The Moldavia EUREF Campaign 99

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1 Introduction

The Moldavia Campaign 1999 was part of an economic cooperation project between Switzerland and the Republic of Moldavia, financed by the Swiss State Secretariat for Economic Affairs. Topics of the project were: Supply of geodetic and photogrammetric equipment, technical assistance, on-site education and training of personnel.

The companies ITV Geomatik AG/Swissphoto Vermessung AG were commissioned to realize the project in the summer of 1997. The equipment was supplied by Leica, Switzerland. Locally the project was run by the National Agency for Cadastre, Land Resources and Geodesy of the Republic of Moldavia.

Within the project two GPS networks were observed: A zero order network, the processing of which is the subject of the presented report, and a first order densification network of about 70 stations.

The zero-order network was to be embedded into the European Reference Network. Therefore the project leaders contacted EUREF and presented their intentions at the TWG meeting in Paris in October 1998. They also asked EUREF to support or even perform the processing of the zero-order network. The Astronomical Institute of the University of Berne agreed to compute this network according to the EUREF guidelines using the Bernese GPS Software and to present the results at an EUREF symposium to be accepted as an official EUREF extension.

2 Description of the Campaign

Five zero order points in Moldavia were occupied by GPS receivers during five consecutive days from May 25 to May 29, 1999 (doy 145 to 149, GPS-week 1011). were acquired during 24 hours each day. During the same time period three points in Ukraine 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 processing 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.

Tab. 1: List of stations, receivers, and antennas.

Abbreviation		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	Ukraine	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	Ukraine	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

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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).

Tab. 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.

Station	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

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. All stations tracked the satellites down to a minimum elevation of 10§.

3 A Priori Information

Orbits and Pole information was obtained from IGS. Precise orbits in SP3 format in ITRF 96 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 fiducial 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 May 27, 1999. The coordinates used for the reference stations are given in Table 3.

In addition global ionosphere maps (GIMs) generated at the Center for Orbit Determination in Europe (CODE) were used for ambiguity resolution (SCHAER, 1999). A priori coordinates for all new stations in the network were generated by processing code observations.

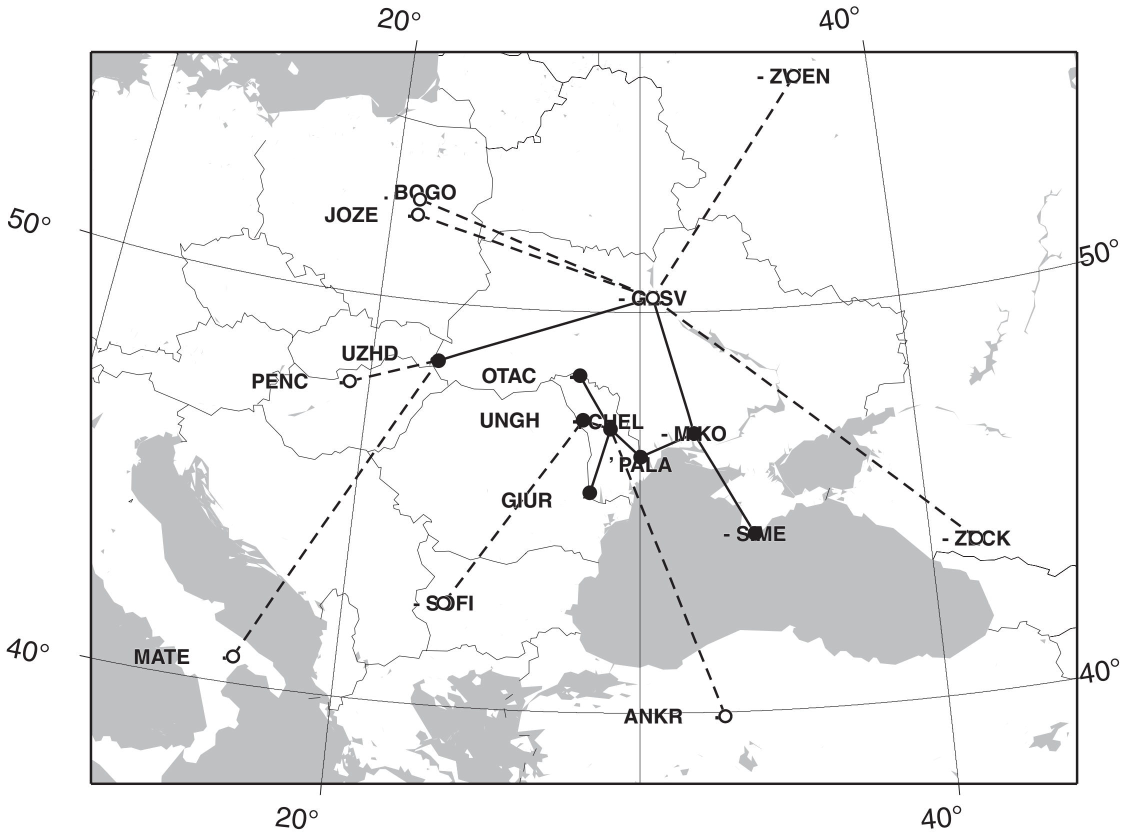

Fig. 1: Location of Moldavian and Ukrainian sites (filled symbols) and IGS stations (circles) together with processed baselines. ANKR was not used in the final solution.

Tab. 3: Geocentric coordinates of the reference stations in the ITRF 97 for the epoch May 27, 99

Station		X–Coordinate	Y–Coordinate	Z–Coordinate
MATE	12734M008	4641949.6771 m	1393045.3248 m	4133287.3621 m
PENC	11206M006	4052449.6009	1417681.0389	4701407.0462
JOZE	12204M001	3664940.2809	1409153.7852	5009571.3216
BOGO	12207M002	3633739.0873	1397434.0499	5035353.4013
ZWEN	12330M001	2886325.5012	2155998.4378	5245816.1464
ZECK	12351M001	3451174.8393	3060335.3602	4391955.5699
GLSV	12356M001	3512889.0770	2068979.8085	4888903.1450
SOFI	11101M002	4319372.1989	1868687.6840	4292063.8671
ANKR	20805M002	4121948.6093	2652187.9767	4069023.7072

4 Processing Strategy

The observations were processed with the Bernese GPS Software Version 4.2 (Rothacher et al, 1996). 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) were estimated for every 2–hours. The cos *z*-mapping function was used for all processing runs for the estimated corrections to the Saastamoinen a priori troposphere model. The ambiguities were resolved baseline by baseline and introduced as known into the subsequent and final solutions. A total of eight IGS fiducial stations located around the network were used to establish the tie to the ITRF 97 coordinates.

4.1 Ambiguity Resolution

The baseline lengths in the Moldavian sub–network range from 80 to 190 km, those in the Ukrainian network from 325 to 616 km. The baselines connecting IGS fiducial stations to sites in the Moldavian–Ukrainian sub–network range from 250 km to 1200 km.

Ambiguities were resolved using the QIF (Quasi Ionosphere Free) strategy (Mervart, 1994). Each baseline was processed independently. Global ionosphere maps from CODE were used as a priori ionosphere model, stochastic ionosphere parameters and twelve troposphere zenith delay parameters per day and station were estimated.

4.2 Final Network Solution

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. 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. In Table 5 the geocentric coordinates of the Moldavian and the Ukrainian sites are given in the ITRF 97 reference frame together with their formal errors (RMS errors a posteriori).

Tab. 4: Percentage of fixed ambiguities for each session day and baseline for the Moldavian and the Ukrainian sub–networks.

Baseline	1	2	3	4	5	
CHEL – GIUR	91	94	87	88	98	%
CHEL – OTAC	82	89	87	85	95	%
CHEL – PALA	86	96	89	98	100	%
CHEL – UNGH	70	81	93	85	93	%
GLSV – MIKO	80	83	76	81	85	%
GLSV – UZHD	81	92	90	93	92	%
MIKO – PALA	81	83	76	74	77	%
MIKO – SIME	84	81	74	71	78	%

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%. Individual values range from 70% to 100%. Table 4 gives the percentage for all session days.

The mean percentage for ambiguity resolution for the baselines connecting IGS stations to the Moldavian–Ukrainian network is 85%. However, exceptionally a value as low as 52% was observed for the baseline Ankara–Ungheni for one session day.

5 Quality Checks

5.1 Daily Repeatability

Using the ionosphere–free linear combination and correct correlations between all double difference observations and introducing the previously fixed ambiguities, free network solutions were computed for the entire network for each day. The central station Cheltuitorul was kept fixed on its a priori coordinates. 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).

For all stations, except Simeiz, the coordinates vary within one centimeter in horizontal position. The RMS in the North and East components is between 1 and 5 mm. For most stations the variations are around one centimeter even for the height component. The RMS in the height component is between 3 and 9 mm. 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 is fixed. The repeatability study, therefore, confirms the good quality of the observational data.

Constrained network solutions generated for each day with the fiducial stations constrained to 0.1 mm to their ITRF 97 values gives similar values for the repeatability of the Moldavian and Ukrainian stations. Values may be found in Table 6. 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. For all stations, including Simeiz, the accuracy of the horizontal components is expected to be well below the centimeter.

Tab. 5: Geocentric coordinates in the ITRF 97 reference frame for the Moldavian and Ukrainian stations.

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

Tab. 6: Repeatability for the station coordinates in the Moldavian–Ukrainian network in the three components North/East/Up in millimeters. Constrained network solution with eight IGS stations constrained to 0.1 mm to their ITRF 97 coordinates.

Station		RMS	1	2	3	4	5
CHEL	N	2	2.3	–2.3	1.9	–1.3	–0.6
	E	1.8	–2.5	0.3	1	–1.1	2.3
	U	4.9	0.3	6.2	–5.3	3.3	–4.5
GIUR	N	1.1	–0.5	–1	1.6	0.7	–0.7
	E	1.6	–2.4	0.2	2	–0.1	0.2
	U	3.4	2.6	3.2	–1.8	1	–4.9
OTAC	N	1.4	–1.6	–1	2	–0.2	0.7
	E	1.6	–2.1	–1	2	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
	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
	E	1.8	0.5	–2.5	2.4	–0.5	0
	U	2.8	–0.1	4.7	–2.4	0	–2.1
MIKO	N	0.8	–0.7	–0.3	1.4	–0.2	–0.2
	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
	E	2	–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
	E	1.7	–1.7	–1	–1	1.6	2.1
	U	5.5	–6.6	4.8	5.1	1.6	–4.9

5.2 Position Tests: Free Network Solution

The coordinates of the reference stations, determined by a free network solution with Cheltuitorul fixed, were compared with their ITRF 97 coordinates after a seven–parameter Helmert transformation. Table 7 gives the residuals of the coordinates with station ANKR included (left) and excluded (right).

With ANKR excluded the RMS after the Helmert transformation is 1.5 mm the horizontal components and 5 mm in the height component. Maximum residuals are 3 mm in the horizontal and 8 mm in the height components.

5.3 Coordinates of ANKR

The Helmert transformation indicates a problem with the coordinates of the station ANKR. To investigate the problem an additional solution was computed with the station included but left free while all other eight IGS stations were constrained to their ITRF 97 coordinates. Table 8 shows the offset of the determined coordinates with respect to the ITRF 97 values showing an offset in the height component of about 6 cm.

The repeatability, on the other hand, does not indicate a problem with the observations. A first examination indicates a problem with the ITRF 97 velocities of the station. The problems with ANKR have to be studied further.

The effect of including or excluding the station ANKR on the coordinates of the Moldavian and Ukrainian sites is a shift in the Z–direction of 4 mm.

Tab. 7: Residuals after a 7–parameter Helmert transformation between the coordinates of the reference stations computed in a free network solution and their ITRF 97 values with (left) and without ANKR included (right).

Station	Residuals			Residuals		
	N	E	U	N	E	U
ANKR	−8	3.7	33.3	−12	5.9	57 0
BOGO	0.5	−1	3.6	0.5	−1	−2
GLSV	1.8	2.6	−7.6	1.9	3.1	−4
JOZE	0	0.1	−1.9	−0.3	0	−7
MATE	2.6	2	−7.3	−0.4	1.6	2.3
PENC	1.9	0.5	7.6	1.1	0	8.1
SOFI	−1	−1	−15	−2.3	−1	−3
ZECK	2.1	−5	−22	−0.5	−2	−1
ZWEN	0.6	−2	9.2	0.1	0	6.3
RMS	3.3	2.6	16.1	1.3	1.6	5.2

Tab. 8: Offsets of the IGS station ANKR with respect to the ITRF 97 coordinate values, if the station is left free.

X	−39.4 mm	Height	−58.2 mm
Y	−28.0	Latitude	5.7
Z	−33.0	Longitude	−2.2

5.4 Position Tests: Coordinates of GLSV

In a solution with the reference stations constrained within 0.1 mm of their ITRF 97 coordinates the station GLSV (Kiev) was left free which allows a direct comparison of the computed coordinates with their a priori values. Table 9 gives the offsets of the coordinates with respect to the ITRF 97 values. They are all well below one centimeter.

The influence of including or excluding GLSV from the set of reference stations on the coordinates of the Moldavian and Ukrainian sites is below 1 mm.

Tab. 9: Offsets of the IGS station GLSV (Kiev) with respect to the ITRF 97 coordinate values, if the station is kept fixed.

X–coord.	4.5 mm	Height	0.8 mm
Y–coord.	−2.7	Latitude	−2.6
Z–coord.	−1.0	Longitude	−4.6

5.5 Influence of Elevation Cutoff Angle and Elevation Dependent Weighting

A test solution was computed with the elevation cutoff angle set to 10§ and elevation dependent weighting of the obser–vations with weight $\cos^2 z$ to study the effect of a change in the processing strategy. No a priori troposphere model was introduced and the dry Neill mapping function was used. All other options remained unchanged.

As expected (Rothacher et al., 1997), the lowering of the elevation cutoff angle together with the elevation dependent weighting reduces the scattering in the height component for most of the stations. The horizontal components for the stations agree to within 4 mm, while the variations of the height component may reach a level of 20 mm between the two solutions.

Table 10 gives the residuals of the sites after a 3–parameter Helmert transformation between the two solutions with elevation–cutoff 10 and 15 . Only the height component shows significant differences.

Tab. 10: Residuals after a three–parameter Helmert transfor–mation between solutions with an elevation cutoff angle of 15 and 10 .

Station	Residuals (mm)		
	N	E	U
Cheltuitorul	2.5	1	−5.3
Giurgiulesti	−2.1	−0.5	8.9
Otaci	0.2	−0.9	6.5
Palanca	2.1	1	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	−9.3
RMS / Component	1.8	1.2	9.3

5.6 Comparison with Coordinates from other Sources

For the three sites Simeiz, Mikolaev, and Uzgorod coordi–nates from the EUVN'97 campaign (Ineichen et al., 1999) exist. Furthermore the GPS point in Simeiz has coordinates which were determined by SLR. The coordinates of the EUVN campaign are available in the ITRF 96 at the epoch 1997.4, those derived from SLR are in ITRF 97 at the epoch 1997.0. They were transformed to the epoch 1999.4 using the ITRF 97 velocity for the Simeiz SLR station and compared to the ITRF 97 coordinates obtained from the Moldavia campaign 99. Coordinate differences in longitude, latitude, and height are given in Table 11.

The horizontal coordinates are in good agreement, in longitude the differences are a few millimeters. The height of the stations differs, however, by 4 cm compared to EUVN and 7 cm compared to the SLR coordinates. The SLR coor–dinates of the site in Simeiz were, however, determined using a mobile SLR station and are not tied to the coordinates of the Simeiz permanent SLR station. A problem with the antenna height for the EUVN campaign may exist and account for the 4 cm observed. Tests carried out during the processing of the Moldavia campaign, in particular the position test with the station GLSV (Section 5.4), did not reveal inconsistencies.

Tab. 11: Difference of the coordinates of the Ukrainian sites with coordinates from EUVN and SLR (for Simeiz).

Coordinate Differences			Longitude	Latitude	Height	
UZHD UK02 EUVN	–	UZHD Moldavia–99	–1.5	4.3	40.2	mm
MIKO UK03 EUVN	–	MIKO Moldavia–99	3.9	5.7	49.4	mm
SIME UK04 EUVN	–	SIME Moldavia–99	–1.3	–1.0	36.7	mm
SIME 12337M001 SLR	–	SIME Moldavia–99	1.4	11.1	73	mm

5.7 The Coordinates in ETRS–89

The coordinates of the stations in Moldavia and Ukraine were determined 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 Boucher et al., 1998. Table 12 gives the final coordinates of the measured stations in the ETRS–89 system for the epoch May 27, 1999.

Tab. 12: Geocentric coordinates for the Moldavian and Ukrainian sites in the ETRS–98 for the epoch May, 1999.

Station	X–Coordinate (m)	RMS (mm)	Y–Coordinate (m)	RMS (mm)	Z–Coordinate (m)	RMS (mm)
Cheltuitorul	3807536.886	0.2	2104493.713	0.1	4648842.511	0.3
Giurgiulesti	3946301.683	0.3	2117866.135	0.2	4526149.151	0.3
Otaci	3754452.446	0.2	1976193.205	0.1	4746725.141	0.3
Palanca	3814919.626	0.2	2204325.924	0.2	4596482.244	0.3
Ungheni	3829765.199	0.3	2029340.213	0.1	4663860.203	0.3
Mikolaev	3698609.726	0.3	2308760.736	0.2	4639661.978	0.3
Simeiz	3783746.653	0.3	2551362.553	0.2	4441444.987	0.3
Uzgorod	3908590.717	0.3	1615205.658	0.1	4758733.035	0.3

6 Conclusions

The Moldavia 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 6). 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.

Unclear is the cause for a difference of the vertical position of the Ukrainian stations with respect to EUVN–97 of the order of 4 cm. A comparison of the coordinates of the Ukrainian site at Kiev did, however, not show any inconsistency.

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 Ukraine 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 (Boucher et al., 1998); the final coordinates are given in Table 12.

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