Slovak Terrestrial Reference Frame SKTRF 2001

– Its Computation and Connection to the EUREF –

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Abstract

Global positioning reference basis ETRS89, its model realization process on the territory of Slovakia by means of the Slovak Terrestrial Reference Frame SKTRF 2001 and its official connection to the EUREF points. Description of SKTRF as a homomorph model of a dynamic, stochastic, stage-by-stage built spatial geodetic network. Effective connection of stochastic, spatial and dynamic structures, with minimum loss of information obtained by GPS measurement with emphasis on the estimate of parameters and their linear functionals of the 1st and 2nd order of kinematic terrestrial reference frame.

1. Introduction

In geodetic practice the building of new geodetic control as far as its quality and significance are concerned, which fulfils most strict scientific requirements for the quality of information and unity in world-wide, that is also in the European extent, means a significant event and challenge which only rarely occurs. This challenge is to build a service, which will allow the positioning of objects and phenomena in real time with high precision and reliability in the European Terrestrial Reference System ETRS 89. Slovak Terrestrial Reference Frame SKTRF is also one of systematic steps towards such service.

2. Slovak Geodynamic Reference Network – SGRN

Basis of Slovakia's geodynamics research are repeated GPS measurements on the points of Slovak Geodynamic Reference Network (SGRN). Essentially it is about geo-kinematics, because for the research of geodynamics also forces effecting the given points should be researched. Repeated measurements on SGRN points were carried out in GPS observation campaigns SGRN '95, '98, '99, '00 and '01. They are described in detail in 2.2.

SGRN points are divided into the points of SGRN Permanent Observation Station (SPOS) and the points of SGRN Epoch Observation Station (SEOS). At present there are 47 SGRN points, three of which are SPOS points (MOPI-EPN, BBYS, PRES), the GANO point is being prepared as a point of permanent observation, in perspective to be included in EUREF Permanent Network (EPN) and 44 SEOS. Their configuration is given in the figure below fig. 1.

2.1 Establishing SGRN Points

SGRN points are located preferably in rock coming above to the ground and continuously passing into bedrock. In choosing such rock there was a close co-operation with a geologist. Into chosen rock special modules enabling forced centering of GPS antennas are permanently imbedded, which allows the elimination of centering error. In region without bedrock exceptionally also in-depth-embedded pillars established for other purposes, or markings of control stations by an iron bar nailed down were chosen. The depth of pillar's base or iron bar's nailing-down is 4 m as a minimum. To the top part of the pillar and the last part of the bar also centering modules for forced centering of GPS antennas were fixed. Sites of chosen rocks, pillars and iron bars meet the requirements for high-quality measurement, namely: undisturbed reception of signals from GPS satellites at elevation angle larger than 15°, access to the point by a terrain car.

2.2 Description of GPS Measurement Campaigns

Since 1993, when the first measurement in SGRN network was carried out, repeated measurements were performed in 1995, 1998, 1999, 2000 and 2001. List of points measured in single years is given in tab. 1.

SGRN campaign 1993

SGRN 93 measurement took place from 30 to 31 August and from 2 to 3 September 1993 on 17 points. The observation sessions lasted for 36 hours. For the measurement there were used exclusively equipments Trimble 4000 SST and 4000 SSE, antennas of the TRM14532.00 type. Processing results are given in (HEFTY, 1996).

SGRN campaign 1995

Since the number of 17 points from 1993 was not sufficient to cover the territory of Slovakia, in 1995 the network was densed to 42 points. During 26 September-5 October 1995 and 14-15 November 1995 the measurement of these points was carried out. There were used again only Trimble 4000 SST, 4000 SSE and 4000 SSi instruments and two types of antennas – TRM14532.00 and TRM22020.00+GP. The observation sessions lasted for 36 hours. Processing results are given in (HEFTY, 1996).

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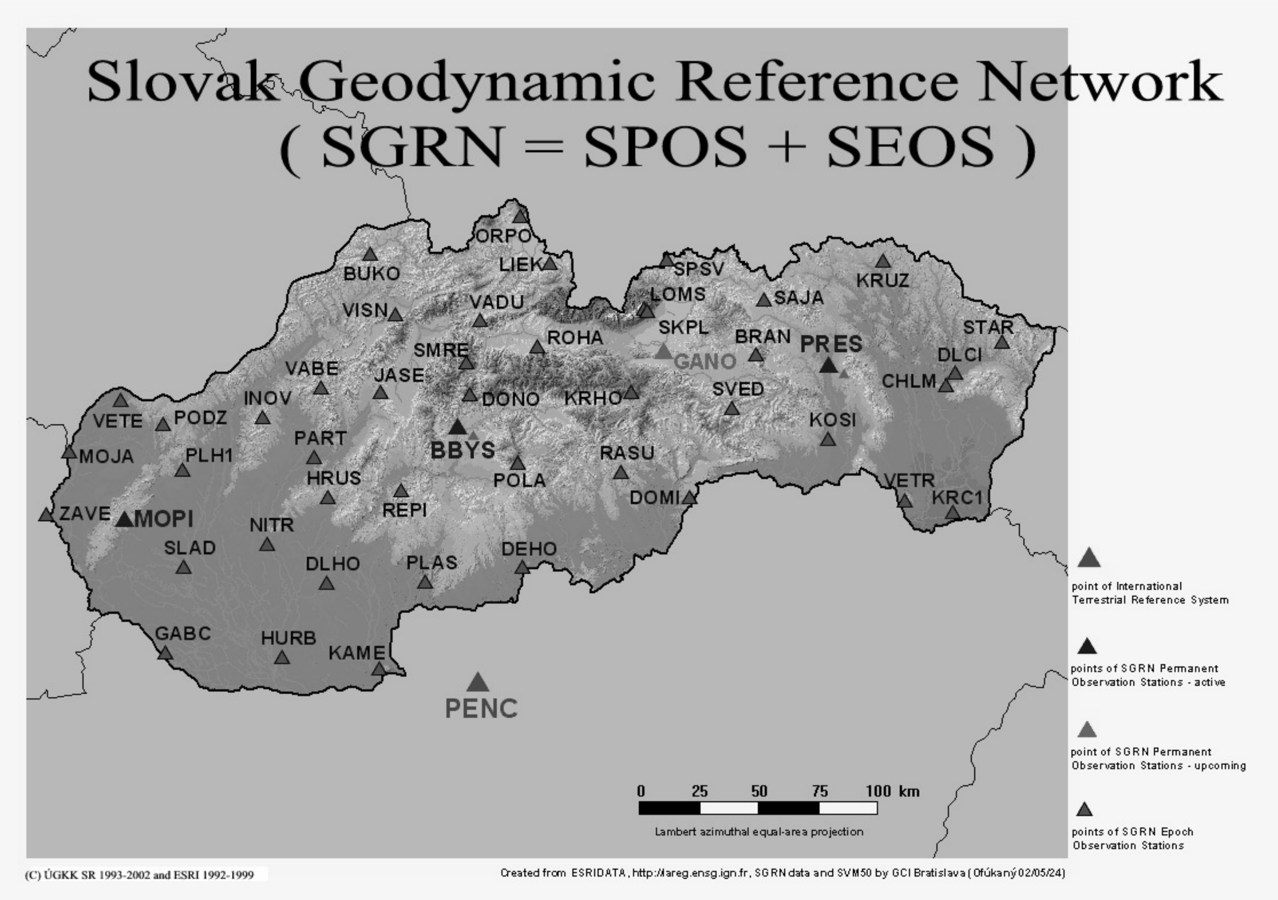

Fig. 1 Configuration of SGRN points

SGRN campaign 1998

Within the EXTENDED SAGET 98 international project measurement took place continuously on three SGRN points, namely: DEHO, SKPL and MOPI. This period of 26 June-1 July 1998 was used for measurement on certain points of SGRN. However, due to a small number of GPS instruments only 9 points were measured. The points were chosen in the way that allows repeated measurement of those which already had been determined in SGRN 93. Length of observation session was 24 – 30 hours. For the measurement the Trimble receivers 4000 SSE, 4000 SSi with antennas TRM22020+GP were used. Processing results are given in (LEITMANNOVÁ, 1998).

SGRN campaign 1999

In the period 20 – 24 September 1999 the SGRN 99 measurement was carried out. 42 points were measured, the length of observation session was 42 hours. For the measurement there were again used receivers Trimble 4000 SST, 4000 SSE and 4000 SSi with TRM14532.00 and TRM22020.00+GP antennas. Processing results are given in (LEITMANNOVÁ, 2000).

SGRN 2000 campaign

In the period 3 – 5 May 2000 and 25 – 27 July 2000 two campaigns of a smaller extent were carried out in the western part of the Slovakia territory, aimed at positioning four new SGRN points, namely: DEKO, HURB, MOJA and SLAD. Length of observation session was 50 hours. For the measurement there were used receivers Trimble 4000 SSE and 4000 SSi with TRM22020+GP and TRM33429.00+GP antennas. Processing results are given in (LEITMANNOVÁ, 2001).

SGRN 2001 campaign

SGRN 2001 campaign was carried out in the period 18 – 23 June 2001, when at the same time an international campaign CEGRN'01 was taking place within the Central European Regional Geodynamic Projects (CERGOP). From the territory of Slovakia five SGRN points participate in this project. Since 1994 they have been points: MOPI, SKPL, DEHO (in CERGOP it is designated as STHO) and since 1999 PART and DLCI (in CERGOP designated as KAME). In the campaign 38 SGRN points with the length of observation session 52 – 65 hours were measured. There were used receivers Trimble 4000SSE, 4000SSi and 4700 with TRM14532.00, TRM22020.00+GP, TRM33429.00+GP, TRM39105.00 and TRM41249.00 antennas. In order to eliminate uncertainties of a real position of the antenna phase centre the antennas were rotated through 180° in the middle of the measurement (except for the points measured within the framework of CERGOP) (LEITMANNOVÁ, KLOBUŠIAK 2001). Processing results are given in (LEITMANNOVÁ, 2002).

Tab. 1: List of SGRN points

	SGRN	*1993*	*1995*	*1998*	*1999*	*2000*	*2001*
I	Site	Time in hours					
1	BBYS				88		138
2	BRAN		36		42		52
3	BUKO		36		42		52
4	DEHO	36	36	126	42		120
5	DEKO					50	
6	DLCI						120
7	DLHO	36	36	25	42	50	47
8	DOMI	72	108	33	39		52
9	DONO		36		42		52
10	GABC		36		42	50	52
11	GANO				56		
12	HLOH		36		42		
13	HRUS		36		42		65
14	HURB					50	120
15	CHLM		36		42		24
16	INOV		36		42		
17	JASE		36		42		
18	KAME		108		42	50	16
19	KOSI	36	36				60
20	KRHO		36		42		55
21	KRC1				42		52
22	KRCH	36	36	31			
23	KRUZ	36	36	31	42		61
24	KVET		36				
25	LIEK				59		120
26	LIES	36	36				
27	LOMS				59		
28	MOJA					50	46
29	MOPI	72	36	168	120	72	144
30	NITR	36	36		42	50	45
31	ORPO		36		42		
32	PART				42		120
33	PLAS		36		42		75
34	PLH1				42	50	
35	PLHO	36	36	24			
36	PODZ		36		42		30
37	POLA		36		42		66
38	PRES						114
39	RASU				42		
40	REPI		36		42		74
41	ROHA		36	29	59		52
42	SAJA	36	36		42		
43	SAND	36	36				
44	SKPL	72	108	126	59		120
45	SLAD					50	67
46	SMRE		36		42		
47	SPHR	36	36				
48	SPSV						67
49	STAR		36		42		67
50	STRE	36	36				
51	SVED		36		76		52
52	VABE		36		42		
53	VADU		36		42		67
54	VEIN	36					
55	VETE		36		38	50	
56	VETR		36		42		67
57	VISN				42		67
58	ZAVE		36		42	50	43

2.3 Preprocessing of measurement campaigns using Bernese GPS software

In order to make possible the estimation of even very small changes in the position of geodynamic points, which within the framework of Euroasian lithospheric plate reach only several mm in a year, it is necessary to use a unified method of processing. For processing all campaigns in SGRN the Bernese university software (HUGENTOBLER et al., 2001) was used, developed by the Astronomical Institute of the University of Bern. For processing the following strategy was used, given Tab. 2.

All SGRN 1993 – 2001 campaigns were solved independently as free network solutions. Connection to ITRFyy was provided by constraining the coordinates of one IGS point, namely GRAZ (in 2001 point PENC) with a priori sigma *0.0001* m. By setting the condition of such a high a priori sigma for X,Y,Z coordinates of the point a stable connection of SGRN to ITRFyy was actually secured. The coordinates of the reference point were shifted to the epoch of measurement using known values of velocities of the motion in ITRFyy.

Such way of connection is advantageous for geodynamic analyses of the network, since neither shape nor scale of the net are deformed.

In the processing of all SGRN campaigns there were included also the observations on IGS (International GPS Service for Geodynamics) European permanent stations. The purpose of common processing of SGRN and stations of IGS is to secure the transformation of points SGRN to ITRFyy, or ETRFyy (European Terrestrial Reference Frame), where *yy* means the epoch of measurement. Summary of these points is given in Tab. 3.

Tab. 2: Processing strategy

interval of measurements	30s
precise orbits	1993-1999; precise orbits from CODE, parameters of Earth rotation (IERS), since 2000: precise orbits of final IGS with corresponding parameters of the Earth rotation
tropospherical effects	1993-1999; Saastamoinen's a priori model and estimate of one troposphere zenith-delay parameter for every point with 2-hour interval and a priori sigma 0.10 m for absolute and 0.01 m for relative parameters since 2000: unused a priori model of troposphere, total trop. parameters in zenith estimated using dry-Niell mapping function for every 2-hour interval with a priori sigma 5m for absolute and 5m for relative parameters, option used for observations: elevation-dependent weighting $\cos^2 (z)$ since 2001: for IGS points included into the processing a troposphere model from the CODE global solution
ionospherical effects	elimination using linear combination L3
corrections of antenna phase centres (APC)	known models of eccentricities and variations from the file phas-igs.01 were applied *ftp://igscb.jpl.nasa.gov/igscb/station/general/igs 01.pcv* *http://www.grdl.noaa/GRD/GSP/Projects/ANTCAL/Files/ant.-info.003* since 2000 for antennas tested at GCI our own values of eccentricities APC were applied
ambiguity solutions	estimate of integer values of ambiguities using Quasi Ionosphere Free (QIF) method for each single baseline from all observations, then ELIMIN for all-day solution also from every observation SAMPLING RATE:0
correlations	option for correct modelling of correlations was used
estimate of unknown parameters	independent solution for every day of measurement using GPSEST program, combination of normal equations from daily solutions to the common solution of the whole campaign using ADDNEQ program

Tab. 3: IGS sites used for connection SKTRF to ITRF

Id.	Name of point	Country	SGRN 93	SGRN 95	SGRN 98	SGRN 99	SGRN 2000	SGRN 2001
BOR1	Borowiec	Polsko				X	X	X
GOPE	Pecný	Cesko					X	X
GRAZ	Graz	Rakúsko	X	X	X	X	X	X
JOZE	Jozefoslaw	Polsko	X	X	X	X	X	X
KOSG	Kootwijk	Holandsko	X			X		
MATE	Matera	Taliansko	X	X	X			
METS	Metsahovi	Fínsko	X		X	X		
ONSA	Onsala	Švédsko	X	X	X	X		
PENC	Penc	Malarsko					X	X
UZHL	Uzhorod	Ukrajina					X	X
WETT	Wettzell	SRN	X	X				
WTZR	Wettzell	SRN			X	X		

3. Slovak Terrestrial Reference Frame – SKTRFyy

Every geodetic network laid-out both on the Earth's surface and underground is effected by geodynamic forces. Once this fact is not taken in account, motions of the points will be interpreted as measurement errors. For simultaneous effective estimate of motion equations and coordinates of the control points measured using GPS technology a mathematical model (KLOBUSIAK, 1997c), (HEFTY, 1998c) and (ROGOWSKI, HEFTY et al. 1998), (HEFTY, 2001) and its realization using the WIGS program system (KLOBUSIAK, 1995-2002) have been proposed. The procedure describes factors considered in the mathematical model, their parameters, and there are formulated equations of functional dependence of measured quantities on the parameters of the mathematical model and their co-variance matrix. From the above-mentioned papers there was set-up a complete mathematical model of the effective estimate of the coordinates of newly-determined points, of local motions of repeatedly measured non-identical points, of the estimate of nuisance parameters of a systematic effect of the deterministic character of every single campaign and of correction parameters of points eccentricity, if they have occurred.

3.1 Mathematical Model of Creating SKTRF

In building a national representative of a kinematic terrestrial reference frame in ETRS89 system there has been respected the fact that an object on which the system is realized using reference points (SGRN) is a dynamic one. In realizing the national kinematic terrestrial reference frame the motion of the points has been considered in respect of time.

Another problem that has been respected is a stochastic phenomenon of the xTRFyy terrestric frame. The coordinates of reference points are, in addition to temporal dependence, also random quantities.

We are forced to build National Spatial Network (NSN) stage-by-stage (K UBICEK, 1986) because it is to be extended (FERIANC, 2000) on the territory of Slovakia in the density and quality required. Results must be the same as if NSN would have been built at the same time. Basic criterion of NSN building was jointed effectivity, reliability and unbiasedness.

Description of a dynamic, stochastic, stage-by-stage built model of the kinematic frame

Basis of the kinematic terrestrial reference frame description is a definition of the mathematical model of geodetic network (GN), fulfilling all modern probabilistic requirements. Model (1) gives a description and a model of all important conceptual factors of the network.

In 1978 Kubicek described a mathematical model of a modern GN (K UBICEK 1978, p. 64). Analogy of the stochastic modelling of information in GN given in references that are not entirely complete (KUBICKOVI, KUBICEK, KUKUCA 1982), (KUBICEK, PIZMAN 1979), (KUBICEK 1983), (KUBICEK, KUBICKOVI, VOLAUFOVI 1995) was applied also in the definition of a homomorphic model of a dynamic, stochastic, stage-by-stage built SKTRF. For its description the following model was applied

$$\left\{\boldsymbol{\kappa}^0, \boldsymbol{h}, [U_i,\ \zeta_i, N_i,\ \xi_i,\ \beta_i]_{i=0}^{s}, \boldsymbol{F}\right\} \qquad (1)$$

where $\boldsymbol{k}/$ Î Â^{6n} is a configuration vector $\boldsymbol{k}/ = (X/_1, Y/_1, Z/_1, r_{X1}, r_{Y1}, r_{Z1}, \ldots, X/_n, Y/_n, Z/_n, r_{Xn}, r_{Yn}, r_{Zn})$¢ defined by at least appoximate 3D coordinates of GN points and by their annual velocities, $\boldsymbol{h}$: Â^{6n} ® Â^{m} where representation of $\boldsymbol{Q} = \boldsymbol{h}(\boldsymbol{k})$, by which to the real coordinates of GN points $\boldsymbol{k} = \boldsymbol{k}/ + d\boldsymbol{k}$ a vector parameter of the network $\boldsymbol{Q} = (Q_1, \ldots, Q_m)$¢ is added using function $\boldsymbol{h}$, U_i is an identification set for i-epoch, $i = 0, 1, \ldots, s$, while if $i=0$ it is a chosen reference frame xTRFyy and if $i=1, \ldots, s$, they are campaigns of GPS observations, z_i is a structure, design, project of i-epoch, whose spectrum $Sp(z_i)$ defines a set of the GN nodes that are simultaneously observed using GPS technology, N_i is a natural number indicating the number of performed measurements for each stage, or the length of observation (time investment, or "sampling rate"), $\boldsymbol{x}_i$ is a random vector obtained by processing i-campaign of GPS as a free network (KLOBUŠIAK 1996), (BROCKMANN 1997), (ROGOWSKI, HEFTY a i. 1998), $\boldsymbol{b}_i$: Â^{ti} ® Â^{mi} is a representation that defines the method of processing and connecting GPS campaigns, if in estimates $\boldsymbol{b}_i$ instead of $\boldsymbol{Q}^{(0)}, \boldsymbol{Q}^{(1)}, \boldsymbol{Q}^{(2)}, \ldots, \boldsymbol{Q}^{(i)}$ the estimates are used, $\boldsymbol{b}_0(\boldsymbol{x}_0)$, $\boldsymbol{b}_1(\boldsymbol{x}_1, \boldsymbol{b}_0)$, $\boldsymbol{b}_2(\boldsymbol{x}_2, \boldsymbol{b}_1)$, ..., $\boldsymbol{b}_i(\boldsymbol{x}_i, \boldsymbol{b}_{i-1})$, since if conditions of linearity, jointed effectivity and unbiasedness are observed it must be valid that (KUBICEK 1986, p. 96) $\boldsymbol{b}_i(\boldsymbol{x}_i, \boldsymbol{b}_{i-1}) = \boldsymbol{b}(\boldsymbol{x}_0, \boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_i)$, $\boldsymbol{F}$ is a class of parameter $\boldsymbol{Q}$, functions which may be considered in using SKTRF (positioning, kinematics, geodynamics etc.).

In this place we would also like to mention the SKTRF mathematical model defined in this way allows the full study and use of the structure z optimum, $\boldsymbol{b}$ estimate optimum and reliability of the SKTRF as a stochastic model. Estimates of the parameters values $\boldsymbol{Q}$ will always be considered as a realization of this stochastic object.

Motion of a point and its functional expression in xTRFyy frame

Background of the GPS campaigns processing carried out in Slovakia and their connection to the international reference frame xTRFyy (where x Î {I, E, C}, yy is an epoch of the reference frame, I means International, E-Europe, C-Central Europe) must be the acceptance of a kinematic model of the network as a minimum. xTRFyy represents the realization of such model and therefore it represents a kinematic and stochastic large-space standard. Using Fig.2 there is represented a schematic idea of connecting new GPS campaign to a kinematic standard respecting its above-given characteristics.

The aim is to describe the motion of a point with a motion equation. Significance of the point motion is modelled in kinematic models. It means in the models in which we are interested only in direction and magnitude of the motion. Reason of this motion cannot be stated by such model.

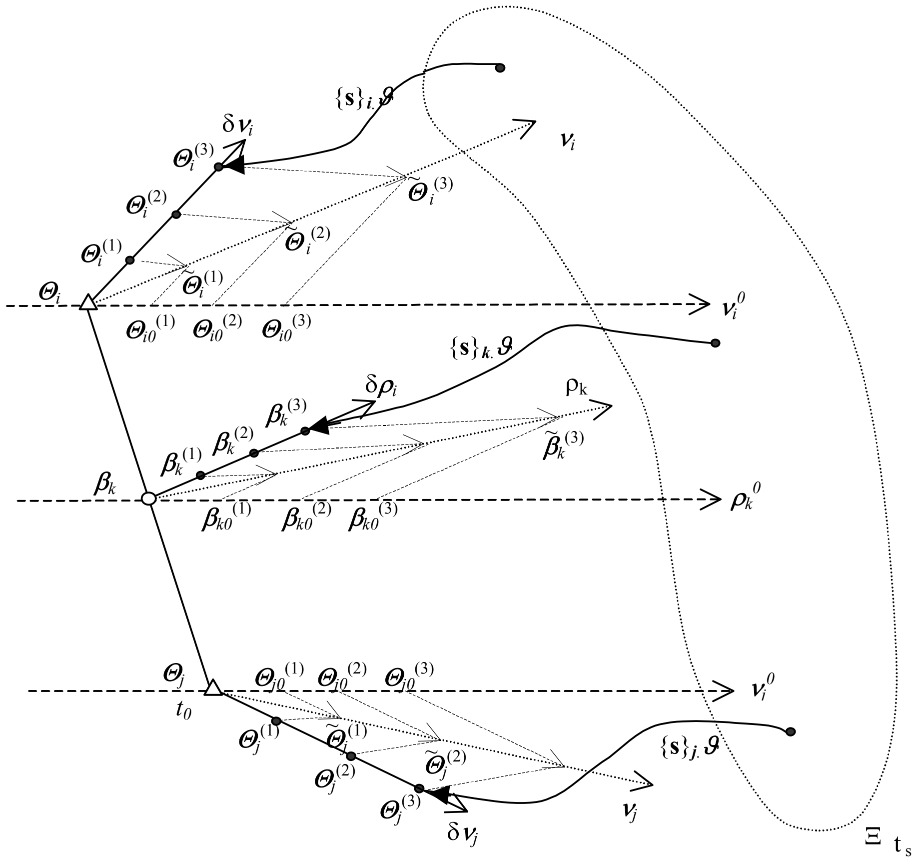

Fig. 2 Connection of a campaign to the points of a kinematic standard

From the Fig.2 the motion equations of three points *i,j,k* represented by parameters Q_i, Q_j, b_k are evident.

$$
\begin{aligned}
\xi_{i_{t_s}} &= \Theta_i + (t_s - t_0)(\nu_i^0 + \delta\nu_i) + \{\mathbf{S}\}_{i,.}\vartheta + \varepsilon_{i_{t_s}} \Rightarrow E[\xi_{i_{t_s}}] = \widetilde{\Theta}_i^{(t_s)} \\
\xi_{j_{t_s}} &= \Theta_j + (t_s - t_0)(\nu_j^0 + \delta\nu_j) + \{\mathbf{S}\}_{j,.}\vartheta + \varepsilon_{j_{t_s}} \Rightarrow E[\xi_{j_{t_s}}] = \widetilde{\Theta}_j^{(t_s)} \qquad (2) \\
\xi_{k_{t_s}} &= (\beta_k^0 + \delta\beta_k) + (t_s - t_0)(\rho_k^0 + \delta\rho_k) + \{\mathbf{S}\}_{k,.}\vartheta + \varepsilon_{k_{t_s}} \Rightarrow E[\xi_{k_{t_s}}] = \widetilde{\beta}_k^{(t_s)}
\end{aligned}
$$

where

Ξ_{t_s} is a GPS campaign determined in the epoch t_s as a free network solution represented by the vector of coordinates ξ_{t_s} and its global co-variance matrix (GCM) $\mathbf{S}_x$, $E[x]$ is an operator of the mean value of the random variable x, $\widetilde{\Theta}_i^{(t_s)}$ are the coordinates of the global position of the reference point determined in time t_s, $\Theta_i^{(t_s)}$ are the coordinates of the local position of the reference point determined in time t_s, $\widetilde{\beta}_k^{(t_s)}$ are the coordinates of the global position of the point determined in time t_s, $\beta_k^{(t_s)}$ are coordinates of the local position of the point determined in time t_s, ξ is a measured quantity , $\Theta_{i,j}$ is a reference coordinate of the point *i, j* in the defined reference frame *x*TRF*yy*, $(\beta_k^0 + \delta\beta_k)$ is the point *k* coordinate being newly determined, t_0 *and* t_s is a basic time of the reference frame (epoch t_0) and the time of s-epoch observation, $\nu_{i,j}^0$ is a model motion of the points *i, j* of the reference frame determined from the model NNR-NUVEL1A, $\delta\nu_{i,j}$ is a local-differential motion of the points *i, j* with respect to the model motion $\nu_{i,j}^0$, $\nu_i = \nu_i^0 + \delta\nu_i$ is a reference frame point global motion, ρ_k^0 is a new point model motion, $\delta\rho_k$ is a new point local-differential motion estimated from repeated measurements, $\mathbf{S}\,\vartheta$ is an effect (using orthogonal transformation) of the connection of two non-identical realizations of reference systems of campaigns ***x*** and reference frame ***Q***, ***e*** is a measurement error, *i, j =1,2, ..., p* are indexes of the reference frame points, where *p* is a number of the reference frame points and finally *k = 1,2, ... , r* is an index of the point being newly determined, where *r* is a number of points being newly determined.

Factors considered in the mathematical model of a national kinematic terrestrial reference frame and their parameters

1. Coordinates of reference points in the defined epoch e.g. ITRF96 epoch 1997.0, ITRF2000 epoch 1997.0, ETRF93 epoch 1989.0, ETRF89 epoch 1989.0, CETRF94 epoch 1995.42 and the like. Parameter ***Q***.
2. Reference point motion equations (velocities) defined by the reference frame *x*TRF*yy*. Parameters ***n***. The parameter of velocity can be divided into a model velocity of the whole tectonic lithospheric plate from NNR-NUVEL1A ***n***/ and a local velocity (differential motion) of the point ***dn***. It is valid ***n = n***/+ ***dn***.
3. Estimated velocities of non-identical points ***r***. The vector of the global velocity of non-identical points ***r*** can be divided into the sum of model ***r***/ and local-differential

velocity $d\boldsymbol{r}$, $\boldsymbol{r} = \boldsymbol{r}/ + d\boldsymbol{r}$.

4. Estimate of the coordinates *XYZ* of non-identical points. Parameter $\boldsymbol{b}$.
5. Transformation of the *j*-epoch of the network, which has been obtained by processing the measurement campaign as a free network, into a reference frame, e.g. *x*TRF*yy*. Transformation parameters $\boldsymbol{J}_j$ are nuisance parameters. It is possible to use orthogonal *7, 6, 4, 3* parametric similar transformation. Parameters $\boldsymbol{J}_l$ and $\boldsymbol{J}_k$, where $l = 0, 1, \ldots, s, k = 0, 1, \ldots, s$ & $l^1 k$ are mutually independent, i.e. parameters $\boldsymbol{J}_l$ or $\boldsymbol{J}_k$ have impact only on the parameters $\boldsymbol{Q}$, $\boldsymbol{b}$, $\boldsymbol{r}$, $\boldsymbol{n}$ of the epoch *l* or *k*.
6. Uncertainty in determining the centricity of the point. In case in some epochs there was the influence resulting in the eccentricity of the point, then such an inconsistency of the non-identity of the point is modelled by unknown parameters of eccentricity $\boldsymbol{c}$ (KLOBUŠIAK 1996, 1997a,b), (HEFTY 1998c, 2001).

Equation of the i-campaign measured quantities functional dependence on the parameters of a kinematic model and its co-variance matrix

$$\xi_i = \mathbf{F}_i \boldsymbol{\tau} + \mathbf{L}_i \boldsymbol{\gamma} + \varepsilon_i \,, \tag{3}$$

where $i = 0, 1, 2, \ldots, s$ is a designation of epoch ; $\mathbf{F}_i = [\mathbf{X}_i, \mathbf{D}_i]$, $\mathbf{L}_i = [\mathbf{R}_i, \mathbf{B}_i, \mathbf{S}_i, \mathbf{K}_i]$, $\mathbf{t}¢ = (\boldsymbol{Q}¢, \mathbf{n}¢)$, $\boldsymbol{g}_i¢ = (\boldsymbol{r}¢, \boldsymbol{b}_i¢, \boldsymbol{J}_i¢, \boldsymbol{c}_i¢)$. It is valid $\boldsymbol{t} = \boldsymbol{t}/ + d\boldsymbol{t}$ a $\boldsymbol{g}_i = \boldsymbol{g}/_i + d\boldsymbol{g}_i$.

Now if a model global motion taken from the model NNR-NUVEL1A is considered, then for parameters $\boldsymbol{n}$ and $\boldsymbol{r}$ it is valid

$$\boldsymbol{n} = \boldsymbol{n}/ + d\boldsymbol{n} \text{ a } \boldsymbol{r} = \boldsymbol{r}/ + d\boldsymbol{r}. \tag{4}$$

The equation (3) can be re-written

$$\xi_i = \mathbf{F}_i \tau^\circ + \mathbf{L}_i \gamma^\circ + \mathbf{F}_i \delta\tau + \mathbf{L}_i \delta\gamma + \varepsilon_i \,. \tag{5}$$

For co-variance matrix of the realizations vector $\boldsymbol{x}_i$ gained by the processing using Bernese GPS software (ROTHACHER, MERVART 1996) we obtain

$$\Sigma_{\varepsilon_i} = \Sigma_{\xi_i} = \sigma_i^2 \mathbf{H}_i \,.$$

The parameters $\boldsymbol{t}$ and their co-variance matrix $\mathbf{S}_t$ are defined by the reference frame *x*TRF*yy* epoch $t/$. For reference point motion realization it is valid (4), then for co-variance matrix of this vector it is valid $\boldsymbol{\Sigma}_v = \boldsymbol{\Sigma}_{\delta v}$, because $\boldsymbol{n}/$ is a deterministic component in our model.

The equation (5) will change to the form:

$$\boldsymbol{\eta}_i = \mathbf{F}_i \delta\boldsymbol{\tau} + \mathbf{L}_i \delta\boldsymbol{\gamma}_i + \boldsymbol{\varepsilon}_i \,, \tag{6}$$

where

$$\boldsymbol{\eta}_i = \boldsymbol{\xi}_i - \mathbf{F}_i \boldsymbol{\tau}^\circ - \mathbf{L}_i \boldsymbol{\gamma}^\circ . \tag{7}$$

For covariance matrix of a reduced random vector $\boldsymbol{\eta}_i$ we obtain

$$\Sigma_\eta = \Sigma_{\xi_i} + \mathbf{F} \Sigma_\tau \mathbf{F}' - Cov(\xi_i, \mathbf{F}\tau) - Cov(\mathbf{F}\tau, \xi). \tag{8}$$

Purism in computing GCM and its specific characteristics with emphasis on a minimum loss of statistical information is not an end in itself (KLOBUŠIAK, 1999a p. 6-8).

A complete mathematical model of an efficient estimate of newly-determined point coordinates, local motions of repeatedly measured non-identical points, nuisance parameters of the systematic influence of deterministic character of every campaign and point eccentricity corrections

A complete model is based on the efficient stochastic model of the networks connection (KLOBUŠIAK, 1996, 1997, 1998, 1999) and its extension with additional factors. The complete mathematical model is described as follows

$$\boldsymbol{\xi} = \mathbf{F}\boldsymbol{\tau} + \mathbf{L}\boldsymbol{\gamma} + \boldsymbol{\varepsilon} \,, \tag{9}$$

where for covariance matrix of the vector of realizations $\boldsymbol{\xi}$ it is valid

$$\Sigma_\xi = \sigma_0^2 \mathbf{H} \,. \tag{10}$$

Structure and dimensions of the matrixes and vectors used are:

$\mathbf{F} = [\mathbf{X}, \mathbf{D}]$, $\mathbf{L} = [\mathbf{R}, \mathbf{B}, \mathbf{S}, \mathbf{K}]$, $\mathbf{t}¢ = (\boldsymbol{Q}¢, \mathbf{n}¢)$,

$\gamma' = (\rho', \beta', \vartheta', \chi')$, $\xi' = (\xi_0', \xi_1', \ldots\ldots, \xi_s')$; $\xi \in \Re^m, m = \sum_{i=0}^{s} m_i$,

$\mathbf{X}' = [\mathbf{X}_0', \mathbf{X}_1', \ldots\ldots, \mathbf{X}_s']$, $\mathbf{X} \in M_{\mathrm{m,p}}$, $\mathbf{X}_i \in M_{m_i,p}$;

$\mathbf{D}' = [\mathbf{D}_0', \mathbf{D}_1', \ldots\ldots, \mathbf{D}_s']$ & $\mathbf{D}_0 = 0$; $\mathbf{D} \in M_{\mathrm{m,u}}$,

;$\mathbf{R}' = [\mathbf{R}_0', \mathbf{R}_1', \ldots\ldots, \mathbf{R}_s']$ $\mathbf{R}_0 = 0$; $\mathbf{R} \in M_{\mathrm{m,r}}$ $\mathbf{R}_i \in M_{m_i,r}$

$\mathbf{B}' = [\mathbf{B}_0', \mathbf{B}_1', \ldots\ldots, \mathbf{B}_s']$, $\mathbf{B} \in M_{\mathrm{m,n}}$, $\mathbf{B}_i \in M_{m_i,n}$;

$\mathbf{S}' = Diag(\mathbf{S}_0', \mathbf{S}_1', \ldots\ldots, \mathbf{S}_s')$ & $\mathbf{S}_0 = \mathbf{0}$; $\mathbf{S} \in M_{\mathrm{m,t}}$,

$\mathbf{S}_i \in M_{m_i,t_i}$; $\mathbf{K}' = [\mathbf{K}_0', \mathbf{K}_1', \ldots\ldots, \mathbf{K}_s']$ & $\mathbf{K}_0 = \mathbf{0}$; $\mathbf{K} \in M_{m,k}$,

$\mathbf{K}_i \in M_{m_i,k}$, $\mathbf{H} = Diag(k_0 \mathbf{H}_0, k_1 \mathbf{H}_1, \ldots\ldots, k_s \mathbf{H}_s)$, $\mathbf{H} \in S_{m,m}$,

$\mathbf{H}_i \in S_{m_i,m_i}$, where $k_i = \sigma_i^2 / (q_i \sigma_0^2)$, q_i is used "*sampling rate*" ; $\beta' = (\beta_0', \beta_1', \ldots\ldots, \beta_s')$, $\beta \in \Re^n, n = \sum_{i=0}^{s} n_i$; $\vartheta' = (\vartheta_0', \vartheta_1', \ldots\ldots, \vartheta_s')$ & ϑ_0' is not defined, $\vartheta \in \Re^t, t = \sum_{i=1}^{s} t_i$, $\vartheta_i \in \Re^{t_i}$, $i = 0, 1, \ldots, s$.

Description of the model objects meanings (9): *i* is an epoch of the group points measurement, *i = 0* is a basic epoch of the reference frame *x*TRF*yy*, *i = 1, 2, ... , s* are epochs of the repeated measurement of points, $\mathbf{X}_i$ (m_i, p) is a design matrix creating the relations between a random vector $\boldsymbol{x}_i$ and the parameters of identical points $\boldsymbol{Q}$, m_i is a number of realizations in *i*-epoch, *p* is a number of the identical points parameters, $\mathbf{D}_i$ (m_i, u) is a design matrix creating the relations between the vector $\boldsymbol{x}_i$ and the parameters of defined velocities $\boldsymbol{n}$ on identical points, *u* is a number of defined velocities parameters, $\mathbf{R}_i$ (m_i, r) is a design matrix creating the relations between the observation vector $\boldsymbol{x}_i$ and the parameters of chosen points motion equations $\boldsymbol{r}$, *r* is a number of all annual velocities parameters, $\boldsymbol{r}(r)$ is a vector of the motion equations parameters and it is the aim of effective estimate, $\mathbf{B}_i$ (m_i, n_i) is a plan matrix creating the relations between the vector $\boldsymbol{x}_i$ and the parameters (coordinates) of non-identical points. Non-identical points result from densifying the existing set of points, n_i is a number of the non-identical points parameters of *i*-epoch, $\mathbf{S}_i$ (m_i, t_i) is a design matrix of the campaigns transformation-connection with target reference frame, creating the relations between the vector $\boldsymbol{x}_i$ and the transformation parameters $\boldsymbol{J}_i$. As transformation relations can be taken an orthogonal 7, 6, 4, 3 element similar transformation, t_i is a number of transformation parameters. Every epoch can have different number of parameters estimated. In general it can be valid that t_i ¹ t_j, $\mathbf{K}_i\,(m_i, k)$ is a design matrix of *i*-epoch creating the relations between the vector $\boldsymbol{x}_i$ and the eccentricity parameters of point $\boldsymbol{c}$, k is a total number of eccentricity parameters, $\mathbf{H}_i$ is co-factor matrix of the random vector's $\boldsymbol{x}_i$ GCM, k_i expresses the ratio of the *i*-campaign dispersion

σ_i^2 with a product of the reference frame dispersion $\left(q_i \sigma_0^2\right)$ and the coefficient q_i, where q_i is a coefficient eliminating different "*sampling rate*".

1. SKTRF 2001 Points Coordinates and Annual Velocities Determination

The SGRN kinematic terrestrial reference frame 2001 (SKTRF 2001) represents part of a spatial reference system. For (NSN) and additional positioning purposes it is under stood as a positioning standard. It is created from connecting, or transforming the solution of SGRN to the ITRFyy and then to the ETRFyy.

All repeated epoch measurements on the points of SGRN carried out in the period 1993-2001 were entered in the common processing of the estimate of coordinates and annual velocities of points in one model. They are especially the campaigns (see Tab. 4).

- SGRN 1993 – 2001 (6x),
- CEGRN 1994 – 2001 campaigns (6x) (Hefty, 2001)
- TATRY 1998 – 2001 campaigns (4x) – a local geodynamic network,
- WHS 2001 campaign (1x) (World Height System).

Tab. 4: GPS campaigns on SGRN points

Project	Epoch of measurement t	Length of observations in hours	Number of SGRN points	Reference frame	Reference point
ITRF2000	1997	permanent		ITRF2000	
SGRN'93	199366	36	17	ITRF94	GRAZ
CEGRN'94	1994.34	120	3	ITRF92	GRAZ
CEGRN'95	199541	120	3	ITRF92	GRAZ
SGRN'95	199574	36	42	ITRF94	GRAZ
CEGRN'96	199645	120	3	ITRF94	GRAZ
CEGRN'97	199743	120	3	ITRF94	GRAZ
SGRN'98	199848	24 – 30	15	ITRF96	GRAZ
TATRY'98	199867	72	6	ITRF96	ROHA
CEGRN'99	199945	120	5	ITRF97	GRAZ
SGRN'99	199972	42	42	ITRF97	GRAZ
TATRY'99	1999.73	72	6	ITRF97	ROHA
SGRN'00-1st part	2000.34	48	6	ITRF2000	GRAZ
SGRN'00-2nd part	200057	52	11	ITRF2000	GRAZ
TATRY'00	200078	72 – 90	5	ITRF2000	ROHA
CEGRN'01	200146	120	5	ITRF2000	GRAZ
SGRN'01	2001.46	55 – 62	38	ITRF2000	PENC
TATRY'01	2001.69	72	6	ITRF2000	ROHA
WHS'01	2001.75	96	11	ITRF2000	PENC

CERGOP project is focussed on the long-term GPS monitoring of tectonic processes in the Central European region by means of a high quality network of the CEGRN points. Five points from the SGRN network are part of the CEGRN network. By using CEGRN and SGRN in the common processing the more real estimate of a kinematic model of tectonic processes on the territory of Slovakia will be obtained, related to the neighbouring territory of the Central European region.

As a target reference system the ITRF2000, epoch 1997.0 with the selected sub-set of points in Tab. 3 was used, in which mean values of the IGS points coordinates and their motion velocities are defined.

The processing was carried out in accordance with following principles:

1. all campaigns enter the processing as free network solutions after the pre-processing using Bernese GPS software with constraining the coordinates of one IGS point with a priori sigma *0.0001* m,
2. 7-parameter linear transformation for connecting free networks is used,
3. the target reference frame ITRF2000 epoch 1997.0 has the coordinates of IGS reference points (they act as a standard) fixed, but their inaccuracy considered in GCM is respected, which will influence the estimates of the national reference frame points coordinates and their RMS.

The estimate of SGRN points coordinates, co-variance matrix as well as the estimate of their global and local motion was carried out according to the mathematical model (9) described in chap. 3.1.

Into the processing was included IGS site PENC as a control site. In Tab. 5 are compared the official ITRF 2000 values with computed ones. Since these differences are considered insignificant, in final solution there was used site PENC as IGS reference site.

Tab. 5: Comparison of coordinates on IGS site PENC

SKTRF 2001 in ITRF 2000				ITRF 2000		differences			
site		epoch 1997.0 [m]	RMS [mm]	epoch 1997.0 [m]	RMS [mm]	d*X* / d*Y* / d*Z* [mm]	RMS [mm]	dn / de / du [mm]	RMS [mm]
PENC	*X*	4 052 449.622	0.7	4 052 449.626	2.6	3.9	2.7	-0.3	0.1
	Y	1 417 680.986	0.3	1 417 680.986	1.2	0.7	1.2	0.7	0.2
	Z	4 701 407.034	0.8	4 701 407.038	3.1	4.0	3.2	5.6	4.4

5. Transformation of SKTRF 2001 to ETRS 89

Transformation from ITRF 2000 to ETRS 89 was carried out on the basis of *Specifications for reference frame fixing in the analysis of a EUREF GPS campaign* (Boucher, Altamimi, 2001):

The results of SKTRF 2001 computed in above described way were compared with the results of EUVN 1997 GPS campaign (Ineichen et al., 1998). See Tab. 6.

Tab. 6: Comparison of coordinates on EUVN sites

SKTRF 2001 in ETRS 89				EUVN in ETRS 89		differences			
site		epoch 1997.4 [m]	RMS [mm]	epoch 1997.4 [m]	RMS [mm]	d*X* / d*Y* / d*Z* [mm]	RMS [mm]	dn / de / du [mm]	RMS [mm]
GANO	*X*	3 929 173.041	6.7	3 929 173.045	0.5	4.1	6.7	-3.3	0.2
	Y	1 455 278.650	2.8	1 455 278.647	0.2	-3.3	2.8	-4.4	0.5
	Z	4 793 644.403	8.0	4 793 644.401	0.6	-1.9	8.1	0.3	10.8
KAME	*X*	4 062 233.405	2.4	4 062 233.403	0.5	-2.0	2.4	0.1	0.2
	Y	1 377 316.070	0.9	1 377 316.074	0.2	4.2	0.9	4.3	1.2
	Z	4 704 896.481	2.7	4 704 896.483	0.6	2.3	2.8	3.0	3.6

We propose to integrate into the EUREF database ten selected points from the amount of 47 SGRN points. Their coordinates, annual velocities and RMS in ETRS 89 are given in Table 7.

Tab. 7: ETRS 89 coordinates and velocities of proposed sites

SKTRF 2001 in ETRS 89, reference frame ETRF2000, epoch 1997.0									
site	epoch	number of campaigns		coordinates [/ ' "] / [m]	RMS [mm]	global velocity [mm/y]	local velocity [mm/y]	RMS [mm/y]	monumentation
BBYS	1997.0	4	*B*	48 45 6.47591	1.0	14.9	2.6	0.3	pillar prepared for EPN
			L	19 9 3.59484	0.8	21.1	-0.3	0.2	
			H	487.427	5.6	-2.6	-2.7	1.5	
			X	3 980 359.143	3.6	-19.2	-3.4	0.9	
			Y	1 382 291.877	14	15.7	-15	0.4	
			Z	4 772 771.760	43	7.9	-3	1.1	
BUKO	1997.0	3	*B*	49 23 40.15269	0.8	14.0	1.5	0.3	rod
			L	18 38 22.03965	0.9	21.9	0.6	0.3	
			H	650293	57	-10	-10	1.7	
			X	3 941 468.886	36	-177	-19	1.1	
			Y	1 329 473.138	15	171	0	0.4	
			Z	4 819 721.052	44	84	2	1.3	
DEHO	19970	10	*B*	48 13 28.10589	0.4	13.7	1.4	0.2	rod
			L	19 31 53.52101	0.4	22.4	0.9	0.1	
			H	360.234	2.6	-1.9	-1.9	1.0	
			X	4 012 396.858	1.7	-18.3	-2.5	0.6	
			Y	1 423 349.936	7	173	1	0.2	
			Z	4 733 809.973	20	77	-5	0.7	
GABC	1997.0	5	*B*	47 52 40.33588	0.8	14.6	2.0	0.2	pillar
			L	17 31 50.30764	0.6	22.0	0.7	0.2	
			H	163478	56	-34	-34	1.6	
			X	4 086 854.463	36	-191		-38	
			Y	1 290 983.540	13	170		-4	
			Z	4 707 900.438	41	73		-12	
CHLM	19970	4	*B*	48 53 26.76245	0.8	11.9	0.0	0.2	rock
			L	21 56 12.66861	0.6	22.3	0.5	0.2	
			H	301.949	5.3	-5.6	-5.7	1.4	
			X	3 897 567.777	3.3	-20.0	-3.7	0.9	
			Y	1 569 724.972	1.5	16.0	-1.0	0.4	
			Z	4 782 807.963	4.0	3.6	-4.2	1.1	
KRC1	1997.0	5	*B*	48 25 5.86930	1.0	13.1	1.3	0.3	rock
			L	21 57 41.60278	1.0	22.7	0.8	0.3	
			H	296.917	6.9	-2.2	-2.2	1.9	
			X	3 933 470.874	4.3	-18.9	-2.6	1.2	
			Y	1 586 156.166	2.0	16.8	-0.2	0.5	
			Z	4 748 094.766	5.2	7.1	-0.8	1.4	
KRHO	1997.0	3	*B*	48 53 0.21287	0.8	13.4	1.2	0.3	rock
			L	20 8 13.94609	0.7	20.4	-1.2	0.2	
			H	1 978.744	56	-16	-16	1.7	
			X	3 946 557.265	35	-174	-14	1.1	
			Y	1 447 141.623	14	153	-18	0.4	
			Z	4 783 531.909	43	76	-4	1.3	
KRUZ	1997.0	5	*B*	49 21 52.49537	0.6	13.3	1.4	0.2	pillar
			L	21 35 30.18891	0.6	22.3	0.6	0.2	
			H	376.756	3.8	-6.1	-6.2	1.3	
			X	3 869 946.616	2.4	-21.3	-5.0	0.8	
			Y	1 531 573.300	1.1	15.6	-1.3	0.4	
			Z	4 817 347.923	3.0	4.0	-3.7	1.0	
MOPI	1997.0	18	*B*	48 22 21.80781	0.7	13.8	1.1	0.2	rock, point of EPN
			L	17 16 25.94682	0.6	22.0	0.9	0.1	
			H	578.984	4.5	2.4	2.3	0.8	
			X	4 053 738.193	2.9	-14.9	0.5	0.5	
			Y	1 260 571.383	11	185	11	0.2	
			Z	4 744 940.649	34	109	24	0.6	
ROHA	1997.0	8	*B*	49 3 2.60227	0.6	12.6	0.3	0.2	rock
			L	19 36 31.32393	0.5	21.3	-0.1	0.2	
			H	779.590	3.7	0.7	0.7	1.1	
			X	3 945 770.374	2.3	-15.6	0.3	0.7	
			Y	1 405 700.859	0.9	17.1	0.0	0.3	
			Z	4 794 846.443	2.8	8.8	0.7	0.9	

3. Conclusion

By acceptance of the selected SGRN points with determined spatial coordinates and annual velocities in SKTRF 2001 epoch 1997.0 to the family of the EUREF points, for Slovakia will be fulfilled a basic authorization requirement usable in the common building of the *E*uropean *S*patial *D*ata *I*nfrastructure *ESDI* built on the *G*eographical *I*nformation *S*ystem's technology and coordinated by the European Commission in ETRS 89.

By gradual rebuilding of the SGRN points to the SPOS points and by their gradual connecting to the European Integrated Permanent Network the Slovak Permanent GNSS Service can be started. This keeps the door open for us in building the Integrated Global Geodetic Observation System IGGOS developed by IAG activities.

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