<u>Reply to</u> *Interactive comment of Franjo Šumanovac (Referee)* on "Estimation of near-surface attenuation in the tectonically complex contact area of the Northwestern External Dinarides and the Adriatic foreland" *by* S. Markušić et al.

The authors wish to thank Franjo Šumanovac for the very constructive remarks. Below are listed the answers (in italic) to the reviewer's comments/suggestions.

The main problem of the manuscript is that there is no clear connection between geophysical and geological data, so geological interpretation should be improved. For example, the sentence at lines 29-30 (page 7) should be replaced with more detailed discussion, especially "the mentioned lithospheric decoupling".

The last paragraph in the Chapter 4 is replaced with: "Belinić et al (2018) indicated the presence of a boundary area between the thicker lithosphere under the Northwestern External Dinarides and the thinned lithosphere under the Lika region that is recognized by Šumanovac et al (2017) as the ND-anomaly (North Dinaridic fast velocity anomaly, discovered by the teleseismic tomography). Interestingly, the ND-anomaly in the area of Gorski kotar (e.g., Šumanovac and Dudjak, 2016; Šumanovac et al., 2017) partly fit the observed kappa decrease. It could be speculated that the ND-anomaly may be related to the lithospheric transform zone striking transversally to the Dinarides below the Kvarner area (Korbar, 2009), delineating the boundary between the NW and SE Adriatic microplate fragments recognized by Oldow et al. (2002). If that is the case, the differential movements of the two Adria fragments is accommodating along crustal faults that evidently have not fully dissected the thin-skinned tectonic cover, given that there is more or less continuous but bent fold-and-thrust belt in the NW part of the External Dinarides (Placer et al., 2010). Thus, it may be speculated that the rather complex tectonic structure and North Dinaric fast velocity anomaly (ND-anomaly) identified on the teleseismic tomography for the wider Kvarner region is superimposed on the lithospheric decoupling of the NW and SE fragments of the Adriatic microplate."

Also, as a comment to reviewer – It is possible that the attenuation in the wider Rijeka and Kvarner area is due to the highly cracked rocks in the upper part of the carbonate sequence (Cretaceous-Paleogene) that is intensely deformed in the fold-and-thrust thin-skin tectonic cover, and in the area of southern Istria (where carbonates are much less cracked) the attenuation is actually possible because of the very shallow Moho?! So, we think that, for now, the only possible geological explanation for attenuation is the combination of the two geological causes of attenuation: the cracked rocks at the intersection of the Dinaric and Kvarner faults and shallow Moho in southern Istria, although this broad zone of attenuation is generally present along the possible wide cross-section of the Kvarner (possible lithospheric) fault that separates NW and SE Adria.

Last two sentences in the Abstract (lines 16-19, page 1) are too general and should be replaced with concrete statements.

Last two sentences in the Abstract are replaced with: "The complex pattern of longitudinal and transversal major late-orogenic fault zones dissecting early-orogenic thin-skinned tectonic cover *in the Kvarner area, and the shallow depth to the Moho in the Adriatic foreland (southern Istria) are probably responsible for significant part of wave attenuation and for the anisotropy of attenuation. Regional near-surface attenuation distribution and modelled macroseismic fields point to conclusion that attenuation properties of rocks in the Northwestern External Dinarides are far from isotropic and the most likely anisotropy sources are the preferential orientations of cracks and fractures under the local tectonic stress field, trapping of waves along major faults (waveguides), and/or attenuation within the fault zones. These results are important for gaining further insight into the attenuation of near-surface crust layers in the Northwestern External Dinarides and the associated Adriatic foreland, as well as in similar geotectonic settings."*

"The most important seismic data were recorded during the 1960s and 1970s." I do not agree with this statement! And what is with the results of the ALP 2002 and ALPASS-DIPS projects which are published in many references?

The mentioned sentence (and the previous one) are replaced with: "Upper crustal geological structures are the result of tectonic movements in the deeper parts of the lithosphere which in turn feature deformations of the supposed basement of sediments and Mohorovičić discontinuity, provided by gravimetric and seismic data (Aljinović and Blašković, 1981; Aljinović et al., 1984; Šumanovac et al., 2009; Šumanovac, 2010), that are the deep seismic data from the area recorded during the 1960s, 1970s, and within the ALPASS-DIPS projects (ALP 2002, Šumanovac et al., 2009)."

"The distribution of seismic intensity is generally influenced by major geological and tectonic features and, on a smaller scale, by local geological conditions, such as type of surface soil, surface-to bedrock soil structure in sedimentary basins and depth of the saturated zone. The distribution of macroseismic intensities, when studied through isoseismals, usually reveals the main tectonic features of the felt areas. Furthermore, by studying the macroseismic field, the main characteristics of near-surface 5 attenuation can be defined." General claims, only. Please, rewrite.

The whole Chapter 5 is rewritten (and the Figures 7-12 are all compiled into one, Figure 8): "Spatial distribution of macroseismic intensities is generally influenced by major geological and tectonic features (Bottari et al., 1984) and, on a smaller scale, by local geological conditions, such as the surface soil, the surface-to bedrock soil structure in sedimentary basins and the depth of the saturated zone (Seed and Schnabel, 1972). Also, the distribution of macroseismic intensities may reveals the large tectonic features (Besane et al., 1997; Bottari et al., 1984; Hashida et al., 1988; Lekkas, 2001). Study of the macroseismic field can give information about near-surface attenuation of the seismic waves in frequency range of 0.4-13 Hz (Sokolov, 2002).

In this paper, are displayed macroseismic fields for the chosen set of six earthquakes (Table 4) with epicenters located in the study area. Earthquakes occurred in the period 1870 – 2013, and for majority of them macroseismic intensities are more reliable source of information than instrumental data. Magnitude range of chosen events is 4.7 – 5.8. The strongest earthquake was on March 12, 1916 near Grižane. It was very strong event with maximum intensity I_{max} = VIII °MSK. Macroseismic fields (the synthetic isoseismals) are modelled using the SAF (Strong Attenuation at Faults zones) model (Sović and Šariri, 2016) (Figure 8). This model assumes that the active faults

attenuate macroseismic intensities, hence the most important input data is a map of the active faults. For that purpose, the information on faults were taken from the Map of Active Faults in Croatia (Ivančić et al., 2006). The synthetic isoseismals (Figure 8) are compared with the empirical ones by using image moments analysis method (Sović et al, 2013; 2016; Sović and Šariri, 2018). The results show that synthetic isoseismals are 31.4% better approximation of empirical macroseismic field (Sović and Šariri, 2018) than circular model (Kövesligethy, 1907). From these results it is evident that fault zones are responsible for significant part of wave attenuation and for the anisotropy of attenuation. Synthetic isoseismals are similar but not identical to the empirical ones because the wave attenuation at fault zones is only one of the mechanisms which modify macroseismic field. The shape of macroseismic field also depends on the other factors like amplification of the shallow sedimentary layers (Seed et al., 1972), topography (Geli et al., 1988; Buech et al., 2010) and deamplification due to nonlinear effects (Beresnev and Wen, 1996). Intensity amplification by site effects can be seen on the Figure 8 (cases b-f), where empirical intensities in deep soil zones NE from epicentral areas (river valleys in Gorski Kotar, Slovenia and Pannonian basin) are greater than synthetic ones. Similarity of synthetic and empirical isoseismals in areas with negligible site effects means that the strong attenuation of macroseismic intensity at fault zones is correct assumption.
Attenuation of macroseismic intensity is consequence of attenuation of seismic waves caused by high level of fracturing in fault zones (Gentili and Franceschina, 2011), and temporary decrease of shear modulus in fault core under the influence of incoming waves (Johnson and Jia, 2005), thus, the attenuation of macroseismic field can be linked to the parameter kappa by the same physical mechanisms."

I do not agree with the chapter 6 "Estimation of near surface attenuation - a summary and some conclusions". This chapter should be completely rewritten and the conclusions should only be kept, which means the main results of the work should be clearly emphasized. I also suggest to create the chapter Discussion with detailed interpretation of the data and explanations about the geological meaning of the geophysical results. The chapter Macroseismic field can be also included in this chapter.
Authors believe that this concept of the last chapters is appropriate for the proposed manuscript. Namely, each chapter ends with a kind of discussion, so in the last chapter all this is summarized and the conclusions are specified. Only the last bullet (of conclusions) is added: "The attenuation properties of rocks in the Northwestern External Dinarides are far from isotropic. The most likely anisotropy sources are the preferential orientations of cracks and fractures under the local tectonic stress field, trapping of waves along major faults (waveguides), and/or attenuation within the fault zones."

There are also several incorrect or imprecise quotations.
The all marked quotations are corrected according to the reviewer's suggestions.