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2nd Geomagnetic Information Renewal Cycle in the Republic of Croatia – First Results

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Abstract. The 2nd Geomagnetic Information Renewal Cycle started in 2017, pursuant to a request from the State Geodetic Administration and Ministry of Defence to ensure actual declination and its annual variation across the territory of Republic of Croatia. A test survey was performed at POKUpsko as part of the project in 2017. The PRM1 Primary Repeat Station had been destroyed, and the survey performed at a secondary location established in 2011, which subsequently became the primary location, known as PRM2. In this paper, the results of 2017 measurements reductions are presented, along with reductions in PRM1 and PRM2 measurements in 2011, and differences between the PRM1 and PRM2 locations, which are necessary to maintain the continuity of measurements at Pokupsko.

Keywords: geomagnetic networks, geomagnetic survey, geomagnetic reduction

1 Introduction

Geomagnetic information (GI), that is, declination (*D*) and its annual variation (*AVD*), is an integral part of the marginal information of official and military maps (see e.g. Campbell 2003; Newitt et al. 1996). Declination is the angle between the geographic and local magnetic meridian at a point on the Earth's surface. Knowledge of declination across Croatia is not negligible for ensuring reliable navigation and orientation. When a magnetic compass and map are used for navigation, *D* must relate the true bearing (*TB*) to the magnetic bearing (*MB*); with east (positive) *D*, $TB = MB + D$ (see URL01). When declination is not known in the field, or is overlooked, potential navigation bearing errors across Croatia may occur, as illustrated in Figure 2. Ignoring real spatial and temporal changes in geomagnetic declination may result in unexpected scenarios (Brkić et al. 2017).

The importance of knowing geomagnetic information has been recognized by the State Geodetic Administration (SGA) and Ministry of Defence (MoD) of the Republic of Croatia through the projects of the 1st Geomagnetic Information Renewal Cycle. In the 1st Cycle, the Basic Geomagnetic Network of the Republic of Croatia (BGNRC) was established (Fig. 1), and models of geomagnetic information were created (Brkić et al. 2013). Each Croatian Geomagnetic Repeat Stations Network (Fig. 1) location consists of several points: the primary (PRM) repeat station (SV) used for absolute declination and inclination (*D-I*) observations, an auxiliary point (POM) used for total intensity (*F*) observations, and at least three azimuth marks or geomagnetic orientation points (GOT). All these points have coordinates determined in national geodetic datums. Later research (Vujić et al. 2015; Vujić and Brkić 2016; Vujić et al. 2017) and limited financial funds defined the 2nd Geomagnetic Information Renewal Cycle in the Republic of Croatia in 2017. The goal of this 5-year cycle (2017-2021) is to ensure reliable *D* and *AVD* across the territory of the Republic of Croatia, primarily through surveys of the repeat station network. A precondition of reliability of *AVD* is repeating the observations at the same repeat stations and is not fulfilled if a location is destroyed. Reliable GI will enable predictions of *D* with a standard accuracy of 0.1° at BGNRC locations for the period 2020.5 to 2025.5.

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II. ciklus obnove geomagnetske informacije Republike Hrvatske – prvi rezultati

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Sažetak. Na zahtjev Državne geodetske uprave i Ministarstva obrane 2017. godine započeo je II. ciklus obnove geomagnetske informacije u cilju osiguranja aktualne deklinacije i njene godišnje promjene na prostoru RH. Prošlogodišnjim projektom provedena je test izmjera na lokaciji POKUpsko, primarna sekularna točka PRM1 je uništena, a izmjera je provedena na sekundarnoj lokaciji iz 2011. godine. Sada je ta lokacija primarna i nosi oznaku PRM2. U ovom su radu prikazani rezultati redukcija izmjere 2017. Dodatno je u ovom radu reducirana izmjera PRM1 i PRM2 iz 2011. te određena razlika lokacija PRM1 i PRM2 potrebna za očuvanje kontinuiteta opažanja na Pokupskom.

Ključne riječi: geomagnetske mreže, geomagnetska izmjera, geomagnetska redukcija

1. Uvod

Geomagnetska informacija (GI), tj. deklinacija (*D*) i njena godišnja promjena (*GPD*), sastavni su dio izvanokvirnog sadržaja službenih i vojnih karata (vidi npr. Campbell 2003; Newitt i dr. 1996). Deklinacija je kut između geografskog i lokalnog magnetskog meridijana u promatranoj točki na Zemljinoj površini. Deklinacija na teritoriju Hrvatske nije zanemariva za pouzdanu navigaciju i orijentaciju. Prilikom korištenja magnetskog kompasa i karte za navigaciju potrebno je poznavati *D* da bi se mogao odrediti odnos pravog azimuta (*PA*) i magnetskog azimuta (*MA*); u slučaju istočne (pozitivne) *D*, vrijedi odnos: $PA = MA + D$ (vidi npr. URL01). Ako na terenu deklinacija nije poznata ili je zanemarena, moguća pogreška smjera navigacije preko Hrvatske ilustrirana je slikom 2. Nepoznavanje stvarne prostorne distribucije i vremenske promjene geomagnetske deklinacije može predstavljati izvor izvanrednih situacija (vidi npr. Brkić i dr. 2017).

Da je poznavanje geomagnetske informacije nužnost, potvrdili su Državna geodetska uprava (DGU) i Ministarstvo obrane (MORH) projektima I. ciklusa obnove geomagnetske informacije. Tijekom I. ciklusa uspostavljena je Osnovna geomagnetska mreža Republike Hrvatske – OGMRH (slika 1), te su izrađeni modeli geomagnetske informacije (Brkić i dr. 2013). Svaka lokacija mreže sastoji se od više točaka: primarne (PRM) točke sekularne varijacije (SV), koja se koristi za apsolutna opažanja deklinacije i inklinacije (*D-I*), pomoćne točke (POM) za mjerenja totalnog inteziteta (F) te najmanje tri oznake azimuta ili geomagnetske orijentacijske točke (GOT). Položaj svih točaka određen je u državnim geodetskim datumima. Istraživanja koja su uslijedila (npr. Vujić i dr. 2015; Vujić i Brkić 2016; Vujić i dr. 2017), kao i ograničenost resursa s druge strane, definirali su II. ciklus obnove geomagnetske informacije Republike Hrvatske (II. COGIRH) pokrenut 2017. Cilj je petogodišnjeg II. ciklusa (2017. – 2021.) osigurati pouzdane *D* i *GPD* na teritoriju Republike Hrvatske, prvenstveno kroz izmjere sekularne mreže. Preduvjet pouzdanosti GPD-a – ponavljanje opažanja točno na istoj sekularnoj točki (en. *repeat stations*) – nije ispunjen u slučaju uništenja lokacije. Pouzdana GI omogućuje predikciju *D* unutar standardne točnosti 0,1° na lokacijama OGMRH za razdoblje 2020,5 – 2025,5.

Fig. 1 Basic Geomagnetic Network of the Republic of Croatia locations (yellow and red labels on GoogleEarth map). In 2010, there were 98 stations with an average distance of 26 km. The Croatian Geomagnetic Repeat Stations Network (CGRSN) is part of BGNRC, and POKU is the central of ten repeat stations (red labels).

Slika 1. Osnovna geomagnetska mreža Republike Hrvatske lokacije (žute i crvene oznake na karti GoogleEartha); u 2010. godini postojalo je 98 lokacija prosječne međusobne udaljenosti 26 km. Hrvatska geomagnetska sekularna mreža (HGSM) dio je OGMRH; centralna od 10 lokacija (crvene oznake) je POKU.

In the meantime, up to 2020, GI will be obtained from the GI2015v1.2 geomagnetic model. The aim of geomagnetic information models is to ascertain declination of standard accuracy in comparison to *D* absolute observations during optimum conditions. Such models should include the Earth's internal magnetic field (sum of the core and lithospheric fields), and exclude significant local crustal anomalies, transient external magnetic fields and associated induced fields, as well as civilisation noise. All GI models are designed as digital models i.e. the declination and annual variation data files for latitudes between 41.3° and 46.6°, and longitudes 12.9°and 19.5° in a raster of 0.01°. The BGNRC 2009.5 declination data (Brkić et al. 2013) and selected new Italian data (Dominici et al. 2017), British Geological Survey (URL 02) and Enhanced Magnetic Model (URL 03) data were reduced to 2015.0 epoch. The means of reduction to 2015.0 is outlined in (Brkić et al. 2017): at the location the reduction assumes equality $D^{2015.0}_{reduced} - D^{epoch}_{measured} = D^{2015.0}_{IGRF-12} - D^{epoch}_{IGRF-12}$, where IGRF-12 model is described in (Thébault et al. 2015). The GI2015v1.2 declination digital model file was made by radial basis function interpolation (applied as an exact interpolator) at 98 BGNRC station and 258 stations outside Croatia, as in Brkić et al. (2013). As there had been no

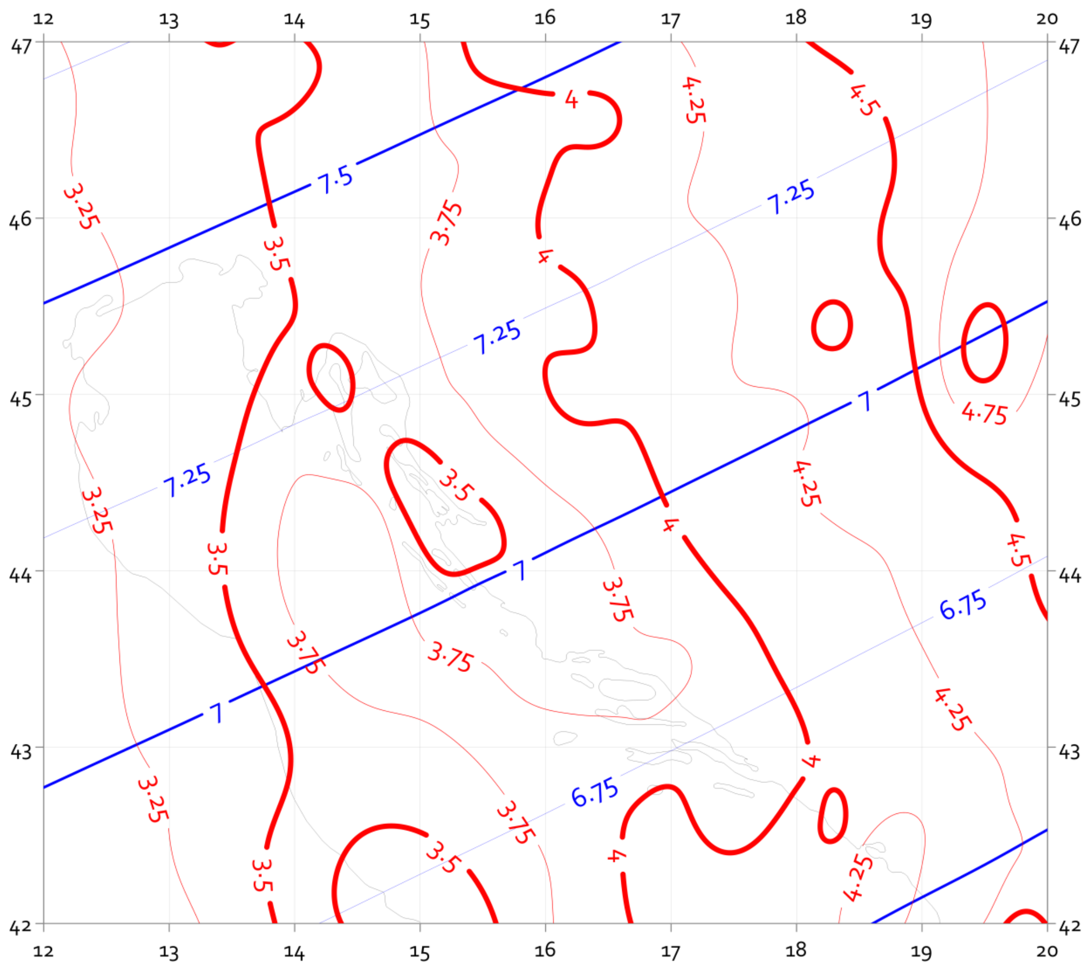

Fig. 2 GI2015v1.2 model at 2018.0; D in dec.deg. (red) and AVD in dec.min./yr. (blue).
Slika 2. Model GI2015v1.2 za 2018,0.; D je u dec. st. (crveno) i GPD je u dec.min./god. (plavo).

U međuvremenu, do 2020. godine, GI pruža aktualni model GI2015v1.2. Cilj je modela geomagnetske informacije osigurati deklinaciju standardne točnosti u usporedbi s apsolutno mjerenim *D* tijekom povoljnih uvjeta. Takvi modeli trebaju uključiti Zemljino unutarnje magnetsko polje (zbroj polja jezgre i litosfere), a da su bez doprinosa značajnih lokalnih anomalija Zemljine kore, tranzientnih vanjskih i pridruženih induciranih magnetskih polja te civilizacijskih šumova. Svi modeli GI dizajnirani su kao digitalni modeli koji uključuju datoteke podataka deklinacije i godišnje promjene za geografske širine od 41,3° do 46,6° i geografske dužine od 12,9° do 19,5°, u rasteru 0,01°. Podatci deklinacije OGMRH 2009,5 (Brkić i dr. 2013), odabrani novi talijanski podatci (Dominici i dr. 2017), te podatci British Geological Surveya (URL02) i Enhanced Magnetic Modela (URL03) reducirani su na epohu 2015,0. Postupak redukcije na epohu 2015,0 opisan je u radu Brkića i dr. (2017): na lokaciji redukcija pretpostavlja da vrijedi jednakost gdje je $D^{2015,0}_{reducirana} - D^{epoha}_{mjerena} = D^{2015,0}_{IGRF-12} - D^{epoha}_{IGRF-12}$, model IGRF-12 opisan u (Thébault i dr. 2015). Digitalni model deklinacije GI2015v1.2 izrađen je interpolacijom *radial basis function* (kao egzaktnog interpolatora) na ukupno 98 točaka OGMRH te 258 točaka izvan Hrvatske (kao u Brkić i dr. 2013).

Budući da od 2010. godine nije bilo opažanja sekularnih točaka, a da je kontinuacija 2009,5 – 2010,5 normalne godišnje varijacije ocijenjena nepouzdanom (Brkić i dr. 2013), digitalni model godišnjih varijacija GI2015v1.2 izrađen je računanjem deklinacija IGRF-12 i određivanjem srednje godišnje varijacije za razdoblje 2015,0 – 2020,0. U točkama OGMRH model GI2015v1.2 zanemarivo se razlikuje od prethodnog modela GI2015v1.0 (Brkić i dr. 2017). Procijenjena maksimalna pogreška deklinacije modela GI2015v1.2 za 2018. godinu u točkama OGMRH je $\leq 7'$; drugdje je nepoznata (slika 2 je ilustrativna). Za razliku od modela GI2015v1.1 (Brkić 2018), godišnja promjena modela GI2015v1.2 je IGRF-12 *GPD*; procijenjena pouzdanost joj je unutar nekoliko min./god. U ovom su radu mjerenja na POKU iz 2017. iskorištena za procjenu pouzdanosti modela.

U radu je namjera predstaviti rezultate projekta II. ciklusa provedenog u 2017. To su poglavito iskustva repeat stations surveys since 2010, and the continuation of 2009.5 – 2010.5 normal annual variation (Brkić et al. 2013) was reckoned unreliable, the GI2015v1.2 annual variation digital model was made by calculating IGRF-12 declinations and finding the average annual variation for 2015.0 – 2020.0. The GI2015v1.2 model differs insignificantly at BGNRC stations from the previous GI2015v1.0 model (Brkić et al. 2017). The maximum estimated error of declination from the GI2015v1.2 model for 2018 at BGNRC locations is ≤ 7' and is unknown elsewhere (Fig. 2 is illustrative). Unlike the GI2015v1.1 model (Brkić 2018), the annual variation of the GI2015v1.2 model is the IGRF-12 annual variation of declination, and the estimated reliability is within a few minutes per year. In this paper, the 2017 measurements at POKU were used to estimate the reliability of GI2015v1.2.

The aim of this paper is to present the results of the 2nd Cycle project in 2017, mainly survey experiences, and the reduced values of repeat station POKUpsko, which is of special interest, as it has a long survey history in BGNRC, and has not been occupied since 2012 (Šugar et al. 2013).

2 Survey at POKUpsko and Analysis

The 2nd Cycle test survey was performed at POKUpsko repeat station (latitude 45.47412° and longitude 15.97780° in ETRS89, and orthometric height 104 m – Fig. 1). Field surveys were performed on three days: 30 September, 1 October and 28 October 2017. On the first day of the survey, the azimuth mark GOT2 was staked out and measured using the GNSS RTK method within CROPOS (Croatian Positioning System) VPPS (high-precision positioning real-time service). Geomagnetic orientation points, GOT1, GOT3 and GOT4, were visually identified and it was concluded that they could be used as orientation points because of their height, stability and visibility. However, orientation point GOT1 may not be suitable for future geomagnetic surveys because of the dense vegetation which surrounds it. While the primary geomagnetic repeat station PRM1 was being staked out, dense, high vegetation was identified in the proximity. The attempt to find surface and underground stabilizations was unsuccessful, as the point had probably destroyed. After repeated GNSS measurements on 28 October 2017 it was confirmed that all marks of primary station PRM1 had been destroyed. For that reason, a secondary location (SEK1) was sought.

A secondary geomagnetic station (SEK, set up on 14 April 2011 and now called PRM2), was staked out using the GNSS RTK method within CROPOS VPPS and coordinates available from the station's positional description. After GNSS measurements were performed, the location suitability for performing absolute *D-I-F* measurements (see Newitt et al. 1996) was investigated using gradiometry methods (Brkić et al. 2005). The measurements performed that day were rejected due to unsettled geomagnetic conditions. On the second day of the survey (1 October 2017), an obstructed line of sight was verified from orientation point GOT1 to GOT2 and to PRM2, so GOT1 could not be used as an orientation point during a terrestrial method for staking out the PRM location. A new auxiliary point (POM1) was established and used for short-time F measurements, the first step in inspecting the suitability of a location for absolute *D-I-F* measurements. Next, gradiometry methods were performed at PRM2 and POM1, with measurements of the differences between total intensity (*dF*) between them. After gradiometry, four sets of absolute *D-I-F* measurement were performed using the null-method. During the last measurement, eight sets of absolute *D-I-F* measurements were performed while the Kp index of geomagnetic disturbance was low (Kp = 1-2). The measuring instruments were upgraded and serviced in 2017: a Bartington *D/I* MAG01H fluxgate with MAG Probe A and Zeiss 010B theodolite (Declination Inclination Magnetometer – DIM) with non-magnetic tripod, and GEMSys GSM-19G Overhauser Proton Precession Magnetometer (PPM). Magnetometers are regularly compared in a geomagnetic observatory, before and after survey campaigns. In the 2nd Cycle, the magnetometers were compared at LON.

In absolute *D* and *I* observations the azimuth taken from the PRM2 description was used. Thus GNSS measurements were performed at PRM2 and GOT2 to check the 2011 coordinates and compute the geodetic (ellipsoidal) azimuth. The new coordinates in an official map projection of the Republic of Croatia (HTRS96/TM) are given in Table 1, while a comparison of the newly determined geodetic azimuth and geodetic azimuth from the point description of PRM2 is given in Table 2.

Table 1 Newly determined coordinates of PRM2 and GOT2 points.

Point	$E_{HTRS96/TM}$[m]	$N_{HTRS96/TM}$ [m]
POKU_SV_PRM2	459170.940	5037264.800
POKU_SV_PRM2_GOT2	459227.381	5037726.391

Table 2 Comparison of geodetic azimuths from PRM2 to GOT2.

$\alpha_{POKU\_SV\_PRM2}^{GOT2}$ (from position description)	$\alpha_{POKU\_SV\_PRM2}^{GOT2}$ (newly determined)	$\lvert\Delta\alpha\rvert$
6° 36′ 01″	6° 35′ 56″	0° 00′ 05″

izmjere te reducirane vrijednosti za sekularnu lokaciju POKUpsko, koja je od posebnog interesa, jer je najdužeg staža mjerenja u OGMRH, a nije joj bilo pristupljeno od 2012. godine (Šugar i dr. 2013).

2. Izmjera na POKUpskom i analiza

Testna izmjera u okviru II. ciklusa provedena je na sekularnoj lokaciji POKUpsko (geog. širina 45,47412° i dužina 15,97780° u ETRS89, te ortometrijska visina 104 m – slika 1). Terenska izmjera izvedena je, kao i obično, tijekom tri dana: 30. rujna, 1. i 28. listopada 2017. Prvoga dana izmjere iskolčena je i izmjerena geomagnetska orijentacijska točka GOT2 primjenom metode izmjere RTK korištenjem servisa VPPS (visokopreciznog servisa pozicioniranja u realnom vremenu) CROPOS-a (Hrvatskog pozicijskog sustava). Vizualno su identificirane geomagnetske orijentacijske točke GOT1, GOT3 i GOT4 te je utvrđeno kako mogu služiti kao orijentacijske točke zbog nadmorske visine, stabilnosti i jasne vizualne uočljivosti. Ipak, očekuje se da točka GOT1 neće biti pogodna za buduću geomagnetsku izmjeru zbog bujanja guste vegetacije u okolici. Pri pokušaju iskolčenja primarne geomagnetske sekularne točke PRM1 uočena je visoka i gusta vegetacija u neposrednoj okolini točke. Pokušaj pronalaska nadzemne i podzemne stabilizacijske točke bio je neuspješan s obzirom na to da je točka vjerojatno uništena. Ponovljenim mjerenjima 28. 10. 2017. definitivno je potvrđeno uništenje fizičkih oznaka primarne točke PRM1. Zbog toga se tražila sekundarna lokacija.

Sekundarna geomagnetska točka SEK (uspostavljena 14. travnja 2011.), a sada PRM2, iskolčena je GNSS metodom na temelju položajnog opisa i dostupnih koordinata. Obavljena je GNSS izmjera, a u svrhu ispitivanja prikladnosti lokacije za apsolutna opažanja *D-I-F* (vidi npr. Newitt i dr. 1996), provedene su metode gradiometrije (Brkić i dr. 2005). Obavljena mjerenja odbačena su zbog nemirnih geomagnetskih uvjeta. Drugog dana izmjere, 1. listopada 2017., utvrđen je nepostojanje dogledanja točke GOT1 s GOT2 i PRM2 te GOT1 ne može služiti kao orijentacijska točka u slučaju korištenja teresitričke metode iskolčenja lokacije PRM. Za potrebe izmjere stabilizirana je nova pomoćna točka POM1 na kojoj su prikupljena kratkotrajna mjerenja *F*, što je prvi korak u ispitivanju prikladnosti lokacije za obavljanje apsolutnih mjerenja. Zatim su obavljene metode gradiometrije na PRM2 i POM1 te mjerenja razlika totalnog intenziteta magnetskog polja (*dF*) između PRM2 i POM1. Nakon gradiometrije izvedena su četiri skupa apsolutnih opažanja *D-I-F* nul-metodom. Posljednjeg dana izmjere izvedeno je osam skupova apsolutnih opažanja *D-I-F* pri niskom indeksu geomagnetskih poremećaja, Kp = 1-2.

Tablica 1. Novoodređene koordinate točaka PRM2 i GOT2.

Točka	$E_{HTRS96/TM}$[m]	$N_{HTRS96/TM}$ [m]
POKU_SV_PRM2	459170,940	5037264,800
POKU_SV_PRM2_GOT2	459227,381	5037726,391

Tablica 2. Usporedba azimuta s PRM2 na GOT2.

$\alpha_{POKU\_SV\_PRM2}^{GOT2}$ (preuzet s položajnog opisa)	$\alpha_{POKU\_SV\_PRM2}^{GOT2}$ (novoodređen)	$\lvert\Delta\alpha\rvert$
6° 36′ 01″	6° 35′ 56″	0° 00′ 05″

Korišteni instrumenti su obnovljeni i servisirani Bartington D/I MAG01H fluxgate s MAG Probe A i Zeiss 010B theodolite (DI Magnetometer – DIM) s nemagnetičnim stativom, zajedno s GEMSys GSM-19G Overhauser Proton Precession Magnetometer (PPM). Magnetometri se redovito uspoređuju na geomagnetskom opservatoriju prije i poslije kampanja izmjere. U II. ciklusu magnetometri se uspoređuju na LON.

Pri apsolutnim opažanjima *D* i *I* koristio se azimut preuzet iz položajnog opisa geomagnetske točke PRM2. Stoga je provedena GNSS izmjera na PRM2 i GOT2 u svrhu kontrole koordinata određenih 2011. godine, odnosno određivanja geodetskog (elipsoidnog) azimuta. U tablici 1 prikazane su novoodređene koordinate u službenoj kartografskoj projekciji Republike Hrvatske HTRS96/TM, a u tablici 2 usporedba novoodređenog geodetskog azimuta i geodetskog azimuta preuzetog iz položajnog opisa točke PRM2.

Jedna pogreška u mjerenju deklinacije je, stoga, razlika preuzetog i novoodređenog geodetskog azimuta s PRM2 na GOT2 u iznosu od 5". Druga pogreška dolazi od dvostruke kolimacijske pogreške korištenog teodolita (2c = –10"). Ispitivanje teodolita provodi se redovito prije i poslije kampanja izmjere u Laboratoriju za mjerenja i mjernu tehniku Geodetskog fakulteta. Ostale pogreške eliminiraju se nul-metodom opažanja, te primjenom postupka viziranja na geomagnetsku orijentacijsku točku u dva položaja instrumenta na početku i na kraju svakog skupa apsolutnih mjerenja.

Rekognosciranje lokacije POKUpsko ukazalo je na problematiku održavanja lokacija HGSM između mjernih kampanja. Ispitivanje prikladnosti PRM2 i njene pomoćne točke POM1 pokazalo je da je lokacija povoljna za provedbu apsolutnih opažanja *D-I-F*. Sukcesivna apsolutna opažanja *D-I* su konzistentna, posebice 28. 10. 2017., uz mirne geomagnetske uvjete. Gradiometrije su potvrdile izvrstan izbor te lokacije, budući da su svi gradijenti iznosili manje od 5 nT/m, a lokacija nije

One error in declination measurement was the difference between the azimuth taken from the position description and the newly determined azimuth from PRM2 to GOT2, which amounted to 5". Another error arose from a theodolite double collimation error (2c = -10"). The theodolite is examined regularly at the Laboratory of Measuring and Measuring Technology of the Faculty of Geodesy, before and after survey campaigns. Other errors were eliminated by the null-method of absolute *D* and I observations, and by applying the procedure of sighting towards the geomagnetic orientation point using two instrument positions at the beginning and end of each absolute measurement set.

Reconnaissance of the primary location POKUpsko revealed problems maintaining network locations between survey campaigns. An investigation of the suitability of PRM2 and corresponding auxiliary point POM1 showed that the location was favourable for performing absolute *D-I-F* measurements. Successive absolute *D-I* measurements were consistent, especially those on 28 October 2017, performed in quiet geomagnetic conditions. Gradiometry confirmed the excellent choice of the site, as all the gradients were less than 5 nT/m, and the location was not contaminated. The difference in SV and POM points for location PRM2 was negligible. Software for control analysis, which aims to check the suitability of observations for reductions the next year, did not indicate any disturbances or noise during the measurement time, while a comparison with daily graphs from Fürstenfeldbruck (FUR), Tihany (THY) and/or Lonjsko Polje (LON) observatories and preliminary minute INTERMAGNET data from LON indicated acceptable conditions and comparability of variations at LON and POKU. Twelve *D-I-F* sets were acquired. A comparison of absolute measurement of *D* at POKU showed that the reliability of the GI2015v1.2 model was within a standard accuracy of 6'. The differences between the IGRF-12 model and WMM2015 (Chulliat et al. 2015) calculated to measured declination were found to be comparable and also within the standard accuracy.

3 Reduction of POKU 2017 Survey

The reduction of the 2017 *D* observations at POKU PRM2 site meant repeating the control analysis for both observations days, but with definitive LON data for 2017 and filtered POKU F minute data. The final minute data and averages for 2017, and K index for the LON have been available since April 2018 (URL 04). On the first observation day (1 October 2017) K_{LON} indices were 2 2 2 3 4 2 4, indicating increased geomagnetic activity (K = 4) in a three-hour interval from 3-6 p.m. UTC. The presence of these disturbances was also confirmed by magnetogram spectra. The control analysis examined the comparability (resemblance) of the total field (*F*) at the station and the observatory, particularly at the moments of absolute *D* and *I* observations. It is always good practice to check data visually alongside statistics. Small values of st. dev. of the fourth derivation (0.1 and 0.5 nT/min^4) indicated no civilisation noises (URL 05) present at POKU or LON; the other indicators of the field resemblance were a small average variation of F (i.e. range /max. no. of observations) during the observation time (both 0.04 nT/min.), small (centred) differences POKU-LON (min. -0.61, max. 0.45 nT), and a very strong correlation coefficient (CC (POKU/LON) = 0.9663). The analysis concluded that *D-I-F* observations were conducted in the undisturbed part of the 3-hour K interval (later confirmed by the reduction scatter).

The second observation day (28 October 2017) was not disturbed, with K_{LON} indices of 2 1 1 2 1 2 2 1. The comparison of the *F* magnetograms for POKU and LON on the second day showed parameters similar to those on the first day, indicating even more favourable conditions, and confirming comparable variations at POKU and LON. This was expected, since the distance between POKU and LON is only 53.8 km, and the regional map of anomalies shows no inhomogeneities between them.

In reduction, a 'simple' model assumes that all time changes (external, induced, and secular) at an observatory O and station S are equal (Newitt et al. 1996):

$$E_s^{epoch} = E_s(t_m) - E_o(t_m) + E_o^{epoch}, \quad (1)$$

where $E_S(t_m)$ is the element of the Earth's magnetic field at the station and time of measurement t_m, $E_0(t_m)$, is the value of the element at the same time at the observatory, while E_s^{epoch} and E_o^{epoch} are the annual means at the station and the observatory. Thereat the measure of reliability of the solution is scatter:

$$\max\left\{\left|E_S^{epoch} - \bar{E}_S^{epoch}\right|\right\} \quad (2)$$

The expected difference between the simple reduction method and one with different secular variations at the station and the observatory is small in our case. Thus, the short distance between POKU and LON, and the comparability of the Earth's magnetic field variation at POKU and LON, justifies use of the 'simple' reduction method.

In fact, only the definitive data from the LON observatory were available via INTERMAGNET service at the time of writing this paper. In total, 12 absolute values of declination and inclination and 24 values of total intensity were reduced (Table 3). The reduction kontaminirana. Razlika točaka SV i POM lokacije PRM2 je zanemariva. Program za kontrolne analize, koji ima svrhu procijeniti prikladnost opažanja za redukcije sljedeće godine, nije indicirao nemirne ili šumom opterećene uvjete za vrijeme izmjera, dok su usporedbe s dnevnim grafovima opservatorija Fürstenfeldbruck (FUR), Tihany (THY) i/ili Lonjsko polje (LON), te INTERMAGNET preliminarnim podatcima LON ukazali na prihvatljive uvjete i usporedivost varijacija na LON i POKU. Ostvareno je ukupno 12 skupova apsolutnih opažanja *D-I-F*. Usporedbe apsolutnih mjerenja *D* na POKU pokazale su da je pouzdanost modela GI2015v1.2 unutar standardne točnosti od 6'. Usporedive su razlike deklinacija izračunanih uz pomoć modela IGRF-12, kao i WMM2015 (Chulliat i dr. 2015), u odnosu na izmjerene te također unutar standardne točnosti.

3. Redukcija izmjere POKU iz 2017.

Redukcija opažanja *D* na lokaciji POKU PRM2 iz 2017. najprije podrazumijeva ponavljanje kontrolne analize za oba dana opažanja, ali sada s definitivnim podatcima LON za 2017., kao i s filtriranim minutnim podatcima POKU F. Definitivni minutni podatci, kao i srednjaci za 2007., te K-indeks za LON dostupni su od travnja 2018. (URL04). Na prvi dan opažanja, 1. 10. 2017., indeksi K_{LON} iznosili su 2 2 2 3 4 2 4, što ukazuje na povećanu geomagnetsku aktivnost (K=4) baš u trosatnom intervalu 15 – 18 h UTC. Prisutnost poremećaja potvrđuju i spektri magnetograma.

Kontrolna analiza provjerava usporedivost (podudarnost) totalnog intenziteta (*F*) na lokaciji POKU i opservatoriju, posebice u trenutcima mjerenja *D-I*. Osim izrade statistike, dobra je praksa vizualna provjera podataka. Male vrijednosti standardnog odstupanja četvrte derivacije (0,1 i 0,5 nT/min^4) ukazale su na odsustvo civilizacijskih šumova (URL05) na POKU i LON. Ostali pokazatelji usporedivosti bili su: mala srednja varijacija *F* (tj. raspon po broju mjerenja) za vrijeme mjerenja (obje 0,04 nT/min.), male (centrirane) razlike POKU-LON (min. –0,61, maks. 0,45 nT), kao i vrlo jaki koeficijent korelacije (CC (POKU/LON) = 0,9663). Analizom je utvrđeno da su mjerenja *D-I-F* provedena tijekom neporemećenih dijelova trosatnih K-intervala (potvrđeno kasnije rasapom redukcije).

Drugi dan opažanja, 28. 10. 2017., bio je miran, s indeksima K_{LON} 2 1 1 2 1 2 2 1. Usporedba drugog dana magnetograma *F* za POKU i LON pokazala je slične rezultate kao i prvoga dana, čak uputila na povoljnije uvjete te potvrdila usporedivost varijacije na POKU i LON. To se i očekivalo, budući da međusobna udaljenost POKU i LON iznosi samo 53,8 km, a regionalne karte anomalija ne upućuju na nehomogenosti između tih dviju lokacija.

U primijenjenoj redukciji, „jednostavan" model pretpostavlja da su sve vremenske (vanjske, inducirane i sekularne) promjene na opservatoriju O i lokaciji S jednake (vidi npr. Newitt i dr. 1996):

$$E_s^{epoch} = E_s(t_m) - E_o(t_m) + E_o^{epoch}, \quad (1)$$

gdje je $E_S(t_m)$ element Zemljina magnetskog polja na lokaciji u vremenu mjerenja t_m, $E_0(t_m)$ vrijednost elementa u istom trenutku na opservatoriju, a E_s^{epoch} i E_o^{epoch} vrijednosti godišnjih srednjaka na lokaciji i opservatoriju. Pritom je mjera pouzdanosti rješenja rasap:

$$\max\left\{\left|E_S^{epoch} - \bar{E}_S^{epoch}\right|\right\} \quad (2)$$

Očekivana razlika metoda jednostavne redukcije i one s različitom sekularnom varijacijom na lokaciji i opservatoriju u našem je slučaju malena. Stoga, mala udaljenost POKU i LON, te usporedivost varijacije Zemljina magnetskog polja na POKU i LON, opravdava uporabu „jednostavne" metode redukcije.

Zapravo, za vrijeme pripreme rada jedino su definitivni podatci opservatorija LON bili su raspoloživi preko servisa INTERMAGNET. Ukupno je reducirano 12 apsolutnih vrijedosti deklinacije i inklinacije te 24 totalnog intenziteta (tablica 3). Redukcija je potvrdila prihvatljivost sva četiri skupa *D-I-F* dana 1. 10. 2017. i zaista je sretna okolnost što su se izbjegli poremećaji.

Tablica 3. Reducirani elementi POKU SV PRM2 na epohu 2017,5. Zbog obveza projekta dane su zaokružene vrijednosti.

	D	*I*	*F*
sredina	3,75 °	62,08°	47803 nT
rasap	32''	4''	0,5 nT

4. Razlika POKU PRM1 i PRM2

Radi uništenja lokacije PRM1, a za povezivanje prošlih reduciranih vrijednosti geomagnetskih elemenata na PRM1 s onima na PRM2 iz 2017., kao i budućih, potrebno je poznavati razliku sekularnih točaka PRM1 i PRM2. Prema tome, reducirani su podatci apsolutnih opažanja D-I-F na POKU PRM1 na dane 14. 4. 2011. i 4. 7. 2011. (Vučković 2011) koristeći se opservatorijima THY i Grocka (GCK) kao 2011. najbližim referentnim opservatorijima s raspoloživim definitivnim minutnim podatcima i godišnjim srednjacima INTERMAGNET-a.

Osam skupova mjerenih podataka od 14 izvorno opažanih na POKU PRM1 odabrano je za obradu. Razlozi odbacivanja bili su prolazni antropogeni šum, geomagnetski confirmed the acceptability of all 4 *D-I-F* sets taken on 1 October 2017. We were indeed fortunate to avoid disturbances.

Table 3 Reduced elements at POKU SV PRM2 for the epoch 2017.5. Due to the project obligations, the given values were rounded.

	D	*I*	*F*
mean	3.75 °	62.08°	47803 nT
scatter	32''	4''	0.5 nT

4 Difference between POKU PRM1 and PRM2

Since PRM1 had been destroyed and the past reduced values of geomagnetic elements at PRM1 needed to be linked to the 2017 and future values at PRM2, it was necessary to know the difference between the PRM1 and PRM2 repeat stations. Accordingly, absolute *D-I-F* observations at POKU PRM1 on 14 April 2011 and 4 July 2011 (Vučković 2011) were reduced using THY and Grocka (GCK) as the closest reference observatories with available INTERMAGNET definite minute data and annual means.

Only eight measurements from the fourteen sets of the measurements obtained at POKU PRM1 were selected. The reasons for rejecting measurements were transient anthropogenic noise, geomagnetic disturbances and an untrained student. All the finally accepted *D-I-F* sets were observed by D. Šugar. Before reduction, it is common to compare *F* magnetograms from the site and observatories and to check *D-I-F* observation sets. The K index (downloaded from THY; URL 06) was 1 during the afternoon observations at PRM1 on 14 April 2011, therefore quiet, as indicated by the mean variation *F* throughout the entire observation time on THY (0.02 nT/min.) and POKU (0.01 nT/min.), with a strong correlation coefficient of *F* magnetograms, CC = 0.7330. On the second day (4 July 2011), during the morning observations at PRM1, the K index was 3 and 1, and mean variation *F* at THY and POKU were 0.04 nT/min. and 0.06 nT/min., respectively, while the CC of *F* time series was 0.9519. For the second reference observatory GCK on 14 April 2011, the results are similar, except the correlation coefficient was weak, CC = 0.1946; there was no GCK minute data for 4 July 2011. Finally, only the 4 *D* and *I* GCK and POKU values from 14 April 2011 and the 8 *D* and *I*, and 16 *F* values from 14 April 2011 and 4 July 2011 THY and POKU values were accepted as input to the reduction.

During the observations (D. Šugar) at the secondary, now POKU PRM2 repeat station, on 8 July 2011 (Tonković 2011), the K index was 2, the average variation of *F* magnetogram at POKU and THY was 0.05 nT/min., and CC of *F* series was 0.9257; the mean variation *F* both at POKU and GCK was 0.05 and 0.04 nT/min., but CC was 0.5366. The analysis of the observation sets showed weak to moderate CC at PRM2 in relation to THY/GCK for all *D, I*, and *F* observations. After rejecting an outlier set and *F* values resulting in weak CC, reduction data consisted of 4 *D* and *I* values, with eight corresponding *F* values at PRM2 POKU, the same number at THY, while at GCK, D and I were the same but with four fewer F values. Of course, the number of selected measurements was small.

A simple reduction (1) was also performed as described in Brkić et al. (2012). Each observation was reduced to the epoch 2011.5 in relation to the reference observatories using INTERMAGNET minute data and averaged into the particular solutions for the site. There was a small difference between the particular reduced solutions of POKU PRM1 compared to THY and GCK: 0.1' and 0.1' for *D* as well as *I*. In both particular solutions, the scatter was less than the target accuracy of 1' for *D*, 30" for *I*, and 5 nT for *F* (Newitt et al. 1996), with amounts for elements *D, I* and *F* at THY: 0.3', 0.1', and 1.5 nT, respectively, and 0.2 'and 0.03' for *D* and *I* at GCK as the reference observatory.

The averaged definitive solution derived from two (n=2) particular solutions was computed from:

$$\left(\overline{E}_S^{epoch}\right)_W = \frac{\sum_{i=1}^{n}\left(w_i \cdot \left(\overline{E}_S^{epoch}\right)_i\right)}{\sum_{i=1}^{n} w_i}, \tag{3}$$

where the empirical weights w_i equal inverse of the square of the standard deviation of the differences $E_S(t_m)-E_0(t_m)$. The corresponding scatter $\left(\overline{E}_S^{epoch}\right)_W$ of the definitive solution is defined as:

$$\max\left\{\left|\left(\overline{E}_S^{epoch}\right)_i - \left(\overline{E}_S^{epoch}\right)_W\right|\right\}. \tag{4}$$

Empirical weights w_i, which equal to the inverse of the scatter of the particular solutions, and the simple averaging that evens the weights for all the observatories, were also investigated. As expected, all three cases resulted in very similar solutions, with simple averaging providing a slightly lower scatter of the definitive solution (Table 4).

Table 4 Reduced elements at POKU SV PRM1 2011.5

	D	*I*	*F*
mean	3.1975°	62.0443°	47641.4 nT
scatter	2''	2''	1.5 nT

The absolute observations at POKU PRM2 on 8 July 2011 were reduced using the same method. Simple poremećaji ili neuvježbanost studenta. Sve konačno prihvaćene skupove *D-I-F* opažao je D. Šugar. Prethodno redukciji, uobičajeno je usporediti F magnetograme s lokacije i opservatorija te iskontrolirati *D-I-F* skupove opažanja. K indeks (preuzet s THY, URL06) na 14. 4. 2011. za vrijeme popodnevnih opažanja PRM1 bio je 1, dakle mirno, na što ukazuje i srednja varijacija *F* preko cijelog vremena opažanja i na THY (0,02 nT/min.) i na POKU (0,01 nT/min.), a koeficijent korelacije *F* magnetograma jak, CC = 0,7330. Drugoga dana, 4. 7. 2011, za jutarnjih opažanja PRM1, K indeks bio je 3 i 1, srednja varijacija *F* na THY 0,04 nT/min. i na POKU 0,06 nT/min., dok je CC *F* vremenskih nizova bio 0,9520. Za drugi referentni opservatorij GCK i dan 14. 4. 2011. rezultati su slični, jedino je koeficijent korelacije slab, CC = 0,1946, dok za 4. 7. 2011. GCK nema definitivnih minutnih podataka. Na koncu su prihvaćene samo po četiri vrijednosti *D* i *I* GCK i POKU od 14. 4. 2011.; dok je za 14. 4. 2011. i 4. 7. 2011. prihvaćeno 8 *D*, 8 *I* i 16 *F* vrijednosti THY i POKU kao ulazne u redukciju.

Opažanja (D. Šugar) na sekundarnoj, a sada sekularnoj točki POKU PRM2, dana 8. 7. 2011. (Tonković 2011) odvijala su se pri K indeksu 2, srednja varijacija *F* magnetograma i na POKU i na THY bila je 0,05 nT/min., a CC *F* nizova za vrijeme opažanja iznosio je 0,9257. Srednja varijacija F i na POKU i na GCK bila je 0,05 i 0,04 nT/min., ali je CC iznosio 0,5366. Analiza skupova pokazuje slabe do umjerene CC PRM2 u odnosu na THY/GCK kod svih *D*, *I*, i *F* opažanja. Nakon odbacivanja skupa u kojem je utvrđeno grubo odstupanje, kao i *F* vrijednosti za koje je utvrđen slab CC, podatci za redukciju sadržavali su četiri vrijednosti *D* i I zajedno s osam pripadnih vrijednosti F na PRM2 POKU, jednako tako i na THY, dok na GCK isto za D i I, ali bez četiriju vrijednosti F.

Jednostavna redukcija (1) provedena je dalje na način opisan u Brkić i dr. (2012a) Pojedina opažanja su reducirana na epohu 2011,5 u odnosu na referentne opservatorije koristeći se minutnim podatcima INTERMAGNET-a, te osrednjena u partikularna rješenja za lokaciju. Malena je razlika partikularnih reduciranih rješenja POKU PRM1 u odnosu na THY i GCK - 0,1' i 0,1' za *D*, odnosno *I*. U oba partikularna rješenja rasap je manji od ciljanih točnosti od 1' za *D*, 30'' za *I* i 5 nT za *F* (Newitt i dr. 1996), i za elemente *D, I* i F iznosi 0,3' i 0,1' te 1,5 nT u slučaju THY, odnosno 0,2' i 0,03' za *D* i *I* u slučaju GCK kao referentnog opservatorija.

Osrednje konačno rješenje, koje uključuje navedena n=2 partikularna, izračunano je prema:

$$\left(\overline{E}_S^{epoch}\right)_W = \frac{\sum_{i=1}^{n}\left(w_i \cdot \left(\overline{E}_S^{epoch}\right)_i\right)}{\sum_{i=1}^{n} w_i}, \qquad (3)$$

gdje su empirjske težine w_i jednake inverzu kvadrata standardne devijacije razlika $E_S(t_m) - E_0(t_m)$. Pripadni rasap konačnog rješenja $\left(\overline{E}_S^{epoch}\right)_W$ definiran je kao

$$\max\left\{\left|\left(\overline{E}_S^{epoch}\right)_i - \left(\overline{E}_S^{epoch}\right)_w\right|\right\}. \qquad (4)$$

Ispitane su i empirijske težine w_i jednake inverzu rasapa partikularnih rješenja, kao i obično osrednjavanje koje svim opservatorijima daje jednaku težinu. U sva tri slučaja dobivena su očekivano vrlo slična rješenja, dok je obično osrednjavanje dalo zanemarivo manji rasap konačnog rješenja (tablica 4).

Tablica 4. Reducirani elementi POKU SV PRM1 2011,5

	D	*I*	*F*
sredina	3,1975°	62,0443°	47641,4 nT
rasap	2''	2''	1,5 nT

Istom metodom reducirana su opažanja s POKU PRM2 na dan 8. 7.2011. I ovdje je obični srednjak dao nešto manji rasap konačnog rješenja (tablica 5).

Tablica 5. Reducirani elementi POKU SV PRM2 2011,5

	D	*I*	*F*
sredina	3,1970°	62,0401°	47641,9 nT
rasap	13''	9''	0,4 nT

Razlika POKU PRM2 – PRM1 (2011,5) sekularnih točaka je mala: –2'' za *D*, –15'' za *I*, te 0,5 nT za *F*, a lokacija POKU PRM2 dobro je izabrana.

5. Zaključak

Provedba projekta II. ciklusa obnove geomagnetske informacije COGIRH 2017. godine osvjetljava važnost održavanja Osnovne geomagnetske mreže Republike Hrvatske u vremenu između izmjera. Održavanje mreže treba uključiti buduću sustavnu uspostavu sekundarnih lokacija. U praksi izmjere važno je provoditi dovoljno velik broj apsolutnih mjerenja *D-I-F* na lokaciji kako bi se dio mjerenja mogao odbaciti u procesu redukcije zbog različitih razloga. To je kritično posebice kod povezivanja sekundarnih i primarnih lokacija. U redukciji se pokazalo ukoliko postoje dostupni definitivni podatci, da je korisno reducirati s obzirom na više bliskih opservatorija te usporediti rješenja, dok je pri osrednjavanju u konačno rješenje moguće koristiti se različitim definicijama težina. Iz usporedbe redukcija na 2017,5 i na 2011,5 slijedi da se u II. ciklusu očekuje bolja pouzdanost redukcija budući da danas postoji nacionalni opservatorij LON.

averaging also resulted in a slightly smaller scatter of the definitive solution also (Table 5).

Table 5 Reduced elements at POKU SV PRM2 2011.5

	D	*I*	*F*
mean	3.1970°	62.0401°	47641.9 nT
scatter	13''	9''	0.4 nT

The differences between POKU PRM2 – PRM1 repeat stations (at 2011.5) were small: -2'' for *D*, -15'' for *I* and 0.5 nT for *F*; therefore, the choice of POKU PRM2 site was approved.

5 Conclusion

The realization of the 2nd Geomagnetic Information Renewal Cycle project in 2017 sheds light on the importance of maintaining the Basic Geomagnetic Network of the Republic of Croatia in the period between surveys. Maintenance of the network should include the systematic establishment of secondary locations in the future. In survey practice it is important to carry out sufficient absolute *D-I-F* measurements at the location, since some may need to be rejected during the reduction process for various reasons. This is crucial, especially when connecting secondary locations to primary ones. The reductions showed that if definitive data were available, it was useful to reduce with respect to close observatories and compare solutions, while in averaging to a definitive solution, the different definitions of the weights could be used. From the comparison of reductions to 2017.5 and 2011.5, it is evident that in the 2nd Cycle, better reduction reliability is expected due to the existence of the LON national observatory.

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