Seismology in Croatia, 2015–2018

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During the period 2015–2018, most of the research in seismology was done in the frameworks of the VELEBIT project (funded by the Croatian Science Foundation), as well as AlpArray and AlpArray-CASE projects that were executed in cooperation with ETH, Switzerland (Hetenyi et al., 2018; Molinari et al., 2018). The seismic network density has been considerably increased, as 18

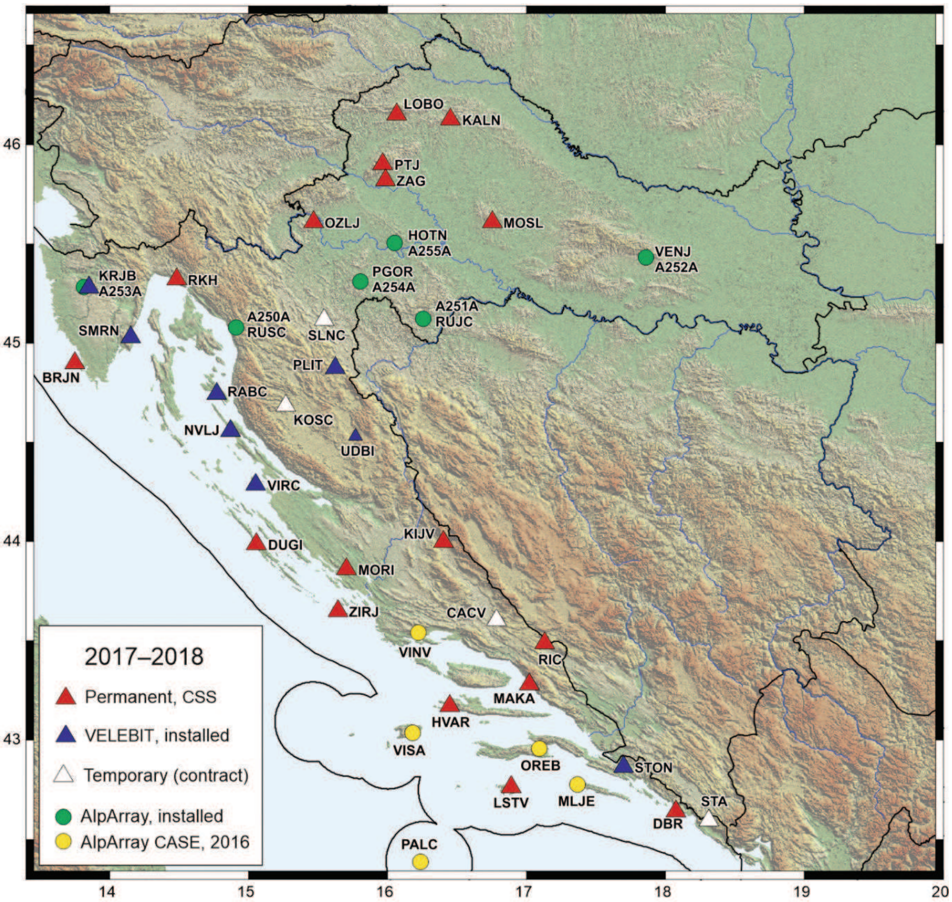

Figure 1. Seismic network in Croatia in the period 2017–2018.

temporary BB-stations were deployed and maintained from project funds (see Fig. 1).

The VELEBIT project was focused around the greater region of Mt. Velebit, dealing with multidisciplinary research of its seismicity (including historical seismicity), earthquake relocation, tectonics, etc. In particular, four important historical events in the Bakar and Rijeka areas were studied together with the Slovenian colleagues, thus adding valuable information on historical seismicity of the area (Fig. 2; Herak et al., 2017; 2018). Macroseismology was also the topic of papers by Sović and Šariri (2016), Markušić et al. (2017) and Tertulliani et al. (2018).

The work on attenuation was primarily concentrated on the area of Central External Dinarides (CED). Dasović et al. (2015) analysed the coda, P-wave and S-wave attenuation there, concluding that the body-wave attenuation is strongly frequency-dependent and comparatively strong. Majstorović et al. (2017) attempted to separate the contribution of scattering and intrinsic attenuation to observed total attenuation in the CED (Fig. 3). A study of κ-parameter controlling the high-frequency strong-motion attenuation was done by Stanko et al. (2017) for a set of Croatian stations.

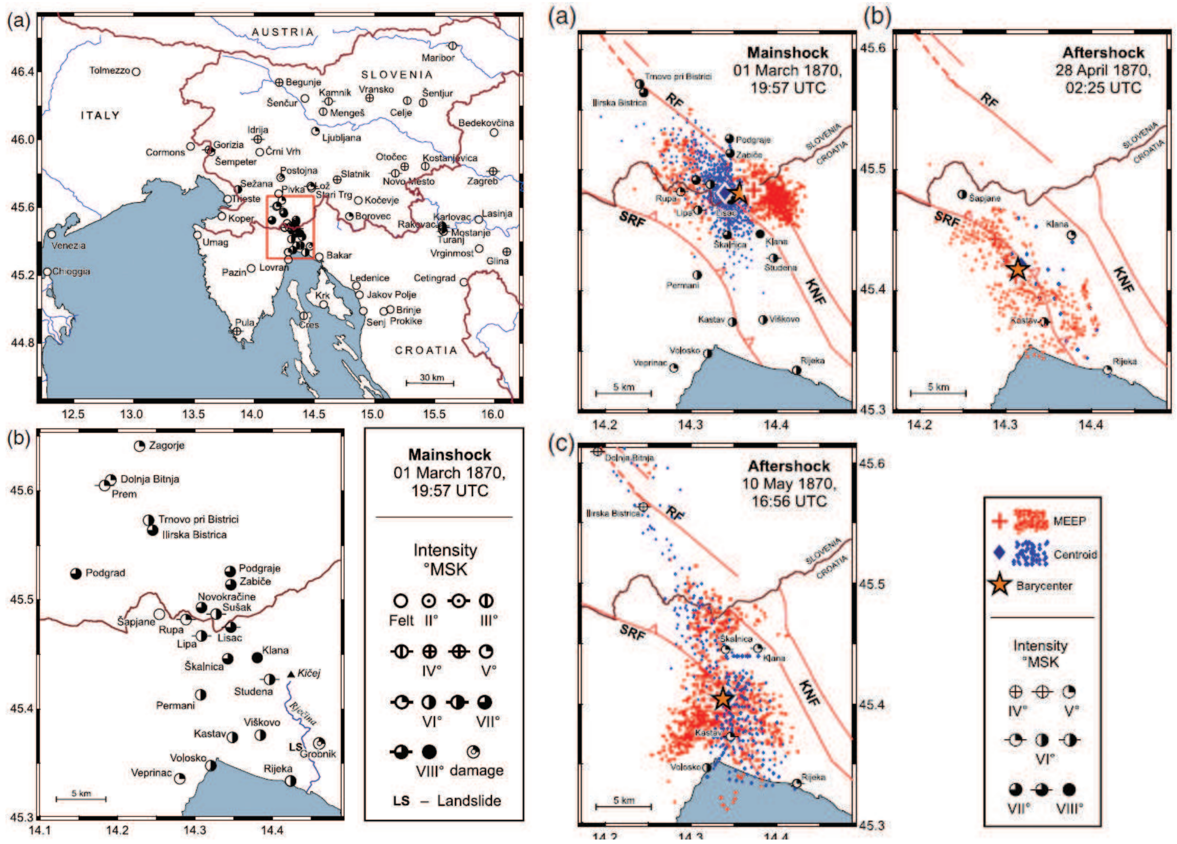

Figure 2. Macroseismic analyses of the Klana eartqhuake of 1870. *Left:* assigned intensities. *Right:* determination of the macroseismic epicentre (from Herak et al., 2018).

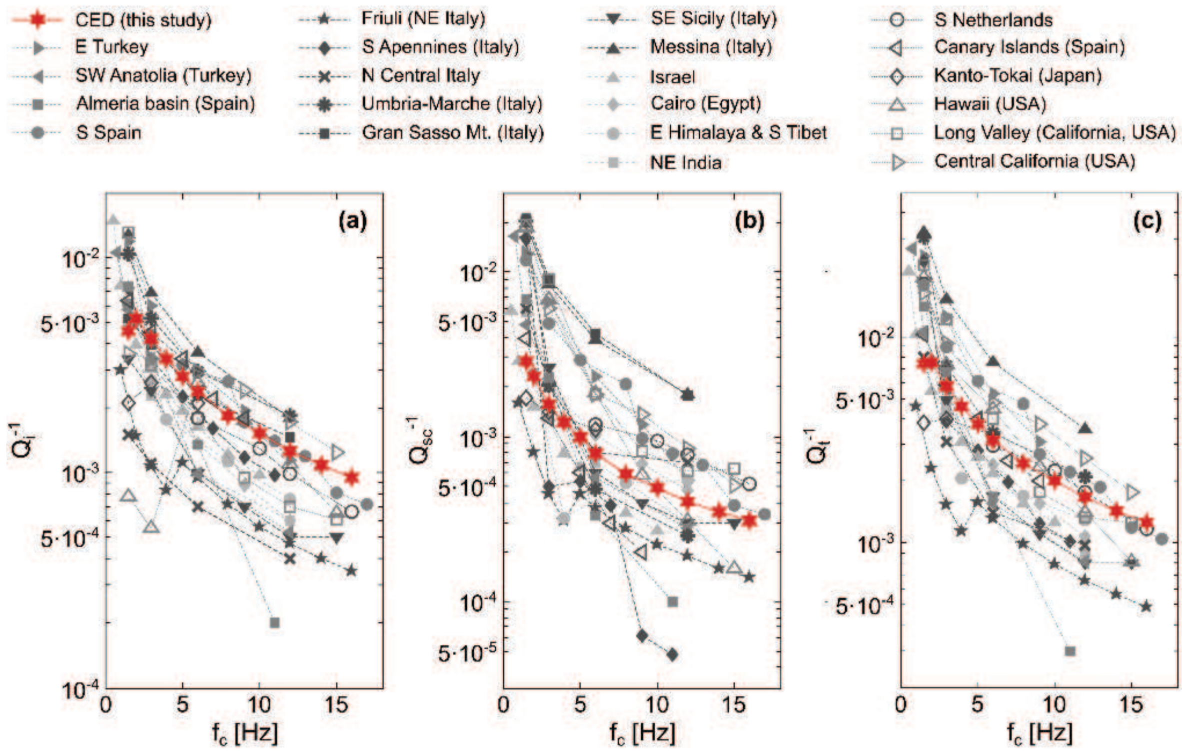

Figure 3. Intrinsic (*a*), scattering (*b*) and total (*c*) attenuation in the Central External Dinarides (CED), compared to a number of regions worldwide (from Majstorović et al., 2017).

The series of papers on seismicity of Croatia was continued by the review of seismicity in the period 2006–2015 by Ivančić et al. (2018). In the framework of the BSHAP-2 project, Markušić et al. (2016) described the updated and unified earthquake catalogue for the Western Balkan Region (WBR). Šalić et al. (2017) presented the BSHAP project Ground Motion Database, whereas Mihaljević et al. (2017) proposed the seismic source model for the WBR.

SKS-splitting measurements and their interpretation was the topic of the paper by Subašić et al. (2017) (Fig. 4, left), who analysed seismograms from stations in the Central External Dinarides concluding that the fast axis is oriented perpendicularly to the strike of the Dinarides. Dettmer et al. (2015) presented direct-seismogram inversion technique to map receiver-side structure by treating source signal as a vector of unknown parameters in a Bayesian framework. Belinić and Markušić (2017) wrote about empirical criteria for earthquake location accuracy. Belinić et al. (2018) used S-receiver functions to infer the lithospheric thickness under the Dinarides area, detecting three distinct domains (see Fig. 4, right). Several other seismological investigations were conducted during this period focusing on the transition zone between Dinarides and Pannonian basin. Šumanovac and Dudjak (2016) employed inversion of the teleseismic P-wave travel times to map deep reaching high velocity anomaly in the NW Dinarides. Šumanovac et al. (2017) extended this investigation to the central-southern portion of the Dinarides and found similar deep reaching high velocity

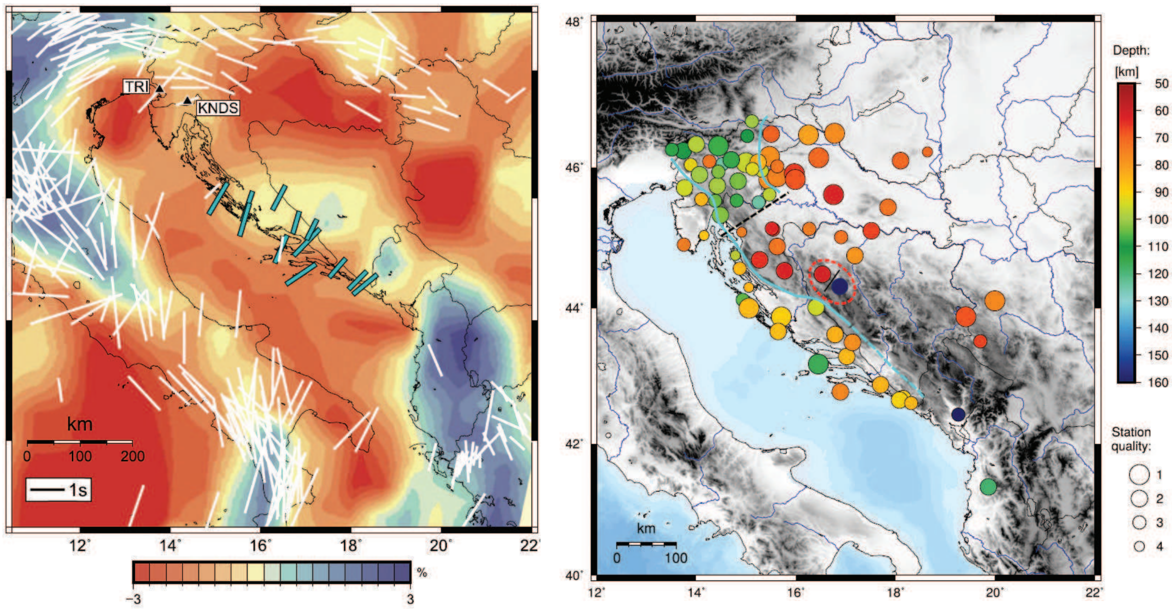

Figure 4. *Left*: Directions of fast axes from SKS-splitting (Subašić et al., 2017). *Right*: Lithospheric thickness estimated by S-receiver function analyses (Belinić et al., 2018).

body under this region too (Fig. 5). In contrast to these deep investigations Šumanovac et al. (2016) used various seismic methods to map crustal structure in the northern Dinarides-southwestern Pannonian basin transition zone.

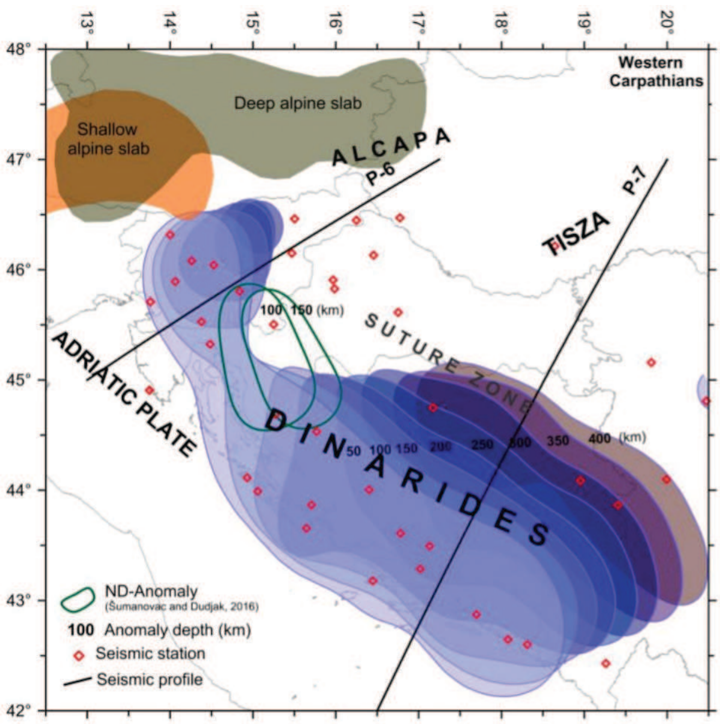

Figure 5. Overview display of the fast anomaly in the Dinarides area from Šumanovac et al. (2017).

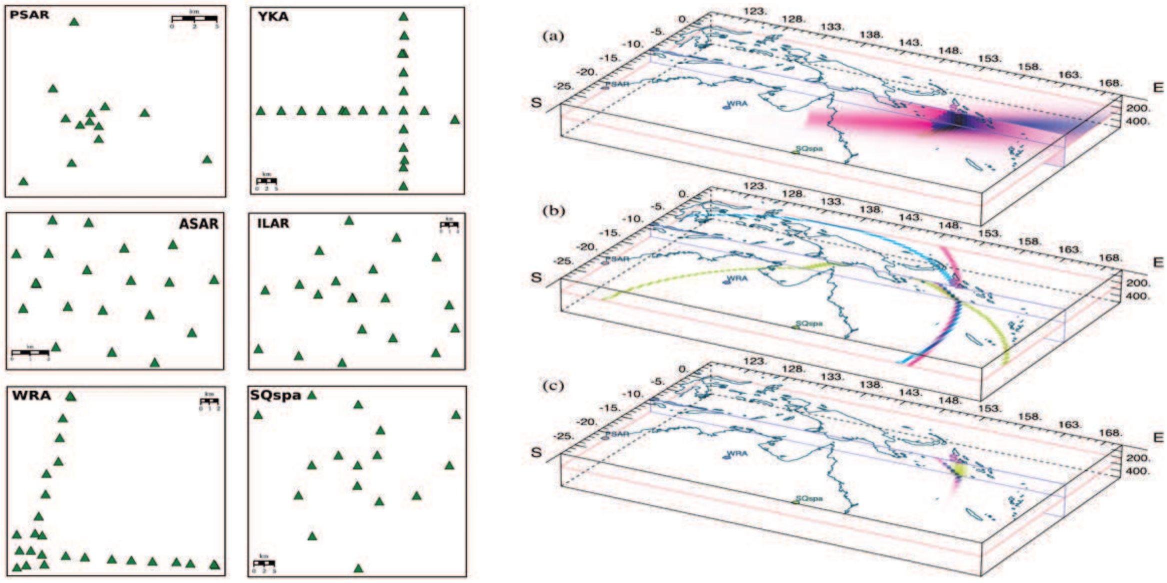

Figure 6. *Left*: Configuration of the six arrays used for multiple array analysis (Kennett et al., 2015; Stipčević et al., 2017). *Right*: Illustration of the interaction of spatial constraints for multiple arrays target (Stipčević et al., 2017).

Kennett et al. (2015) used spiral shaped seismic arrays to enhance the resolution in comparison with more traditionally shaped seismic array (Fig. 6, left). Stipčević et al. (2017) published a paper on the simultaneous use of multiple seismic arrays (Fig. 6, right).

A series of papers (Lee et al., 2015; Lee et al., 2017a-c) were devoted to seismic hazard assessment in the Balkan countries. Local soil amplification for a site in northern Croatia was analysed by Stanko et al. (2017a,b).

The Seismological Survey of Croatia is in charge of maintaining the permanent network, archiving of seismograms, regular compilation of the Croatian Earthquake Catalogue (CEC), data exchange and interaction with Civil Protection authorities. Their duties were duly executed during the reporting period. In particular, the CEC is now finalized up to the end of 2017 and contains about 120,000 records (Fig. 7). Current rate of event inclusion into the catalogue exceeds 10,000 earthquakes/year.

Fault-plane solutions (FPS) using first-motion polarity data are computed for all events in the Croatian neighbourhood, roughly for magnitudes exceeding 3.5. The corresponding data-base of FPS now contains 278 solutions as shown in Fig. 7.

Current research includes efforts to map the mantle transition zone and to reassess the Moho depth beneath the Dinarides using newly collected data and P-receiver functions. Study of anisotropy of attenuation properties is also under way, as well as a continuation of SKS-splitting analyses using data from other stations. It is also planned to perform a thorough relocation of the instrumental

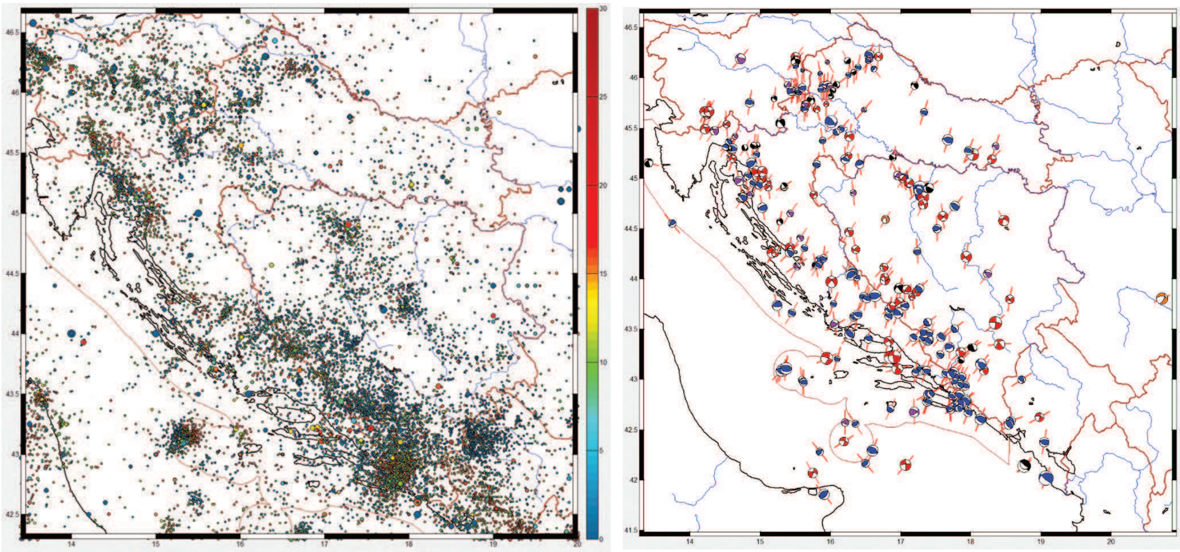

Figure 7. *Left*: Epicentres from the Croatian Earthquake Catalogue (BCE–2017, $M \geq 2.2$). Focal depth is indicated by the colour scale and symbols scale with magnitude. *Right:* First-motion polarity fault-plane solutions (FPS; blue – reverse, red – strike slip). Short red lines are oriented in the direction of the P-axes.

part of the catalogue using improved models and source-specific station corrections. Historical seismicity of the Međimurje region (northern Croatia) is currently also being studied. The Ston-Slano earthquake sequence of 1996 is being revisited using DInSAR data to resolve complex faulting of the mainshock.

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