

THE ANALYSIS OF GPS MEASUREMENTS IN TATRA MOUNTAIN

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ABSTRACT

The geodynamic investigation of Tatra Mountain is a local crust movements project supported by Slovak Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences No. 1/8251/01. The annual GPS measurements from 1998 to 2002 were realised by the Slovak University of Technology, Department of Theoretical Geodesy Bratislava together with the Warsaw University of Technology, Institute of Geodesy and Geodetic Astronomy. The GPS network consists of 11 special monument sites, 7 in the Slovak and 4 in the Polish part. The five GPS observation campaigns were processed with three different models. The preliminary results show the non-linearity horizontal and vertical movements of the measured points. The results and discussion are presented in this paper.

KEYWORDS: GPS measurements, crust movements, Tatra Mountain

1. INTRODUCTION

The investigation of the Tatra Mountains crust movements is a local project for determination of horizontal and vertical displacements. The Tatra Mountain is the highest mountain belt in the Carpathian. It is a very complicated area for application of GPS satellite techniques for determination of tectonic movements in specific atmospheric conditions. The area Tatra Mountains is approximately 1200 km² (40 km x 60 km). The GPS network for geodynamic investigation was established in 1998 and consists of 11 special monument sites, 7 in the Slovak and 4 in the Polish part of the Tatra Mountain. The elevation of the sites varies between 560 m and 2660 m.

2. GEOLOGICAL STRUCTURE OF TATRA MOUNTAIN

The Tatra Mountain region is a relatively highly elevated block drained by four rivers: Dunajec and Poprad flowing to the Baltic Sea, and the Vah and Orava rivers flowing to the Black Sea. The Tatra Mountain region is divided into two main sub regions: the West Tatra Mountain and the High Tatra Mountain almost completely lowered by overlying sediments of the Central Carpathian Paleocene Basin. The outcropping crystalline rocks of the pre-Mesozoic basements form the southern and the central parts of this block. The Mesozoic sediments cover the northern and the northeastern parts of this region. The lowermost structural unit of the Tatra block is called

the Tatricum. The crystalline basement and Permian-Mesozoic sequence forms the Tatra Mountains. The basement of the High Tatra Mountains predominantly consists of the granitites while the granitites and the metamorphic rocks forms the West Tatra Mountain (Nemčok *et al.*, 1994).

The Tatra Mountains main structural development had been in Neogene and Pleistocene. The Tatra Mountains was raised 15 million years ago. Its vertical elevation was 7 times smaller than in Alps. The Tatra Mountain can be described as a typical one-side horst with the south part lifted up (Fusán, 1981). The tectonic movements monitoring involves the main fault lines to be identified (Fig. 1). The largest effect is caused by the Chočsko-Podtatranský fault (in west-east direction) and its cross branches subsidiary perpendicular faults. Among the cross faults the most important lines are in northeast-southwest direction. These faults represent an activation of the older fault systems.

3. THE GPS OBSERVATION CAMPAIGNS

Eleven sites have been chosen for monitoring of tectonic activity of the Tatra Mountain (Fig. 1). The GPS ground network is divided in two parts. The first one is situated outside of the Tatra Mountain zone and the second one serves for monitoring of movements of the Tatra Mountain. The inner network is constructed by the method of so-called twin-points. One is situated on the mountain and the other is in the valley. The twin-points are dedicated to monitoring of local motions.

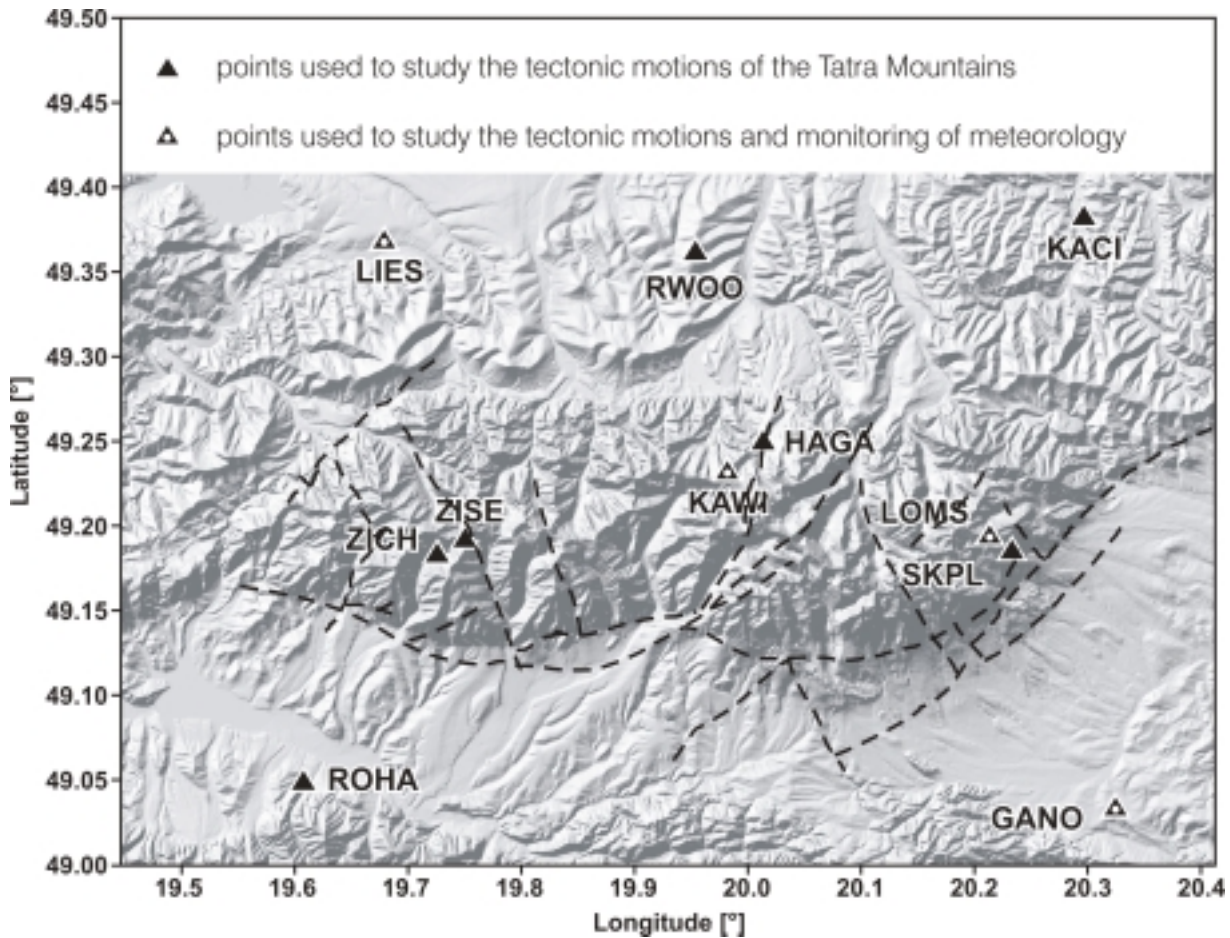


Fig. 1 Tectonic lines and configuration of GPS network of the Tatra Mountains

3.1. THE MONUMENT OF THE POINTS

The 7 points (ROHA, ZICH, ZISE, KAWI, HAGA, SKPL, KACI) of the special GPS network are stabilized on the rock, 2 points (LIES, GANO) are stabilized on concrete pillars into the ground and 2 points (LOMS, RWOO) are stabilized on the pillars with height 1.5 m. Each monument is made of a special brass module, connected with bedrock or pillar by concrete. The antenna adapter is screwed onto the brass module with accuracy of 0.1 mm. The points RWOO and KAWI are stabilized a special template modules and the GPS antenna is screwed direct into template module only with accuracy 0.4 mm.

3.2. REALIZATION OF GPS CAMPAIGNS

The five GPS observation campaigns (Table 1) were performed in the 1998-2002 period. The first was carried out from August 31 to September 3, 1998. The 8 points (GANO, KACI, KAWI, LIES, LOMS, ROHA, RWOO, and SKPL) were observed for four days continuously (Czarnecki, Mojzeš, 2000). The second GPS observation campaign was realized between 22 and 25 of September 1999. The same 8

points were observed four days full time. The third observation campaign was performed from 9 to 13 of October 2000 with 11 GPS stations. Three new GPS stations (HAGA, ZICH, and ZISE) were added to the network and 10 points (GANO, KAWI, LIES, ROHA, SKPL, HAGA, ZICH, ZISE) were observed continuously 5 days. The fourth GPS campaign was carried out in September 7-10, 2001. The 11 points (GANO, KACI, KAWI, LIES, LOMS, ROHA, SKPL, HAGA, ZICH, ZISE, RWOO,) were observed four days full time. The fifth GPS campaign was carried out between 5 and 9 September 2002. The 11 GPS stations (GANO, LIES, LOMS, ROHA, SKPL, ZICH, ZISE, HAGA, KACI, KAWI, and RWOO) were observed permanently for 4 days.

4. THE PROCESSING OF GPS MEASUREMENTS

All the GPS campaigns were processed with two different processing strategies. The first solution named STU-FIX uses only one fixed point ROHA with one set of fixed coordinates for each epoch. The second solution named STU-IGS uses IGS permanent stations with change of coordinates in time.

Table 1 Observation campaigns performed in the Tatra Mountains

Point	Acronym	Performed GPS campaigns				
		1998 31.8 - 3.9	1999 22.9 - 25.9	2000 9.10 - 13.10	2001 7.9 - 10.9	2002 5.9 - 9.9
Gánovce	GANO	x	x	x	x	x
Hala	HAGA			x	x	x
Kacwin	KACI	x	x		x	x
Kasprowy	KAWI	x	x	x	x	x
Liesek	LIES	x	x	x	x	x
Lomnický štít	LOMS	x	x		x	x
Roháčka	ROHA	x	x	x	x	x
Rolow Wierch	RWOO	x	x		x	x
Skalnaté pleso	SKPL	x	x	x	x	x
Žiarska chata	ZICH			x	x	x
Žiarske sedlo	ZISE			x	x	x

Table 2 Differences $\delta n, \delta e, \delta v$ between observation campaigns in the STU-FIX processing

Station	Differences												
	99 - 98	σ	00 - 98	σ	01 - 98	σ	02 - 98	σ	01 - 00	σ	02 - 00	σ	
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	
GANO	n	2.83	1.62	9.79	4.10	6.84	1.35	4.34	3.42				
	e	0.31	2.83	-4.41	3.42	-4.64	2.97	1.10	4.00				
	v	15.00	8.32	16.10	6.56	18.90	6.56	24.00	7.38				
LIES	n	-1.71	1.27	-2.42	2.85	7.01	2.10	-2.40	4.10				
	e	3.93	2.24	4.17	3.42	8.02	2.28	4.49	3.42				
	v	6.20	6.02	2.00	4.66	-13.60	8.39	-3.00	12.33				
KACI	n	-0.07	2.33			5.85	2.70	-1.21	3.19				
	e	2.59	1.27			1.61	3.04	4.04	2.28				
	v	4.70	4.13			-10.90	6.30	-7.10	8.93				
KAWI	n	-1.23	3.01	-2.28	3.70	5.92	5.44	2.49	3.57				
	e	8.97	4.08	19.33	2.50	10.94	2.60	7.01	3.26				
	v	1.10	9.32	-21.00	5.20	10.90	5.71	-2.10	6.80				
LOMS	n	-10.87	2.20			5.11	1.41	0.84	3.31				
	e	3.94	2.92			9.02	2.40	5.68	2.86				
	v	-2.20	5.63			10.60	11.32	4.90	10.47				
RWOO	n	1.59	2.66			2.55	3.18	-0.57	3.18				
	e	10.13	2.09			5.21	3.52	4.53	2.97				
	v	19.20	8.51			25.50	7.56	15.30	7.43				
SKPL	n	-6.37	1.93	-6.19	5.35	2.57	1.93	1.20	4.16				
	e	0.22	3.34	3.16	3.97	-0.37	3.55	6.75	3.91				
	v	4.90	11.56	-5.30	6.94	7.10	17.13	-6.80	13.12				
HAGA	n									-1.87	12.53	-5.46	12.82
	e									-6.02	4.36	-9.04	4.41
	v									42.40	14.92	23.20	9.30
ZICH	n									-5.33	5.02	-10.40	9.66
	e									0.49	3.78	-13.36	5.33
	v									5.80	8.51	19.10	12.47
ZISE	n									-11.87	9.45	-13.74	9.55
	e									1.84	2.56	-0.33	1.58
	v									7.00	6.72	-2.30	9.24

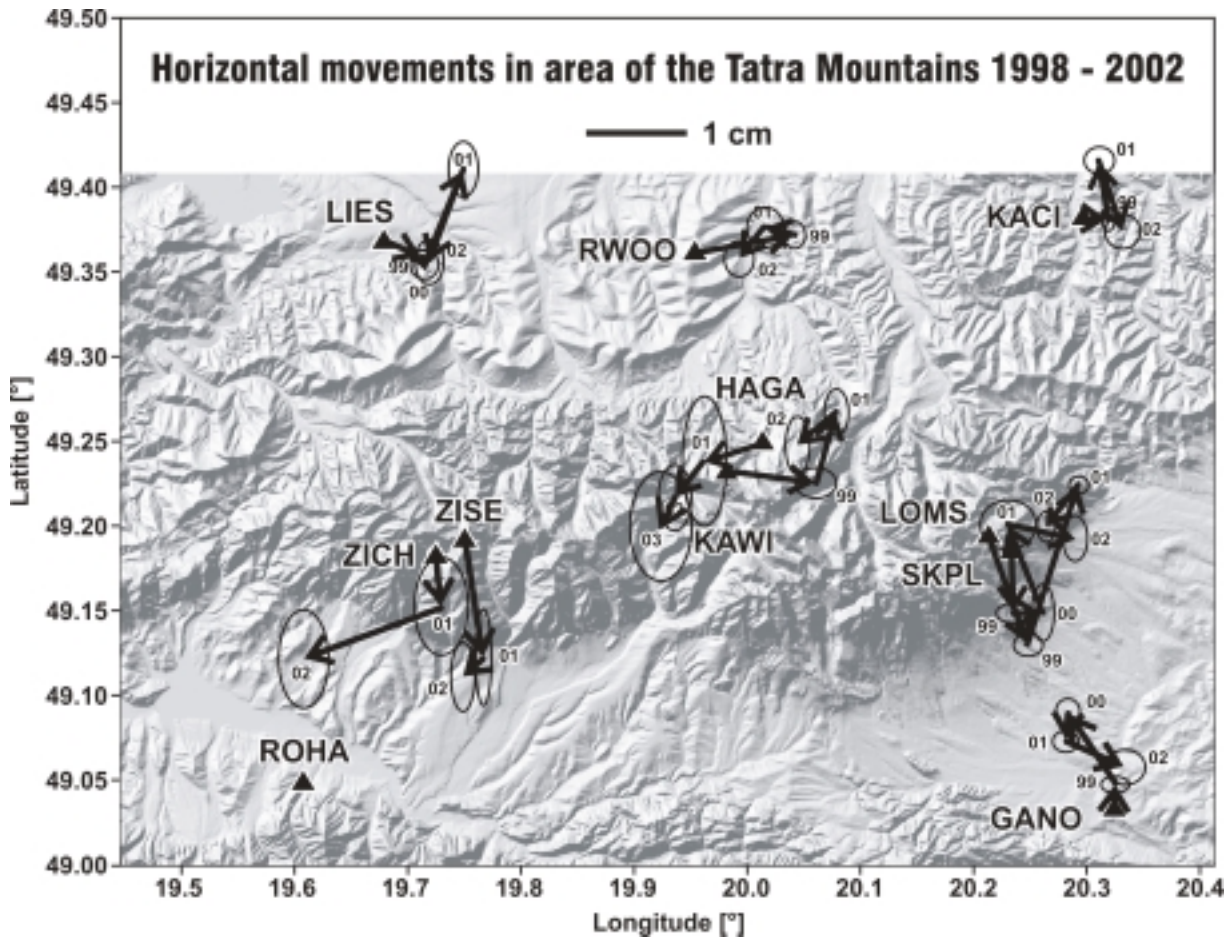


Fig. 2 Horizontal movements of the sites and error ellipses (1σ) determined in the STU-FIX processing

4.1. THE STU-FIX SOLUTION

All data from the performed GPS campaigns were processed in 2 steps. In the first step all GPS measurements were processed using the Bernese Software 4.2 (Beutler *et al.*, 2000) where the default method of processing for epoch measurement was used. Input parameters, such as precise ephemeris's and information about the phase centre of the GPS antennas were obtained from an International GPS Service. The total troposphere effect was reduced using a-priori a Saastamoinen model. For the supplement troposphere effect estimation was used a special mapping function ($1/\cos z$). Every GPS campaign was processed as a free network for each day and each observation campaign. Connection to the reference frame ITRF2000 was established by setting a stochastic condition of the a-priori of 1 mm accuracy for the fixed station ROHA coordinates.

In the second step the analysis of the results was done. Inconsistency of spatial coordinates X, Y, Z with the first year's solution we obtained the coordinate differences $\delta X, \delta Y, \delta Z$. The coordinate differences were transformed to the local horizontal coordinate system $\delta n, \delta e, \delta v$ (Leick, 1989). The results were

subsequently tested statistically and the final results are summarized in Table 2 and illustrated in Fig. 2 (horizontal movements) and Fig. 3 (vertical movements).

4.2. THE STU-IGS SOLUTION

This processing strategy has also divided into 2 steps. In the first step all GPS measurements were processed using the Bernese Software 4.2 (Beutler *et al.*, 2000) with default method of processing for each epoch measurement. In this strategy we used five permanent IGS stations: BOR1, GOPE, GRAZ, PENC, JOZE (see Fig. 4). The coordinates and velocities of permanent stations were derived from reference frame ITRF2000, epoch 1997.0 for each epoch. The processing was very similar with STU-FIX type solution.

The analysis was performed with a specific mathematical model (Kubáček and Kubáčková, 1991) and realized using the WIGS program system (Klobušíak *et al.*, 2002).

The final $\delta X, \delta Y, \delta Z$ results were transformed to the local horizontal coordinate system $\delta n, \delta e, \delta v$. The horizontal and vertical displacements of the sites

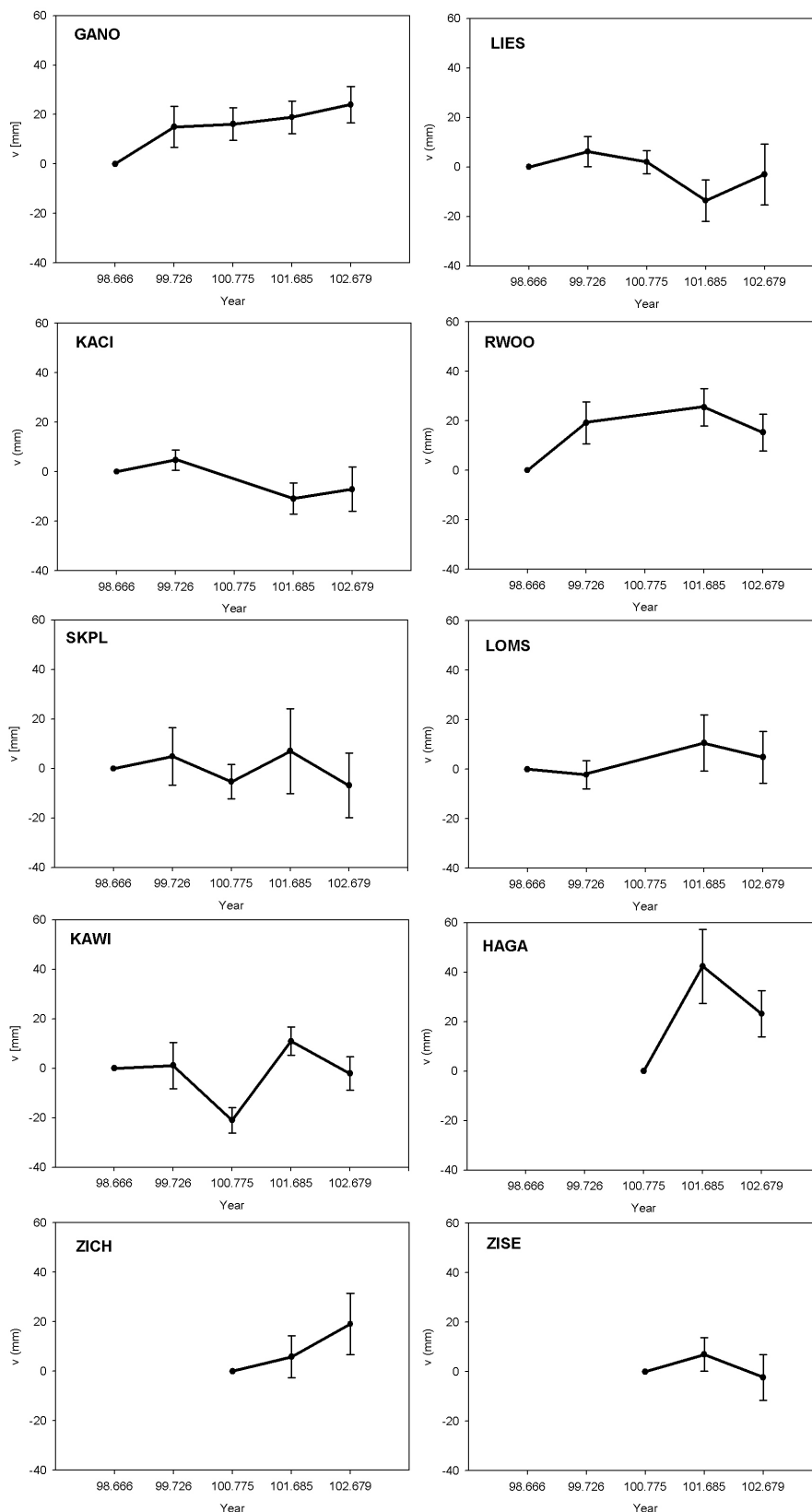


Fig. 3 Vertical movements of the sites and error interval (1σ) determined in the STU-FIX processing

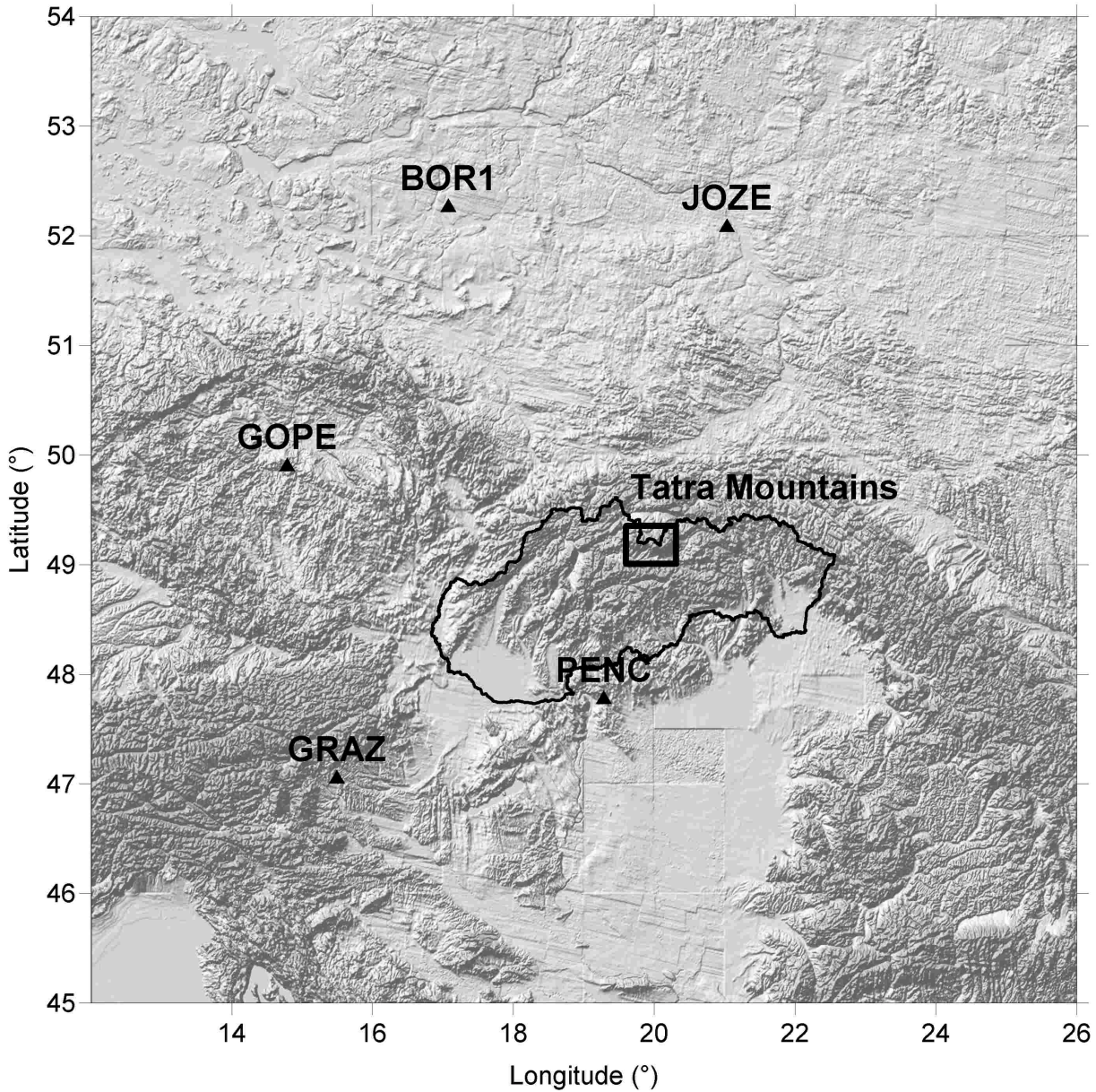


Fig. 4 Position of reference stations used in the STU-IGS processing

are illustrated in Fig. 5 and Fig. 6. The numerical results of local velocities for the complete GPS network are presented in Table 3 and are shown in Fig. 7.

5. CONCLUSIONS

The analysis of the GPS epoch measurements in the Tatra network has been performed at Slovak University of Technology using two different analysis methods. The GPS epoch measurements have been realized in the period 1998-2002. From the preliminary results described in this contribution we can formulate the following conclusions:

- The differences in variation of horizontal position in not significant between STU-FIX and STU-IGS solutions as shown Fig. 5.
- The sites ROHA, GANO, LIES, RWOO, KACI have a lower variation in horizontal position than sites located on the top of mountains as KAWI, LOMS and SKPL.
- From the Fig. 5 can be clearly seen so called “returning point effect”, which can be caused by unknown phenomena.
- The mean local horizontal velocity of the High Tatra Mountain sub region is 2.26 mm/year in northeast direction as represented by points LOMS, SKPL and KAWI.

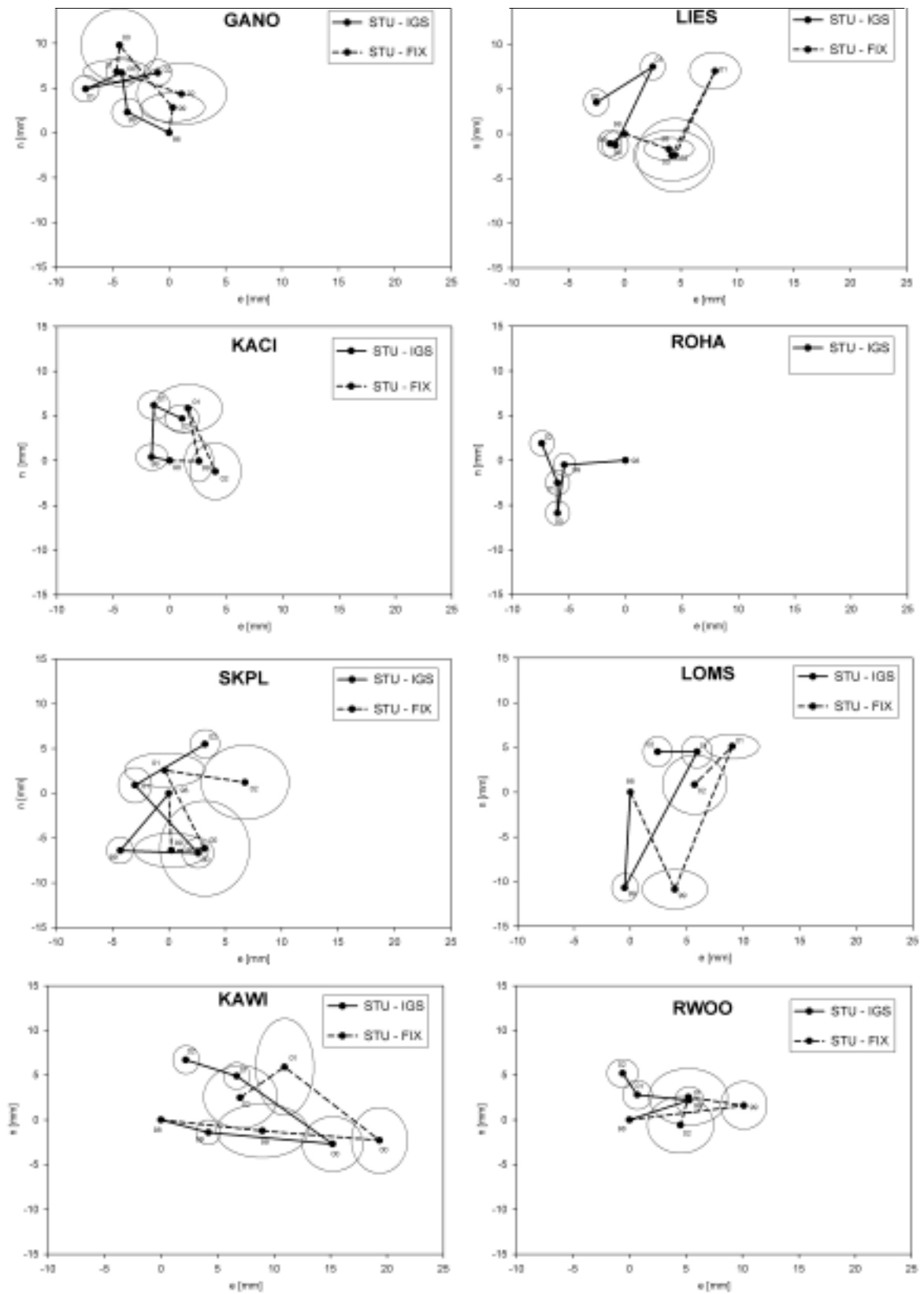


Fig. 5 Horizontal movements of the sites in the STU-FIX and the STU-IGS processing

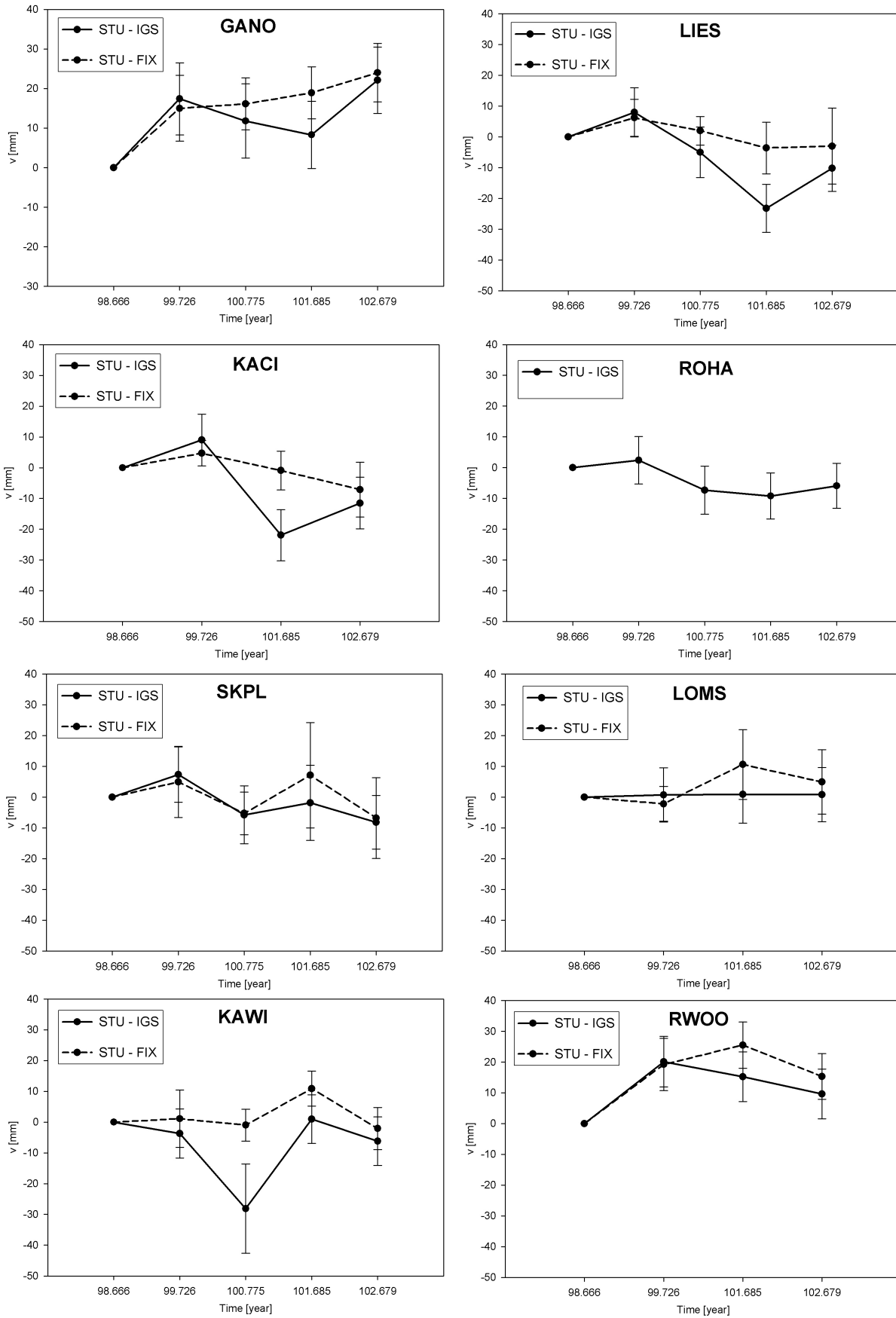


Fig. 6 Vertical movements of the sites in the STU-FIX and the STU-IGS processing

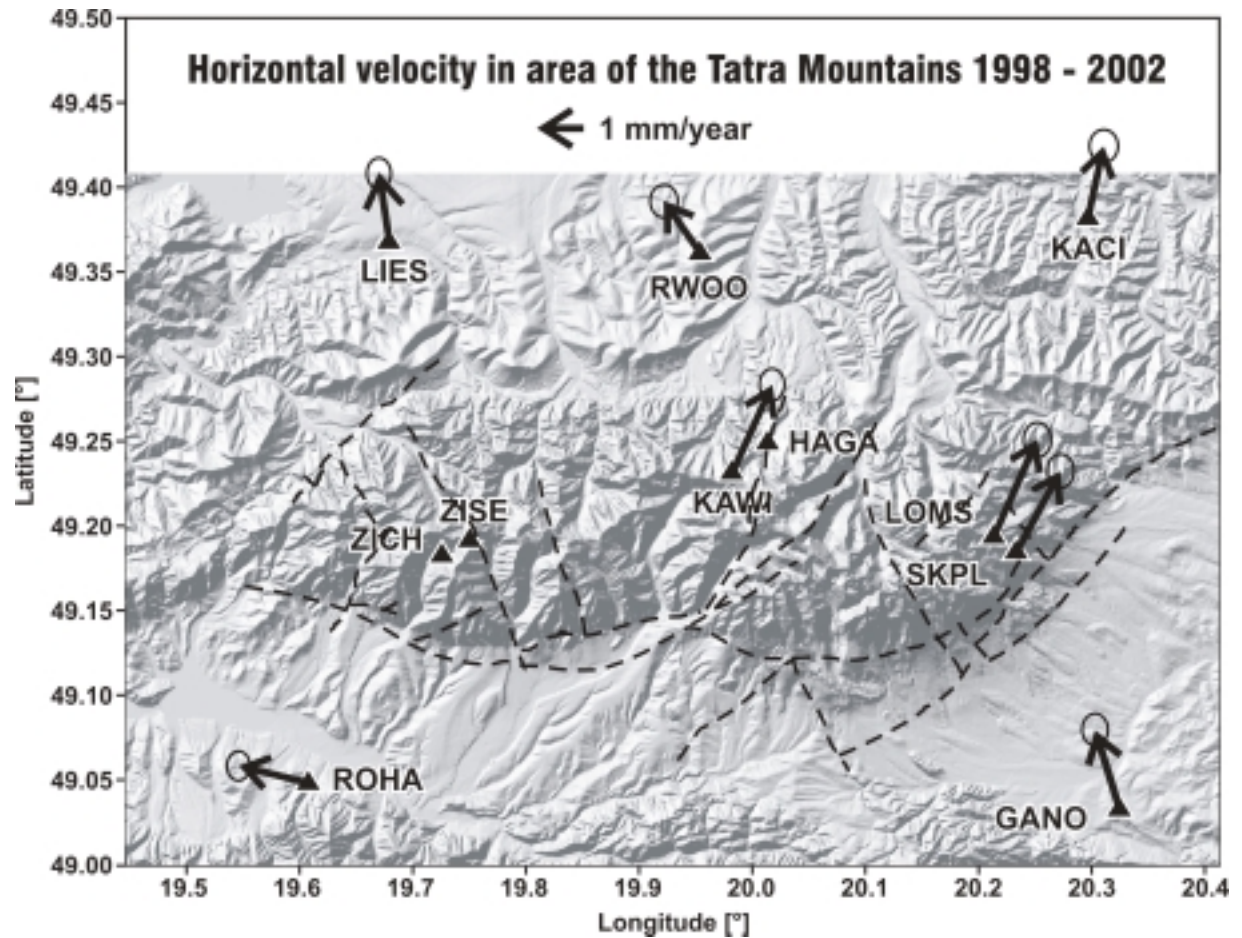


Fig. 7 Local horizontal velocities of the sites determined from the STU-IGS processing

- The mean local horizontal velocity of the flysch sub region is 1.5 mm/year in north direction represented by points LIES, ROWI and KACI.
- The local motion of point ROHA is 1.67 mm/year in the west direction. The point ROHA is located in the Low Tatra geological block.
- For analysis of local horizontal velocities can't be used different time period (compare Table 1 and Table 3 for sites ZICH, ZISE, HAGO).
- The five-year period is very short time for reliable horizontal tectonic movement determination.

Suggestions for the future:

- The GPS observation campaign must be at least 6 days long for better determination of horizontal and vertical positions of the points in complicated troposphere conditions.
- The adequate statistical model must be studied for estimation of motion parameters of velocity field.

Further investigation with GPS campaigns observations are necessary in order to improve the reliability of the obtained results, especially velocities determined by longer time span of observations.

ACKNOWLEDGEMENTS

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Table 3 Horizontal and vertical velocities of the points

Station		Velocity		σ
		Global (mm/year)	Local (mm/year)	
GANO	φ	14.32	1.84	0.36
	λ	21.03	-0.57	0.29
	h	4.75	3.56	1.86
LIES	φ	14.18	1.52	0.35
	λ	21.27	-0.23	0.27
	h	-3.89	-5.01	1.68
LOMS	φ	14.72	2.22	0.39
	λ	22.57	0.99	0.31
	h	1.78	0.58	1.95
KACI	φ	14.17	1.69	0.37
	λ	21.96	0.37	0.32
	h	-4.35	-5.61	1.83
KAWI	φ	14.62	2.05	0.36
	λ	22.48	0.93	0.28
	h	0.45	-0.71	1.76
ROHA	φ	13.08	0.40	0.33
	λ	19.87	-1.62	0.26
	h	-1.46	-2.48	1.62
RWOO	φ	13.81	1.23	0.37
	λ	20.69	-0.86	0.31
	h	2.20	1.03	1.78
SKPL	φ	14.38	1.87	0.38
	λ	22.59	1.01	0.30
	h	-1.88	-3.09	1.94
HAGA	φ	12.21	-0.35	0.86
	λ	15.97	-5.58	0.67
	h	8.03	6.86	4.06
ZICH	φ	9.97	-2.68	0.94
	λ	12.66	-8.85	0.66
	h	12.31	11.23	4.64
ZISE	φ	9.20	-3.44	0.74
	λ	20.05	-1.46	0.57
	h	-2.40	-3.49	3.52

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