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COMPUTATION OF THE COMBINED SOLUTION OF EUREF GPS CAMPAIGNS 1994-1996 IN THE REPUBLIC OF CROATIA

The GPS Campaigns in the Republic of Croatia and the Republic of Slovenia carried out in 1994, 1995 and 1996 were used to establish a connection to EUREF reference system and to establish a reference GPS network in participating countries. The project was done with great support of the German *Institut für Angewandte Geodäsie* (today Bundesamt für Kartographie und Geodäsie - BKG) in cooperation with *State Geodetic Administration of the Republic of Croatia, Surveying and Mapping Authority of the Republic of Slovenia* and *Faculty of Geodesy, University of Zagreb*. The great effort on the succesful finishing of the whole project was made by Hermann Seeger, the late Krešimir Èoliæ, Branimir Gojèeta, the late Dušan Miškoviæ, Yueksel Altiner, Tomislav Bašiæ, Bož ena Lipej, Zlatko Mediæ, Ljerka Rašiæ and Aleš Seliškar.

1. Introduction

The EUREF 1994 Croatia and Slovenia GPS Campaign was carried out in order to connect Croatian and Slovenian networks to the EUREF-89 reference network. Fifteen new sites were included in this campaign (10 in Croatia and 5 (+3) in Slovenia). The observations were performed from May 30 to June 3, 1994 (four days with a session length of 24 hours each). In order to establish reference GPS network in Slovenia, the SLOVENIA 1995 GPS Campaign was carried out together with CROREF 1995 GPS Campaign in Croatia. The GPS network consists of 47 stations in Slovenia and 14 stations in Croatia. The observations were performed from September 25 to October 2, 1995, in two phases with 3 day observation each (session length of each observation day was 24 hours). The CROREF 1996 GPS Campaign was the second EUREF campaign in Croatia and also GPS campaign to determine the first and second order Croatian reference network. The GPS campaign was observed from August 29 to September 12, 1996 (four phases, altogether nine sessions with session length of 24 hours). In CROREF-96 campaign were also included all GPS sites observed within CRODYN-96 GPS campaign (phase four).

After each observation campaign the data were processed using the Bernese GPS Software with respect to the procedures specified by the EUREF Technical working group (Boucher and Altamimi, 1993). In view of different epochs of observation and therefore different orbit reference frames used in the data processing, the results of computed coordinates in the individual GPS campaigns were expressed based on different ITRF realizations. The

processing of the SLOCRO-94 GPS Campaign (Lj. Rašiæ, M. Marjanoviæ) was computed in ITRF-92, epoch 1994.4, the processing of SLOVENIA-95/CROREF-95 (D. Tavèar) was computed in ITRF-93, epoch 1995.7, and the processing of CROREF-96 and CRODYN-96 (M. Marjanoviæ, Lj. Rašiæ) was computed in ITRF-94, epoch 1996.7. The differences between individual solutions at identical observed sites displayed significant discrepancies after transformation to the ETRS-89. A possible reason for resulting differences could be the use of different reference systems. The ITRF reference system was improved with every realization due to improvement of measurement techniques, increasing number of included solutions achieved by different observation methods and increasing number of included reference and permanent sites.

Because of all these reasons, at one of TWG meetings the idea was born to re-compute each campaign in the ITRF-96 reference frame at observation epoch and then to compute one combined solution in ITRF-96 reference frame at the middle epoch. Because of some problems noted in combined solution and impossibility of using data of first original computation due to different computer systems, we decided at State Geodetic Administration to re-compute all three observed GPS campaigns and to compute a new combined solution.

2. GPS observation campaigns

The re-computed GPS campaigns SLOCRO-94, SLOVENIA-95/CROREF-95 and CROREF-96 were observed in three epochs. Complete set of data for the re-computation was used for GPS campaigns SLOCRO-94 and CROREF-96; for the SLOVENIA-95/CROREF-95 the data of 9 GPS sites in Slovenia (of altogether 47) were used for control and better combination:

Site	SLOCRO-94	SLOVENIA-95/ CROREF-95	CROREF-96
IGS reference site	3	4	4
IGS control site	2	5	7
Austria	1	-	-
Bosnia and Herz.	-	-	5
Croatia	10	14	76
Slovenia	8	9	5
Ó	24	32	97

Altogether 105 GPS sites were included in the combined solution: 11 IGS sites, 1 site in Austria, 5 sites in Bosnia and Herzegowina, 78 sites in Croatia and 10 sites in Slovenia. All new GPS stations were occupied with TRIMBLE (SSE or SSI) GPS receivers using corresponding TRIMBLE GPS antennas (4000ST L1/L GEOD or TR GEOD L1/L2 GP). For more information about GPS campaigns, observed sites and duration of the GPS measurements see Figure 1 and Table 1.

3. Coordinates of Reference IGS Sites

The coordinates of the reference IGS sites Graz, Matera, Zimmerwald and Wettzell-1202 were used for the computation. The official set of coordinates in ITRF-96 reference frame is given for epoch 1997.0 together with the corresponding velocity field.

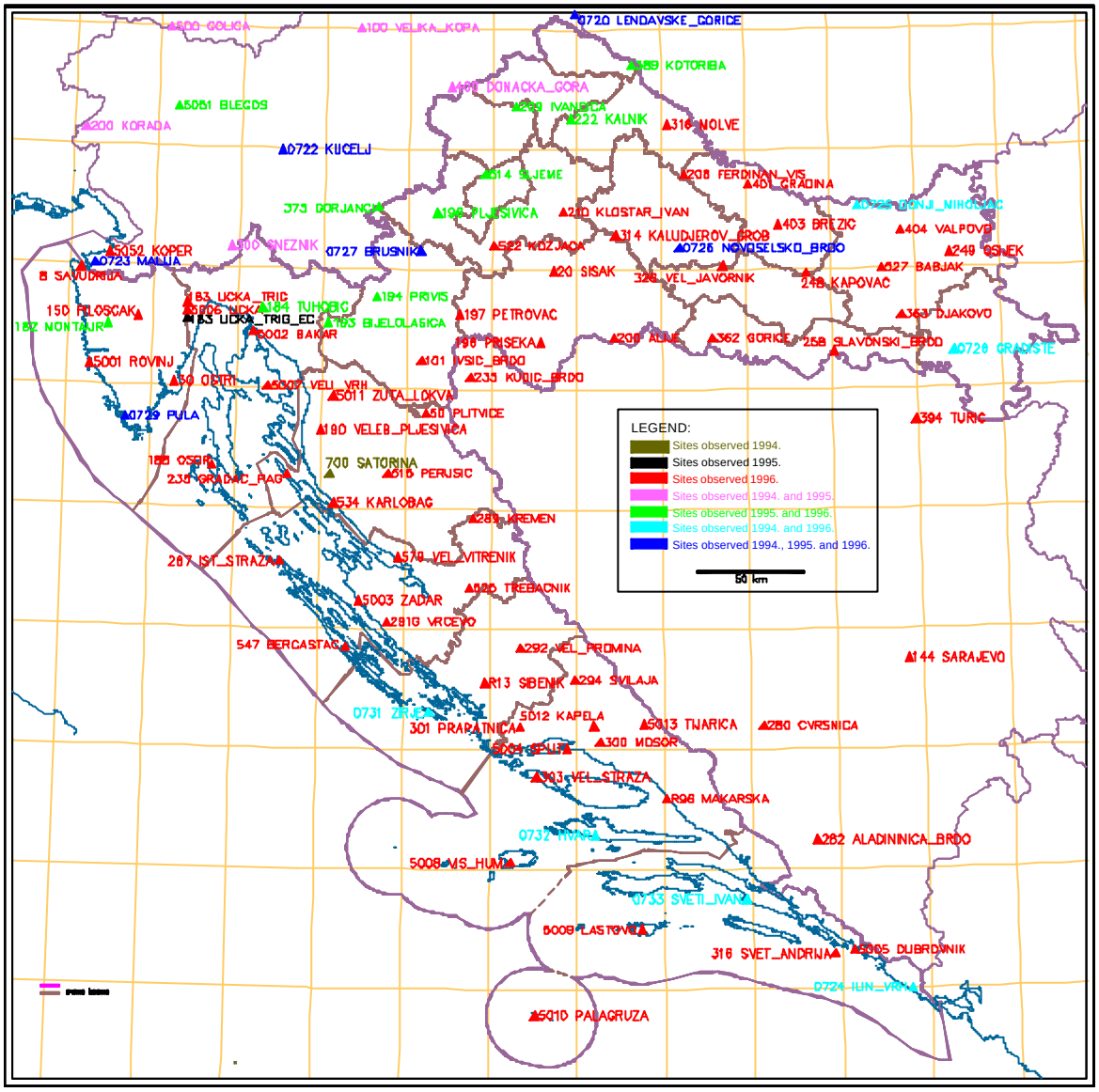


FIGURE 1: OBSERVED GPS SITES (SLOCRO-94, SLOVENIA-95/CROREF-95, CROREF-96)

NUM	STATION NAME	NUMBER OF SESSIONS	1994. 30.05.1994 - 3.06.1994.				1995. 25.09.1995 - 2.10.1995.							1996. 29.08.1996 - 12.09.1996.								
			150	151	152	153	268	269	270	271	272	273	274	242	243	245	246	249	250	253	254	255
1	BRUS	20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	KOSG	13	X	X	X	X								X	X	X	X	X	X	X	X	X
3	BRUSNIK 0727	20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	DONACKA GORA	7	X	X	X	X					X	X	X									
5	LEND GORICE 0720	16	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
6	VELIKA KOPA	7	X	X	X	X					X	X	X									
7	DONJI MIHOL 0725	6	X	X	X	X								X	X							
8	GRADISTE 0728	8	X	X	X	X								X	X	X	X					
9	NOVOS BRDO 0726	16	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
10	GRAZ	20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
11	GOLICA	7	X	X	X	X	X	X	X													
12	KORADA	11	X	X	X	X	X	X	X	X	X	X	X									
13	REISSECK	4	X	X	X	X																
14	ILIN VRH 0724	13	X	X	X	X								X	X	X	X	X	X	X	X	X
15	SVETI IVAN 0733	7	X	X	X	X														X	X	X
16	MALIJA 0724	20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
17	KUCELJ 0722	20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
18	SNEZNIK	11	X	X	X	X	X	X	X	X	X	X	X									
19	MATERA	20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
20	PULA 0729	16	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X
21	SATORINA	4	X	X	X	X																
22	ZIRJE 0731	13	X	X	X	X								X	X	X	X	X	X	X	X	X
23	HVAR 0732	7	X	X	X	X														X	X	X
24	ZIMMERWALD	19	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
25	KALNIK 222	9					X	X	X	X	X	X	X	X	X							

TABLE 1: SLOCRO-1994, SLOVENIA-1995/CROREF-1995, CROREF-1996

NUM	STATION NAME	NUMBER OF SESSIONS	1994. 30.05.1994 - 3.06.1994.				1995. 25.09.1995 - 2.10.1995.							1996. 29.08.1996 - 12.09.1996.								
			150	151	152	153	268	269	270	271	272	273	274	242	243	245	246	249	250	253	254	255
26	PRIVIS 194	5					X	X	X							X	X					
27	MONTAUR 182	5					X	X	X							X	X					
28	PADOVA	16					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
29	BLEGOS 5051	6					X	X	X											X	X	X
30	UCKA TRIG 183 EC	3					X	X	X													
31	BIJELA LASIC 193	5					X	X	X							X	X					
32	TUHOBIC 184	5					X	X	X							X	X					
33	GOPE	16					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
34	BOR1	15					X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
35	HFLK	16					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
36	WETTZELL-1202	16					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
37	SAMOB PLJES 196	5									X	X	X	X	X							
38	GORJANCI 375	5									X	X	X			X	X					
39	SLJEME 514	7									X	X	X	X	X	X	X					
40	KOTORIBA 389	5									X	X	X	X	X							
41	IVANCICA 209	5									X	X	X	X	X							
42	KALUD GROB 314	2												X	X							
43	KLOSTAR IVAN 210	2												X	X							
44	KOZJACA 522	2												X	X							
45	KUDIC BRDO 235	2												X	X							
46	VALPOVO 404	2												X	X							
47	PENC	9												X	X	X	X	X	X	X	X	X
48	GRADINA 401	2												X	X							
49	VEL JAVORNIK 326	2												X	X							
50	DAKOVO 363	2												X	X							
51	SLAV BROD 258	2												X	X							

Continuation of TABLE 1

NUM	STATION NAME	NUMBER OF SESSIONS	1994. 30.05.1994 - 3.06.1994.				1995. 25.09.1995 - 2.10.1995.							1996. 29.08.1996 - 12.09.1996.								
			150	151	152	153	268	269	270	271	272	273	274	242	243	245	246	249	250	253	254	255
52	TURIC 394	2												X	X							
53	BREZIC 403	2												X	X							
54	KAPOVAC 248	2												X	X							
55	FERDINAN VIS 208	2												X	X							
56	OSIJEK 249	2												X	X							
57	MOLVE 316	2												X	X							
58	BABJAK 527	2												X	X							
59	GORICE 362	2												X	X							
60	ALIJE 200	4												X	X	X	X					
61	SARAJEVO 1447	4												X	X	X	X					
62	PETROVAC 197	2														X	X					
63	SISAK 20	2														X	X					
64	ROVINJ 5001	2														X	X					
65	SAVUDRIJA 8	2														X	X					
66	PERUSIC 215	2														X	X					
67	VELEB PLJES 190	2														X	X					
68	PLITVICE 50	2														X	X					
69	PRISEKA 198	2														X	X					
70	VELI VRH 5007	2														X	X					
71	BAKAR 5002	2														X	X					
72	UCKA TRIG 183	2														X	X					
73	IVSIC BRDO 101	3														X		X	X			
74	GRADAC PAG 235	2														X	X					
75	OSOR 188	4														X	X	X	X			
76	PILOSCAK 150	2														X	X					
77	OSTRI 30	2														X	X					

Continuation of TABLE 1

NUM	STATION NAME	NUMBER OF SESSIONS	1994. 30.05.1994 - 3.06.1994.				1995. 25.09.1995 - 2.10.1995.							1996. 29.08.1996 - 12.09.1996.								
			150	151	152	153	268	269	270	271	272	273	274	242	243	245	246	249	250	253	254	255
78	VEL STRAZA 303	2																X	X			
79	PRAPATNICA 301	2																X	X			
80	BERCASTAC 547	2																X	X			
81	IST STRAZA 287	2																X	X			
82	KARLOBAG 534	4																X	X		X	X
83	VRCEVO 291G	2																X	X			
84	SIBENIK R13	2																X	X			
85	SVILAJA 294	5																X	X	X	X	X
86	VIS HUM 5008	5																X	X	X	X	X
87	TREBACNIK 525	2																X	X			
88	VEL VITRENIK 579	2																X	X			
89	KREMEN	2																X	X			
90	TIJARICA 5013	5																X	X	X	X	X
91	CVRSNICA 280	2																X	X			
92	VEL PROMINA 292	2																X	X			
93	SVET ANDRIJA 316	2																		X	X	
94	MAKARSKA R96	3																		X	X	X
95	DUBROVNIK 5005	3																		X	X	X
96	ALADIN BRDO 282	3																		X	X	X
97	ZUTA LOKVA 5011	3																		X	X	X
98	ZADAR 5003	3																		X	X	X
99	UCKA 5006	3																		X	X	X
100	KOPER 5052	3																		X	X	X
101	KAPELA 5012	3																		X	X	X
102	SPLIT 5004	3																		X	X	X
103	MOSOR 300	3																		X	X	X
104	LASTOVO 5009	3																		X	X	X
105	PALAGRUZA 5010	3																		X	X	X

Continuation of TABLE 1

The following table contains the coordinates of reference sites in ITRF-96, 1997.0, with their velocities and transformed coordinates in ITRF-96, epochs 1994.4, 1995.5, 1996.7 and 1995.55.

Site name	ITRF96 Epoch 1997.0 X,Y,Z	ITRF96 Epoch 1997.0 Vx,Vy,Vz	ITRF96 Epoch 1994.4 X,Y,Z	ITRF96 Epoch 1995.7 X,Y,Z	ITRF96 Epoch 1996.7 X,Y,Z	ITRF96 Epoch 1995.55 X,Y,Z
Graz	4194423.968	-0.0154	4194424.0080	4194423.9880	4194423.9726	4194423.9903
	1162702.559	0.0187	1162702.5104	1162702.5347	1162702.5534	1162702.5319
	4647245.314	0.0104	4647245.2870	4647245.3005	4647245.3109	4647245.2989
Matera	4641949.718	-0.0189	4641949.7671	4641949.7426	4641949.7237	4641949.7454
	1393045.282	0.0192	1393045.2321	1393045.2570	1393045.2762	1393045.2542
	4133287.333	0.0136	4133287.2976	4133287.3153	4133287.3289	4133287.3133
Zimmerwald	4331297.201	-0.0111	4331297.2299	4331297.2154	4331297.2043	4331297.2171
	567555.740	0.0173	567555.6950	567555.7175	567555.7348	567555.7149
	4633133.843	0.0126	4633133.8102	4633133.8266	4633133.8392	4633133.8247
Wettzell	4075580.697	-0.0159		4075580.7177	4075580.7018	4075580.7201
	931853.669	0.0174		931853.6464	931853.6638	931853.6438
	4801568.044	0.0070		4801568.0349	4801568.0419	4801568.0339

In the new re-computation were also included permanent IGS sites which were handled and processed as any other new GPS site in order to provide control of computed coordinates in individual campaign solutions and combined solution.

The following table contains the coordinates of permanent IGS sites in ITRF-96, 1997.0, with their velocities and transformed coordinates in ITRF-96, epochs 1994.4, 1995.5, 1996.7 and 1995.55.

Site name	ITRF96 Epoch 1997.0 X,Y,Z	ITRF96 Epoch 1997.0 Vx,Vy,Vz	ITRF96 Epoch 1994.4 X,Y,Z	ITRF96 Epoch 1995.7 X,Y,Z	ITRF96 Epoch 1996.7 X,Y,Z	ITRF96 Epoch 1995.55 X,Y,Z
Kootwijk	3899225.259	-0.0132	3899225.2933		3899225.2630	3899225.2781
	396731.819	0.0163	396731.7766		396731.8141	396731.7954
	5015078.345	0.0100	5015078.3190		5015078.3420	5015078.3305
Borowiec	3738358.611	-0.0158		3738358.6315	3738358.6157	3738358.6339
	1148173.592	0.0153		1148173.5721	1148173.5874	1148173.5698
	5021815.697	0.0083		5021815.6862	5021815.6945	5021815.6850
Brussels	4027893.866	-0.0103	4027893.8928	4027893.8794	4027893.8691	4027893.8809
	307045.699	0.0176	307045.6532	307045.6761	307045.6937	307045.6735
	4919475.031	0.0120	4919474.9998	4919475.0154	4919475.0274	4919475.0136
Hafelekar	4248505.189	-0.0147		4248505.2081	4248505.1934	4248505.2103
	855575.605	0.0207		855575.5781	855575.5988	855575.5750
	4667172.186	0.0117		4667172.1708	4667172.1825	4667172.1690
Pecny	3979316.275	-0.0138		3979316.2929	3979316.2791	3979316.2950
	1050312.351	0.0182		1050312.3273	1050312.3455	1050312.3246
	4857067.013	0.0092		4857067.0010	4857067.0102	4857066.9997
Penc	4052449.640	-0.0152			4052449.6446	4052449.6620
	1417680.998	0.0184			1417680.9925	1417680.9713
	4701407.027	0.0090			4701407.0243	4701407.0140
Padova	4389531.299	-0.0140		4389531.3172	4389531.3032	4389531.3193
	923253.651	0.0166		923253.6294	923253.6460	923253.6269
	4519256.340	0.0121		4519256.3243	4519256.3364	4519256.3225

4. Processing Strategy

The data were processed using the post-processing Bernese GPS Software Version 4.0 with respect to the procedures specifed by EUREF Technical working group.

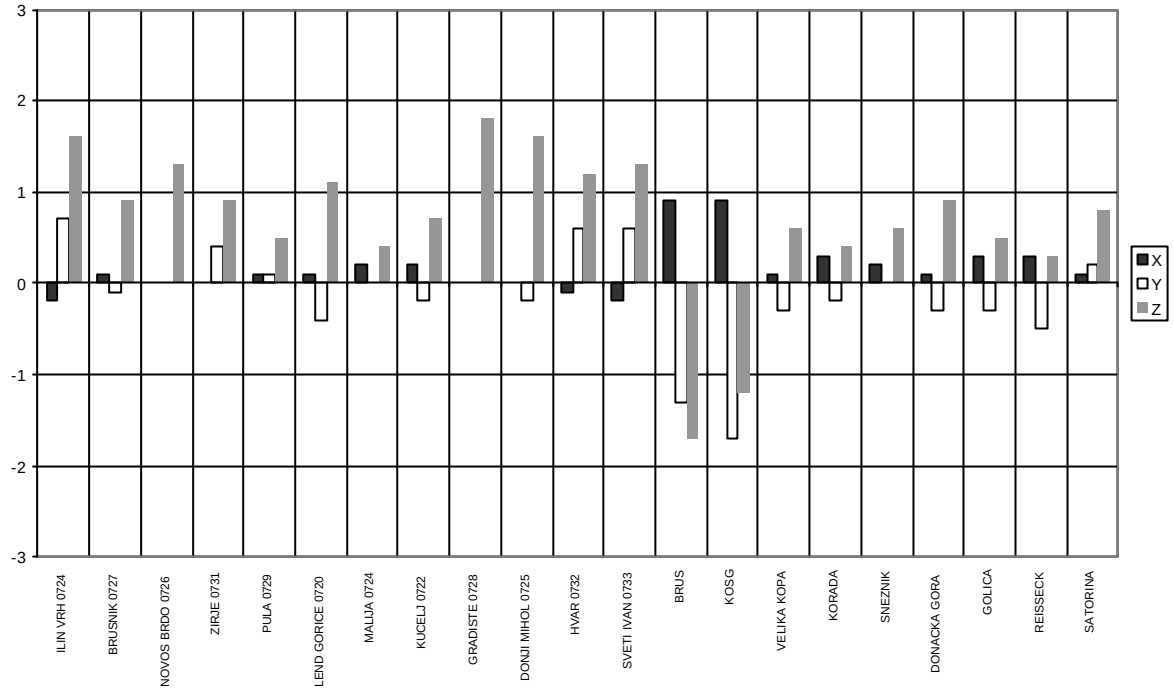
The following principles were applied in the data processing:

- use of final IGS precise orbits with corresponding earth rotation parameters,
- for the pre-processing and processing 24 hours of 15-second-interval data were used,
- minimun elevation angle of 15 degrees was used for the 1994. and 1995. campaigns, and 20 degrees for the 1996. campaign,
- application of antenna elevation-dependent phase center corrections, because different types of antennas were combined,
- the standard troposphere model of Saastamoinen was applied (one site troposphere parameter on each 2 hours; a-priori sigma for absolute and relative troposphere parameters is ± 9.999 m),
- processing of the double-difference measurements based on the ionosphere-free carrier phase linear combination L3,
- ionosphere model was used for the resolving of L5 ambiguities,
- ambiguity resolution L1 and L2 (sigma resolution for baselines up to 100 km and QIF resolution for longer baselines), approximately 90% of ambiguities were solved,
- correlations modelled correctly,
- free solution of each session (normal equations, estimated station coordinates and troposphere parameters were saved),
- the normal equations from each processing session were combined using ADDNEQ program to create a free campaign solution,
- the normal equations from each processing session were combined using ADDNEQ program to create a constrained campaign solution in order to compare the coordinates of control IGS sites with computed values.

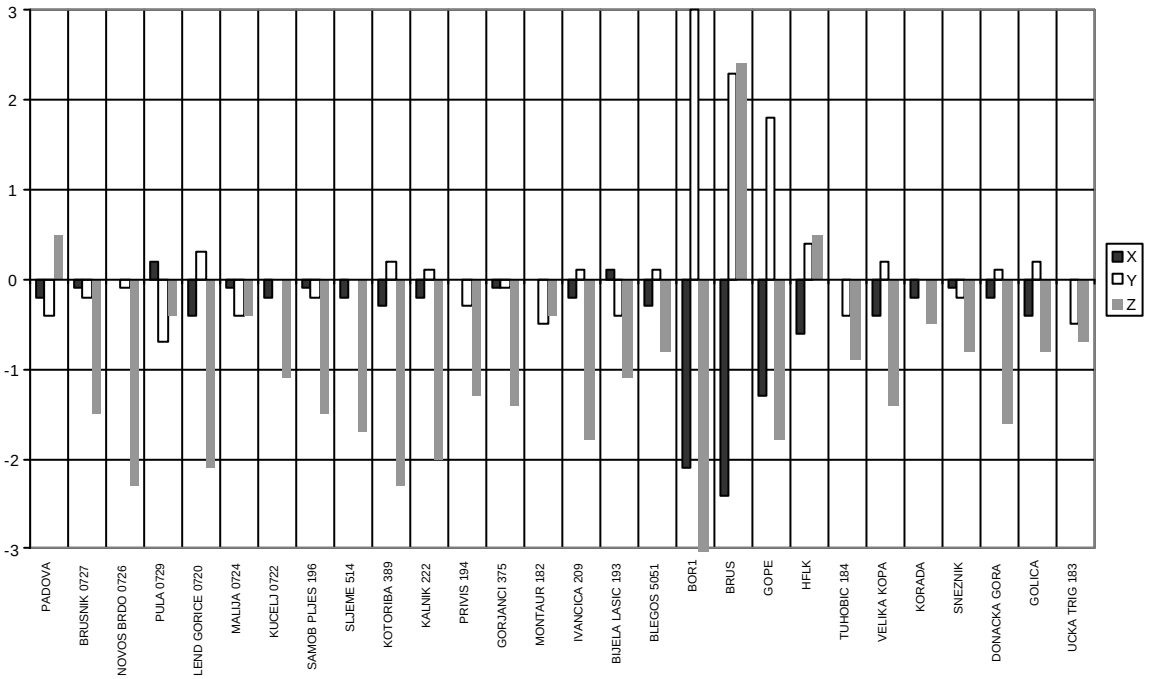
In order to compute the combined solution, all three GPS campaigns have to be processed in the same reference frame, therefore precise IGS orbits from its original ITRF reference frame (ITRF-92, ITRF-93, ITRF-94) were transformed into the ITRF-96 reference frame using the program TRNFSP3N of J. Kouba with associated transformation parameters. The same program was also used for the transformation of corresponding IGS earth rotation parameters.

The computations of individual GPS campagins was done using orbits in its original reference frame (ITRF-92, ITRF-93 and ITRF-94) and transformed orbits in ITRF-96 with fixing of reference IGS sites in ITRF-96 in order to investigate influence of orbit transformation to computed coordinates and to control transformation procedure. The differences of solutions of each GPS campaign for X, Y, and Z component in millimeters are presented in the following diagrams:

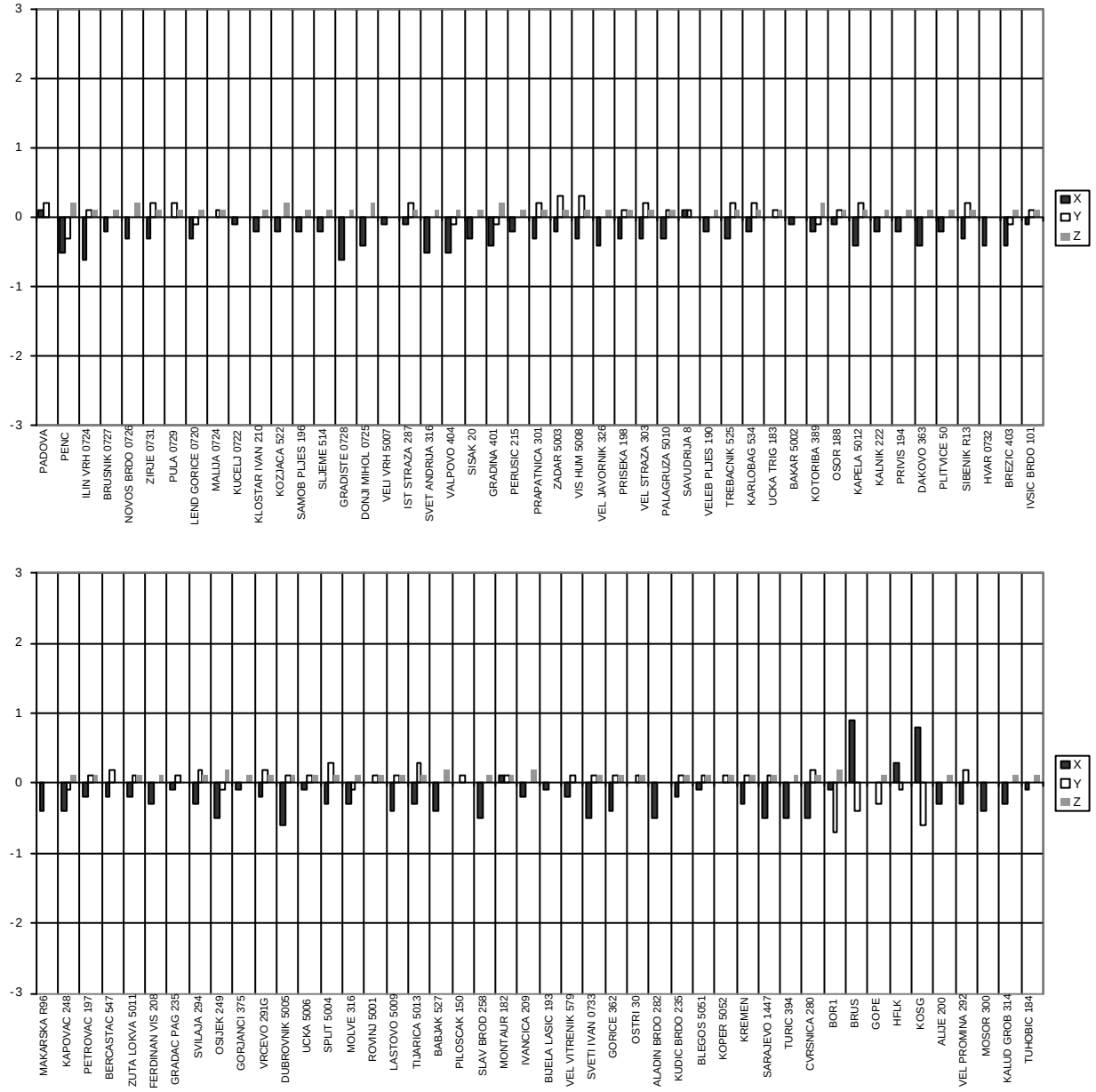
SLOCRO-1994 GPS Campaign:



CROREF-1995 GPS Campaign:



CROREF-1996 GPS Campaign:



5. Individual Campaign Solutions

The re-computation started with the processing of each individual GPS campaign to get information about the quality and accuracy of each campaign and to produce all necessary data needed for the computation of the combined solution. The information about antenna types and antenna heights was once again independently controlled for all observed GPS sites within each of individual GPS campaigns.

The computations were carried out on the basis of the ITRF-96 reference frame. Due to the use of differenced phase observations in the Bernese GPS Software, single differences of phase data were formed between stations for each session following the principles of baseline minimum length and using identical baselines for all days of one campaign if possible. In the pre-processing and processing steps complete set of data was used without decreasing the sampling rate used during the observation time. The cycle slips were fixed, bad data were

marked and new ambiguities were set up. In the first processing step the initial phase ambiguities were solved for each baseline using SIGMA strategy for baselines up to 100 km (at first L5 linear combination + ionosphere model, than L3 linear combination) and QIF strategy for longer baselines, approximately 90% of ambiguities were solved. In the second step the daily solutions were computed in which the fixed ambiguities were used, the coordinates of reference sites were estimated with a-priori constraints of ± 0.0005 m and 12 troposphere parameters per station and session were estimated.

In order to get information about the quality of the data and to analyse comparisons with the official reference coordinates of control sites in ITRF-96 for each campaign, one constrained solution (included all sessions of individual campaign) was computed.

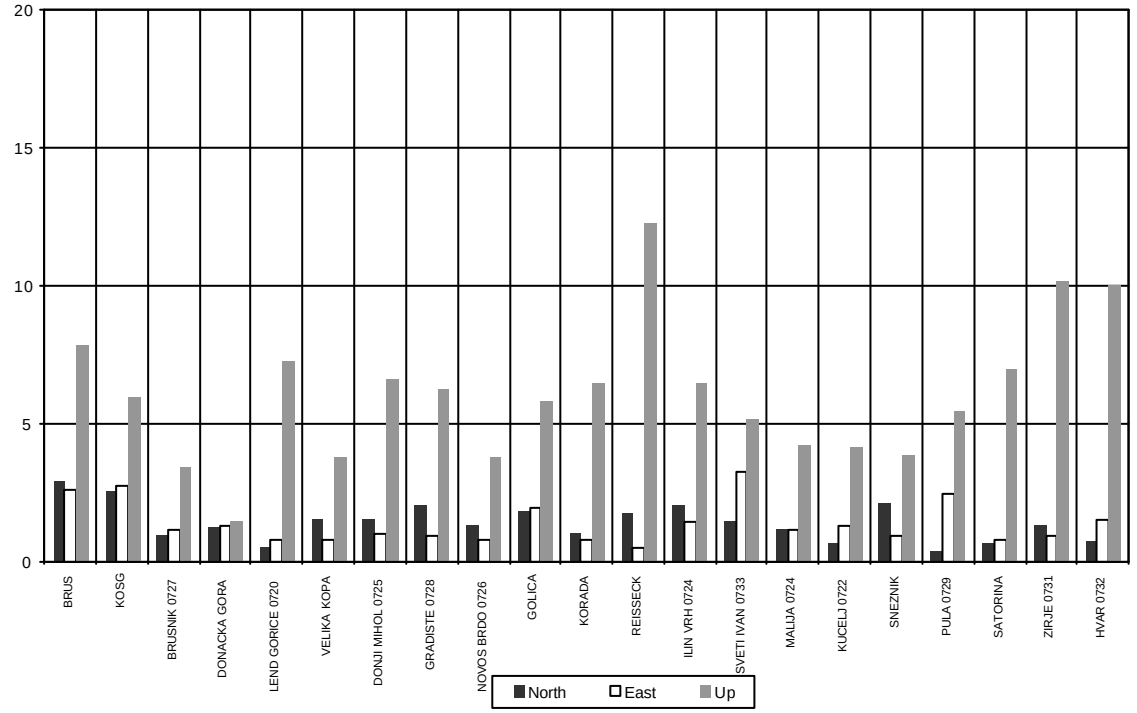
In the next paragraphs the following results are presented for the each of individual GPS campaigns:

a) comparison of station coordinates with respect to the combined campaign solution (RMS of individual coordinate residuals) in millimeters,
b) RMS values with respect to the combined solution (daily solutions – combined campaign solution) in millimeters.
c) comparison of computed IGS control sites with official ITRF-96 values.

5.1 SLOCRO-1994 GPS Campaign

In the SLOCRO-1994 GPS campaign a total of 24 GPS sites (3 reference IGS sites + 2 control IGS sites + 21 new GPS sites) was included. The complete network contains 92 baselines divided in four sessions.

a)



b)

Param.	RMS	150	151	152	153
North	1.2	1.4	1.2	1.3	1.1
East	1.3	1.6	1.4	0.9	1.1
Up	5.3	5.6	5.5	3.8	6.2
Stations	24	24	24	24	24

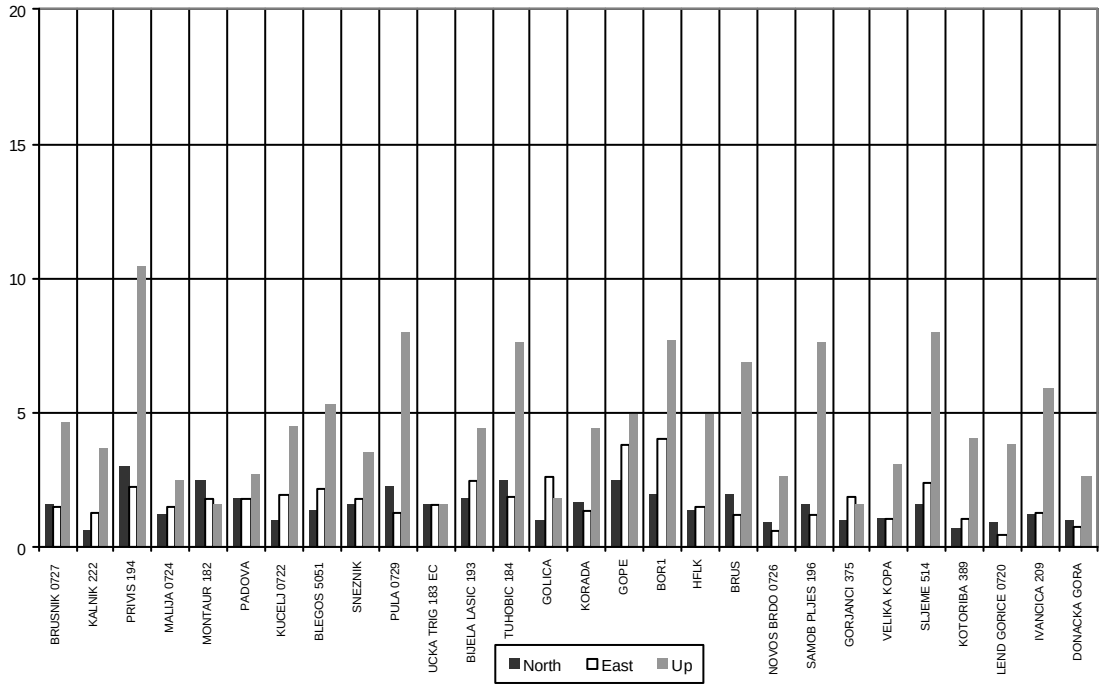
c)

Num	Station name	Parameter	ITRF Coordinates ITRF96, Epoch 1994.4	Computed coordinates ITRF96, Epoch 1994.4	Difference (m)
88	BRUS	X	4027893.893	4027893.902	0.009
		Y	307045.653	307045.653	0.000
		Z	4919475.000	4919475.003	0.003
		HEIGHT	149.667	149.675	0.008
		LATITUDE	50 47 52.139134	50 47 52.138956	-0.006
		LONGITUDE	4 21 33.179766	4 21 33.179742	-0.001
91	KOSG	X	3899225.293	3899225.298	0.005
		Y	396731.777	396731.775	-0.002
		Z	5015078.319	5015078.319	0.000
		HEIGHT	96.855	96.857	0.003
		LATITUDE	52 10 42.330379	52 10 42.330269	-0.003
		LONGITUDE	5 48 34.708758	5 48 34.708642	-0.002

5.2 SLOVENIA-1995/CROREF-1995

In the SLOVENIA-1995/CROREF-1995 GPS campaign a total of 32 GPS sites (4 reference IGS sites + 5 control IGS sites + 23 new GPS sites) was included. The complete network contains 149 baselines divided in seven sessions.

a)



b)

Param.	RMS	268	269	270	271	272	273	274
North	1.3	1.2	1.5	1.8	0.9	1.2	0.9	1.5
East	1.5	1.5	1.0	2.7	0.7	0.9	1.1	1.5
Up	4.0	3.7	5.0	4.8	4.5	3.9	3.0	3.8
Stations	32	23	23	23	15	24	24	24

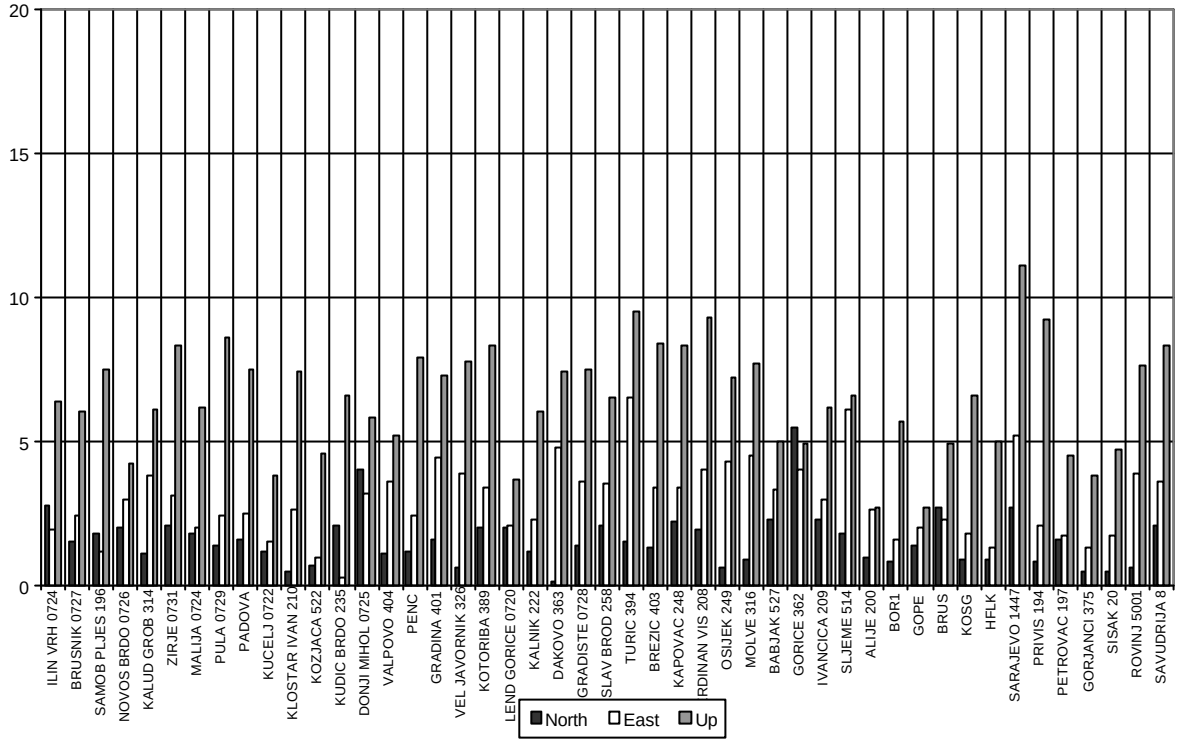
c)

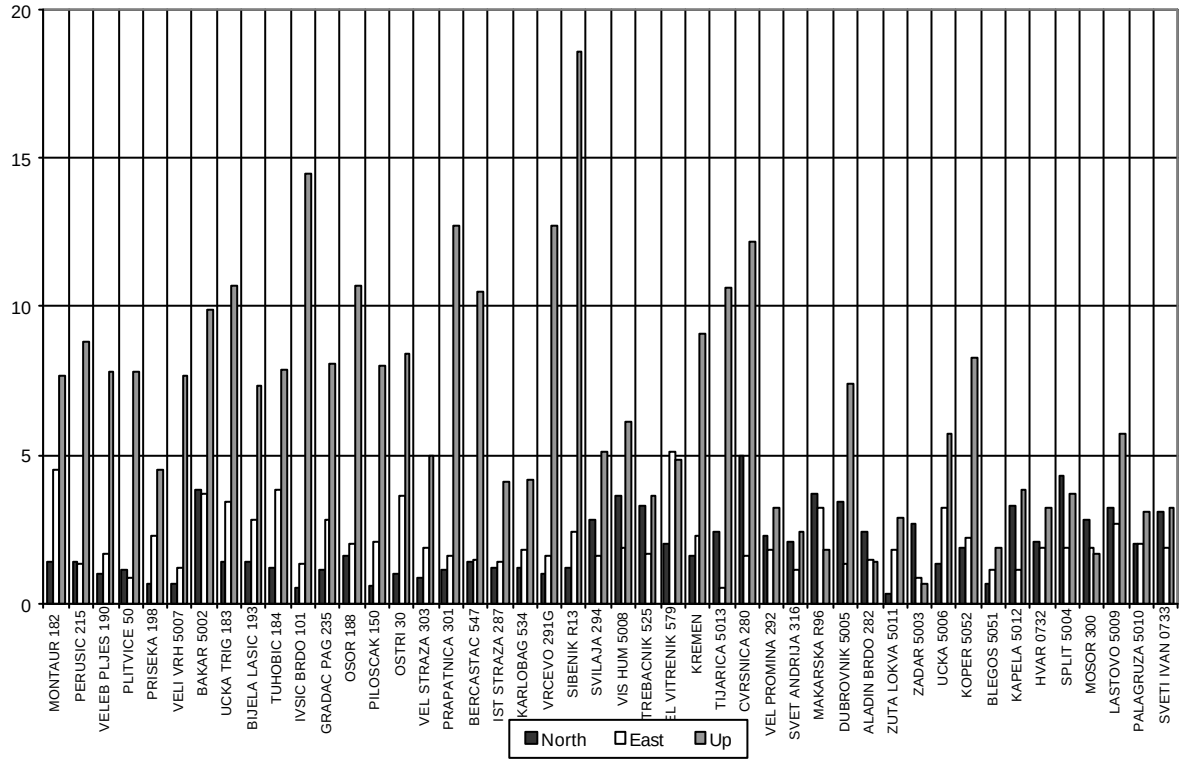
Num	Station name	Parameter	ITRF Coordinates ITRF96, Epoch 1995.7	Computed coordinates ITRF96, Epoch 1995.7	Difference (m)
3	PADOVA	X	4389531.317	4389531.318	0.001
		Y	923253.629	923253.629	-0.001
		Z	4519256.324	4519256.322	-0.002
		HEIGHT	84.042	84.041	-0.001
		LATITUDE	45 24 24.180613	45 24 24.180546	-0.002
		LONGITUDE	11 52 40.550741	11 52 40.550693	-0.001
89	GOPE	X	3979316.293	3979316.296	0.003
		Y	1050312.327	1050312.336	0.009
		Z	4857067.001	4857067.006	0.005
		HEIGHT	592.598	592.605	0.007
		LATITUDE	49 54 49.331703	49 54 49.331662	-0.001
		LONGITUDE	14 47 8.231090	14 47 8.231485	0.008
87	BOR1	X	3738358.632	3738358.627	-0.005
		Y	1148173.572	1148173.576	0.004
		Z	5021815.686	5021815.681	-0.005
		HEIGHT	124.374	124.368	-0.006
		LATITUDE	52 16 37.039403	52 16 37.039385	-0.001
		LONGITUDE	17 4 24.433430	17 4 24.433697	0.005
90	HFLK	X	4248505.208	4248505.213	0.005
		Y	855575.578	855575.583	0.005
		Z	4667172.171	4667172.171	0.000
		HEIGHT	2384.141	2384.145	0.004
		LATITUDE	47 18 46.452315	47 18 46.452179	-0.004
		LONGITUDE	11 23 9.922859	11 23 9.923052	0.004
88	BRUS	X	4027893.879	4027893.879	0.000
		Y	307045.676	307045.678	0.002
		Z	4919475.015	4919475.016	0.001
		HEIGHT	149.672	149.673	0.001
		LATITUDE	50 47 52.139745	50 47 52.139762	0.001
		LONGITUDE	4 21 33.180984	4 21 33.181088	0.002

5.3 CROREF-1996 GPS Campaign

In the CROREF-1996 GPS campaign a total of 97 GPS sites (4 reference IGS sites + 7 control IGS sites + 86 new GPS sites) was included. The complete network contains 353 baselines divided in nine sessions.

a)





b)

Param.	RMS	242	243	245	246	249	250	253	254	255
North	1.6	1.9	1.5	1.1	1.2	1.3	1.8	1.4	1.6	2.3
East	2.0	1.9	3.4	2.3	2.1	1.9	1.3	1.2	1.5	1.5
Up	5.4	5.8	5.5	5.9	5.2	7.6	5.8	3.8	4.0	4.8
Stations	97	45	45	44	43	36	35	37	39	38

c)

Num	Station name	Parameter	ITRF Coordinates ITRF96, Epoch 1996.7	Computed coordinates ITRF96, Epoch 1996.7	Difference (m)
3	PADOVA	X	4389531.303	4389531.305	0.002
		Y	923253.646	923253.649	0.003
		Z	4519256.336	4519256.337	0.001
		HEIGHT	84.043	84.045	0.002
		LATITUDE	45 24 24.181126	45 24 24.181084	-0.001
		LONGITUDE	11 52 40.551621	11 52 40.551726	0.002
4	PENC	X	4052449.645	4052449.642	-0.003
		Y	1417680.993	1417680.992	-0.001
		Z	4701407.024	4701407.023	-0.002
		HEIGHT	291.749	291.746	-0.003
		LATITUDE	47 47 22.566566	47 47 22.566605	0.001
		LONGITUDE	19 16 53.494784	19 16 53.494803	0.000
87	BOR1	X	3738358.616	3738358.609	-0.007
		Y	1148173.587	1148173.585	-0.002
		Z	5021815.695	5021815.685	-0.009
		HEIGHT	124.374	124.362	-0.012
		LATITUDE	52 16 37.039839	52 16 37.039845	0.000
		LONGITUDE	17 4 24.434446	17 4 24.434442	0.000
89	GOPE	X	3979316.279	3979316.271	-0.008
		Y	1050312.346	1050312.345	-0.001
		Z	4857067.010	4857066.999	-0.011
		HEIGHT	592.599	592.585	-0.014
		LATITUDE	49 54 49.332110	49 54 49.332081	-0.001
		LONGITUDE	14 47 8.232148	14 47 8.232220	0.001
88	BRUS	X	4027893.869	4027893.865	-0.005
		Y	307045.694	307045.694	0.000
		Z	4919475.025	4919475.021	-0.004
		HEIGHT	149.674	149.668	-0.006
		LATITUDE	50 47 52.140159	50 47 52.140199	0.001
		LONGITUDE	4 21 33.181920	4 21 33.181932	0.000
91	KOSG	X	3899225.263	3899225.254	-0.009
		Y	396731.814	396731.812	-0.002
		Z	5015078.342	5015078.329	-0.013
		HEIGHT	96.857	96.841	-0.016
		LATITUDE	52 10 42.331509	52 10 42.331497	0.000
		LONGITUDE	5 48 34.710883	5 48 34.710817	-0.001
90	HFLK	X	4248505.193	4248505.190	-0.004
		Y	855575.599	855575.599	0.000
		Z	4667172.183	4667172.177	-0.005
		HEIGHT	2384.143	2384.137	-0.006
		LATITUDE	47 18 46.452817	47 18 46.452780	-0.001
		LONGITUDE	11 23 9.923963	11 23 9.924004	0.001

6. Combined Solution

After the re-computation of individual GPS campaigns and analysis of computed results, the second group of information needed for the computation of combined solution was prepared. At first, the dimension of arrays in ADDNEQ program and its subroutines were adjusted due to the large number of parameters and unknows. The free adjustment of three GPS campaigns was performed in three epochs (1994.4, 1995.7 and 1996.7) and as a result the normal equation files were saved.

In order to compute combined solution of all three GPS campaigns at the middle epoch, beside normal equation files also station velocities have to be given as input values. The velocities of four reference IGS sites (Graz, Matera, Zimmerwald and Wettzell) are ITRF-96 velocities. The velocities of all other GPS sites were computed with the Bernese GPS Software program NUVELO on the basis of NUVEL1A-NNR model and station coordinates in the EURA plate.

The estimated coordinates of the combined solution of all GPS campaigns refer to the ITRF-96 reference frame, at middle epoch 22.07.1995. which corresponds to epoch 1995.55.

RMS values with respect to the combined solution (individual campaign solutions – combined solution) in millimeters are:

Param.	RMS	SLOCRO-94	CROREF-95	CROREF-96
North	5.1	9.3	1.3	4.5
East	3.0	2.2	3.6	3.0
Up	6.3	7.9	3.4	6.7
Stations	105	24	32	97

Again, the coordinates of control IGS sites computed in combined solution with official ITRF-96 (epoch 1995.55) coordinates were compared. The differences between the two sets of coordinates are presented in the following table:

Num	Station name	Parameter	ITRF Coordinates ITRF96, Epoch 1995.55	Combined Solution ITRF96, Epoch 1995.55	Difference (m)
3	PADOVA	X	4389531.319	4389531.321	-0.002
		Y	923253.627	923253.626	0.001
		Z	4519256.323	4519256.322	0.001
		HEIGHT	84.042	84.042	0.000
		LATITUDE	45 24 24.180537	45 24 24.180492	0.001
		LONGITUDE	11 52 40.550609	11 52 40.550569	0.001
4	PENC	X	4052449.662	4052449.659	0.003
		Y	1417680.971	1417680.973	-0.001
		Z	4701407.014	4701407.010	0.004
		HEIGHT	291.748	291.743	0.005
		LATITUDE	47 47 22.566116	47 47 22.566073	0.001
		LONGITUDE	19 16 53.493546	19 16 53.493651	-0.002

Num	Station name	Parameter	ITRF Coordinates ITRF96, Epoch 1995.55	Combined Solution ITRF96, Epoch 1995.55	Difference (m)
87	BOR1	X	3738358.634	3738358.629	0.005
		Y	1148173.570	1148173.570	-0.001
		Z	5021815.685	5021815.678	0.007
		HEIGHT	124.374	124.366	0.008
		LATITUDE	52 16 37.039338	52 16 37.039321	0.001
		LONGITUDE	17 04 24.433277	17 4 24.433378	-0.002
89	GOPE	X	3979316.295	3979316.295	0.000
		Y	1050312.325	1050312.330	-0.005
		Z	4857067.000	4857066.998	0.001
		HEIGHT	592.598	592.598	0.000
		LATITUDE	49 54 49.331642	49 54 49.331573	0.002
		LONGITUDE	14 47 08.230932	14 47 8.231192	-0.005
88	BRUS	X	4027893.881	4027893.882	-0.001
		Y	307045.674	307045.674	0.000
		Z	4919475.014	4919475.014	0.000
		HEIGHT	149.671	149.672	-0.001
		LATITUDE	50 47 52.139675	50 47 52.139651	0.001
		LONGITUDE	4 21 33.180846	4 21 33.180861	0.001
91	KOSG	X	3899225.278	3899225.274	0.004
		Y	396731.795	396731.793	0.002
		Z	5015078.331	5015078.325	0.005
		HEIGHT	96.855	96.849	0.006
		LATITUDE	52 10 42.330945	52 10 42.330938	0.000
		LONGITUDE	5 48 34.709824	5 48 34.709719	0.002
90	HFLK	X	4248505.210	4248505.212	-0.002
		Y	855575.575	855575.579	-0.004
		Z	4667172.169	4667172.168	0.001
		HEIGHT	2384.141	2384.142	-0.001
		LATITUDE	47 18 46.452239	47 18 46.452157	0.003
		LONGITUDE	11 23 09.922694	11 23 9.922874	-0.004

7. Transformation into ETRS-89

The transformation into the ETRS-89 reference system was done following Specifications for reference frame fixing in the analysis of a EUREF GPS campaign (C.Boucher, Z. Altamimi, 1998.):

$$\mathbf{X}e(t_c) = \mathbf{X}yy(t_c) + \mathbf{T}yy + \begin{vmatrix} 0 & -R_3yy & R_2yy \\ R_3yy & 0 & -R_1yy \\ -R_2yy & R_1yy & 0 \end{vmatrix} \cdot \mathbf{X}yy(t_c) \cdot (t_c - 1989.0),$$

where

$\mathbf{X}e(t_c)$ - coordinates in ETRS-89,

$\mathbf{X}yy(t_c)$ - coordinates in ITRF-96,

Tyy - translation parameters (ITRF-96 to ETRS-89),

R_i yy - rotation parameters (ITRF-96 to ETRS-89),

t_c - observation epoch – 1995.55.

Transformation parameters:

T_1 (cm)	4.1
T_2 (cm)	4.1
T_3 (cm)	-4.9
R_1 (0.001 sec)	0.20
R_2 (0.001 sec)	0.50
R_3 (0.001 sec)	-0.65

In order to provide control of combined solution, the coordinates of all individual constrained GPS campaign solutions were transformed from their epoch of observation to ETRS-89 as described:

GPS Campaign	**Reference Frame**	**Epoch**
SLOCRO-94	ITRF-96	1994.4
CROREF-95	ITRF-96	1995.7
CROREF-96	ITRF-96	1996.7
COMBINED SOLUTION	ITRF-96	1995.55

The differences between each of individual GPS campaign solution after transformation to ETRS-89 system and combined solution in ETRS-89 for all GPS sites are given in the following tabel in millimeters:

GPS Campaign	**94 - COM**			**95 - COM**			**96 - COM**			**GPS Campaign**	**94 - COM**			**95 - COM**			**96 - COM**		
GPS Site	**dX**	**dY**	**dZ**	**dX**	**dY**	**dZ**	**dX**	**dY**	**dZ**	**GPS Site**	**dX**	**dY**	**dZ**	**dX**	**dY**	**dZ**	**dX**	**dY**	**dZ**
PADOVA				-1	0	-1	0	1	4	ZUTA LOKVA 5011							1	0	4
PENC							1	-1	3	FERDINAN VIS 208							-1	3	3
ILIN VRH 0724	1	-3	-8				1	1	5	GRADAC PAG 235							0	-3	1
BRUSNIK 0727	-10	-1	-16	1	-1	1	2	2	5	SVILAJA 294							1	-1	4
NOVOS BRDO 0726	-7	-1	-12	1	-4	2	3	3	4	OSIJEK 249							0	4	3
ZIRJE 0731	2	-4	-7				0	1	3	GORJANCI 375				-1	1	-2	0	3	4
PULA 0729	2	1	-5	0	-1	-4	1	1	5	VRCEVO 291G							0	-1	4
LEND GORICE 0720	20	12	-10	-9	16	-10	-4	-16	10	DUBROVNIK 5005							1	1	5
MALIJA 0724	13	2	3	-5	2	-2	1	-2	-1	UCKA 5006							1	-1	4
KUCELJ 0722	-2	0	-10	-1	0	-2	2	2	7	SPLIT 5004							1	-1	4
KLOSTAR IVAN 210							-1	3	2	MOLVE 316							1	3	3

GPS Campaign	94 - COM			95 - COM			96 - COM			GPS Campaign	94 - COM			95 - COM			96 - COM		
GPS Site	dX	dY	dZ	dX	dY	dZ	dX	dY	dZ	GPS Site	dX	dY	dZ	dX	dY	dZ	dX	dY	dZ
KOZJACA 522							-1	3	2	ROVINJ 5001							0	0	2
SAMOB PLJES 196				0	0	0	-5	6	-3	LASTOVO 5009							1	1	5
SLJEME 514				-2	0	-3	-2	6	4	TIJARICA 5013							1	-1	4
GRADISTE 0728	1	-3	-9				2	7	7	BABJAK 527							0	3	3
DONJI MIHOL 0725	4	1	-2				-4	3	-6	PILOSCAK 150							0	0	2
VELI VRH 5007							0	-3	2	SLAV BROD 258							0	3	3
IST STRAZA 287							0	-1	3	MONTAUR 182				0	0	-1	-4	2	1
SVET ANDRIJA 316							1	1	5	IVANCICA 209				0	0	-1	-4	5	0
VALPOVO 404							0	4	3	BIJELA LASIC 193				-3	1	-2	6	-3	7
SISAK 20							1	2	4	VEL VITRENIK 579							1	-1	4
GRADINA 401							1	3	3	SVETI IVAN 0733	2	-2	-8				1	4	8
PERUSIC 215							0	-2	1	GORICE 362							0	3	3
PRAPATNICA 301							0	-1	4	OSTRI 30							0	0	2
ZADAR 5003							1	-1	4	ALADIN BRDO 282							1	1	5
VIS HUM 5008							1	-1	4	KUDIC BRDO 235							-1	3	2
VEL JAVORNIK 326							0	3	3	BLEGOS 5051				-5	2	-4	8	-2	10
PRISEKA 198							1	2	4	KOPER 5052							1	-1	4
VEL STRAZA 303							1	-1	4	KREMEN							1	-1	4
PALAGRUZA 5010							0	2	5	SARAJEVO 1447							0	2	3
SAVUDRIJA 8							0	0	2	TURIC 394							0	4	3
VELEB PLJES 190							0	-3	2	CVRSNICA 280							1	-1	4
TREBACNIK 525							1	-1	4	BOR1				0	3	2	-2	-4	-2
KARLOBAG 534							1	-1	4	BRUS	5	0	0	-1	2	1	-2	0	-4
UCKA TRIG 183							0	0	2	GOPE				3	4	6	-7	-5	-9
BAKAR 5002							0	-3	1	HFLK				3	1	1	-6	-1	-2
KOTORIBA 389				-2	-1	-2	2	7	4	KOSG	8	2	4				-5	-1	-6
OSOR 188							0	-2	2	ALIJE 200							0	2	3
KAPELA 5012							1	-1	5	VEL PROMINA 292							1	-1	4
KALNIK 222				-2	0	-2	8	9	11	MOSOR 300							1	1	5
PRIVIS 194				3	0	3	-8	3	-4	KALUD GROB 314							0	3	3
DAKOVO 363							0	4	3	TUHOBIC 184				-4	4	2	1	-10	-8
PLITVICE 50							0	-2	1	VELIKA KOPA	5	2	-1	-2	1	-5			
SIBENIK R13							1	-1	4	KORADA	-4	1	-10	1	1	0			
HVAR 0732	3	0	-9				-1	1	9	SNEZNIK	2	2	-4	-1	1	-2			
BREZIC 403							0	4	3	DONACKA GORA	4	2	-3	-2	1	-4			
IVSIC BRDO 101							0	-2	3	GOLICA	7	0	-2	-5	2	-4			
MAKARSKA R96							0	1	5	REISSECK	3	1	-5						
KAPOVAC 248							0	3	3	SATORINA	2	0	-6						
PETROVAC 197							0	2	3	UCKA TRIG 183 EC				-1	1	-1			
BERCASTAC 547							1	-1	4										

The above presented differences show good consistence of individual solutions in relation to the combined solution. Specially the differences of GPS sites observed in only one campaign have order of magnitude of few millimeters to combined solution. Those differences were probably caused by different weighting through adjustment process of combined solution of all three GPS campaigns.

The EUREF GPS Sites *0730 Šatorina* and *0732 Sveti Nikola* estimated within SLOCRO-1994 GPS Campaign during the last years were damaged or destroyed, therefore we propose to replace them with new sites *0730 Kremen* and *0732 Vis Hum.*

The EUREF GPS Sites in the Republic of Croatia with associated coordinates in ETRS-89 system is presented in the following table:

EUREF No.	SITE NAME	X	Y	Z
0725	DONJI MIHOLOLJAC	4235413.420	1389394.706	4546864.155
0726	NOVOSELSKO BRDO	4273227.943	1314661.906	4533896.905
0727	BRUSNIK	4307966.079	1200393.194	4532778.716
0728	GRADIŠTE	4267436.938	1445417.698	4499533.451
0729	PULA	4396624.036	1083670.705	4476822.858
0730	KREMEN	4386479.599	1248397.099	4446190.519
0731	Ž IRJE	4450950.365	1246404.433	4380514.136
0732	VIS HUM	4486667.279	1296165.147	4330366.220
0733	SVETI IVAN	4466232.614	1404551.057	4317584.872
0734	ILIN VRH	4469744.080	1485678.377	4287027.880

The location of the proposed EUREF GPS Sites in the Republic of Croatia is presented in Figure 2.

8. Comparison with solutions of other GPS Campaigns

The results of EUREF GPS sites computed in the combined solution were compared with the results of EUVN 1997 GPS Campaign and EUREF-FYROM 1996 GPS Campaign:

GPS Campaign	GPS Site	ETRS-89 X Y Z (m)	GPS Campaign - Combined Solution dX dY dZ (m)	 North East Up (m)
EUVN-1997	BRUSNIK 0727	4307966.082 1200393.195 4532778.725	0.003 0.001 0.009	0.004 0.000 0.009
EUVN-1997	GRADISTE 0728	4267436.949 1445417.704 4499533.467	0.011 0.006 0.016	0.003 0.002 0.020
EUVN-1997	MALIJA 0724	4351694.762 1056274.718 4526994.584	-0.003 -0.002 0.003	0.005 -0.001 0.000
EUREF FYROM-1996	ILIN VRH	4469744.084 1485678.378 4287027.880	0.004 0.002 0.000	-0.003 0.000 0.003

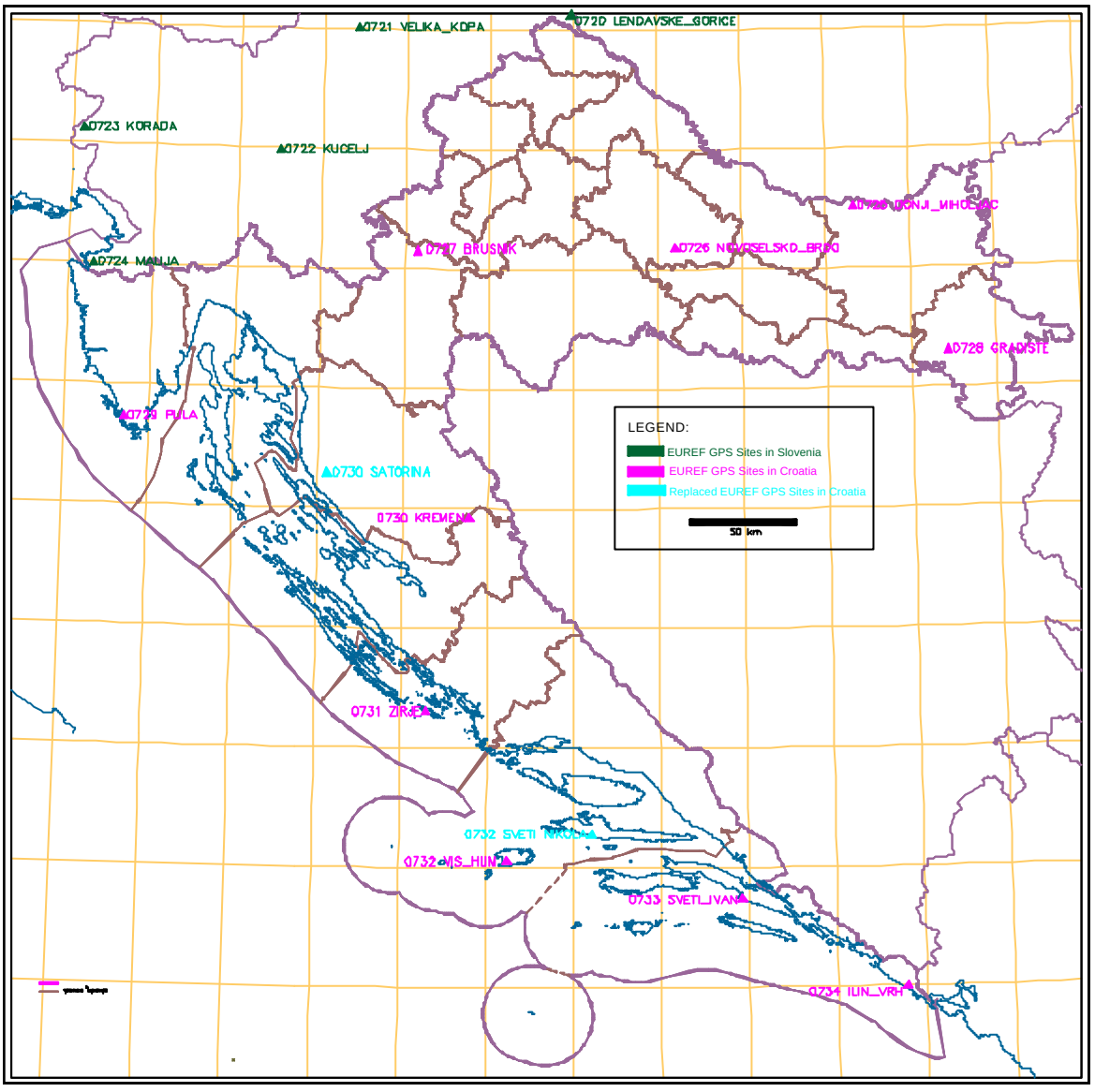


FIGURE 2 EUREF GPS SITES IN CROATIA AND SLOVENIA

9. References

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