ANALYSIS METHOD

DATA

ERI archived Epoch'92 data through INTERNET of the University of Tokyo. The Epoch'92 spans the **15** day period of July 25, GPS Week 655 (July 26-August 1, 1992) and Week 656 (August 2-8, 1992). The study described in this paper used data collect ed by the Rogue receivers from the IGS core sites. The orbit and parameter estimation is based on L1 /L2 phase data which are processed as *double differences* (DD) from the operating 18 GPS satellites including Block-I satellites: PRNs 3,11,12,13, and Block–II satellites: PRNs 2,14,15,16,17,18,19,20,21,23,24,25,26,28. The cut–off angle of 10 deg was used. Raw L1/L2 phase data (given in the RINEX format) were first cycle-slip edited at ERI, and the corrected data were transmitted to NAL where the independent, ionosphere-free DDs from all operating satellites and the selected core sites were created. Also, during this process DD passes having length shorter than 25 min were edited and the remaining DDs were further sampled nominally at 2 min interval. Usually, 130,000 to 180,000 raw DDs were reduced to about 15,000 for each day.

TRACKING SITES

The following 19 sites, all used the Rogue receivers, were chosen for orbit determination: ALGO, FAIR, HART, KOKB, MADR, STJO, MCMU, SANT, WETT, YAR1, YELL, RCM2, TIDB, GOLD, KOSG, MATE, ONSA, TAIW, and USUD. Site coordinates adopted in the orbit determination are shown in Table 1. Tabulated there are position coordinates of *L1-phase centers* computed at NAL on the basis of IGSMail no. 90. Note that IGSMail no.90 provides coordinates of the monument or geodetic markers which are referred to either Very Long Baseline Interferometry (VLBI) or Satellite Laser Ranging (SLR). The eccentricity vector attached is used to relate the VLBI or SLR reference point to the phase center of the GPS antenna. Of particular importance is to note that this system of coordinates refers to the *ITRF91 at the epoch* 1992.5, *which is hereafter refereed to as ITRF92.5. No* plate motion is applied. In the approach used in this study the sites except for TAIW, USUD, RCM2, and TIDB were assumed to be fiducial and fixed with the values given in Table 1. The coordinates of 4 non-fixed sites were adjusted on a daily base.

SOFTWARE AND MODELS

MSOP 3.0 (Multi–Satellite Orbit Processor) was used for orbit and parameter estimation [1,2]. The MSOP 3.0 was developed at NAL on the basis of COSMOS program for satellite geodesy and laser geodynamics. The performance of COSMOS has been demonstrated through the analysis of LAGEOS laser ranging data [3]. The forces and kinematic models adopted in the analysis adhered to most of the IERS Standards [4].

Table I

POSITIONS OF L1 PHASE CENTER FOR THE EPOCH 1992.5 (48804.0 MJD)
(IERS/IGS STATION COORDINATES - ITRF91)

Site	Plate	Long. (deg)	Lati.(deg)	Hgt.(m)	Location
ALGO	NOAM	281.92863507	45.95580010	201.077	Algonquin, Canada
FAIR	NOAM	212.50076238	64.97800237	319.215	Fairbanks, AK, USA
HART	AFRC	27.70775958	-25.88710429	1565.193	Hartebeesthoek, S.A.
KOKB	PCFC	200.33507944	22.12625906	1167.536	Kokee Park, HI, USA
MADR	EURA	355.75033860	40.42915990	829.517	Madrid, Spain
STJO	NOAM	307.32225357	47.59523843	153.081	St.Johns, Canada
MCMU	ANTA	166.67376928	-77.84784020	-14.377	McMurdo, Antarctica
SANT	SOAM	289.33144318	-33.15029064	723.214	Santiago, Chile
WETT	EURA	12.87889993	49.14422361	666.148	Wettzell, Germany
YAR1	INDI	115.34697188	-29.04656108	241.436	Yarragadee, Austr.
YELL	NOAM	245.51930293	62.48089564	181.022	Yellowknife, Canada
GOLD	NOAM	243.11075267	35.42515700	986.726	Goldstone, CA, USA
KOSG	EURA	5.80964098	52.17842475	97.061	Kootwijk,Netherlands
MATE	EURA	16.70445601	40.64912939	535.880	Matera, Italy
ONSA	EURA	11.92551418	57.39529698	46.641	Onsala, Sweden
TAIW	PCFC	121.53654020	25.02133156	45.769	Tai-Shi, Taiwan
USUD	EURA	138.36204141	36.13311654	1508.665	Usuda, Japan
RCM2	NOAM	279.61588655	25.61335395	-22.591	Richmond, FL, USA
TIDB	INDI	**148.97999540**	**-35.39921098**	**665.630**	Tidbinbilla, Aust.

Note: Taken from IGSMail No.90, 9-SEP-1992.
$Ae = 6378137.0$ m, $f = 1/298.257$

PARAMETER ESTIMATION METHOD

– Weighted least squares
– No a priori covariance on any parameters
-Each DD weighted with theobservation error of 1. 0 cycle
– Arc length of one day, all arcs beginning at 00:00:00 GPS Time of the respective day.

ADJUSTED PARAMETERS

– 6 epoch cartesian elements (in the J2000 system) for each satellite
– Two scale parameters for solar radiation pressure for each satellite
– One y-bias for each satellite
– Ambiguities for each DD pass
– Day–by–day zenith delay parameter for each site
– Coordinates of non–fixed sites
– Daily pole position

In the first phase of analysis, we tried to adjust both pole coordinates and UT1 simultaneously using DD phase for one-day arc. This approach looked promissing for a time, but a later close examination of the quality revealed that the estimate of UT1 was less accurate. So, only pole coordinates were estimated in the final runs, while keeping UT1 held fixed with values taken from IERS Bulletin B finals. In the present estimation, poles were assumed to be constant over the whole one–day interval.

ANALYSIS PRODUCT AND EVALUATION

Under the assumptions and strategies described in the previous sections, global orbits with earth rotation parameters (pole position only) have been determined. Table 2 summarizes the solution statistics for Epoch'92. The upper row indicates the number of DD phases used over each one–day arc, and the lower row shows the corresponding DD residual root–mean-square (RMS) in cycles. We see that DD RMS is in the range of 0.11 to 0.18 cycles except for Day 218 (August 5) for which DD RMS is relatively large so that the corresponding orbit could be less accurate than those of the other dates. The reason for large overall residual on Day 218 needs further investigation.

Table 2
SUMMARY OF SOLUTION STATISTICS

Day	207	208	209	210	211	212	213	217	218	219	220
DD	10959	12569	14787	12068	16231	13614	13390	15693	11889	13397	10169
RMS*	0.13	0.14	0.16	0.14	0.12	0.12	0.11	0.18	0.24	0.14	0.18

*Root Mean Square in cycles.

The NAL/ERI ephemeris, which is designated as EPH(NAL/ERI) 92 G 01, is represented in the earth-centered and earth-fixed system (ECEF) system which is consistent with the ITRF92.5 system, and also given at 15 min interval in the NGS SP1 format in that both position and velocity vectors are given. It should be mentioned that *the estimated user positions using our ephemerides have to fix at least one site of the network with the ITRF92.5 coordinates.*

Table 3 tabulates day–by–day orbit repeatability which shows the discontinuities of the orbit in position at the time points common to adjacent one day arcs. As can be seen, root–sum–square (RSS) position differences are of the order of within 5 m for almost all satellites and of the order of some 10 m for the remaining few satellites. On the basis of this table, 4 satellites are picked up for orbit comparison: PRNs 16 and 24 both with overall small RSS; and PRNs 14 and 23 being worst two with relatively large RSS. As representative examples, Figs. 1 through 4 show direct position differences between NAL/ERI orbits and CODE orbits for PRNs 16, 24, 14, and 23, which are shown in the conventional radial, along-track, and cross–track orbit frame for the first 7 days of Epoch'92, from July 25 to July 31. These four plots were developed *without applying 7–parameter transformation.* They show the 3–dimensional RMS position difference of 3.5 to 5.0 m with a maximum RMS difference of 3.0 to 4.5 m all occurring in the along-track direction. Figs. 3 and 4 give the worst orbit comparison clearly indicating large discontinuities at the time points common to the adjacent arcs as shown in Table 3.

Table 3
ORBIT REPEATABILITY

PRN NO.	Day 208 7/26	209 7/27	210 7/28	211 7/29	212 7/30	213 7/31
02	4.63	2.94	3.31	1.32	2.69	11.03
03	1.79	4.32	3.00	0.85	4.87	4.27
11	4.58	1.84	2.08	5.43	0.57	1.97
12	9.26	14.53	0.70	2.70	5.36	4.22
13	5.55	5.70	1.14	3.58	3.88	6.20
14	4.77	13.42	2.97	15.28	15.96	26.30
15	32.43	3.15	0.47	2.34	11.43	7.64
16	2.63	4.15	1.27	3.09	1.03	2.08
17	0.25	1.08	1.64	6.07	1.06	3.89
18	4.55	4.06	14.48	3.05	4.77	0.54
19	3.45	1.12	2.10	35.37	12.37	0.75
20	9.01	2.95	0.62	8.15	12.08	4.61
21	22.71	11.80	9.89	8.38	20.83	4.78
23	20.03	18.00	7.60	8.07	11.00	12.57
24	2.05	2.46	3.03	0.84	1.45	1.64
25	4.16	4.47	0.48	5.80	8.87	2.46
26	2.89	6.34	3.17	10.87	2.63	7.59
28	17.85	2.93	13.42	9.96	1.55	7.85

Note: The RSS position differences, in meters, at the arc epoch of the day.

Table 4 summarizes our polar motion results for Epoch'92. Solutions for the first 7 days are well adjusted, but the estimation results for Week 656 seem to be less accurate, in particular, for Day 217 and 218. Re-analysis for Week 656, including cycle-slip correction and DD generation, is required.

The quality of day-by-day estimates of site coordinates varies depending on the length of DD passes per day. The time history of the site estimate is given in Table 5 which shows position differences of the estimates from ITRF92.5 values in Table 1 in the up, east and north directions. The missing days for each site simply indicate no good DDs available for the site by our edit criterion. For the sites with longer arcs of DDs per day, the differences in height, latitude and longitude components from the ITRF92.5 values are smaller than 10 to 20 cm but the difference in height is generally larger than those of horizontal component. However, for the sites and days with smaller length of arcs, the differences tend to increase to several 10 cm to over one meter. The large daily variation of USUDA site needs further investigation. In addition, unless we *estimate a zenith delay parameter per site (per day), the differences* become even much larger.

Table 4
ESTIMATE OF POLE POSITIONS : EOP(NAL/ERI) 92 P 01
Units : 0.0001" for x, y, 0.00001s for UT1

Date 1992			MJD	X	y	Uncertainties x	y
207	JUL	25	48828.5	-1084.3	4304.5	0.5	0.4
208	JUL	26	48829.5	-1022.3	4312.4	0.6	0.5
209	JUL	27	48830.5	-1036.4	4349.7	0.4	0.4
210	JUL	28	48831.5	-1056.8	4238.5	0.6	0.4
211	JUL	29	48832.5	-962.2	4392.6	0.4	0.4
212	JUL	30	48833.5	-976.0	4399.9	0.5	0.5
213	JUL	31	48834.5	-928.1	4425.0	0.6	0.5
214	AUG	1	48835.5				
215	AUG	2	48836.5	*Anti-Spoofing activated*			
216	AUG	3	48837.5				
217	AUG	4	48838.5	-590.2	4310.1	0.5	0.3
218	AUG	5	48839.5	-1512.5	4295.7	0.5	0.4
219	AUG	6	48840.5	-754.1	4744.0	0.6	0.4
220	AUG	7	48841.5	-734.1	4956.9	0.5	0.4
221	AUG	8	48842.5	*Anti-Spoofing activated*			

Finally, Table 6 illustrates baseline day to day consistency for WETT - TIDB (12000 km). With the exception of Week 656, differences between the estimates and the ITRF92.5 are some 10 cm or better and are consistent with a few parts in 108.

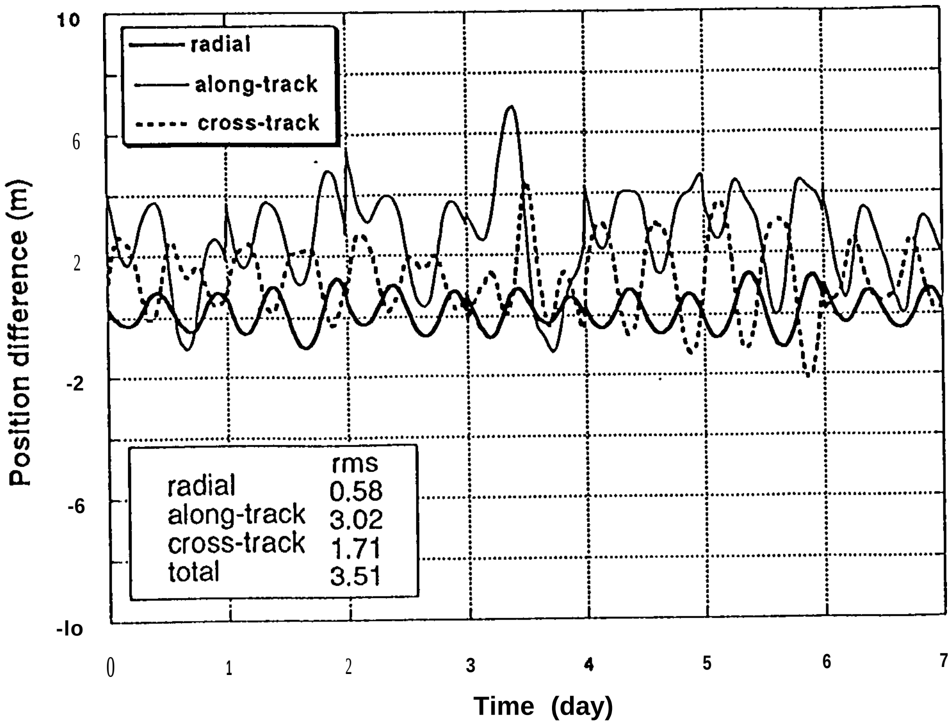

Fig.1 Position difference for PRN 16 (CODE - NAL/ERI).

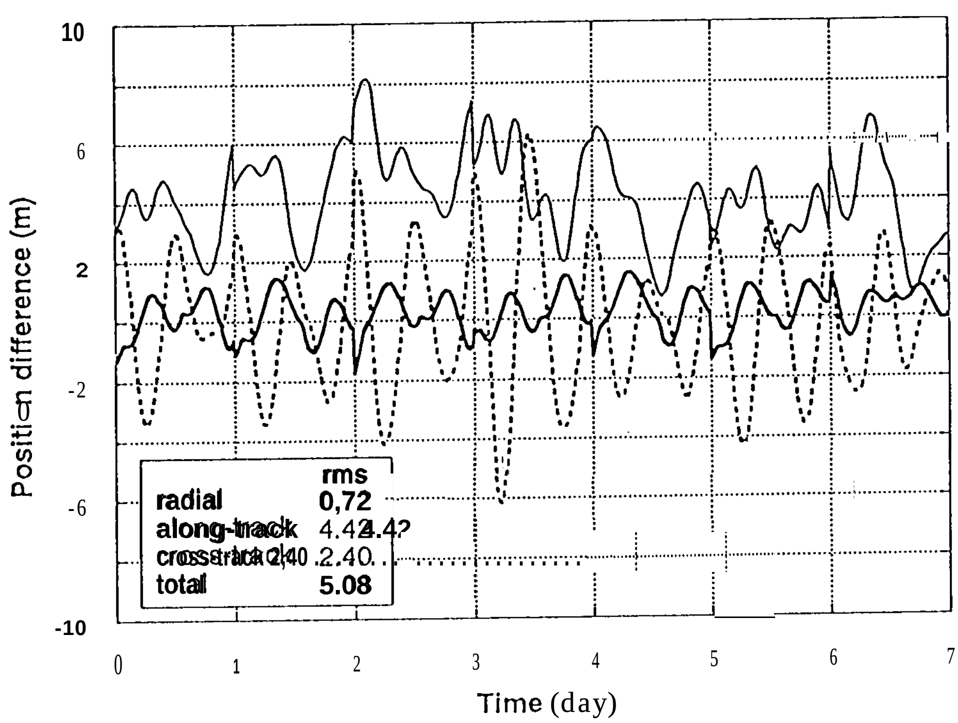

Fig.2 Position difference for PRN 24 (CODE - NAL/ERI).

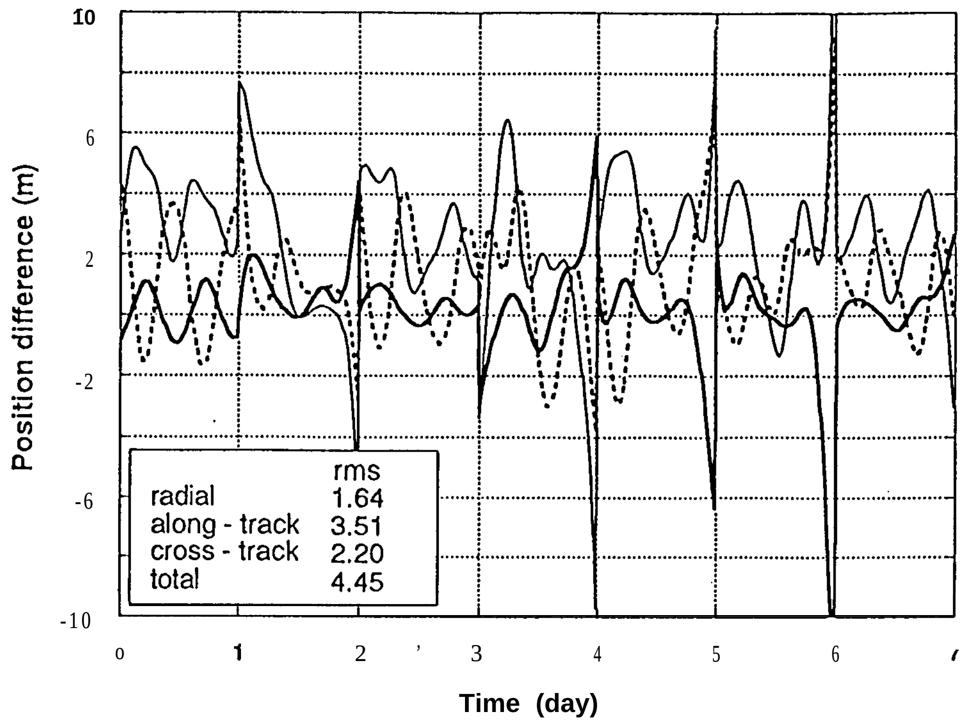

Fig.3 Position difference for PRN 14 (CODE - NAL/ERI).

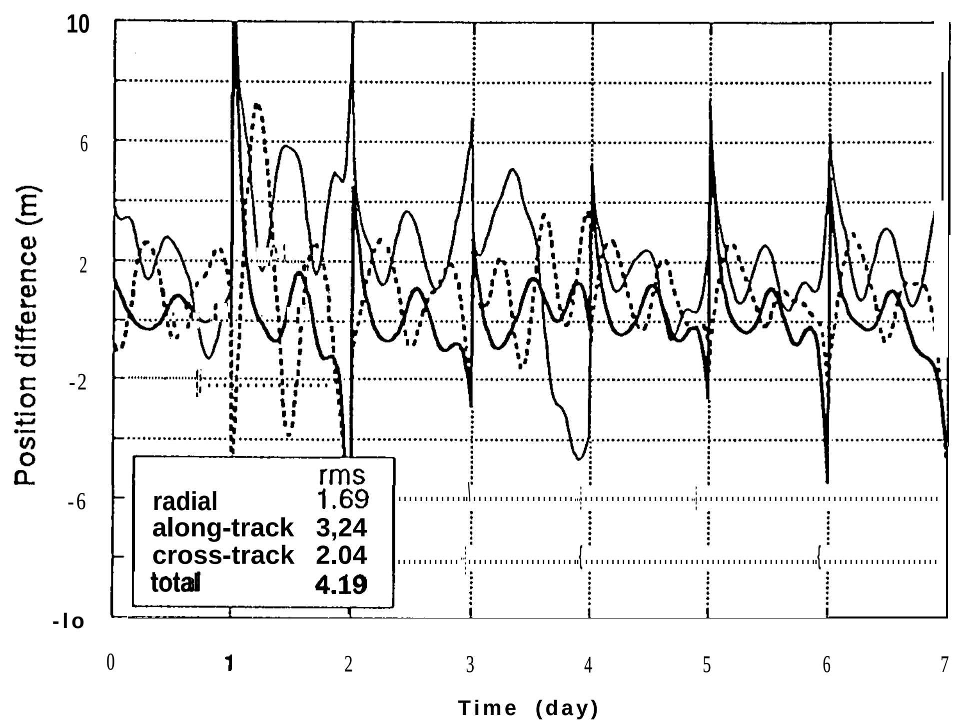

Fig.4 Position difference for PRN 23 (CODE - NAL/ERI).

Table 5
ESTIMATE OF L1 PHASE CENTERS FOR NON-FIXED SITES

Site	Day	Difference from ITRF92.5 AHeight (cm)	AEast (cm)	ANorth (cm)
RCM2 Richmond (USA)				
	D207	-2.9	0.8	5.3
	D217	-14.5	23.7	23.3
	D218	8.5	-23.1	9.3
	D219	-3.3	21.1	-5.6
	D220	-12.4	14.1	-0.7
TIDB Tidbinbilla (Australia)				
	1)207	-2.6	2.4	-4.9
	D208	-8.3	6.1	4.9
	1)209	-5.9	0.9	-2.2
	D211	-17.3	11.8	-4.4
	D212	0.9	3.7	2.9
	1)213	-16.9	-6.8	5.2
	D217	-74.3	10.3	30.9
	D218	-16.8	59.9	-92.9
TAIW Tai-Shi (Taiwan)				
	D208	62.7	-7.5	-3.7
	D209	42.5	-16.1	-4.7
	1)211	-5.4	9.1	17.5
	D212	24.0	6.7	6.3
	D213	-14.4	46.2	4.8
	D217	18.1	14.1	-27.2
USUD Usuda (Japan)				
	D209	103.6	135.5	-54.1
	D217	24.8	10.0	1.2
	D218	195.1	-208.2	-113.3
	D220	59.7	126.8	88.2

CONCLUSIONS

Comparison of current NAL/ERI Epoch'92 orbits with the corresponding CODE orbits shows overall agreement at the level of better than 5 m (RMS) for all GPS satellites (no 7–parameter transformation applied), although orbit repeatability shows discontinuities between the adjacent one-day arcs at several 10 m level for some satellites. It has also been shown that the baseline day to day consistency is a few parts in 108 for baselines up to 12000 km. Furthermore, ephemerides for non–AS satellites during AS periods are not available at present. Future analyses will focus on data during AS periods as well as the WING'92 campaign data [6] enhanced with the IGS

Epoch'92 data.

Table 6
TIDB/WETT BASELINE DAY TO DAY COMPARISON

Day	Baseline (m)	Difference* (m)
208	12156516,368	0.074
209	12156516.391	-0.051
211	12156516.313	-0.129
212	12156516.454	0.012
213	12156516.255	-0.187
217	12156516.702	-0.740
218	12156516.588	0.146
ITRF92.5	12156516.442	

* Difference from ITRF92.5 baseline

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COMPARISON OF GLOBALLY AND LOCALLY DETERMINED SITE TIES FOR THE METSÄHOVI GPS STATION

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This paper presents comparisons of 3 km site ties from the Metsähovi GPS station to the mobile VLBI reference point, obtained from local GPS calculations and survey measurements and also using the differences in the global absolute coordinates. Three GPS postprocessing softwares are unanimous about the local tie, which differs from the globally determined tie in the height component at a level of 50 mm. Data from local geodetic measurements do not yet conclusively solve the discrepancy because of uncertainties in the available geoid data.

INTRODUCTION

A permanent GPS receiver has been in continuous operation at the Metsähovi Observatory of the Finnish Geodetic Institute since May 1, 1991, supplying data to CIGNET (Cooperative International GPS Network), operated by the National Geodetic Survey, Rockville, USA) and since June 1992 to the IGS (International GPS Geodynamics Service) as well. In the first year an Ashtech receiver was used (upgraded to P-code capability in November 1991) on a 24 m high tower (model Bilby). After the new MiniRogue SNR-8C GPS receiver arrived, operations were transferred April 30, 1992 to a new 20 m high height-stabilized tower system [1] at a distance of about 40 m. Tower installations are necessary due to the high trees around the station. A 5 MHz external frequency is received from the neighboring Radio Research Station of the Helsinki University of Technology. Statens Kartverk, Norway, retrieves the data directly from the receiver via modem every day. The current IGS classification of Metsähovi is a secondary core station.

The connection to the other world geodetic systems is obtained through the mobile VLBI point (CDP 7601, established in 1989) and a DORIS ground locating beacon at Sjökulla, a site at a distance of about 3 km. For this purpose an accurate site tie was required. The classical survey and precise levelling to the station point SF348 was done earlier. Although the coordinates of the Metsähovi laser station (CDP 7805) are also available, they are not accurate enough to give support to the GPS site tie. Because of the primary task of the GPS site, it was quite natural to use the

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tie obtained from GPS data directly concerning the both ends of the baseline. The survey value also agreed well. However, the first global solutions [2,3] showed height deviations of 50-60 mm, the horizontal position being consistent within 10 mm. Thus the problem seemed to be mainly connected with the notoriously uncertain results of the GPS height determination and the possibly uncertain geoid data. Next a survey tie was delivered to the IGS [4] . The fit seems to have been satisfactory. This report describes some supporting material and GPS calculations that should help to solve this question.

SITE TIE FROM RELATIVE GPS POSITIONING AND SURVEY

The initial tie vector between the Sjökulla VLBI point and the Metsähovi MiniRogue GPS antenna reference point for IGS use was determined from a relative GPS positioning on May 14, 1992 (Day 135). A P-code Ashtech P-12 , with an external good quality 5 MHz oscillator, was on the VLBI point. The data interval was 120 s, as this was the interval used in the MiniRogue at the time. The spring weather was good and stable. An integer fixed L1 solution obtained with OMNI GPS software at the NGS [5] is shown as the first entry in Table 1. The calculations using Ashtech GPPS postprocessing software gave similar results, when default weather parameters were used. Comparison of the vector with the survey data from station point SF348 to the VLBI point, levelling data [6] and a local station survey [7], produced a geoid difference dN of about 0.1 m in the formula [8]

$$dN = dh - dH ,$$

where dh is the ellipsoidal height difference obtained from the GPS calculation and dH the orthometric height difference obtained from levelling. Use of a recently introduced NKG Scandinavian geoid 1989 [9] gave a 0.094 m geoid difference. It was therefore quite a surprise to hear about the 0.06 m height misfit at the position of the Metsähovi GPS site in global solutions [2,3], the horizontal position being within 0.01 m. Another calculation made later using the Bernese software v. 3.3 and different observations [10] gave similar results as OMNI, see entry 5, Table 1.

Next step was to introduce the classical survey data mentioned above [6] , but now corrected by the old time geoid data using linear interpolation from the three nearest triangulation points (average distance 35 km, giving O.O5 m difference in Levallois geoid between the sites in question [7]). The tie produced in the ED-87 datum is shown in Table 1, entry 2. Because the coordinate differences in the IFRF90 frame are practically the same, no corrections were made. The changes in the local coordinates with respect to the initial position were then dn= –0.004 m, de= 0.003 m, du= 0.060 m, which are near the suspected position deviation. This tie is now used in the IGS site catalogue [4].

Because of the general interest in this topic, a more detailed calculation was done with Ashtech GPPS software (Linecomp 4 .2). This program is automatic and wellbehaving, but its height solution in particular is very sensitive to ground meteorological data, typical differential sensitivities being dh/dT= –11 mm/°C, dh/dP= -9 mm/hPa, and dh/d(RH)= -2 mm/%. Thus it is understandable that the use of meteorological data in GPS calculations may be problematic [11], at least with this program. Because the distance between the sites is only 2.8 km and the height difference of the antennas was 34 m (Metsähovi is up), it was reasonable to keep temperature and relative humidity constant and to try scaling the pressure down by 4.0 hPa according to the height difference, It should be noted that this is against some general advices of the G PP S manual. The absolute values were near their true values (1 0°C, 75%, 1028 hPa). GPPS program uses only one reference satellite and a maximum of 13 satellites without computing problems. Here , unconventionally, a double pass, from 1)135 : 19 h 10 min to D136 : 10 h 20 min (time span 15 h 10 rein) was selected, the cut-off elevation angle being 10 degrees, The result of an integer fixed double difference L1 solution was calculated, see Table 1, entry 3. The location of the L1 phase centre of the Mini Rogue was assumed to be 0.075 m [12] above the antenna reference point (ARP) and 0.076 m for Ashtech (0,013 m over the upper surface, the earlier reference). These values were found to reproduce the surveyed offsets between the earlier and current CIGNET antennas [7] within a millimetre using the GPPS program and 0.5 hPa pressure offset due to the tower heights. Some small modelling inadequacy was visible in the residuals (9 mm). Single pass solutions produced almost the same result (also the mismodelling), only the z- component was some 5 mm larger (–1324.632 m), The L2 solution using the published ARP values were almost the same, although the L3 solution deviated considerably.

Because the regular undulations of the residuals may originate from the incorrect position of the receiver, estimation of the height was done by varying the pressure of the Metsähovi GPS receiver and looking for the minimum of the orbital fit. It proved out that the best fit (6.3 mm) was obtained with a pressure difference of 1.2 hPa up (!), neither 4 hPa down nor O hPa. A plot of the optimized residuals is shown in Fig. 1, and the tie solution in Table 1, entry 4. It can be seen that all three regular GPS solutions agree well (the solutions 1, 4, and 5 in Table 1).

Earlier measurements made in winter (Day 361 of 1991 to Day 2 of 1992) using similar P-code Ashtech P-12 receivers on the VLBI point and on the Bilby tower were studied as an additional check. It turned out that, in general, the L1 and L2 solutions had quite large disturbances in residuals, but that the L3 solutions were very good, the repeatability being a few millimetres in each coordinate, The origin of the disturbances was most likely ionospheric phenomena. The result was translated to the MiniRogue ARP using the station survey [7]. An average of five integer fixed L1 solutions (via L3) is shown in Table 1, entry 6. The offsets agree at the 8 mm level with the direct estimated GPPS solution (Table 1, entry 4).

Table 1
Site ties of Sjökulla VLBI point (CDP 7601) to Metsähovi MiniRogue GPS point in different solutions.

	dx(m)	dy(m)	dz(m)	Notes
1.	1918.159	1547.985	-1324.677	Original IGS, a.
2.	1918.188	1548.001	-1324.627	Survey, b.
3.	1918.187	1548.001	-1324.628	GPPS, emul. P, c.
4.	1918.165	1547.991	-1324.668	GPPS, est. h, d.
5.	1918.164	1547.991	-1324.682	Bernese 3.3, e.
6.	1918.171	1547.999	-1324.668	Combined, f.
7.	1918.183	1547.993	--1324.616	S10 global, g.

Notes

a. Original IGS value, from IGS Mail No. 33, July 1, 1992.

b. From survey results with 0.05 m Levallois geoid difference in the ED-87 datum [7], this is the present IGS tie.

c. Ashtech GPPS integer fixed L1 solution, double pass over 15 h time span, emulated atmosphere, a pressure difference of 4 hPa used.

d. Ashtech GPPS integer fixed L1 solution, same as in 3, but the orbit fit optimised by varying pressure at the Metsähovi GPS antenna.

e. Bernese 3.3 solution by Poutanen [10].

f. Combined path, from the VLB1 point to the Bilby tower using Ashtech P-12 receivers and then to Mini Rogue using station survey data (dx= 11.265 m, dy= 32.048 m, dz= --18.051 m), same weather data used, Ashtech GPPS integer fixed L] (via 1,3) solution

g. Global coordinate solution from Sjökulla (ITRF91 at 1992.5) to Metsähovi (S10 GPS solution at epoch 1992.836), sce Table 2, after transforming the data to a common epoch using the published site velocities, $\dot{x}$= --0.0169 m/a, $\dot{y}$= 0.0170 m/a, $\dot{z}$= 0.0049 m/a, from IGS Mail No. 177, January 18, 1993.

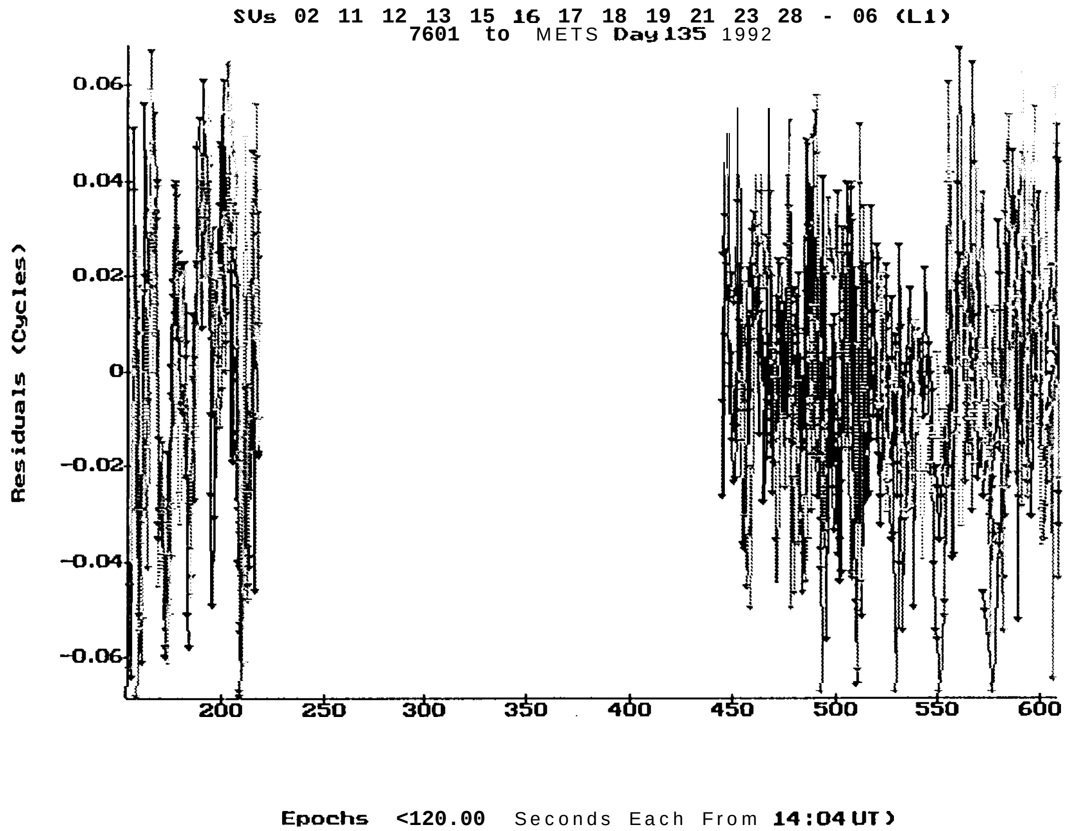

Figure 1: Residuals of a double pass integer fixed L1 solution (Ashtech GPPS).

SITE TIE FROM GLOBAL GPS COORDINATES

The initial coordinates of the GPS receiver at Metsähovi were obtained by adding the GPS tie vector (entry 1 in Table 1) to the VLBI coordinates of Sjökulla. As mentioned, the first global results suggested that horizontally the reported position agreed within about 10 mm, but the vertical position was 0.06 m too low. In the global solutions only a stochastic estimation of the zenith path delay was used. So far, only the Scripps Institution of Oceanography (S10) has explicitly released its coordinates for Metsähovi (entry 4 in Table 2). From these data the tie vector can be calculated by noting a small epoch difference and published site velocities (entry 7 in Table 1). Agreement with the present IGS tie is within 11 mm in each coordinate, but the local GPS solutions differ more, Only the GPPS solution using emulated atmosphere agrees with the global GPS solution.

Table 2
Coordinates of Sjökulla VLBI point (CDP 7601) and
Metsähovi MiniRogue GPS point.

Site	x(m)	y(m)	z(m)	Notes
1. Sjökulla	2890652.829	1310295.299	5513958.646	ITRF91, a.
2. Sjökulla	2890652.830	1310295.265	5513958.631	DORIS, b.
3. Metsähovi	2892571.017	1311843.300	5512634.019	ITRF91, c.
4. Metsähovi	2892571.016	1311843.298	5512634.032	Global, d.

Notes

a. IERS I0503MO02, 7601, ITRF91 at Epoch 1992.5 [4], from mobile VLBI campaign 1989 [13].

b. DORIS solution by Watkins et al. [14], the tie to CDP 7601 is dx= 11.609 m, dy= -15.220 m, dz= --6.232 m.

c. IERS 10503S011, METS, ITRF91 at Epoch 1992.5, using site tie No. 2 in Table 1 [4].

d. Global GPS solution by the Scripps Institution of Oceanography, Epoch 1992.836, from IGS Mail 177, January 18, 1993.

DISCUSSION

Because the compilation of common global GPS solutions is still pending, it is not yet possible to fix the deviation between the local and global site solutions.

There is a considerable error margin in the VLBI determination [13]. In five one-day sessions the height component varied by 144 mm (the standard deviation of 38 mm), the horizontal position variation being less than **10** mm. A recent DORIS solution [14] without any consideration for possible known system differences agrees with the VLB1 values within 30 mm in each coordinate , but probably cannot yet improve the VLBI solution.

Stochastic estimation of the atmospheric zenith delay is gaining acceptance. However, it is clear that possible biases in the estimated atmospheric path are mapped to biases in the positional solution.

Dual frequency Ashtech data from the first GPS IERS and Geodynamics experiment (GIG'91) from January 22 to February 13,1991, directly from the Sjökulla VLB1 site, are available and could possibly be used to strengthen the VLBI solution.

The velocity model used (see Note g. in Table 1) when transforming to the local coordinate system gives $\dot{n}$= 0.0097 m/a, $\dot{e}$= 0.0225 m/a and $\dot{u}$= 0.000 m/a. However, it is accepted that the land up-lift at Metsähovi is currently about 0.003 m/a. This may leave some 10 mm additional uncertainty in the present z-component.

It has been argued that the gravity data around Metsähovi station are not sufficient [15], especially to the south of the Gulf of Finland. Local data south of Metsähovi are also sparse. A denser NKG-89 geoid data subset, FINGEOID, gives a geoid difference of 0.083 m, and a downgraded (25 km) subset, NKGGEOID.U25, gives 0.070 m between the sites in question. Additionally, the result of the common adjustment of the southwest Finnish triangulation net [16] gave the vertical deflection of Falkberg station (No 27, 2.4 km from Sjökulla), as ξ= -3.51" and η= 5.85". These can be used with the formula for the geoid difference [8]

$$dN = ds * (\cos A * \xi + \sin A * \eta),$$

where ds is the distance and A the azimuth, to obtain dN = 0.064 m. Then the discrepancy of the height solution would be no more than 0.03 m. More information about the fine structure of the geoid is needed to solve the height question definitely.

ACKNOWLEDGMENT

The cooperation of Miranda Chin, the National Geodetic Survey, in GPS calculations and CIGNET operations is greatly appreciated.

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PROGRAMME OF RESEARCH WORKS AT THE IGS FIDUCIAL STATION JÓZEFOSŁAW AND THE IGS EVALUATION CENTRE OF THE IG&GA WUT

Janusz Śledziński*, Jerzy B. Rogowski*

Satellite station of the Institute of Geodesy and Geodetical Astronomy of Warsaw University of Technology (IG&GA WUT) at Józefosław was accepted as the fiducial station of the International GPS Geodynamics Service (IGS).The programme of scientific works performed at this station results mainly from a specific geologic and geotectonic location of the station just at the border of two great tectonic plates and at the edge of the Teisseyre-Tornquist zone.This programme is shortly outlined in the paper.

IGS Evaluation Centre which is organized at the Institute uses GPS observations collected by the IGS stations during IGS' GPS campaigns and orbital data for establishment of geodetic frame for geodynamic studies of the Teisseyre-Tornquist zone and Carpathian region. Observations of IGS EPOCH'92 and GPS campaign EXTENDED SAGET'92 organized and coordinated by the Institute have been processed lately at the Evaluation Centre giving an excellent geodetic control for geodynamic projects in Central European region.

INTRODUCTION

Astrogeodetic Observatory of the Institute of Geodesy and Geodetical Astronomy of Warsaw University of Technology (IG&GA WUT) at Józefosław was accepted in 1991 as the IGS (International GPS Geodynamics Service) Fiducial Station (Ref Nr 043). At the Institute was also organized an IGS Evaluation Centre.

Almost all geodynamic projects running at the Institute take advantage of a very specific and particular geotectonic position of

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Poland. This results from the fact that three great geological units contact on the territory of Poland: East European Precambrian Platform, Paleozoic Platform of the Central and Eastern Europe and South European Alpine Orogeny (Fig. 1]. It is easy to recognize that all these three geotectonic units form in south-eastern part of Poland so called “tectonic knot”. The Teisseyre-Tornquist zone also crossing the territory of Poland and separating the two above mentioned platforms is of prime importance for the regional geodynamics of Central Europe.

All projects is which the Institute is engaged focus on above described key geotectonic position of Poland and concern the investigation of geodynamic parameters which may contribute to better knowledge of geodynamics of both the T-T zone itself and the contact, close to the T-T zone, region. The specific location of the Institute’s Astrogeodetic Observatory at Józefosław just at the edge of the Teisseyre-Tornquist zone makes the conducted research much more essential.

CONCISE OVERVIEW OF GEODYNAMIC PROJECTS

The following geodynamic projects now running at the Institute are particularly worth mentioning:

Satellite Geodynamical Traverses (Project SAGET)

Project SAGET was initiated at the Institute in 1986 [11 as a long term geodynamical research programme. The essence of this project is to establish a network of precise traverses which would connect points located on various geotectonic units within Poland and to collect satellite, geodetic, astronomical and gravimetric measurements which could be used in broad and detailed geodetic and geodynamic analyses. The traverses are based on six Polish observatories (Borowa Góra, Borowiec, Grybów, Józefosław, Lamkówko and Śnieżka) four of which are IGS fiducial stations (Borowa Góra, Borowiec, Józefosław, Lamkówko). They cross the boundaries between geological units and connect points located on various units. The present stage of realization of the project is shown in Fig. 2.

So far, the following observational data are available:

- GPS observations collected during several GPS campaigns along SAGET traverses of about 700 km in length and during campaigns joining basic SAGET points;
- precise absolute gravity measurements on 7 points;
- relative gravimetric measurements of 300 km long SAGET traverses;
- precise levelling ties;
- astronomical measurement of latitude and longitude at 7 points;
- precise terrestrial traversing of 250 km long SAGET traverses.

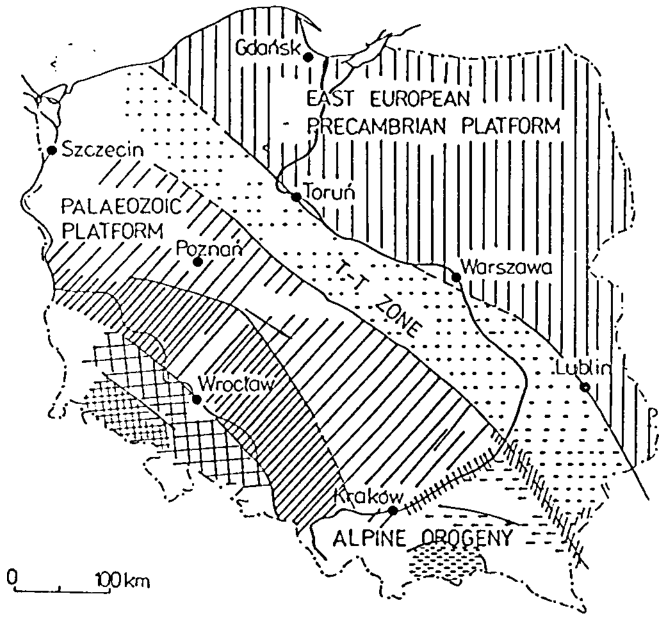


Fig. 1. Major tectonic units and the territory of Poland

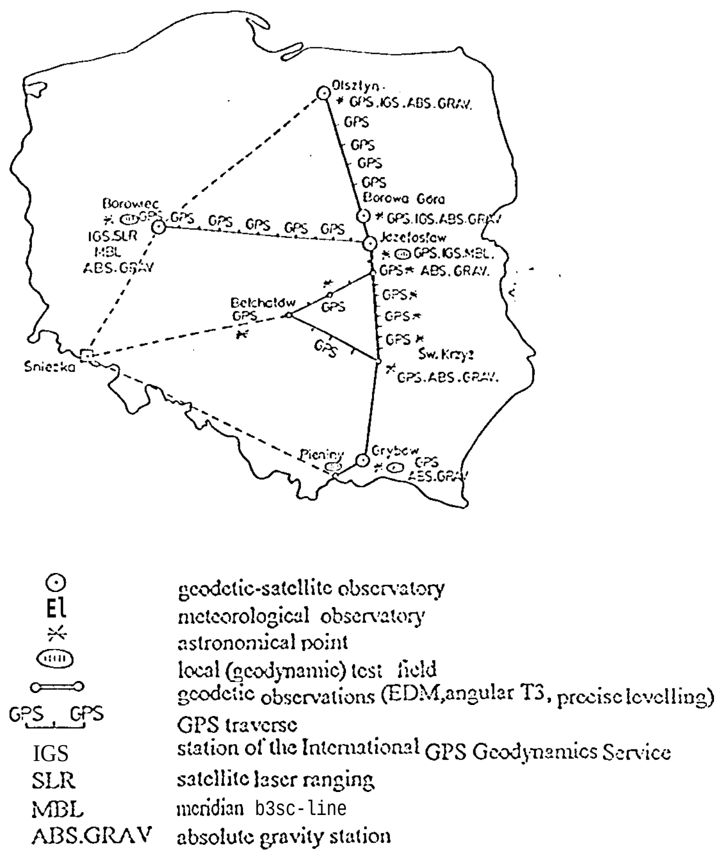


Fig. 2. Present stage of the project SAGET

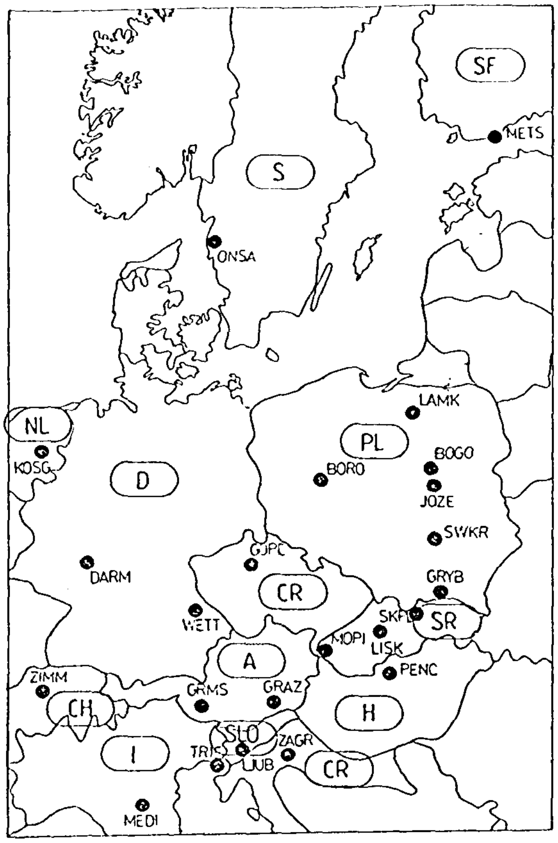


Fig. 3. EXTENDED SAGET Network

The geoidal heights have been calculated along a 165 km long traverses crossing T-T zone. For calculation several methods were used: satellite Doppler and precise levelling, satellite GPS and precise levelling, astro-geodetic levelling, astro-gravimetric levelling, geopotential models GEM 10B and OSU 86F; the obtained results indicate good compatibility of all applied methods [21 .

EXTENDED SAGET Project

In 1991 the concept was developed to extend the SAGET traverses over Slovak, Czech and Hungarian territory so they could reach the satellite observatories in Wettzell (Germany), Graz (Austria), Triest and Bologna (Italy) as well as other main European satellite observatories. The EXTENDED SAGET network can be seen in Fig. 3. First GPS campaign was organized in September' 92. About 20 European stations participated in this campaign. Results of the campaign processed at the Institute's IGS Evaluation Centre jointly with observations from IGS EPOCH'92 campaign are also presented at this Berne Workshop as a separate paper. The established base-lines form an excellent frame for geodynamical projects in Central Europe (WEGENER, EUROPROBE). They can also be regarded as a part of GPS crustal 3D deformation network of an international standard establishment of which was lately recommended by the group of Central European Initiative (CEI) countries.

PIENINY Geodynamic Test Network

The network called PIENINY is located in the southern part of Poland in the region of Pieniny Mts. where a dam is being constructed on the River Dunajec. The network consists of points situated in the area of the Pieniny Klippen Belt. The complex geologic structure of Southern Poland requires that a special approach is adapted for this region to study its geodynamics. The test field on the borders between the three local geological structures was established in 1978. Over the period 1978-1992 geodetic (EDM, angular and precise levelling) and gravimetric measurements were repeated 8 times with the aim to detect the horizontal and vertical crustal movements and the time variations of gravity. The geodetic, satellite GPS and gravimetric measurements are also planned to be made in the period when the reservoir will be filling with water which is supposed to take place in a few years time; repeated surveys will also be performed after filling the reservoir.

Investigation of local technogene deformations in Silesia Region.

Joint use of quick GPS technologies, photogrammetric mapping and gravimetric precise surveys, all three kinds of measurements performed simultaneously gave excellent results in areas suffering from intensive mining. The WODZISŁAW network established in the region of Upper Silesia consisting of about 45 points which was measured in this way four times in the last 3 years has confirmed that the displacements of some points in this region are as big as 20 cm/month. The gravimetric Bouguer anomalies calculated for the same epoch have confirmed and supplemented the achieved results and gave more exhaustive view in the dynamic processes occuring in this region. Quite new complete technologies were developed and practically applied. Execution of next observation cycles is scheduled for this year.

STUDIES ON DEFORMATION MODELS

As it is shown in Fig. 4 the Astrogeodetic Observatory Józefosław (located about 15 km south of Warsaw) is probably situated on the north-east edge of the Teisseyre-Tornquist zone. Permanent astronomical observations of the latitude changes were undertaken in 1959. Since 1976 the gravimetric measurements, carried out 3-4 times a year along special meridional base-line, have been utilized for investigations of changes of the plumb line direction. Gravimetric measurements have been accompanied by determination of ground water level and soil humidity. The changes of ground water level and soil humidity are used to correct the gravity differences and plumb line variations obtained by collocation of astronomic and gravimetric methods. It was noted that these variations have an one-year period and an amplitude of 0″012 [3]. The main part of these changes has been probably produced by processes in the deeper part of the Earth's crust and in the vicinity of the Moho boundary. They may be produced by anomalous deformations of the crust connected with the depression of the Moho boundary in the T-T zone (see Fig. 4) and discountinuities of the geotectonic structures which appear mainly due to the tidal influences.

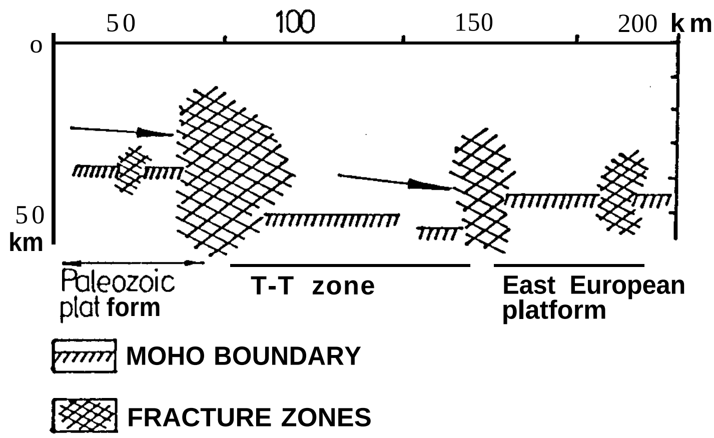


Fig. 4. The model of the hypothetic motion of the Paleozoic Platform and depression of the Moho boundary within the T-T zone, [71

These changes were also confirmed by the two-week gravimetric observation cycle made by the LaCoste&Romberg, model G gravity-meter during IGS EPOCH'92 campaign. In these determinations significant discrepancies reaching up to 30 microgals, i.e. more than 30% of tidal amplitude can be noted between the theoretical tide and the observed one (see Fig.5).

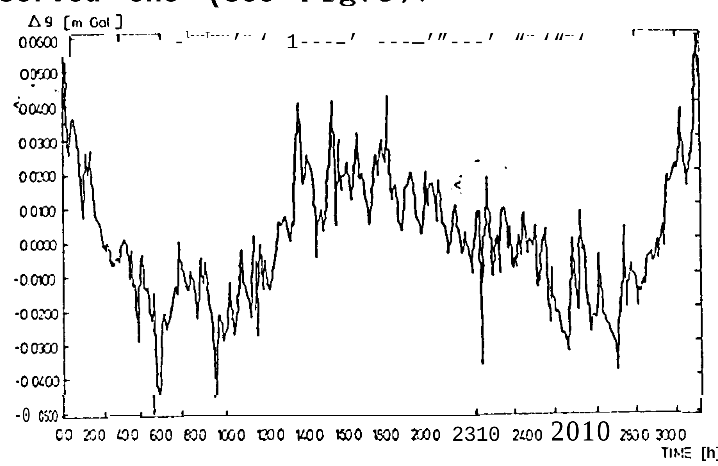
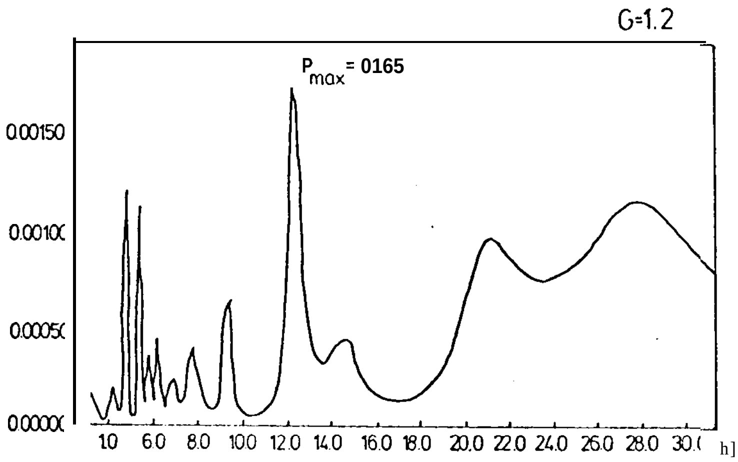


Fig. 5. Discrepancies between the theoretical and observed values of the tide amplitude at the station Józefosław.

A period of the differences between the observed gravity and the tidal variations of about 12,5 hours can be detected using MESA method of the spectral analysis (see Fig. 6) . This period may be also determined independently on the adopted value of the factor $G = 1 + h - 3/2\ k$.



Fig, 6. Results of the spectral analysis of the non-tidal gravity variations.

In view of the fact that the Astrogeodetic Observatory Józefosław is the basic and reference station of the Project SAGET as well as the IGS Fiducial Station, it is absolutely necessary to intensify the local studies of geodynamical deformations using gravimetric, astronomic and GPS techniques.

RELATIONSHIP BETWEEN IGS AND OTHER LOCAL AND REGIONAL GEODYNAMIC PROJECTS

IGS stations provide an excellent link to the International Terrestrial Reference Frame (ITRF). Since many of IGS European stations are also the EUREF (European Reference Frame) points, they assure very precise ties to the ETRS-89 (European Terrestrial Reference System) system. By connection of local projects with IGS stations we can achieve a transformation of all points involved in these projects to one common global reference system represented by IGS core and fiducial stations. Four IGS fiducial stations established in Poland give a possibility of easy transferring of the IGS system to all geodynamic networks over the territory of Poland, The connection of all projects is given by common GPS campaigns and precise orbit ephemeris and parameters of the Earth rotation produced by IGS.

IGS EVALUATION CENTRE AT THE IG&GA WUT

The aims of research which is envisaged to be realized at the IGS Evaluation Centre at the Institute of Geodesy and Geodetical Astronomy of Warsaw University of Technology are:

- to process the data from the IGS and other GPS campaigns in order to establish the geodetic frame for geodynamic studies in the region of the Teisseyre-Tornquist zone, the Carpathian and Subalpine regions of Central Europe,

- to link Polish geodynamic network with those established in other countries, in particular in Slovakia, Czech Republic, Hungary and Austria.

- to investigate recent movements of the Earth's crust in contact area of three great geotectonic units (Paleozoic Platform, Precambrian Platform, Alpine Orogeny) using collocation of satellite, geodetic, gravimetric and astronomical techniques,

- to determine the geoidal heights with centimetre accuracy in some particularly interesting areas.

- to support the activities of the Section C "Geodesy" of the CEI (Central European Initiative countries) Committee of Earth's Sciences by an active participation in the Central Europe Regional Geodynamics Project (CERGOP) and in establishment of the Central European Regional GPS Geodynamic Reference Network (CEGRN).

The Evaluation Centre collects GPS observations of IGS and other campaigns related to the Central European region. Also IGS products, i.e. GPS satellite orbits and parameters of the Earth rotation are archieved.

EQUIPMENT AND SOFTWARES

To perform the work the Institute's IGS Fiducial Station Józefosław and the Evaluation Centre use the following main precise equipment and software:

* 7 GPS TRIMBLE receivers:

3 GEODETIC SYSTEM SURVEYOR 4000SSE (dual frequency, P-code, 6th Observable™ technology),

2 GEODETIC SURVEYOR 4000SST-IIP (dual frequency, P-code),

2 FIELD SURVEYOR 4000ST (single frequency, C/A code);

* LaCoste&Romberg gravity meter;

* 2 Absolute gravity meters (in cooperation with Research-Industrial Institute "METROLOGIA", Kharkov, Ukraine);

* Zeiss zenith telescope;

* Workstation Apollo 720, System of PC 486, PC 386 computers,

* Softwares:

  BERNESE versions 3.2 and 3.3,
  DIPOP,
  NETVAL ,
  GPSurvey,
  TRIMNET and TRIMNETP (3 versions),
  TRIMVEC Plus Rev. B, C, D, E.
  a package of softwares developed at the Institute:
    - GEPES,
    - transformation of GPS coordinates to geodetic systems.

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RESULTS OF THE GPS CAMPAIGNS EXTENDED SAGET AND THE IGS EPOCH'92 FOR THE REGION OF CENTRAL EUROPE

Janusz Śledziński*, Jerzy Rogowski*, Mieczysław Piraszewski*, Mariusz Figurski*, Janusz Wale*

First GPS observation campaign of the geodynamic project EXTENDED SAGET (Satellite-Geodetic Traverses) was organized by the IG&GA WUT in the period from 1992, September 7th to 11th. The action aims at the establishment of the precise GPS network which comprises the region of the tectonic contact. Teisseyre-Tornquist zone in Central Europe. 23 European satellite stations from 13 countries participated in the campaign. The paper contains first results of the campaign; also some comparisons with results of EPOCH'92 are given. All computations were made at the IGS Evaluation Centre at the IG&GA.

INTRODUCTION

The key geotectonic position of Poland has encouraged the Institute of Geodesy and Geodetical Astronomy of Warsaw University of Technology to initiate some particular geodynamic projects. This key position results from the following facts:

1. Three large geotectonic units meet on the territory of Poland:

   - West-European Paleozoic Platform,
   - East-European Precambrian Platform,
   - Alpine Orogeny.

   They form in south-eastern part of Poland so called "tectonic knot".

2. Poland is cut by Teisseyre-Tornquist zone.

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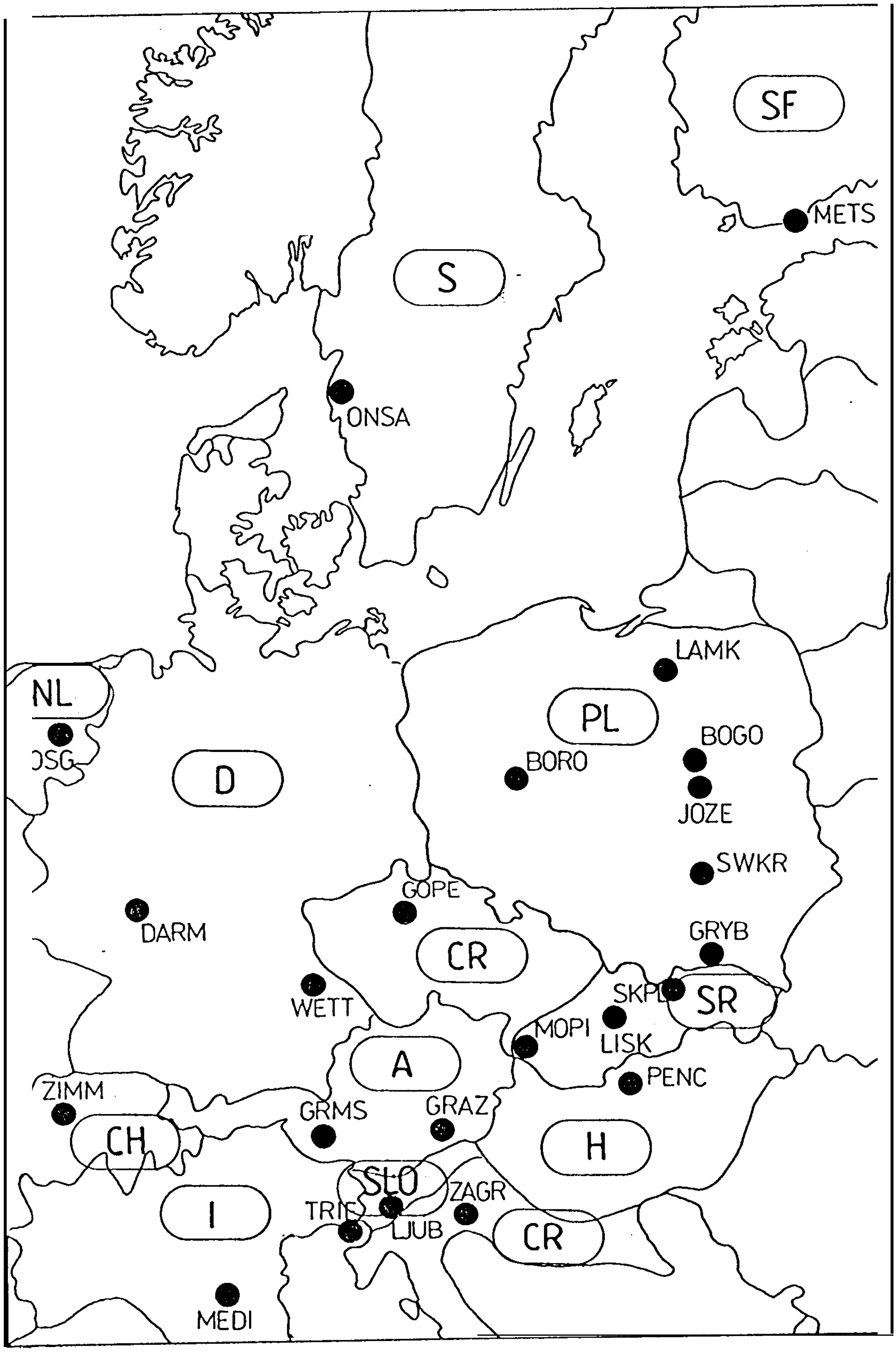

Fig. 1. GPS stations participating in the EXTENDED SAGET Campaign

Institute's Astrogeodetic Observatory Józefosław (JOZE) was accepted as the IGS Fiducial Station No. 043. At the Institute was also organized the IGS Evaluation Centre which is involved in the processing of the GPS data from Central European stations.

Using this specific situation Institute of Geodesy and Geodetical Astronomy of Warsaw University of Technology has initiated the following geodynamic projects:

1. Project SAGET which consists in establishing satellite-geodynamical traverses in Poland connecting points located on various geotectonic units.

2. Contribution of the geodynamical investigation in the T-T zone to the regional studies in Central Europe, First step action of this project was establishment of the EXTENDED SAGET network which comprises all region of the T-T zone in Central Europe. This paper is a concise report of the EXTENDED SAGET'92 GPS campaign.

3. Studies on recent crustal movements of the Carpathian erogenic belt. Programme of this complex project comprises establishment of local geodynamic networks on the territory of Czech Republic, Slovakia, Poland and Ukraine.

EXTENDED SAGET'92 GPS CAMPAIGN

GPS observation campaign of the project EXTENDED SAGET was organized by the IG&GA WUT from 1992,September 7th to September 11th. Twenty three GPS stations from 13 European countries participated in this campaign. These stations are shown in Fig.1. and listed in Table 1.

DATA PROCESSING

All GPS observations were processed at the IGS Evaluation Centre of the IG&GA WUT. The BERNESE software, versions 3.3 and 3. 4 were used for calculation of the point coordinates. Two kinds of orbital data were applied: ephemeris CODE from the University of Berne, Switzerland and UTX from the University of Texas, USA. The results of the EXTENDED SAGET campaign were compared with some results of the IGS EPOCH'92 campaign. Nine stations of the IGS EPOCH'92 campaign (5 core and 4 fiducial stations) were also computed at the Institute's IGS Evaluation Station. Results of the processing of the EPOCH'92 data for four fiducial stations (BORO, GOPE, JOZE and MOPI) are shown in Table 2 (X, Y, Z coordinates) and Table 3 (B, L, H coordinates). These are mean values from all days of the EPOCH'92 campaign for the CODE and UTX ephemeris. Figs 2 and 3 show the day by day north, east and height components of the position of the stations BORO, GOPE, JOZE and MOPI calculated with CODE and UTX ephemeris. As an example of consistency of the achieved results we give in Fig. 4. the day by day D(LAT), D(LON), D(HGT) and D(LGT) components of two baselines JOZE-METS and JOZE-MOPI. These components are shown for both CODE and UTX ephemeris.

Results of the EXTENDED SAGET campaign are presented in Table 4. This table contains the coordinates of 17 stations participating besides core stations in the EXTENDED SAGET campaign.

Table 1

LIST OF STATIONS

PARTICIPATING IN THE EXTENDED SAGET'92 CAMPAIGN

Country	Station	Code	Receiver	251	252	253	254	255
Switzerland	Zimmerwald	ZIMM	4000SST-P	yes	no	yes	yes	yes
Netherlands	Kootwijk	KOSG	ROGUE-8C	yes	yes	yes	yes	yes
Sweden	Onsala	ONSA	ROGUE-8C	yes	yes	yes	yes	yes
Finland	Metsahovi	METS	ROGUE-8C	yes	yes	yes	yes	no
Austria	Graz	GRAZ	ASHTECH LM-XIIP	yes	yes	yes	yes	yes
Austria	Reiseeck	GRMS	ASHTECH LM-XIIP	yes	yes	yes	yes	yes
Germany	Wettzell	WETT	Rogue-8C	yes	yes	yes	yes	yes
Germany	Darmstadt	DARM	4000SST-P	yes	yes	yes	yes	yes
Croatia	Zagreb	ZAGR	ASHTECH LM-XIIP	yes	yes	yes	yes	yes
Slovenia	Ljubliana	LJUB	ASHTECH LM-XIIP	yes	yes	yes	yes	yes
Italy	Medicina	MEDI	4000SST-P	yes	yes	yes	yes	yes
Italy	Triest	TRIE	4000SST-P	yes	yes	yes	yes	yes
Hungary	Pent	PENC	4000SST	yes	yes	yes	yes	yes
Czech Rep.	Pecny	GOPE	4000SST-P	no	no	yes	yes	yes
Slovakia	Mod.Pieski	MOPI	4000SST-P	no	no	yes	yes	yes
Slovakia	Skal.Pleso	SKPL	4000SST-P	no	no	yes	yes	yes
Slovakia	Liskovec	LISK	4000SST-P	yes	yes	yes	no	no
Poland	Józefosław	JOZE	4000SST-P	yes	yes	yes	yes	yes
Poland	Grybów	GRYB	4000SST-P	yes	yes	yes	yes	yes
Poland	Św.Krzyż	SWKR	4000SST	yes	yes	yes	yes	yes
Poland	Borowiec	BORO	4000SST	yes	yes	yes	yes	yes
Poland	Bor. Gora	BOGO	ASHTECH LM-XII	yes	yes	yes	yes	yes
Poland	Lamkówko	LAMK	ASHTECH LM-XII	yes	yes	yes	yes	yes

Table 2

X,Y,Z coordinates of the four fiducial stations BORO, GOPE, JOZE, MOPI, as obtained from EPOCH'92 campaign (CODE and UTX ephemeris)

Point	Ephemeris	X [ml	mx [ml	Y [ml	my [ml	Z [ml	mz [ml
BORO	CODE UTX	3738397 .1570 , 1559	O. 0042 0.0065	1148285 0.8136 0.8121	0.0042 0.0046	5021752 0.3491 0.3535	O. 0089 0.0080
GOPE	CODE UTX	3979316 .4487 .4518	0.0062 0.0070	1050312 0.3239 0.3297	0,0041 0.0052	4857067 0.0580 0.0656	0.0076 0.0073
JOZE	CODE UTX	3664940 .5105 .5087	0.0043 0.0050	1409153 0.7483 0.7493	O. 0046 0.0059	5009571 0.3913 0.3968	0.0068 0.0061
MOP I	CODE UTX	4053738 .2222 .2255	0.0067 0.0073	1260571 0.4417 0.4459	0.0042 0.0052	4744940 0.8171 0.8258	0.0080 0.0073

Table 3

B,L,H coordinates of the four fiducial stations BORO, GOPE, JOZE, MOPI, as obtained from EPOCH'92 campaign (CODE and UTX ephemeris)

Point	Ephemeris	B	mB	L	mL	H	mH
		[0 ' "1	["1	[0 ' "1	["1	[ml	[ml
BORO	CODE UTX	52 16 33.99992 34.00005	*0.0001* *0.0001*	17 4 29,49588 29.49582	0.0002 0.0003	116.9728 116.9753	0.0097 9.0094
GOPE	CODE UTX	49 54 49.32917 49.32922	*0.0001* *0.0001*	14 47 8.22893 8.22917	0.0003 0.0003	592.7379 592.7465	0. 0090 D. 0090
JOZE	CODE UTX	52 5 50.18268 50.18282	*0.0001* *0.0001*	21 1 53.52756 53.52764	0.0002 0.0003	141..6142 141.6177	0.0079 D. 0072
MOP I	CODE UTX	48 22 21.81032 21.81040	*0.0001* *0,0001*	17 16 25.94914 25.94928	0.0002 0.0003	579.1395 579.1489	0. 0098 0.0093

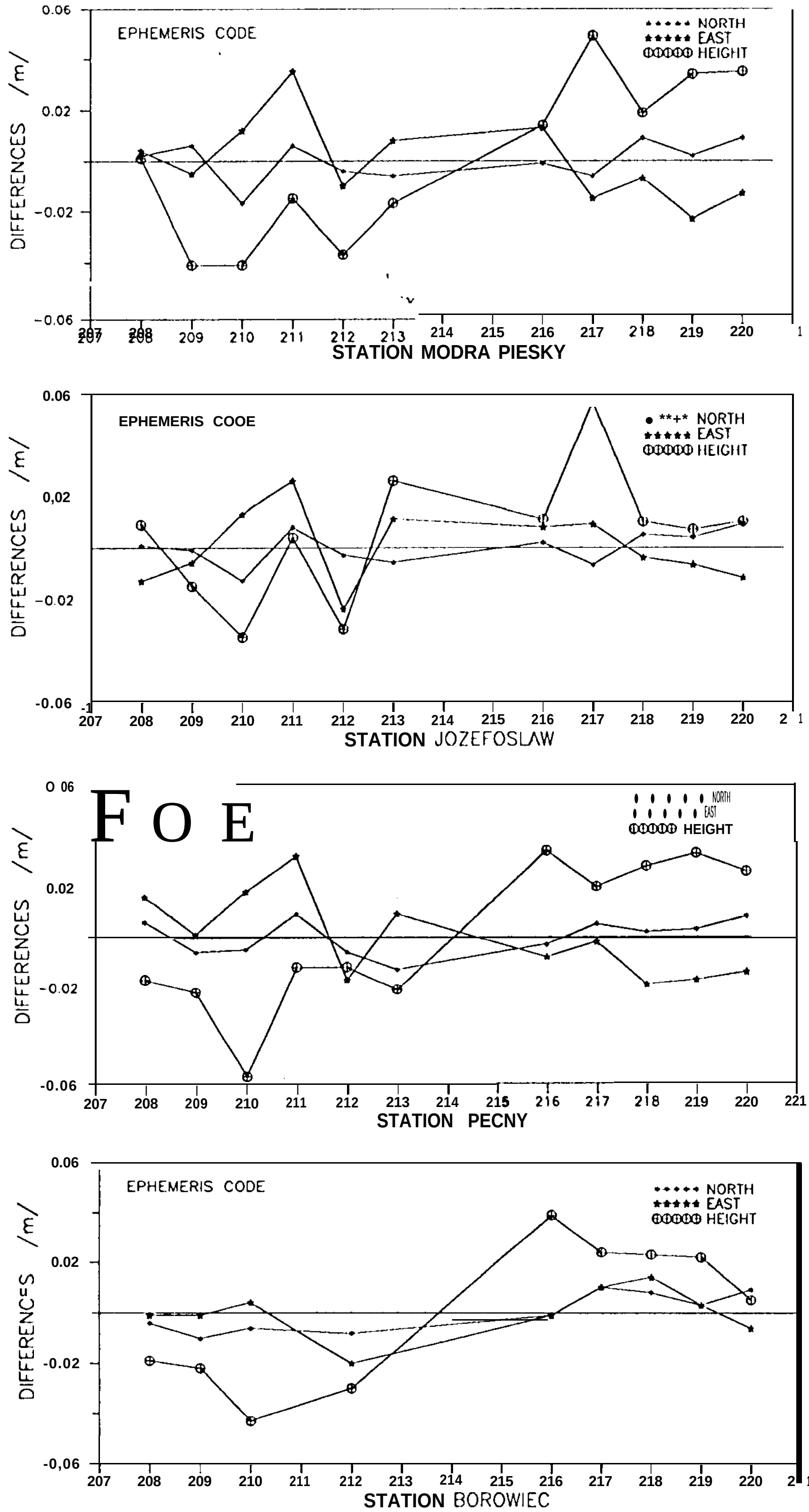

Fig.2 Day by day northeast and height components of position of the stations BORO, GOPE, JOZE, MOPI (Campaign EPOCH'92, CODE - ephemeris)

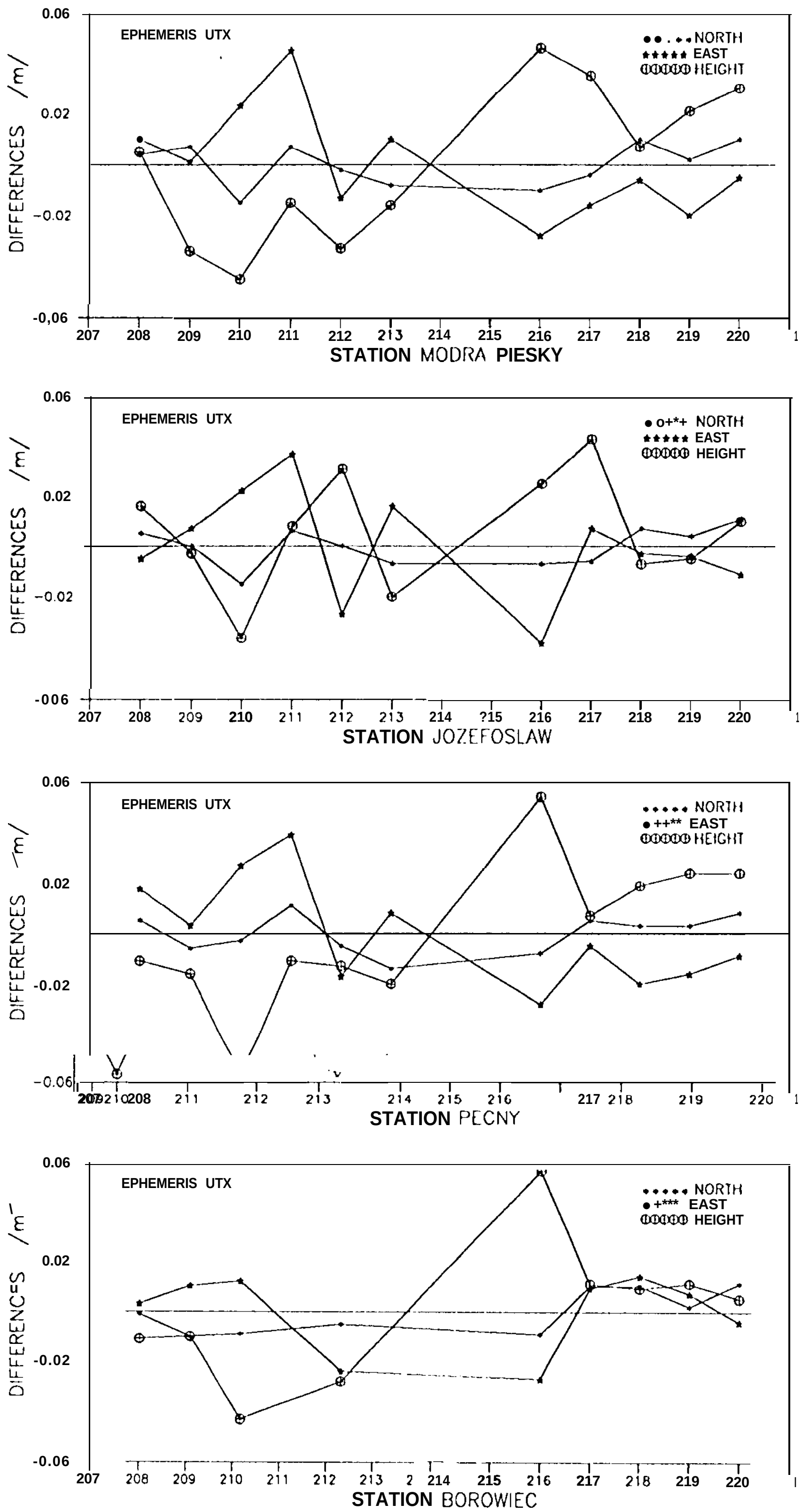

Fig.3 Day **by day north,east and height components of position of the stations BORO, GOPE, JOZE, MOPI (Campaign EPOCH'92,** UTX-ephemeris)

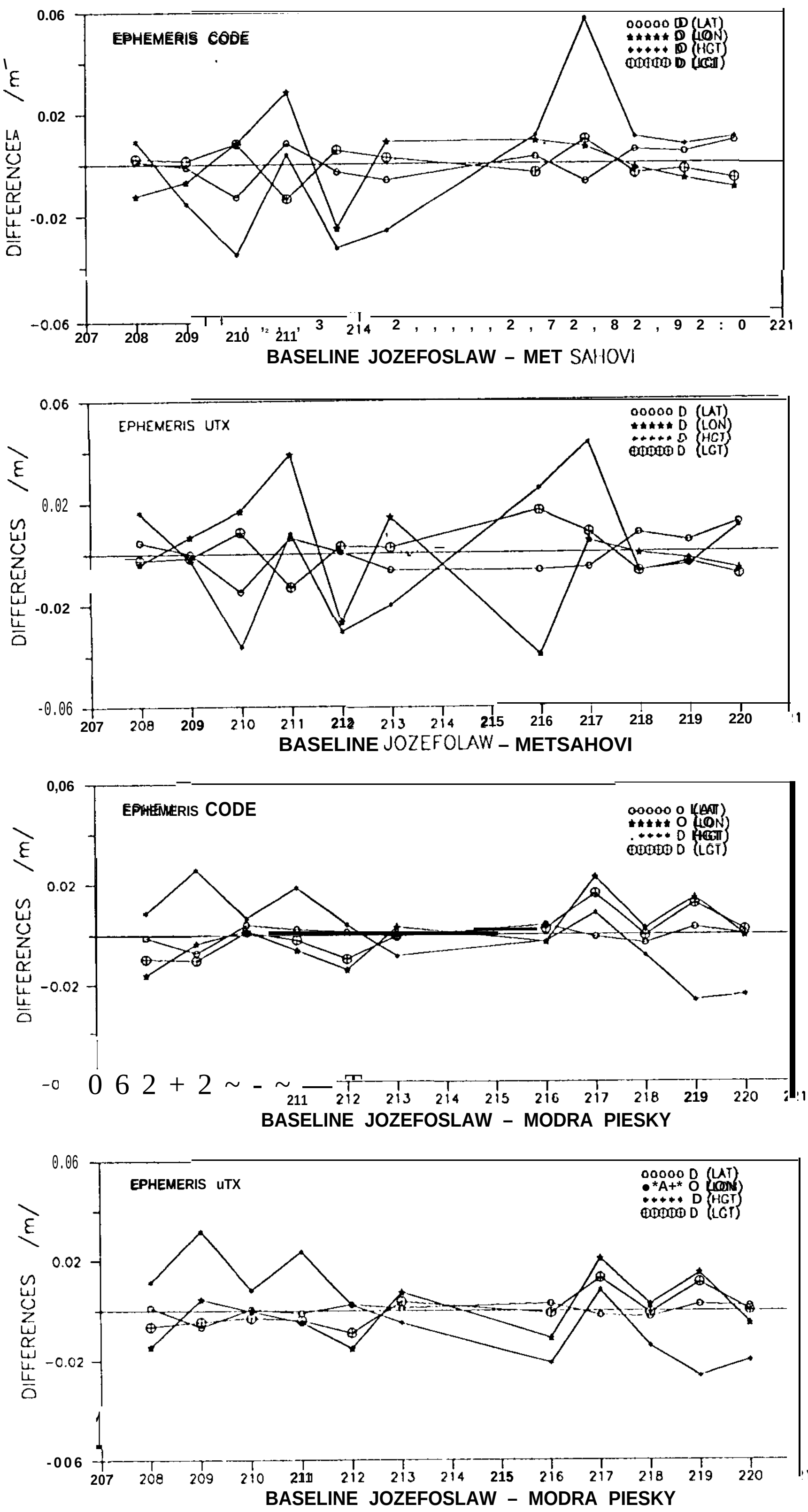

Fig.4 Day by day D(LAT), D(LON), D(HGT) and D(LGT) components of the base-lines JOZE-METS and JOZE-MOPI (Campaign EPOCH'92 mean value for CODE and UTX ephemeris) .

Table 4

B,L,H coordinates of GPS stations participating in EXTENDED SAGET'92 campaign.

St.	B	mB	L	mL	H	mH
	[° ' "]	["]	[° ' "]	["]	[m]	[m]
	EPHEMERIS CODE					
BGO1	52 28 33.4050	0.0002	21 2 7.2254	0.0003	149.5901	0.0104
DARM	49 51 43.7571	0.0001	8 40 43.9553	0.0001	252,2282	0.0118
GRMS	46 55 3.2300	0.0001	13 22 3.3696	0.0003	2378.9750	0.0321
GRYB	49 37 43.0442	0.0002	20 56 49.1054	0.0002	408.4167	0.0120
JOZE	52 05 50.1832	0.0002	21 1 53.5272	0.0003	141.5530	0.0112
LAMK	53 53 32.6340	0.0002	20 40 11.7791	0.0011	187.0116	0.0272
LISK	48 34 35.9273	0.0002	19 10 53.1883	0.0004	364.0195	0.0117
LJUB	46 2 44.9092	0.0001	14 29 43.4108	0.0004	367.6465	0.0300
MEDI	44 31 11.9912	0.0001	11 38 47.3572	0.0003	49.6789	0.0197
PENC	47 47 22.5643	0.0001	19 16 53.4896	0.0007	291.5817	0.0133
SWKR	50 51 31.5050	0.0003	21 3 15.4357	0.0002	611.2657	0.0089
TRIE	45 38 34.4168	0.0001	13 52 30.0669	0.0002	445.9855	0.0159
ZAGR	45 48 25.2225	0.0001	15 57 49.8749	0.0003	202.5593	0.0194
BORO	52 16 37.0377	0.0001	17 4 24.4305	0.0007	124.4583	0.0074
GOPE	49 54 49.3295	0.0002	14 47 8.2283	0.0003	592.7169	0.0056
MOPI	48 22 21.8111	0.0001	17 16 25.9485	0.0003	579.0937	0.0069
SKPL	49 11 15.0662	0.0002	20 13 52.7849	0.0005	1814.8662	0.0235
	EPHEMERIS UTX					
BGO1	52 28 33.4050	0.0001	21 2 7.2254	0.0002	149.5958	0.0139
DARM	49 51 43.7571	0.0001	8 40 43.9554	0.0001	252.2276	0.0111
GRMS	46 55 3.2300	0.0001	13 22 3.3696	0.0003	2378.9725	0.0319
GRYB	49 37 43.0445	0.0000	20 56 49.1054	0.0002	408.4236	0.0111
JOZE	52 05 50.1832	0.0000	21 1 53.5272	0.0004	141,5576	0.0093
LAMK	53 53 32.6340	0.0001	20 40 11.7790	0.0012	187.0213	0.0241
LISK	48 34 35.9275	0.0001	19 10 53.1884	0.0004	364.0198	0.0124
LJUB	46 2 44.9092	0.0001	14 29 43.4108	0.0005	367.6431	0.0290
MEDI	44 31 11.9913	0.0001	11 38 47.3575	0.0003	49,6741	0.0189
PENC	47 47 22.5645	0.0001	19 16 53.4894	0.0007	291.5795	0.0095
SWKR	50 51 31.5051	0.0001	21 3 15.4357	0.0001	611.2727	0.0075
TRIE	45 38 34.4170	0.0001	13 52 30.0670	0.0002	445.9815	0.0164
ZAGR	45 48 25.2225	0.0001	15 57 49.8750	0.0002	202.5520	0.0165
BORO	52 16 37.0375	0.0000	17 4 24.4305	0.0006	124.4696	0.0097
GOPE	49 54 49.3294	0.0002	14 47 8.2283	0.0003	592.7325	0.0092
MOPI	48 22 21.8110	0.0001	17 16 25.9481	0.0002	579.1090	0.0157
SKPL	49 11 15.0663	0.0000	20 13 52.7842	0.0003	1814.8712	0.0124

CONCLUSION

As a result of the EXTENDED SAGET campaign, a GPS network of points comprising the entire T-T zone in Central Europe was established. All precise point positions were computed by BERNESE software (versions 3.3 and 3.4) using both CODE and UTX orbital data. The results from both ephemeris show, in general, a very good consistency. As the reference points, some IGS core stations were used. Comparisons of the results of the EXTENDED SAGET'92 and IGS EPOCH'92 campaigns indicate also a very good agreement. EXTENDED SAGET network will be used for further studies of interactions in the T-T zone region; it will serve as the reference control network for some local geodynamical investigations in Czech Republic, Slovakia, Poland and Ukraine and will be also included to the CERGOP Project (Central Europe Regional Geodynamics Project) which in proposed by the CEI (Central European Initiative - former HEXAGONAL) group countries. The next, EXTENDED SAGET' 93, campaign is scheduled for September 1993.

ACKNOWLEDGEMENT

The Institute's initiative of EXTENDED SAGET GPS campaign has met with a very warm response of all Central European countries. Many European stations have given a very substantial and valuable contribution to the establishment of the geodynamic network strengthening the geodynamical investigations in the Teisseyre-Tornquist zone. Their contribution is gratefully acknowledged.

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COMPUTATION OF EPOCH*92 DATA AT GRAZ

G. Stangl*, P. Pesec**

This report comprizes the results of the first computational stage as only part of the complete data material has been used by now. Most of the stations of the eastern part of EPOCH'92 are collocated to EUREF stations providing an independent external control. At the present stage a horizontal accuracy of * 2 cm and a height accuracy of * 4 cm can be achieved by very careful processing.

INTRODUCTION

During the IGS campaign of 1992 two weeks were dedicated for intensive measurements to establish national fiducial points. National responsibility for monumentation, logistics and data collection was anticipated. To get an optimum of simultaneous data 2 sessions (6.45 - 17.45.20.00 -3.00 UT) were defined for the first week, the respective observation times were retarded by half an hour for the second week.

STATIONS

According to our announcement we considered mainly points in countries of the CEI (Central European Initiative), Some core-stations were added for stabilization. Fig. 1 shows the geographical distribution of the actual network, a comprehensive station list was communicated by IGS mail.

DATA

The majority of stations covered all sessions. Data were collected by different receiver types, therefore phase center values are important. For Ashtech, ROGUE and Trimble (assuming that all sub-types and Geotracer products having the same value) the values were taken from IGS Mail No. 65. No height-correction was applied to the WM-102 so far. Nearly all stations provided meteorological measurements. At Graz all data are available in RINEX-format and can be distributed on request by FTP.

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Unfortunately only few P-Code were receivers available: 3 Rogue (Graz, Wettzell, Pfaender first week), 1 Ashtech (Graz) and 2 Trimbles (Borowiec first week, Grosser Muehldorfer See). On the other hand, antispoofing affected only the Rogue-receivers (degraded accuracy) and P-Code-Ashtech (no automatic mode-switch). 4 further Ashtech receivers (3 Croatian , 1 Polish) recorded only few L2-observations. Figure 2 shows the worst-case single-difference combination of the data treated so far.

PROCEDURE

At Graz all computations were done with the Bernese Software. A new Version (Menu Version 3.3 *or 3.?)* was installed and adjusted to the IBM AIX workstation during the data processing, the order of processing modules remaining the same as e.g. in version 3.2. The following steps were performed :

Orbits

Transformation of precise ephemerides to standard orbits;
using the CODE orbit solutions together with extrapolated earth rotation parameters one-day-arcs (2 sessions) were formed.

Clock

Clock information was extracted from broadcast ephemerides.

Code Computations

After a rough screening of code observations with a marking of outliers receiver clock errors (1 per epoch) and station coordinates were computed.

Single Differences

Although the new version offers automatic baseline-combinations, all selections were done manually according to a "maximum reliability" principle. Starting with a station containing no gaps and extending over the whole time-span a first radial network was formed with moderate baseline lengths. The "best" station of those already connected was chosen as the knot of the next radial network and so on. Stations with only few or bad observations were always tried to set at the end of a branch abandoning the shortest length principle. In this way a strong backbone was created with, sometimes, weak extremities. Thus, the failure of one station could not affect the remainder.

Data Screening

Single and double differences were screened by searching for cycle slips and marking outliers. After processing of each frequency separately, the ionosphere-free combination L3 was screened. A polynomial of degree 2 was used to eliminate long-wave external influences (e.g. bad station coordinates).

Coordinate Estimation

From preliminary studies it could be seen that, trying to fix ambiguities, was not the best approach. Therefore all baselines were processed separately in L3. By keeping the orbit

fixed only coordinates were estimated. The tropospheric model of Saastamoinen with modified values (a crude mean of all available ground values per session) was added.

Control

The network was controlled by redundant baselines for each session. Remaining cycle slips are presumably existent and should be detected at a later stage.

All sessions were compared by a 7-parameter Helmert transformation in order to detect weak stations and to check the assumption of the tropospheric models.

Solution

Having eliminated all doubtful components, session solutions are to be computed always fixing the same station. With sufficient core stations available, all solutions should be transformed on those fixed stations and the mean of the resulting values should be taken.

PROCESSING

Hampered by the time consuming software upgrading only three days (207,209,218) have been processed. Yet, it was enough to get an insight into the quality of the data. Neglecting minor sessional problems we detected some general features:

The rms of the standard orbits of 1 m indicate the necessity of a regional orbit improvement to get a higher accuracy. Unfortunately there are no core stations in the eastern part and the unfavorable form of the network is not well designed for orbit improvement.

Short-wave ionospheric disturbances (1 - 10 minutes) disturb data screening heavily. The recording interval of 30 seconds should be set to 15 in the future to reduce the ionospheric hub (sometimes as large as 0.4 cycles). Especially, screening squaring-type receivers, with the possibility of half cycles, is heavily disturbed. Short gaps with high ionosphere disturbances produce common cycle slips which could not always been detected.

Satellite PRN 25 had to be eliminated at some stations (GOPE, BORO, PENC) due to frequent jumps (0.25 -0.4 cycles) in L2.

Some stations have unreliable, few or not accurate computable data:

Unreliable (doubtful half cycles, SV 25 bad): BORO, GOPE

Few data: LAMK, RGNZ, NOBR, VLPE; all results of CRVR and VELG differ by meters due to lack of data!

Not accurately computable: PENC ! We have no explanation for this amount of jumps in all satellites leading to an accuracy of only *some* decimeters!

On the other hand, some stations had good receivers, especially BOR1, GRAZ, GRMS, LJUB, PFAN and WETT. The noise-competion was, by far, won by the Rogue receivers showing only 50 % of the noise of the next best candidate.

The combination of different receiver types posed no problems, in most cases no distinction between the different types can be seen. However, the group of P-Code receivers showed much lower noise than CA-code receivers.

As an example, Fig. 1 shows a specificly selected baseline configuration.

RESULTS

The present study is not intending to publish preliminary coordinates. But, some disclosure values and residuals may give a first impression of the available data set.

Disclosures

Table 1 shows some disclosure values of the daily sessions. The dominance of low values seems to be encouraging. Yet one can recognize, that, sometimes, errors of about 10 cm occur in the horizontal components. In most cases a wrong common cycle slip instead of a half cycle slip in L2 was applied due to disturbing gaps and ionospheric influences.

Residuals

The results of the different sessions and days could not be combined generally. Systematic height residuals of more than 10 cm at baselines with remarkable height differences (> 500 m) indicate that the simple Saastamoinen approach might not be sufficient. The different daily standard orbits may cause further daily variances.

Some session-transformations are shown in table 2, which also includes some bad stations for demonstration. Apart from some sessional outliers one can expect for the horizontal components an accuracy of 1 -2 cm and for height components below 5 cm.

RECOMMENDATIONS

For this Campaign

Computations should rely on L3 combinations only. Stations with possible half cycle slips should be screened very carefully and their baselines checked more than once. Core stations should be added where ever possible in order to strengthen the network for acceptance of longer baselines. Baseline selection should always favour combinations with the stations BOR1, GRAZ, GRMS, LJUB, PFAN, WETT.

Stations CRVR, PENC and VELG should be excluded from the solution. The meteorological values should be investigated to distinguish possibly existing weather zones (e. g. north and south of the Alps) and corresponding models of the troposphere should be applied and/or estimated.

For Future Campaigns

The recording interval should be set to 15 seconds to diminish the big annoying ionospheric hub and fixing short disturbances of 1 minute duration;

Low-noise receivers with P-Code or similar techniques, optionally able to overcome antispoofing problems, should be widely used.

CONCLUSIONS

The processing the eastern part of EPOCH'92 has to consider the different quality of the national sites. Main short-comings which prevent, partly, accurate results are the strong ionospheric influences in combination with the large recording interval, different weather conditions to be modelled, and few observations in L2 for some stations. For stations CRVR, PENC, and VELG no reasonable coordinates could be computed up to now (we doubt they it ever would be for this campaign). Combining all daily solutions yields 1 - 2 cm accuracy for the horizontal components and better than 5 cm for the height component.

We think that, despite of some short-comings which can never be avoided, EPOCH'92 was a great success, especially with regard to the fact that inhomogeneus equipment has been used and the organisation of such a campaign just required some faxes. Most of stations can be computed according to EUREF standard, thus enlargening the network by more than 1000 km.

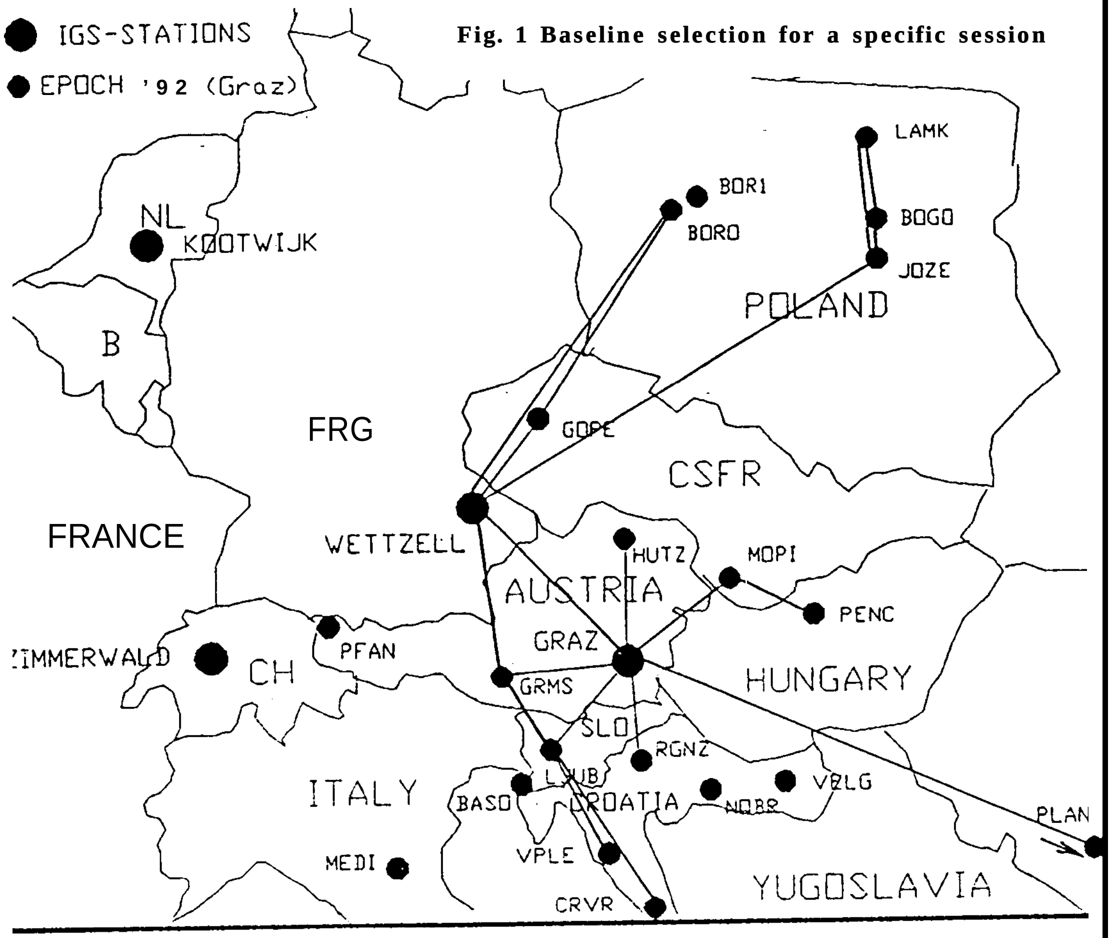
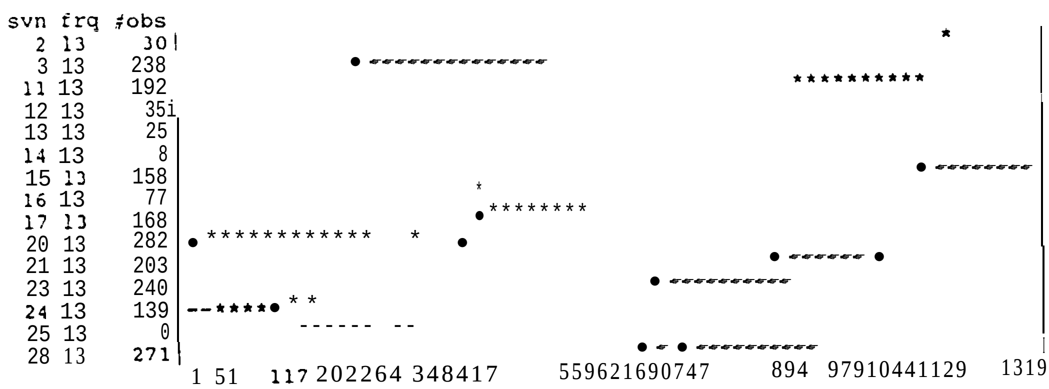


Fig. 1 Baseline selection for a specific session

Fig. 2 **Single-difference data scenario worst-case**

```
EPOCH 92
----------------------------------------------------
campaign: testv33          station 1: ljub          station 2: crvr -
typ of observation: phase single difference
reference epoch  :  1992- 13- 5   6:16:30.00    one character  =  10.50 minutes
total number of  observations:     2066
```



Misclosure values of base lines in mm

Day	session	stations	North	East	Up
207	1	graz - pfan - ljub	32	3	66
207	1	graz - mopi - hutz	2	17	12
207	1	graz - mopi - nobr	25	32	36
207	2	graz - mopi - nobr	2	87	29
207	1	graz - mopi - rgnz	6	10	32
207	2	graz - mopi - rgnz	48	50	- 185
207	1	mopi - borl - boro	3	20	11
207	2	mopi - borl - boro	- 118	206	2
207	1	mopi - joze - borl	2	11	11
207	2	mopi - joze - borl	3	27	14
207	1	mopi - joze - bogo	4	3	6
207	2	mopi - joze - bogo	5	5	2
207	1	mopi - joze - lamk	15	3	1
207	1	graz - mopi - gope	7	16	10
207	2	graz - mopi - gope	9	6	15
209	1	wett - pfan - graz	5	4	14
209	2	wett - pfan - graz	3	16	40
209	1	wett - gope - graz	4	11	- 6
209	2	wett - gope - graz	12	11	65
209	1	wett - gope - borl	2	21	27
209	2	wett - gope - borl	3	24	e
209	1	wett - gope - boro	22	- 119	- 36
209	2	wett - gope - boro	5	20	6
209	1	wett - borl - boro	19	20	- 62
209	2	wett - borl - boro	0	2	0
218	1	wett - gope - boro	1	12	18
218	2	wett - gope - boro	3	5	- O
218	1	joze - bogo - lamk	1	2	18
218	2	joze - bogo - lamk	5	8	2
218	1	graz - grins - ljub	4	2	- 9
218	2	graz - grms - ljub	5	3	21
218	1	graz - wett - grms	3	9	12
218	2	graz - wett - grins	2	10	16

Tab. 1 Disclosure values for daily sessions

helmert transformation

file 1: EPOCH92
file 2: EPOCH92 Eastern part

local geodetic datum: wgs - 84
residuals in local system (north, east, up)

num	name	flg	residuals in meters			
1	graz lustbuehel	f f	-.0016	.0056	.0206	
2	joze	P P	.0104	-.0374	.0133	
3	lamk	P P	.0101	-.0180	-.0326	
7	boro	P P	-.0122	-.0119	.0206	
8	gope	PP	-.0189	.0172	.0266	
9	1 jub	P P	-.0059	.0402	.0476	
10	mopi	P P	-.0042	-.0071	-.0681	
11	pent	P P	.0805	-.1678	1.1325	m
13	plan	p p	.0624	.0277	.0011	
14	rgnz	p p	-.0072	-.0252	.0207	
16	bogo	P P	.0133	-.0253	.0236	
17	wett	P P	-.0213	.0257	.0045	
19	9rms	P P	-.0272	.0123	-.0575	
20	crvr	PP	-.1592	-.1760	-1.5526	m
21	vple	PP	.0024	-.0039	.0188	

number of parameters : 7
number of coordinates : 39
rms of transformation : .0292 m

parameters:

translation in	x :		-.010 +-	.008 m
translation in	y :		-.028 +-	.008 m
translation in	z :		.007 +-	.008 m
rotation around	x-axis:	- 0 0	.005 +-	.007 "
rotation around	y-axis:	- 0 0	.013 +-	.005 "
rotation around	z-axis:	0 0	.024 +-	.004 "
scale factor			.020 +-	.018 mm/km

number of Iterations : 2

Tab. 2 Example of a session-transformation

EVALUATION OF IGS-DISTRIBUTED GPS EPHEMERIDES BY REGIONAL BASELINE ANALYSIS IN JAPAN

Hiromichi Tsuji, Yuki Hatanaka, Akifusa Itabashi, Hiromitsu Dei, and Yoshiaki Abe*

In order to investigate the precision of GPS ephemerides distributed from the International GPS Geodynamics Service (IGS) campaign, we processed a regional baseline in Japan using different GPS ephemerides for several weeks during the campaign. The daily repeatability of baseline solutions from each ephemeris is on the order of 10-8. The difference of baseline solutions from each ephemeris is also on the same level. Since the baseline length seems to show a trend which exceeds any plate motion models, mid-term precision of the baseline is now under investigation.

INTRODUCTION

The International Association of Geodesy (IAG) initiated a test campaign of the International GPS Geodynamics Service (IGS) from July 22,19921. This first official campaign continued for 3 months and turned into the IGS pilot service from November 1992 (IGS Electronic mail #141). Many geodetic and aerospace institutes from the world participated in the campaign, producing large amounts of tracking data, precise ephemerides, and Earth orientation parameters (EOP). These products are open to the public through the Internet, which is a world-wide, non-commercial computer network. At the moment, there are seven sources for GPS orbits and EOP, which are calculated from global tracking data by independent agencies. They are COD (Center for Orbit Determination in Europe), EMR (Department of Energy Mines and Resources, Canada), ESA (European Space Agency), GFZ (GeoForschungsZentrum Potsdam, Germany), JPL (Jet Propulsion Laboratory, USA), S10 (Scripps Institute of Oceanography, USA), and UTX (University of Texas, USA).

Since the main target of the campaign is to prepare for the establishment of a permanent service, precision and timeliness of products are of great concern. Official comparisons of orbits and EOP are conducted and summarized in IGS reports, which are weekly distributed by an e-mail service on the Internet. Direct comparisons of orbits show sub-meter agreement after seven-parameter coordinate transformations (e.g. IGS Electronic reports #30). But in geodetic application of GPS, users are more interested in precision of baseline solutions, not in that of orbits. According to a rule of thumb, sub-meter orbit precision corresponds to baseline precision of about 10^{-8}, Since this is just a rough estimate, precision of baseline solutions with IGS ephemerides should be evaluated by actual statistics. For this purpose, we processed a regional baseline in Japan using different GPS ephemerides for several week.. during the campaign.

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We have another reason for the research. The Geographical Survey Institute (GSI) started a regional orbit production from April in 19922. This routine analysis yields cycle slip free phase data in the Rinex format every day. Thus, the data are ready to process for estimating baseline solutions.

Although we show baseline repeatability with IGS ephemeris, readers should be reminded that it does not necessarily show the highest precision that can be achieved by GPS. The solution is also a function of quality of data, software, and processing strategy. Here we show the precision as a typical example of routinely available GPS results with fixed "precise ephemeris" without ambiguity resolution for a regional scale network.

IGS EPHEMERIDES

In reply to the call for participation to IGS, several geodetic and aerospace agencies have submitted their products. Although basic physical data such as the value of GM and physical models such as solid earth tides are given by the IGS standard, there remains a wide variety of processing strategies. Table 1 shows official processing centers and their methods during the IGS Epoch'92. Epoch'92 was a core period of the Campaign'92. Note that these strategies are time dependent and subject to change according to the GPS week.

All IGS ephemerides use global tracking data from Rouge receivers distributed all over the world. The final output is a precise ephemeris in the National Geodetic Survey's SP1 or SP3 formats. They are tables of satellites' positions at certain intervals of time in the IERS terrestrial reference frame (ITRF). These format can be accepted as orbit information to many commercial GPS software.

Table 1
PROCESSING STRATEGY OF EACH IGS EPHEMERIS AT GPS WEEK 650.

Acronym	COD	EMR	ESA	GFZ	JPL	SIO	UTX
Agency	Center for Orbit Determination in Europe	Department of Energy Mines and Resources	European Space Agency	GeoForshungs Zentrum Potsdam	Jet Propulsion Laboratory	Scripps Institute of Oceanography	University of Texas at Austin
Country	Switzerland	Canada	Germany	Germany	USA	USA	USA
Software	BERNESE	GIPSY/OASIS II	GPSOBS/ BAHN5	GEPARD4.0	GIPSY/OASIS II	GAMIT/ GLOBK	MSODP1/ TEXGAP
Clock Elimination	double-difference	filter	double-difference	filter	filter	double-difference	double-difference
# of Fixed stations	?	~11	~8	~9	~3	~26	~5?
# of Estimated stations	?	-8	-lo	-6	-26	-4	~11
Orbit arcs	1 dav	1 day	1 day	2 davs	1 dav	2 davs	7 davs
Observable	phase	pseudo range, phase	phase	phase	pseudo range, phase	phase	phase
Tropospheric delay	4 parameters/ dav	Random walk	1 parameter / 3 hours	1 parameter / day	Random walk	1 parameter / dav	1 parameter / 2.5 hours
Radiation pressure	2 parameters	3 parameters	2 parameters	2 parameters	3 parameters	3 parameters	2 parameters
Format	s P3	SP3	SP3	S P 3	SP1/SP3	SP1	SP3
Interval	15 minutes	15 minutes	15 minutes	5	15 minutes i	22.5 minutes	15 minutes s

METHOD OF EVALUATION

We evaluated the precision of GPS ephemerides by daily repeatability of baseline solutions derived from each ephemeris. The repeatability is a function of orbits, data, software, and processing strategies. Fixing parameters other than the orbits, we can compare the effect of each ephemeris. The following explains the method of our eval uat ion.

Regional GPS network

Fig.1 illustrates a GSI's regional GPS tracking network in Japan. Although this network is used for regional orbit generation, it can also be used as a test field with known coordinates for orbit comparison. Carrier phases from Minimac 2816 receivers at Tsukuba and Chichijima stations are used for the comparison. The baseline length between the two stations is about 1000 km.

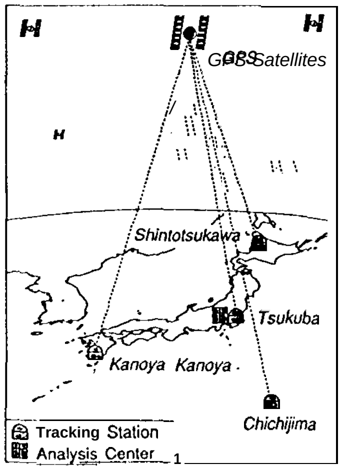

Fig. 1 A regional baseline used in the study,

Baseline Processing by EMANON

For the baseline analysis, we used our in-house GPS processing software named EMANON (EMbryo of Automatic Numerical Orbit Navigator). This forms double-differences from carrier phases to estimate orbit initial conditions and station coordinates. In the current analysis, orbits are fixed and only station coordinates are solved for. Table **2** summaries the processing method.

Table 2
METHOD OF BASELINE PROCESSING

Baseline:	Tsukuba-Chichijima (-1000 km)
Receiver:	Minimac 2816AT
Software:	EMANON/baseline
Orbit:	IGS ephemerides (cf. Table 1)
Observable:	Ionospheric-free linear combination (L3) of double-difference phases
Data sampling:	30 seconds
Elevation cutoff:	20 degrees
Session:	3 sessions/ day
Ambiguity:	not fixed
Tropospheric delay:	Saastamoinen zenith delay+ CFA mapping function, not estimated.
EOP:	IERS Bulletin A
Solid Earth tide:	IGS standard
Ocean loading:	not corrected
Interpolation of orbit:	Lagrange method with 11 -th order polynomial

In this processing, we form 3 sessions per day, which last about 8 hours each. Each session contains more than 9 satellites. Fig.2 shows satellite visibility at Tsukuba during the Campaign '92.

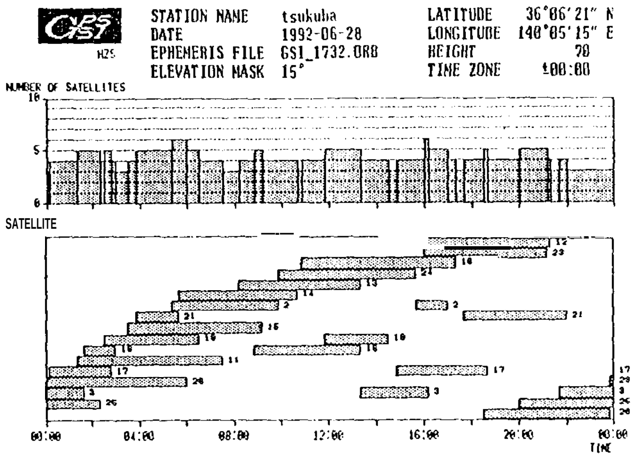

Fig.2 Satellite visibility during the campaign at Tsukuba.

RESULTS AND DISCUSSIONS

Our comparison consists of two different periods. One is for the GPS week 650-651, when six IGS ephemerides in Table 1 except EMR are used for baseline processing. The other is for the week 655-656 (Epoch'92), when only COD, JPL, and S10 are used. Before going to a repeatability analysis, there are two topics to be noted from a practical point of view.

Interpolation of ephemeris

Since each satellite's positions are given in ITRF at discrete intervals of time, the processing software must interpolate in order to calculate a satellite's position at each phase measurement. Some of the IGS ephemerides consist of a separate file for 1 or 2-day period. This will be problematical when a position near the beginning or the end of an ephemeris is required. In this analysis, we formed a combined orbit with two consecutive ephemerides and deleted the overlapping part. But S10 ephemeris originally includes some extrapolated part outside its estimated orbits, being immune from the above procedure. We think their approach is more appropriate for an end user.

SA and AS

Selective availability (SA) has been activated during the Campaign. But there is no difficulty in processing data with double difference phase observable. What affected the baseline processing is an intermittent implementation of Anti-Spoofing (AS) from the week 655. Because of an initial firmware problem at Rouge receivers, no pseudo range data was available for AS periods during the campaign. Since pseudo ranges are essential for an automatic cycle slip correction, most of ephemerides do not include orbits during the AS periods. The evaluation below does not include the AS periods, either.

Daily repeatability

Fig.3 is an example of daily repeatability of the 1000 km baseline. JPL ephemerides are used to process the Tsukuba-Chichijima baseline for the week 650-651. Deviations from the nominal values determined by VLBI measurements are expressed in North-South (NS), East-West (EW), and Up-Down (UD) components. This was a typical daily repeatability for regional baselines.

Fig.4 shows standard deviations of daily repeatability for the GPS week 650-651 and 655-656. Compared to horizontal components (NS, EW), the vertical component (UD) has a large standard deviation, which can be explained as tropospheric mis-modeling. Note that in this analysis tropospheric delays are not estimated. We think the precision of the vertical component can be improved with more sophisticated tropospheric treatment.

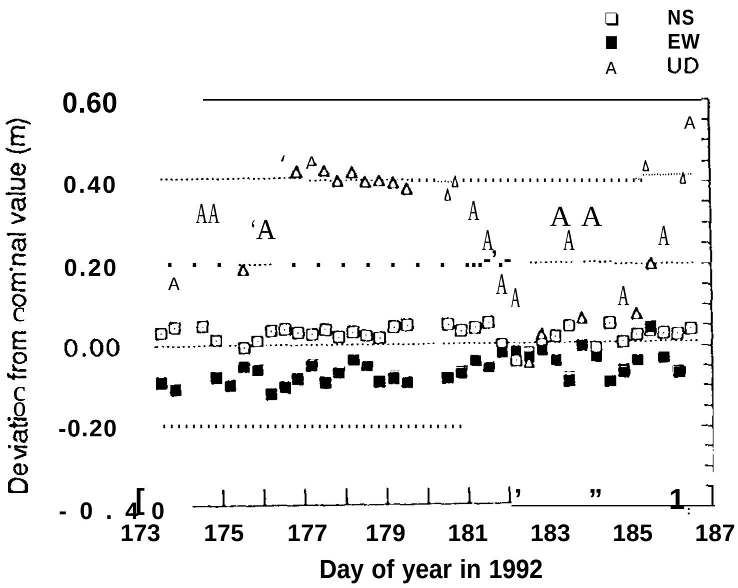

Fig.3 An example of daily repeatability of baseline vectors.

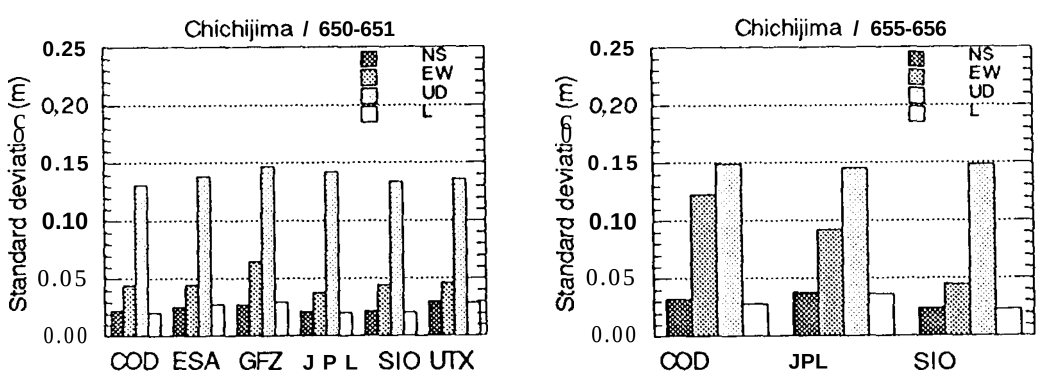

Fig.4 Comparisons of daily repealability.
(left) GPS weeks 650-651
(right) GPS weeks 655-656 (Epoch '92)

Coordinate difference of estimated station

To evaluate the accuracy of baseline solutions, averages of estimated coordinates of Chichijima station over 2 weeks are compared. Fig.5 shows the difference between these averages of coordinates. Although there are some gaps between the two periods, differences between ephemerides of the same period are about 0.04 ppm (NS), 0.12 ppm (EW), and 0.06 ppm (UD).

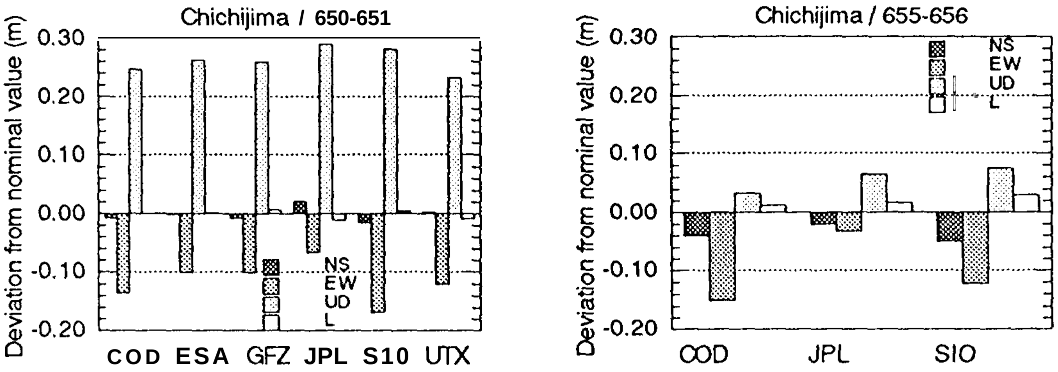

Fig.5 Comparisons of estimated coordinates of Chichijima.
(left) GPS weeks 650-651
(right) GPS weeks 655-656 (Epoch '92)

Mid-term repeatability of baseline length

When we looked at mid-term repeatability, we found a large trend in the baseline length. Fig.6 shows a baseline length solution with JPL ephemerides for the Tsukuba-Chichijima baseline. Although the baseline length should get smaller as any plate motion models suggest, it seems to have a linear trend of increase. This trend appears for other ephemerides, too. But it is too large to be an actual crustal movement. Currently we consider the trend as a mid-term fluctuation of GPS solutions due to some un-modeled parameters. We are now investigating a mid-term precision.

Summary

Table 3 summarizes the precision and accuracy of a typical IGS ephemeris. In this table the precision refers to an average of daily baseline repeatability with several IGS ephemerides. The accuracy refers to a maximum difference of averaged baseline solutions *over* 2 weeks.

Table 3
TYPICAL PRECISION OF REGIONAL BASELINE SOLUTIONS WITH FIXED IGS EPHEMERIS

component	precision	accuracy
NS	0,03 ppm	0.04 ppm
EW	0.07	0.11
UD	0.13	0.05
Length	0.02	0.03

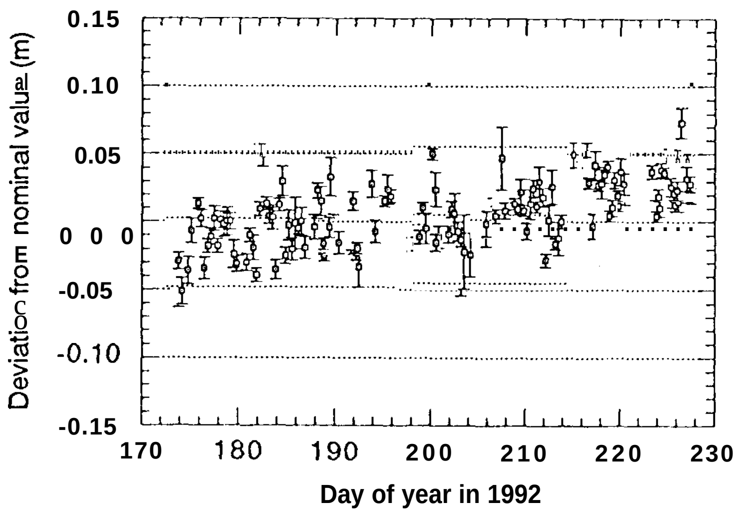

Fig.6 Time series of a baseline length between Tsukuba and Chichijima with JPL ephemeris for GPS weeks 6S0-657. The VLBI solution at the epoch (=1,017,.5S4. 71m) is used as the nominal value. The trend does not correspond to any plate motion models. It is considered to be apart of mid-term fluctuations of GPS solutions.

CONCLUDING REMARKS

Processing a 1000 km baseline in Japan using different GPS ephemerides for several weeks, we evaluated the precision and accuracy of IGS ephemerides. Using IGS ephemerides, we can routinely obtain baseline precision better than 0.1 ppm in every component. Horizontal components shows better repeatability on the order of 10^{-8}. Since the baseline length showed a trend which exceeded any plate motion models, mid-term precision is now under investigation.

In this analysis, only IGS ephemerides are compared. In future, we would like to include a broadcast ephemeris and our regional ephemeris (GSI ephemeris) in comparisons.

ACKNOWLEDGMENT

The IGS ephemerides used in the study are taken from the GPS Data Information Center on the Internet at the Earthquake Research Institute, the University of Tokyo. We would like to thank Dr.T.Kato and Dr. S. Nakao for their GDIC operations.

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IONOSPHERIC MONITORING USING IGS DATA

Lambert Wanninger[1]

Though neither GPS nor IGS are designed to contribute to ionospheric research, IGS provides valuable data sets of GPS observations for ionospheric monitoring. GPS users are mainly interested in the disturbing effects of ionospheric irregularities such as scintillations, for example. They can be analysed with the help of dual-frequency GPS phase observations. The interpretation of the Kokee data for 1992 gives a detailed picture of the scintillation occurrence in the region of Hawaii.

INTRODUCTION

The satellites of the Global Positioning System (GPS) are often considered as "satellites of opportunity" for ionospheric investigations [1]. GPS was not designed for ionospheric research. Nevertheless, the dual-frequency signals offer an excellent means of monitoring ionospheric disturbances and determining the total electron content (TEC) of the ionosphere. The main objectives of the International GPS Geodynamics Service (IGS) are orbit determination and earth rotation monitoring. But the vast amount of continuous dual-frequency GPS tracking data presents a valuable resource for ionospheric research. IGS offers the opportunity to investigate the ionosphere with GPS and without the need to run a GPS network dedicated exclusively to ionospheric research.

IONOSPHERIC EFFECTS ON GPS AND THEIR MONITORING BY IGS

It is widely believed that ionospheric corrections from dual-frequency GPS observations solve all GPS user problems which are due to ionospheric refraction. But this is only true for an undisturbed ionosphere in the mid-latitudes. The worst ionospheric effects are caused by equatorial scintillations which can prevent the tracking of the GPS satellite signals. Both equatorial and polar scintillations are known to cause cycle slips and to complicate their determination. Strong horizontal gradients in the electron distribution can make ambiguity resolution impracticable even for baselines

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as short as 10 km. The world-wide continuous dual-frequency GPS observations of IGS offer an excellent resource to monitor these ionospheric effects. The TEC can be determined from dual-frequency GPS observations. IGS can contribute to the global mapping of the TEC and provide TEC models for the correction of single-frequency measurements of, for example, GPS, VLBI and altimeters.

Equatorial Scintillations

Ionospheric scintillations are caused by small scale irregularities in the electron content of the ionosphere with wavelengths from a few meters to a few kilometers. These electron density irregularities can produce both diffraction and refraction effects. Scintillation or fluctuation in received signal level are variations of amplitude and phase.

The region of equatorial scintillations extends from ± 30° either side of the earth's magnetic equator. The strongest effects are found at approximately ± 10°. Scintillations take place between sunset and midnight with activity on occasion continuing until dawn. There is a seasonal dependence: in the American, African and Indian longitude regions, effects are strongest between September and March, but from April through August chances are small of having significant scintillations. In the Pacific region, however, the sit uation is reversed [2]. Furthermore, scintillation effects depend on the 1 l-year solar cycle. Their occurrence increases with an increase in the solar sunspot numbers. From 1989 to 1993, they are especially strong due to the maximum of solar cycle No. 22. After 1994, minimal occurrence and minimal strength can be expected for about 5 years. But around the year 2000, scintillation effects will increase again.

The severest effects of small scale irregularities are signal fading and signal enhancement, called amplitude scintillations. The signal level can drop below the receiver's lock threshold. This threshold depends on the bandwidth of the GPS receiver system and on the type of tracking channel. A code-correlation channel can stand lower signal levels than a squaring channel or a cross-correlation channel. Squaring the received signal results in a low S/N (Signal to Noise Ratio), roughly 30 dB lower than that obtained by code-correlation. The data loss and the number of cycle slips due to amplitude scintillations are larger for squaring channels than for code-correlation channels. The data loss can reach up to 100% during scintillation occurrence [3]. Cross-correlating the L_1 and L_2 signals in order to obtain the ionospheric group delay also results in a low S/N. An increased data loss and an increased number of cycle slips are expected. However, detailed studies on the effects of equatorial scintillations on cross-correlation channels are still lacking.

Amplitude scintillations can be monitored by the interpretation of S/N time series provided by geodetic GPS receivers for each observable. Rapidly changing values indicate scintillation activity. S/N are stored in the raw data. Unfortunately, the Receiver INdependent EXchange format (RINEX) contains the signal strength only projected onto the interval 1-9, i.e. most of the information gets lost. Since IGS works with the RINEX format, IGS data are not appropriate for the detection of amplitude scintillations.

Phase scintillations are a result of sudden changes in ionospheric refraction or of diffraction effects. They can reach up to some cycles of L_1- or L_2-signals between two epochs with a common epoch rate of 10, 20 or more seconds. They complicate cycle slip detection and determination. These refractive effects can cause GPS receiver systems to lose lock due to the rapid frequency changes in the received signal. The apparent range-rate errors can produce a Doppler shift change of greater than 1 Hz per second, which is more than the bandwidth of many receivers. Usually, ionospheric refraction causes the $L_1 - L_2$ phase difference to change slowly. In the case of phase scintillation however, the phase differences can change rapidly by more than 0.5 cycles of L_2 so that L_2-channels which are aided by L_1 tracking data lose lock.

Phase scintillations can easily be detected in single-station dual-frequency phase data. Even with a low data rate of 1 min they can be identified, localized and their strength can be estimated. Hence, IGS can contribute to climatological studies of phase scintillation occurrence.

Polar Scintillations

Polar scintillations are not as strong as those near the equator. Their occurrence is closely related to magnetic storm activity. Phase and amplitude scintillations have been observed with GPS signals, but no code tracking problems have been reported. However, users relying on continuous carrier phase data are seriously affected by scintillation activity, because of an increased number of cycle slips and difficulties in their determination [4,5].

The strongest ionospheric activity does not take place in the polar cap regions but rather in the auroral zones situated between magnetic latitudes of about 64° and about 70°. During very strong magnetic storms, these auroral effects can extend well into the mid-latitudes.

The equatorward extension of polar scintillation activity is of primary interest to GPS users in the mid-latitudes. IGS can provide information on scintillation occurrence, scintillation intensity and the equatorward boundary of ionospheric activity. Thereby it can contribute to the understanding of the dependence of L-band scintillations on magnetic activity and to reliable scintillation activity prediction.

Traveling Ionospheric Disturbances

Traveling Ionospheric Disturbances (TIDs) are wavelike structures which may imply variations in the ionospheric electron density of several percent of the total electron content. Large-scale TIDs (LSTIDs) have horizontal phase speeds of 300 – 1000 m/s, periods ranging from 30 min – 3 h and horizontal wavelength exceeding 1000 km. They propagate equatorward from the polar regions, where they are supposed to be generated in the auroral zones. Medium-scale TIDs (MSTIDs) have horizontal phase speeds of 100 – 300 m/s, periods from 12 min to about 1 hour and horizontal wavelengths of several hundred of km. They occur much more frequently than LSTIDs, and their origin is not known, although many possible excitation mechanisms have been proposed [6].

Gradients in the electron density attributed to MSTIDs affect the double difference observable. Ionospheric effects of more than half a cycle of L_1 or L_2 were found in double differences of baselines even shorter than 10 km. Algorithms for rapid-static or on-the-fly ambiguity resolution can fail in the presence of MSTIDs. Single-frequency relative positioning can experience coordinate errors of 15 ppm and more [7].

MSTIDs can be detected in time series of single-station dual-frequency phase data. IGS can contribute to climatological studies of TIDs.

Large Scale Horizontal Gradients

In the case of relative positioning with GPS, not the Total Electron Content (TEC) but horizontal gradients of TEC are the determining factor. The largest horizontal gradients in the electron density are found in the regions of the equatorial anomalies ($\pm$ 10-20° magnetic latitude). On the one hand there are large gradients from the equatorial crest to the mid-latitudes and in the opposite direction to the magnetic equator (north-south gradients). On the other hand, minor gradients are caused by the diurnal cycle of the ionospheric electron content (east-west gradients). In the region of the southern equatorial anomaly in South America, horizontal gradients observed with GPS were as large as 30. $10^{16}\, el/m^2$ per 100 km in north-south [3]. This value is equivalent to an ionospheric effect on single differences between stations of a 10 km baseline of up to several cycles of L_1 or L_2 or up to about 1 cycle of the widelane linear combination. The resolution of double difference ambiguities is impossible under these conditions with standard algorithms or single-frequency data.

A modelling of these gradients can only be successful in regional networks. However, IGS can contribute to the localization of the equatorial anomalies and to studies on their temporal variations.

Total Electron Content

The Total Electron Content (TEC) can be determined from dual-frequency code or carrier-phase measurements. However, the codes transmitted from GPS satellites at the two frequencies show a synchronization bias due to different hardware paths inside the transmitter. Similar effects are also known for the receiver hardware. The phases experience biases due to the unknown carrier phase ambiguities and due to differential equipment phase delays. An estimation of the combined satellite and receiver differential delays (and ambiguities) can be performed from GPS observations [8,9]. In areas and time periods of very small horizontal gradients (mid-latitude, night-time) the achievable accuracy is about 2.1016 el/m^2. But in areas and time periods of large gradients (e.g. equatorial anomaly), the accuracy deteriorates considerably

[10]. Then predetermined satellite differential group delays and internally calibrated receivers give better results.

IGS can contribute to the global mapping of the TEC and the observation of long term changes in TEC. Correction values for single-frequency GPS positioning, single-frequency VLBI or single-frequency altimeter measurements can be provided in the form of global models [11,12]. More precise regional models can only be produced for regions of a dense network of IGS stations (e.g. in Europe).

DETECTION OF SCINTILLATIONS

Severe effects on GPS measurements are caused by equatorial scintillations. Amplitude scintillations, being the main cause of data loss, can be detected in the measured S/N. However, the RINEX format does not provide this information in a usable form. Phase scintillations can easily be detected in the "geometry-free" linear combination of single-station dual-frequency phase measurements. In order to eliminate the unknown carrier-phase ambiguities, differences between epochs (Rate of Total Electron Content - RoT) are formed [10]:

$$RoT(t_j, \Delta t_{ij}) = S \cdot \Big((\phi_1(t_j) - \phi_1(t_i)) \cdot \lambda_1 - (\phi_2(t_j) - \phi_2(t_i)) \cdot \lambda_2 \Big) \tag{1}$$

with

$$\Delta t_{ij} = t_j - t_i = 1 \ [min] \tag{2}$$

and

$$S = \frac{1}{40.3} \cdot \frac{f_1^2 \cdot f_2^2}{f_1^2 - f_2^2} = 9.5201016 \quad [el/m^3]. \tag{3}$$

Subscripts 1 and 2 identify the signals L_1 and L_2, t_i and t_j are the measurement epochs, ϕ [cycles] are the measured carrier phases, λ [m] the carrier wavelengths and f [Hz] the GPS frequencies. S converts the differences of dual-frequency phase measurements from [m] to $[el/m^2]$. Often the unit $TECU$ is used: 1 $TECU = 10^{16}\, el/m^2$. All frequency independent errors are removed by forming the "geometry-free" linear combination. Significant remaining errors are multipath, which can reach up to 0.3 $TECU/min$, and the random observation errors, which usually do not exceed 0.07 $TECU/min$. Cycle slips have to be detected in the pre-processing. They do not need to be estimated.

RoT time series contain the complete ionospheric information of dual-frequency phase data. They are especially suitable for the detection of ionospheric disturbances (scintillations, TIDs), but they also show the absolute electron content and large-scale horizontal gradients. A smooth and increasing RoT curve indicates an undisturbed satellite path. Phase scintillations appear as jumps due to sudden changes in ionospheric refraction. A phase scintillation index I_{ROT} can be computed from RoT. In a first processing step the low frequent changes of RoT are removed. They are a result of the absolute electron content and of large-scale horizontal gradients. The index is computed as RMS over the remaining parts of the RoT time series:

$$I_{ROT} = 10 \; . \; \text{RMS}\left(\overline{RoT}_{\Delta t=1\,min}\right) \tag{4}$$

In order to separate TIDs from scintillations, the frequency spectra of RoT time series are analysed. Periods of 10 to 30 min indicate the occurrence of MSTIDS. Disturbances of higher frequencies are considered to be scintillations. If scintillations are only to be detected but not to be classified by their strength, the zenith angle dependence of the index is negligible.

EXAMPLE: KOKEE, HAWAII 1992

Hawaii is located at 20”N magnetic latitude. It belongs to the ionospheric equatorial region. Though the main scintillation activity takes place around $\pm 10°$ magnetic latitude, Hawaii is also expected to be affected. Moreover, large-scale gradients at the northern boundary of the northern equatorial anomaly are believed to affect GPS data from Kokee.

Kokee data for 1992 are available for more than the three months of the IGS test campaign. Wit h the exception of a data gap from mid-September to mid-November, one GPS receiver was continuously working. Average months show data loss of 10% to 30% due to receiver failures and other causes (Table 1).

RoT plots provide pictures of the ionospheric conditions (Fig. 1). Large-scale horizontal gradients were strong from January to March and in November and December. Disturbances of periods of 10 to 30 minutes were detected a couple of times during day-time hours. No scintillation occurrence was detected from January to April and in November and December (exception: December 16). The observed scintillation activity from March to September/October was not as severe as scintillation activity monitored closer to the magnetic equator [3]. No significant data loss could be justified with scintillation activity. Detailed pictures of percentage occurrence of phase scintillations were produced with the help of I_{ROT} for 15-min blocks of data. The coordinates of the intersection points of the satellite signals with a single-layer ionosphere model at a height of 400 km (ionospheric points) were attributed to each

Month	1992	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Data Rate	[see]	120	120	120	120	120/30	30	30	30	30	–	30	30
Available Data	[%]	80	81	90	83	90	67	93	68	33	0	49	21

Table 1: Available Kokee data for 1992.

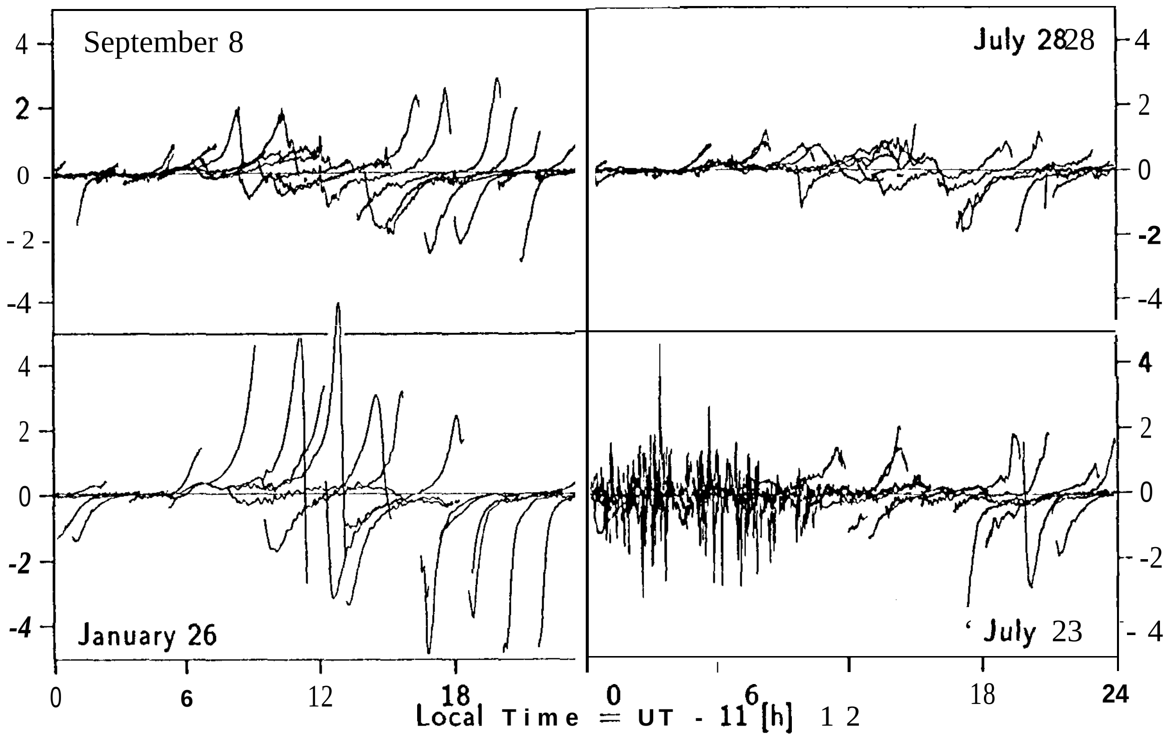

Figure 1: RoT plots of all satellites and of 24-hour data sets provide a survey of the ionosphere. The figure shows examples from Kokee in 1992. RoT units are [TECU/min], elevation mask **10°**, *local time of observation site.*

September 8: *average ionospheric conditions, no disturbances, the effects of large-scale horizontal gradients dominate over the effects of a high TEC, large-scale horizontal gradients in the electron content occur because of a low electron content north of the station (mid-latitude) and a high electron content in the south (equatorial anomaly), satellites travelling south-north cause large negative RoT-values with their rising, satellites travelling north-south cause large positive RoT-values with their setting, in contrast to mid-latitude sites there is no single diurnal maximum of the electron content but rather two maxima around local noon and in the early night, the large-scale gradients of the second maximum usually exceed the gradients of the first maximum.*

July 28: *low electron content and only little effects of gradients, no significant disturbances, second maximum recognizable.*

January 26: very *strong large-scale horizontal gradients in the electron content, gradient effects of this strength were common from January to March and in November and in December of 1992.*

July 23: *night-time equatorial scintillations of medium strength (as compared to scintillations observed in South Brazil in 1992 [3]),* $I_{RoT} = 3...11$, *no data loss due to scintillation activity.*

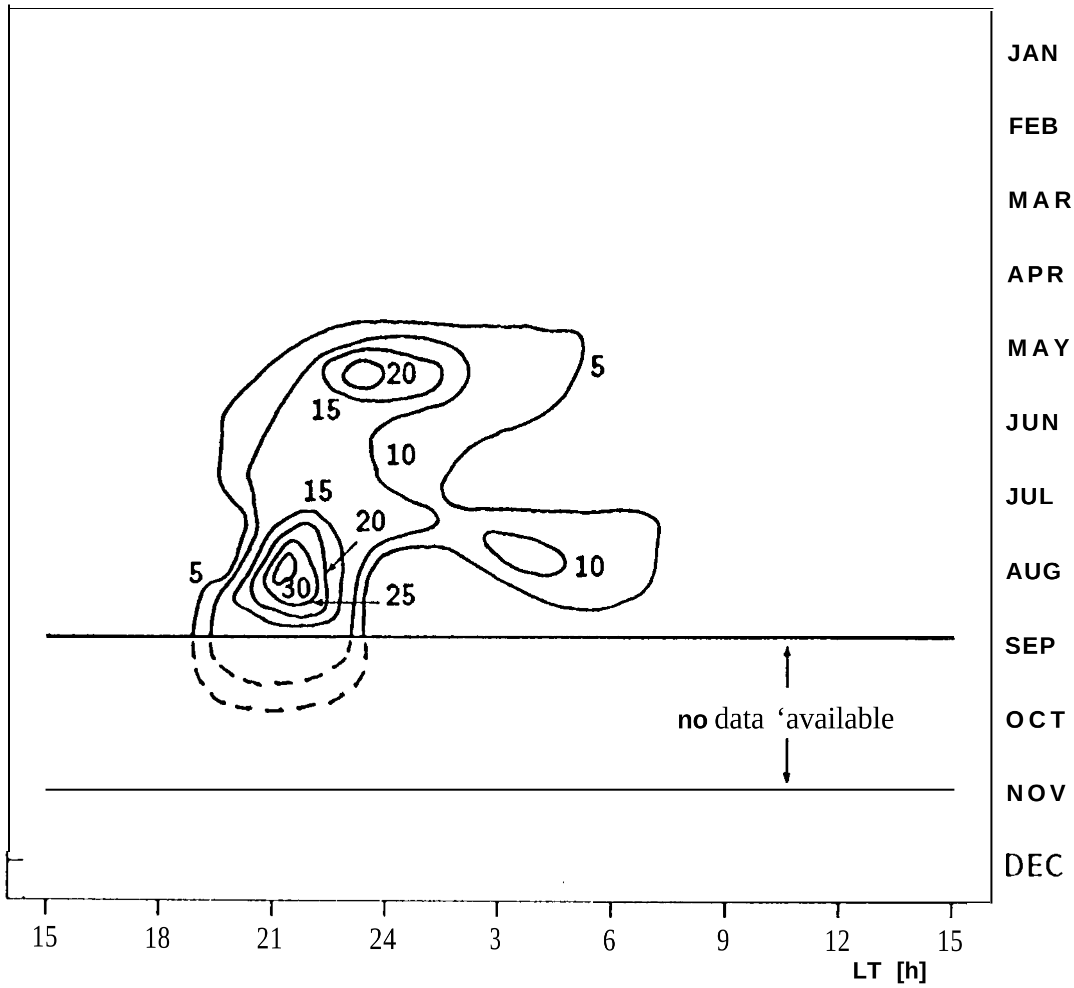

Figure 2: Percentage occurrence of phase scintillations with $I_{ROT} \geq 3$ in periods of 30 minutes, elevation mask 15°, mid-month marked, local time of ionospheric points (400 km).

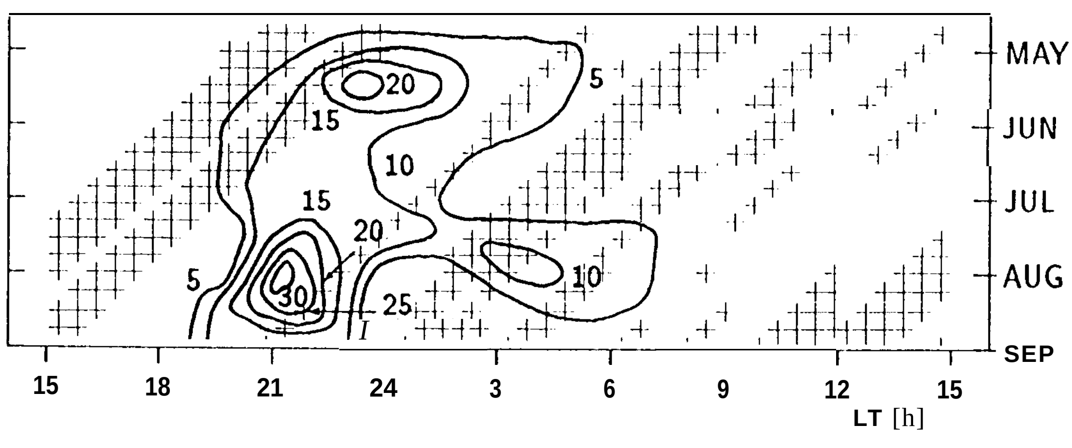

Figure 3: Part of Figure 2 superimposed on a map which shows periods of 30 minutes without any GPS observations south of 18°N latitude of ionospheric points (400 km).

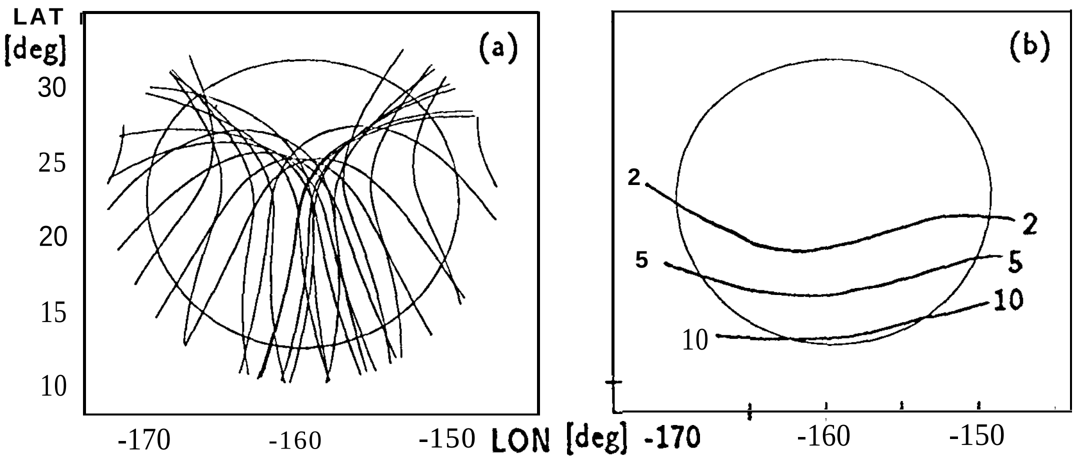

Figure 4: (a) Ionospheric points (400 km) of the satellite orbits for Kokee, September 1992, "circle" shows 15° deg elevation mask. (b) Percentage occurrence of night-time phase scintillations with $I_{ROT} \geq 3$ during May and mid-September, 20 h and 6 h LT, ionospheric points (400 km), "circle" shows 15° deg elevation mask.

index value. Hence, GPS ionospheric observations cover an area with a radius of more than 1000 km (Fig.4a). The figures reveal that the main activity *was* limited from sunset to local midnight, but on occasion continuing until dawn (Fig.2). Latitudinal and longitudinal distribution of scintillation activity shows a decrease in scintillation activity with an increase in latitude. North of Kokee hardly any scintillation activity took place (Fig.4b). Though only 12% of the observations were collected south of 18°N latitude of the ionospheric points, more than 50% of the detected scintillations occurred in this region. The incomplete coverage of GPS satellite passes south of 18°N causes periods of up to some hours without any data in this region (Fig.3). This incompleteness explains some features of the scintillation occurrence map such as the late beginning of scintillation activity at approximately 21 h LT in May and the activity hole after midnight in August/September.

In 1993, decreased scintillation activity can be expected due to the decrease in sun activity. Otherwise similar ionospheric conditions can be predicted. At the beginning and at the end of the year, the ambiguity resolution of GPS baseline measurements will be affected by large-scale gradients. From May through September/October equatorial night-time scintillations will occur. With the possible introduction of Anti-Spoofing (A-S) and thereby the necessity to track the L_2-signal with squaring or cross-correlation channels, data loss due to scintillations will increase.

CONCLUSION

The vast amount of continuous dual-frequency GPS data gathered by IGS provides a valuable resource for ionospheric research. Users of the GPS positioning service are mainly interested in the disturbing effects of ionospheric irregularities such as scintillations. A phase scintillation index can be computed from single-station dual-frequency GPS phase observations. Statistical analyses of scintillation activity can be performed with its help.

The interpretation of the Kokee data for 1992 shows that Hawaii lay at the northern boundary of scintillation activity in 1992 and that the occurrence of these disturbances were limited to the month of May to September/October and to a period of approximately 19 h to 6 h local time. The example demonstrates the usefulness of ionospheric monitoring using permanent tracking data for the planning of GPS campaigns.

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IONOSPHERE AND AMBIGUITY RESOLUTION

Urs Wild*

The data of the International GPS Geodynamics Service (IGS) may be used to model the total electron content of the ionosphere as a function of geographical latitude and the hour angle of the sun. Such simple ionosphere models may then be used (among other applications) for the improvement of the wide-lane ambiguity resolution on medium-size baselines. We discuss the application of this technique for the new first order GPS survey in Switzerland carried out by the Federal Office of Topography (L+T).

INTRODUCTION

In two cases the ionosphere plays an important role for the ambiguity resolution:

- for long baselines (> 20 km)
- for short baselines (< 5 km) and short observation times (< 5 minutes) (Rapid Static Processing Techniques)

In this paper we will focus on the first case. For long baselines the direct resolution for the original L_1 and L_2 ambiguities is usually not possible because of the increasing systematic effects (orbit errors and atmospheric influences). Several authors have proposed different methods to solve this problem.

In the Bernese GPS Processing system the following procedure is suggested[1, 2]:

(1) If no good a priori coordinates are available:
compute a solution without resolving ambiguities using the ionosphere-free linear combination L_3. This solution will provide good a priori station coordinates.

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(2) Compute a L_5 solution (= "wide-lane" linear combination) fixing all stations on the coordinates computed in step (1) (or given by an independent source) and solve for the L ambiguities (differences between the L_1 and L_2 ambiguities). Because of the wavelength of 86 cm (43 cm resp. for squaring type receivers) the ambiguity resolution L_5 is easier than for the original carriers L_1 and L_2.

(3) Introduce the L_5 ambiguities (= difference between the L_1 and L_2 ambiguities) as known values into an L_3 solution and solve for the remaining L_1 ambiguities (= narrow-lane ambiguity resolution).

The problem in this procedure is the influence of the ionosphere on the L_5 linear combination, although the remaining ionospheric effect in L_5 (if measured in units of the wavelength of L_5) is only -0.28 times the corresponding effect in L_1.

In this chapter we analyze a medium size GPS network and try to answer the following questions:

- do the computed ionosphere models improve the ambiguity resolution in L_5?

  what is the best minimum elevation for the wide-lane ambiguity resolution?

THE TEST DATA SET

In August 1992 the five Swiss stations of the EUREF-89 network were remeasured in a special GPS campaign, named the EUREF-CH-92 campaign.[3] The campaign was performed during the EPOCH'92 campaign of IGS[4,5], in order to benefit from the highest possible orbit accuracy. The main goal of the campaign was to improve the accuracy of the geometry of the five EUREF points in Switzerland. In the final solution of EUREF-89 the ionosphere-free linear combination L_3 was used and the ambiguities were not fixed. The overall accuracy over Europe seems to be of the order of 3 - 5 cm.[6] Fixing the ambiguities for all baselines between the EUREF points in Switzerland and using high-accuracy orbits should increase the accuracy to within the 1 cm level. The new Swiss first order GPS network (LV95)[7] will be transformed into this improved reference frame.

Figure 1 shows the LV95 network and the 5 EUREF stations (underlined). A total of 6 Trimble receivers was used in the EUREF-CH-92 campaign:

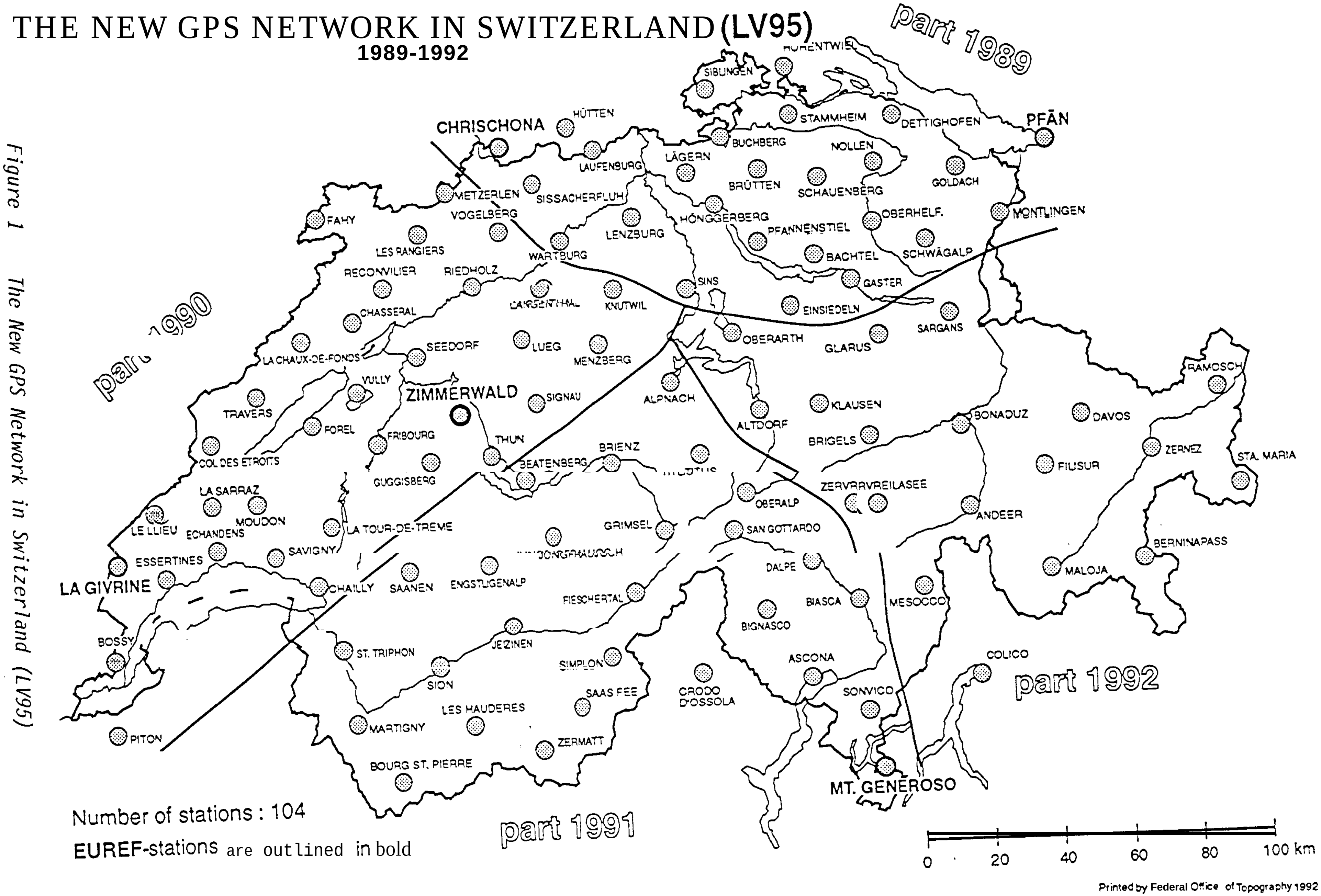

Figure 1 The New GPS Network in Switzerland (LV95)

4 Trimble 4000SLD (operating in the old so called 'Standard Format', where the observation epochs may differ from the full second by up to 256 milliseconds) and two Trimble 4000SST (observing in the 'Compact Format', where the observation epoch corresponds to full GPS seconds). Under Selective Availability (SA) data from two receivers measuring in different observation formats may no longer be combined because the behaviour of the satellite clock may not be modelled accuratly enough between the two observation epochs. This problem could be resolved by operating two receivers of the two different types at the SLR site Zimmerwald. We then formed the baselines of Table 1:

Station 1	Station 2	Receiver 1	Receiver 2	Length (km)
Zimmerwald	Mt. Generoso	4000SST	4000SST	185
Zimmerwald	Chrischona	4000SLD	4000SLD	78
Zimmerwald	Pfänder	4000SLD	4000SLD	232
Zimmerwald	La Givrine	4000SLD	4000SLD	114

Table 1
BASELINES OF THE EUREF-CH-92 CAMPAIGN

Two sessions per day were observed: session 1 from 08:15 - 19:45 (local time) and session 2 from 20:00 - 08:00. The elevation mask was set to 15°, the observation interval to 30 seconds.
For all days of the EUREF-CH-92 campaign the program IONEST[8] has been used to generate 6 single-layer ionosphere models per day (each of them valid for 4 hours). Two variants of ionsphere models have been computed: a first one using the data of the permanent GPS tracking station Zimmerwald only and a second one using the data of all 5 stations in the network.

RESULTS

For the ambiguity resolution on L all unmodelled systematic inf" uences like orbits, clocks and ionosphere) will result in increased fra ional parts of the ambiguities. In our case the systematic influence o orbit errors may be considered as neglectible, since we are using very accurate IGS orbits. In order to test the effectiveness of the ionosphere models we therefore directly may compare the fractiona parts of the L_5 ambiguities computed without and with ionosphere model.

We have compared the fractional parts using different minimum elevations (15°, 20°, 25° and 30°) in order to study at the same time the elevation dependency of the ambiguity resolution on L_5. In the comparison we made the distinction between the full -wavelength receiver (Trimble 4000SST) and the squaring type receivers (Trimble 4000SLD). In addition two types

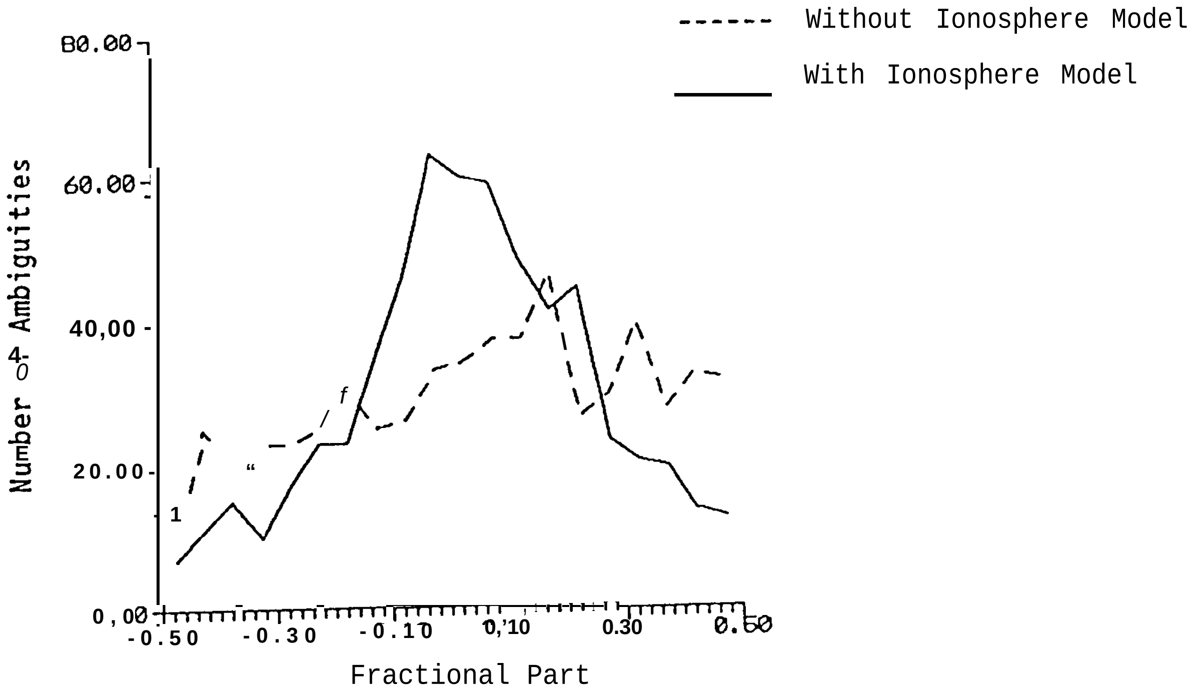

Figure 2 Fractional parts of L_5 ambiguities, Elevation = 15°
Ionosphere model: Zimmerwald, Half wavelength on L_5
EUREF-CH campaign (3 - 8 August 1992)

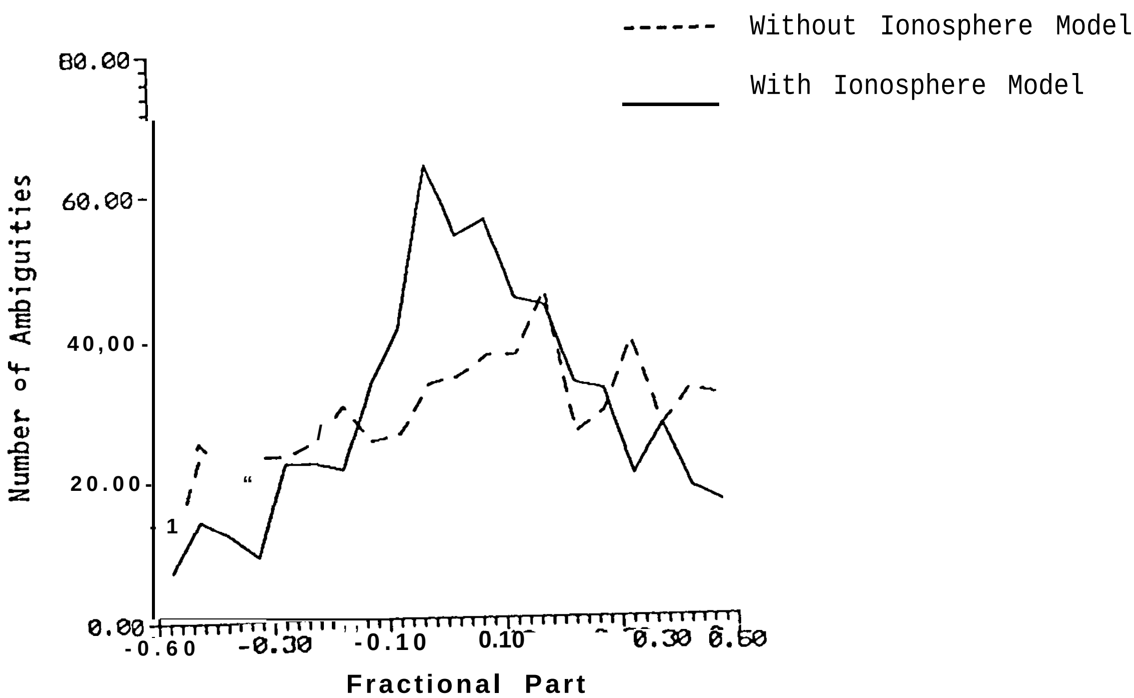

Figure 3 Fractional parts of L_5 ambiguities, Elevation = 15°
Ionosphere model: All stations, Half wavelength on L_5
EUREF-CH campaign (3 - 8 August 1992)

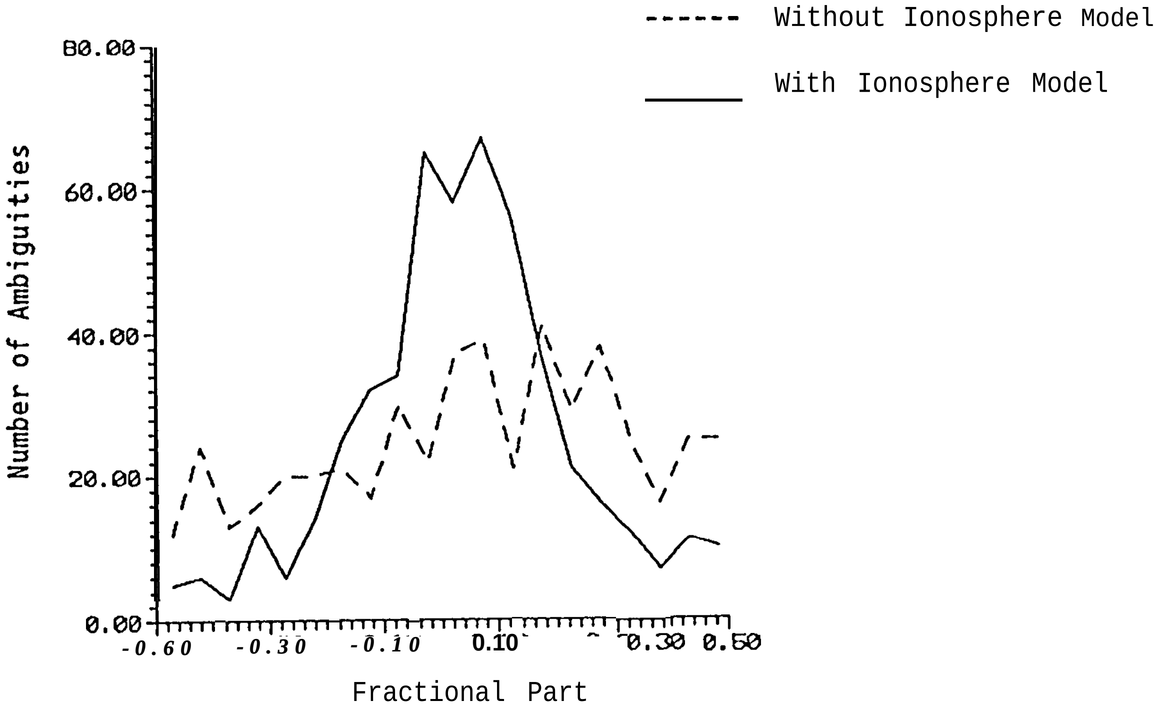

Figure 4 Fractional parts of L_5 ambiguities, Elevation = 20°
Ionosphere model: Zimmerwald, Half wavelength on L_5
EUREF-CH campaign (3 - 8 August 1992)

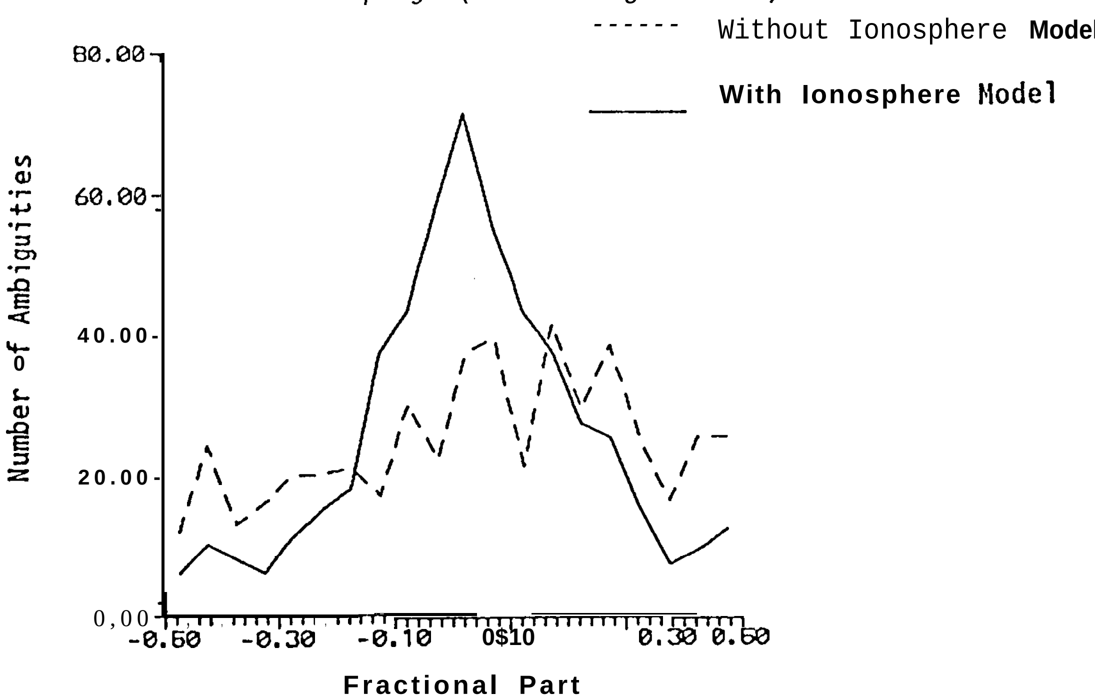

Figure 5 Fractional parts of L_5 ambiguities, Elevation = 20°
Ionosphere model: All stations, Half wavelength on L_5
EUREF-CH campaign (3 - 8 August 1992)

of ionosphere models have been used: a first type using only the data from the permanent GPS tracking station Zimmerwald and a second type using the data of all stations in the network.

Figures 2 - 5 show the histograms of the fractional parts of the L_5 ambiguities of all days for the squaring type receivers for two different minimum elevations (15° and 200).

As general impression one may note that the fractional parts of the L_5 ambiguities are significantly smaller when ionosphere models are used. No significant difference between the two types of ionosphere models could be observed. This indicates that the data of one permanent tracking station are sufficient to compute ionosphere models which can be used (at least over distances of 200 - 300 km) to improve the ambiguity resolution on L_5. It becomes obvious that the best value for the elevation for the ambiguity resolution on L_5 is 20°, whereas higher minimum elevations do no longer improve the ambiguity resolution. The histograms in Figures 2 - 5 show an asymmetry with respect to zero, which is caused by the arbitrary choice of a reference satellite in the ambiguity definition. This reference satellite may be biased by different error sources (orbits, troposphere or remaining ionospheric effects).

Different ambiguity resolution strategies have been developed and tested at the Astronomical Institute of the University of Berne(AIUB).[8] In the "classical" ambiguity resolution approach (used at the AIUB) all ambiguities are estimated as real values in a first step and then set to integers using a 3-sigma criterion in a second step. A new method (called the iterative approach) estimates the ambiguities as real values first and then resolves in a first iteration step just the n ambiguities (where n is an input option) with the smallest rms. Then the procedure is repeated without the previously solved n ambiguities.

Both techniques have been tested for the EUREF-CH-92 campaign. No major difference between the two strategies could be observed, which indicates that the problems in the ambiguity resolution are caused by the systematic influences of the ionosphere and not by the resolution method. Figure 6 shows the benefit of ionosphere models for the L_5 ambiguity resolution (using the "classical" approach) for all baselines and all days (splitted up in day and night sessions). For the 3-sigma criterion a sigma value of 0.08 has been used, the minimum elevation was set to 20". As ionosphere model the model with the data of the station Zimmerwald has been used.

As a first general impression one may note that the ionosphere models improve the ambiguity resolution considerably during the day, whereas the benefit is less obvious during the night (in some cases even more ambiguities are solved without ionosphere models). It becomes also obvious that the percentage of solved ambiguities decreases with increasing baseline length.

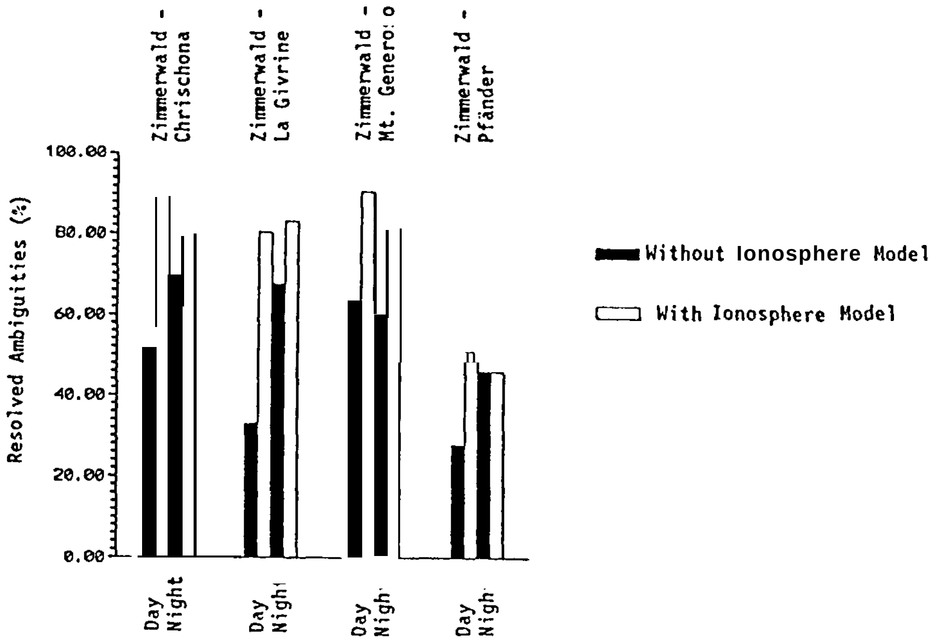

Figure 6 L_5 Ambiguity resolution ("classical" approach) EUREF-CH campaign (3 - 8 August 1992)

CONCLUSION

In conclusion one may note that the ionosphere models improve in-all cases the wide-lane ambiguity resolution. Using these models and the fixed wide-lane ambiguities it was possible to fix about 85% of the narrow-lane ambiguities in the final solution of the first order GPS network, It is therefore recommended that ionosphere models become a product of the IGS.

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