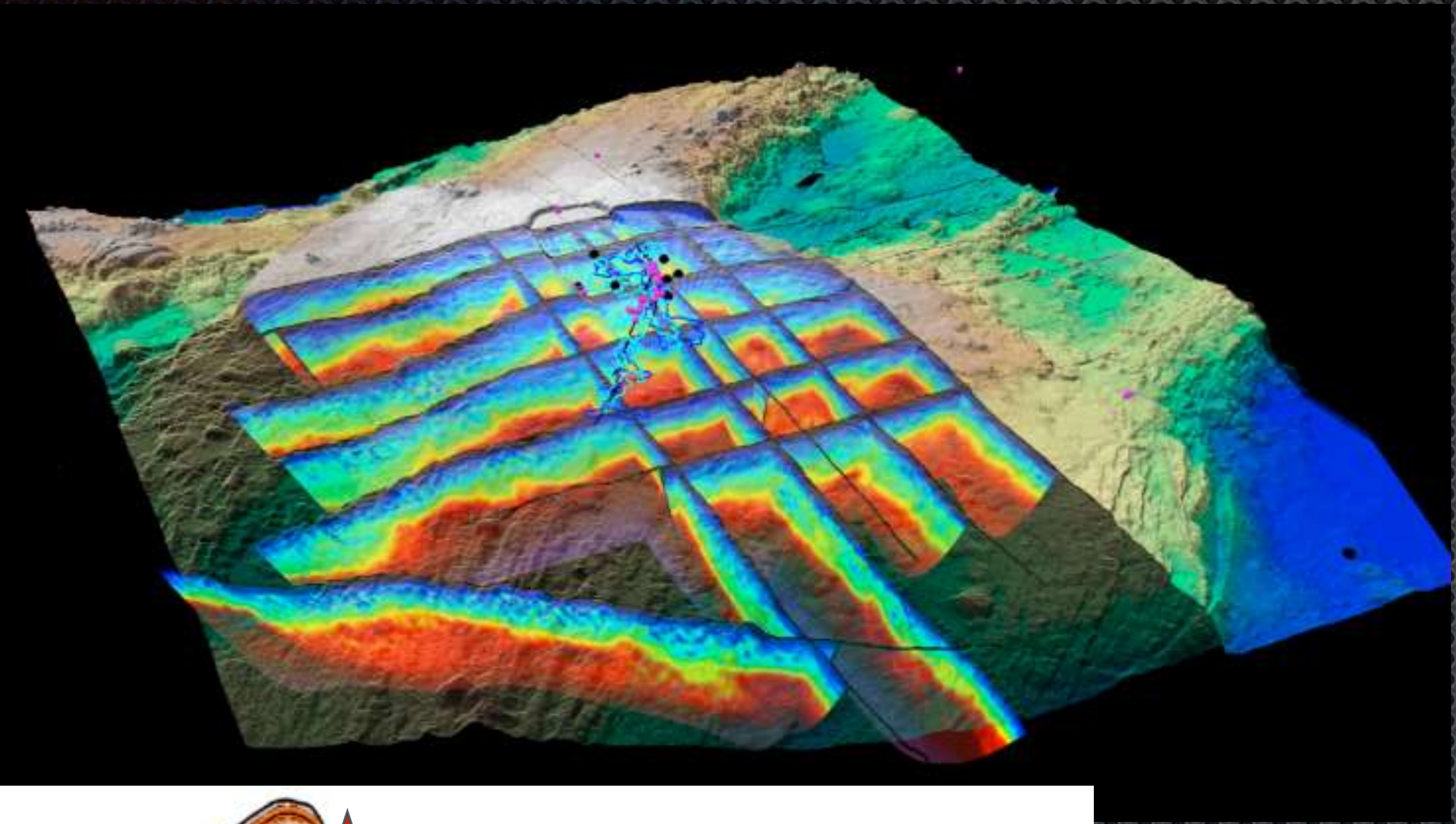
INSTITUTE FOR GEOPHYSICS

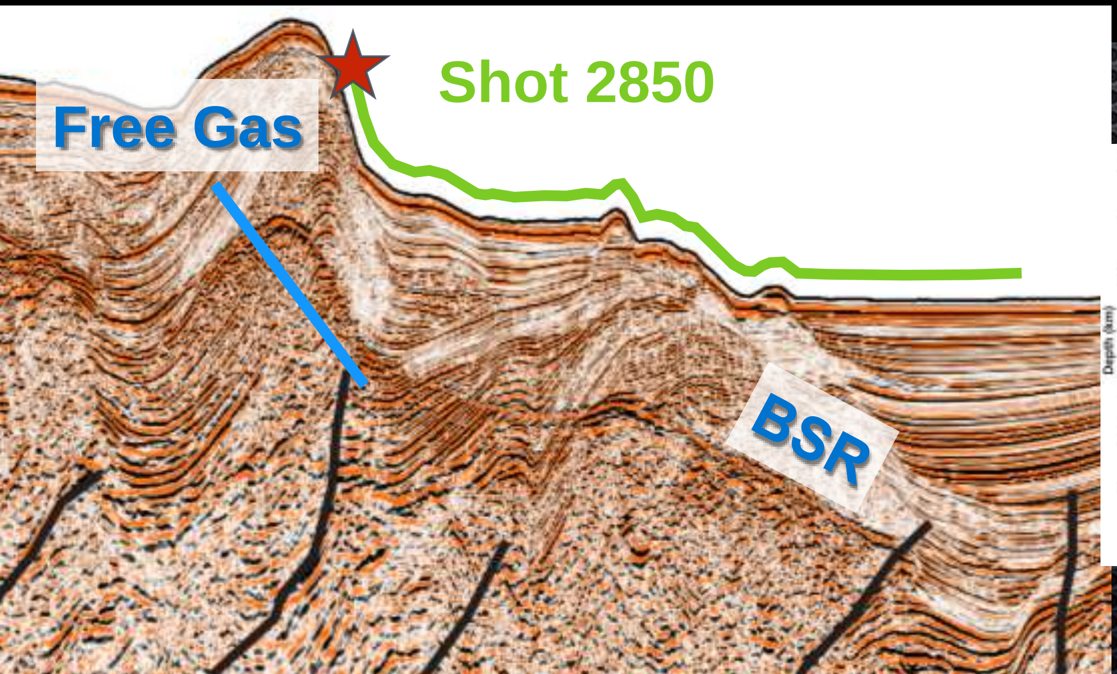
TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences
Institute for Geophysics

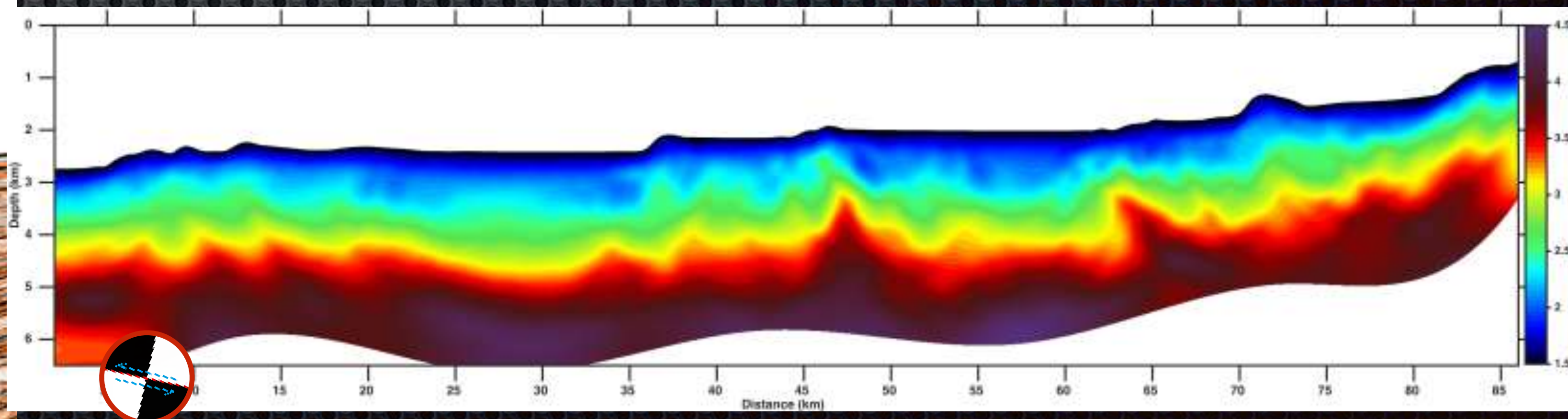
Adrien Arnulf

Science opportunities with Langseth long streamer/OBS & FWI

MLSOC / MSROC meeting - San Francisco Dec 11th, 2016







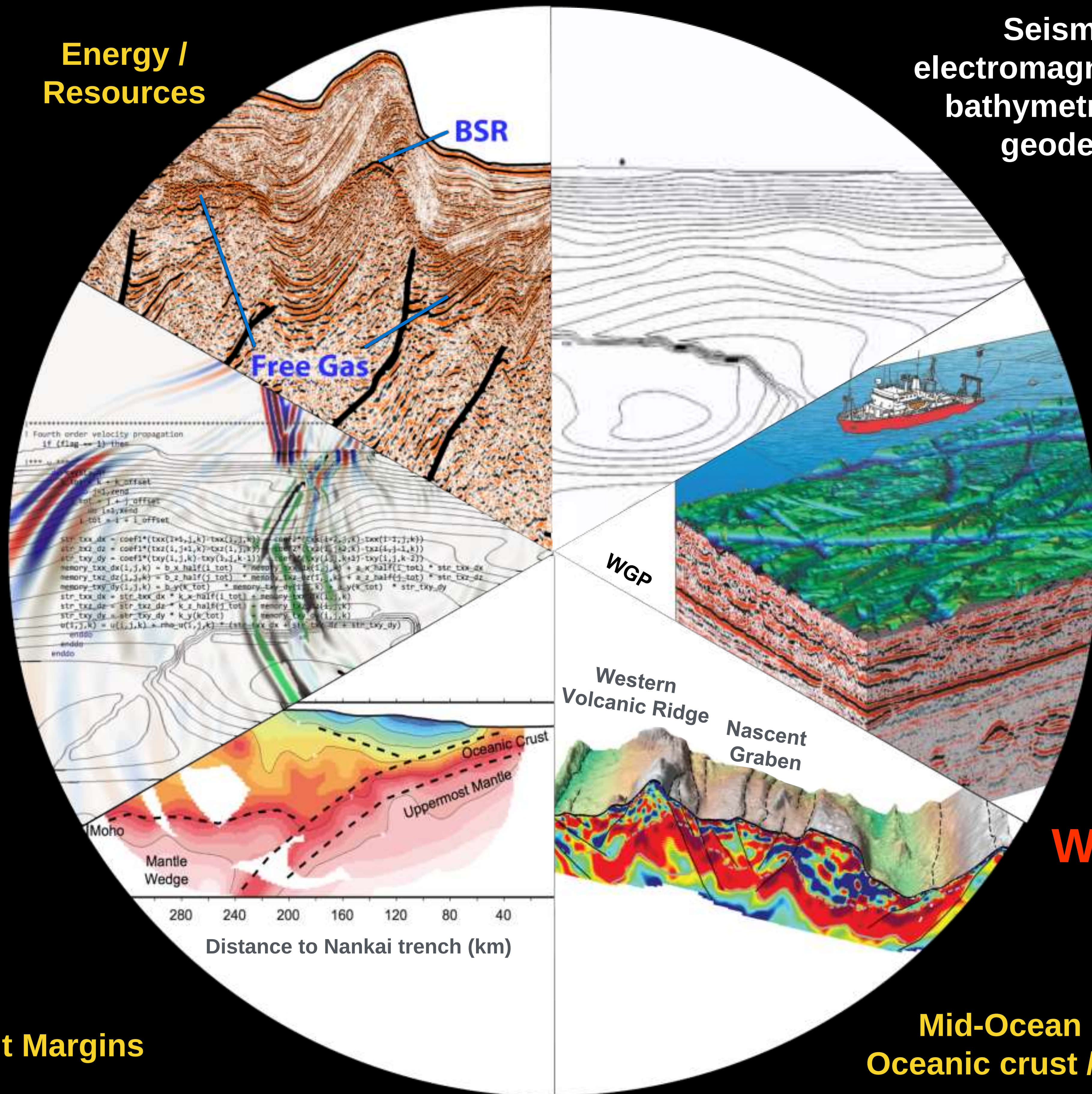
Marine Geophysicists - Who are we ?

Energy / Resources

Seismology, electromagnetic, gravity, bathymetry, seafloor geodesy, etc.

Numerical Methods

Measurements from a research vessel
R/V M. Langseth



What do we study ?

Convergent Margins

Mid-Ocean Ridges / Oceanic crust / Seamounts

Today’s focus

Science opportunities with Langseth long streamer/OBS & FWI

Seismic capabilities:

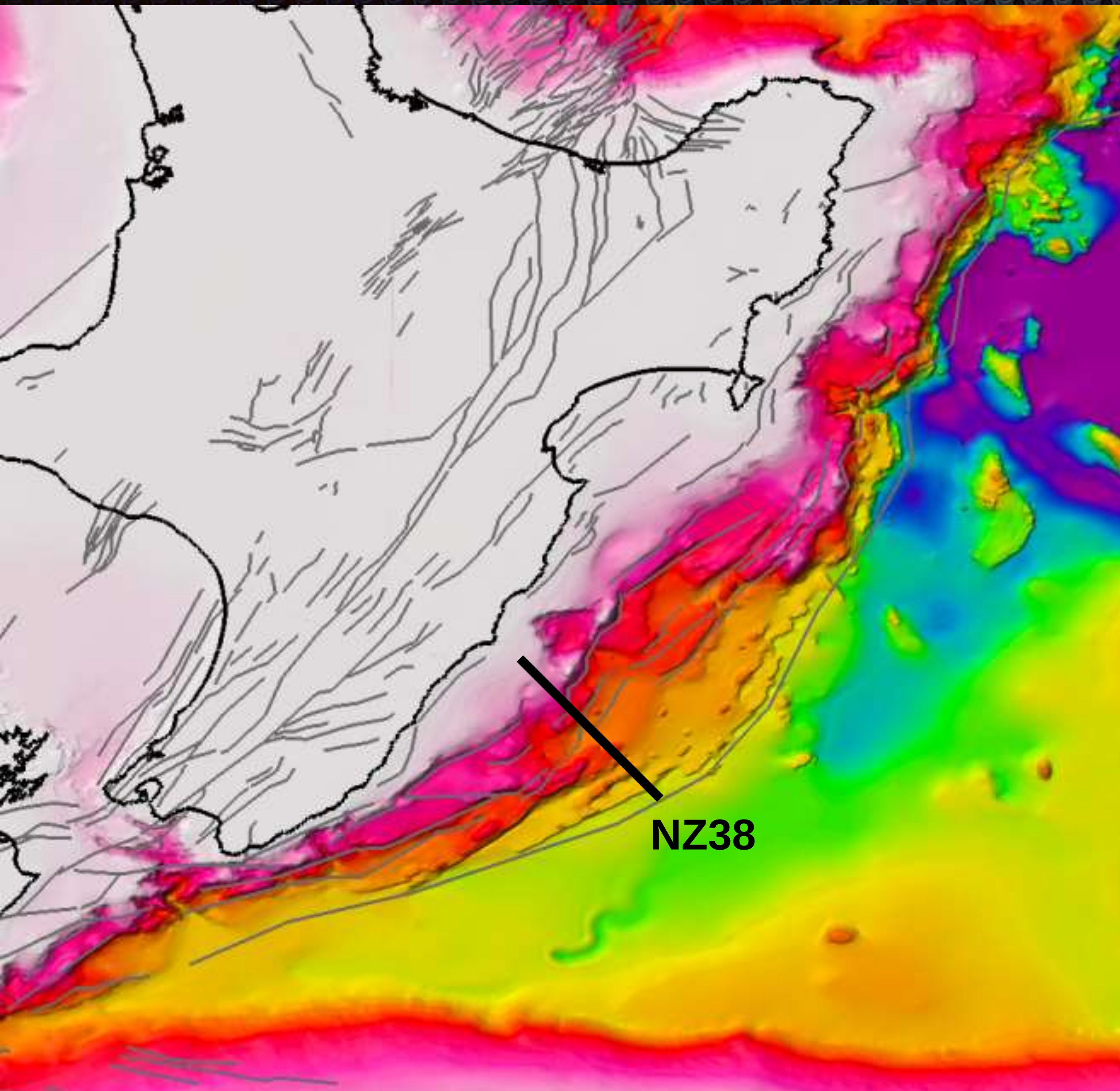
_ For 2D seismic:
  15 km long streamer

_ For 3D seismic:
  4*6 km-long streamers

_ Deployment and recovery of OBSs

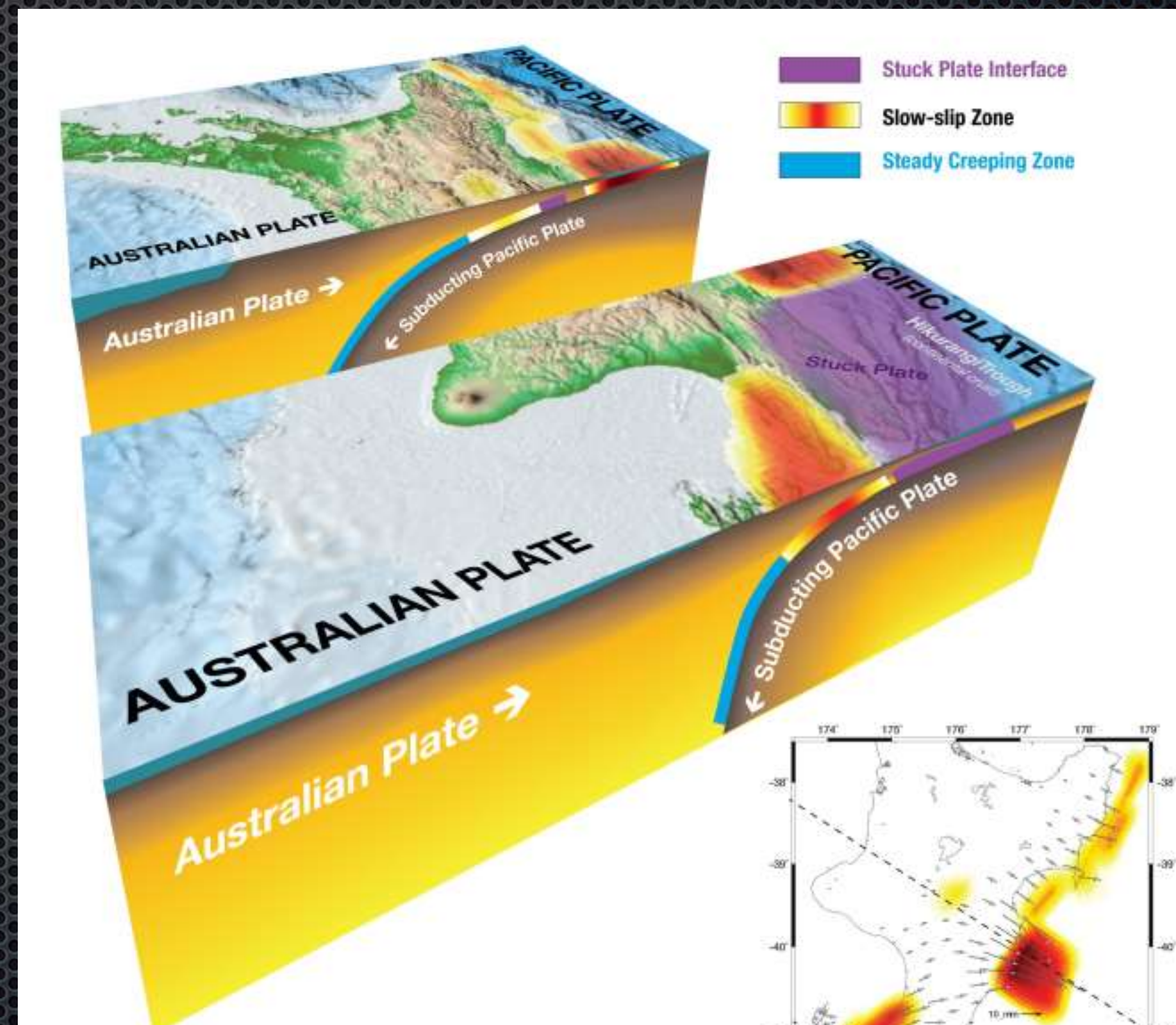
Seismic Investigation of the Hikurangi margin, NZ

Science opportunities with Langseth long streamer/OBS & FWI



250 m resolution bathymetry data courtesy of NIWA

http://info.geonet.org.nz/

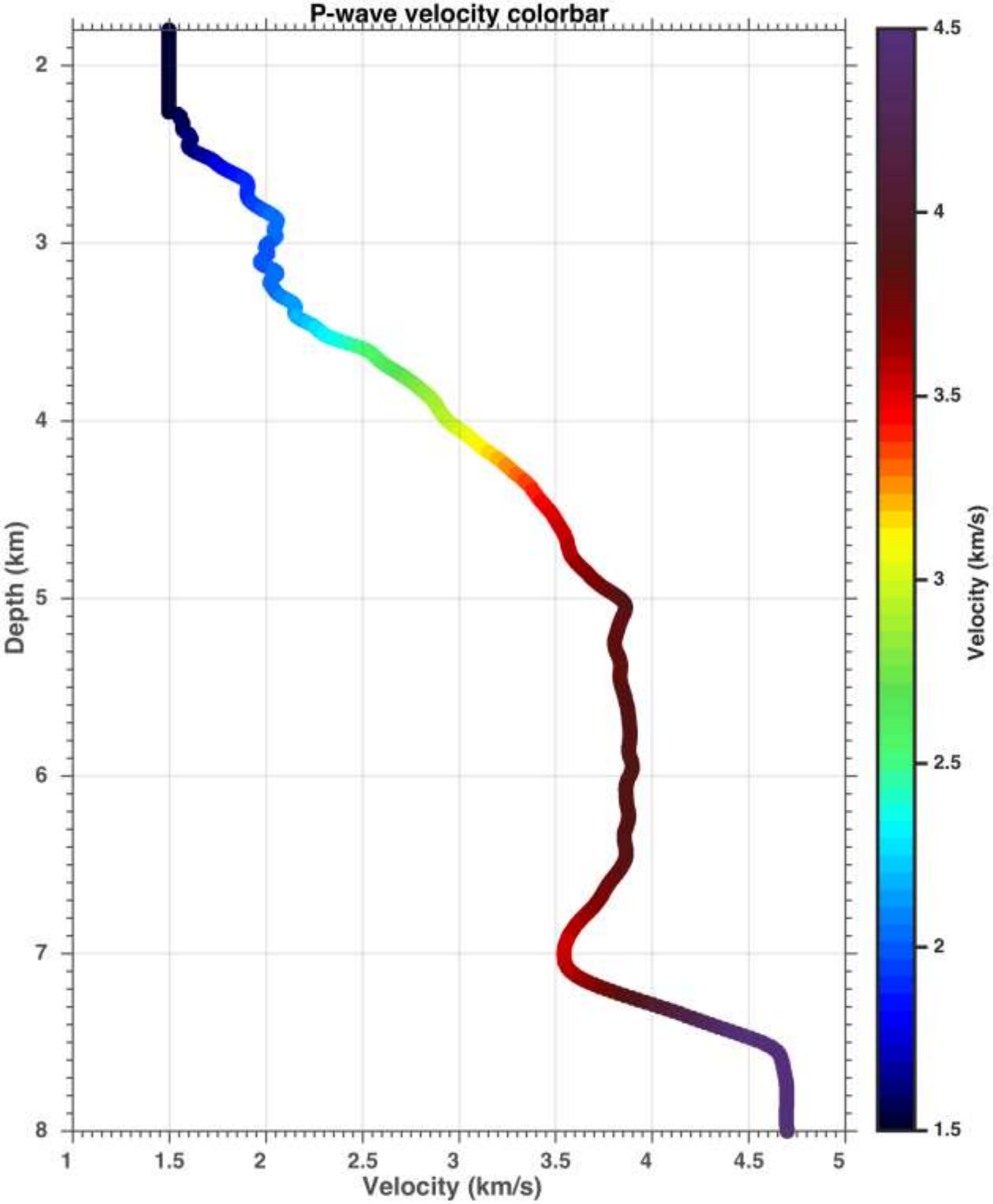


Slow-slip events following the Nov 14th, 2016 Kaikoura Earthquake

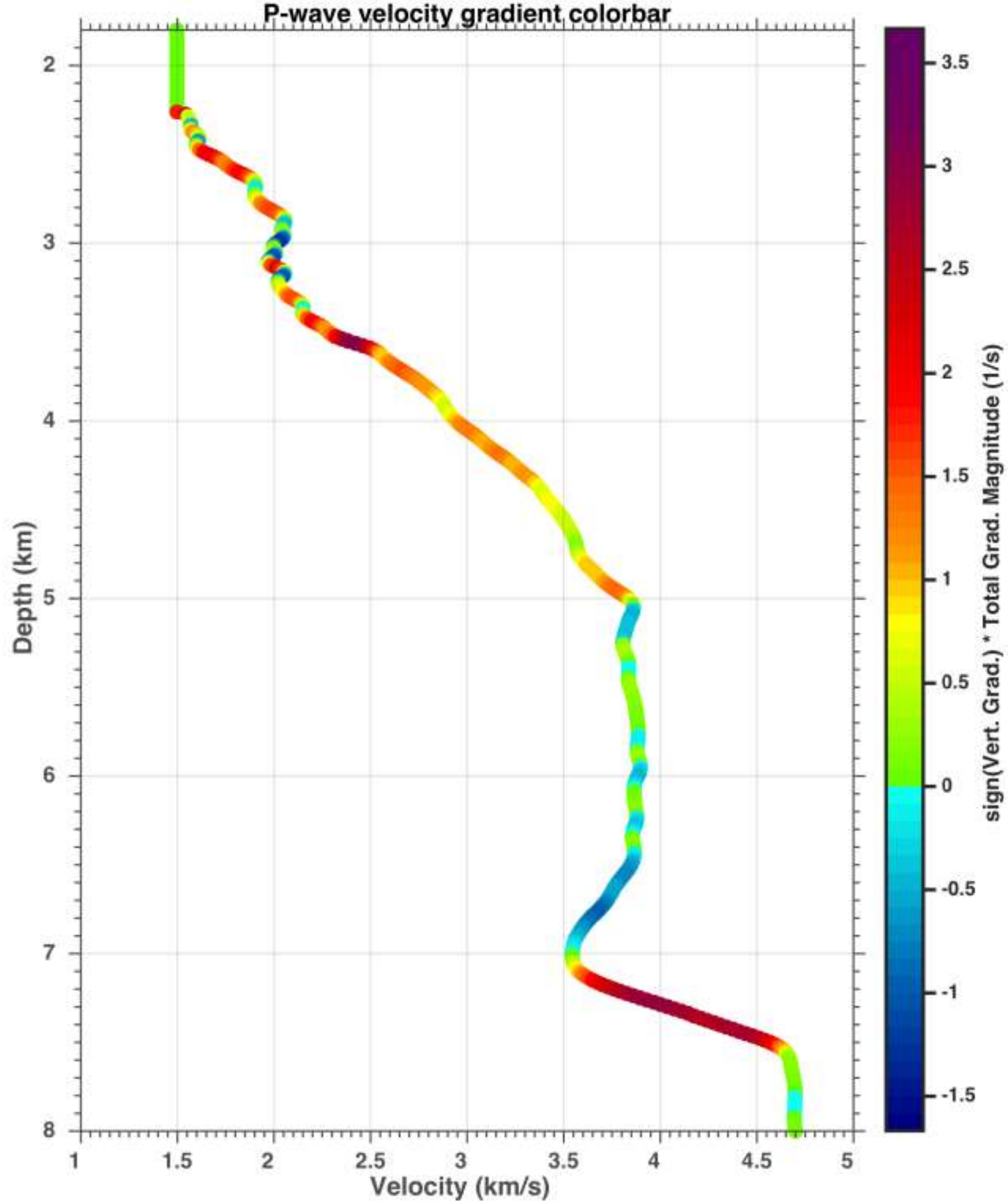
Seismic Investigation of the Hikurangi margin, NZ

Science opportunities with Langseth long streamer/OBS & FWI

Velocity

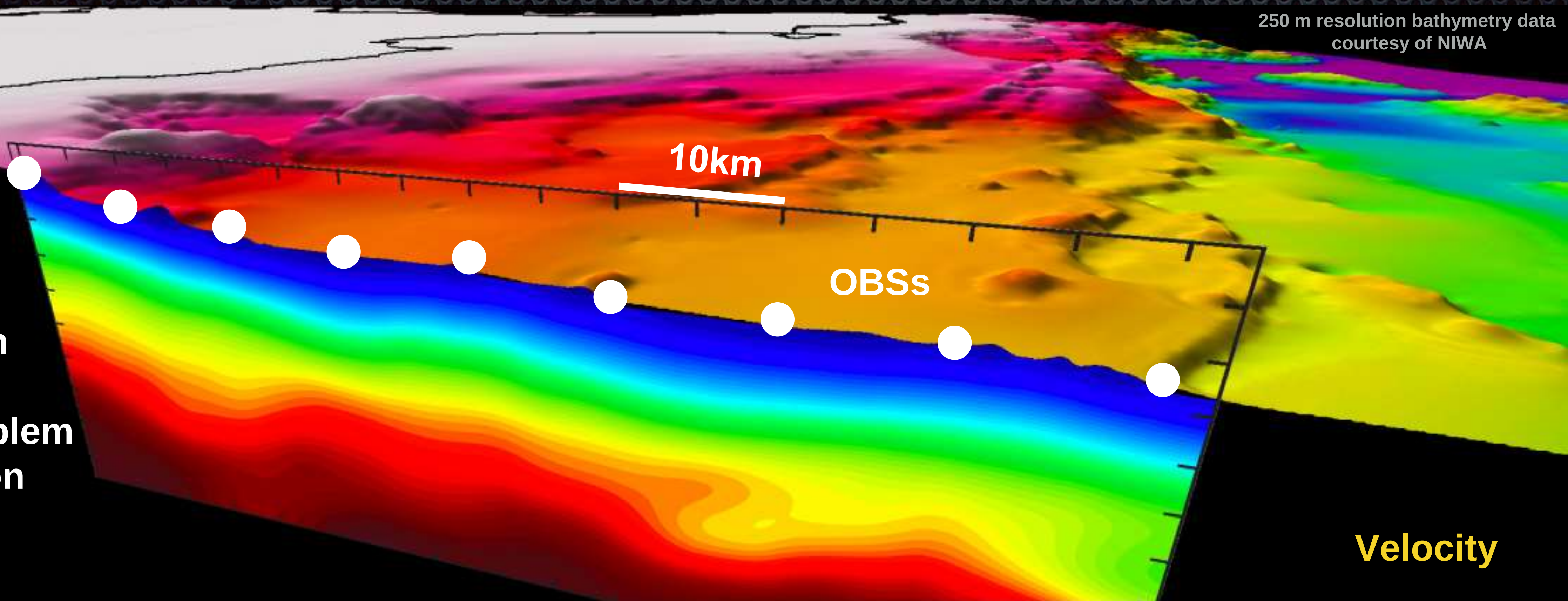


Velocity gradient



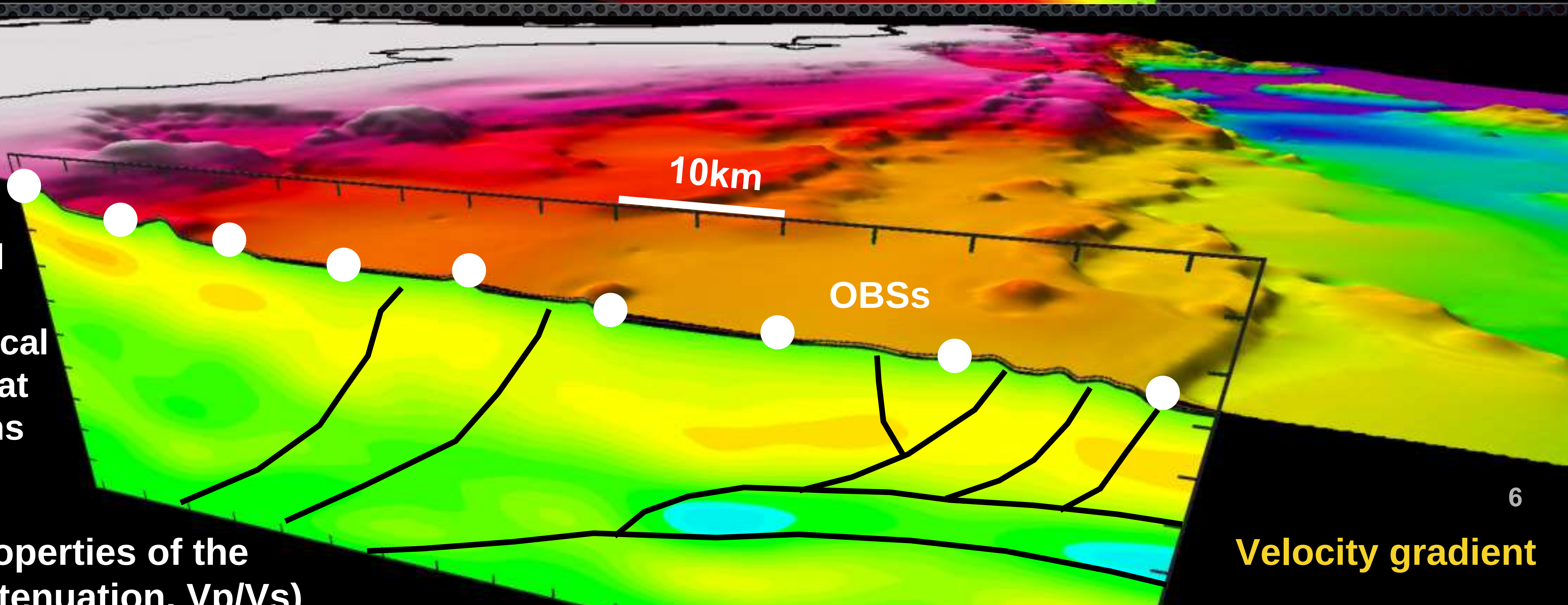
Seismic Investigation of the Hikurangi margin, NZ

Typical OBS tomography



CONs: Sparse Instrumentation

Ill-constrained problem relying heavily on Regularization

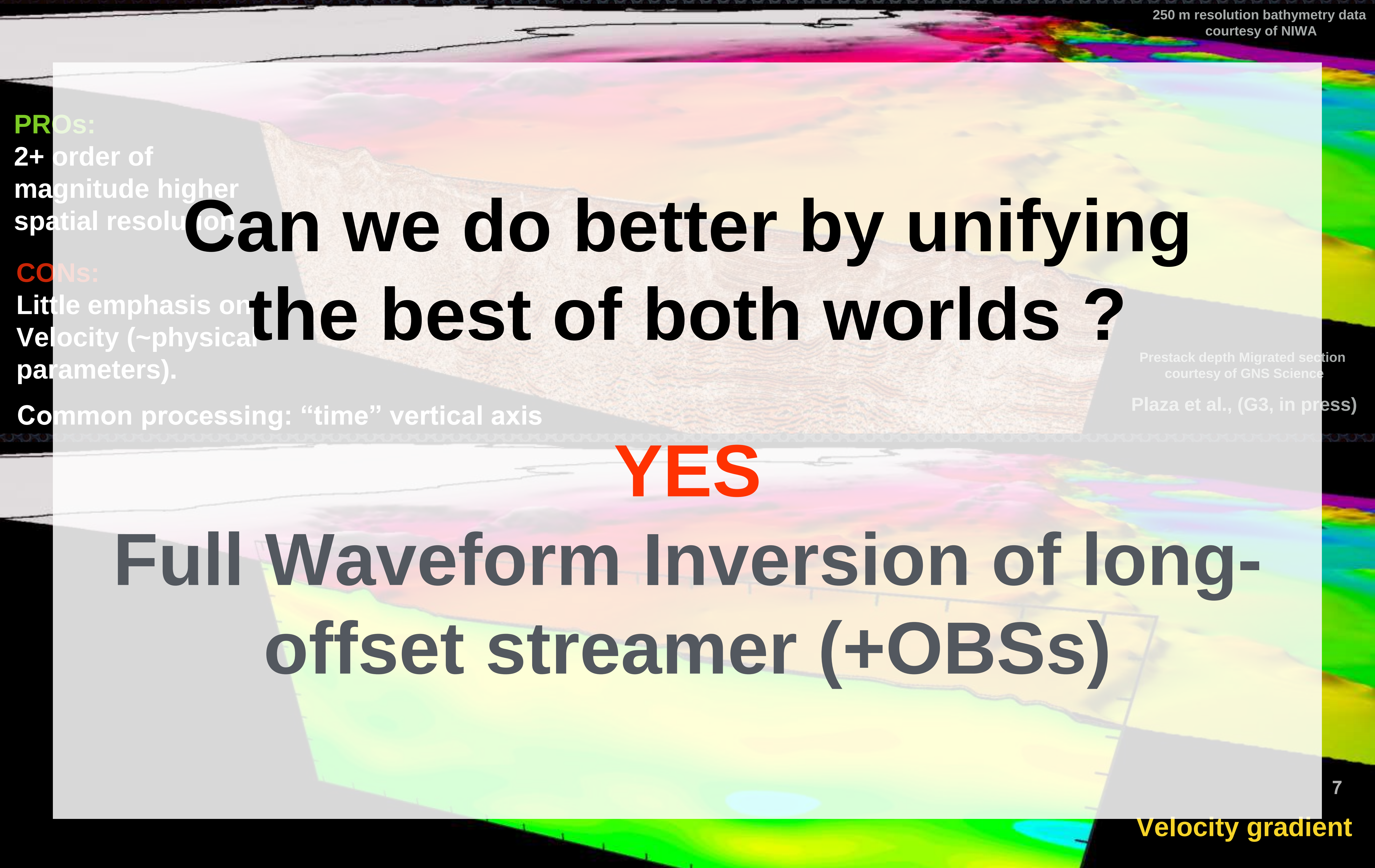


Resolution is well below the typical definition of geological features observed at convergent margins

PROs:
Gives physical properties of the Earth (Velocity, attenuation, Vp/Vs)

Seismic Investigation of the Hikurangi margin, NZ

Alternative - MCS processing



PROs:
2+ order of magnitude higher spatial resolution

CONs:
Little emphasis on Velocity (~physical parameters).

Common processing: "time" vertical axis

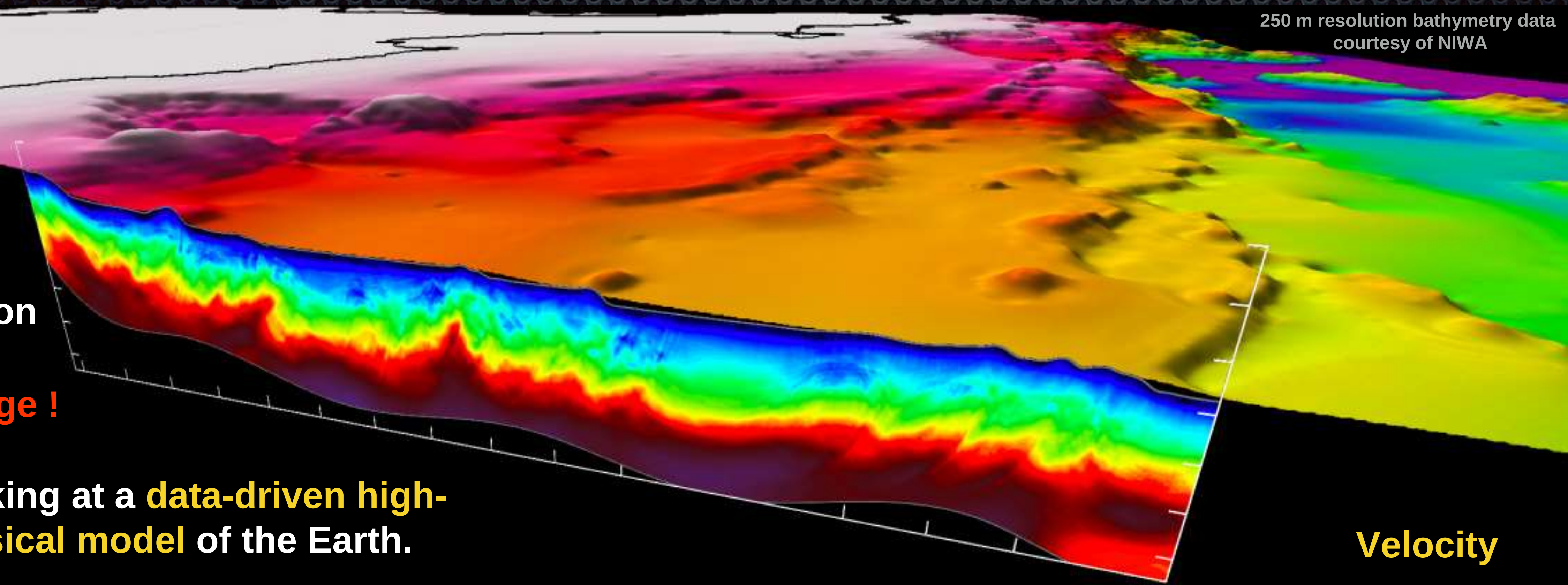
Can we do better by unifying the best of both worlds ?

YES

Full Waveform Inversion of long-offset streamer (+OBSs)

Seismic Investigation of the Hikurangi margin, NZ

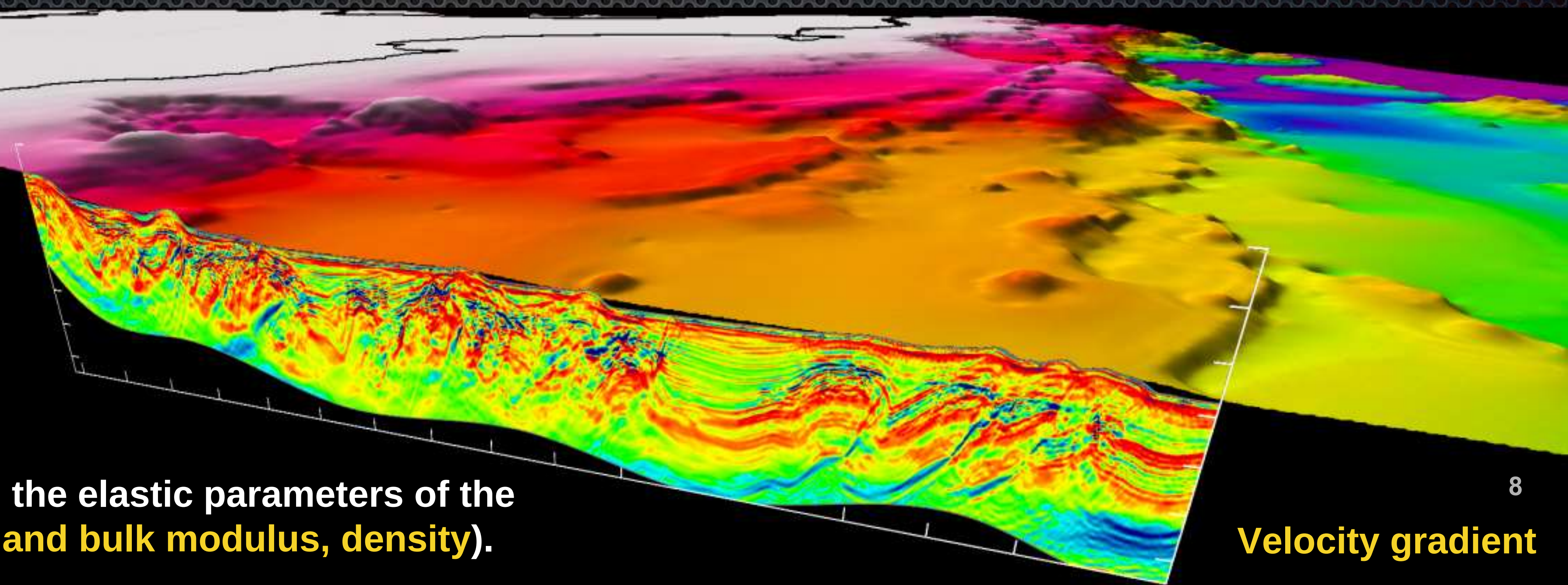
Advanced streamer processing



Elastic Full Waveform Inversion Model

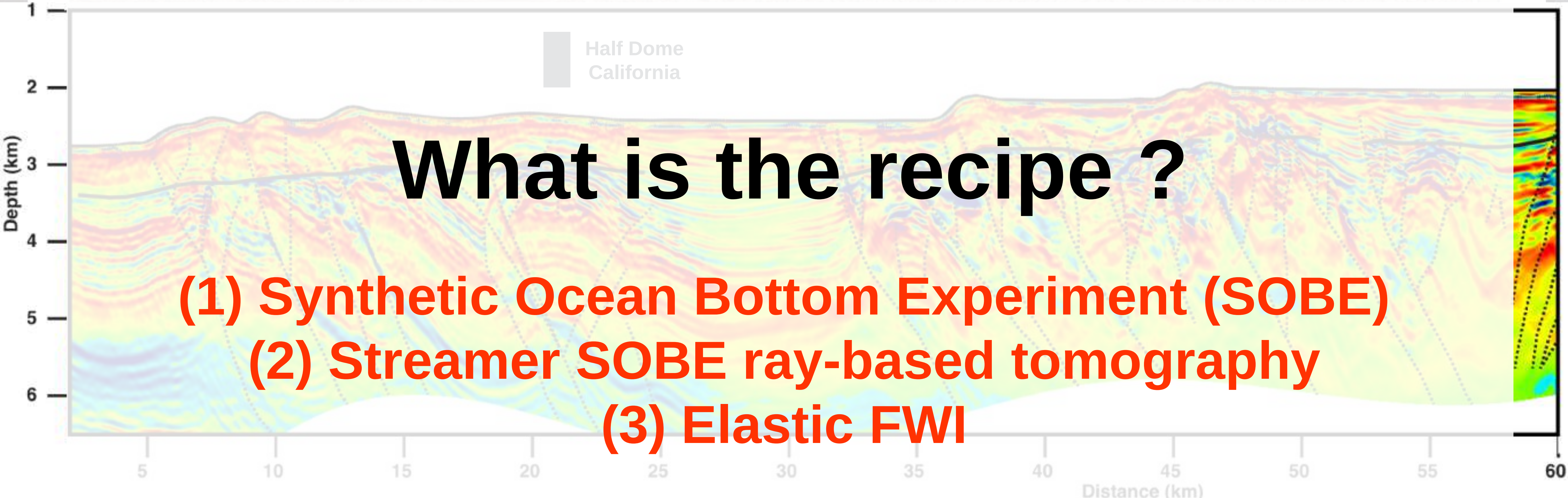
This is not an Image !

Here you are looking at a data-driven high-resolution physical model of the Earth.



Elastic FWI infers the elastic parameters of the Earth (i.e. shear and bulk modulus, density).

Resolving power of FWI



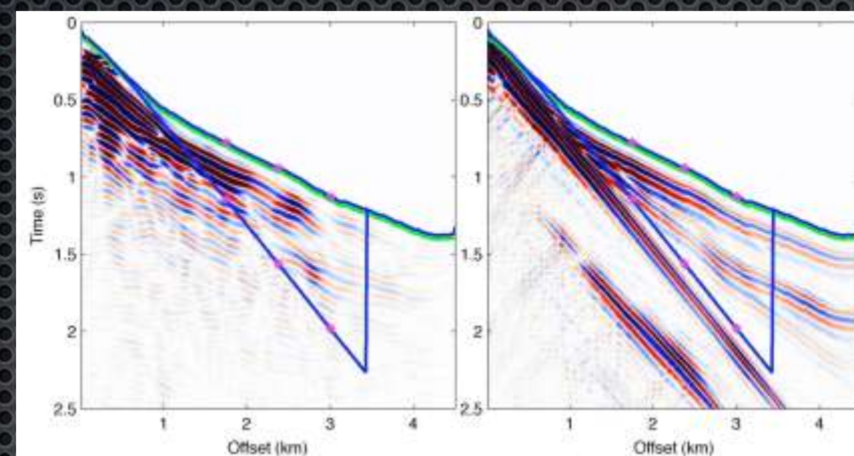
What is the recipe ?

(1) Synthetic Ocean Bottom Experiment (SOBE)
(2) Streamer SOBE ray-based tomography
(3) Elastic FWI

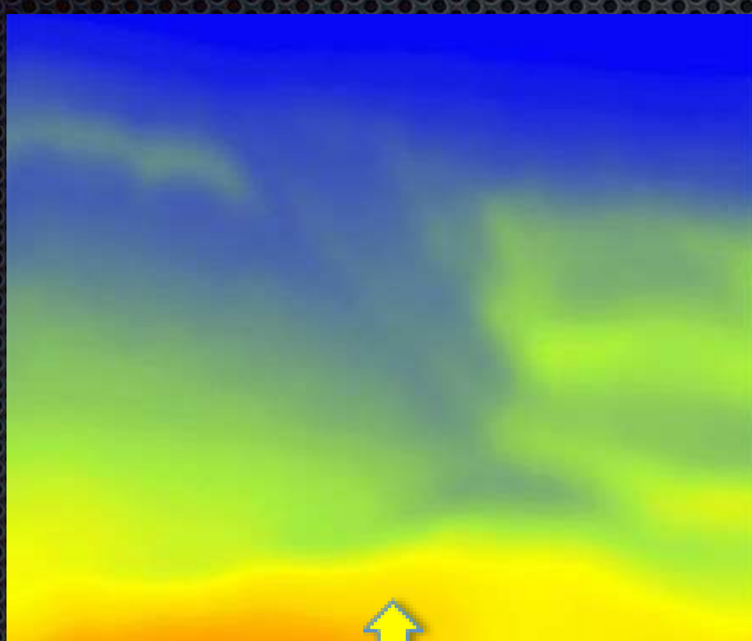
athways along existing fault zones

“Demystifying The Adjoint-State Method”

Full Waveform Data Fitting



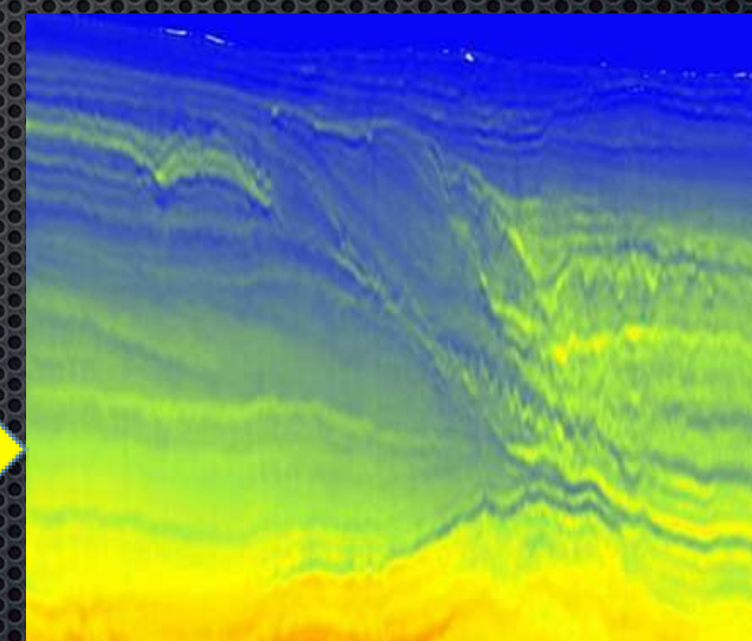
Smoothed Velocity Model



(1) SOBE
(2) SOBE tomography

(3) Iterative “Adjoint State Method”

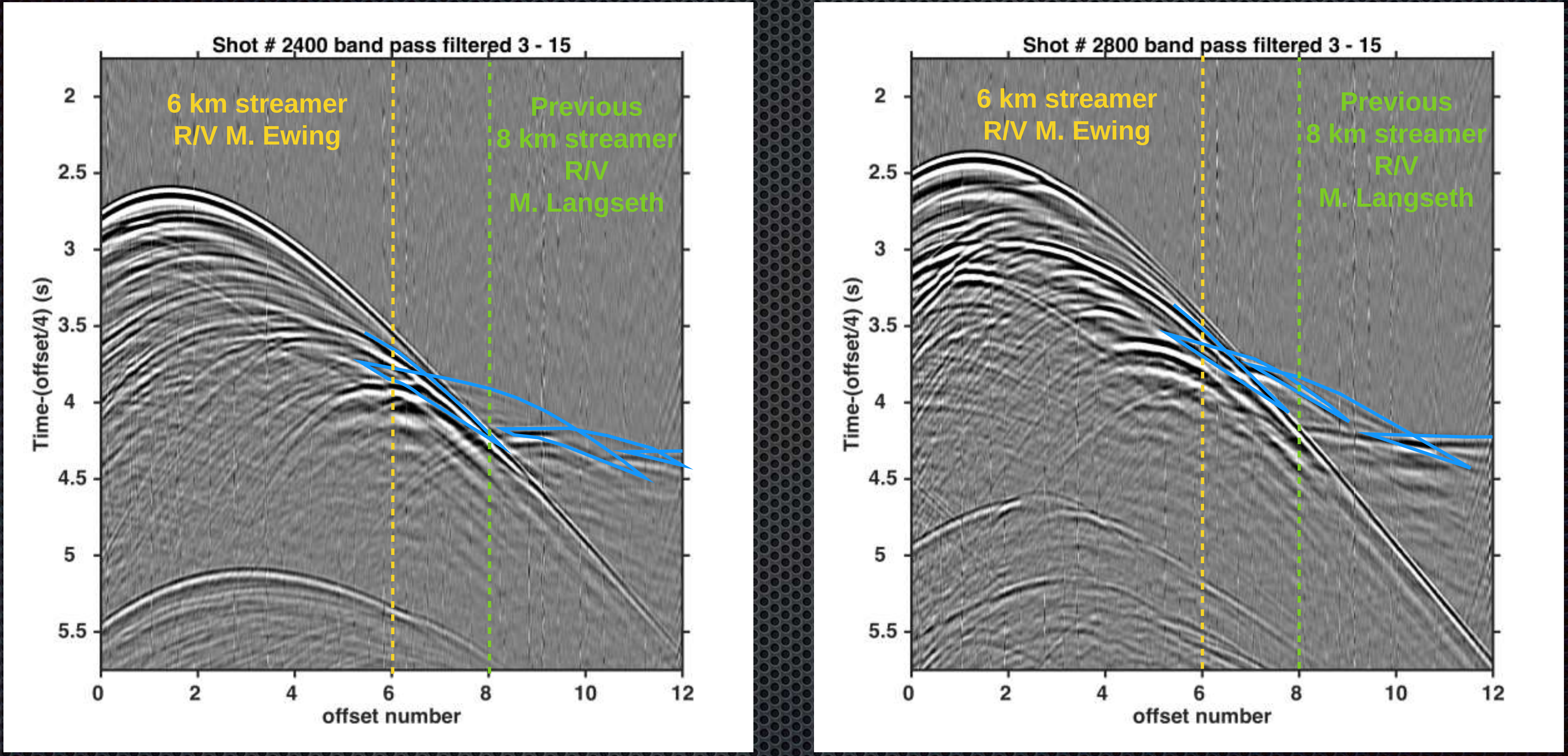
High-Resolution Velocity Model



From: Shlumberger

Synthetic Ocean Bottom Experiment (SOBE)

"Mimicking a seafloor tomography experiment from surface data"



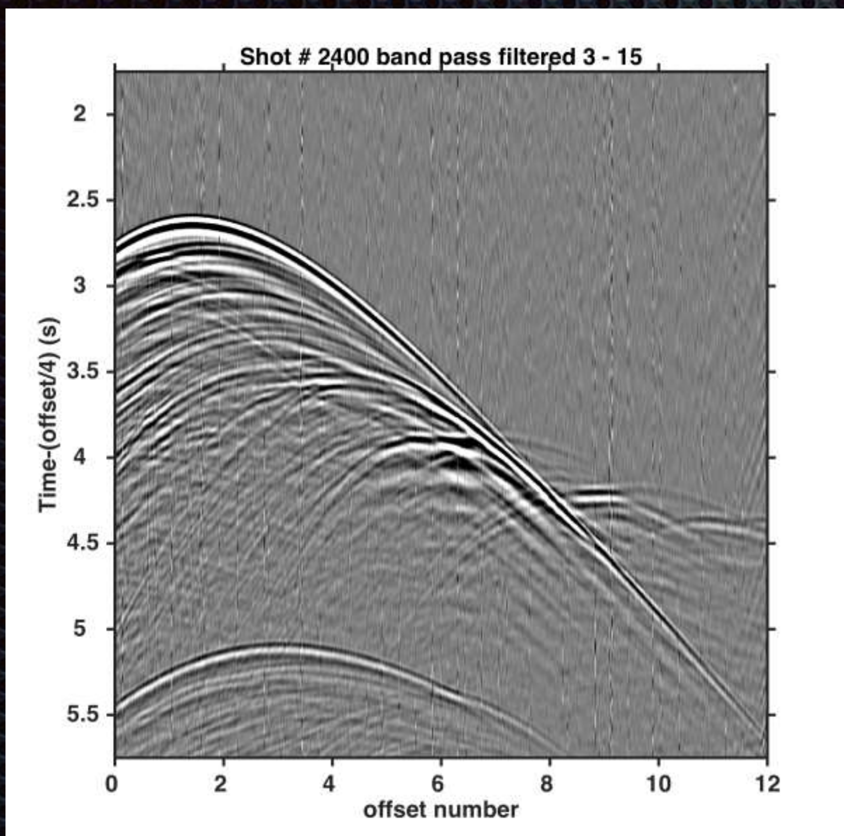
Crucial information contained in the refracted wave.

The current *M. Langseth,* 2D, 15-km-long streamer is a "state-of-the-art" data acquisition tool. Future data acquisition and processing will undoubtedly have a dramatic scientific impact !

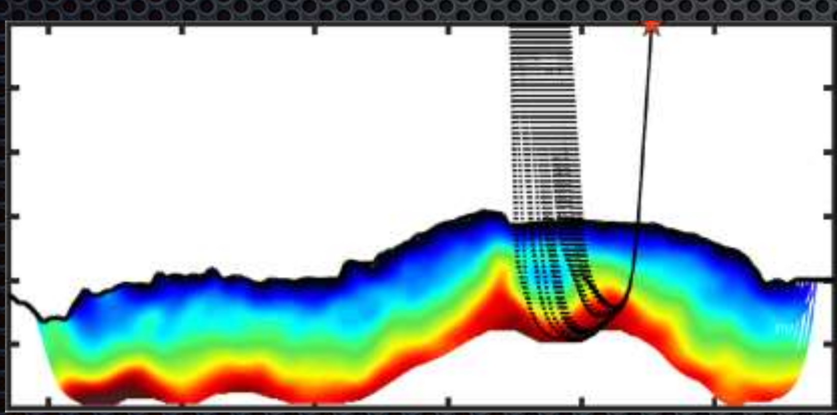
Synthetic Ocean Bottom Experiment (SOBE)

"Mimicking a seafloor tomography experiment from surface data"

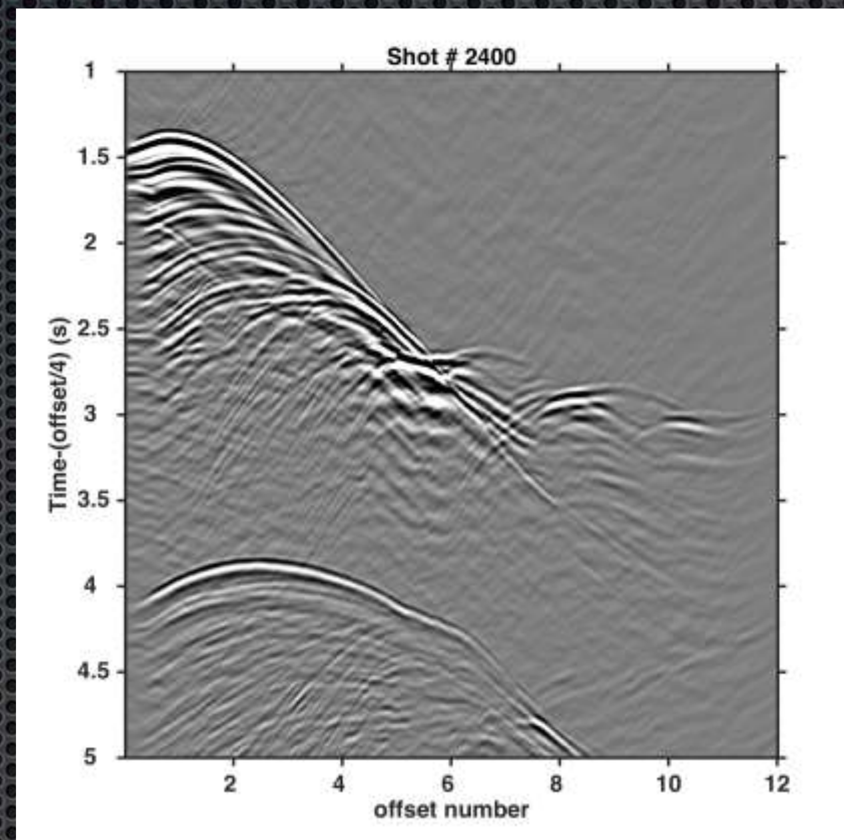
Sea surface deployment



Source & Receivers on the sea surface

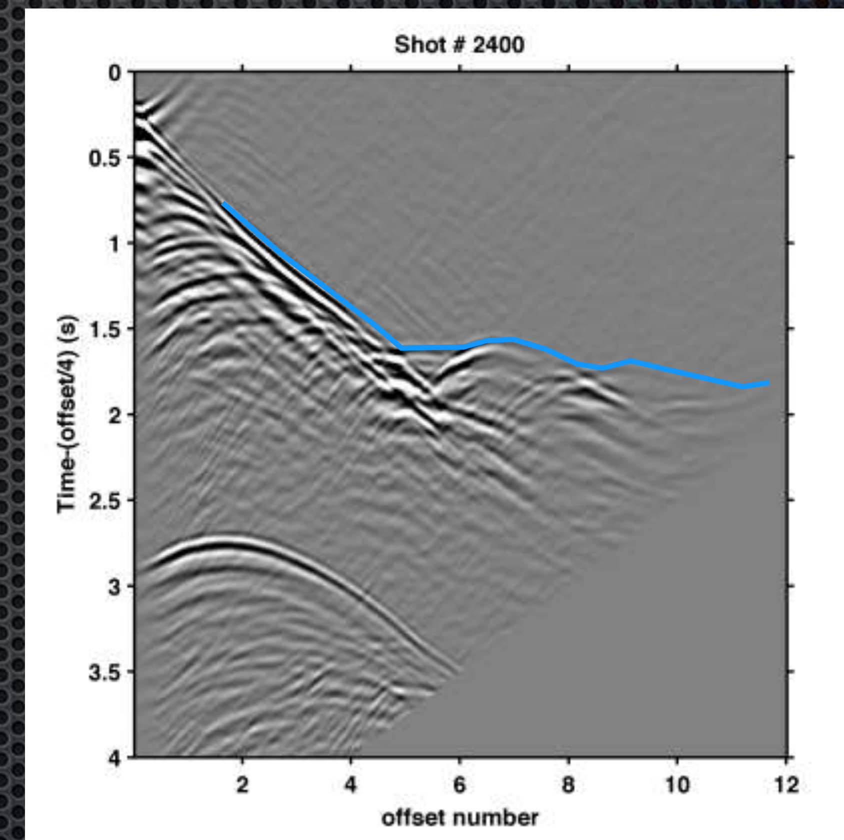


Half SOBE deployment

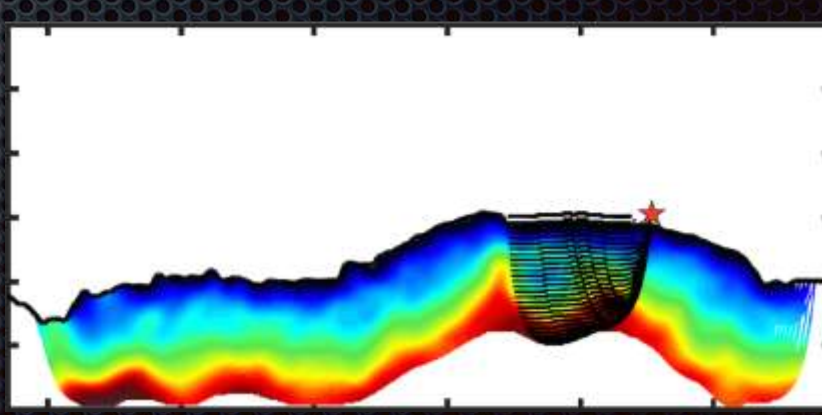


Source on the sea surface & Receivers on the seafloor

Full SOBE deployment



Source & Receivers on the seafloor



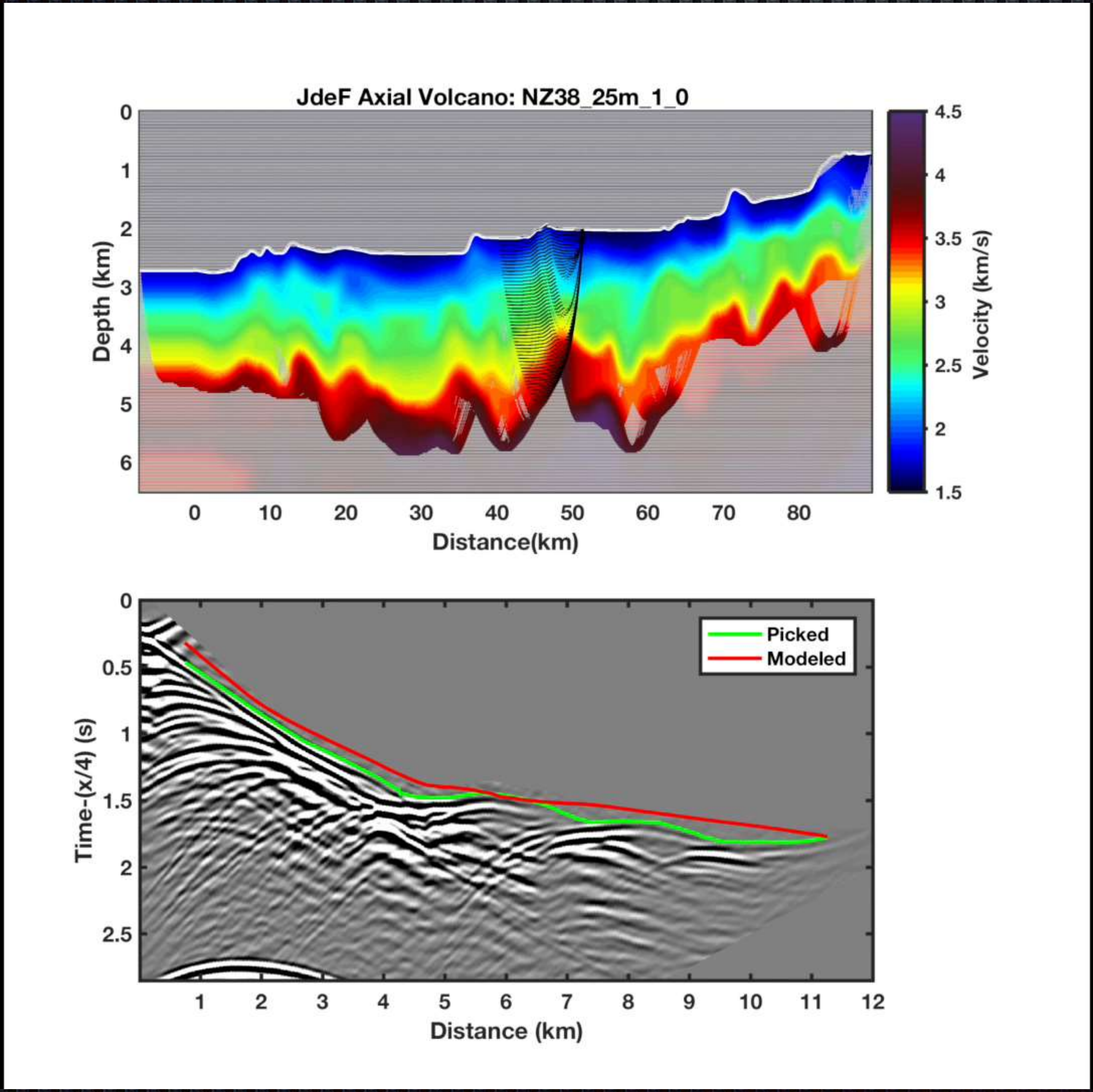
SOBE ray-based tomography

Creating a “not so smooth” starting model for FWI

inversion NZ38:
_ 465 shots (every 5th)
_ 15 iterations

Model:
_ 4481*321 pts
~1.4 M grid points
_ 25m regular grid

Starting model was a smooth version of the PSDM model



FWI Method

“Demystifying The Adjoint-State Method”

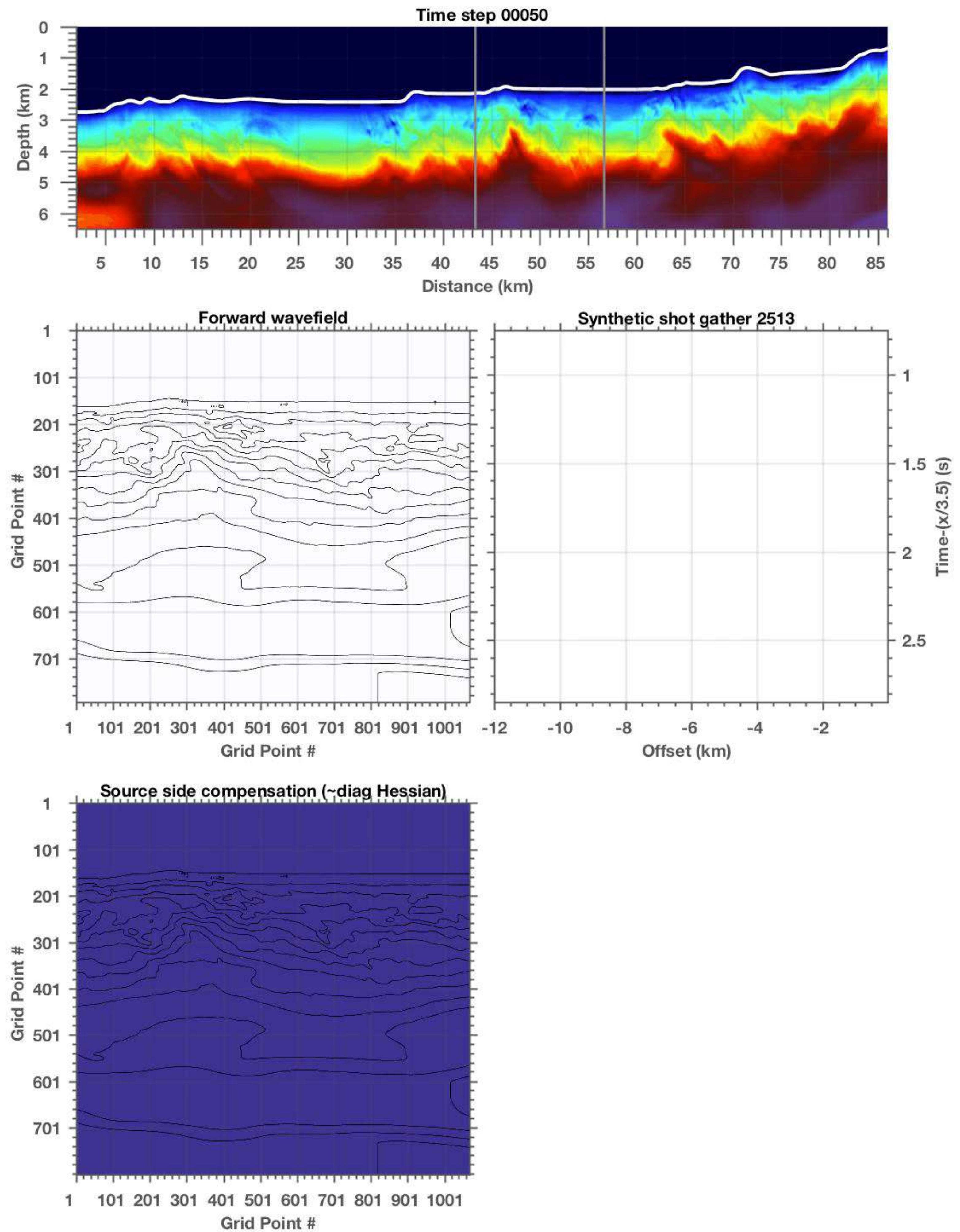
1st stage:

“Calculating the adjoint wave field”

&

Source-side illumination compensation

~Hessian



FWI Method

"Demystifying The Adjoint-State Method"

2nd stage:

Lamé parameters and density gradient (Mora 1987) + receiver-side illumination compensation

$$\mathbf{G}^T\delta\mathbf{u}_\rho = -\sum_{shots}\int_0^T dt\,(\overleftarrow{v_x}\overrightarrow{v_x} + \overleftarrow{v_z}\overrightarrow{v_z}),$$

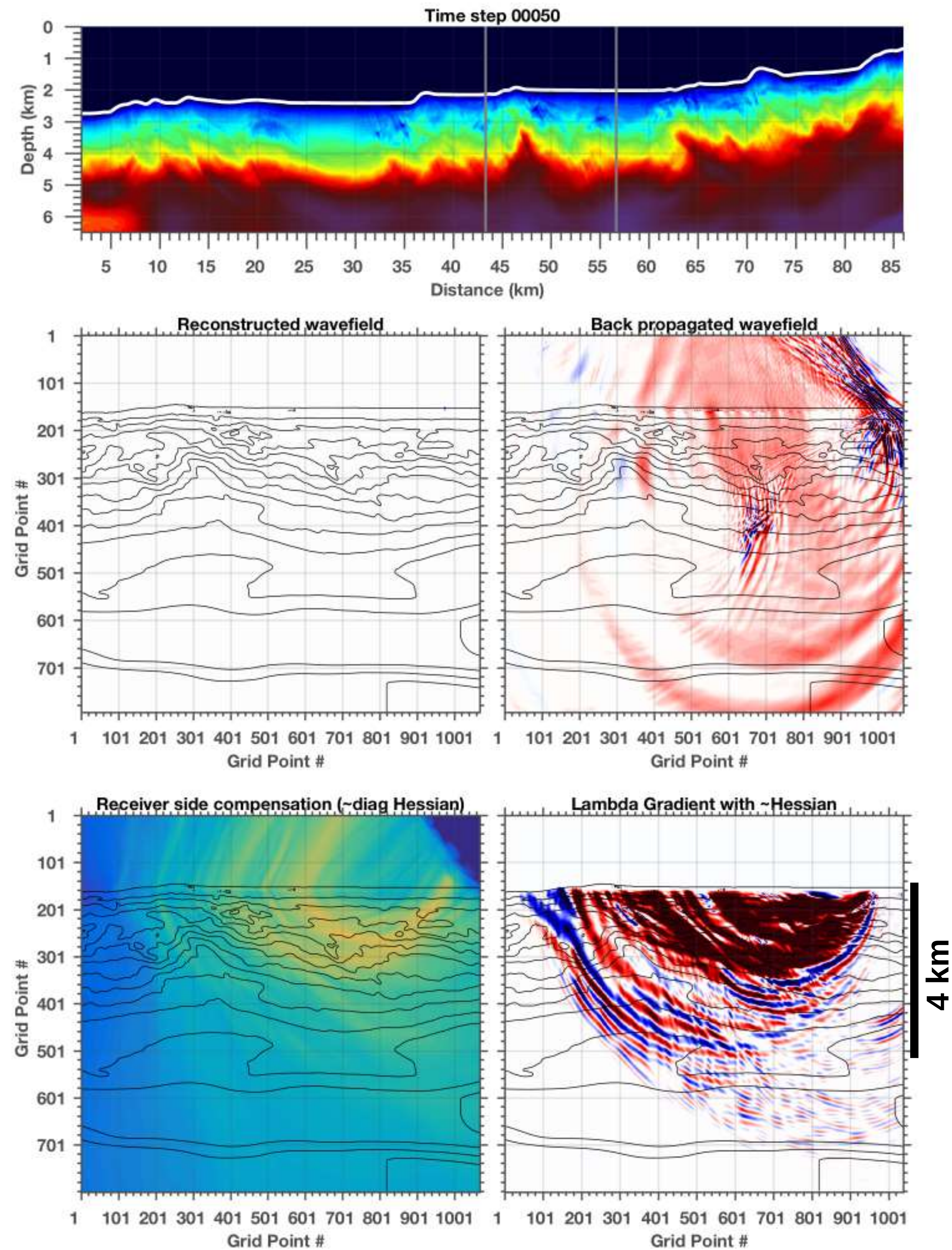
$$\mathbf{G}^T\delta\mathbf{u}_\lambda = -\frac{1}{4(\lambda+\mu)^2}\sum_{shots}\int_0^T dt\,(\overleftarrow{\tau_{xx}} + \overleftarrow{\tau_{zz}})(\overrightarrow{\tau_{xx}} + \overrightarrow{\tau_{zz}}),$$

$$\mathbf{G}^T\delta\mathbf{u}_\mu = \frac{\lambda(\lambda+2\mu)}{4\mu^2(\lambda+\mu)^2}\sum_{shots}\int_0^T dt\,(\overleftarrow{\tau_{xx}}\overrightarrow{\tau_{zz}} + \overleftarrow{\tau_{zz}}\overrightarrow{\tau_{xx}})$$
$$-\frac{\lambda^2+(\lambda+2\mu)^2}{8\mu^2(\lambda+\mu)^2}\sum_{shots}\int_0^T dt\,(\overleftarrow{\tau_{xx}}\overrightarrow{\tau_{xx}} + \overleftarrow{\tau_{zz}}\overrightarrow{\tau_{zz}})$$
$$-\frac{1}{\mu^2}\sum_{shots}\int_0^T dt\,(\overleftarrow{\tau_{xz}}\overrightarrow{\tau_{xz}}).$$

The gradient calculation is a type of "Prestack Depth Migration"

Velocity and density updates:

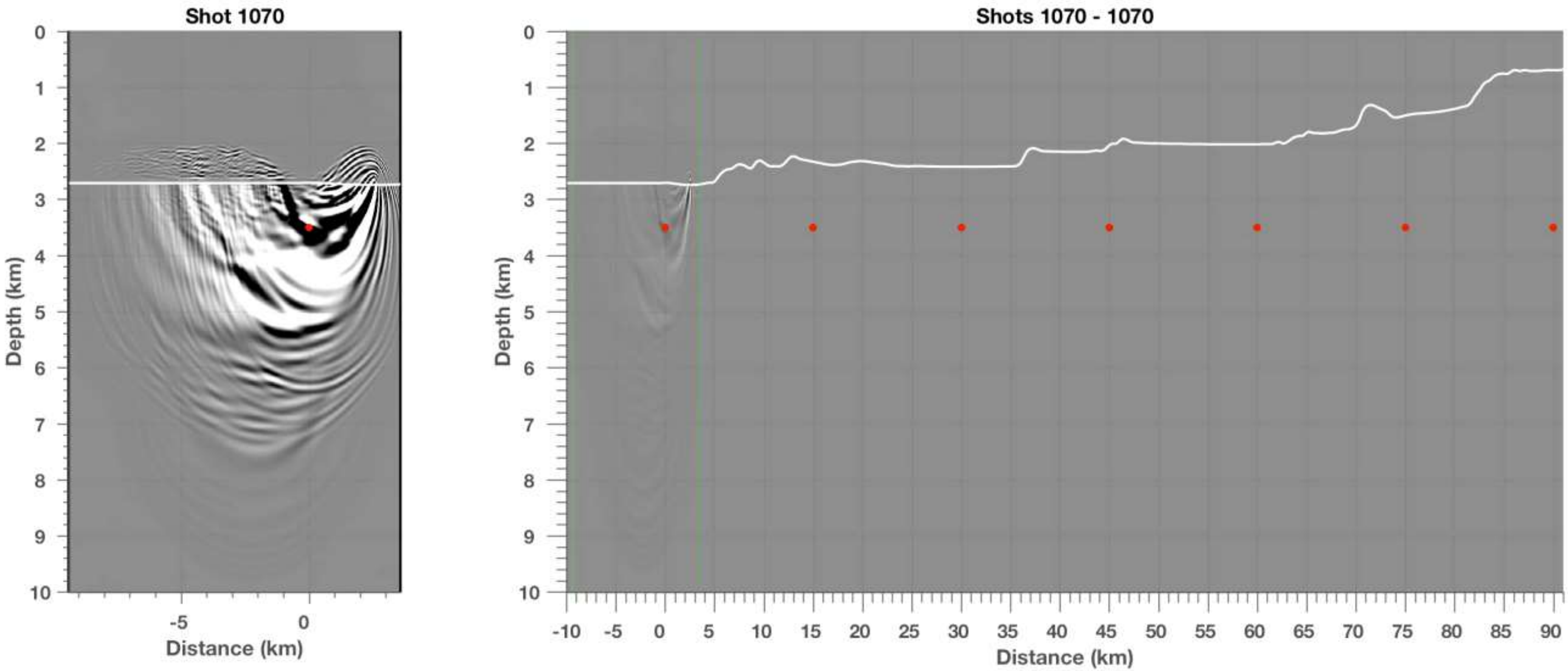
$$\delta\alpha = 2\rho\alpha\delta\lambda,$$
$$\delta\beta = -4\rho\beta\delta\lambda + 2\rho\beta\delta\mu,$$
$$\delta\hat{\rho} = (\alpha^2 - 2\beta^2)\,\delta\lambda + \beta^2\delta\mu + \delta\rho.$$



FWI Method

"Gradient summation between iterations 50 & 51"

FWI is based on the summation of constructive energy

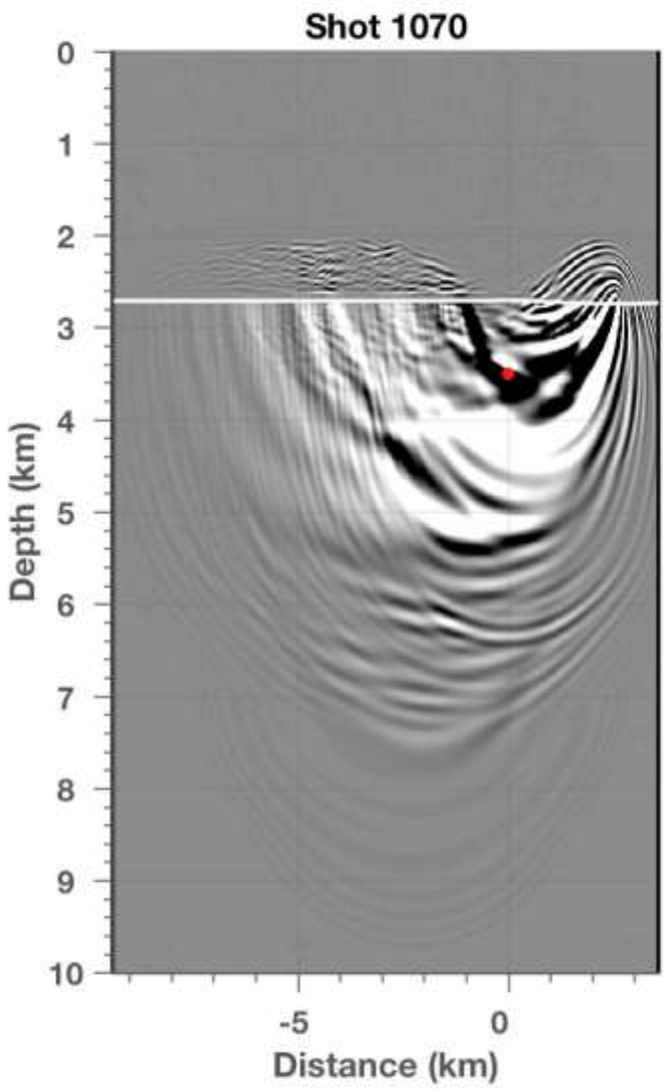


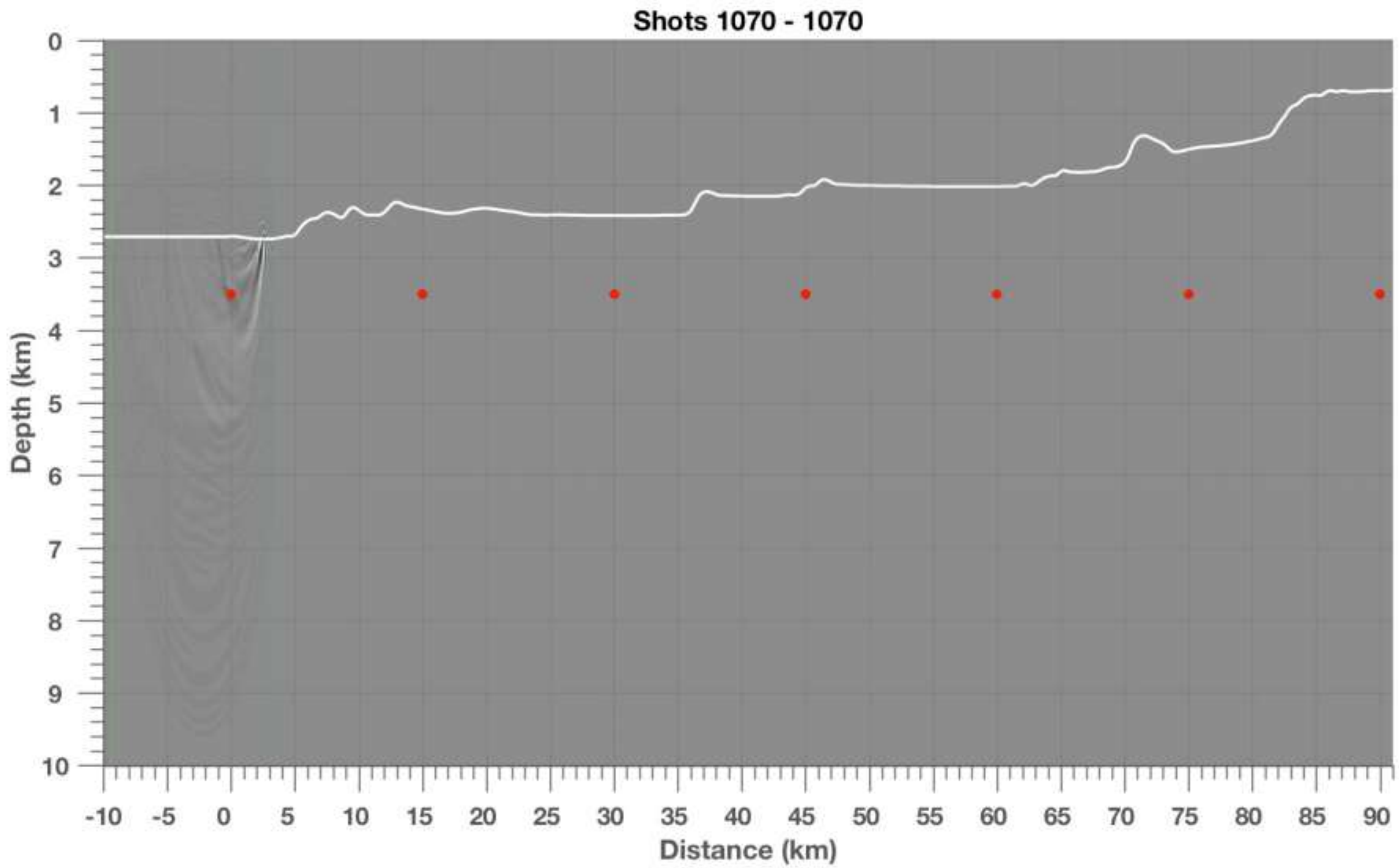
_ 2321 SOBE shots (spacing: 37.5 m) run in parallel.
_ 12.5 m regular grid
_ 0 to 5 s data window
_ 3-20 Hz inversion (pick frequency: 12 Hz)

FWI Method

FWI is based on the summation of constructive energy

1 shot every 200m

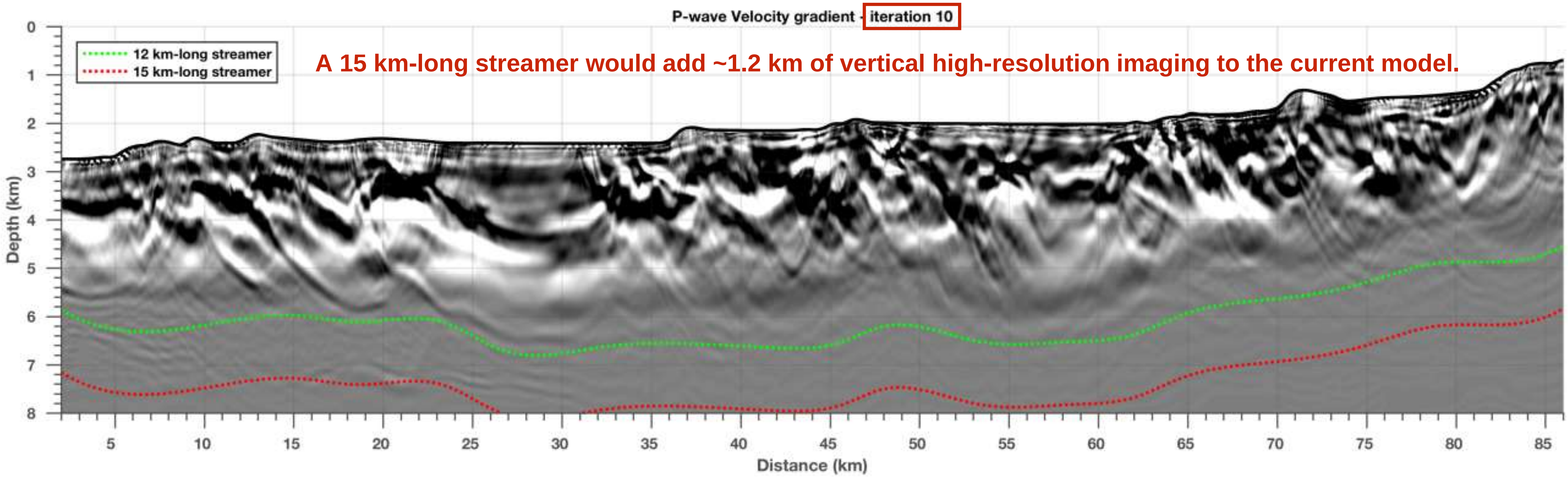


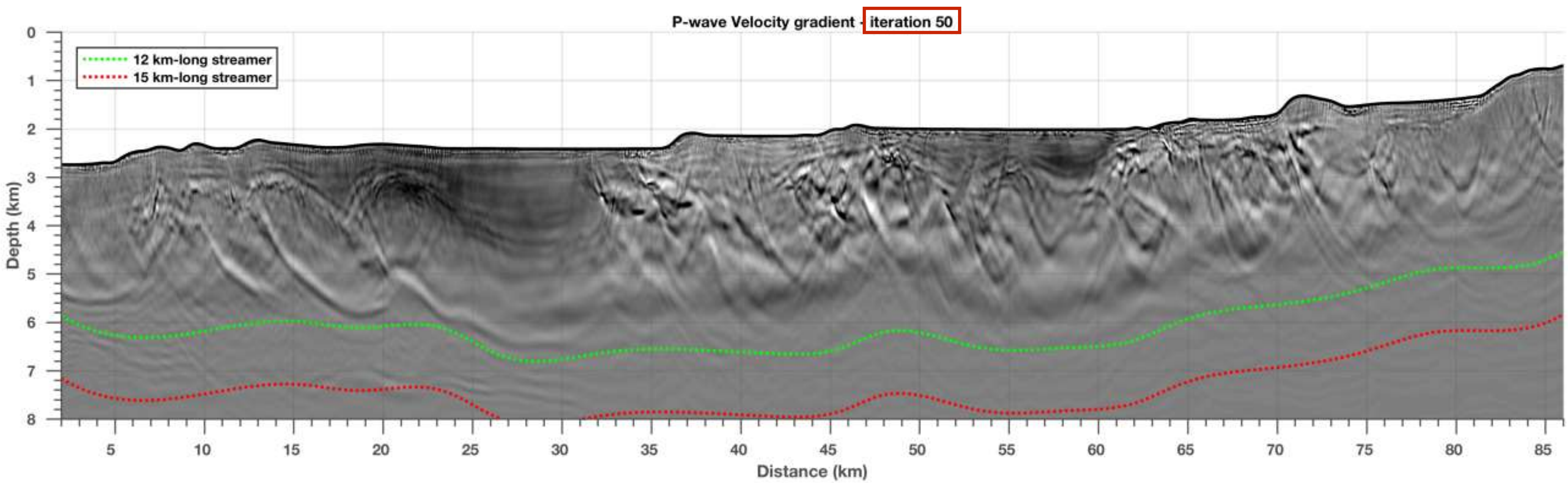


Spatial sampling is ESSENTIAL (streamer or OBS)

FWI Method

FWI is based on the summation of constructive energy





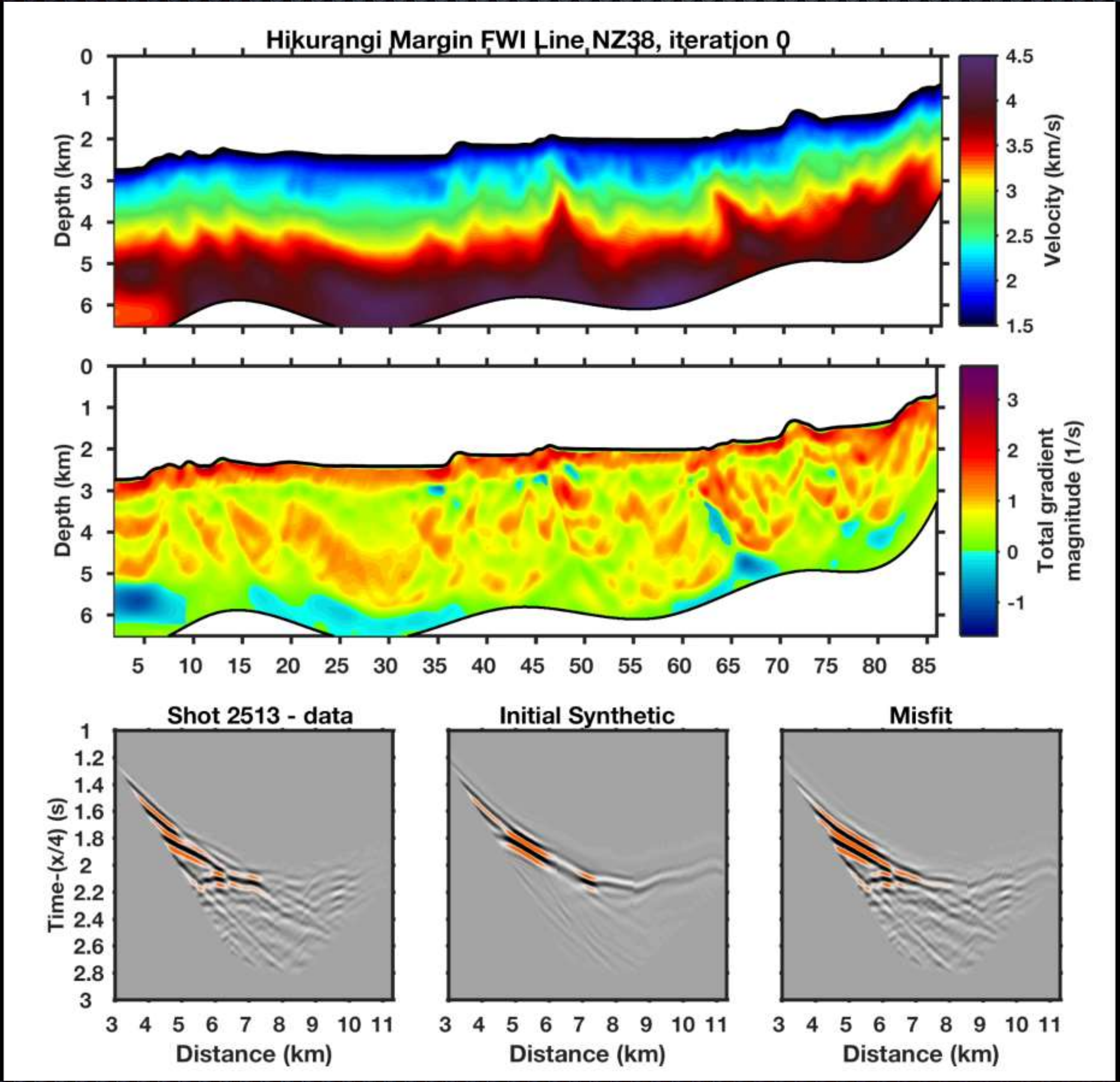
Elastic Full Waveform Inversion - Hikurangi Margin, NZ

Seismic Line NZ38 - velocity structure evolution

inversion NZ38:
_ 2321 shots
_ 60 iterations

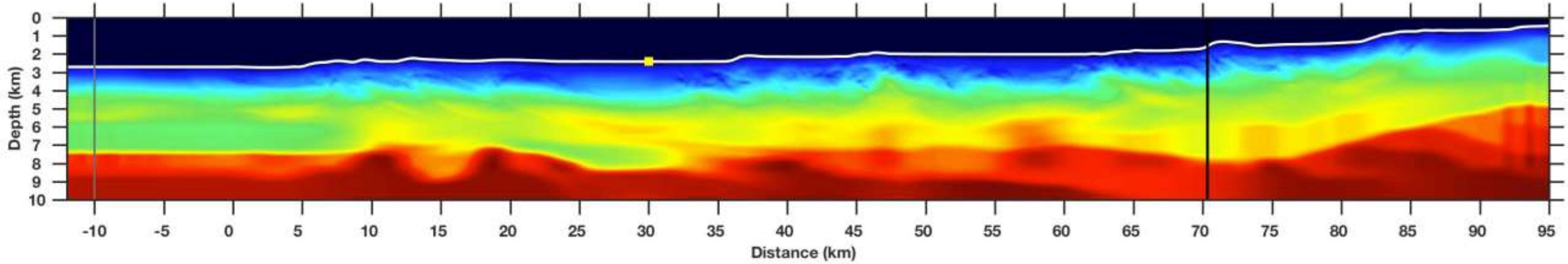
Model:
_ 8976*801 pts
~7.2 M grid points
_ 12.5m regular grid
_ 5001 timesteps
_ time window 0-5 s
_ dt = 0.001s

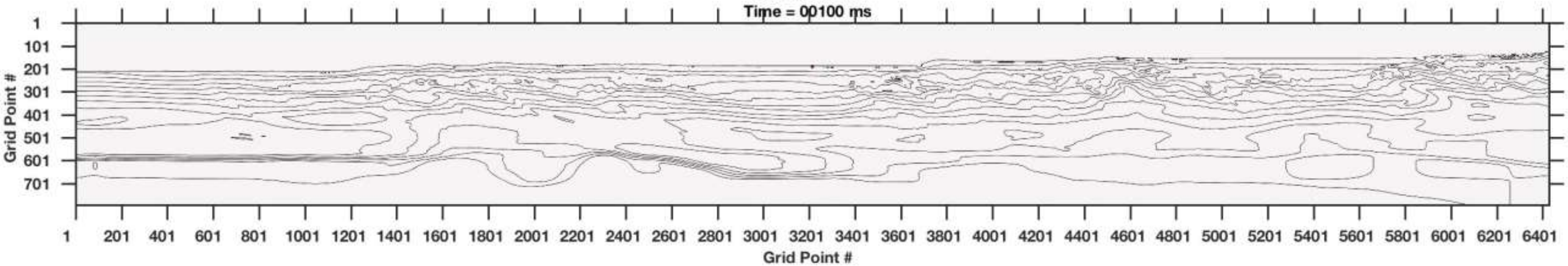
Data:
_ ~4 to 20 Hz
_ pick f. 12Hz
_ target data:
refraction then
reflectivity

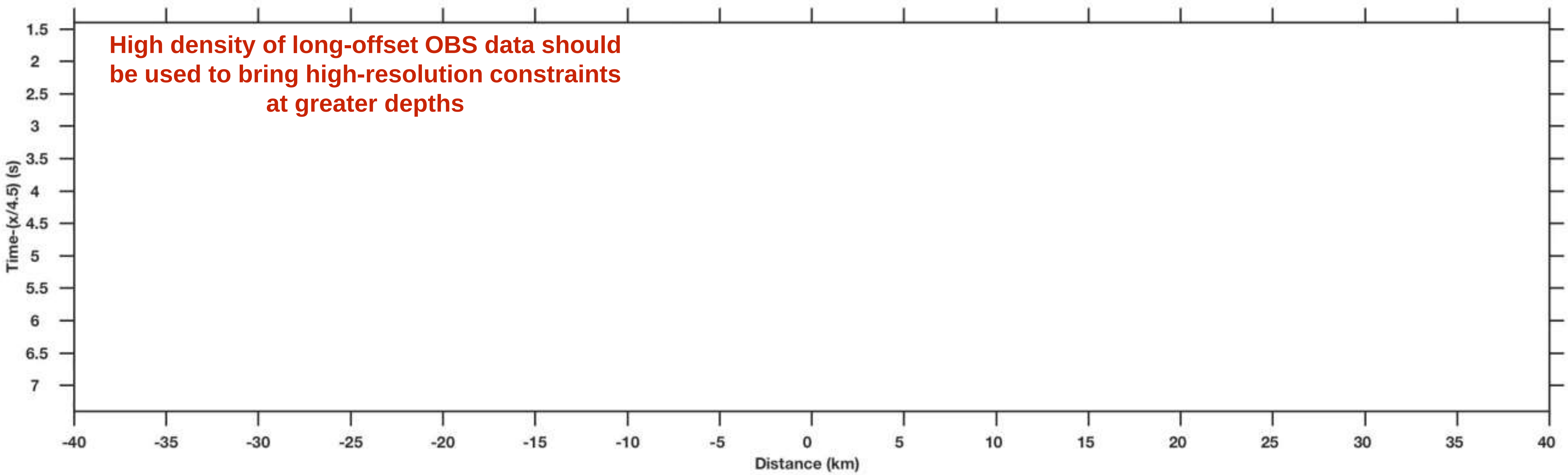


FWI of OBS data

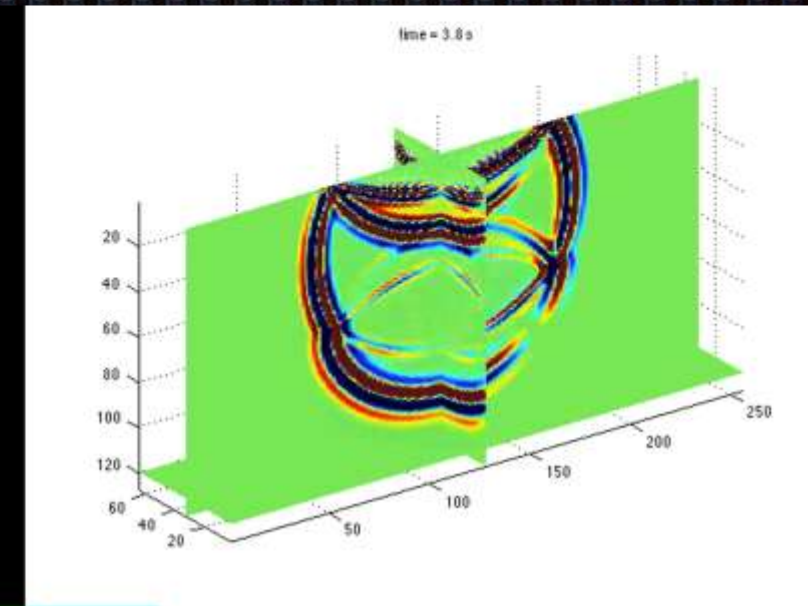
Long streamer and OBS data could and *SHOULD* be inverted jointly.





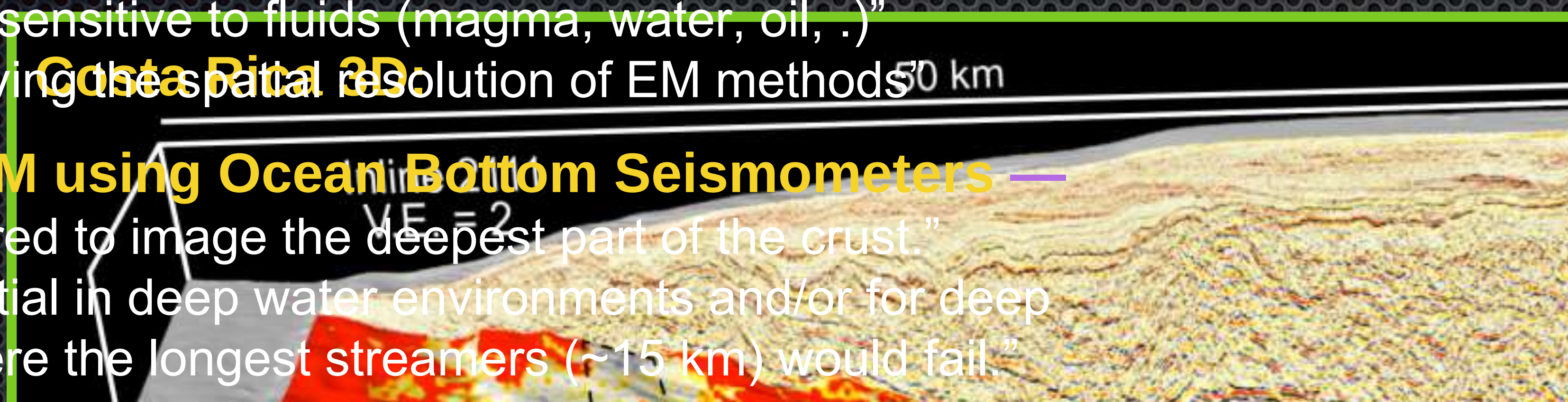


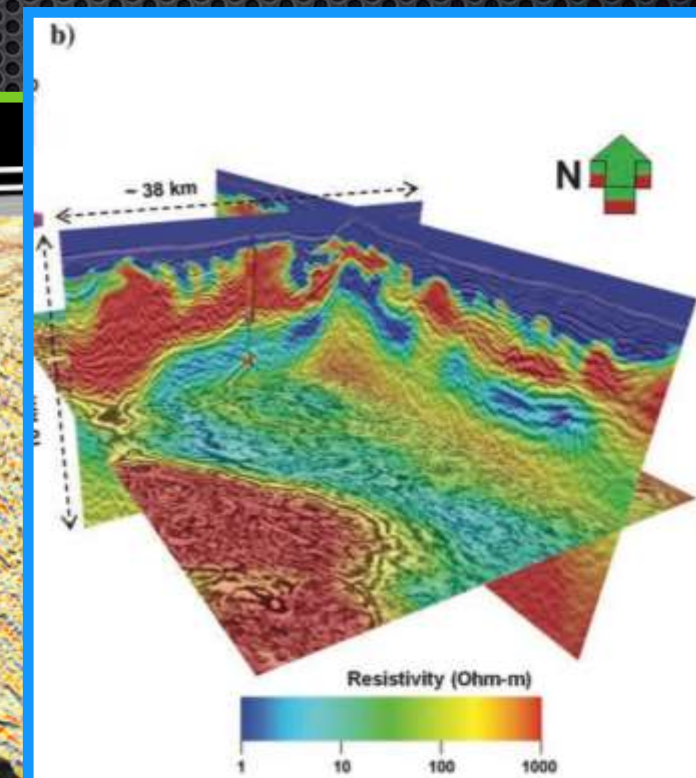
Future FWI applications



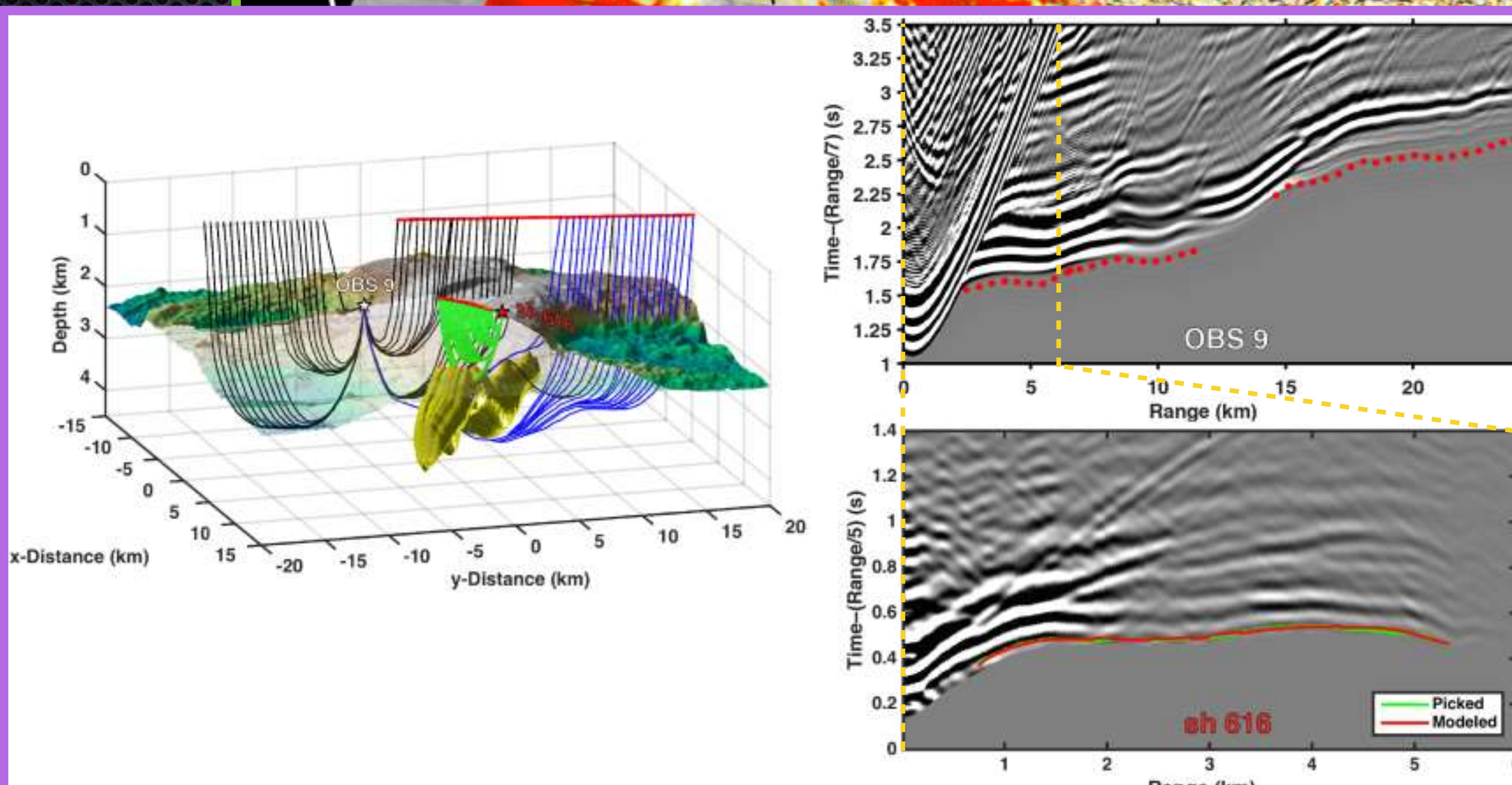
Application of 3D Elastic FWI.
(… Viscoelastic & Poroelastic & Anisotropic) —
—> “To better characterize Earth properties and processes which are highly 3D.”

Multi-parameters inversion: Seismic + Electromagnetic (CSEM, MT) + Gravity —
—> “EM is sensitive to fluids (magma, water, oil, .)”
—> “Improving the spatial resolution of EM methods”

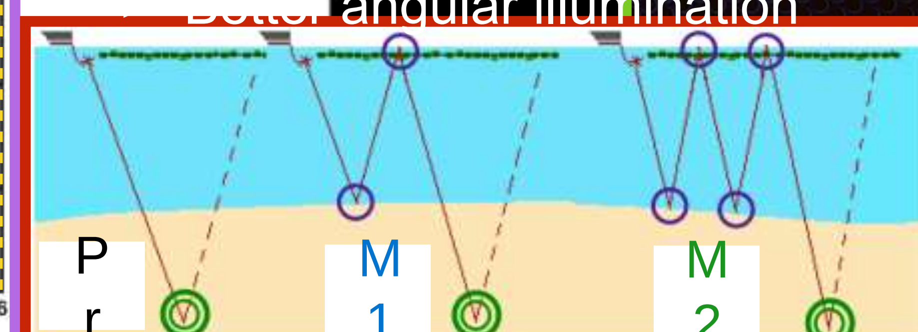




FWI & RTM using Ocean Bottom Seismometers —
—> “Required to image the deepest part of the crust.”
—> “Essential in deep water environments and/or for deep targets where the longest streamers (~15 km) would fail.”

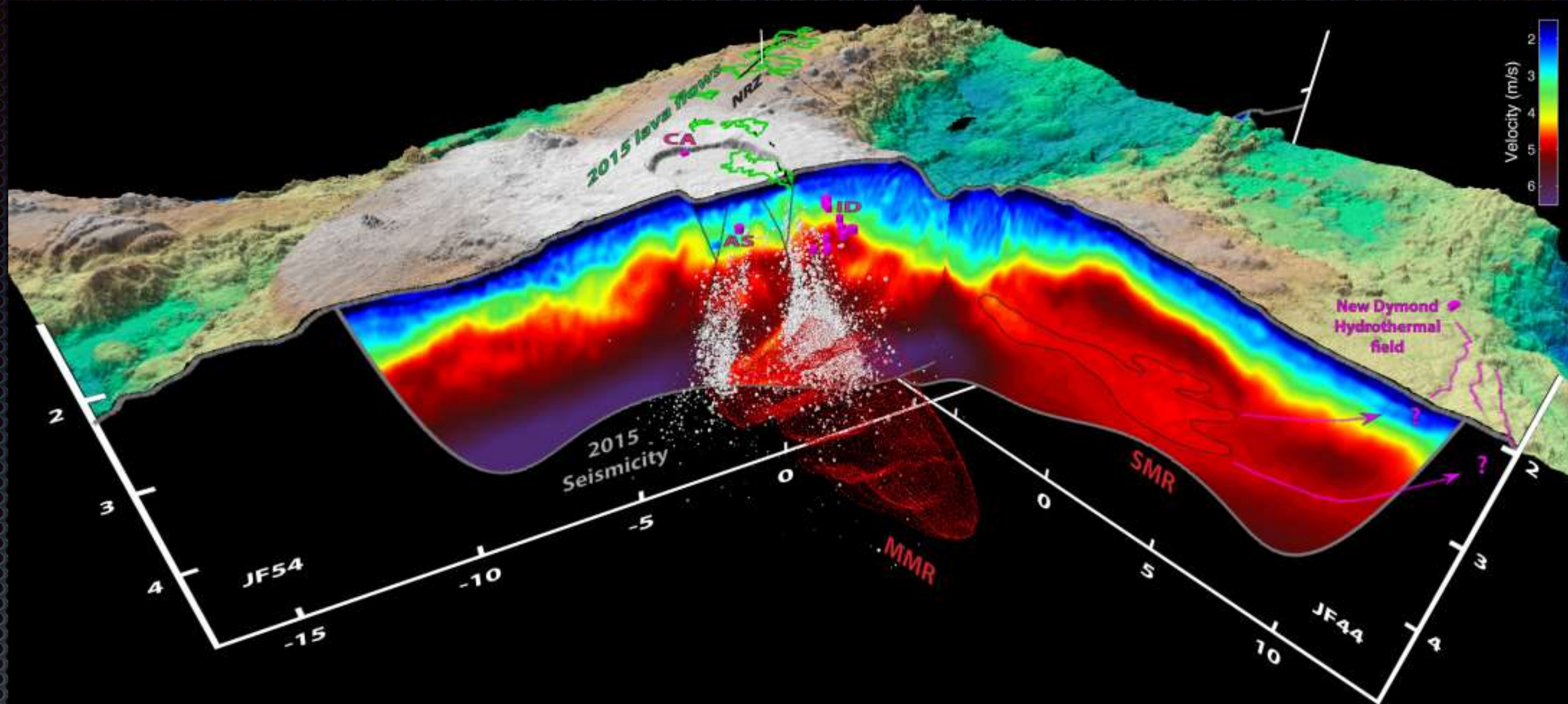


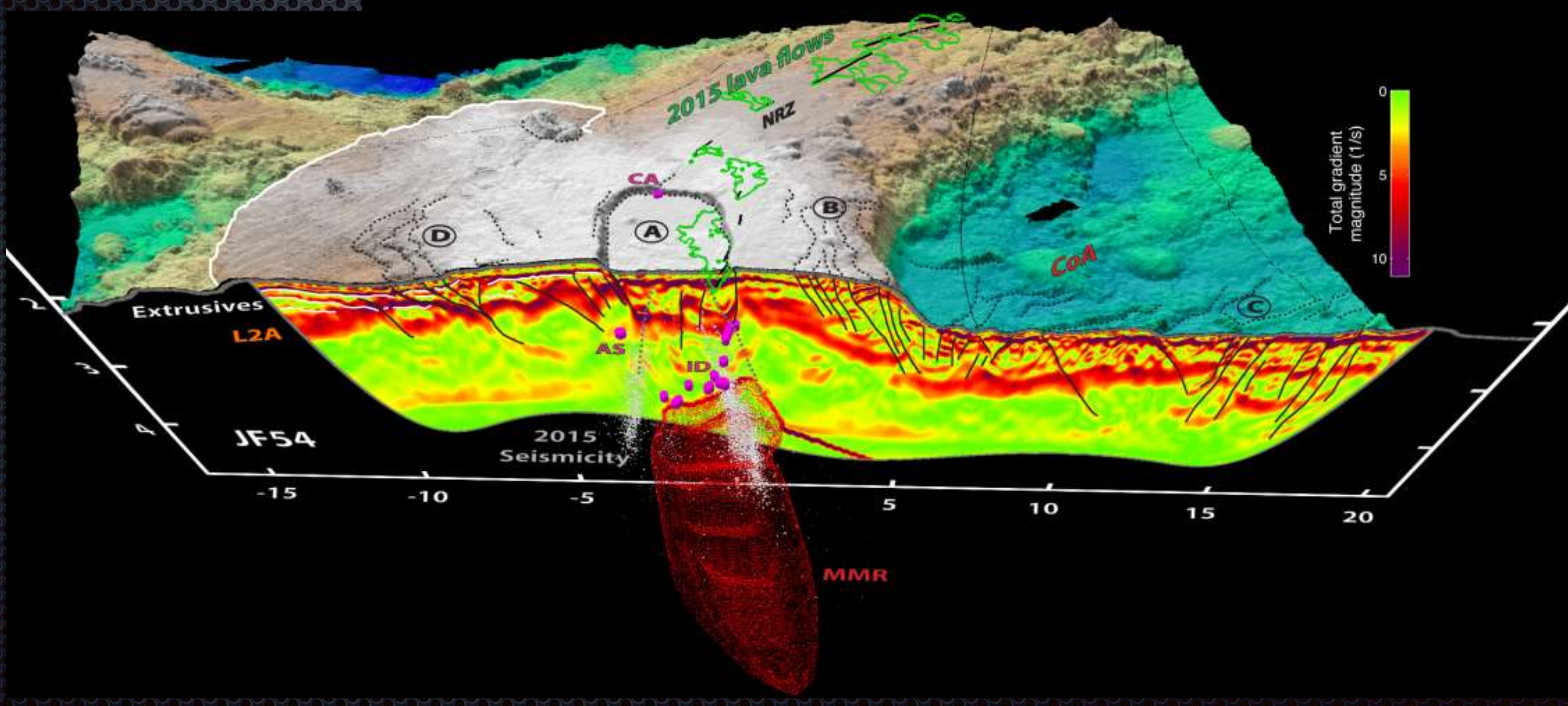
Using the entire seismogram in FWI and RTM including the multiples —
—> “Better angular illumination”



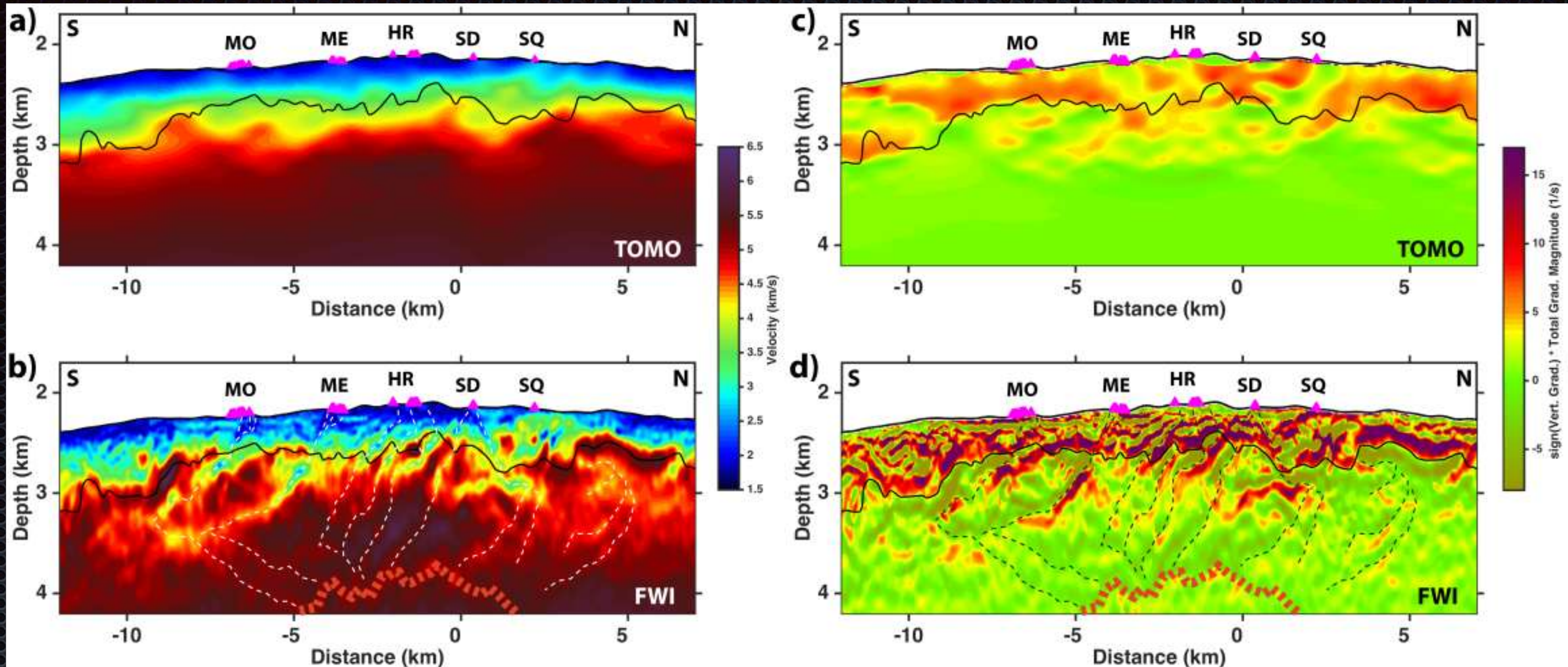
Other application of FWI

Axial Volcano Magmatic system

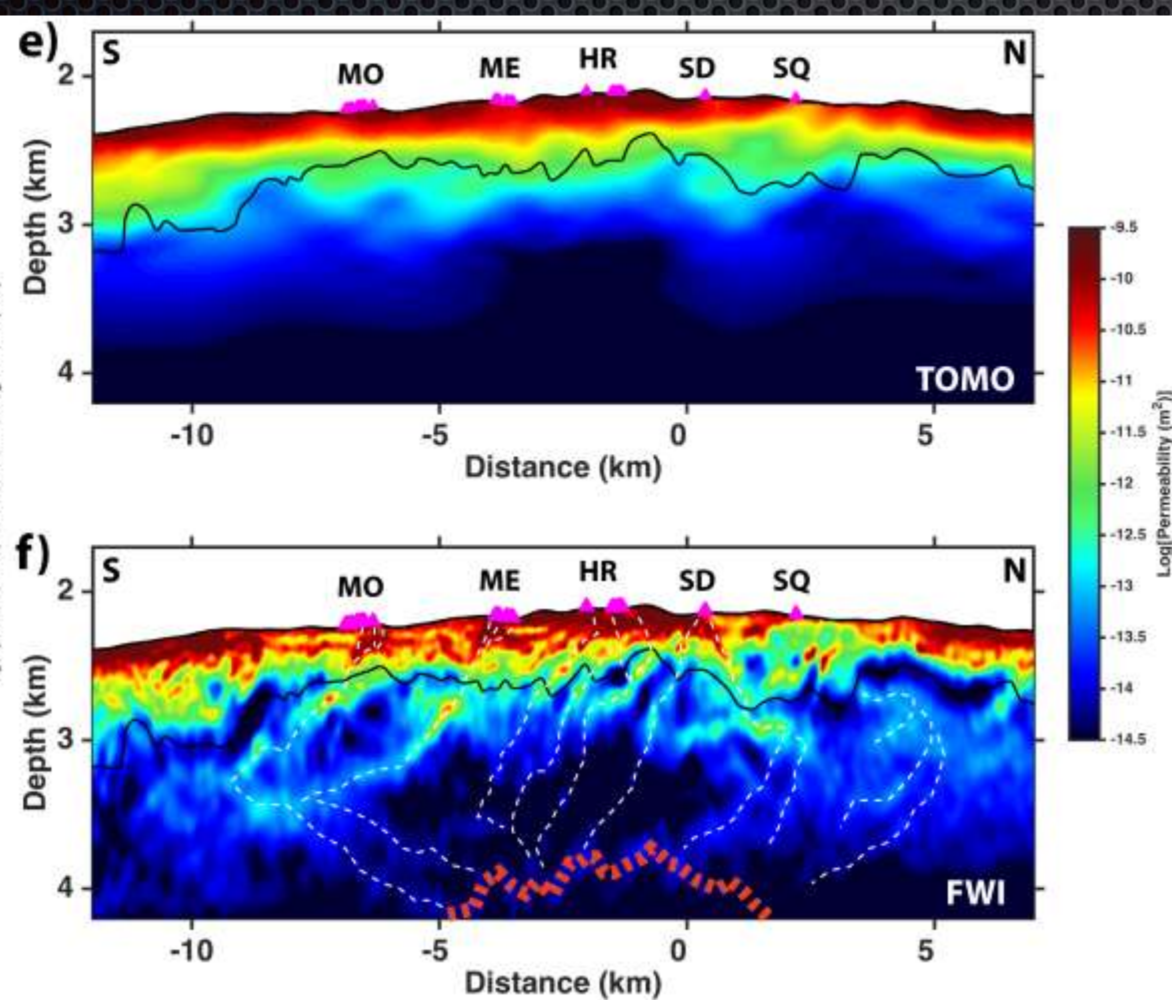




Velocity



Velocity Gradient



Other application of FWI

Imaging hydrothermal roots beneath Endeavor vent fields, JDFR

Estimated permeability