Report of the
Croatian Committee of Geodesy and Geophysics
on activities carried out between 2015 and 2018

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Photo by Sandro Puncet
Mali Lošinj, 3 September 2017

Contents

Introduction

Croatia was admitted to the International Union of Geodesy and Geophysics (IUGG) soon after gaining independence: its membership status had been provisionally granted by the IUGG Executive Committee already in 1992 and the status was ratified by the IUGG Council at the meeting held in Boulder in 1995. From the beginning, the Croatian Academy of Sciences and Arts was the adhering organization, which supervised the election of members of the Croatian Committee of Geodesy and Geophysics. After being admitted to the IUGG, Croatian geodesists and geophysicists took part in the activities of IUGG associations and in the general assemblies. Moreover, they prepared reports on their work, covering four intervals: 1991–1994 (*Geofizika*, **11**, 1994), 1995–1998 (*Geodetski list*, **53**, 1999), 1999–2002 (*Geofizika*, **18/19**, 2001/2002), and 2011–2014 (*Geofizika*, **32**, 2015). With this report, the practice of informing the IUGG community on Croatian geodetic and geophysical measurements and investigations is continued.

In the following pages, the work carried out between the years 2015 and 2018 by Croatian scientists, active in geodesy and in five geophysical disciplines (geomagnetism and aeronomy, hydrology and physical limnology, meteorology, physical oceanography, and seismology), is documented. The report confirms that Croatian geodesists and geophysicists represent a vibrant part of the scientific community: most often their findings are relevant for Croatia and sometimes their results and methodological improvements turn out to be useful to colleagues working in other countries. Moreover, the report reveals that the activities of Croatian scientists have expanded recently. Thus, for example, hydrological measurements and modelling have been extended so as to include the Plitvice Lakes – a world-famous system of sixteen cascading lakes that are subjected to a considerable anthropogenic pressure. Physical oceanographic investigations have been related more closely than before to meteorological studies, with the aim of addressing generation of meteotsunamis and storm surges in the Adriatic Sea and in some other basins. Finally, seismologists and geodesists have strengthened their cooperation, aiming at a combined use of *in situ* and remotely sensed data in the analysis of seismicity and tectonics of the region. The expansion was apparently stimulated by an improved access to international scientific projects, which supplement the relatively modest national funding of research activities. It is to be hoped that international collaboration of Croatian scientists will further intensify in the future and that the IUGG-related activities will contribute to the intensification.

Mirko Orlić,
President,
Croatian Committee of Geodesy and Geophysics

Geodesy in Croatia, 2015–2018

Report submitted to the International Association of Geodesy of the International Association of Geodesy and Geophisics

Tea Duplančić Leder

Faculty of Civil Engineering, Architecture and Geodesy, University of Split, Croatia

This report presents a brief overview of research activities in the field of geodesy in Croatia in the period from 2015 to the end of 2018. The geodetic research has been carried out mainly at the Geodetic Faculty (GEOF), University of Zagreb, and to a smaller extent at the Faculty of Civil Engineering, Architecture and Geodesy (FGAG), University of Split, and at the State Geodetic Administration (SDA) and University North of Varaždin. Research activities resulted in about a dozen international peer-review (WoS) publications and a dozen of editor's books and book chapters.

FP7 and Horizon 2020 projects:

High-Resolution Solar Physics Network (SOLARNET), Duration: 1/4/2013–31/3/2017, Leader: Roman Brajša PhD.

European Solar Telescope Preparatory Phase (PRE-EST), Duration: 2017–2021, Principal Investigator: Davor Sudar PhD.

Croatian Science Foundation scientific projects:

Development of Multipurpose Land Administration System (DEMLAS), Duration: 1/9/2014–31/8/2018, Principal Investigator: Prof. Miodrag Roić.

Solar and Stellar Variability (SOLSTEL), Duration: 1/9/2014–31/8/2018, Principal Investigator: Bojan Vršnak PhD.

Geospatial Monitoring of Green Infrastructure by Means of Terrestrial, Airborne and Satellite Imagery (GEMINI), Duration: 1/3/2017–1/3/2021, Principal Investigator: Prof. Damir Medak.

Education of New Doctors of Science, Duration: 1/1–31/12/2015, Principal Investigator: Bojan Vršnak PhD.

Projects where the Faculty of Geodesy is a partner:

Advanced Forest Environmental Services Assessment (AFORENSA), Duration 1/7/2014–30/6/2018, Leader: Ivan Pilaš PhD, Leader at the Faculty of Geodesy: Prof. Damir Medak.

Other international scientific-research projects:

ESO Development Plan Study: Solar Research with ALMA, Duration: 1/11/2014–30/4/2017, Principal Investigator: Roman Brajša PhD.

Cosmic Ray Modulation by Solar Coronal Mass Ejections (CORAMOD), bilateral project Croatia–Germany, MZOS–DAAD, Duration: 1/1/2015–31/12/2016, Principal Investigator: Roman Brajša PhD.

European Social Fund (Operational Program "Human Resources Development" 2007–2013): Increasing Competitiveness by Developing Researchers in Physics of the Sun (PoKRet), Duration: 22/7/2015–22/10/2016, Principal Investigator: Mateja Dumbović PhD.

World Bank scientific project: Implementation of the Land Governance Assessment Framework (LGAF) in the Republic of Croatia, Duration: 2–10/2015, Principal Investigator: Prof. Miodrag Roić.

International Croatian-Montenegrin scientific project „GIS baza podataka zaštićenih područja na primjeru objekata geonasljeđa", Duration: 2015–2016, Principal Investigator: Prof. Miljenko Lapaine.
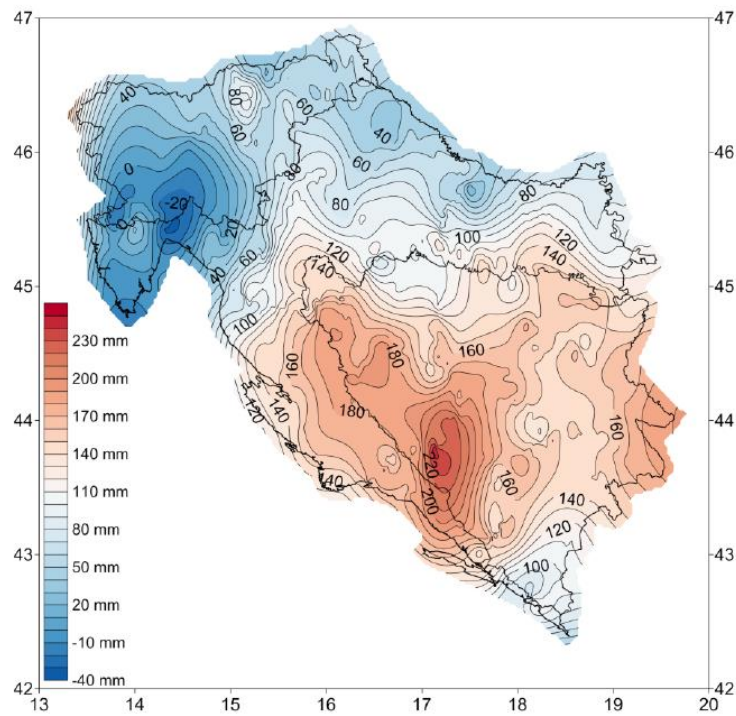
Figure 1. Grid model – parameter ΔH_0 (according to Rožić, 2017).

List of publications

Abramić, A., Kotsev, A., Cetl, V., Kephalopoulos, S., and Paviotti, M. (2017): A spatial data infrastructure for environmental noise data in Europe, *Int. J. Environ. Res. Public Health*, **14 (7)**, 726–740.

Bačić, Ž., Ključanin, S., and Poslončec-Petrić, V. (2017): Analysis of mid-term national spatial data infrastructure strategies in the Western Balkan, *Sci. J. Civ. Eng.*, **6 (2)**, 85–92.

Bačić, Ž., Jogun, T., and Majić, I. (2018): Integrated sensor systems for smart cities, *Teh. vjesn.*, **25 (1)**, 277–284.

Balenović, I., Gašparović, M., Simić Milas, A., Berta, A., and Seletković, A. (2018): Accuracy assessment of digital terrain models of lowland pedunculate oak forests derived from airborne laser scanning and photogrammetry, *Cro. J. For. Eng.*, **39 (1)**, 117–128.

Banak, A., Pikelj, K., Lužar-Oberiter, B., and Kordić, B. (2017): Characteristics of Pleistocene aeolian – alluvial sediments of the northern coastal cliff of Vrgada island (Adriatic sea, Croatia), *Rev. Paralia*, **4**, 17–22.

Baričević, V., Landek, I., and Šantek, D. (2018): Poboljšanje modela podataka CROTIS-a za temeljni paket i objektne cjeline Građevine i Promet, *Geod. list*, **95 (4)**, 277–292.

Batinić, M., Galić, M., Trogrlić, B., Divić, V., Racetin, I., and Mihanović, A. (2018): Combined photogrammetry and mechanical testing of fired clay brick, *Materwiss Werksttech* (0933-5137), **49**, 1399–1408.

Baučić, M. and Medak, D. (2015): Web GIS for Airport Emergency Response – UML Model, *Promet*, (1848-4069), **27 (2)**, 155–164.

Brajša, R., Sudar, D., Benz, A. O., Skokić, I., Bárta, M., De Pontieu, B., Kim, S., Kobelski, A., Kuhar, M., Shimojo, M., Wedemeyer, S. et al. (2018): First analysis of solar structures in 1.21 mm full-disc ALMA image of the Sun, *Astron. Astrophys.* (Berlin), **613**, doi: 10.1051/0004-6361/201730656.

Cetl, V., Kliment, T., and Jogun, T. (2017): A comparison of address geocoding techniques – case study of the city of Zagreb, Croatia, *Surv. Rev.*, **50**, 1–10.

Cetl, V., Kotsev, A., and Dusart, J. (2018): Data-driven economies in the Western Balcans, *Int. Sci. J.: MMM GI*, **10 (1)**, 7–21.

Dumbović, M., Devos, A., Vršnak, B., Sudar, D., Rodriguez, L., Ruždjak, D., Leer, K., Vennerstrøm, S., and Veronig, A. (2015): Geoeffectiveness of coronal mass ejections in the SOHO era, *Sol. Phys.*, **290**, 579–612.

Dumbović, M., Vršnak, B., and Čalogović, J. (2016): Forbush decrease prediction based on remote solar observations, *Sol. Phys*, **291**, 285–302.

Dumbović, M., Srivastava, N., Rao, Y., Vršnak, B., Devos, A., and Rodriguez, L. (2017): Validation of the CME geomagnetic forecast alerts under the COMESEP alert system, *Sol. Phys.*, **292**, doi: 10.1007/s11207-017-1120-5.

Dumbović, M., Čalogović, J., Vršnak, B., Temmer, M., Mays, L., Veronig, M. A., and Piantschitsch, I. (2018): The drag-based ensemble model (DBEM) for coronal mass ejection propagation, *Astrophys. J.*, **854**, doi: 10.3847/1538-4357/aaaa66.

Duplančić Leder, T., Leder, N., and Hećimović; Ž. (2016): Split Metropolitan area surface temperature assessment with remote sensing method – Određivanje površinske temperature tla područja Splita metodom daljinske detekcije, *Građevinar*, **68 (11)**, 895–905.

Duplančić Leder, T. and Leder, N. (2018): Land surface temperature determination in the town of Mostar area, *Teh. vjes.*, **25 (4)**, 1219–1226.

Flego, V. and Roić, M. (2018): Land tenure registration on the marine areas in Croatia, *Ocean Coast. Manage.*, **166**, 72–81.

Forstner, J. L., Guo, J., Wimmer-Schweingruber, R. F., Hassler, D. M., Temmer, M., Dumbović, M., Jian, L. K., Appel, J. K., Čalogović, J., Ehresmann, B. et al. (2018): Using forbush decreases to derive the transit time of ICMEs propagating from 1 AU to Mars, *J. Geophys. Res. – Space Physics*, **123 (1)**, 39–56.

Gašparović, M., Seletković, A., Berta, A., and Balenović, I. (2017): The evaluation of photogrammetry-based DSM from low-cost UAV by LiDAR-based DSM, *Seefor – South-East Eur. For.*, **8 (2)**, 117–125.

Gašparović, M., Dobrinić, D., and Medak, D. (2018): Analiza prostorne točnosti zračnih i satelitskih snimaka grada Zagreba, *Geod. list*, **72 (1)**, 1–14.

Gašparović, I., Gašparović, M., and Medak, D. (2018): Determining and analysing solar irradiation based on freely available data: A case study from Croatia, *Environ. Dev.*, **26**, 55–67.

Gašparović, M. and Jogun, T. (2018): The effect of fusing Sentinel-2 bands on land-cover classification, *Int. J. Remote Sens.*, **39 (3)**, 822–841.

Gorički, M., Poslončec-Petrić, V., Frangeš, S., and Bačić, Ž. (2017): Analysis of solar potential of roofs based on digital terrain model, *ISPRS Archives* (Print), XLII-4/W3, 37–41.

Green, L., Torok, T., Vršnak, B., Manchester, W., and Veronig, A. (2018): The origin, early evolution and predictability of solar eruptions, *Space Sci. Rev.*, **214**, doi: 10.1007/s11214-017-0462-5.

Grgić, M., Varga, M., and Bašić, T. (2015): Empirical research of interpolation methods in distortion modeling for the coordinate transformation between local and global geodetic datums, *J. Surv. Eng.*, **142**, doi: 10.1061/(ASCE)SU.1943-5428.0000154.

Grgić, M., Jukić, S., Nerem, R. S., and Bašić, T. (2017): Satelitska altimetrija: tehnologija i primjena u geodeziji, *Geod. list*, **71 (4)**, 307–326.

Grgić, M., Nerem, R. S., and Bašić, T. (2017): Absolute sea level surface modeling for the Mediterranean from satellite altimeter and tide gauge measurements, *Mar. Geod.*, **40 (4)**, 239–258.

Gulam, V., Gajski, D., and Podolszki, L. (2018): Photogrammetric measurement methods of the gully rock wall retreat in Istrian badlands, *Catena*, **160**, 298–309.

Hećimović, Ž., Župan, R., and Duplančić Leder, T. (2015): Unique grid cell identification of Croatian official map grids, *J. Maps*, **11 (3)**, 506–514.

Hofmeister, S. J., Veronig, A., Reiss, M. A., Temmer, M., Vennerstrom, S., Vršnak, B., and Heber, B. (2017): Characteristics of low-latitude coronal holes near the maximum of solar cycle 24, *Astrophys. J.*, **835**, doi: 10.3847/1538-4357/835/2/268.

Ibrahim, S., Shanmugaraju, A., Moon, Y.J., Vršnak, B., and Umapathy, S. (2018): Properties and relationship between solar eruptive flares and coronal mass ejections during rising phase of solar cycles 23 and 24, *Adv. Space Res.*, **61 (1)**, 540–551.

Jajac, N., Kilić, J., and Rogulj, K. (2018): An integral approach to sustainable decision- making within maritime spatial planning – A DSC for the planning of anchorages on the Island of Šolta, Croatia, *Sustainability*, **11 (1)**, 1–27.

Jeleč, M., Varevac, D., and Rajčić, V. (2018): Cross-laminated timber (CLT) – a state of the art report, *Građevinar*, **70 (2)**, 75–95.

Jovanović, N. and Župan, R. (2017): Analiza stanja vegetacije prije i nakon šumskih požara pomoću satelitskih snimaka Sentinel-2 na području Dalmacije, *Geod. list*, **71 (3)**, 233–248.

Jurkin, E., Šimić Horvath, M., Volenec, V., and Beban-Brkić, J. (2018): Harmonic quadrangle in isotropic plane, *Turk. J. Math.*, **42 (2)**, 666–678.

Kilić, J., Jajac, N., and Marović, I. (2018): GIS-based decision support concept to planning of land acquisition for realization of urban public projects, *Croat. Oper. Res. Rev.*, **9 (1)**, 11–24.

Kranjčić, N., Župan, R., and Rezo, M. (2018): Satellite-based hyperspectral imaging and cartographic visualization of bark beetle forest damage for the city of Čabar, *Teh. vjes.*, **12 (1)**, 39–43.

Krtalić, A., Poslončec-Petrić, V., and Vrgoč, S. (2018): Koncept otkrivanja ilegalnih odlagališta otpada na području grada Zagreba primjenom metoda daljinskih istraživanja, *Geod. list*, **72**, 37–54.

Landek, I., Frangeš, S., and Marjanović, M. (2017): Proposal for establishment of the basic national topographic model (BNTM) in the Republic of Croatia, *Geod. vestn.*, **61 (2)**, 263–277.

Lawrance, M. B., Shanmugaraju, A., and Vršnak, B. (2015): Investigation of X-class flare- associated coronal mass ejections with and without DH Type II radio bursts, *Sol. Phys.*, **290**, 3365–3377.

Lefèvre, L., Vennerstrøm, S., Dumbović, M., Vršnak, B., Sudar, D., Arlt, R., Clette, F., and Crosby, N. (2016): Detailed analysis of solar data related to historical extreme geomagnetic storms: 1868–2010, *Sol. Phys.*, **291 (5)**, 1483–1531.

Long, D. M., Bloomfield, D. S., Chen, P. F., Downs, C., Gallagher, P. T., Kwon, R. Y., Vanninathan, K., Veronig, A. M., Vourlidas, A., Vršnak, B., Warmuth, A., and Žic, T. (2017): Understanding the physical nature of coronal "EIT waves", *Sol. Phys.*, **292**, doi: 10.1007/s11207-016-1030-y.

Lužar-Oberiter, B., Kordić, B., and Mezga, A. (2017): Digital modelling of the Late Albian Solaris dinosaur tracksite (Istria, Croatia), *Palaios.*, **32 (12)**, 739–749.

Mađer, M., Matijević, H., and Roić, M. (2015): Analysis of possibilities for linking Land Registers and Other Official Registers in the Republic of Croatia based on LADM, *Land Use Policy*, **49**, 606–616.

Mahrous, A., Alielden, K., Vršnak, B., and Youssef, M. (2018): Type II solar radio burst band-splitting: Measure of coronal magnetic field strength, *J. Atmos. Solar-Terr. Phys.*, **172 (1)**, 75–82.

Manchester, W., Kilpua, E. K., Liu, J., Ying D., Lugaz, N., Riley, T., Török, T., and Vršnak, B. The physical processes of CME/ICME evolution, *Space Sci. Rev.*, **212 (3-4)**, 1159–1219.

Matoš, B., Zajc, M., Kordić, B., Tomljenović, B., and Gosar, A. (2017): Quaternary fault activity in the SW Pannonian Basin: GPR surveying in Bilogora (NE Croatia), *Geol. Q.*, **61 (1)**, 18–36.

Miler, M., Todić, F., and Ševrović, M. (2016): Extracting accurate location information from a highly inaccurate traffic accident dataset: A methodology based on a string matching technique, *Transp. Res. Part. Emerg. Technol.*, **68**, 185–193.

Miljković, V., Gajski, D., and Vela, E. (2017): Spatial calibration of the hyperspectral line scanner by the bundle block adjusting method, *Geod. list.*, **71 (2)**, 127–142.

Möstl, Ch., Rollett, T., Frahm, R. A., Liu, Y. D., Long, D. M., Colaninno, R. C., Reiss, M. A., Temmer, M., Farrugia, Ch. J., Posner, A., Dumbović, M., Janvier, M., Démoulin, P., Boakes, P., Devos, A., Kraaikamp, E., Mays, M. L., and Vršnak, B. (2015): Strong coronal channelling and interplanetary evolution of a solar storm up to Earth and Mars, *Nat. Commun.*, **6**, 7135.

Odak, I., Tomić, H., and Mastelić Ivić, S. (2017): Vrednovanje fragmentacije poljoprivrednog zemljišta, *Geod. list*, **71 (3)**, 215–232.

Paunzen, E., Handler, G., Lendl, M., Baumann, B., Rab, Ch., Meingast, S., Rode-Paunzen, M., Netopil, Martin, A., Victoria, Z., Liying et al. (2017): Search for variables in six Galactic open clusters, *New. Astron.*, **52**, 133–139.

Piantschitsch, I., Vršnak, B., Hanslmeier, A., Lemmerer, B., Veronig, A., Hernandez-Perez, A., Čalogović, J., and Žic, T. (2017): A numerical simulation of coronal waves interacting with coronal holes, I, basic features, *Astrophys. J.*, **850 (1)**, doi: 10.3847/1538-4357/aa8cc9.

Piantschitsch, I., Vršnak, B., Hanslmeier, A., Lemmerer, B., Veronig, A., Hernandez-Perez, A., and Čalogović, J. (2018): Numerical simulation of coronal waves interacting with coronal holes, II, Dependence on Alfvén speed inside the coronal Hole, *Astrophys. J.*, **857 (2)**, doi: 10.3847/1538-4357/aab709.

Piantschitsch, I., Vršnak, B., Hanslmeier, A., Lemmerer, B., Veronig, A., Hernandez-Perez, A., and Čalogović, J. (2018): Numerical simulation of coronal waves interacting with coronal holes, III, Dependence on initial amplitude of the incoming wave, *Astrophys. J.*, **860 (1)**, doi: 10.3847/1538-4357/aabe7f.

Pikelj, K., Ružić, I., Ilić, S., James, M. R., and Kordić, B. (2018): Implementing an efficient beach erosion monitoring system for coastal management in Croatia, *Ocean. Coast. Manage.*, **156**, 223–238.

Pokupić, M., Varga, M., and Bašić, T. (2018): Modeli geomorfometrijskih parametara i drenažnih mreža za prostor Republike Hrvatske, *Hrvatski geografski glasnik*, **80 (1)**, 61–76.

Poljančić Beljan, I., Jurdana-Šepić, R., Brajša, R., Sudar, D., Ruždjak, D., Hržina, D., Pötzi, W., Hanslmeier, A., Veronig, A., Skokić, I., and Wöhl, H. (2017): Solar differential rotation in the period 1964–2016 determined by the Kanzelhöhe data set, *Astron. Astrophys.*, **606**, doi: 10.1051/0004-6361/201731047.

Pribičević, B., Govorčin, M., and Đapo, A. (2017): Surface deformation monitoring in the Republic of Croatia with MT-InSAR, *Annual of the Croatian Academy of Engineering*, **1 (25)**, 371–381.

Racetin, I. (2015): Feature definitions in feature catalogues, *Cartogr. J.*, **52(1)**, 67–72.

Radanović, M. and Bašić, T. (2018): Accuracy assessment and comparison of interpolation methods on geoid models, *Geod. vestn.*, **62 (1)**, 68–78.

Radanović, M., Razumović, I., and Rožić, N. (2017): Analiza kvalitete Hrvatskog transformacijskog modela visina primjenom računalnog programa HTMV_bbi_v.2, *Geod. list*, **71 (2)**, 109–126.

Radanović, M. and Rožić, N. (2018): Ispitivanje kvalitete kinematičkog modela recentnih relativnih visinskih gibanja Zemljine kore na teritoriju poluotoka Istre, *Geod. list*, **72 (2)**, 75–92.

Rotter, T., Veronig, A., Temmer, M., and Vršnak, B. (2015): Real-time solar wind prediction based on SDO/AIA coronal hole dana, *Sol. Phys.*, **290 (5)**, 1355–1370.

Rožić, N. (2017): Quality evaluation of height movement kinematic model of the Earth's crust on the Croatian territory, *Geofizika*, **34**, 67–92

Rumora, L., Miler, M., and Medak, D. (2018): Utjecaj fuzije snimki na promjenu površine šumskog područja koristeći nenadziranu klasifikaciju, *Šumar. list*, **1–2**, 67–75.

Ruždjak, D., Brajša, R., Sudar, D., Skokić, I., and Poljančić Beljan, I. (2017): A relationship between the solar rotation and activity analysed by tracing sunspot groups, *Sol. Phys.*, **292 (179)**, 1–11.

Ruždjak, D., Sudar, D., Brajša, R., Skokić, I., Poljančić Beljan, I., Jurdana Šepić, R., Hanslmeier, A., Veronig, A., and Pötzi, W. (2018): Meridional motions and Reynolds stress determined by using Kanzelhöhe drawings and white light solar images from 1964 to 2016, *Sol. Phys.*, **293 (59)**, 1–12.

Selvarani, G., Shanmugaraju, A., Vršnak, B., and Lawrance, B. (2017): Investigation on m-class flare-associated coronal mass ejections with and without DH Type II radio bursts, *Sol. Phys.*, **292**, doi: 10.1007/s11207-017-1097-0.

Schmieder, B., Aulanier, G., and Vršnak, B. (2015): Flare-CME models: An observational perspective, *Sol.Phys.*, **290**, 3457–3486.

Shimojo, M., Bastian, T. S., Hales, A. S., White, S. M., Iwai, K, Hills, R. E., Hirota, A., Phillips, N. M., Sawada, T., Yagoubov, P. et al. (2017): Observing the sun with the Atacama large millimeter/submillimeter array (ALMA): High-resolution interferometric imaging, *Sol. Phys.*, **292**, doi: 10.1007/s11207-017-1095-2.

Sudar, D., Skokić, I., Brajša, R., and Saar S. H. (2015): Steps towards a high precision solar rotation profile: Results from SDO/AIA coronal bright point dana, *Astron. Astrophys.*, **575**, doi: 10.1051/0004-6361/201424929.

Sudar, D., Saar, Steven H., Skokić, I., Poljančić Beljan, I., and Brajša, R. (2016): Meridional motions and Reynolds stress from SDO/AIA coronal bright points dana, *Astron. Astrophys.*, **587**, doi: 10.1051/0004-6361/201527217.

Sudar, D., Vršnak, B., and Dumbović, M. (2016): Predicting coronal mass ejections transit times to Earth with neural network, *Mon. Not. R. Astron. Soc.*, **456 (2)**, 1542–1548.

Sudar, D., Brajša, R., Skokić, I., Poljančić Beljan, I., and Wöhl, H. (2017): Meridional motion and Reynolds stress from Debrecen photoheliographic Dana, *Sol. Phys.*, **292**, doi: 10.1007/s11207-017-1105-4.

Tavra, M., Duplančić Leder, T., and Cetl, V. (2018): Stakeholders needs requisite analysis: towards Croatian marine spatial data infrastructure establishment, *Teh. vjes.*, **25**, Supplement 1, 176–182.

Šljivarić, M., Rezo, M., and Grgić, I. (2018): Methods of modelling the distortion caused by different amount and orientation of coordinate corrections between two coordinate systems at various locations, *Teh. vjes.*, **25 (1)**, 1–9.

Šljivarić, M., Rezo, M., and Pavasović, M. (2018): Residual filtering methods for the purpose of computing the coordinate transformation distortion model, *Teh. vjes.*, **25 (6)**, 1650–1658.

Tavra, M., Jajac, N., and Cetl, V. (2017): Marine spatial data infrastructure development framework: Croatia case study, *ISPRS Int. J. of Geo-Inf.*, **6 (4)**, 1–15.

Tomić, H., Mastelić Ivić, S., and Roić, M. (2018): Land consolidation suitability ranking of cadastral municipalities: information-based decision-making using multi-criteria analyses of official registers' Dana, *ISPRS Int. J. of Geo.-Inf.*, **7 (3)**, 1–17.

Tutić, D., Jogun, T., Kuveždić Divjak, A., and Triplat Horvat, M. (2017): World political map from OpenStreetMap data, *J. Maps*, **13 (1)**, 67–73.

Tutić, D., Štanfel, M., and Triplat Horvat, M. (2018): Multi-criteria land evaluation of suitability for the sport of foot orienteering: a case study of Croatia and Slovenia, *ISPRS Int. J. of Geo.-Inf.*, **7**, doi: 10.3390/ijgi7060227.

Varga, M. and Bašić, T. (2015): Accuracy validation and comparison of global digital elevation models over Croatia, *Int. J. Remote Sens.*, **36 (1)**, 170–189.

Varga, M., Grgić, M., and Bašić, T. (2015): Empirical comparison of the geodetic coordinate transformation models: a case study of Croatia, *Surv. Rev.*, **48**, 1–13.

Vennerstrom, S., Lefevre, L., Dumbović, M., Crosby, N., Malandraki, O., Patsou, I., Clette, F., Veronig, A., Vršnak, B., Leer, K., and Moretto, T. (2016): Extreme geomagnetic storms – 1868–2010, *Sol. Phys.*, **291 (5)**, 1447–1481.

Vlastelica, G., Pikelj, K., and Kordić, B. (2017): Erosional processes acting on coastal cliffs in the Split urban zone, Croatia, *Rev. Paralia*, **4**, 79–84.

Vranić, S., Matijević, H., and Roić, M. (2015): Modelling outsourceable transactions on polygon based cadastral parcels, *Int. J. Geog. Inf. Sci.*, **29** (3), 454–474.

Vršnak, B. (2016): Solar eruptions: The CME-flare relationship, *Astron. Nachr.*, **337 (10)**, 1002–1009.

Vršnak, B., Žic, T., Lulić, Slaven, Temmer, M., and Veronig, A. (2016): Formation of coronal large-amplitude waves and the chromospheric response, *Sol. Phys.*, **291**, 88–115.

Vršnak, B., Dumbović, M., Čalogović, J., Verbanac, G., and Poljančić Beljan, I. (2017): Geomagnetic effects of corotating interaction regions, *Sol. Phys.*, **292**, doi: 10.1007/s11207-017-1165-5.

Vučić, N., Roić, M., Mađer, M., Vranić, S., and van Oosterom, P. (2017): Overview of the Croatian Land Administration System and the possibilities for its upgrade to 3D by existing data, *ISPRS Int. J. of Geo.-Inf.*, **6**, doi: 10.3390/ijgi6070223.

Vujić, E. (2015): Short-term tests of Potassium dIdD vector magnetometer, *Acta Geophys.*, **63 (5)**, 1276–1295.

Vujić, E. and Brkić, M. (2015): Data reduction of Croatian geomagnetic repeat stations surveys by using the spherical elementary current systems method, *Studia Geophys. Geod.*, **59 (4)**, 635–646.

Vujić, E. (2016): On data interpolation at three Croatian repeat stations by using the spherical elementary currents systems method, *Acta Geophys.*, **64 (2)**, 320–335.

Vujić, E. and Brkić, M. (2016): Estimation of influence of unequal secular variation on geomagnetic data reduction, *Stud.. Geophys. Geod.*, **60 (1)**, 162–176.

Vujić, E. and Brkić, M. (2016): Spherical elementary current systems method applied to geomagnetic field modeling for Adriatic, *Acta Geophys.*, **64 (4)**, 930–942.

Wang, Y., Zhang, Q., Liu, J., Shen, Ch., Shen, F., Yang, Z., Žic, T., Vršnak, B., Webb, D.F., Liu, R., Wang, S., Zhang, J., Hu, Q., and Zhuang, B. (2016): On the propagation of a geoeffective coronal mass ejection during 15–17 March 2015, *J. Geophys. Res. – Space Physics*, **121 (8)**, 7423–7434.

Wedemeyer, S., Bastian, T., Brajša, R., Barta, M., Hudson, H., Fleishman, G., Loukitcheva, M., Fleck, B., Kontar, E., DePontieu, B., Tiwari, S., Kato, Y., Soler, R., Yagoubov, P., Black, J. H., Antolin, P., Gunar, S., Labrosse, N., Benz, A. O., Nindos, A., Steffen, M., Scullion, E., Doyle, J. G., Zaqarashvili, T., Hanslmeier, A., Nakariakov, V. M., Heinzel, P., Ayres, T., and Karlicky, M., (2015): The SSALMON Group, SSALMON – The solar simulations for the atacama large millimeter observatory network, *Adv. Space Res.*, **56**, 2679–2692.

Wedemeyer, S., Bastian, T., Brajša, R., Hudson, H., Fleishman, G., Loukitcheva, M., Fleck, B., Kontar, E., DePontieu, B., Yagoubov, P., Tiwari, S. K., Soler, R., Black, J. H., Antolin, P., Scullion, E., Gunar, S., Labrosse, N., Ludwig, H.-G., Benz, A. O., White, S. M., Hauschildt, P., Doyle, J. G., Nakariakov, V. M., Ayres, T., Heinzel, P., Karlicky, M., Van Doorsselaere, T., Gary, D., Alissandrakis, C. E., Nindos, A., Solanki, S. K., Rouppe van der Voort, L., Shimojo, M., Kato, Y., Zaqarashvili, T., Perez, E., Selhorst, C. L., and Barta, M. (2016): Solar science with the atacama large millimeter/submillimeter array – a new view of our Sun, *Space Sci. Rev.*, **200**, 1–73.

White, S. M, Iwai, K., Phillips, N. M., Hills, R. E., Hirota, A., Yagoubov, P., Siringo, G., Shimojo, M., Bastian, T. S., Hales, A. S. et al. (2017): Observing the Sun with the Atacama Large Millimeter/submillimeter Array (ALMA): fast-scan single-dish mapping, *Sol. Phys.*, **292 (7)**, 88–91.

Žic, T., Vršnak, B., and Temmer, M. (2015): Heliospheric propagation of coronal mass ejections: Drag-based model fitting, *Astrophys. J. Suppl. S.*, **218 (2)**, 32–39.

Župan, R. and Frangeš, S. (2015): Map of the Diocese of Požega (Dioecesis Posegana), *J. Maps*, **11 (3)**, 496–505.

Župan, R., Frangeš, S., and Jagetić, J. (2018): Roman Catholic Diocese of Varaždin (Dioecesis Varasdinum), *J. Maps*, **14 (2)**, 509–516.

Geomagnetism and aeronomy in Croatia, 2015–2018

Giuliana Verbanac

Geophysical Department, Faculty of Science, University of Zagreb, Croatia

This report aims to provide an overview of the research, professional and education activities in the field of geomagnetism and aeronomy that have been carried out at the Department of Geophysics, Faculty of Science, University of Zagreb and some other institutions during the time span 2015–2018. The report is organized as follows. First, the research activity is outlined. Second, the professional work is described. The educational engagement follows. Finally the public outreach is reported.

The performed research studies in this period are very interdisciplinary embracing different parts of the geomagnetic field, aeronomy, changes on the Sun, in the interplanetary space, and related responses of the Earth's magnetosphere and ionosphere. Accordingly, the research topics are also related to space weather and therefore are of broad interests and applications. Ground based data and data from satellites with orbits both within the magnetosphere and in the interplanetary space are generally employed in the analyses.

The temporal changes in the monthly magnetic observatory biases at 42 stations within the 2000–2009 interval are analysed by employing the model entirely based on geomagnetic observatory data and data provided by the CHAMP satellite. The bias evolution over several years to three decades (long-term trends) as well as its variation on a timescale of several months to one year is investigated. The comparison with biases based on two months of MAGSAT and Ørsted satellite data, related to the 1979.92 and 1992.92 epochs, is performed. The results indicate that the crustal magnetic field has probably not changed over the studied time span. This investigation and the obtained results are presented in the work by Verbanac et al. (2015).

Brajša et al. (2015) investigated the possibility to predict and reconstruct the solar cycle 24 by applying the modified minimum–maximum method, which belongs to the precursor class of methods, to the smoothed monthly sunspot values. A comparison between the observed and predicted amplitude of the 24th solar cycle is performed. The obtained results indicate that the applied minimum–maximum method is a reliable one for the solar cycle prediction, and moreover allow to predict the subsequent solar maximum amplitude already three years before the preceding minimum of solar activity.

Relationship between plasmapause, solar wind and geomagnetic activity between 2007 and 2011 is obtained using ACE and CLUSTER satellite data (Verbanac at al., 2015). The time delay of the plasmapause response to solar wind parameters and geomagnetic activity in different magnetic local times (MLT) is obtained by applying the cross-correlation analyses. In the study by Bandić at al. (2016) the MLT plasmapause dependence is further analysed for different phase of the solar cycle using CRRES satellite data. MLT propagation of the plasmapause is inferred from THEMIS satellite data by investigating the cross-corellation curves in each 1 hour MLT bin and the results are given in the study by Bandić at al. (2017).

Verbanac et al. (2018) compared the plasmapause characteristics obtained from THEMIS satellite data with the numerical simulations based on the interchange instability physical mechanism. The global plasmapause characteristics as the MLT sectors of the plasmapause erosion and azimuthal plasmapause motion are derived. This work has shown

that the global plasmapause behaviour is indeed in agreement with interchange instability mechanism. The great importance of this study is that it contributes to resolve some of the long-lasting issues related to plasmapause formation and dynamics.

Observations from the European quasi-Meridional Magnetometer Array (EMMA) and their comparison with Dynamic Global Core Plasma Model (DGCPM) are considered by Jorgensen et al. (2017). The DGCPM model is modified in order to better fit the observations. The results suggest faster daytime refilling and nighttime loss.

In the study by Mandić and Korte (2017) the method for automatic estimation of the observatory baselines is presented. It is demonstrated that preparation of definitive geomagnetic data is possible within one year. The performed comparison with the baselines reported on INTERMAGNET DVDs for the period 2009–2011 has shown that the proposed method may be suitable for automatic data processing when automated absolute instruments are placed at remote sites.

Geomagnetic effects of corotating interaction regions from 2005 throughout 2008, the period belonging to the declining phase of Solar Cycle 23 which are characterized by a particularly low number of interplanetary coronal mass ejections, is presented by Vršnak (2017). The statistical relationship between solar wind flow speed, magnetic field, and the convective electric field based on the southward magnetic field component is quantified.

Research results were presented at international conferences. Status report related to research activity in the fields was also presented at Europlanet NA1 Annual Meeting and Inclusiveness Forum in 2018 by G. Verbanac. There, the ongoing activities at Geophysical Department were especially emphasized.

The topics related to geomagnetism, aeronomy and space weather in general have been promoted within the Adriatic Aerospace Association since spring 2018 contributing to the professional activity in the fields. Further, the professional work was dedicated to geomagnetic observatory practice. Based on the quality of the data collected at geomagnetic observatory Lonjsko Polje during 2014 and 2015, the observatory took part in the INTERMAGNET network in February 2016. The official IAGA code LON was associated to the observatory. The verification of the quality of the first collected data is documented by Mandić et al. (2016). The observatory has been working almost permanently until today. In 2017 and 2018 the problems with the LEMI-03 magnetometar occurred. Fortunately, the problems were fixed at the end of 2018. Thereafter, the data have been continuously sent to European quasi-Meridional Magnetometer Array (EMMA) network reqularly in real time. Additional problems with running the observatory occurred in 2018 caused by natural disasters (flood). Since 2017 the observatory also serves for testing the instrumentation which has been used for reapeat station measurements in the framework of the project "Second Geomagnetic Information Renewal Cycle in the Republic of Croatia" that is led by the Faculty of Geodesy, University of Zagreb. Three workshops were attended (two IAGA and one MagNetE workshops) which contributed to new knowledge and enlarged experience related to observatory practice and instrumentation.

Except for the contacts that have been already put in place, the international collaboration in the fields of geomagnetism, aeronomy, solar physics and generally in planetary science is further extended in the period 2015–2018.

The education is actively performed at the Geophysical Department through the university undergraduate courses: Planetology, Geomagnetism, Aeronomy, Geophysical Practicum as well as university doctoral course: Planetary Magnetism. Important to note is that these courses for the first time in Croatia embrace fundamentals of plasma physics, magnetospheric physics, solar physics, geomagnetism in all aspects, high ionospheric levels (ionosphere and thermosphere), and planetary science in general. Through these courses the students gain diverse knowledge that allow them to easily fit in different international groups.

The appropriate examples are the current visits of six months to one year of two students at the very well known international institutions (University of Graz, Austria and Max-Planck institute Goetingen, Germany) where they have so far demonstrated great capability to successfully face with all physical problems and tasks within the fields. Further, within the course Geophysical Practicum student visit to the geomagnetic observatory LON is organized, which helps them to better adopt the knowledge attained at other regular courses. Students acquire additional knowledge in the fields by preparing diploma theses and publications. In the reported period, one doctoral thesis that focused on quality and proposals for improvements in the baseline adaption at geomagnetic observatories was defended (Mandić, 2017).

Last, but not the least, it is important to note that geomagnetism, aeronomy and space science are regularly promoted to the wider audience through public talks, tribunes, festivals, talks at schools, and popular scientific articles (e.g., Jerčić and Verbanac, 2018; Andrić and Verbanac, 2017; Majstorović and Verbanac, 2015; Belinić and Verbanac, 2015).

List of publications

Andrić, T. and Verbanac, G. (2017): Pregled unutrašnje građe planeta Sunčeva sustava, *Čovjek i svemir*. Zvjezdarnica Zagreb – Zagrebački astronomski savez.

Bandić, M., Verbanac, G., Moldwin, M. B., Pierrard, V., and Piredda, G. (2016): MLT dependence in the relationship between plasmapause, solar wind, and geomagnetic activity based on CRRES: 1990–1991, *J. Geophys. Res. Space Physics*, **121**, 4397–4408, doi: 10.1002/2015JA022278.

Bandić, M., Verbanac, G., Pierrard, V., and Cho, J. (2017): Evidence of MLT propagation of the plasmapause inferred from THEMIS data, *J. Atmosph. Sol. Terr. Phys.*, **161**, 55–63, doi: 10.1016/j.jastp.2017.05.005.

Belinić, T. and Verbanac, G. (2015): Unutrašnjosti planeta Sunčevog sustava, *Čovjek i svemir*. Zvjezdarnica Zagreb – Zagrebački astronomski savez.

Brajša, R., Verbanac, G., Sudar, D., Skokic, I., Zic, T., Hanslmeier, A., Woehl, H., Roth, M., Mursula, K., and Zhang, L. (2015): A comparison between the observed and predicted amplitude of the 24th solar cycle, *Cent. Eur. Astrophys. Bull.*, **39**, 135–144.

Jerčić, V. and Verbanac, G. (2018): Jupiterov satelit Io i njegova vulkanska aktivnost, *Čovjek i svemir*. Zvjezdarnica Zagreb – Zagrebački astronomski savez.

Jorgensen, A. M., Heilig, B., Vellante, M., Lichtenberger, J., Reda, J., Valach, F., and Mandić, I. (2017): Comparing the Dynamic Global Core Plasma Model with ground-based plasma mass density observationsm, *J. Geophys. Res. Space Physi*cs, **122**, 8, 7997–8013.

Mandić, I., Vujić, E., Heilig, B., Pelajić, I., and Herak, D. (2016): Recent efforts toward the establishment of the Lonjsko Polje Geomagnetic Observatory, *Acta Geophys*., **64**, 5, 1311–1339.

Mandić, I. and Korte, M. (2017): On the possibility of producing definitive magnetic observatory data within less than one year, *Acta Geophys*., **65**, 2, 275–286.

Mandić, I. (2017): *Quality issues and proposals for improvements in the baseline adaption at geomagnetic observatories,* PhD Thesis, University of Zagreb, Zagreb, 101 pp.

Verbanac, G. and Majstorović, J. (2015): Vulkanizam u Sunčevom sustavu, *Čovjek i svemir*. Zvjezdarnica Zagreb – Zagrebački astronomski savez.

Verbanac, G., Pierrard, V., Bandić, M., Darrouzet, F., Rauch, J.-L., Décréau, P. (2015): Relationship between plasmapause, solar wind and geomagnetic activity between 2007 and 2011, *Ann. Geophys.*, **33**, 1271–1283, Special Issue: Dynamic Processes in Geospace, doi: 10.5194/angeo-33-1271-2015.

Verbanac, G., Mandea, M., Bandić, M., and Subasic, S. (2015): Magnetic observatories: biases over CHAMP satellite mission, *Solid Earth*, **6**, 775–781, doi: 10.5194/se-6-775-2015.

Verbanac, G., Bandić, M., Pierrard, V., and Cho, J. (2018): MLT plasmapause characteristics: Comparison between THEMIS observations and numerical simulations, *J. Geophys. Res. Space Physics*, **123**, 2000–2017, doi: 10.1002/2017JA024573.

Vršnak, B., Dumbović, M., Čalogović, J., Verbanac, G., and Poljančić Beljan, I. (2017): Geomagnetic effects of corotating interaction regions, *Solar Phys.*, **292**, 140-1-140-20, doi: 10.1007/s11207-017-1165-5.

Hydrology and physical limnology in Croatia, 2015-2018

Vesna Denić-Jukić

University of Split, Faculty of Civil Engineering, Architecture and Geodesy, Split, Croatia

This report presents the research activities in the field of hydrology in Croatia in the period from 2015 to the end of 2018. Several institutions were involved in the hydrological investigations during this period (Faculty of Civil Engineering, Zagreb; Faculty of Civil Engineering, Architecture and Geodesy, Split; Faculty of Civil Engineering, Rijeka; Faculty of Civil Engineering, Osijek; Faculty of Mining, Geology and Petroleum Engineering, Faculty of Science, Zagreb; Croatian Waters; Croatian Meteorological and Hydrological Service). The scientific interest of Croatian hydrologists ranged from local to world-wide hydrology. The scientific work of the scientists involved in the students education is mostly continuation of previous investigation in the field of karst hydrology and hydrogeology. The results of their scientific researches are published and presented through the international conferences and scientific papers in well recognized scientific journals covering hydrological topics (*Journal of Hydrology, Catena, Natural Hazards and Risk, Hydrological Processes, Hydrological Sciences Journal, Hydrology Research, Water, Geoscience, Environmental Earth Sciences, Journal of Hydroinformatics, Theoretical and Applied Climatology, Acta Carsologica …*).

The hydrological projects were mostly performed by the experts from the Croatian Meteorological and Hydrological Service. The projects are enumerated as follows:

1. CroClimGoGreen – Croatian Climate Variability and Change – From Global Impacts to Local Green Solutions.
2. AdriaMORE – Adriatic decision support system exploitation for integrated MOnitoring and Risk management of coastal flooding and Extreme weather.
3. DriDanube – Drought Risk in the Danube Region.
4. Flood Risk Slovenia-Croatia Operations – Strategic Project 1 – Nonstructural Measures (FRISCO 1).
5. EUMETNET**:** Climate service is currently a rapidly growing area due to different initiatives and additional players (e.g. Copernicus Climate Change Service C3S). Therefore it is necessary that European NMHSs as a EUMETNET members follow up on the associated innovations and development. Moreover interaction between the NMHS, and between the NMHS and European organisations and stakeholders, is necessary. This programme aims at supporting the members of EUMETNET in both tasks.
6. PannEx: Regional Hydroclimate Project (RHP) of the World Climate Research Programme (WCRP).
7. HyMeX is an international project which aims at: improving our understanding of the water cycle, with emphases on extreme events by means of monitoring and modelling the Mediterranean coupled system (atmosphere-land-ocean), its variability (from the event scale to the seasonal and interannual scales) and characteristics over one decade in the context of global change, evaluating societal and economical vulnerability and adaptation capacity to extreme meteorological and climate events.

Considering physical limnology, during the reporting period one study of surface seiches was performed (Pasarić and Slaviček, 2016) and an ongoing research project (*Hydrodynamic modeling of Plitvice Lakes system*, funded by Plitvice Lakes National Park, Croatia) was initiated. The project is interdisciplinary and collaborative between three institutions: Department of Geophysics (Faculty of Science, University of Zagreb), Faculty of Civil Engineering (University of Rijeka), and Faculty of Geotechnical Engineering (University of Zagreb). It encompasses meteorology, hydrology, physical limnology and hydrogeochemistry. The main goal is to establish coupled atmosphere-lake numerical model for prediction of lake temperatures, currents, and water levels, while the main challenge is the complex setup of sixteen karstic lakes, which are interconnected by cascades and waterfalls. This is the first-ever research project performed in Croatia which focuses on physical limnology (Klaić et al., 2018). So far, some preliminary modeling (Fig. 1) and experimental results (Fig. 2) are obtained.
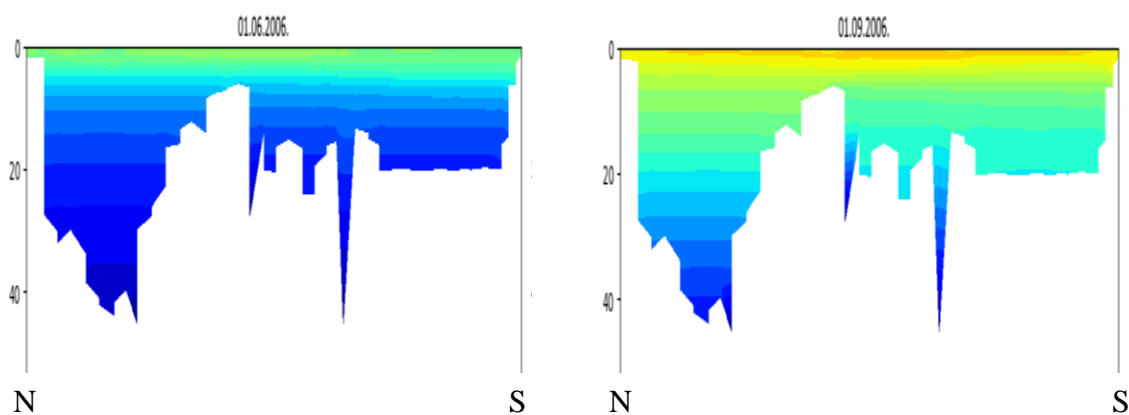

Figure 1. Modeled north-south vertical profile of Kozjak Lake temperature for 1 June 2006 and 1 September 2006 (left and right, respectively). Temperature values (°C) are indicated by a colorbar, while ordinate shows the depth (m).
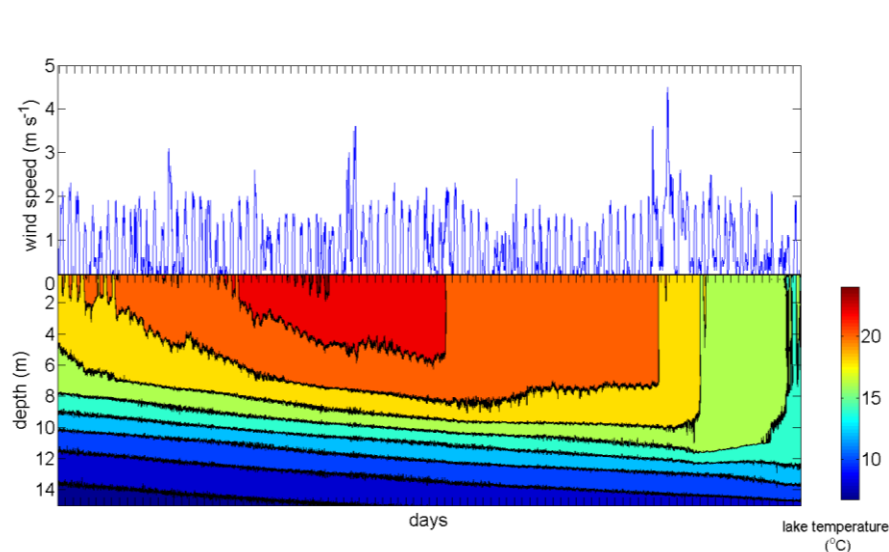

Figure 2. Observed wind speeds and concurrent Kozjak Lake temperatures for the period from 6 July to 10 October 2018. Wind and lake temperature data were recorded at resolution of 1 h and 2 min, respectively.

Croatian scientists from other institutions have been included in activities of numerous international and national conferences and a number of scientific papers were published covering theoretical and practical topics in hydrology. Mostly, the papers are ralated to the numerical modelling, rainfall-runoff modeling in karst areas, water balance modelling, time series analysis, hydrometry of uninvestigated area in karst, and the determination of hydrogeological properties of a complex Dinaric karst catchments. Also, the 6th Croatian Water Conference with international participation, named Croatian Waters on the Investment Waves, was organized in Opatija (2015).

The whole scientific work regarding hydrology in Croatia is documented in the publications the list of which is attached to this report. The list contains scientific papers published in Croatian and international journals.

List of publications

Andrić, I., Bonacci, O., and Jukić, B. (2017): Hidrološka mjerenja na Crvenom jezeru u razdoblju od 28. rujna 2013. do 10. rujna 2015., *Hrvatske vode*, **25 (102)**, 255–260.

Babić Mladenović, M., Bekić, D., Grošelj, S., Mikoš, M., Kupusović, T., and Oskoruš, D. (2015): Establishment of the sediment monitoring system for the Sava River basin, *Water Research and Management*, **5 (4)**, 3–14.

Barbalić, D. and Kuspilić, N. (2015): Indikatori unutardnevnih hidroloških promjena, *Teh. vjesn.*, **22 (5)**, 1345–1352.

Belušić, A., Telišman Prtenjak, M., Güttler, I., Ban, N., Leutwyler, D., and Schär, C. (2017): Near-surface wind variability over the broader Adriatic region: insights from an ensemble of regional climate models, *Clim. Dynam.*, **50**, 4455–4480.

Benac, Č., Rubinić, J., Ružić, I., and Radišić, M. (2017): Geomorfološka evolucija riječnih dolina i ušća na istarskom poluotoku, *Hrvatske vode*, **24 (100)**, 71–80.

Berbić, J., Ovcirk, E., and Gilja, G. (2018): Usporedba metoda nadziranog učenja u svrhu predviđanja srednjeg mjesečnog protoka, *Građevinar*, **70**, 643–656.

Biondić, R., Meaški, H., and Biondić, B. (2016): Hydrogeology of the sinking zone of the Korana River deownstream of the Plitvice Lakes, Croatia, *Acta Carsol.*, **45**, 43–56.

Blagus, M. and Tadić, L. (2018): Obnova vodotoka – mjera zaštite i poboljšanja riječnog ekosustava, *Hrvatske vode*, **26 (106)**, 239–247.

Blöschl, G., Hall, J., Parajka, J., Perdigão, R., Merz, B., Arheimer, B., Aronica, G., Bilibashi, A., Bonacci, O., Borga, M., Čanjevac, I., Castellarin, A., Chirico, G., Claps, P., and Živković, N. (2017): Changing climate shifts timing of European floods, *Science*, **357**, 588–590.

Bonacci, O. (2015): Surface waters and groundwater in karst, Karst aquifers characterization and engineering, Berlin, Heidelberg: Springer Verlag, 149–167.

Bonacci, O. (2015): Karst hydrogeology/hydrology of Dinaric chain and Isles, *Environ. Earth Sci.*, **74**, 37–55.

Bonacci, O. (2015): Hidrološka analiza krškog izvora Rumin Veliki, *Hrvatske vode*, **23 (93)**, 201–210.

Bonacci, O. (2015): Space for the river – prostor za rijeku, Hrvatske vode, **23 (93)**, 222–231.

Bonacci, O. (2015): Quo vadis hydrologia? (Kuda ideš hidrologijo?), *Vodoprivreda*, **47**, 15–28.

Bonacci, O. (2015): Podnebne spremembe – dvomi iz preteklosti in sedanjosti, *Acta Hydrotehnica*, **28**, 39–47.

Bonacci, O. and Andrić, I. (2015): Karst spring catchment: an example from Dinaric karst, *Environ. Earth Sci.*, **74**, 6211–6223.

Bonacci, O. and Andrić, I. (2015): Hidrološka analiza krškog izvora Žrnovnice kod Splita, *Hrvatske vode*, **23 (94)**, 39–47.

Bonacci, O., Popovska, C., and Geshovska, V. (2015): Analysis of transboundary Dojran Lake mean annual water level changes, *Environ. Earth Sci.*, **73**, 3177–3185.

Bonacci, O. and Roje-Bonacci, T. (2015): Drastic hydrological changes caused by hydroelectrical development in karst: a case of the karst river Zrmanja (Croatia), *Environ. Earth Sci.,* **74**, 6767–6777.

Bonacci, O. and Roje-Bonacci, T. (2015): Analiza hidroloških promena duž toka reke Zrmanje, *Vodoprivreda*, **47**, 177–186.

Bonacci, O. (2016): Hidrološka analiza pojave mutnoće na izvorima u kršu: interpretacija podataka mjerenih na izvoru Omble, *Hrvatske vode*, **24 (95)**, 47–57.

Bonacci, O. (2016): Špilje u kršu kao mjesta koja sadržavaju brojne i značajne informacije ključne za razumijevanje prošlosti i korisne za sadašnjost i budućnost, *Hrvatske vode*, **24 (97)**, 233–240.

Bonacci, O. (2016): River – the bloodstream of landscape and catchment reka; Reka – življenski tok krajine in porečja, *Acta Hydrotehnica*, **29**, 1–12.

Bonacci, O., Buzjak, N., and Roje-Bonacci, T. (2016): Changes in hydrological regime caused by human intervention in karst: a case of the Rumin Springs, *Hydrolog. Sci. J.*, **61**, 2387–2398.

Bonacci, O., Andrić, I., and Roje-Bonacci, T. (2017): Hydrological analysis of Skradinski Buk tufa waterfall (Krka River, Dinaric karst, Croatia), *Environ. Earth Sci.*, **76**, doi: 10.1007/s12665-017-7023-9.

Bonacci, O., Oštrić, M., and Roje-Bonacci, T. (2017): Prilog hidrologiji krškog izvora Rječine, *Hrvatske vode*, **25 (100)**, 99–108.

Bonacci, O. and Roje-Bonacci, T. (2017): Jezera u Hrvatskoj – koliko ih stvarno poznajemo?, *Hrvatske vode*, **25 (100)**, 109–115.

Bonacci, O., Roje-Bonacci, T., and Andrić, I. (2017): Prilog izučavanju hidrologije Skradinskog buka na rijeci Krki, *Hrvatske vode*, **25 (99)**, 27–36.

Bonacci, O., Roje-Bonacci, T., and Željković, I. (2017): Usporedba srednje vrijednosti temperature zraka (na različitim vremenskim skalama) izračunata pomoću dvije različite metode, *Hrvatske vode*, **25 (101)**, 169–176.

Bonacci, O. (2018): Preliminary analysis of the decrease in water level of Vrana Lake on the mall carbonate island of Cres (Dinaric karst, Croatia), Advances in karst research theory, fieldwork and applications, Parise, M., Gabrovšek, F., Kaufmann, G., Ravbar, N. (Ed). London: Geological Society, London, 307–317.

Bonacci, O. (2018): Prilog hidrologiji krškog izvora Vrelo Une, *Hrvatske vode*, **26 (104)**, 129–134.

Bonacci, O. (2018): Megapoplave: nekoć i danas, *Hrvatska vodoprivreda*, **225**, 33–36.

Bonacci, O., Oštrić, M., and Roje-Bonacci, T. (2018): Water resources analysis of the Rječina karst spring and river (Dinaric karst), *Acta Carsol.*, **47**, 123–137.

Bonacci, O. and Roje-Bonacci, T. (2018): Analyses of the Zagreb Grič observatory air temperatures indices for the period 1881 to 2017, *Acta Hydrotechnica*, **31**, 67–85.

Bonacci, O. and Roje-Bonacci, T. (2018): Analiza odnosa razina podzemne vode i vodostaja Vranskog jezera na otoku Cresu, *Hrvatske vode*, **26 (103)**, 39–47.

Bonacci, O., Terzić, J., and Roje-Bonacci, T. (2018): Hidrološka analiza krške rijeke Čikole, *Hrvatske vode*, **26 (106)**, 281–292.

Bonacci, O. and Željković, I. (2018): Analyses of differences between true mean temperatures and those calculated with four different approaches: a case study from three Croatian stations, *Theor. Appl. Climatol.*, **131**, 733–743.

Borović, S., Marković, T., and Larva, O. (2015): Protection of transboundary aquifers of Međimurje County (Croatia): status and prospects, *Int. J. Environment and Health*, **7**, 97–214.

Brkić, Ž., Briški, M., and Marković, T. (2016): Use of hydrochemistry and isotopes for improving the knowledge of groundwater flow in a semiconfined aquifer system of the Eastern Slavonia (Croatia), *Catena*, **142**, 153–165.

Brkić, Ž. and Briški, M. (2018): Hydrogeology of the western part of the Drava Basin in Croatia, *J. Maps.*, **14**, 173–177.

Brkić, Ž., Kuhta, M., and Hunjak, T. (2018): Groundwater flow mechanism in the well-developed karst aquifer system in the western Croatia: Insights from spring discharge and water isotopes, *Catena*, **161**, 14–26.

Cindrić, K., Telišman-Prtenjak, M., Herceg-Bulić, I., Mihajlović, D., and Pasarić, Z. (2016): Analysis of the extraordinary 2011/2012 drought in Croatia, *Theor. Applied Climatol.,* **123**, 503–522.

Cindrić Kalin, K. and Pasarić, Z. (2018): Modelling dry spells by extreme value distribution with Bayesian inference, *Pure. Appl. Geophys.*, **175**, 3891–3908.

Cindrić Kalin, K., Juras, J., and Pasarić, Z. (2018): On precipitation monitoring with theoretical statistical distributions, *Theor Applied Climatol.*, **136**, 145–156.

Čanjevac, I. and Orešić, D. (2015): Contemporary changes of mean annual and seasonal river discharges in Croatia, *Hrvatski geografski glasnik*, **77**, 7–27.

Čanjevac, I. and Orešić, D. (2018): Changes in discharge regimes of rivers in Croatia, *Acta Geographica Slovenica – Geografski Zbornik*, **58**, 7–18.

Ćosić Flajsig, G., Belaj, M., and Karleuša, B. (2017): Upravljanje površinskim vodama primjenom kombiniranog pristupa (Combined approach to surface water management), *Građevinar*, **8**, 617–631.

Dadić, T., Tadić, L., and Bonacci, O. (2015): Utjecaj Drave i Dunava kroz povijest na poplave u Osijeku, *Hrvatske vode*, **23 (94)**, 287–294.

Dragičević, N., Karleuša, B., and Ožanić, N. (2016): Pregled primjene Gavrilovićeve metode (metoda potencijala erozije), *Građevinar*, **68**, 715–725.

Dragičević, N., Karleuša, B., and Ožanić, N. (2017): Effect of land cover/use change on soil erosion assessment in Dubračina catchment (Croatia), *European Wat*er, **57**, 171–177.

Dragičević, N., Karleuša, B., and Ožanić, N. (2017): Erosion potential method (Gavrilović Method) sensitivity analysis, *Soil Water Res*., **12**, 51–59.

Dragičević, N., Karleuša, B., and Ožanić, N. (2018): Modification of erosion potential method using climate and land cover parameters, *Geomat. Nat. Haz. Risk*., **9**, 1085–1105.

Drobinski, P., Da Silva, N., Panthou, G., Bastin, S., Muller, C., Ahrens, B., Borga, M., Conte, D., Fosser, G., Giorgi, F., Güttler, I., Kotroni, V., Li, L., Morin, E., Onol, B., Quintana-Segui, P., Romera, R., and Torma, Cz. (2018): Scaling precipitation extremes with temperature in the Mediterranean: past climate assessment and projection in anthropogenic scenarios, *Clim. Dynam*., **51**, 1237–1257.

Đurin, B., Ptiček Siročić, A., and Muhar, A. (2017): Analiza povezanosti pokazatelja kakvoće otpadne vode s temperaturom i oborinama pomoću RAPS metode, *Hrvatske vode*, **25 (102)**, 247–252.

Giacopetti, M., Crestaz, E., Materazzi, M., Pambianchi, G., and Posavec, K. (2016): A multi-model approach using statistical index and information criteria to evaluate the adequacy of the model geometry in a fissured carbonate aquifer (Italy), *Water*, **8**, 1–25.

Giacopetti, M., Materazzi, M., Pambianchi, G., and Posavec, K. (2017): Analysis of mountain springs discharge time series in the Tennacola stream catchment (central Apennine, Italy), *Environ. Earth Sci*., **76**, 1–11.

Gajić-Čapka, M., Cindrić, K., and Pasarić, Z. (2015): Trends in precipitation indices in Croatia, 1961–2010, *Theor. Appl. Climatol*., **121**, 167–177.

Gajić-Čapka, M., Güttler, I., Cindrić, K., and Branković, Č. (2017): Observed and simulated climate and climate change in the lower Neretva river basin, *J. Water Clim. Change*, **9**, 124–136.

Gilja, G., Kuspilić, N., and Potočki, K. (2017): Analiza primjenjivosti empirijskih modela za opis karakteristika polja dina, *Građevinar*, **69**, 427–436.

Gilja, G., Ocvirk, E., and Kuspilić, N. (2018): Joint probability analysis of flood hazard at river confluences using bivariate copulas, *Građevinar*, **70**, 267–275.

Güttler, I., Stepanov, I., Branković, Č., Nikulin, G., and Jones, C. (2015): Impact of horizontal resolution on precipitation in complex orography simulated by the regional climate model RCA3, *Mon. Weather Rev*., **143**, 3610–3627.

Ivezić, V., Bekić, D., and Žugaj, R. (2017): A review of procedures for water balance modelling, *Journal of Environmental Hydrol*ogy, **25**, 1–20.

Ivezić, V., Bekić, D., and Horvat, B. (2018): Modelling of basin wide daily evapotranspiration with a partial integration of remote sensing data, *Atmosphere*, **9**, 120–138.

Ivezić, V., Bekić, D., and Kerin, I. (2018): Estimating basin-wide air temperature by partial integration of remote sensing data, *Can. J. Earth S*ci., **55**, 1196–1206.

Jukić, D. and Denić-Jukić, V. (2015): Investigating relationships between rainfall and karst-spring discharge by higher-order partial correlation functions, *J. Hyd*rol., **530**, 24–36.

Kadić, A., Denić-Jukić, V., and Jukić, D. (2018): Revealing hydrological relations of adjacent karst springs by partial correlation analysis, *Hydrol. Res*., **49**, 616–633.

Karleuša, B., Rubinić, J., Radišić, M., and Krvavica, N. (2017): Analysis of climate change impact on water supply in Northern Istria (Croatia), *Teh. vjesn.*, **20**, 366–374.

Kerin, I., Giri, S., and Bekić, D. (2018): Simulation of levee breach using Delft Models: a case study of the Drava River flood event, Advances in Hydroinformatics, Singapore: Springer Water, 1117–1131.

Klaić, Z. B., Rubinić, J., and Kapelj, S. (2018): Review of research on Plitvice Lakes, Croatia in the fields of meteorology, climatology, hydrology, hydrogeochemistry and physical limnology, *Geofizika*, **35**, 189–278.

Knez, M., Rubinić, J., Slabe, T., and Šegina, E. (2015): Karren of the Kamenjak Hum (Dalmatian karst, Croatia); from the initial dissection of flat surfaces by rain to rocky points, *Acta Carsol.*, **44**, 191–201.

Kovač, Z., Cvetković, M., and Parlov, J. (2017): Gaussian simulation of nitrate concentration distribution in the Zagreb aquifer, *J. Maps.*, **13**, 727–732.

Kovač, Z., Nakić, Z., and Pavlić, K. (2017): Influence of groundwater quality indicators on nitrate concentrations in the Zagreb aquifer system, *Geol. Croat.*, **70**, 93–103.

Kovač, Z., Nakić, Z., Špoljarić, D., Stanek, D., and Bačani, A. (2018): Estimation of nitrate trends in the groundwater of the Zagreb aquifer, *Geosciences*, **8 (159)**, doi: 10.3390/geosciences805015.

Krvavica, N., Ružić, I., and Ožanić, N. (2016): Analiza procjene intenziteta oborine pomoću X-band radara, *Hrvatske vode*, **24 (96)**, 137–146.

Krvavica, N., Travaš, V., and Ožanić, N. (2016): A field study of interfacial friction and entrainment in a microtidal salt-wedge estuary, *Environ. Fluid Mech.*, **16**, 1223–1246.

Krvavica, N., Kožar, I., Travaš, V., and Ožanić, N. (2017): Numerical modelling of two-layer shallow water flow in microtidal salt-wedge estuaries: Finite volume solver and field validation, *J. Hydrol. Hydromech.*, **65**, 49–59.

Krvavica, N., Travaš, V., and Ožanić, N. (2017): Salt-wedge response to variable river flow and sea-level rise in the microtidal Rječina River estuary, Croatia, *J. Coast. Res.*, **33**, 802–814.

Krvavica, N., Jaredić, K., and Rubinić, J. (2018): Metodologija definiranja mjerodavne oborine za dimenzioniranje infiltracijskih sustava, *Građevinar*, **7**, 657–669.

Krvavica, N., Kožar, I., and Ožanić, N. (2018): The relevance of turbulent mixing in estuarine numerical models for two-layer shallow water flow, *Coupled Syst. Mech.*, **7**, 95–109.

Krvavica, N., Ružić, I., and Ožanić, N. (2018): Integrated computational model for Sea Organ simulation, *Građevinar*, **70**, 287–295.

Loborec, J., Kapelj, S., and Novak, H. (2015): Analiza opasnosti od onečišćenja podzemnih voda u kršu na primjeru sliva izvora Jadro i Žrnovnica, *Građevinar*, **67**, 1093–1103.

Loborec, J. and Đurin, B. (2016): Primjena višekriterijske analize u svrhu odabira optimalne metode procjene prirodne ranjivosti krških vodonosnika, *Hrvatske vode*, **24 (97)**, 193–202.

Lončar, G., Šreng, Ž., Bekić, D., and Kunštek, D. (2018): Hydraulic-hydrology analysis of the turbulent seepage flow within karst aquifer of the Golubinka spring catchment, *Geofluids*, doi:10.1155/2018/6424702.

Ljubenkov, I. and Cindrić Kalin, K. (2016): Ocjena suše primjenom standardiziranog indeksa oborine i protoka te njihov odnos na primjeru Sinjskog polja, *Građevinar*, **68**, 135–143.

Mance, D., Lenac, D., and Rubinić, J. (2017): Isotope studies of karst springs included in the water supply system of the City of Rijeka (Croatia), *SEEMEDJ*, **1**, 46–54.

Mance, D., Mance, D., and Vukić Lušić, D. (2018): Environmental isotope 18O in coastal karst spring waters as a possible predictor of marine microbial pollution, *Acta Adriat.*, **59 (1)**, 3–16.

Maradin, M., Orešić, D., Madžar, I., and Putica, J. (2018): Procjena pouzdanosti neinstitucionalnog mjerenja temperature zraka u Vitini, BiH, u razdoblju 1992.–2011., *Acta Geographica Croatica*, **41/42**, 1–112.

Marović, I., Sušanj, I., and Ožanić, N. (2017): Development of ANN model for wind speed prediction as a support for early warning system, *Complexity*, doi: 10.1155/2017/3418145.

Marković, T., Borović, S., and Larva O. (2015): Geochemical characteristics of thermal waters of Hrvatsko zagorje, *Geol. Croat.*, **68**, 67–77.

Marković, M., Filipović, V., Legović, T., Josipović, M., and Tadić, V. (2015): Evaluation of different soil water potential by field capacity threshold in combination with a triggered irrigation module, *Soil Water Res.*, **10**, 164–171.

Mlinarić, M., Loborec, J., and Biondić, R. (2016): Zaštita podzemnih voda – primjer procjene ranjivosti sliva izvora Gradole (Hrvatska) metodom SINTACS, *Inženjerstvo okoliša*, **3**, 21–31.

Nakić, Z., Mileusnić, M., Pavlić, K., and Kovač, Z. (2018): Environmental geology and hydrology, Environmental engineering – basic principles, Berlin/Munich/Boston: Walter de Gruyter GmbH, 121–158.

Nimac, I. and Perčec Tadić, M. (2017): Complete and homogeneous monthly temperature series for construction of the new 1981–2010 climatological normals for Croatia, *Geofizika*, **34**, 225–249.

Orešić, D., Čanjevac, I., and Maradin, M. (2017): Changes in discharge regimes in the middle course of the Sava River in the 1931–2010 period, *Prace geograficzne*, **151**, 93–119.

Oskoruš, D., Berbić, J., Macek, K., and Lončar, T. (2017): Ekstremne rujanske poplave u Zadru i Ninu, *Hrvatska vodoprivreda*, **25**, 25–34.

Parlov, J., Kovač, Z., Bačani, L., and Bačani, A. (2016): Hydrogeological characteristics of south hills, Ivanščica Mountain, *J. Maps.*, **12**, 53–57.

Pasarić, M. and Slaviček, L. (2016): Seiches in the Plitvice Lakes, *Geofizika*, **33**, 35–52.

Pavlin, Ž. and Kuspilić, N. (2018): Mjerodavni vodostaji za dimenzioniranje hidrotehničkih nasipa i nasutih brana, *Građevinar,* **70**, 225–233.

Peranić, J., Arbanas, Ž., Cuomo, S., and Maček, M. (2018): Soil-water characteristic curve of residual soil from a flysch rock mass, *Geofluids*, doi: 10.1155/2018/6297819.

Perčec Tadić, M., Zaninović, K., and Sokol Jurković, R. (2015): Mapping of maximum snow load values for the 50-year return period for Croatia, *Spat. Stat.*, **14**, 53–69.

Plantak, M., Čanjevac, I., and Vidaković, I. (2016): Morfološko stanje tekućica u poriječju Ilove, *Hrvatski geografski glasnik*, **78**, 5–24.

Posavec, K., Giacopetti, M., Materazzi, M., and Birk, S. (2017): Method and excel VBA algorithm for modeling master recession curve using trigonometry approach, *Ground Water*, **55**, 891–898.

Posavec, K., Vukojević, P., Ratkaj, M., and Bedeniković, T. (2017): Cross-correlation modelling of surface-water-groundwater interaction using excel spreadsheet application, *Rudarsko-geološko-naftni zbornik*, **32**, 25–32.

Potočki, K., Gilja, G., and Kunštek, D. (2017): An overview of the applications of wavelet transform for discharge and suspended sediment analysis, *Teh. vjesn.*, **24**, 1561–1569.

Rabi, A., Hadzima-Nyarko, M., and Šperac, M. (2015): Modelling river temperature from air temperature: case of the River Drava (Croatia) (Modélisation de température de l'air et de la température de la rivière Drava (Croatie)), *Hydrolog. Sci. J.*, **60**, 1490–1507.

Ružičić, S., Mileusnić, M., Posavec, K., Nakić, Z., Durn, G., and Filipović, V. (2016): Water flow and solute transport model of potentially toxic elements through unsaturated zone at regional wellfield Kosnica, *Hydrol. Process.*, **30**, 4113–4124.

Ružičić, S., Kovač, Z., Nakić, Z., and Kireta, D. (2017): Fluvisol permeability estimation using soil water content variability, *Geofizika*, **34**, 141–155.

Sarajlić, A., Raspudić, E., Lončarić, Z., Josipović, M., Brmež, M., Ravlić, M., Zebec, V., and Majić, I. (2017): Significance of irrigation treatments and weather conditions on European corn borer appearance, *Maydica*, **62**, 1–8.

Sironić, A., Barešić, J., Horvatinčić, N., Brozinčević, A., Vurnek, M., and Kapelj, S. (2017): Changes in the geochemical parameters of karst lakes over the past three decades – The case of Plitvice Lakes, Croatia, *Appl. Geochem.*, **78**, 12–22.

Sokač, M., Jerković, M., and Tadić, L. (2016): Matematická simulácia scenárov vývoja kvality vody v rieke Dráva, *Acta Hydrologica Slov*aca, **17**, 89–98.

Sušanj, I., Ožanić, N., and Marović, I. (2016): Methodology for developing hydrological models based on an artificial neural network to establish an early warning system in small catchments, *Adv Meteorol.*, doi: 10.1155/2016/9125219.

Sušanj, I., Ožanić, N., and Karleuša, B. (2018): Methodology for developing hydrological discharge model for small catchments, *Građevinar*, **70**, 325–335.

Šegina, E., Benac, Č., Rubinić, J., and Knez, M. (2018): Morphometric analyses of dolines – the problem of delineation and calculation of basic parameters, *Acta Carsol.*, **47**, 23–33.

Tadić, L., Dadić, T., and Bosak, M. (2015): Usporedba različitih metoda za ocjenu suše na području kontinentalne Hrvatske, *Građevinar*, **67**, 11–22.

Tadić, L., Bonacci, O., and Dadić, T. (2016): Analysis of the Drava and Danube rivers floods in Osijek (Croatia) and possibility of their coincidence, *Environ. Earth Sci.*, **75**, 1238–1241.

Tadić, L., Dadić, T., and Leko-Kos, M. (2016): Variability of hydrological parameters and water balance components in small catchment in Croatia, *Adv. Meteorol.*, doi: 10.1155/2016/1393241.

Travaš, V., Krvavica, N., and Rubeša, J. (2015): Modeliranje morfologije otvorenih korita za provedbu jednodimenzijske analize toka, *Hrvatske vode*, **23 (92)**, 123–132.

Urumović, K. and Urumović, K. (2016): The referential grain size and effective porosity in the Kozeny-Carman model, *Hydrol. Earth Syst. Sci.,* **20**, 1669–1680.

Vlahović, T. and Šumanovac, F. (2015): Defining a general hydrogeological model for Susak Island, Adriatic Sea, Croatia, *Q. J. Eng. Geol. Hydrog.*, **48**, 135–146.

Volf, G., Atanasova, N., Kompare, B., Precali, R., and Ožanić, N. (2015): Study of the impact of TIN/PO4 ratio on mucilage formation in the northern Adriatic using regression trees, *Acta Adriat.*, **56**, 207–222.

Volf, G., Atanasova, N., Škerjanec, M., and Ožanić, N. (2018): Hybrid modeling approach for the northern Adriatic watershed management, *Sci. Total Environ.*, **635**, 353–363.

Volf, G., Žic, E., and Ožanić, N. (2018): Prediction of groundwater level fluctuations on Grohovo landslide using rule based regression, *Eng. Rev.*, **38**, 51–61.

Zaharia, L., Ioana-Toroimac, G., Morosanu, G., Galie, A., Moldoveanu, M., Čanjevac, I., Belleudy, P., Plantak, M., Buzjak, N., Bočić, N., Legout, C., Bigot, S., and Gobotaru, N. (2018): Review of national methodologies for rivers' hydromorphological assessment: A comparative approach in France, Romania, and Croatia, *J. Environ. Manage.*, **217**, 735–746.

Žic, E., Arbanas, Ž., Bićanić, N., and Ožanić, N. (2015): A model of mudflow propagation downstream from the Grohovo landslide near the city of Rijeka (Croatia), *Nat. Hazard Earth Sys.*, **15**, 293–313.

Meteorology in Croatia, 2015–2018

Zvjezdana Bencetić Klaić[1], Branka Grbec[2], and Kristian Horvath[3]

[1]Department of Geophysics, Faculty of Science, University of Zagreb, Croatia
[2]Institute of Oceanography and Fisheries, Split, Croatia
[3]Meteorological and Hydrological Service, Zagreb, Croatia

Based on the published books, international peer-review scientific papers, and PhD theses, here we present a short overview of the topics of meteorological research in Croatia during the 2015–2018 period. In Croatia, the meteorological research is performed at several institutions: Department of Geophysics, Faculty of Science, University of Zagreb (hereafter, DG), Croatian Meteorological and Hydrological Service (MHS), the Physics Department, Faculty of Science, University of Split (PDS), and the Institute of Oceanography and Fisheries (IOF) in Split. During the reporting period, at these institutions in total forty-six projects (both, completed and still ongoing) were implemented. These were founded by European Union (17 projects), Croatian Science Foundation (12), other sources (9), funds of Cooperative Projects of European Meteorological and Hydrological Services (6), and Ministry of Science and Education of the Republic of Croatia (2). Research efforts resulted in over ninety international peer-review scientific papers, eight PhD theses and several book chapters.

Researchers have addressed a wide span of relevant meteorological issues, such as present and anticipated future climate; turbulence characteristics over inhomogeneous surfaces and complex terrain under various atmospheric conditions; and mesoscale thermal circulations and their interplay with different multi-scale phenomena. Additionally, intensive research activity has been associated with efforts to improve numerical weather and climate prediction models. Severe weather and extreme events, such as, high winds, extraordinary droughts, heat waves, severe convective storms and consequent heavy rainfall, hail, lighting activity and waterspouts, as well as the ability of numerical weather forecast models to predict such episodes, have also been investigated.

Furthermore, a number of interdisciplinary studies dealt with meteorology and closely related disciplines, such as, the air quality, hydrology, oceanography, physical limnology, agronomy, forestry, energetics and engineering. Among others, impacts of weather and/or climate on the air and precipitation quality, agricultural and forest systems, ocean currents, sea-level variability, and occurrence of the storm surges and meteotsunamis were investigated. Within the framework of meteotsunami research, new equipment (two weather stations and six microbarographs) was installed at several coastal locations, and an operational one-way coupled numerical atmosphere-ocean model for forecast of the Adriatic meteotsunamis was developed. The observed data can be visualized at http://faust.izor.hr/autodatapub/postaje2 and downloaded from http://faust.izor.hr/autodatapub/mjesustdohvatpod?jezik=eng, while meteotsunami forecasts are available at http://faust.izor.hr/autodatapub/adrisc?jezik=eng.

Overall, meteorological community was very active during the reporting period. International and national inter-institutional cooperation was intense. Furthermore, research results were based on the state-of-the-art methodologies. Finally, some of the studies provided information on specific phenomena for Croatia for the first time (e.g., lighting activity and waterspouts events). Additional information on the conducted research is available at the web

sites of individual institutions: http://www.pmf.unizg.hr/geof/en (DG), https://meteo.hr/index_en.php (MHS), https://www.pmfst.unist.hr/odjel-za-fiziku/ (PDS) and http://www.izor.hr/web/guest/home (IOF).

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List of publications

Anić, M. Ostrogović Sever, M. Z., Alberti, G., Balenović, I., Paladinić, E., Peressotti, A., Tijan, G., Večenaj, Ž., Vuletić, D., and Marjanović, H. (2018): Eddy covariance *vs*. biometric based estimates of net primary productivity of pedunculate oak (*Quercus robur* L.) forest in Croatia during ten years, *Forests*, **9**, 764, doi: 10.3390/f9120764.

Antabak, A., Halužan, D., Chouehne, A., Mance, M., Fuch, N. Prlić, I., Bešlić, I., and Klaić, Z. B. (2017): Analysis of airborne dust as a result of plaster cast saring, *Acta Clin. Croat.*, **56**, 600–608, doi: 10.20471/acc.2017.56.04.04.

Babić, K. (2016): *Low-level turbulence characteristics over inhomogeneous surface during wintertime*, PhD Thesis, University of Zagreb, Faculty of Science, Zagreb, 163 pp.

Babić, K., Rotach, M. W., and Klaić, Z. B. (2016): Evaluation of local similarity theory in the wintertime nocturnal boundary layer over heterogeneous surface, *Agric. For. Meteorol.*, **228**, 164–179 , doi: 10.1016/j.agrformet.2016.07.002.

Babić, N., Večenaj, Ž., Kozmar, H., Horvath, K., De Wekker, S. F. J., and Grisogono, B. (2016): On turbulent fluxes during strong winter bora wind events, *Boundary-layer Meteorol.*, **158**, 331–350, doi: 10.1007/s10546-015-0088-7.

Babić, N., Večenaj, Ž., Kozmar, H., Horvath, K., and De Wekker, S. F. J. (2016): Flux-variance similarity in complex terrain and its sensitivity to different methods of treating non-stationarity, *Boundary-layer Meteorol.*, **159**, 123–145, doi: 10.1007/s10546-015-0110-0.

Babić, N., Večenaj, Ž., and De Wekker, S. F.J. (2017): Spectral gap characteristics in a daytime valley boundary layer, *Q. J. R. Meteorol. Soc.*, **143**, 2509–2523, doi: 10.1002/qj.3103.

Babić, K. and Rotach, M. W. (2018): Turbulence kinetic energy budget in the stable boundary layer over a heterogeneous surface, *Q. J. R. Meteorol. Soc.*, **144**, 1045–1062, doi: 10.1002/qj.3274.

Babić Mladenović, M., Bekić, D., Grošelj, S., Mikoš, M., Kupusović, T., and Oskoruš, D. (2015): Establishment of the sediment monitoring system for the Sava River basin, *Water Res. Manag.*, **5**, 3–14.

Baranka, G., Bartók, B., Bozó, L., Croitoru, A.-E., Ferenczi, Z., Firanj Sremac, A., Grisogono, B., Jeričević, A., Labancz, K., Lalic, B., Lázár, D., Mahon, A., Prtenjak, M. T., Semenova, I., Szintai, B., and Weidinger, T. (2017): Understanding Air Quality under Different Weather and Climate Conditions in the Pannonian Basin, In *Regional Hydroclimate Project over the Pannonian Basin (PannEx)*, Weidinger, T. (Ed.), Department of Meteorology, Eötvös Loránd University, Budapest, 8–67.

Belušić, A., Herceg-Bulić, I., and Klaić, Z. B. (2015): Using a generalized additive model to quantify the influence of local meteorology on air quality in Zagreb, *Geofizika*, **32**, 47–77, doi: 10.15233/gfz.2015.32.5.

Belušić, A., Prtenjak, M. T. Güttler, I., Ban, N., Leutwyler, D., and Schär, C. (2018): Near-surface wind variability over the broader Adriatic region: insights from an ensemble of regional climate models, *Clim. Dynam.*, **50**, 4455–4480, doi: 10.1007/s00382-017-3885-5.

Belušić, D., Večenaj, Ž., and LeMone, M. A. (2015): Possible observation of horizontal roll vortices over the Adriatic Sea during bora, *Front. Earth Sci.*, **3**, 1–7, doi: 10.3389/feart.2015.00023.

Belušić Vozila, A. (2018): *Wind characteristics in the present and future climate obtained from regional climate models' simulations over broader Adriatic region*, PhD Thesis, University of Zagreb, Faculty of Science, Zagreb, 133 pp (in Croatian).

Berbić, J., Ocvirk, E., Carević, D., and Lončar, G. (2017): Application of neural networks and support vector machine for significant wave height prediction, *Oceanologia*, **59**, 331–349, doi: 10.1016/j.oceano.2017.03.007.

Bubalo, M., Janeković, I., and Orlić, M. (2018): Chrystal and Proudman resonances simulated with three numerical models, *Ocean Dyn.*, **68**, 497–507, doi: 10.1007/s10236-018-1146-8.

Cindrić, K., Prtenjak, M. T., Herceg-Bulić, I., Mihajlović, D., and Pasarić, Z. (2016): Analysis of the extraordinary 2011/2012 drought in Croatia, *Theor. Appl. Climatol.*, **123**, 503–522, doi: 10.1007/s00704-014-1368-8.

Cindrić, K. and Pasarić, Z. (2018): Modelling dry spells by extreme value distribution with Bayesian inference, *Pure Appl. Geophys.*, **175**, 3891–3908, doi: 10.1007/s00024-018-2007-6.

Cram, T. A., Compo, G. P., Yin, X., Allan, R. J., McColl, C., Vose, Russell S., Whitaker, J. S., Matsui, N., Ashcroft, L., Auchmann, R., Bessemoulin, P., Brandsma, T., Brohan, P., Brunet, M., Comeaux, J., Crouthamel, R., Gleason Jr, B. E., Groisman, P. Y., Hersbach, H., Jones, P. D., Jonsson, T., Jourdain, S., Kelly, G., Knapp, K. R., Kruger, A., Kubota, H., Lentini, G., Lorrey, A., Lott, N., Lubker, S. J., Luterbacher, J., Marshall, G. J., Maugeri, M., Mock, C. J., Mok, H. Y., Nordli, Ø., Rodwell, M. J., Ross, T. F., Schuster, D., Srnec, L., Valente, M. A., Vizi, Z., Wang, X. L., Westcott, N., Woollen J. S., and Worley, S. J. (2015): The International Surface Pressure Databank version 2, *Geosci. Data J.*, **2**, 31–46, doi: 10.1002/gdj3.25.

Cvitan, L. and Jurković, R. S. (2016): Secular trends in heating and cooling monthly demands in Croatia, *Theor. Appl. Climatol.*, **125**, 565–581, doi: 10.1007/s00704-015-1534-7.

Drobinski, P., Da Silva, N., Panthou, G., Bastin, S., Muller, C., Ahrens, B., Borga, M., Conte, D., Fosser, G., Giorgi, F., Güttler, I., Kotroni, V., Li, L., Morin, E., Onol, B., Quintana-Segui, P., Romera, R., and Torma, C. Z. (2018): Scaling precipitation extremes with temperature in the Mediterranean: past climate assessment and projection in anthropogenic scenarios, *Clim. Dynam.*, **51**, 1237–1257, doi: 10.1007/s00382-016-3083-x.

Gajić-Čapka, M., Cindrić, K., and Pasarić, Z. (2015): Trends in precipitation indices in Croatia, 1961–2010, *Theor. Appl. Climatol.*, **121**, 167–177, doi: 10.1007/s00704-014-1217-9.

Gajić-Čapka, M., Güttler, I., Cindrić, K., and Branković, Č. (2017): Observed and simulated climate and climate change in the lower Neretva river basin, *J. Water Clim. Change*, **9**, 124–136, doi: 10.2166/wcc.2017.034.

Gašparac, G.; Jeričević, A., and Grisogono, B. (2016): Influence of WRF Parameterization on Coupled Air Quality Modeling Systems, In *Air Pollution Modeling and its Application XXIV*, Steyn, D. G. and Chaumerliac, N. (Eds.), Springer International Publishing, Cham, 557–561.

Glasnović, Z., Margeta, K., and Premec, K. (2016): Could Key Engine, as a new open-source for RES technology development, start the third industrial revolution?, *Renew. Sust. Energ. Rev.*, **57**; 1194–1209, doi: 10.1016/j.rser.2015.12.152.

Gobin, A., Kersebaum, K., Christian, Eitzinger, J., Trnka, M., Hlavinka, P., Takáč, J., Kroes, J., Ventrella, D., Dalla M., Deelstra, A., Lalić, J., Nejedlik, B., Orlandini, P., Peltonen-Sainio, S., Rajala, P., Saue, A., Şaylan, T., Stričević, R., Vučetić, V., and Zoumides, C. (2017): Variability in the water footprint of arable crop production across European regions, *Water*, **9**, 93, doi: 10.3390/w9020093.

Grbec, B., Matić, F., Paklar, G. B., Morović, M., Popović, R., and Vilibić, I. (2018): Long-term trends, variability and extremes of in situ sea surface temperature measured along the eastern Adriatic coast and its relationship to hemispheric processes, *Pure Appl. Geophys.*, **175**, 4031–4046, doi: 10.1007/s00024-018-1793-1.

Güttler, I., Stepanov, I., Branković, Č., Nikulin, G., and Jones, C. (2015): Impact of horizontal resolution on precipitation in complex orography simulated by the regional climate model RCA3, *Mon. Wea. Rev.*, **143**, 3610–3627, doi: 10.1175/MWR-D-14-00302.1.

Güttler, I., Marinović, I., Večenaj, Ž., and Grisogono, B. (2016): Energetics of slope flows: linear and weakly nonlinear solutions of the extended Prandtl model, *Front. Earth Sci.*, **4**, UNSP72, doi: 10.3389/feart.2016.00072.

Güttler, I., Marinović, I., Večenaj, Ž., and Grisogono, B. (2017): Corrigendum: Energetics of slope flows: linear and weakly nonlinear solutions of the Extended Prandtl Model, *Front. Earth Sci.*, **5**, UNSP76, doi: 10.3389/feart.2017.00076.

Herceg-Bulić, I., Mezzina, B., Kucharski, F., and King, M. P. (2017): Wintertime ENSO influence on late spring European climate: the stratospheric response and the role of North Atlantic SST, *Int. J. Climatol.*, **37S1**, 87–108, doi: 10.1002/joc.4980.

Horvath, K., Šepić, J., and Prtenjak, M. T. (2018): Atmospheric forcing conducive for the Adriatic 25 June 2014 meteotsunami event, *Pure Appl. Geophys.*, **175**, 3817–3837, doi: 10.1007/s00024-018-1902-1.

Hunjak, T. (2015): *Spatial distribution of oxygen and hydrogen stable isotopes from precipitation in Croatia*, PhD Thesis, University of Zagreb, Faculty of Science, Zagreb, 82 pp (in Croatian).

Ivančan-Picek, B., Tudor, M., Horvath, K., Stanešić, A., and Ivatek-Šahdan, S. (2016): Overview of the first HyMeX special observing period over Croatia, *Nat. Hazards Earth Syst. Sci.*, **16**, 2657–2682, doi: 10.5194/nhess-16-2657-2016.

Ivatek-Šahdan, S., Stanešić, A., Tudor, M., Plenković, I. O., and Janeković, I. (2018): Impact of SST on heavy rainfall events on eastern Adriatic during SOP1 of HyMeX, *Atmos. Res.*, **200**, 36–59, doi: 10.1016/j.atmosres.203.7.09.019.

Jeričević, A., Grgičin, V. D., Prtenjak, M. T., Vidič, S., and Bloemen, H. (2016): Analyses of urban and rural particulate matter mass concentrations in Croatia in the period 2006-2014, *Geofizika*, **33**, 157–181, doi: 10.15233/gfz.2016.33.8.

Jimenez, M. A., Simó, G., Wrenger, B., Prtenjak, M. T. Guijarro, J. A., and Cuxart, J. (2016): Morning transition case between the land and the sea breeze regimes, *Atmos. Res.*, **172**, 95–108, doi: 10.1016/j.atmosres.2015.12.019.

Jurković, P. M., Mahović, N. S., and Počakal, D. (2015): Lightning, overshooting top and hail characteristics for strong convective storms in Central Europe, *Atmos. Res.*, **161**, 153–168, doi: 10.1016/j.atmosres.2015.03.020.

Kalinić, H., Mihanović, H., Cosoli, S., Tudor, M., and Vilibić, I. (2017): Predicting ocean surface currents using numerical weather prediction model and Kohonen neural network: a northern Adriatic study, *Neural Comput. & Applic.*, **28**, S1; 611–620, doi: 10.1007/s00521-016-2395-4.

Kilibarda, M., Perčec Tadić, M., Hengl, T., Luković, J., and Bajat, B. (2015): Global geographic and feature space coverage of temperature data in the context of spatio-temporal interpolation, *Spat. Stat.*, **14A**, 22–38, doi: 10.1016/j.spasta.2015.04.005.

Kehler-Poljak, G., Prtenjak, M. T., Kvakić, M., Šariri, K., and Večenaj, Ž. (2017): Interaction of sea breeze and deep convection over the northeastern Adriatic coast: an analysis of sensitivity experiments using a high-resolution mesoscale model, *Pure Appl. Geophys.*, **174**, 4197–4224, doi: 10.1007/s00024-017-1607-x.

King, M. P., Herceg-Bulić, I., Blade, I., Garcia-Serrano, J., Keenlyside, N., Kucharski, F. Li, C., and Sobolowski, S. (2018): Importance of late fall ENSO teleconnection in the Euro-Atlantic Sector, *Bull. Amer. Meteor. Soc.*, **99**, 1337–1344, doi: 10.1175/BAMS-D-17-0020.1.

King, M. P., Herceg-Bulić, I., Kucharski, F., and Keenlyside, N. (2018): Interannual tropical Pacific sea surface temperature anomalies teleconnection to Northern Hemisphere atmosphere in November, *Clim. Dynam.*, **50**, 1881–1899, doi: 10.1007/s00382-017-3727-5.

Klaić, Z. B., Ollier, S. J., Babić, K., and Bešlić, I. (2015): Influences of outdoor meteorological conditions on indoor wintertime short-term PM_1 levels, *Geofizika*, **32**, 237-264, doi: 10.15233/gfz.2015.32.12.

Klaić, Z. B., Rubinić, J. and Kapelj, S. (2018): Review of research on Plitvice Lakes, Croatia in the fields of meteorology, climatology, hydrology, hydrogeochemistry and physical limnology, *Geofizika*, **35**, 189–278, doi: 10.15233/gfz.2018.35.9.

Kokkini, Z., Gerin, R., Poulain, P.-M., Mauri, E., Pasarić, Z., Janeković, I., Pasarić, M., Mihanović, H., and Vilibić, I. (2017): A multiplatform investigation of Istrian Front dynamics (north Adriatic Sea) in winter 2015, *Medit. Mar. Sci.*, **18**, 344–354, doi: 10.12681/mms.1895.

Križan, J., Gašparac, G., Kozmar, H., Antonić, O., and Grisogono, B. (2015): Designing laboratory wind simulations using artificial neural networks, *Theor. Appl. Climatol.*, **120**, 723–736, doi: 10.1007/s00704-014-1201-4.

Kuzmić, M., Grisogono, B., Li, X. Mi., and Lehner, S. (20105): Examining a deep and a shallow Adriatic bora event, *Q. J. Roy. Meteor. Soc.*, **141**, 3434–3438, doi: 10.1002/qj.2578.

Lepri, P., Večenaj, Ž., Kozmar, H., and Grisogono, B. (2015): Near-ground turbulence of the Bora wind in summertime, *J. Wind Eng. Ind. Aerod.*, **147**, 345–357, doi: 10.1016/j.jweia.2015.09.013.

Lepri, P., Večenaj, Ž., Kozmar, H., and Grisogono, B. (2017): Bora wind characteristics for engineering applications, *Wind Struct.*, **24**, 579–611, doi:10.12989/was.2017.24.6.579.

Mayr, G. J, Plavcan, D., Armi, L., Elvidge, A., Grisogono, B., Horvath, K., Jackson, P., Neururer A., Seibert P., Steenburgh, J. W., Stiperski, I., Sturman, A., Večenaj, Ž., Vergeiner, J., Vosper, S., and Zängl G. (2018): The Community Foehn Classification Experiment, *Bull. Amer. Meteor. Soc*, **99**, 2229–2235, doi: 10.1175/BAMS-D-17-0200.1.

Međugorac, I., Pasarić, M., and Orlić, M. (2015): Severe flooding along the eastern Adriatic coast: the case of 1 December 2008, *Ocean Dynam.*, **65**, 817–830, doi: 10.1007/s10236-015-0835-9.

Međugorac, I., Pasarić, M., Pasarić, Z., and Orlić, M. (2016): Two recent storm-surge episodes in the Adriatic, *Int. J. Safety Security Eng.* **6**, 589–596, 10.2495/SAFE-V6-N3-589-596.

Međugorac, I., Orlić, M., Janeković, I., Pasarić, Z., and Pasarić, M. (2018): Adriatic storm surges and related cross-basin sea-level slope, *J. Mar. Sys.*, **181**, 79–90, doi: 10.1016/j.jmarsys.2018.02.005.

Mikuš Jurković, P. (2017): *Satellite signatures and lightning characteristics of severe convective storms*, PhD Thesis, University of Zagreb, Faculty of Science, Zagreb, 112 pp (in Croatian).

Nimac, I. and Herceg-Bulić, I. (2017): An intermediate complexity AGCM simulations of climate response to a doubling of atmospheric carbon dioxide, *Geofizika*, **34**, 175–197 doi: 10.15233/gfz.2017.34.8.

Orlić, M. and Pasarić, Z. (2015): Some pitfalls of the semiempirical method used to project sea level, *J. Climate*, **28**, 3779–3785, doi: 10.1175/JCLI-D-14-00696.1.

Orlić, M., Pasarić, M., and Pasarić, Z. (2018): Mediterranean sea-level variability in the second half of the twentieth century: a Bayesian approach to closing the budget, *Pure Appl. Geophys.*, **175**, 3973–3988, doi: 10.1007/s00024-018-1974-y.

Oskoruš, D. (2015): *Contribution to the analysis of suspended load dynamics in the transfer zone of the Sava River*, PhD Thesis, University of Zagreb, Faculty of Civil Engineering, Zagreb, 161 pp (in Croatian).

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rousseva, S., Perčec Tadić, M., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymszewicz, A., Dumitrescu, A., Beguería, S., and Alewell, C. (2015): Rainfall erosivity in Europe, *Sci. Total Environ.*, **511**, 801–814, doi: 10.1016/j.scitotenv.2015.01.008.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Beguería, S., Klik, A., Rymszewicz, A., Michaelides, S., Olsen, P., Tadić, M. P., Aalto, J., Lakatos, M., Dumitrescu, A., Rousseva, S., Montanarella, L., and Alewell, C. (2015): Reply to the comment on "Rainfall erosivity in Europe" by Auerswald et al., *Sci. Total Environ.*, **532**, 853–857, doi: 10.1016/j.scitotenv.2015.05.020.

Panagos, P., Borrelli, P., Spinoni, J., Ballabio, C., Meusburger, K., Beguería, S., Klik, A., Michaelides, S., Petan, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymszewicz, A., Dumitrescu, A., Tadić, M. P., Diodato, N., Kostalova, J., Rousseva, S., Banasik, K., and Alewell, C. (2016): Monthly rainfall erosivity: conversion factors for different time resolutions and regional assessments, *Water*, **8**, 119, doi: 10.3390/w8040119.

Pasarić, M. and Slaviček, L. (2016): Seiches in the Plitvice Lakes, *Geofizika*, **33**, 35–52, doi: 10.15233/gfz.2016.33.6.

Plenković, I. O., Delle Monache, L., Horvath, K., and Hrastinski, M. (2018): Deterministic wind speed predictions with analog-based methods over complex topography, *J. Appl. Meteorol. Climatol.*, **57**, 2047–2070, doi: 10.1175/JAMC-D-17-0151.1.

Počakal, D., Večenaj, Ž., Jurković, P. M., and Grisogono, B. (2018): Analysis of orographic influence on hail parameters in NW Croatia, *Int. J. Climatol.*, **38**, 5646–5658, doi: 10.1002/joc.5769.

Prtenjak, M. T., Horvat, I., Tomažić, I., Kvakić, M., Viher, M., and Grisogono, B. (2015): Impact of mesoscale meteorological processes on anomalous radar propagation conditions over the northern Adriatic area, *J. Geophys. Res.–Atmos.*, **120**, 8759–8782, doi: 10.1002/2014JD022626.

Prtenjak, M. T., Klaić, M., Jeričević, A., and Cuxart, J. (2018): The interaction of the downslope winds and fog formation over the Zagreb area, *Atmos. Res.*, **214**, 213–227, doi: 10.1016/j.atmosres.2018.08.001.

Renko, T., Kuzmić, J., Šoljan, V., and Mahović, N. S. (2016): Waterspouts in the Eastern Adriatic from 2001 to 2013, *Nat. Hazards*, **82**, 441–470, doi: 10.1007/s11069-016-2192-5.

Renko, T. (2018): *Waterspouts in Adriatic – frequency, characteristics, conditions in which they occur and forecast possibilities*, PhD Thesis, University of Zagreb, Faculty of Science, Zagreb, 91 pp (in Croatian).

Renko, T., Ivušić, S., Prtenjak, M. T., Šoljan, V., and Horvat, I. (2018): Waterspout forecasting method over the eastern Adriatic using a high-resolution numerical weather model, *Pure Appl. Geophys.*, **175**, 3759–3778, doi: 10.1007/s00024-018-1833-x.

Serafin, S., Adler, B., Cuxart, J., De Wekker, S. F. J., Gohm, A., Grisogono, B., Kalthoff, N., Kirshbaum, D. J., Rotach, M. W., Schmidli, J., Stiperski, I., Večenaj, Ž., and Zardi, D. (2018): Exchange processes in the atmospheric boundary layer over mountainous terrain, *Atmosphere*, **9**, 1–32, doi: 10.3390/atmos9030102.

Sikirić, M. D., Ivanković, D., Roland, A., Ivatek-Šahdan, S., and Tudor, M. (2018): Operational wave modelling in the Adriatic Sea with the Wind Wave Model *Pure Appl. Geophys.*, 175, 3801–3815, doi: 10.1007/s00024-018-1954-2.

Soares, P., Maraun, D., Brands, S., Jury, M., Gutiérrez, J., San Martin, D., Hertig, E., Huth, R., Belušić Vozila, A., Cardoso, R., Kotlarski, S., Drobinski, P., and Obermann-Hellhund, A. (2018): Process-based evaluation of the VALUE perfect predictor experiment of statistical downscaling methods, *Int. J. Climatol.*, **9**, 102, doi: 10.1002/joc.5911.

Stanešić, A. and Brewster, K. A. (2016): Impact of radar data assimilation on the numerical simulation of a severe storm in Croatia, *Meteorol. Z.*, **25**, 37–53, doi: 10.1127/metz/2015/0574.

Stiperski, I., Serafin, S., Paci, A., Ágústsson, H., Belleudy, A., Calmer, R., Horvath, K., Knigge, C., Sachsperger, J., Strauss, L., and Grubišić, V. (2017): Water tank experiments on stratified flow over double mountain-shaped obstacles at high-Reynolds number, *Atmosphere*, **8**, 13, doi: 10.3390/atmos8010013.

Sun, J., Nappo, C. J., Mahrt, L., Belušić, D., Grisogono, B., Stauffer, D. R., Pulido, M., Staquet, C., Jiang, Q., Pouquet, A., Yague, C., Galperin, B., Smith, R. B., Finnigan, J. J., Mayor, S. D., Svensson, G., Grachev, A. A., and Neff, W. D. (2015): Review of wave-turbulence interactions in the stable atmospheric boundary layer, *Rev. Geophys.*, **53**, 956–993, doi: 10.1002/2015RG000487.

Sviličić, P., Vučetić, V., Filić, S., and Smolić, A. (2016): Soil temperature regime and vulnerability due to extreme soil temperatures in Croatia, *Theor. Appl. Climatol.*, **126**, 247–263, doi: 10.1007/s00704-015-1558-z.

Šepić J. (2015): *Meteorological tsunamis in the Adriatic*, PhD Thesis, University of Zagreb, Faculty of Science, Zagreb, 105 pp.

Šepić, J., Vilibić, I., and Fine, I. (2015): Northern Adriatic meteorological tsunamis: Assessment of their potential through ocean modelling experiments, *J. Geophys. Res. Oceans*, **120**, 2993–3010, doi: 10.1002/2015JC010795.

Šepić J., Vilibić, I., Lafon, A., Macheboueuf, L., and Ivanović, Z. (2015): High-frequency sea level oscillations in the Mediterranean and their connection to synoptic patterns. *Progr. Oceanogr.*, **137**, 284–298, doi: 10.1016/j.pocean.2015.07.005.

Šepić J., Vilibić, I., Rabinovich, A. B., and Monserrat, S. (2015): Widespread tsunami-like waves of 23-27 June in the Mediterranean and Black Seas generated by high-altitude atmospheric forcing, *Sci. Rep.*, **5**, 11682, doi: 10.1038/srep11682.

Šepić, J., Međugorac, I., Janeković, I., Dunić, N., and Vilibić, I. (2016): Multi-meteotsunami event in the Adriatic Sea generated by atmospheric disturbances of 25–26 June 2014, *Pure Appl. Geophys.*, **173**, 4117–4138, doi: 10.1007/s00024-016-1249-4.

Šepić, J., Vilibić, I., and Monserrat, S. (2016): Quantifying probability of meteotsunami occurrence from synoptic atmospheric patterns, *Geophys. Res. Lett.*, **49**, 10377–10384, doi: 10.1002/2016GL070754.

Šepić, J., Rabinovich, A. B., and Sytov, V. N. (2018): Odessa tsunami of 27 June 2014: Observations and numerical modelling, *Pure Appl. Geophys.*, **175**, 1545–1572, doi: 10.1007/s00024-017-1729-1.

Šepić, J., Vilibić, I., Rabinovich, A. B., and Tinti, S. (2018): Meteotsunami ("marrobbio") of 25–26 June 2014 on the southwestern coast of Sicily, Italy, *Pure Appl. Geophys.*, **175**, 1573–1593, doi: 10.1007/s00024-018-1827-8.

Šoljan, V., Belušić, A., Šarović, K., Nimac, I., Brzaj, S., Suhin, J., Belavić, M., Večenaj, Ž., and Grisogono, B. (2018): Micro-scale properties of different bora types, *Atmosphere*, **9**, 116, doi: 10.3390/atmos9040116.

Tadić, M. P., Zaninović, K., and Jurković, R. S. (2015): Mapping of maximum snow load values for the 50-year return period for Croatia, *Spat. Stat.*, **14A**, 53–69, doi: 10.1016/j.spasta.2015.05.002.

Templ, B., Templ, M., Filzmoser, P., Lehoczky, A., Baksiene, E., Fleck, S., Hilppa, G., Hodžić, S., Kalvane, G., Kubin, E., Palm, V., Romanovskaja, D., Vučetić, V., Žust, A., and Czucz, B. (2017): NS-Pheno Team. Phenological patterns of flowering across biogeographical regions of Europe, *Int. J. Biometeorol.*, **61**, 1347–1358, doi: 10.1007/s00484-017-1312-6.

Templ, B., Koch, E., Bolmgren, K., Ungersböck, M., Paul, A., Scheifinger, H., Rutishauser, T., Busto, M., Chmielewski, F. M., Hájková, L., Hodžić, S., Kaspar, F., Pietragalla, B., Romero-Fresneda, R., Tolvanen, A., Vučetić, V., Zimmermann, K., and Žust, A. (2018): Pan European Phenological database (PEP725): a single point of access for European data, *Int. J. Biometeorol.*, **62**, 1109–1113, doi: 10.1007/s00484-018-1512-8.

Termonia, P., Fischer, C., Bazile, E., Bouyssel, F., Brožková, R., Bénard, P., Bochenek, B., Degrauwe, D., Derková, M., El Khatib, R., Hamdi, R., Mašek, J., Pottier, P., Pristov, N., Seity, Y., Smolíková, P., Španiel, O., Tudor, M., Wang, Y., Wittmann, C., and Joly, A. (2018): The ALADIN System and its canonical model configurations AROME CY41T1 and ALARO CY40T1, *Geosci. Model Dev.*, **11**, 257–281, doi: 10.5194/gmd-11-257-2018.

Trnka, M., Olesen, J. E., Kersebaum, K. C., Rötter, R. P., Brázdil, R., Eitzinger, J., Jansen, S.,Skjelvåg, A. O., Peltonen-Sainio, P., Hlavinka, P., Balek, J. H. Eckersten, H., Gobin, A., Vučetić, V., A. Dalla M., A., Orlandini, S., Alexandrov, V., Semerádová, D., Šteěpánek, P., Svobodová, E., and Rajdl, K. (2016): Changing regional weather−crop yield relationships across Europe between 1901 and 2012, *Clim. Res.*, **70**, 195–214, doi: 10.3354/cr01426.

Trošić, T. (2015): The onset of a severe summer bora episode near Oštarijska Vrata Pass in the Northern Adriatic, *Meteorol. Atmos. Phys.*, **127**, 649–658, doi: 10.1007/s00703-015-0393-1.

Tudor, M. (2015): Methods for automatized detection of rapid changes in lateral boundary condition fields for NWP limited area models, *Geosci. Model Dev.*, **8**; 2627–2643, doi: 10.5194/gmd-8-2627-2015.

Tudor, M. (2018): *Improvements in the operational forecast of detrimental weather conditions in the numerical limited area model ALADIN*, PhD Thesis, University of Zagreb, Faculty of Science, Zagreb, 156 pp.

Večenaj, Ž. and De Wekker, S. F. J. (2015): Determination of non-stationarity in the surface layer during the T-REX experiment, *Q. J. R. Meteorol. Soc.*, **141**, 1560–1571, doi: 10.1002/qj.2458.

Vilibić, I., Kalinić, H., Mihanović, H., Cosoli, S., Tudor, M., Žagar, N., and Jesenko, B. (2016): Sensitivity of HF radar-derived surface current self-organizing maps to various processing procedures and mesoscale wind forcing, *Comput. Geosci.*, **20**, 115–131, doi: 10.1007/s10596-015-9550-3.

Vilibić, I., Šepić, J., Mihanović, H., Kalinić, H., Cosoli, S., Janeković, I., Žagar, N., Jasenko, B., Tudor, M., Dadić, V., and Ivanković, D. (2016): Self-Organizing Maps-based ocean currents forecasting system, *Sci. Rep.*, **6**, 22924, doi: 10.1038/srep22924.

Vilibić, I., Šepić, J., Rabinovich, A. B., and Monserrat, S. (2016): Modern approaches in meteotsunami research and early warning, *Front. Mar. Sci.*, **3**, 57, doi: 10.3389/fmars.2016.00057.

Vilibić, I. and Šepić J., (2017): Global mapping of nonseismic sea level oscillations at tsunami timescales, *Sci. Rep.*, **7**, 40818, doi: 10.1038/srep40818.

Vilibić, I., Šepić, J., Pasarić, M., and Orlić, M. (2017): The Adriatic Sea: a long-standing laboratory basin for sea level studies, *Pure Appl. Geophys*., **174**, 3765–3811, doi: 10.1007/s00024-017-1625-8.

Vilibić, I., Horvath, K., and Palau, J. L. (2018): Meteorology and Climatology of the Mediterranean and Black Seas: Introduction, *Pure Appl. Geophys*., **175**, 3721–3725, doi: 10.1007/s00024-018-2021-8.

Vilibić, I., Mihanović, H., Janeković, I., Denamiel, C., Poulain, P. M., Orlić, M., Dunić, N., Dadić, V., Pasarić, M., Muslim, S., Gerin, R., Matić, F., Šepić, J., Mauri, E., Kokkini, Z., Tudor, M., Kovač, Ž., and Džoić, T. (2018): Wintertime dynamics in the coastal northeastern Adriatic Sea: the NAdEx 2015 experiment, *Ocean Sci*., **14**, 237–258, doi: 10.5194/os-14-237-2018.

Vilibić, I., Šepić, J., Dunić, N., Sevault, F., Monserrat, S., and Jordà, G. (2018): Proxy-based assessment of strength and frequency of meteotsunamis in future climate, *Geophys. Res. Lett.*, **45**, 10501–10508, doi: 10.1029/2018GL079566.

Wang, Y., Belluš, M., Ehrlich, A., Mile M., Pristov, N., Smolíková., Španiel, O. Trojákova, A., Brođková, R., Cedilnik, J., Klarić, D., Kovačić, T., Mašek, J., Meier, F., Szintai, B., Tascu, S., Vivoda, J., Wastl, C., and Wittman, C. (2018): 27 years of Regional Co-operation for Limited Area Modelling in Central Europe (RC LACE), *Bull. Am. Meteorol. Soc*., **99**, 1415–1432, doi: 10.1175/BAMS-D-16-0321.1.

Physical oceanography in Croatia, 2015–2018

Gordana Beg Paklar

Institute of Oceanography and Fisheries, Split, Croatia

Between 2015 and 2018 physical oceanographic research in Croatia has mainly been carried out in the following institutions: Institute of Oceanography and Fisheries, Split; Hydrographic Institute of the Republic of Croatia, Split; Center for Marine Research in Rovinj and Division for Marine and Environmental Research in Zagreb, both part of the Rudjer Bošković Institute; and Department of Geophysics, Faculty of Science, University of Zagreb.

Altogether 26 investigators (20 PhD's and 6 MSc's), supported by technical staff, were involved in the research. Field work was carried out by research vessels and boats owned by institutes in Split (*Bios dva, Navicula, Hidra, Palagruža*) and Rovinj (*Vila Velebita, Triton, Burin*). The oceanographic equipment used to study the hydrographic properties included several Seabird CTD probes and a Biospherical profiling radiometer. A towed undulating vehicle, equipped by a Seabird CTD probe, was used to perform hydrographic measurements of high temporal and spatial coverage. Sono.Vault acoustic recorders manufactured by Develogic GmbH Subsea Systems were used to monitor acoustic emissions along the eastern Adriatic coast. Sea currents were measured with a number of current meters, both bottom and vessel mounted (Nortek and RDI ADCP's), and high frequency radars (WERA), while tide gauges (analogue, digital and radar instruments, all manufactured by OTT GmbH) and directional wave riders (Datawell) were used to measure low- and high-frequency sea level oscillations. One buoy, designed and manufactured in Croatia, was deployed in the east Adriatic coastal area in front of the town of Rovinj in order to collect various meteorological and oceanographic data. The Division for Marine and Environmental Research at the Rudjer Bošković Institute possesses satellite antennas. Atmospheric conditions during oceanographic investigations were recorded using ultrasonic Vaisala anemometers, microbarographs and several automatic meteo-oceanographic stations placed in front of the Institute of Oceanography and Fisheries in Split and at Vela Luka (Korčula Island) and Stari Grad (Hvar Island). All institutions had a local computer network with a mainframe computer and a series of personal computers, connected to internet through Carnet (Croatian Academic Research Network). Moreover, complex ocean model simulations with POM, ROMS, ADCIRC and SCHISM models were run on computer clusters and servers at the home institutions as well as at the University Computing Centre in Zagreb and the ECMWF Supercomputer Centre in Reading, UK.

During the four-year interval considered, some previously established measurement programs were maintained and new ones were started. Thus, basic oceanographic data were collected on a monthly or seasonal basis all along the east Adriatic coast, as well as along some cross-shore transects (Rovinj-Po, Split-Gargano, Šibenik-Ortona) within the framework of national projects and studies. Sea surface temperature was measured daily at a number of coastal stations by the Croatian Meteorological and Hydrological Service. Several campaigns of high-frequency CTD measurements with an undulating vehicle were performed in the northern and middle Adriatic. The water column profiling was done between the surface and a depth of 40 to 50 meters, at a horizontal resolution of approximately 200 meters, and a

vertical resolution of about 10 centimeters. The northern Adriatic cruises (March 2015, October 2016, February 2017, April 2017) were organized to document mesoscale variability and dense water formation in the area, whereas cruises in the middle Adriatic (May 2017, June 2018) were aimed at documenting upwelling in the area of the Jabuka Pit.

Continuous measurements of various physical parameters were established and carried out. Four directional wave riders for measuring wave parameters (height, direction and period) were deployed in the Ploče area and near the towns of Dubrovnik (CoRE project), Split and Rovinj in the period from December 2016 to May 2018 by the Hydrographic Institute staff. Two ultrasonic anemometers and a microbarograph were installed in the Ploče area and on the Hydrographic Institute building. A pair of high frequency radars installed in the middle Adriatic within the framework of the HAZADR project, at Cape Ražanj, Island of Brač, and Cape Stončica, Island of Vis, in April 2014 is still collecting data on surface currents and waves. Tide-gauge measurements were continued at a previously established network of seven stations (Rovinj, Bakar, Zadar, Split-Marjan, Split-harbor, Ploče, Dubrovnik) using float-operated (analog and digital) and radar instruments. New OTT RLS (Radar Level Sensor) sea level measuring stations were installed at Vela Luka (Korčula Island), Stari Grad (Hvar Island) and Sobra (Mljet Island). High frequency air pressure measurements were carried out at previously established stations at Vis, Vela Luka and Vrboska and were started at six new microbarograph stations at Ražanj (Brač Island), Svetac Island, Palagruža Island, Ancona, Vieste and Ortona within the MESSI project. Vela Luka (Korčula Island) and Stari Grad (Hvar Island) were also equipped with GMX Gill weather stations measuring air pressure, temperature, relative humidity, wind speed and direction. Continuous ADCP measurements were carried out at three locations in the northern entrance of Kvarner Bay (Vela Vrata) and at two locations in the central entrance (close to Premuda/Skarda) within the NAdEx experiment, as well as in the Rovinj area (still measuring) and in the Ploče region (2017). Occasional measurements were carried out near the towns of Umag and Biograd, and the islands of Krk, Brač and Hvar.

Over the preceding four years Croatian institutions participated in national projects funded by the Croatian Science Foundation (HRZZ), Unity through Knowledge Fund (UKF) and Fund for Environment and Energetic Efficiency. HRZZ projects CARE, SCOOL, MARIPLAN and EcoRENA were dedicated to climate research, while interannual variability in the Adriatic was studied within the BIOTA and ADIOS projects. The scope of the ADAM-ADRIA project was to measure physical properties of the Adriatic Sea with advanced (e.g. ship towed CTD, ship-borne ADCP, and gliders) and conventional instruments, all to identify fine scale features along sharp density fronts, particularly the Istrian Front (IF). Project MARRES is devoted to modelling Rogoznica Lake and other meromictic lakes. A new multidisciplinary project, MAUD, designed to investigate upwelling and downwelling in the area of the Jabuka Pit in the middle Adriatic, started in 2018. UKF funded projects were MESSI, dedicated to meteotsunamis, and NEURAL, concentrating on interpreting and forecasting Adriatic surface currents. Project POZOR was dedicated to potentially dangerous sea level oscillations in the present and future climate. Research work was also done within numerous international projects. Projects BALMAS, HAZADR, JASPPer and ADRIATIC+ were funded by the IPA Adriatic Cross-border Cooperation Programme, while PERSEUS, EUROFLEETS 2, BLUEMED, SeaDataNet-II and SeaDATACloud projects were supported by the European Commission within the Seventh and H2020 framework programmes. Projects MEDCIS and QUIETMED were supported by the DG Environment Programme and project Emodnet Data Ingestion by the DG-mare. In addition to the research, physical oceanographers participated in a series of professional studies dealing with physical parameters relevant to ecosystem analysis and categorization of water within the European directives. Moreover, Croatian physical oceanographers joined international investigations of

areas outside the Adriatic, such as the southwestern Australian coast (Mihanović et al., 2017; Hetzel et al., 2018), the north Atlantic (Perrie et al., 2018), the southwestern coast of Sicily (Šepić et al., 2018b), the Black Sea (Šepić et al., 2015c; 2018a), the Balearic Islands (Šepić et al., 2016b) and the German Bight (Fenoglio-Marc et al., 2015). Croatian physical oceanographers also took part in the IOC assemblies, MedGOOS and EuroGOOS meetings, as well as in a number of international conferences and workshops.

The work done is documented in the publications listed at the end of this report. The list contains scientific papers, books and theses. A short review of topics covered by Croatian physical oceanographers follows. Scientific research in the reporting period was carried out in several fields such as climate change studies, air-sea interaction related to extreme sea level events (meteotsunami, storm surge), mesoscale dynamics, dense water generation, surface circulation, surface waves, optics, pollution problems and different aspects of numerical modelling and forecasting systems. A number of papers resulted from collaboration of physical oceanographers with their colleagues from other closely related oceanographic disciplines: chemists, biologists, fishery scientists and geologists.

The climate-related studies focused on formation and transport of dense water in the Adriatic Sea, and on sea level changes, both global and Mediterranean. They were supported by long-term measurements of parameters collected at permanent oceanographic stations in the middle Adriatic (Mihanović et al., 2015; Vilibić et al., 2015a; 2015b; Matić et al., 2017) and of sea surface temperatures along the eastern Adriatic coast (Grbec et al., 2018). When considering formation of the Adriatic dense water, it is of special interest how the water is exchanged between two sites of formation – the open north Adriatic and the Croatian coastal sea. A simple two-box model was developed in order to interpret the exchange (Orlić, 2018). The model allows for surface heat loss from the two basins and for an advective exchange of heat between the basins. Explicit solutions were obtained for both the original, nonlinear problem and the simplified, linearized problem. The solutions point to a continuous temperature decrease in the two basins, with the sum of surface heat loss and advective heat gain in one basin tending to become equal to the sum of surface and advective heat losses in the other basin. The solutions also reveal which factors control the direction of dense-water transport.

High-resolution hydrographic measurements in the northern Adriatic, performed within the NAdEx 2015 experiment (Vilibić et al., 2018a), show that during a strong bora event a very sharp and strong thermohaline front, with fresher and colder water to the north and saltier and warmer water to the south, extending vertically throughout the entire water column, is formed in the region of the Istrian Front (IF). On some occasions, like in 2015, the front is not density compensated, but is also characterized by a strong density gradient. Under weaker wind conditions, the IF becomes much weaker, wider and inclined. Current measurements in the region and numerical model simulations demonstrated that during strong bora the outflow of cold water from the Kvarner Bay is deflected northward, closer to the Istrian coast (Kokkini et al., 2017).

The dense water formed on the Adriatic shelf is eventually transported across the Palagruža Sill whereupon it enters the south Adriatic. A recent study by Bonaldo et al. (2018) showed that the transport could be influenced by continental shelf waves developing at the Adriatic shelf break. Starting from the observations of high-intensity velocity pulses with a period of approximately 2 days, a sequence of operations was carried out on the results of a high-resolution, wave-ocean coupled numerical modelling experiment aiming to reproduce dense water formation and migration in the Adriatic Sea in winter-spring 2012. It was shown that the observations had been related to a perturbation system propagating southeastward along the Italian coast and amplified as a train of continental shelf waves along the shelf break and on the continental slope, thus providing the first evidence on the existence of such waves

in the Adriatic Sea. Moreover, it was pointed out that the waves could influence the dense water dynamics and therefore also the benthic environments.

With the aim of analyzing and projecting global sea level, three variants of a semi-empirical method were considered (Orlić and Pasarić, 2015). They differ in assuming that the response of sea level to temperature forcing is equilibrium, inertial or a combination of the two. All variants produce a successful regression of the temperature and sea level data, albeit with controlling parameters that differ among the cases. The related response times vary considerably, with a realistic value (ca. 50 years) obtained only if both the equilibrium and the inertial dynamics are taken into account. A comparison of sea levels projected by using the three variants shows that the time series are similar through the middle of the 21st century but they radically diverge by the end of the 23rd century. This result is interpreted with the aid of the underlying transfer functions. It suggests that one should be cautious when using the semi-empirical method to project sea level beyond the 21st century.

Analysis of Mediterranean sea level in the second half of the 20th century was performed using long-term tide-gauge measurements, in order to identify long-term trends against decadal and multidecadal changes in each subbasin (Orlić et al., 2018). Linear trends in the 1950–1990 interval were analyzed using Bayesian statistics. Individual contributions, coming from direct atmospheric forcing and from thermosteric and halosteric changes, were determined and the sea level budget was examined within each region. In the Atlantic off Gibraltar and in the Black Sea regional sea level trends were close to the global values, in the Mediterranean they were close to zero. Throughout the Mediterranean and in the Black Sea, atmospheric forcing and steric effects induced lowering of sea level. In the Mediterranean, and partly in the Black Sea, these regional effects compensated the effect of global mass increase. It is concluded that over the 1950–1990 interval the sea level budget is closed within the, rather wide, credible limits.

The study of short-term processes encompassed the phenomena of storm surges and meteotsunamis. The analysis of storm surges in the north Adriatic showed that during these episodes sea level can significantly slope not only in the along-basin but also in the cross-basin direction, which leads to stronger flooding of either the eastern or the western coastline. The eastern coastline, compared to the western side, is more exposed to flooding during the action of deeper Mediterranean cyclones that are shifted to the north. On these occasions the wind field over the Adriatic is characterized by a shear of along-basin wind and a strong cross-basin wind directed towards the eastern coast (Međugorac et al., 2015; Međugorac et al., 2016; Međugorac et al., 2018). Analysis of sirocco-like wind fields from climate simulations showed that their characteristics in future climate scenarios will remain similar to those in the present climate (Međugorac, 2018).

A study of Chrystal and Proudman resonances in a simple, rectangular closed basin of uniform depth was conducted to explore and compare how well the two resonant mechanisms are reproduced with different, nowadays widely used, numerical ocean models (Bubalo et al., 2018). The test case was based on air pressure disturbances of two commonly used shapes (a sinusoidal and a boxcar), having various wave lengths, and propagating at different speeds. In total, 2250 simulations were performed for each of the three different numerical models: ADCIRC, SCHISM and ROMS. An inter-model comparison of the results showed that different models represent the two resonant phenomena in a slightly different way. For Chrystal resonance, all the models showed similar behavior; however, ADCIRC model is providing slightly higher values of the mean resonant period than the other two models. In the case of Proudman resonance, the most consistent results, closest to the analytical solution, were obtained using ROMS model whereas ADCIRC and SCHISM models showed small deviations from that value. The findings may seem small but could play an important role when resonance is a crucial process producing enhancing effects by two orders of magnitude

(i.e., meteotsunamis).

Meteotsunamis were intensively studied during the reporting period. A potential for generation of meteotsunami waves via open ocean resonance has been investigated for the shallow northern Adriatic (Šepić et al., 2015a). Results based on a set of barotropic numerical modeling experiments were related to occurrence of the real events. The strong coherence between high-frequency sea level events and synoptic patterns introduced the possibility of a timely forecast of these events (Šepić, 2015; Šepić et al., 2015b). The MESSI project resulted in a number of papers aimed to build a reliable prototype of a meteotsunami warning system (Vilibić et al., 2016e). During the project both real-time measurements and modelling (Denamiel et al., 2018; Horvath et al., 2018; Vilibić et al., 2018b) were conducted. A catalogue of meteotsunamis was compiled for the Croatian part of the Adriatic Sea (Orlić, 2015). It included 21 flooding events, observed between the years 1931 and 2010. Vela Luka on the Island of Korčula and Stari Grad on the Island of Hvar were the most often affected locations. A majority of the events occurred in the warm part of the year. They tended to start either early in the morning or late in the afternoon, last between 1 and 6 hours, and be dominated by sea level oscillations of the 10-40 min periods. The largest trough-to-crest height of 6 m was observed in Vela Luka on 21 June 1978.

In addition, Vilibić et al. (2017) provided a comprehensive review of all aspects of the Adriatic sea level research covered by the literature, while Vilibić and Šepić (2017) analyzed nonseismic sea level oscillations at tsunami timescales in the global data sets.

A number of publications dealt with high-frequency (HF) radar measurements in the northern and middle Adriatic. Sensitivity experiments of high-frequency (HF) radar-derived surface current Self-Organizing Maps (SOM) to various processing procedures and mesoscale wind forcing were conducted by Vilibić et al. (2016b) within the NEURAL project. Moreover, an ocean surface currents forecasting system, based on a SOM neural network algorithm, HF ocean radar measurements and numerical weather prediction products, has been developed for a coastal area of the northern Adriatic and compared with operational ROMS-derived surface currents (Vilibić et al., 2016d). The SOM-based forecasting system has a slightly better forecasting skill, especially during strong wind conditions, with potential for further improvement when data sets of higher quality and longer duration will be used for training. As the HF radars and high-resolution weather prediction models are strongly expanding in coastal oceans, providing reliable and long-term data sets, the applicability of the proposed SOM-based forecasting system is expected to be high (Kalinić et al., 2017). Sensitivity and performance of the SOM method were analyzed by Kalinić et al. (2015) using HF radar data set, while Matić et al. (2018) used temperature and salinity data collected in the middle Adriatic to obtain quality measures for the method.

Morović et al. (2015) and Kraus et al. (2018a) studied pollution problems caused by oil spills and ballast waters, respectively. Kraus et al. (2018b) aimed at developing a strategy of ballast water management within BALMAS project.

Results of the numerical model simulations were used in a variety of research and application studies. POM model was used to study the influence of synoptic conditions on the north Adriatic circulation (Beg Paklar et al., 2015), while ROMS model was applied in studies of meteotsunamis (Bubalo et al., 2018; Denamiel et al., 2018), dense water formation (Vilibić et al., 2016c; Mihanović et al., 2018) and mesoscale dynamics in the northern and middle Adriatic. A majority of the data collected during 2015 within the NAdEx experiment were used in ROMS 4DVar data assimilation experiment to obtain optimal analysis of the Adriatic dynamics. On the other hand, a two-dimensional model was setup in order to simulate copper concentration dynamics in the Punat Bay waters (Lončar et al., 2015). A modelling study conducted by MIKE 3fm revealed the impact of winds, tidal oscillations and density distribution on the water mass exchange and wave field in marinas (Lončar et al., 2016;

2017). In addition, two operational systems were established in the reporting period: a surface wave forecast described by Dutour Sikirić et al. (2018) and a one-way coupled numerical atmosphere-ocean model for meteotsunamis forecast (Denamiel et al., 2018). Perrie et al. (2017) assessed the impact of source term parametrizations on wave forecasts for the NorEaster tempests. This is important as Cycle III parameterizations are commonly used despite their shortcomings. Fenoglio et al. (2015) investigated the impact of using SAR vs altimeter in the quality of determined wave height. Bio-physical interactions in phyto- (Kovač, 2016) and ichthyoplankton dynamics (Džoić, 2018) were also investigated by analytical and numerical models. An inverse modelling procedure was developed in order to recover photosynthesis parameters from measured profiles of primary production and tested on data collected off Hawaii (Kovač et al., 2016a; 2016b; 2017a) and Bermuda Islands (2017b) and in the Adriatic Sea (Kovač et al., 2018b). Moreover, a coupled modelling system consisting of ROMS and individual based model ICHTHYOP was developed to study the early stage dynamics of two commercially important species: Atlantic bluefin tuna (Džoić et al., 2017) and gilthead seabream (Džoić, 2018). Useful results were obtained from rigorous model skill assessments in study of dense water formation (Dunić et al., 2018) and atmospheric forcing for ocean models (Dutour Sikirić et al., 2015).

Collaboration with chemists, biologists, fishery scientists and geologists was intensified and resulted in a number of interdisciplinary papers dealing with climate and circulation impact on the ecosystem variability (Babić et al., 2017; 2018; Batistić et al., 2016; Brautović et al., 2018; Bušelić et al., 2015; Bužančić et al., 2016; Ciglenečki et al., 2015; Džoić et al., 2017; Grbec et al., 2015; Grbin et al., 2017; Hure et al., 2018; Lučić et al., 2017; Ninčević-Gladan et al., 2015; Peharda et al., 2016; Peharda et al., 2018a; 2018b; Skejić et al., 2015; 2018; Šegvić-Bubić et al., 2018; Šilović et al., 2018; Šolić et al., 2018; Šupraha et al., 2016; Vidjak et al., 2016; Vilibić et al., 2016a; Živković et al., 2018; Žuljević et al., 2016). Based on data collected in the northern Adriatic, several investigations relating physical influence to biogeochemical conditions were performed. The role of geostrophic currents in distribution of bottom oxygen concentration (Djakovac et al., 2015) and macroaggregates spreading (Kraus and Supić, 2015) was found to be important. Changes in winter oceanographic conditions reflected on zooplankton abundance in the region with implications on the Adriatic anchovy stock prognosis (Kraus et al., 2015). Factors favoring phytoplankton blooms in the northern Adriatic were analyzed showing that in winter and early spring the phytoplankton abundances depend on existing circulation fields, whereas in summer and autumn they are related to the Po River discharge rates recorded 1–15 days earlier and to the concomitant circulation fields; in late spring they increase 1–3 days after high Po River discharge rates regardless of the circulation fields (Kraus et al., 2016).

The Laboratory of Physical Oceanography at the Institute of Oceanography and Fisheries, Split in cooperation with the Croatian Meteorological and Hydrological Service maintained a Virtual Laboratory (http://www.izor.hr/web/guest/virtual-laboratory) and continued to study interactions between climate change and marine ecosystem through monitoring variability of physical parameters in the atmosphere, the sea and at the air-sea interface. Through the interactive interface, the measured oceanographic data have been made available in near real time, as was the weather forecast over the Adriatic Sea.

Finally, it may be concluded that in the period from 2015 to 2018 many new research topics were opened and many problems and questions in the Croatian physical oceanography were resolved. Improvement and modernization of the equipment used were important for new achievements. The list of publications as well as the number of realized and ongoing national and international projects for the Adriatic and other ocean and coastal areas were significantly enlarged in comparison to the previous periods.

List of publications

Babić, I., Petrić, I., Bosak, S., Mihanović, H., Dupčić Radić, I., and Ljubešić, Z. (2017): Distribution and diversity of marine picocyanobacteria community: Targeting of *Prochlorococcus* ecotypes in winter conditions (southern Adriatic Sea), *Mar. Genom.*, **36**, 3–11, doi: 10.1016/j.margen.2017.05.014.

Babić, I., Mucko, M., Petrić, I., Bosak, S., Mihanović, H., Vilibić, I., Dupčić Radić, I., Cetinić, I., Balestra, C., Casotti, R., and Ljubešić, Z. (2018): Multilayer approach for characterization of bacterial diversity in a marginal sea: From surface to seabed, *J. Marine Syst.*, **184**, 15–27.

Batistić, M., Garić, R., and Morović, M. (2016): Changes in the non-crustacean zooplankton community in the middle Adriatic Sea during the Eastern Mediterranean Transient, *Period. Biol.*, **118**, 1, 21–28.

Beg Paklar, G., Džoić, T., and Dadić, V. (2015): Numerical study of the north Adriatic circulation during two successive bora episodes, *Acta Adriat.*, **56** (1), 115–138.

Bonaldo, D., Orlić, M., and Carniel, S. (2018): Framing continental shelf waves in the southern Adriatic Sea, a further flushing factor beyond dense water cascading, *Sci. Rep.,* **8** (660), 1–11.

Brautović, I., Bojanić, N., Vidjak, O., Grbec, B., and Gangai Zovko, B. (2018): Composition and distribution patterns of marine planktonic ostracods (Crustacea, Ostracoda) in the Adriatic Sea – a historical perspective, *Acta Adriat.*, **59** (1), 71–90.

Bubalo, M., Janeković, I., and Orlić, M. (2018): Chrystal and Proudman resonances simulated with three numerical models, *Ocean Dynam.*, **68**, 497–507.

Bušelić, I., Peharda, M., Reynolds, D.J., Butler, P.G., Román González, A., Ezgeta-Balić, D., Vilibić, I., Grbec, B., Hollyman, P., and Richardson, C.A. (2015): *Glycymeris bimaculata* (Poli, 1795) – a new sclerochronological archive for the Mediterranean?, *J. Sea Res.*, **95**, 139–148.

Bužančić, M., Ninčević Gladan, Ž., Marasović, I., Kuspilić, G., and Grbec, B. (2016): Eutrophication influence on phytoplankton community composition in three bays on the eastern Adriatic coast, *Oceanologia*, **58** (4), 302–316.

Ciglenečki, I., Janeković, I., Marguš, M., Bura-Nakić, E., Carić, M., Ljubešić, Z., Batistić, M., Hrustić, E., Dupčić, I., and Garić, R. (2015): Impacts of extreme weather events on highly eutrophic marine ecosystem (Rogoznica Lake, Adriatic coast), *Cont. Shelf Res.*, **108**, 144–155, doi: 10.1016/j.csr.2015.05.007.

Denamiel, C., Šepić, J., and Vilibić, I. (2018): Impact of geomorphological changes to harbor resonance during meteotsunamis: The Vela Luka Bay test case, *Pure Appl. Geophys.*, **175**, 3839–3859.

Djakovac, T., Supić, N., Bernardi Aubry, F., Degobbis, D., and Giani, M. (2015): Mechanisms of hypoxia frequency changes in the northern Adriatic Sea during the period 1972–2012, *J. Mar. Syst.*, **141**, 179–189.

Dunić, N., Vilibić, I., Šepić, J., Somot, S., and Sevault, F. (2018): Dense water formation and BiOS-induced variability in the Adriatic Sea simulated using an ocean regional circulation model, *Clim. Dynam.*, **51**, 1211–1236.

Dutour Sikirić, M., Janeković, I., Tomažić, I., Kuzmić, M., and Roland, A. (2015): Comparison of ALADIN and IFS model wind speeds over the Adriatic, *Acta Adriat.*, **56** (1), 67–82.

Dutour Sikirić, M., Ivanković, D., Roland, A., Ivatek-Šahdan, S., and Tudor, M. (2018): Operational Wave Modelling in the Adriatic Sea with the Wind Wave Model, *Pure Appl. Geophys.*, **175** (11), 3801–3815.

Džoić, T., Beg Paklar, G., Grbec, B., Ivatek-Šahdan, S., Zorica, B., Šegvić-Bubić, T., Čikeš Keč, V., Lepen Pleić, I., Mladineo, I., Grubišić, L., and Verley, P. (2017): Spillover of the Atlantic bluefin tuna offspring from cages in the Adriatic Sea: A multidisciplinary approach and assessment, *PLoS One*, **12** (11), e0188956, 20, doi: 10.1371/journal.pone.0188956.

Džoić, T. (2018): *Application of Lagrangian methods in numerical modelling of dispersion in the Adriatic Sea*, PhD Thesis, University of Zagreb, Zagreb, 153 pp.

Fenoglio-Marc, L., Dinardo, S., Scharroo, R., Roland, A., Dutour Sikirić, M., Lucas, B., Becker, M., Benveniste, J., and Weiss, R. (2015): The German Bight: A validation of CryoSat-2 altimeter data in SAR mode, *Adv. Space Res.*, **55** (11), 2641–2656.

Grbec, B., Morović, M., Matić, F., Ninčević Gladan, Ž., Marasović, I., Vidjak, O., Bojanić, N., Čikeš Keč, V., Zorica, B., Kušpilić, G., and Matić-Skoko, S. (2015): Climate regime shifts and multi-decadal variability of the Adriatic Sea pelagic ecosystem, *Acta Adriat.*, **56** (1), 47–66.

Grbec, B., Matić, F., Beg Paklar, G., Morović, M., Popović, R., and Vilibić, I. (2018): Long-term trends, variability and extremes of in situ sea surface temperature measured along the eastern Adriatic coast and its relationship to hemispheric processes, *Pure Appl. Geophys.*, **175**, 4031–4046.

Grbin, D., Pfannkuchen, M., Babić, I., Mejdandžić, M., Mihanović, H., Marić Pfannkuchen, D., Godrijan, J., Peharec Štefanić, P., Olujić, G., and Ljubešić, Z. (2017): Multigene phylogeny and morphology of newly isolated strain of *Pseudo-nitzschia mannii* Amato & Montresor (Adriatic Sea), *Diatom Res.*, **32**, 127–131, doi: 10.1080/0269249X.2017.1284158.

Hetzel, Y., Pattiaratchi, C., and Mihanović, H. (2018): Exchange flow variability between hypersaline Shark Bay and the ocean, *J. Mar. Sci. Eng.*, **65**, doi: 10.3390/jmse6020065.

Horvath, K., Šepić, J., and Telišman Prtenjak, M. (2018): Atmospheric forcing conducive for the Adriatic 25 June 2014 meteotsunami event, *Pure Appl. Geophys.*, doi: 10.1007/s00024-018-1902-1.

Hure, M., Mihanović, H., Lučić, D., Ljubešić, Z., and Kružić, P. (2018): Mesozooplankton spatial distribution and community structure in the South Adriatic Sea during two winters (2015, 2016), *Mar. Ecol.-Evol. Persp.,* **39**, e12488, doi: 10.1111/maec.12488.

Kalinić, H., Mihanović, H., Cosoli, S., and Vilibić, I. (2015): Sensitivity of Self-Organizing Map surface current patterns to the use of radial versus Cartesian input vectors measured by high-frequency radars, *Comp. Geosci.*, **84**, 29–36.

Kalinić, H., Mihanović, H., Cosoli, S., Tudor, M., and Vilibić, I. (2017): Predicting ocean surface currents using numerical weather prediction model and Kohonen neural network – a northern Adriatic study, *Neural Comput. Appl.*, **28**, S611–S620.

Kokkini, Z., Gerin, R., Poulain, P.-M., Mauri, E., Pasarić, Z., Janeković, I., Pasarić, M., Mihanović, H., and Vilibić, I. (2017): A multiplatform investigation of Istrian Front dynamics (North Adriatic Sea) in winter 2015, *Mediterr. Mar. Sci.*, **18**, 344–354.

Kovač, Ž. (2016): *Inverse modeling of primary production*, PhD Thesis, University of Zagreb, Zagreb, 151 pp.

Kovač, Ž., Platt, T., Sathyendranath, S., and Morović, M. (2016a): Analytical solution for the vertical profile of daily production in the ocean, *J. Geophys. Res.–Oceans*, **121**, doi: 10.1002/2015JC011293.

Kovač, Ž., Platt, T., Sathyendranath, S., Morović, M., and Jackson, T. (2016b): Recovery of photosynthesis parameters from in situ profiles of phytoplankton production, *ICES J. Mar. Sci.*, **73** (2): 275–285. doi:10.1093/icesjms/fsv204.

Kovač, Ž., Platt, T., Sathyendranath, S., and Antunović, S. (2017a): Models for estimating photosynthesis parameters from in situ production profiles, *Prog. Oceanogr.,* **159**, 255–266. doi: 10.1016/j.pocean.2017.10.013.

Kovač, Ž., Platt, T., Antunović, S., Sathyendranath, S., Morović, M., and Gallegos, C. (2017b): Extended formulations and analytic solutions for watercolumn production integrals, *Front Mar. Sci.*, **4**, (163), doi: 10.3389/fmars.2017.00163.

Kovač, Ž., Platt, T., Ninčević Gladan, Ž., Morović, M., Sathyendranath, S., Raitsos, D. E., Grbec, B., Matić, F., and Veža, J. (2018a): A 55-year time series station for primary production in the Adriatic Sea: Data correction, extraction of photosynthesis parameters and regime shifts, *Remote Sens.*, **10** (9), 1460. doi: 10.3390/rs10091460.

Kovač, Ž., Platt, T., Sathyendranath, S., and Lomas, M. W. (2018b): Extraction of photosynthesis parameters from time series measurements of in situ production: Bermuda Atlantic time-series study, *Remote Sens.,* **10** (6), 915. doi: 10.3390/rs10060915.

Kraus, R. and Supić, N. (2015): Sea dynamics impacts on the macroaggregates: A case study of the 1997 mucilage event in the northern Adriatic, *Prog. Oceanogr.*, **138**, 249–267.

Kraus, R., Supić, N., Lučić, D., and Njire, J. (2015): Impact of winter oceanographic conditions on zooplankton abundance in northern Adriatic with implications on Adriatic anchovy stock prognosis, *Estuar. Coastal Shelf Sci.*, **167**, 56–66.

Kraus, R., Supić, N., and Precali, R. (2016): Factors favouring phytoplankton blooms in the northern Adriatic: towards the northern Adriatic empirical ecological model, *Ocean Sci.*, **12**, 19–37.

Kraus, R., Grilli, F., Supić, N., Janeković, I., Brailo, M., Cara, M., Bratoš Cetinić, A., Campanelli, A., Cozzi, S., D'Adamo, R., Djakovac, T., Dutour-Sikirić, M., Flander Putrle, V., Francée, J., Joksimović, D., Klun, K., Kolitari, J., Kralj, M., Kušpilić, G., Marini, M., Matić, F., Mikus, J., Ninčević-Gladan, Ž., Pansera, M., Pećarević, M., Precali, R., Prusina, I., Relitti, F., Santucci, A., Specchiulli, A., and Škalic, D. (2018a): Oceanographic characteristics of the Adriatic Sea – support to secondary HAOP spread through natural dispersal, *Mar. Pollut. Bull.*, doi: 10.1016/j.marpolbul.2018.10.062.

Kraus, R., Ninčević-Gladan, Ž., Auriemma, R., Bastianini, M., Bolognini, L., Cabrini, M., Cara, M., Čalić, M., Campanelli, A., Cvitković, I., Despalatović, M., Drakulović, D., Flander-Putrle, V., Grati, F., Grego, M., Grilli, F., Jaklin, A., Janeković, I., Kolitari, J., Lipej, L., Magaletti, E., Marini, M., Mavrič, B., Mikus, J., Mozetič, P., Orlando-Bonaca, M., Petović, S., Precali, R., Supić, N., Trabucco, B., Travizi, A., and

Žuljević, A. (2018b): Strategy of port baseline surveys (PBS) in the Adriatic Sea, *Mar. Pollut. Bull.*, doi: 10.1016/j.marpolbul.2018.08.067.

Lončar, G., Tudor, M., Beg Paklar, G., and Oreščanin, V. (2015): Numerička analiza koncentracije bakra u akvatoriju Puntarskog zaljeva, *Hrvatske vode*, **23** (92), 93–110.

Lončar, G., Bekić, D., Carević, D., Bujak, D., Bartolić, I., and Beg Paklar, G. (2016): Utjecaj kanalskih propusta na izmjenu mora i valovanje u akvatoriju marina, *Hrvatske vode*, **24** (98), 275–284.

Lončar, G., Carević, D., Bujak, D., Bartolić, I., and Beg Paklar, G. (2017): Analiza utjecaja vjetra, plimnih oscilacija i razdiobe gustoće na izmjenu mora kroz propuste u marinama: primjer marine Ičići, *Hrvatske vode*, **24** (101), 139–148.

Lučić, D., Ljubešić, Z., Babić, I., Bosak, S., Cetinić, I., Vilibić, I., Mihanović, H., Hure, M., Njire, J., Lučić, P., and Kružić, P. (2017) Unusual winter zooplankton bloom in the open southern Adriatic Sea. *Turk. J. Zool.*, **41**, 1024–1035.

Matić, F., Kovač, Ž., Vilibić, I., Mihanović, H., Morović, M., Grbec, B., Leder, N., and Džoić, T. (2017): Oscillating Adriatic temperature and salinity regimes mapped using the Self-Organizing Maps method, *Cont. Shelf Res.*, **132**, 11–18.

Matić, F., Kalinić, H., and Vilibić, I. (2018): Interpreting Self-Organizing Map errors in the classification of ocean patterns, *Comp. Geosci.*, **119**, 9–17.

Međugorac, I., Pasarić, M., and Orlić, M. (2015): Severe flooding along the eastern Adriatic coast: the case of 1 December 2008, *Ocean Dynam.*, **65**, 817–830.

Međugorac, I., Pasarić, M., Pasarić, Z., and Orlić, M. (2016): Two recent storm-surge episodes in the Adriatic, *Int. J. Saf. Secur. Eng.*, **6**, 589–596.

Međugorac, I. (2018): *Exceptionally high sea levels in the Northern Adriatic and the east-to-west sea-level slope*, PhD Thesis, University of Zagreb, Zagreb, 105 pp.

Međugorac, I., Orlić, M., Janeković, I., Pasarić, M., and Pasarić, Z. (2018): Adriatic storm surges and related cross-basin sea-level slope, *J. Marine Syst.*, **181**, 79–90.

Mihanović, H., Vilibić, I., Dunić, N., and Šepić, J. (2015): Mapping of decadal middle Adriatic oceanographic variability and its relation to the BiOS regime, *J. Geophys. Res.–Oceans*, **120**, 5615–5630, doi: 10.1002/2015JC010725.

Mihanović, H., Pattiaratchi, C., and Verspecht, F. (2016): Diurnal sea breezes force near-inertial waves along Rottnest continental shelf, southwestern Australia, *J. Phys. Oceanogr.,* **46**, 3487–3508, doi:10.1175/JPO-D-16-0022.1.

Mihanović, H., Janeković, I., Vilibić, I., Kovačević, V., and Bensi, M., (2018): Modelling interannual changes in dense water formation on the northern Adriatic shelf. *Pure Appl. Geophys.*, **175**, 4065–4081.

Morović, M., Ivanov, A., Oluić, M., Kovač, Ž., and Terleeva, N. (2015): Oil spills distribution in the Middle and Southern Adriatic Sea as a result of intensive ship traffic, *Acta Adriat.*, **56** (2), 145–156.

Ninčević-Gladan, Ž., Bužančić, M., Kušpilić, G., Grbec, B., Matijević, S., Skejić, S., Marasović, I., and Morović, M. (2015): The response of phytoplankton community to anthropogenic pressure gradient in the coastal waters of the eastern Adriatic Sea, *Ecol. Indic.*, **56**, 106–115

Orlić, M. (2015): The first attempt at cataloguing tsunami-like waves of meteorological origin in Croatian coastal waters, *Acta Adriat.,* **56**, 83–95.

Orlić, M. and Pasarić, Z. (2015): Some pitfalls of the semiempirical method used to project sea level, *J. Clim.,* **28**, 3779–3785.

Orlić, M. (2018): Exchange of dense water between the open North Adriatic and the Croatian coastal sea: explicitly solving a nonlinear problem, *Geofizika*, **35**, 159–175.

Orlić, M., Pasarić, M., and Pasarić, Z. (2018): Mediterranean sea-level variability in the second half of the twentieth century: a Bayesian approach to closing the budget, *Pure Appl. Geophys.,* **175**, 3973–3988.

Peharda, M., Black, B. A., Purroy, A., and Mihanović, H. (2016): The bivalve *Glycymeris pilosa* as a multidecadal environmental archive for the Adriatic and Mediterranean Seas, *Mar. Environ. Res.,* **119**, 79–87, doi: 10.1016/j.marenvres.2016.05.022.

Peharda, M., Thébault, J., Markulin, K., Schöne, B.R., Janeković, I., and Chauvaud, L. (2018a): Contrasting shell growth strategies in two Mediterranean bivalves revealed by oxygen-isotope ratio geochemistry: The case of Pecten jacobaeus and Glycymeri spilosa, *Chem. Geol.*, doi: 10.1016/j.chemgeo.2017.09.029.

Peharda, M., Vilibić, I., Black, B.A., Markulin, K., Dunić, N., Džoić, T., Mihanović, H., Gačić, M., Puljas, S., and Waldman, R. (2018b): Using bivalve chronologies for quantifying environmental drivers in a semi-enclosed temperate sea, *Sci. Rep.*, **8**, 5559, doi: 10.1038/s41598-018-23773-w.

Perrie, W., Toulany, B., Roland, A., Dutour Sikirić, M., Chen, C., Beardsley, R., Qi, J., Hu, Y., Casey, M., and Shen, H. (2018): Modeling North Atlantic Nor'easters with modern wave forecast models, *J. Geophys. Res.–Oceans*, **123** (1), 1–25.

Skejić, S., Vilibić, I., Matijević, S., Jozić, S., Ninčević Gladan, Ž., Morović, M., and Prelesnik, H. (2015): Long-term regulating mechanisms of phytoplankton biomass in a traditional shellfish aquaculture area, *Fresen. Environ. Bull.*, **24**, 3001–3013.

Skejić, S., Arapov, J., Kovačević, V., Bužančić, M., Bensi, M., Giani, M., Bakrač, A., Mihanović, H., Ninčević Gladan, Ž., Urbini, L., and Grbec, B. (2018): Coccolithophore diversity in open waters of the middle Adriatic Sea in pre- and post-winter periods, *Mar. Micropaleontol.*, **143**, 30–45, doi:10.1016/j.marmicro.2018.07.006.

Šegvić-Bubić, T., Arechavala-Lopez, P., Vučić, I., Talijančić, I., Grubišić, L., Žužul, I., and Kovač, Ž. (2018): Site fidelity of farmed gilthead seabream Sparus aurata escapees in a coastal environment of the Adriatic Sea, *Aquacult. Env. Interac.*, **10**, 21–34, doi: 10.3354/aei00251.

Šilović, T., Mihanović, H., Batistić, M., Radić Dupčić, I., Hrustić, E. and Najdek, M. (2018): Picoplankton distribution influenced by thermohaline circulation in the southern Adriatic, *Cont. Shelf Res.,* **155**, 21–33, doi:10.1016/j.csr.2018.01.007.

Šepić, J. (2015): *Meteorological tsunamis in the Adriatic*, PhD thesis, University of Zagreb, 105 pp.

Šepić, J., Vilibić, I., and Fine, I. (2015a): Northern Adriatic meteorological tsunamis: Assessment of their potential through ocean modeling experiments, *J. Geophys. Res.–Oceans*, **120**, 2993–3010, doi: 10.1002/2015JC010795.

Šepić, J., Vilibić, I., Lafon, A., Macheboeuf, L., and Ivanović, Z. (2015b): High-frequency sea level oscillations in the Mediterranean and their connection to synoptic patterns, *Prog. Oceanogr.*, **137**, 284–298.

Šepić, J., Vilibić, I., Rabinovich, A.B., and Monserrat, S. (2015c): Widespread tsunami-like waves of 23–27 June in the Mediterranean and Black Seas generated by high-altitude atmospheric forcing, *Sci. Rep.*, **5**, 11682, doi: 10.1038/srep11682.

Šepić, J., Međugorac, I., Janeković, I., Dunić, N., and Vilibić, I. (2016a): Multi-meteotsunami event in the Adriatic Sea generated by atmospheric disturbances of 25–26 June 2014, *Pure Appl. Geophys.*, **173**, 4117–4138.

Šepić, J., Vilibić, I., and Monserrat, S. (2016b): Quantifying the probability of meteotsunami occurrence from synoptic atmospheric patterns, *Geophys. Res. Lett.*, **43**, 10377–10384, doi: 10.1002/2016GL070754.

Šepić, J., Rabinovich, A. B., and Sytov. V. N. (2018a): Odessa tsunami of 27 June 2014: Observations and numerical modelling, *Pure Appl. Geophys.*, **175**, 1545–1572, doi.org/10.1007/s00024-017-1729-1.

Šepić, J., Vilibić, I., Tinti, S., and Rabinovich, A. B. (2018b): Meteotsunami ("marrobbio") of 25–26 June 2014 on the southwestern coast of Sicily, Italy, *Pure Appl. Geophys*, **175**, 1573–1593, doi.org/10.1007/s00024-018-1827-8.

Šolić, M., Grbec, B., Matić, F., Šantić, D., Šestanović, S., Ninčević Gladan, Ž., Bojanić, N., Ordulj, M., Jozić, S., and Vrdoljak, A. (2018): Spatio-temporal reproducibility of the microbial food web structure associated with the change in temperature: Long-term observations in the Adriatic Sea, *Prog. Oceanogr.*, **161**, 87–101.

Šupraha, L., Ljubešić, Z., Mihanović, H., and Henderiks, J. (2016): Coccolithophore life-cycle dynamics in a coastal Mediterranean ecosystem: seasonality and species-specific patterns, *J. Plankton Res.,* **38** (5), 1178–1193, doi: 10.1093/plankt/fbw061.

Vidjak, O., Bojanić, N., Ninčević Gladan, Ž., Skejić, S., and Grbec, B. (2016): First record of small tropical calanoid copepod Parvocalanus crassirostris (Copepoda, Calanoida, Paracalanidae) in the Adriatic Sea, *Mediterr. Mar. Sci.*, **17** (3), 627–633.

Vilibić, I., Mihanović, H., Kušpilić, G., Ivčević, A., and Milun, V. (2015a): Mapping of oceanographic properties along a middle Adriatic transect using Self-Organising Maps*, Estuar. Coast. Shelf Sci.*, **163**, 84–92.

Vilibić, I., Pištalo, D., and Šepić, J. (2015b): Long-term variability and trends of relative geostrophic currents in the middle Adriatic, *Cont. Shelf Res.*, **93**, 70–80.

Vilibić, I., Čikeš Keč, V., Zorica, B., Šepić, J., Matijević, S., and Džoić, T. (2016a): Hydrographic conditions driving sardine and anchovy populations in a land-locked sea, *Mediterr. Mar. Sci.*, **17** (1), 1–12.

Vilibić, I., Kalinić, H., Mihanović, H., Cosoli, S., Tudor, M., Žagar, N., and Jesenko, B. (2016b): Sensitivity of HF radar-derived surface current Self-Organizing Maps to various processing procedures and mesoscale wind forcing, *Computat. Geosci.*, **201**, 115–131.

Vilibić, I., Mihanović, H., Janeković, I., and Šepić, J. (2016c): Modelling the formation of dense water in the northern Adriatic: sensitivity studies, *Ocean Model.*, **101**, 17–29.

Vilibić, I., Šepić, I., Mihanović, H., Kalinić, H., Cosoli, S., Janeković, I., Žagar, N., Jesenko, B., Tudor, M., Dadić, V., and Ivanković, D. (2016d): Self-Organizing Maps-based ocean currents forecasting system, *Sci. Rep.*, **6**, 22924, doi: 10.1038/srep22924.

Vilibić, I., Šepić, J., Rabinovich, A.B., and Monserrat, S. (2016e): Modern approaches in meteotsunami research and early warning, *Front. Mar. Sci.*, **3** (57), doi: 10.3389/fmars.2016.00057.

Vilibić, I. and Šepić, J. (2017): Global mapping of nonseismic sea level oscillations at tsunami timescales, *Sci. Rep.*, **7**, 40818, doi: 10.1038/srep40818.

Vilibić, I., Šepić, J., Pasarić, M., and Orlić, M. (2017): The Adriatic Sea: A long-standing laboratory for sea level studies, *Pure Appl. Geophys.*, **174**, 3765–3811.

Vilibić, I., Mihanović, H., Janeković, I., Denamiel, C., Poulain, P.-M., Orlić, M., Dunić, N., Dadić, V., Pasarić, M., Muslim, S., Gerin, R., Matić, F., Šepić, J., Mauri, E., Kokkini, Z., Tudor, M., Kovač, Ž., and Džoić, T. (2018a): Wintertime dynamics in the coastal northeastern Adriatic Sea: the NAdEx 2015 experiment, *Ocean Sci.*, **14**, 237–258.

Vilibić, I., Šepić, J., Dunić, N., Sevault, F., Monserrat, S., and Jordà, G. (2018b): Proxy-based assessment of strength and frequency of meteotsunamis in future climate, *Geophys. Res. Lett.*, **45**, 10501–10508.

Živković, I., Fajon, V., Kotnik, J., Shlyapnikov, Y., Obu Vazner, K., Begu, E., Šestanović, S., Šantić, D., Vrdoljak, A., Jozić, S., Šolić, M., Lušić, J., Veža, J., Kušpilić, G., Ordulj, M., Matić, F., Grbec, B., Bojanić, N., Ninčević Gladan, Ž., and Horvat, M. (2018): Relations between mercury fractions and microbial community components in seawater under the presence and absence of probable phosphorus limitation conditions, *J. Environ. Sci.,* doi: 10.1016/j.jes.2018.03.012.

Žuljević, A., Peters, A.F., Nikolić, V., Antolić, B., Despalatović, M., Cvitković, I., Isajlović, I., Mihanović, H., Matijević, S., Shewring, D. M., Canese, S., Katsaros, C., and Küpper, F. C. (2016): The Mediterranean deep-water kelp *Laminaria rodriguezii* is an endangered species in the Adriatic Sea, *Mar. Biol.,* **163**, doi: 10.1007/s00227-016-2821-2.

Seismology in Croatia, 2015–2018

Marijan Herak, Davorka Herak, Josip Stipčević

University of Zagreb, Faculty of Science, Department of Geophysics,
Andrija Mohorovičić Geophysical Institute, Zagreb, Croatia

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 temporary BB-stations were deployed and maintained from project funds (see Fig. 1).
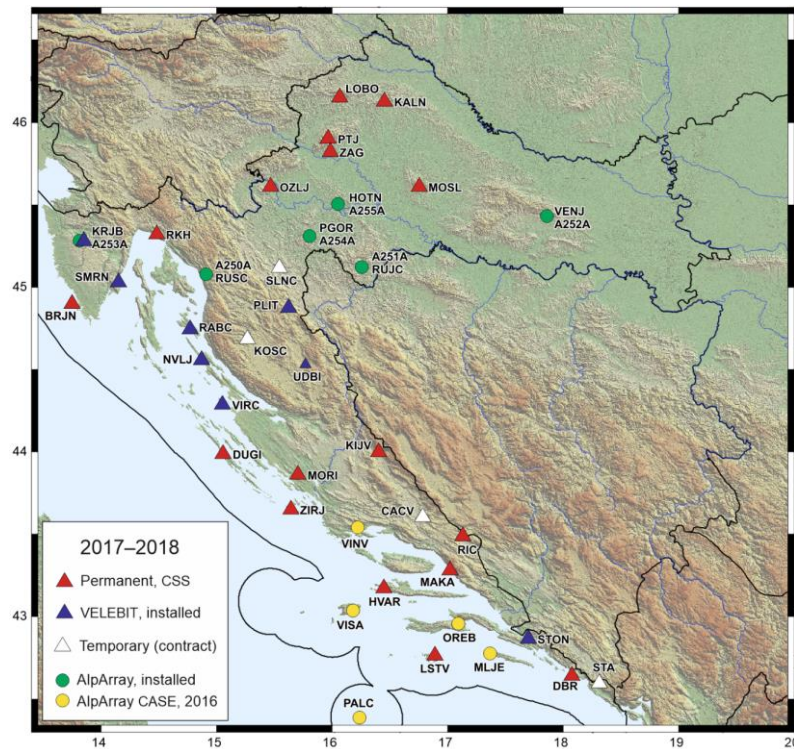
Figure 1. Seismic network in Croatia in the period 2017–2018.

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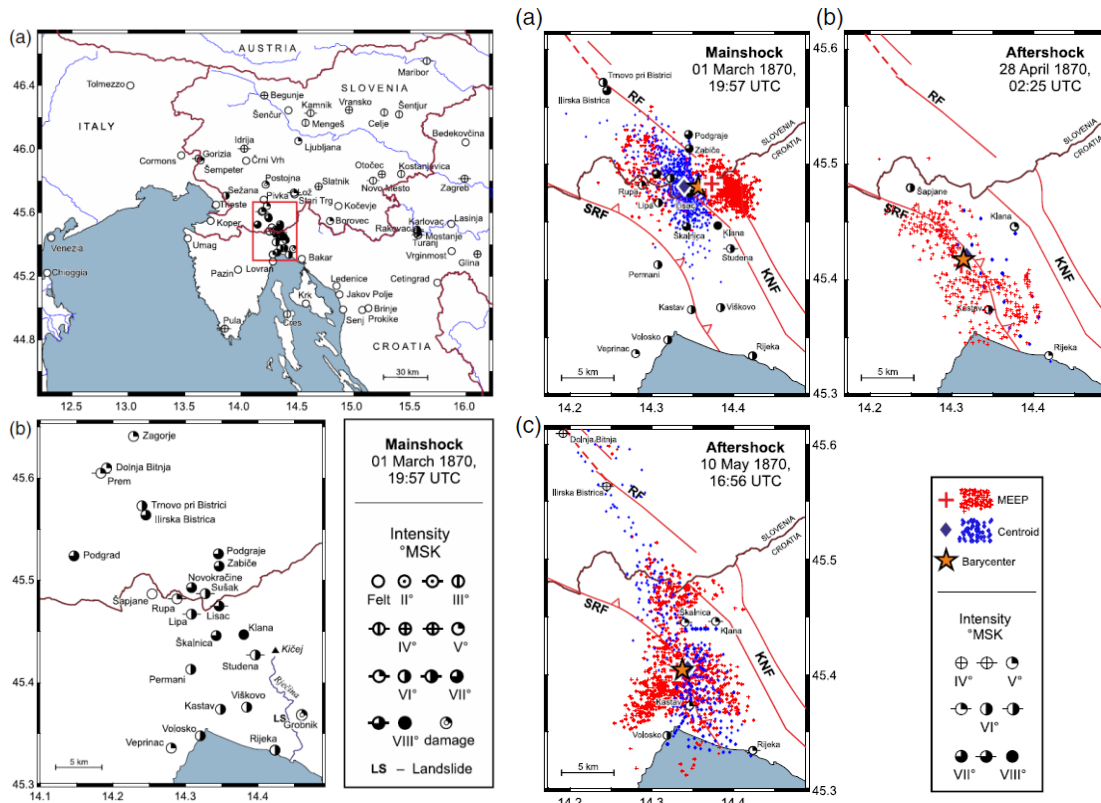
Figure 2. Macroseismic analyses of the Klana eartqhuake of 1870. *Left:* assigned intensities. *Right:* determination of the macroseismic epicentre (from Herak et al., 2018).

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.
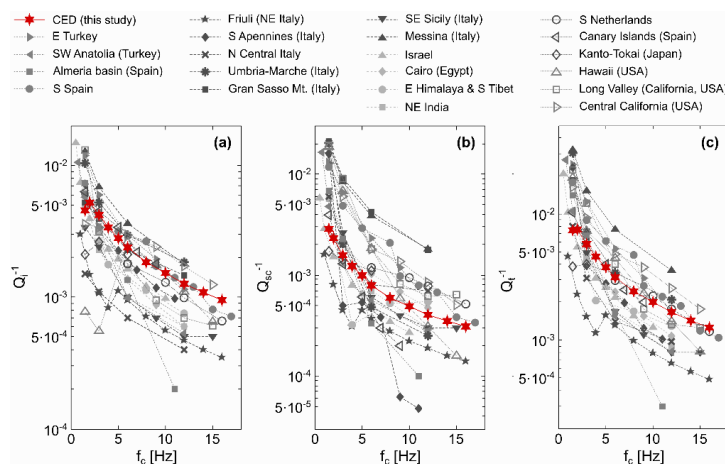

Figure 3. Intrinsic (a), scattering (b) and total (c) attenuation in the Central External Dinarides (CED), compared to a number of regions worldwide (from Majstorović et al., 2017).

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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 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.
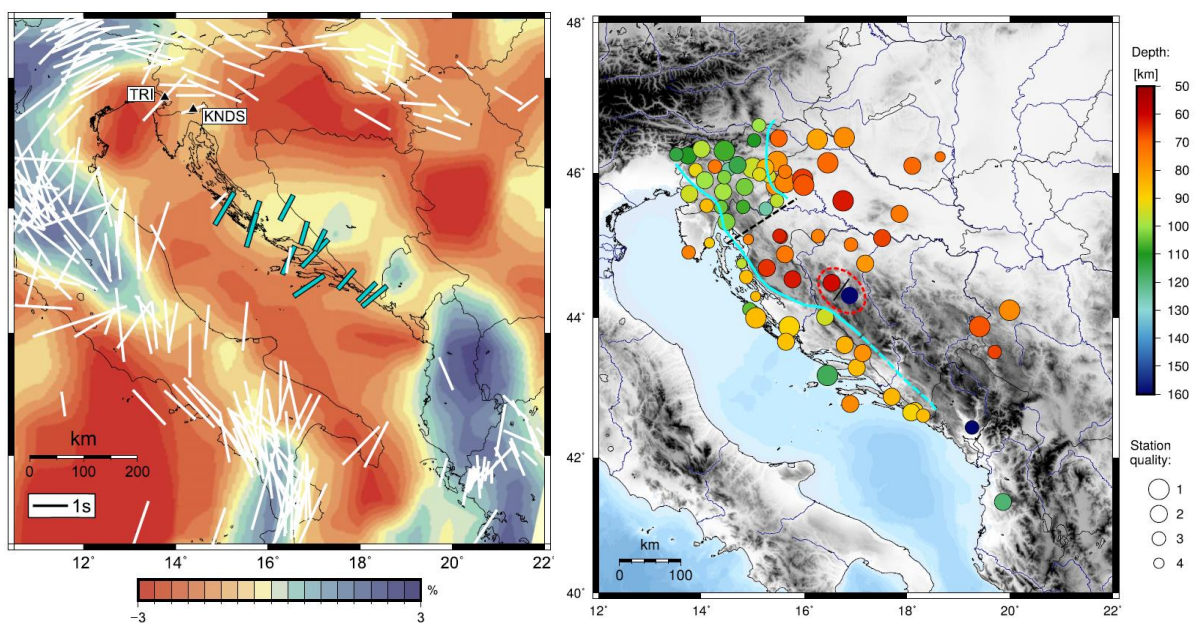

Figure 4. *Left*: Directions of fast axes from SKS-splitting (Subašić et al., 2017). *Right*: Lithospheric thickness estimated by S-receiver function analyses (Belinić et al., 2018).
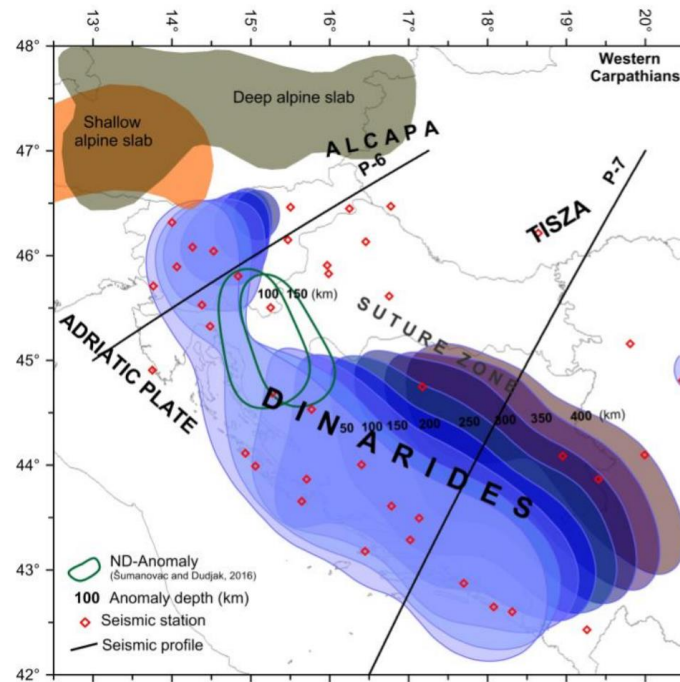
Figure 5. Overview display of the fast anomaly in the Dinarides area from Šumanovac et al. (2017).

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).
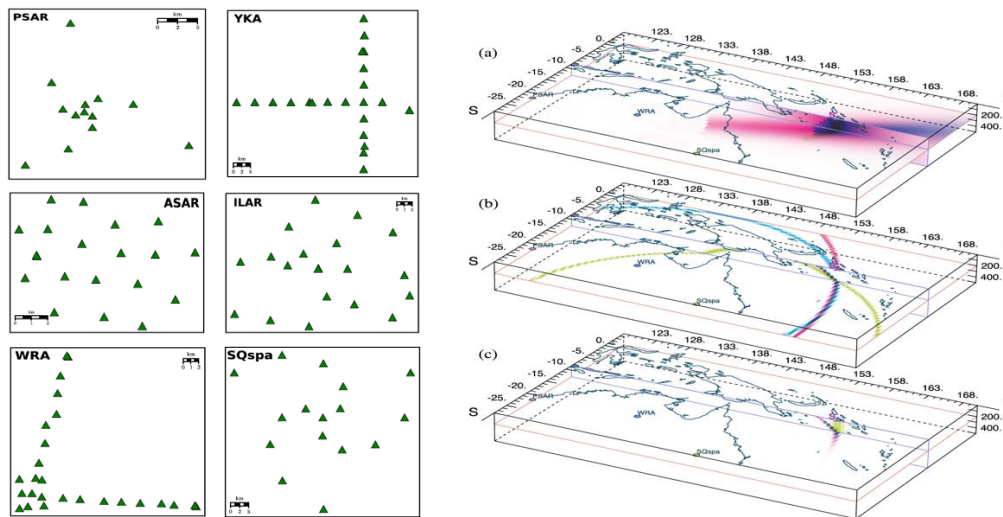

Figure 6. *Left*: Configuration of the six arrays used for multiple array analysis (Kennett et al., 2015; Stipčević et al., 2017). *Right*: Illustration of the interaction of spatial constraints for multiple arrays target (Stipčević et al., 2017).

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.
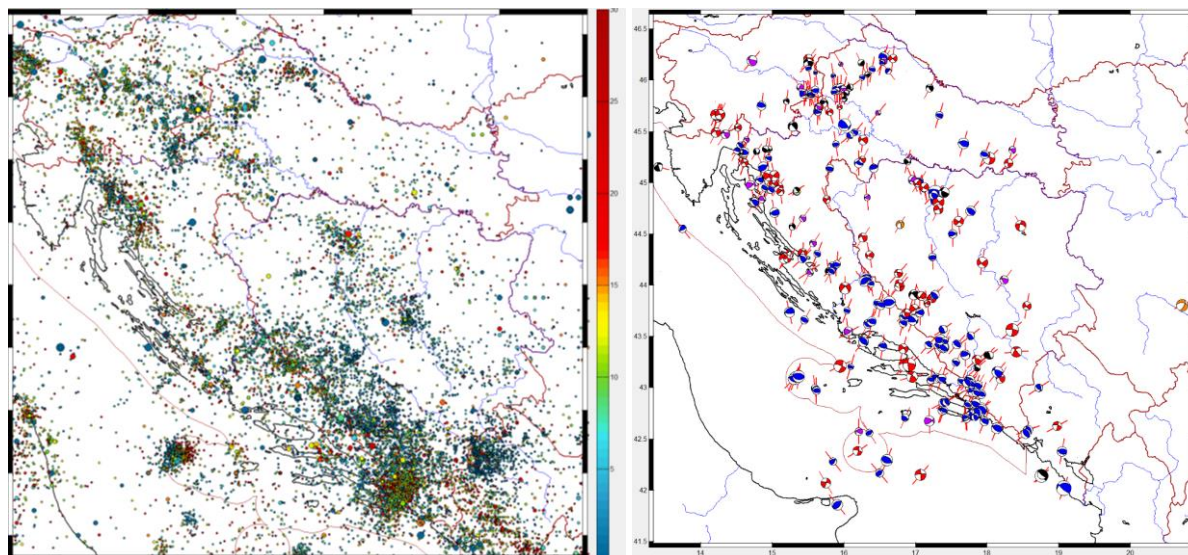

Figure 7. *Left*: Epicentres from the Croatian Earthquake Catalogue (BCE–2017, M ≥ 2.2). Focal depth is indicated by the colour scale and symbols scale with magnitude. *Right:* First-motion polarity fault-plane solutions (FPS; blue – reverse, red – strike slip). Short red lines are oriented in the direction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

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 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.

List of publications

Belinić, T. and Markušić, S. (2017): Empirical criteria for the accuracy of earthquake locations on the Croatian territory, *Geofizika*, **34** (1), 1–17, doi: 10.15233/gfz.2017.34.5.

Dasović, I., Ruščić, M., Herak, D., and Herak, M. (2015): Attenuation of high-frequency body waves in the crust of the Central External Dinarides, *J. Seismol.*, **19** (4), 849–860, doi: 10.1007/s10950-015-9498-8.

Dettmer, J., Dosso, S., Bodin, T., Stipčević, J., and Cummins, P. (2015): Direct-seismogram inversion for receiver-side structure with uncertain source–time functions, *Geophys. J. Int.*, **203** (2), 1355–1372, doi: 10.1093/gji/ggv375.

Herak, D., Sović, I., Cecić, I., Živčić, M., Dasović, I., and Herak, M. (2017): Historical seismicity of the Rijeka region (NW External Dinarides, Croatia) – Part I: Earthquakes of 1750, 1838 and 1904 in the Bakar epicentral area, *Seismol. Res. Lett.*, **88** (3), 904–915, doi: 10.1785/0220170014.

Herak, M., Živčić, M., Sović, I., Cecić, I., Dasović, I., Stipčević, J., and Herak, D. (2018): Historical seismicity of the Rijeka region (NW External Dinarides, Croatia) – Part II: The Klana earthquakes of 1870, *Seismol. Res. Lett.*, **89** (4), 1524–1536, doi: 10.1785/0220180064.

Hetényi, G., Molinari, I., Clinton, J., Bokelmann, G., Bondár, I., Crawford, W., Dessa, J., Doubre, C., Friederich, W., Fuchs, F., Giardini, D., Gráczer, Z., Handy, M., Herak, M., Jia, Y., Kissling, E., Kopp, H., Korn, M., Margheriti, L., Meier, T., Mucciarelli, M., Paul, A., Pesaresi, D., Piromallo, C., Plenefisch, T., Plomerová, J., Ritter, J., Rümpker, G., Šipka, V., Spallarossa, D., Thomas, C., Tilmann, F., Wassermann, J., Weber, M., Wéber, Z., Wesztergom, V., Živčić, M., AlpArray Seismic Network Team, AlpArray OBS Cruise Crew, and AlpArray Working Group (2018): The AlpArray Seismic Network – a large-scale European experiment to image the Alpine orogeny, *Surv. Geophys.*, **39**, doi: 10.1007/s10712-018-9472-4.

Ivančić, I., Herak, D., Herak, M., Allegretti, I., Fiket, T., Kuk, K., Markušić, S., Prevolnik, S., Sović, I., Dasović, I., and Stipčević, J. (2018): Seismicity of Croatia in the period 2006–2015, *Geofizika*, **35** (1), 69–98, doi: 10.15233/gfz.2018.35.2.

Kennett, B., Stipčević, J., and Gorbatov, A. (2015): Spiral-Arm Seismic Arrays. *B. Seismol. Soc. Am.*, **105** (4), 2109-1, doi: 10.1785/0120140354.

Lee, V., Manić, M., Bulajić, B., Herak, D., Herak, M., Stojković, M., and Trifunac, M. (2015): Microzonation of Banja Luka for performance-based earthquake-resistant design, *Soil Dyn. Earthq. Eng.*, **78**, 71–88, doi: 10.1016/j.soildyn.2014.06.035.

Lee, V.W., Trifunac, M.D., Bulajić, B., Manić, M., Herak, D., Herak, M., and Dimov, G. (2017a): Seismic microzoning in Skopje, Macedonia, *Soil Dyn. Earthq. Eng.*, **98**, 166–182, doi: 10.1016/j.soildyn.2017.04.007.

Lee, V., Trifunac, M., Bulajić, B., Manić, M., Herak, D., and Herak, M. (2017b): Seismic microzoning of Belgrade, *Soil Dyn. Earthq. Eng.*, **97**, 395–412, doi: 10.1016/j.soildyn.2017.02.002.

Lee, V., Trifunac, M., Bulajić, B., Manić, M., Herak, D., Herak, M., Dimov, G., and Gičev, V. (2017c): Seismic microzoning of Štip in Macedonia, *Soil Dyn. Earthq. Eng.*, **98**, 54–66, doi: 10.1016/j.soildyn.2017.04.003.

Majstorović, J., Belinić, T., Namjesnik, D., Dasović, I., Herak, D., and Herak, M. (2017): Intrinsic and scattering attenuation of high- frequency S-waves in the central part of the External Dinarides, *Phys Earth Planet. In.*, **270**, 73–83, doi:10.1016/j.pepi.2017.06.005.

Markušić, S., Gülerce, Z., Kuka, N., Duni, L., Ivančić, I., Radovanović, S., Glavatović, B., Milutinović Z., Akkar, S., Kovačević, S., Mihaljević, J., and Šalić, R. (2016): An updated and unified earthquake catalogue for the Western Balkan Region, *B. Earthq. Eng.*, **14** (2), 321–343, doi: 10.1007/s10518-015-9833-z.

Markušić, S., Ivančić, I., and Sović, I. (2017): The 1667 Dubrovnik earthquake – some new insights, *Stud. Geophys. Geod.*, **61** (3), 587–600, doi: 10.1007/s11200-016-1065-4.

Mihaljević, J., Zupančič, P., Kuka, N., Kaluđerović, N., Koçi, R., Markušić, S., Šalić, R., Dushi, E., Begu, E., Duni, L., Živčić, M., Kovačević, S., Ivančić, I., Kovačević, V., Milutinović, Z., Vakilinezhad, M., Fiket, T., and Gülerce, Z. (2017): BSHAP seismic source characterization models for the Western Balkan Region, *B. Earthq. Eng.*, **15** (10), 3963–3985, doi: 10.1007/s10518-017-0143-5.

Molinari, I., Dasović, I., Stipčević, J., Šipka, V., Kissling, E., Clinton, J., Salimbeni, S., Prevolnik, S., Giardini, D., Wiemer, S., AlpArray-CASE Field Team, and AlpArray-CASE Working Group (2018): Investigation of the Central Adriatic Lithosphere structure with the AlpArray-CASE seismic experiment, *Geofizika*, **35** (2), 103–128, doi: 10.15233/gfz.2018.35.6.

Sović, I. and Šariri, K. (2016): Explaining anisotropic macroseismic fields in terms of fault zone attenuation – A simple model, *Tectonophysics*, **680**, 113–121, doi: 10.1016/j.tecto.2016.05.018.

Stanko, D., Markušić, S., Strelec, S., and Gazdek, M. (2016): Seismic response and vulnerability of historical Trakošćan Castle, Croatia using HVSR method, *Environ. Earth Sci.*, **75** (5), 368-1, doi: 10.1007/s12665-015-5185-x.

Stanko, D., Markušić, S., Strelec, S., and Gazdek, M. (2017a): Equivalent-linear site response analysis on the site of the historical Trakošćan Castle, Croatia using HVSR method, *Environ. Earth Sci.*, **76**, 642, 21, doi: 10.1007/s12665-017-6971-4.

Stanko, D., Markušić, S., Strelec, S., and Gazdek, M. (2017b): HVSR analysis of seismic site effects and soil-structure resonance in Varaždin city (North Croatia), *Soil Dyn. Earthq. Eng.*, **92**, 666–677, doi: 10.1016/j.soildyn.2016.10.022.

Stanko, D., Markušić, S., Ivančić, I., and Z. Gülerce (2017): Preliminary estimation of kappa (κ) in Croatia, *IOP C Ser. Earth Env.*, doi: 10.1088/1755-1315/95/3/032014.

Stipčević, J., Kennett, B., and Tkalčić, H. (2017): Simultaneous use of multiple seismic array, *Geophys. J. Int.*, **209** (2), 770–783, doi:10.1093/gji/ggx027.

Subašić, S., Prevolnik, S., Herak, D., and Herak, M. (2017): Observations of SKS splitting in the Central External Dinarides-Adria collision zone, *Tectonophysics*, **705**, 93–100, doi: 10.1016/j.tecto.2017.03.027.

Šalić, R., Sandikkaya, A., Milutinović, Z., Gulerce, Z., Duni, L., Kovačević, V., Markušić, S., Mihaljević, J., Kuka, N., Kaludjerović, N., Kotur, N., Krmpotić, S., Kuk, K., and Stanko, D. (2017): BSHAP project strong ground motion database and selection of suitable ground motion models for the Western Balkan Region, *B. Earthq. Eng.*, **15** (4), 1319–1343, doi: 10.1007/s10518-016-9950-3.

Šalić, R., Sandikkaya, A., Milutinović, Z., Gülerce, Z., Duni, L., Kovačević, V., Markušić, S., Mihaljević, J., Kuka, N., Kaludjerović, N., Kotur, N., Krmpotić, S., Kuk, K., and Stanko, D. (2017): Reply to "Comment to BSHAP project strong ground motion database and selection of suitable ground motion models for the Western Balkan Region" by Carlo Cauzzi and Ezio Faccioli, *B. Earthq. Eng.*, **15** (4), 1349–1353, doi: 10.1007/s10518-017-0095-9.

Šumanovac, F. and Dudjak, D. (2016): Descending lithosphere slab beneath the Northwest Dinarides from teleseismic tomography, *J. Geodyn.*, **102**, 171–184, doi: 10.1016/j.jog.2016.09.007.

Šumanovac, F., Hegedűs, E., Orešković, J., Kolar, S., Kovács, A., Dudjak, D., and Kovács, I. (2016): Passive seismic experiment and receiver functions analysis to determine crustal structure at the contact of the northern Dinarides and southwestern Pannonian Basin, *Geophys. J. Int.*, **205** (3), 1420–1436, doi: 10.1093/gji/ggw101.

Šumanovac, F., Markušić, S., Engelsfeld, T., Jurković, K., and Orešković, J. (2017): Shallow and deep lithosphere slabs beneath the Dinarides from teleseismic tomography as the result of the Adriatic lithosphere downwelling, *Tectonophysics*, **712/713**, 523–541, doi: 10.1016/j.tecto.2017.06.018.

Tertulliani, A., Cecić, I., Meurers, R., Sović, I., Kaiser, D., Grünthal, G., Pazdirkova, J., Sira, C., Guterch, B., Kysel, R., Camelbeeck, T., Lecocq, T., and Szanyi, G. (2018): The 6 May 1976 Friuli earthquake: re-evaluating and consolidating transnational macroseismic data, *B. Geofis. Teor. Appl.*, **59** (4), 417–444, doi: 10.4430/bgta0234.