[Journal of Geophysical Research Solid Earth]

Supporting Information for

Physics-Informed Neural Networks (PINNs) for Wave Propagation and Full Waveform Inversions

Majid Rasht-Behesht[1], Christian Huber[1], Khemraj Shukla[2] and George Em Karniadakis[3]

[1]Department of Earth Environmental and Planetary Sciences, Brown University, Providence, RI 02906, USA
[2]Division of Applied Mathematics, Brown University, Providence, RI 02906, USA
[3]Division of Applied Mathematics and School of Engineering, Brown University, Providence, RI 02906, USA

Contents of this file

Figures S1 to S6

Introduction

In this section we discuss two main points regarding training PINNs for FWIs: (a) How does using a smaller NN affect the inversion results? (b) How accurate is a PINN that has been trained for a smaller number of epochs for the same number of hidden layers and neurons? We perform two additional inversions to address each of these questions.

To address the first question, we design a smaller NN with 4 hidden layers and 50 neurons in each layer to redo the inversion for the case study with an ellipsoidal anomaly and a 20 Hz point source (Case 2. In the main text). All parameters of the system and PINN's setup are the same as in Case 2. From fig. S1 we can see that the main features of the anomaly (location, approximate size, and strength) have been recovered well by PINNs, despite an uneducated initial guess. However, the smearing at the boundaries of the anomaly is larger than Case 2 in the main text with the larger NN. From fig. S2 we can also see that the estimation error for the wavefield has slightly increased compared to Case 2 in areas close to the boundaries of the velocity anomaly. The fit to the seismograms has not been affected greatly, which is confirmed from fig. S3. This exercise shows that it is important for the chosen NN to be expressive enough (large enough number of layers and neurons) for a correct estimation of the ground truth wavespeed and the wavefield.

To understand the effect of a shorter training episode, we record the results of the inversion for the ellipsoidal anomaly with two teleseismic plane waves (Case 4 from the main text) after 70,000 epochs, instead of 400,000. Fig. S4 shows that even with a shorter training process, the inverted wavespeed is acceptable, however with slightly larger smearing at the boundaries of the velocity anomaly compared to fig. 13c in the main text. Furthermore, fig. S5 shows that the overall shape of the waveforms is well preserved, however with slightly bent wavefronts (instead of straight plane waves) at later times. From fig. S5 we can also see that the free-surface constraint and hence the resulting reflection is well captured by a shorter training process. Additionally, there is no noticeable violation of the absorbing boundary conditions at the right, left and bottom boundaries. We can also see that the seismograms are fit equally well for the shorter training of PINNs (Fig. S6).

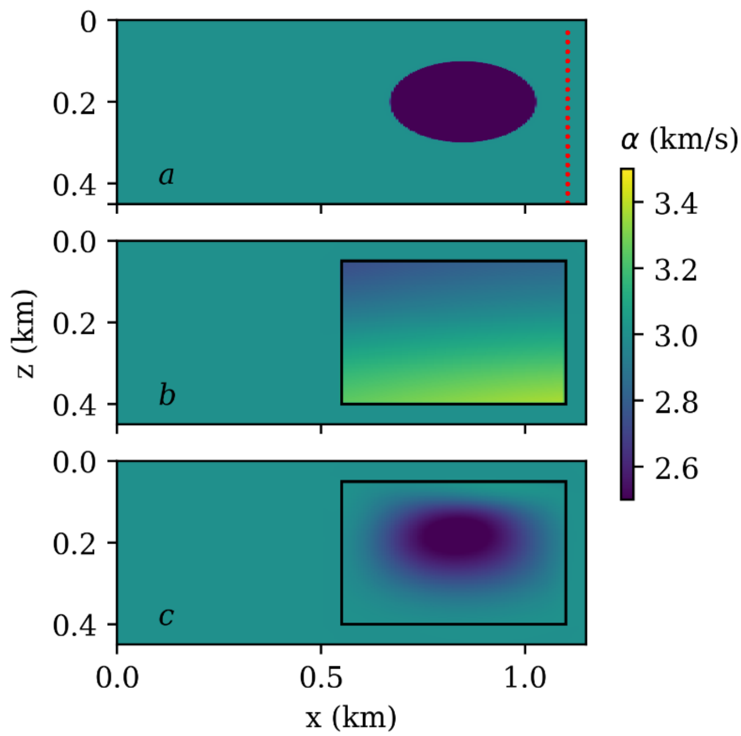

Figure S1. (a) Ground truth, (b) Initial guess (c) Inversion results for the synthetic crosswell experiment. A PINN with 4 hidden layers and 50 neurons in each layer has been used. The black rectangles in (b) and (c) show the area that we have inverted for with PINN. The red dots in (a) show the locations of the seismometers.

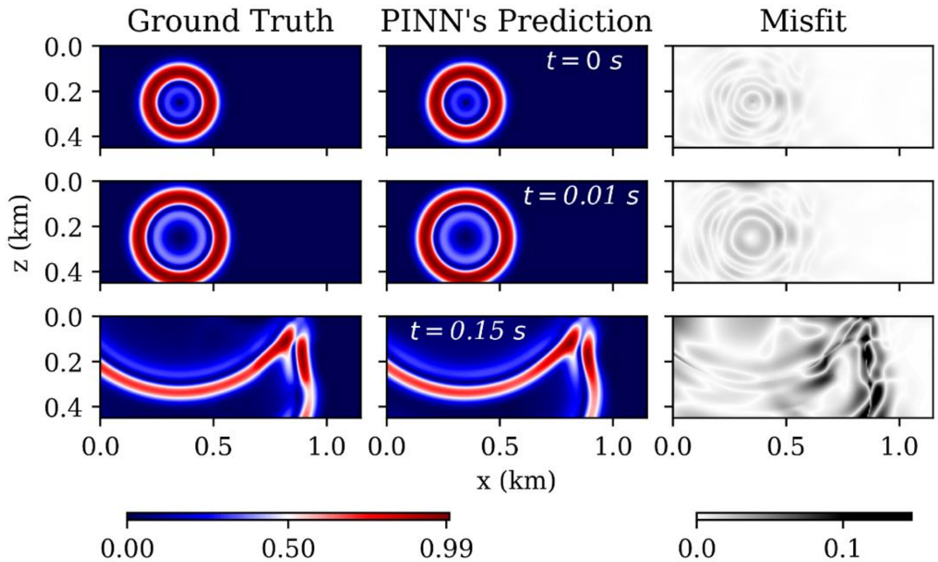

Figure S2. Wavefields for the synthetic crosswell experiment. Ground truth versus predicted magnitude of the wavefields from PINN and their absolute pointwise differences with a NN with 4 hidden layers and 50 neurons in each layer.

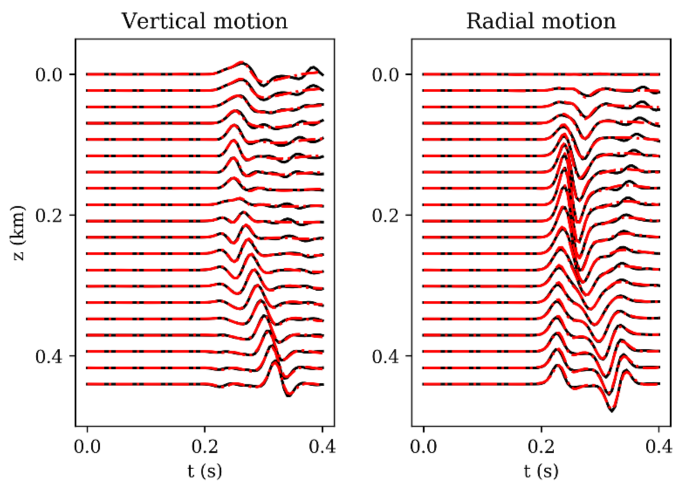

Figure S3. Vertical (left) and radial (right) motion seismograms for the synthetic crosswell experiment. black line: input, red dashed line: PINNs' prediction.

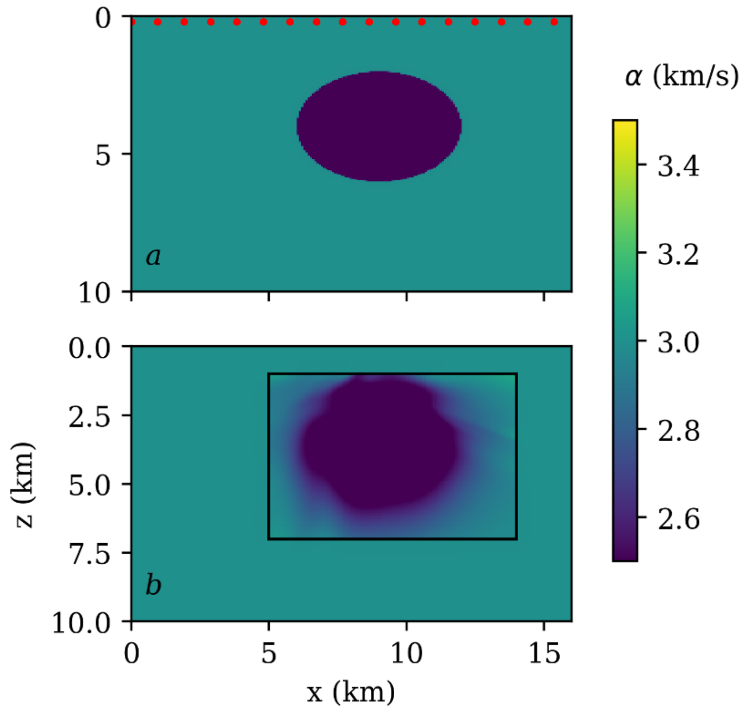

Figure S4. (a) Ground truth (b) inverted acoustic wave velocity from PINN after 70,000 epochs of training, for the teleseismic case study.

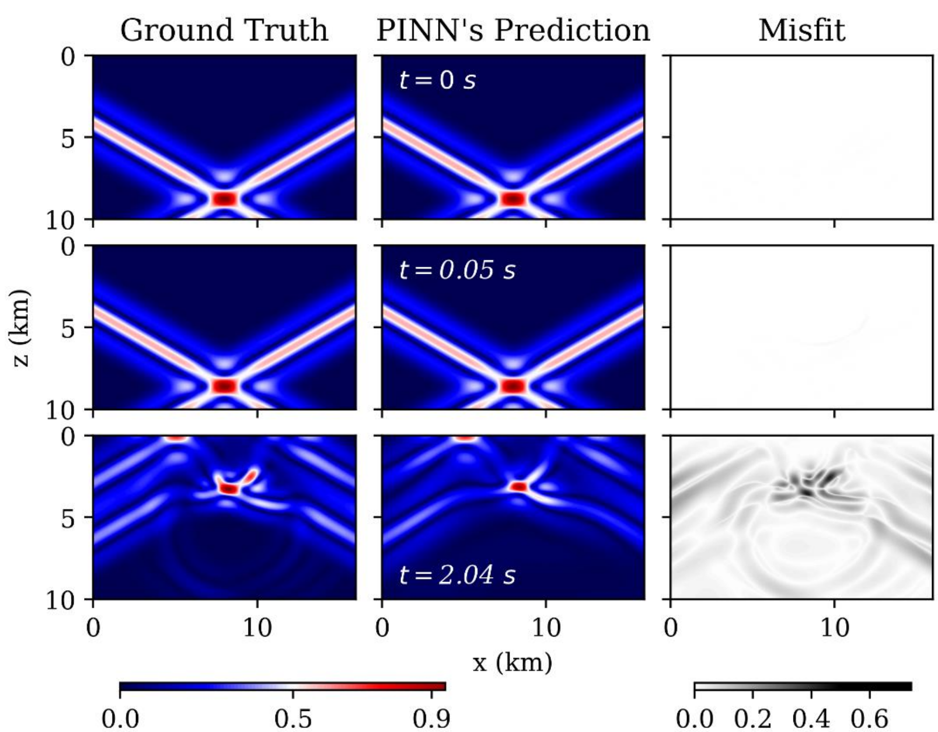

Figure S5. Ground truth versus predicted magnitude of the wavefields from PINN and their absolute pointwise differences after 70,000 epochs.

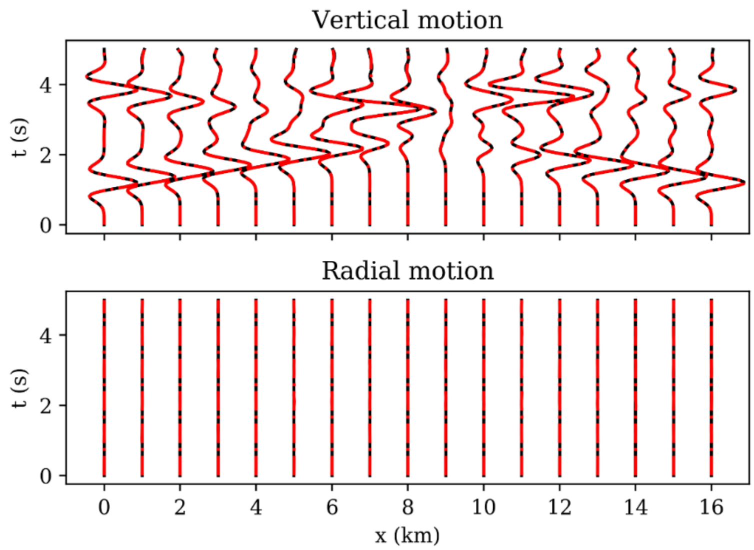

Figure S6. Vertical (top) and radial (bottom) motion seismograms after 70,000 epochs, for the teleseismic case study. black line: input, red dashed line: PINNs' prediction.