MOLDOVA EUREF CAMPAIGN 99

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1 Description of the Campaign

Five zero order points in Moldavia were occupied by GPS receiversduring five consecutive days from May 25 to May 29, 1999 (doy 145 to 149, GPS-week 1011). During the same time period three points in Ukraina were measured. This network of eight stations was processed at the Astronomical Institute of the University of Bern. Nine IGS stations located around the network were included into the precessing in order to connect the Moldavian and Ukrainian sites to the ITRF-97. Table 1 lists the station information including the receiver and antenna types. The new antenna designations according to the IGS nomenclature are used.

Abbr		Station	State	Receiver	Antenna
CHEL		Cheltuitorul	Moldavia	LEICA SR9500	LEIAT202-GP
GIUR		Giurgiulesti	"	LEICA SR9500	LEIAT202-GP
OTAC		Otaci	"	LEICA SR9500	LEIAT202-GP
PALA		Palanca	"	LEICA SR9500	LEIAT202-GP
UNGH		Ungheni	"	LEICA SR9500	LEIAT202-GP
MIKO		Mikolaev	Ukraina	TRIMBLE 4000SSE	TRM14532.0
SIME		Simeiz	"	TRIMBLE 4000SSE	TRM14532.0
UZHD		Uzgorod	"	TRIMBLE 4000SSE	TRM14532.0
ANKR	20805M002	Ankara	Turkey	ROGUE SNR-8000	AOAD/M_T
BOGO	12207M002	Borowa Gora	Poland	ASHTECH Z-XII3	ASH7009366A_M
GLSV	12356M001	Kijev	Ukraina	TRIMBLE 4000SSI	TRM29659.00
JOZE	12204M001	Jozefoslav	Poland	TRIMBLE 4000SSE	TRM14532.0
MATE	12734M008	Matera	Italy	ROGUE SNR-8100	AOAD/M_T
PENC	11206M006	Penc	Hungary	TRIMBLE 4000SSE	TRM14532.0
SOFI	11101M002	Sofia	Bulgaria	ROGUE SNR-8000	AOAD/M_T
ZECK	12351M001	Zelenchukskaya	Russia	ROGUE SNR-8000	AOAD/M_T
ZWEN	12330M001	Zwenigorod	Russia	ROGUE SNR-8000	AOAD/M_T

Table 1: List of stations, receivers, antennas.

The antenna heights of all the eight stations in the measured network were transformed to the antenna reference point (ARP). Antenna heights were in most cases different in the protocols as well as in the RINEX headers. The corresponding values are given in Table 2. All antenna heights were transformed to the ARP when reformatting the data from RINEX to Bernese format. For the LEIAT202-GP (LEICA AT202/302) the ARP refers to the top of the mounting pole (TOP), for the TRM14532.0 (Trimble 4000ST L1/L2 GEOD) it corresponds to the bottom of the preamplifier (BPA).

For the Simeiz site the antenna height value is unclear. A correction was applied during the transformation to RINEX. No correction was applied, however, when reformatting from RINEX to Bernese format (due to the unclear situation).

Antenna specific phase center variations and offsets were taken from IGS and applied. The satellites were tracked by all stations down to a minimum elevation of 10°.

Stat.	Protocol	RINEX	ARP
CHEL	0.139 m	0.2130 m	0.1740 m
GIUR	0.139	0.2150	0.1760
OTAC	0.139	0.2310	0.1920
PALA	0.139	0.2170	0.1780
UNGH	0.139	0.2180	0.1790
MIKO	0.159	0.1590	0.0960
SIME	1.360	1.2801	1.2801 *)
UZHD	0.144	0.1440	0.0850

Table 2: Antenna heights as given in the protocols, the RINEX headers, and the values used for the processing. *) For Simeiz the situation is not completely clear.

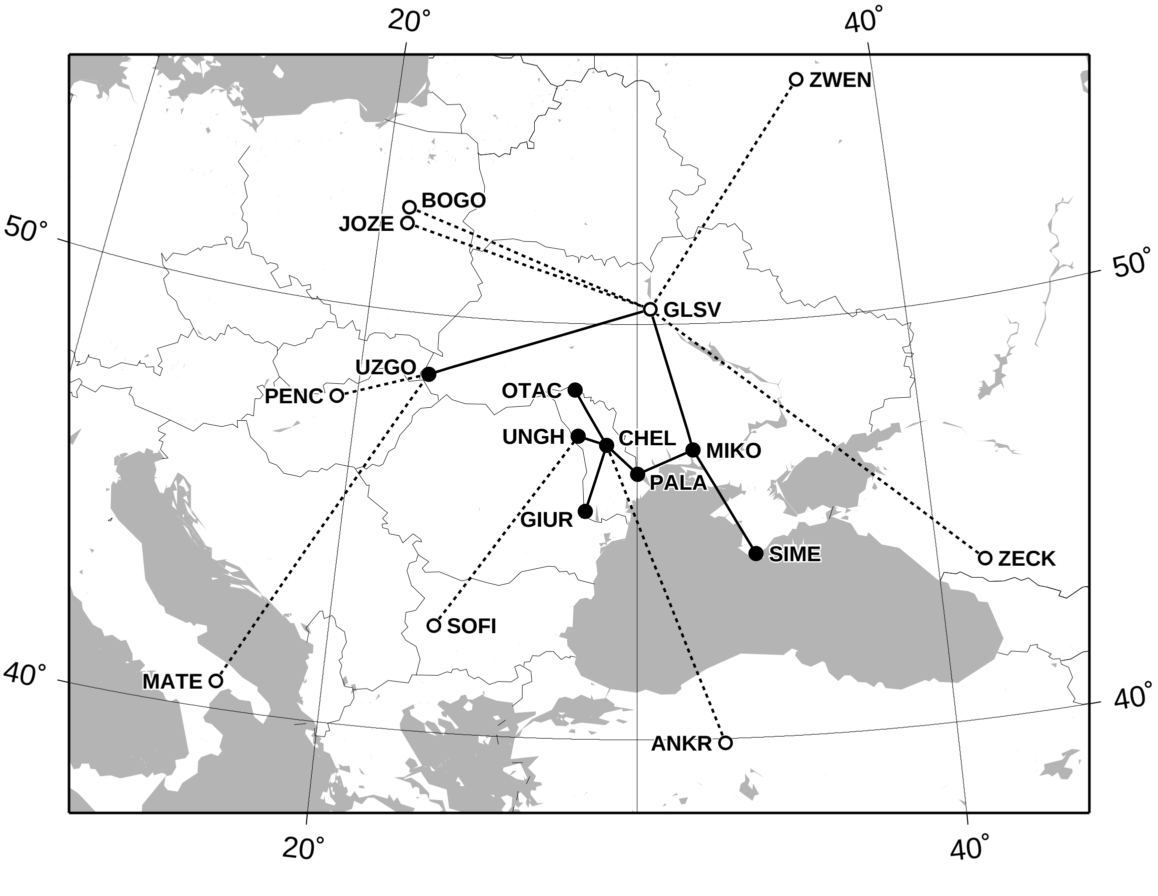

Figure 1: Location of Moldavian and Ukrainian sites (filled symbols) and IGS stations (circles) together with processed baselines (see Section 3.1). ANKR was not used in the final solution.

2 A Priori Information

2.1 Orbits and ITRF 97 Coordinates of IGS Stations

Orbits and Pole information was obtained from IGS. Precise orbits in SP3 format and a consistent file containing Earth Rotation Parameters (ERPs) were used from the IGS final solution. Observations of the IGS stations were downloaded in RINEX format from the responsible IGS resp. EUREF data centers.

ITRF 97 coordinates and velocities for the nine IGS stations were downloaded from IERS (ftp site `lareg.ensg.ign.fr`, directory `pub/itrf/itrf97`) in the form of a SINEX file (`ITRF97_GPS.SNX`). The coordinates and velocities were extracted from the file and the coordinates transformed to the epoch 1999 May 27.

In addition global ionosphere maps (GIMs) generated at the Center for Orbit Determination in Europe (CODE) [5] were used for ambiguity resolution.

2.2 A Priori Coordinates for Moldavian and Ukrainian Stations

A priori coordinates for all new stations in the network were determined by processing code observations. To get precise a priori coordinates of the stations for all subsequent steps, the coordinates of Cheltuitorul (CHEL), which is situated near the geographical center of the Moldavian network, were determined relative to the IGS station Borowa Gora (BOGO). The length of the baseline BOGO-CHEL is about 824 km.

Borowa Gora was selected for that purpose because of the long EUREF data history of this site and the good receiver performance during the measurement campaign (number of observations). A similarly good performance was archived by the IGS station GLSV (Kijev) the coordinates of which will, however, be used as a quality indicator by comparing the network coordinates with the ITRF 97 coordinates.

After establishing sufficiently precise coordinates for CHEL, the coordinates of all other stations in the Moldavian-Ukrainian network were determined by processing the baselines in the network and keeping the coordinates for CHEL fixed. The resulting coordinates of this test were within a few centimeters of the final coordinates.

3 Processing Strategy

The observations were processed with the Bernese GPS Software Version 4.2 [3]. The standard EUREF procedures were applied, i.e., a cutoff elevation angle of 15° was used, no elevation dependent weighting was invoked, and troposphere zenith delay parameters with loose absolute and relative constraints (5 m for both) estimation for every 2-hours. The

$\cos z$ mapping function was used for all processing runs. The ambiguities were resolved baseline by baseline and introduced as known into the subsequent and final solutions. A total of eight IGS stations located around the network were used to establish the tie to the ITRF 97 coordinates.

For comparison, several solutions were computed. In a first solution the reference station GLSV was left free to check the behavior of its coordinates relative to its ITRF 97 values (see Sections 4.3 and 4.4). In a second solution the station ANKR was included into the solution although the ITRF 97 coordinates (or the observations) for that station seem to have a problem (see Section 4.4) in order to see the effect on the coordinates of the network. To document the problem with the station ANKR a solution was generated with this station left free (see Section 4.5).

Finally all solutions (except the solution with ANKR left free) were repeated with a minimum elevation cutoff angle of $10°$ using elevation dependent weighting (see Section 4.6).

3.1 Formation of Baselines

The baselines connecting the stations were formed in a hierarchical way (see Fig. 1): The Moldavian points were connected to Cheltuitorul to get a 'starlike' network. The baselines between the Ukrainian sites were formed by minimizing the lengths and the two sub-networks were connected by one baseline between Palanca and Mikolaev.

The baseline lengths in the Moldavian sub-network range from 80 to 190 km, those in the Ukrainian network from 325 to 616 km. Table 3 summarizes the length of each baseline.

GIUR - CHEL :	186	km	PALA - MIKO :	172	km
OTAC - CHEL :	170		MIKO - SIME :	325	
PALA - CHEL :	113		MIKO - GLSV :	393	
UNGH - CHEL :	80		UZHD - GLSV :	616	

Table 3: Lengths of the baselines in the Moldavian and Ukrainian sub-networks.

The eight IGS stations listed in Table 1 were used together with the site GLSV which is embedded in the Ukrainian network. Baselines for the full network containing all 17 stations were formed by maximizing the single difference observations. The baselines formed for the individual sessions as well as their lengths are given in Table 4. All solutions were generated by taking into account correct correlations between all observations except when resolving the ambiguities (which was carried out baseline by baseline). The baselines connecting ANKR to the network were not used for generating the final solution.

3.2 Preprocessing

Preprocessing single difference data did not pose any problem. This step was carried out using automated procedures (program MAUPRP).

Baseline	Length (km)	145	146	147	148	149
ANKR - CHEL	857.329	x				
ANKR - GLSV	1176.132		x	x		
ANKR - PALA	757.007				x	
ANKR - UNGH	909.473					x
BOGO - GLSV	697.873	x	x	x	x	x
JOZE - CHEL	796.214		x		x	
JOZE - GLSV	687.787	x		x		x
MATE - UZHD	989.117	x	x	x	x	x
PENC - UNGH	652.016					x
PENC - UZHD	250.994	x	x	x	x	
SOFI - UNGH	635.419	x	x	x	x	x
ZECK - GLSV	1110.654	x	x	x	x	x
ZWEN - GLSV	726.320	x	x	x	x	x

Table 4: Lengths of the baselines connecting the Moldavian-Ukrainian network with IGS stations. Day of year on which the specified baseline was used.

It was observed that in the Moldavian-Ukrainian network for baselines between Ukrainian points the number of observations marked as bad as well as the number of cycle slips and ambiguities was higher than for the baselines between Moldavian points. Table 5 lists statistical information concerning the data quality for all the different baselines used and for all sessions.

Baseline	L(km)	# Cycle Slips	# Marked Areas	# Multiple Amb.
CHEL - GIUR	186	0 0 0 0 0	127 129 127 128 122	17 22 22 24 16
CHEL - OTAC	170	0 0 0 0 0	141 132 133 139 126	24 21 20 22 16
CHEL - PALA	113	0 0 0 0 0	147 136 142 147 125	24 23 23 23 16
CHEL - UNGH	80	0 0 0 0 0	127 126 126 135 123	30 23 15 23 16
GLSV - MIKO	393	1 1 2 0 1	323 253 269 297 291	40 32 35 38 32
GLSV - UZHD	616	7 2 3 4 5	369 362 355 340 356	36 37 36 32 31
MIKO - PALA	162	0 0 0 0 0	302 225 235 271 262	31 27 29 34 26
MIKO - SIME	325	4 0 3 2 1	232 199 190 226 227	28 33 25 33 24

Table 5: Number of cycle slips, removed observation blocks, and multiple ambiguities (all ambiguities except the initial) for each session and baseline.

3.3 Ambiguity Resolution

Ambiguities were resolved using the QIF (Quasi Ionosphere Free) strategy [2]. Each baseline was processed independently. Global ionosphere maps from CODE and the Saastamoinen model were used as a priori ionosphere and troposphere model. Stochastic ionosphere parameters and twelve troposphere zenith delay parameters per day and station were estimated. Two independent solutions were generated, one with an elevation cutoff angle of 15° without elevation dependent weighting, the other with a cutoff angle of 10° and elevation dependent weighting ($\cos z^2$) of the observations.

Table 6 gives the percentage of ambiguities resolved to integer numbers for each baseline and session day for the Moldavian and Ukrainian networks. On the average 89% of the ambiguities could be fixed for the baselines between Moldavian stations. For the baselines between Ukrainian station the corresponding value is 82%. The average RMS for both sub-networks is 2.7 mm, the maximum RMS is 3.1 mm.

Baseline	145	146	147	148	149	
CHEL - GIUR	90.7	93.5	87.2	87.8	97.6	%
CHEL - OTAC	81.6	88.9	86.7	85.1	95.2	%
CHEL - PALA	85.7	95.7	89.4	97.9	100.0	%
CHEL - UNGH	70.4	80.9	92.7	85.4	92.9	%
GLSV - MIKO	79.7	83.0	76.4	80.7	84.9	%
GLSV - UZHD	81.0	91.7	89.7	92.9	92.5	%
MIKO - PALA	81.1	83.0	76.0	73.6	77.1	%
MIKO - SIME	83.7	80.9	73.5	71.2	78.3	%

Table 6: Percentage of fixed ambiguities for each session and baseline for the Moldavian and the Ukrainian sub-networks.

Table 7 documents the success of ambiguity fixing for the baselines connecting IGS stations to the Moldavian-Ukrainian network. The mean percentage for ambiguity resolution is 85%. However, exceptionally a value as low as 52% was observed for the baseline Ankara-Ungheni for session 149. The mean RMS of the parameter estimation runs on these baselines is 2.1 mm with a maximum value of 2.6 mm.

Station	145	146	147	148	149	
ANKR	69.8	83.7	79.2	70.2	52.2	%
BOGO	96.1	94.4	95.9	96.1	96.2	%
JOZE	86.4	83.6	90.0	87.3	88.3	%
MATE	89.1	83.6	81.8	81.8	77.3	%
PENC	88.1	83.9	90.6	94.3	95.1	%
SOFI	88.5	82.2	80.4	75.6	77.6	%
ZECK	78.0	77.4	78.4	82.6	91.3	%
ZWEN	84.2	87.9	85.5	96.1	83.9	%

Table 7: Percentage of fixed ambiguities for each session and baseline connecting an IGS station to the Moldavian-Ukrainian network (refer to Table 4 to get the second station for the baselines for each day).

3.4 Repeatability Studies and Data Quality Checks

In order to check the data quality for the stations in the full network a free solution was computed for each day. For the IGS stations the determined coordinates were combined to one set of coordinates which were then compared to the ITRF 97 values after a Helmert transformation. For the remaining stations the repeatability was studied.

Using the ionosphere-free linear combination and correct correlations between all double difference observations and introducing the previously fixed ambiguities, solutions were computed for the entire network for each day. Cheltuitorul was kept fixed on the a priori coordinates generated as described in section 2.2. As usual, an elevation cutoff angle of 15° was used and no elevation-dependent weighting was applied. The Saastamoinen model was used as a priori model as well as the $\cos z$ mapping-function. Twelve troposphere zenith delay parameters were estimated for each station and day. The a posteriori RMS of unit weight of the solutions varies between 1.2 and 1.3 (corresponding to a sigma of 2.4 to 2.6 mm of the one-way L1 phase observable).

Table 8 gives the residuals of the coordinates from the free solution to the ITRF 97 values after a 7-parameter Helmert transformation with station ANKR included (left) and excluded (right). The RMS of the transformation with Ankara included is 10.5 mm and with Ankara excluded 36 mm. Obviously the ANKR site has a problem in both, the horizontal and vertical positions. The nature of this problem is unclear and is subject for further analyses (see Section 4.5). In view of this situation we decided to exclude the station for the final solution.

Station		Residuals (mm)			Residuals (mm)			
		N	E	U	N	E	U	
ANKR	20805M002	-8.3	3.7	33.3	-12.0	5.9	56.6	*
BOGO	12207M002	0.5	-0.5	3.6	0.5	-0.8	-2.3	
GLSV	12356M001	1.8	2.6	-7.6	1.9	3.1	-3.9	
JOZE	12204M001	-0.4	0.1	-1.9	-0.3	-0.3	-7.2	
MATE	12734M008	2.6	2.0	-7.3	-0.4	1.6	2.3	
PENC	11206M006	1.9	0.5	7.6	1.1	-0.1	8.1	
SOFI	11101M002	-0.7	-1.2	-14.9	-2.3	-1.3	-2.7	
ZECK	12351M001	2.1	-4.9	-21.9	-0.5	-1.9	-0.6	
ZWEN	12330M001	0.6	-2.4	9.2	0.1	-0.4	6.3	
RMS / Component		3.3	2.6	16.1	1.3	1.6	5.2	

Table 8: Residuals after a seven-parameter Helmert transformation between the computed coordinates of the IGS stations in the network and their ITRF 97 values with (left) and without ANKR included (right).

Table 9 shows the RMS and the range of the repeatability of the coordinates for each of stations in the Moldavian-Ukrainian network in the three components. For all stations, except Simeiz, the coordinates vary within one centimeter in horizontal position. For most stations the variations are around one centimeter even for the height component. For Simeiz the variation in horizontal position exceeds 1 cm and reaches more than 2 cm in elevation. It has to be mentioned, however, that for stations far from the center of the network (such as Simeiz or Uzgorod) larger variations of the coordinates have to be expected in free network solutions when a station near the center of the network was fixed. The repeatability study, therefore, confirms the good quality of the observational data.

Station	RMS (mm)			Range (mm)		
	N	E	U	N	E	U
GIUR	1.8	1.3	2.8	4.9	3.1	6.7
OTAC	2.2	1.4	3.6	5.4	2.9	8.7
PALA	2.4	2.5	4.9	5.7	6.1	12.2
UNGH	1.3	2.5	2.6	3.5	6.0	6.1
GLSV	2.7	2.0	5.6	7.0	4.4	14.9
MIKO	1.9	2.5	2.8	5.0	5.9	7.7
SIME	5.0	1.9	9.0	10.4	4.1	23.2
UZHD	2.0	1.7	6.7	4.8	4.3	18.6

Table 9: RMS and range of the repeatability for the station coordinates in the Moldavian-Ukrainian network in the three components North/East/Up in millimeters. The station Cheltuitorul was kept fixed.

4 Results

4.1 Network Solutions

To get the final coordinates in the ITRF 97 coordinate system the network consisting of all Moldavian and Ukrainian sites was processed together with the eight IGS stations listed in Table 1 (incl. GLSV but excl. ANKR) which were constrained to 0.1 mm to their ITRF 97 coordinates for the measurement epoch. Correct correlations between the baselines were taken into account for each session and the individual solutions for each day were combined by stacking the corresponding normal equation systems.

The fixed ambiguities were assumed known from the previous steps (Section 3.3) and the ionosphere free linear combination L3 was processed. Following the EUREF standards the elevation cut-off angle was set to 15° and no elevation dependent weighting was applied. Saastamoinen was used as a priori troposphere model together with the $\cos z$ mapping function, and 12 troposphere zenith delay parameters were estimated per station and day.

4.2 Coordinate Repeatability

Each session was processed independently. The individual solutions were combined on the normal equation level (program ADDNEQ). The RMS of the combination is 2.6 mm. In Table 10 the geocentric coordinates of the Moldavian and the Ukrainian stations are given in the ITRF 97 reference frame. The coordinates transformed to ETRS-89 will be presented in Section 4.7.

The coordinates in Table 10 are given together with their formal errors (RMS errors a posteriori) as given by the parameter estimation process. An impression of coordinate precision may also be obtained from the repeatability values of the coordinates for the individual days given in Table 11. Not surprisingly, the repeatability is improved in

Station	X-Coordinate (m)	RMS (mm)	Y-Coordinate (m)	RMS (mm)	Z-Coordinate (m)	RMS (mm)
Cheltuitorul	3807536.6591	0.2	2104493.8441	0.1	4648842.6344	0.3
Giurgiulesti	3946301.4587	0.3	2117866.2689	0.2	4526149.2785	0.3
Otaci	3754452.2200	0.2	1976193.3352	0.1	4746725.2643	0.3
Palanca	3814919.3964	0.2	2204326.0541	0.2	4596482.3673	0.3
Ungheni	3829764.9737	0.3	2029340.3441	0.1	4663860.3279	0.3
Mikolaev	3698609.4925	0.3	2308760.8632	0.2	4639662.0969	0.3
Simeiz	3783746.4164	0.3	2551362.6811	0.2	4441445.1057	0.3
Uzgorod	3908590.5029	0.3	1615205.7926	0.1	4758733.1667	0.3

Table 10: Geocentric coordinates in ITRF 97 for the Moldavian and Ukrainian stations with eight IGS stations constrained.

the horizontal components compared to the solution in Section 3.4 where the station Cheltuitorul was fixed and no IGS stations were constrained. The repeatability in height, on the other hand, is somewhat reduced.

Station	C	RMS	145	146	147	148	149	
CHEL	N	2.0	2.3	-2.3	1.9	-1.3	-0.6	mm
	E	1.8	-2.5	0.3	1.0	-1.1	2.3	
	U	4.9	0.3	6.2	-5.3	3.3	-4.5	
GIUR	N	1.1	-0.5	-1.0	1.6	0.7	-0.7	mm
	E	1.6	-2.4	0.2	2.0	-0.1	0.2	
	U	3.4	2.6	3.2	-1.8	1.0	-4.9	
OTAC	N	1.4	-1.6	-1.0	2.0	-0.2	0.7	mm
	E	1.6	-2.1	-1.0	2.0	0.3	0.9	
	U	3.6	-4.2	4.7	-2.1	2.3	-0.7	
PALA	N	0.9	-1.3	-0.4	0.9	0.7	0.1	mm
	E	1.2	0.5	0.7	-2.1	0.5	0.4	
	U	5.1	-1.9	8.8	-0.6	-4.2	-2.1	
UNGH	N	0.9	0.3	-0.9	1.4	-0.7	-0.1	mm
	E	1.8	0.5	-2.5	2.4	-0.5	0.0	
	U	2.8	-0.1	4.7	-2.4	-0.0	-2.1	
MIKO	N	0.8	-0.7	-0.3	1.4	-0.2	-0.2	mm
	E	0.9	1.2	0.5	-0.9	-0.9	0.1	
	U	4.5	0.7	6.8	-1.5	-0.5	-5.5	
SIME	N	4.5	-3.5	2.3	5.5	1.3	-5.6	mm
	E	2.0	-0.4	-2.4	-0.3	-0.1	3.2	
	U	10.9	13.3	7.4	-15.1	-3.5	-2.1	
UZHD	N	1.3	0.2	0.4	1.6	-0.2	-2.0	mm
	E	1.7	-1.7	-1.0	-1.0	1.6	2.1	
	U	5.5	-6.6	4.8	5.1	1.6	-4.9	

Table 11: Repeatability for the station coordinates in the Moldavian-Ukrainian network in the three components North/East/Up in millimeters. Full network solution with eight IGS stations constrained.

The RMS for the repeatability in the horizontal components for all stations except Simeiz is below 2 mm and the range of variability is below 5 mm. In the height component the RMS reaches 5.5 mm. Simeiz is an exception: The repeatability in the North and the Up components is at least a factor of two worse than for all other stations. The reason for this reduced quality of the solution is unclear. Nevertheless: For all stations, including Simeiz, the accuracy of the horizontal components is expected to be well below the centimeter.

4.3 Repeatability and Coordinates of GLSV

For comparison and quality control an additional run with identical settings of the parameters was run except that the coordinates of the IGS station GLSV (Kijev) were not constrained to their ITRF 97 values. The offset of the estimated coordinate values to the ITRF 97 values as well as the repeatability of the coordinates indicate the quality of the other stations in the Moldavian and Ukrainian network.

Table 12 gives the offsets of the coordinates with respect to the ITRF 97 values. They are all well below one centimeter. Table 13 shows the repeatability of the coordinate values for GLSV for the five sessions. The values are comparable to the repeatabilities of other stations in the network (see Table 11).

GLSV 12356M001	X	4.5	mm	Height	0.8	mm
	Y	-2.7		Latitude	-2.6	
	Z	-1.0		Longitude	-4.6	

Table 12: Offsets of the IGS station GLSV (Kijev) with respect to the ITRF 97 coordinate values, if the station is left free.

Station	C	RMS	145	146	147	148	149	
GLSV 12356M001	N	1.9	-2.7	-0.2	2.6	0.1	0.1	mm
	E	0.8	-0.1	-1.1	-0.2	1.0	0.3	
	U	3.6	5.2	-1.7	1.3	-0.1	-4.6	

Table 13: RMS of repeatability for the IGS station GLSV if the station is left free.

4.4 Comparison Between Different Solutions

A total of three solutions was generated with an elevation cutoff angle of 15° and not using elevation dependent weighting (according to EUREF standards):

A) The final solution presented in Section 4.2 where eight IGS stations, including GLSV, were constrained to their ITRF 97 coordinates in order to determine the coordinates of the Moldavian and Ukrainian stations. ANKR was not used.

B) A solution where the coordinates of the Ukrainian IGS station GLSV were determined, too, and only the remaining seven IGS stations were constrained to their ITRF 97 coordinates (see Section 4.3). ANKR was not used.

C) A solution where nine IGS stations, including ANKR, were used and constrained to their ITRF 97 coordinates (disregarding problems with the ITRF 97 coordinates of the ANKR site (see Section 4.5)).

The solutions were compared through a 3-parameter Helmert transformation between the coordinates of the 8 Moldavian and Ukrainian stations (except GLSV).

Table 14 lists the translation parameters between solutions A) and B) (left) and solutions A) and C) (right). As expected the solutions A) and B) are in essence identical. The RMS of the transformation is below 0.1 mm. The offset between solutions A) and C), too, is below below 4 mm, and the residuals are around 0.1 mm in the horizontal components, up to 1.3 mm in height component. Obviously the coordinates of the stations in the Moldavian and Ukrainian network are affected by the problems with the ITRF 97 coordinates of ANKR by only a few millimeters.

Parameters:	A) $\rightarrow$ B)	
Translation in X :	0.3 $\pm$ 0.0	mm
Translation in Y :	0.6 $\pm$ 0.0	mm
Translation in Z :	-0.3 $\pm$ 0.0	mm

Parameters:	A) $\rightarrow$ C)	
Translation in X :	0.5 $\pm$ 0.1	mm
Translation in Y :	-0.2 $\pm$ 0.1	mm
Translation in Z :	-3.8 $\pm$ 0.1	mm

Table 14: Translation parameters of a three parameter Helmert transformation between the solutions A) and B), i.e. with and without constraining GLSV (left), and solutions A) and C), i.e. without and with ANKR used and constrained.

4.5 Coordinates of ANKR

To document the problem with the ITRF 97 coordinates of ANKR an additional solution was produced with the station included but left free while all other eight IGS stations were constrained to their ITRF 97 coordinates. Table 15 shows the offset of the determined coordinates with respect to the ITRF 97 values and Table 16 lists the repeatability of the coordinates for all session days. According to Table 15 the height of the station seems to be in error by about 6 cm. The repeatability does not indicate a problem with the observations. A first examination indicate a problem with the ITRF 97 velocities of the station. The problems with ANKR have to be further studied.

ANKR 20805M002	X	-39.4	mm	Height	-58.2	mm
	Y	-28.0		Latitude	5.7	
	Z	-33.0		Longitude	-2.2	

Table 15: Offsets of the IGS station ANKR with respect to the ITRF 97 coordinate values, if the station is left free.

Station	C	RMS	145	146	147	148	149	
ANKR 20805M002	N	1.0	-0.3	-1.3	0.2	-1.3	-0.5	mm
	E	1.1	-0.4	1.0	1.2	-1.4	0.4	
	U	4.3	-7.3	0.9	-0.1	3.4	-2.5	

Table 16: RMS of repeatability for the IGS station ANKR if the station is left free.

4.6 Influence of Elevation Cutoff Angle and Elevation Dependent Weighting

In order to study the influence of a lower minimum elevation angle and elevation dependent weighting the same three solutions as discussed in Section 4.4 were computed with the elevation cutoff angle set to 10° and elevation dependent weighting ($\cos z^2$) switched on. No a priori troposphere model was introduced and the dry Neill mapping function was used. All other options remained unchanged.

The solutions are labeled A10, B10 and C10, the corresponding solutions from Section 4.4 which were computed with an elevation cutoff angle of 15° without elevation dependent weighting are called A15, B15, and C15. The solution A15 is the reference solution providing the final coordinates.

Parameters:	A15 → A10	
Translation in X :	-0.9 ± 1.9	mm
Translation in Y :	0.1 ± 1.9	mm
Translation in Z :	5.9 ± 1.9	mm

Table 17: Translation parameters of a three parameter Helmert transformation between the solutions A) (all eight IGS stations used and constrained) with elevation cutoff angle 15° and 10°.

Station	Residuals (mm)		
	N	E	U
Cheltuitorul	2.5	1.0	-5.3
Giurgiulesti	-2.1	-0.5	8.9
Otaci	0.2	-0.9	6.5
Palanca	2.1	1.0	13.5
Ungheni	0.2	-1.8	3.6
Mikolaev	-0.9	1.5	-6.7
Simeiz	-2.4	0.7	-11.2
Uzgorod	0.4	-1.0	-9.3
RMS / Component	1.8	1.2	9.3

Table 18: Residuals after a three-parameter Helmert transformation between the solutions A) with cutoff angle 15° and 10°.

The translation parameters of a 3-parameter Helmert transformation between the two solutions A15 and A10 are given in Table 17. The RMS of the transformation is 5.5 mm. The difference between the two solutions is 6 mm. A 7-parameter Helmert transformation shows no significant rotation nor scale change. In Table 18 we may inspect the residuals after the transformation. Only in the height component significant differences may be observed (which are due to the different processing strategies).

Table 19 gives the offset of the IGS station GLSV with respect to its ITRF 97 coordinates for the solution with an elevation cutoff angle of 10° and elevation dependent weighting. Compared to the solution with a cutoff of 15° without weighting (see Table 12) the absolute value of the offset is slightly increased from 5.3 mm to 7.4 mm. The main effect is a change in the vertical position by 3.8 mm.

GLSV 12356M001	X	3.5	mm	Height	-3.0	mm
	Y	-4.9		Latitude	-3.2	
	Z	-4.4		Longitude	-5.9	

Table 19: Offsets of the IGS station GLSV (Kijev) with respect to the ITRF 97 coordinate values using an elevation cutoff angle of 10° and elevation dependent weighting, if the station is left free.

Station	C	A15	B15	C15	A10	B10	C10	Range	RMS A15	A10	
CHEL	N	1.0	0.7	0.5	-0.6	-1.0	-1.6	2.6	2.0	1.9	mm
	E	0.8	0.2	0.9	-0.8	-1.6	-0.3	2.5	1.9	1.4	
	U	-0.9	-0.5	3.2	-1.5	-1.8	2.0	5.0	5.0	4.6	
GIUR	N	-0.8	-1.2	-1.3	1.7	1.4	0.9	3.0	1.1	1.2	mm
	E	0.2	-0.4	0.4	-0.0	-0.9	0.5	1.4	1.6	1.2	
	U	5.2	5.6	9.3	-9.6	-9.9	-6.0	19.2	3.4	4.0	
OTAC	N	-0.1	-0.5	-0.7	0.9	0.5	0.0	1.6	1.4	1.1	mm
	E	-0.0	-0.6	0.2	0.2	-0.5	0.7	1.3	1.6	0.9	
	U	4.3	4.6	8.1	-8.2	-8.4	-4.8	16.5	3.7	3.9	
PALA	N	0.9	0.6	0.4	-0.5	-0.9	-1.4	2.3	1.0	1.1	mm
	E	0.7	-0.0	0.8	-0.6	-1.4	-0.1	2.2	1.2	1.1	
	U	7.2	7.5	11.3	-12.2	-12.5	-8.6	23.8	5.2	4.4	
UNGH	N	0.0	-0.3	-0.5	0.7	0.3	-0.1	1.2	0.9	0.9	mm
	E	-0.3	-1.0	-0.2	0.8	-0.0	1.2	2.2	1.8	1.3	
	U	3.0	3.3	6.9	-6.5	-6.8	-3.0	13.7	3.0	3.7	
MIKO	N	-0.5	-0.8	-1.0	1.3	1.0	0.5	2.3	0.8	0.6	mm
	E	1.0	0.3	1.1	-1.0	-1.8	-0.6	2.9	1.0	1.0	
	U	-1.4	-1.1	2.5	-0.7	-1.0	2.9	4.3	4.5	3.7	
SIME	N	-1.3	-1.5	-1.8	2.3	2.0	1.5	4.1	4.5	4.1	mm
	E	0.7	0.0	0.9	-0.6	-1.4	-0.4	2.3	2.0	2.0	
	U	-3.4	-3.1	0.8	1.7	1.3	5.9	9.3	10.9	5.9	
UZHD	N	0.1	-0.3	-0.4	0.6	0.1	-0.3	1.0	1.3	1.2	mm
	E	-0.3	-0.8	0.1	0.4	-0.3	1.1	1.9	1.7	1.5	
	U	-2.1	-1.8	0.3	1.3	1.0	3.5	5.6	5.7	5.5	

Table 20: Comparison between the different solutions A), B) and C) for elevation cutoff angle of 15° (no weighting) and 10° (with weighting). Column 'Range' lists the range of the values in the previous columns, columns 'RMS A15' and 'A10' give the repeatability RMS for the two solutions A15 and A10.

The last two columns in Table 20 give the repeatability of the station coordinates in the three components for the two solutions A15 and A10. As is well known [4] the lowering of the elevation cutoff angle together with an elevation dependent weighting reduces the scattering in the height component as may be seen for most of the stations. Using an elevation cutoff angle of $5°$ would further improve the results but antenna phase variations are not calibrated for these low elevations for most antenna types.

Table 20 gives a comparison of the coordinates for all Moldavian and Ukrainian stations for the six solutions computed. The first six columns show the offsets of the coordinates with respect to the average solution. The first column corresponds to the solution presented in Section 4.2 providing the final coordinates. The column 'Range' gives the range of the coordinates for all solutions. The horizontal components agree for all solutions to within 4 mm, while the variations of the height component may reach a level of 2.4 cm between the individual solutions.

From the comparison of the different solutions and the comparison of the coordinates of GLSV to its ITRF 97 values (Tables 12 and 19) we conclude that the coordinates of the Moldavian and Ukrainian stations given in Table 10 are accurate to within a few millimeters.

4.7 The Coordinates in ETRS-89

We determined the coordinates of the stations in Moldavia and Ukraina by constraining IGS stations to their ITRF 97 coordinates and using satellite orbits and ERP information in the same system. We therefore get the station coordinates in the system ITRF 97 for the epoch May 27, 1999. As a final step we transform these coordinates into the ETRF 97 Reference Frame of the European Reference System 89 (ETRS-89). The procedure used is given in [1].

Table 21 gives the final coordinates of the measured stations in the ETRS-89 system for the epoch May 27, 1999.

Station	X-Coordinate (m)	RMS (mm)	Y-Coordinate (m)	RMS (mm)	Z-Coordinate (m)	RMS (mm)
Cheltuitorul	3807536.8863	0.2	2104493.7134	0.1	4648842.5106	0.3
Giurgiulesti	3946301.6832	0.3	2117866.1349	0.2	4526149.1514	0.3
Otaci	3754452.4455	0.2	1976193.2053	0.1	4746725.1406	0.3
Palanca	3814919.6255	0.2	2204325.9237	0.2	4596482.2443	0.3
Ungheni	3829765.1988	0.3	2029340.2125	0.1	4663860.2028	0.3
Mikolaev	3698609.7262	0.3	2308760.7362	0.2	4639661.9779	0.3
Simeiz	3783746.6530	0.3	2551362.5533	0.2	4441444.9870	0.3
Uzgorod	3908590.7168	0.3	1615205.6575	0.1	4758733.0354	0.3

Table 21: Geocentric coordinates in the ETRS-89 for the epoch May 27, 1999.

5 Conclusions

The Moldova EUREF Campaign 99 was successfully processed using Bernese GPS Software Version 4.2. For the final run eight IGS stations located around moldavia were constrained to their ITRF 97 coordinates. The official IGS orbits and IGS ERP series were used. The other options of the solution strategy may be summarized as follows:

- The same baselines were used within the Moldavian-Ukrainian network for all sessions, for connecting the IGS stations to the network baselines with maximum number of observations were selected.
- On the average 89% of the ambiguities in the Moldavian-Ukrainian network and 85% in the large network including the IGS stations were resolved to the (hopefully) correct integer values.
- Correct inter-baseline correlations have been taken into account.
- An elevation cutoff angle of 15° without elevation dependent weighting was used.
- 12 troposphere parameters per day and station have been estimated.
- The five daily solutions were stacked on the normal equation level to give the final five day solution.

The internal consistency of the coordinates for all stations (except Simeiz) is 1–2 mm in the horizontal components and 3–6 mm in the vertical component (repeatability RMS, see Table 11). For Simeiz the repeatability values are slightly worse. The coordinate values for different solutions vary by 1–4 mm for the horizontal and 4–25 mm for the vertical component. The comparatively big values in the vertical component result if the elevation cutoff angle is lowered to 10° and elevation dependent weighting is enabled.

The study revealed problems with the ITRF 97 coordinates of the station ANKR. The station was not used for the generation of the final coordinates. It was shown, however, that the use of ANKR would change the coordinates of the stations in Moldavia and Ukraina by a few millimeters only.

The resulting coordinates in ITRF 97 epoch May 27, 1999, have been transformed into ETRF 97 using the standard transformation parameters [1]; the final coordinates are given in Table 21.

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