Answers to editor comments

https://doi.org/10.5194/se-2021-55-EC1

Title: 3D crustal structure of the Ligurian Sea revealed by ambient noise tomography using ocean bottom seismometer data

Dear Topical Editor Mark Handy,

We thank you for the fair and constructive editing and review of our manuscript se-2021-55. We carefully revised the manuscript on all levels, restructuring the sections results and discussion, improving the clarity of the manuscript and also improving the language. Also, we had a native speaker check the manuscript. Please find below the responses to all points raised. The editor comments are indicated in **black** and our replies are in red colour.

Abstract

The abstract should have a better balance of methodology (compilation of methodological steps used to obtain the images) and interpretation (only the 2 final sentences contain interpretation). The final sentence should be rephrased, because it is unclear how separation of the SW and NE Ligurian Basin is related to the promoted prolongation (do you mean southward continuation?) of the Alpine front.

We reworked this part of the abstract and added more detail to the results.

Old: "The shear-wave velocity results show a deepening of the Moho from 12 km at the southwestern basin centre to 20-25 km at the Ligurian coast in the northeast and over 30 km at the Provençal coast. We find no hint on mantle serpentinisation and no evidence for an Alpine slab, at least down to depths of 25 km. However, we see a separation of the southwestern and northeastern Ligurian Basin that coincides with the promoted prolongation of the Alpine front."

New: "*The group velocity and shear-wave velocity results compare well to existing large-scale studies that partly include the study area. Onshore France, we observe a high-velocity area beneath the Argentera Massif, roughly 10 km below sea level. Our results, in addition to existing seismic profiles, expand the knowledge on seismic velocities in the Ligurian Basin, adding spatial information. In accordance with existing seismic studies, our shear-wave velocity maps indicate a deepening of the Moho from 12 km at the southwestern basin centre to 20-25 km at the Ligurian coast in the northeast and over 30 km at the Provençal coast. We see a separation of the southwestern and northeastern Ligurian Basin. We do not observe high crustal* v_P/v_S *ratios as proxy for mantle serpentinisation in the southwestern Ligurian Bain.*"

L17: "Attentively"...what do you mean? You may mean "carefully".

Yes, we mean "carefully" and changed this accordingly.

Introduction

L34: Add more references, e.g., Dewey et al.1989, Sérrane 1999, Speranza et al. 2002, Schettino and Turco 2006, Le Breton et al. 2017 and many references therein.

We added more references and the prefix "e.g.", because many authors stated this before. Furthermore, we added a sentence referring to Le Breton et al. (2017).

L36: No way did it ever collide! It was stranded as a rift block (horst) between the Apennines and the European margin in S. France.

We agree and rephrased the sentence accordingly.

L38: That is a huge range; please add a sentence saying why.
We added a sentence that says that the Ligurian Sea broadens from the northeast to the southwest. Old: "Today, the Ligurian Sea is 150-225 km wide, while the basin itself has a width of 70-170 km (Dannowski et al., 2020)."
New: "*Today, the Ligurian Sea is 150-225 km wide, while the basin itself has a width of 70-170 km (Dannowski et al., 2020), broadening from the northeast to the southwest. The continental margin is narrow (10-20 km) and steep at the Ligurian coast (Finetti et al., 2005) and broader (20-50 km) on the Corsican side (e.g. Rollet et al., 2002).*"

L39: Reference? How do you know?
We added references to Rollet et al., 2002, Finetti et al., 2005, and Dannowski et al., 2020 (see above).

L43: See also Schettino & Turco 2006 and papers since
Added the Schettino & Turco, 2006, reference and also added "e.g." to make clear that these references to this generic statement are not complete.

L43: Neighbor is a noun, not a verb! Better to say "This area is located next to..."
We rephrased this sentence as suggested.

L45: Better "...seafloor spreading did not occur..." rephrased accordingly.

L45: "...that beneath the SW part of the basin..." rephrased accordingly.

L49: Where in Italy? The Alpine front on the European continent is in southern France. In Italy, the orogenic front is of the Apennines, not the Alps.
We totally agree and changed this to "France".

L52: also Kaestle et al. 2020
We cite different ambient noise studies. Kästle et al. (2020) is a review paper, comparing existing studies. Therefore, we prefer to cite the original work, which is Kästle et al. (2018).

Results
Figure 6: Refer to discussion of this interpretation in the text.
We removed the dashed line in Figure 6. The proposed offshore prolongation of the Alpine front is discussed in Sect. 5.4.

Figure 8: As in Fig. 6, please mention a discussion of this interpretation in the text. The reader will want to know if you have just connected the onshore trace of the Alpine front, or if you have independent seismological criteria for drawing the line.
The dashed line only represents the proposed offshore front, connecting the onshore trace of the Alpine front. We added the Rollet et al. (2002) citation to make this clearer.

Discussion
L317: Reference? e.g., Bigi et al. 1989
We moved the citation to Molinari et al., (2015a) to clarify: "*Similarly, the Po plain has an average sedimentary cover of 7-8 km (Molinari et al., 2015a) [...]*"

L320: To save this entire section (lines 320-340), make a figure that allows the reader to visibly compare the images from the different works. You could save a lot of text that way. As it stands, one must read your long text and imagine the images of the previous work or have them printed out and laid side-by-side.
This is a good idea, however this comparison of the onshore regions is not the main focus of our study. We focus on the Ligurian Sea, where the other studies have only little resolution. We compare our onshore results to document the robustness of our tomography and inversion images. To make it easier to follow the comparison, we added figure numbers of the compared works in the text (e.g.: "*The large-scale structures also compare nicely to the results of Kästle et al. (2018, their Fig. 9) and Lu et al. (2018, their Fig. 7).*").

L352: The real reason might be the exhumation of dense upper mantle rock at or near the basin axis.
We rephrased these sentences.
Old: "We deduce that for fast areas along the basin axis, due to the thinning of continental crust, the velocity gradient is stronger than away from the basin axis. This would lead to a higher S-wave velocity near the basin axis."
New: "*We deduce that for fast areas along the basin axis, the velocity gradient is stronger than away from the basin axis. This is probably caused by the thinning of continental crust (Dannowski et al., 2020) and possible exhumation of denser lower crust and upper mantle rock (Gailler et al., 2009; Jolivet et al., 2015) observed further southwest. Both scenarios would lead to a higher S-wave velocity near the basin axis.*"

L375: "poor" instead of "sparce"
We changed the word accordingly..

L393: and that the mantle is closer to the surface.
This is true for the southwestern basin. For shallow layers in the northeastern basin, we link the increased v_S (compared to the southwest) to thinner sediments and therefore to shallower bedrock. No changes were made in the manuscript.

L407: The exact location of the rotation pole of Corsica is a matter of debate and I would quote more than just one recent reference, unless you state good reasons to quote only Gattacceca et al. 2007). For example, see Seton et al. 2012, https://doi.org/10.1016/j.earscirev.2012.03.002
Seton et al. (2012) state that they base their reconstruction on Speranza et al. (2002). Therefore, we added the citation of Speranza et al. (2002). Speranza et al. (2002) use the same present-day coordinates as Gattacceca et al. (2007).

L414: If there has been even limited spreading in the Liguria Sea, then I would not expect the Alpine front to be continuous across this sea.
As Dannowski et al. (2020) state that a spreading center would be located further to the southwest of their profile, we assume no spreading this far northeast. Therefore, an offshore front could be detectable in the crust. No changes were made to the manuscript.

L415: Why beneath the crust? If the crust is merely attenuated, then the Alpine front (an Oligo-Miocene structure) would also be attenuated and may in fact be exposed throughout the crust and reach the seafloor.
We changed the whole section and took this into account. See comment on L421.

L416: subperpendicular.... This sentence was deleted while rewriting section 5.4 (“Alpine front”).

L417: I would only expect an anomaly if the front juxtaposes very different types of rock. If not, then the front will not be imaged.
This sentence was also deleted.

L418: at high angles.... This sentence was also deleted.

L420: Please state where! This sentence was also deleted.

L421: There is a flaw in the argumentation here, because you implicitly equate the Alpine Front with a slab. The two are not the same. The front is merely the surface expression of the furthest (most external) and may have little if anything to do with a slab. The slab is the expression of subduction, but the expression of subduction at the surface is a suture (the occurrence of ophiolites in the mountain belt). This section needs fixing.
Thank you for pointing this out. We investigate the proposed offshore prolongation of the Alpine front, as proposed by Rollet et al. (2002). It might be detectable in the crust, existing seismic data and our results do not show evidence of it, though. We rewrote the whole section 5.4 accordingly: *“Rollet et al. (2002) raised the question of an offshore prolongation of the Alpine front that can be observed onshore France and onshore Corsica. Rollet et al. (2002) suggested the Alpine front to separate the southwestern and northeastern parts of the Ligurian Basin. This proposed front is roughly located at the separation of the northeastern and southwestern crustal domains that we observe in our data (illustrated by the dashed line in Fig. 8e). However, the location and even existence of such a prolongation of the Alpine front beneath the Ligurian sea is not yet resolved.*
As mentioned, the seismic records indicate no spreading this far northeast in the basin. Therefore, the proposed offshore Alpine front could be detectable in the crust. Dannowski et al. (2020) observe a gradual thickening of the continental crust towards the northeastern Ligurian Basin. They do not need the sharp step that Makris et al. (1999) introduced between Corsica and the Liguro-Provencal coast to explain the free-air anomaly derived by Sandwell et al. (2014). Our spatial shear-wave velocity data also supports that interpretation. We do not observe a sharp lateral boundary but also observe a gradual change of the velocity layers that fits the model of Dannowski et al. (2020). With the given resolution, an offshore prolongation of the Alpine front is not detectable.”

Author contributions
L465: Please write out all the names in your acknowledgements and avoid abbreviations (except for OBS). Abbreviations of names appear to devalue the contributions of the very people who stand behind the paper.
We changed that and avoided abbreviations.