Reply of the author on behalf of co-authors to anonymous referee #2 comments.

We really appreciate your detailed technical and syntax comments on our study. They will help to improve the manuscript of our research mainly in two directions. On the one hand, it improves in completeness and clarity with the inclusion of additional information in the description of the method. On the other hand, it gains in richness and accuracy by explaining better the limits of the results.

We have written each answer followed by the re-phrased text (between quotation marks) just below to each comment written in bold.

Interactive comment on "A 3-D shear velocity model of the southern North America and the Caribbean plates from ambient noise and earthquake tomography" by B. Gaite et al.

Anonymous Referee #2

Received and published: 2 December 2014

This paper investigates the 3-D shear velocity structure of the southern North America and Central America using both ambient noise tomography and surface wave tomography.

To better constrain both the crust and upper mantle structures, we need highly accurate dispersion information in a wide frequency range that cannot readily be derived only from either ambient noise or surface waves. Thus, the joint use of the ambient noise and seismic surface waves, like the approached taken in this study, should be of help for the better understanding of the crust and uppermost mantle structures. The method and data used in this study are explained clearly, providing interesting results that represent apparent correlations with the tectonic features of this region. This paper is well written, providing interesting results of the velocity structure and some insightful discussion, although additional explanations and information are necessary in some parts as suggested below. Most of my comments are rather minor, and I recommend the acceptance of this paper with minor revision.

- Some major comments:

1. Page 2975 line 14-21

The current figure on the model resolution (Fig 4) is invisible. It is better to be displayed

in color. It may also be better to add equations for resolution kernels or refer to a

relevant reference(s).

Figure 4 now is displayed in color to show the resolution results.

In order to provide more information about the resolution computation, we have added the references of the method we use. We also have rewritten the description of the method to gain in clarity. The changed text is the following:

"These kernels help to provide accurate estimate of spatial resolution. To compute the spatial resolution we follow the method described by Barmin et al. (2001) with modifications of Levshin et al. (2005). Firstly, we construct a resolution kernel at each node of the model grid, which is a row of the resolution matrix. Secondly, we fit this kernel with a 2-D Gaussian function. Finally we compute the scalar spatial resolution as twice the standard deviation of the Gaussian."

As a result of these changes, we have added the following citation to the references:

Levshin, A. L., Barmin, M. P., Ritzwoller, M., and Trampert, J.: Minor-arc and major-arc global surface wave diffraction tomography, Phys. Earth Planet. Inter., 149, 205-223, 2005.

2. Page 2977 line 13: "3 velocity measurements"

What do you mean here by "3 measurements"? (Phase/group velocities at 3 discrete frequencies?) It is somewhat ambiguous. Give more clear explanations.

To be clearer, we have rewritten the paragraph as follows:

"To assure the inversion of high quality dispersion curves, we only invert dispersion curves with velocity measurements at more than 3 discrete frequencies. Doing this we avoid inverting nodes with high resolution at narrow frequency ranges."

3. Page 2978 line 12: "Inversion tests show that our Vs model is sensitive to 5km-thick layers"

Add the results of these tests.

We based the affirmation that the inversion resolution is to 5 km thick layers on tests with shallow layers. We observed that a 5-km thick layer depth was solved by the inversion, but three 2-km-thick layers into the first 6 km where not solved. This test was useful to check the limits of the inversion and its sensitiveness to the models obtained in areas with extended crust, like, for example, from the Gulf of California with a strong velocity contrast at shallow depths (e.g., ~8 km at 103ºW23ºN).

In order to answer the requirement of the referees and to confirm the resolution of the inversion we have computed new tests in other cases (e.g., to solve internal layers with different thickness). Figures 1 and 2 show these tests to check the sensitivity of our inversion to 1st layer thickness (Figure 1) and to the 2nd layer thickness (Figure 2). Tests in Figure 1 show that we are able to retrieve the depth of the first layer for layers from 2 to 10 km-thick, however, there is a trade-off with velocities and other layer depths. In the case of sensitiveness to the 2nd layer thickness (Figure 2) the trade-off between velocities and depths is clear and we do not recover the thickness and the velocity from the second layer. With these new tests we cannot state that our inversion has a resolution to 5-km-thick layers, but only that the inversion is sensitive to 5 km depth velocity contrasts.

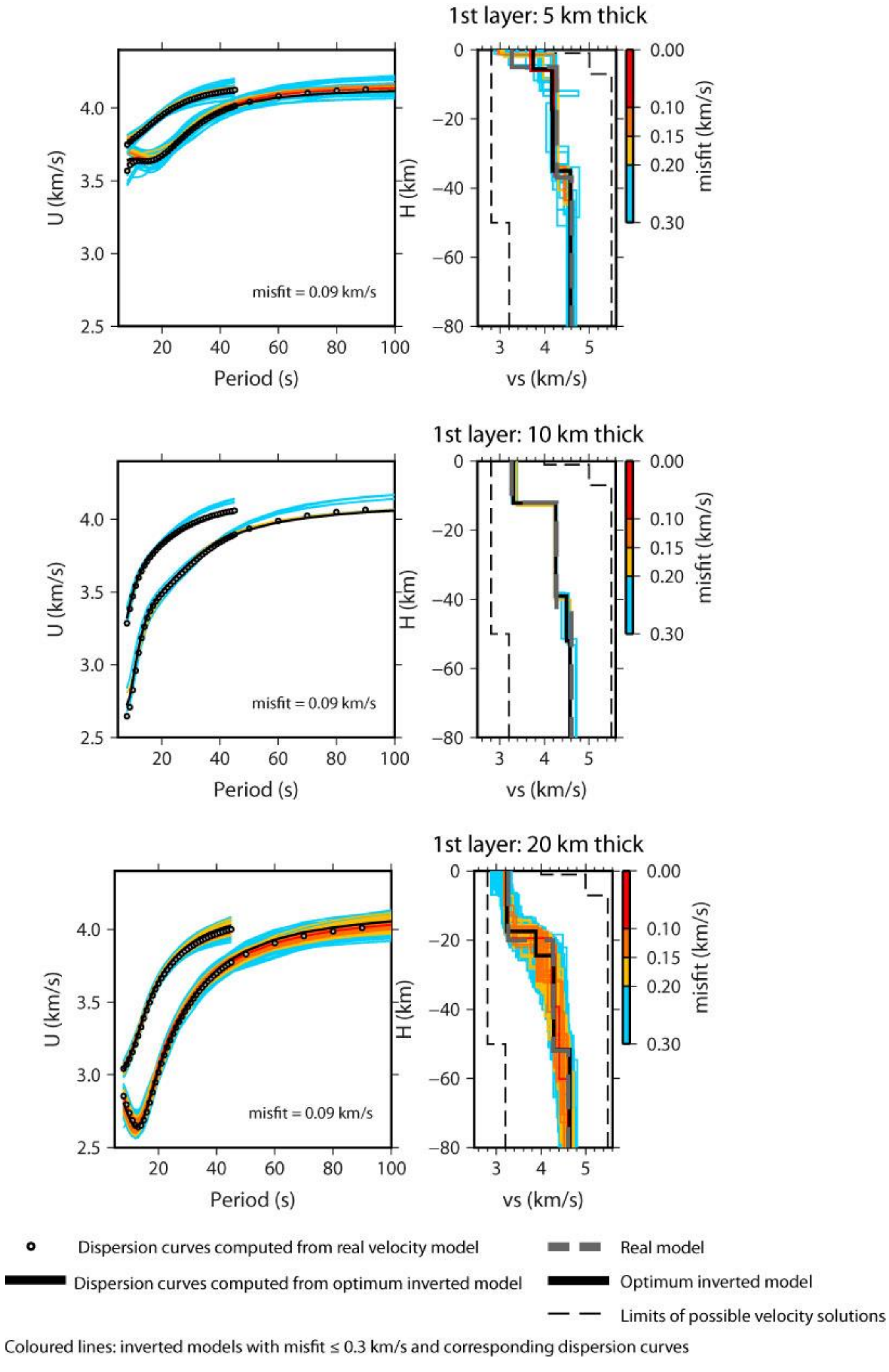

Figure 1: Tests of inversion sensitivity to the shallowest layer thickness.

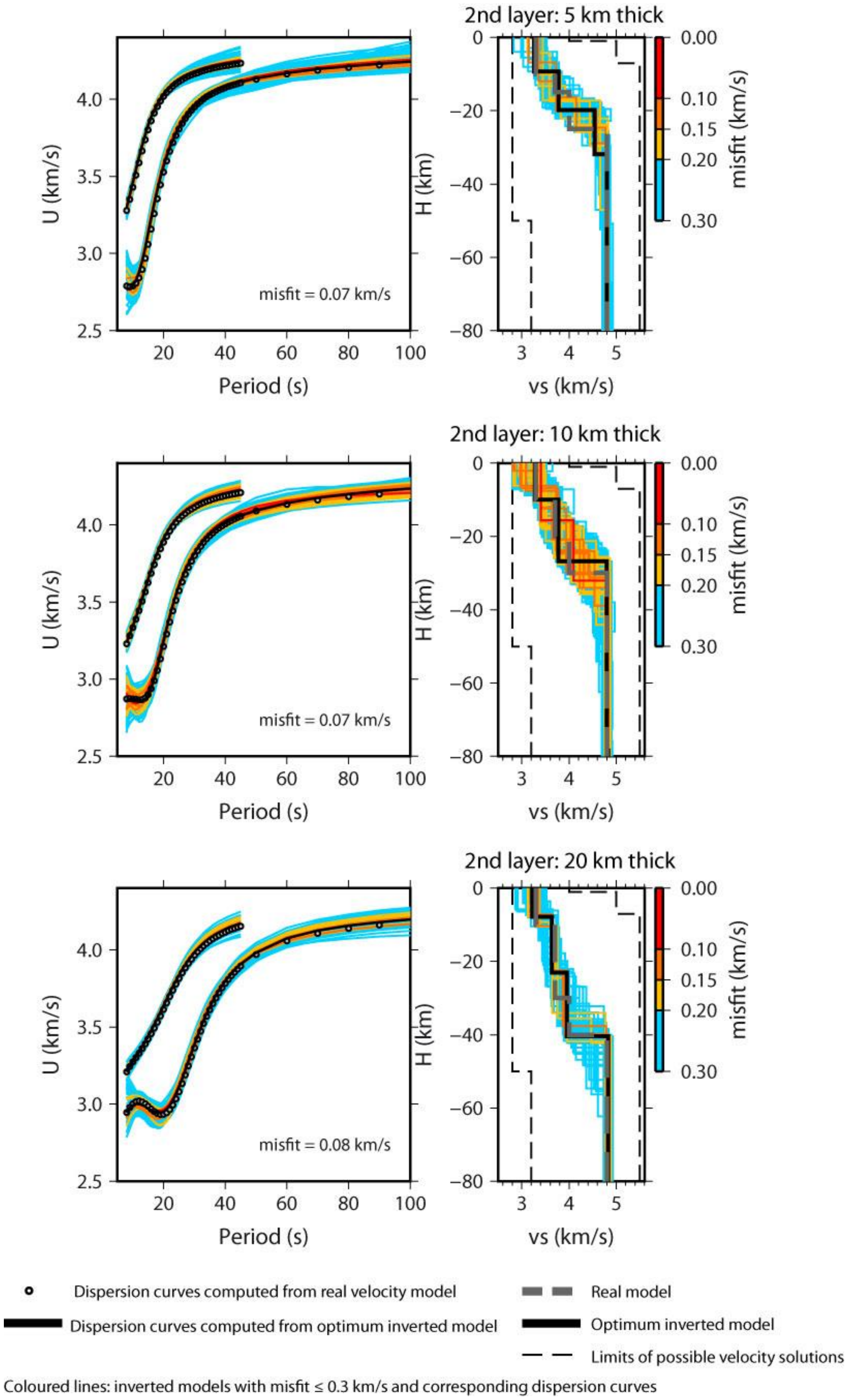

Figure 2: Tests of inversion sensitivity to the second layer thickness.

Considering these tests we have removed the affirmation (page 2978 line 13): "Inversion tests show that our v_S model is sensitive to 5 km thick layers."

And we have re-phrase the text (page 2980 line 22-24) as follows:

"Crustal thickness differences under SMOc and SMOr between the results of this study and previous studies are within the range of our vertical resolution."

4. Page 2981 line 3-5: ... in crustal thickness between ...

Why not show the Moho depth map in Fig 11?

The reason to not show the Moho depth map in Figure 11 is that surface waves are mainly sensitive to lateral than vertical changes of the seismic structure of the medium when propagating. Because of that, the Moho depth is not well constrained only from surface wave tomography.

5. Page 2982 line 16-21: "At 30 km depth . . . a narrow NNE high velocity area . . ."

This is an interesting feature if it is real, but this high velocity anomaly does not appear in the group velocity maps in Figs 3 and 6. Is there any possibility that this feature is an artifact due to the relatively sparse path coverage or lower resolution of this area in the ambient noise data? (e.g., Fig 6b shows that ANT cannot resolve this area.) Also, the authors have mentioned that the achieved horizontal resolution of their model is about 2 degrees, but this linear high velocity feature seems to be as narrow as 100 km or so. Can you really resolve it? Furthermore, as far as I see the phase and group velocity maps of Gaite et al. (2012), which is the original ANT models used in this study, I cannot see such linear high velocity anomalies. So, I strongly suspect that this is an artifact generated during the inversions for the local shear velocity structure. The interpretation of this feature should be made more carefully.

The elongated high shear-wave velocity observed at 30 km depth in the Gulf of Mexico is not displayed neither in ANT or earthquake tomography results. We only invert in this area dispersion curves from 20 s to longer periods. Therefore, the shallow crust of the inverted model is not well constrained. However, at 20 s period the two maximums of the Rayleigh wave sensitivity kernels are around 15 and 20 km for group velocity and around 25 and 30 km for phase velocity. Taking this into account, we can consider that 30 km depth is well constrained with our input data. At 20 s some of the dispersion curves come from earthquake tomography because the low resolution of ANT in the middle of the Gulf of Mexico (Fig. 10 from Gaite et al., 2012). The Gulf of Mexico is well covered and with a variety of azimuths from earthquake tomography path distribution at 20 s (Fig. 2). From 30 s to longer periods input data comes from ANT and earthquake tomography.

The narrow width of this feature corresponds to the inversion of isolated nodes. This can be thought as an outlier model, but is surprising the continuity of the high velocity feature and the correspondence with different geophysical research results.

Considering the arguments exposed, we agree with the comment of the referee about interpreting this feature more carefully. In order to do this, we have rephrased the text as follows. We also have added a citation to a recent study that is related with our results.

> "At 30 km depth our results show a narrow NNE high velocity area (Fig. 9d) indicating a thinner crust than at the rest of the GOM. This high velocity feature should be interpreted with caution because the lack of path coverage at periods shorter than 20 s to constrain the uppermost crust and the large misfits in western GOM (Fig. 7). This feature might be related with the gulf opening during the Jurassic, since it matches with the youngest crust in the gulf (Müller et al., 2008) and roughly with recent gravity results of Sandwell et al. (2014). However, its orientation does not coincide with the ENE direction of the extinct ridge proposed by Pindell and Kennan (2009), the results by Swayer et al. (1991), and with the GOM largest gravity anomalies by Bird et al. (2005)."

We have added the corresponding reference:

Sandwell, D.T., Müller, R.D., Smith, W. H. F., Garcia, E., Francis, R.: New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure, Science, 346, 6205, 65-67, doi: 10.1126/science.1258213, 2014.

- Minor comments / suggestions for corrections:

6. Page 2975 line11: ". . . frequency-dependent sensitivity of surface waves"

How did the authors determine the width of the Gaussian smoothing across the path?

Additional explanations will be helpful.

We try to minimize the penalty function (Eq. 15 of Barmin et al., 2001) using a set of observed travel-time residuals relative to a reference model (in our case the mean velocity of the inversion) for different paths and at each period,. The second term of the penalty function is the spatial smoothing condition and it is weighted by the damping parameter α. The minimization of this term ensures that the inverted model approximates to a smoothed version of the model. The smoothing kernel for an isotropic model (*S_0)* depends on the smoothing parameter *σ* as follows (eq. 16 of Barmin et al., 2001 with k =0 for a purely isotropic model):

$$S_0(r,r')=K_{00}\exp\left(-\left|r-r'\right|^2 \big/ 2\sigma_0^2\right)$$

where, $\int_S S_0(r,r')dr'=1$, S is the , r and r' are surface position vectors and σ_0 is the spatial smoothing width or correlation length. In our study we have named "σ" to "σ_0", as we are computing an isotropic model.

In our inversion we determine the width of the Gaussian smoothing σ across the path trying a wide range of parameters (from 100 to 500) combined with different values of the other damping parameters α (from 650 to 2000) and β (from 1 to 100). We compare all the inverted models visually at different periods. We select the damping parameter values as a compromise between good data fit, stability of the features of the computed models and small model roughness. We make the search of damping parameters twice. Firstly with all data, and secondly only with data whose residuals are lesser than 3 times the time-residual standard deviation to avoid outliers.

We have rephrased the description of the inversion to explain the meaning of the damping parameters and clarify our selection (page 2974 line 15-25):

> "We invert these group velocity measurements to obtain a 2-D group velocity models by the method of Barmin et al. (2001). This inversion procedure tries to minimize a penalty function (Eq. 15 of Barmin et al., 2001) that depends on three damping parameters. These parameters are: α the data misfit damping, σ the width of the Gaussian Kernel and β the penalty parameter to low path density regions. We perform a large number of inversions varying the value of the damping parameters. We test α values from 650 to 2000 combined with different values of σ (from 100 to 500) and β (from 1 to 100). The final values used are selected as a compromise between good data fit, stability of the features of the computed models and small model roughness. We follow a two-step tomographic inversion similar as the one described in Gaite et al. (2012). At each step we select the damping parameters. In the first step, we invert all the dispersion curves to obtain dispersion maps with damping

values α=2000, σ =400 and β =1. In the second one, we remove outliers and re-invert the remaining data, in this case with α=1000, σ =500 and β =1. We mark an observation as outlier when:

$$\delta t > 3(SD) \tag{1}$$

where δt is the travel time residual, and SD is the standard deviation."

We also have rephrased the text in page 2075 line 10-13 to gain in clarity:

"The tomographic inversion used is similar to a Gaussian beam method and considers propagation of 'fat' rays along the great circle. Following this, the frequency-dependent spatial sensitivity of the surface waves is described by Gaussian lateral sensitivity kernels."

The text that follows this paragraph has also been changed to answer the major comment number 1 of this referee (see major comment 1 for further details).

7. Page 2975 line 17: ". . . lower or equal than" => ". . . lower than or equal to"

We have changed this text as follows taking into account also the comments of another anonymous referee:

"lesser than or equal to"

8. Page 2975 section 3.2:

Add some more explanations on the ambient noise tomography, e.g., stations info,

spatial coverage and resolution, etc.

We have added the following explanations referring to ambient noise tomography in section 3.2.:

"To compute ANT we used 2 years and a half of continuous vertical component seismic records from the same stations used in this study. Firstly, we computed 1-day long ambient noise cross-correlations between each station pair and stacked them along their available time period. Secondly, we measured phase and group velocity of the fundamental mode Rayleigh wave. Finally, we inverted the dispersion curves to get phase and group velocity maps with the same method used for earthquake records on this study. The path coverage at periods shorter than 20 s is mostly limited to mainland North America that is well covered from 10s."

9. Page2976 line 16: ". . . due in part to"=> ". . . due in part to the fact that"

We have changed it.

10. Page 2976 line 18: use to be => are

We have changed it.

11. Page 2977 line 5 and 9: Where => where

We have changed it.

12. Page 2977 line 20: . . . shows the misfit geographical distribution. => . . . shows the geographical distribution of the misfit.

We have changed it as follows:

"shows the geographical distribution of the model misfit"

13. Page 2978 line 21-22: "... their different origin and tectonic evolution."

Add relevant references.

We have added relevant references and re-phrased the text as follows:

> "This seismological lower crustal difference agrees with their different origin and tectonic evolution proposed by several studies from geologic evidences and paleotectonic reconstructions (e.g., Burke 1988; Rogers et al, 2007; Pindell and Kenan, 2009)."

We have added the following references:

Burke, K.: Tectonic evolution of the Caribbean, Ann. Rev. Earth Planet. Sci., 16, 201-230, 1988.

Rogers, R.D, Mann, P., Emmet, P.A., Tectonic terraines of the Chortis block based on integration of regional aeromegnetic and geologic data, The Geol. Soc. of Am., Special Paper, 428, 65-88, doi: 10.1130/2007.2428(04), 2007.

14. Page 2978 line 25: ... North America => ... North American

We have changed it.

15. Page 2980 line 5: ... the western of ... => ... the west of ...

We have changed it.

16. Page 2981, line 15: Jalisco block

A label for this block is missing in the maps.

We have labeled Jalisco Block as “JB” in Figure 9c and added “JB Jalisco Block;” to Figure 9 caption.

17. Page 2981, line 17: North America plate => North American plate

It has been changed.

18. Page 2982, line 25: ... Veracruz basin

A label is missing in the maps.

We have labeled Veracruz Basin in Figure 9c as “VeB” and added “VeB Veracruz Basin;” to Figure 9 caption.

Besides, we have found a typo and we have changed the text (Pag. 2982, Line 25) “Fig. 9d” by “Fig. 9c”.

19. Page 2983 line 4: high number => large number

We have changed it.

20. Page 2983 line5: ... on western => in the western

We have changed it

21. Page 2983 line 6: ... on central-east => in the central-east

We have changed it.

22. Page 2983 lines18-19: ... coincide with a lack of active volcanism

It may be better to plot the locations of active volcanoes in Fig 11 or in a relevant figure.

We have plotted the active volcanoes in Figure 11c. We have added to the caption of Figure 11 the following text:

”(c) Map with the location of volcanoes (red triangles) exhibiting current unrest or with eruptions during the Holocene (Siebert and Simkin, 2002).”

And we have added the corresponding reference:

“Siebert, L., and Simkin, T. Volcanoes of the world: an illustrated catalog of Holocene volcanoes and their eruptions, http://www.volcano.si.edu (last accessed December 17, 2014), 2002.”

23. Page 2984 line 13: ... actual => ... present

We have changed it.

24. Page 2984 line 14: ... showed on => ... shown in

We have changed it.

25. Page 2984 line 15-16: ... seismic features => ... seismological features

We have changed it.

Interactive comment on Solid Earth Discuss., 6, 2971, 2014.