Adjoint-tomography for a Local Surface Structure: Methodology and a Blind Test

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motivation

in recent international numerical exercises
on numerical prediction of earthquake ground motion
in local surface sedimentary structures,

ESG 2006 for Grenoble Valley, France
(e.g., Chaljub et al. 2010)
E2VP for Mygdonian basin, Greece
(e.g., Chaljub et al. 2015, Maufroy et al. 2015, 2016)

4 teams with the most advanced versions
of FDM, SPEM, DGM and PSM
reached very good level of agreement

motivation

the synthetics, however,

were not sufficiently close

to records of real earthquakes

– despite the dedicated efforts

to develop

sufficiently accurate structural models

it was concluded that

improvement of the available structural models

is necessary

for decreasing misfit between synthetics and records

full waveform adjoint inversion

full waveform adjoint inversion

has been successfully applied

in the regional and global scales

here we present

full waveform adjoint inversion

in a local surface sedimentary structure (LSSS)

specific aspects of LSSS

typically several km wide and hundreds of m deep

initial model poorly determined

relatively small # of records of local weak earthquakes

relatively small # of source-receiver pairs

absolute values of target frequencies
are higher than those in the regional and global scales
but
the ratio of characteristic wavelengths to the model dimension
is much larger

complexity of waveforms due to
interference and resonant nature of EGM
(seismic phases not well separated)

relatively large initial waveform misfit

specific aspects

these specific features are reflected

in

choice of misfit,

definition, computation and preconditioning of kernel,

selection of inversion model parameter,

misfit minimization,

selection of an optimal step for updating model,

adaptive multiscale approach,

set of scenarios

and repetitive multiscale inversion

scenario

a complete multiscale inversion

for a set of inversion parameters

set of scenarios

because the best set of values

of the inversion parameters

cannot be determined

at the beginning of the inversion process,

it is necessary to try a set of different scenarios

different scenarios can be compared

using the aggregate misfits

the inverted model from the scenario

with the lowest aggregate misfit

can be selected as the best inverted model

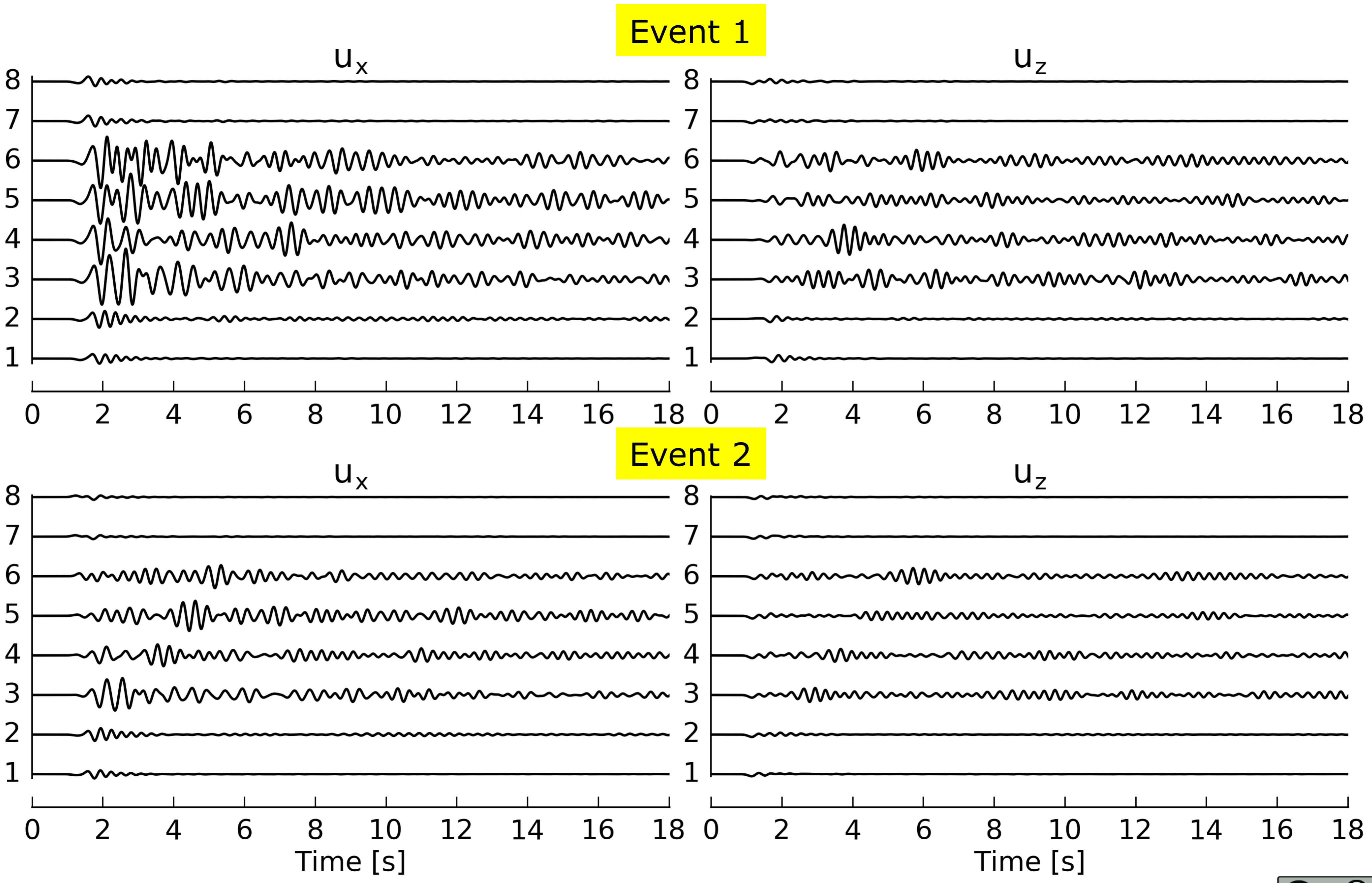
2D P-SV blind test

input data

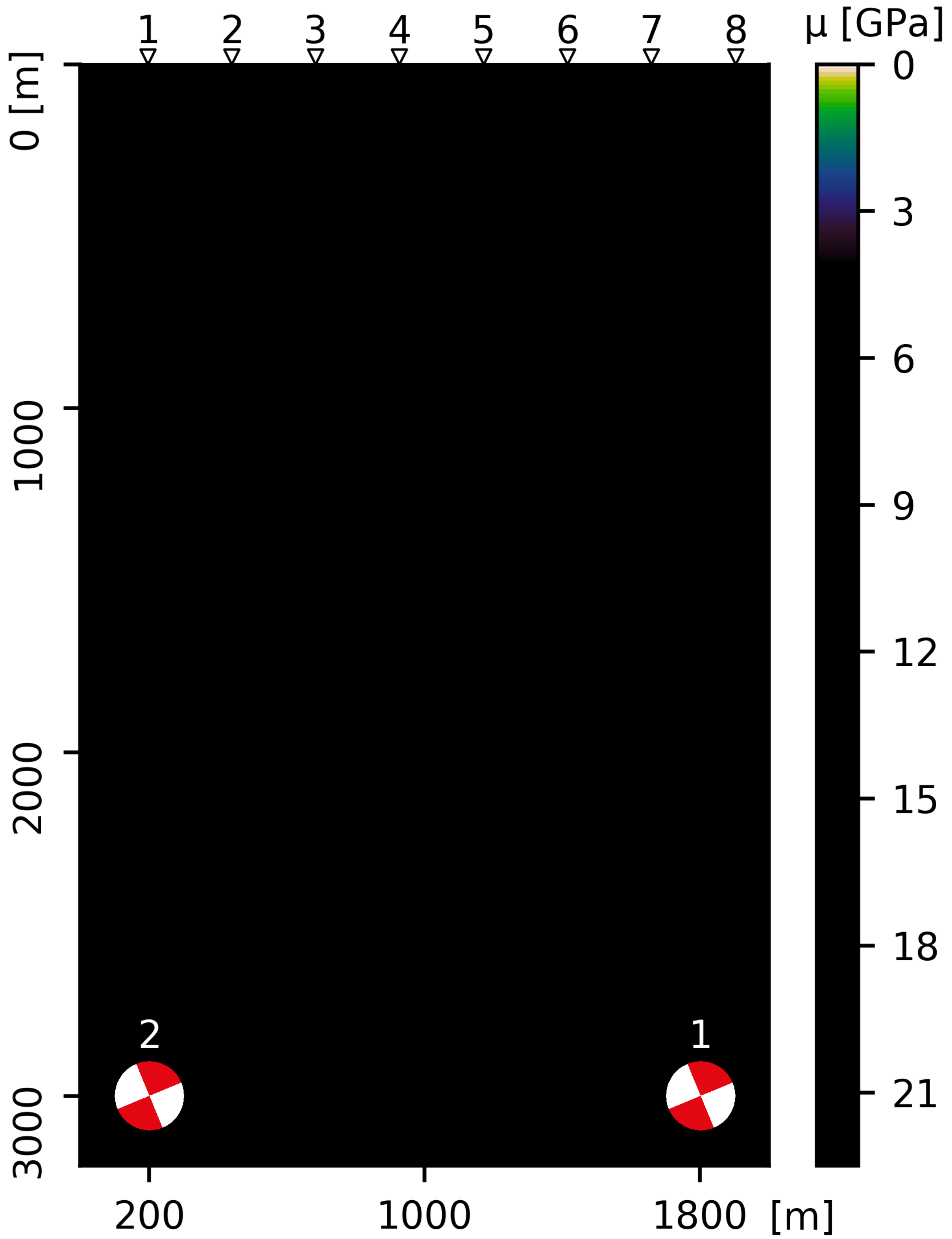
- records (up to 4.5 Hz)
- receiver positions
- source parameters
- material parameters of bedrock

records
≡
synthetics
for the
true model

provided by
the 3rd party



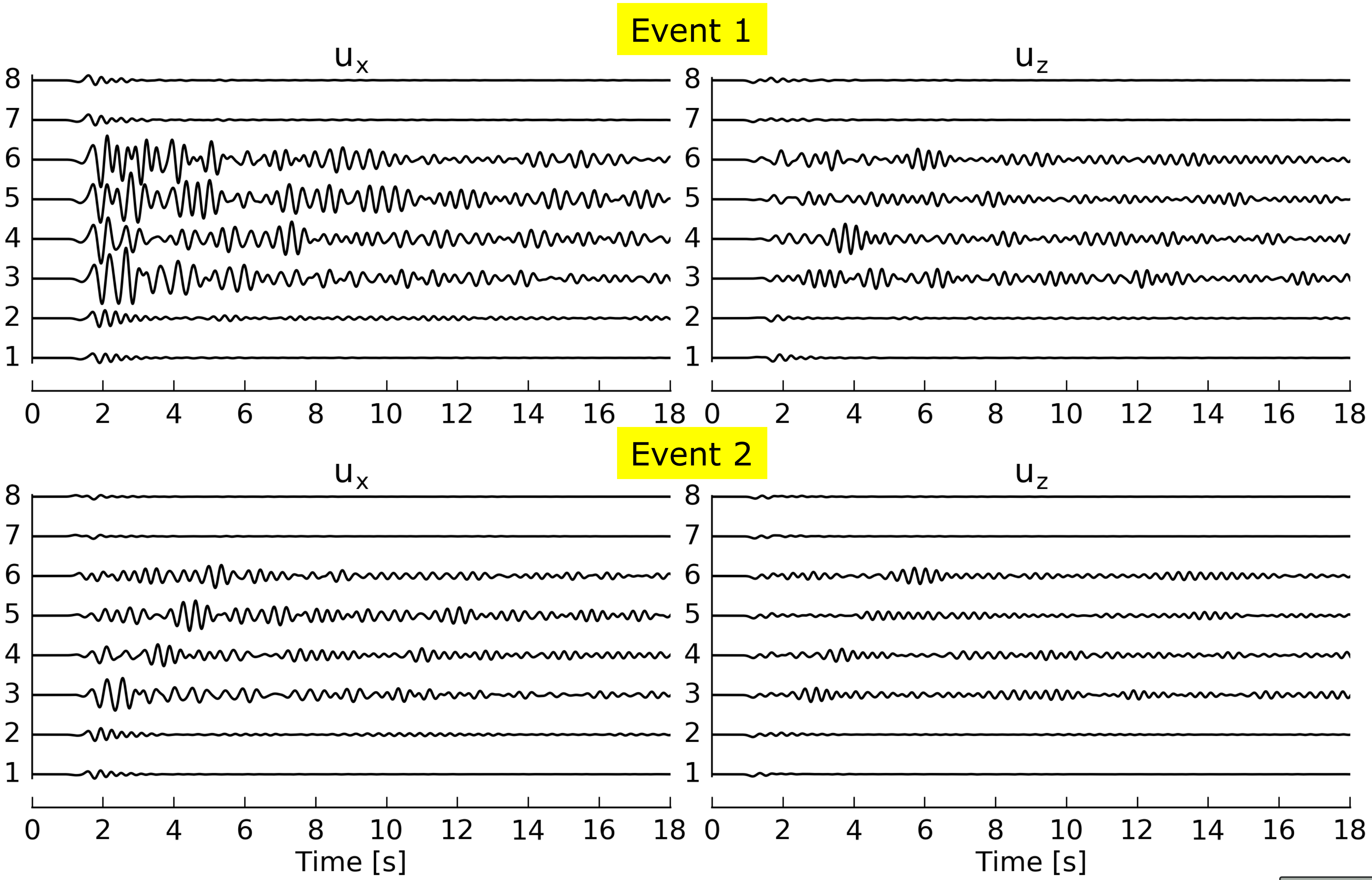
initial model



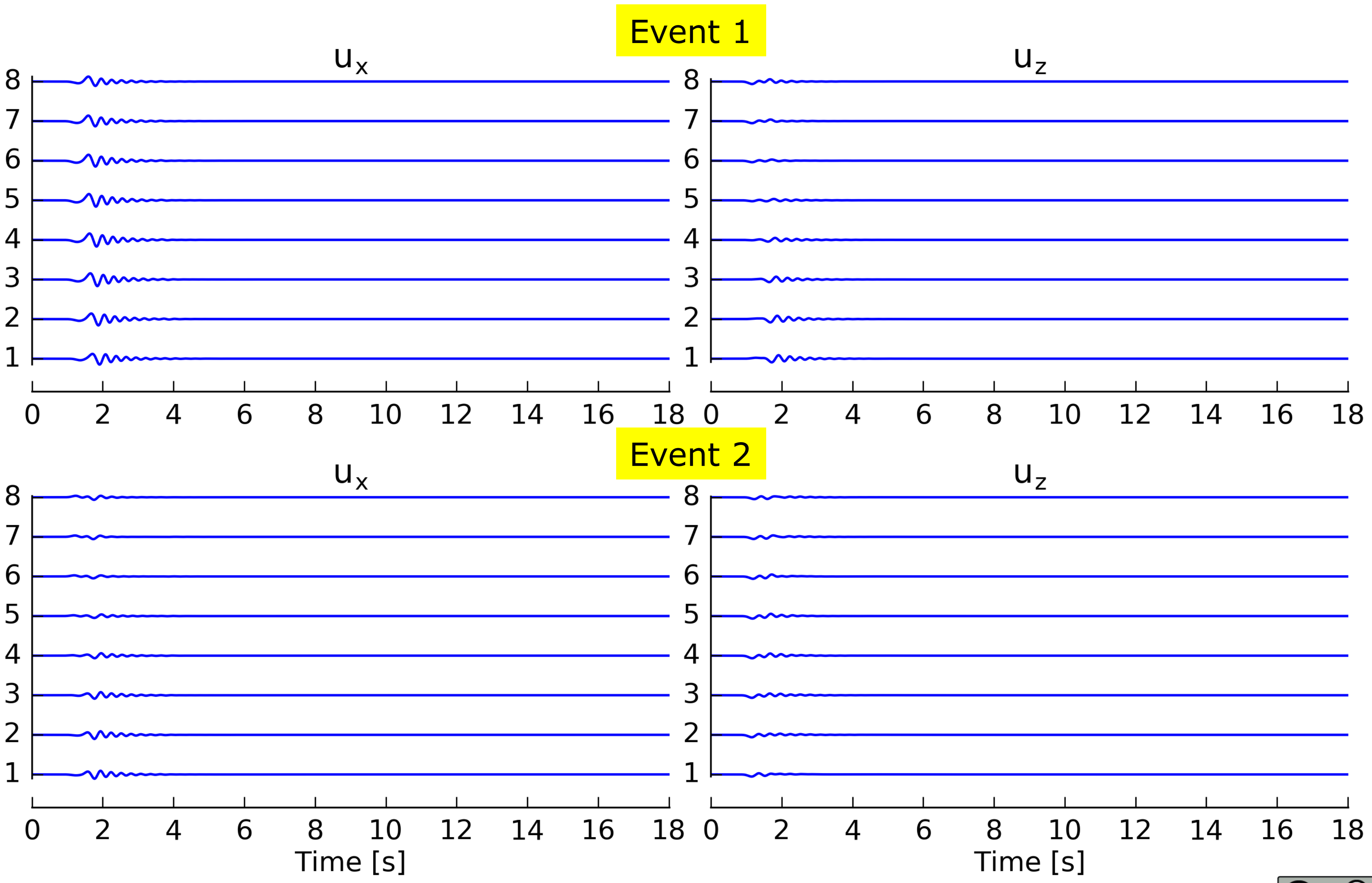
material parameters of bedrock

density	$\rho = 2500\ kg.m^{-3}$
P-wave speed	$\alpha = 5400\ m.s^{-1}$
S-wave speed	$\beta = 3000\ m.s^{-1}$
Lamé constant	$\lambda = 27.9\ GPa$
shear modulus	$\mu = 22.5\ GPa$

„records"


Event 1
u_x
u_z
Event 2
u_x
u_z
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
Time [s]
Time [s]

synthetics for the initial model



final inverted model

obtained after

7 repetitions of the multiscale inversion

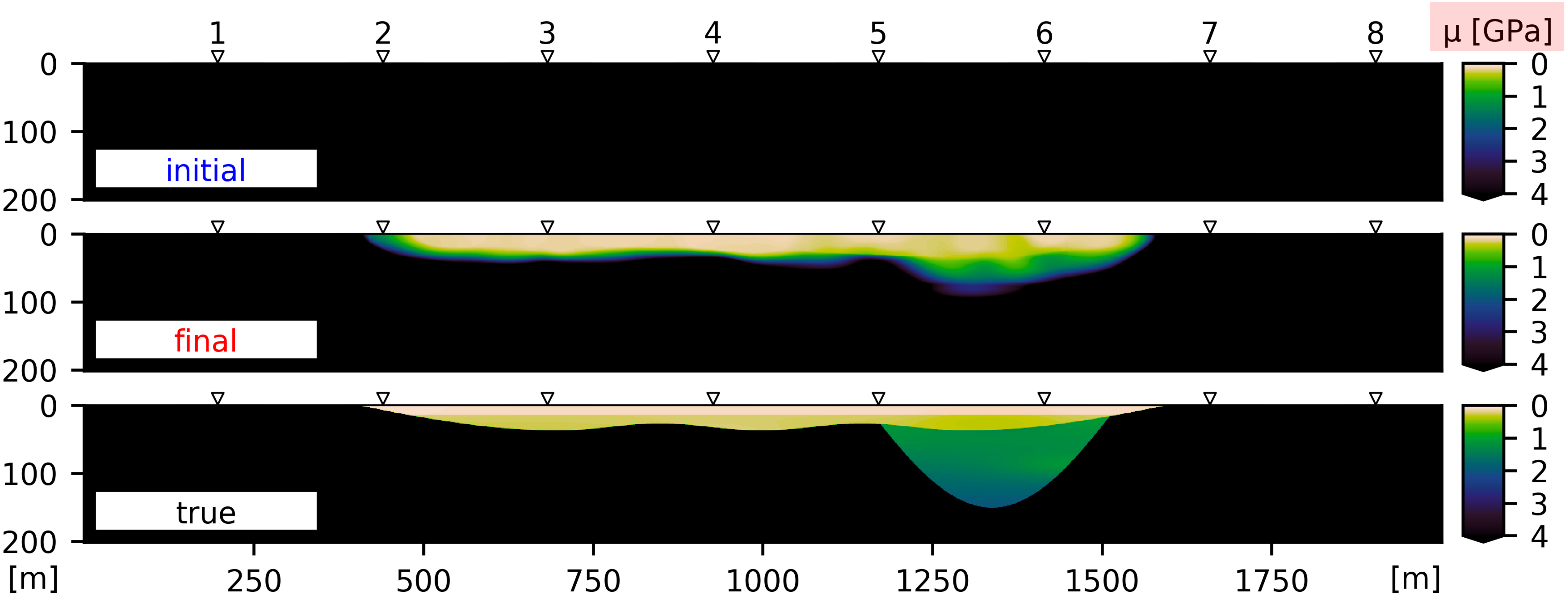
when the rate of improvement of the waveform misfits

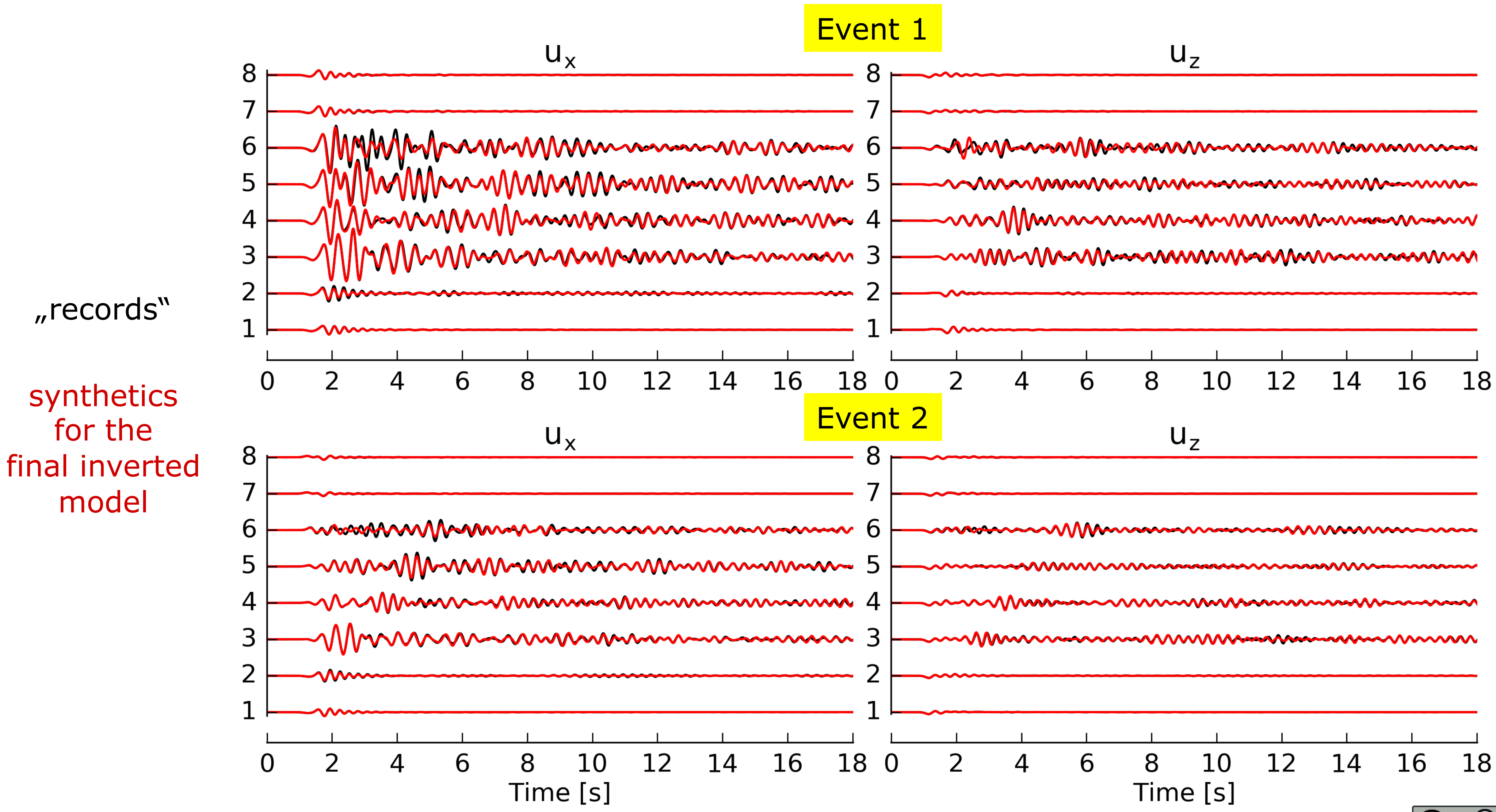
decreased

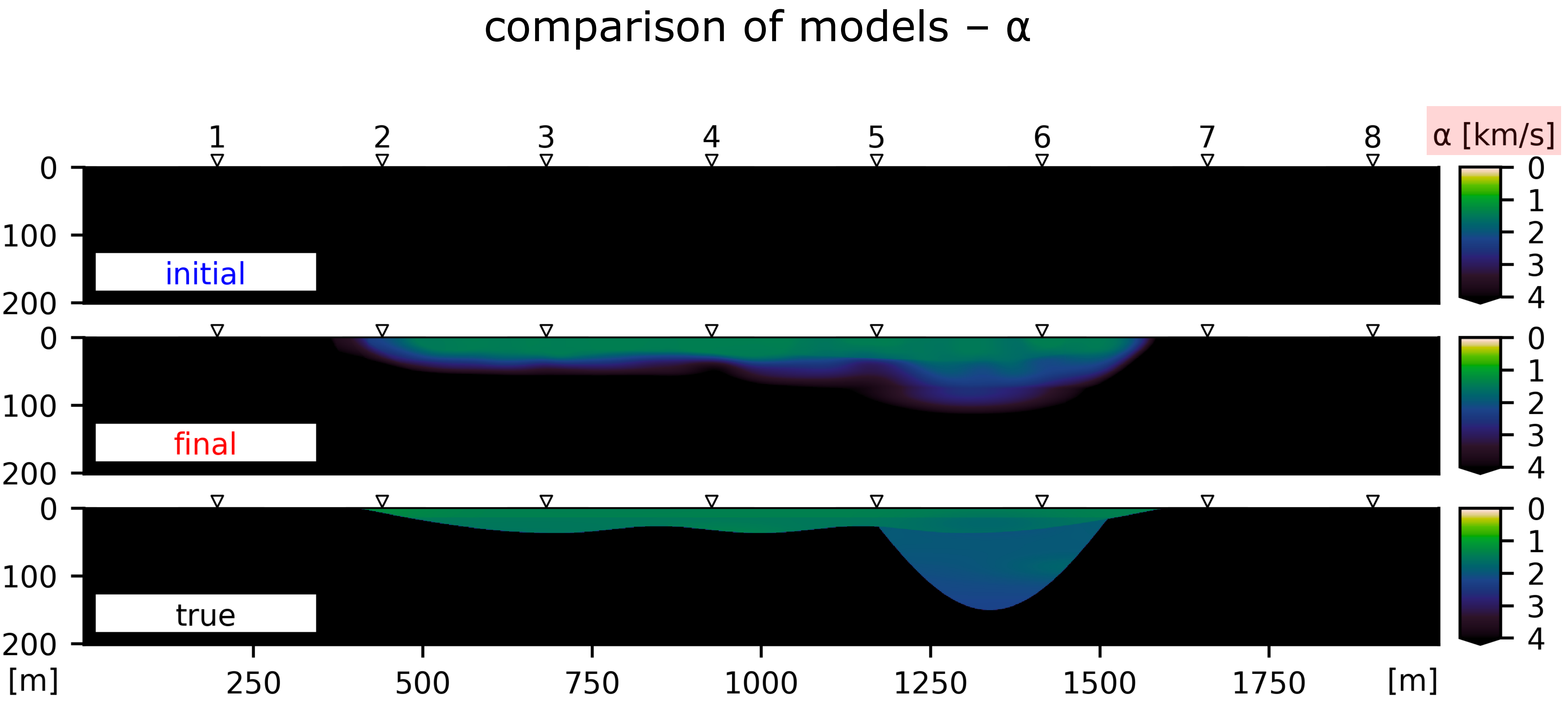
significantly smaller waveform misfits

compared to the initial waveform misfits

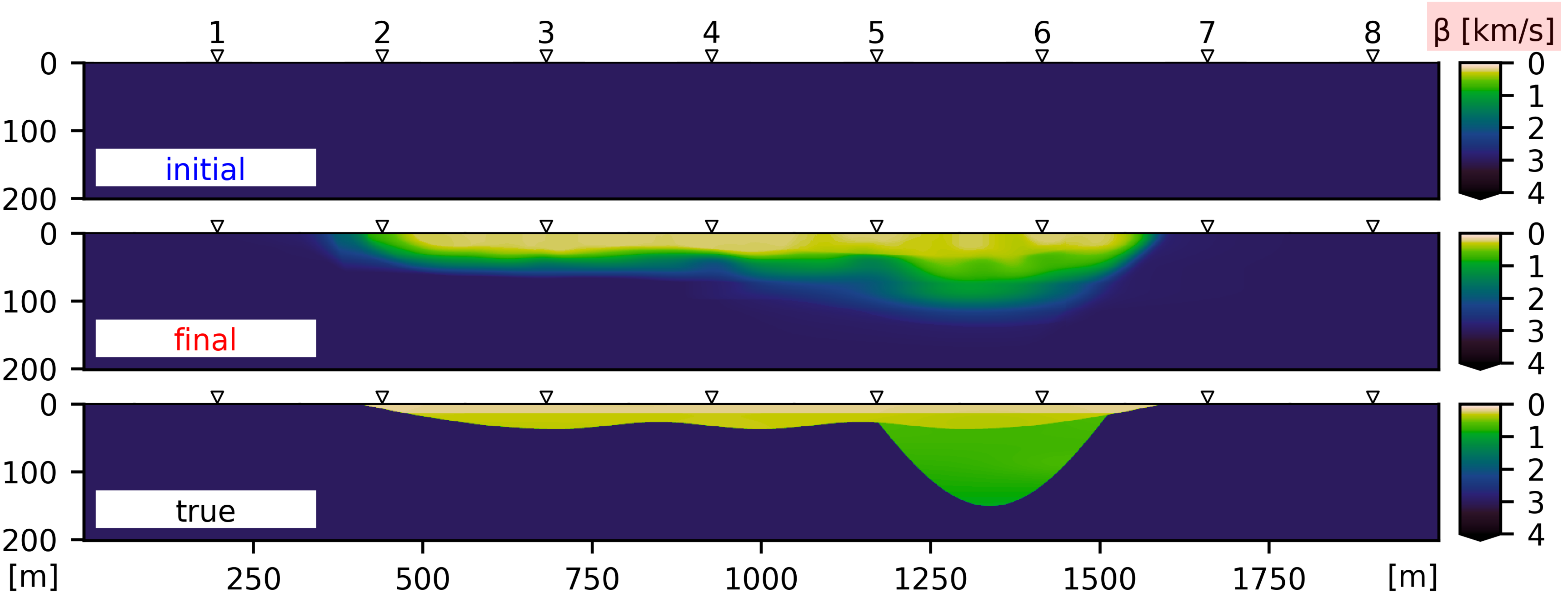
comparison of models – μ




„records"
synthetics for the final inverted model
Event 1
Event 2
u_x
u_z
Time [s]
0 2 4 6 8 10 12 14 16 18
1 2 3 4 5 6 7 8


comparison of models – α
1
2
3
4
5
6
7
8
α [km/s]
0
100
200
initial
final
true
0
1
2
3
4
[m]
250
500
750
1000
1250
1500
1750
[m]

comparison of models – β



how good is the inverted model ?

we evaluated time-frequency based
envelope and phase
goodness-of-fit
for each component at each receiver
for each event
between
the synthetics for the inverted model and „records“

in most cases
the level of agreement was excellent,
in several cases
good

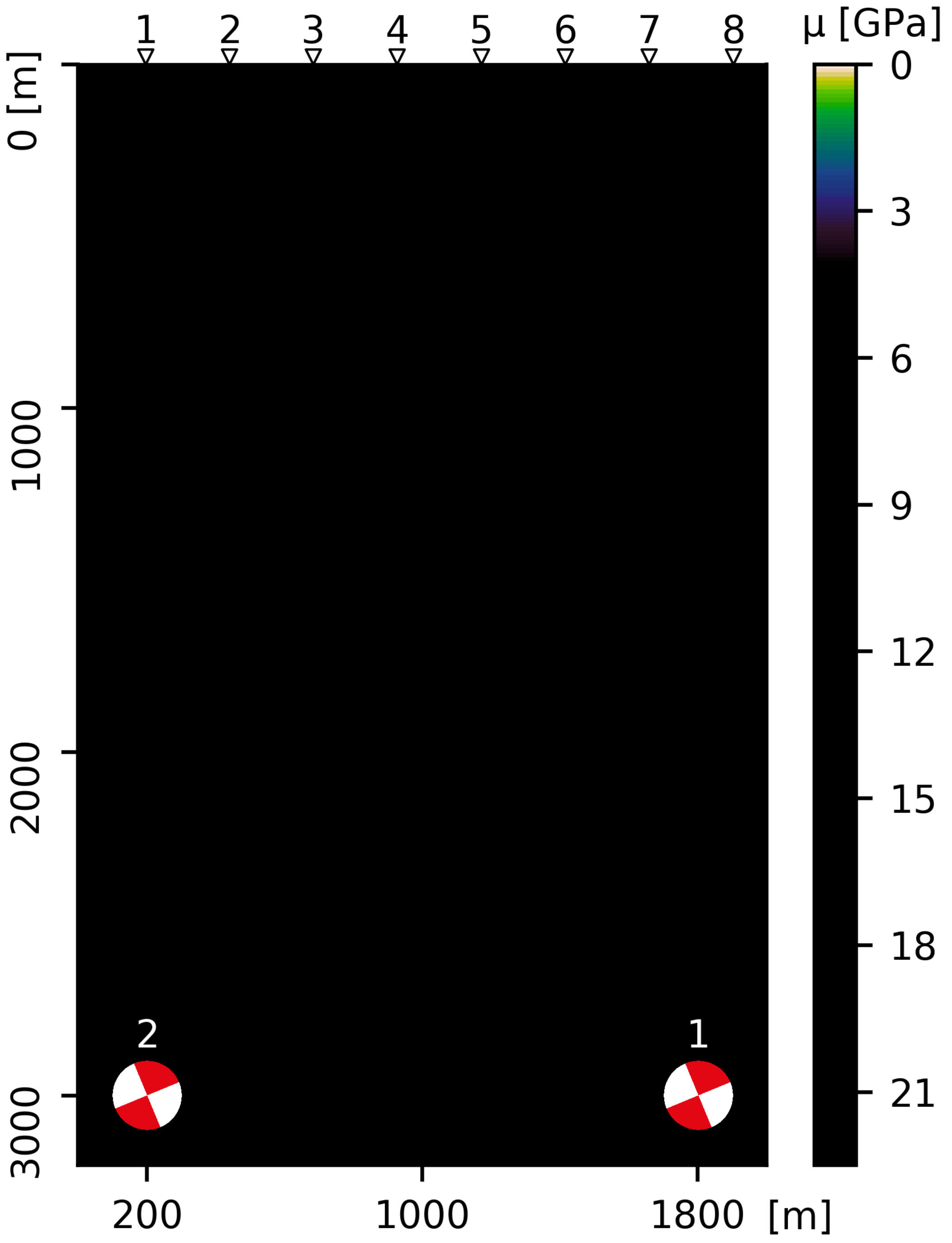
verification

of the inverted model

using

additional receivers and sources

recall that
the inverted model
was obtained using
2 sources
and
8 receivers



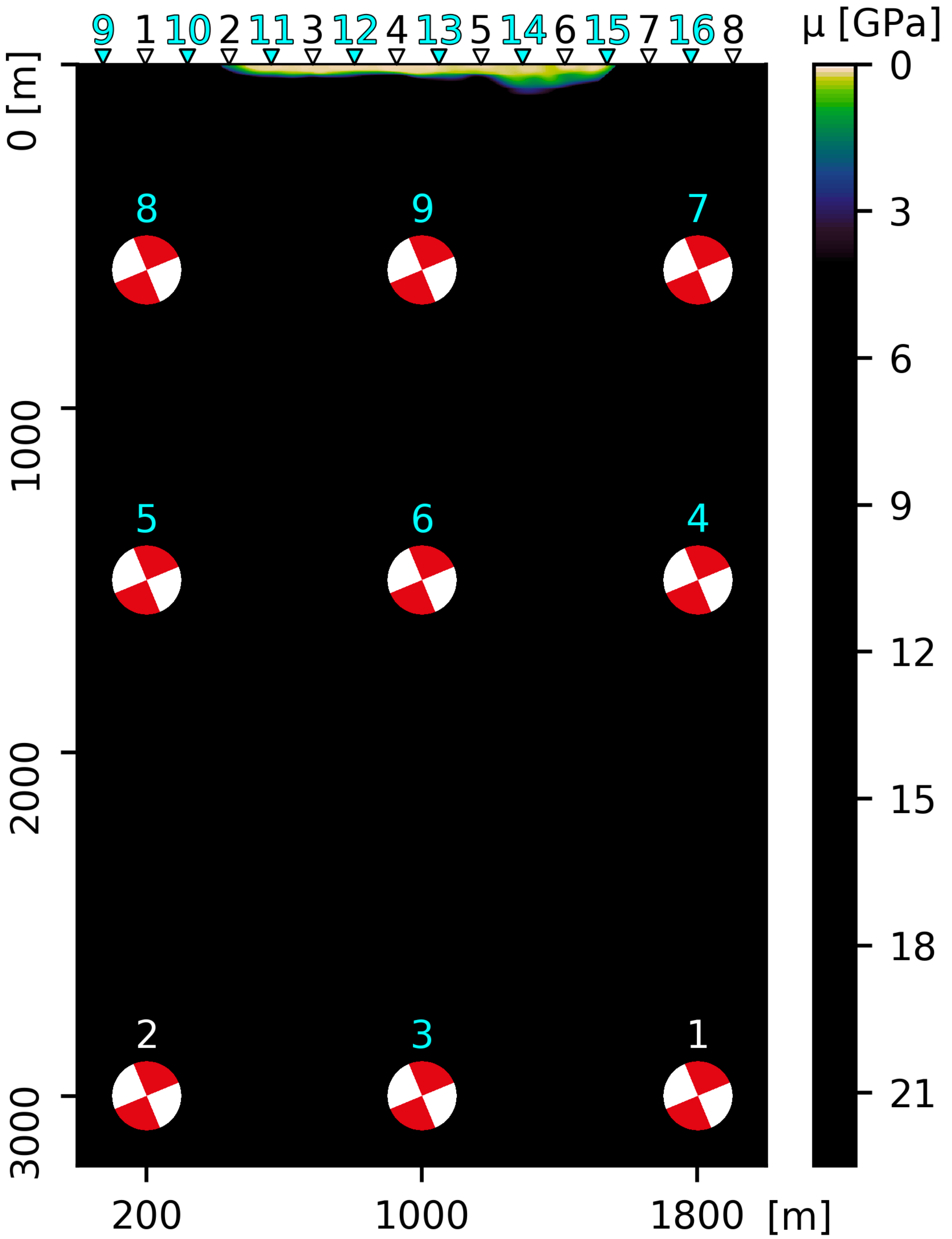
verification

using **additional**

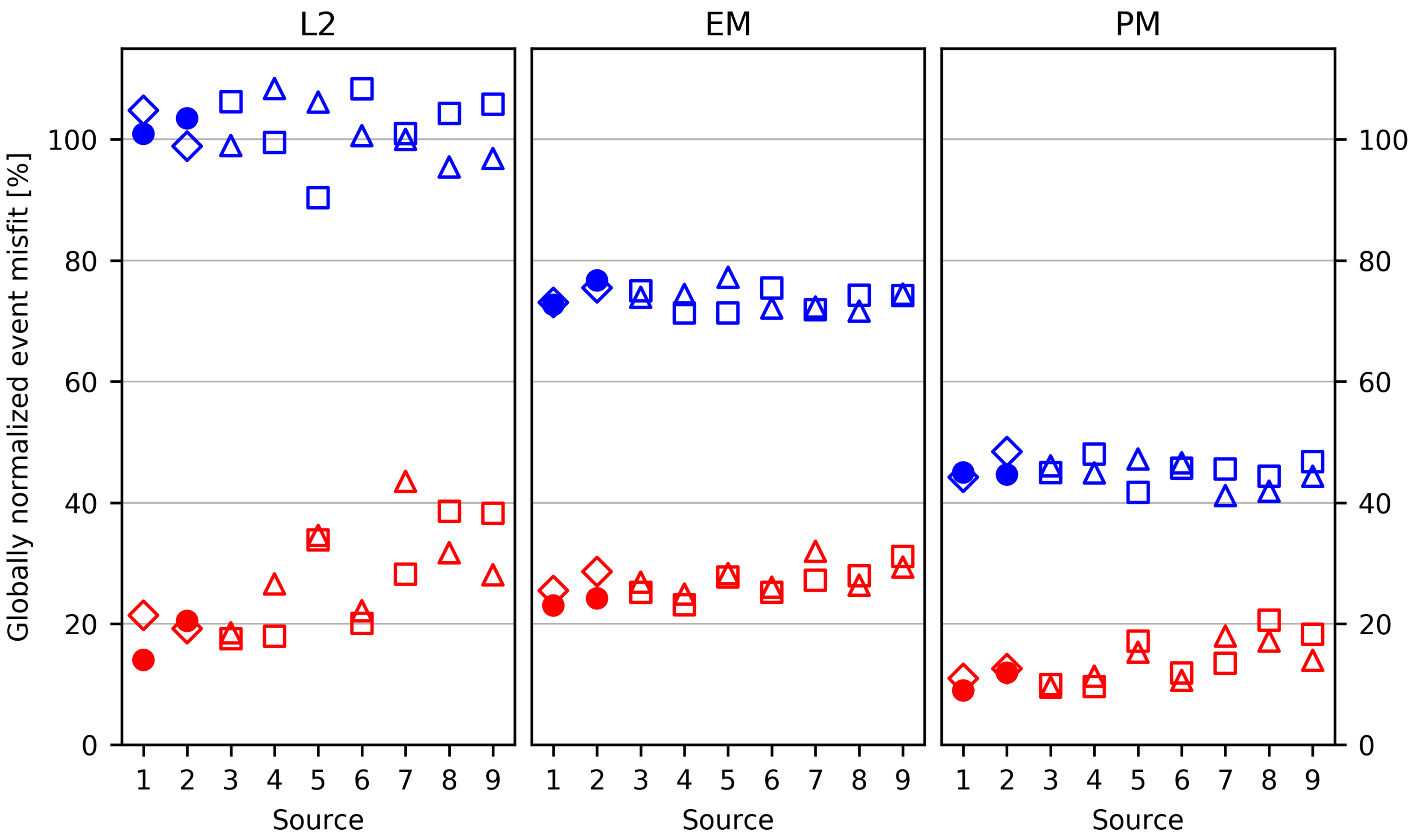
7 sources

and

8 receivers



event misfits

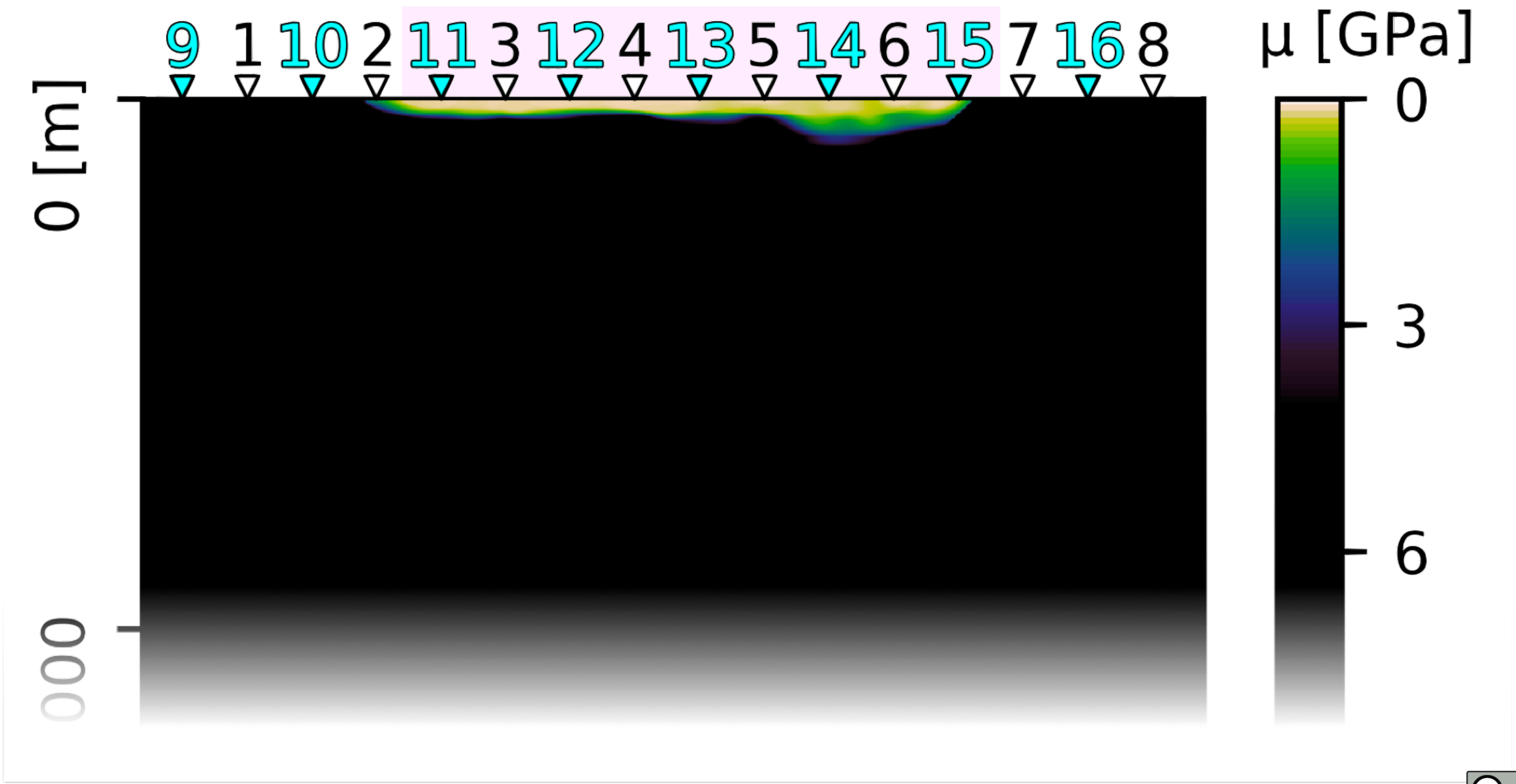


Event mifit calculated for:

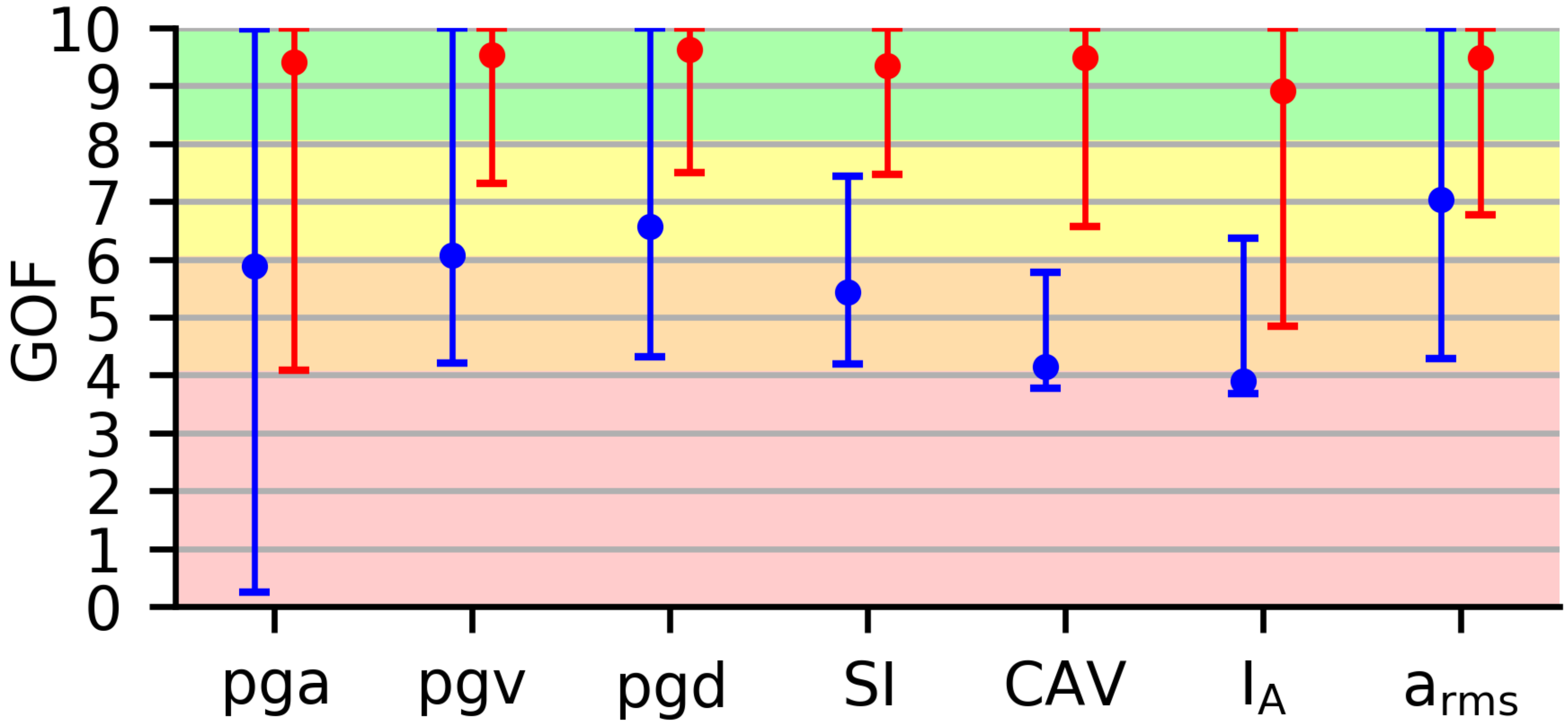
initial model

final inverted model

- ●● source 1 or 2, receivers 1-8 — data used for inversion
- ◇◇ source 1 or 2, receivers 9-16
- □□ source: one of {3,...,9}, receivers 1-8
- △△ source: one of {3,...,9}, receivers 9-16



9 1 10 2 11 3 12 4 13 5 14 6 15 7 16 8
0 [m]
μ [GPa]
0
3
6



initial model

final inverted model

goodness-of-fit (GOF)

for selected
earthquake ground motion characteristics

evaluated for all
7 sources
9 receivers atop sediments

GOF – verbal values

- excellent fit
- good fit
- fair fit
- poor fit

GOFs for CAV

at receivers
atop sediments

(CAV = cumulative absolute velocity)

initial model

final inverted model

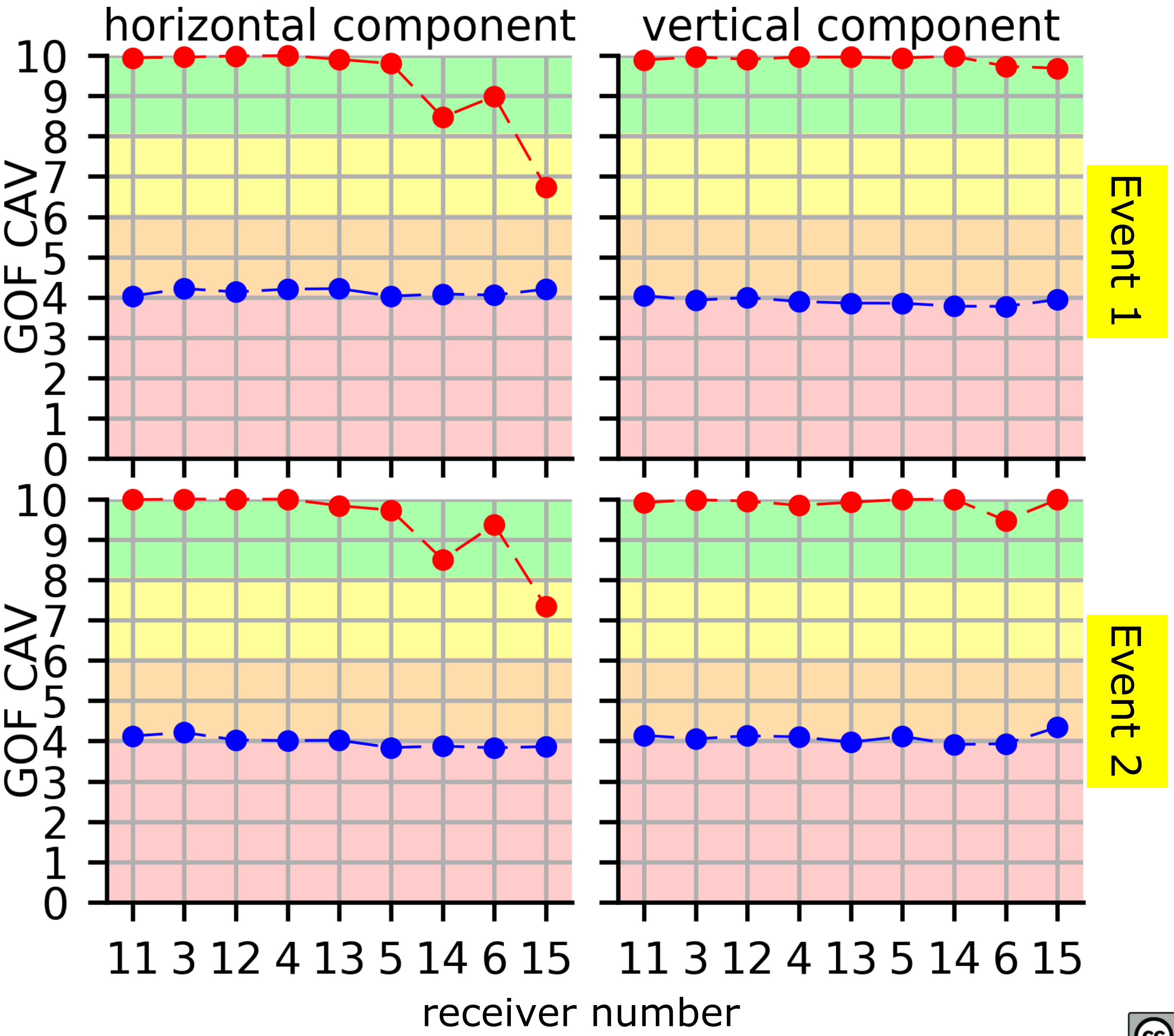
GOF – verbal values

excellent fit

good fit

fair fit

poor fit



conclusions

based on extensive numerical modelling and testing

we have developed

a procedure for adjoint tomography

for 2D local surface sedimentary structures

the procedure is specific in terms of

kernel

kernel computation

kernel preconditioning

inversion model parameter

misfit minimization

selection of an optimal step for updating model

adaptive multiscale approach

set of scenarios

repetitive multiscale inversion

we verified the procedure in a blind test

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by

Kubina, Michlík, Moczo, Kristek and Stripajová

submitted to Geophys. J. Int.

the next step:

adjustment of the procedure
to the 3D problem

thank you

for your attention