Izvješće uz aktivnost **A3.1** Prikupljanje postojećih znanstvenih i stručnih publikacija (M04-06)

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Istraživački projekt | IP-01-2018-8944 | GEOMSAT

Istraživanje recentnih regionalnih i lokalnih geodinamičkih procesa na području Republike Hrvatske primjenom suvremenih satelitskih geodetskih metoda

Rezultat **D3.1**: Napisano izvješće o prethodnoj primjeni MT-InSAR metoda za istraživanje geodinamičkih procesa na seizmogenim rasjednim zonama

Prva primjena MT-InSAR metoda za istraživane geodeinamičkih procesa veže se uz projekt "Geodinamička GPS mreža Grada Zagreba". Riječ je o najdužem geodetsko-geodinamičkom istraživanju na području RH koje je aktivno od 1997. godine. Od uspostave geodinamičke mreže, provedeno je devet serija (kampanja) GPS opažanja (1997, 2001, 2004, 2006, 2007, 2008, 2009, 2015 i 2017) s ciljem karakterizacije i kvantifikacije geodinamičkih procesa koji se odvijaju na širem zagrebačkom području (Pribičević i dr. 2016). Rezultat dobiven izjednačenjem GPS kampanja je geodetski model recentnih trodimenzionalnih tektonski induciranih pomaka koji je pokazao visoku stopu koreliranosti s geološkim modelom (Pribičević i dr. 2011).

Od 2015. godine u projekt je uključena i InSAR metoda, a obrađeno je 40 snimaka ENVISAT satelitske misije s naprednom multi-temporalnom InSAR metodom (MT-InSAR) Stalnih raspršivača (eng. Persistent Scatterers). U MT-InSAR obradi korištene su satelitske radarske snimke uzlazne i silazne orbite navedene satelitske misije, te sukladno tome dobivena su dva modela jednodimenzionalnih prostorno-temporalnih površinskih pomaka na širem zagrebačkom području, za period od 2004. do 2010. godine. MT-InSAR metodom ostvareno je prostorno progušćivanje rezultata GPS kampanja, pogotovo u urbanom dijelu područja, s čime je ostvarena detaljna karakterizacija naprezanja Zemljine fizičke površine na navedenom području (Pribičević i dr. 2017). Trenutno su u obradi i satelitske snimke Sentinel-1 satelitske misije s navedenom MT-InSAR metodom.

U popisu literature napravljen je izbor publikacija koje se bave InSAR metodama u geodinamičkim istraživanjima. Sinteza postojećih istraživanja rezultirala je poglavljem *2.1.2 InSAR for Global and Dense Remote Sensing of Deformation (Primjena InSAR-a za globalno i gusto daljinsko opažanje deformacija)* u radu koji je objavljen u zborniku radova i usmeno izložen na međunarodnoj konferenciji *GeoInformation for Disaster Management Gi4DM 2019*, Prag, 3-6. rujna 2019:

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Literatura:

Arnadottir, T., Jonsson, S., Pollitz, F.F, Jiang, W., Feigl, K.L., 2005. Postseismic deformation following the June 2000 earthquake sequence in the south Iceland seismic zone. Journal of Geophysical Research, Vol 110, doi.org/10.1029/2005JB003701.

Atzori, S., Hunstad, I., Chini, M., Salvi, S., Tolomei, C.B., Stramondo, S., Trasatti, E., Antonioli, A., Boschi, E., 2009. Finite fault inversion of DinSAR coseismic diplacement of the 2009 L'Aquila earthquake (central Italy). Geophysical Research Letters, Vol. 36. L15305, doi: 10.1029/2009GL039293.

Bekaert, D.P.S., Hooper, A., Wright, T.J., 2015. Reassessing the 2006 Guerrero slow-slip event, Mexico: Implications for large earthquakes in the Guerrero Gap. Journal of Geophysical Research Solid Earth, Vol 120, pp 1357-1375, doi.org/10.1002/2014JB011557.

Berardino, P., Fornaro, G., Lanari, R., Sansosti, E., 2002: A new algorthm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Transactions on Geoscience and Remote Sensing, Vol 40, NO. 11, pp 2375-2383.

Cakir, Z., Ergintav, S., Akoglu, A. M., Cakmak, R., Tatar, O., and Meghraoui, M., 2014. InSAR velocit field across the North Anatolian Fault (eastern Turkey): Implications for the loading and release of interseismic strain accumulation. Journal of Geophysical Research Solid Earth, Vol 119, pp 7934-7943, doi.org/10.1002/2014JB011360.

Chaussard, E., Johnson, C.W., Fattahi, H., Burgman, R., 2016. Potential and limits of InSAR to charaterize interseismic deformation independently of GPS data: Application to the southern San Andreas Fault system. Geochemistry, Geophysics, Geosystems, Vol 17, pp 1214-1229, doi.org/10.1002/2015GC006246.

ElGharbawi, T., Tamura, M., 2015. Coseismic and postseismic deformation estiamtion of the 2011 Tohoku earthquake in Kanto Region, Japan, using InSAR time series analysis and GPS. Remote Sensing of Environment, Vol 168, pp 374-387.

Fattahi, H., Amelung, F., 2014. InSAR uncertainty due to orbital errors. Geophysical Journal International, Vol 199, pp 549-560, doi.org/10.1093/gji/ggu276.

Feng, M., Bie, L., Rietbrock, A., 2018. Probing the rheology of continental faults: decade of post-seismic InSAR time-series following the 1997 Manyi (Tibet) earthquake. Geophysical Journal International. Vol 215, pp 600-613, doi.org/10.1093/gji/ggy300.

Govorčin, M., Matoš, B. Herak, M. Pribičević, B., Vlahović, I., 2018: Coseismic deformation analysis of the 1996 Ston-Slano (southern Croatia) ML 6.0 earthquake: preliminary results using DinSAR and geological investigations. 9th International INQUA Meeting on Paleoseismology, Active Tectonics and Archeoseismology, 25-27 June 2018, Possidi, Greece.

Hanssen, R.F., 2001. Radar interferometry: data interpretation and error analysis. Springer Science & Buisness Media, Vol. 2.

Hussain, E., Wright, T.J., Walters, R. J. Bekaert, D.P.S., Lloyd, R., Hooper, A., 2018. Constant strain accumulation rate between major earthquakes on the North Anatolian Fault. Nature Communications, Vol 9. doi.org/10.1038/s41467-018-03739-2.

Jonsson, S., Zebker, H., Segall, P., Amelung, F., 2002. Fault Slip Distribution of the 1999 Mw 7.1 Hector Mine, California, Earthquake, Estimated from Satellite Radar and GPS Measurements. Bulletin of the Seismological Society of America, Vol. 92, No. 4, pp. 1377-1389.

Kaneko, Y., Hamling, I.J., Van Dissen, R.J., Motagh and Samsonov, S.V., 2015. InSAR imaging of displacement on flexural-slip faults triggered by the 2013 Mw 6.6 Lake Grassmere earthquake, central New Zealand. Geophysical Research Letters, 42, pp 781-788, doi:10.1003/2014GL062767.

Massonnet, D., Rossi, M., Carmona, C., Adragna, F., Peltzer, G., Feigl, K., Rabaute, T., 1993. The displacement field of the Landers earthquake mapped by radar interferometry. Nature, 364, pp 138-142, doi: 10.1038/364138a0.

Massonnet, D., Feigl, K.L., 1998. Radar interferometry and its application to changes in the Earth's surface. Reviews of geophysics, 36 (4), pp 441-500.

Motagh, M., Wang, R., Walter, T. R., Burgmann, R., Fileding E., Anderssohn, J. and Zschau, J., 2008. Coseismic slip model of the 2007 August Pisco earthquake (Peru) as constrained by Wide Swath radar observations. Geophysical Journal International, Vol 174, pp 842-848, doi.org/10.1111/j.1365-264X.2008.03852.x.

Nissen, E., Elliot, J.R., Sloan, R.A., Craig, T.J., Funning, G.J., Hutko, A., Parsons, B.E., Wright, T., 2016. Limitations of rupture forecasting exposed by instantaneously triggered earthquake doublet. Nature Geoscience. Vol 9, doi.org/10.1038/NGEO2653.

Osmanoğlu, B., Sunar, F., Wdowinski, S., Cabral-Cano, E., 2016: Time series analysis of InSAR data: Methods and trends. ISPRS Journal of Photogrammetry and Remote Sensing, 115, 90–102.

Pedersen, R., Sigmundsson, F., Feigl, K.L., Arnadottir, T., 2001. Coseismic interferograms of two Ms=6.6 earthquakes in the South Iceland Seismic Zone, June 2000. Geophysical Research Letters, Vol 28, No. 17, pp 3341-3344.

Pribičević, B., Đapo, A., 2016. Movement Analysis on Geodynamic Network of the City of Zagreb from Different Time Epochs // Geodetski list, (0016-710X) 70(93), 3, pp. 207-230.

Pribičević, P., Đapo, A., Govorčin, M., 2017. The application of satellite technology in the study of geodynamic movements in the wider Zagreb. Tehnički vjesnik, Vol 24, No.2 pp 503-512, doi.org/10.17559/TV-20160817013320.

Wang, K. and Fialko, Y., 2018. Observations and Modeling of Coseismic and Postseismic Deformation Due to the 2015 Mw 7.8 Gorkha (Nepal) Earthquake. Journal of Geophysical Research Solid Earth, Vol 123, pp 761-779, doi.org/10.1002/2017JB014620.

Wright, T. J., Lu, Z., Wicks, C., 2003. Source model for the Mw 6.7, 23 October 2002, Nenana Moutain Earthquake (Alaska) from InSAR. Geophysical Research Letters, Vol 30 NO. 18, doi.org/10.1029/2003GL018014.

GEOINFORMATION FOR RESEARCH OF ONGOING GEODYNAMIC PROCESSES IN THE REPUBLIC OF CROATIA

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ABSTRACT:

Multidisciplinary research of surface geodynamic processes is important for understanding mechanisms that lead to sudden release of accumulated strain energy, i.e. earthquakes. It requires development of an original scientific approach which combines data from various geosciences such as geodesy, geology and seismology. This implies that each geoscience contributes to a better understanding by providing specific direct or indirect information on activity (spatial movements) and properties of seismogenic sources (faults). In recent years, new and accessible sources and types of geoinformation have greatly enhanced, enabling a more comprehensive investigation of ongoing geodynamic activity on faults and, therefore, improve our ability to develop approaches to assess and mitigate the seismic hazard and risk within the earthquake-prone areas.

In this paper, we seek to identify the geoinformation required to improve the current knowledge on regional and local geodynamic processes in the Republic of Croatia. Focusing on the complementarity of geodetic, geological and seismological data, we discuss possible sources of the diverse sets of site-specific geospatial data. Examples include: ground/surface movement observations with Global Navigational Satellite Systems (GNSS) and Satellite Radar Interferometry (InSAR); data about historical and instrumental seismicity (e.g. focal mechanism solutions, number of earthquakes, b-value, etc.); fault location, fault geometrical properties and information on their neotectonic activity, paleoseismological data, etc. Challenges regarding the integrated use of these data, such as heterogeneity of data sources, access protocols, metadata standards, data quality, up-to-dateness, and other limitations are also addressed.

1. INTRODUCTION

Geodynamics deals with the processes occurring in the Earth's interior, particularly as regards their effects on the crust and its superficial zone. Research and monitoring of surface geodynamic processes is important for understanding of the mechanisms that lead to seismic activity, i.e. earthquakes. It requires an interdisciplinary approach of various geosciences such as geodesy, geology, and geophysics (seismology), where each discipline contributes with a specific set of measurements in order to get broad understanding of the geodynamic processes.

Geospatial technologies provide capabilities for data collection, processing, analysis, and visualization that are essential in all phases of the geodynamic research. In its initial phase, the research activities that investigate accumulation and release of seismic energy, i.e., earthquakes are mainly associated to geological and seismological research methods. Geological methods are primarily based on the analysis of geological and geophysical data with the objectives of defining timing of structure evolution, structural-geological relationships, identification of principal discontinuities i.e., faults in a research area. On the other hand, seismology and seismotectonics are focused on determination of kinematic properties of active faults, as well as their geometrical parameters, which are crucial in definition of fault's seismic potential. Seismological methods are focused on studying historical and instrumental seismic activity in the research area, with the principal objectives of better defining the seismic hazard, characterization of stress distribution and tectonic processes.

With the development of modern geodetic satellite methods for spatial data collection, the role of geodesy in geodynamic research has gained much importance. Geodesy enables the collection of geometric information on the distribution of Earth's stress and strain on the global, regional and local level through observations in exclusive time period with respect to reference frame. For this reason, geodetic research represents an ideal addition to geological and seismological results when examining and characterizing recent tectonic movements in the research area.

The Republic of Croatia is situated in a collision zone that is part of the Mediterranean convergence zone, a collision zone between the African and Eurasian tectonic plates (e.g., Tari, 2002; Schmid et al., 2008 with references). Based on the previous research, the largest portion of geodynamic movements within the Dinaridic fold-thrust belt and SW Pannonian Basin have been linked to dynamics and kinematics of the Adria microplate that moves independently in respect to the African and Eurasian tectonic plates (D'Agostino et al., 2008 with references). Convergence of the Adria microplate and

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stable Eurasian plate (2-5 mm/yr., e.g., Grenerczy et al., 2005; Bennett et al., 2008; Weber et al., 2010) is reflected through strain accumulation and distribution of tectonic activity along the margins of the Adria microplate, which is due to differential stress distribution in the Earth's crust accompanied by seismic activity, i.e. earthquakes. Tectonic activity is also manifested through heterogeneous distribution of stresses in the Earth's crust, which leads to seismic activity along neotectonic active faults i.e. reverse and/or strike-slip faults mapped within the research area. Recent geodynamic processes that manifest through ongoing seismic activity represent a potential risk for the population living in the area. This implies occurrence of earthquakes that may yield instantaneous release of accumulated seismic energy causing material and non-material damage, and potential human casualties. Geodynamic and kinematic processes are not restricted to national boundaries, so understanding the cause-and-effect relationships is of great importance for the safety of the local community, and for society in the wider area.

In this paper we report possible sources of geoinformation that could be used to address the current knowledge on ongoing geodynamic processes in the Republic of Croatia. We refer to the term geoinformation in its general sense, as the collection and storage of georeferenced data that can be queried by both, attribute and location. We first describe the sources of site-specific geospatial data for each of the contributing geoscience disciplines, giving the scale, precision, and usage to which they were applied. Focusing on the complementarity of geodetic, geological and seismological data, we complete the paper with the discussion of challenges regarding their integrated use, such as heterogeneity of data sources, access protocols, data standards, data quality, up-to-dateness and other limitations.

2. GEOINFORMATION FOR RESEARCH AND MONITORING OF GEODYNAMIC PROCESSES

2.1 Geodesy

A range of techniques exist in geodesy to measure the crustal deformations that are associated with plate motion and active faults. The examples include: traditional, ground-based optical or mechanical methods, such as triangulation, trilateration, and levelling, as well as a number of space-based techniques of which Very Long Baseline Interferometry (VLBI), the Global Navigational Satellite System (GNSS) and Interferometric Synthetic Aperture Radar (InSAR) have imposed as the most significant (Burgmann, Thatcher, 2013).

Geodetic research at the global and regional level are focused on tracking geodynamic processes related to tectonics by conducting observations on the global, continental, and regional networks (such as the International GNSS Service (IGS) or EUREF Permanent Network (EPN)) using the Global Navigational Satellite System (GNSS) (Kreemer et al., 2014), and the long-distance interferometry for a certain period (Jordan, Minster, 1988; Cambell, Nothnagel, 2000).

The geodetic methods most commonly used to collect spatial data on temporal development of surface deformations of the Earth's crust on the local level, i.e. the narrower area around fault zones, are the GNSS networks (Murray-Moraleda, 2009), and the Interferometric Synthetic Aperture Radar (InSAR) (Massonnet, Feigl, 1998). Geodetic methods at the local level provide a very good basis for monitoring seismic cycles on seismogenic sources, starting from inter-seismic phase (stress accumulation process, i.e. ground deformations that precede earthquake), to coseismic phase (ground and surface displacements caused by earthquake released energy) and postseismic phase (ground and surface deformations after earthquake event).

2.1.1 GNSS Data for Crustal Deformation Studies

GNSS tracks a relative three-dimensional position of thousands of campaign-mode and continuously operating stations with sub-centimetre precision (Burgmann, Thatcher, 2013). A number of research papers can be found that provide more detailed introductions into the crustal deformation research with GNSS carried out along plate boundaries all over the world, revealing the complex and variable patterns of the shifting plates and the complex deformation at their boundaries (e.g., see Burgmann, Thatcher, 2013 with references). Rather than attempt to comprehensively review this body of work, we focus here on the brief description of the method and representative results of geodynamic studies employing GNSS observations carried out in Croatia in the last 30 years.

The use of GNSS technique for geodynamic investigations depends on the configuration and the size of the GNSS network, which define the achievable spatial resolution of the ground displacements. The network consists of specially stabilized monuments for installation of GNSS receivers distributed in accordance with the network application (from global, regional to local scale). Frequency of GNSS observations on the network defines the temporal resolution of ground displacements, which can obtained either with continuous (permanent) GNSS (cGNSS) or campaign mode (episodic) GNSS observations. .

GNSS campaign-mode observations are series of repeated measurement campaigns on the network within certain time intervals. Repeating this procedure at different time intervals (e.g. every year) provides the necessary kinematic information of ground deformation field. To acquire sub-centimetre precision of ground displacement detection necessary for most crustal deformation studies, it is recommended to perform GNSS campaigns on the network once per year at the same season for a minimum time-span of 3 years (in order to mitigate seasonal noise in data). On the other hand, continuous GNSS observations work in real-time, acquiring a large amount of data that result in a high temporal resolution and precision of obtained ground displacements. Minimum time-span of GNSS observations on the network needed to mitigate seasonal position variation in the data is considered to be 2.5 years (Blewitt and Lavallee 2002). We consider maximum achievable precision of GNSS measurements with GNSS campaigns after 10 years to be in range of ~1.5 mm/yr due to systematic errors related to antenna offset, whereas cGNSS can achieve 0.2 mm/yr and 0.4 mm/yr horizontal and vertical precision, respectively (Akarsu et al., 2015). GNSS observations result in the three-dimensional velocity field and time series data of the observed area relative to used reference frame for the observed time period.

Several international geodynamic projects have been carried out in Croatia for the past three decades in a form of GNSS campaigns. The most prominent examples include: *Central European Geodynamics Project* CERGOP (carried out in two stages 1994–1999 and 2001–2006) (Medak et al., 2002), *Croatian geodinamyc project* CRODYN (in 1994, 1996, 1998 and 2013) (Marjanović, 2008; Pavasović 2014), *Croatian Reference GPS campaign* CROREF95, 96, and 2005, *Retreating-Trench, Extension and Accretion Tectonics Project* RTREAT (Marjanović, 2008; Pavasović, 2014; Pavasović et al. 2015). There were altogether 21 GPS campaigns with the purpose of determining geodynamic movements on the Croatian territory, all carried out with 24-hour measurement sessions on each point, processed in Bernese software and resulted with velocity models for the research area (Pavasović, 2014). Furthermore, in geodynamic research of potential recently-active fault zones on the territory of Croatia, it is important to mention the project *Geodynamic GPS Network of the City of Zagreb*, which has been active since 1997 until today (Pribičević et al., 2016). Results of the aforementioned projects are relative velocity fields available only in a form of scientific publication.

In terms of cGNSS results, the usage of CROPOS network for determination of Adria microplate geokinematic model can be found in (Pavasović, 2014). CROatian POsitioning System – CROPOS is national network of 33 referential permanent GNSS stations covering the entire Croatian territory since 2008. The baseline length between stations is approx. 70 km. GNSS data is provided through geodetic precise positioning service (GPPS) as receiver independent exchange format (RINEX) via CROPOS RINEX web-shop. Responsible organisation is the State Geodetic Administration of the Republic of Croatia (URL1). Other available sources of cGNSS results on the territory of Croatia are derived velocity and time series solutions on EUREF network provided as position solutions (SINEX format) (see Table 1) based on five EPN permanent stations located on the Croatian territory: CAKO00HRV (Čakovec), POZE00HRV (Požega), PORE00HRV (Poreč), ZADA00HRV (Zadar) and DUB200HRV (Dubrovnik).

For future crustal deformation studies on the Croatian territory, it is also important to identify stations of other GNSS networks in the region: Italy – RING (URL2), Slovenia – Signal (URL3), Hungary – GNSSnet.hu (URL4), Federation Bosnia and Hercegovina – FBiHPOS (URL5), Republika Srpska SRPOS (URL6) and Montenegro – MontePOS (URL7).

2.1.2 InSAR for Global and Dense Remote Sensing of Deformation

Satellite radar interferometry (InSAR) proves to be a very useful remote sensing technique for investigation and monitoring of surface displacements caused by geodynamical processes. The technique is based on the measurement of angular difference in phase information of returned electromagnetic signals over the same area received by spaceborne Synthetic Aperture Radar (SAR) at two distinct times. The result is interferogram, an image of phase differences that contain information on surface displacements in line-of- sight direction, towards or away from the satellite. More on the SAR acquisition principles and interferogram generation can be found in (Hanssen, 2011). Major advantages of the technique are high spatial resolution (~100 pixels/km2), competitive precision (~1cm) and temporal acquisition frequency (1 acquisition per month, or every 6 days nowadays) of ground displacement observations anywhere around the globe (Massonnet, Kiegl, 1998). Since the first mapping demonstration of surface deformation caused by the Landers earthquake in 1992 (Massonnet et al., 1993), InSAR technique has been widely used for investigation of coseismic ground deformations caused by earthquake rupture (Pedersen et al., 2001; Jonsson et al., 2002; Wright et al., 2003; Stramondo et al., 2005; Motagh et al., 2008; Atzori et al., 2009; Kaneko et al., 2015; Nissen et al., 2016).

The applicability of conventional InSAR technique is constrained with several sources of error; phase decorrelation, atmospheric phase delay, inaccurate topographic model and imprecise satellite orbits. The latter technique's limitations were overcome with development of multi-temporal InSAR techniques: Persistent Scatterers (PS-InSAR) (Ferreti et al., 2001) and Small Baseline (SBAS) (Berardino et al., 2002). By connecting multiple interferograms in one data stack, coherent phase differences temporal and spatial characteristics can be exploited to model the aforementioned sources of errors and develop temporal evolution of surface displacements. The result is a relative line-of-sight velocity field with a precision of a few millimetres (~1-3 mm/yr Fattahi, Amelung, 2014; Marinković et al., 2008) and high spatial resolution (~10 000–100 000 per km^2). Overview of key differences between two MT-InSAR techniques and algorithms in use can be found in (Osmanoglu et al., 2016). Ability to develop temporal evolution of surface displacements together with time-series analysis enable InSAR technique to be used for investigation of interseismic (Cakir et al., 2014; Bekaert et al., 2015; Chaussard et al., 2016; Hussain et al., 2018) and postseismic (Arnadottir et al., 2005; ElGharbawi, Tamura, 2015; Wang, Fialko, 2018; Feng et al., 2018) ground deformations.

In the Republic of Croatia, InSAR technique was applied for investigation of interseismic ground deformations over the wider Zagreb area (NW Croatia) and coseismic ground deformation of Ston-Slano 1996 ML 6.0 earthquake (SE Croatia). The conventional InSAR technique was applied to determine coseismic ground deformations caused by the Ston-Slano ML 6.0 earthquake occurred in Dubrovnik County on September 05, 1996 (Govorčin et al., 2018). The technique was applied on two ERS2 satellite images acquired from descending track, one image that predates (August 09, 1996) and one after (July 25, 1997) the earthquake event, and resulted in a coseismic interferogram (Govorčin et al., 2018). Persistent Scatterers MT-InSAR technique was applied though the project *The Geodynamic GPS Network of the City of Zagreb* to characterize ongoing interseismic ground deformations over the wider Zagreb area in 2015. The MT-InSAR techniques resulted in two relative velocity fields (~135 000 points) of the wider Zagreb area in the period 2004–2009. Used data in the processing were 40 Envisat-ASAR images acquired from ascending and descending orbit over the area (Pribičević et al., 2017). Final products (interferograms and velocity fields) of the aforementioned InSAR applications are available only as the cited publications. Available InSAR final products over Croatian territory can be found at COMET-LiCS Sentinel-1 InSAR portal (URL8). COMET-LiCS provides Sentinel-1 generated interferograms covering Himalayan Belt and East African Rift, available via the EU Infrastructure project EPOS (see Table 1).

Source title	EUREF Permanent Network (EPN), station positions and velocities	Geological Maps of the Republic of Croatia	The European Database of Seismogenic Faults (EDSF)	Croatian Earthquake Catalogue (CEC)	SHARE European Earthquake Catalogue (SHEEC) 1000-1899	Croatian Earthquake Hazard Maps	COMET-LiCS Sentinel-1 InSAR Portal
Description	A science-driven network of permanent GNSS tracking stations whose weekly computed positions are used by EUREF to realize the European Terrestrial Reference System (ETRS89).	Official geological maps of the Republic of Croatia at the scale of 1:50 000, 1:100 000 and 1:300 000	EDSF includes only faults that are identified and mapped as neotectonics active faults, i.e., possible seismogenic sources capable of generating earthquakes of magnitude equal to or larger than 5.5. It aims to ensure a homogeneous input for use in ground-shaking hazard assessment in the Euro-Mediterranean area.	CEC is the main database about the past and present earthquakes in Croatia covering period from 373 BC until today compiled using all data on earthquakes from the archives of the Department of Geophysics, Faculty of Science, University of Zagreb (the catalogues, macroseismic reports, seismograms, and other related documents).	SHEEC is a European parametric earthquake catalogue, as much homogeneous as possible, which covers the time window 1000–1899. Developed within the frame of the European Commission project SHARE compiled from European Archive of Historical EArthquake Data.	Maps of seismic hazard in Croatia expressed by the probability of exceedance of PGA for return periods of 475 years and 95 years.	Online Catalog of Sentinel-1 generated interferograms and coherence maps. Results are available for download as Derived Works of Copernicus data (2015–2016) through interactive online map. Products are: Unfiltered wrapped phase (Quicklook, Magnitude, Phase), Coherence (Quicklook, Phase) and filtered unwrapped phase (quicklook, unwrapped interferogram)
Responsible organization	IAG (International Association of Geodesy) Regional Reference Frame sub-commission for Europe, EUREF.	Croatian Geololgical Survey	Italian National Institute of Geophysics and Volcanology (INGV)	Department of Geophysics, Faculty of Science and Mathematics, University of Zagreb	Istituto Nazionale di Geofisica e Vulcanologia, Milan	Department of Geophysics, Faculty of Science and Mathematics, University of Zagreb	COMET, School of Earth and Environment, University of Leeds, England
Source locator	http://www.epncb.oma.be	http://www.hgi-cgs.hr/geoportal.htm	http://diss.rm.ingv.it/share-edsf	https://www.pmf.unizg.hr/geof/	https://emidius.eu/SHEEC	http://seizkarta.gfz.hr	https://comet.nerc.ac.uk/COMET-LiCS-portal
Source type	spatial dataset	spatial dataset	spatial dataset	spatial dataset	spatial dataset	spatial dataset	service
Distribution format	SINEX	PDF, 1:300 000 also as web application	MapInfo mif/mid ESRI shapefile	textual	MS Excel, Interactive web application	PDF, Interactive application	Raster (geotiff)
Reference coordinate system	Geocentric coordinate system for Europe	Projected coordinate system for Croatia HTRS96 / TM	Geodetic coordinate system for World	Geodetic coordinate system for World	Geodetic coordinate system for World	No standard map projection, orthogonal coordinates	Geodetic coordinate system for World
Temporal coverage	Start date: 1995	1982– (1:50 000), 1962–1992 (1:100 000), 2006–2009 (1:300 000)	n/a	Covers the period since 373 BC until today	Time window 1000–1899	Published in 2011	02.09.2016–31.05.2018
Spatial resolution	Station distances between 100 and 500 km or more.	Map scale: 1:50 000, 1:100 000, 1:300 000	n/a	n/a	n/a	Map is compiled at the approximate scale of 1:800 000	260 km x 360 km (per product)
Temporal resolution	Daily Hourly	Does not require frequent updating.	n/a	Regularly updated.	n/a	Planned revision and update every 5–7 years.	12 days
Restrictions and terms of use	Freely available.	Purchase or inquiry upon request.	Designed as "work in progress", and as such it is open to later additions and improvements	Croatian Earthquake Catalogue (CEC) is not available on line. It is stored in the archives of the Department of Geophysics of the Faculty of Science, University of Zagreb.	Open-access upon registration. It can be used for scientific purposes, only, quoting the reference indicated.	Freely available for download as PDF in full resolution. The maps were accepted as a part of the Croatian National Annex to the EC8 in 2012.	Open-access

Table 1. Overview of the availability, scale, precision and usage of the possible sources of geoinformation that could be used to address the current knowledge on ongoing geodynamic processes in the Republic of Croatia

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2.2 Geology

Geological investigations are often based on collected data by field observations, i.e. geological mapping of surface strata and construction of geological cross-sections perpendicular and/or parallel to local and regional-scale faults and associated structures in the study area.

Beside structural data collected by field observations, geological mapping and construction of geological cross-sections incorporates data officially published on geological maps and other publications of the Croatian Geological Survey (e.g. available sheets of basic geological maps of the Republic of Croatia at the scale of 1:300 000, 1: 100 000 and 1: 50 000 (see Table 1), as well as thematic geological maps, e.g., geomorphological map, geochemical map, hydrogeological map, geological engineering map, etc.). Additional datasets used to tackle geodynamic processes may be collected data by geophysical campaigns conducted by INA d.d. Croatian oil company (e.g., 2D seismic profiles, recorded seismic 3D cubes, gravimetric and magnetometric data and borehole data). Available geological data are usually limited by map scale and constrained by temporal and spatial resolution.

Within the scope of the geological field investigations that can be used in investigation of geodynamic processes collected data usually resemble age, structural and textural properties of mapped stratigraphic units. Identification of geological boundaries and contacts, recording and measuring of the microtectonic data on fault and shear planes are used to compute paleostress field of the study area. Based on computed paleostress field for the certain area, geological investigations include correlation analysis between computed paleostress field and recent stress field. This implies that analysis of focal mechanism solution and collected geological data provide foundations that are used in precise reconstruction of the tectonic evolution of the certain area (Tomljenović et al., 2008; Herak et al., 2009; Matoš, 2014; Palenik et al., 2019).

Currently, there is no publicly and online available Croatian database of the seismogenic sources. However, such data bases exist in neighbouring countries. The most prominent examples are the European Database of Seismogenic Faults (EDSF) (URL9) and Database of Individual Seismogenic Sources (DISS) (URL10).

Database of Seismogenic Faults (EDSF) includes only faults that are identified and mapped as neotectonics active faults, i.e. possible seismogenic sources capable of generating earthquakes of magnitude equal to or larger than 5.5 (see Table 1). It aims to ensure a homogeneous input for use in ground-shaking hazard assessment in the Euro-Mediterranean area. The database of seismogenic faults and website are hosted and maintained by The Italian National Institute of Geophysics and Volcanology (INGV).

Database of Individual Seismogenic Sources (DISS) is a georeferenced repository of tectonic, fault, and paleoseismological information expressly devoted, but not limited, to potential applications in the assessment of seismic hazard at Italian and regional scale. All database records are fully parameterized, covering Italy and its surrounding seas and territories, the central Mediterranean (covering the area of the littoral Croatia), and sections of the Aegean Sea.

2.3 Seismology

Seismology provides the main research tools for investigating Earth's structure from surface to the core. Using the data about seismic wave travel times and fault mechanism it provides information about properties of the medium thus enabling inferences about structural and material composition of the Earth. By providing information on earthquake timing and location along with the information on elastic properties of the medium, seismology in combination with the geologic and geodetic data is indispensable in creating broad image about tectonic and surface geodynamics processes.

Earthquake data such as seismic wave travel times, earthquake locations, macroseismic reports, earthquake mechanisms, etc. are routinely collected and archived by the Department of Geophysics, Faculty of Science, University of Zagreb. Seismic hazard map of Croatia is also available (see Table 1), accepted as a part of the National Annex of the Eurocode-8. Earthquake hazard is presented by the values of peak ground acceleration (PGA) expected to be exceeded on the average every 95 and 475 years. Underlying statistical analyses was based on the Croatian Earthquake Catalogue, which was expanded with the data for events well outside Croatian borders.

Currently, there are over 25 permanent broadband seismic stations in Croatia continuously monitoring seismic activity in Croatia and neighbouring regions. Collected seismograms are regularly analysed and all the information about earthquakes are stored in the Croatian Earthquake Catalogue (see Table 1). The number and density of the seismic stations in the region ensures that the precision of earthquake locations will be in the 5 km range and the threshold magnitude about $M = 1.0$.

The Croatian Earthquake Catalogue (CEC) is the main database about the past and present earthquakes in Croatia covering period from 373 BC until today (Herak et al., 1996). The catalogue is routinely updated through combination of data about present earthquakes obtained with a semi-automatic location procedure and historical earthquake data collected thorough ongoing research. In the catalogue there is currently information on over 90,000 events with foci in Croatia and neighbouring regions.

Seismological data on earthquakes in the wider spatial frame (earthquake focal mechanisms, estimated maximal earthquake magnitude with regard to geometric parameters, focal depth, etc.) are publicly available in the form of the WebGIS database. Examples include the ISC-GEM Global Instrumental Earthquake Catalogue (1904–2015) (URL11) and the SHARE European Earthquake Catalogue (SHEEC) (URL12).

3. CONCLUSION AND FUTURE WORK

In this paper, the first step in the systematization of spatial data has been made to establish geodetic-geodynamic basis for future research of crustal deformations that are associated with plate motion and active faults on the territory of the Republic of Croatia.

We identified publically available sources of the diverse sets of site-specific geodetic, geological and seismological geospatial data which show that problems exist related to availability, organization, and sharing of these data. In Table 1 we listed the subjects that provide data, but only a small number of them have developed network services that provide data storage, manipulation or presentation. Specifically, geological and seismological data (such as official Geological Maps of the Republic of Croatia and Croatian Earthquake Catalogue) are only available upon request, whereas geodetic GNSS and InSAR products (Croatia based) can be found only in scientific publications. Thus, we point out the necessity for an online database with visualization and sharing services of the existing and future geodetic data for geodynamic research in the Republic of Croatia. The good practice can be found in external data sources and ongoing projects such as NASA ARIA project for Natural Hazards (URL13). Moreover, geological databases should be focused on improving a usability of the existing data within GIS environment as well as development of database of seismogenic sources similar as the INGV European Database of Seismogenic Faults (URL9).

The future research should strive to identify other sources of geoinformation beside the ones mentioned in this study, which could be effectively used not only for the management and display but also for analysis and interpretation in the research context. Furthermore, considering the spatial component of geodynamic processes, the future research should be expanded to identify available geoinformation in a wider regional frame. Also, a comparison with existing well-established sources in the neighbouring countries could provide a better insight into solutions for integrated use of these data.

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REFERENCES

Akarsu, V., Sanli, D.U., Arslan, E., 2015. Accuracy of velocities from repeated GPS measurements, *Nat. Hazards Earth Syst. Sci.,* 15, 875–884, https://doi.org/10.5194/nhess-15-875-2015, 2015.

Arnadottir, T., Jonsson, S., Pollitz, F.F, Jiang, W., Feigl, K.L., 2005. Postseismic deformation following the June 2000 earthquake sequence in the south Iceland seismic zone. *Journal of Geophysical Research*, Vol 110, doi.org/10.1029/2005JB003701.

Atzori, S., Hunstad, I., Chini, M., Salvi, S., Tolomei, C.B., Stramondo, S., Trasatti, E., Antonioli, A., Boschi, E., 2009. Finite fault inversion of DinSAR coseismic diplacement of the 2009 L'Aquila earthquake (central Italy). *Geophysical Research Letters*, Vol. 36. L15305, doi: 10.1029/2009GL039293.

Bekaert, D.P.S., Hooper, A., Wright, T.J., 2015. Reassessing the 2006 Guerrero slow-slip event, Mexico: Implications for large earthquakes in the Guerrero Gap. *Journal of Geophysical Research Solid Earth*, Vol 120, pp 1357-1375, doi.org/10.1002/2014JB011557.

Berardino, P., Fornaro, G., Lanari, R., Sansosti, E., 2002: A new algorthm for surface deformation monitoring based on small baseline differential SAR interferograms. *IEEE Transactions on Geoscience and Remote Sensing*, Vol 40, NO. 11, pp 2375-2383.

Bennett, R.A., Hreinsdottir, S., Buble, G., Bašić, T., Bačić, Ž., Marjanović, M., Casale, G., Gendaszek, A., Coan, D., 2008: Eocene to present subduction of southern Adria mantle lithosphere beneath the Dinarides. Geology, 36(1), pp. 3–6.

Burgmann, R., Thatcher, W., 2013. Space geodesy: A revolution in crustal deformation measurements of tectonic processes. *Special Paper of the Geological Society of America*. 500. 397-430. doi.org/10.1130/2013.2500(12).

Blewitt, G., Lavallee, D. (2002): Effect of annual signal on geodetic velocity. Journal of Geophysical Research: Solid Earth, Vol 107, doi: 10.1029/2001JB000570

Cakir, Z., Ergintav, S., Akoglu, A. M., Cakmak, R., Tatar, O., and Meghraoui, M., 2014. InSAR velocit field across the North Anatolian Fault (eastern Turkey): Implications for the loading and release of interseismic strain accumulation. *Journal of Geophysical Research Solid Earth*, Vol 119, pp 7934-7943, doi.org/10.1002/2014JB011360.

Cambell, J., Northnagel, A., 2000. Eurpean VLBI for crustal dynamics. *Journal of Geodynamics*, 30 (3), pp. 32-326.

Chaussard, E., Johnson, C.W., Fattahi, H., Burgman, R., 2016. Potential and limits of InSAR to charaterize interseismic deformation independently of GPS data: Application to the southern San Andreas Fault system. *Geochemistry, Geophysics, Geosystems,* Vol 17, pp 1214-1229, doi.org/10.1002/2015GC006246.

D'Agostino, N., Avallone, A., Cheloni, D., D'Anastasio, E., Mantenuto, S., Selvaggi, G., 2008. Active tectonics of the Adriatic region from GPS and earthquake slip vectors. *Journal of Geophysical Research*, Vol. 113, B12413, doi.org/10.1029/2008JB005860.

Dermanis A., Kotsakis C., 2006. Estimating Crustal Deformation Parameters from Geodetic Data: Review of Existing Methodologies, Open Problems and New Challenges. In: Sansò F., Gil A.J. (eds) Geodetic Deformation Monitoring: From Geophysical to Engineering Roles. *International Association of Geodesy Symposia*, vol 131. Springer, Berlin, Heidelberg. doi.org/10.1007/978-3-540-38596-7_2.

ElGharbawi, T., Tamura, M., 2015. Coseismic and postseismic deformation estiamtion of the 2011 Tohoku earthquake in Kanto Region, Japan, using InSAR time series analysis and GPS. *Remote Sensing of Environment*, Vol 168, pp 374-387.

Fattahi, H., Amelung, F., 2014. InSAR uncertainty due to orbital errors. *Geophysical Journal International*, Vol 199, pp 549-560, doi.org/10.1093/gji/ggu276.

Feng, M., Bie, L., Rietbrock, A., 2018. Probing the rheology of continental faults: decade of post-seismic InSAR time-series following the 1997 Manyi (Tibet) earthquake. *Geophysical Journal International*. Vol 215, pp 600-613, doi.org/10.1093/gji/ggy300.

Grenerczy, G., Sella, G., Stein, S., Kenyeres, A., 2005. Tectonic implications of the GPS velocity field in the northern Adriatic region. *Geophys. Res. Lett.* 32, L16311, doi.org/10.1029/2005GL022947.

Govorčin, M., Matoš, B. Herak, M. Pribičević, B., Vlahović, I., 2018: Coseismic deformation analysis of the 1996 Ston-Slano (southern Croatia) ML 6.0 earthquake: preliminary results using

DinSAR and geological investigations. *9th International INQUA Meeting on Paleoseismology, Active Tectonics and Archeoseismology*, 25-27 June 2018, Possidi, Greece.

Hanssen, R.F., 2001. Radar interferometry: data interpretation and error analysis. *Springer Science & Buisness Media*, Vol. 2.

Herak, M., D. Herak, Markušić, S., 1996. Revision of the earthquake catalog and seismicity of Croatia, 1908–1992, *Terra Nova,* **8**, 86–94.

Herak, D., Herak M., Tomljenović, B., 2009: Seismicity and earthquake focal mechanisms in North-Western Croatia, *Tectonophysics* 465, 212–220.

Hussain, E., Wright, T.J., Walters, R. J. Bekaert, D.P.S., Lloyd, R., Hooper, A., 2018. Constant strain accumulation rate between major earthquakes on the North Anatolian Fault. *Nature Communications*, Vol 9. doi.org/10.1038/s41467-018-03739-2.

Jonsson, S., Zebker, H., Segall, P., Amelung, F., 2002. Fault Slip Distribution of the 1999 Mw 7.1 Hector Mine, California, Earthquake, Estimated from Satellite Radar and GPS Measurements. *Bulletin of the Seismological Society of America*, Vol. 92, No. 4, pp. 1377-1389.

Jordan, T.G., Minster, J.B., 1988. Beyond plate tectonics – Looking at plate deformation with space geodesy. The impact of VLBI on astrophysics and geophysics; *Proceedings of the 129th IAU Symposium*, Cambridge, MA, May 10-15, 1987 (A89-13726 03-90). Dordrecht, Kluwer Academic Publishers, pp. 341-350.

Kaneko, Y., Hamling, I.J., Van Dissen, R.J., Motagh and Samsonov, S.V., 2015. InSAR imaging of displacement on flexural-slip faults triggered by the 2013 Mw 6.6 Lake Grassmere earthquake, central New Zealand. *Geophysical Research Letters*, 42, pp 781-788, doi:10.1003/2014GL062767.

Kreemer, C., Blewitt, G., Klein, E.C., 2014. A geodetic plate motion and global strain rate model // Geochemistry, Geophysics, Geosystems, 15 (10), pp 3849-3889.

Marinković, P., Ketelaar, G., van Leijen, F., Hanssen, R., 2008. InSAR quality control, analysis of five years of corner reflector time series. *Proc. Of FRINGE 2007 Workshop*, Frascati, Italy, 26 – 30 November 2007, ESA-SP-649.

Matoš, B., 2014. Neotectonic and recently active faults in Bilogora mountain area and assessment of their seismogenic potential 2014., Doctoral thesis, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb.

Marjanović, M., 2008. Application of GPS measurements for determining horizontal and vertical movements of the Adriatic microplate. Doctoral thesis. Faculty of Geodesy, University of Zagreb.

Massonnet, D., Rossi, M., Carmona, C., Adragna, F., Peltzer, G., Feigl, K., Rabaute, T., 1993. The displacement field of the Landers earthquake mapped by radar interferometry. *Nature*, 364, pp 138-142, doi: 10.1038/364138a0.

Massonnet, D., Feigl, K.L., 1998. Radar interferometry and its application to changes in the Earth's surface. *Reviews of geophysics*, 36 (4), pp 441-500.

Medak, D., Pribičević, B., Đapo, A., 2002. Međunarodni projekti za priključivanje Hrvatske Europskoj geodetskoj zajednici (1992-2001). In T. Bašić (Ed.), *Zbornik Geodetskog fakulteta Sveučilišta u Zagrebu povodom 40. obljetnice samostalnog djelovanja 1962.-2002.*, pp. 71–80.

Motagh, M., Wang, R., Walter, T. R., Burgmann, R., Fileding E., Anderssohn, J. and Zschau, J., 2008. Coseismic slip model of the 2007 August Pisco earthquake (Peru) as constrained by Wide Swath radar observations. *Geophysical Journal International*, Vol 174, pp 842-848, doi.org/10.1111/j.1365-264X.2008.03852.x.

Murray-Moraleda, J., 2009. GPS: Applications in Crustal Deformation Monitoring. In: *Meyers R. (eds) Encyclopedia of Complexity and Systems Science. Springer, New York, NY*, doi.org/10.1007/978-0-387-30440-3_250.

Nissen, E., Elliot, J.R., Sloan, R.A., Craig, T.J., Funning, G.J., Hutko, A., Parsons, B.E., Wright, T., 2016. Limitations of rupture forecasting exposed by instantaneously triggered earthquake doublet. *Nature Geoscience*. Vol 9, doi.org/10.1038/NGEO2653.

Palenik, D., Matičec, D., Fuček, L., Matoš, B., Herak, M. and Vlahović, I., 2019. Geological and structural setting of the Vinodol valley (NW ADRIATIC, CROATIA): insights into tectonic evolution based on structural investigations. *Geologia Croatica; Journal Of The Croatian Geological Survey And The Croatian Geological Society (1330-030X) - accepted for publication.*

Osmanoğlu, B., Sunar, F., Wdowinski, S., Cabral-Cano, E., 2016: Time series analysis of InSAR data: Methods and trends. *ISPRS Journal of Photogrammetry and Remote Sensing*, 115, 90–102.

Pavasović, M., 2014. CROPOS as Croatian Terrestrial Reference Frame and its Application in Geodynamic Researches. Doctoral thesis, Zagreb, Faculty of Geodesy, University of Zagreb.

Pavasović, M., Bašić, T., Marjanović, M., 2015. An overview of scientific and professional projects in the field of basic geodetic works at the territory of Republic of Croatia in period from 1991-2009. *Geodetski vestnik*. 59 (2015), 4; 767-788.

Pedersen, R., Sigmundsson, F., Feigl, K.L., Arnadottir, T., 2001. Coseismic interferograms of two Ms=6.6 earthquakes in the South Iceland Seismic Zone, June 2000. *Geophysical Research Letters*, Vol 28, No. 17, pp 3341-3344.

Pribičević, B., Đapo, A., 2016. Movement Analysis on Geodynamic Network of the City of Zagreb from Different Time Epochs // Geodetski list, (0016-710X) 70(93), 3, pp. 207-230.

Pribičević, P., Đapo, A., Govorčin, M., 2017. The application of satellite technology in the study of geodynamic movements in the wider Zagreb. *Tehnički vjesnik*, Vol 24, No.2 pp 503-512, doi.org/10.17559/TV-20160817013320.

Schmid, S.M., Bernoulli, D., Fugenschuh, B., Matenco, L., Schuster, R., Schefer, S., Tischler, M., Ustaszewski, K., 2008. The Alpine-Carpathian-Dinaridic orogenic system: Correlation and evolution of tectonic units. *Swiss J. Geosci*., 101, pp. 139–183.

Tari, V., 2002. Evolution of the Northern and Western Dinarides: a Tectonostratigraphic Approach. In: *Stephan Mueller Special Publication Series*, vol. 1, pp. 223–236.

Tomljenović, B., Csontos, L., Márton, E., Márton, P., 2008. Tectonic evolution of the northwestern Internal Dinarides as constrained by structures and rotation of Medvednica Mountains, North Croatia, *Geological Society, London, Special Publications* 2008; v. 298; p. 145-167, doi.org/10.1144/SP298.8

Weber, J., Vrabec, M., Pavlocčič-Prešeren, P., Dixon, T., Jiang, Y., Stopar, B., 2010. GPS-derived motion of the Adriatic microplate from Istria Peninsula and Po Plain sites, and geodynamic implications, *Tectonophsics*, 483, pp. 214-222.

Wang, K. and Fialko, Y., 2018. Observations and Modeling of Coseismic and Postseismic Deformation Due to the 2015 Mw 7.8 Gorkha (Nepal) Earthquake. *Journal of Geophysical Research Solid Earth*, Vol 123, pp 761-779, doi.org/10.1002/2017JB014620.

Wright, T. J., Lu, Z., Wicks, C., 2003. Source model for the Mw 6.7, 23 October 2002, Nenana Moutain Earthquake (Alaska) from InSAR. *Geophysical Research Letters*, Vol 30 NO. 18, doi.org/10.1029/2003GL018014.

URL1: CROatian Positioning System (CROPOS), https://www.cropos.hr, Accessed 18 June 2019.

URL2: Rete Integrata Nazionale GPS (RING), http://ring.gm.ingv.it, Accessed 18 June 2019.

URL3: SlovenIja-Geodezija-NAvigacija-Lokacija (SIGNAL), http://www.gu-signal.si, Accessed 18 June 2019.

URL4: Hungarian active GNSS network (GNSSnet.hu) https://www.gnssnet.hu, Accessed 18 June 2019.

URL5: Network of permanent GNSS stations of the Federation of Bosnia and Hercegovina (FBiHPOS), http://www.fgu.com.ba, Accessed 19 June 2019.

URL6: Network of permanent GNSS stations of the Republic of Srpska (SRPOS), https://www.rgurs.org/lat/servisi/srpos, Accessed 18 June 2019.

URL7: GNSS permanent station networks to satisfy accuracy (MontePOS), http://www.nekretnine.co.me/me/Montepos.asp, Accessed 18 June 2019.

URL8: COMET-LiCS Sentinel-1 InSAR portal, https://comet.nerc.ac.uk/COMET-LiCS-portal, Accessed 18 June 2019.

URL9: European Database of Seismogenic Faults (EDSF), http://diss.rm.ingv.it/share-edsf, Accessed 18 June 2019.

URL10: Database of Individual Seismogenic Sources (DISS), http://diss.rm.ingv.it/diss, Accessed 18 June 2019.

URL11: ISC-GEM Global Instrumental Earthquake Catalogue, http://www.isc.ac.uk/iscgem, Accessed 18 June 2019.

URL12: SHARE European Earthquake Catalogue (SHEEC), https://www.emidius.eu/SHEEC, Accessed 18 June 2019.

URL13: Advanced Rapid Imaging and Analysis (ARIA), https://aria.jpl.nasa.gov, Accessed 18 June 2019