CENTRAL LABORATORY OF GEODESY
MILITARY TOPOGRAPHIC SERVICE

NATIONAL GPS NETWORK OF BULGARIA

PROCESSING THE OBSERVATIONS OF THE MAIN ORDER

Ivan Georgiev, Plamen Gabenski,
Georgi Gladkov, Toshko Tashkov, Dimitar Dimitrov

- The design of the National GPS Network and the programme for its measurement were developed by the Military Topographic Service of the Bulgarian Army

- The National GPS Network was developed in compliance with the decree of the Council of Ministers 140 / 04.06.2001, established the Bulgarian Geodetic System and served for the radical updating of the National Geodetic Network (NGN) of the Republic of Bulgaria

- **The National GPS Network of the country is based on**:
  - the permanent GPS stations of the European Permanent Network (EPN);
  - The EUREF points in Bulgaria as a realization of the European Terrestrial Reference System ETRS'89 in the country

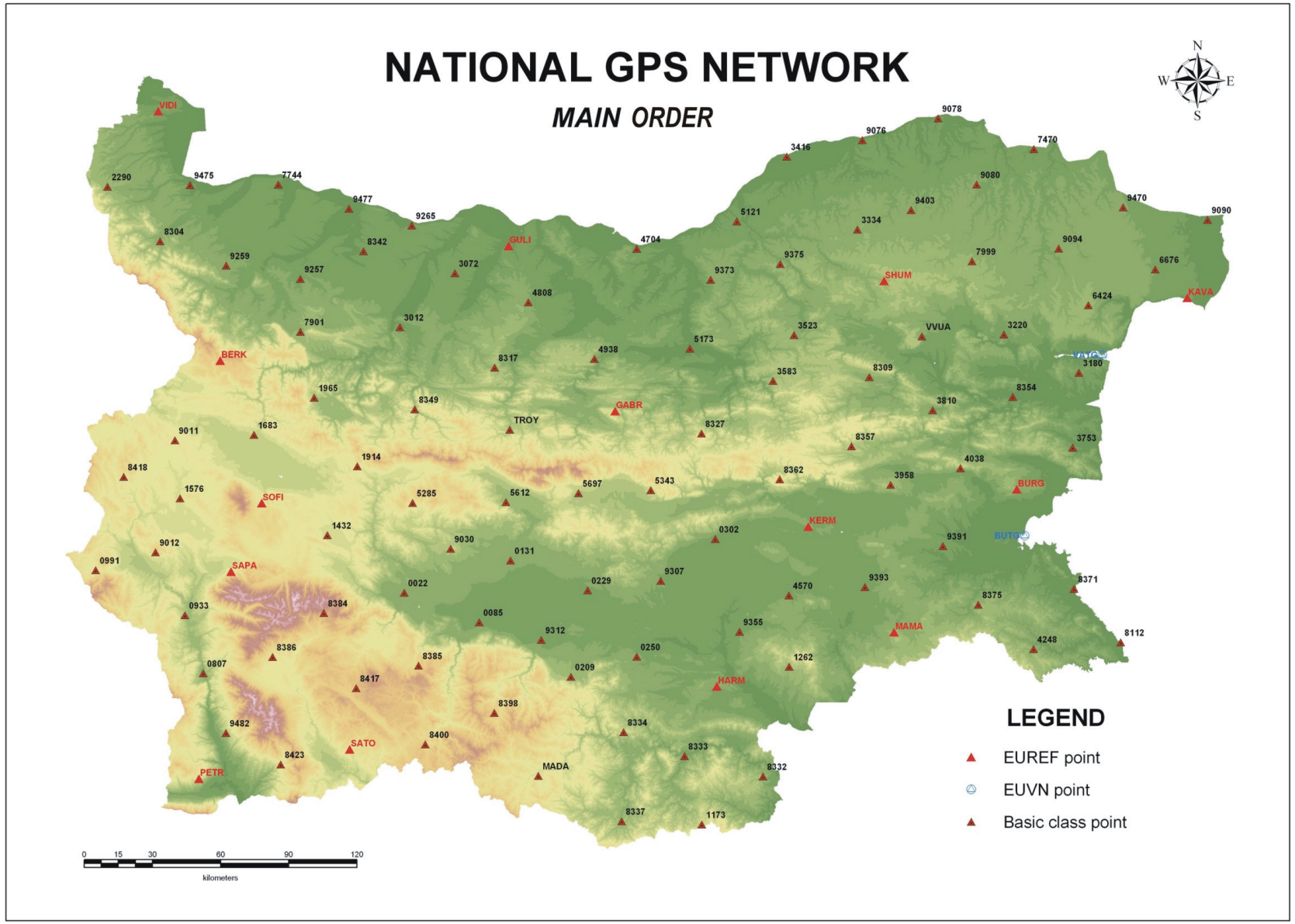
- The National network consists of two orders of points - the Main and the Secondary
- The Main network is created in order to realize, distribute and maintain the European Terrestrial Reference System ETRS'89 on the territory of the country using the GPS technology. The whole realization of the Main and Secondary networks will lead to density, which allow the development of local geodetic networks for the needs of all practical applications.
- The responsibilities for the construction, measurements, processing, result dissemination and maintenance of the National GPS Network are regulated by the Ordinance of the Council of Ministers No 1 / 06.01.2005 for the distribution of the tasks of national importance in geodesy and cartography.

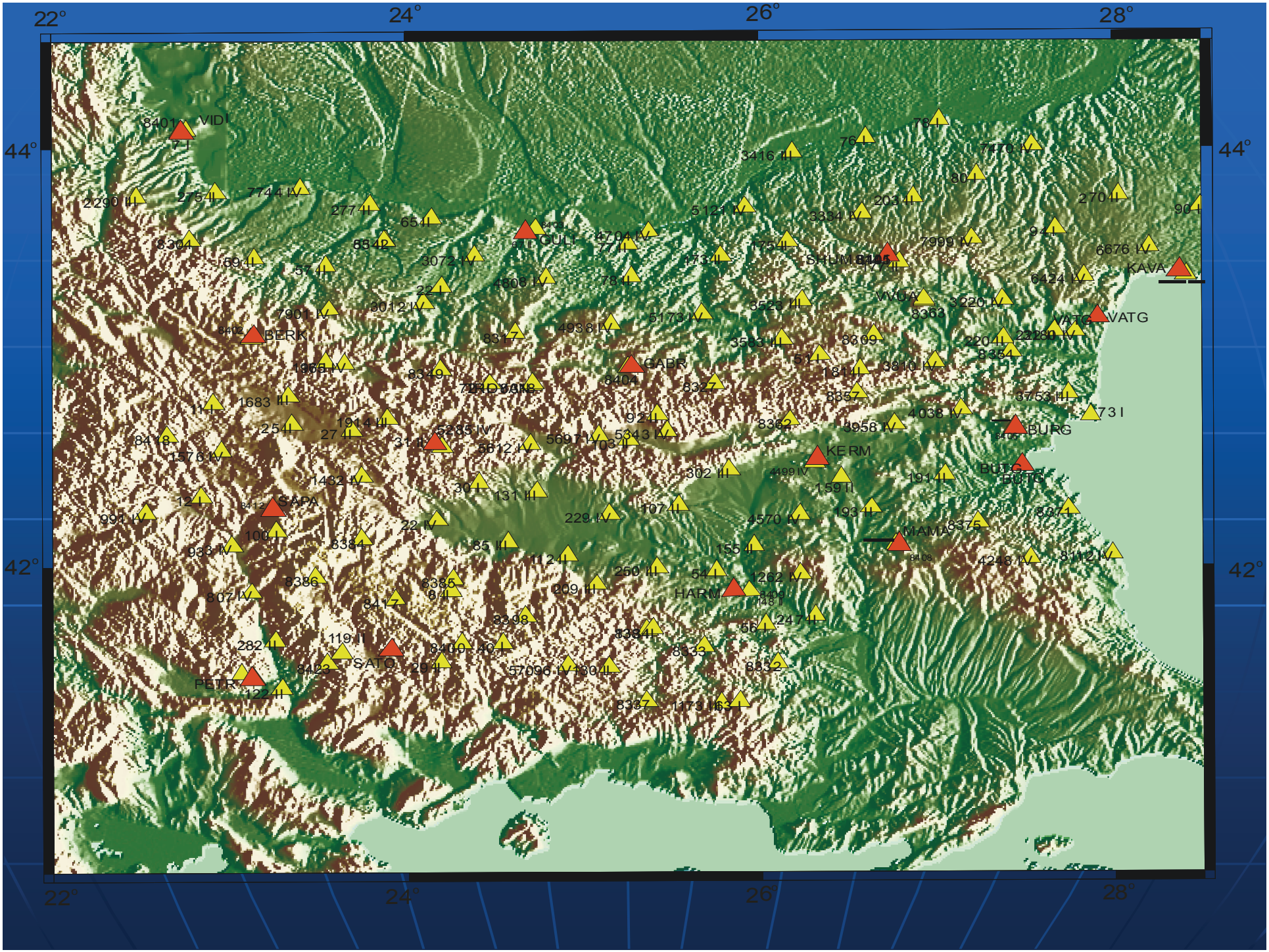
Design of the points of the Main GPS network

- The Main order GPS network includes the following types of points:
- All points from the so-called BULREF network, including the points of the European Vertical Reference Network (EUVN) – Burgas (BUTG) and Varna (VATG);
- Points from the existing (classical) National Geodetic Network I and II order. These points have to be used for computation of the transformation parameters between the ETRS89 and the existing reference systems on the territory of the country.
- Points of the (classical) National Geodetic Network III and IV order;
- Newly constructed points during the period 2002 – 2003 especially for the National GPS Network;
- Points with a special statute (at places, where permanent GPS stations will be probably set in the future).

National GPS Network - Main order

№	Type of the points	Number	Note
1	Points from the BULREF network	15	1 NGN II order point
2			
3	Points from EUVN	2	
4	Points from NGN I and II order	25	
5			
6	Points from NGN III and IV order	46	
	New points	22	
	Points with special statute	2	
	Total	112	


NATIONAL GPS NETWORK
MAIN ORDER
N
W
E
S
VIDI
2290
9475
7744
9477
9265
8304
8342
GULI
4704
9078
9076
3416
7470
9080
9403
9470
9090
5121
3334
9094
9259
9257
3072
9375
7999
6676
9373
SHUM
KAVA
6424
4808
7901
3012
3523
VVUA
3220
BERK
8317
4938
5173
3180
3583
8309
8354
1965
8349
GABR
3810
TROY
8327
9011
1683
8357
3753
1914
4038
8418
8362
3958
1576
SOFI
5285
5612
5697
5343
BURG
1432
0302
KERM
9391
BUTG
9012
9030
0131
0991
SAPA
9307
9393
8371
0022
0229
4570
8375
0933
8384
0085
9355
MAMA
8112
9312
8386
0250
4248
8385
1262
0807
0209
8417
HARM
8398
9482
8334
8400
SATO
8333
8423
MADA
8332
PETR
8337
1173
0
15
30
60
90
120
kilometers
LEGEND
EUREF point
EUVN point
Basic class point


22°
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28°
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42°
VIDI
BERK
GABR
KERM
SAPA
SATO
PETR
GULL
KAVA
VATG
BURG
MAMA
HARM

Държавна GPS мрежа

Measurement of the Main order of the National GPS Network

- The National GPS Network was measured using Trimble geodetic receivers. The measurements of all points from the Main order were measured in sessions with two-day duration, starting from 0 hour UTC; two sessions with duration from 5 to 8 hours being additionally measured before and after the basic two sessions. All measurements were made with 15 seconds sampling rate and 10 degrees elevation mask.

Processing the measurements of the National GPS Network – Main order, year 2004

- The processing of the GPS measurements was carried out in the ITRF'2000 realization of the ITRS reference system.

- The processing was made using the Bernese 5.0 scientific research software - the state-of-art software for GPS processing. The software has been created as a "tool for the highest accuracy in GPS processing in various applications".

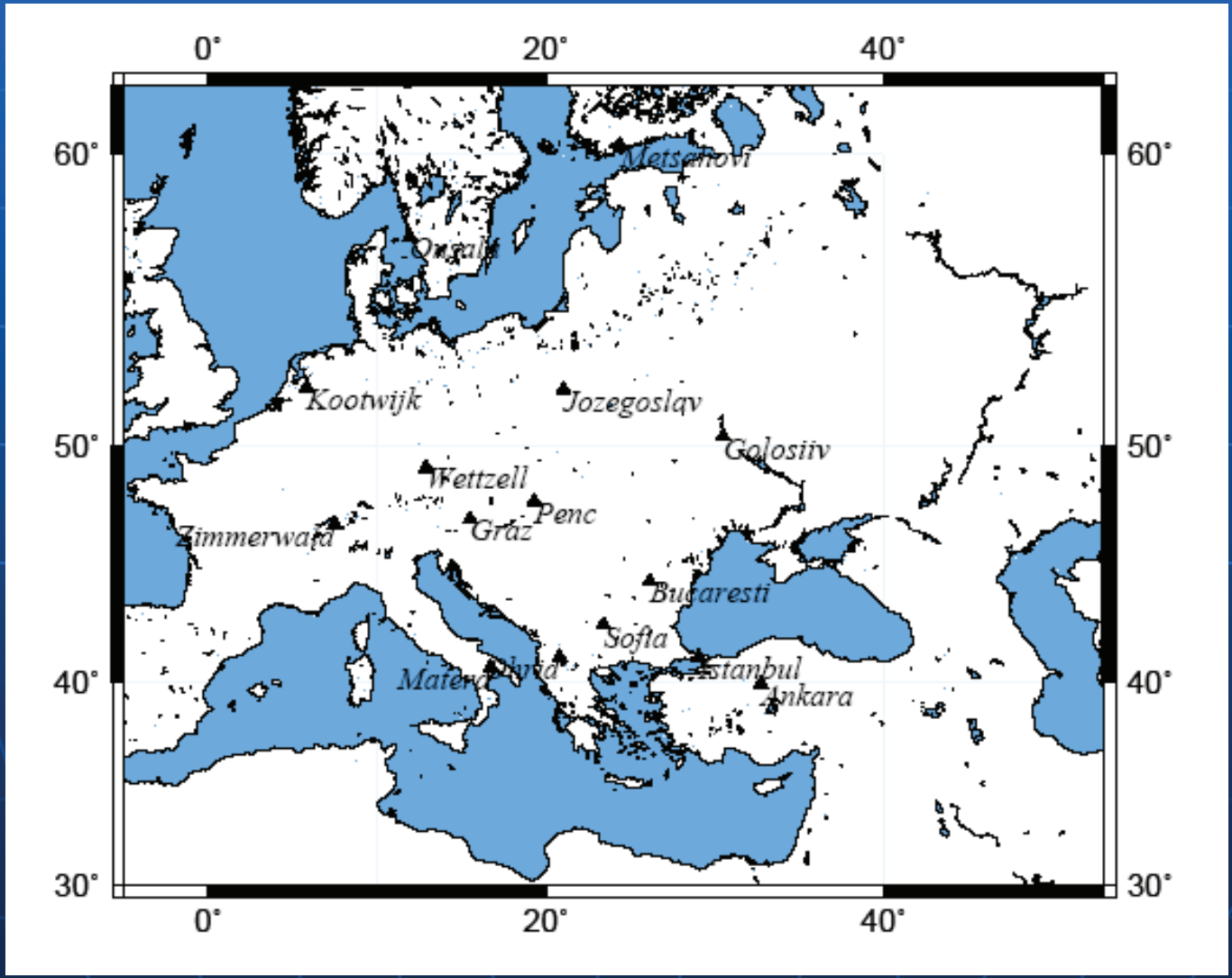
- The GPS campaign for determining the coordinates of the National GPS Network – Main order, is divided in 24 - hours daily sessions. The daily solution is calculated for each session and these solutions (normal equations) are then combined to yield the campaign solution. The determination of velocities of points is obtained by combining the solutions of the single campaigns.

Basics of the processing strategy

- Bernese GPS software, Version 5.0
- IGS orbits of the satellites and IGS coordinates of the pole, transformed in ITRF2000 if received before the year 2000
- Reference system ITRF2000
- IGS_01 model of the variations of antenna phase centres (elevation dependent phase centre corrections)
- 10 and 15 degree mask of the heights (two solutions respectively)
- Weights for the observations depending on the height above the horizon
- Ionospheric models for the region of Europe for each day from CODE
- Quasi-ionospheric strategy for fixing the ambiguities (QIF-Ambiguity resolution)

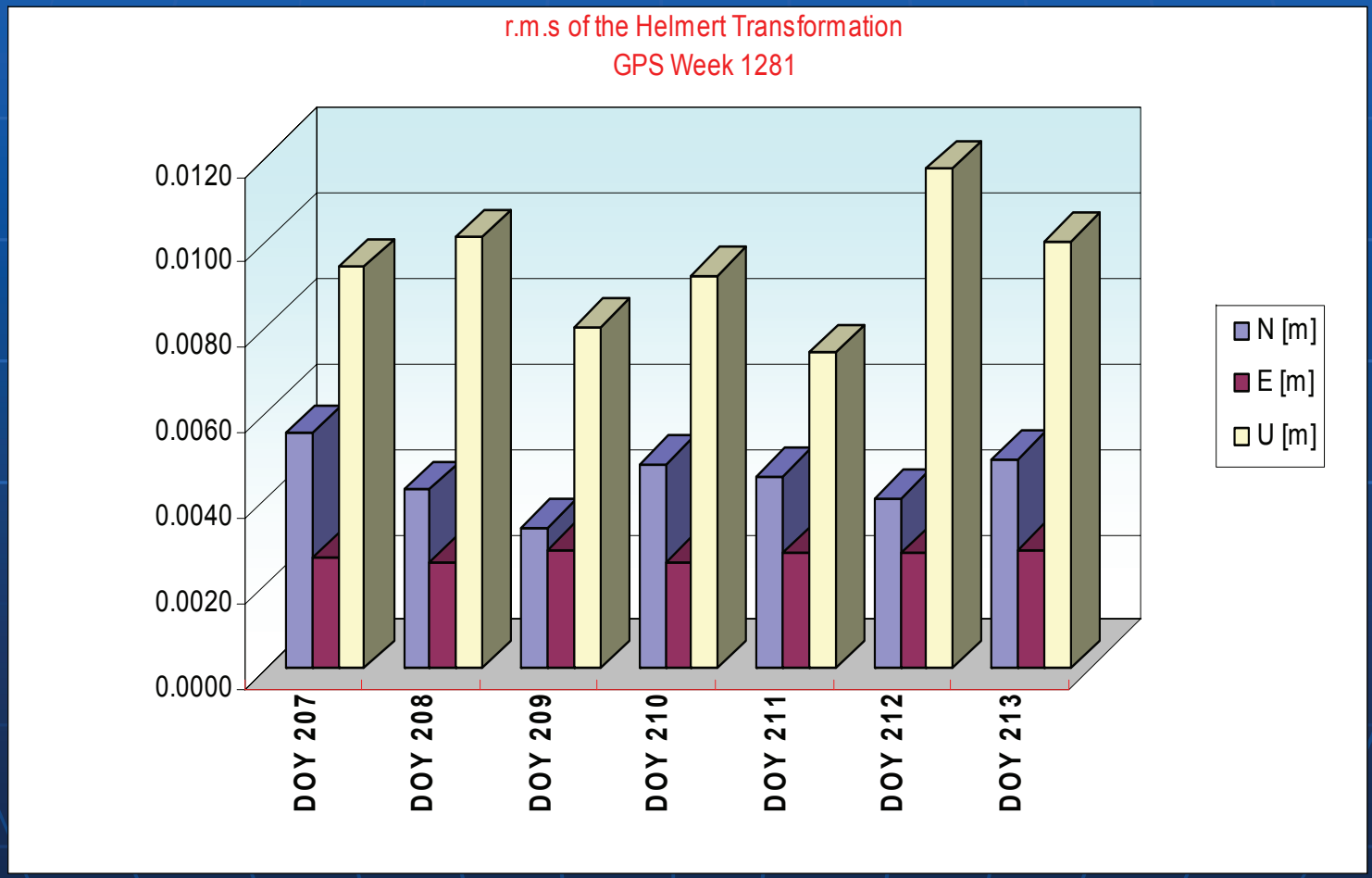
- Tropospheric models – calculated from the measurements of each day, a priori tropospheric model of Niell
- Assessment of tropospheric parameters – one tropospheric parameter per hour for station
- The daily solutions (respectively the normal equations) are calculated with mean square errors of the IGS stations (anchor sites) of 0.01 m (loosely constrained solution)
- The combined normal equations for each campaign/epoch are generated from the daily normal equations
- The IGS/EUREF permanent stations are reference with coordinates and velocities in ITRF2000

EUREF permanent stations used in the processing

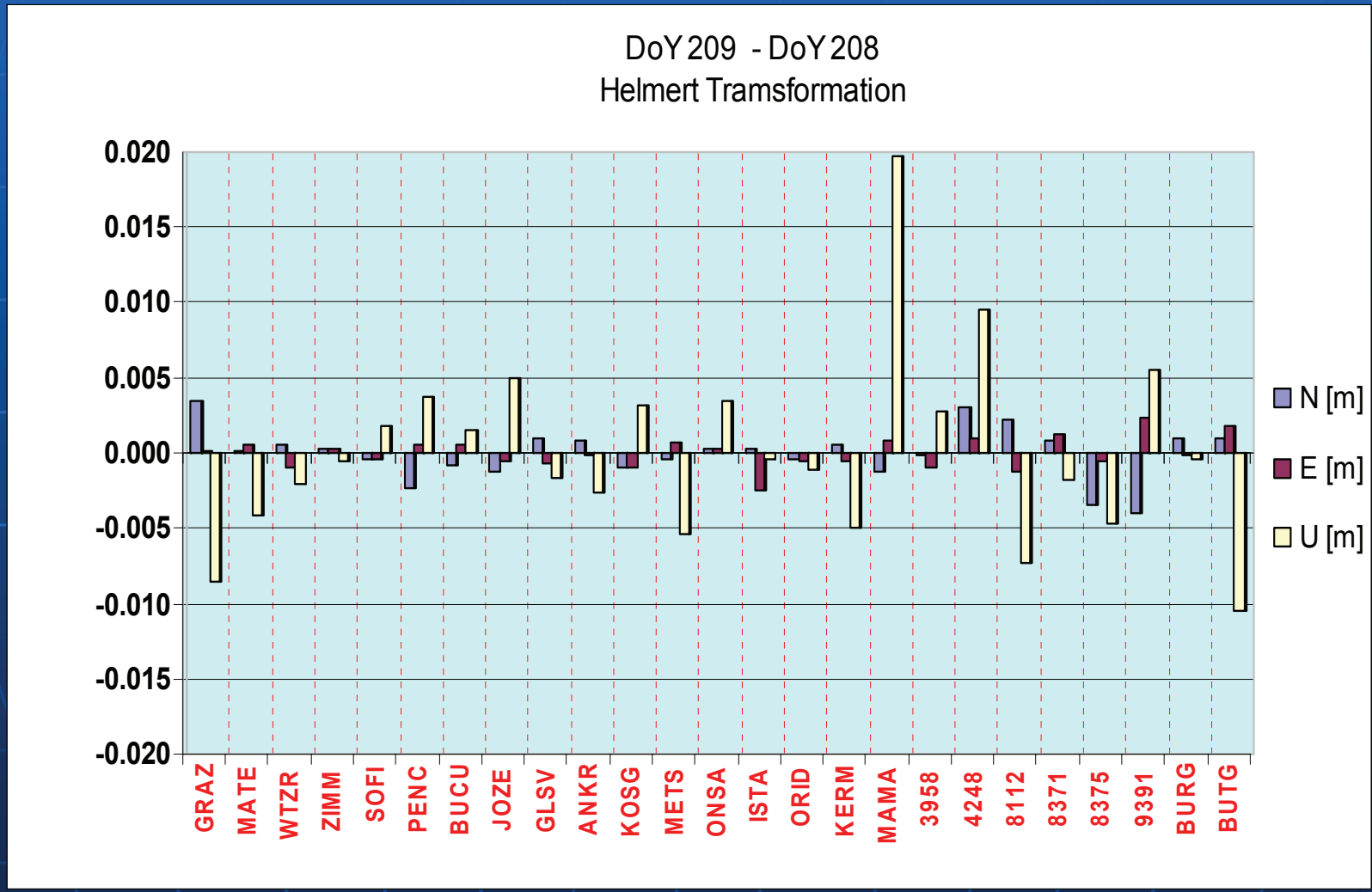


Daily solutions

Rms values – north, east, up of the Helmert's transformations between ITRF2000 and daily solutions for GPS week 1281 (example)

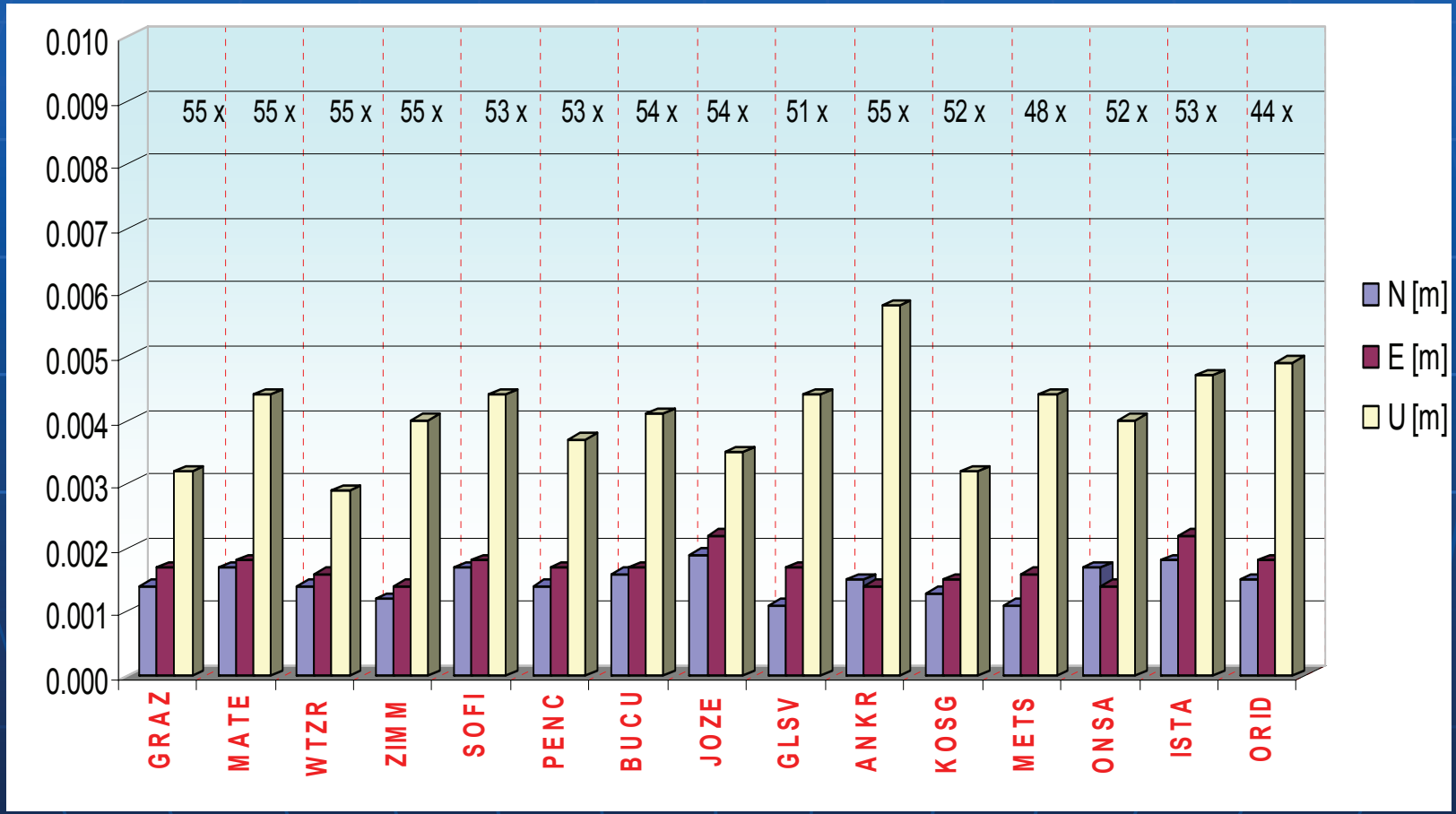


The Helmert's transformations of 24-hour daily solutions with respect to each other (example)

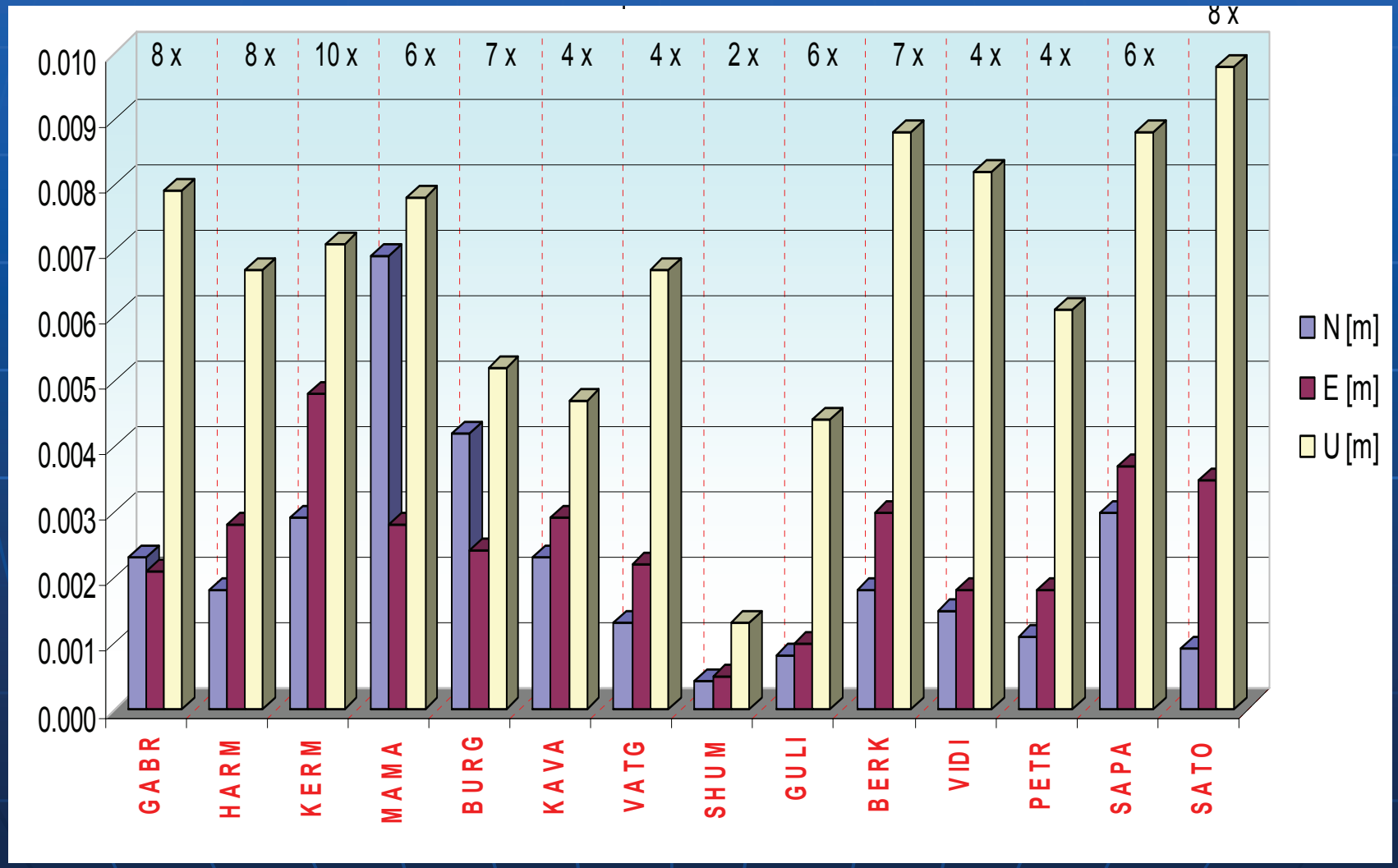


Repeatabilities

of the permanent EUREF stations used in the processing

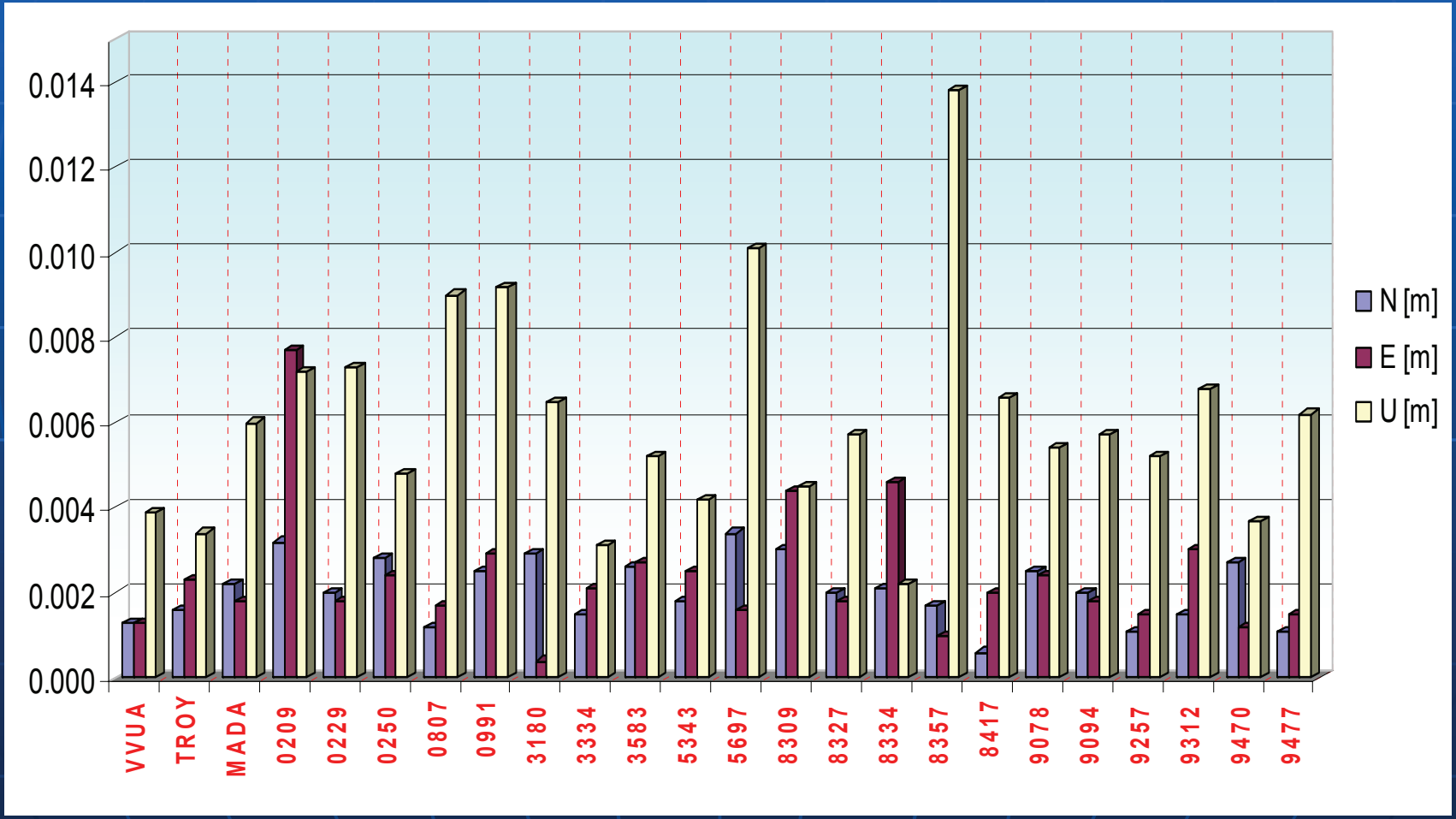


Repeatabilities
of the Bulgarian EUREF stations



Repeatabilities

of the Bulgarian stations from campaign BG'2004 for points with observations in four days and more



Solution for the 2004 campaign (BG'2004)

The final solution for BG 2004 campaign is obtained by combination of the daily solutions. The diagram in Figure 14 shows the principle of the daily solution combination with Bernese 5.0 – a combination of the normal equations of the individual daily solutions. The anchor sites are GLSV, GRAZ, JOZE, KOSG, MATE, METS, ONSA, SOFI, WTZR and ZIMM. The coordinates of these points receive a priori mean square errors of 0.0001 m (0.1 mm) during the adjustment. The coordinates of the points ANKR, BUCU, ISTA, ORID and PENC are estimated in order to check the solution for the obtained velocities.

Results

- Coordinates of the points in the ITRF'2000, epoch 2004.8 (the middle of the observation campaign)
- The final coordinates of the points are obtained by transformation from the ITRF'2000 to the ETRS'89 – ETRF'2000, epoch 2004.8

(Re) Processing of the GPS campaign EUREF BG'1993

- The EUREF BG 1993 campaign was held in October 1993 with the aim of establishing 15 points on the territory of Bulgaria in the ETRS'89 reference system.
- The EUREF BG'93 GPS campaign was performed in the period 12.10–16.10.1993. Fifteen points were measured in four sessions of 24 hours each. Trimble 4000SSE GPS receivers were used.
- For four of the points: Vidin (VIDI), Berkovitsa (BERK), Kavarna (KAVA) and Satovcha (SATO) the observations from 1993 are missing. For their velocity estimation observations from 1994 and 1996 are used.

Processing and analysis

- The processing of the observations of the EUREF BG'93 campaign were made according to the same scheme as the 2004 GPS campaign in the ITRF2000. There were only two specific features of the processing:
- Precise ephemeredes and pole coordinates are obtained from CODE. The ephemeredes and pole coordinates were transformed from the ITRF91 reference system, in which they were originally obtained, to ITRF2000;
- No ionosphere models were used.

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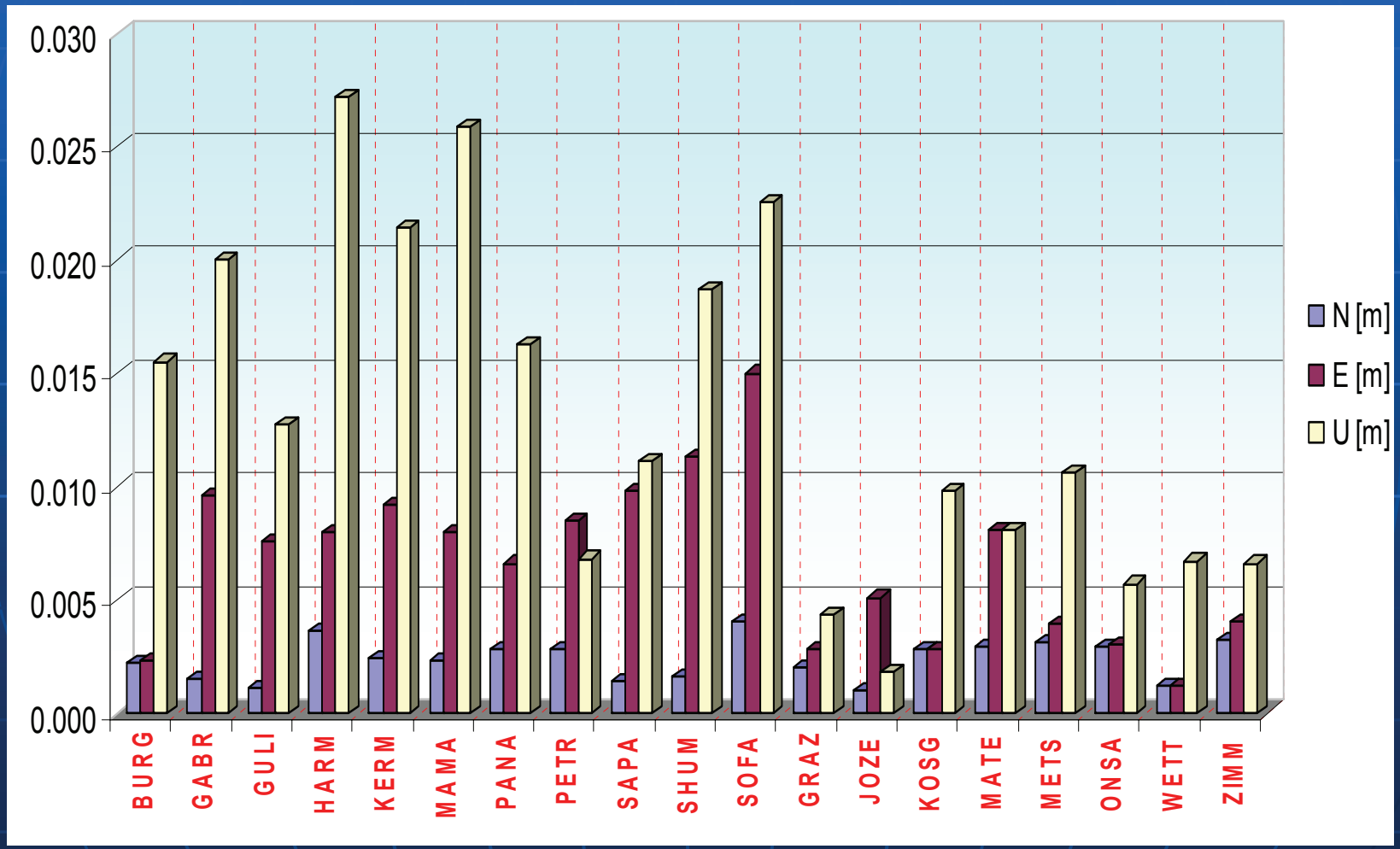
- No ionosphere models were used.

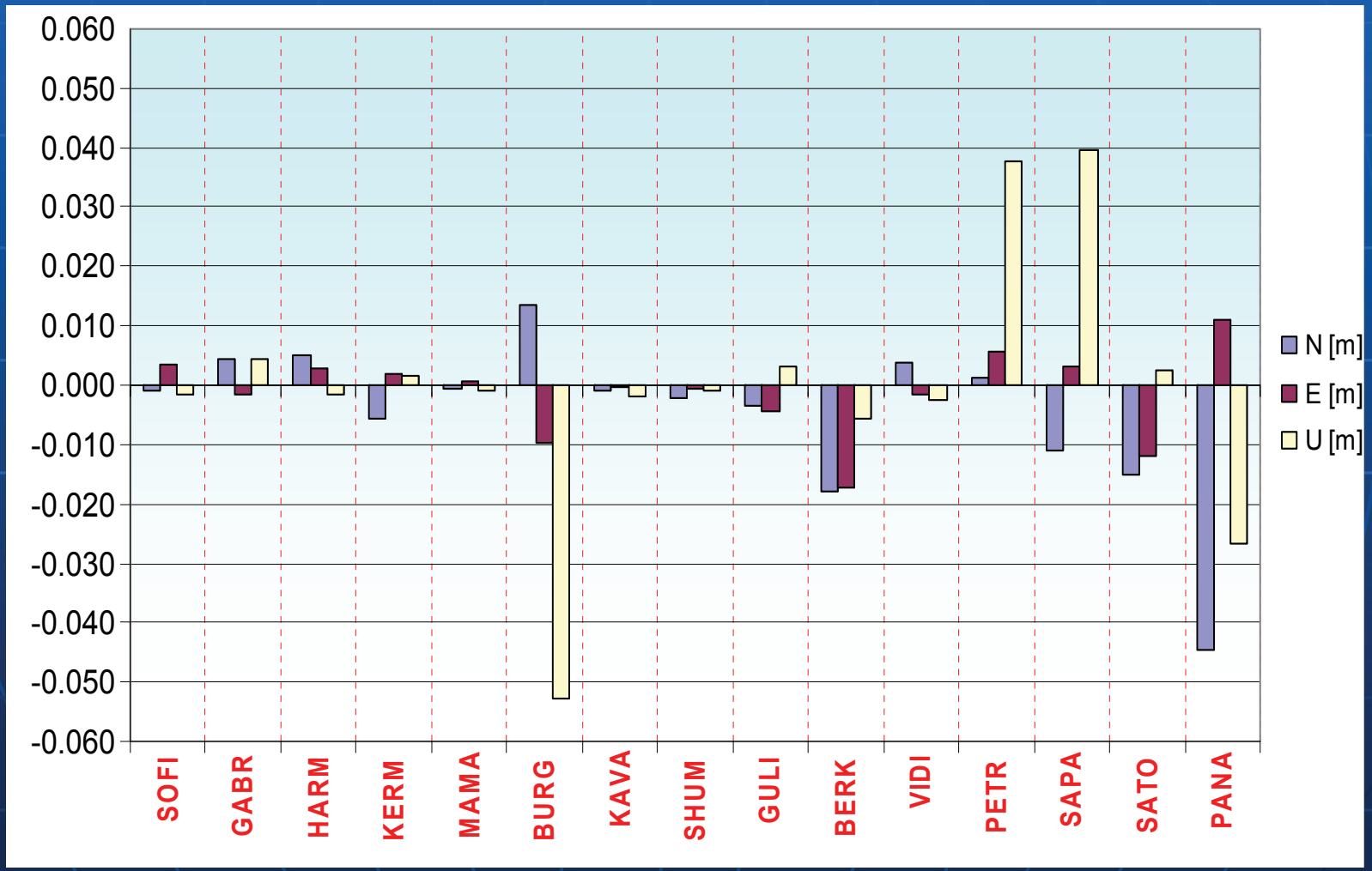
Rms from the repeatabilities for the EUREF points of the new solution for the campaign BG'1993



Comparison of the newly obtained solution for the EUREF BG'93 GPS campaign with the official solution

A comparison was made between the newly obtained solution for the EUREF BG'1993 campaign and the solution obtained from the processing in 1995 in BKG (Milev et al., 1996). The mean square errors of the residuals for the 11 points in north, east, up are respectively 6 mm, 3 mm and 7 mm

Helmert's transformation between the two solutions for the EUREF BG'93 campaign – the official one (1995), and the BG'2004 campaign (2005)



- **The following have to be taken into account when analyzing the comparisons :**
  - use of different versions of the processing software;
  - different ITRFyy realizations;
  - different geometry of the observed satellites and observation conditions;
  - use of estimations for the velocities of the EUREF points for the processing in 1995 according to the NUVEL-1A model.

Comparison between the results of the GPS campaigns EUVN'97 and BG'2004

A comparison has been made of the obtained results from the GPS campaigns BG'2004 and EUVN'97 for the identical points of the two campaigns – SOFI (Sofia), BG'04 (VATG) and BG'01 (BUTG). In order to perform the comparison correctly, the coordinates of these three points obtained in the ITRF'2000 reference system, epoch 2004.8, were extrapolated in ITRF'2000, epoch 1997.4, using the point velocity with respect to the European rotational pole (the velocities determined by observations were applied for the SOFI point). The obtained coordinates were transformed from ITRF'2000 to ETRS'89 (ETRF'2000) for he same epoch – 1997.4, which is the epoch of the EUVN'97 campaign solution.

Differences obtained from the comparison of the results for the solutions of the two campaigns

Point	dX *(BG'04 - EUVN'97)* [m]	dY *(BG'04 – EUVN'97)* [m]	dZ *(BG'04 – EUVN'97)* [m]	dS [m]
BUTG BG'01	0.015	0.004	-0.019	0.024
SOFI BG'03 11101M002	0.002	-0.007	-0.002	0.007
VATG BG'04	0.026	-0.006	-0.011	0.029

- The relatively high residuals for the points BUTG and VATG with respect to that for the point SOFI are most probably due to the applied velocity model (the European rotational pole).
- Other two important circumstances have to be taken into account for the comparison:
- the ITRF96 reference system realization was used in the processing of the EUVN'97 campaign, while the processing of the observations of the National Network were made in the ITRF2000 realization;
- the typical location of the VATG and BUTG points – both of them are located at the quays of harbours and are subjected to the continuous effects of different natural and technogenic factors.

Obtaining the velocities of the EUREF points in Bulgaria

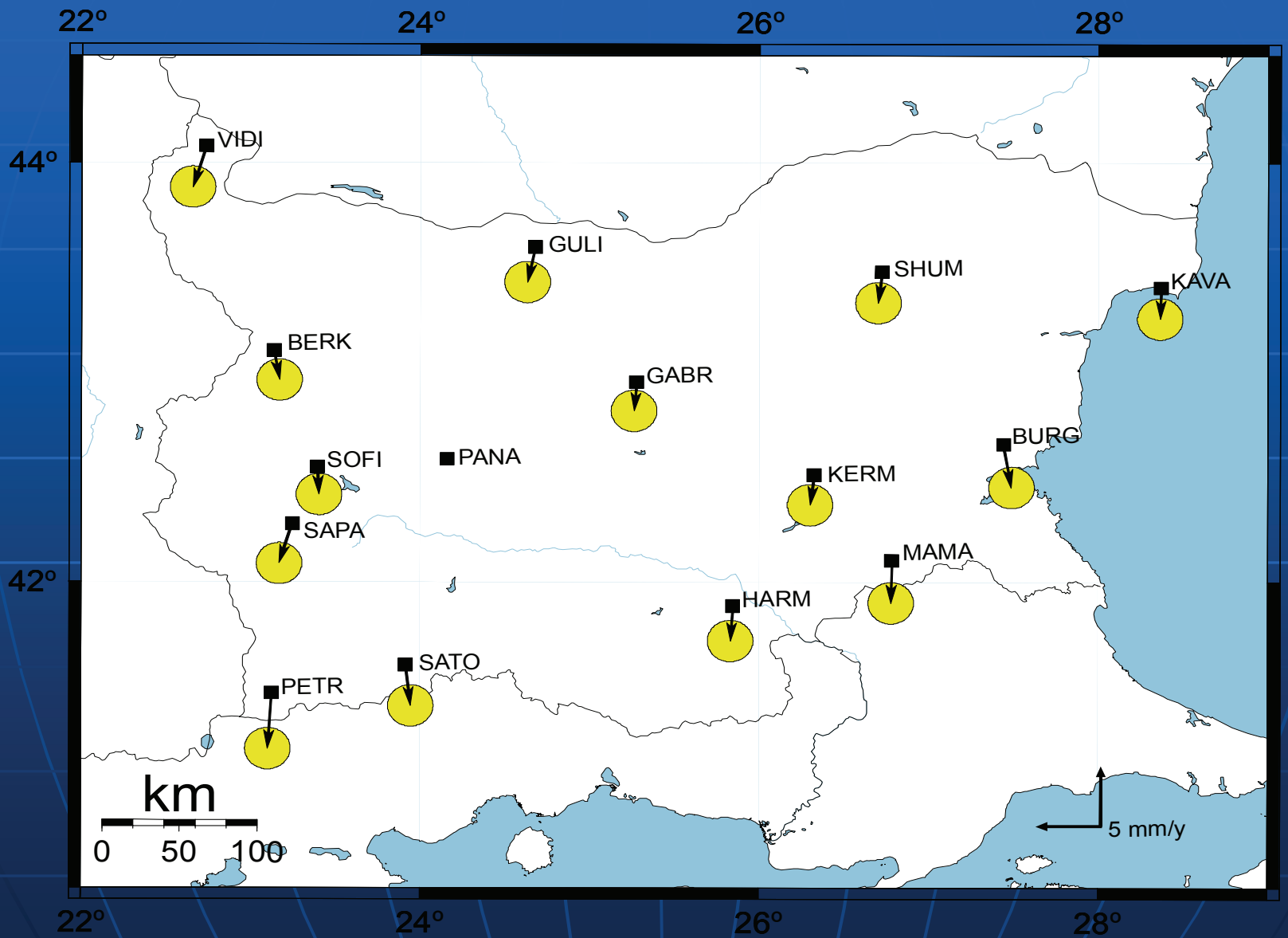
- It is based on the combination of the normal equations obtained in each individual campaign. The combination follows principally the recommendations for densifying EUREF with regional networks. The anchor sites are GLSV, GRAZ, JOZE, KOSG, MATE, METS, ONSA, SOFI, WTZR and ZIMM. The coordinates of these stations have mean square errors of 0.0001 m and the velocities (with the exception of Matera) – 0.0001 m/yr. The velocities of the stations PENC, ANKR, ISTA, BUCU and ORID are estimated in order to check the obtained solution.

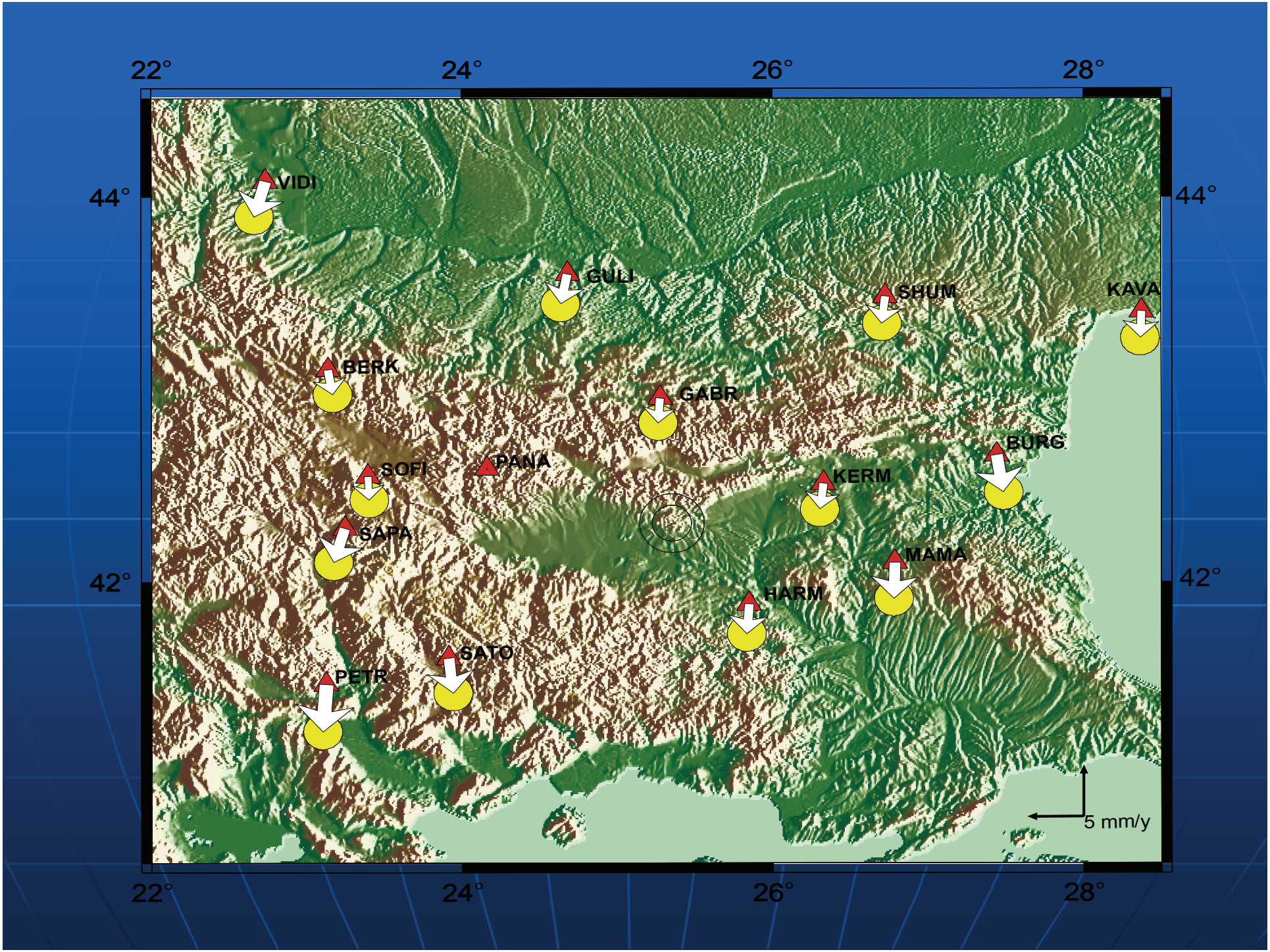
Velocities of the EUREF points Vidin, Kavarna, Sapareva Banya and Satovcha

- Since there are no observations for four points from the EUREF BG'93 campaign, their observation from 1994 (Vidin and Kavarna) and 1996 (Sapareva Banya and Satovcha) had to be additionally processed for finding their velocities. The processing of the two GPS campaigns was performed in an analogous manner.

Point Year	VIDI 8149	KAVA 8142	SATO 8147	PETR 8146
	[hours]	[hours]	[hours]	[hours]
1994	72	72	72	72
1996	72	72	72	72

Relative velocities of the EUREF points




22°
24°
26°
28°
44°
42°
VIDI
GULI
SHUM
KAVA
BERK
GABR
BURG
SOFI
PANA
KERM
SAPA
MAMA
HARM
SATO
PETR
5 mm/y

- The fact that may be noticed immediately is that the EUREF velocities of the points in Bulgaria, or their velocities with respect to stable Eurasia, cannot be considered as negligible (or zero). They vary from 2 to 4 mm/yr and their direction is approximately to the south (as could be expected according to the tectonic features of the whole region).
- The points in South Bulgaria exhibit greater movements than these in North Bulgaria

- **Comparison between the velocities of the points obtained in different time spans**

- Except for the measurements in 1993 (1994, 1996) and 2004, observations made in 1998, 2001, 2002 and 2003 are also available for a significant number of the EUREF points. This provides the possibility for comparing the velocities of these points obtained for different time intervals. For this purpose GPS campaigns carried out in 1998, 2001, 2002 and 2003 were processed.

GPS campaigns used in velocity determination

EUREF BG' 1993
ROMANIA BG' 1994
BG' 1996
BG' 1998
SWBG' 1999
SWBG' 2001
SWBG' 2002
SWBG' 2003
BG NET' 2004

Velocities of stations from different time spans (example)

№	Point/ Span	Vx mm	Vy mm	Vz mm	VN mm	VE mm
1	GABR 8140					
	93-04	-17.5	17.8	6.0	10.1	23.6
	93-96-04	-17.6	17.8	6.1	10.1	23.6
	93-96-98-04	-17.2	16.7	5.9	10.1	22.5
2	HARM 8143					
	93-04	-16.6	18.7	6.9	9.7	24.1
	93-96-04	-16.7	18.5	6.7	9.6	23.9
	93-96-98-04	-16.4	17.4	6.4	9.6	22.8

№	Point/ Span	Vx mm	Vy mm	Vz mm	VN mm	VE mm
3	BURG 8144					
	93-04	-16.2	19.1	6.4	8.4	24.4
	93-96-04	-16.3	19.5	6.7	8.6	24.8
	93-96-98-04	-15.9	18.5	6.5	8.6	23.7
4	SHUM 8141					
	93-04	-17.7	17.6	5.8	9.6	23.7
	93-96-04	-18.0	17.5	5.6	9.7	23.7
	93-96-98-04	-17.7	16.3	16.3	9.7	22.5

Comparison of point velocities obtained from different sources (example)

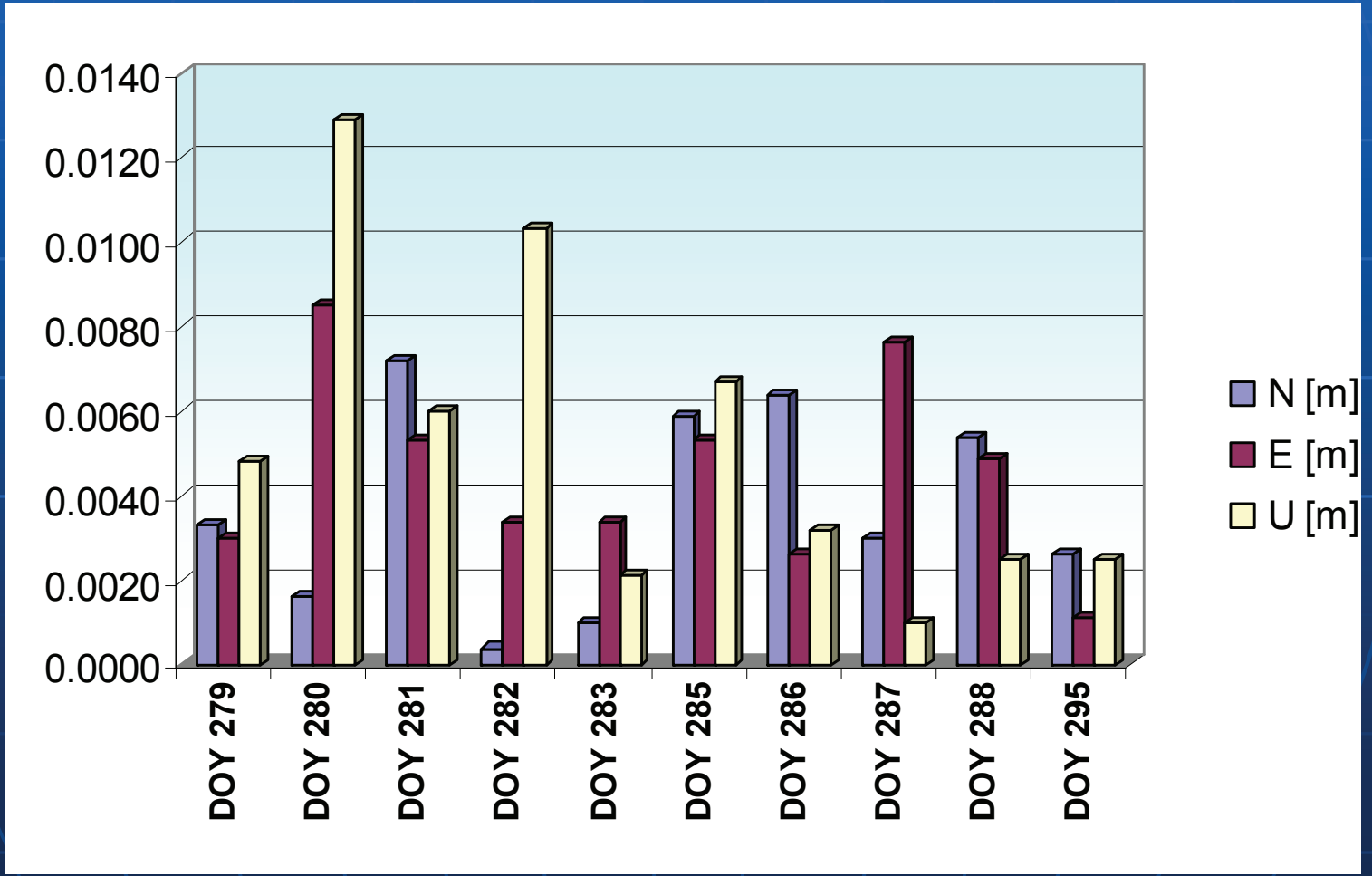
Station	X [mm/yr]	Y [mm/yr]	Z [mm/yr]	N [mm/yr]	E [mm/yr]	Solution
SOFI	-17.8	19.3	7.7	12.2	25.2	CLG'04
	-15.5	18.6	6.0	9.0	23.3	BG'2004
				10.3	27.0	OLG
	-16.5	18.7	7.3	10.6	23.7	ITRF'2000
PENC						CLG'04
	-17.5	17.4	6.5	12.3	22.2	BG'2004
	-16.6	18.1	8.2			ITRF'2000
BUCU	-18.6	16.6	8.4	12.5	23.1	CLG'04
	-16.0	17.0	7.8	10.4	22.3	BG'2004
				10.2	27.2	OLG
	-18.1	16.2	7.4	6.5	29.2	ITRF'2000

Comparison and control of the results from the processing of the National GPS Network with measurements from the Secondary GPS Network

- The check and the assessment of the obtained final solution for the Main Order National GPS Network are made on the basis of the analysis of a fragment from the observations from Secondary network, carried out in the end of 2004. The observations from days 279 to 295 were analyzed.
- The observations of the Secondary Network are performed according to the accepted programme for observation and they are with duration of 8 hours; at least three points from the primary order being observed simultaneously.

- The basic moments of the strategy applied for processing the Secondary GPS Network are:
- the points of the Main Order are used as fiducial points with known coordinates and velocities in ITRF2000, epoch 2004.8. The velocities of the Main Network are obtained according to the introduced European pole;
- using the obtained velocities of the fiducial points, their coordinates are extrapolated for the epoch of observation;
- the further processing is made in compliance with the strategy for the Main GPS Network processing.

Rms residuals between the fiducial points for the corresponding days



Which coordinates should be accepted for use in practice ?

- The coordinates of the National GPS Network (Main and Secondary) obtained in the ETRS'89 reference system, realization ETRF'2000, epoch 2004.8, should be used for practical applications on the territory of the Republic of Bulgaria.

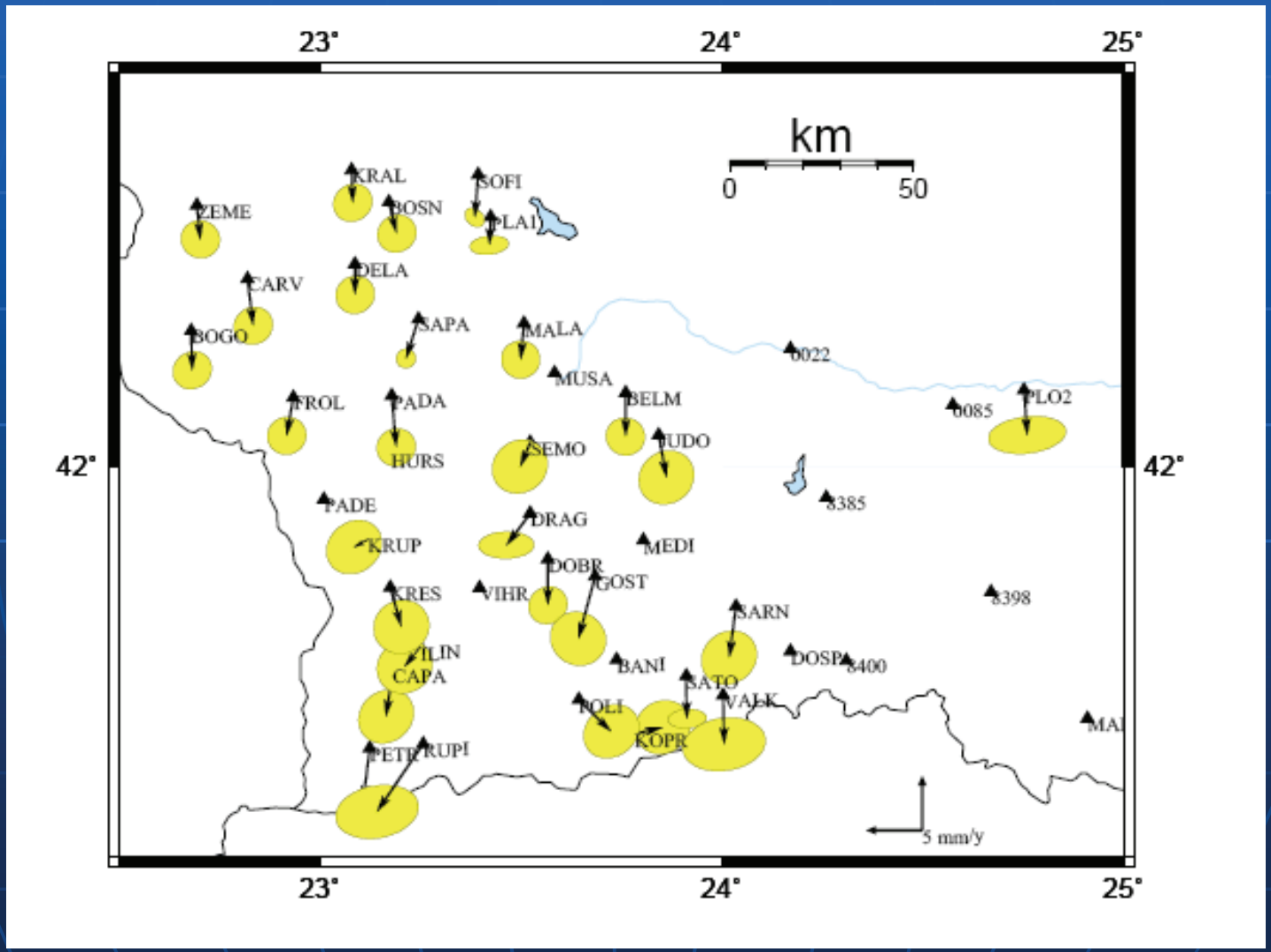
- To avoid using of fractional part of the year is convenient to transform the coordinates into epoch 2005.0. One more reason is that the coordinates of the Secondary National GPS Network obtained for measurements made in 2006 will be transformed back to the same round epoch 2005.0 (01.01.2005)

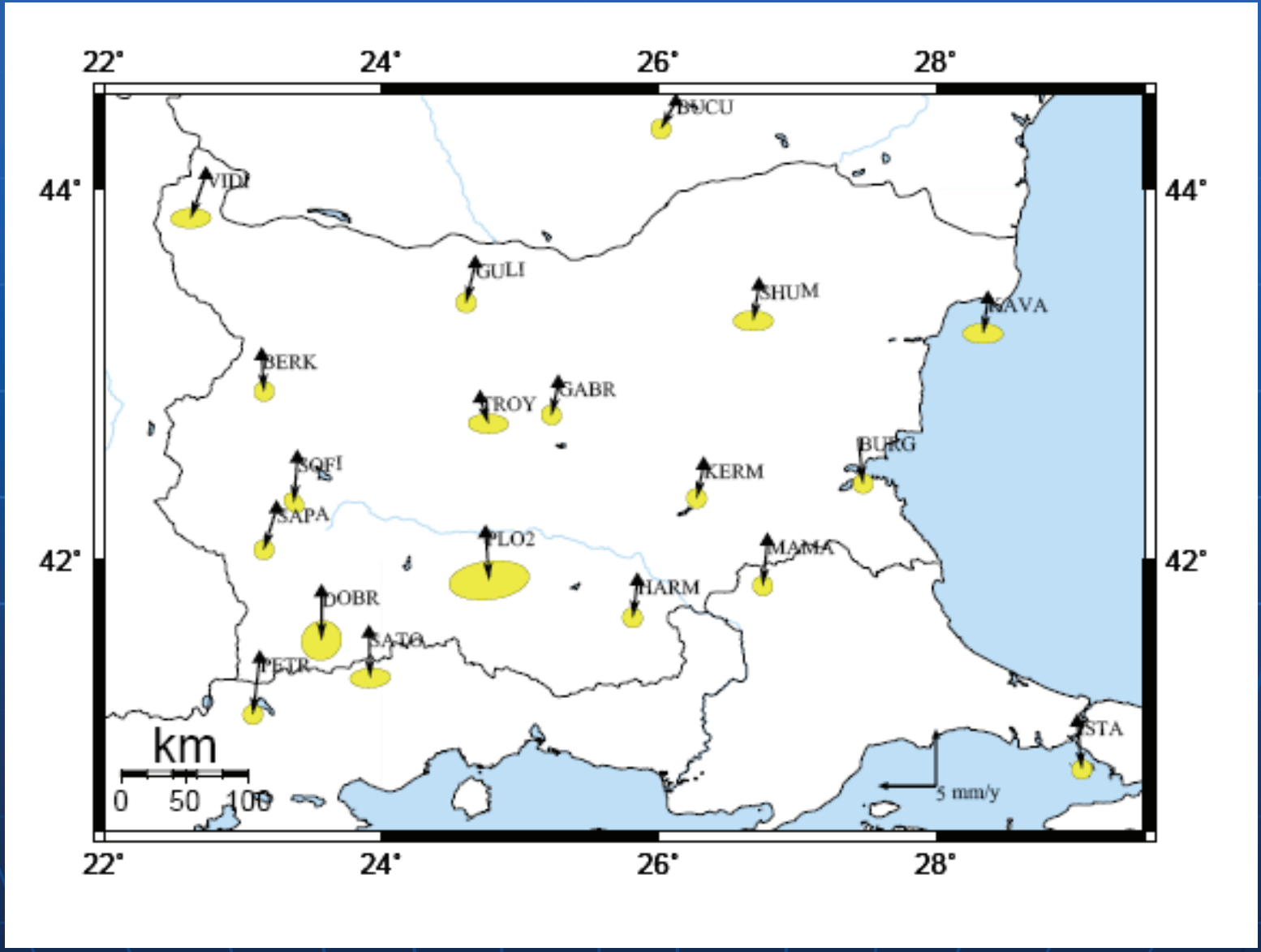
- Taking under consideration the determined velocities of the EUREF points in Bulgaria, the conclusion can be made that for a ten-year period their coordinates will be changed within values of the order of 2-4 cm. This is satisfactory for all applied applications in the geodetic practice.
- However, this does not mean that efforts must not be made for determining and monitoring of point velocities for the National GPS Network. This may be realized during special campaigns as well as during the regular maintenance of the National GPS Network.

The Bulgarian Geodetic System and the results from the processing of the National GPS Network of Bulgaria

- The determining of the point coordinates of the National GPS Network in the ETRS'89 reference system represents practically a densification of EUREF on the territory of Bulgaria.
- The results from the processing – the coordinates of the points in the ETRS'89 reference system, realization ETRF2000, epoch 2004.8, or the epoch that will be officially accepted, together with their velocities, are at the same time a realization of the Bulgarian Geodetic System (BGS) too, as described in the ordinance of the Council of Ministers.

SW'BG (South-West Bulgaria)
GPS geodynamic network




22°
24°
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SOFI
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MAMA
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DOBR
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km
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5 mm/y

CADASTRE AGENCY

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To

Dipl.-Eng. Helmut Hornik
EUREF Sub-commission Secretary

Prof..Zuheir Altamimi
Chair of the EUREF
Technical Working Group

According to: report of the results from processing of the Main and Secondary order National GPS Network of Republic of Bulgaria to the Technical Working Group

Dear Sirs

I would like to inform you that in Bulgaria in the years 2004 – 2005 GPS measurements of the new National GPS network were performed. The National network consists of Main (128 points) and Secondary (345 points) orders, all 473 points. The GPS measurements were implemented by the Military Topographic Department under the General Staff of the Bulgarian Armed Forces and were processed with Bernese software, version 5.0, in the Central Laboratory of Geodesy (CLG) at Bulgarian Academy of Sciences. The realization of this new network in Bulgaria is in practice densification of the EUREF and is a prerequisite for official adopting the ETRS in the country. According to Bulgarian legislation national responsible in geodesy is the Cadastre Agency.

In April, 2006 the Parliament passed the Law of Geodesy and Cartography in which is stated that in short period of time the Cadastre Agency would be renamed to National Geodetic, Cartographic and Cadastral Agency. To participate in the EUREF Symposium in Riga, June 14-17, and to present a paper about the results from processing of the GPS measurements of the new National GPS Network we recommend Assoc. Prof. Dr. Ivan Georgiev from the Central Laboratory of Geodesy.

I also would like to receive information about preparing the materials, which to be presented to the Technical Working Group. For contacts I am sending the e-mail of Assoc. Prof. Dr. Ivan Georgiev – ivan@argo.bas.bg.

Executive Director of Cadastre Agency

Dipl.-Eng. Tsveten Boev

GENERAL STAFF OF THE BULGARIAN ARMED FORCES
MILITARY TOPOGRAPHIC SERVICE

34, Totleben bul., Sofia, Bulgaria; phone: 0035929222320; fax: 0035929804691
e-mail: mts@md.government.bg

To Dipl.-Eng. Helmut Hornik
EUREF Sub-commission Secretary

Prof. Zuheir Altamimi
Chair of the EUREF
Technical Working Group

Dear Sirs,

According to new Law of Geodesy and Cartography, Military Topographic Service (MTS) is responsible for National GPS network. In the years 2004 – 2005 the GPS measurements were implemented by the MTS and were processed by the Central Laboratory of Geodesy at Bulgarian Academy of Sciences.

I will not attend at the EUREF Symposium in Riga, Latvia because of pressure of work and I recommend Assoc. Prof. Dr. Ivan Georgiev from the Central Laboratory of Geodesy to present a paper about the results from processing of the GPS measurements of the new National GPS Network.

Colonel Georgi Gladkov
Chief of the Military Topographic Service
of the Bulgarian Armed Forces