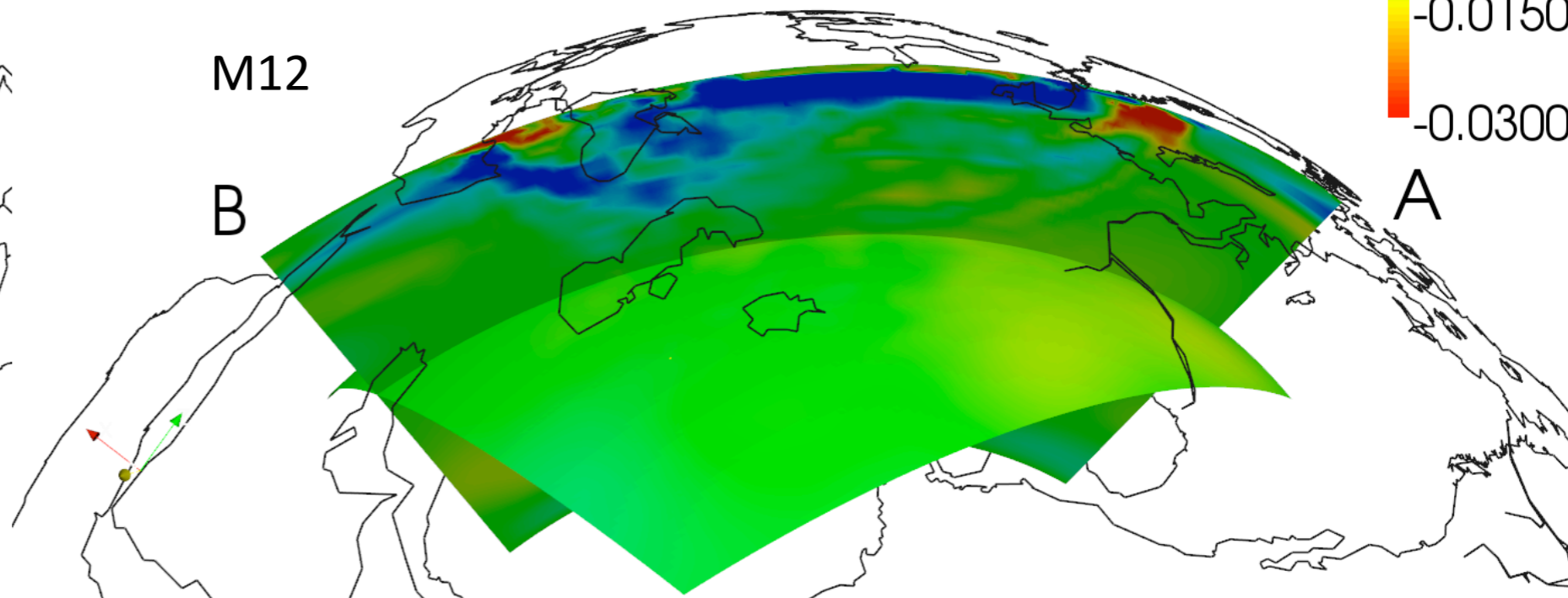


Hellenic Arc

M00



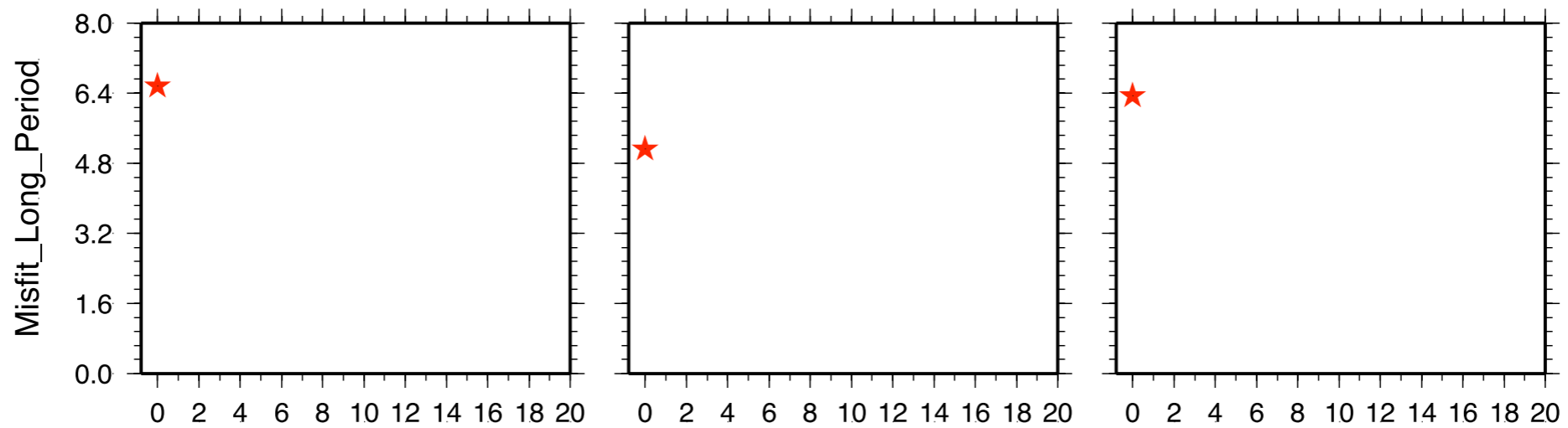
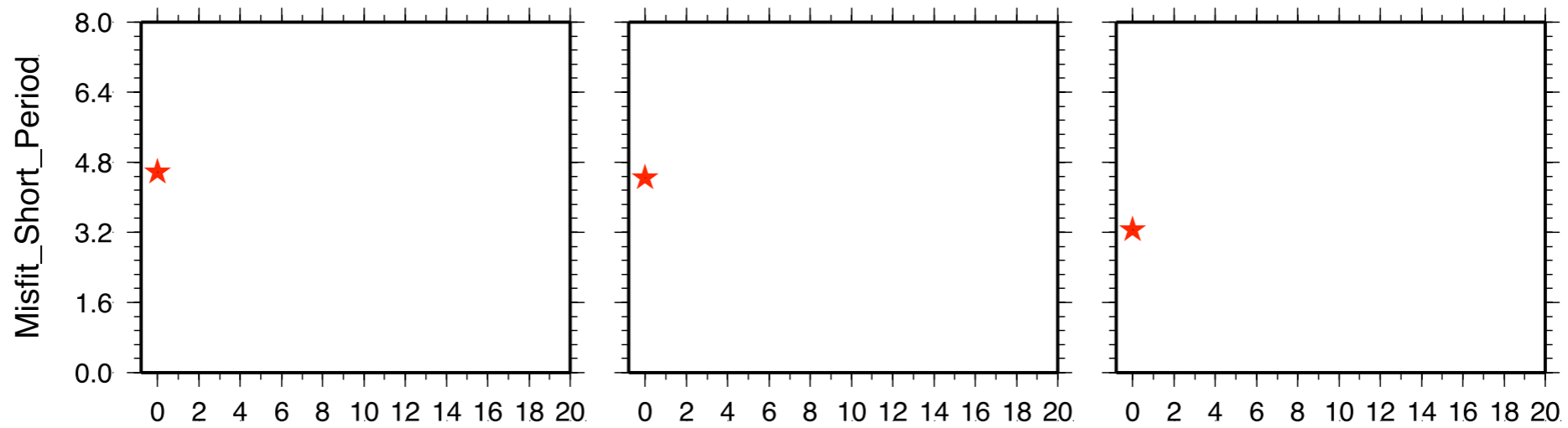
M12



Vertical

Radial

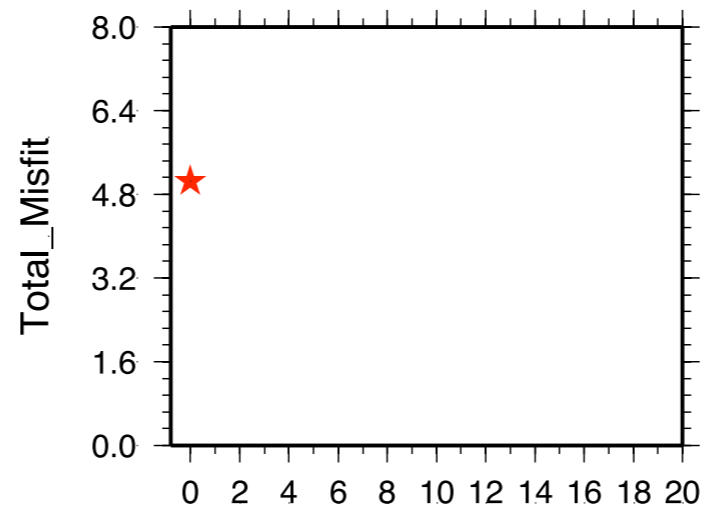
Transverse




Iteration.

Iteration.

Iteration.



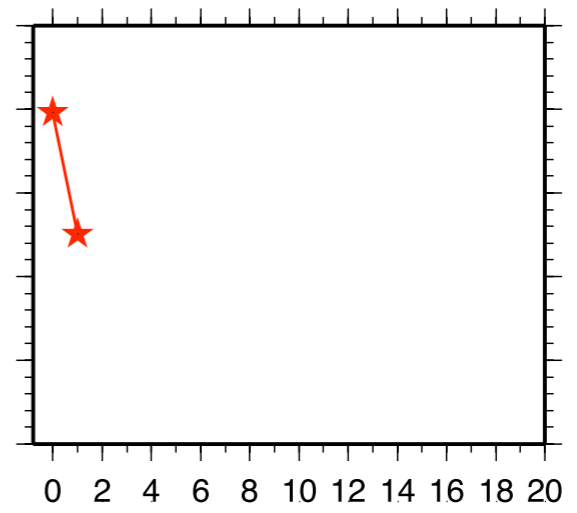
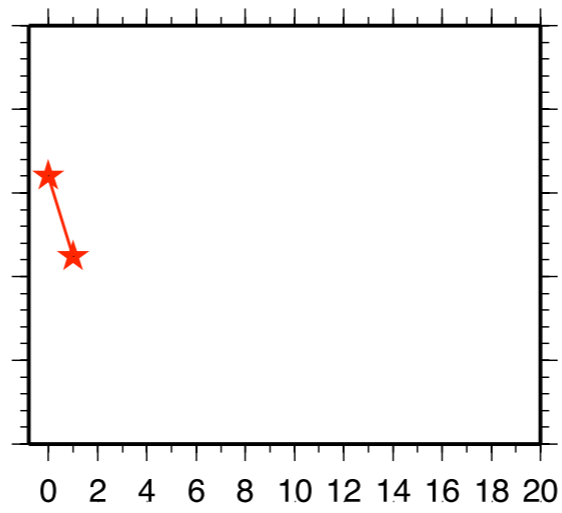
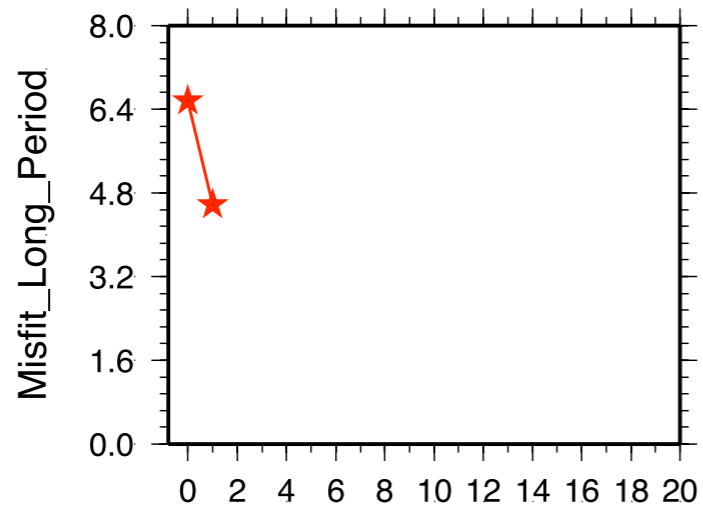
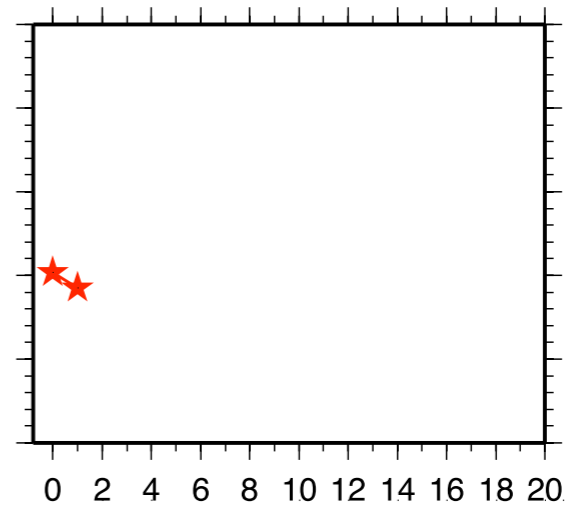
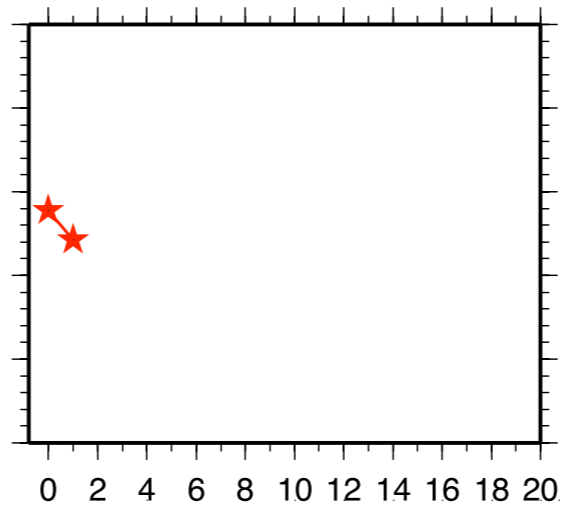
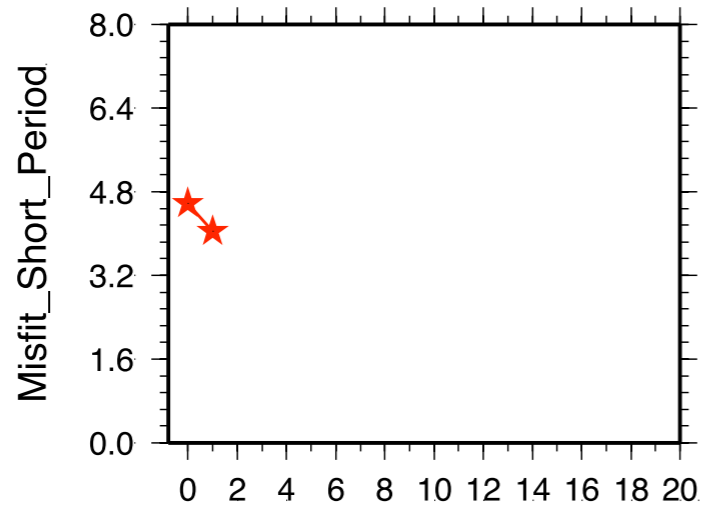
Iteration.

 T015_050 & T050_150

Vertical

Radial

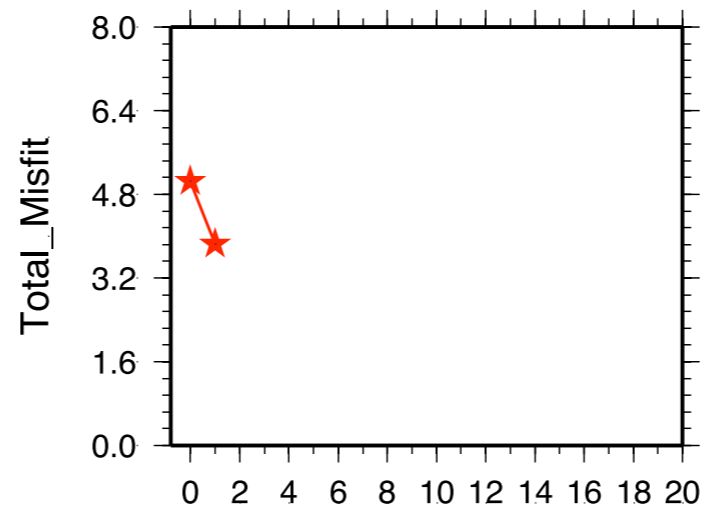
Transverse



Iteration.

Iteration.

Iteration.



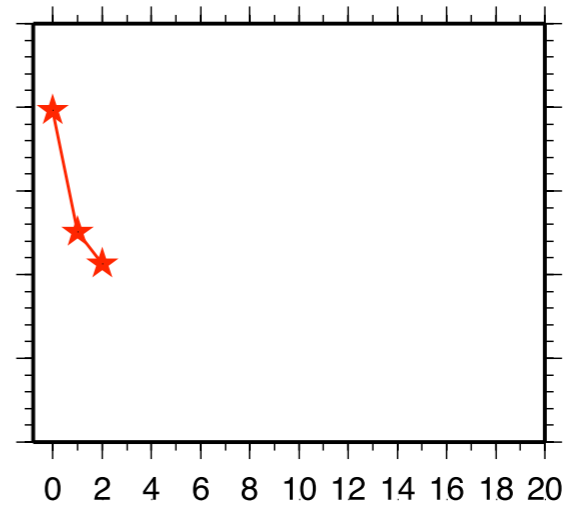
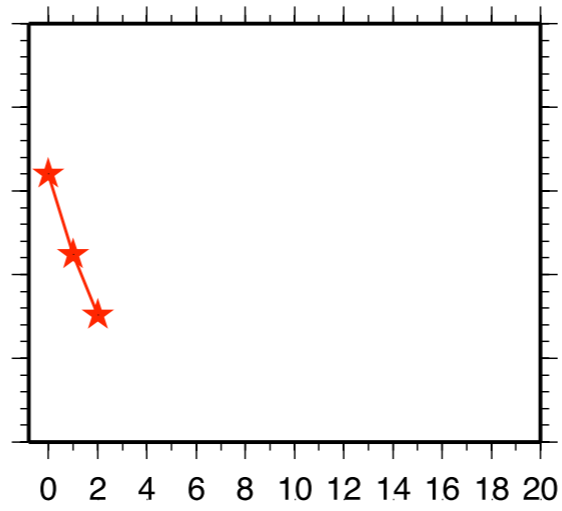
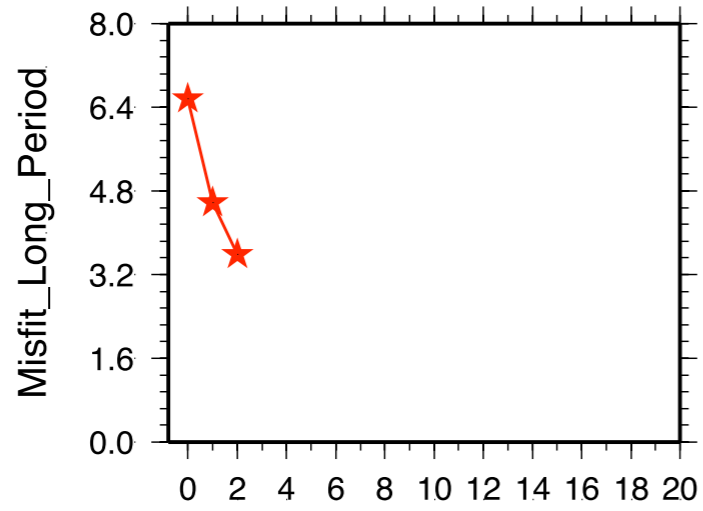
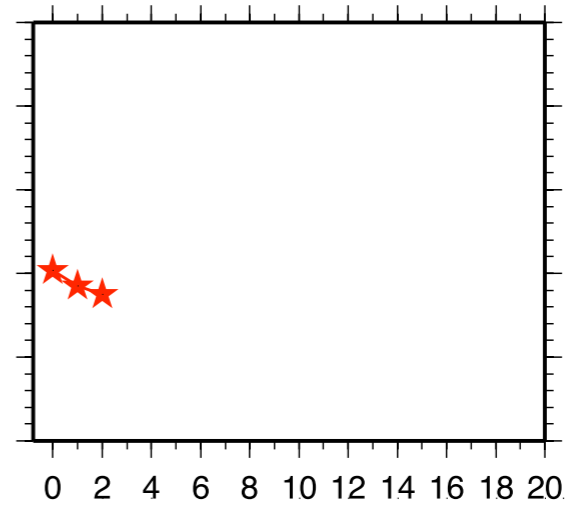
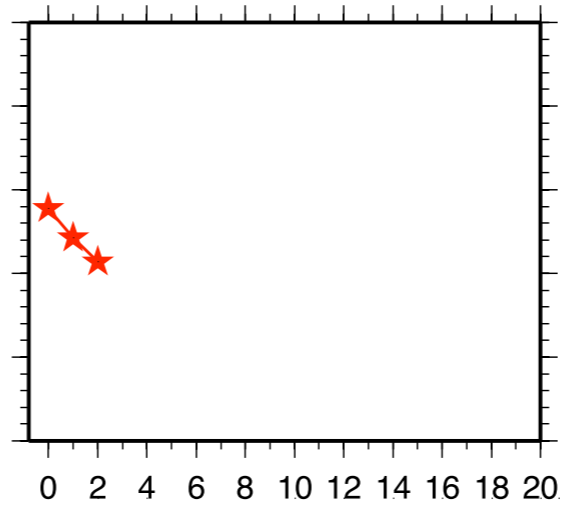
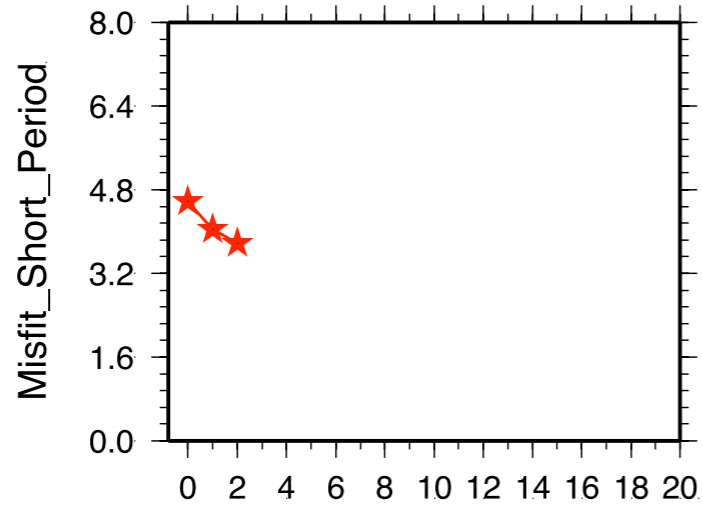
Iteration.

★ T015_050 & T050_150

Vertical

Radial

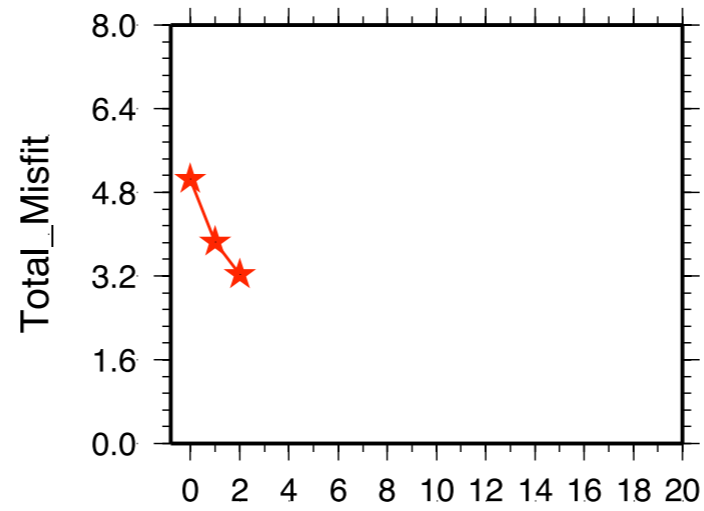
Transverse



Iteration.

Iteration.

Iteration.



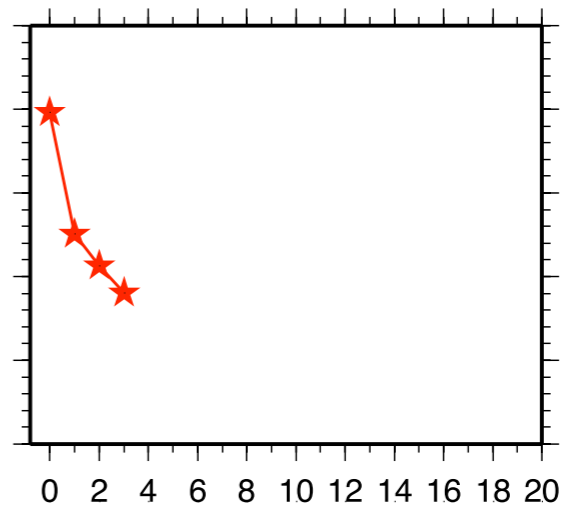
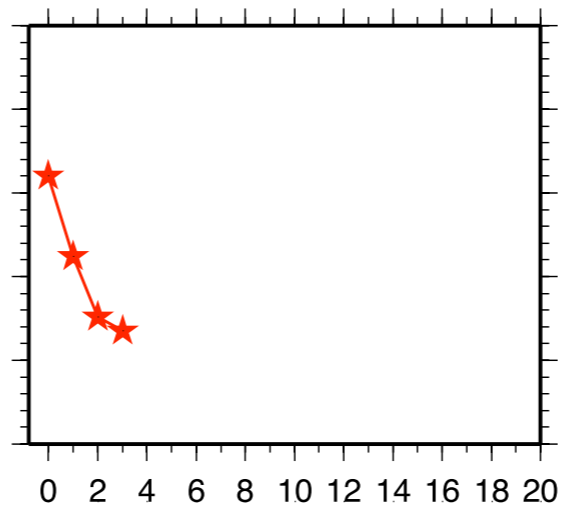
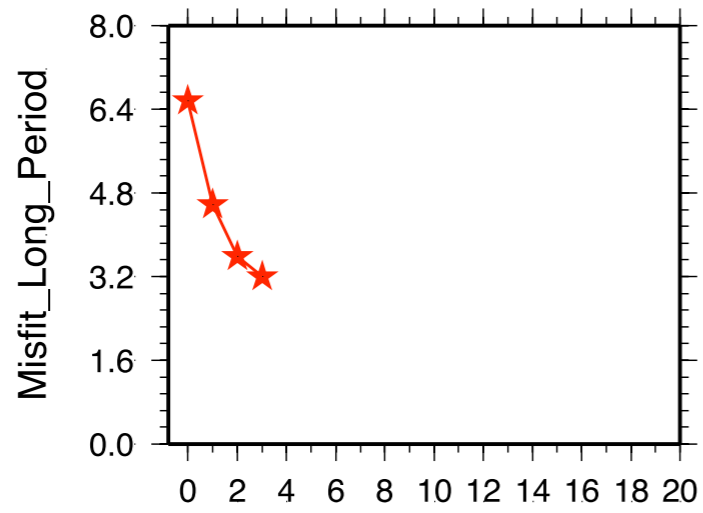
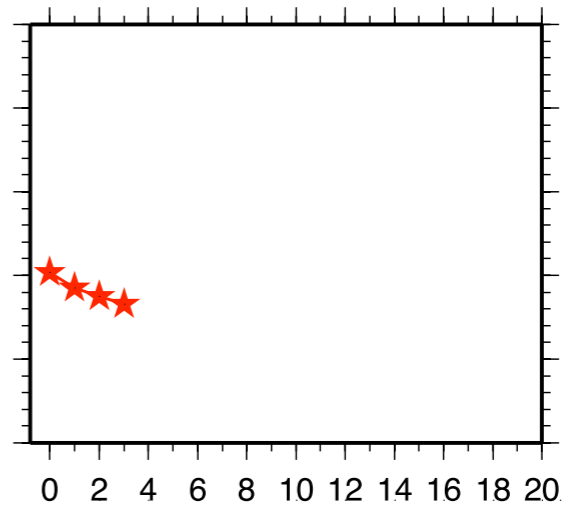
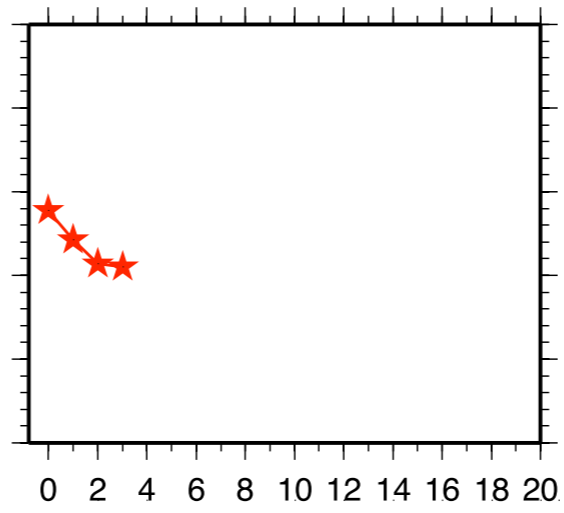
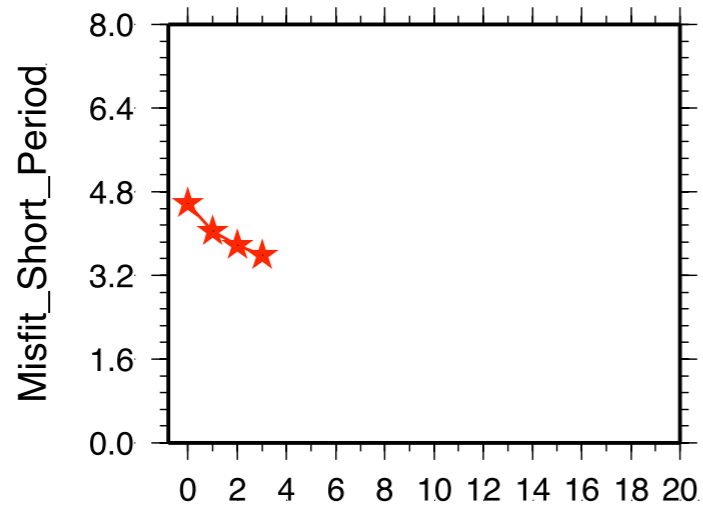
Iteration.

★ T015_050 & T050_150

Vertical

Radial

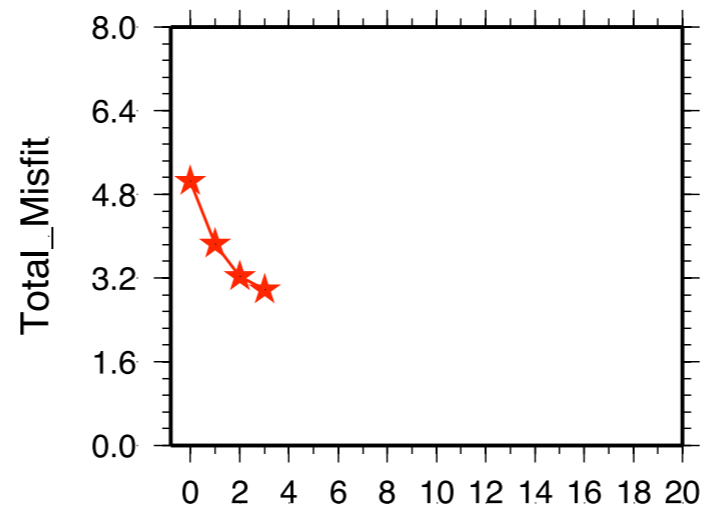
Transverse



Iteration.

Iteration.

Iteration.



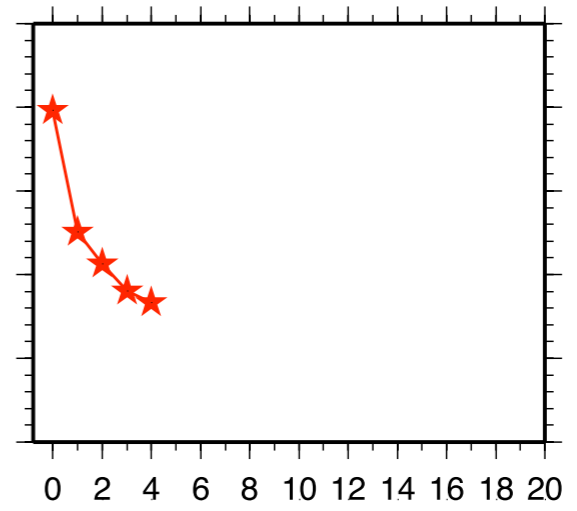
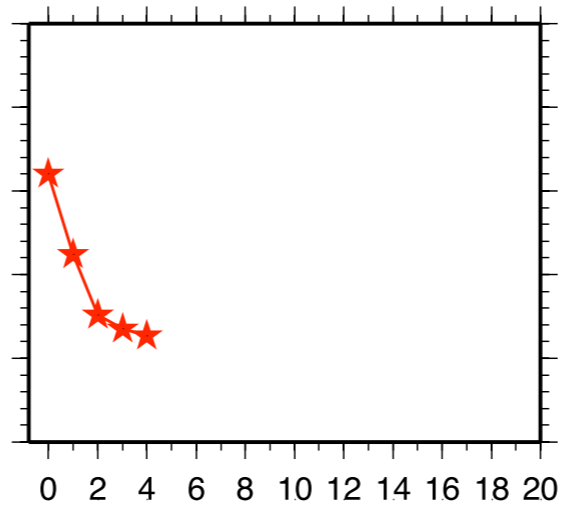
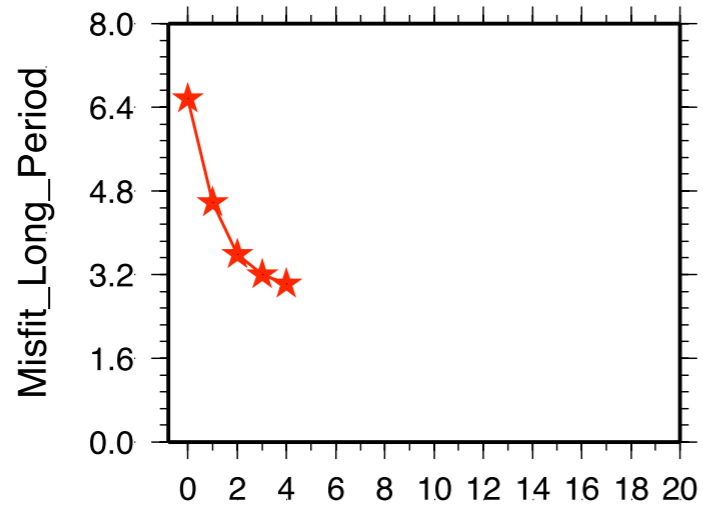
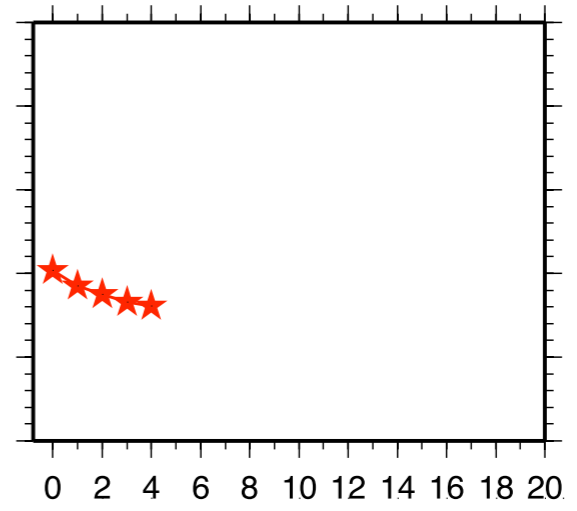
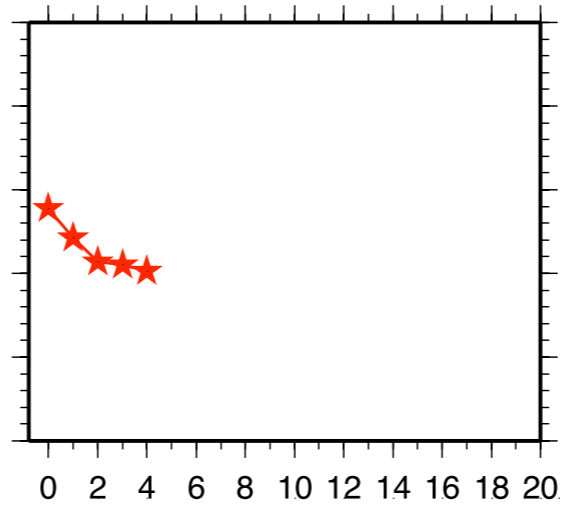
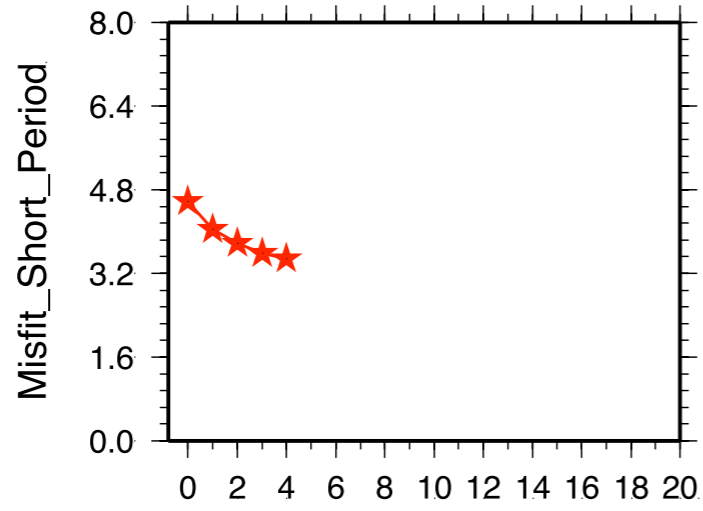
Iteration.

★ T015_050 & T050_150

Vertical

Radial

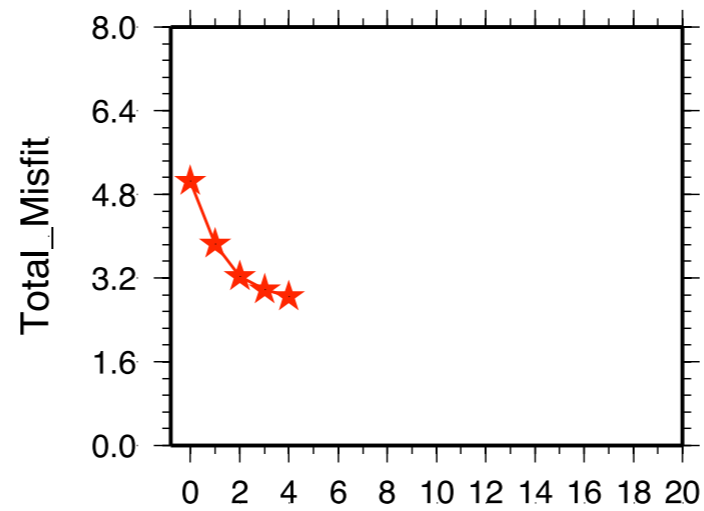
Transverse



Iteration.

Iteration.

Iteration.



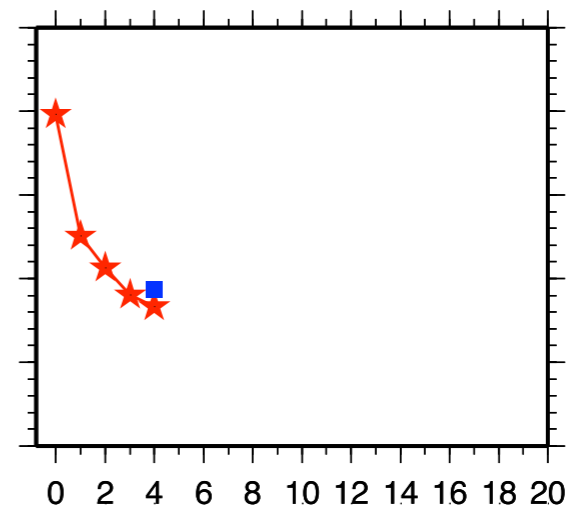
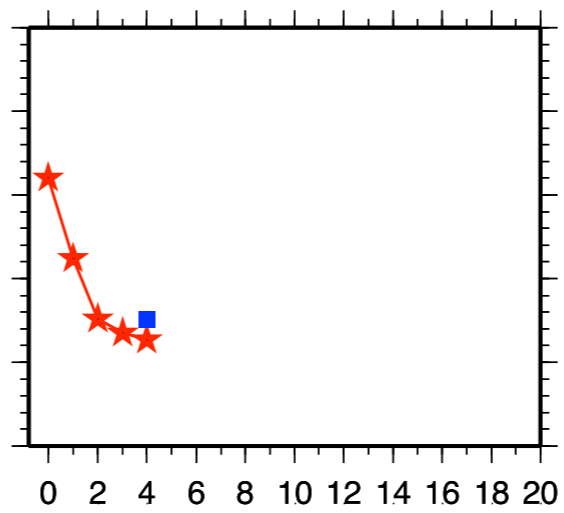
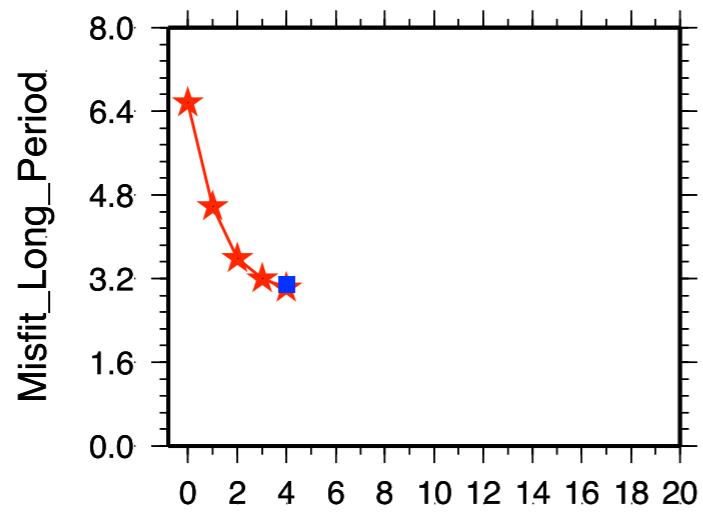
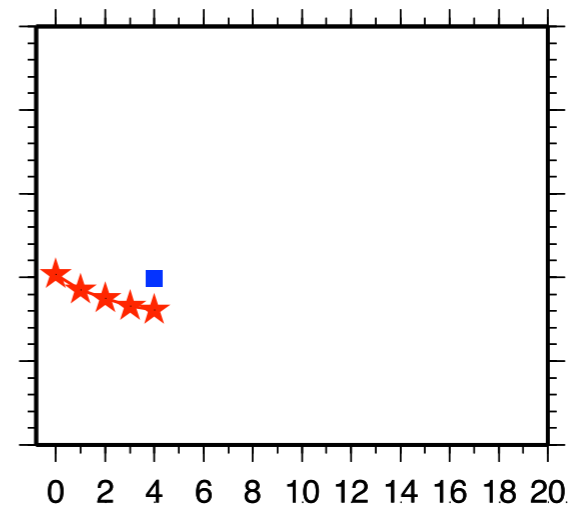
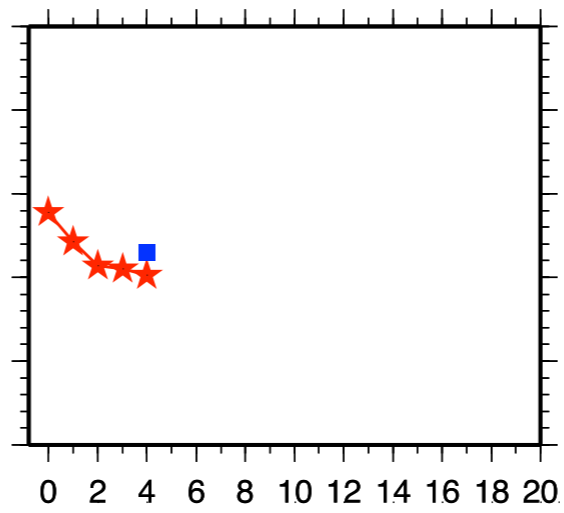
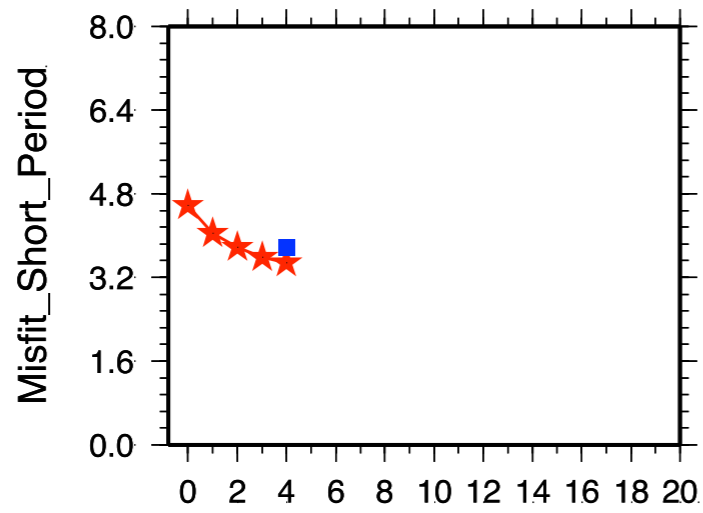
Iteration.

★ T015_050 & T050_150

Vertical

Radial

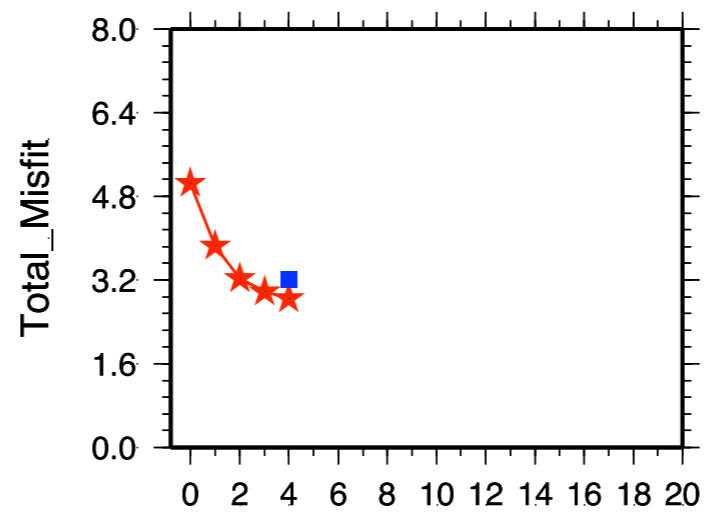
Transverse



Iteration.

Iteration.

Iteration.



Iteration.

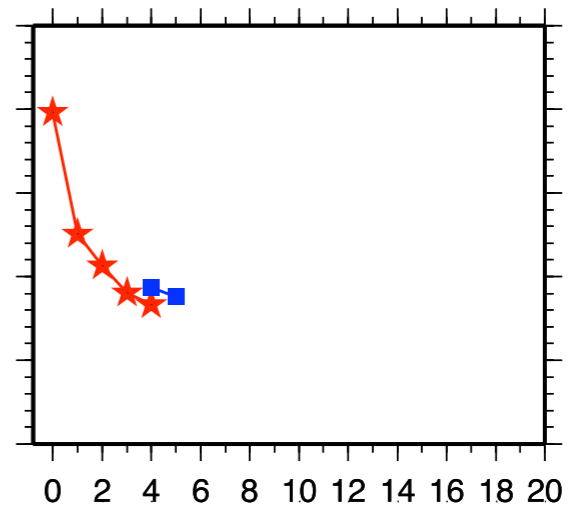
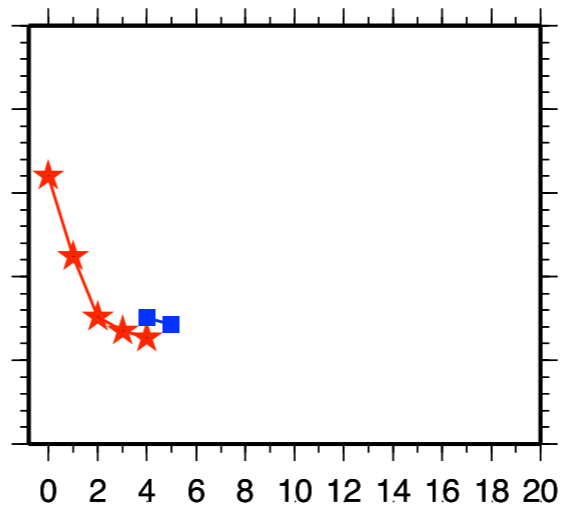
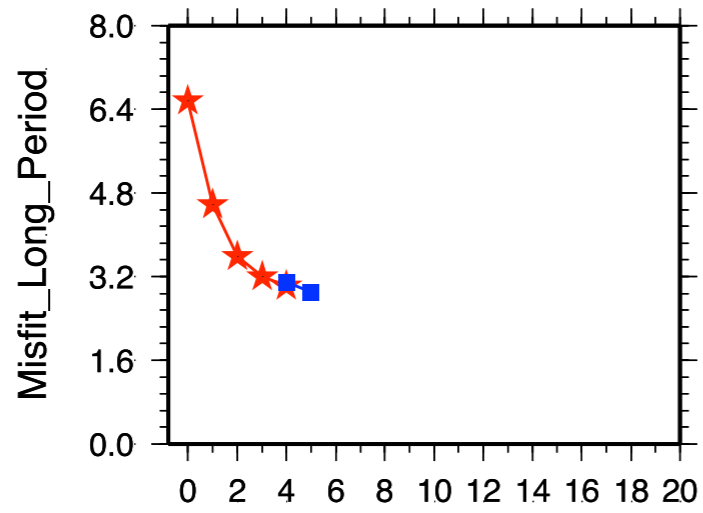
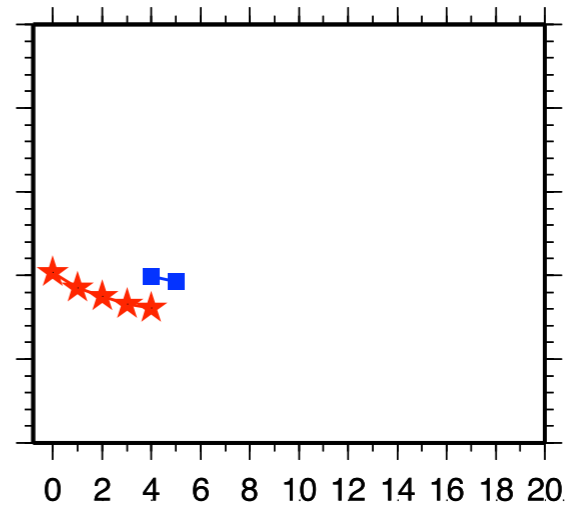
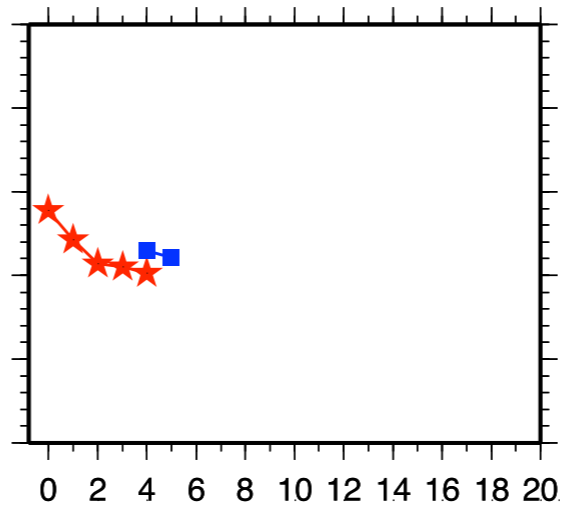
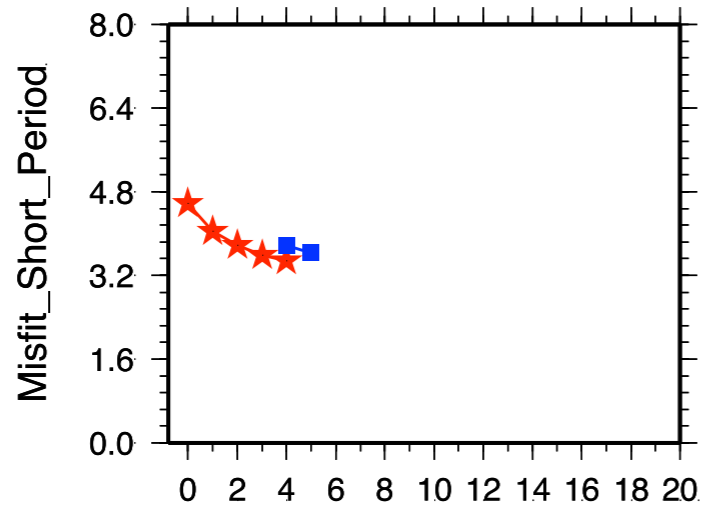
★ T015_050 & T050_150

■ T015_040 & T040_150

Vertical

Radial

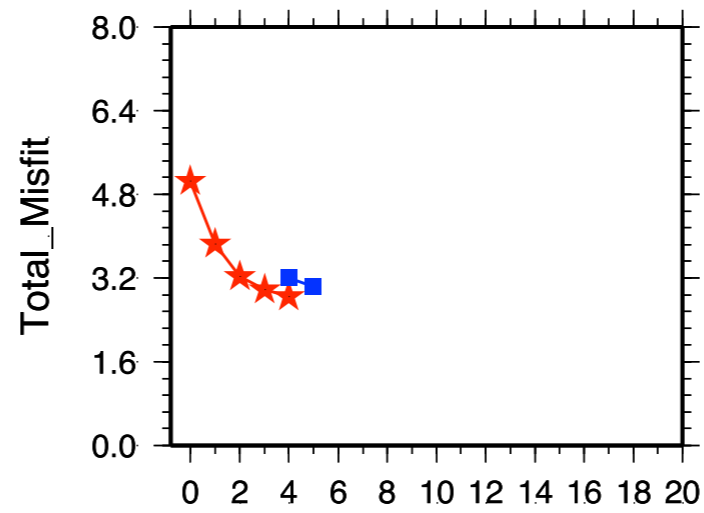
Transverse



Iteration.

Iteration.

Iteration.



Iteration.

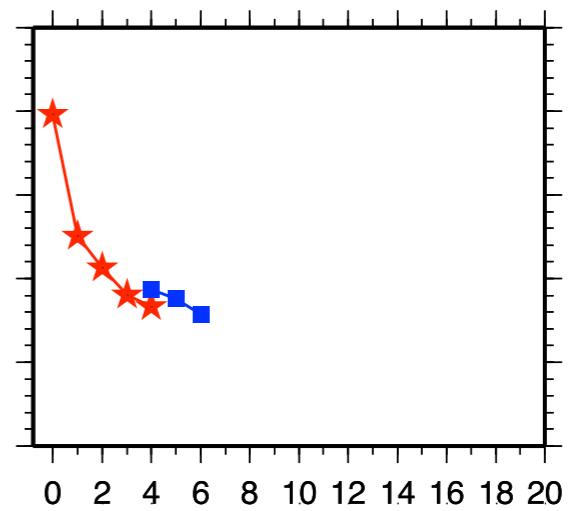
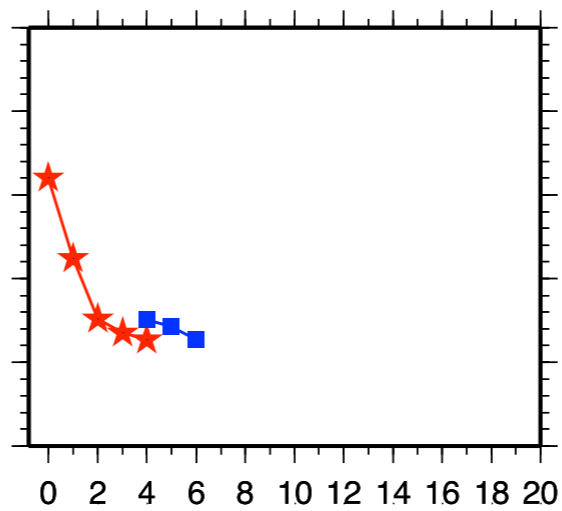
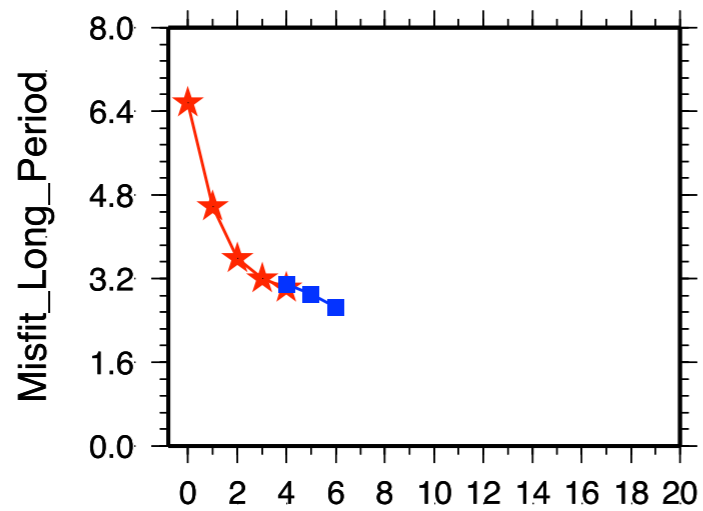
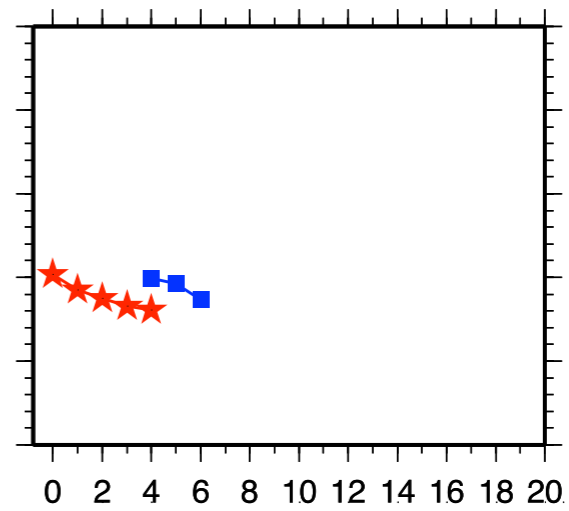
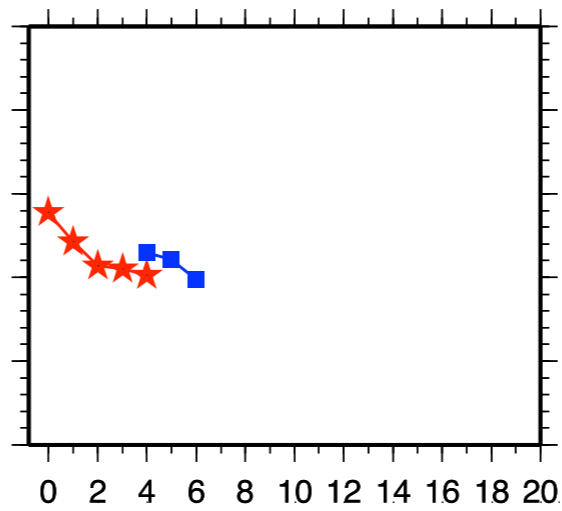
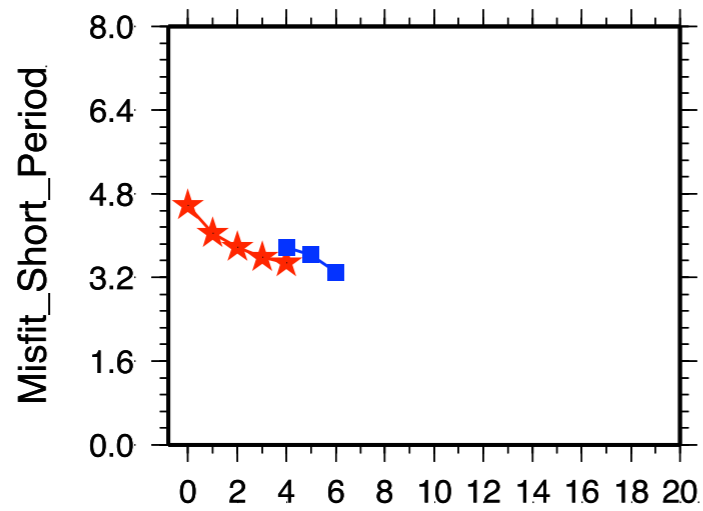
★ T015_050 & T050_150

■ T015_040 & T040_150

Vertical

Radial

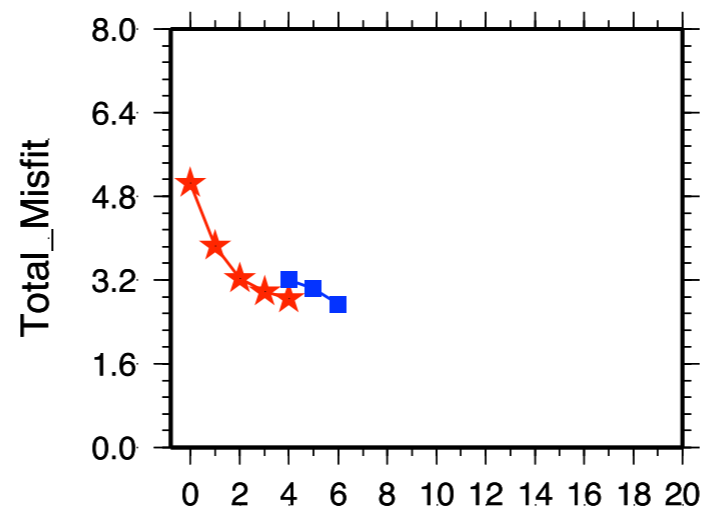
Transverse



Iteration.

Iteration.

Iteration.



Iteration.

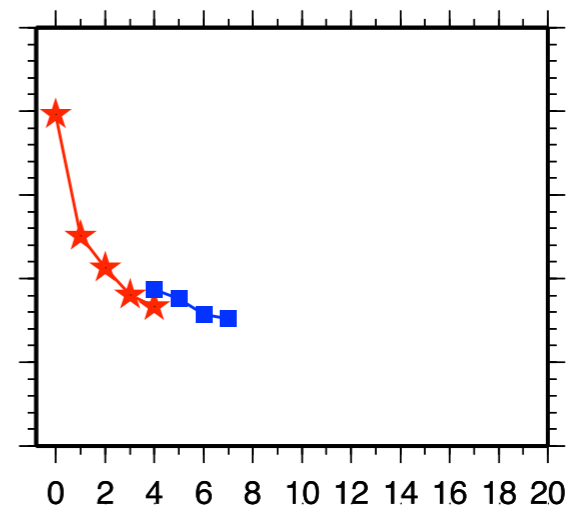
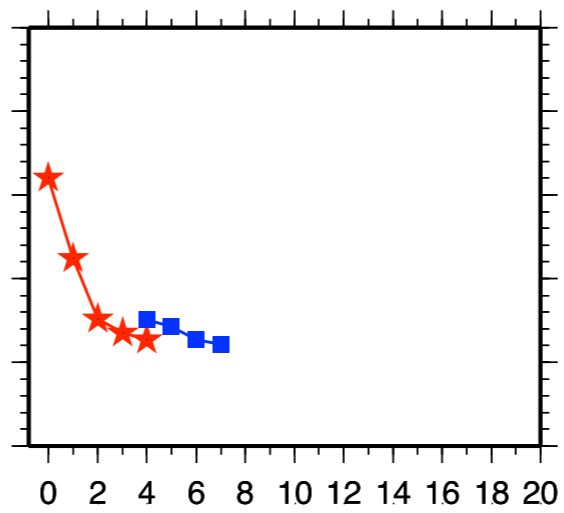
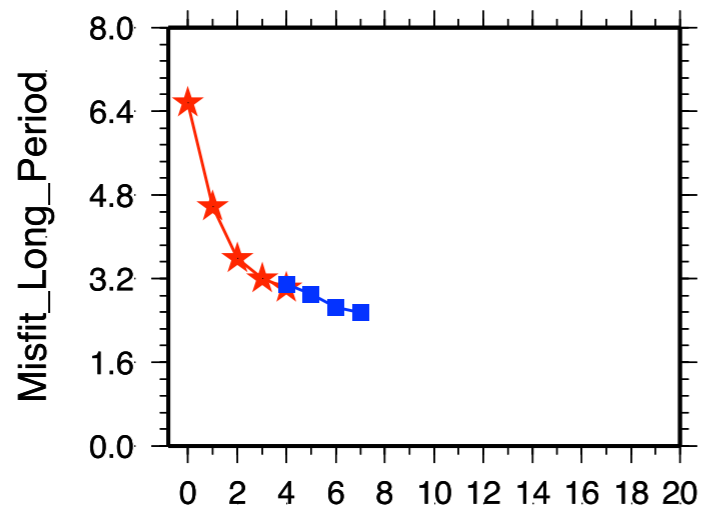
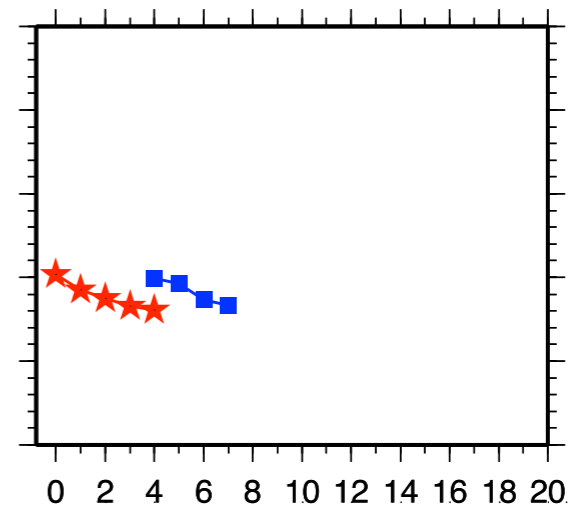
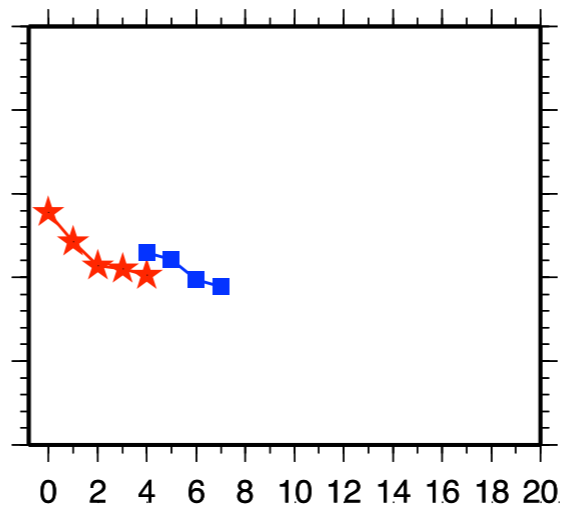
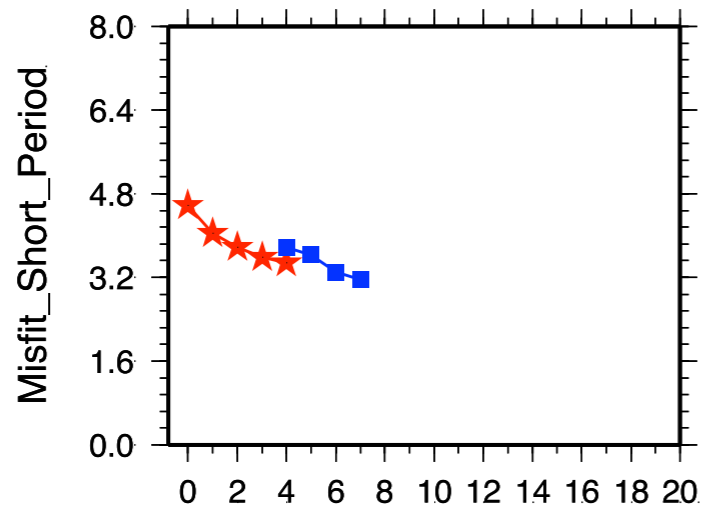
★ T015_050 & T050_150

■ T015_040 & T040_150

Vertical

Radial

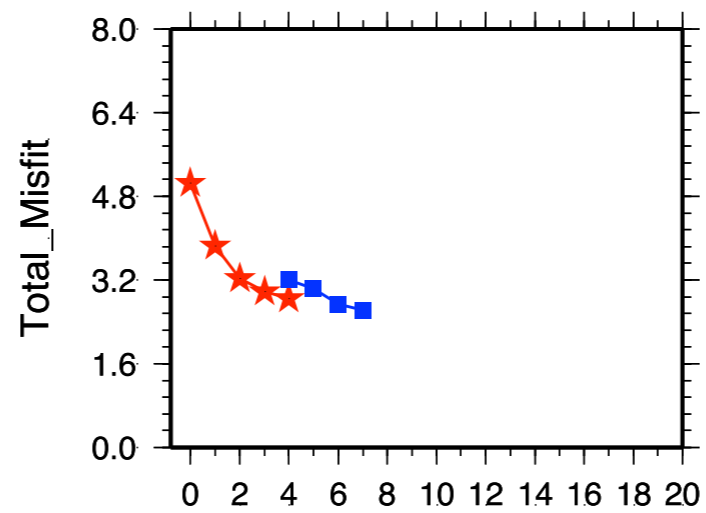
Transverse



Iteration.

Iteration.

Iteration.



Iteration.

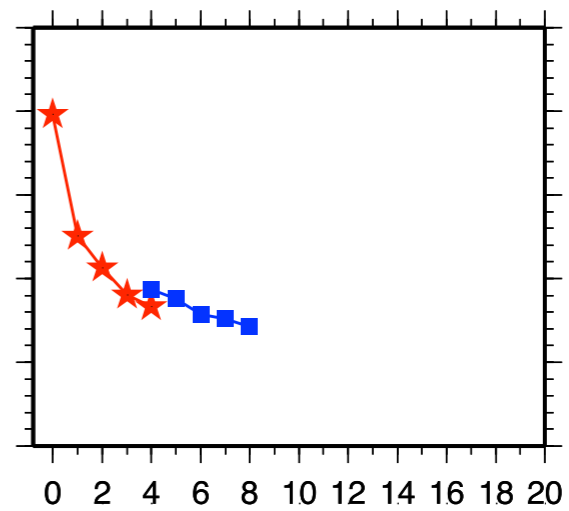
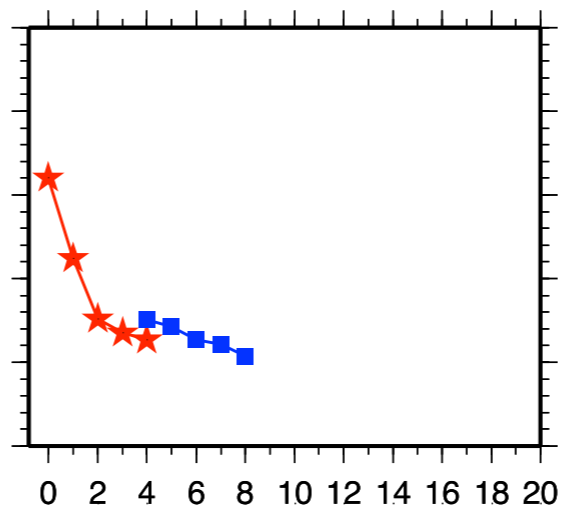
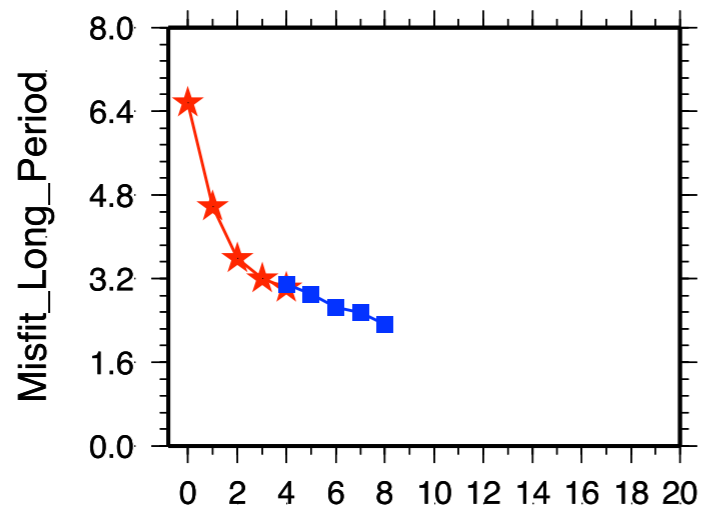
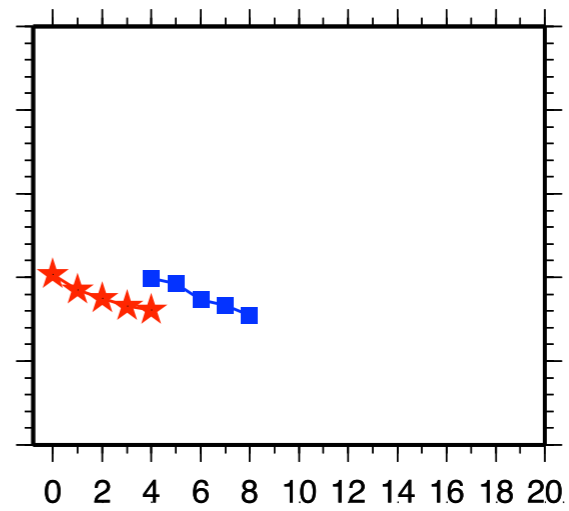
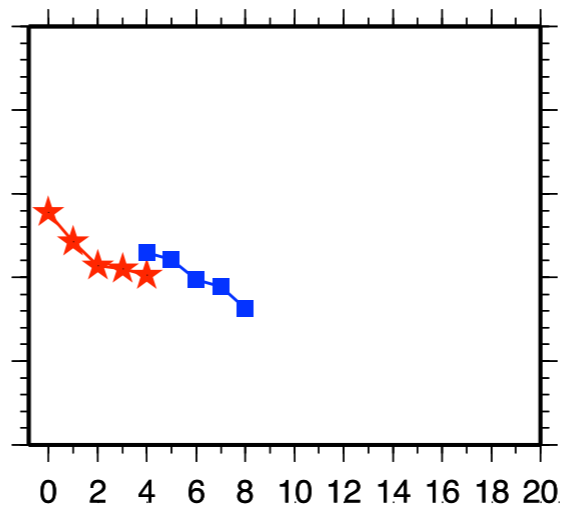
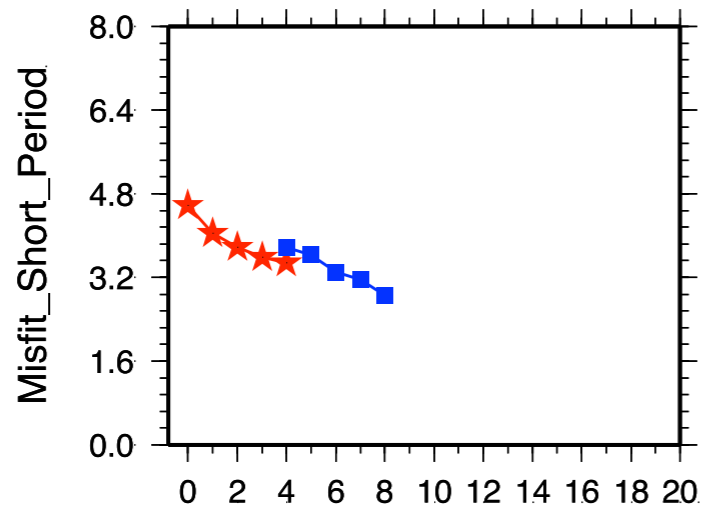
★ T015_050 & T050_150

■ T015_040 & T040_150

Vertical

Radial

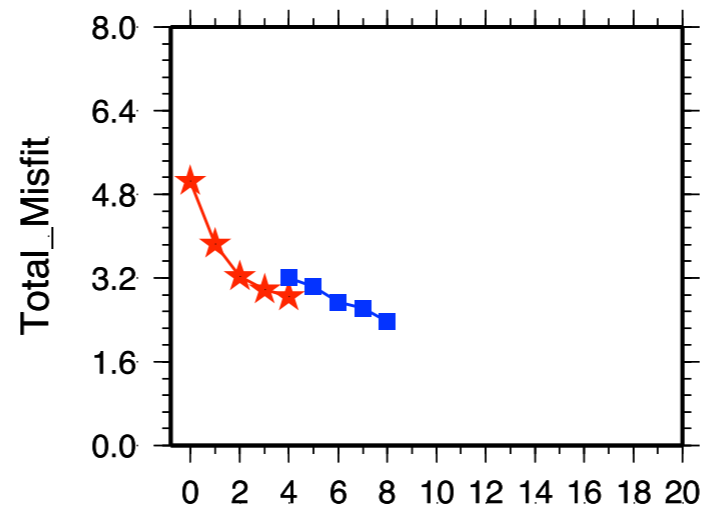
Transverse



Iteration.

Iteration.

Iteration.



Iteration.

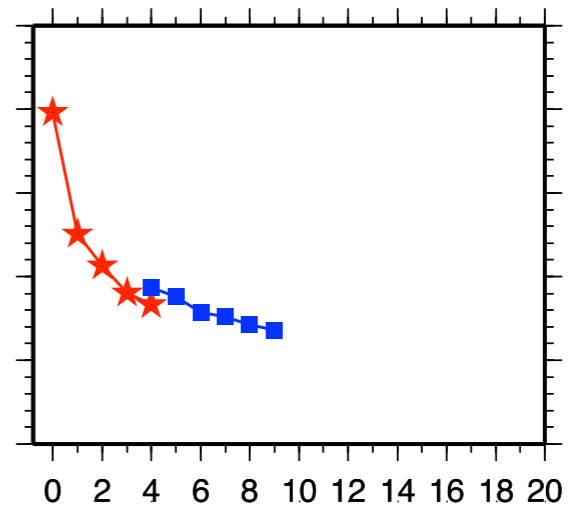
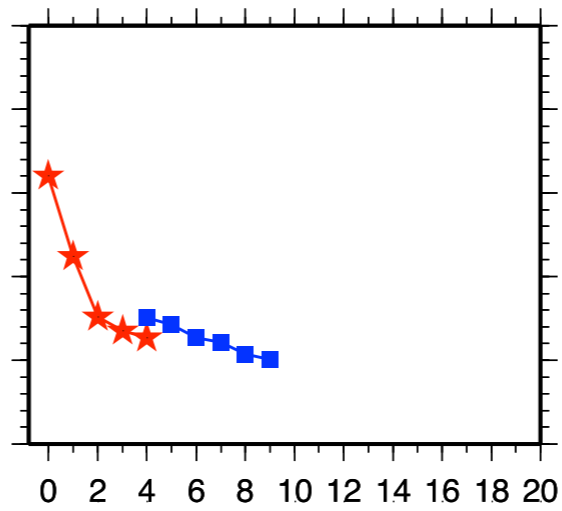
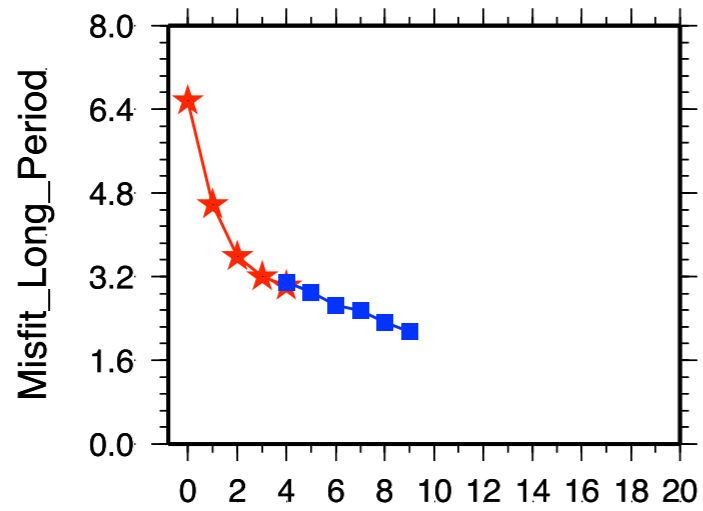
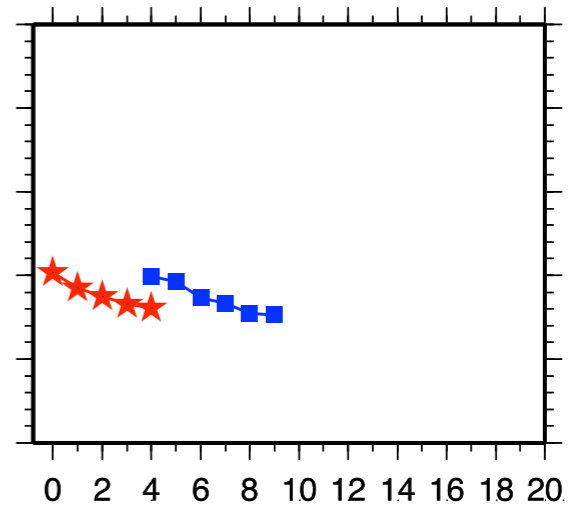
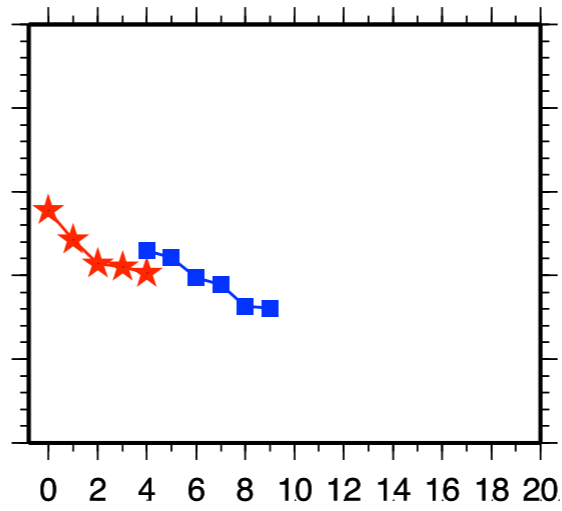
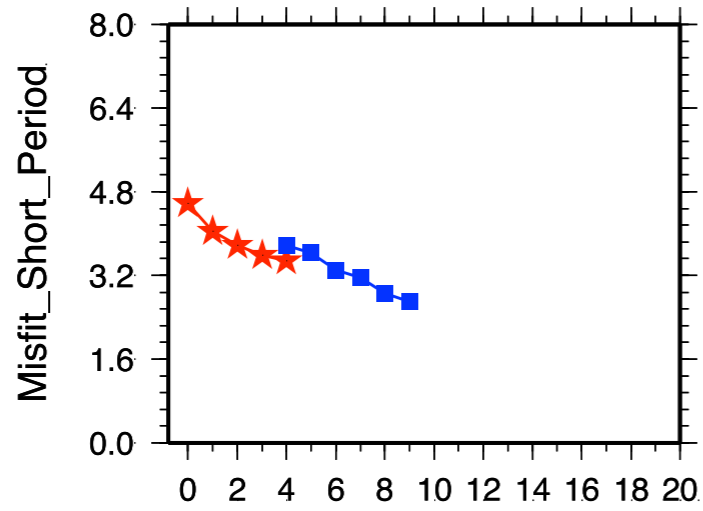
★ T015_050 & T050_150

■ T015_040 & T040_150

Vertical

Radial

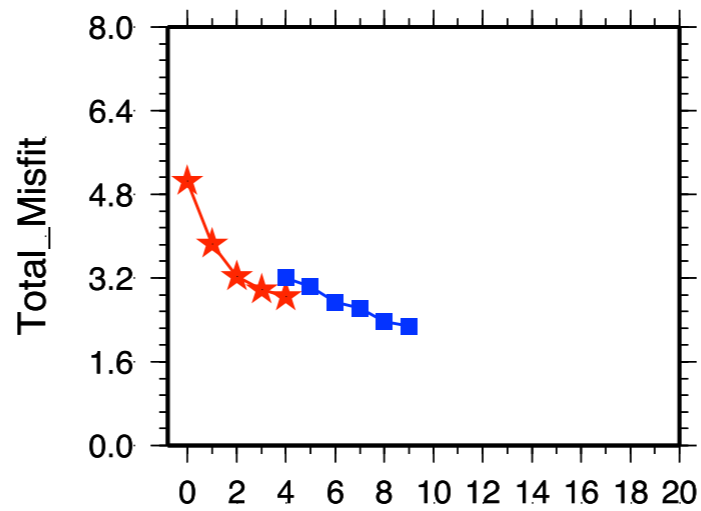
Transverse



Iteration.

Iteration.

Iteration.



Iteration.

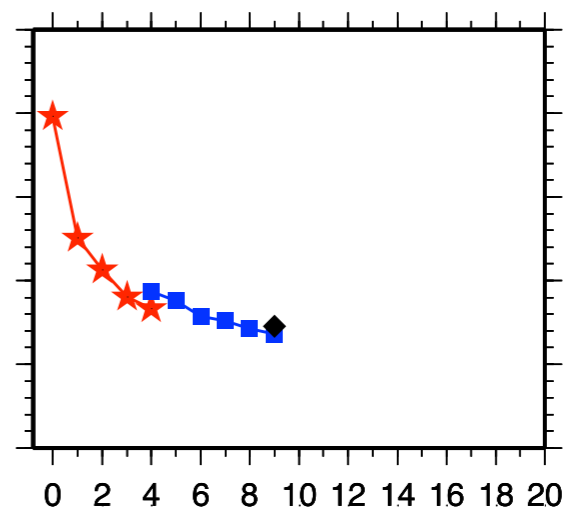
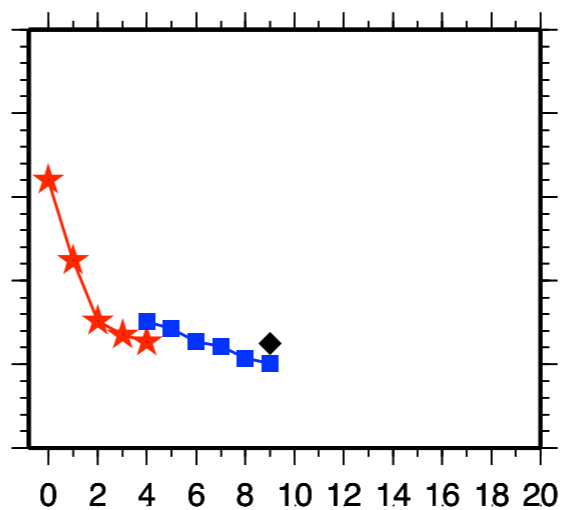
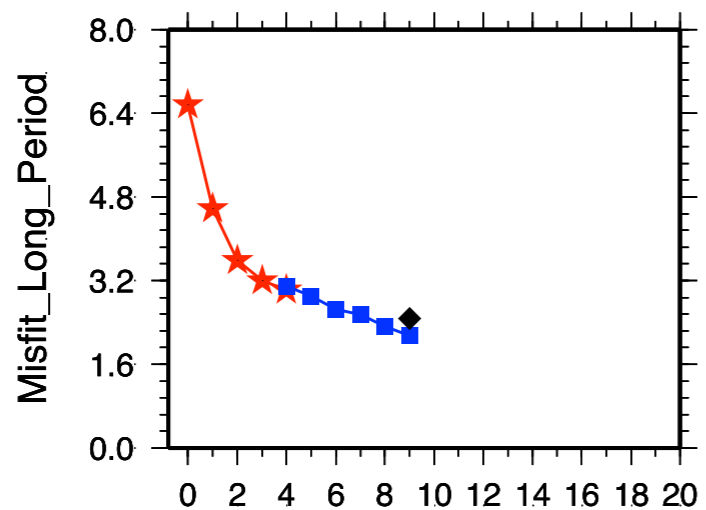
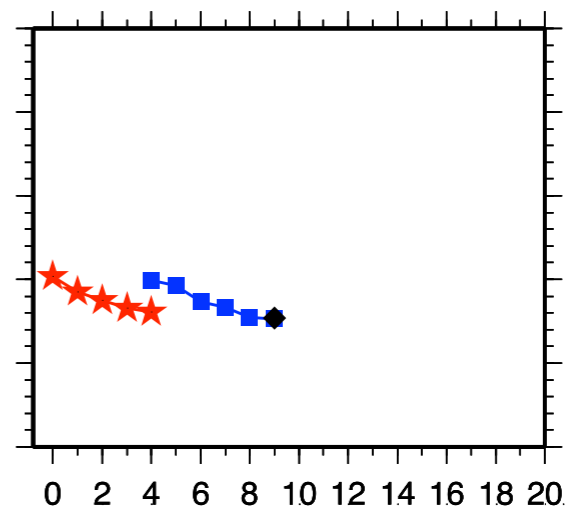
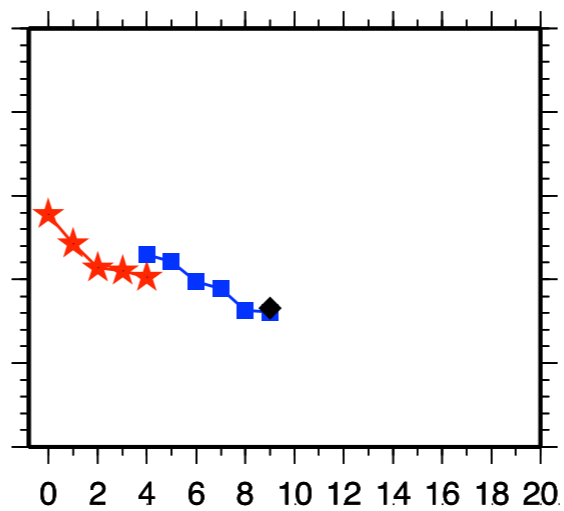
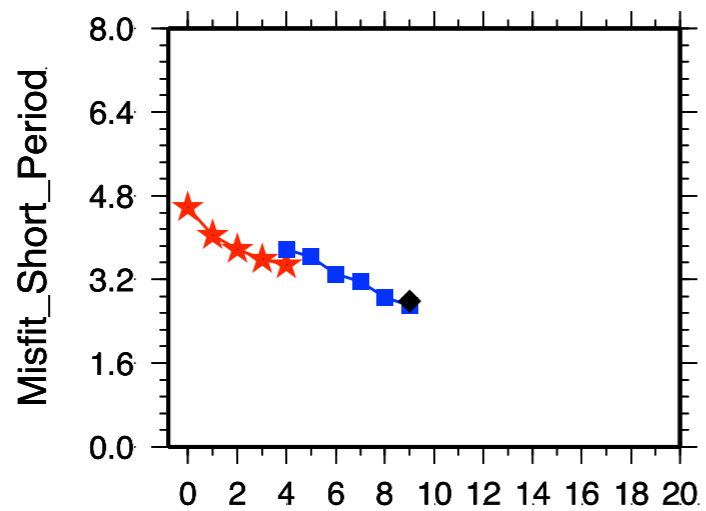
★ T015_050 & T050_150

■ T015_040 & T040_150

Vertical

Radial

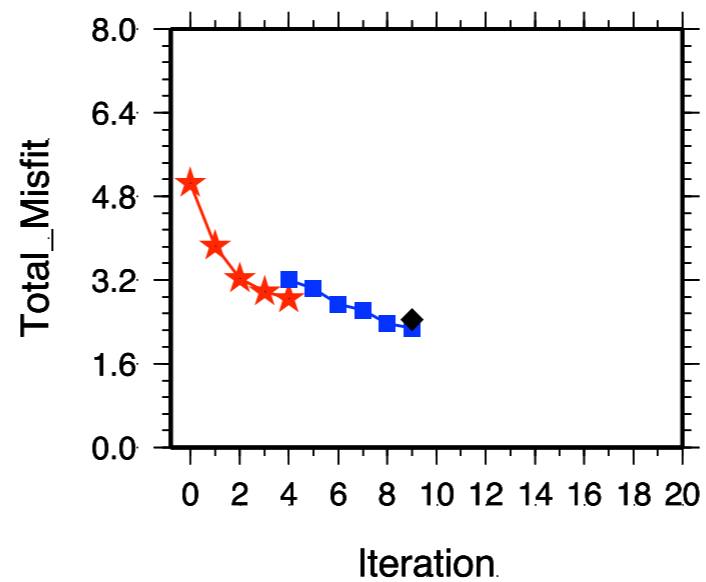
Transverse



Iteration.

Iteration.

Iteration.



Total_Misfit

Iteration.

★ T015_050 & T050_150

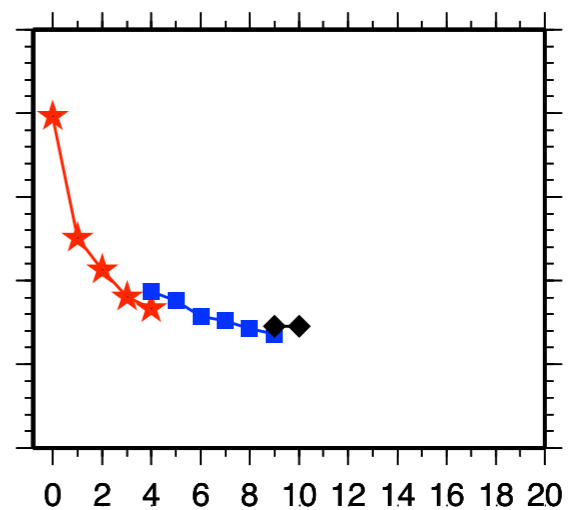
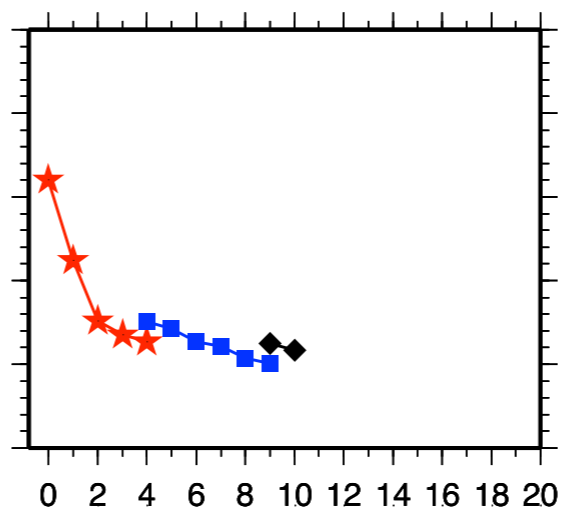
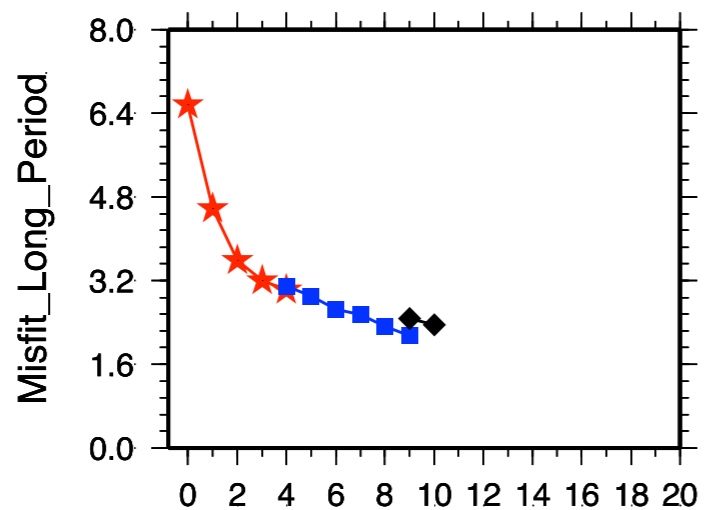
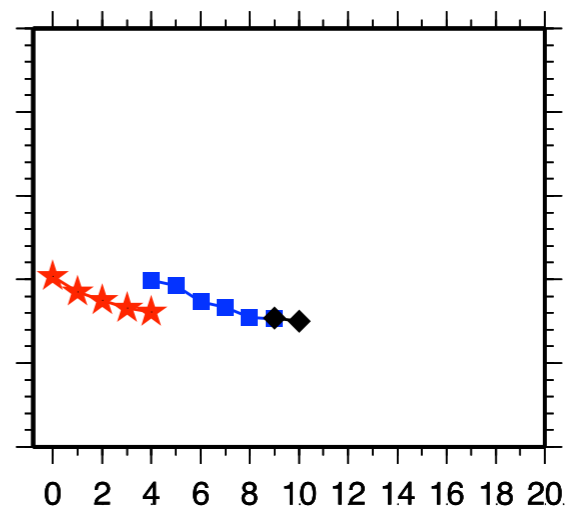
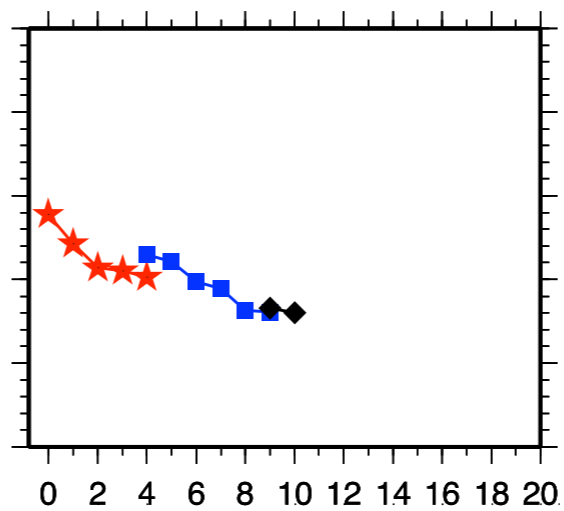
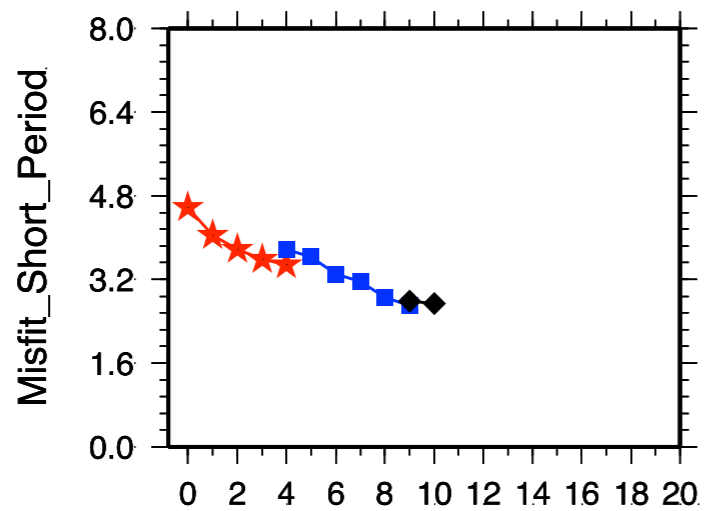
■ T015_040 & T040_150

◆ T015_040 & T030_150

Vertical

Radial

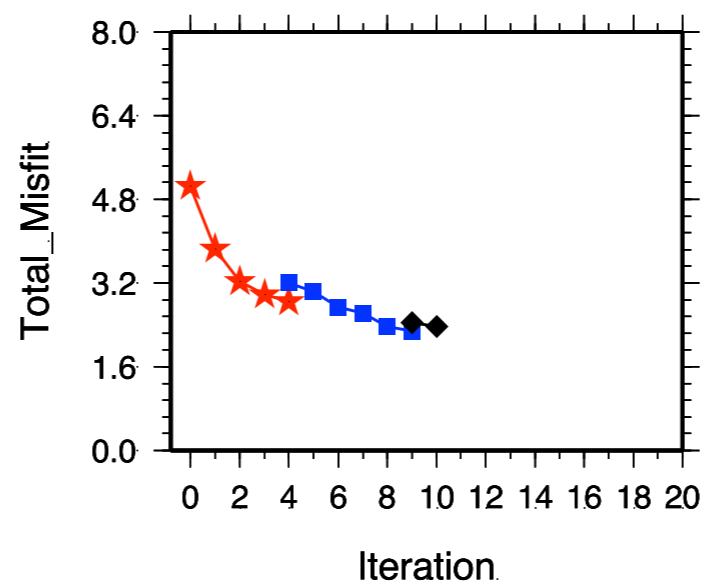
Transverse



Iteration.

Iteration.

Iteration.



Total_Misfit

Iteration.

★ T015_050 & T050_150

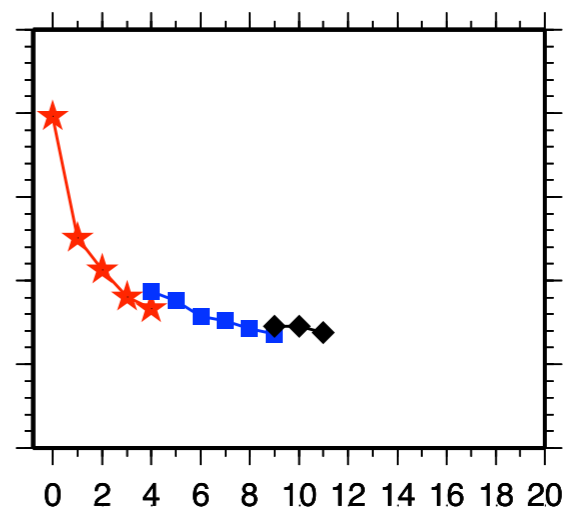
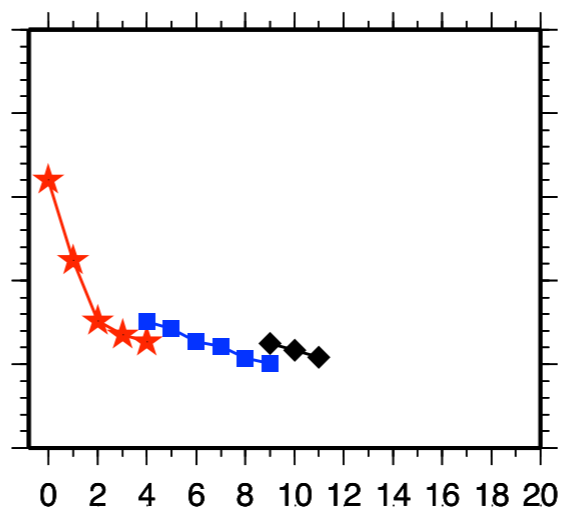
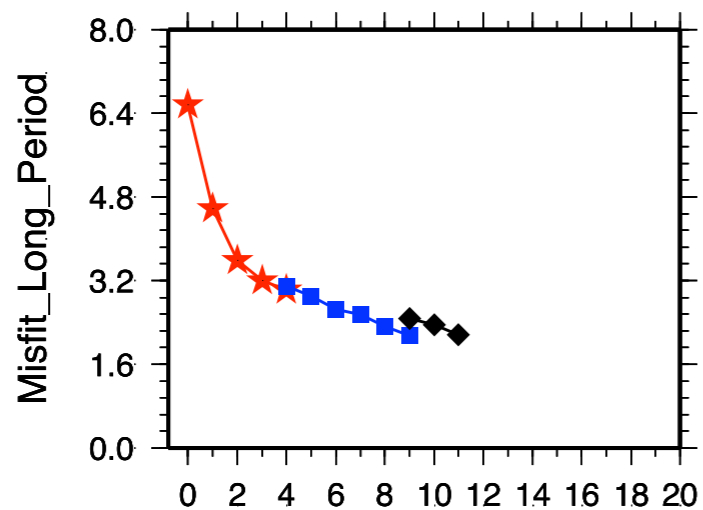
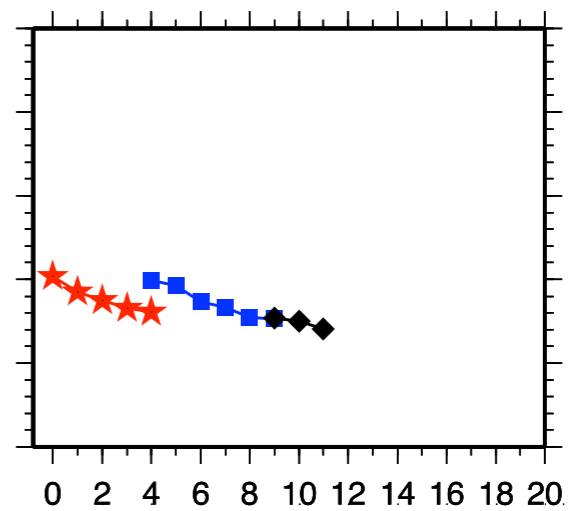
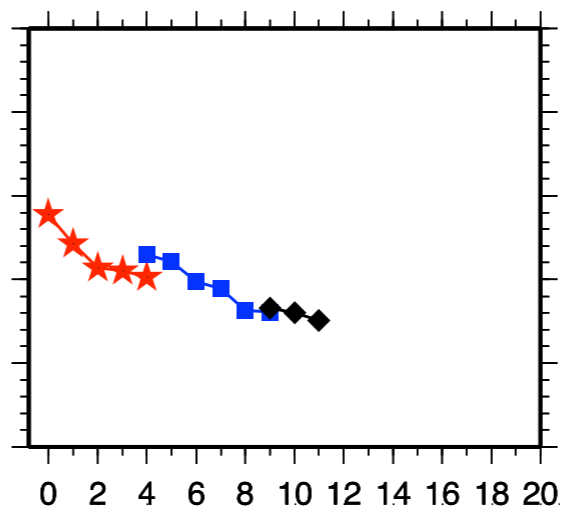
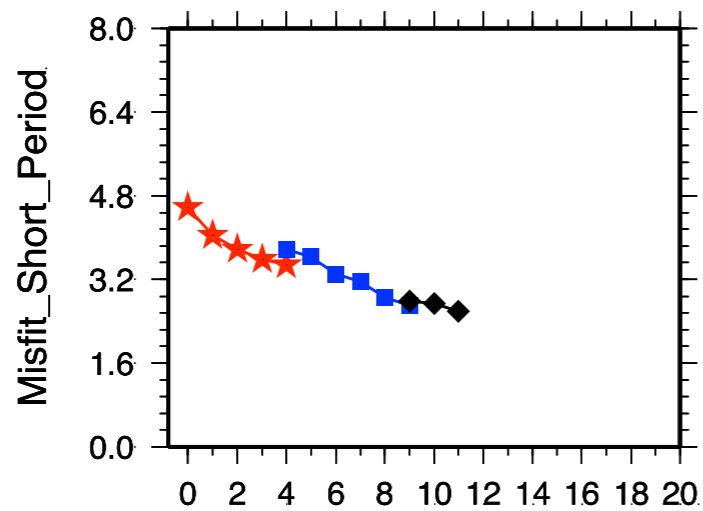
■ T015_040 & T040_150

◆ T015_040 & T030_150

Vertical

Radial

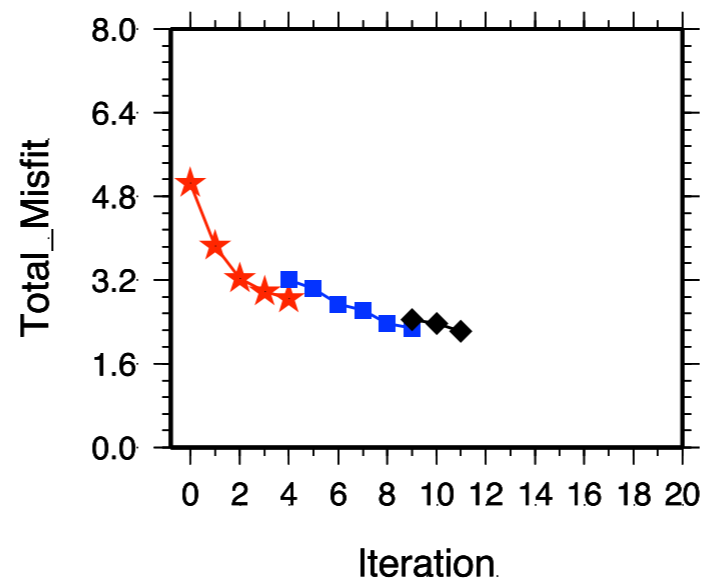
Transverse



Iteration.

Iteration.

Iteration.



Total_Misfit

Iteration.

★ T015_050 & T050_150

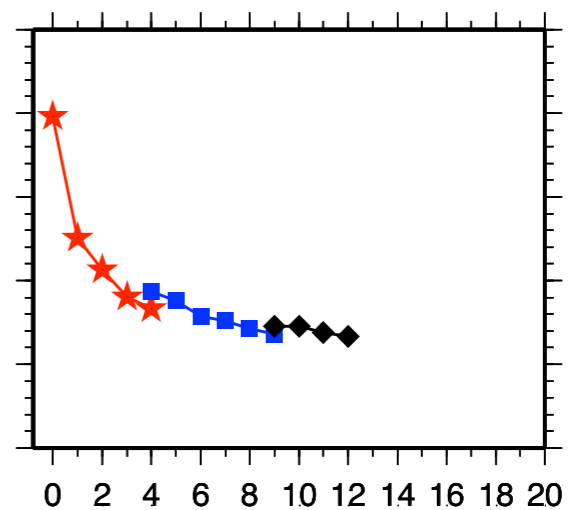
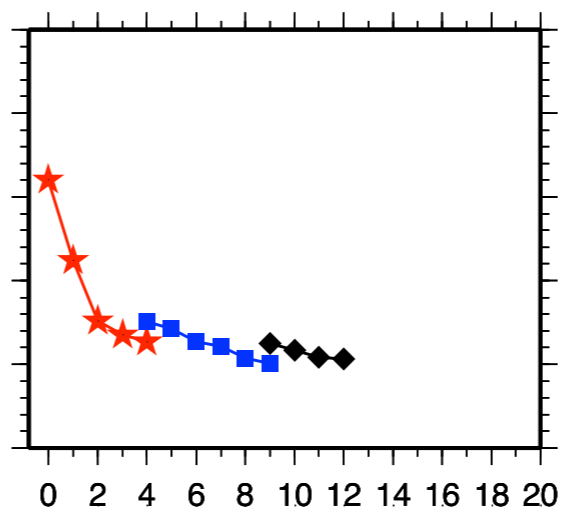
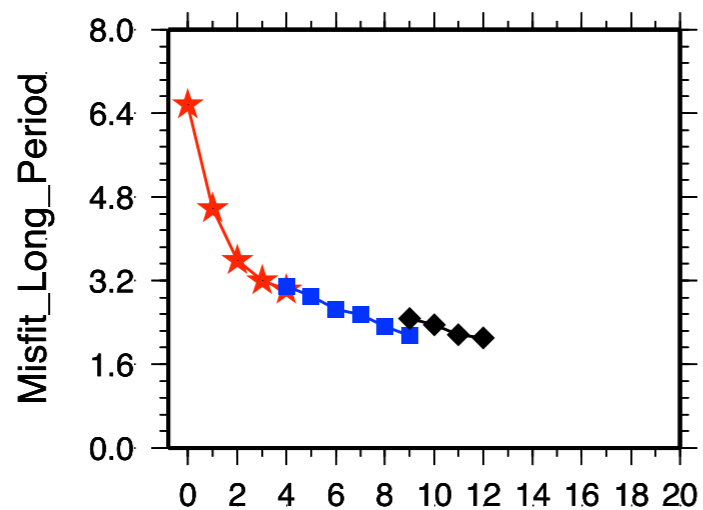
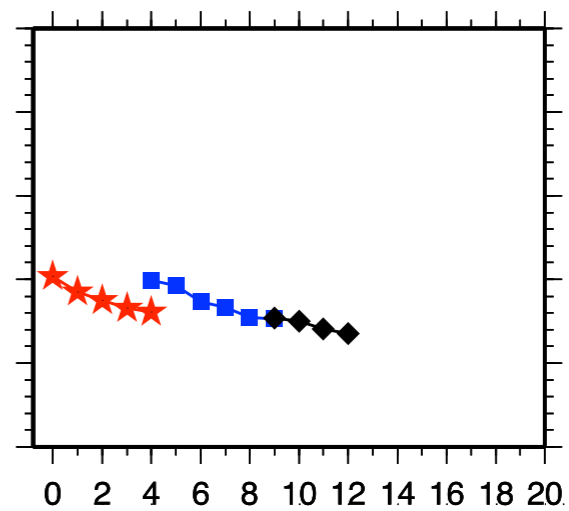
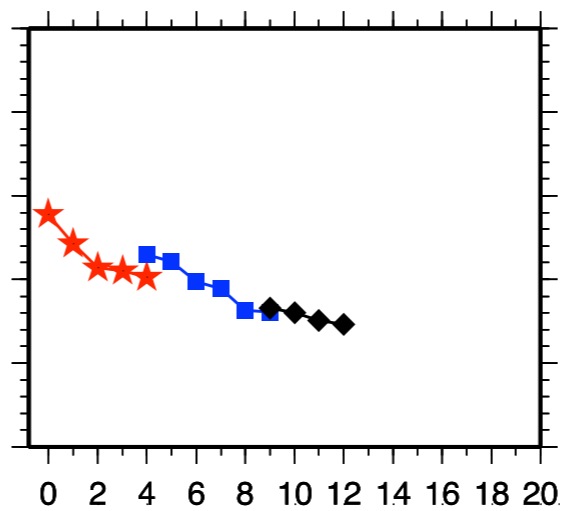
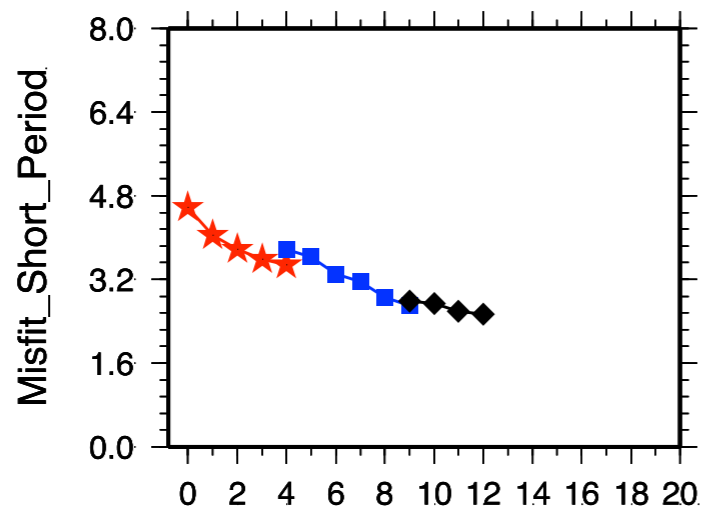
■ T015_040 & T040_150

◆ T015_040 & T030_150

Vertical

Radial

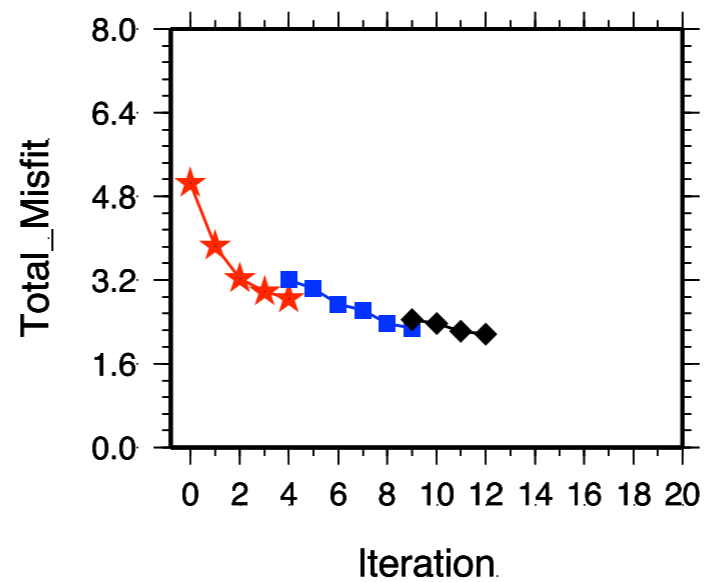
Transverse



Iteration.

Iteration.

Iteration.



Total_Misfit

Iteration.

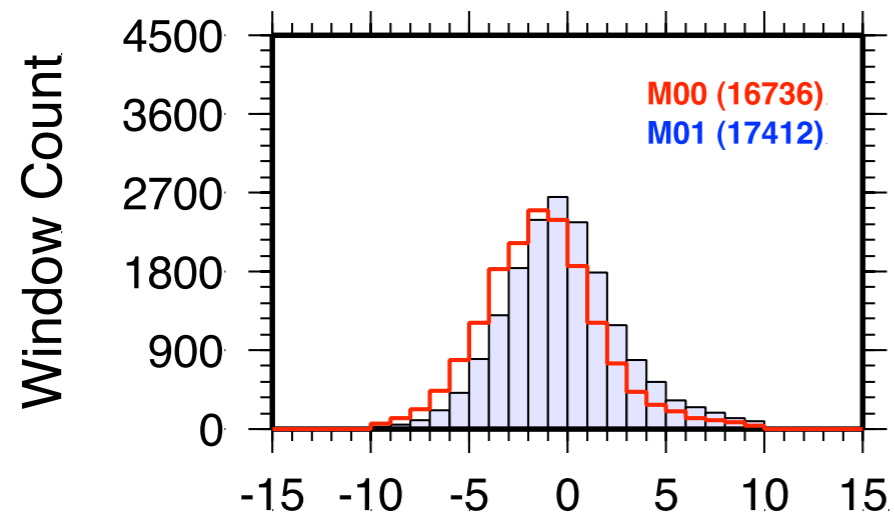
★ T015_050 & T050_150

■ T015_040 & T040_150

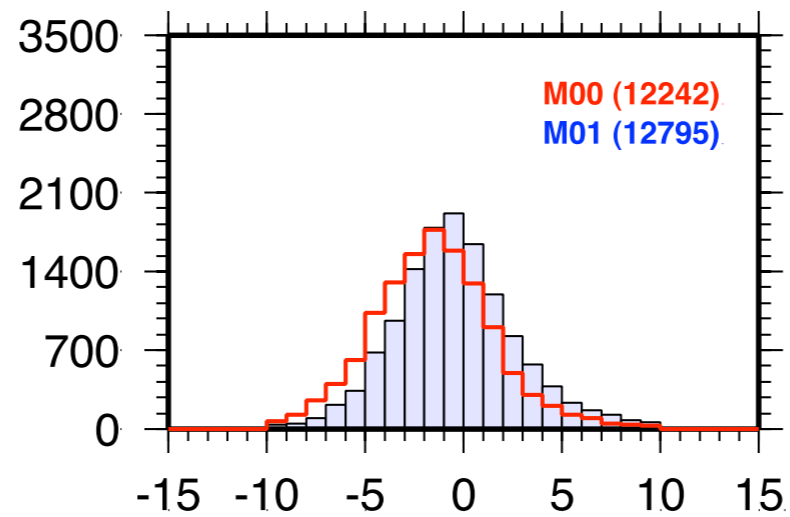
◆ T015_040 & T030_150

T015_050

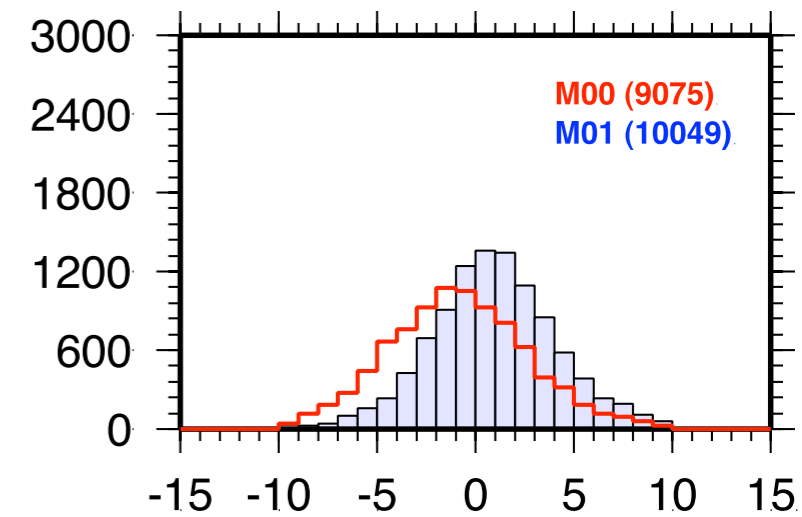
Vertical



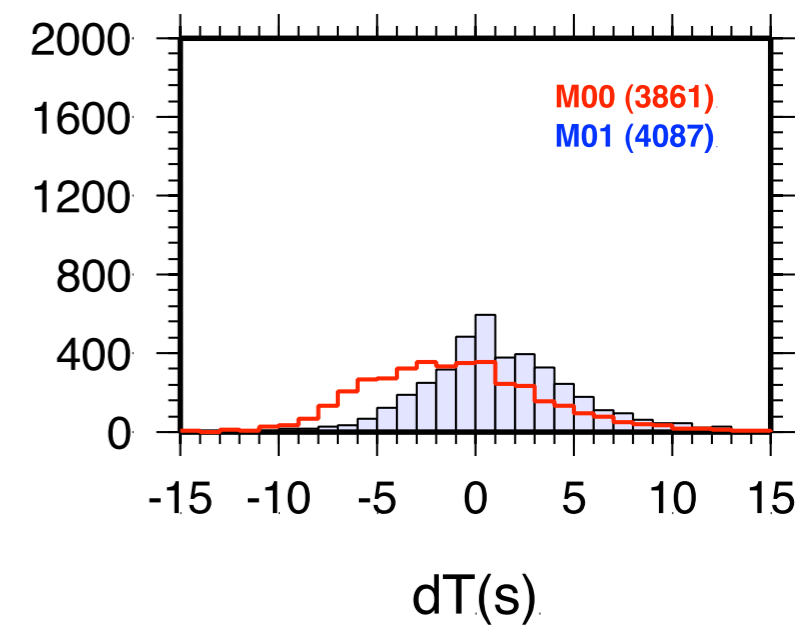
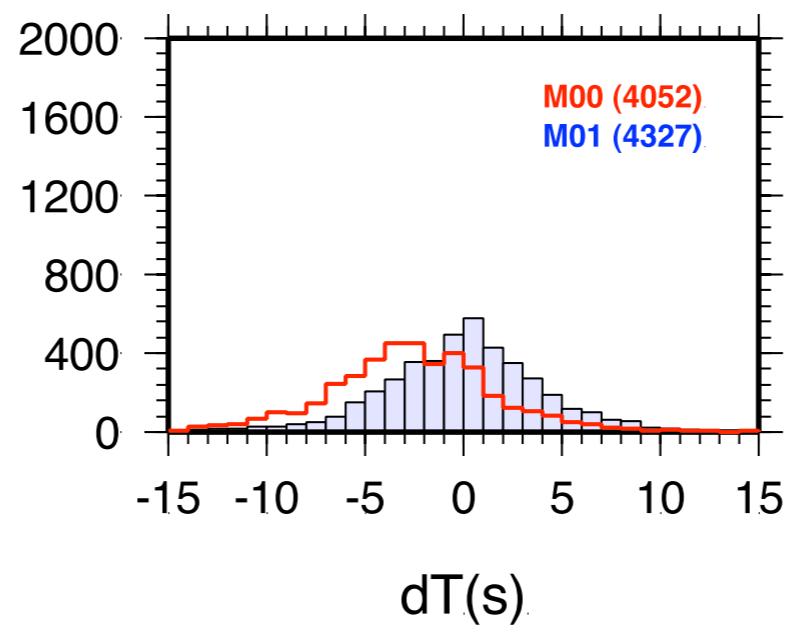
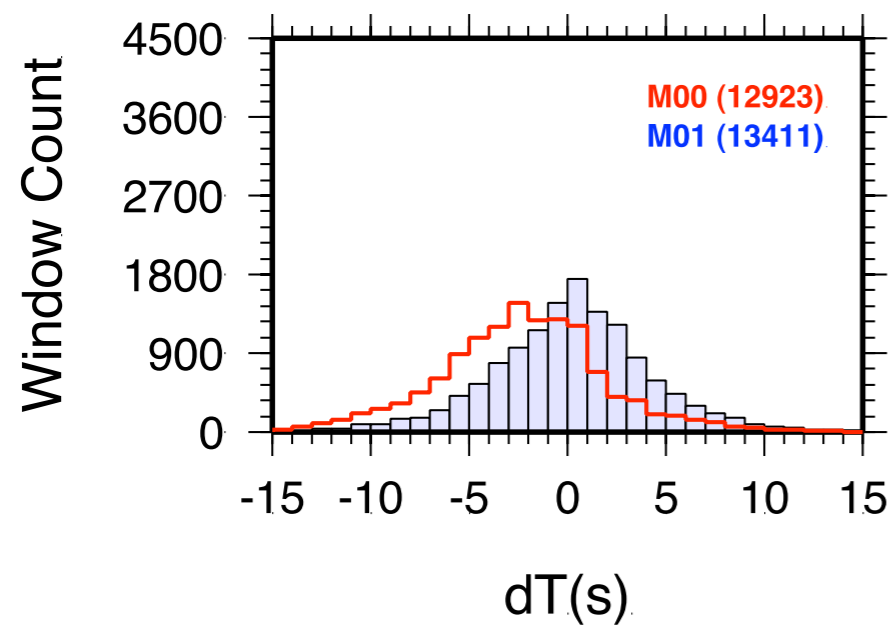
Radial



Transverse

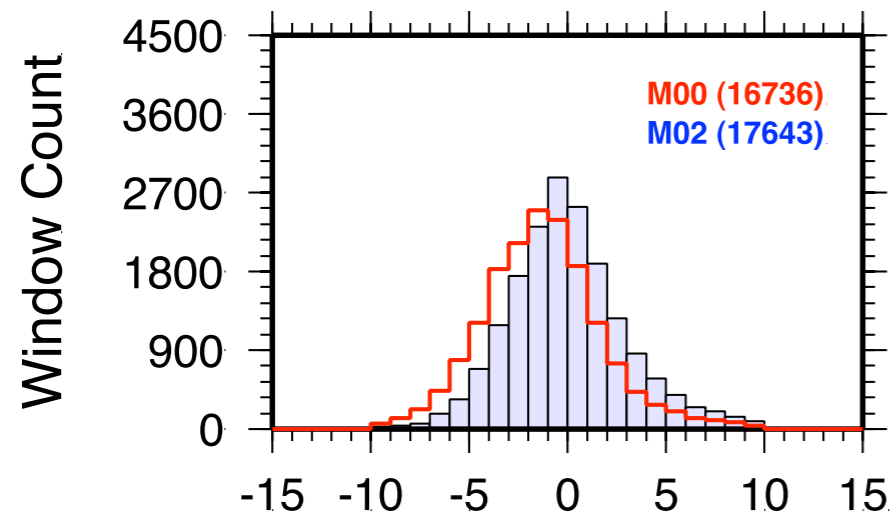


T050_150

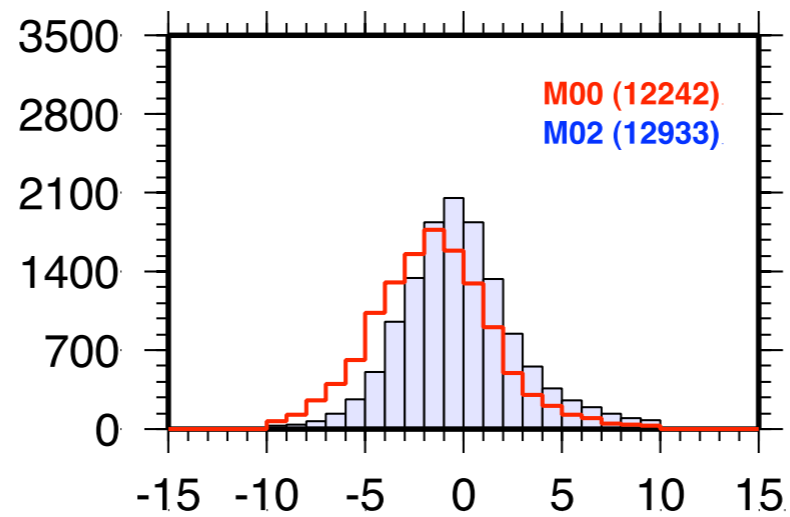


T015_050

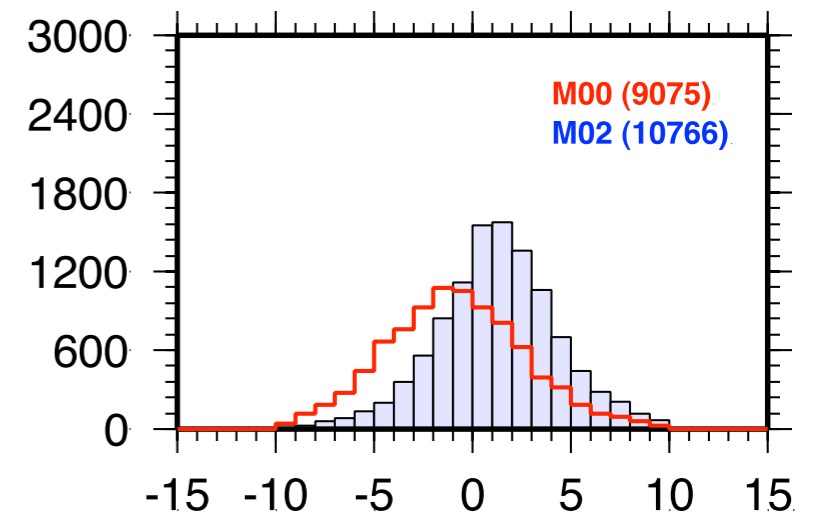
Vertical



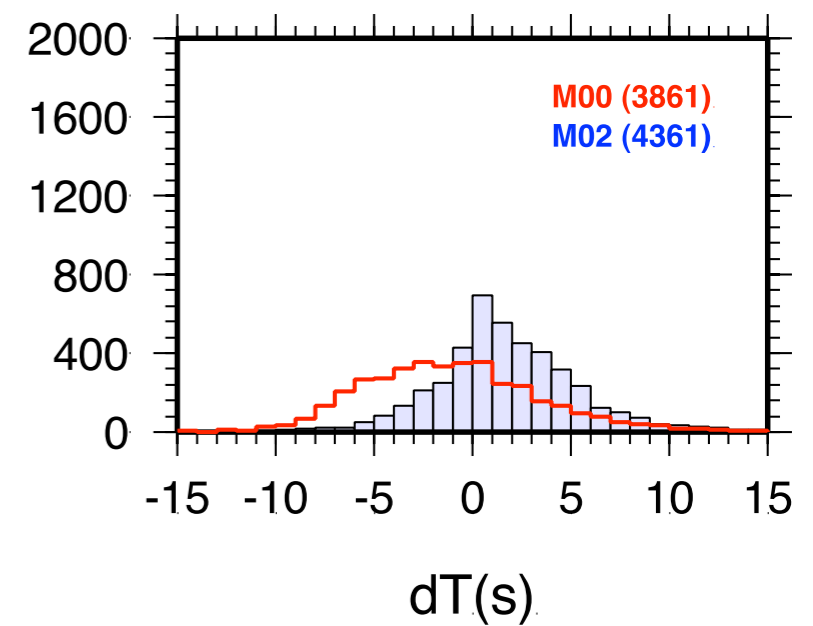
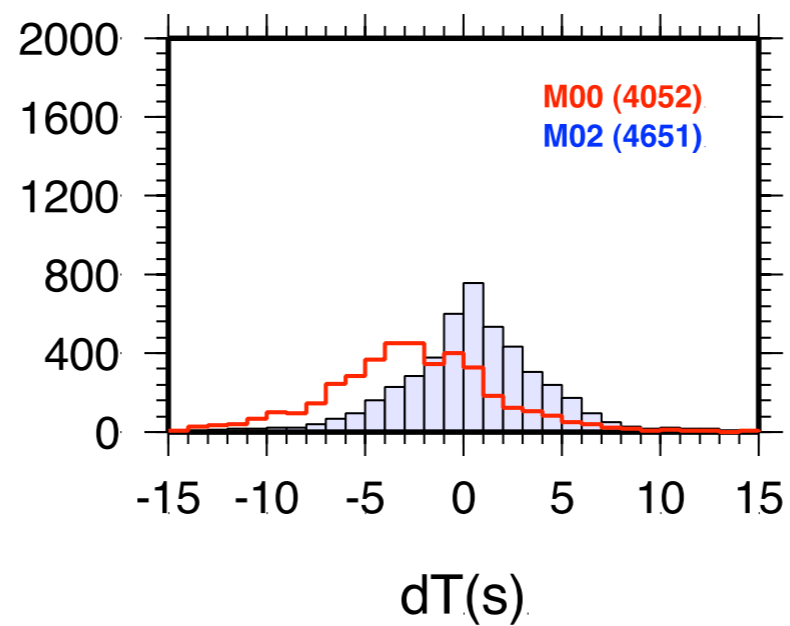
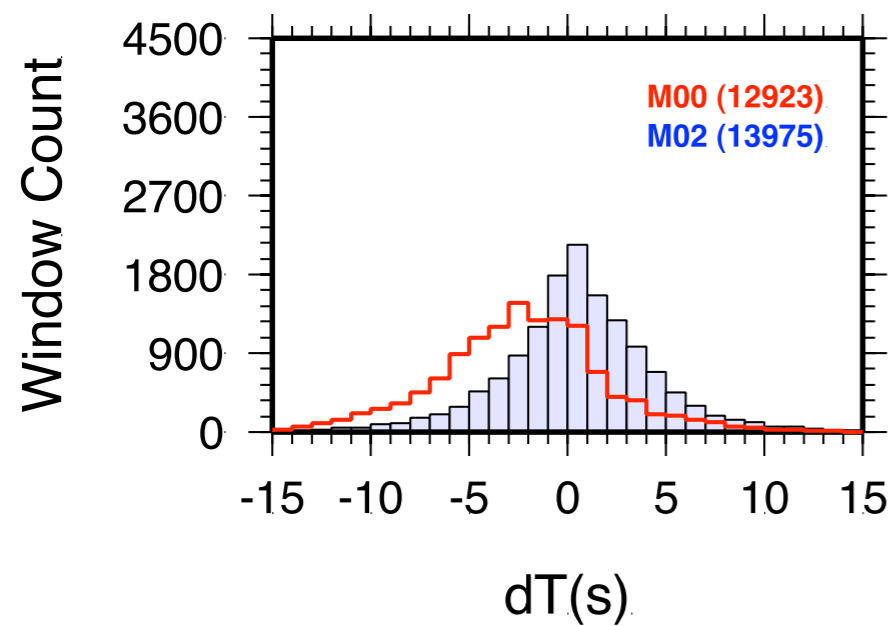
Radial



Transverse

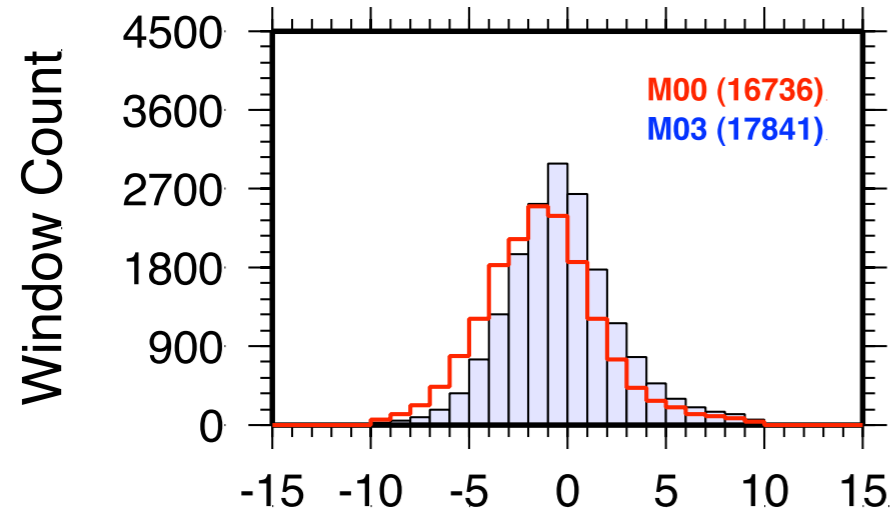


T050_150

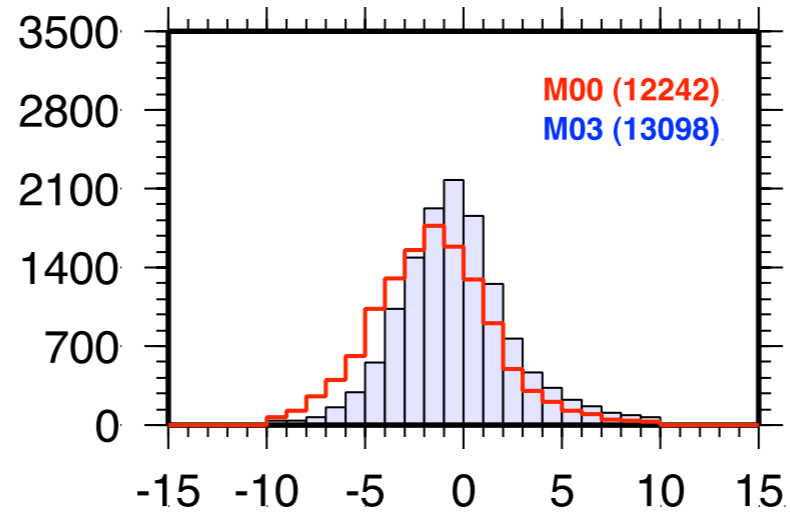


T015_050

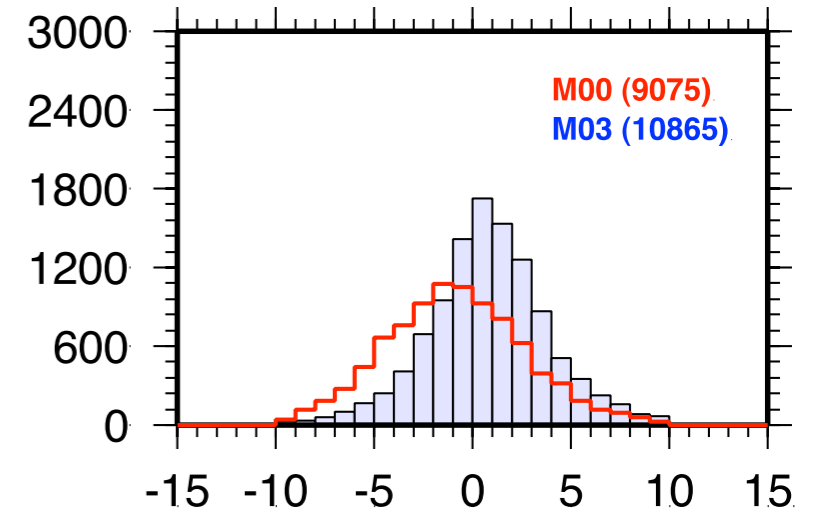
Vertical



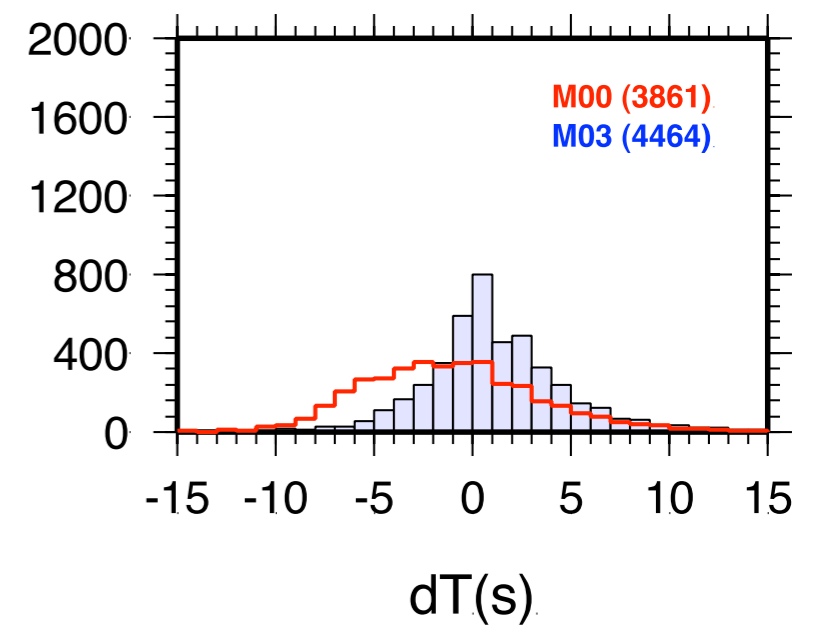
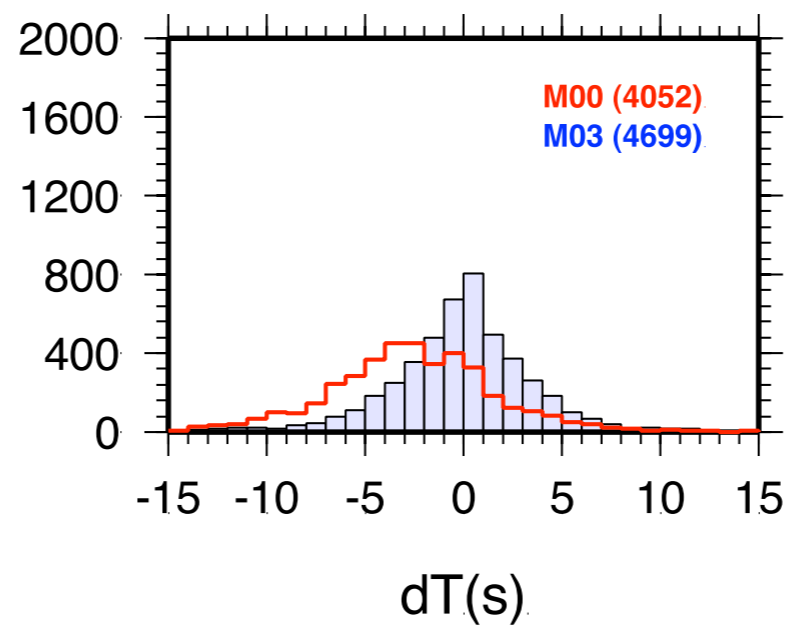
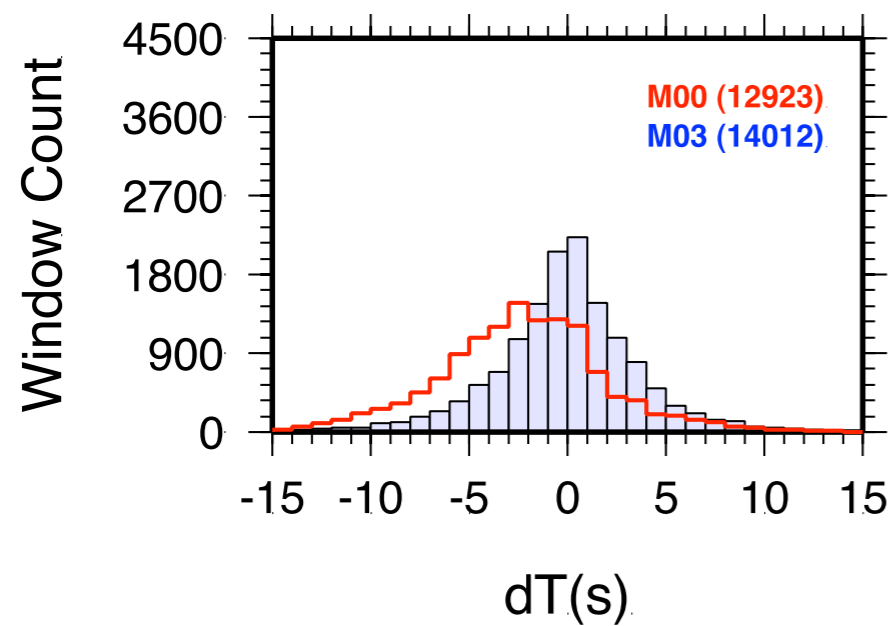
Radial



Transverse

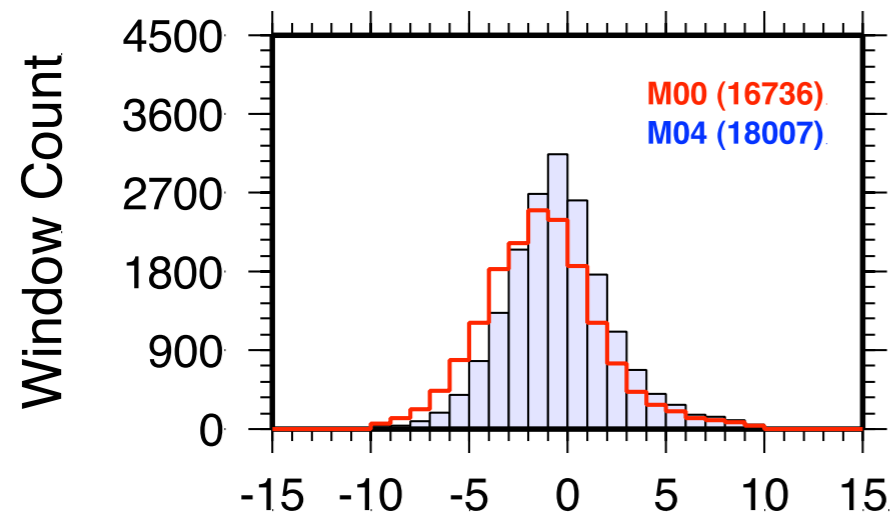


T050_150

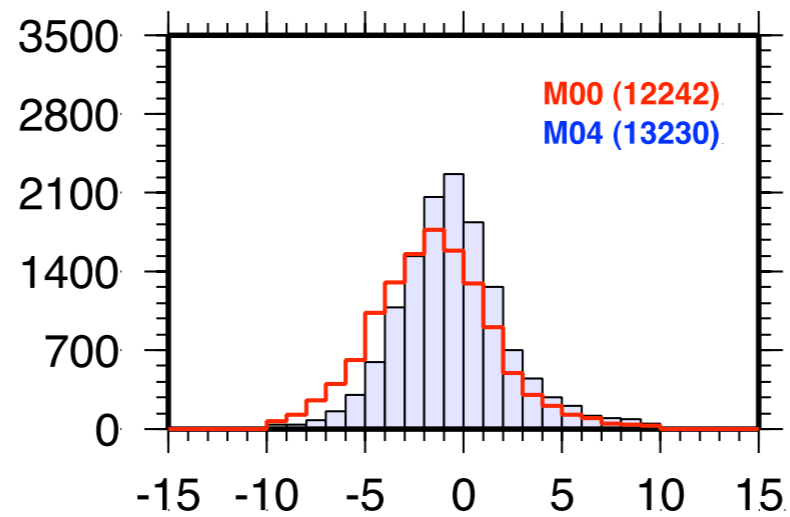


T015_050

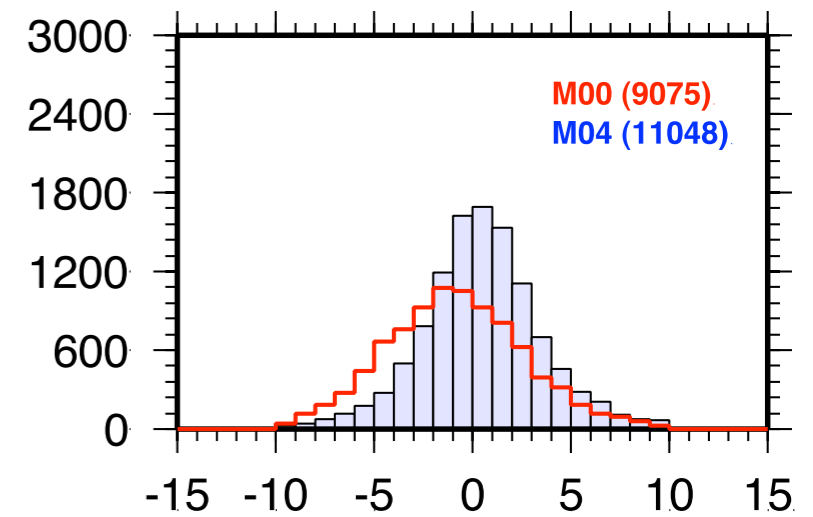
Vertical



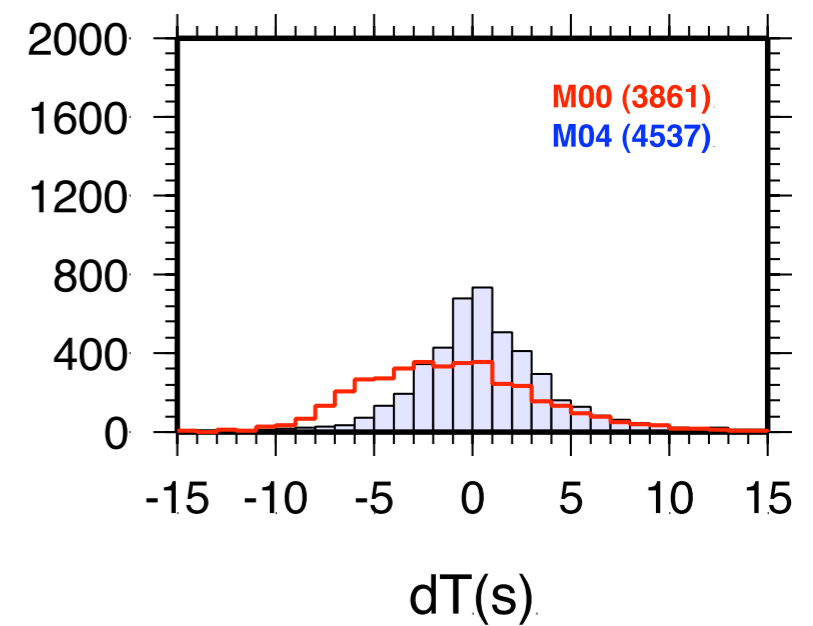
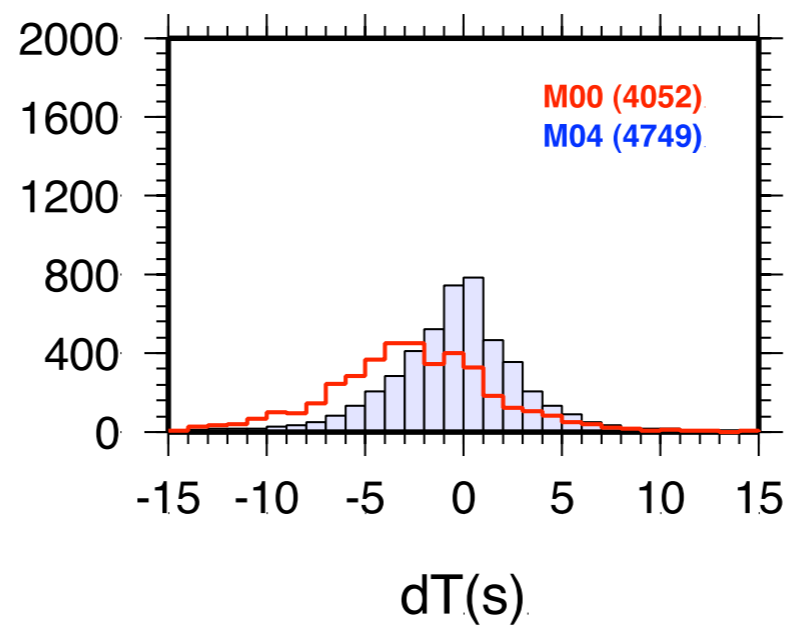
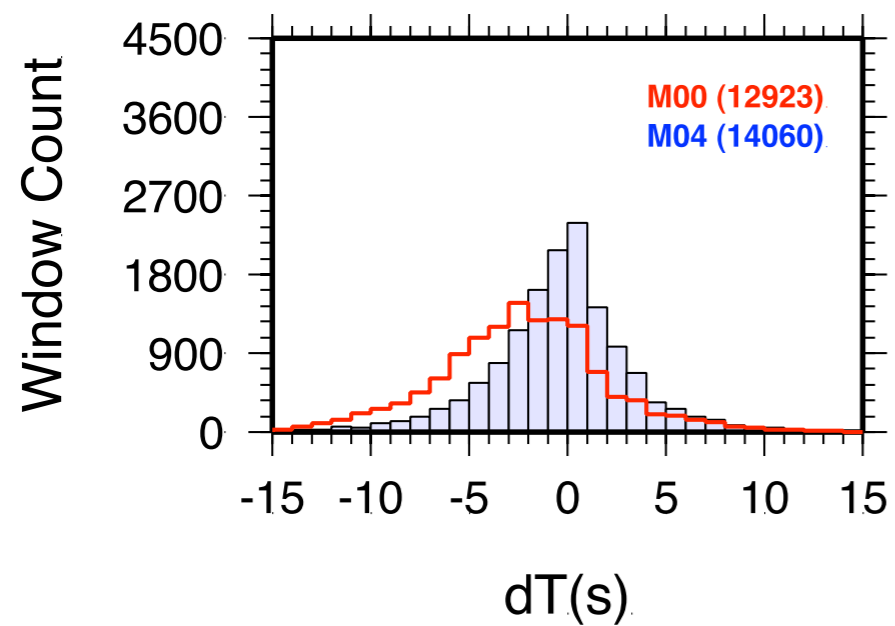
Radial



Transverse

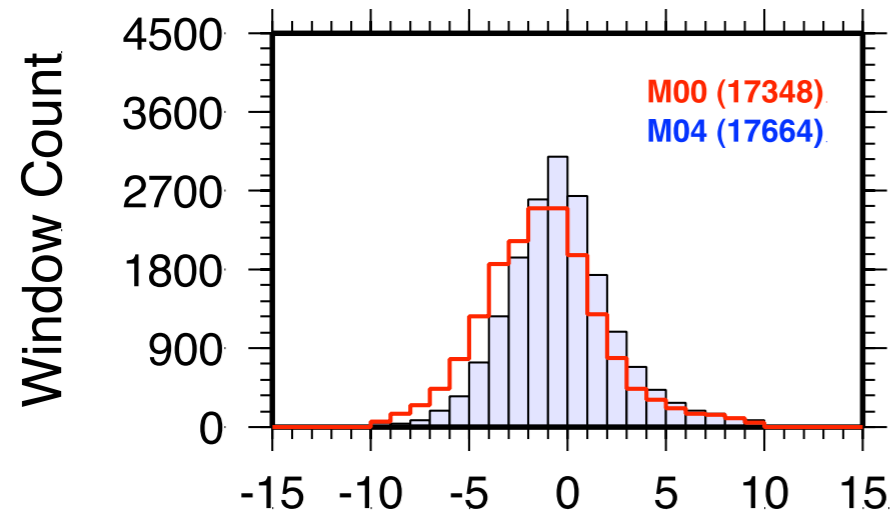


T050_150

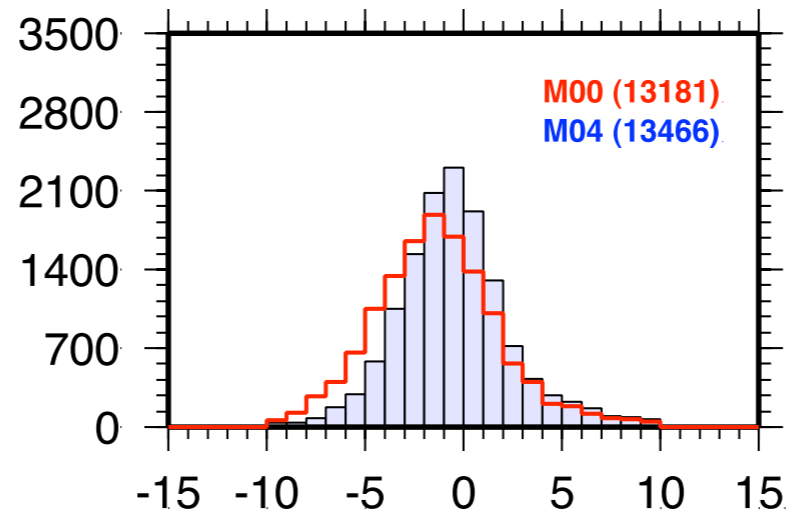


T015_040

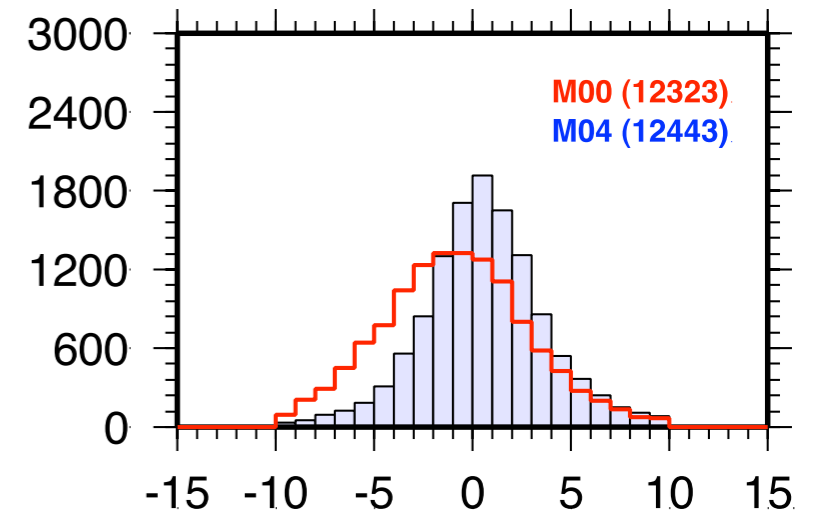
Vertical



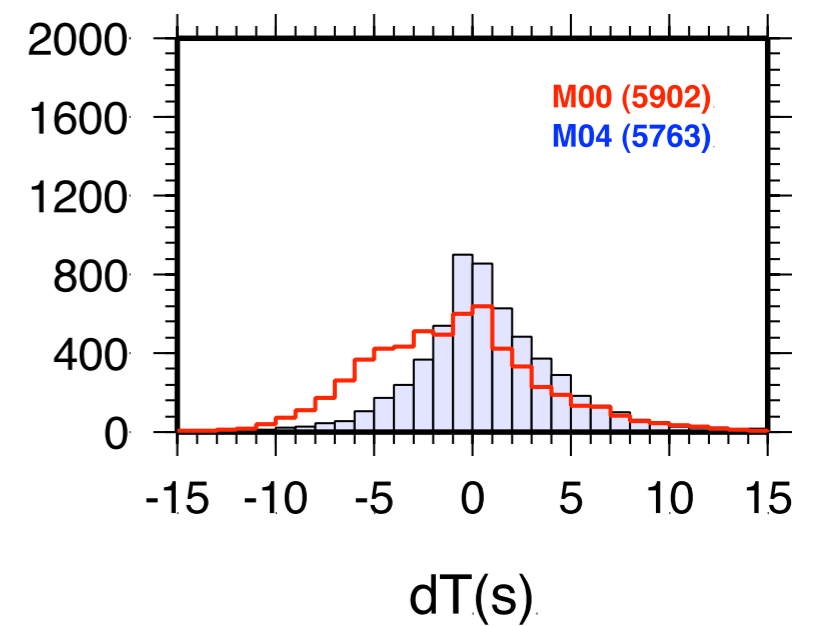
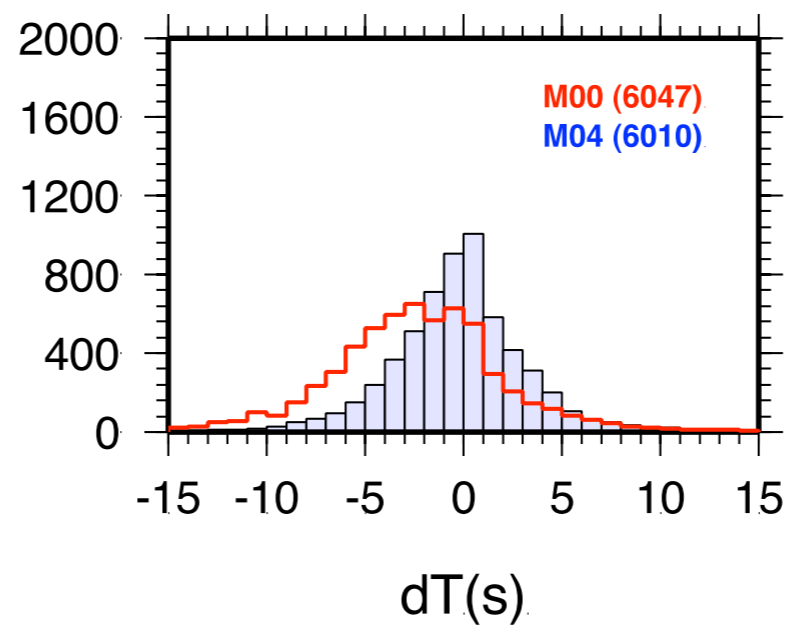
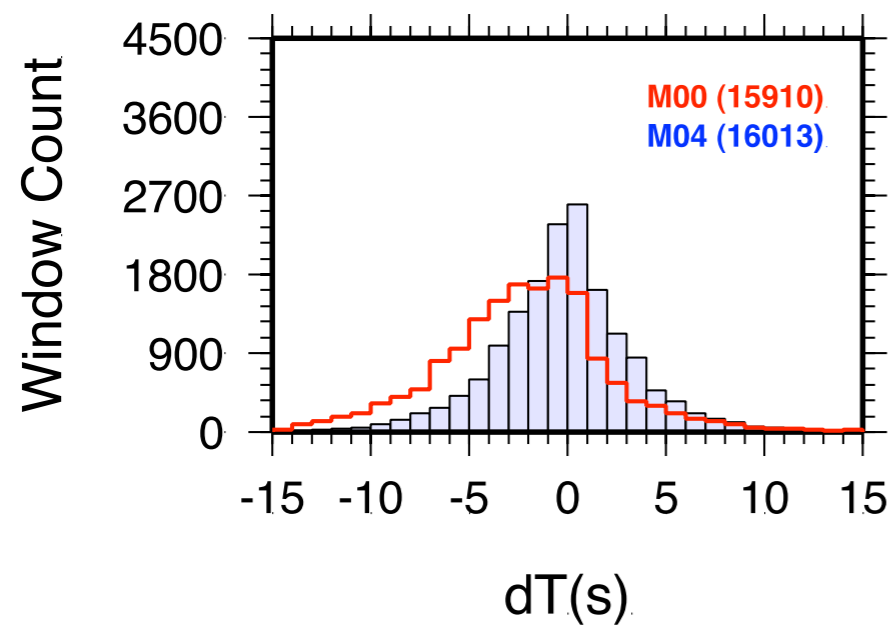
Radial



Transverse

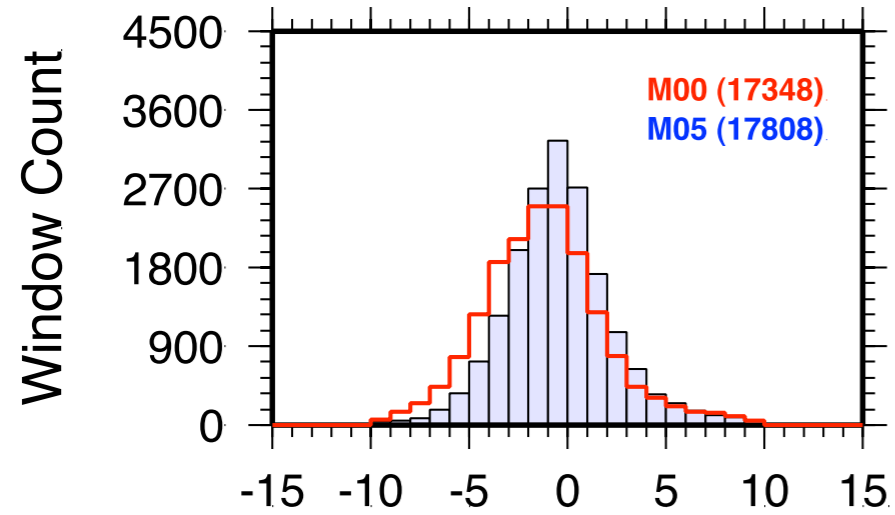


T040_150

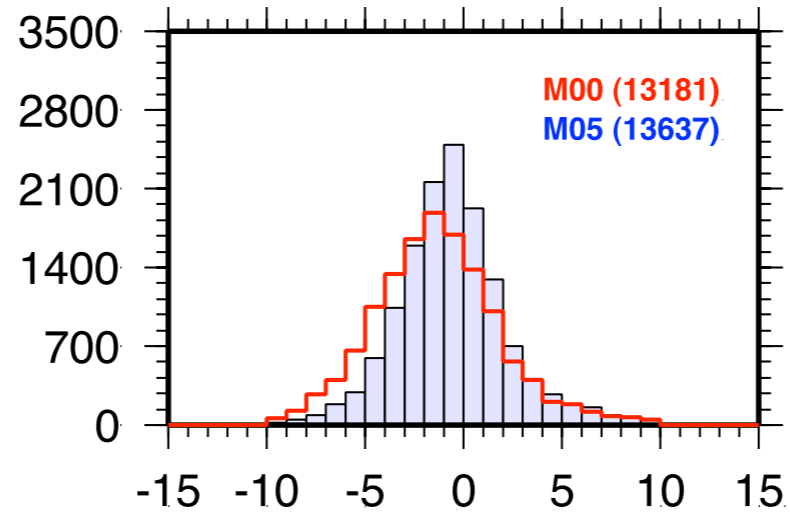


T015_040

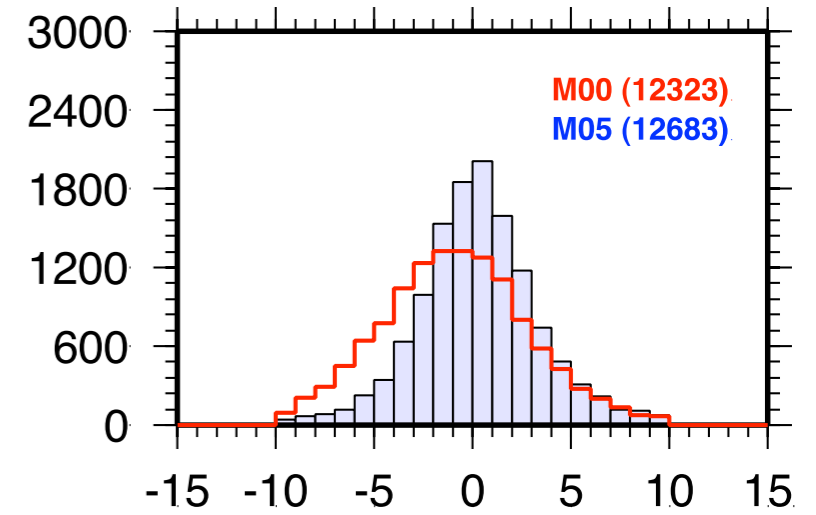
Vertical



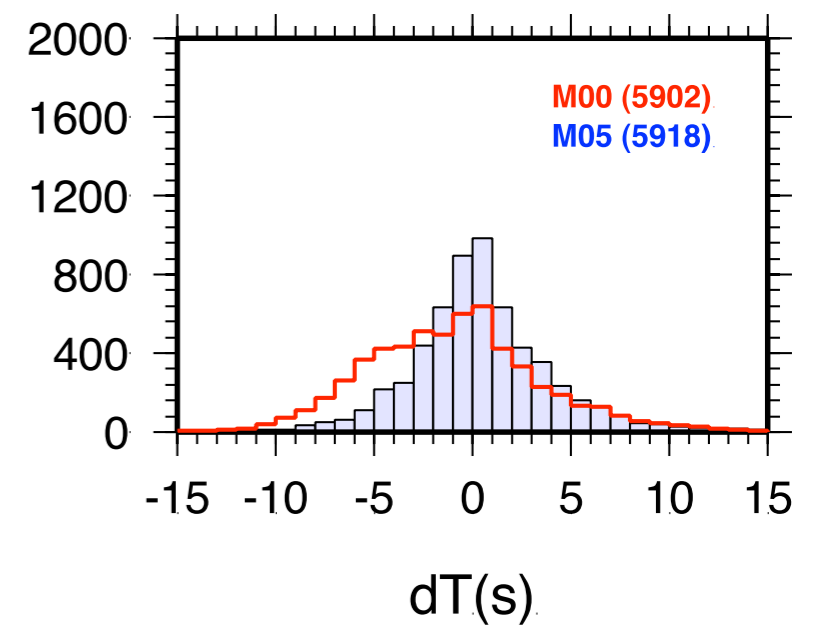
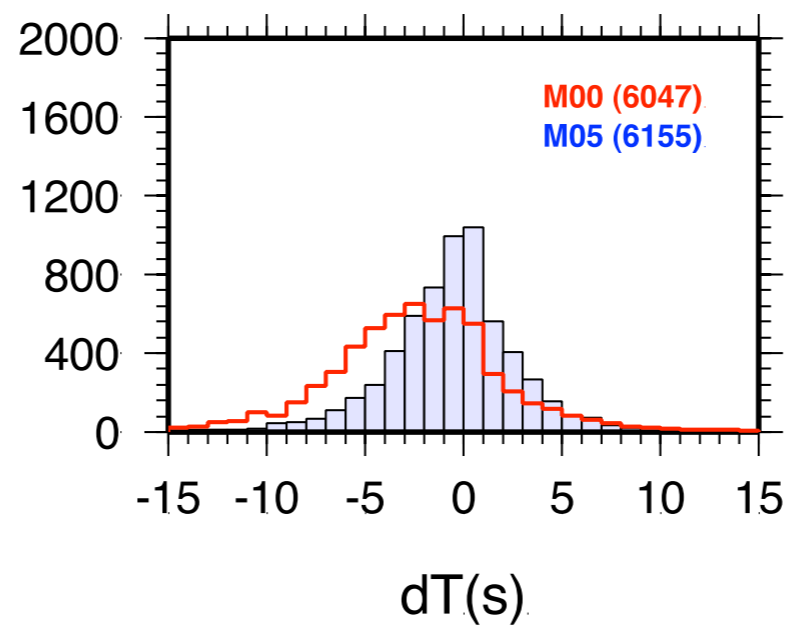
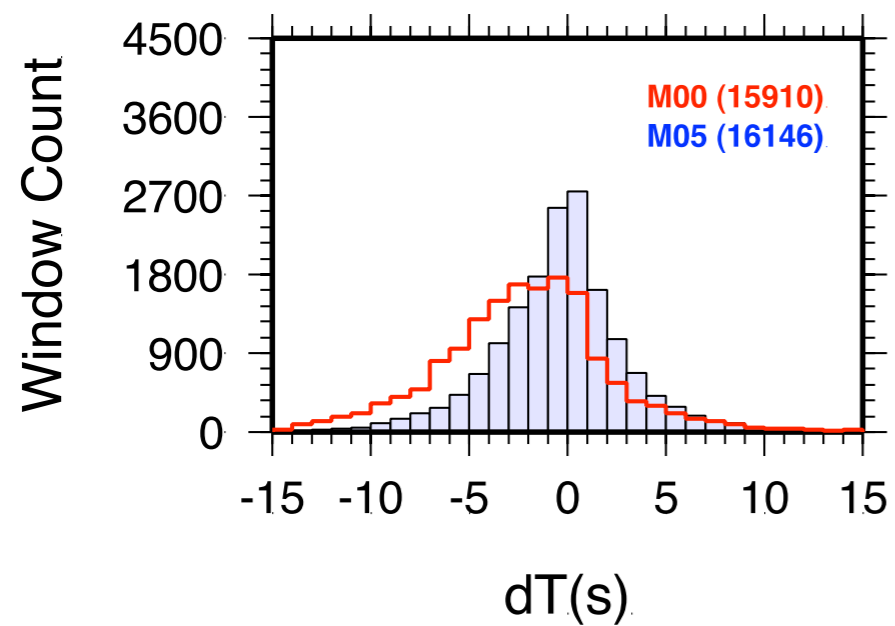
Radial



Transverse

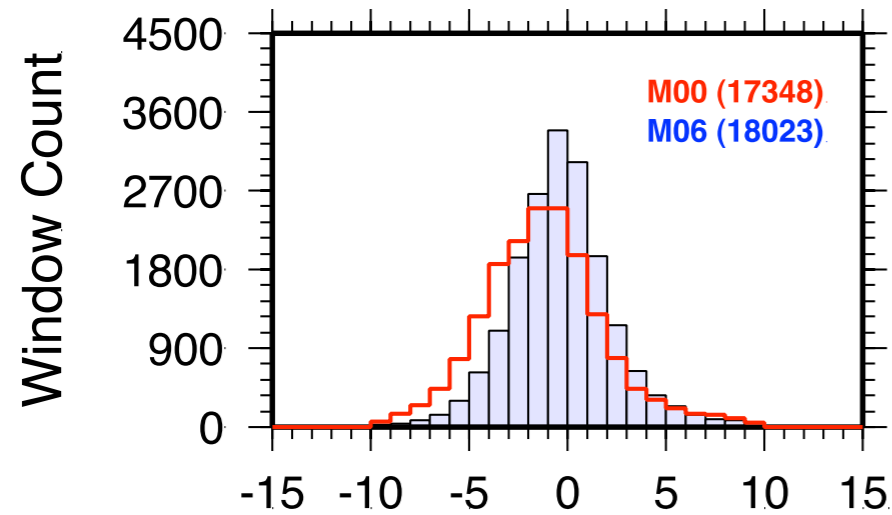


T040_150

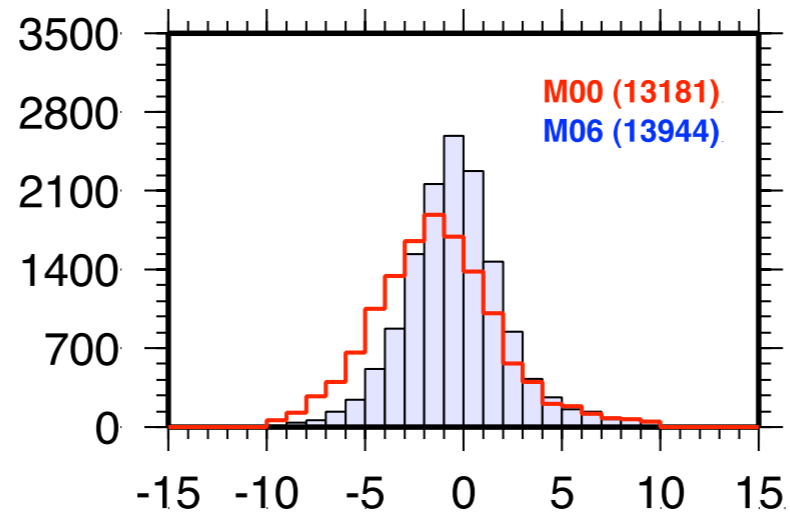


T015_040

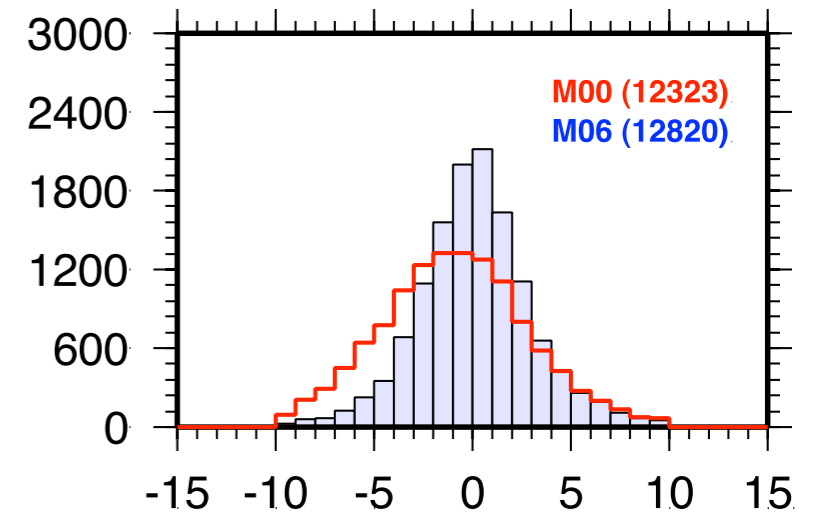
Vertical



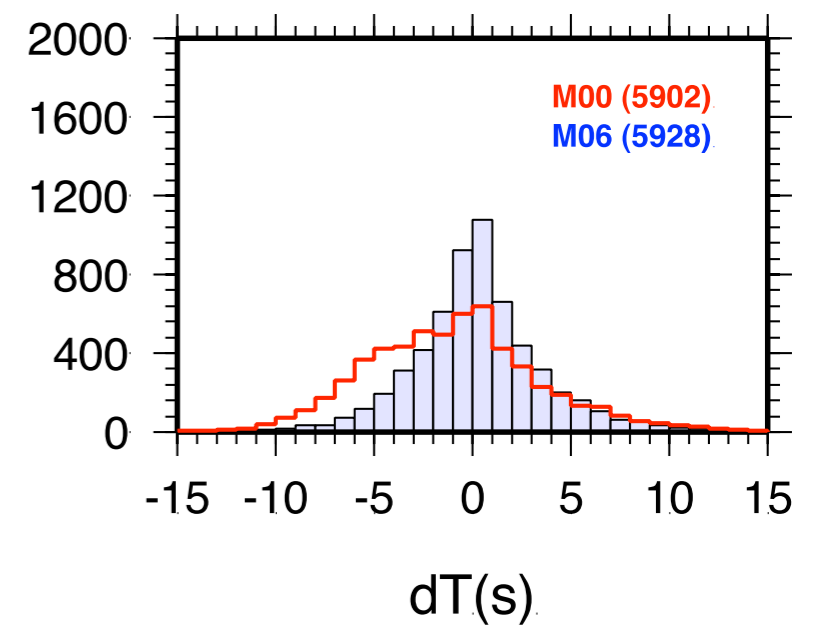
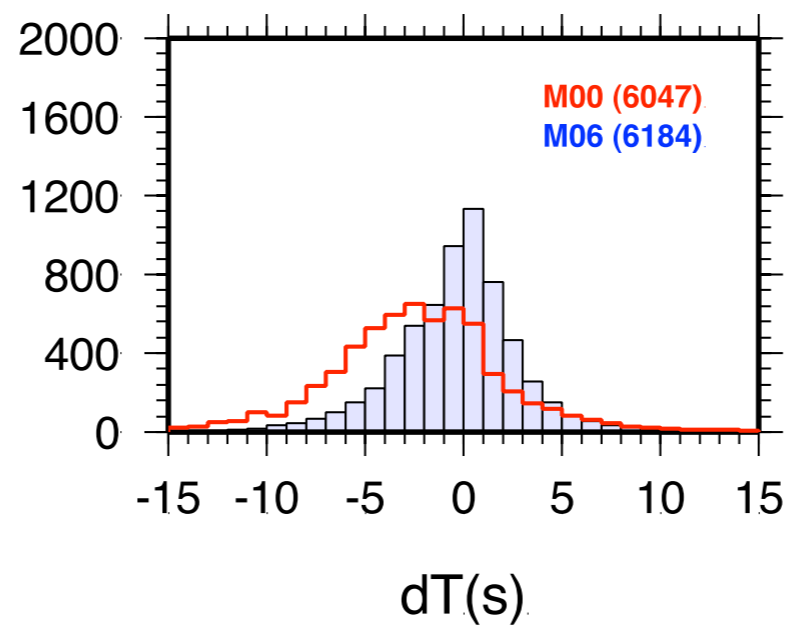
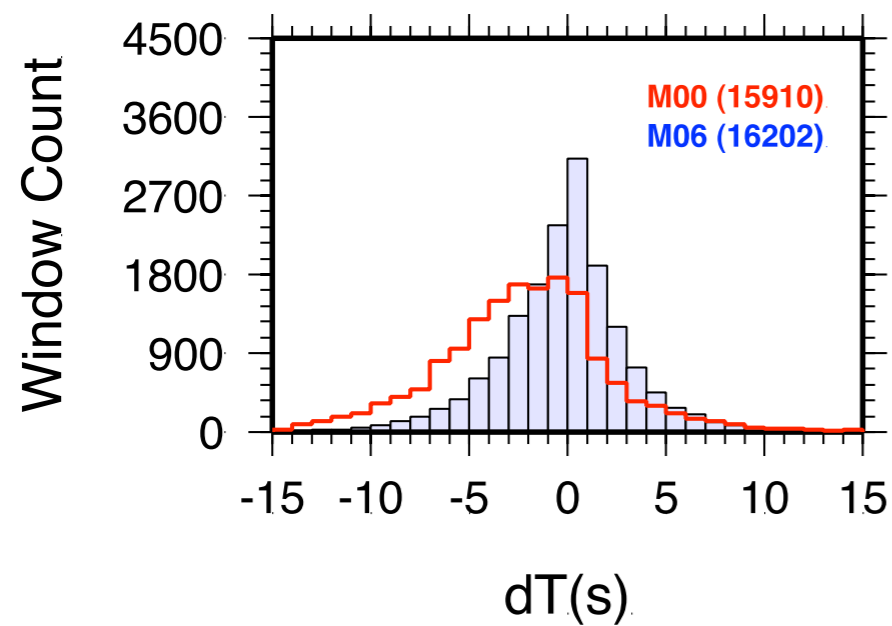
Radial



Transverse

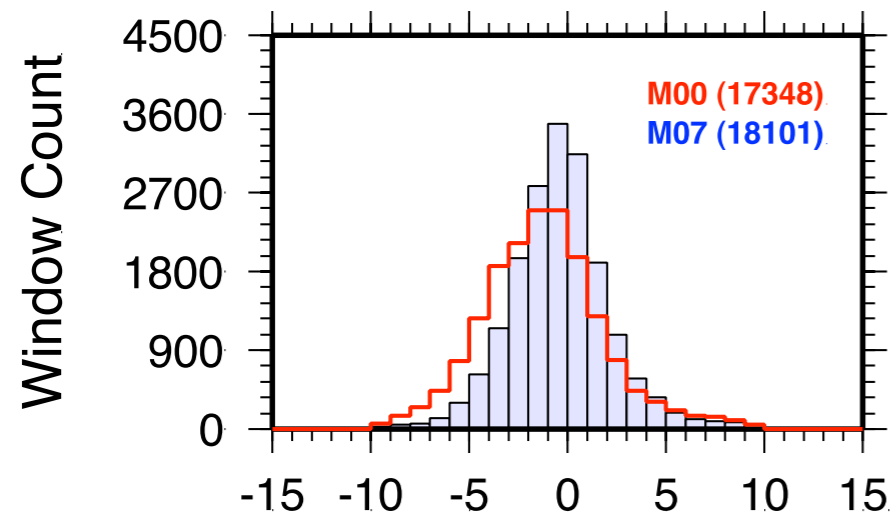


T040_150

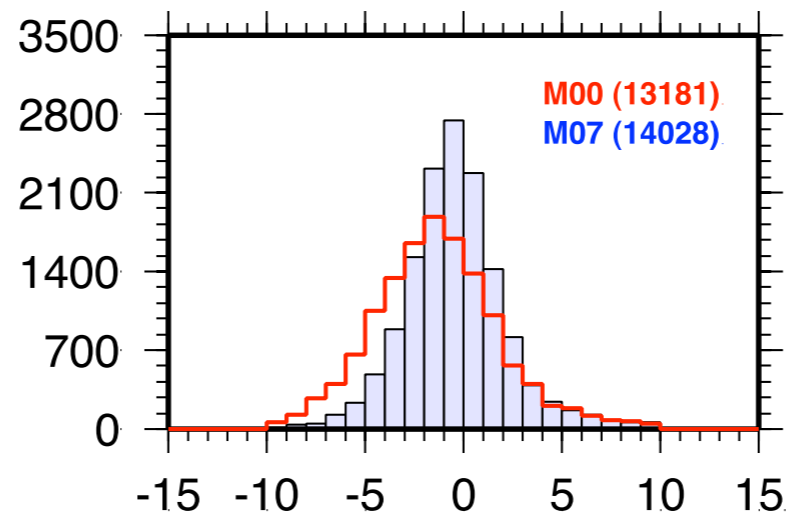


T015_040

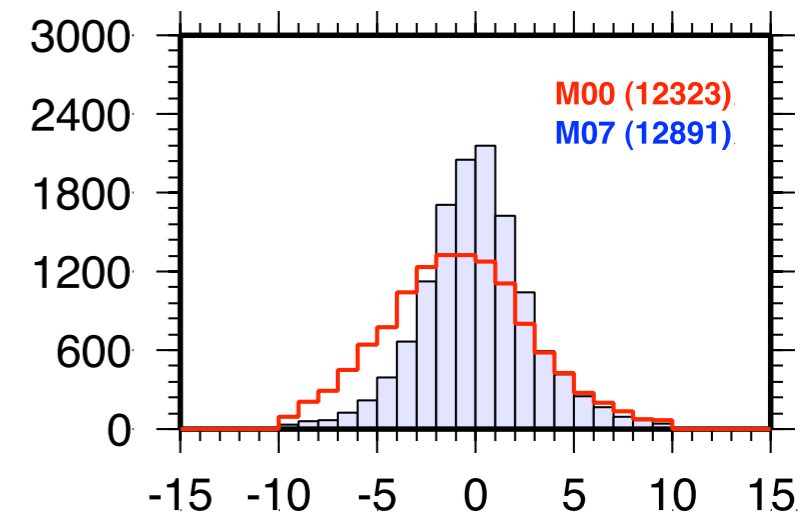
Vertical



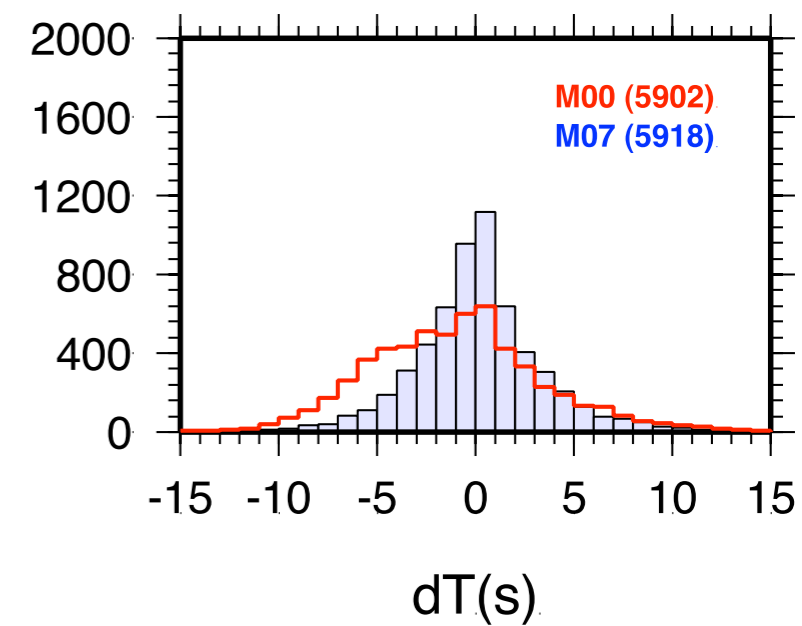
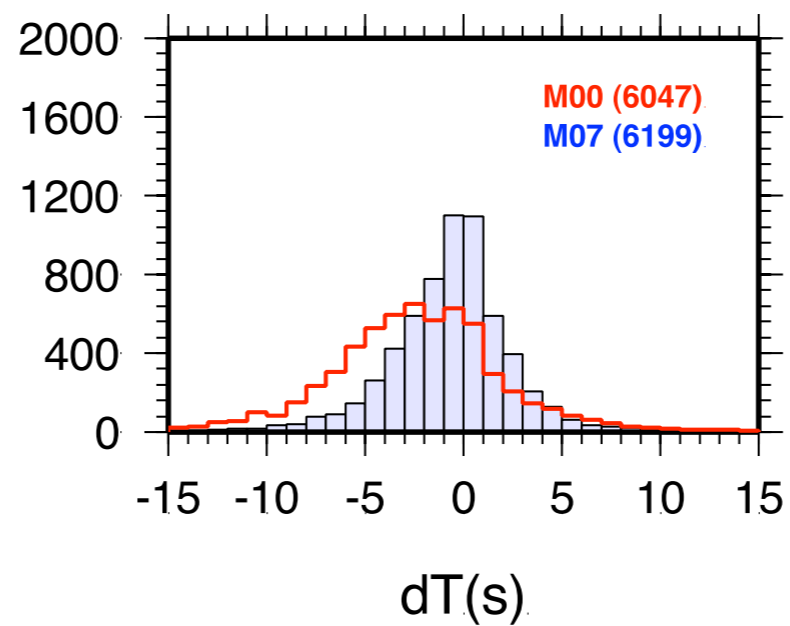
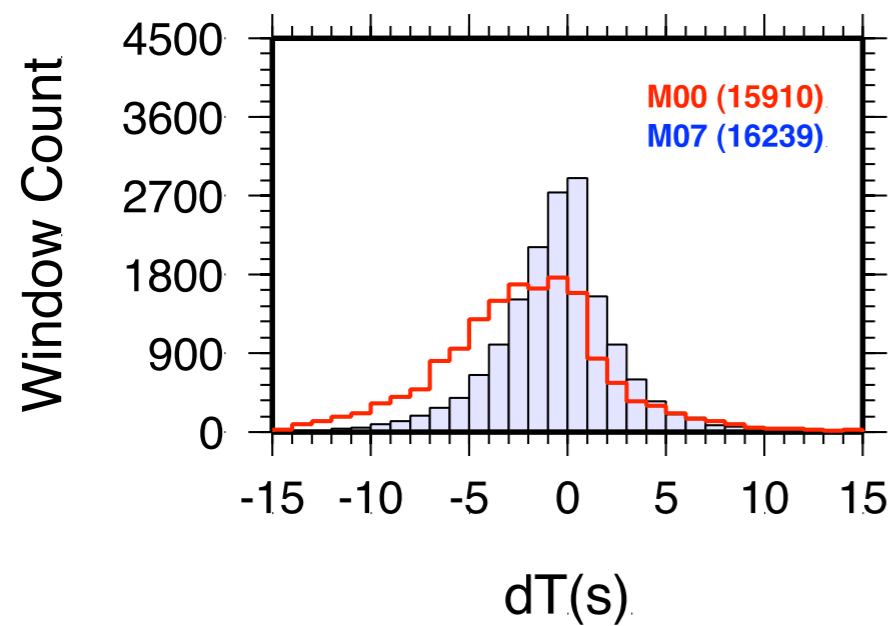
Radial



Transverse

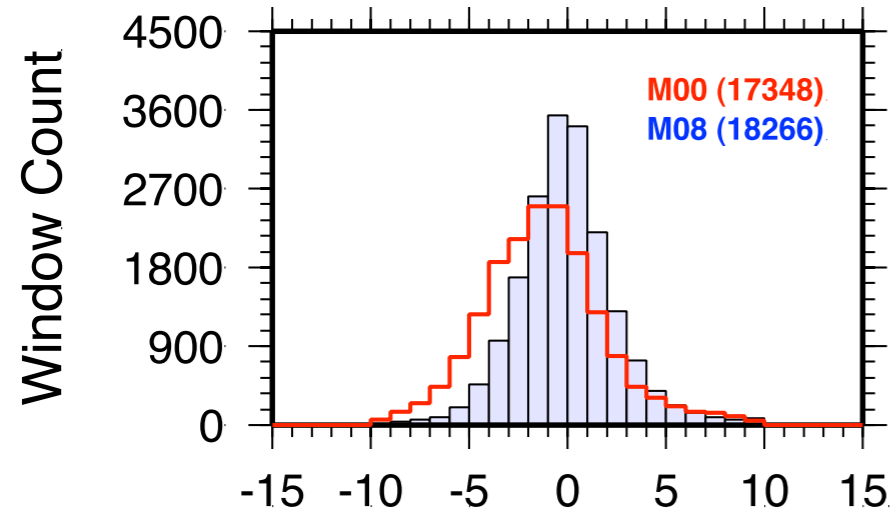


T040_150

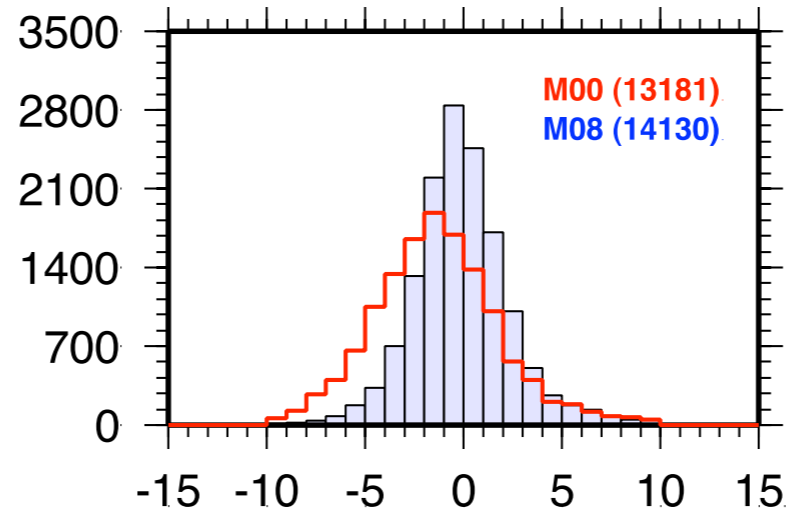


T015_040

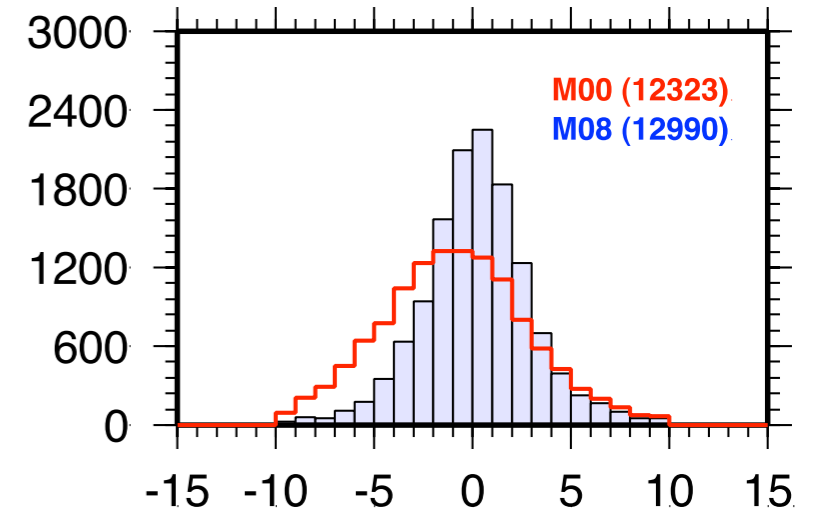
Vertical



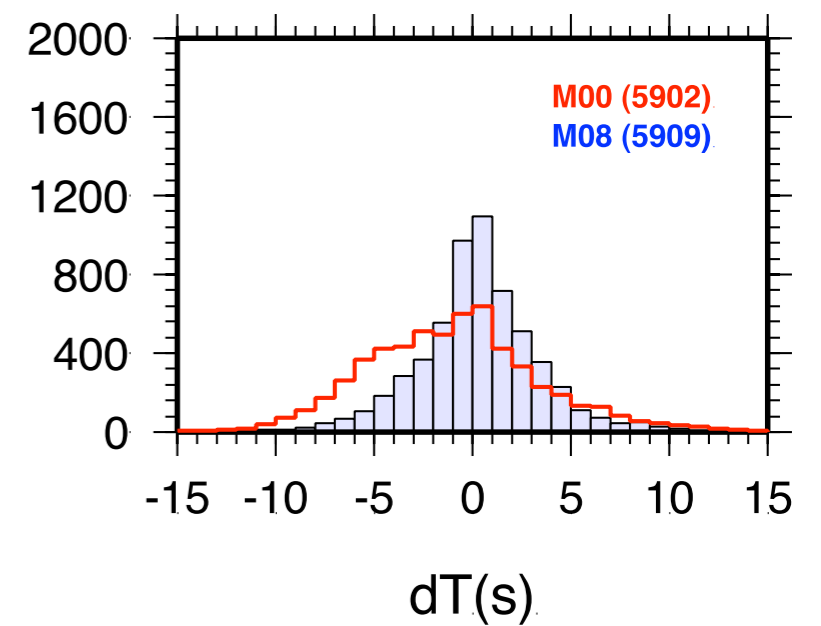
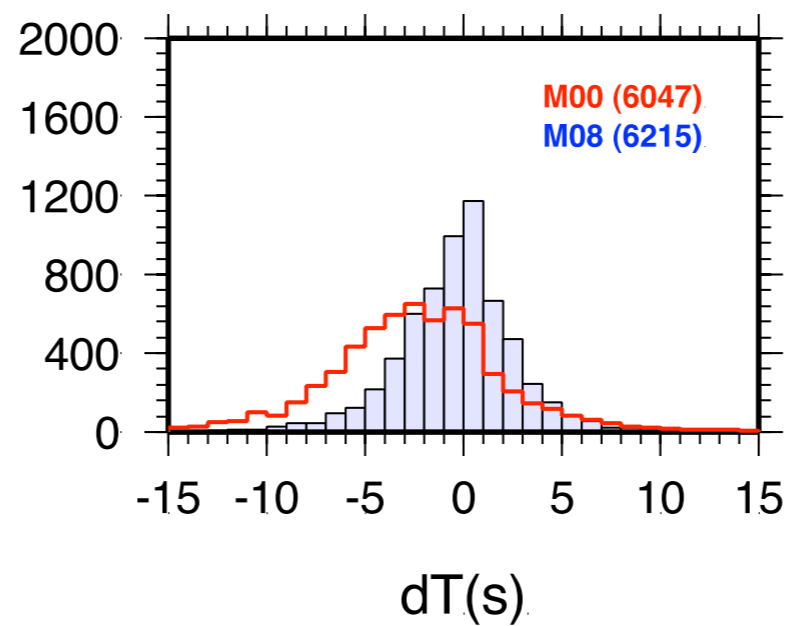
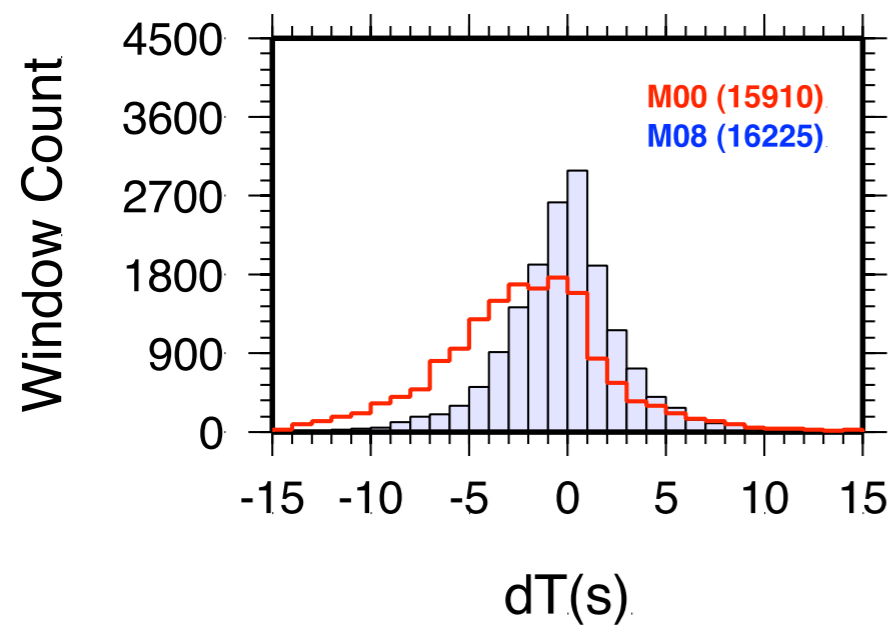
Radial



Transverse



T040_150

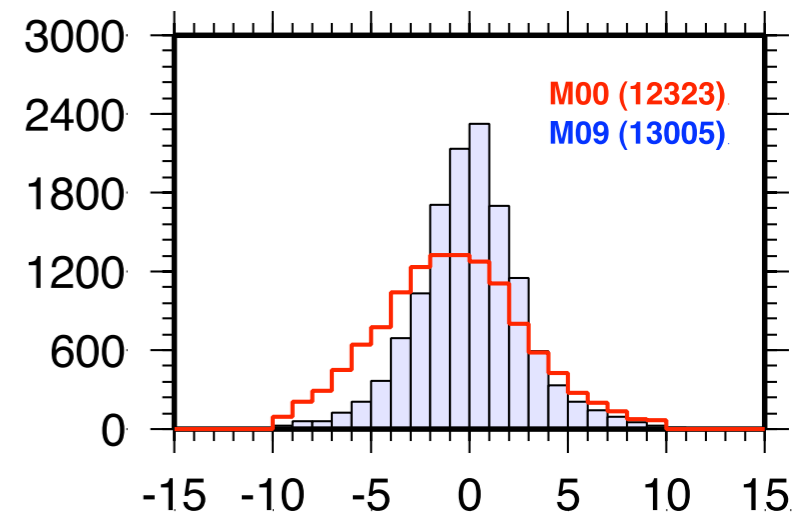
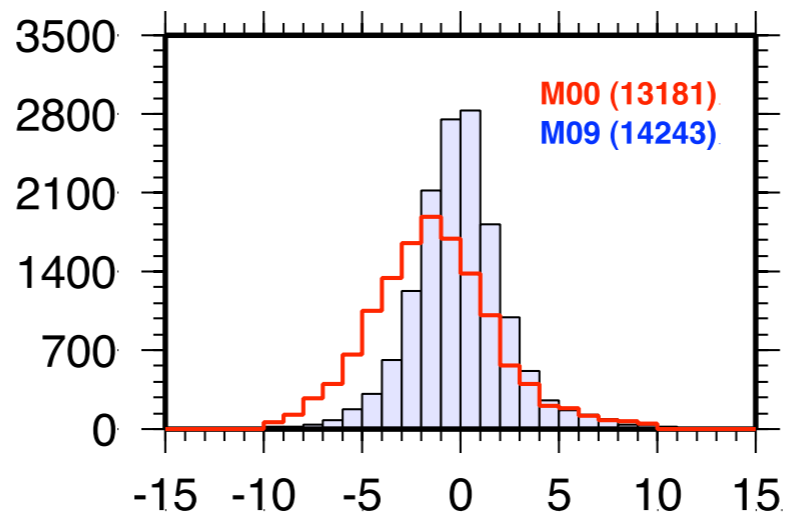
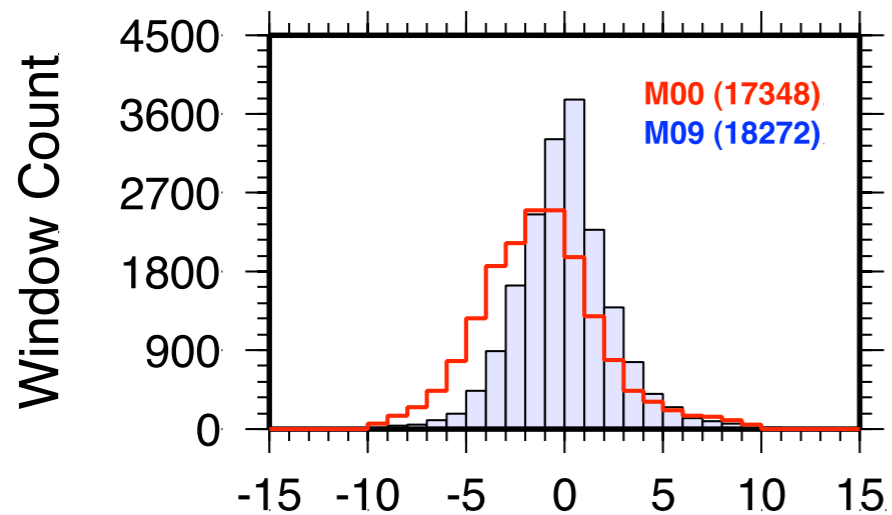


T015_040

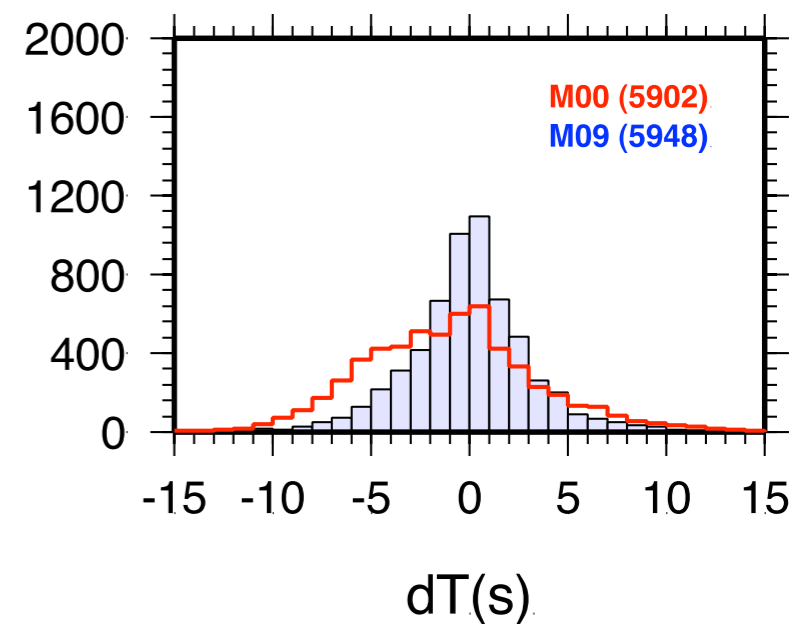
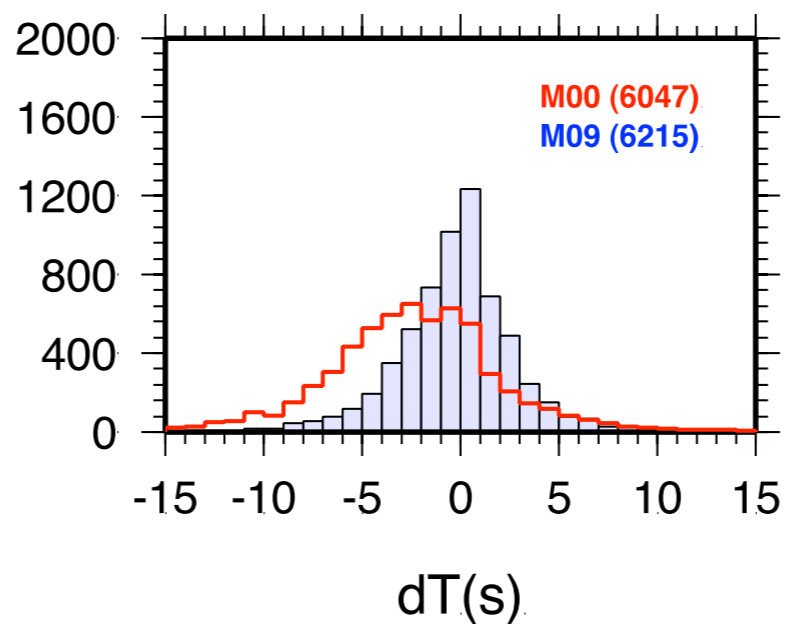
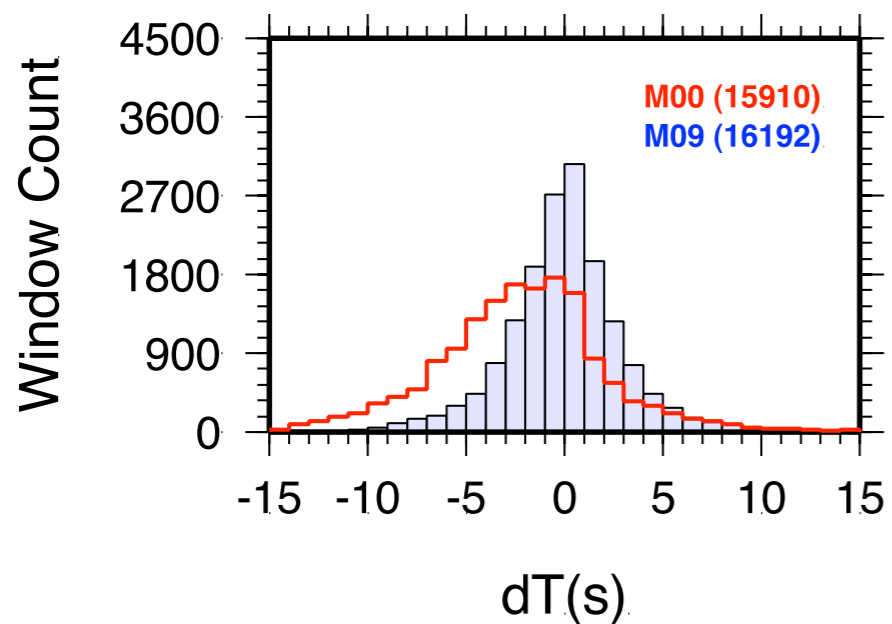
Vertical

Radial

Transverse



T040_150

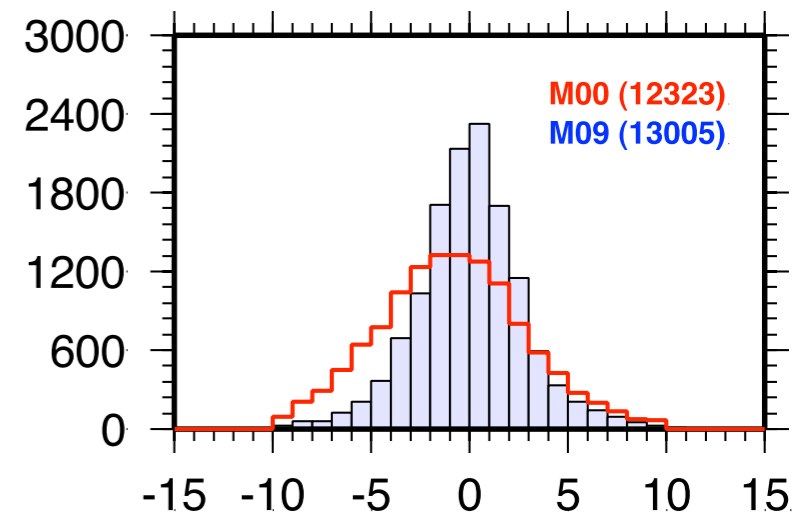
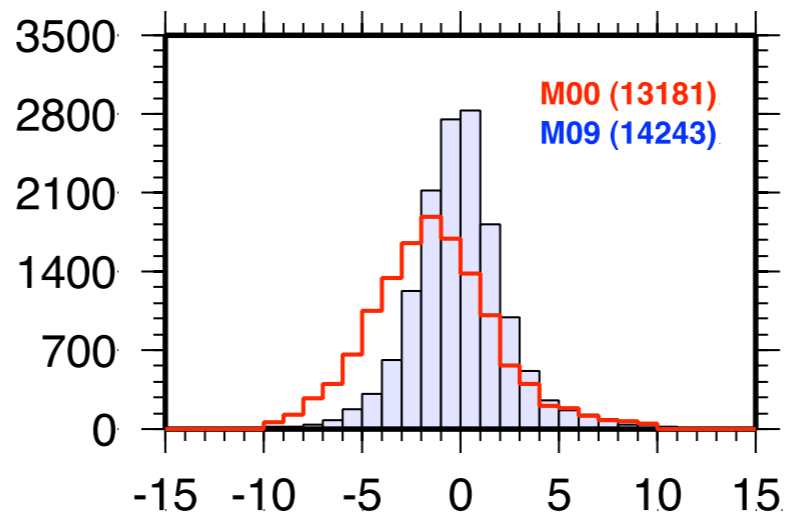
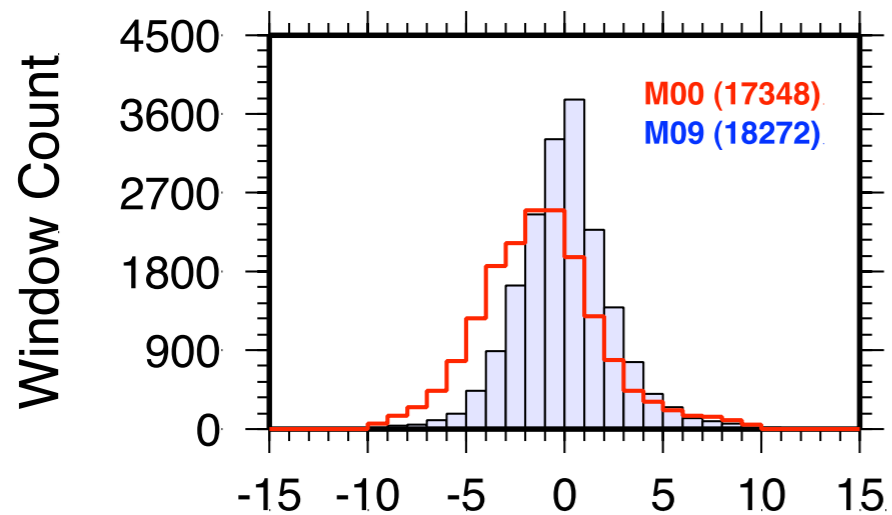


T015_040

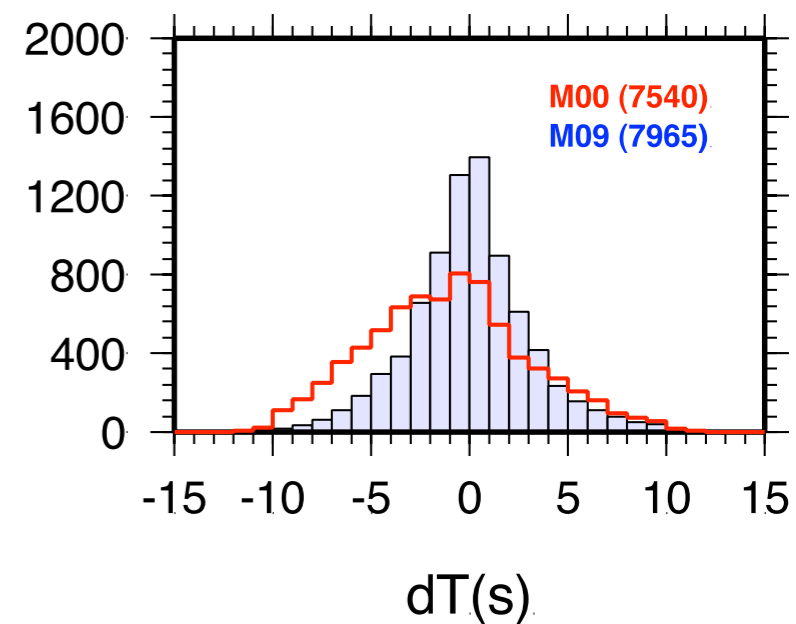
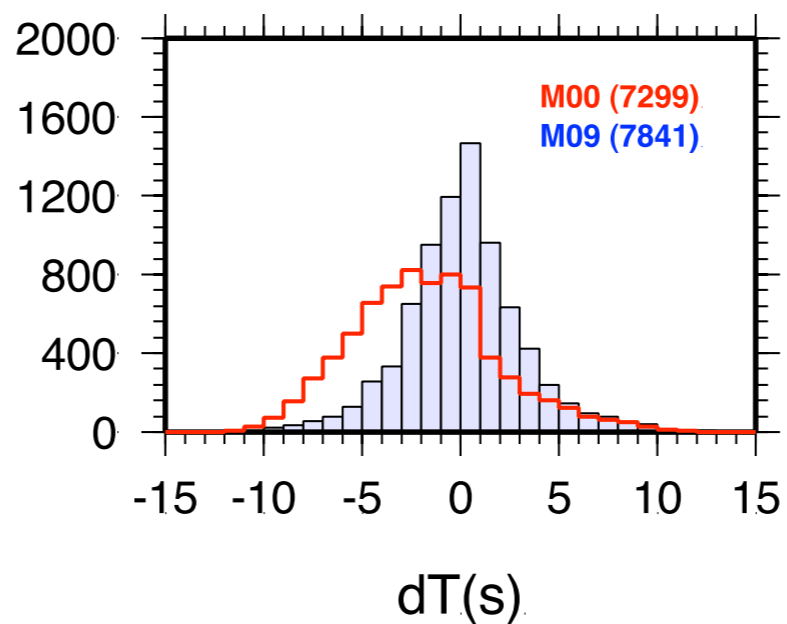
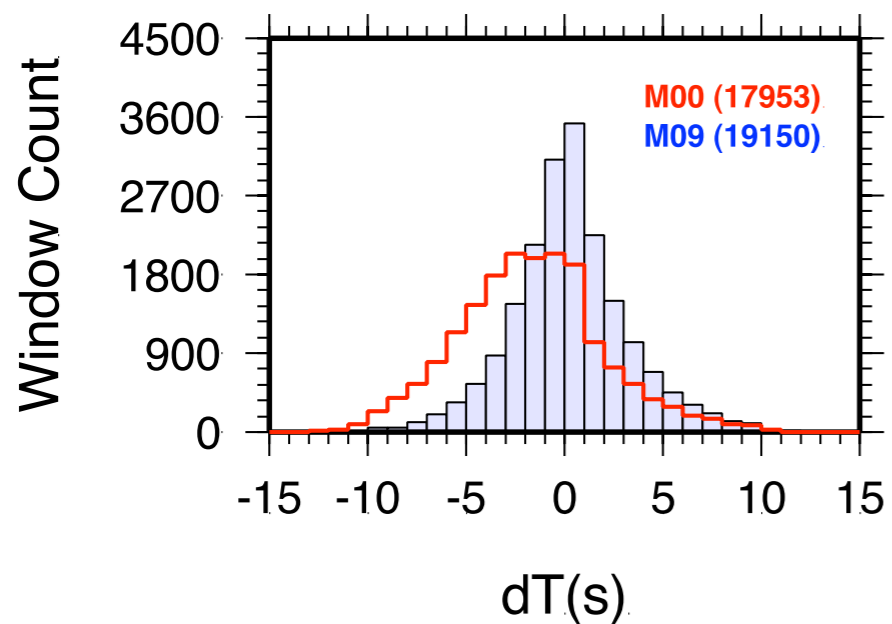
Vertical

Radial

Transverse



T030_150

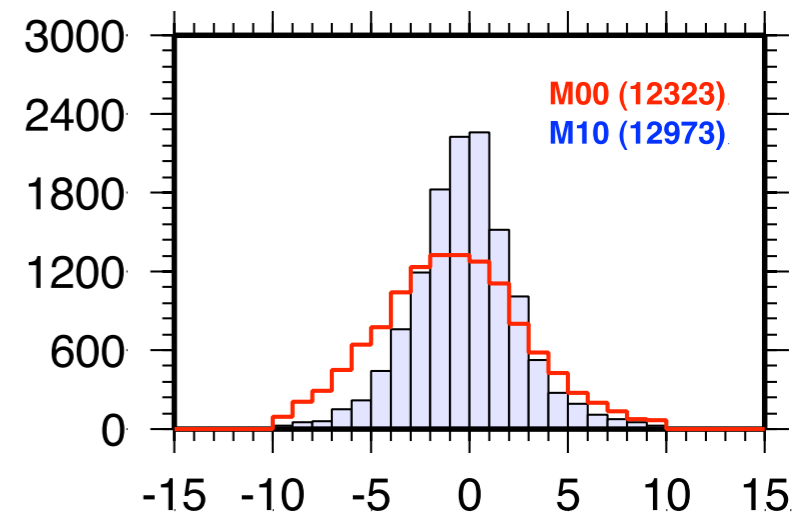
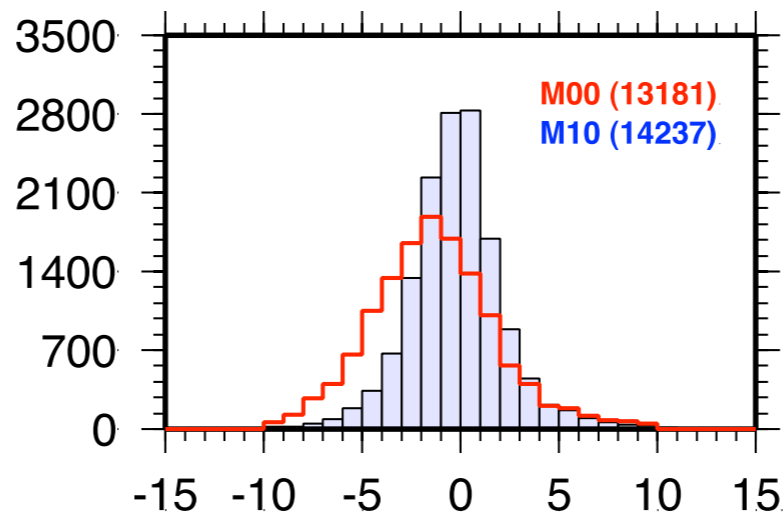
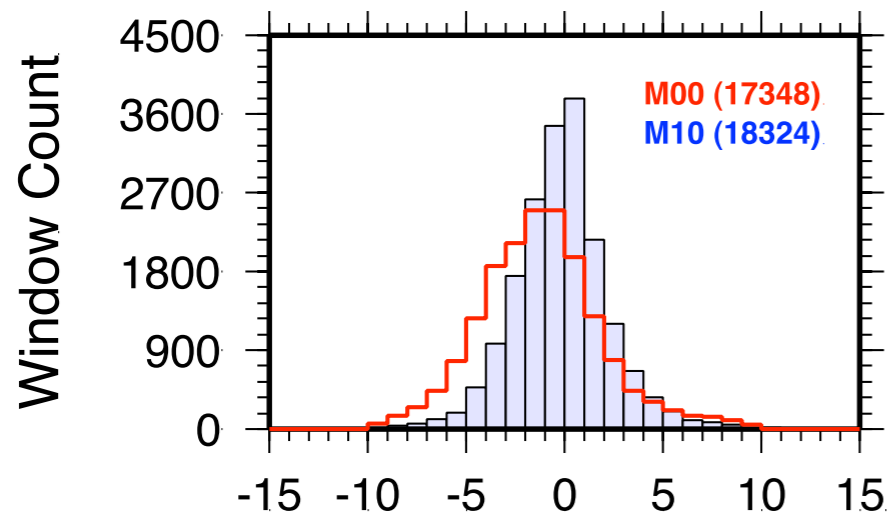


T015_040

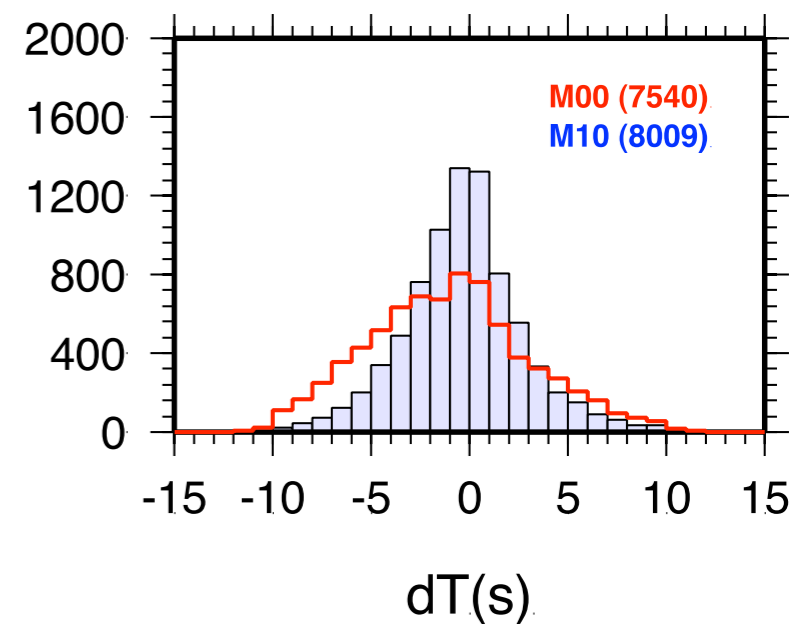
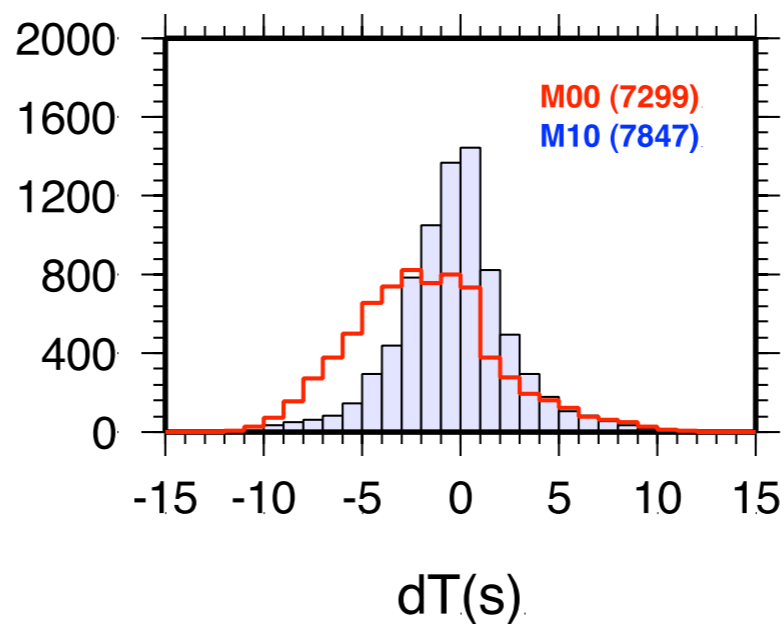
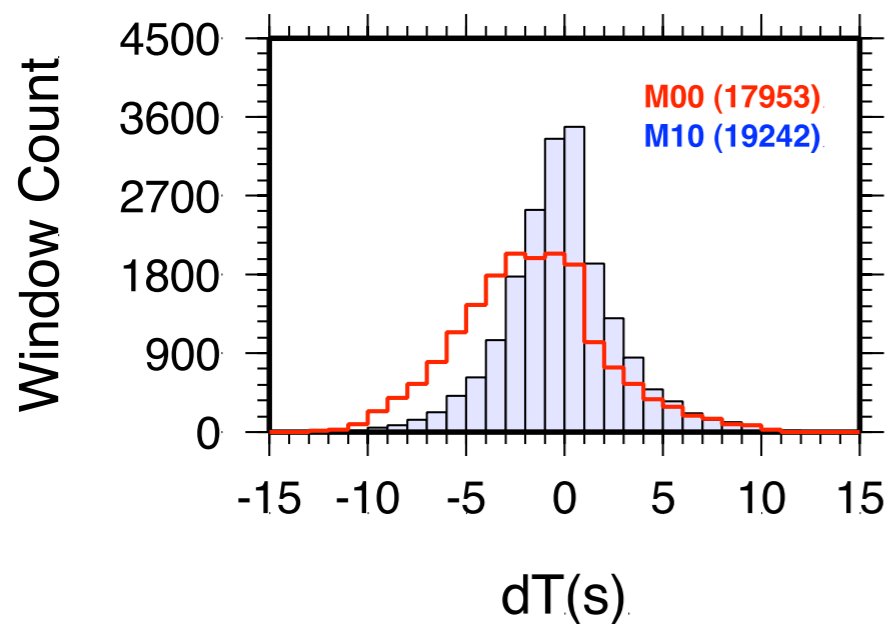
Vertical

Radial

Transverse

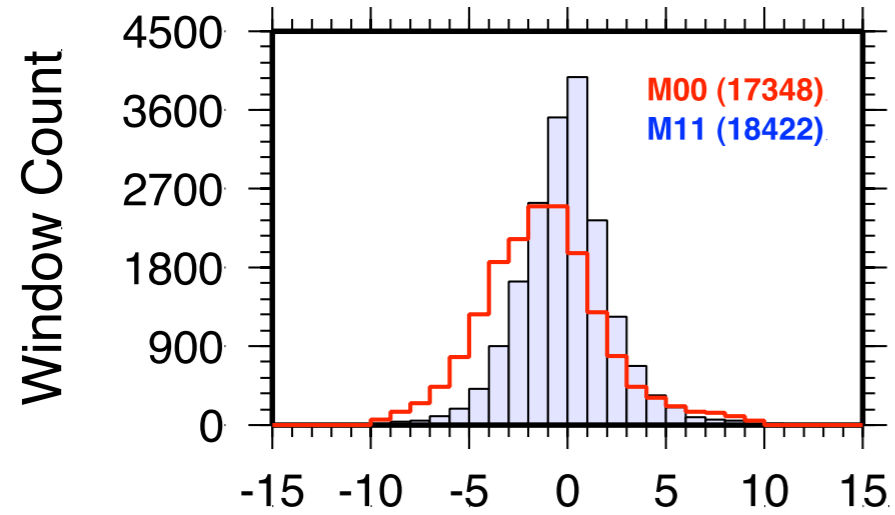


T030_150

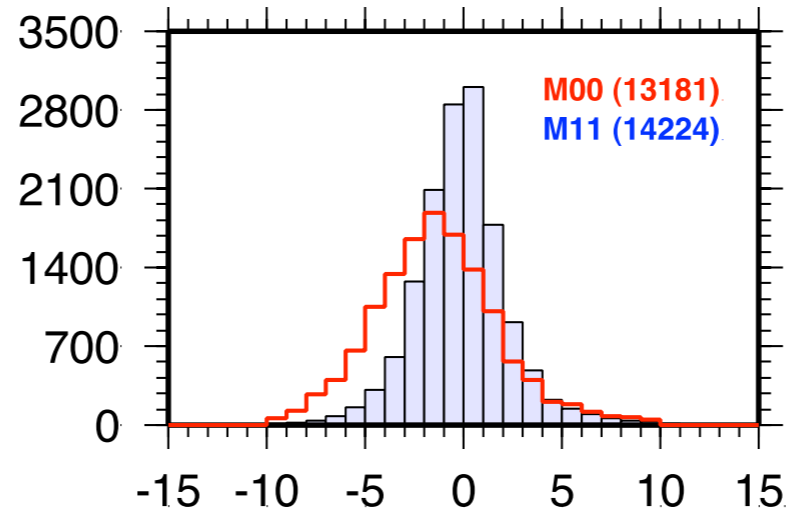


T015_040

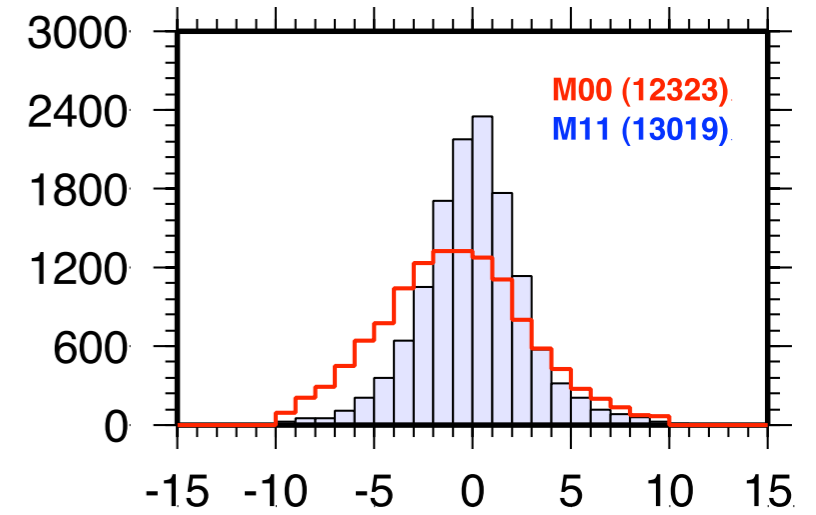
Vertical



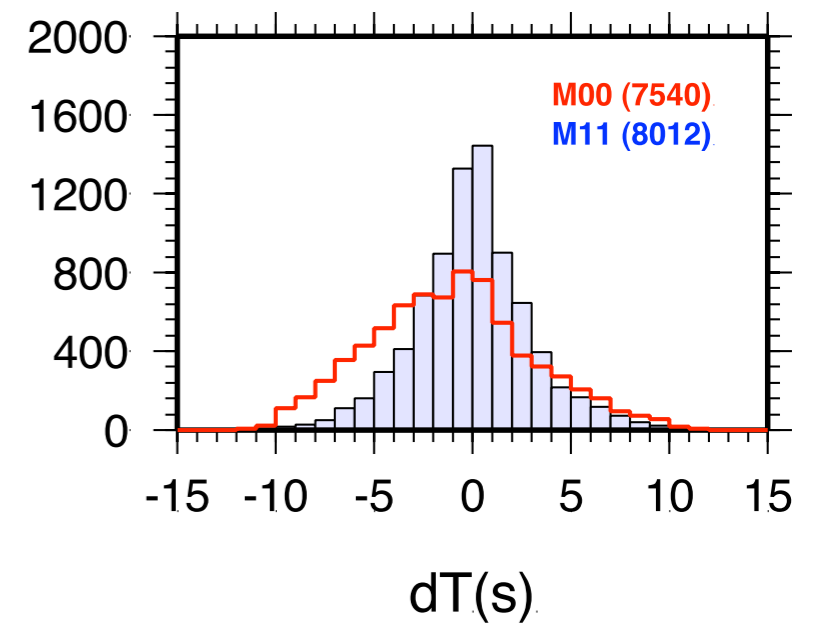
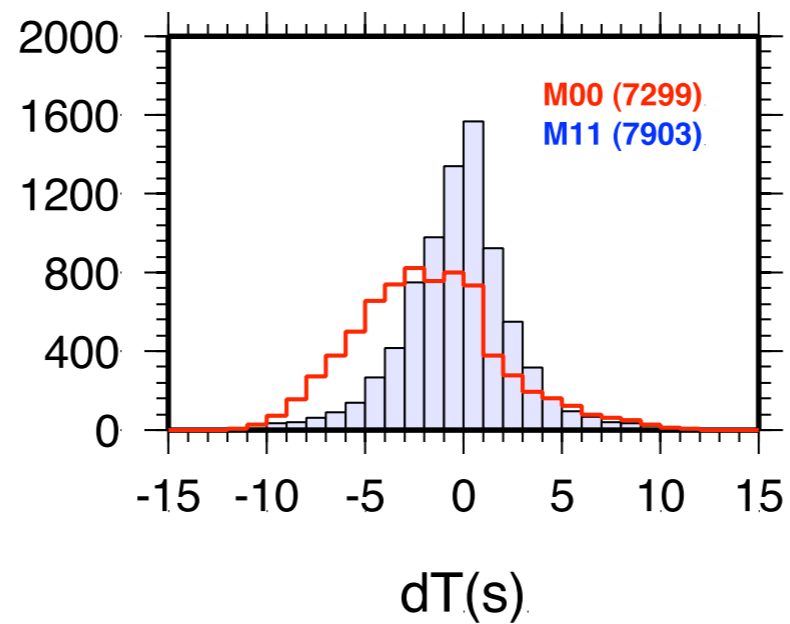
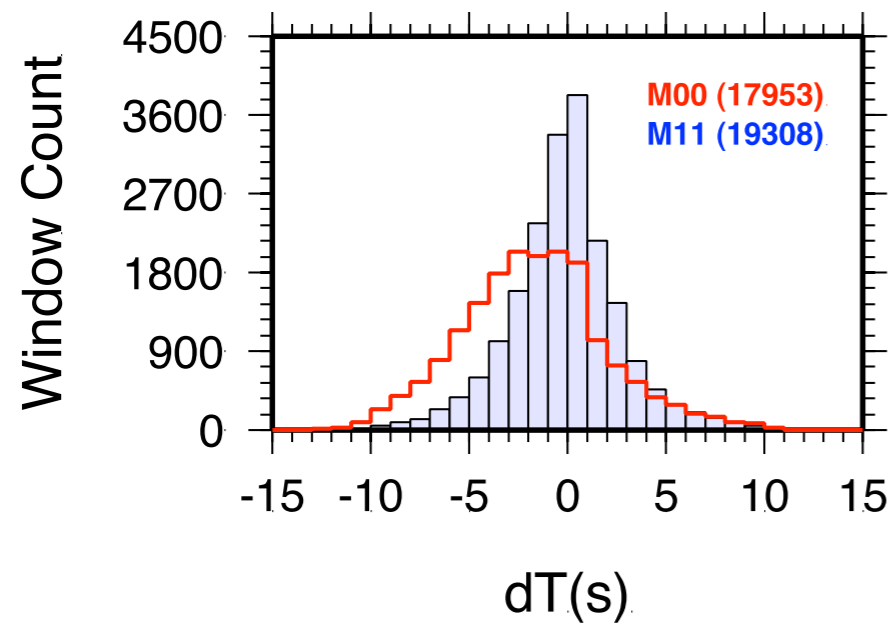
Radial



Transverse



T030_150

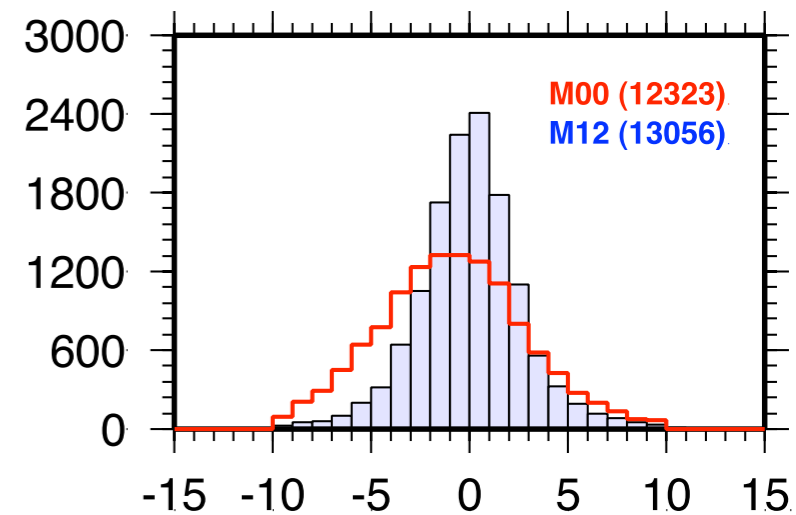
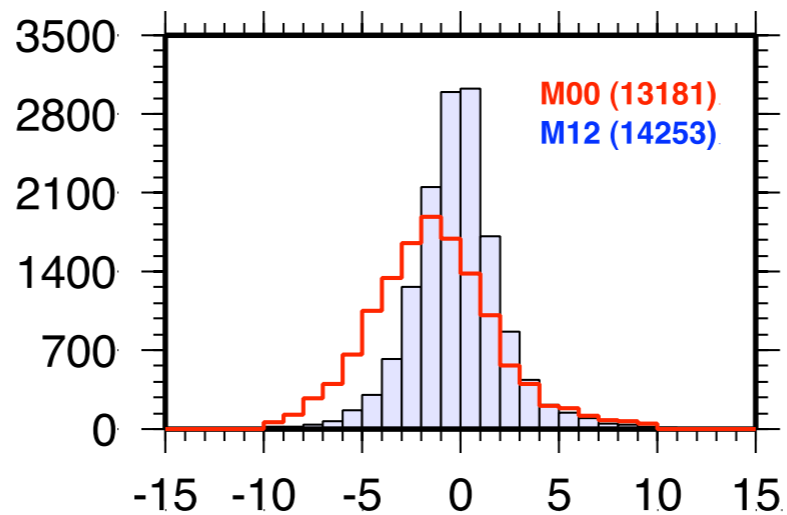
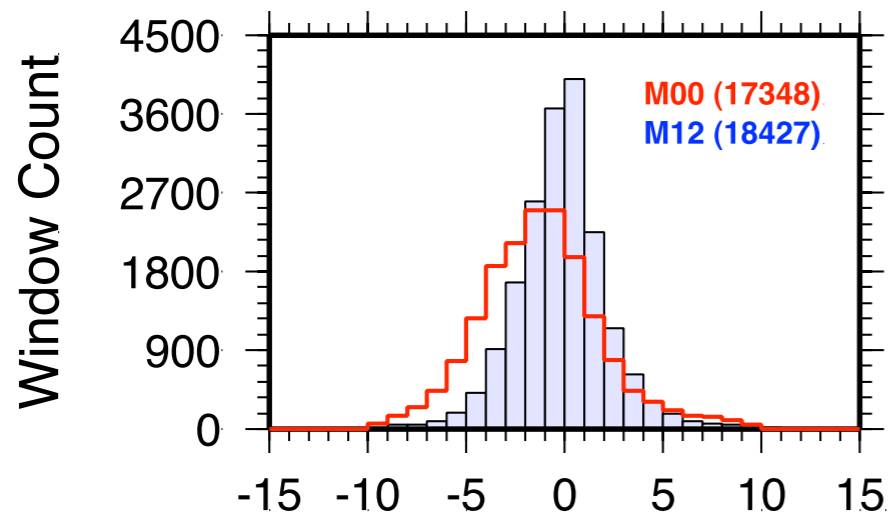


T015_040

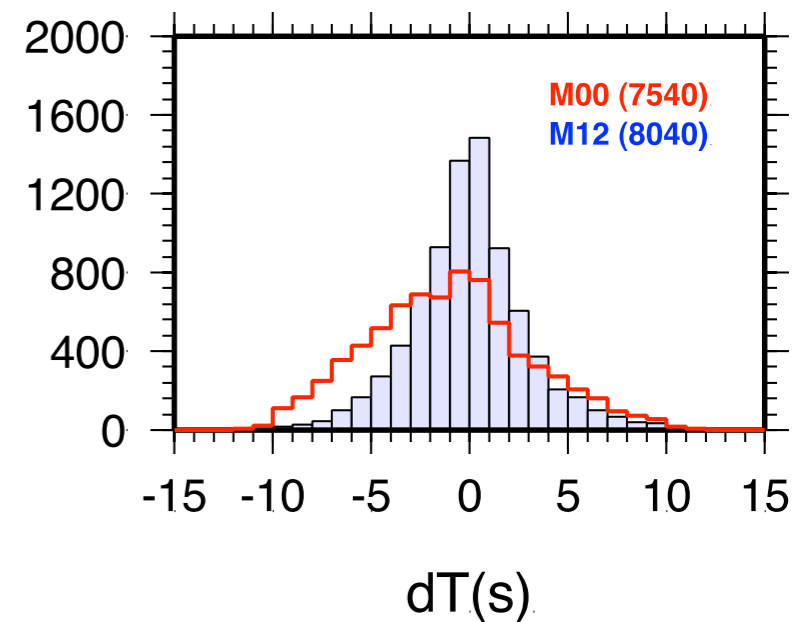
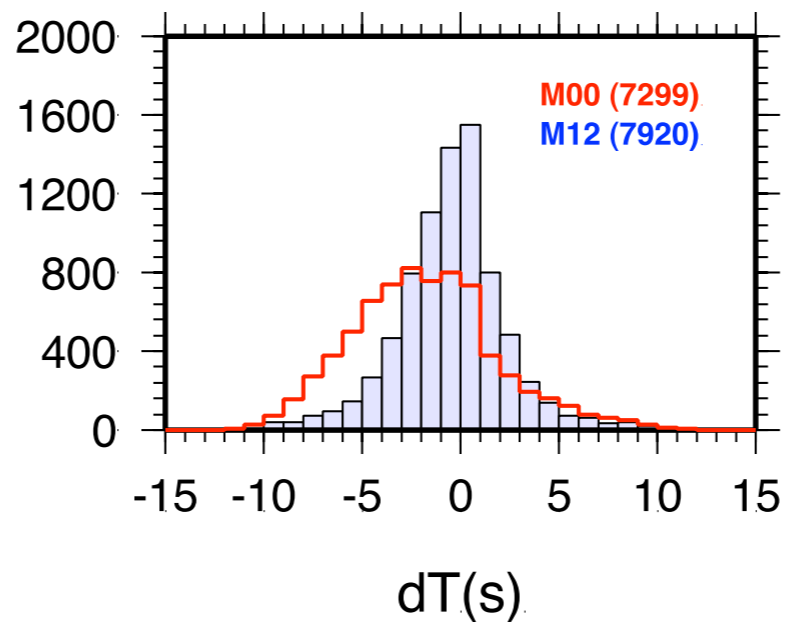
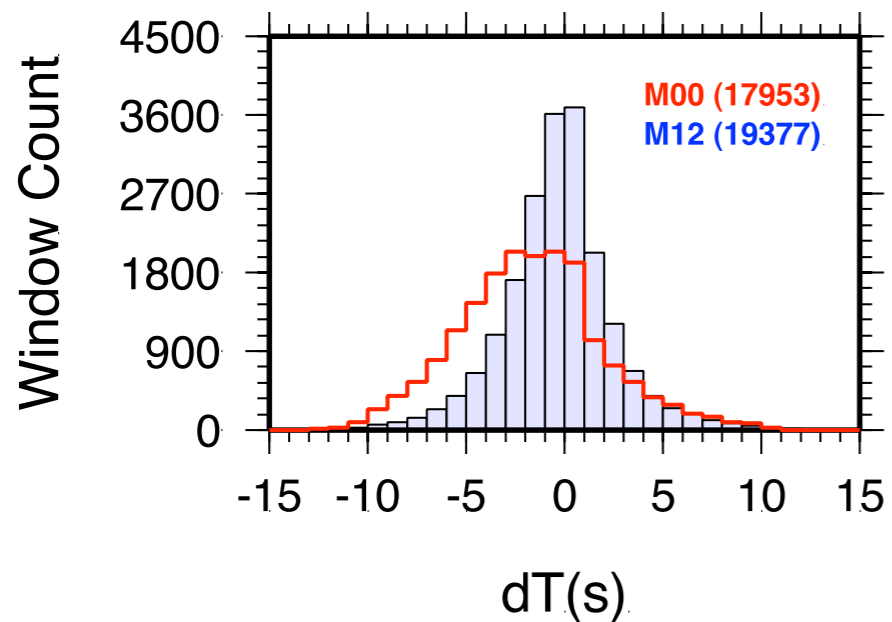
Vertical

Radial

Transverse

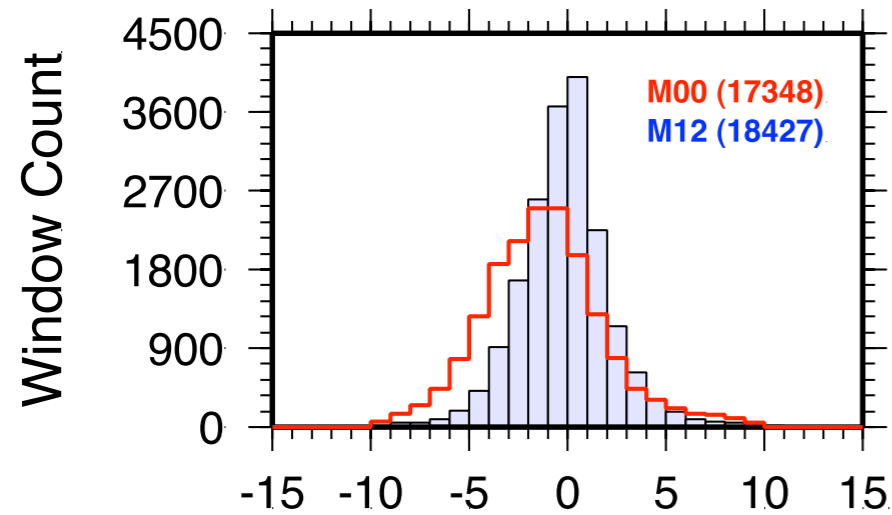


T030_150

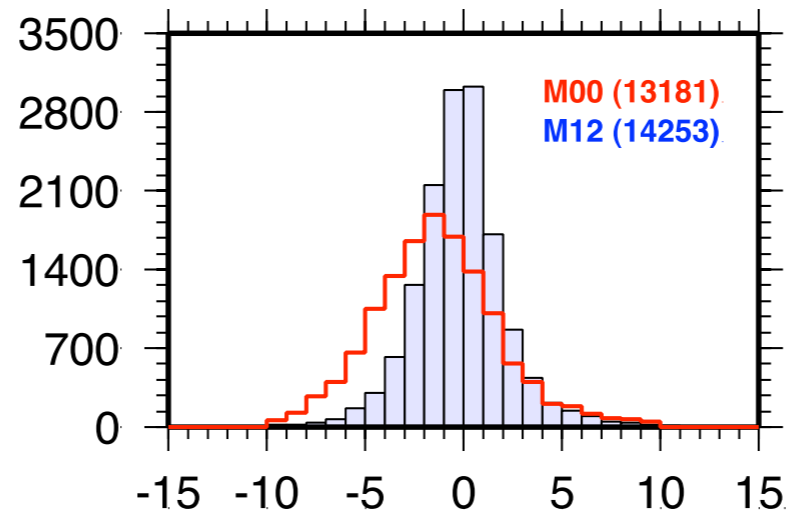


T015_040

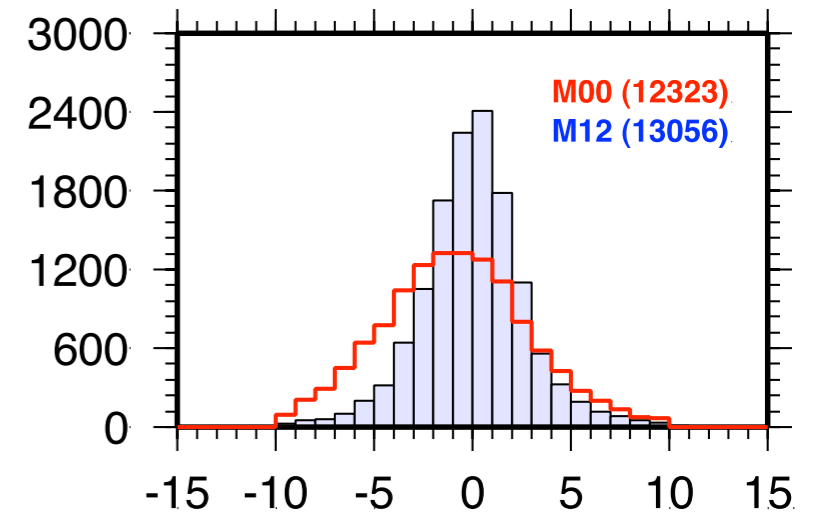
Vertical



Radial

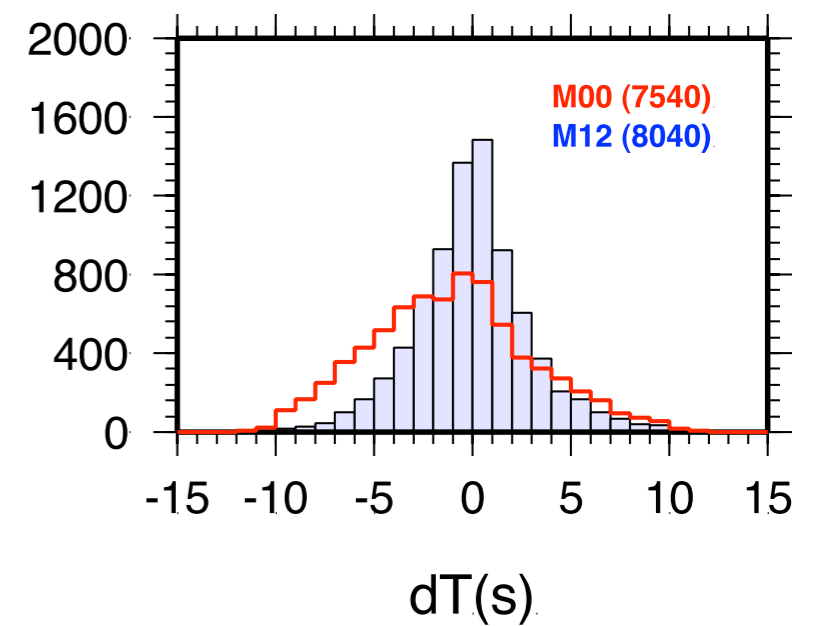
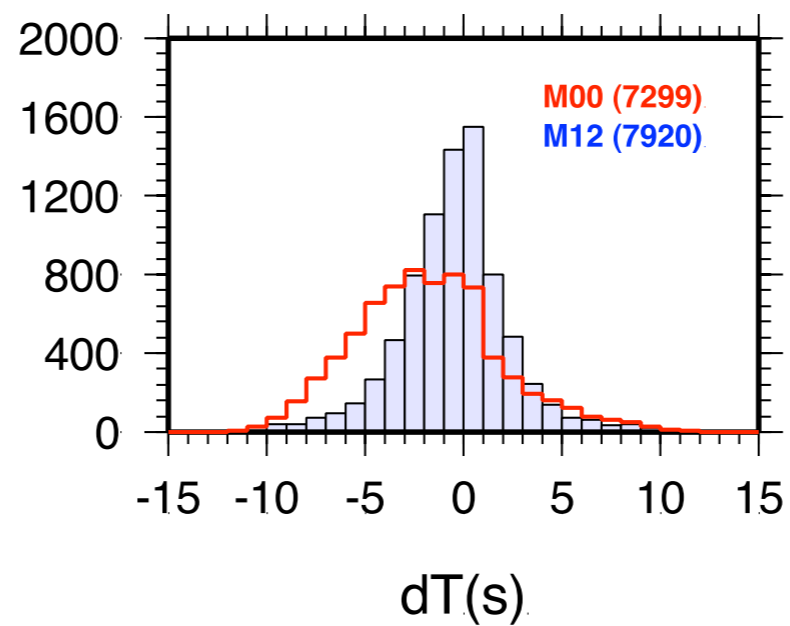
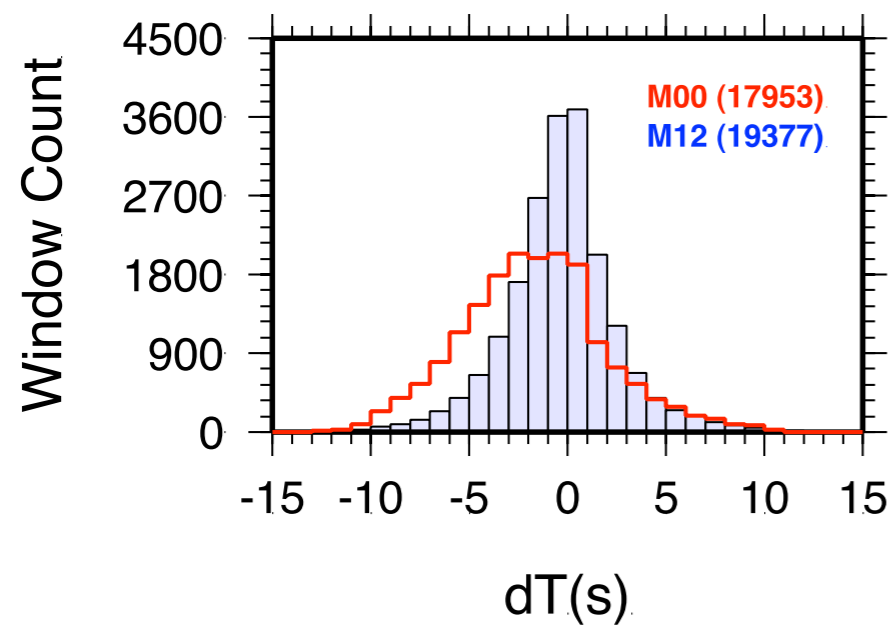


Transverse



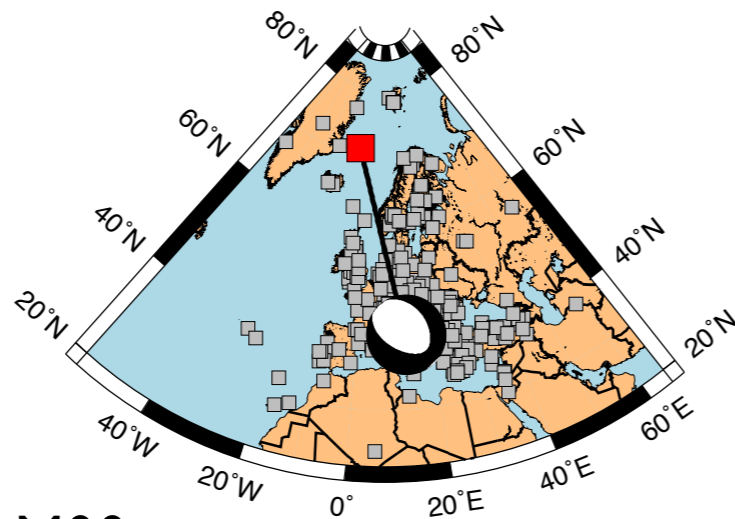
T030_150

M12: 81,073 windows



NO.JMIC

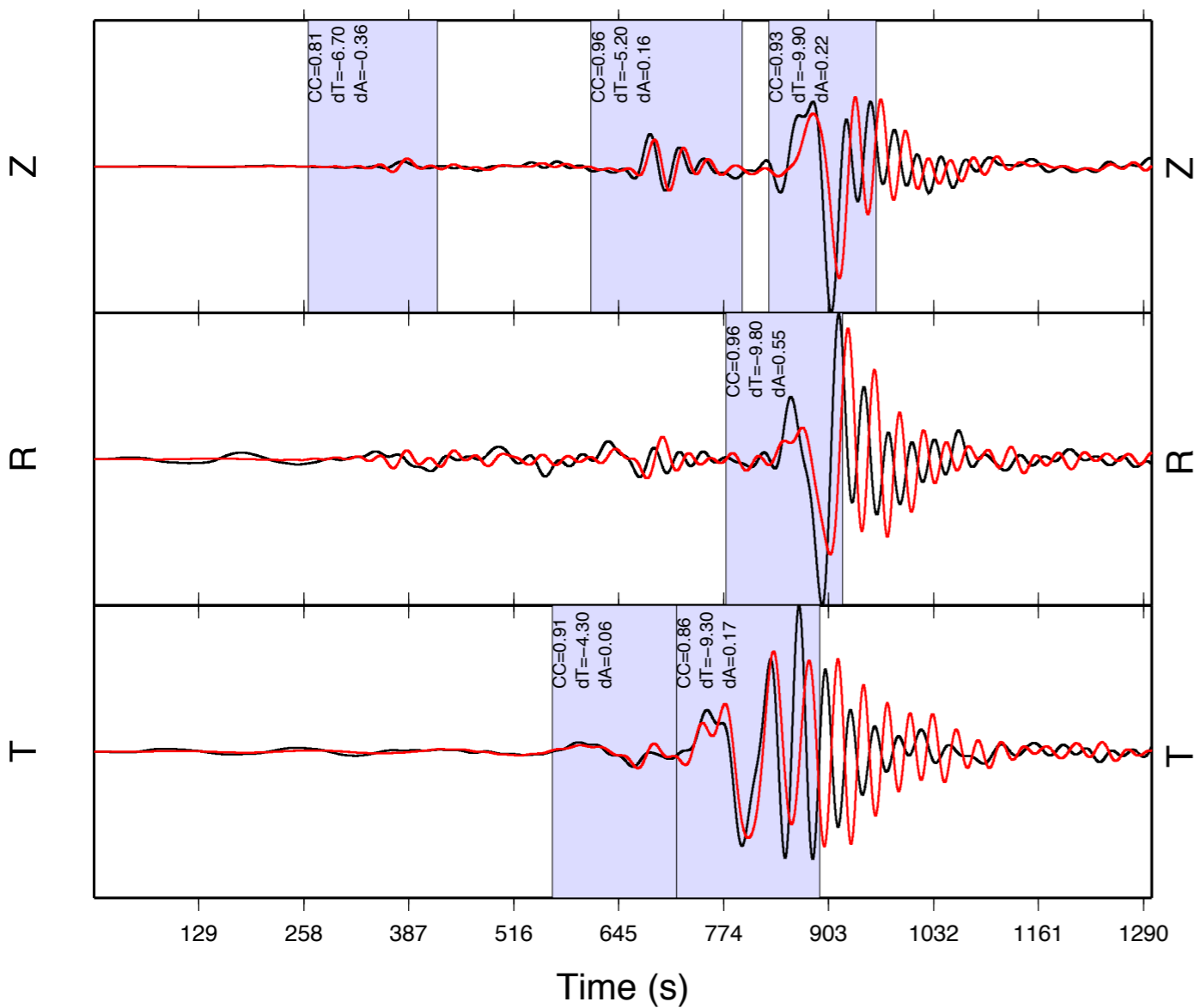
DIST: 30.78
BCAZ: 147.35
EVDP: 8.51
EVLO: 13.34
EVLA: 42.30
STLO: -8.51
STLA: 70.99
MB: 5.9



M00

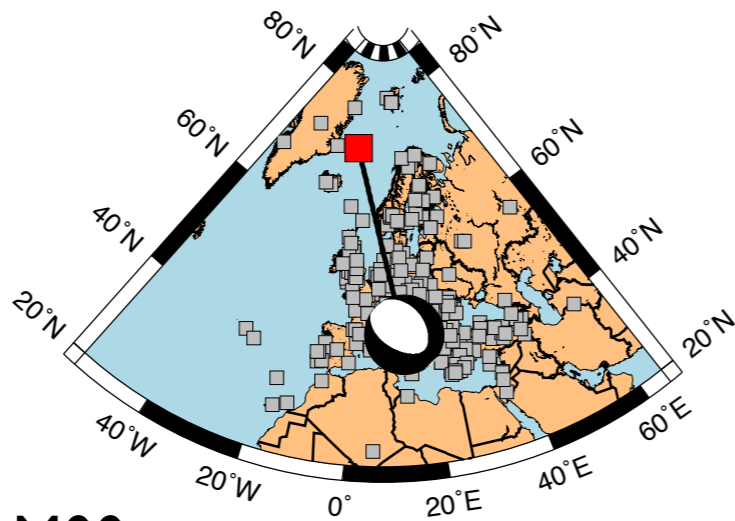
200904060132A

30 - 150 s bandpass



NO.JMIC

DIST: 30.78
BCAZ: 147.35
EVDP: 8.51
EVLO: 13.34
EVLA: 42.30
STLO: -8.51
STLA: 70.99
MB: 5.9

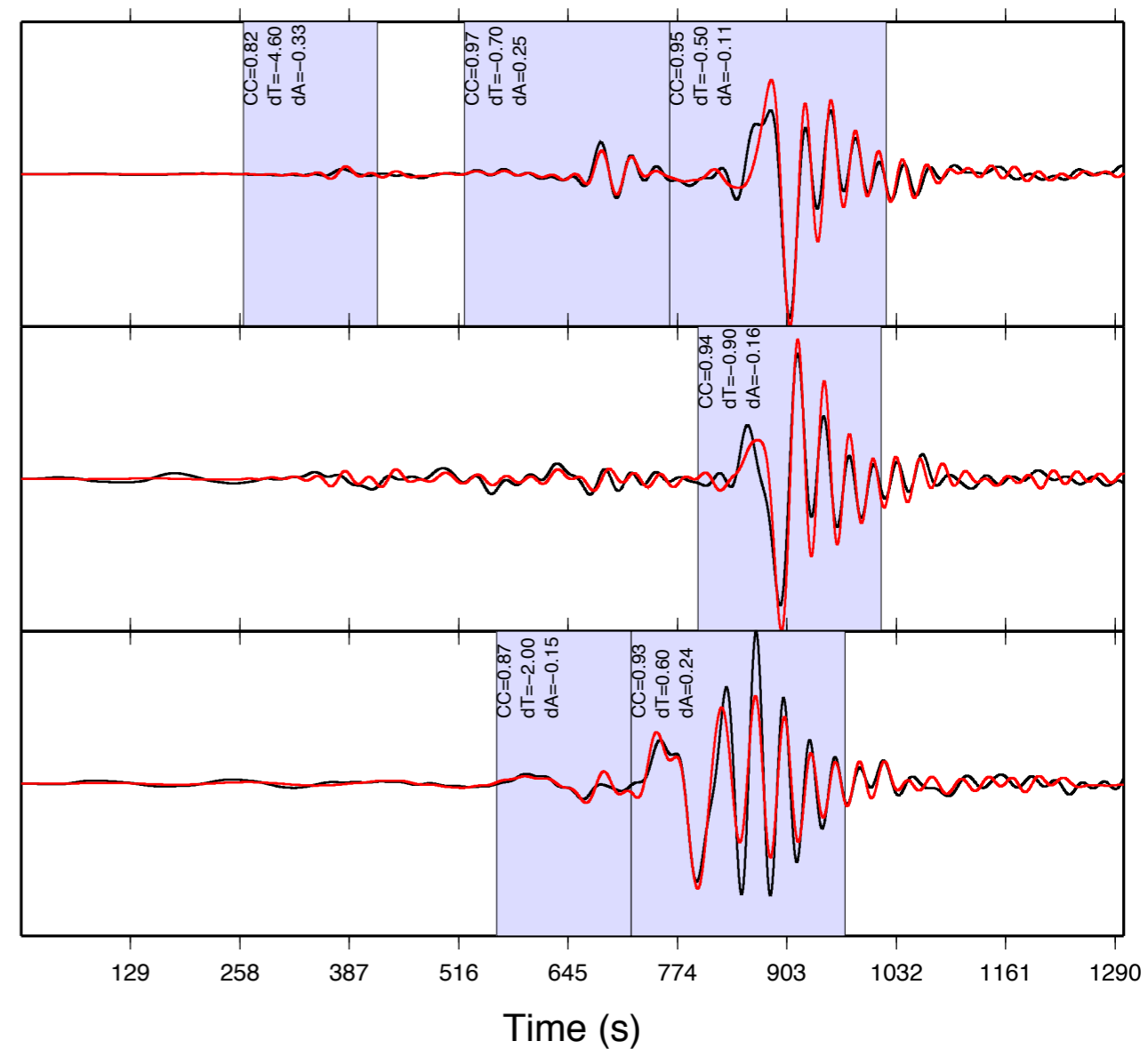
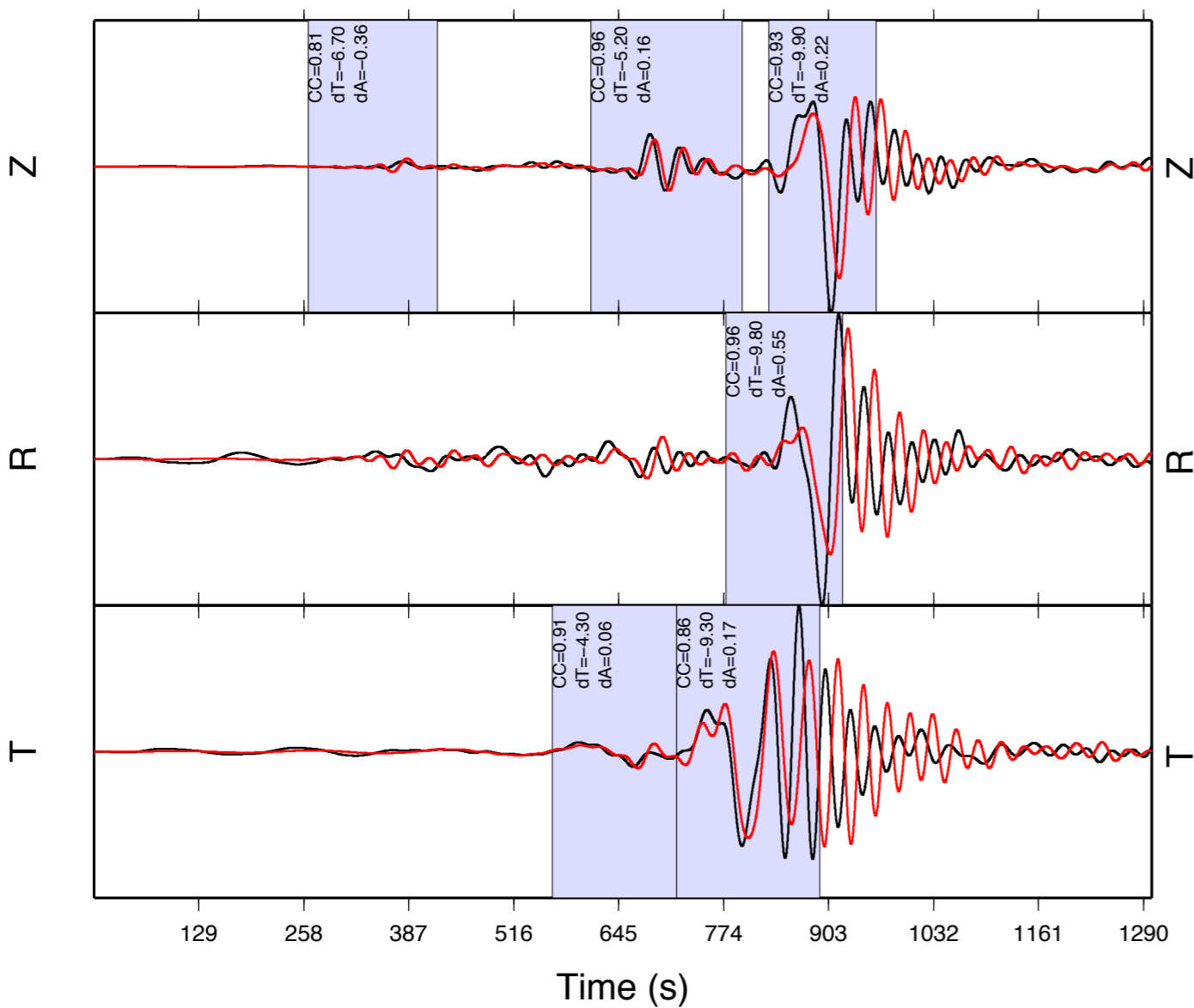


M00

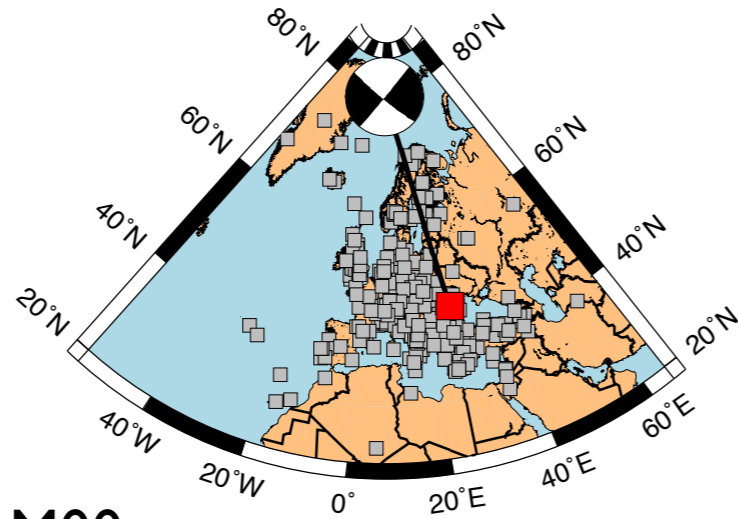
200904060132A

30 - 150 s bandpass

M12

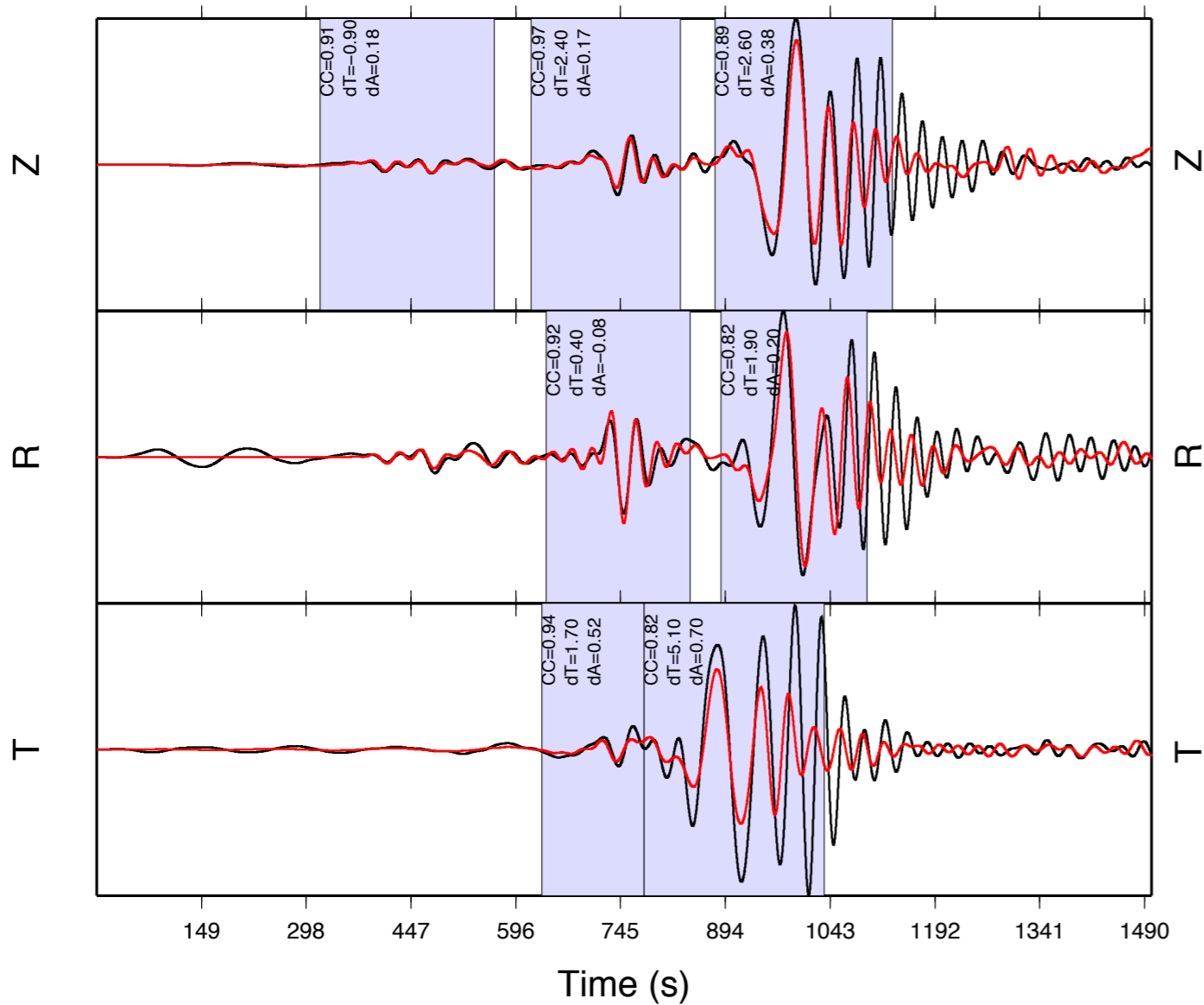


RO.MLR
DIST: 34.26
BCAZ: 352.98
EVDP: 13.16
EVLO: 5.46
EVLA: 78.73
STLO: 25.95
STLA: 45.49
MB: 5.5

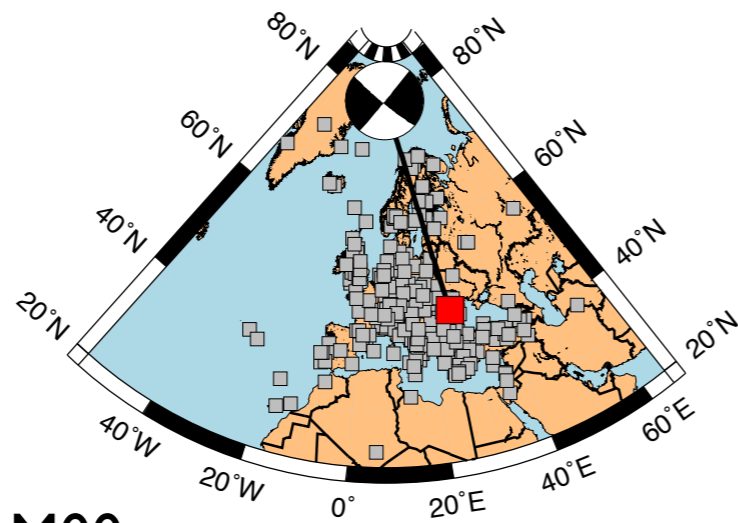


M00

20050402 1252A
 30 - 150 s bandpass



RO.MLR
DIST: 34.26
BCAZ: 352.98
EVDP: 13.16
EVLO: 5.46
EVLA: 78.73
STLO: 25.95
STLA: 45.49
MB: 5.5

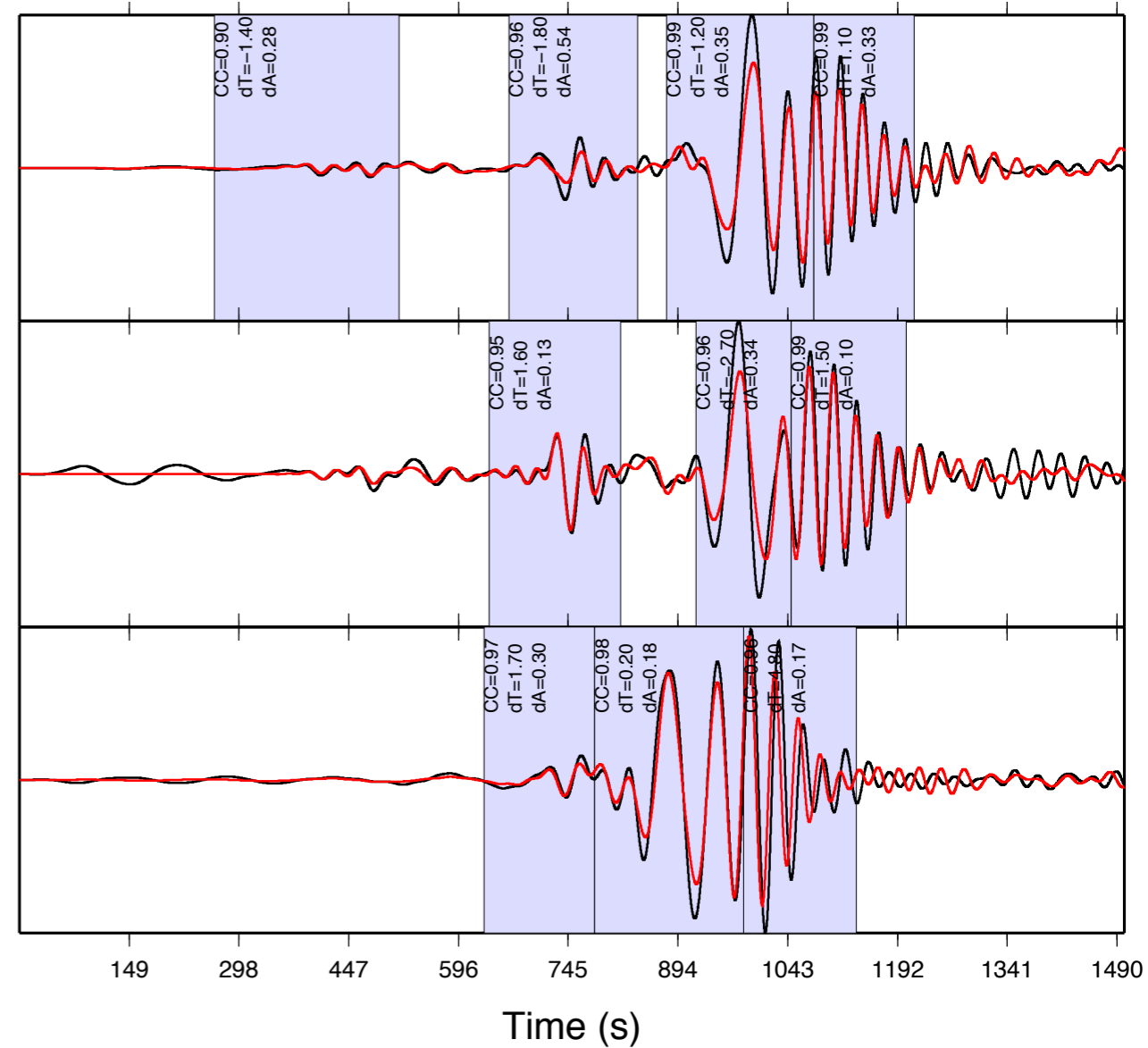
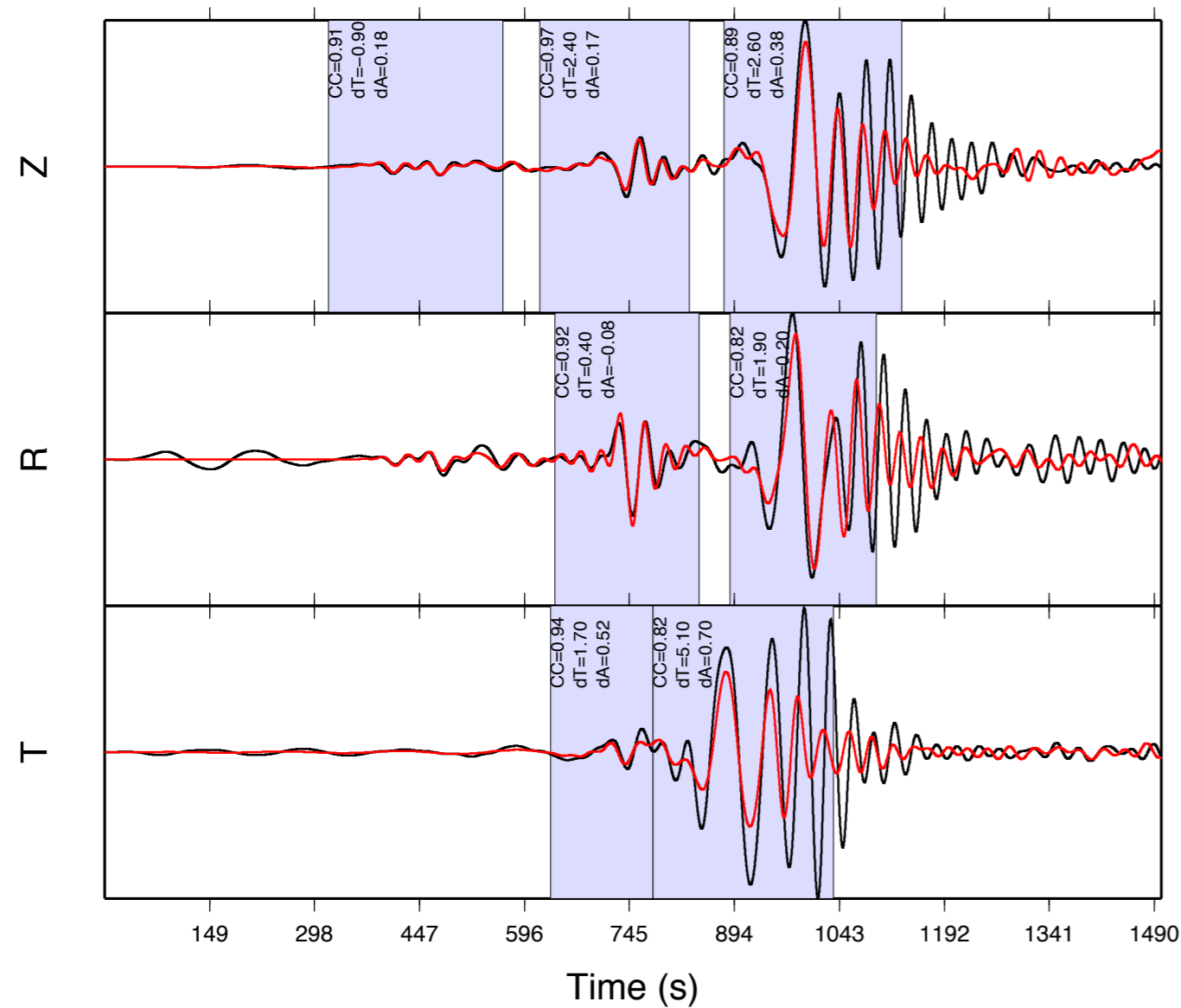


M00

20050402 1252A

30 - 150 s bandpass

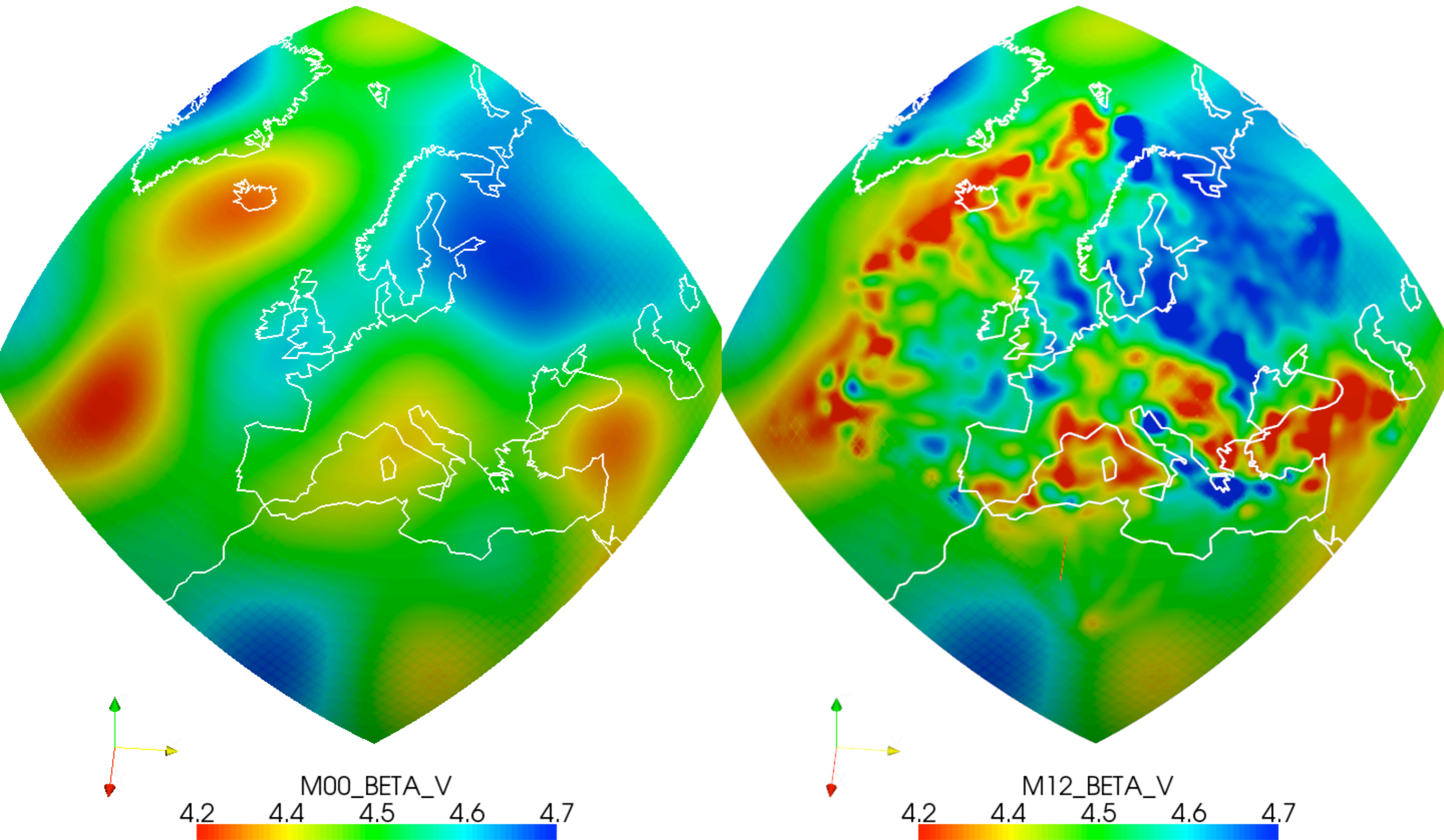
M12



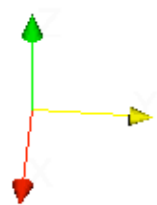
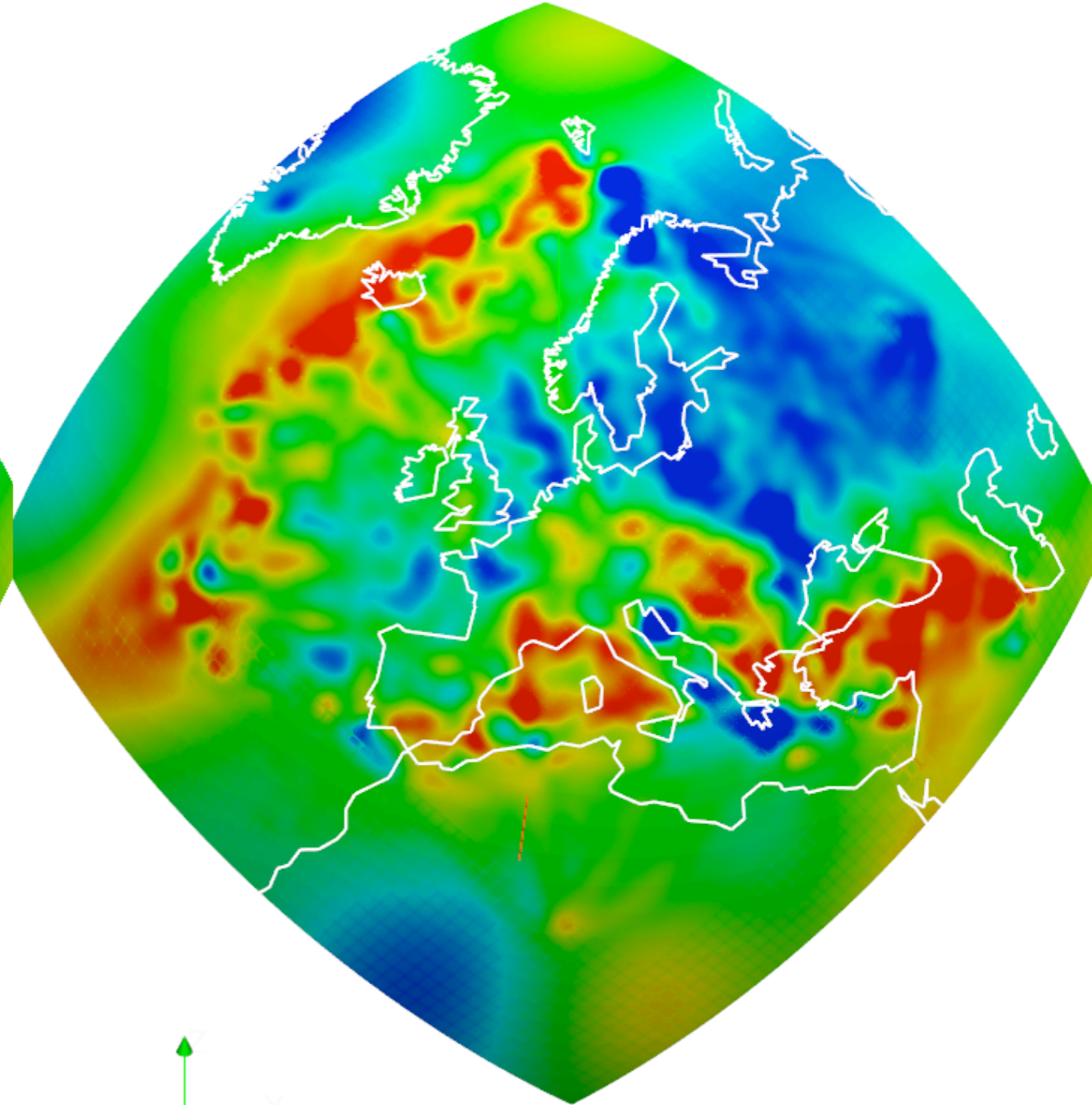
Conclusions

- “Adjoint tomography” is feasible
 - Goal: whole seismogram (frequency-dependent phase & amplitude)
 - Europe (Hejun Zhu)
 - Middle East (See Daniel’s poster)
 - Entire globe! (See Ebru’s poster)
 - Future extensions:
 - Include amplitudes
 - Shear attenuation
 - More general anisotropy
-

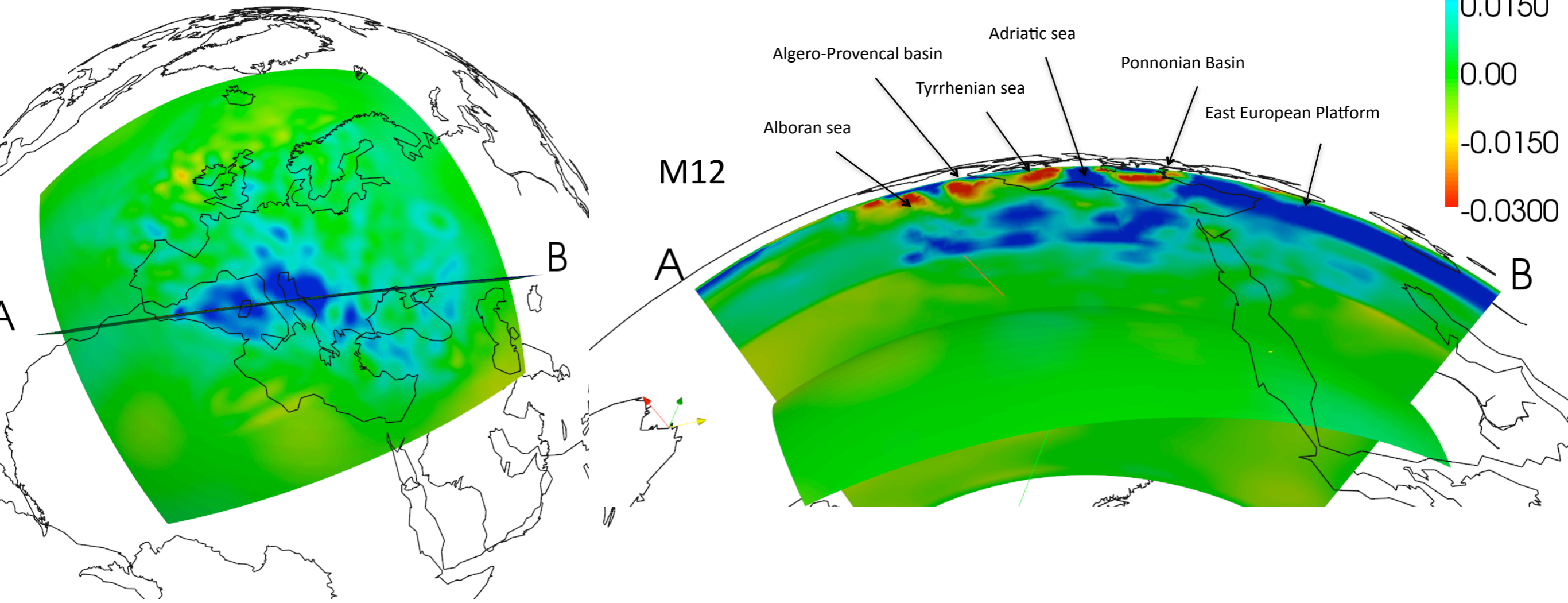
Depth 75 km



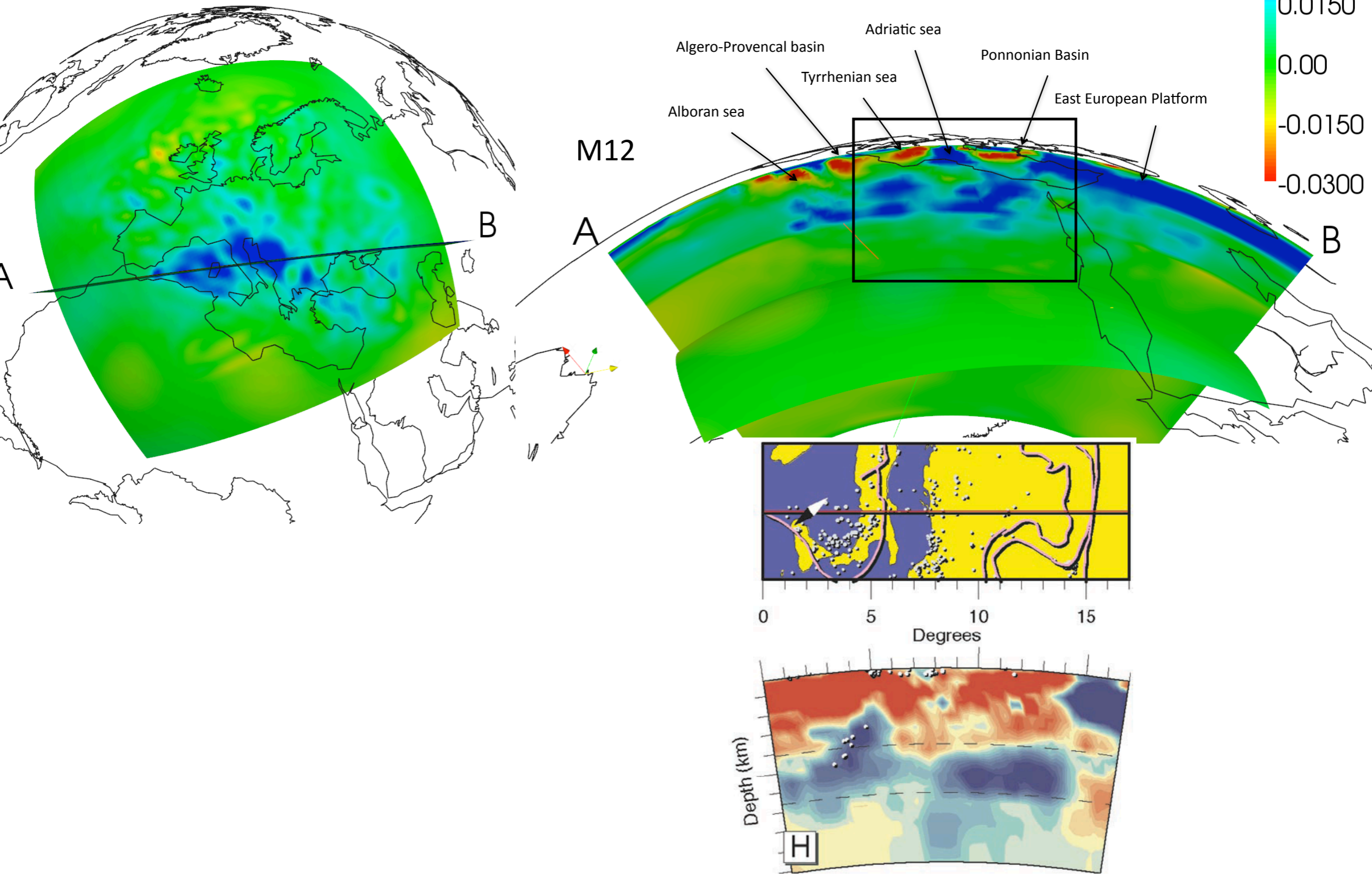
Depth 75 km



Carpathian-Vrancea Arc

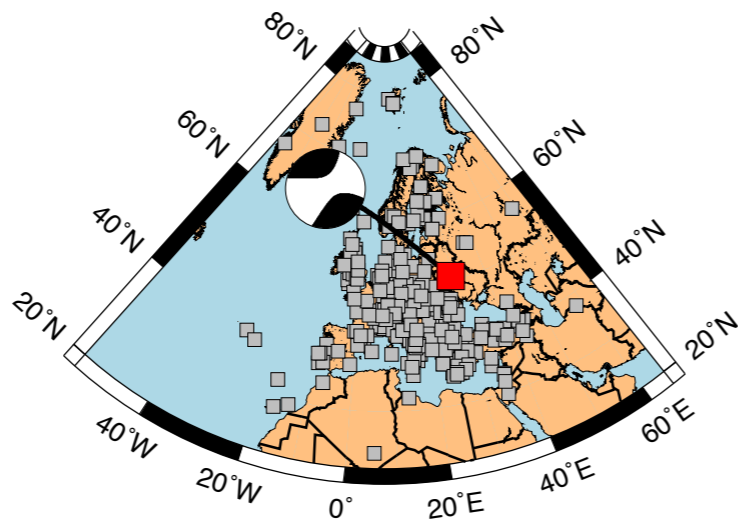


Carpathian-Vrancea Arc



IU.KIEV

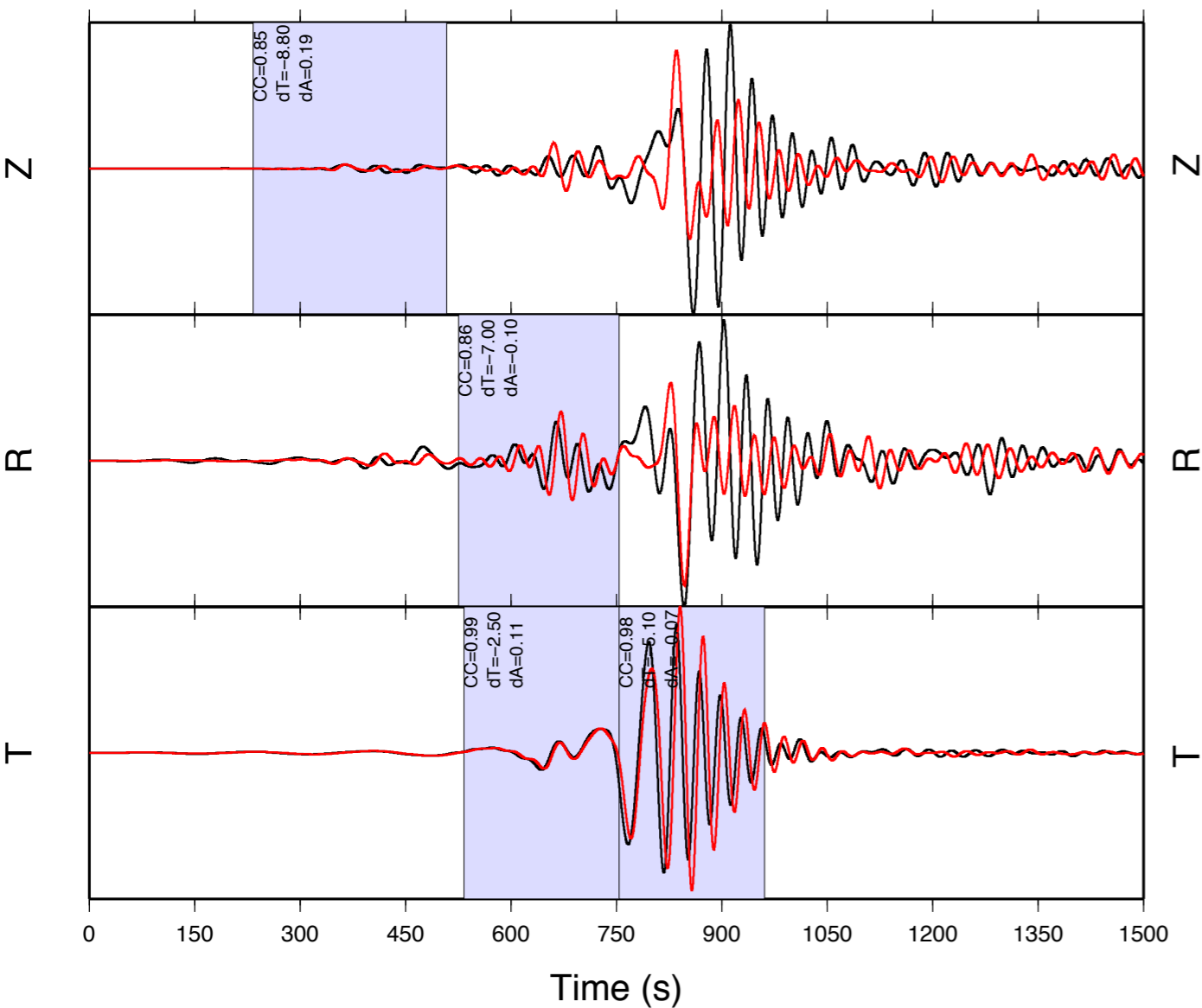
DIST: 29.37
BCAZ: 316.05
EVDP: 8.70
EVLO: -21.17
EVLA: 63.93
STLO: 29.22
STLA: 50.70
MB: 6.0



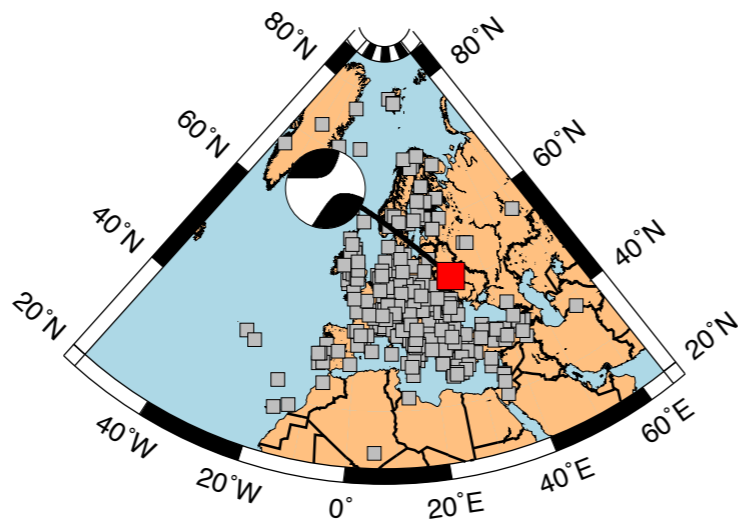
M00

200805291546A

30 - 150 s bandpass



IU.KIEV
DIST: 29.37
BCAZ: 316.05
EVDP: 8.70
EVLO: -21.17
EVLA: 63.93
STLO: 29.22
STLA: 50.70
MB: 6.0

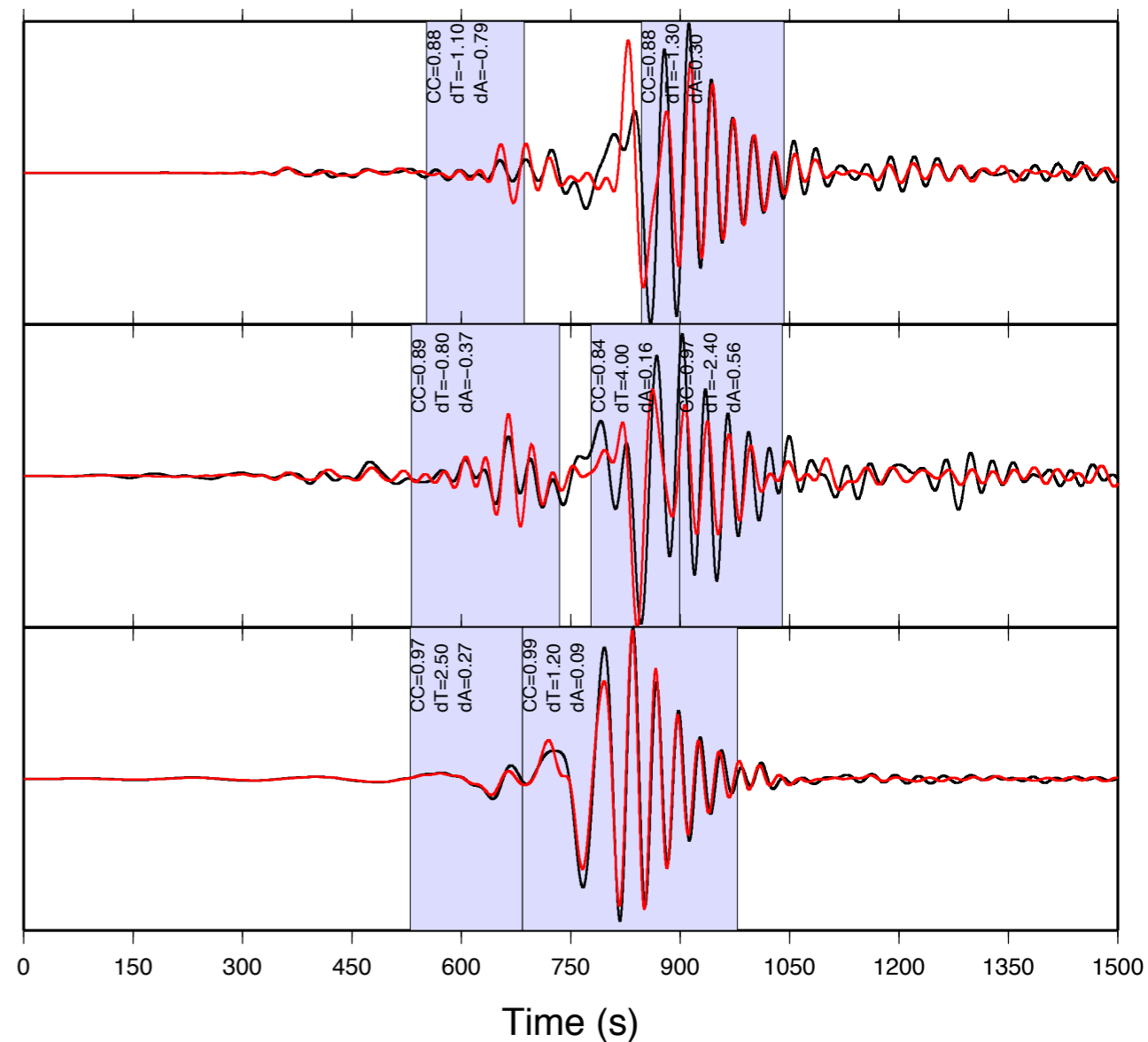
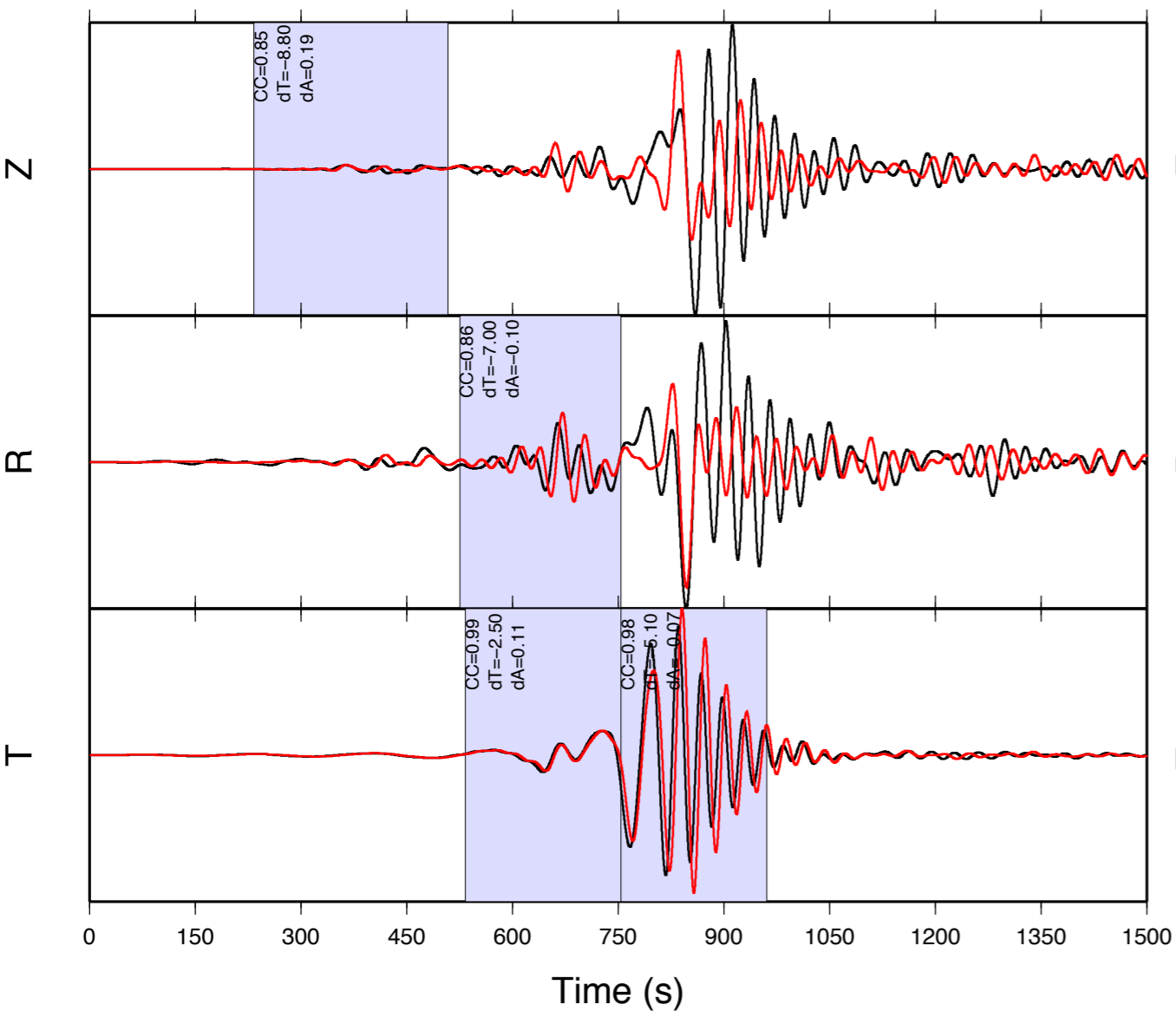


M00

20080529 1546A

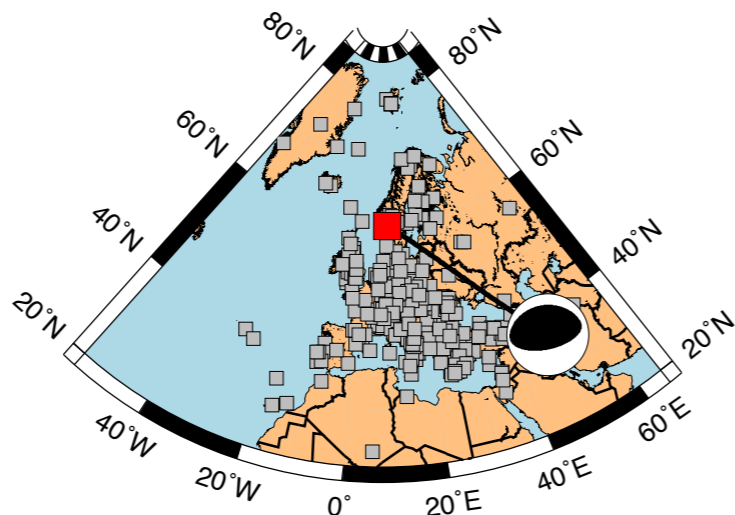
30 - 150 s bandpass

M12



IU.KONO

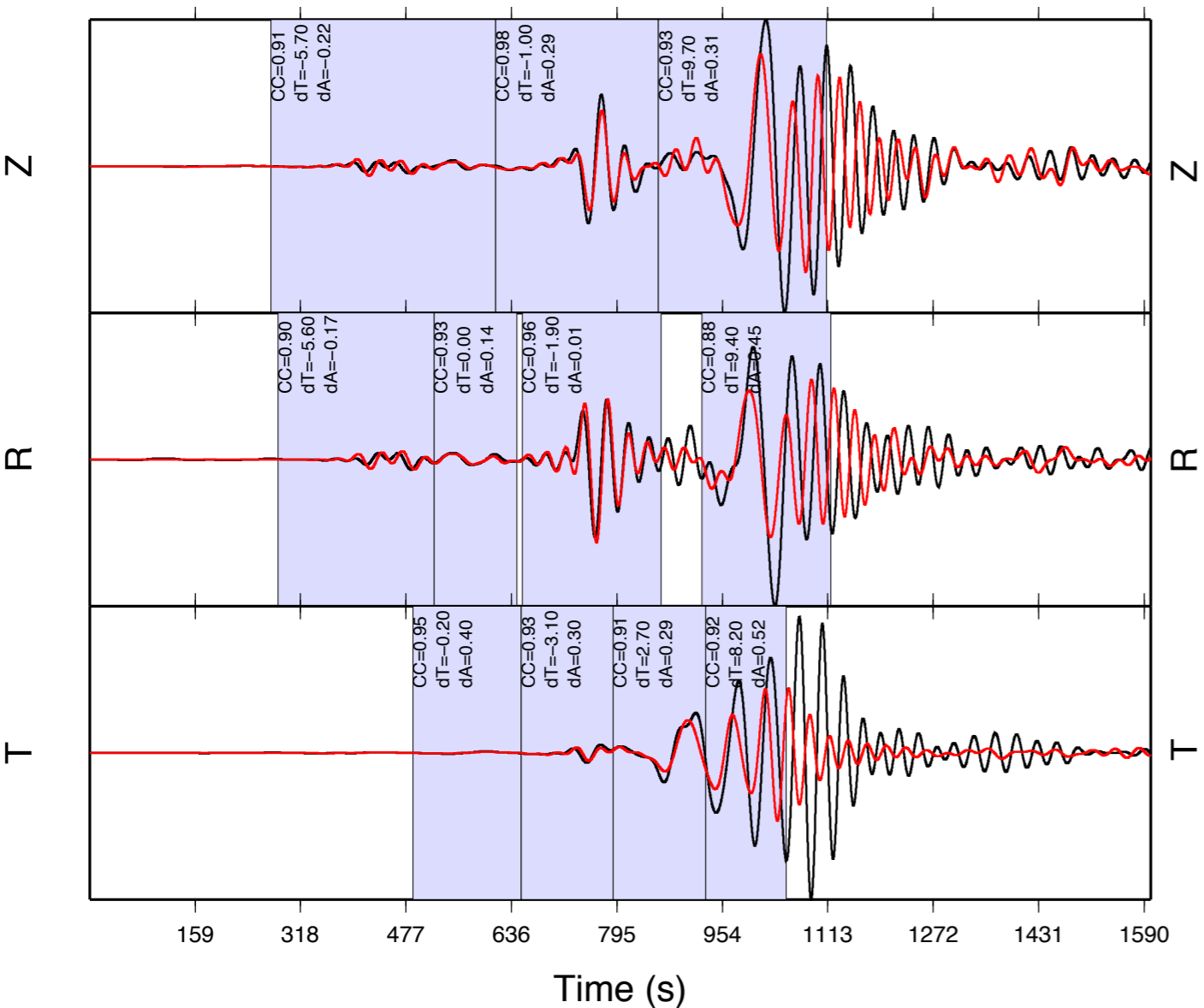
DIST: 34.82
BCAZ: 115.45
EVDP: 10.27
EVLO: 48.97
EVLA: 35.82
STLO: 9.60
STLA: 59.65
MB: 6.2



062202B

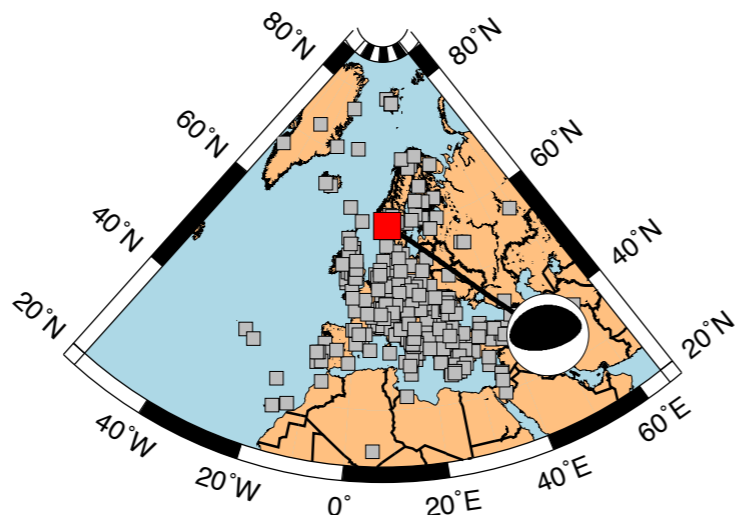
30 - 150 s bandpass

M00



IU.KONO

DIST: 34.82
BCAZ: 115.45
EVDP: 10.27
EVLO: 48.97
EVLA: 35.82
STLO: 9.60
STLA: 59.65
MB: 6.2

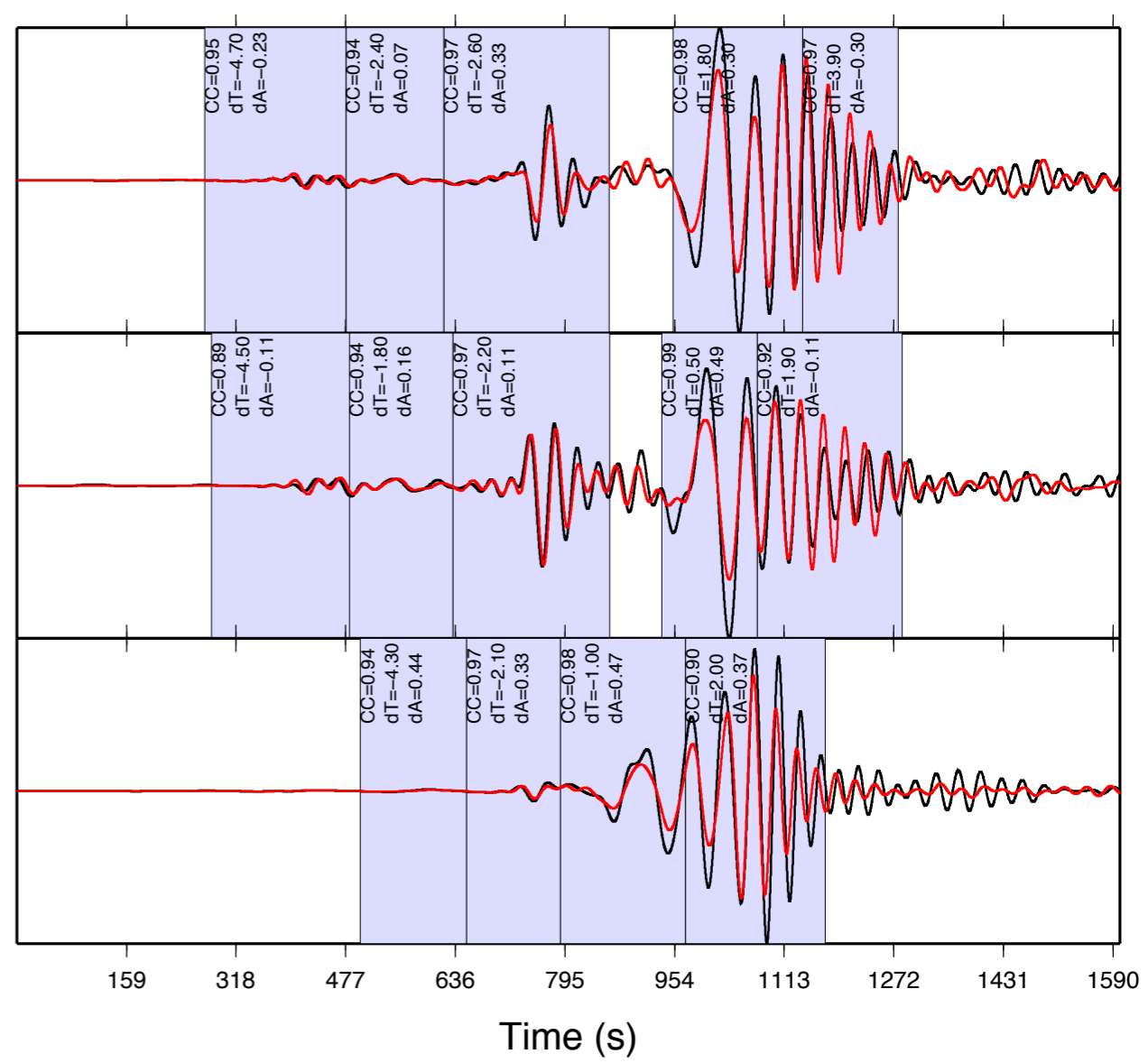
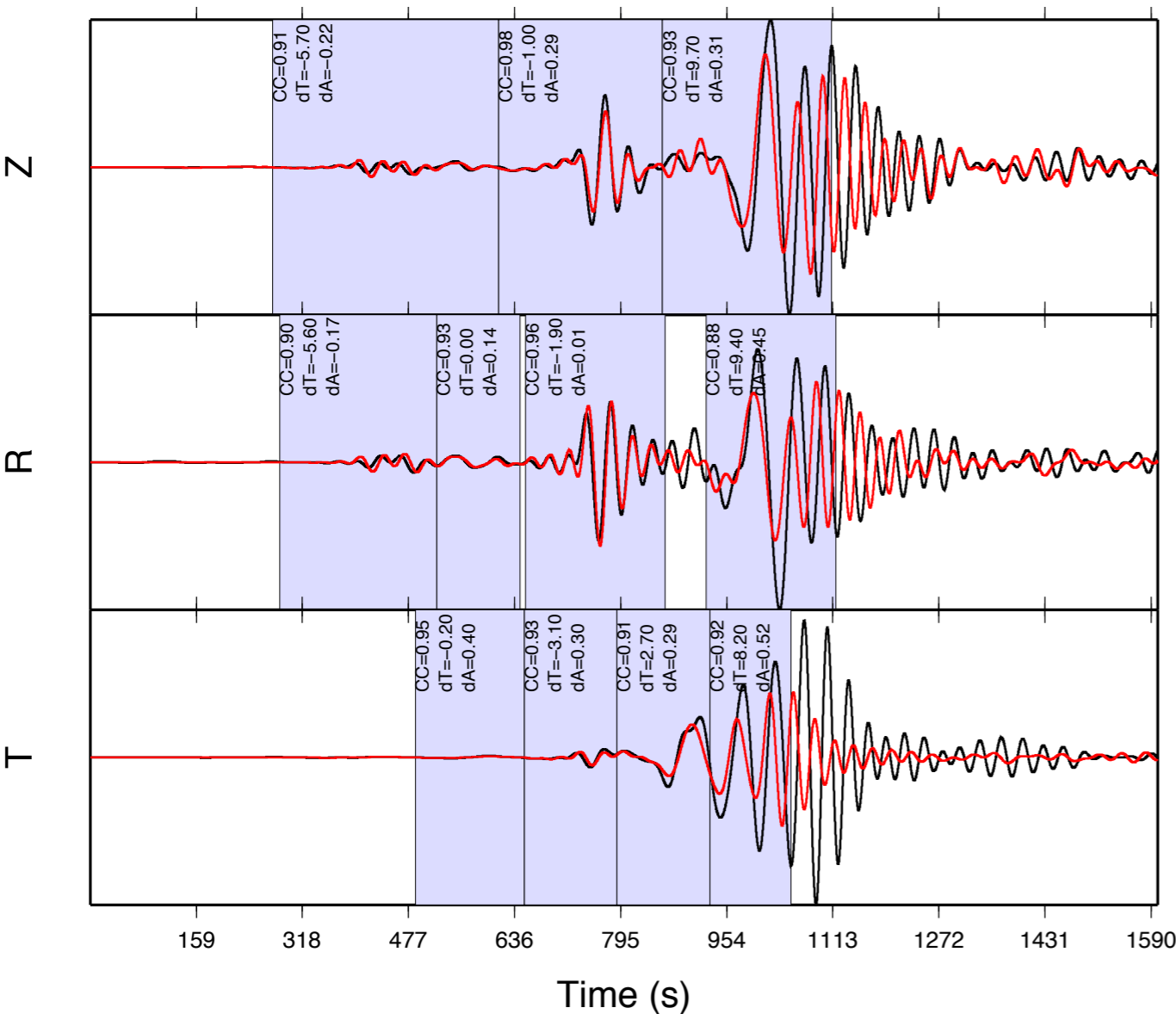


M00

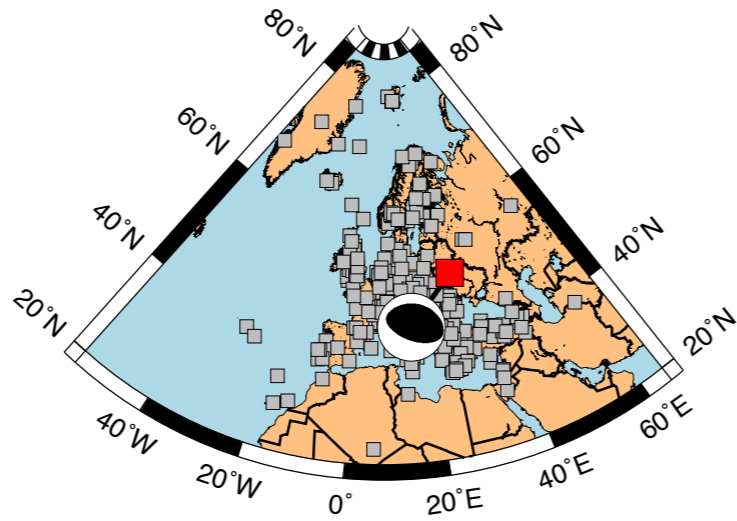
062202B

30 - 150 s bandpass

M12

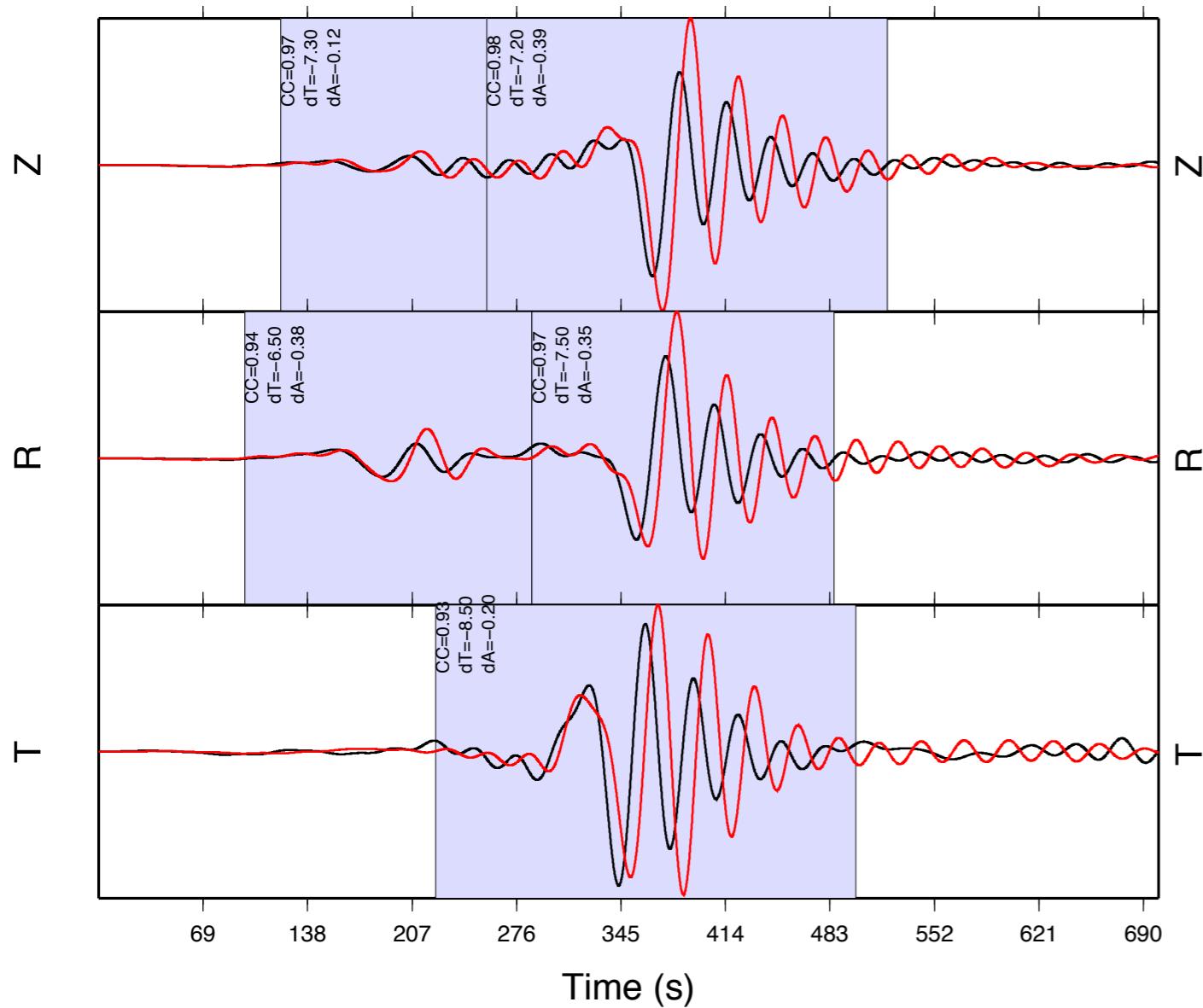


IU.KIEV
DIST: 12.18
BCAZ: 236.99
EVDP: 4.81
EVLO: 15.24
EVLA: 43.14
STLO: 29.22
STLA: 50.70
MB: 5.2

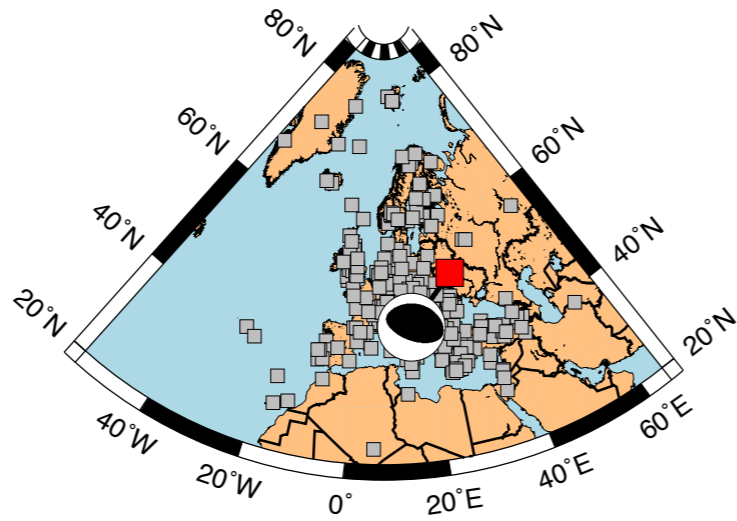


I I2504A
30 - 150 s bandpass

M00



IU.KIEV
DIST: 12.18
BCAZ: 236.99
EVDP: 4.81
EVLO: 15.24
EVLA: 43.14
STLO: 29.22
STLA: 50.70
MB: 5.2

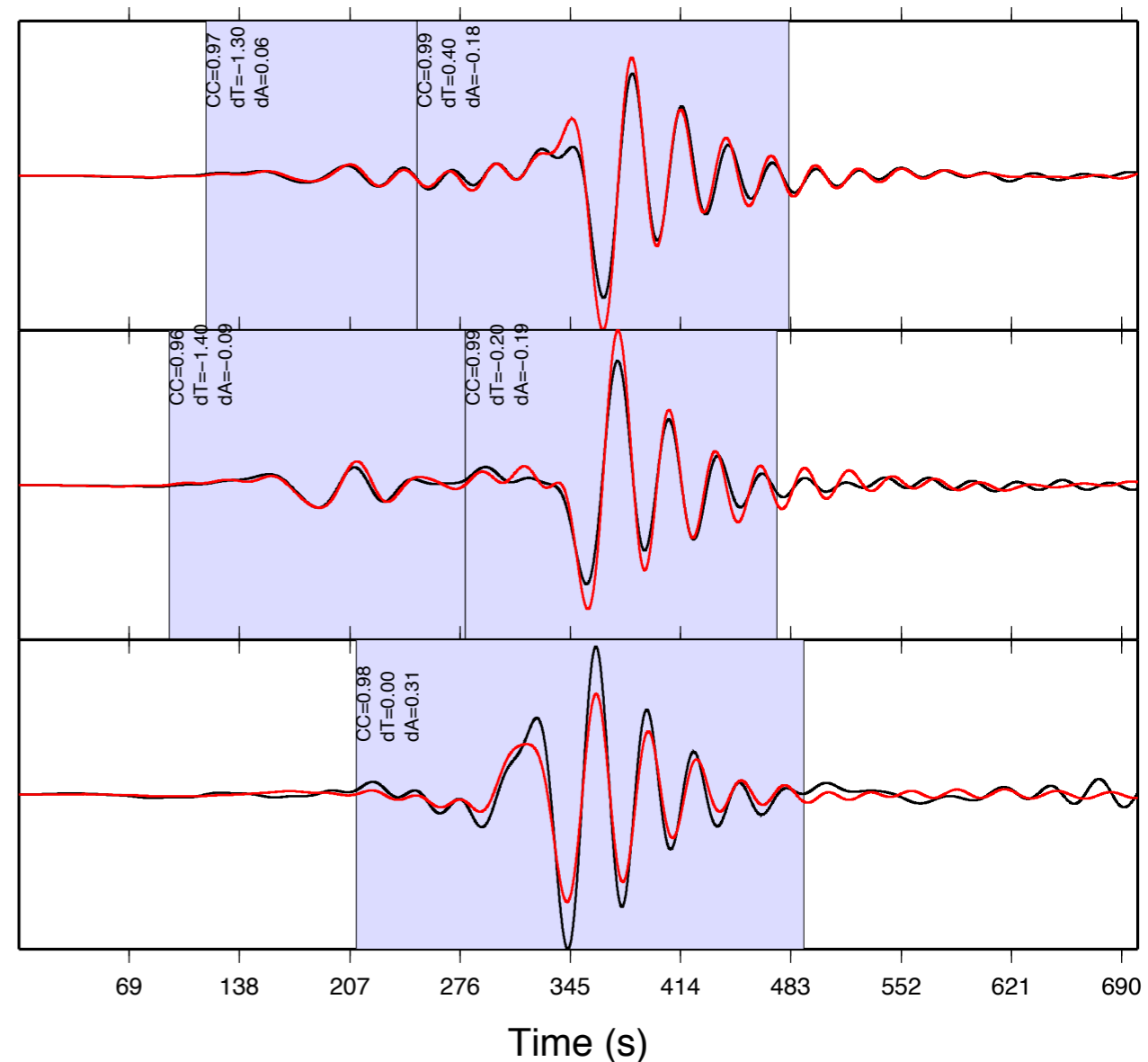
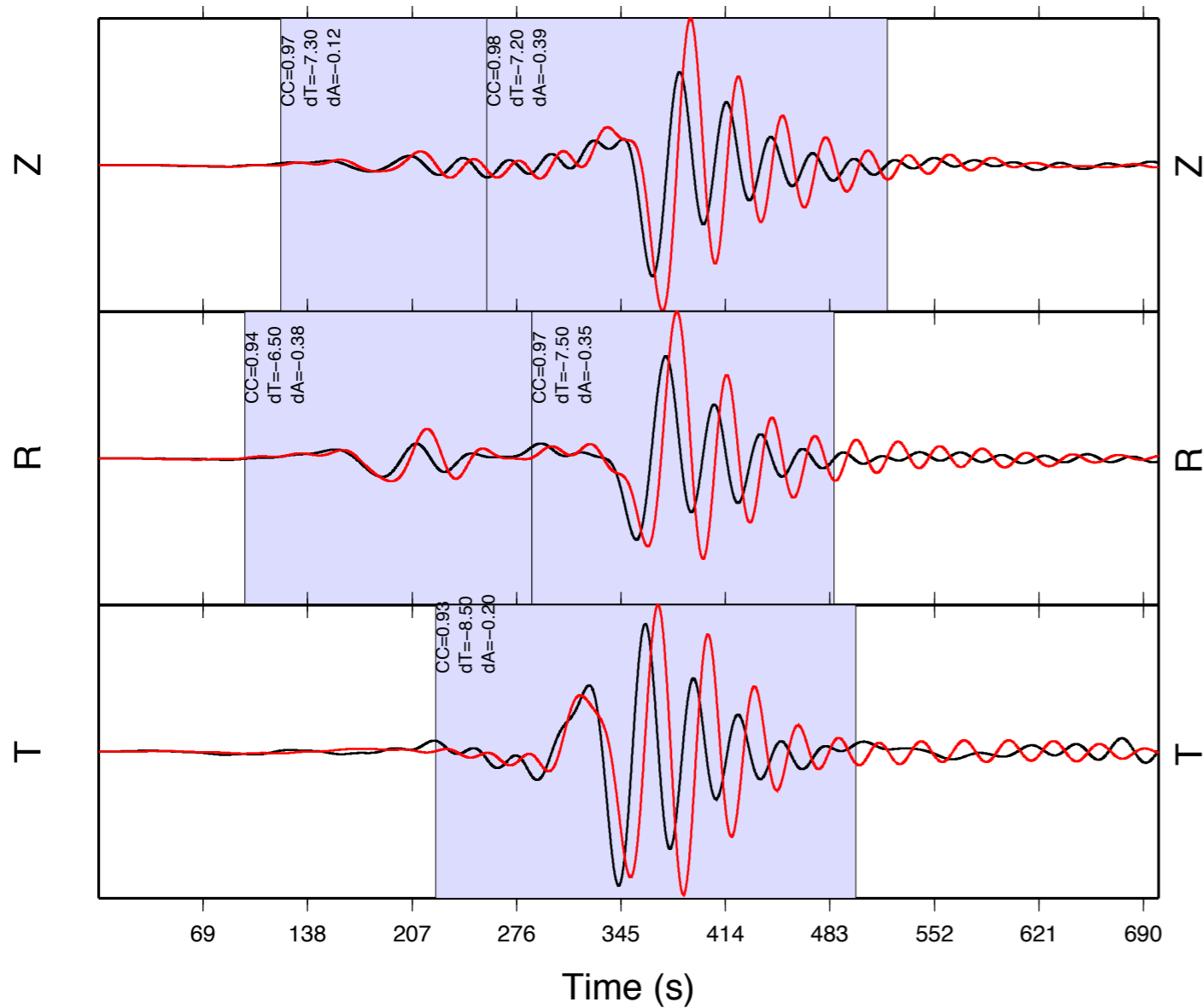


M00

112504A

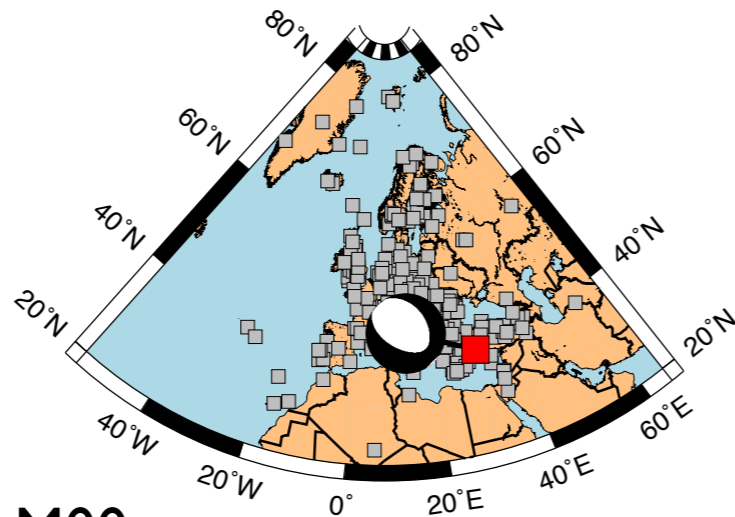
30 - 150 s bandpass

M12



GE.ISP

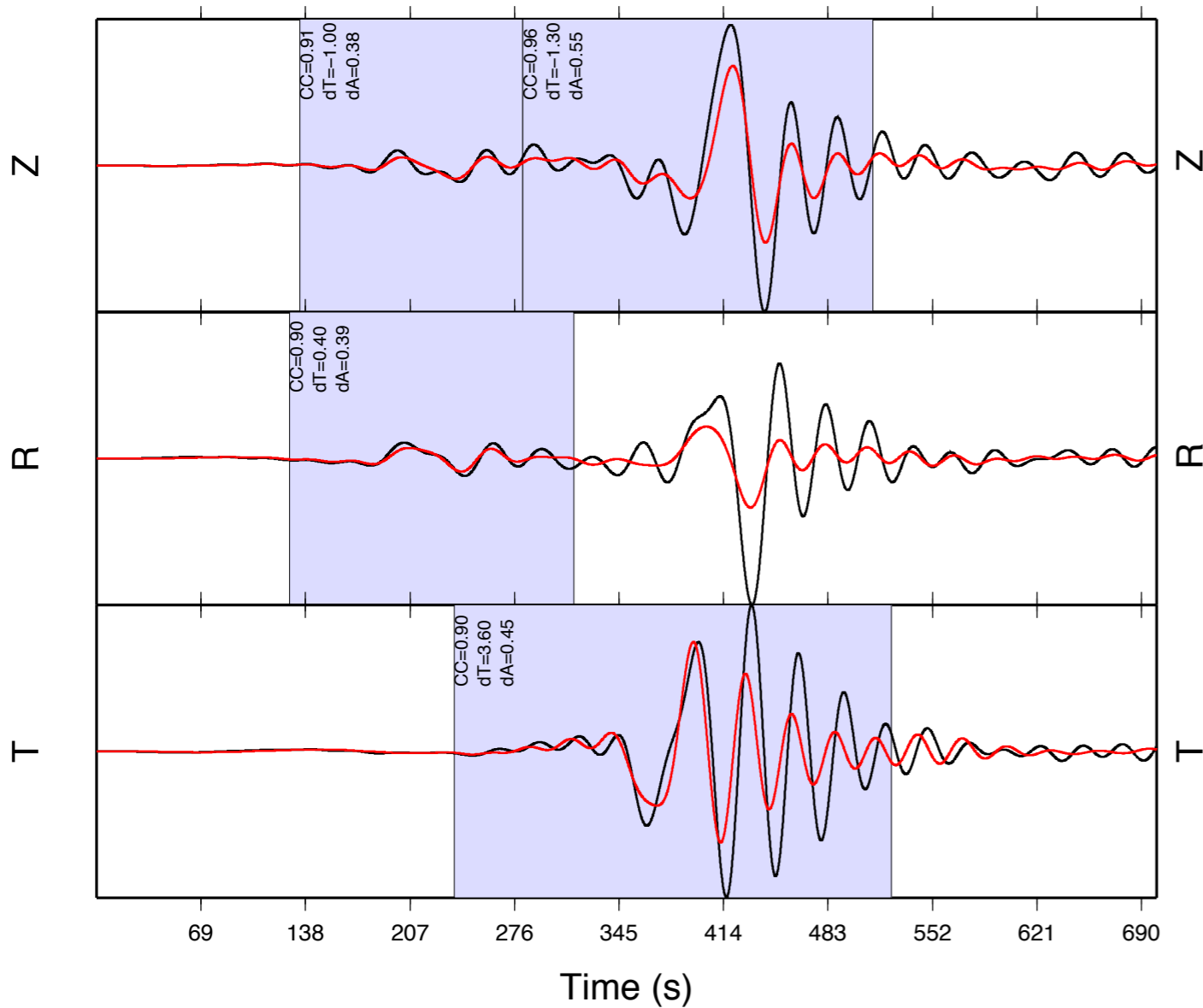
DIST: 13.88
BCAZ: 294.06
EVDP: 8.51
EVLO: 13.34
EVLA: 42.30
STLO: 30.51
STLA: 37.84
MB: 5.9



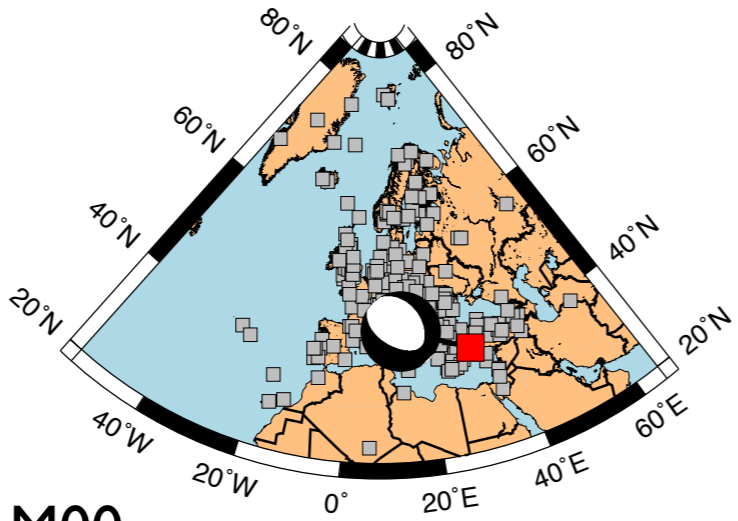
M00

200904060132A

30 - 150 s bandpass



GE.ISP
DIST: 13.88
BCAZ: 294.06
EVDP: 8.51
EVLO: 13.34
EVLA: 42.30
STLO: 30.51
STLA: 37.84
MB: 5.9

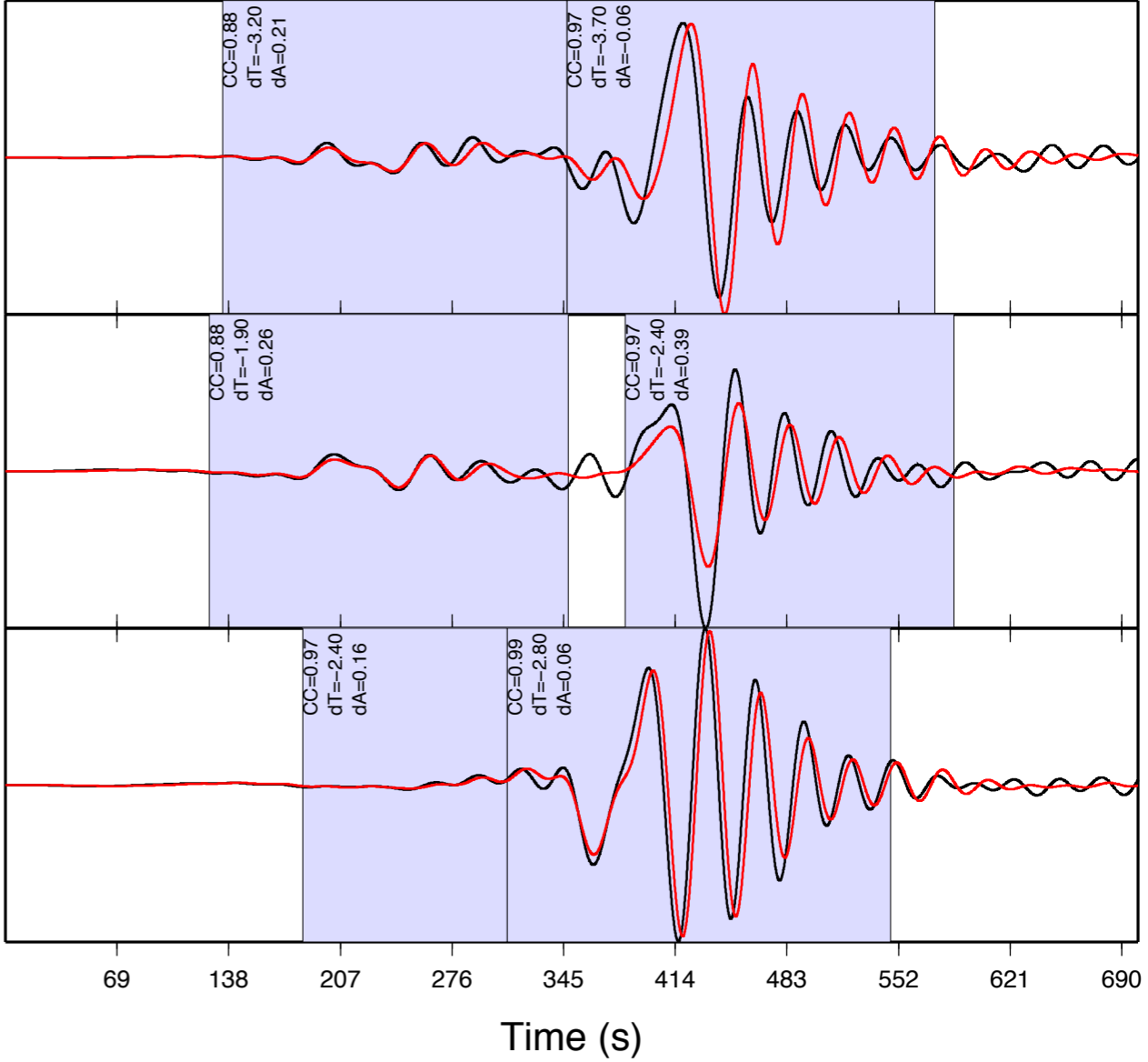
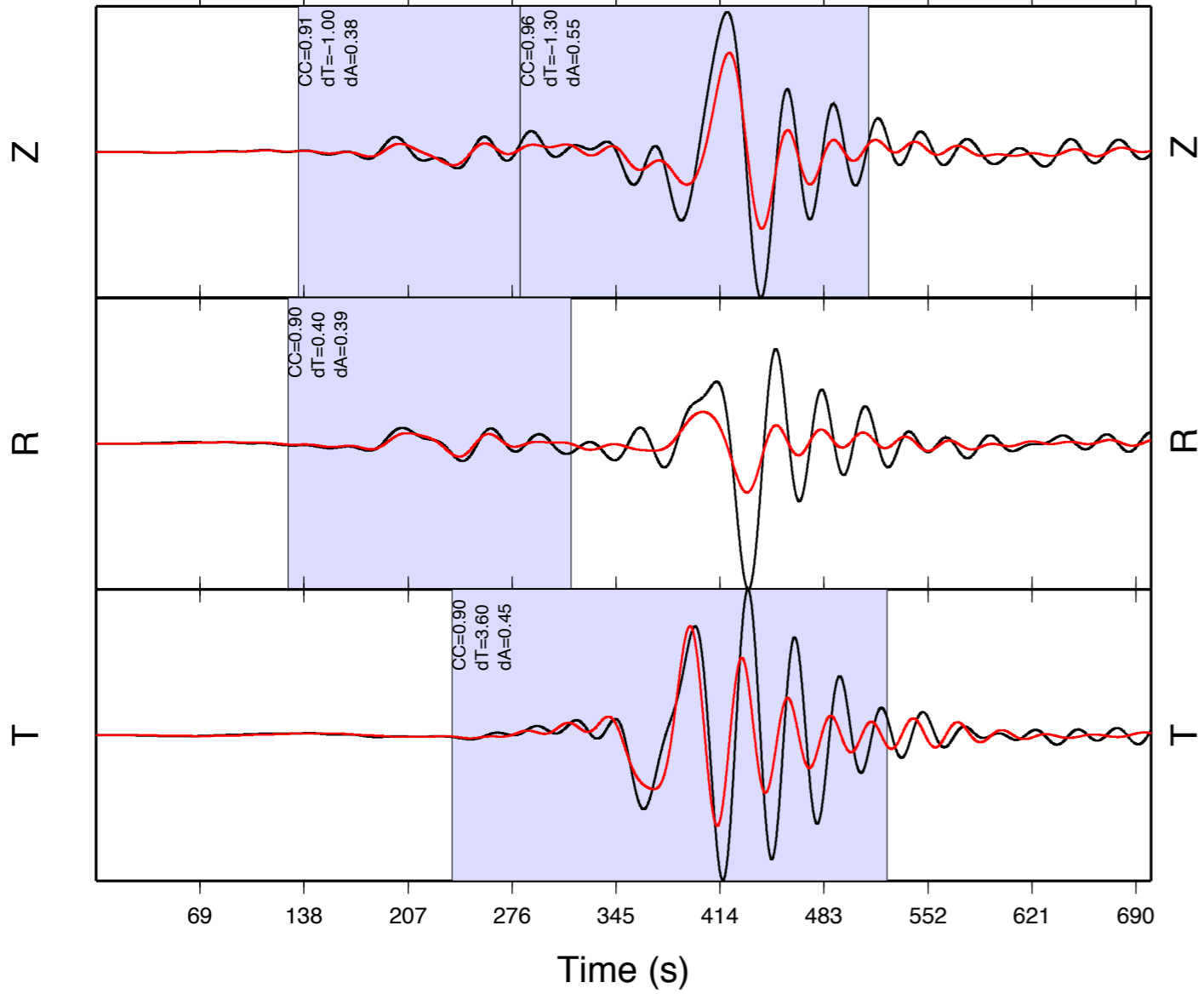


M00

200904060132A

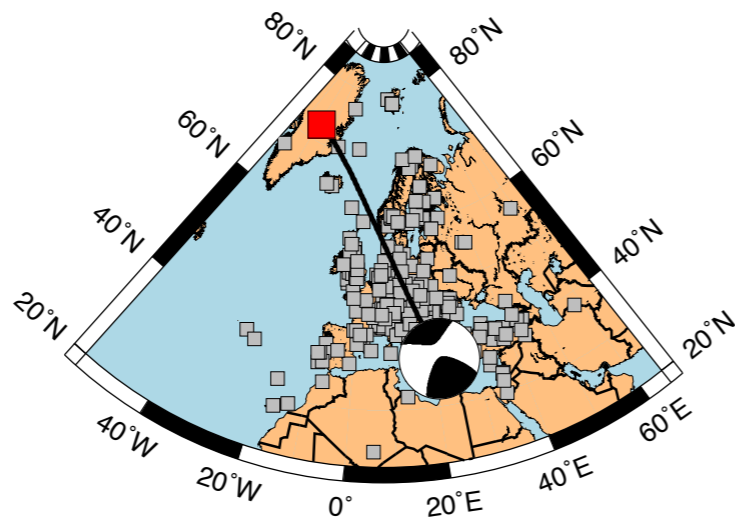
30 - 150 s bandpass

M12



GE.SUMG

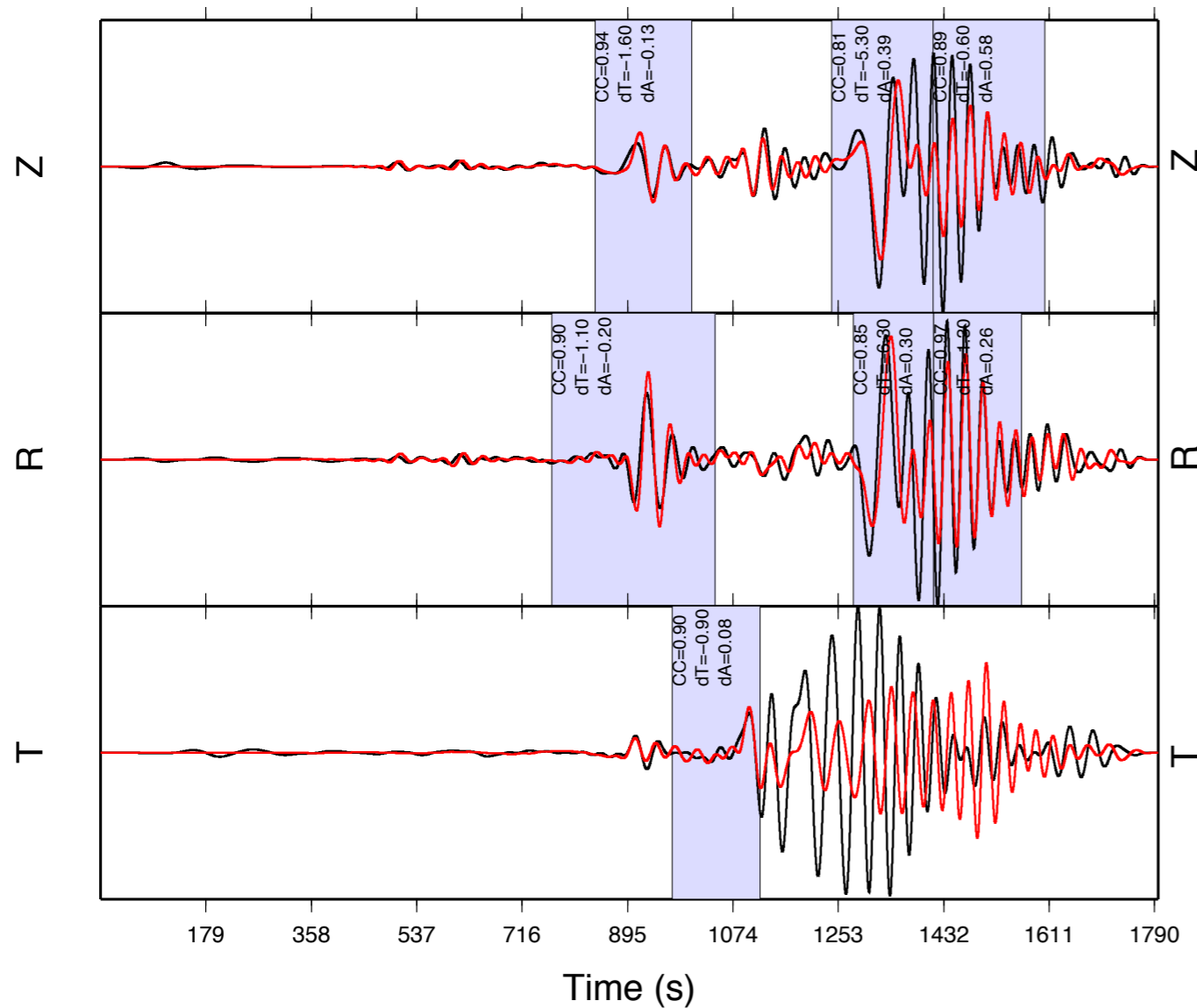
DIST: 45.37
BCAZ: 105.63
EVDP: 22.90
EVLO: 21.62
EVLA: 37.93
STLO: -38.45
STLA: 72.58
MB: 6.2



20080608 1225A

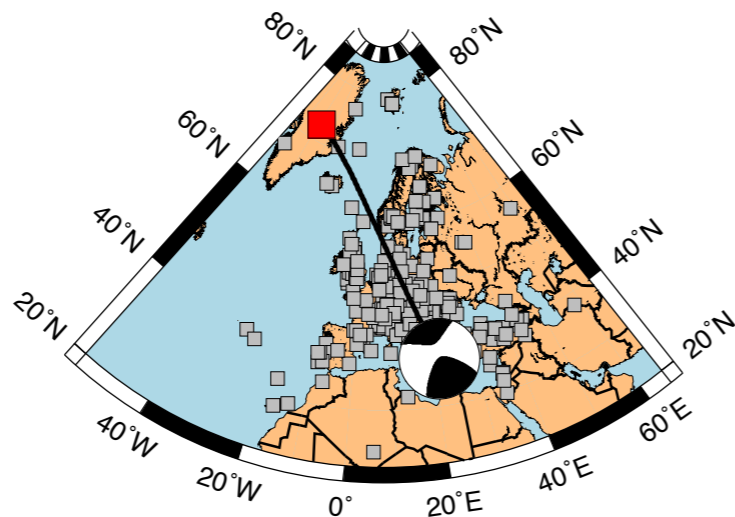
30 - 150 s bandpass

M00



GE.SUMG

DIST: 45.37
BCAZ: 105.63
EVDP: 22.90
EVLO: 21.62
EVLA: 37.93
STLO: -38.45
STLA: 72.58
MB: 6.2

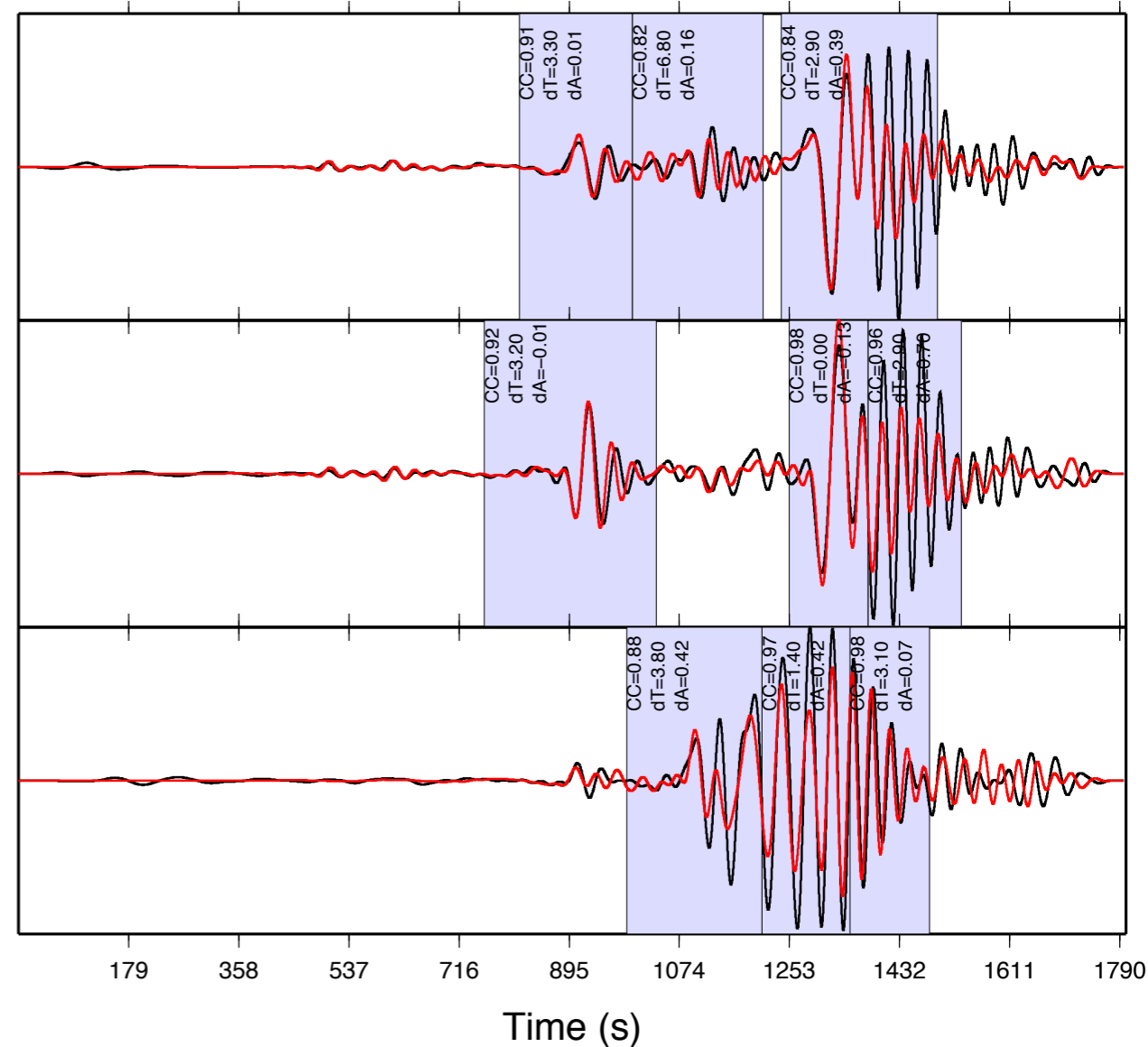
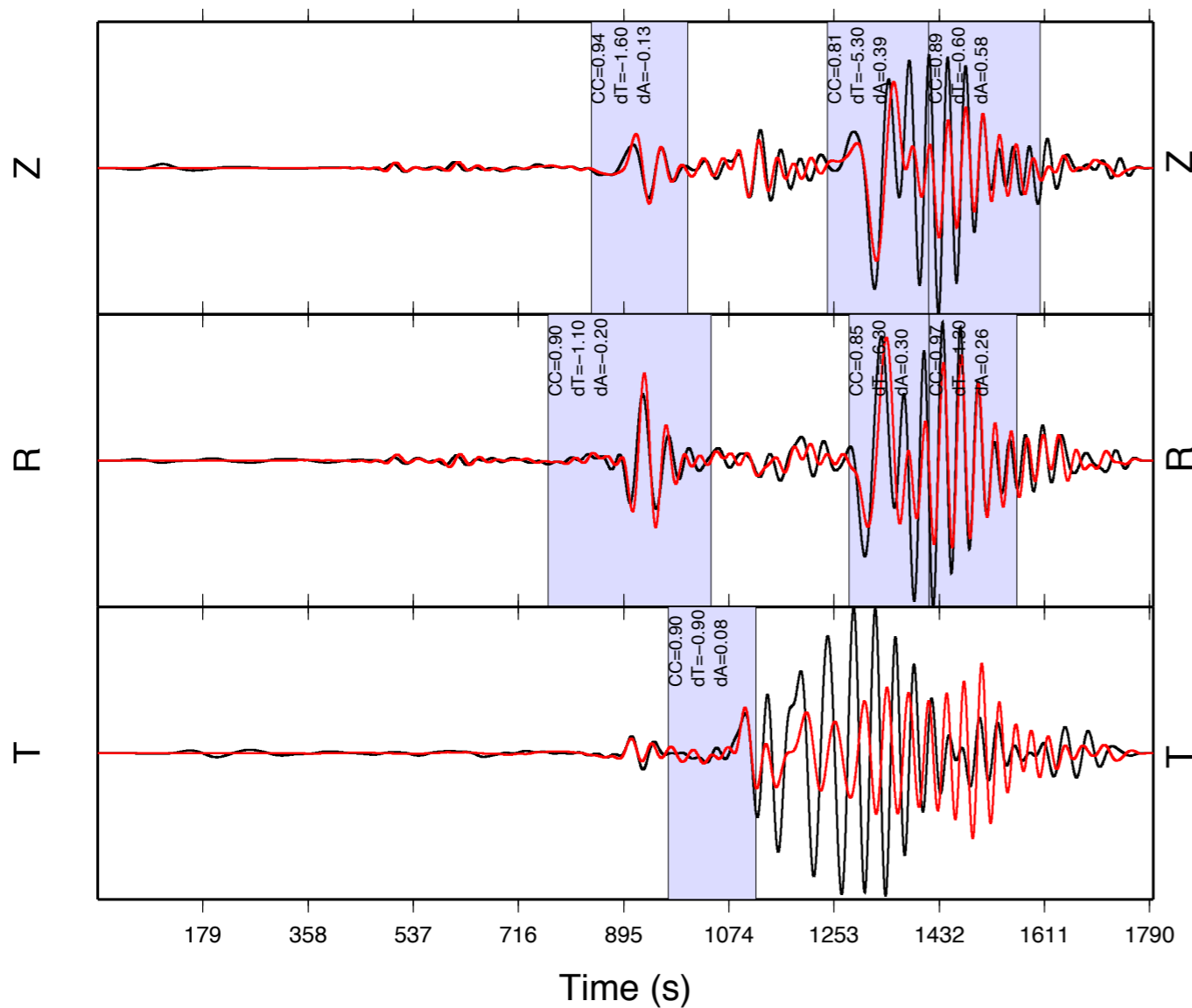


20080608 1225A

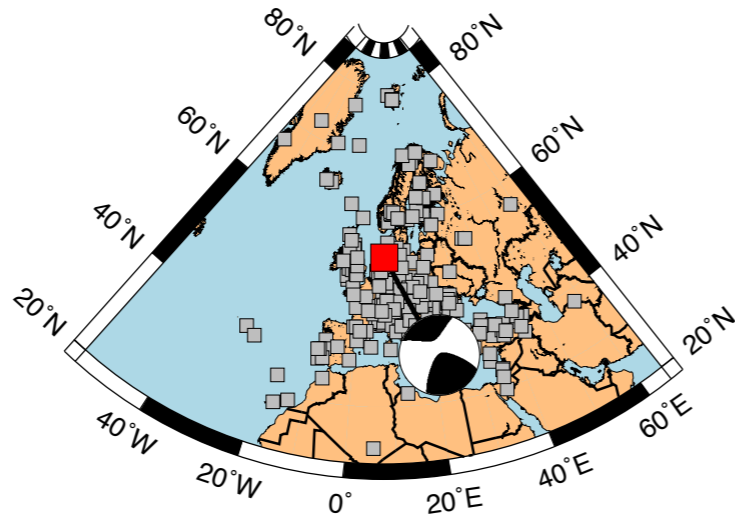
30 - 150 s bandpass

M00

M12

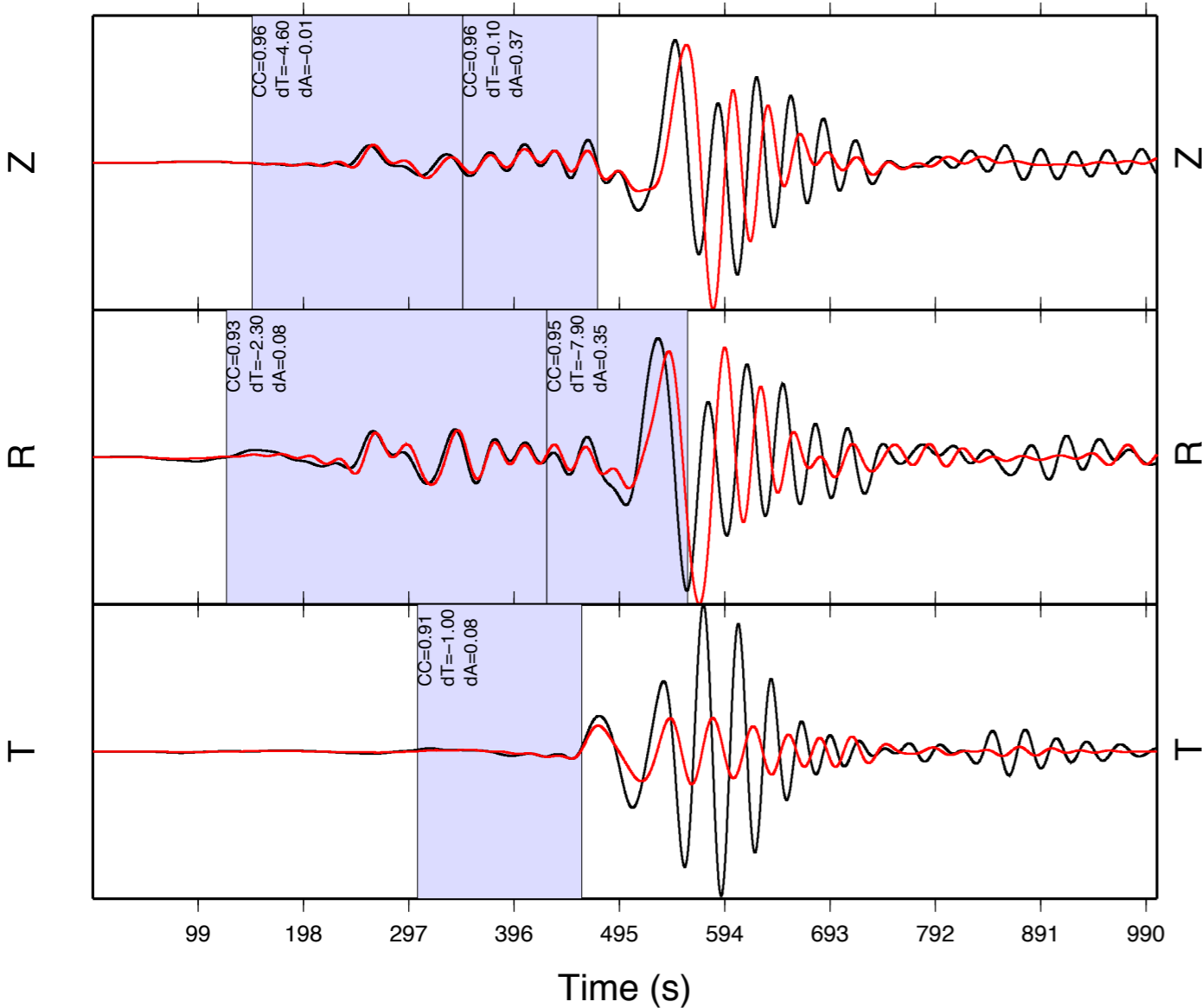


GE.HLG
DIST: 18.79
BCAZ: 144.33
EVDP: 22.90
EVLO: 21.62
EVLA: 37.93
STLO: 7.88
STLA: 54.18
MB: 6.2



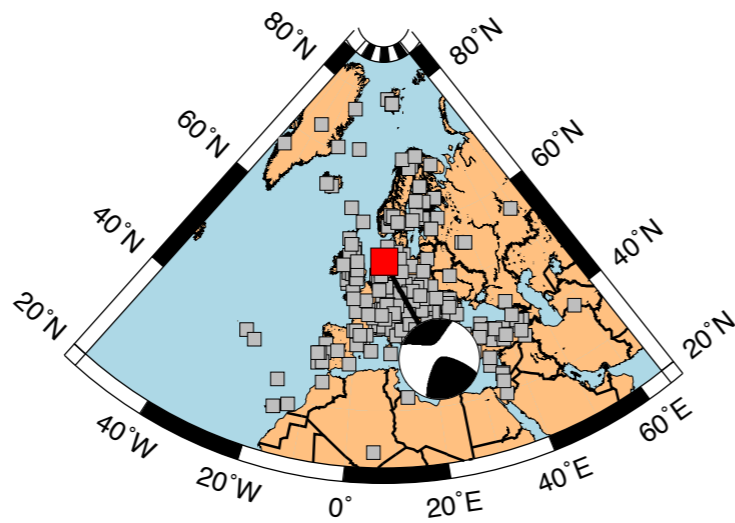
20080608 | 225A
30 - 150 s bandpass

M00



Time (s)

GE.HLG
DIST: 18.79
BCAZ: 144.33
EVDP: 22.90
EVLO: 21.62
EVLA: 37.93
STLO: 7.88
STLA: 54.18
MB: 6.2



20080608 | 225A
30 - 150 s bandpass

M00

M12

