A NEW 10-KM GPS REFERENCE FRAME OF THE REPUBLIC OF CROATIA

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Abstract. *A new 10-km GPS reference frame of the Republic of Croatia has been set up in 2003. based on the official Croatian EUREF GPS network, presented and accepted during the EUREF 2001 meeting in Dubrovnik, a densification with almost 1000 GPS points, covering entire territory of Croatia, was realized. This paper deals with detailed description of data processing, adjustment and result analysis. Since the new established 2nd order GPS network is the practical realization (frame) of the ETRS89 datum for the Republic of Croatia, it is and will be used as basis for other GPS and classical terrestrial geodetic measurements.*

1. Introduction

The State Geodetic Administration (SGA) initiated in 1996 the survey of a 10-km GPS reference network of the Republic of Croatia. The achievement of the project, GPS measurements of a part of the network, was carried out in May and July 1997. The measurements encompassed the survey of about a half of the state territory, north-western Croatia (Istria and Gorski kotar), central Croatia and eastern Croatia (the largest part of Slavonia), altogether 377 new point, 62 already existing trigonometric points and 25 control points. In order to process and adjust the measurements, the contractors, the Institute for Photogrammetry d.d. from Zagreb and the Geodetic Institute d.d. from Split have engaged the Institute for Higher Geodesy at the Faculty of Geodesy of that time (Prof. Dr. Sc. Tomislav Bašić, head of the project).

The measurement contractors have set the following criteria for the observation:

- two-frequency devices by the same manufacturer, and the antennas of the same type are to be used,
- the antennas are to be cantered at all points that allow the procedure,
- 3-4 reference points defined in the campaign CROREF'96 are to be used in each session,
- the registration interval of 15 seconds and the elevation mask of 15° are to be applied, and
- the duration of individual sessions is to be determined from the rules for two-frequency receivers, which is 20 minutes + 2 minutes/km (Hofmann-Wellenhof et al 1997).

There were 7-13 receivers of the firm Trimble used in sessions, the receivers being compatible models 4000SSi and 4000SSE. The minimum duration of the session was then 120 minutes for the planned average distance between the reference points being 50 km.

The measurements were made in the period from the 6th May till the 12th July (DOY 126 - 163), with 64 measurement sessions completed in 18 days. Additional measurements were made later on the181, 245 and 246 day. The part of the network measured in 1997 is presented on Fig. 1 (asterisks).

The vectors were processed simultaneously by the contractors and by the Faculty. There were altogether 3433 vectors processed for all three parts. Unique parameters in the program package Trimble GPSurvey were used for the processing of measurement and optimising of vectors. After the optimising of vectors had been completed, the effect was reflected in two basic statistical indicators how successful their processing was: the ration between the first (accepted) and the second best solution that should as big as possible, and the reference variance that should be as close as possible to the unit (Trimble 1996).

The network adjustment was made with the same program package that was used for the vector processing. The current ITRF94 reference framework was taken as the network datum, and the unique epoch for all three parts of the network was defined as 1997.4. In order to make the results obtained by adjustment as realistic as possible, it was decided that only independent vectors should be used, and the accuracy estimation of the adjusted points should be given with the probability of 95%, which corresponds with $\pm 1.96\sigma$. The first part shows implicitly that only two vectors can be used from each measured triangle, because the third one is completely independent and can raise the accuracy estimation only unrealistically. Similarly, the vectors among reference points were rejected from the adjustment so that each new point in the homogeneous field was actually determined from three of four vectors from reference points. The criterion for adjustment accuracy estimation with $\approx\pm 2\sigma$ probability is the standard for measuring trigonometric networks by means of GPS, as it is stated in e.g. American standards for network adjustment. The overview of the adjustment results for the individual parts of the network can be found in (Bašić et al 2002).

The state Geodetic Administration continued in 2001 the works on the completion of the 10-km GPS network of the Republic of Croatia. The practical realisation of a part of the project was completed in November and December 2001. The measurements encompassed the survey of three individual blocks: Task A covers the area of eastern Croatia – Podunavlje, Task B the area of south Primorje and north Dalmatia, and Task C the area of southern Croatia (Dalmatia) with altogether 417 new points, 123 existing trigonometric points and 26 reference points defined in ITRF96 datum and the epoch 1995.55 (Marjanović and Bačić 2002). The field measurements in individual blocks were made by the Geodetic Institute d.d. Osijek (Task A), the Institute for Photogrammetry d.d. Zagreb (Task B) and the Geodetic Institute d.d. Split (Task C). There were the same observation criteria applied, as in 1997, but being distinguished only by the fact that in 2001 each observation session was observed twice, at different day times (double measurements on new points). The measured parts of the network from 2001 are also shown on Fig. 1 (dots).

The processing and optimising of the vectors was made by means of GPSurvey software. The adjustment of the each of the three networks was carried out with the same program package in collaboration with the Institute for Geomatics at the Faculty of Geodesy, University of Zagreb (Prof. Dr. Sc. Tomislav Bašić, head of the project). ITRF96 reference framework (identical to ITRF94 datum) was used as a network datum, and the accompanying epochs were: 2001.80 for the Task A, 2001.83 for the Task B and 2001.91 for the Task C (see 3 separate studies handed over to SGA by the contractors). Again, only independent vectors were used, and the accuracy estimation of the adjusted point coordinates was given with the probability of 95%.

Since the analysis of the adjustments carried out in individual blocks (see Bašić and Bačić 1997, Bašić and Bačić 1998, Bačić and Bašić 1999, and Bašić et al 2002) indicated rather erratic results among them referring the accuracy estimation and to the fact that new GPS points were determined in 1997 on the basis of single, and in 2001 on the basis of double measurements from the known points, the need was felt to make unique adjustment of the entire 10-km GPS network with the basic goal to have it homogenized.

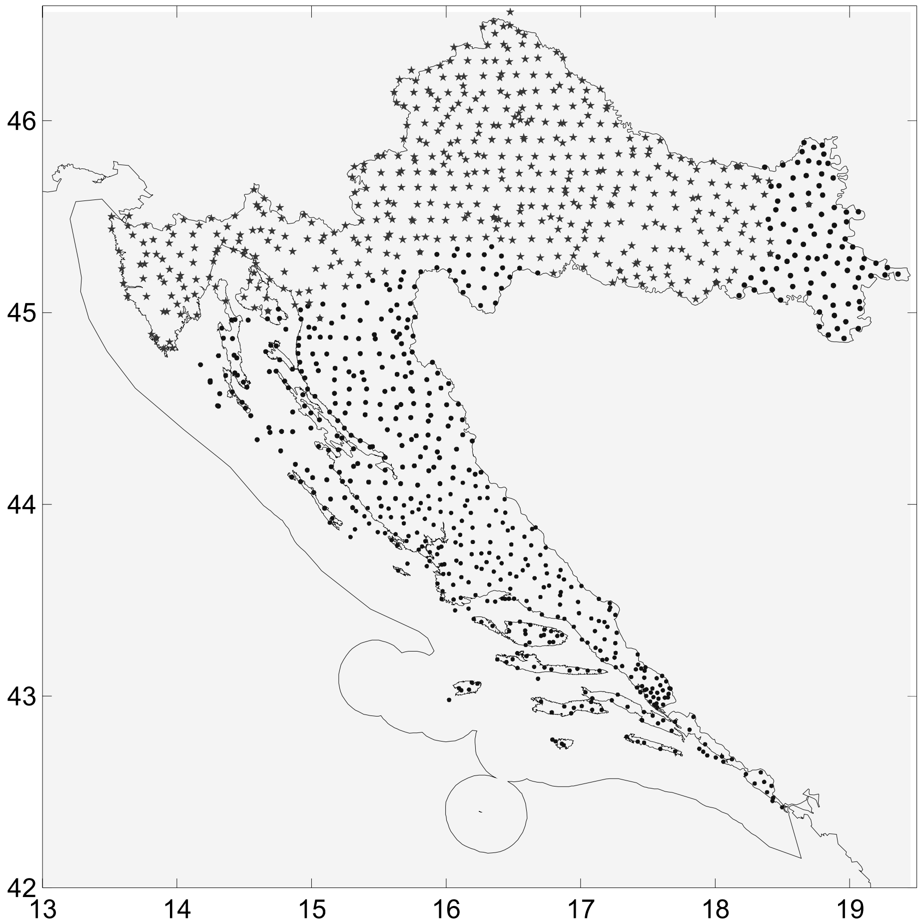


Fig. 1: 10-km GPS network of the Republic of Croatia (asterisks - measured in 1997, dots - measured in 2001)

2. Unique adjustment of all 6 blocks of the 10-km GPS network

Referring to the recently published new mutual adjustment of all GPS measurements at the state level from 1994, 1995 and 1996 (see Marjanović and Bačić 2002), the ITRF96 datum has been selected as a reference framework for the mutual adjustment, and as the mean measurement epoch one has taken 1999.6. The recalculation from ITRF96 datum and the epoch 1995.55 into the ITRF96 datum and the epoch 1999.6 was made by means of our own computer program. Fig. 3 shows the arrangement of altogether 63 reference points (RP). In (Bašić et al 2002) there is a list of ellipsoidal (geodetic) coordinates of reference points (RP) given that have been used for the mutual adjustment in ITRF96 datum and the epoch 1999.6.

One of the most significant problems that had to be solved for the purpose of opening the possibility for the practical realisation of the mutual adjustment of all 6 blocks was the elimination of network singularity that was caused by the following events:

- 16 cases of different points having the same name,
- 10 cases of the same points with different names (see Bašić et al 2002).

Without referring to the reasons for such a phenomenon, a great effort has to be made in editing a large number of vectors and in changing the names of the stations manually in order to make the correction. At the same time the names of new points from 3 block observed in 2001 have been changes from G123 into HP0123, and all reference points have got the prefix RP in order to make everything harmonized with the processing from the year 1997.

There is a numeric (table 1) and graphic (Fig. 2a, 2b, 2c) presentation given below for all optimised vectors in a unique adjustment. As it can be seen, there is a total of 7289 spatial vectors optimised with the mean amount of the length being 34062.87 m, the minimum length being 528.72 m, and the largest 128055.40 m. The majority of measured lengths are situated in the interval from 5 to 60 km (Fig. 2a). The following data have been obtained for the Ratio: minimum value is 1.2, the maximum one 1146.8, and the mean value 33.3, with the largest number of vectors having the value between 5.0 and 50.0 (see Fig. 2b). Regarding the reference variances, being also a very important statistical parameter, they have proved to be more than satisfactory, namely, the mean value is 1.16 (ideally 1.0), and a very small number exceeds the value 10.0 (Fig. 2c).

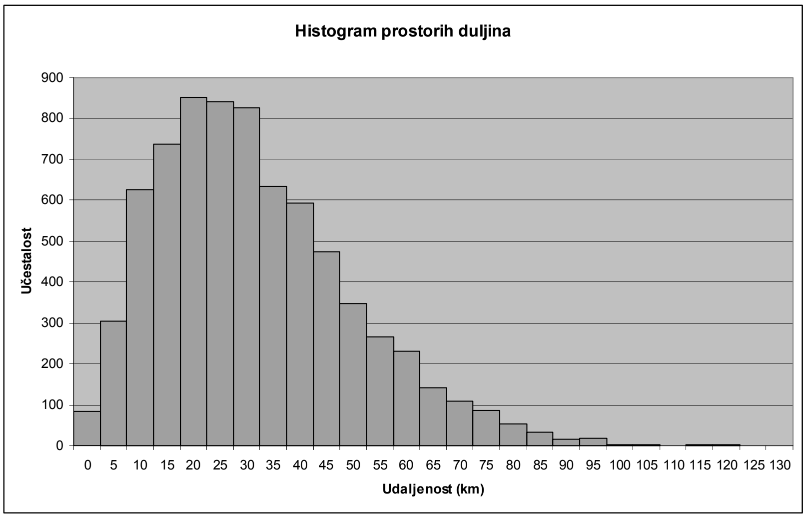
Table 1: Statistical indicators for the distance, ratio and data variance for all vectors

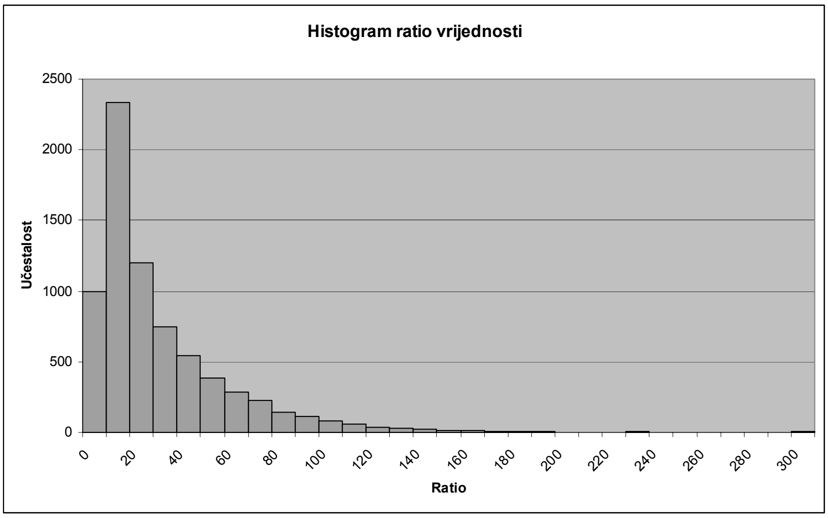
	Distance (m)	Ratio	Ref. Variance
Total number of vectors	7289	7289	7289
Mean value	34062.87	33.28	1.16
RMS value	18311.91	36.34	1.52
Minimum value	528.72	1.20	0.17
Maximum value	128055.40	1146.80	59.46

The final adjustment has been made with the Trimnet module of GPSurvey software, using, as usually done, the iterative procedure (altogether 16 iterations), with 63 control points applied and worse vectors rejected. The following parameters have been used: H.I. error = 0.0040 m (uncertainty in defining the antenna elevation) and Tribrach error = 0.0020 m (uncertainty in centring), and at the end the necessary statistical adjustment parameters have been obtained - Network Reference Factor = 1.00 (reference mean error), Chi-square Test = PASS (chi-square test satisfied), and the Alternative Scalar Set Applied Globally = 6.92 (global factor of scaling variance/covariance matrix). The complete accuracy estimation has been given there for the probability of 95% (a standard for GPS measurements).

Fig. 3 shows the arrangement of all points in the homogeneous field of the 2. order GPS network consisting of 798 newly determined HP points, 193 observed 2. order trigonometric points (TP points) and 63 reference points (RP points; hence, altogether 1054 points). As it can be seen from the figure, in the Task A from the year 2001

(Podunavlje) the procedure of defining the reference points along the edge of the area has not been respected, but the extrapolation of HP and TP points has been made eastwards.





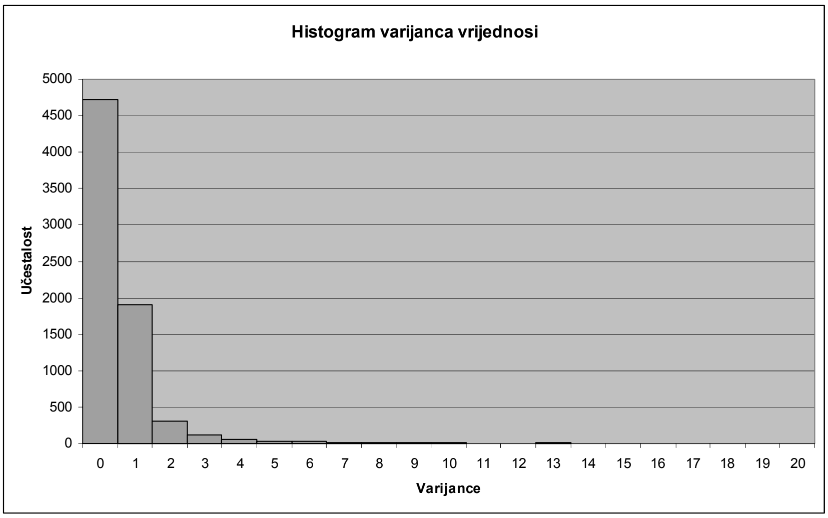


Fig. 2a,b,c: Frequencies for distances, Ratio and Ref. Variances of optimised GPS vectors

Within the scope of this network, the coordinates of altogether 25 special points have been determined additionally: the points the names of which start with the number 1000 (placed in the valley of the river Neretva) and the point GZ (Task C from the year 2001) and those the name of which starts with the letters N and P (Task B from the year 2001) that the contractors have used for other purposes.

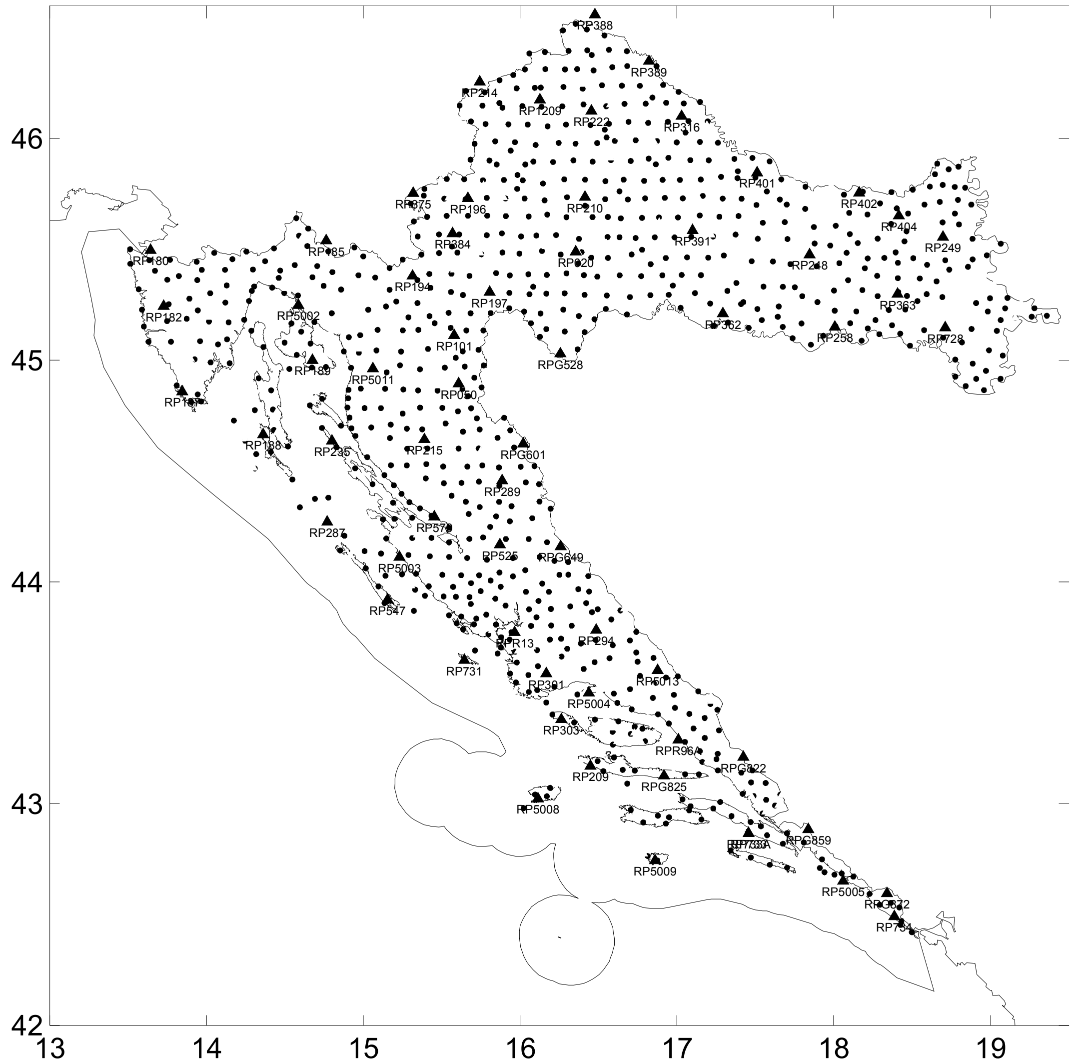


Fig. 3: 10-km GPS network of the Republic of Croatia (1054 points)

3. Accuracy analysis of the unique adjustment of the whole network

A detailed accuracy analysis for 3 blocks observed in 1997 is given in (Bačić and Bašić 1999), and in (Bašić et al 2002) there is the analysis of the achieved accuracies given for blocks observed in 200. The statistics of the realized inner accuracy for the positional coordinates and the heights of newly-determined points after the unique adjustment indicates its high level. In the table 2 there is a numeric overview of the achieved standard deviations for each of the three coordinates, as well as for 2D and 3D positions, and the figures 4 and 5 present the frequency histogram of the 2D and 3D standard deviation. Fig. 6 offers the graphic presentation of those points that have got positional (2D) standard deviation of 2,0 cm after the unique adjustment (only 16, with only 3 HP points and 13 TP points). After that, there is a graphic presentation of all points having spatial (3D) standard deviation bigger than 3,0 cm (altogether 71 points with 42 HP points and 29 TP points) given on Fig. 7.

Table 2: Statistical indicators of coordinates and of 2D and 3D standard deviations

Standard deviations σ (in cm)	σ_φ	σ_λ	σ_h	σ_{2D}	σ_{3D}
Total number of points	1016	1016	1016	1016	1016
Mean value	0.514	0.412	1.684	0.660	1.833
RMS value	0.398	0.256	0.960	0.471	1.026
Minimum value	0.246	0.212	0.547	0.325	0.661
Maximum value	9.800	4.988	12.446	10.997	12.702

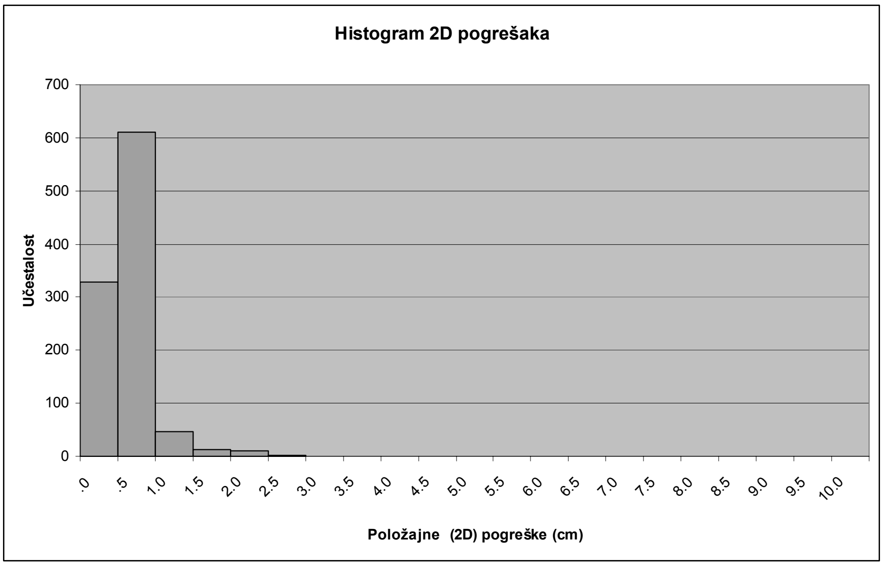


Fig. 4: Graphic presentation of the positional (2D) uncertainty frequency of points

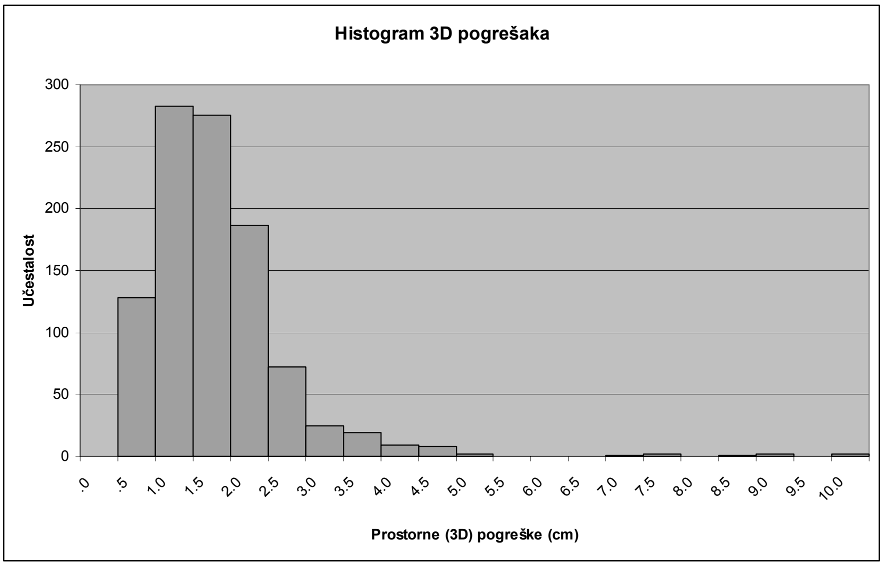


Fig. 5: Graphic presentation spatial (3D) uncertainty frequency of points

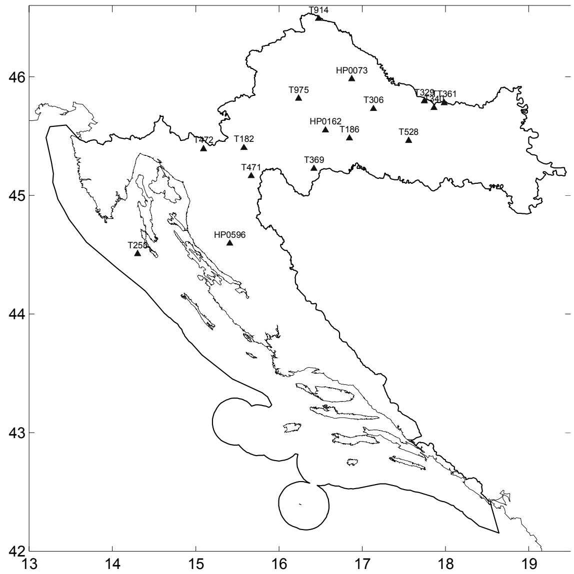


Fig. 6: The points with the horizontal (2D) uncertainty bigger than 2 cm

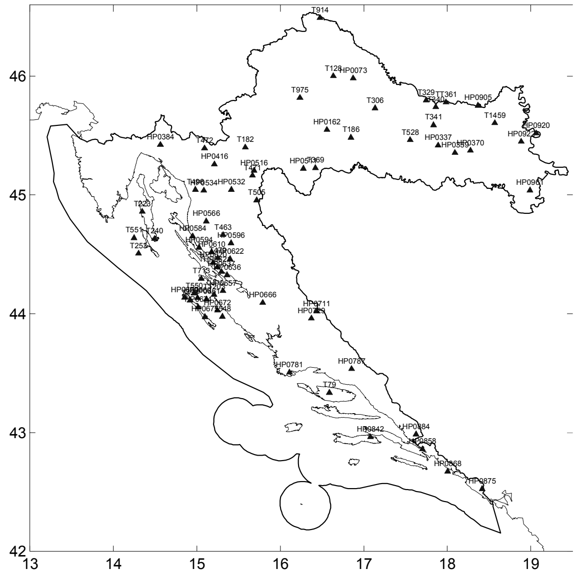


Fig. 7: The points with the spatial (3D) uncertainity larger than 3 cm

The standard deviations for ellipsoidal width (latitude) run from 0,25 cm to 9,80 cm, with 1012 points (99,60%) having standard deviation smaller than 2,0 cm (only 1 point HP0073 has got larger standard deviation than 9,0 cm, 2 have got 3,0 cm 1 has got 2,0 cm). With ellipsoidal length (longitude) the standard deviation are within the interval of 0,21 cm to 4,99 cm, and only 4 points (0,40%) have got standard deviation larger than 2,0 cm. Standard deviations of ellipsoidal height are within the interval of 0,55 cm to 12,45 cm, with 46 points (4,53%) having the standard deviation between 3,0 cm and 4,0 cm, 10 points (0,98%) between 4,0 and 5,0 cm and only 9 points (0,90%) have got standard deviation larger than 5,0 cm. If we analyse the positional (2D) and spatial (3D) standard deviations, we can see that 1000 points (98,42%) have got 2D-standard deviation smaller than 2,0 cm, that 13 points (1,28%) have got 2D-standard deviation larger than 2,0 cm and smaller than 3,0 cm, and only 3 points have got 2D-standard deviation larger than 4,0 cm. Speaking of spatial accuracy estimation, 945 points (93,01%) have got 3D-standard deviation smaller than 3,0 cm, 44 points (4,33%) have got 3D-standard deviation larger than 3,0 cm and smaller than 4,0 cm, 17 points (1,67%) have got 3D-standard deviation larger than 4,0 cm and smaller than 5,0 cm, and only 10 points (1,00%) have got 3D-standard deviation larger than 5,0 cm (see Fig. 4 and Fig. 5).

4. Transformations of the results

Since the results of the unique adjustment have been defined in ITRF96 and the mean epoch 1999.6, they needed to be transformed into the official European terrestrial reference system ETRS89 and the epoch 1989.0 (that has also been suggested as the future Croatian reference terrestrial coordinate system). This transformation was carried out by means of our own computer program that takes into consideration the Boucher and Altamimi 7-parameter transformation between the mentioned datums (Boucher and Altamimi 2001), as well as the velocities through Nuvel1A program for time transformation within the same datum.

In order to have the task achieved, all available identical points in both systems have been used, i.e. EUREF points, CRODYN points, 1. order trigonometric points and the available 2. order trigonometric points (unfortunately, very many last mentioned points obtained from SGA refer to signals, and not to the centres of points). The computation of 7 parameters of Helmert's transformation has been done with our own computer program T7 (see Bašić and Bačić 2000), with HRG2000 geoid used for correct connection of heights (Bašić 2001).

There were altogether 273 points available for the first calculation where after it was found out that there were more hidden signals or significant excenters among them (tens and hundreds of meters) that needed to be excluded from the calculations. After the next calculation the points cropped up with smaller excenters (of a few meters) that were also excluded from the calculations. Hence, new unique transformation parameters and their accuracy estimation were obtained finally for Croatia (table 3) on the basis of data adjustment for the coordinates in 241 identical points (Fig. 8).

Table 3: New transformation parameters and their accuracy estimation

	Transformation parameters	Accuracy estimation (m_0=0.83 m)
Translation: Tx	- 550.5670 m	±2.89 m
Ty	- 164.6118 m	±3.11 m
Tz	- 474,1386 m	±2.77 m
Rotation: Rx	5.976766 "	±0.088 "
Ry	2.099773 "	±0.105 "
Rz	- 11.495481 "	±0.091 "
Scale: μ	5.447925 ppm	±0.353ppm
Accuracy (rms): by φ	On the basis of the residuals in identical points	±0.499 m
by λ		±0.615 m
by h		±0.213 m
Positional (2D)		±0.792 m
Three-dimensional (3D)		±0.820 m

As it can be seen, the calculated unique transformation parameters provide at the territory of the Republic of Croatia the positional (2D) transformation with the accuracy of ±0.79 m and spatial (3D) transformation with the accuracy of ±0.82 m using HRG2000 geoid. If HRG2000 geoid would not be used, the accuracy of spatial (3D) transformation is reduced to ±1.14 m.

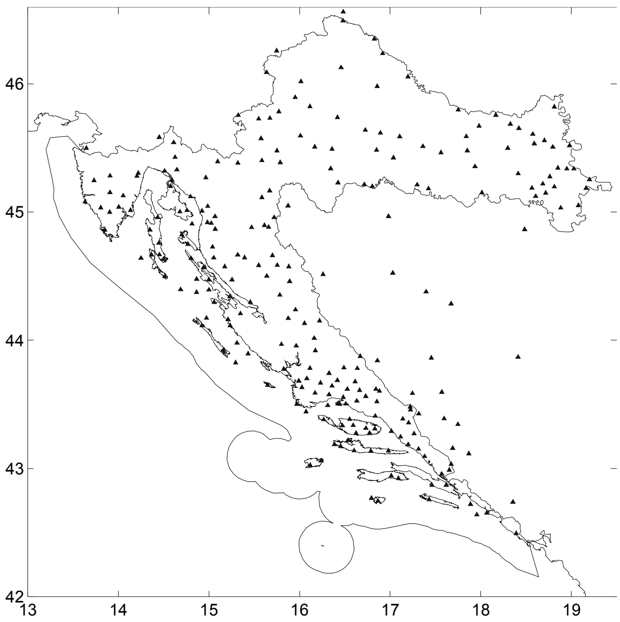


Fig. 8: Identical points (241) used for the computation of transformation parameters

On the basis of the obtained discrepancies in identical points after the transformation with newly defined parameters has been carried out, i.e. the discrepancies in the direction north south, west east, and along the height, the graphic presentations on Fig. 9, 10, 11 and 12 have been obtained. We can see that the inhomogeneous features of the 1. and 2. order trigonometric networks in characteristic horizontal directions are significant and of a random nature (Fig. 9 and 10). The absolute discrepancy throughout the entire area runs along the x-axis over 2.0 m, and along the y-axis even over 3.0 m. The height show the occurrence of absolute changes of residuals up to 1.0 m (Fig. 11), which is the consequence of using HRG2000 geoid. Fig. 12 confirms already known correlation of vectors of positional residuals with 7 blocks of Austro-Hungarian triangulation that the 1. order trigonometric network of that time was adjusted within according to condition observations (see Bašić 2000).

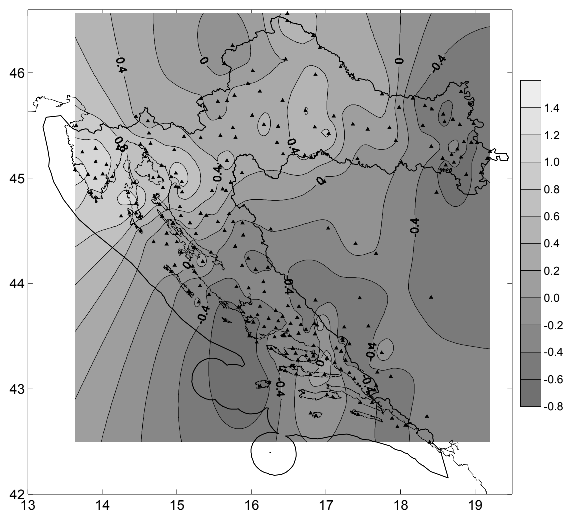


Fig. 9: Discrepancy in the x-direction

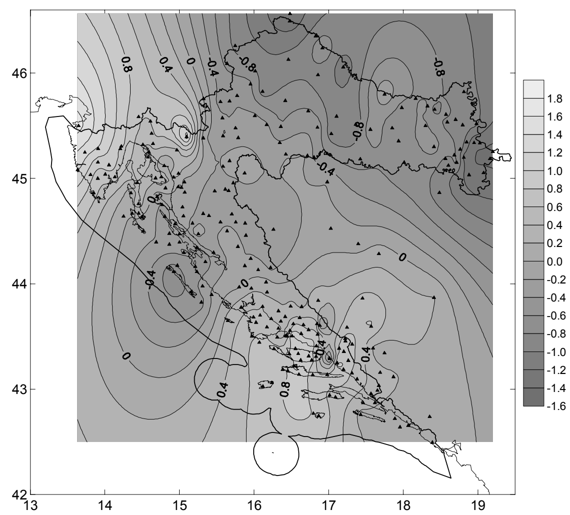
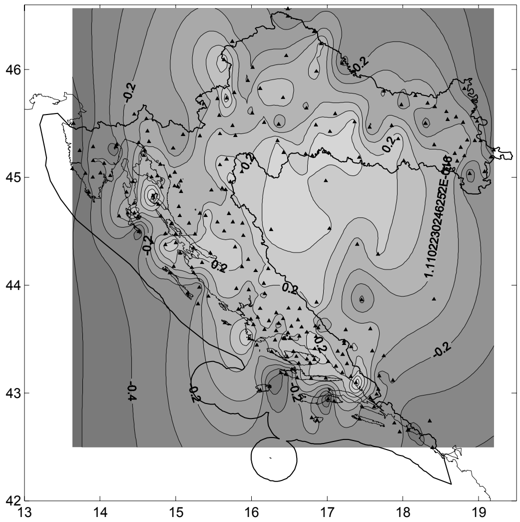


Fig. 10: Discrepancy in the y-direction



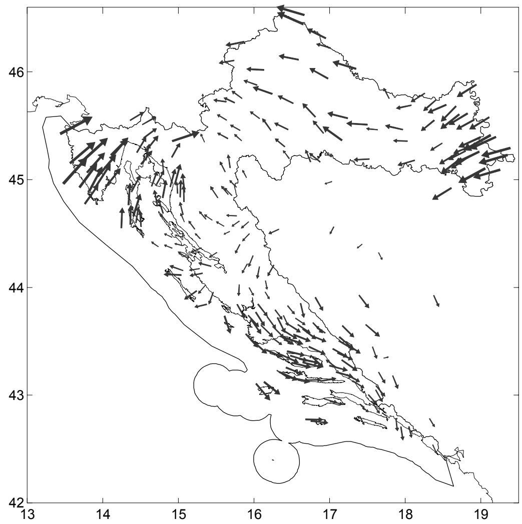


Fig. 11: Height discrepancy   Fig. 12: Positional non-homogeneity in HDKS

5. Conclusion

In May and June 1997, 3 blocks of 10-km GPS network of the Republic of Croatia were measured with GPS technology: Eastern Slavonia, Central Croatia and Northwest Croatia. In November and December 2001 3 more block of the rest of the Croatian territory were measured in the same way: Podunavlje (Task-A), a part of Primorje and the north Dalmatian (Task-B) and South Croatia (Task-C).

Within the frame of this project a unique adjustment of the whole network has been made using commercial GPSurvey software. The analysis of the achieved accuracy of positional coordinates and heights in this unique adjustment as related to the individual adjustments in each block indicates a clear reduction of uncertainty of coordinates with the unique adjustments, and a very successful network homogeneity. The existing deficiencies, as the fact that the new points were determined in 1997 in one session only, and in 2001 in two sessions (double measurements) could not be avoided. The fact that the same points with different names found themselves in various blocks as well as different points with the same names, presents a big problem, hence it was possible to solve the issue of network singularity after the painstaking editing of a great number of vectors and manual changes of the noticed deficiencies.

However, it can undoubtedly be concluded that the 10-km GPS network of the Republic of Croatia has been successfully processed and adjusted as a unique network. Very high inner accuracies of the adjusted coordinates of the points have been achieved, and actually a very small number of points does not meet the criterion of positional uncertainty smaller than 2.0 and of spatial uncertainty smaller than 3.0 cm. The final results, three-dimensional coordinates, are expressed in ITRF96 datum and the mean epoch 1999.6, as well as in ETRS89 datum and the epoch 1989.0. Apart from that, new transformation parameters between ETRS89 datum and the Croatian State Coordinate System (HDKS) have been determined on the basis of 241 identical points where the situation with the availability of such points has been improved especially in south Croatia. New transformation parameters confirm already known inhomogeneous features in the inherited positional network.

References

Bašić, T., Bačić, Ž. (1997): Homogeno polje osnovnih geodetskih točaka Republike Hrvatske (Homogeneous Field of Geodetic Control Points of the Republic of Croatia). Final report on the processing and adjustment of measurements for a part of the territory of the Republic of Croatia - "part of the network Central Croatia". Volume 1-4, Faculty of Geodesy, University of Zagreb.

Bašić, T., Bačić, Ž. (1998): Homogeno polje osnovnih geodetskih točaka Republike Hrvatske. Homogeneous Field of Geodetic Control Points of the Republic of Croatia). Final report on the processing and adjustment of measurements for a part of the territory of the Republic of Croatia - "part of the network "Istria" and "Slavonia". Volume 1-4, Faculty of Geodesy, University of Zagreb

Bačić, Ž., Bašić, T. (1999): Izjednačenje dijela 10-km GPS mreže Republike Hrvatske. (Adjustment of the part of 10.km GPS network of the Republic of Croatia). The Proceedings of the HGD Symposium "State Geodetic References and the Land Information Systems" (editors Z. Kapović and M. Roić), 249-259, Zagreb.

Bašić, T. (2000): Prijedlog službenih geodetskih datuma Republike Hrvatske (Proposal for the Official Geodetic Datums of the Republic of Croatia). Study for the State Geodetic Administration of the Republic of Croatia, 1-93, Zagreb.

Bašić, T., Bačić, Ž. (2000): Transformation between the Local and Global Geodetic Datum in Croatia. Proceedings of the Symposium of the IAG Section I (Positioning), Commission X (Global and Regional Geodetic Networks), Subcommission for Europe (EUREF), Publication No. 9, Tromsø – Norway, June 22-24, 2000, Editors: J. A. Torres and H. Hornik, Veröffentlichungen der Bayerischen Kommission für Internationale Erdmessung der Bayerischen Akademie der Wissenschaften, Heft Nr. 61., 229-236, München.

Bašić, T. (2001): Detaljni model geoida Republike Hrvatske HRG2000 (Detailed Geoid Model of the Republic of Croatia). The Proceedings of the State Geodetic Admionistration "Reports on Scientific and Professional Projects from the year 2000" (editor I. Landek), 11-22, Zagreb.

Bašić, T., Rezo, M., Markovinović, D. (2002): Jedinstveno izjednačenje 10-km GPS mreže Republike (Unique Adjustment of 10-km GPS Network of the Republic of Croatia), Final study for the State Geodetic Administration, 1-126, Zagreb.

Boucher, C., Altamimi, Z. (2001): Memo: Specifications for reference frame fixing in the analysis of a EUREF GPS campaign.

Hofmann-Wellenhof, B., Lichtenegger, H., Collins, J. (1997): GPS – Theory and practice. 4th edition, Springer Verlag, Wien New York.

Marjanović, M., Bačić Ž. (2002): Computation of the Combined Solution of EUREF GPS Campaignes 1994-1996 in the Republic of Croatia. Proceed. of IAG EUREF 2001 Symposium held in Dubrovnik, 16-18 May 2001, 171-188, Euref Publication No. 10, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Frankfurt.

Trimble (1996): GPS Survey software – WAVE Software User's guide. Revision A. Trimble Navigation Limited, Surveying & Mapping Division, Sunnyvale, CA.