Comparison of different regularization schemes for the 1D laterally constrained inversion of seismic surface wave data.

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Context

At the University of Potsdam, we recently have developed 1D (Guillemoteau *et al*, 2016) and 3D (Guillemoteau *et al*, 2017, 2019) inversion procedures for loop-loop electromagnetic induction (EMI) data.

Our 1D non-linear inversion algorithm is a modified version of the OCCAM procedure described in Aster, *et al*, (2005), which incorporates prior information on data uncertainties and inverts the model in the log space to impose positivity constraints:

$$log\mathbf{m}^{\mathbf{k+1}} = \left[\mathbf{G}^T(log\mathbf{m}^{\mathbf{k}})\mathbf{W_d}\mathbf{G}(log\mathbf{m}^{\mathbf{k}}) + \lambda\mathbf{W_m}\right]^{-1}\mathbf{G}^T(log\mathbf{m}^{\mathbf{k}})\mathbf{W_d}\boldsymbol{d}^*$$

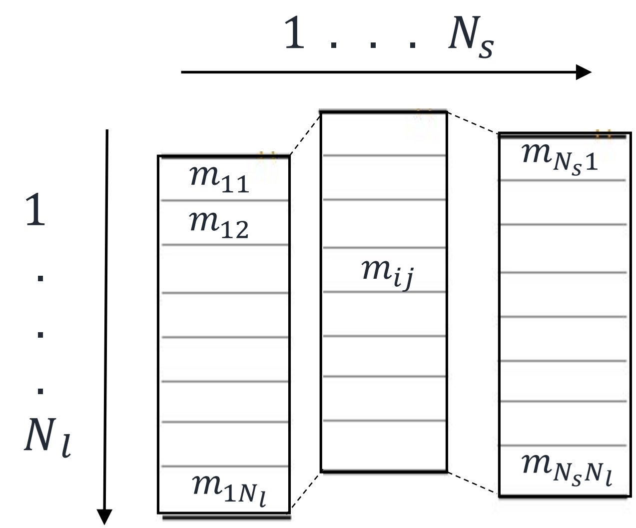
$$\boldsymbol{d}^* = \boldsymbol{d} - \boldsymbol{d}(log\mathbf{m}^{\mathbf{k}}) + \mathbf{G}(log\mathbf{m}^{\mathbf{k}})log\mathbf{m}^{\mathbf{k}}$$

$\mathbf{W_m}$ now (Klose *et al*, in prep) includes smooth (*sm*) (Auken *et al*, 2005, Socco *et al*, 2009) and sharp (*sh*) (Vignoli *et al*, 2014) constraints, which are applied on both x and z directions (LCI):

$$\Phi_m^{sm/sm} = \sum_{i=1}^{N_s}\sum_{j=1}^{N_l}\left[\nabla_z m_{ij}\right]^2 + w_{LCI}.\left[\nabla_x m_{ij}\right]^2$$

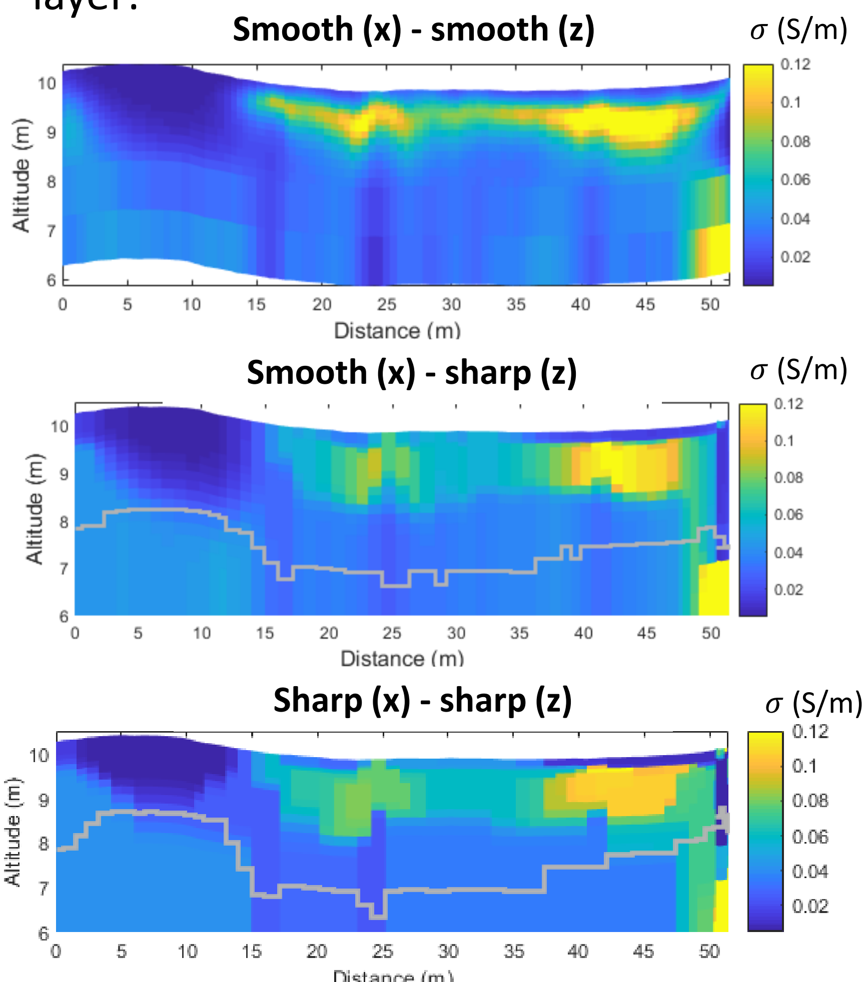
$$\Phi_m^{sm/sh} = \sum_{i=1}^{N_s}\sum_{j=1}^{N_l}\frac{\left[\nabla_z m_{ij}\right]^2}{\sqrt{\left[\nabla_z m_{ij}\right]^2 + \epsilon^2}} + w_{LCI}.\left[\nabla_x m_{ij}\right]^2$$

$$\Phi_m^{sh/sh} = \sum_{i=1}^{N_s}\sum_{j=1}^{N_l}\frac{\left[\nabla_z m_{ij}\right]^2}{\sqrt{\left[\nabla_z m_{ij}\right]^2 + \epsilon^2}} + w_{LCI}.\frac{\left[\nabla_x m_{ij}\right]^2}{\sqrt{\left[\nabla_x m_{ij}\right]^2 + \epsilon^2}}$$



Context

Example of LCI inversions of DUALEM-21 data collected above a conductive peat layer:



(Klose *et al*, in prep):

You can see the most recent application of this algorithm to EMI CMD explorer data in this EGU 2020 presentation!

EGU2020-19011 | Displays | [HS8.1.5/SSS6.12]()

[**Exploration of electromagnetic induction potential to understand groundwater infiltration within the Chalk critical zone**]()

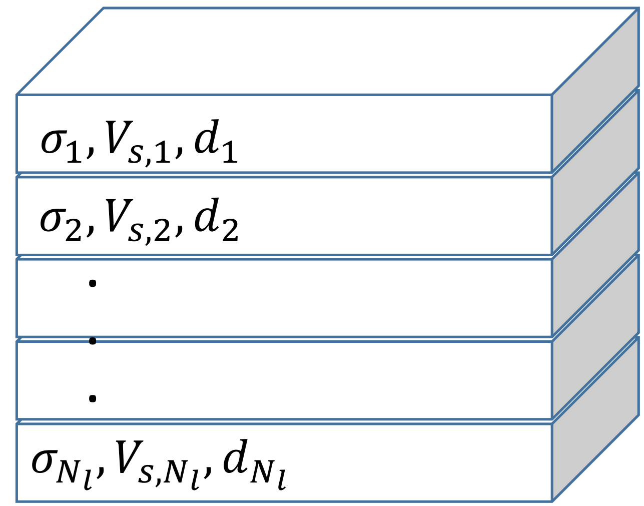
Marc Dumont *et al*, Thu, 07 May, 16:15–18:00 | D370

Goal

Our aim is to develop a common inversion platform for different kinds of geophysical data set, for example, EMI and Surface Wave (SW):

EMI data
+
Surface Wave data

Joint inversion



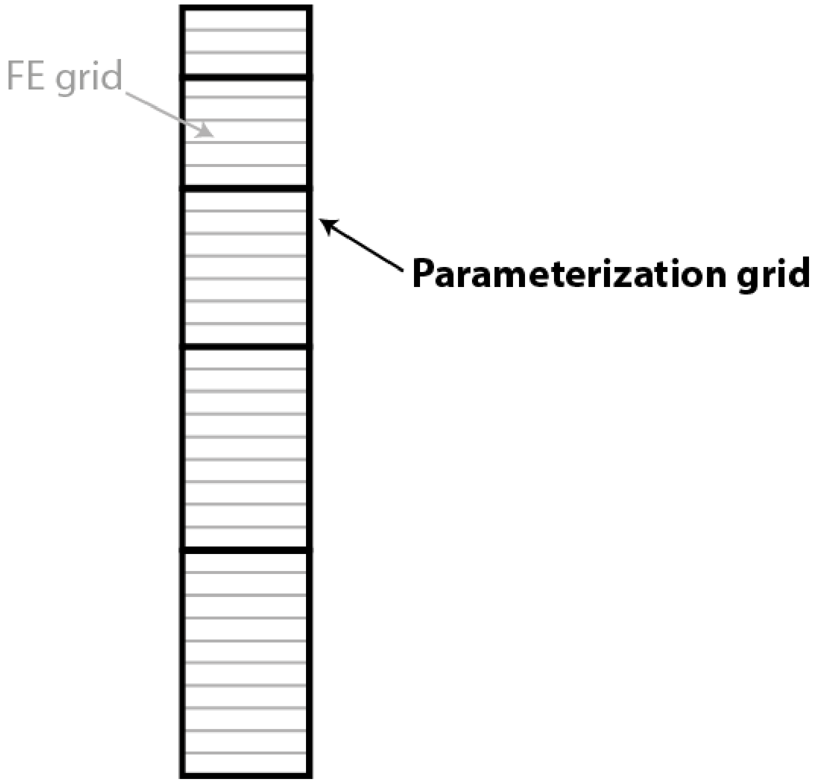
In this respect, the purpose of this study is to evaluate how our inversion strategy for EMI data can be applied to the 1D inversion of SW dispersion curves.

The present study shows preliminary results only.

Forward modelling and inversion

The 1D forward modeling code is based on the finite elements approach described in Haney and Tsai, (2020).

Our novel inversion algorithm relies on two decoupled grids: one discretizing the model parameters, the other (denser) for the FE computation.

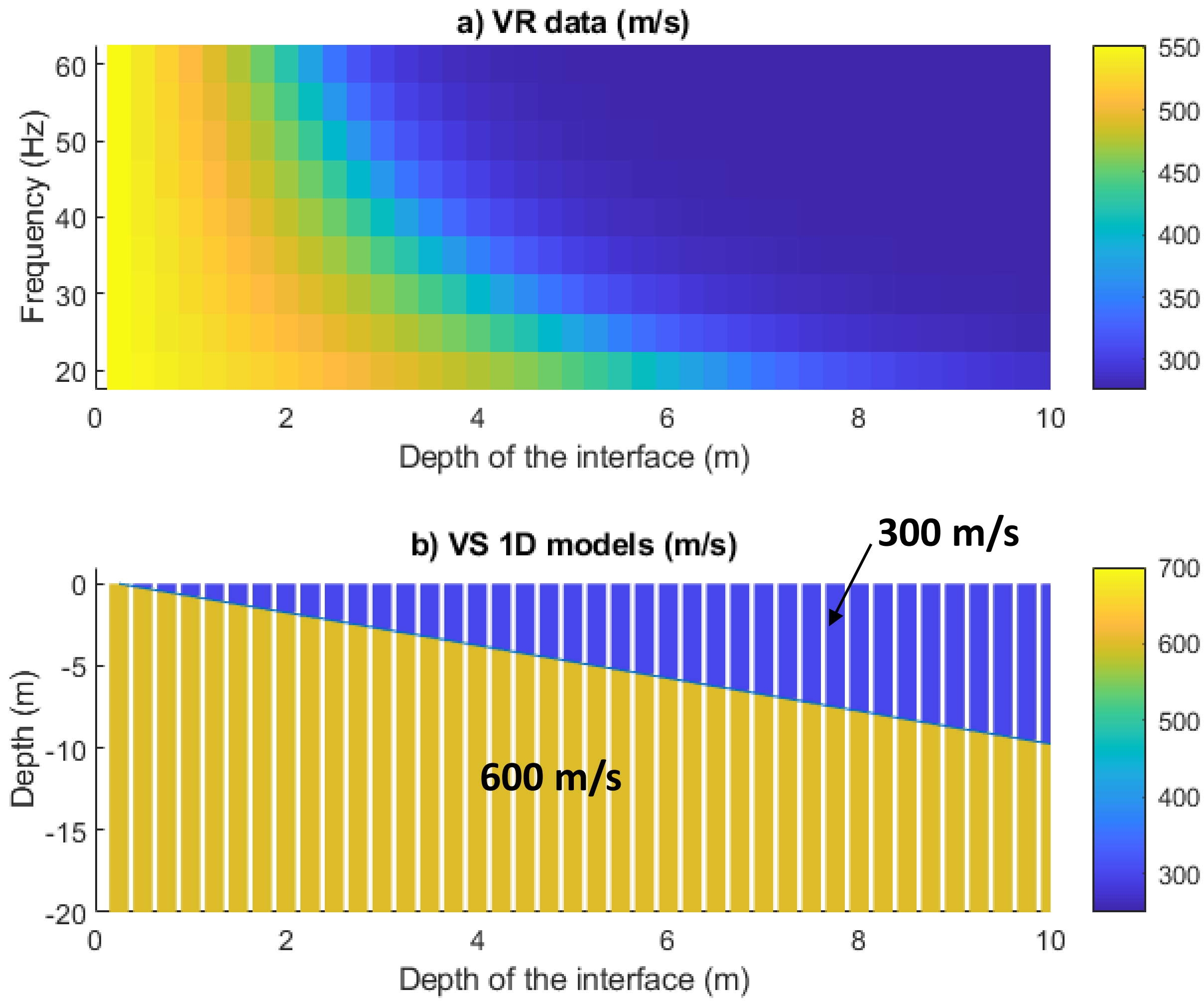


This step is necessary to make our inversion algorithm practical (especially for the LCI) as it reduces by around one order of magnitude the number of model parameters!

It also allows the design of non-homogeneous grid.

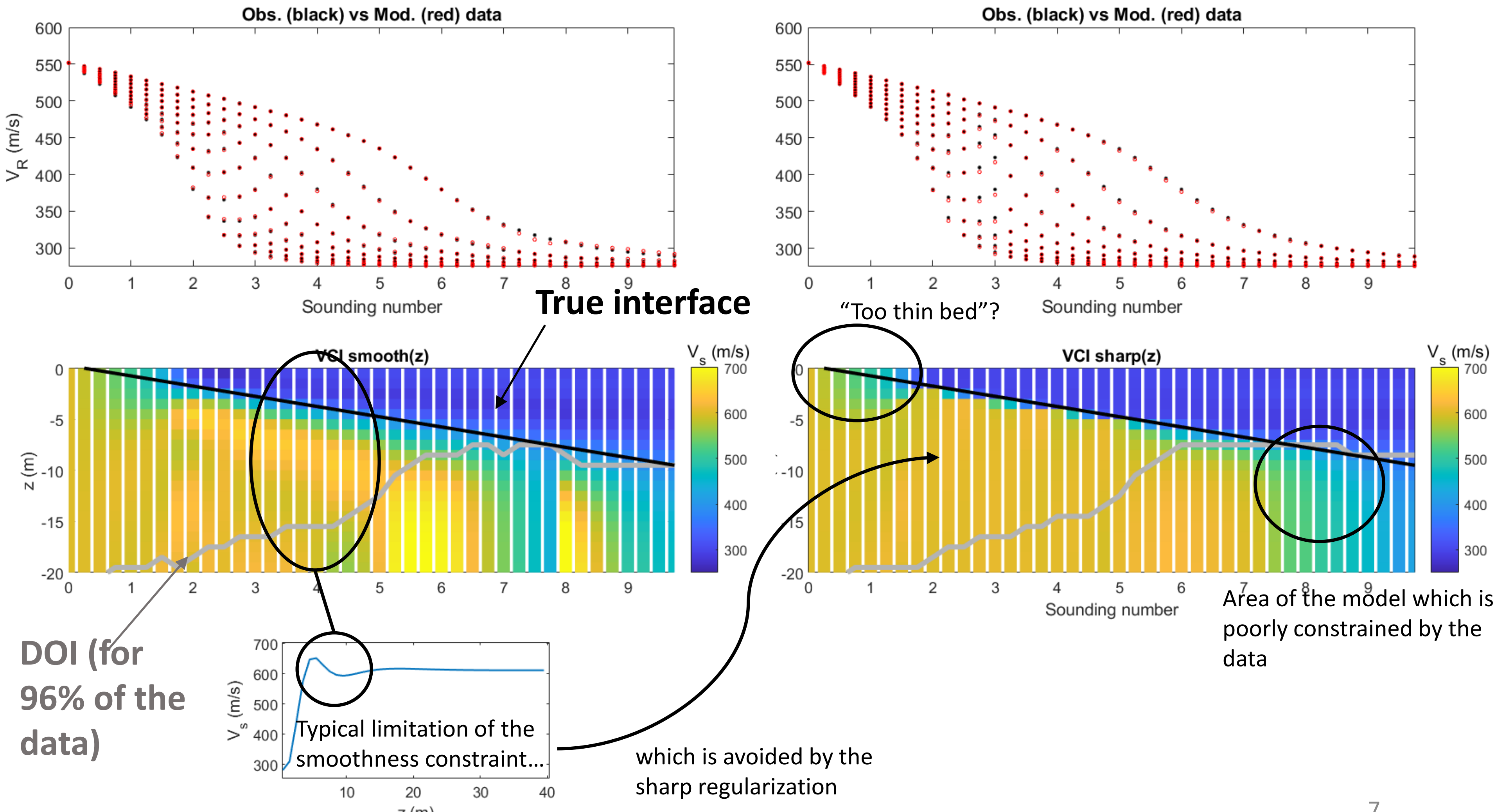
Forward modelling of SW data

First example of 1D synthetic data set



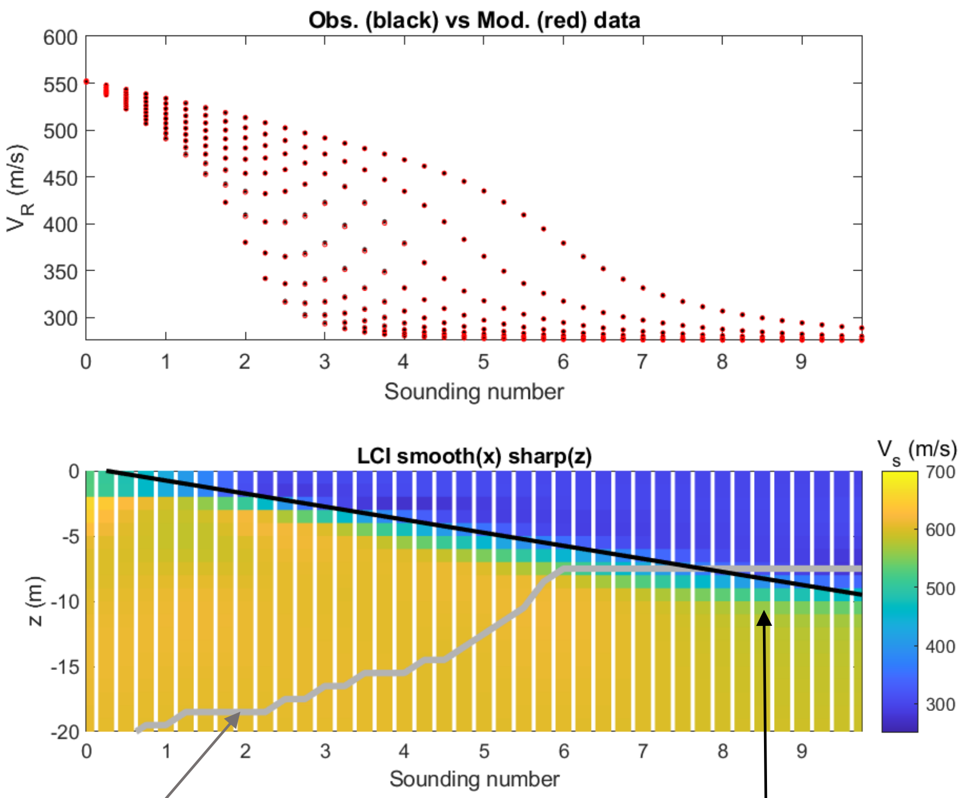
Smooth and sharp VCI inversions

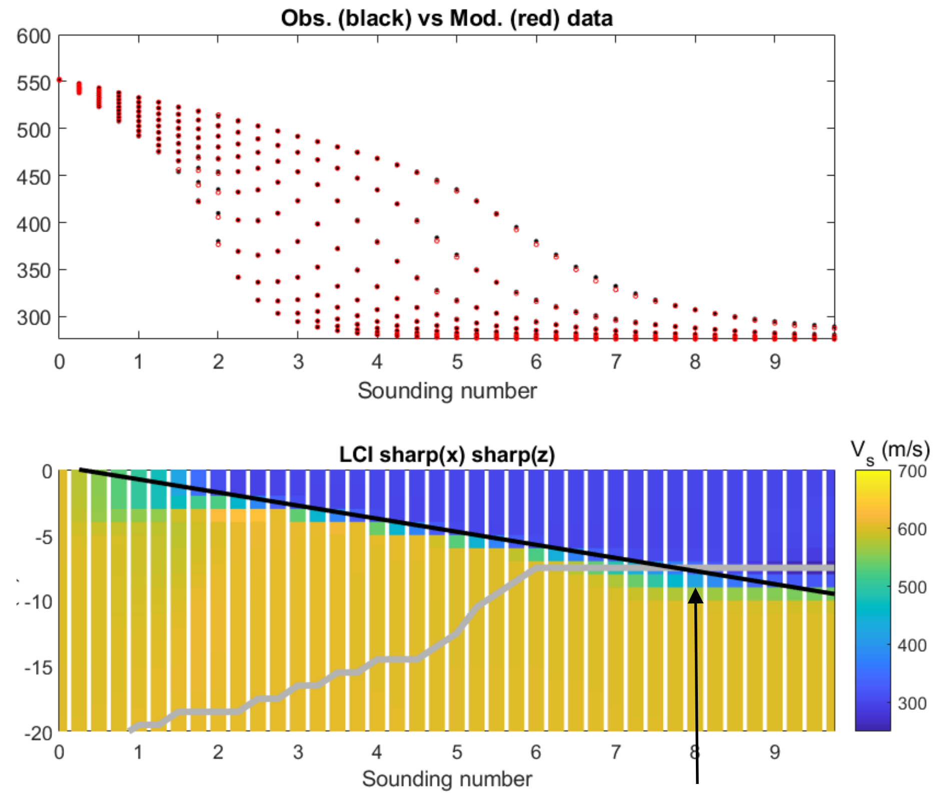
First tests with noise free data: smooth(z) vs sharp(z)



Hybrid smooth and sharp LCI inversions

LCI: smooth(x)sharp(z) vs sharp(x)sharp(z)





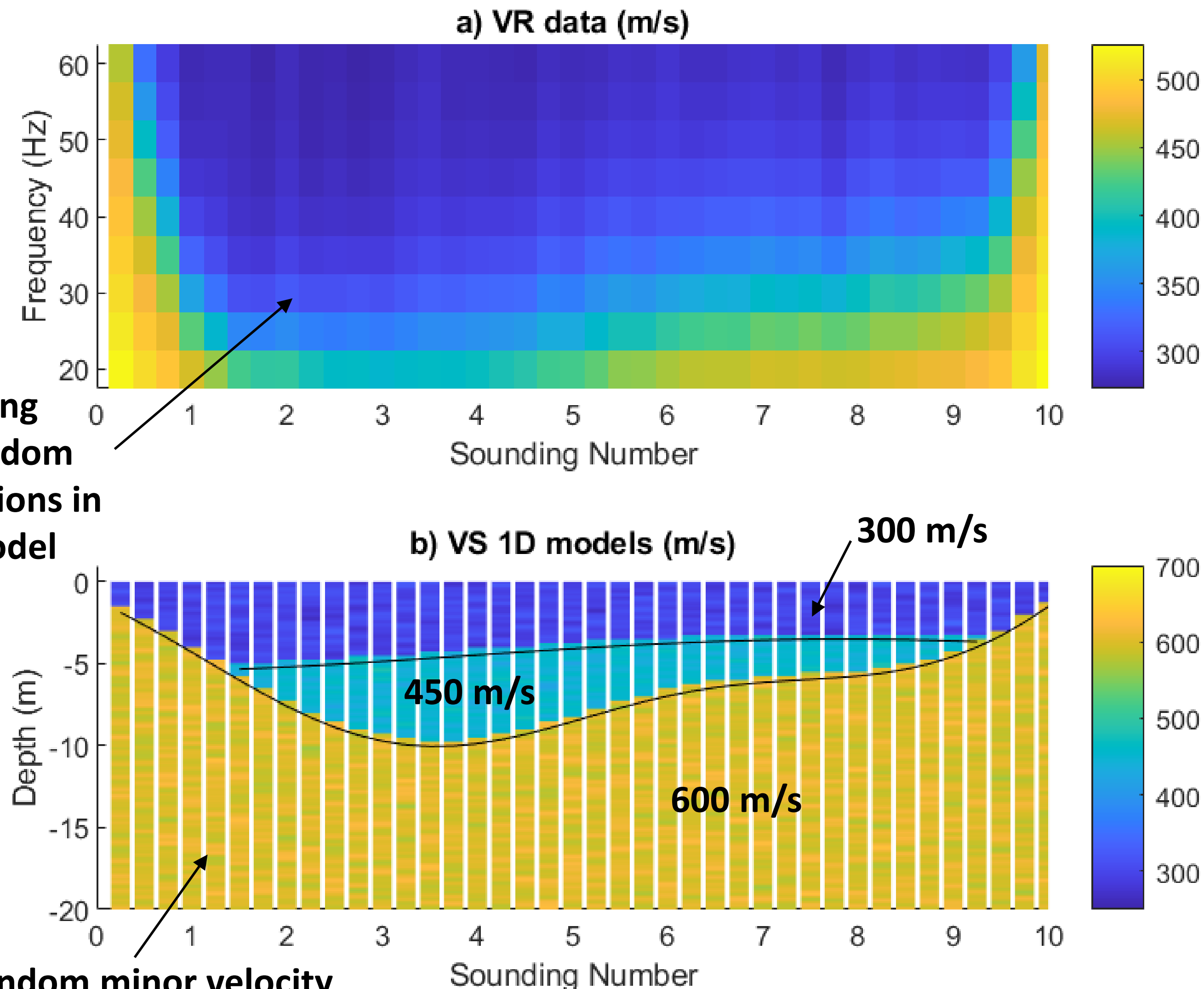
DOI (for 96% of the data)

The LCI improves the continuity of the structures in areas that are less constrained by the data

The LCI improves the continuity of the structures in areas that are less constrained by the data

Forward modelling of SW data

Second example of 1D synthetic data set: adding some geological complexity

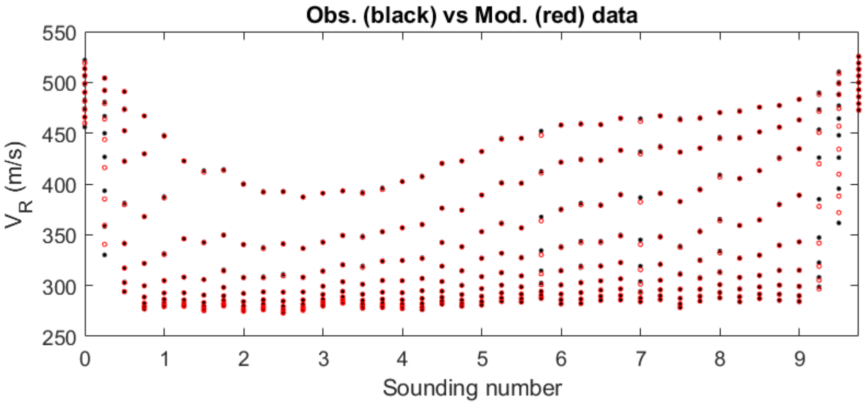


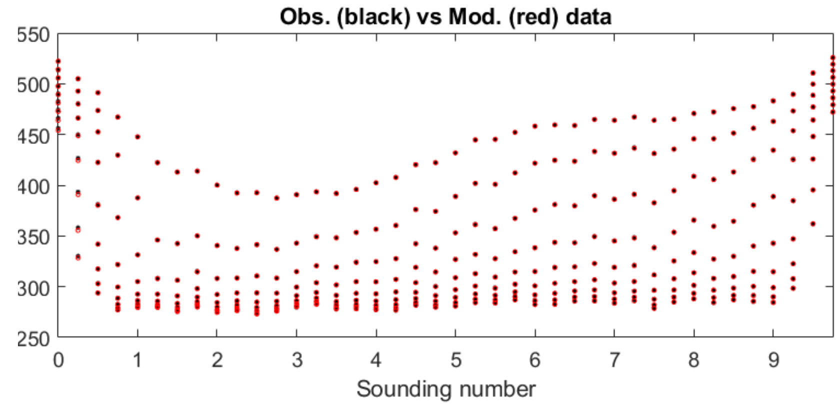
Noise resulting from the random minor variations in the input model

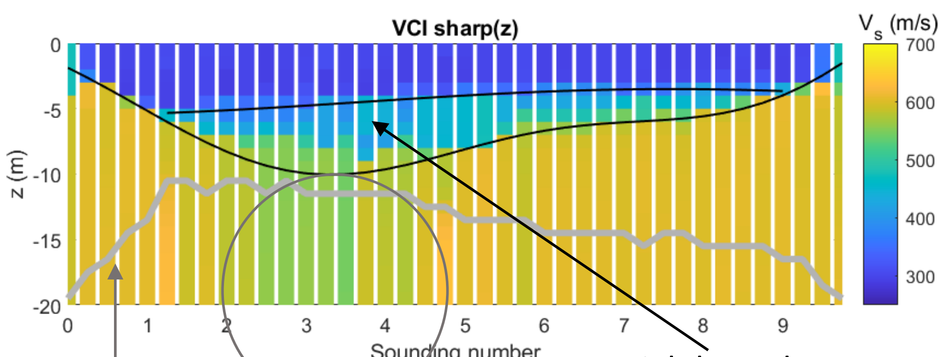
Random minor velocity variations

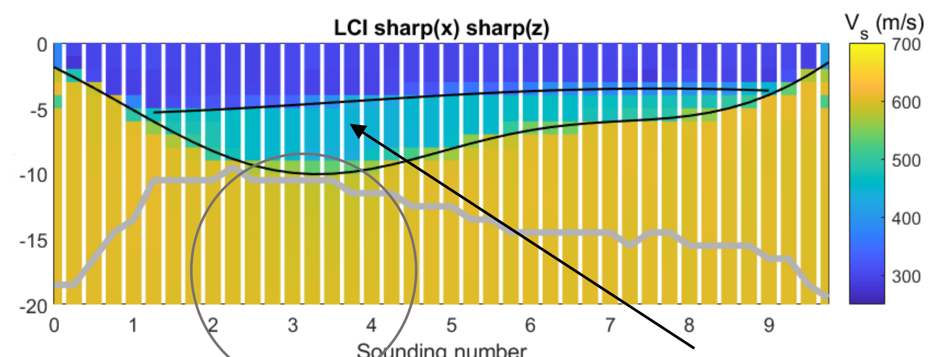
VCI sharp vs LCI sharp

VCI sharp(z) vs LCI sharp(x) sharp(z)









DOI (for 96% of the data)

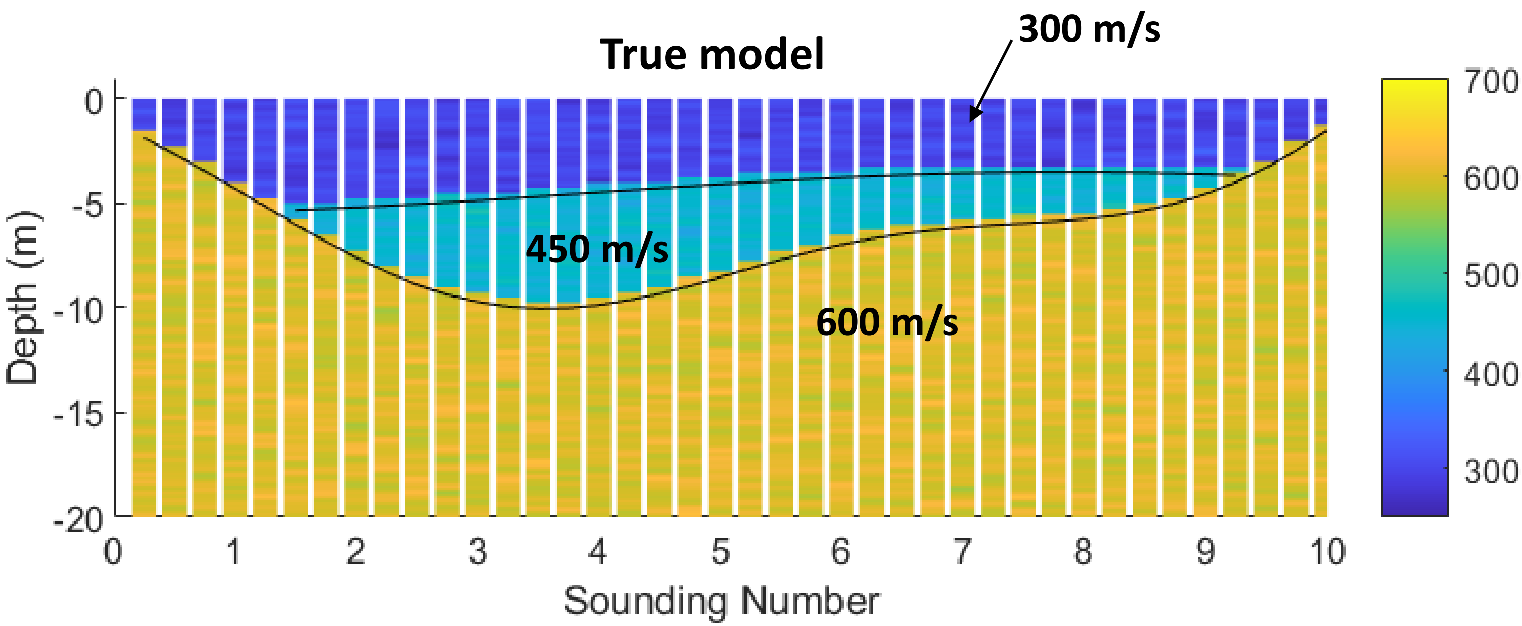
Poorly resolved third layer velocity

High lateral variations due to the geological noise added to the input model

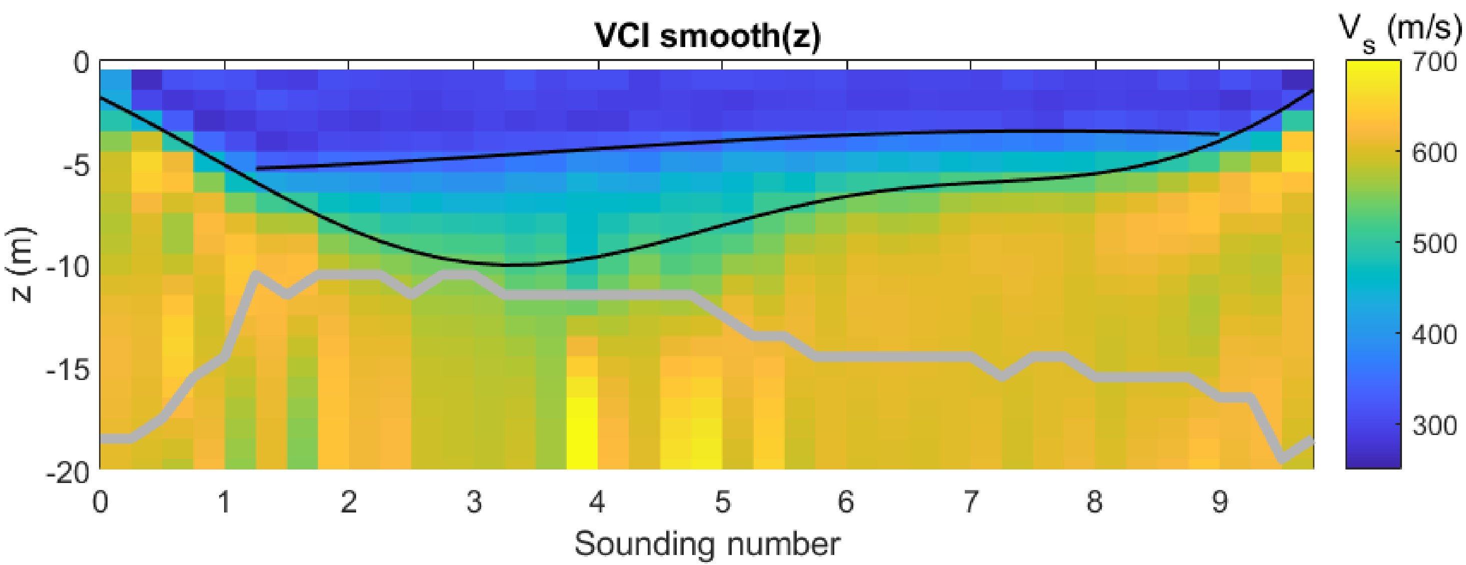
Better constrained here thanks to the hypothesis of lateral consistency imposed by the LCI

No more high lateral variations while still fitting the data! (i.e., no data smoothing induced at all)

VCI smooth(z)

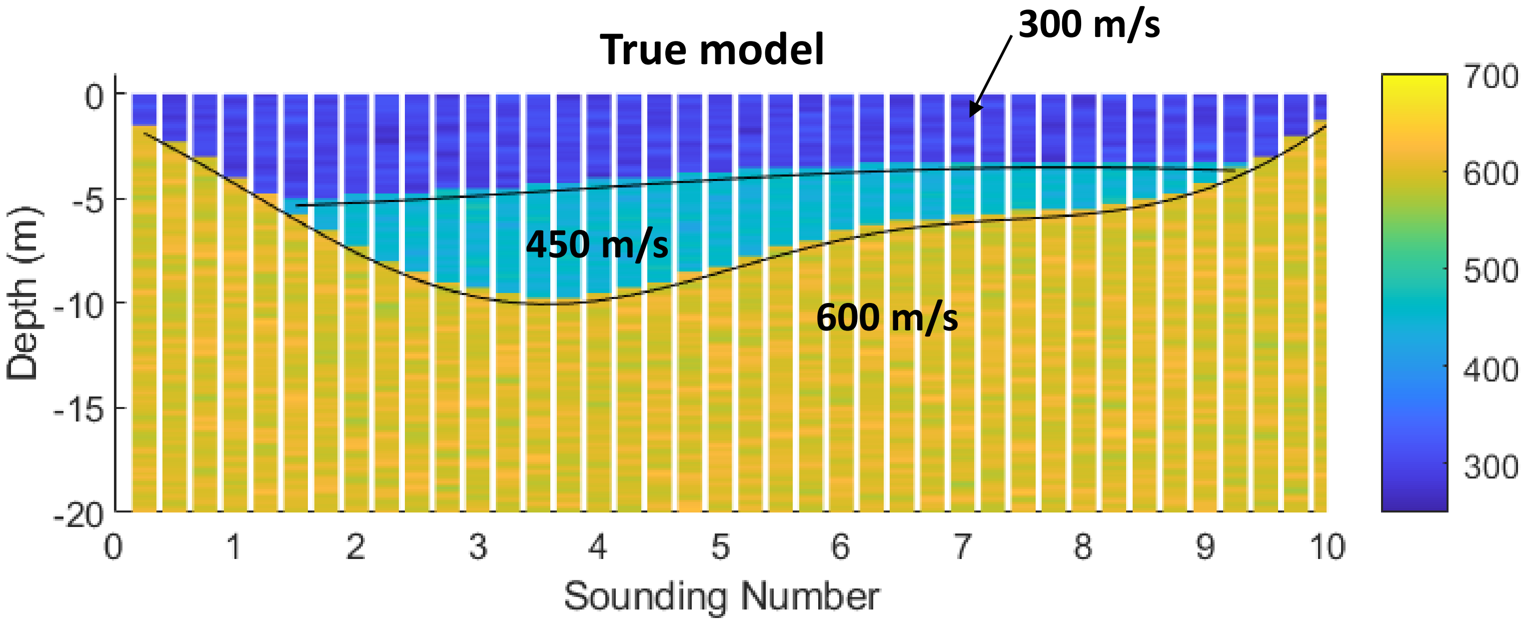


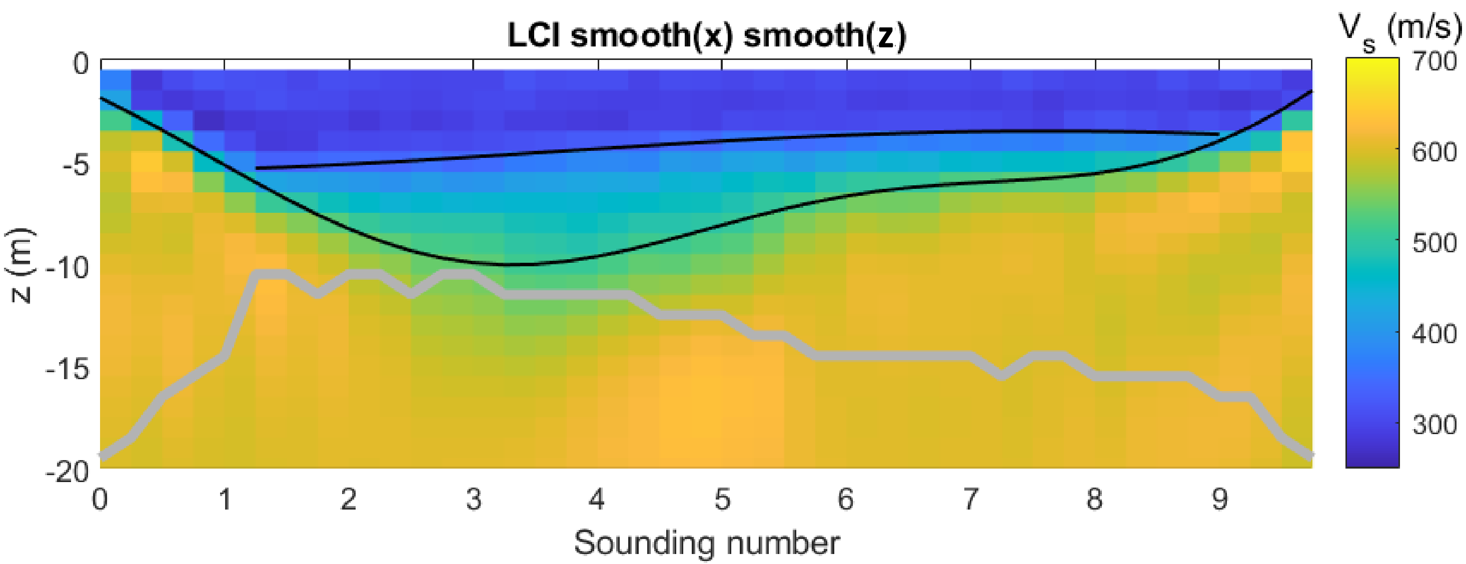
True model
300 m/s
450 m/s
600 m/s
Depth (m)
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10
Sounding Number
700
600
500
400
300



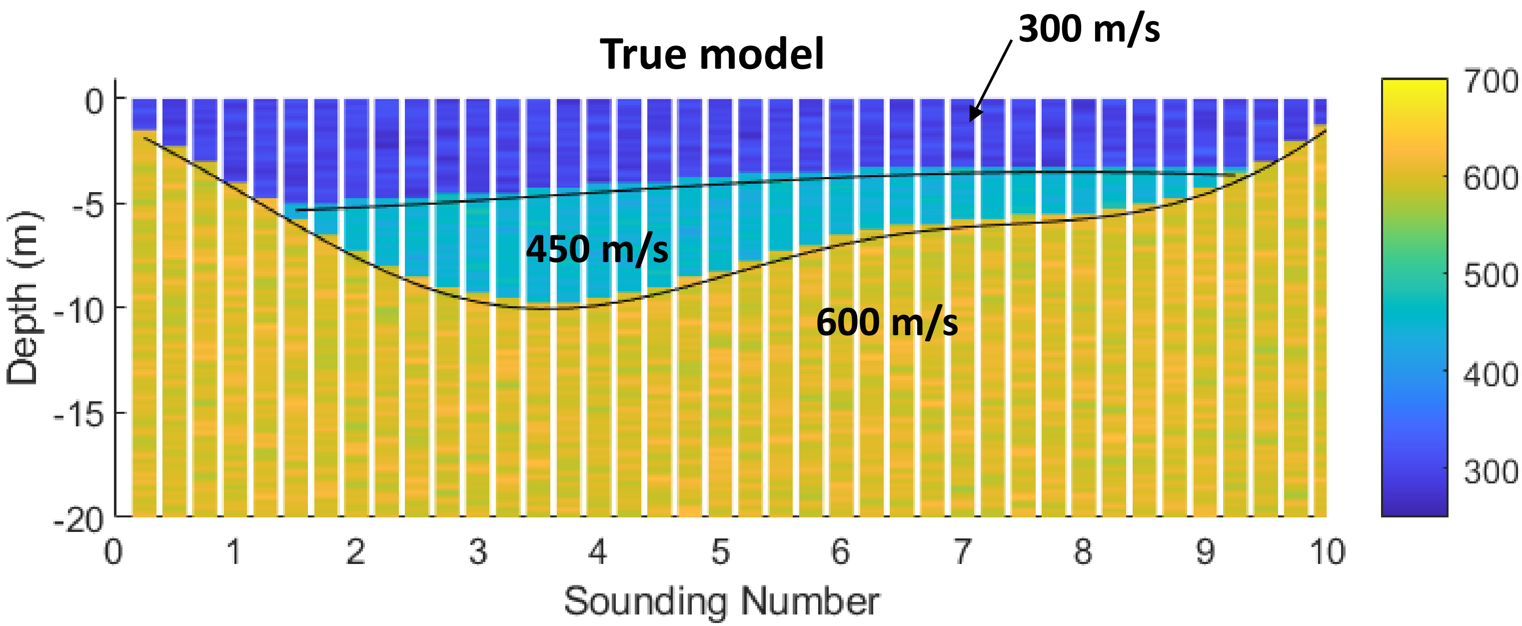
VCI smooth(z)
V_s (m/s)
z (m)
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
Sounding number
700
600
500
400
300

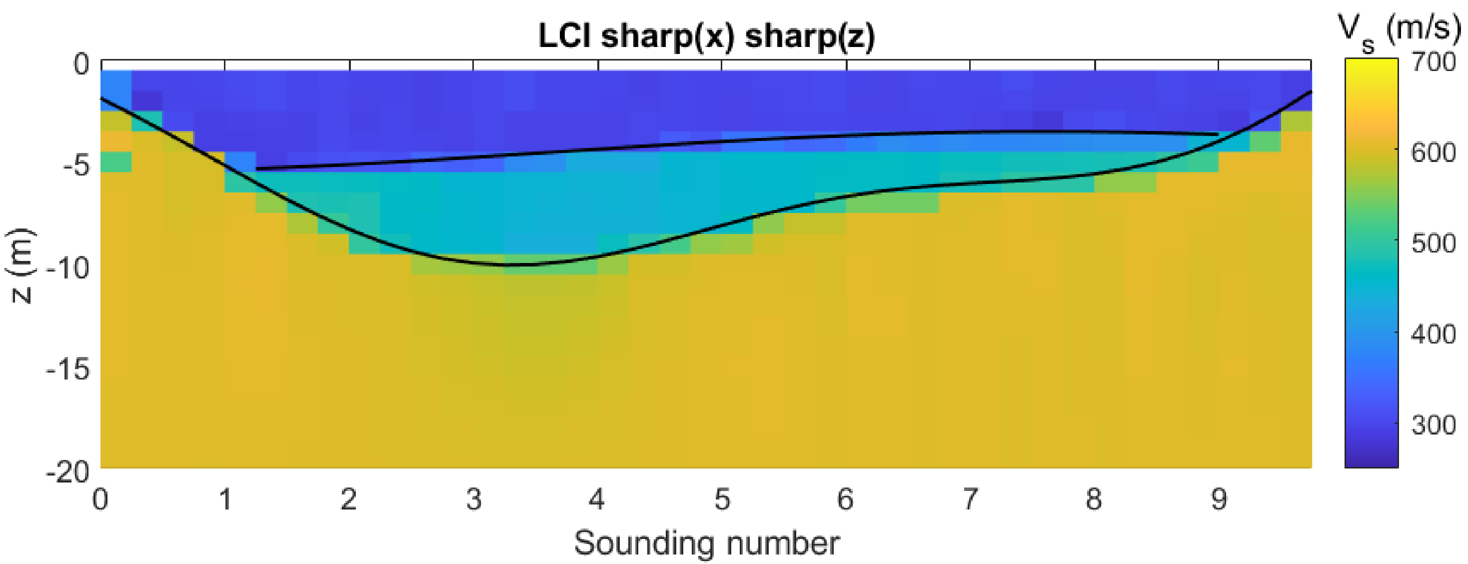
LCI smooth(x) smooth(z)



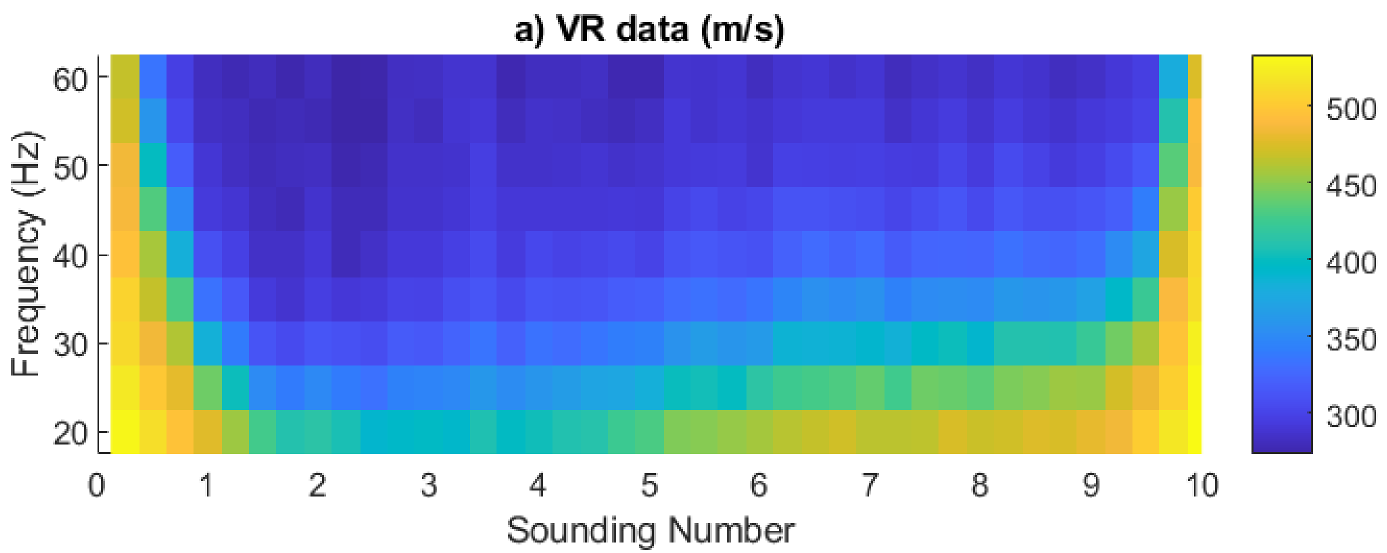


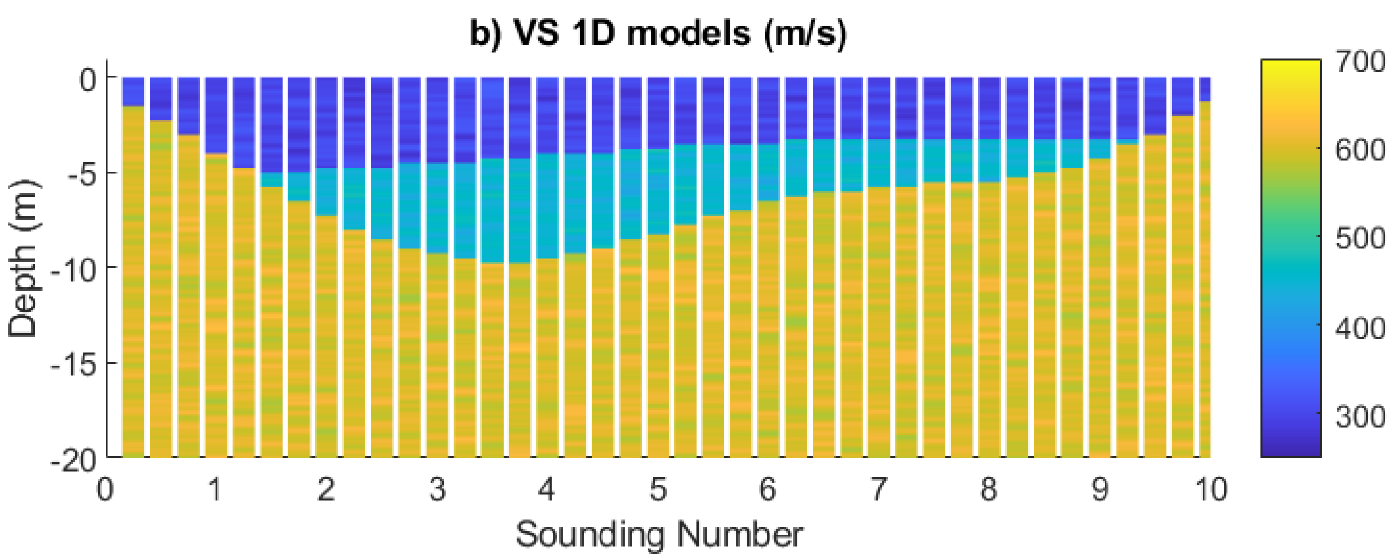
LCI sharp(x) sharp(z)



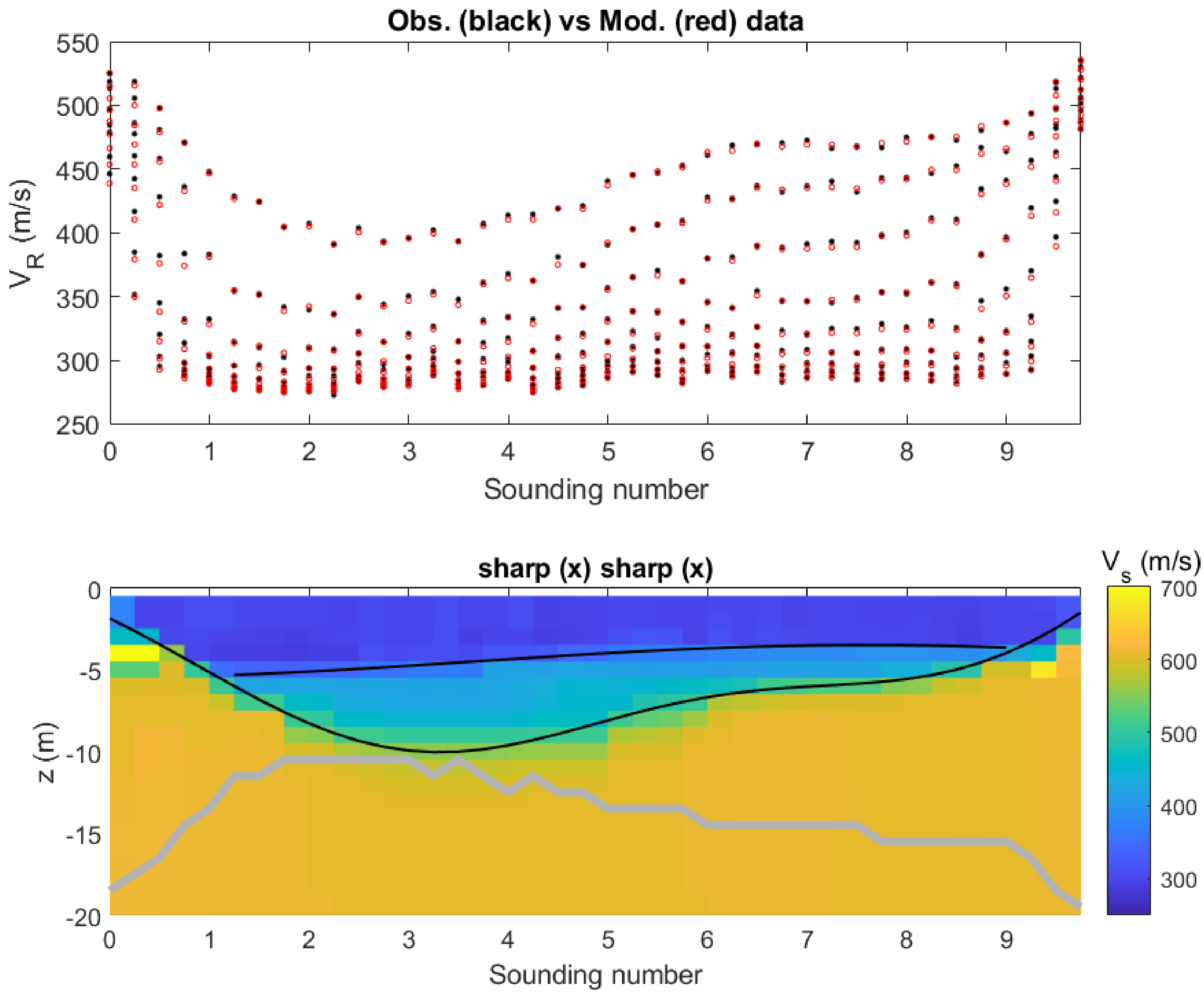


Synthetic data + model noise+ 2% data random noise

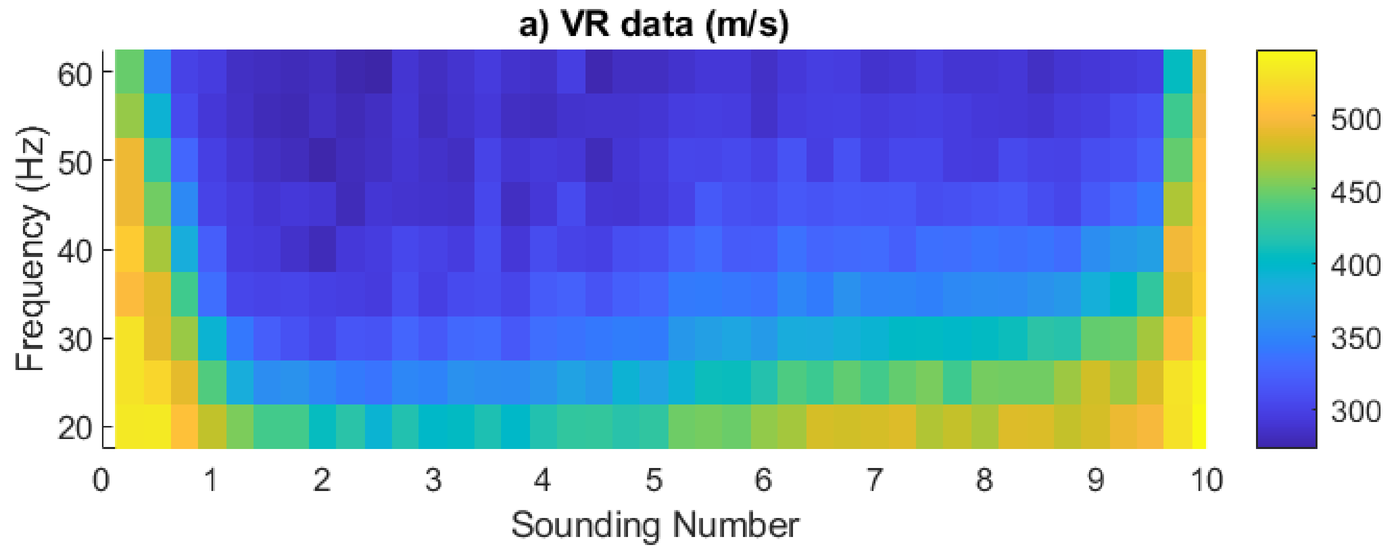


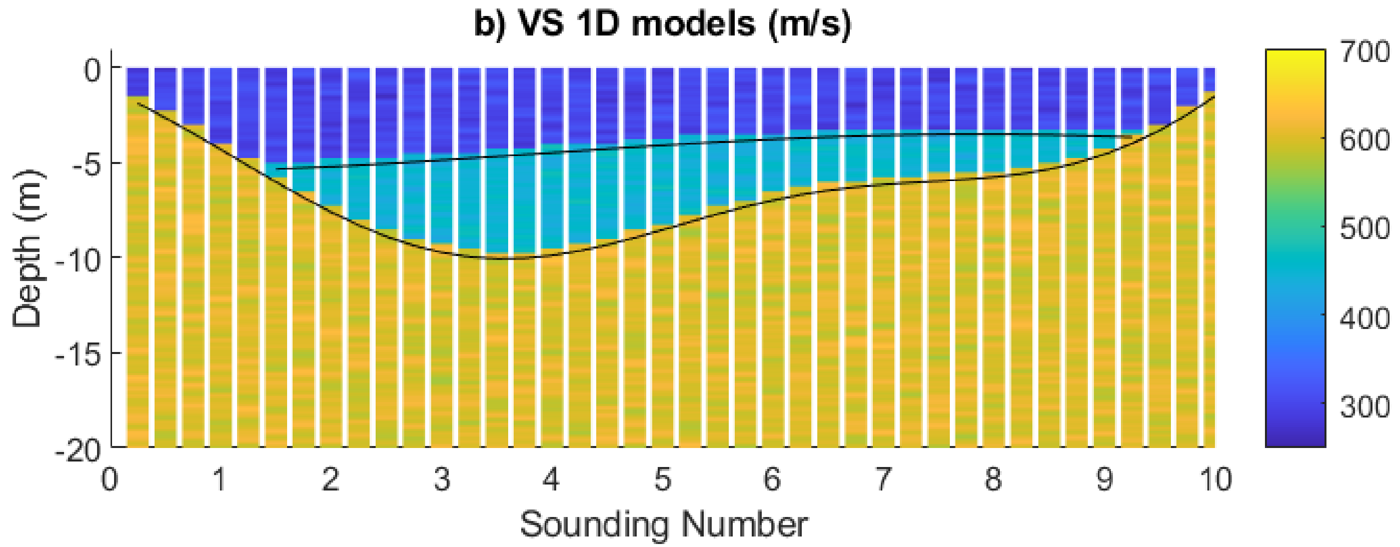


Synthetic data + model noise+ 2% data random noise

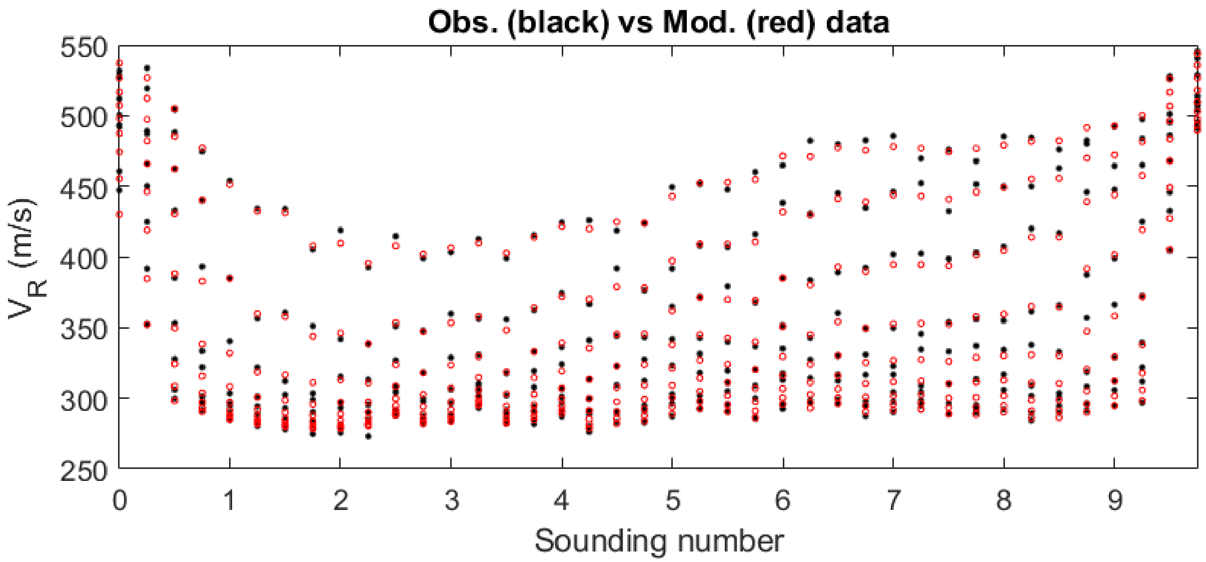


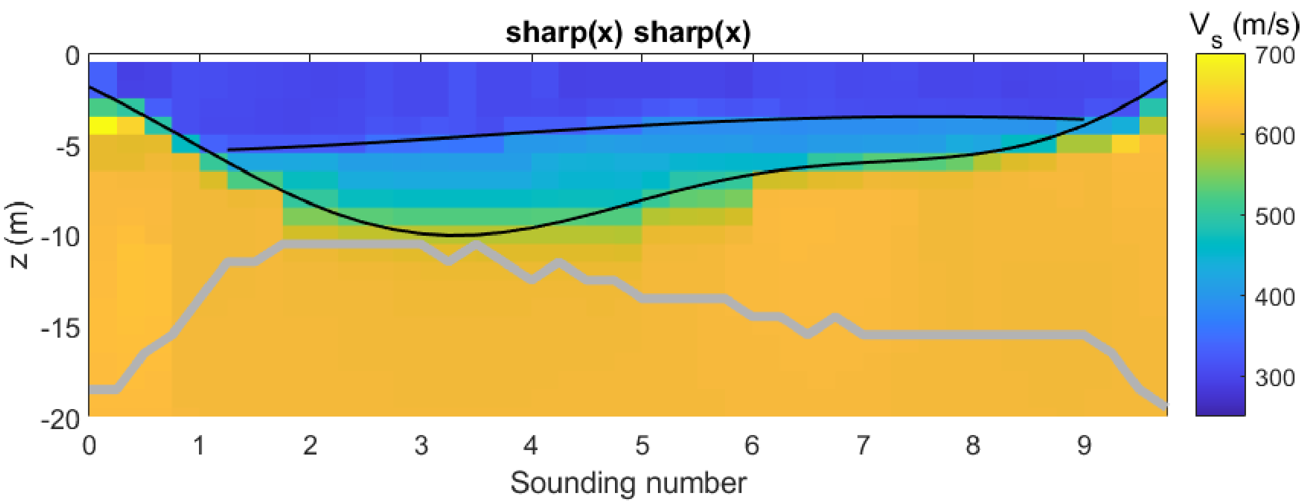
Synthetic data + model noise+ 5% data random noise



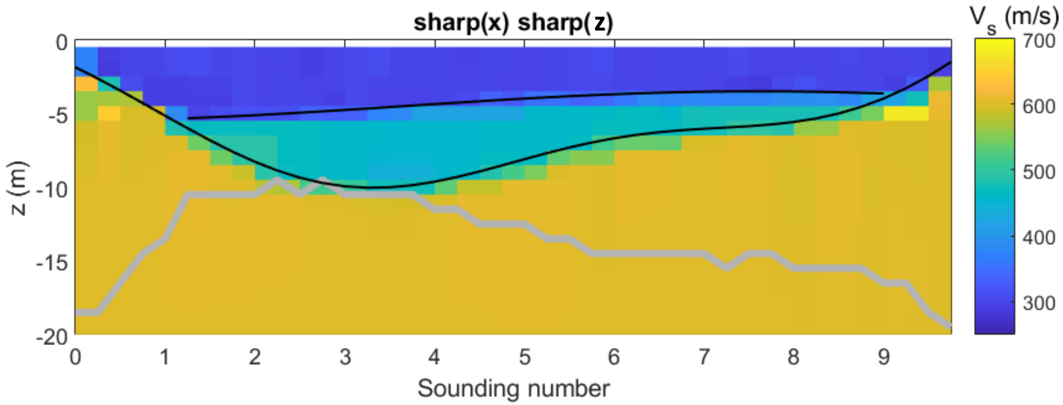


Synthetic data + model noise+ 5% data random noise

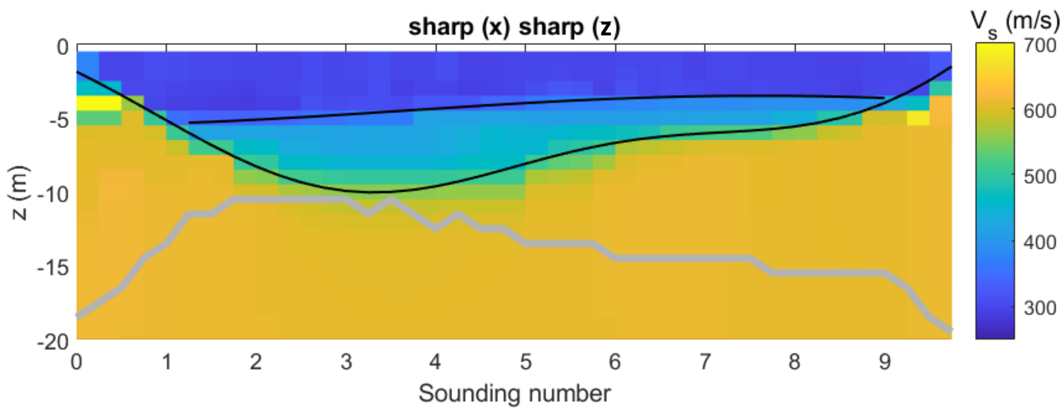




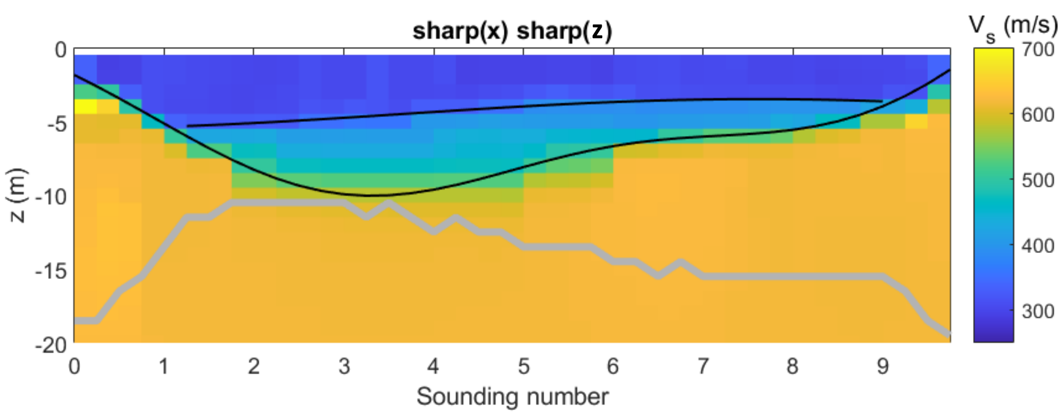
Summary: results obtained with the same inversion setup



Model noise only



Model noise + 2% data noise



Model noise + 5% data noise

Conclusion

- We applied our EMI inversion tools to the 1D inversion of seismic surface wave data
- We implemented both VCI and LCI approaches incorporating smooth and sharp constraints in both directions (x,z)
- From this preliminary synthetic study, the LCI with sharpness constraints in both directions (x,z) shows the best imaging capabilities
- Next step is to invert a real data set!

Thank you for your comments and feedback!

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References

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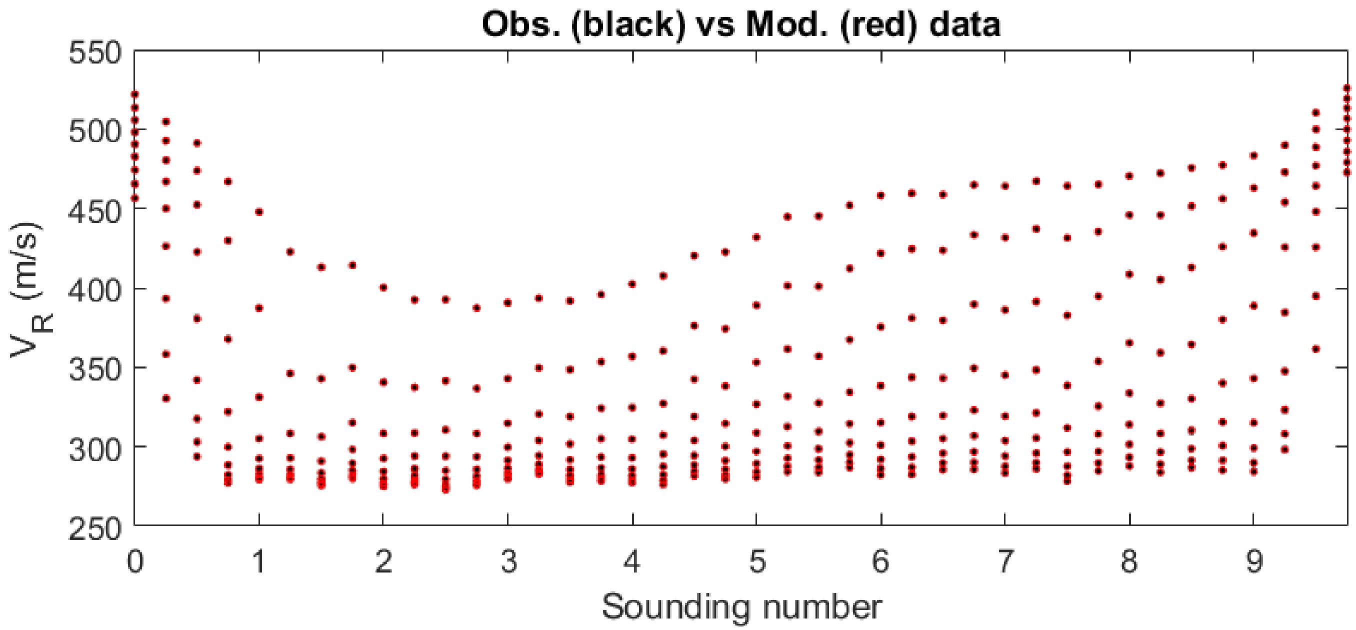
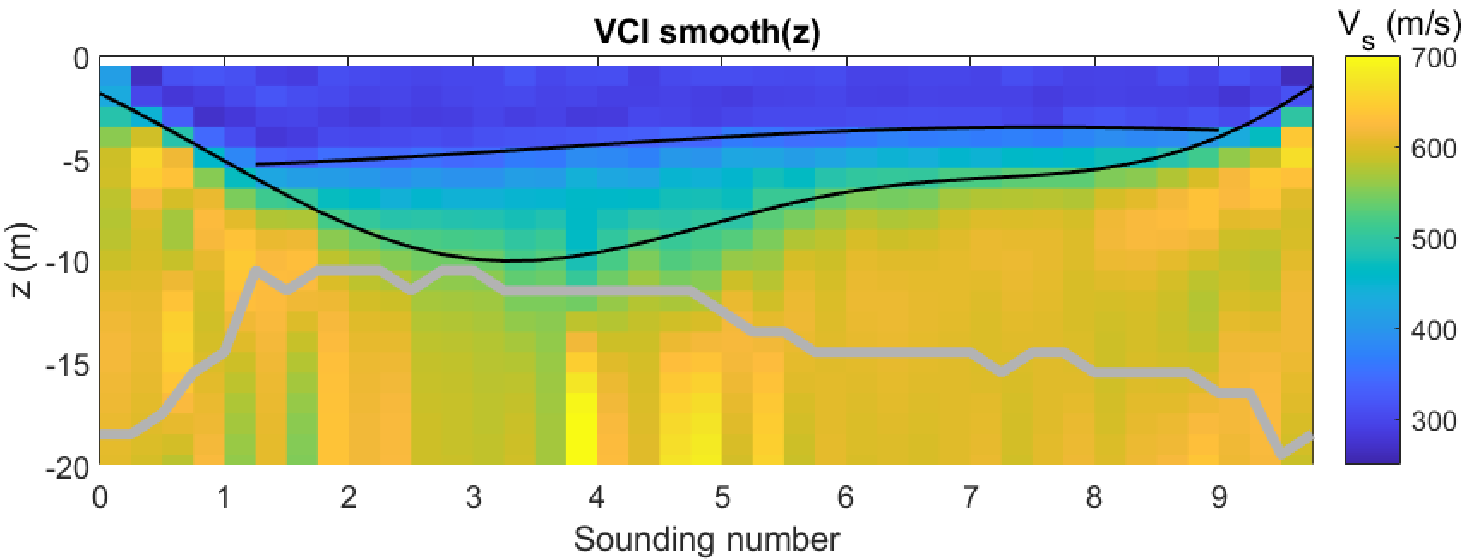
Data misfit

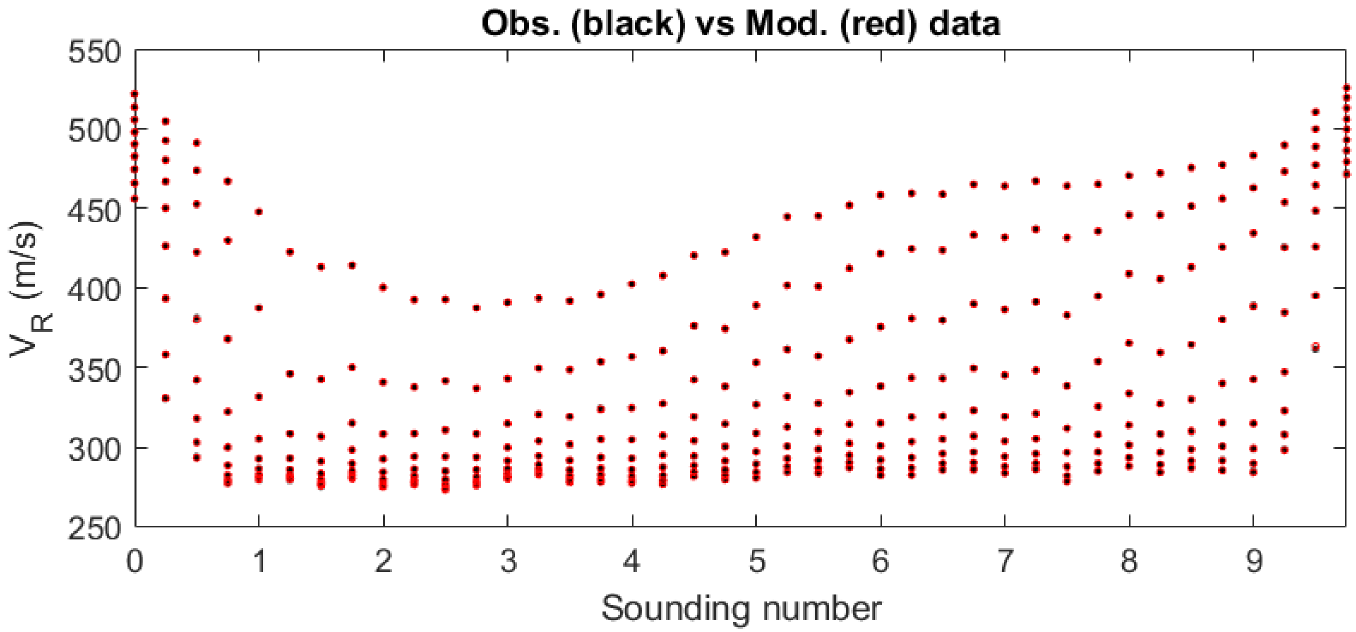


Obs. (black) vs Mod. (red) data
V_R (m/s)
550
500
450
400
350
300
250
0 1 2 3 4 5 6 7 8 9
Sounding number



VCI smooth(z)
V_s (m/s)
700
600
500
400
300
z (m)
0
-5
-10
-15
-20
0 1 2 3 4 5 6 7 8 9
Sounding number

Data misfit



Obs. (black) vs Mod. (red) data
V_R (m/s)
550
500
450
400
350
300
250
0
1
2
3
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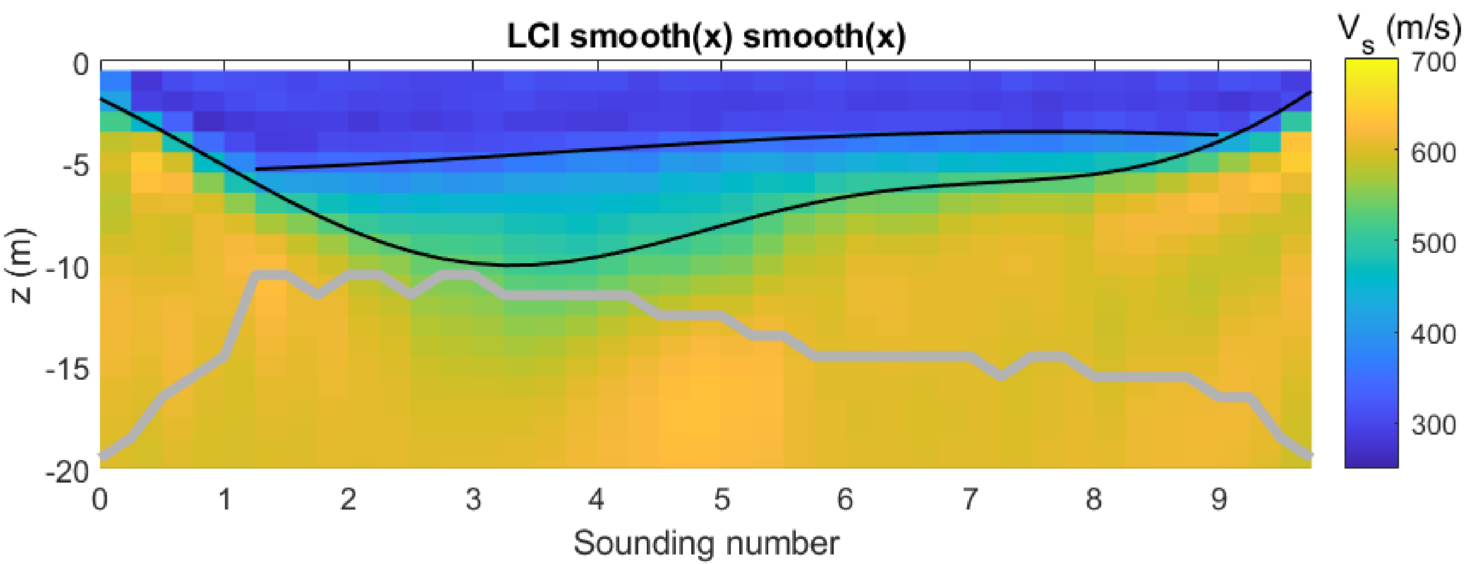
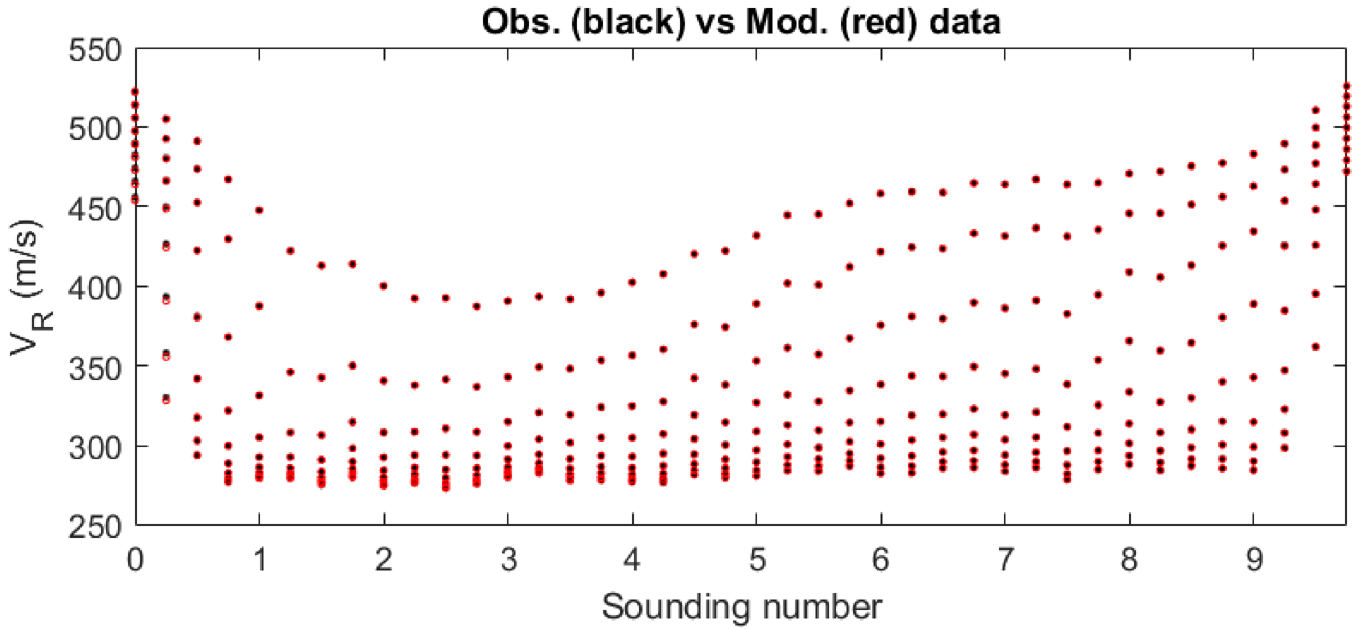
5
6
7
8
9
Sounding number

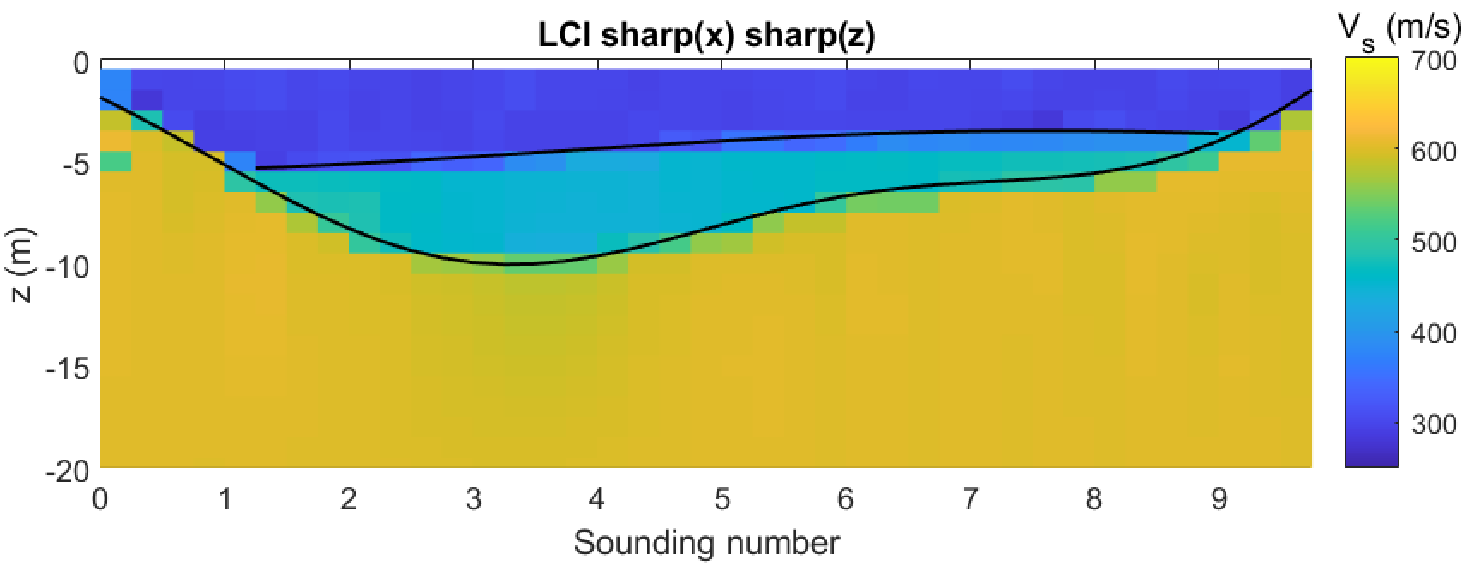


LCI smooth(x) smooth(x)
z (m)
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
Sounding number
V_s (m/s)
700
600
500
400
300

Data misfit



Obs. (black) vs Mod. (red) data
550
500
450
400
350
300
250
V_R (m/s)
0
1
2
3
4
5
6
7
8
9
Sounding number



LCI sharp(x) sharp(z)
V_s (m/s)
700
600
500
400
300
0
-5
-10
-15
-20
z (m)
0
1
2
3
4
5
6
7
8
9
Sounding number