IGS

ANALYSIS CENTER REPORTS

1999 Analysis Coordinator Report

T. A. Springer, J. Kouba, and Y. Mireault
Astronomical Institute, University of Berne, Switzerland
Geodetic Survey Division, Geomatics Canada, Natural Resources Canada

Introduction

This reports complements the Analysis Activities Report found in the 1999 IGS Annual Report [*Springer,* 2000]. It focuses on the combination statistics of orbits, clocks, and Earth Rotation Parameters (ERPs). Furthermore, an overview of the most important changes and highlights of the IGS Analysis Activities in 1999 is given.

Changes in 1999

From an Analysis point of view the Analysis center (AC) workshop held at the Scripps Institution of Oceanography in La Jolla, California is certainly the main event of 1999. The AC workshops usually result in a lot of additional work for the ACs. However, the new ideas and directions which are discussed and initiated at the AC workshops are also very stimulating for the workshop participants. A summary of the 1999 AC workshop may be found in IGSMAIL #2359. The 1999 workshop dealt with two major topics: "real- and near-real-time products and applications" and "long-term stability and accuracy of GPS Reference Frame".

The position paper "Moving IGS products towards real-time" by Gerd Gendt, Peng Fang, and Jim Zumberge, proposed the generation of both more rapid and frequent IGS products for (near-) real-time usage. These products, which are delivered every 12 hours (twice a day), contain a 48 hour orbit arc from which 24 hours are real orbit estimates and 24 hours are orbit predictions. The latency of this product is 3 hours. The first Analysis Center Ultra rapid solutions were provided by GFZ by the end of October 1999. The generation of a combined ultra rapid product (IGU) has started in March 2000 based on contributions from up to five different Analysis Centers. It is again remarkable to see how soon the IGS ACs have managed to reach a new and very ambitious goal within only a few months time. Like the IGS Predicted orbits (IGP) the ultra rapid product are available for real-time usage, but the quality should be significantly better because the average age of the predictions is reduced from 36 to 9 hours. In the months to come, the quality and the reliability of the IGS Ultra rapid (IGU) orbits will be assessed against the IGS Predicted (IGP) and IGS Rapid (IGR) products. When it reaches a satisfactory level (which could be sooner than we think) the IGU products will replace the IGP and IGR products.

Besides the initiation of the ultra rapid products the ACs agreed on adopting the new realization of the ITRS, the ITRF97 [*Boucher et. Al.,* 1999]. The effects of this change on the IGS products is described below. The ACs also agreed on using the same 4-character

IDs for the stations. Over recent years the ACs had diverged somewhat in their naming conventions of the stations because several stations had a change in their names like, e.g., the station Richmond (USA) which used several different 4-character IDs (RCM2, RCM4, RCM5). Some ACs used these changing names, others used a single 4-character ID. Because this was becoming confusing for the IGS as a whole it was decided that all ACs should use the same naming conventions. After long and sometime quite lively "virtual" (e-mail) and "real" (meetings) discussions the ACs finally managed to come to an agreement during the AC workshop. The official IGS convention is now that the 4-character ID used for both the site-log and the RINEX filename becomes the official 4-character ID for the respective site–receiver–antenna combination. This 4-character ID should be used to label **all** results from this site–receiver–antenna combination, including SINEX and clock files. New 4-character IDs will be the responsibility of the IGSCB but, of course, new stations may propose their 4-char ID. The IGSCB will notify the IGS about changes in the 4-character IDs and new stations by sending an IGSMAIL.

Change of Terrestrial Reference Frame (ITRF97)

As discussed and agreed upon during the Analysis Center workshop the IGS changed its realization of the International Terrestrial Reference System by switching from the ITRF96 to the ITRF97 on 1 August 1999. At the same time the set of reference stations (RF) was slightly enhanced from 47 to 51 sites. The main change was the inclusion of a few sites for which the accuracy was insufficient in the ITRF96 but which are well determined in the ITRF97. A SINEX file containing the necessary information about these 51 reference stations may be found at the IGS Central Bureau. Although the ITRF96 and ITRF97 frames are nominally aligned globally in all 7 Helmert components and their rates, comparison of the IGS subset of RF sites shows significant differences between the ITRF96 and ITRF97 realizations. The expected differences between the IGS products based on the ITRF96 and ITRF97 reference frames are given in Table 1. More information about this ITRF change may be found in IGSMAIL #2432. Besides this last IGS terrestrial reference frame change, Table 1 contains all previous IGS terrestrial reference frame changes and the associated transformations for the IGS products. The epochs of the transformations is given by the GPS week in with which the terrestrial reference frame change took effect. More information about the earlier reference frame changes may be found in previous IGS Annual and Technical Reports, and in the IGSMAIL archives.

It is interesting, but also a bit disturbing, to notice the relatively large differences between the ITRF96 and ITRF97. Especially the Z-translation (14.7 mm) and the scale (-1.4 ppb) constitute quite large changes given the fact that the ITRF96 and ITRF97 nominally have the same orientation (i.e., ITRF94). Also the X-, and Y-rotations are quite significant (-0.159 and 0.263 mas). The cause of these relatively large transformation parameters for the IGS RF station subset of the ITRF97 is not exactly known. However, it seems to be related to the fact that for the alignment of the ITRF97 the full covariance matrix was used. This was the first time it was possible to use the full station covariance matrix for the ITRF alignment. When the full ITRF96 and ITRF97 realizations are compared using only the diagonal of the covariance matrix very similar transformation parameters are found as those given in Table 1.

Table 1: Transformation parameters from IGS(ITRFnn) to IGS(ITRFnn). The IERS convention for the transformation parameters was followed. The equivalent changes in polar motion may be obtained using PMx = RY and PMy = RX.

ITRFnn from	to	Epoch (GPS-week)	TX (mm) (mm/y)	TY (mm) (mm/y)	TZ (mm) (mm/y)	RX (mas) (mas/y)	RY (mas) (mas/y)	RZ (mas) (mas/y)	Scale (ppb) (ppb/y)
92	93	782	-20.0	-8.0	-3.0	-1.660	-0.680	-0.550	0.100
			-2.3	-0.4	0.8	-0.120	-0.150	0.040	-0.110
93	94	860	21.0	1.0	-1.0	1.270	0.870	0.540	0.200
			2.7	0.0	-2.0	0.130	0.200	-0.040	0.090
94	96	947	0.0	-1.0	1.0	-0.100	-0.010	-0.220	-0.400
			0.2	-0.9	0.2	-0.020	0.010	0.010	-0.070
96	97	1021	0.3	0.5	-14.7	0.159	-0.263	-0.060	1.430
			-0.7	0.1	-1.9	0.013	-0.015	0.003	0.192

IGS ITRF Realization

The plans for the new and improved IGS ITRF (IGSRF) realization, as proposed during the 1998 Analysis Center workshop [*Kouba et. Al.,* 1998] have been finalized in March 2000. Starting with GPS week 1050 the weekly IGSRF realization, as generated at NRCan by Remi Ferland, has become official, see IGSMAIL #2740 and [*Ferland.,* 2000] for more details. In this new IGSRF realization the IGS Final combined orbits are made consistent with the combined IGSRF solution by using both the transformation parameters and the combined ERPs stemming from the IGSRF combination. Sometime in the year 2000 the IGS will switch from using the ITRF97 to using it's own internal IGS ITRF realization. Because the IGSRF is tied to the ITRF97 this change should not cause any discontinuities in the GPS time series. Of course this change will require careful monitoring of the results and the change will be announced through the usual channels, e.g., IGSMAIL.

Combination Results in 1999

The statistics from the Final, Rapid, and Prediction combinations and comparisons are given in the Tables and Figures in the Appendix of this report. Tables 2 and 3 give the statistics of the Final and Rapid combinations over the year 1999. Table 4 gives the statistics of the Prediction comparisons over the year 1999. Table 5 gives the comparison statistics between the individual AC ERP series (both Final and Rapid) to the IGS Final ERP series. The IGS Rapid ERP series is also compared to the IGS Final ERP series and the results are also included in this table. Figures 1 and 2 show the time series of the weighted orbit RMS and the Clock RMS of the Final and Rapid orbit and clock combinations, respectively. Figures 3 to 27 show the time series of the transformation parameters over 1999 for the Final, Rapid, and Predicted solutions of the ACs. Figures 28 to 31 show the time series of ERP differences over 1999 in X-, and Y-pole and their rates for the Final and Rapid ERP solutions of the ACs compared to the IGS Final ERP series. Figure 32 shows the time series of LOD differences over 1999 for the Final and Rapid AC solutions compared to the IGS Final LOD series. Note that all LOD results reflect the actual LOD estimates and not LOD values derived from UTC.

Figures 1 and 2 demonstrate the high quality and stability of both the orbit quality and the clock products. For the final solutions several ACs have reached the 30 mm level whereas for the rapid solutions some of the ACs have come near the 50 mm level which is quite an achievement given the limited time available for computing the rapid solutions (only 16 hours after the end of the observation day). Consequently the combined IGS Rapid products (IGR) are comparable or even better than most of the AC Final solutions. The stability of both the final and rapid clock solutions is not as high as that of the orbit solutions. Nevertheless, the clock solutions seem to be at the level of 0.1 to 0.3 ns (30 to 90 mm).

Tables 2 and 3 indicate that there are no significant translation and rotation biases in the individual AC orbits compared to the IGS Final and Rapid orbits. However, for some ACs the standard deviations of the translations are higher for their final solutions than for their rapid solutions. For the Z-translation most of the ACs show a higher standard deviation for their final solutions than for their rapid solutions. This is a consequence of the fact that the final solutions are generated using minimal constraints where only three rotational constraints are applied to the final solutions [*Kouba.,* 1998]. For the rapid solutions the ACs use the fiducial strategy in which the positions of several RF stations are constrained to their ITRF positions. The standard deviation of the Z-translation reflects that this is one of the weakest determined components in the global GPS solutions, which is a well known fact. It is disturbing to see that some of the final solutions are less stable than the rapid solutions. We will therefore have to monitor these variations very carefully and the ACs should try to improve the stability of their final solutions. Some of the ACs clearly demonstrate that the minimal constrained solutions can be more stable than the fiducial solutions.

Besides large standard deviations some of the AC Final solutions also showed small biases from time to time during 1999. The main problem with these orbit translation biases is that they can not easily be corrected by using the translations of the station coordinates as they may be obtained from comparing the SINEX solutions. Contrary to the rotations, where the correlation between the orbit rotations and the station coordinate rotations is practically 1, the correlation's between the orbit and station translations is not very clear. Nevertheless during 1999 there were a number of occasions where the translations of the orbits of some of the ACs had to be corrected. In those cases the correlation between the orbit and SINEX translations were (empirically) taken to be 1.0 for X- and Y-translations and 0.5 for the Z-translation. The statistics presented here are after subtracting these empirical corrections, because they were applied prior to the orbit combinations.

In Table 2 and 3 significant biases may be observed for the orbit scale. The largest average scale being found for the COD orbits (-0.19 ppb) and the smallest average scale for JPL (0.33 ppb). The scale differences between the ACs is very consistent for both the final and rapid solutions. The scale factors of the predicted orbits also show a similar picture with the exception of the JPL Predictions. The JPL Predictions seem to have a larger scale than then JPL Final and Rapid solutions. The EMR Final orbit scale shows an abrupt change in GPS week 1039, see Figure 4. This is the time when EMR switched to a new version of the GIPSY software. It seems we have two "scale groups" within the IGS. On one hand we have COD, NGS, GFZ, and SIO (scale in decreasing order), on the other hand we have EMR, ESA, JPL, and USN. The ACs EMR, JPL, and USN all use the same software. The jump in the EMR time series indicates that the scale may be caused by a change in the software. If we look at the time series of the scale parameter since 1994 a small jump is present in both the COD and JPL time series. For COD this jump takes place in GPS week 873 and is being caused by a change in the estimated orbit parameters [*Springer.,* 1999]. The jump in the JPL time series happens a little bit earlier around GPS week 870. Although this has been discussed in the past, the precise cause of this change has remained unclear. As mentioned before the scale of the EMR orbits shows a jump starting with GPS week 1039. The scale of the ESA orbits seems to drift, getting smaller, but very slightly, over the years. The SIO orbit scale has increased significantly over 1999 as can be seen in Figure 9. There may be a jump around GPS week 1021 in the SIO Final orbit scale time series. The average scale of the GFZ and NGS orbits seems to have remained relatively constant over the years.

The average scale difference between COD and JPL orbits corresponds to a radial orbit difference of 14 mm which is quite significant. It is interesting to point out that the orbits having the smaller scale, EMR, ESA, JPL, and USN, are in closer agreement with the SLR observations of the GPS satellites. It has been demonstrated that there is a bias of approximately 50 mm between the observed SLR ranges of the GPS satellites and the computed ranges based on using the COD orbits and the ITRF SLR station positions [*Springer,* 1999]. The bias being such that the SLR observations are short compared to the computed ranges. Therefore the bias for, e.g., the JPL orbits will be around the 30 mm. From this point of view it is quite important to study and find the cause of the differences in orbital scale. It may help us in explaining and solving the observed GPS–SLR bias.

In the prediction time series, Figures 19 to 27, there are a couple of interesting phenomena. First the rotations of the orbits of several ACs are very similar. This is an indication that the ACs are making similar errors in their ERP predictions. At the AC workshop it was therefore requested to provide the ERP predictions with the orbit predictions. However, because of the advent of the IGS Ultra rapid products and because not all ACs actually provide ERPs with their predicted orbits this action item has not (yet) been pursued. It is also interesting to see that the ESA predicted orbits show an annual period in the Z-translation (also visible in last years technical report). Something similar, but much larger and with the opposite sign, is also observed for the broadcast orbits. In Table 4 it is interesting to note that the stability of the transformation and scale parameters of the IGS orbit predictions is about a factor of 10 better than those of the broadcast orbits. This is a significant advantage of the IGS Predicted orbits over the broadcast orbits. It means that the IGS Predicted orbits are very closely aligned to the ITRF reference frame which is clearly not the case for the broadcast orbits. Last but not least in 1999 we welcomed USNO to the list of ACs providing orbit predictions. In the pole comparisons, Table 5, it is impressive to see the quality of the IGR ERP series. The standard deviation of the IGS series is clearly better than the standard deviation of the individual AC Rapid solutions. Also the IGR series shows a 100% availability which none of the ACs has managed. This shows the importance of the IGS combinations: both the reliability and the quality of the combined products are improved compared to the individual AC solutions. It is quite an achievement that the Final ERP series of the ACs agree better than 0.1 mas (3 mm on the Earth surface) with the IGS combined series, and the AC Rapid series agree at the 0.2 mas level. This ERP quality, as expected, agrees very well with the standard deviations from the orbit rotation parameters (Tables 2 and 3).

Summary and Outlook

There is one significant problem we are faced with in the year 2000. The increasing ionospheric activity will increase the problems with the remaining TurboRogue receivers in the IGS network. For a detailed description of the problem please see IGSMAIL #2071. There are still a significant number of IGS sites which are using TurboRogue receivers. The solutions based on the data of these stations will suffer severely in the coming years, see also IGSMAIL #2761. Because some of these stations are located in remote areas this may pose a serious threat to the quality of the IGS results. Ideally these receivers should be replaced, alternatively they may be set to track at 1 Hz and using some post-processing software to generate good 30 second data which, fortunately, is done at several locations. In 2000 we may look forward to a number of new and challenging IGS activities. First of all during 2000 the IGS will switch from using the ITRF realizations to a GPS internal ITRF realization (IGSRF) which, however, will be tied very closely to the latest ITRF. This switch should significantly improve the internal consistency of the IGS products. It is also very likely that this year the IGS Ultra rapid products will replace the IGS Predicted products. The quality of the Ultra rapid products is already quite comparable to the IGS Predicted products and significant improvements may be expected as the ACs get more Ultra rapid experience. However, it may take a bit longer before the Ultra rapid products replace the IGS Rapid products, especially in view of the very high quality of the IGS Rapid combined products. It will probably be necessary to have a larger number of “hourly” stations and a better geographical distribution of these stations than the current 40–45 stations provide.

If all goes well the year 2000 should provide us with a few Low Earth Orbiting (LEO) satellites equipped with GPS receivers. A number of missions (CHAMP, SAC-C) are scheduled for launch this year. These LEO mission will add a new and exiting dimension to the IGS activities. However, for the LEO missions it will be mandatory to continue the good cooperation, coordination, and open information exchange as we have practiced in the past IGS years.

The development of the IGS Ultra rapid products has once again have shown the capability of the IGS to set and reach new and ambitious goals in a short period of time.

This shows that the IGS spirit of friendly competition is still very much “alive and kicking.”.

References

Boucher, C., Z. Altamimi, and P. Sillard (1999), The 1997 International Terrestrial Reference Frame (ITRF97), *IERS Technical Note 27*, Central Bureau of IERS – Observatoire de Paris, Paris, May 1999.

Ferland, R. (2000), 1999 ITRF Reference Frame Working Group, in *IGS 1999 Technical Reports*, this volume.

Kouba, J., J. Ray, and M. M. Watkins (1998), IGS Reference Frame Realization, in *Proceedings of the 1998 IGS Analysis Center Workshop*, edited by J. Dow *et al.*, ESA/ESOC, Darmstad, Germany, February 1998.

Springer, T.A. (1999), *Modeling and Validating Orbits and Clocks Using the Global Positioning System*, Ph.D. dissertation, Astronomical Institute, University of Berne, Berne, Switzerland, November 1999.

Springer, T.A. (2000), Analysis Activities, in *IGS 1999 Annual Report*, IGS Central Bureau, Jet Propulsion Laboratory, Pasadena, California U.S.A., to be publised.

Springer, T.A., G. Beutler, and M. Rothacher (1999), Improving the Orbit Estimates of the GPS Satellites, *Journal of Geodesy*, *73*(3), 147–157.

Tables and Figures

Table 2: IGS Final Combination mean (*μ*) and standard deviations (σ) of the daily transformation parameters, weighted orbit RMS, and Clock RMS. Based on GPS weeks 990–1042 (371 days).

AC		Days	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	Scale (ppb)	WRMS (mm)	CRMS (ns)
cod	μ	371	0.1	0.0	-3.6	0.01	0.01	0.04	-0.19	28.5	0.50
	σ		4.6	3.8	9.6	0.09	0.08	0.07	0.09	4.8	0.16
emr	μ	370	6.1	-7.8	10.3	0.15	-0.02	0.14	0.02	103.2	0.41
	σ		12.4	22.9	40.1	0.21	0.19	0.21	0.22	16.9	0.17
esa	μ	371	0.1	-0.7	-1.0	0.03	-0.02	-0.12	0.24	69.9	0.69
	σ		7.3	6.7	14.5	0.17	0.19	0.21	0.13	13.2	0.56
gfz	μ	371	0.2	-0.8	0.4	-0.00	0.03	0.01	-0.11	31.3	0.19
	σ		3.6	5.0	9.7	0.07	0.09	0.09	0.08	6.9	0.12
jpl	μ	364	1.5	2.3	1.2	-0.06	0.01	0.02	0.33	35.8	0.24
	σ		8.6	9.4	15.0	0.13	0.11	0.09	0.09	9.7	0.10
ngs	μ	357	-7.0	-0.2	24.1	0.02	-0.19	-0.13	-0.17	90.6	-
	σ		8.9	9.4	36.9	0.21	0.24	0.25	0.26	15.6	
sio	μ	364	-1.7	0.8	-8.2	0.02	0.02	-0.05	-0.07	52.9	-
	σ		5.5	7.1	16.7	0.13	0.10	0.20	0.18	8.8	
igr	μ	371	0.4	-0.7	-2.7	0.01	0.03	0.02	-0.00	38.0	0.28
	σ		5.5	6.0	7.5	0.10	0.10	0.11	0.10	6.9	0.22

Table 3: IGS Rapid Combination mean (μ) and standard deviations (σ) of the daily transformation parameters, weighted orbit RMS, and Clock RMS. Based on GPS week 990 day 5 to GPS week 1042 day 5 (365 days).

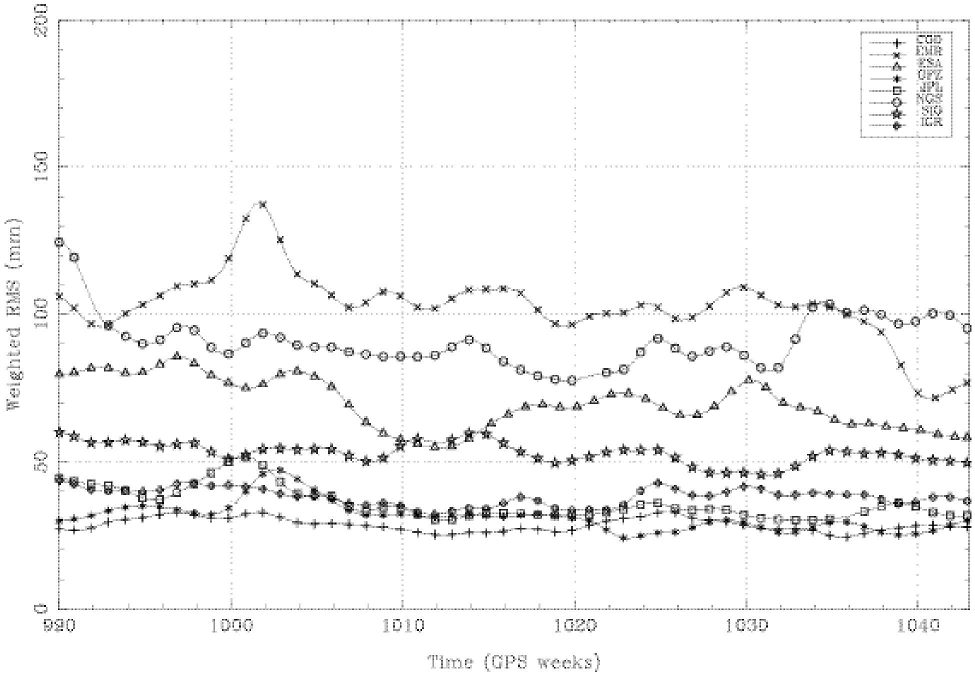
AC		Days	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	Scale (ppb)	WRMS (mm)	CRMS (ns)
cod	μ	362	-1.6	0.7	-3.6	-0.10	-0.06	-0.06	-0.14	55.8	-
	σ		6.8	6.4	11.1	0.19	0.21	0.19	0.12	12.7	
emr	μ	311	4.6	-11.0	2.3	0.31	-0.06	0.19	0.06	135.5	0.38
	σ		13.6	13.1	12.1	0.30	0.26	0.35	0.29	32.0	0.38
esa	μ	330	-1.3	-0.8	-1.5	0.07	-0.05	-0.20	0.24	104.0	3.05
	σ		9.2	8.7	13.7	0.23	0.24	0.28	0.15	32.7	4.44
gfz	μ	356	0.9	-3.8	6.7	0.04	0.07	-0.01	-0.13	62.9	0.26
	σ		5.8	11.5	9.7	0.15	0.13	0.13	0.11	13.8	0.17
jpl	μ	227	8.9	6.6	3.6	0.03	-0.04	0.12	0.20	106.0	0.58
	σ		22.4	15.0	14.6	0.50	0.38	0.87	0.31	43.0	1.05
ngs	μ	310	-7.6	0.9	-4.3	-0.15	-0.07	-0.12	-0.17	117.1	-
	σ		9.4	11.6	14.0	0.22	0.21	0.20	0.21	38.1	
sio	μ	321	-2.4	-0.4	-4.2	-0.03	0.01	-0.01	-0.04	79.5	-
	σ		8.1	11.0	9.4	0.39	0.35	0.18	0.22	26.3	
usn	μ	347	3.0	3.1	-1.2	0.01	0.05	0.13	0.19	70.7	0.25
	σ		7.5	7.3	8.6	0.12	0.12	0.17	0.11	28.8	0.27

Table 4: IGS Prediction Comparison mean (μ) and standard deviations (σ) of the daily transformation parameters, weighted orbit RMS, and Clock RMS. Based on GPS week 990 day 5 to GPS week 1042 day 5 (365 days). USP joined the IGS predictions in June 1999.

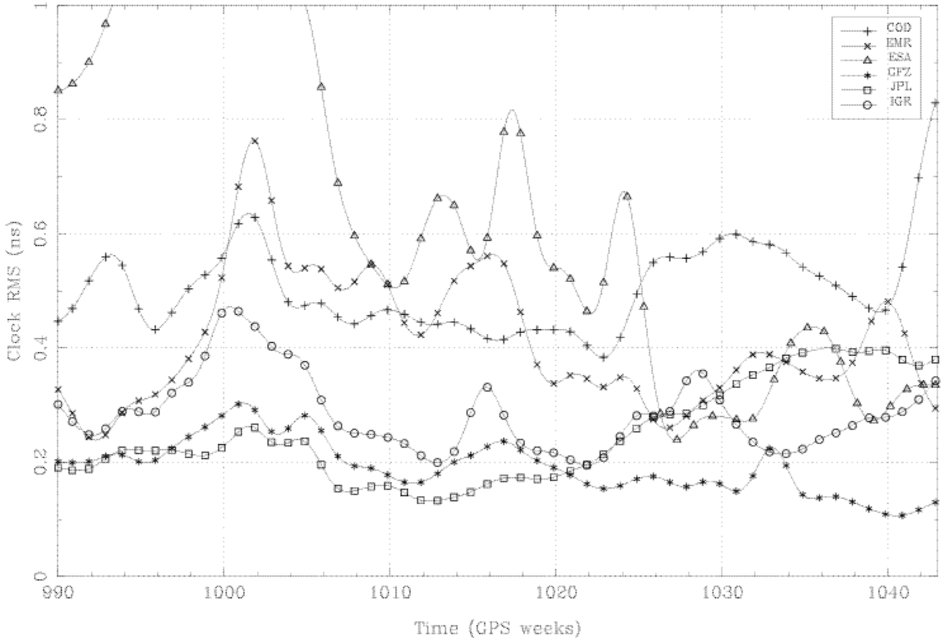
AC		Days	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	Scale (ppb)	WRMS (mm)	CRMS (ns)
cop	μ	364	-0.2	-0.7	-6.3	-0.11	-0.07	-0.20	-0.15	2589.6	86.07
	σ		11.4	11.1	25.3	1.00	1.18	3.14	0.38	9071.7	2.36
emp	μ	363	-1.8	1.7	2.2	-0.02	-0.03	-0.22	0.04	2647.8	-
	σ		16.0	12.7	27.7	1.16	1.43	1.97	0.52	4049.6	
esp	μ	357	-3.0	1.6	-22.9	0.03	0.02	-0.72	0.18	2708.9	-
	σ		33.2	49.9	99.7	4.05	1.27	6.81	0.78	5547.8	
gfp	μ	359	-1.8	2.5	11.1	0.09	0.07	-0.08	-0.13	2039.7	-
	σ		11.4	10.6	20.9	0.82	1.08	1.68	0.39	3375.9	
jpp	μ	339	0.1	3.1	-2.5	0.25	-0.28	0.06	-0.15	1675.0	-
	σ		22.2	17.5	44.9	2.20	2.34	4.96	1.38	2789.8	
sip	μ	347	-1.1	4.4	-4.3	-0.15	-0.01	-2.11	-0.12	3404.6	-
	σ		19.0	19.1	44.0	1.02	1.14	6.34	0.98	4268.0	
usp	μ	184	1.4	2.5	1.9	-0.17	-0.08	-0.11	0.25	2363.5	-
	σ		11.8	9.9	21.1	0.64	0.82	2.31	0.32	4206.2	
igp	μ	365	-0.7	1.0	0.0	-0.05	-0.03	-0.25	-0.02	1717.5	85.60
	σ		10.9	10.3	20.0	0.86	1.01	2.20	0.34	3374.9	7.34
brd	μ	365	7.3	24.0	103.7	0.14	0.23	3.07	-2.05	3519.0	80.24
	σ		114.0	105.0	190.7	1.93	2.42	5.32	3.05	6562.6	1.81

Table 5: IGS Final Pole Comparison mean and standard deviation (σ) of the daily ERP values (X-, and Y-pole) and their rates and LOD. Based on GPS week 990 day 5 to GPS week 1042 day 5 (365 days). The upper part of the table is based on the Final solutions and the lower part is based on the Rapid solutions of the ACs.

AC	Days	X-Pole (mas)		Y-Pole (mas)		X-Rate (mas/d)		Y-Rate (mas/d)		LOD (μs/d)	
		Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
cod	365	0.027	0.076	-0.004	0.100	0.019	0.140	-0.023	0.162	13	29
emr	365	-0.117	0.201	0.037	0.163	-0.534	0.557	0.094	0.549	1	32
esa	365	0.030	0.181	0.158	0.200	0.048	0.418	-0.010	0.708	-16	29
gfz	365	-0.002	0.103	-0.030	0.068	0.025	0.119	-0.010	0.145	3	20
jpl	358	-0.011	0.073	-0.029	0.080	-0.063	0.221	-0.102	0.226	14	35
ngs	358	-0.270	0.345	0.038	0.281	0.227	0.720	0.482	1.050	10	74
sio	358	0.040	0.078	0.016	0.100	0.030	0.150	-0.020	0.182	6	28
igr	365	0.038	0.116	0.019	0.105	0.086	0.297	0.088	0.290	2	23
cod	362	-0.033	0.240	-0.102	0.242	-0.004	0.356	-0.012	0.334	3	45
emr	311	-0.060	0.324	0.322	0.328	-0.167	1.096	-0.011	1.068	6	60
esa	330	-0.009	0.287	0.184	0.264	0.345	0.667	0.014	0.967	-19	34
gfz	356	0.088	0.146	0.042	0.161	0.092	0.347	0.134	0.350	2	33
jpl	227	-0.025	0.462	0.133	0.624	0.010	0.471	-0.023	0.502	8	82
ngs	310	0.068	0.354	-0.174	0.344	0.421	1.106	0.473	1.299	1	77
sio	321	0.071	0.426	-0.041	0.457	0.134	1.114	0.182	0.963	15	90
usn	347	0.080	0.149	0.037	0.139	-0.072	0.586	-0.012	0.572	-5	32

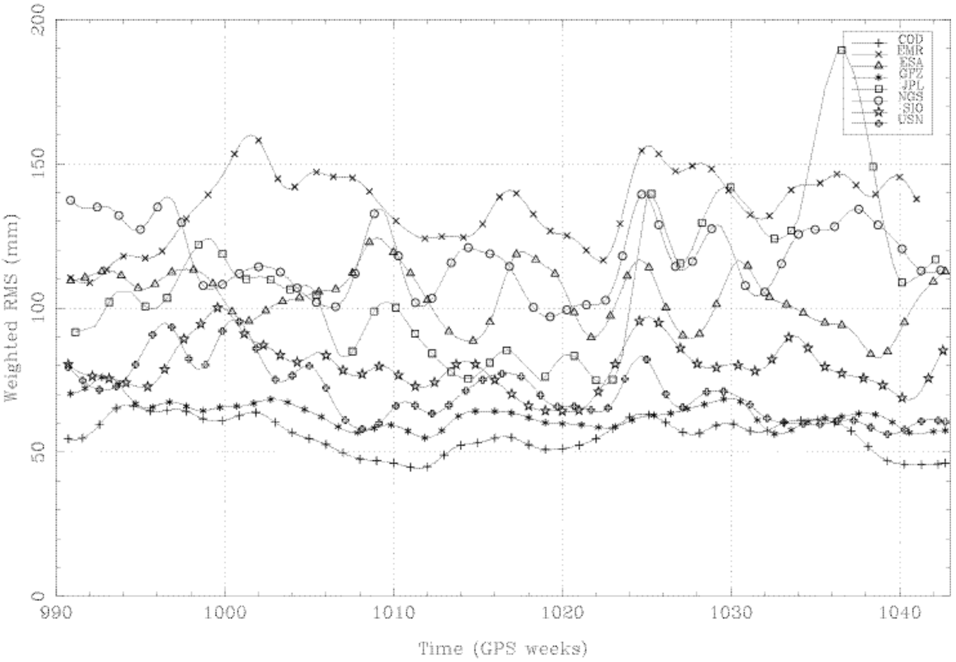


(a) Final Weighted Orbit RMS (mm)

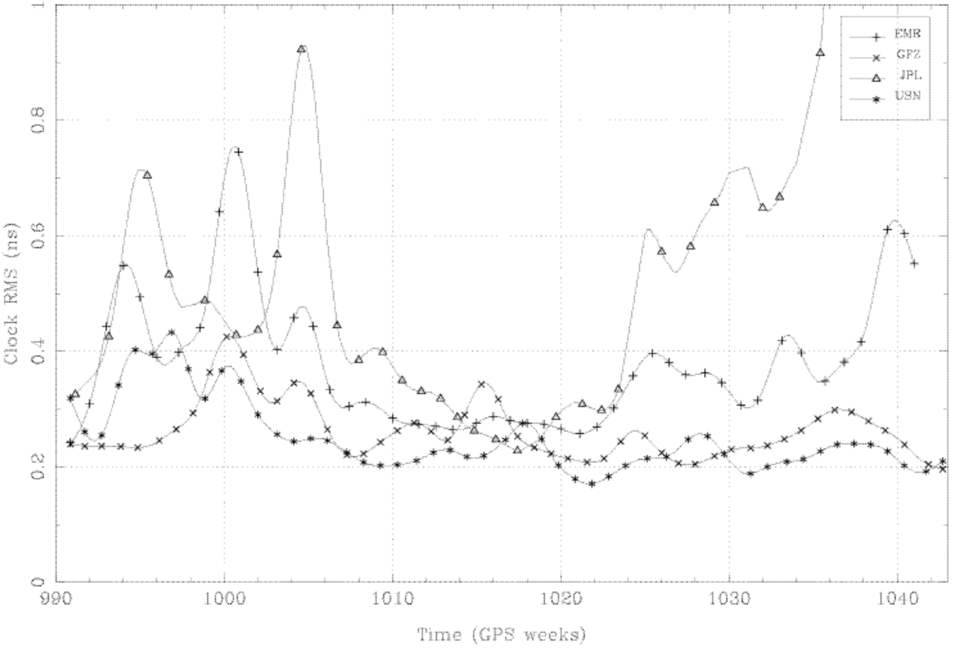


(b) Final Clock RMS (ns)

Figure 1: Final Weighted orbit RMS (mm) and Clock RMS (ns) of the AC and of the daily ERP values (X-, and Y-pole) and their rates and LOD.
Based on GPS week 990 day 5 to GPS week 1042 day 5 (365 days).
The upper part of the table is based on the Final solutions
and the lower part is based on the Rapid solutions of the ACs.

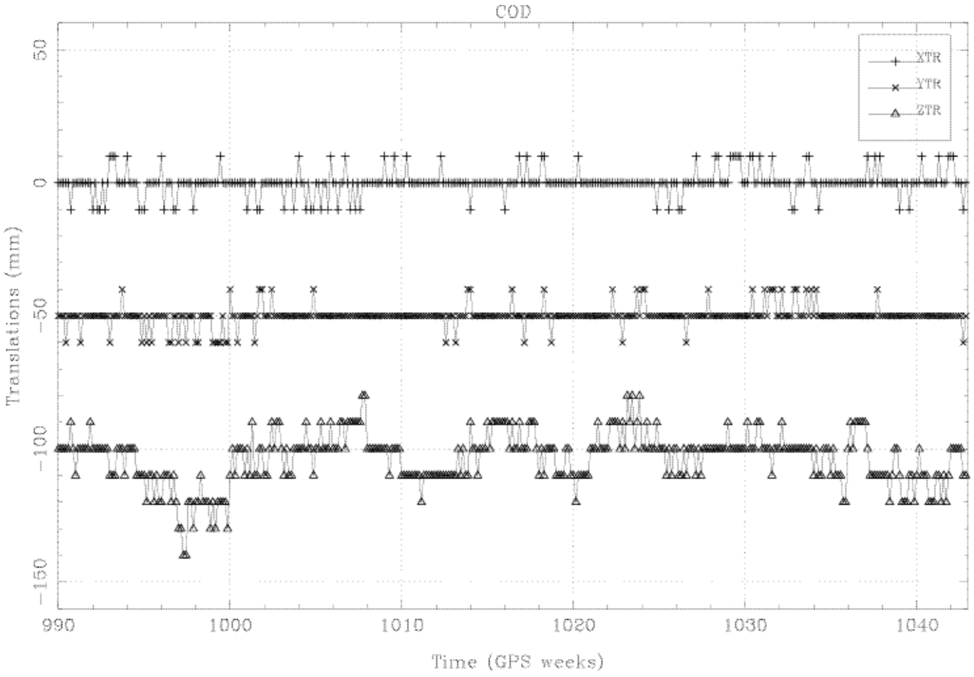


(a) Rapid Weighted Orbit RMS (mm)

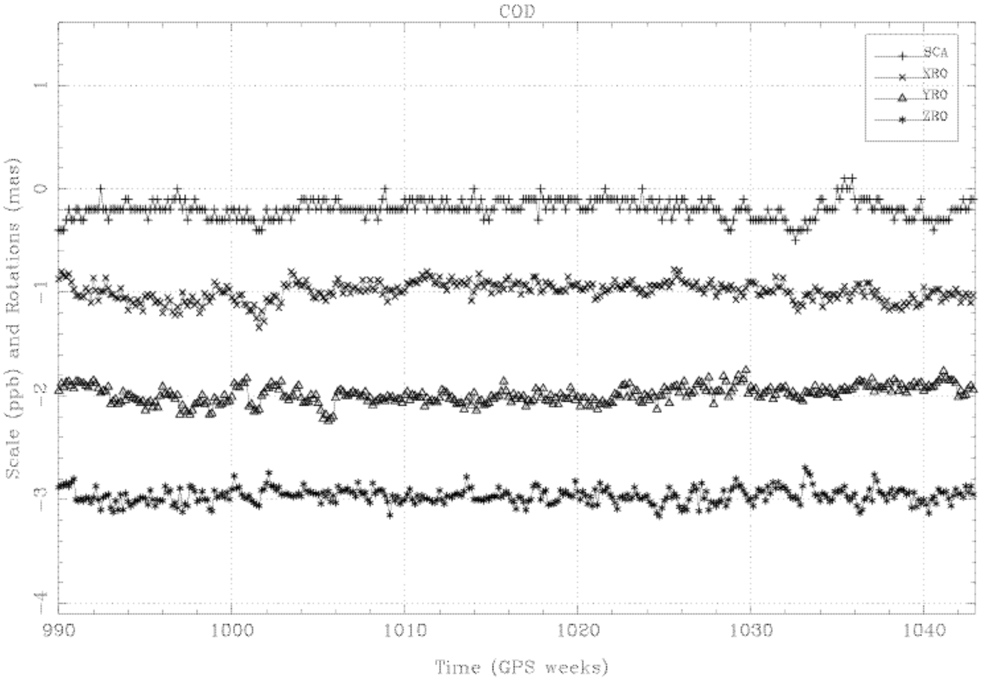


(b) Rapid Clock RMS (ns)

Figure 2: Rapid Weighted orbit RMS (mm) and Clock RMS (ns) of the AC orbit solutions with respect to the IGS Final orbits.
The daily RMS values from the combination summaries were smoothed for plotting purposes, using a sliding 7 day window.

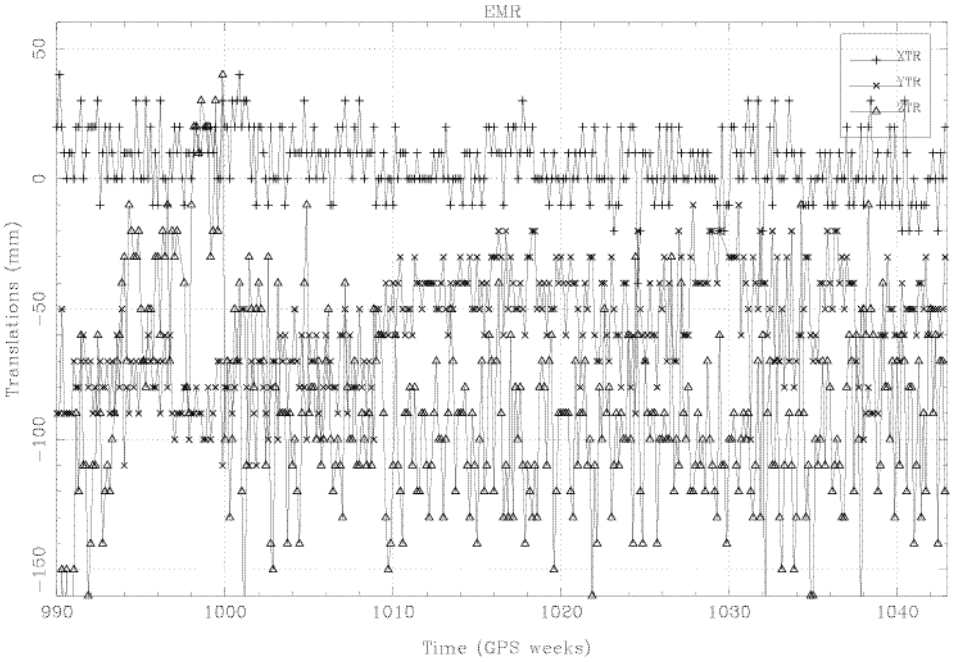


(a) Translations (X, Y, and Z)

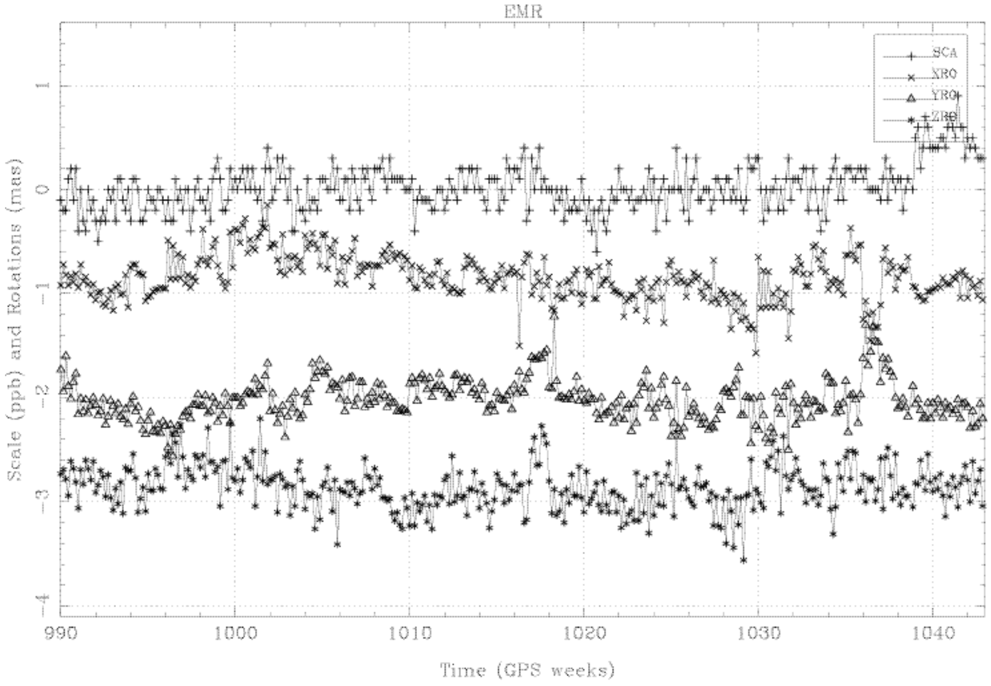


(b) Scale and Rotations (X, Y, and Z)

Figure 3: Daily Transformation parameters of the AC Final orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

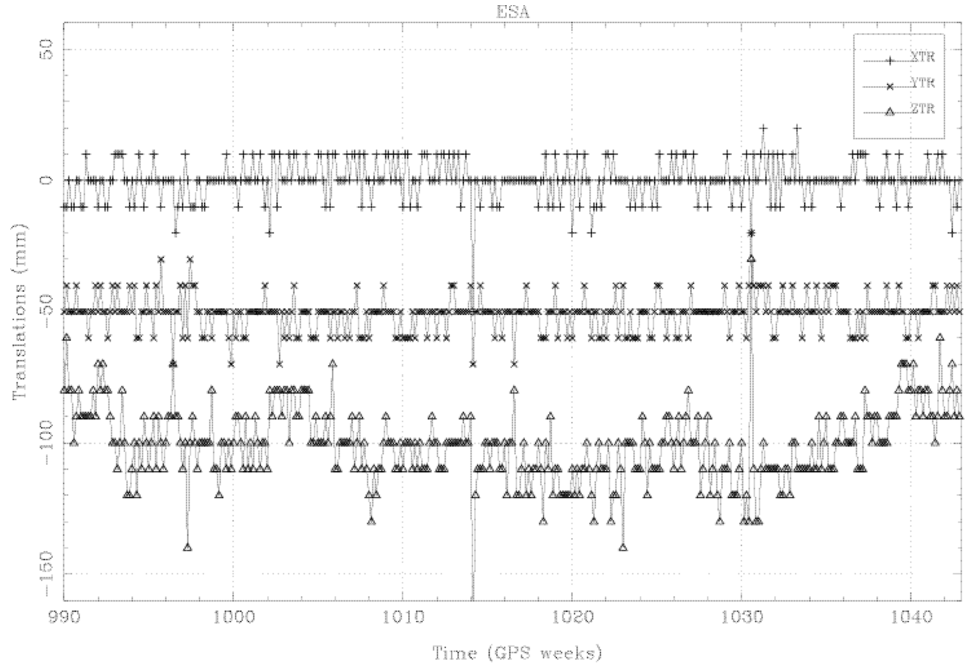


(a) Translations (X, Y, and Z)

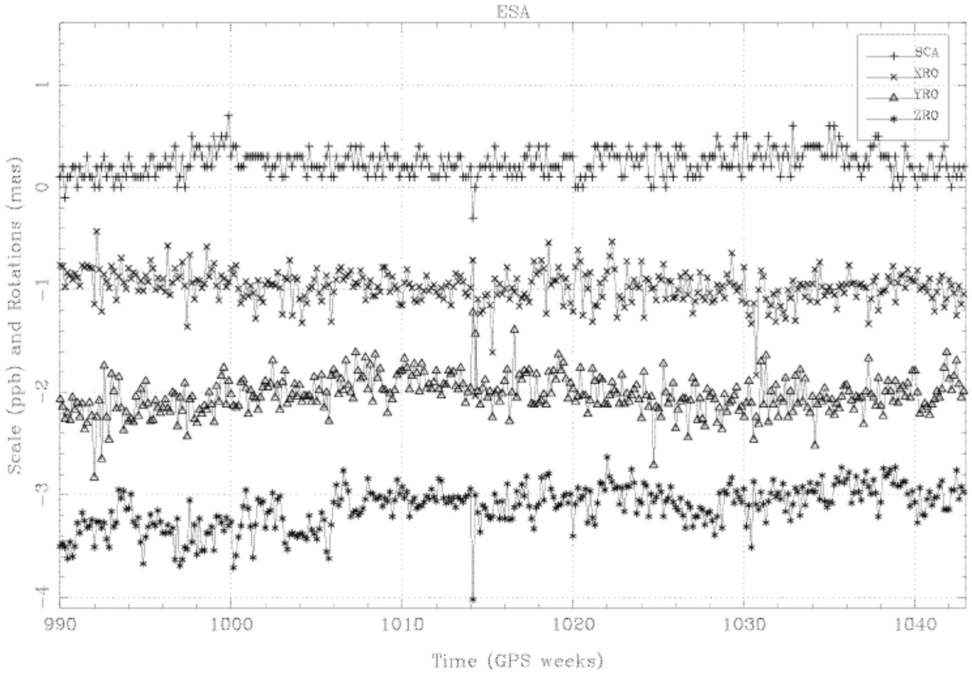


(b) Scale and Rotations (X, Y, and Z)

Figure 4: Daily Transformation parameters of the AC Final orbits with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

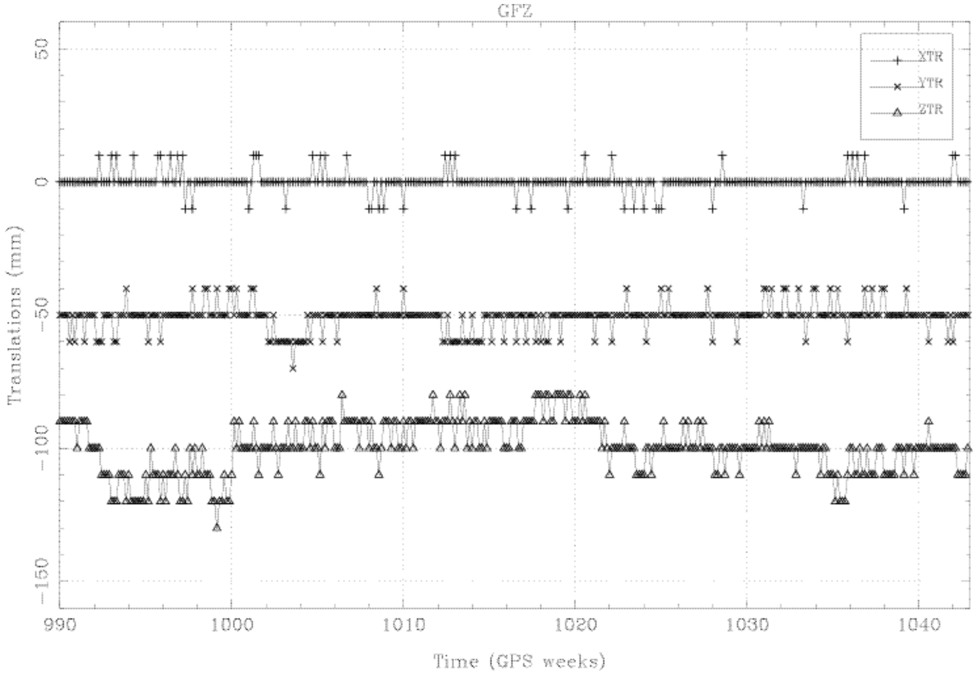


(a) Translations (X, Y, and Z)

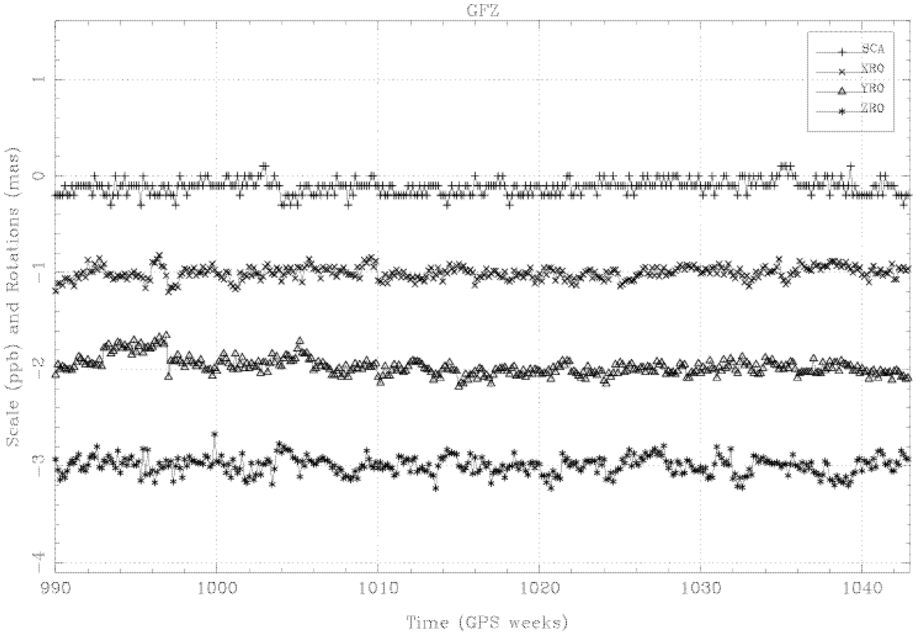


(b) Scale and Rotations (X, Y, and Z)

Figure 5: Daily Transformation parameters of the AC Final orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

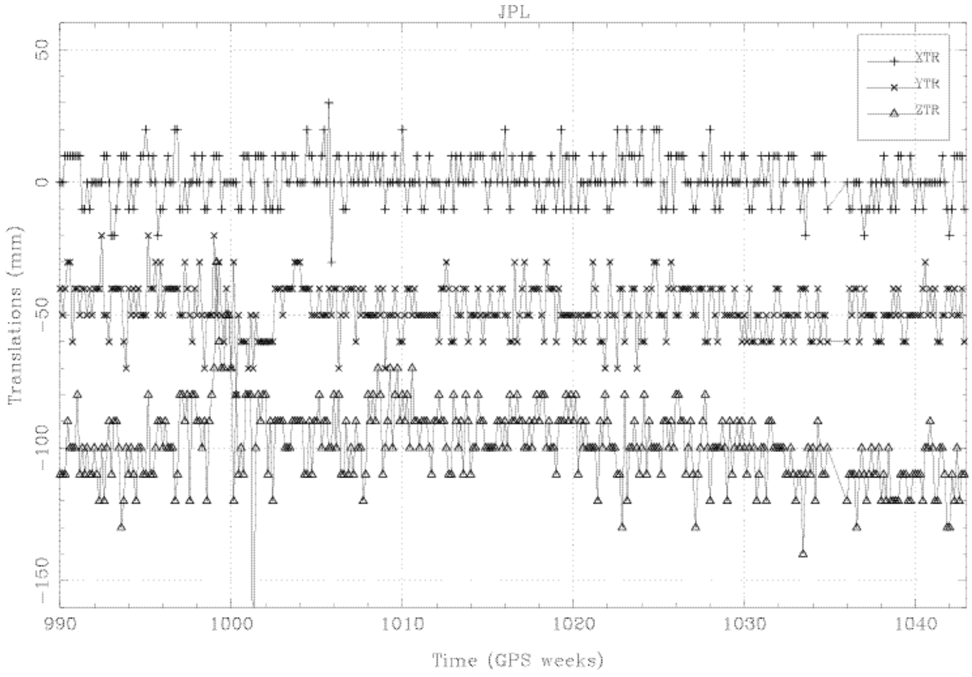


(a) Translations (X, Y, and Z)

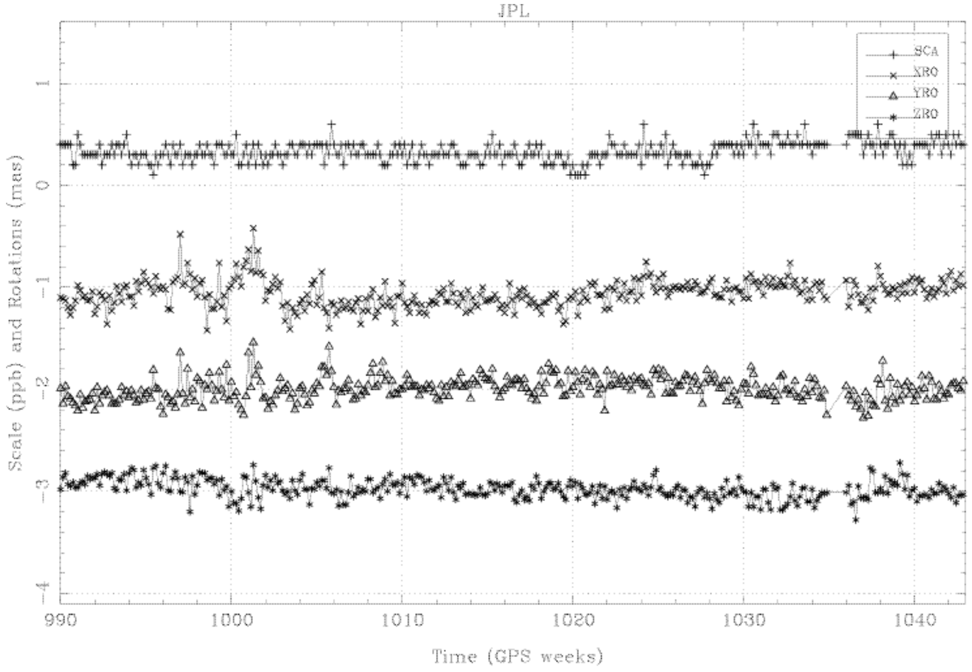


(b) Scale and Rotations (X, Y, and Z)

Figure 6: Daily Transformation parameters of the AC Final orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

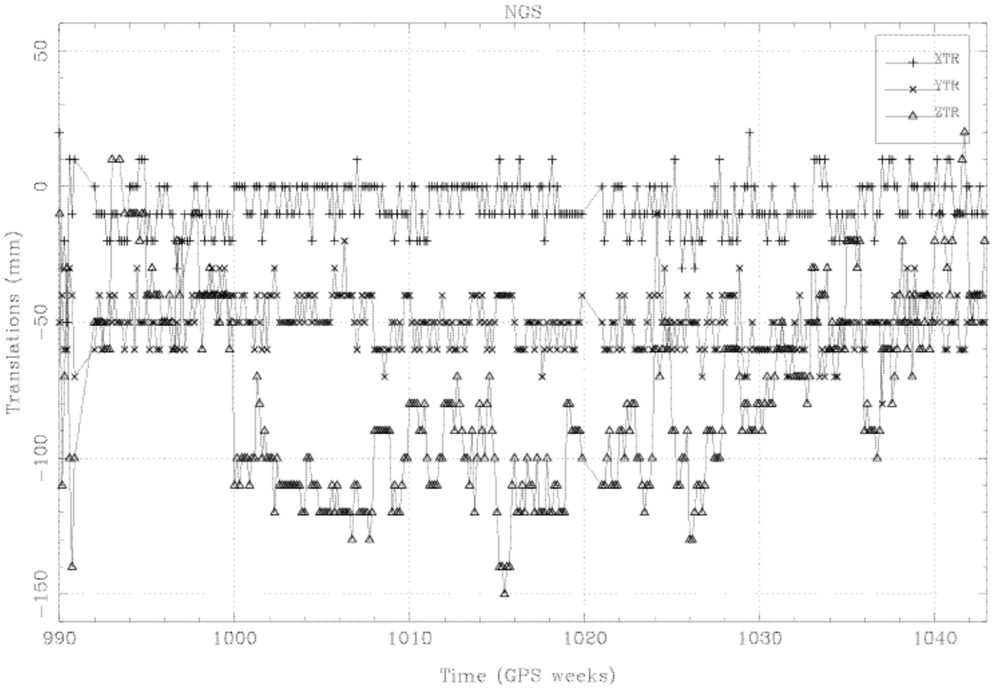


(a) Translations (X, Y, and Z)

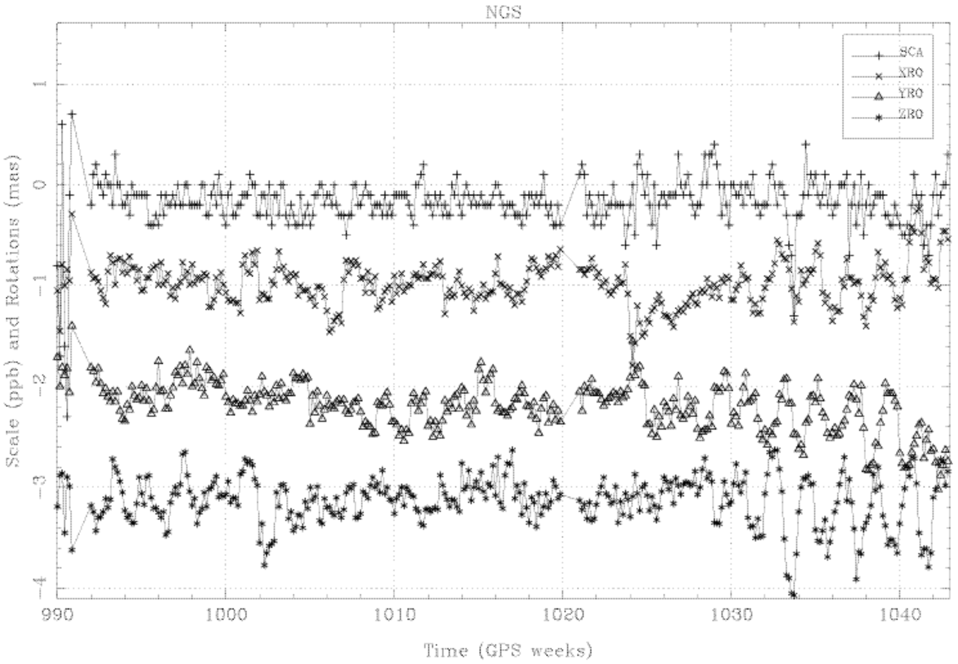


(b) Scale and Rotations (X, Y, and Z)

Figure 7: Daily Transformation parameters of the AC Final orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

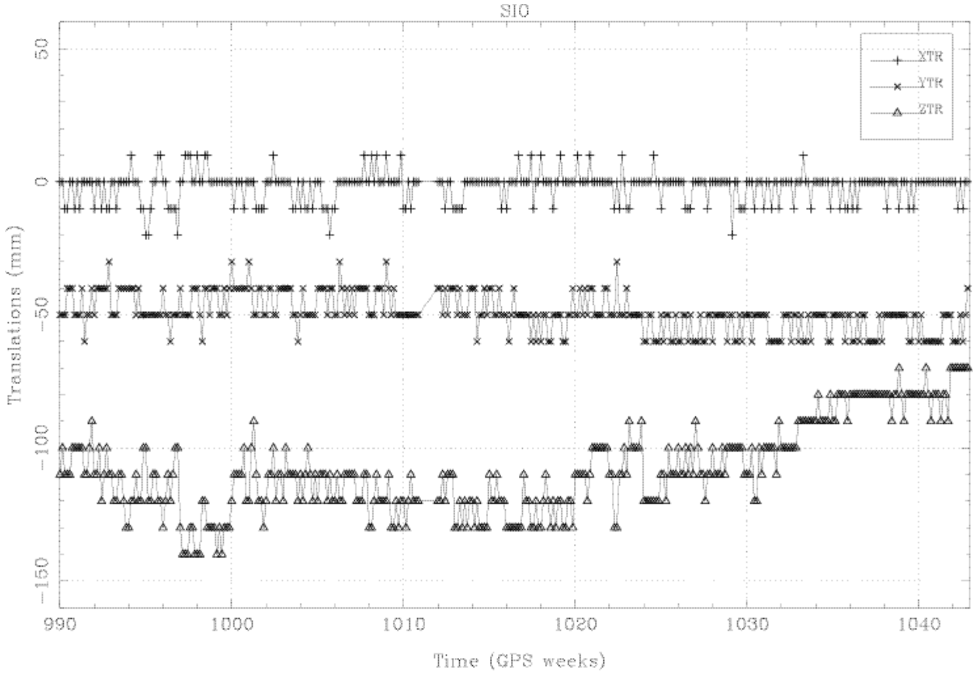


(a) Translations (X, Y, and Z)

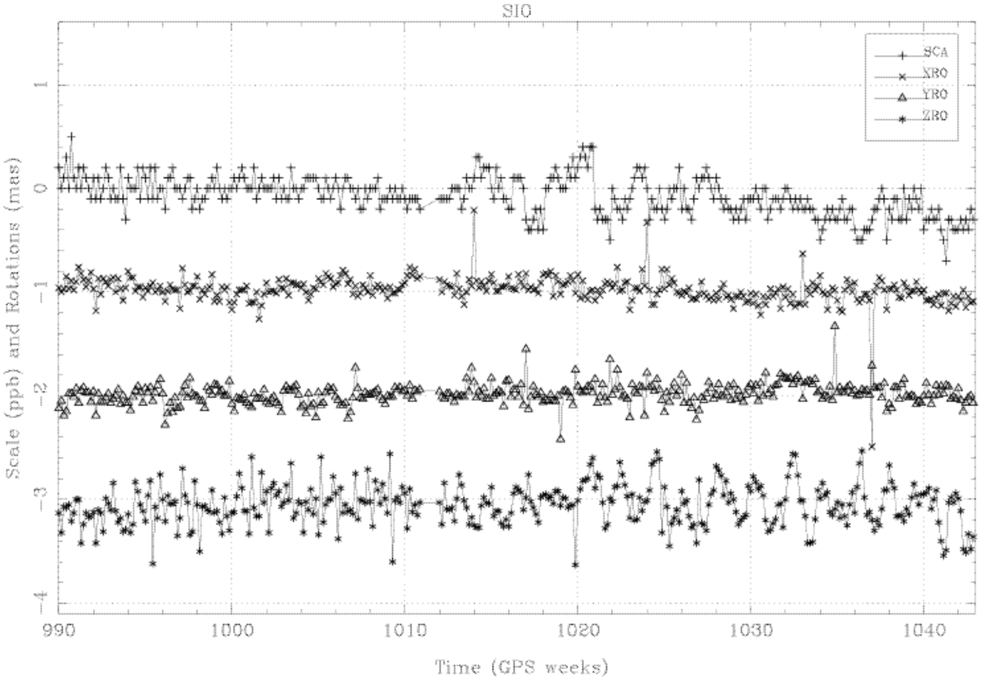


(b) Scale and Rotations (X, Y, and Z)

Figure 8: Daily Transformation parameters of the AC Final orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

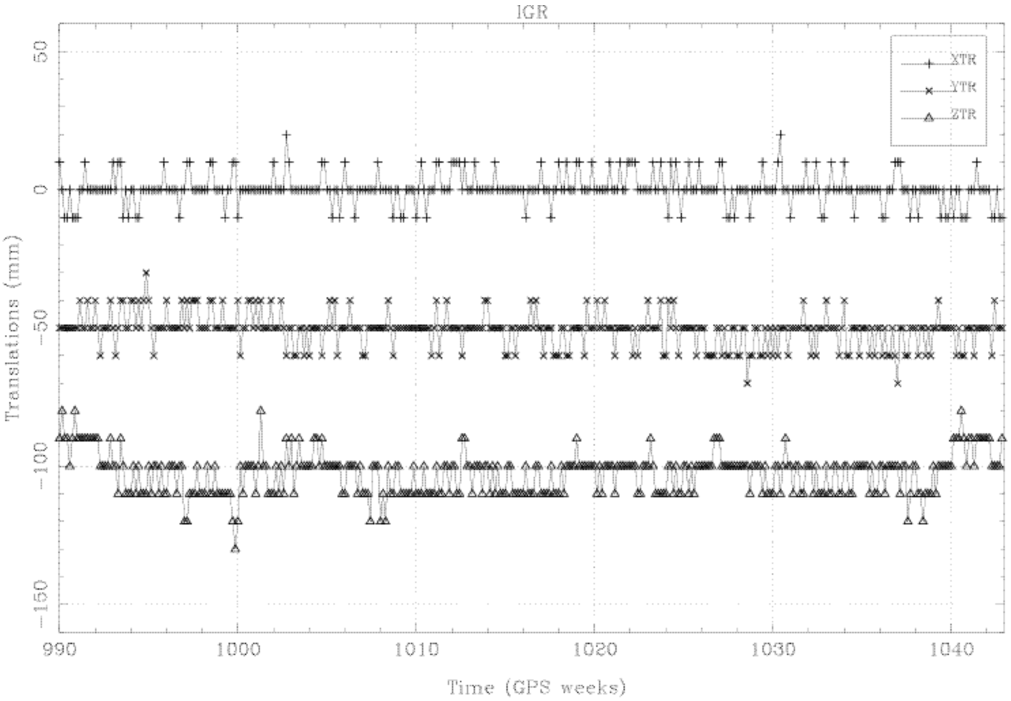


(a) Translations (X, Y, and Z)

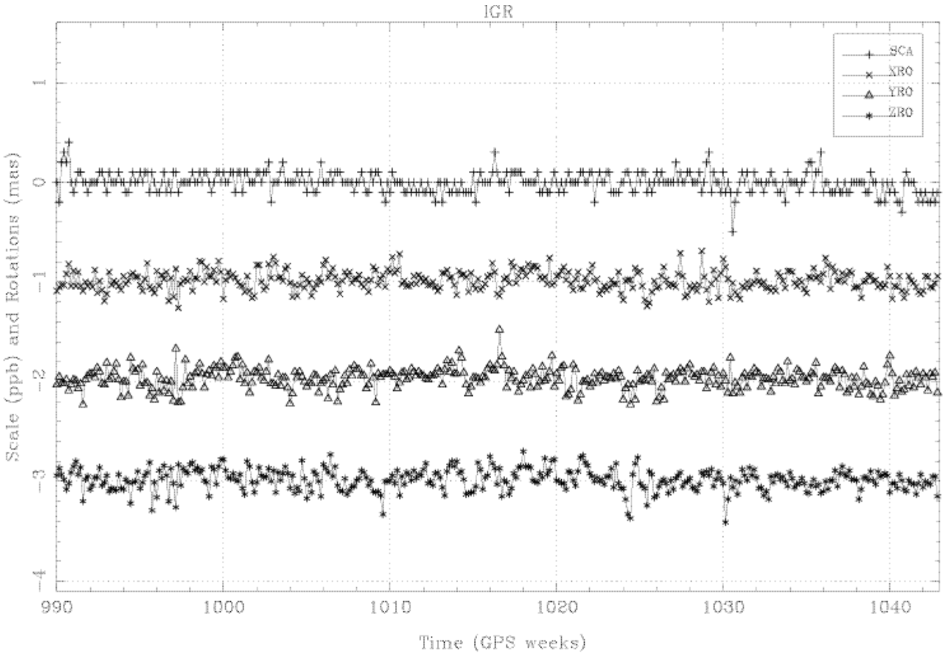


(b) Scale and Rotations (X, Y, and Z)

Figure 9: Daily Transformation parameters of the AC Final orbits
with respect to IGS Final orbitsTranslations are shifted by 50 mm, rotations as shifted by 1 mas.

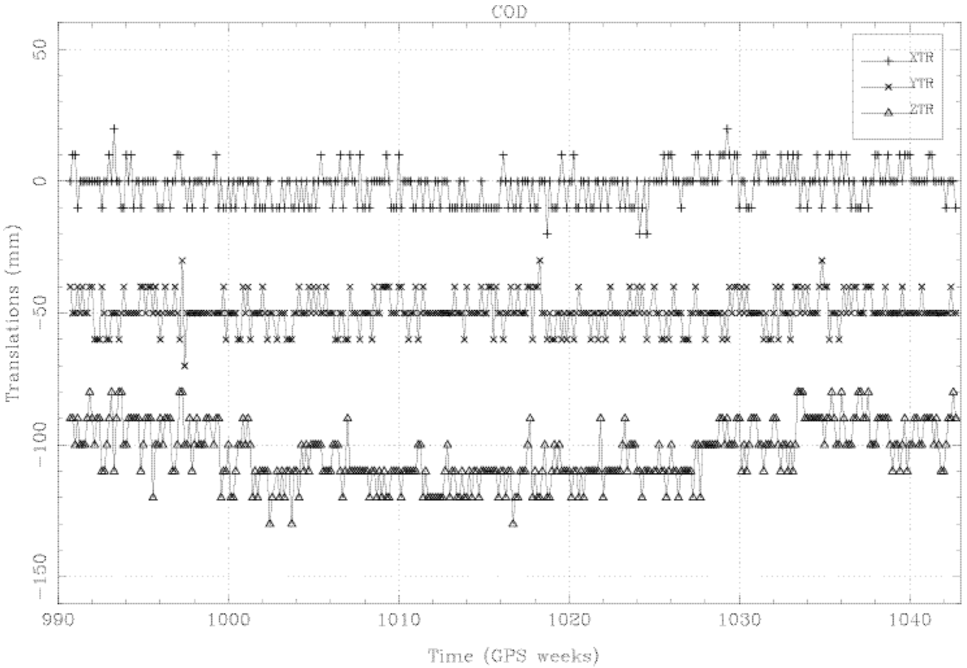


(a) Translations (X, Y, and Z)

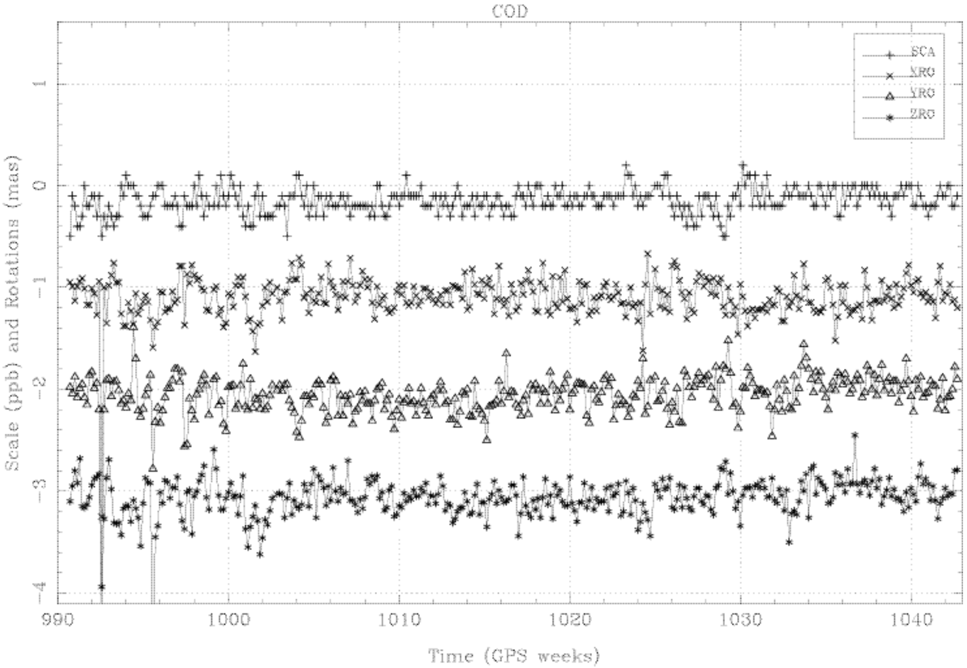


(b) Scale and Rotations (X, Y, and Z)

Figure 10: Daily Transformation parameters of the AC Final orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

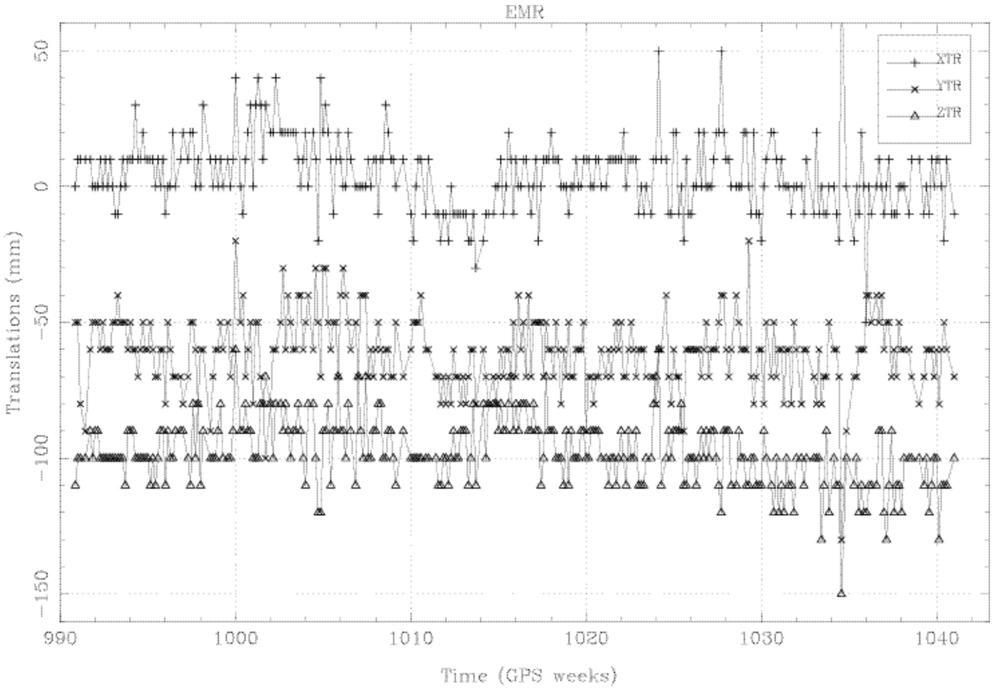


(a) Translations (X, Y, and Z)

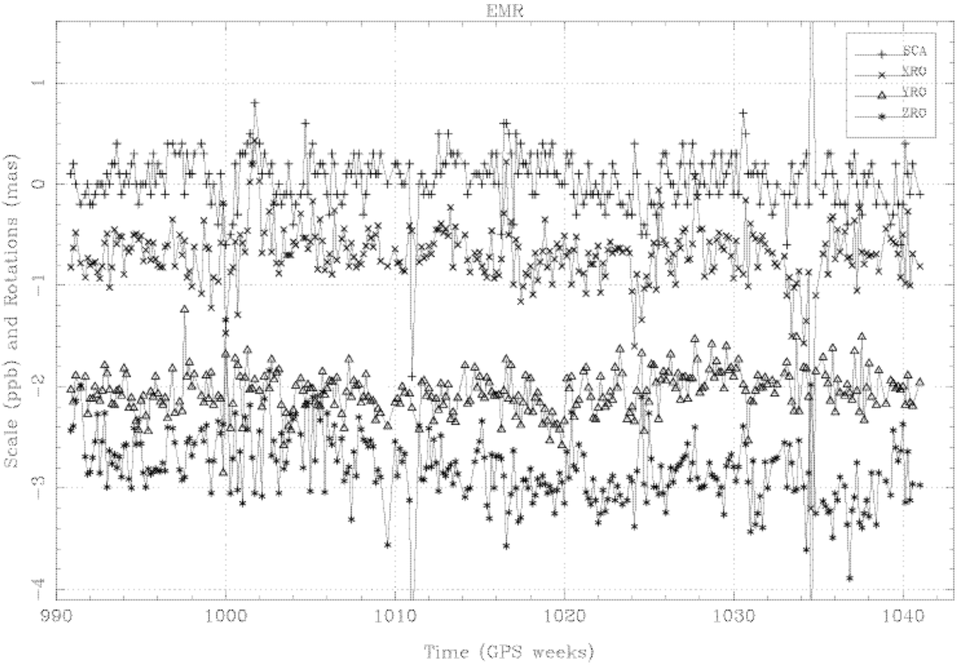


(b) Scale and Rotations (X, Y, and Z)

Figure 11: Daily Transformation parameters of the AC Rapid orbits with respect to IGS Final orbits. Translations are shifted by 50 mm, rotations are shifted by 1 mas.

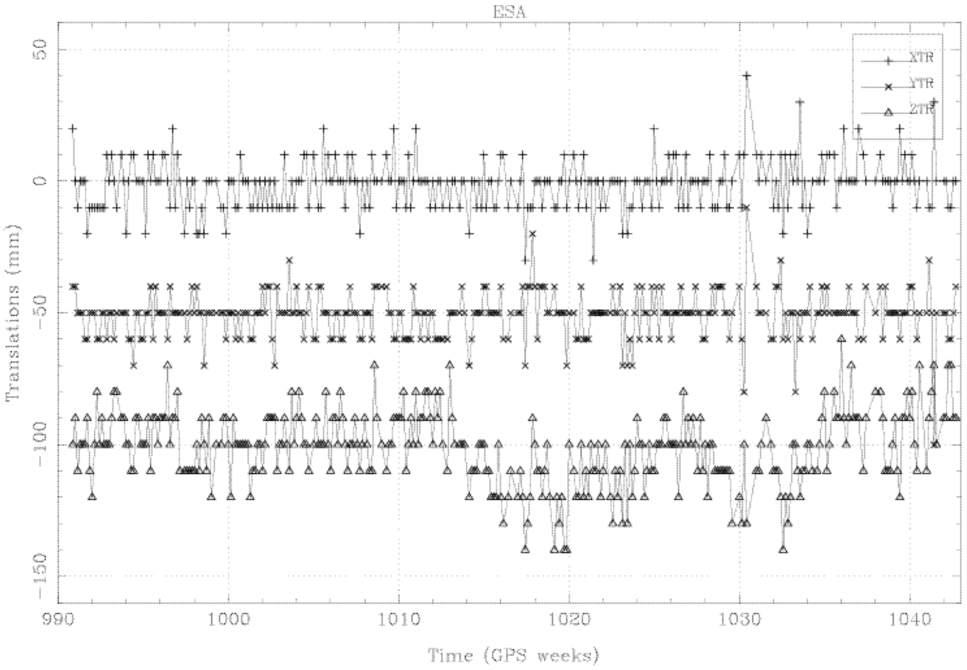


(a) Translations (X, Y, and Z)

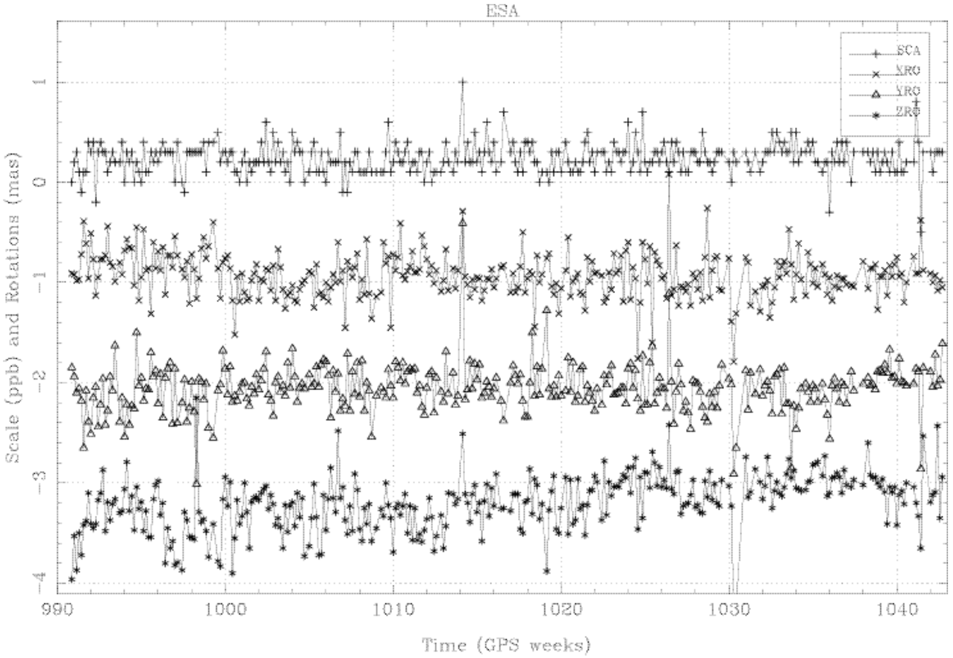


(b) Scale and Rotations (X, Y, and Z)

Figure 12: Daily Transformation parameters of the AC Rapid orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

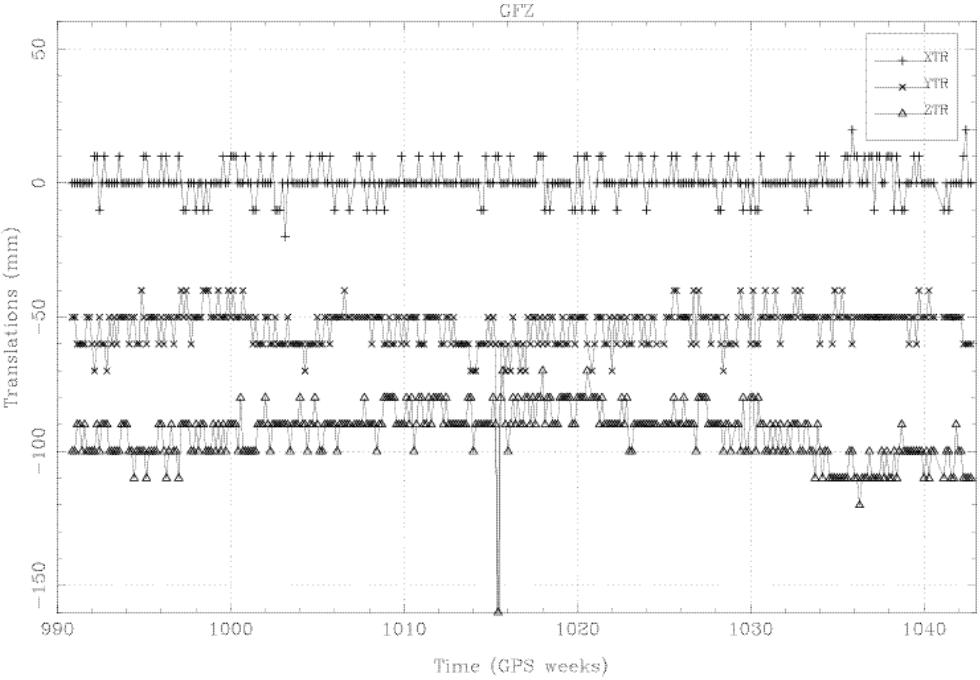


(a) Translations (X, Y, and Z)

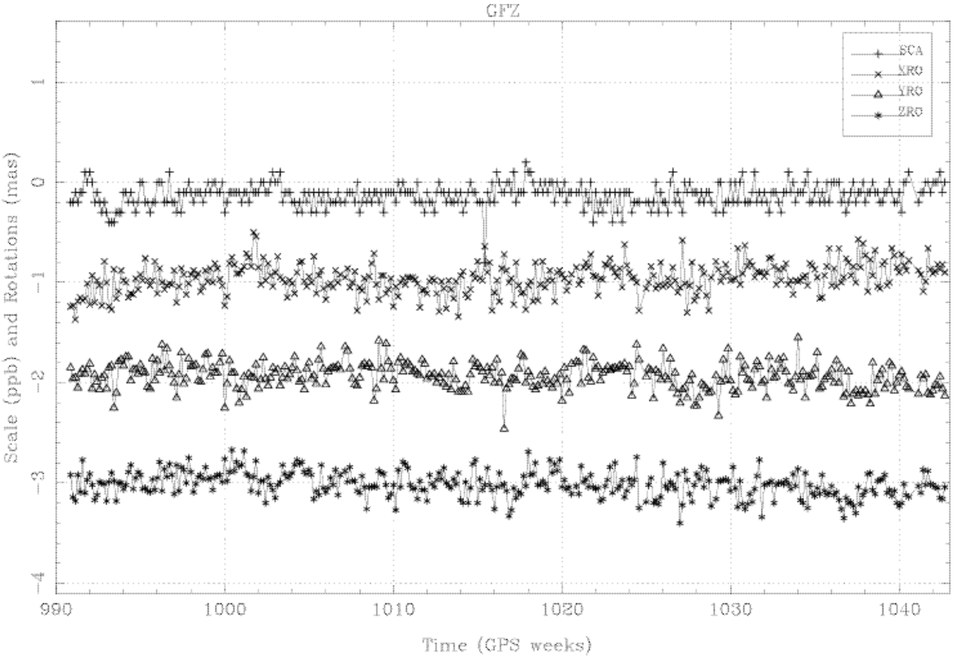


(b) Scale and Rotations (X, Y, and Z)

Figure 13: Daily Transformation parameters of the AC Rapid orbits with respect to IGS Final orbits. Translations are shifted by 50 mm, rotations are shifted by 1 mas.

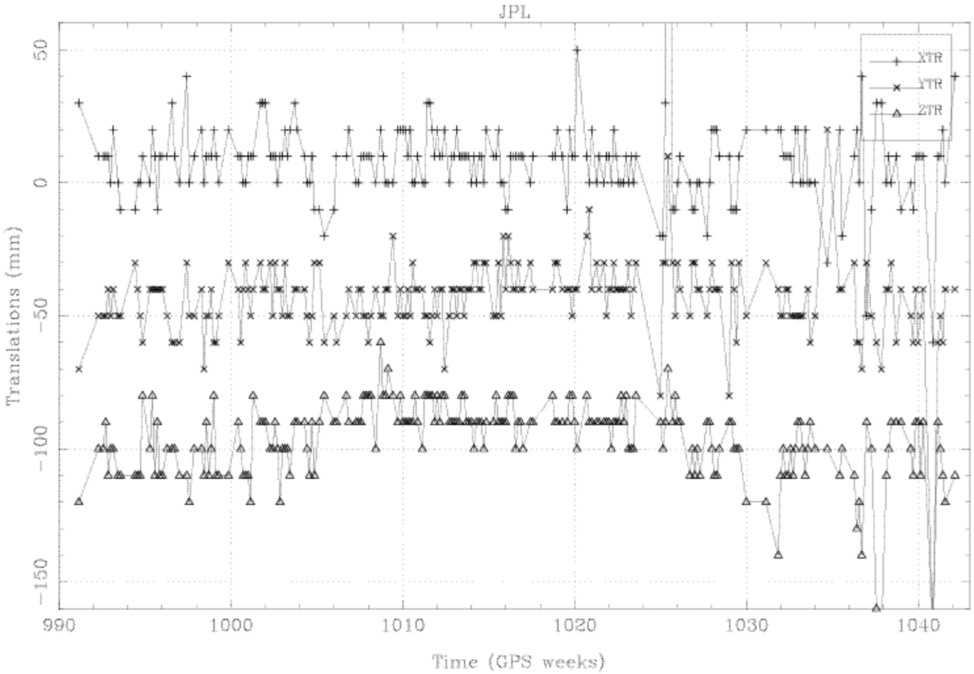


(a) Translations (X, Y, and Z)

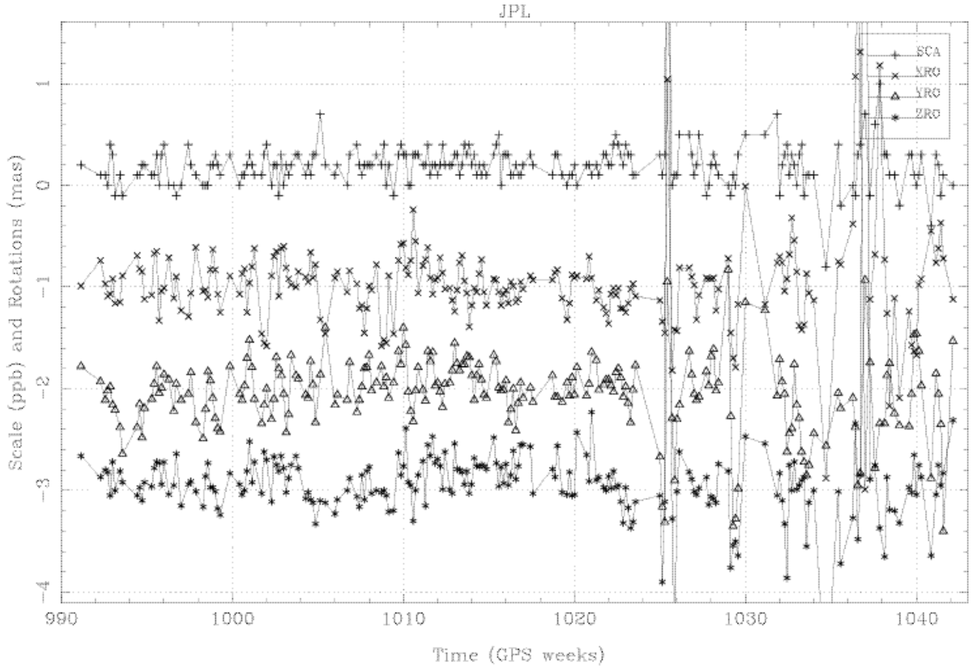


(b) Scale and Rotations (X, Y, and Z)

Figure 14: Daily Transformation parameters of the AC Rapid orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

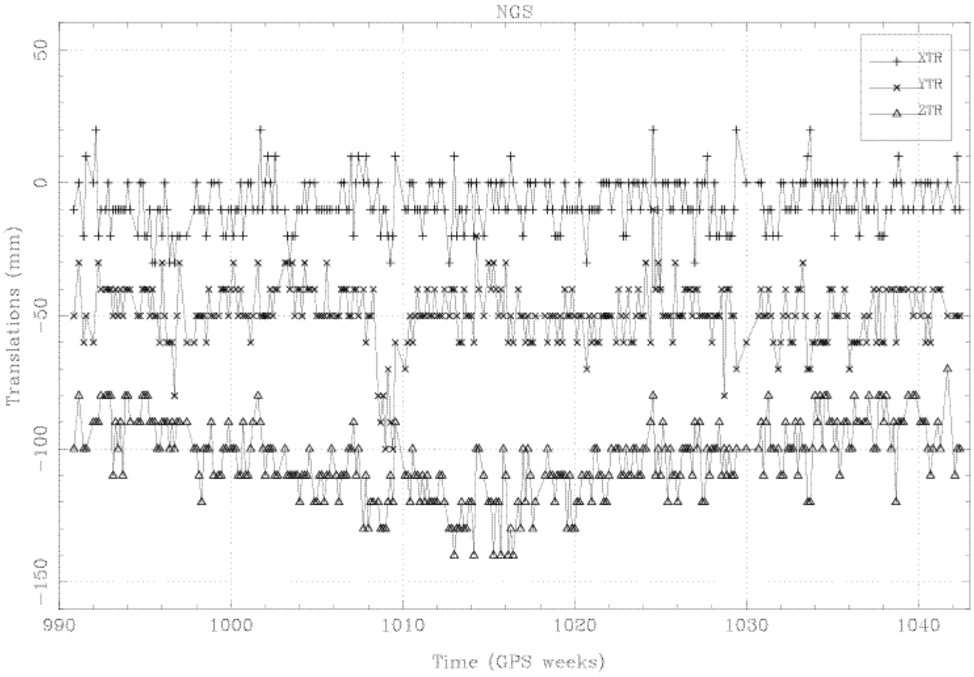


(a) Translations (X, Y, and Z)

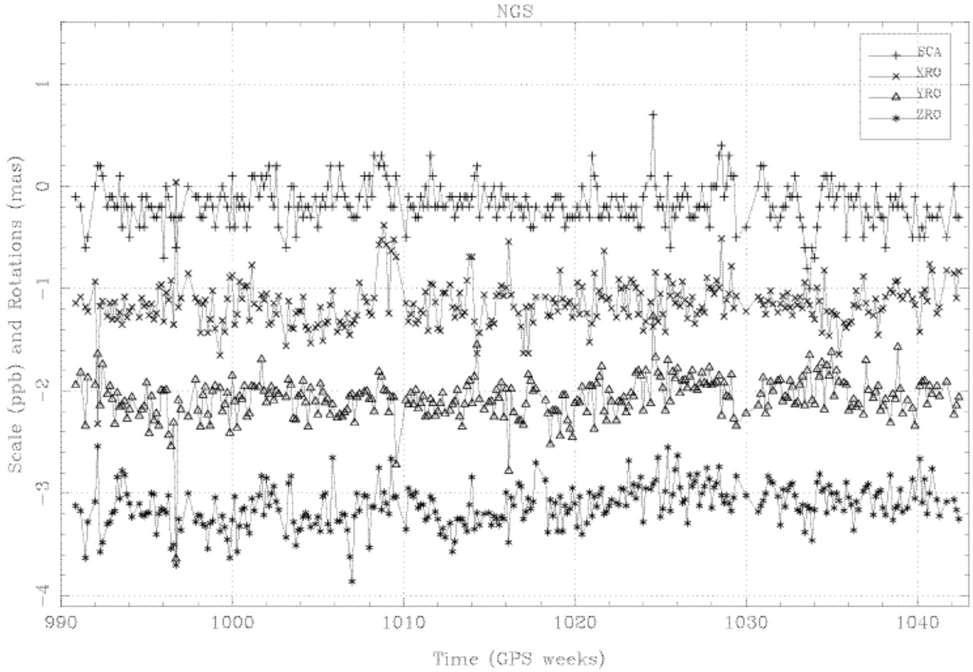


(b) Scale and Rotations (X, Y, and Z)

Figure 15: Daily Transformation parameters of the AC Rapid orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

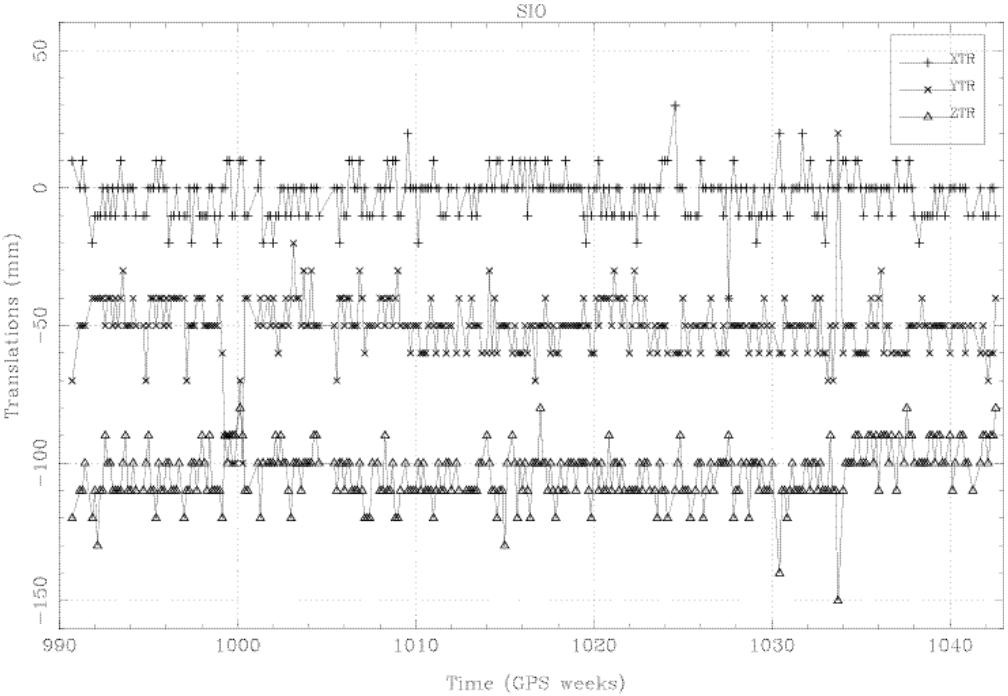


(a) Translations (X, Y, and Z)

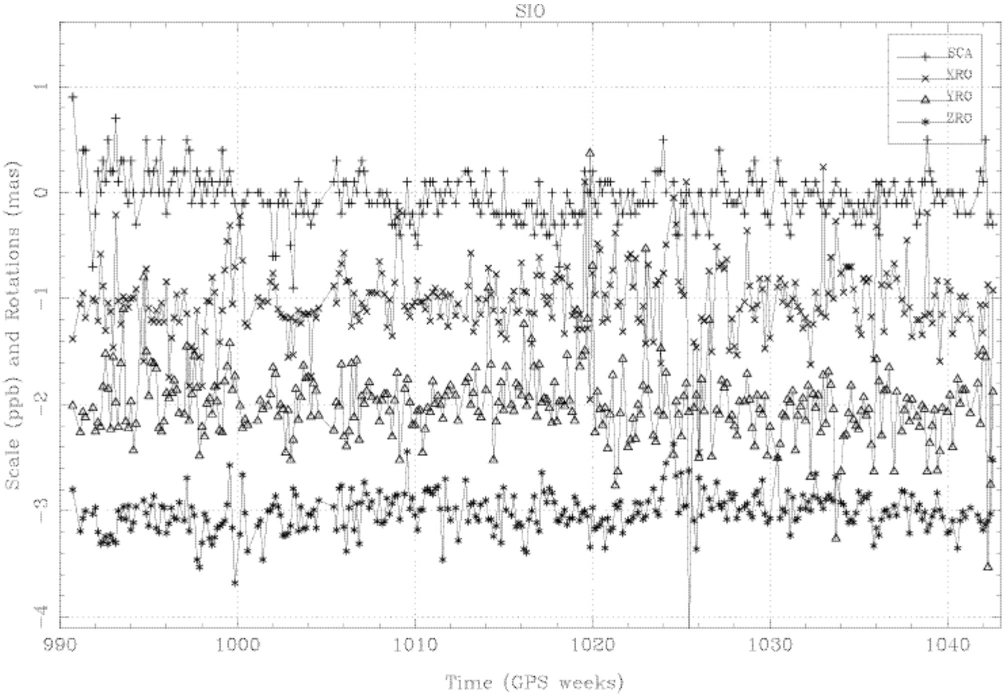


(b) Scale and Rotations (X, Y, and Z)

Figure 16: Daily Transformation parameters of the AC Rapid orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

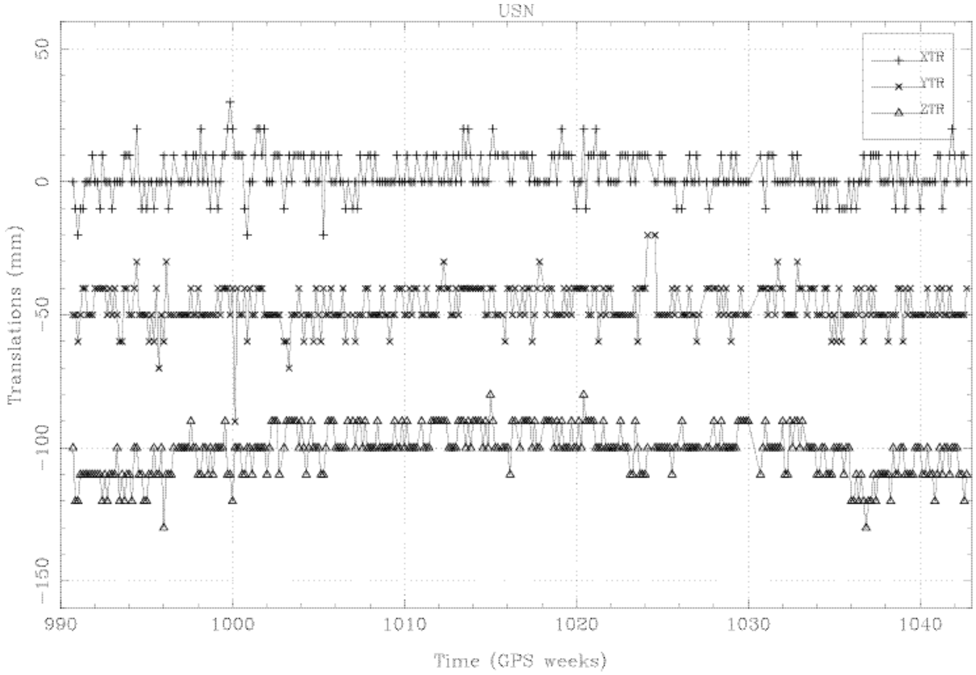


(a) Translations (X, Y, and Z)

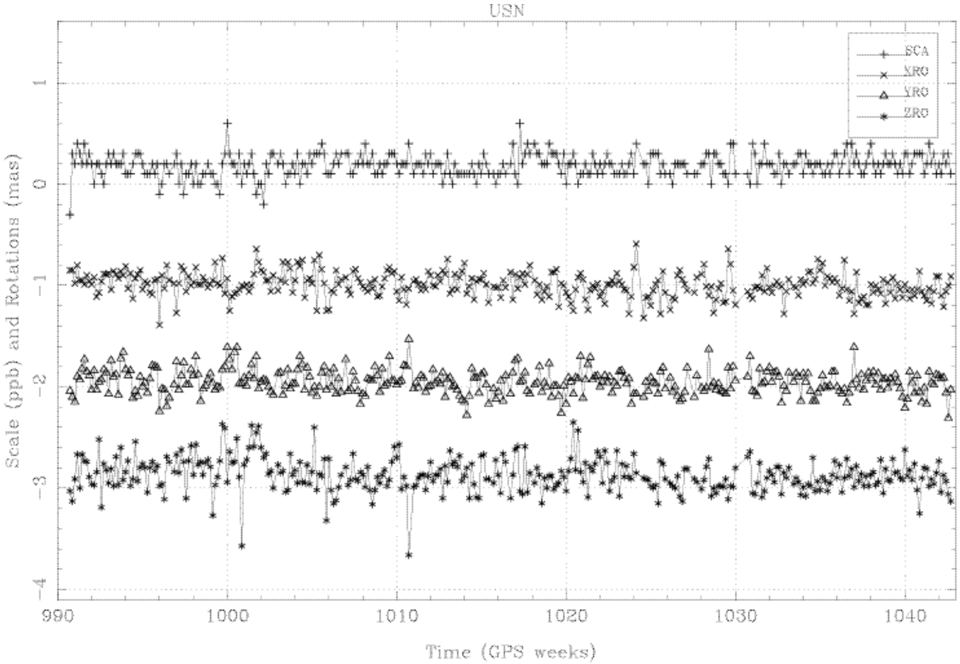


(b) Scale and Rotations (X, Y, and Z)

Figure 17: Daily Transformation parameters of the AC Rapid orbits with respect to IGS Final orbits. Translations are shifted by 50 mm, rotations are shifted by 1 mas.

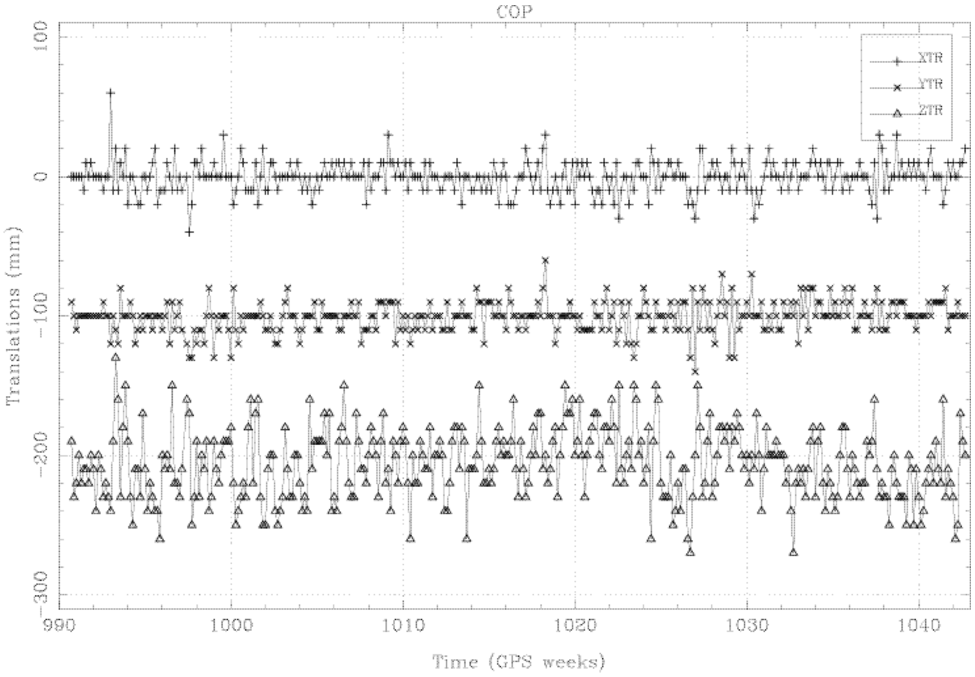


(a) Translations (X, Y, and Z)

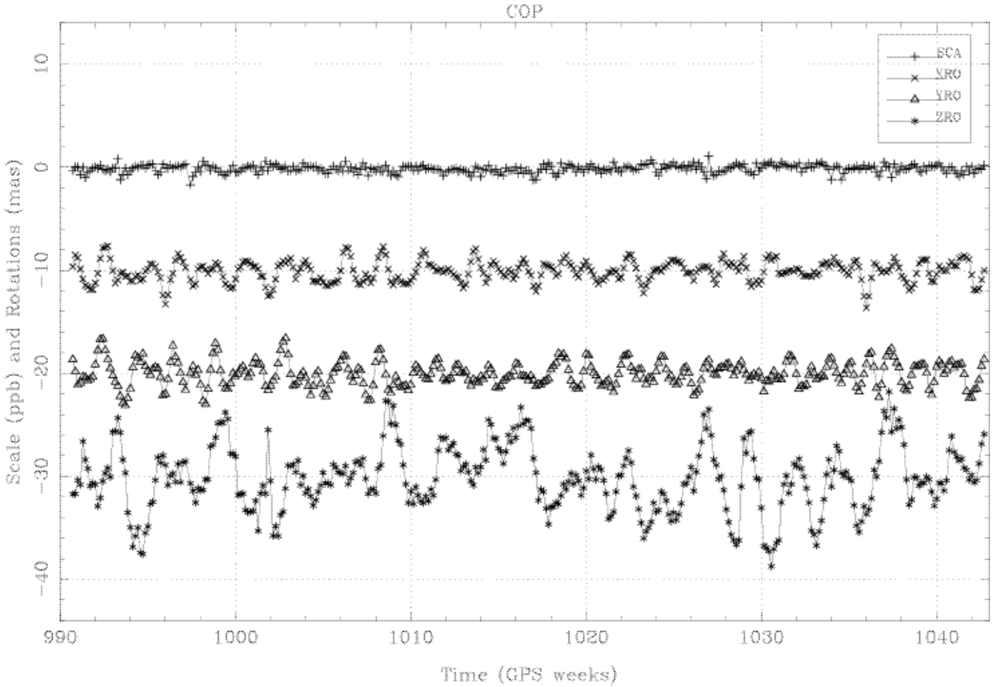


(b) Scale and Rotations (X, Y, and Z)

Figure 18: Daily Transformation parameters of the AC Rapid orbits
with respect to IGS Final orbits.
Translations are shifted by 50 mm, rotations are shifted by 1 mas.

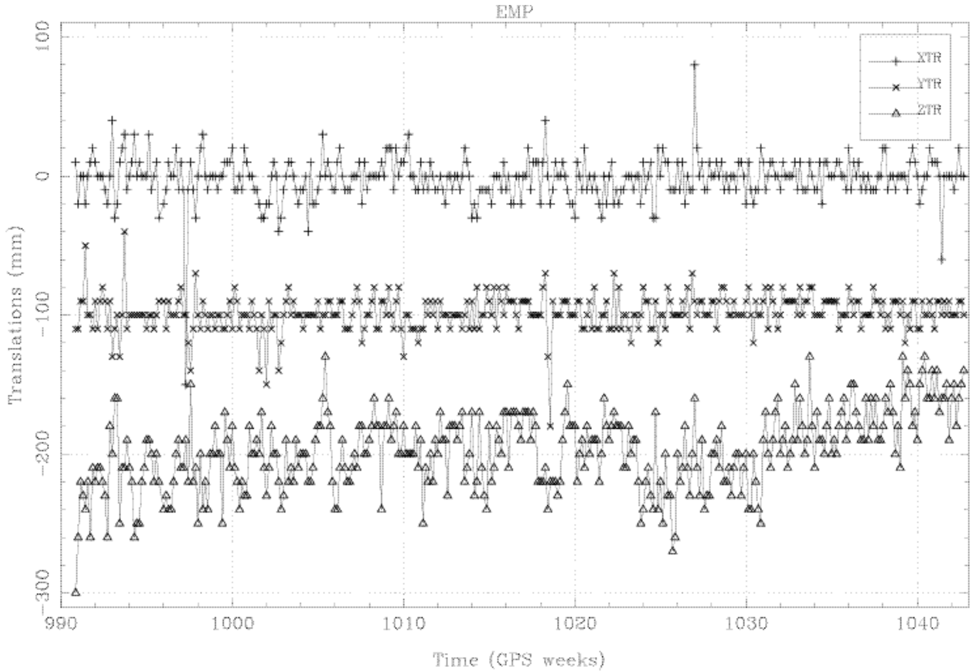


(a) Translations (X, Y, and Z)

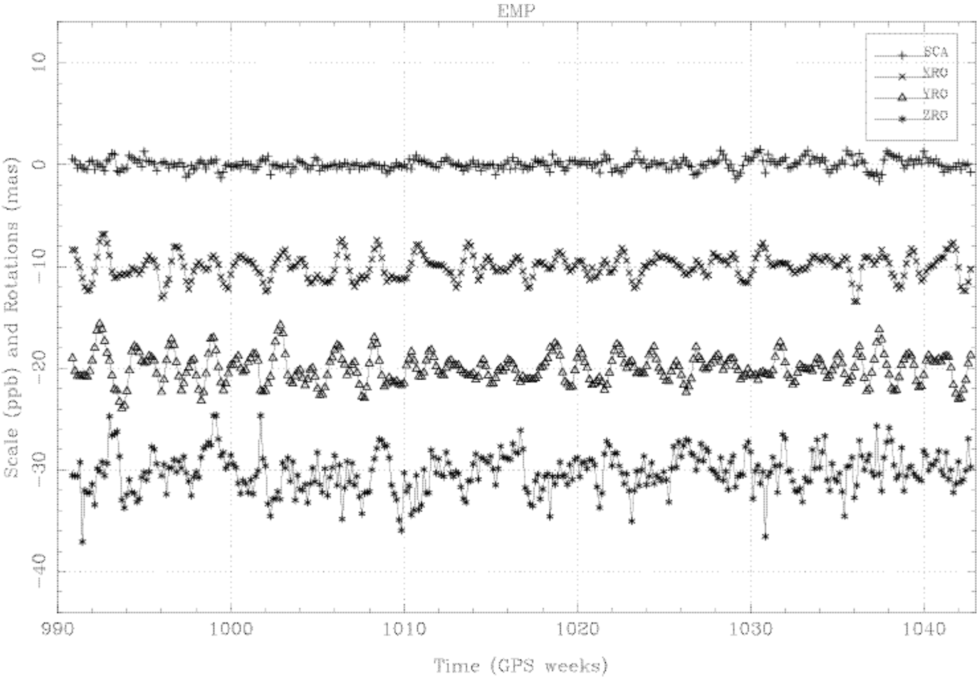


(b) Scale and Rotations (X, Y, and Z)

Figure 19: Daily Transformation parameters of the AC Predicted orbits with respect to IGS Rapid orbits. Translations are shifted by 100 mm, rotations are shifted by 10 mas.

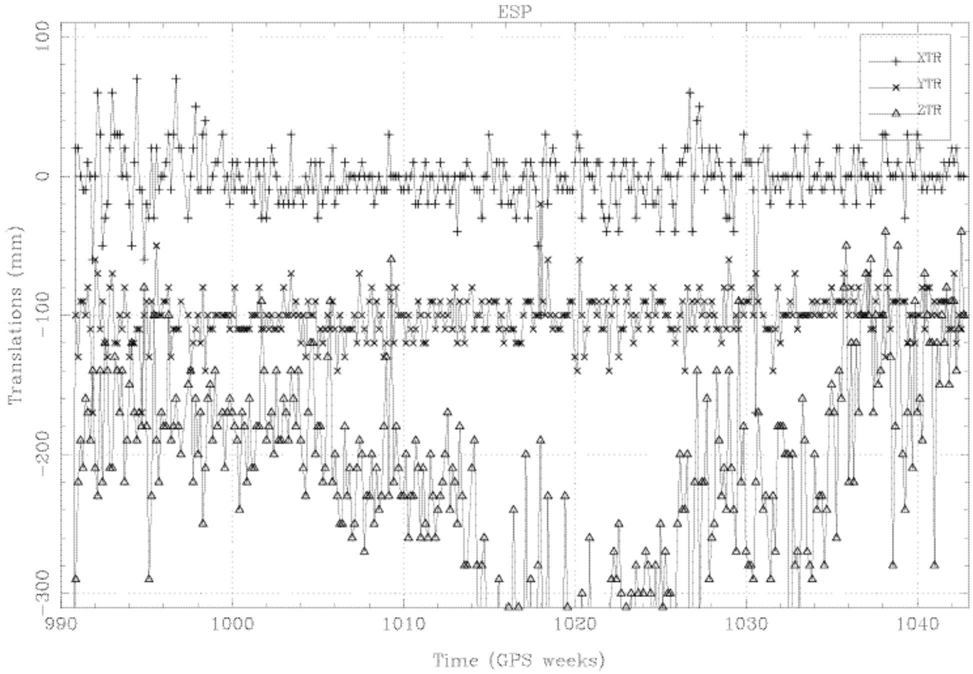


(a) Translations (X, Y, and Z)

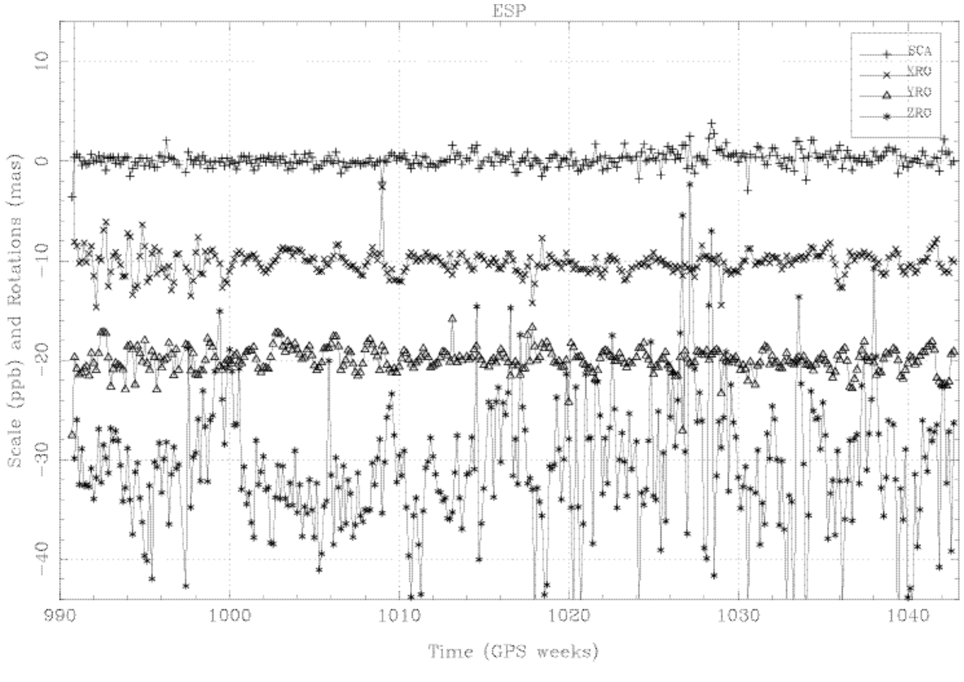


(b) Scale and Rotations (X, Y, and Z)

Figure 20: Daily Transformation parameters of the AC Predicted orbits
with respect to IGS Rapid orbits.
Translations are shifted by 100 mm, rotations are shifted by 10 mas.

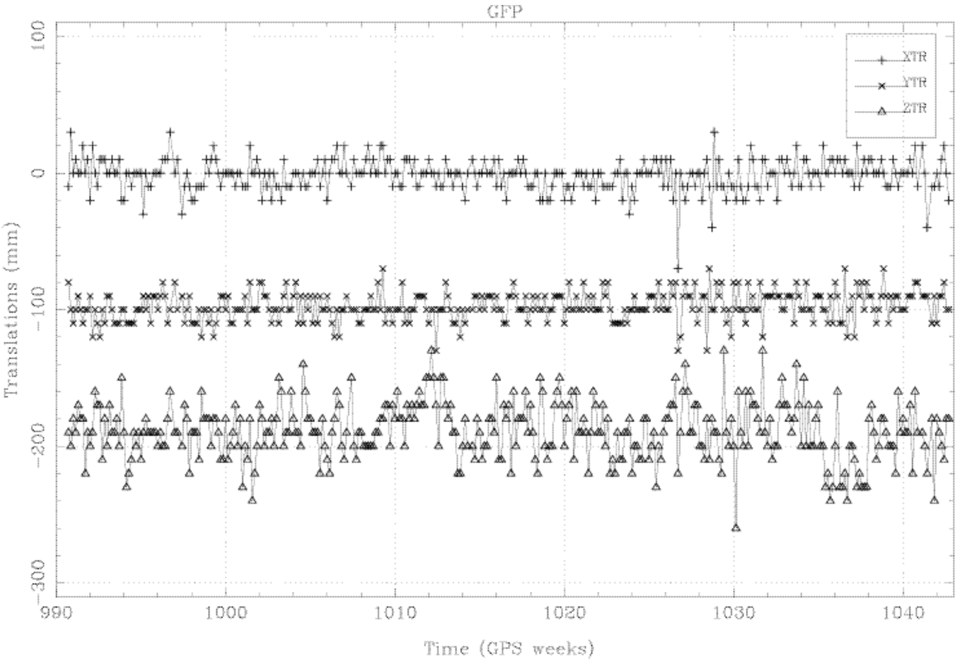


(a) Translations (X, Y, and Z)

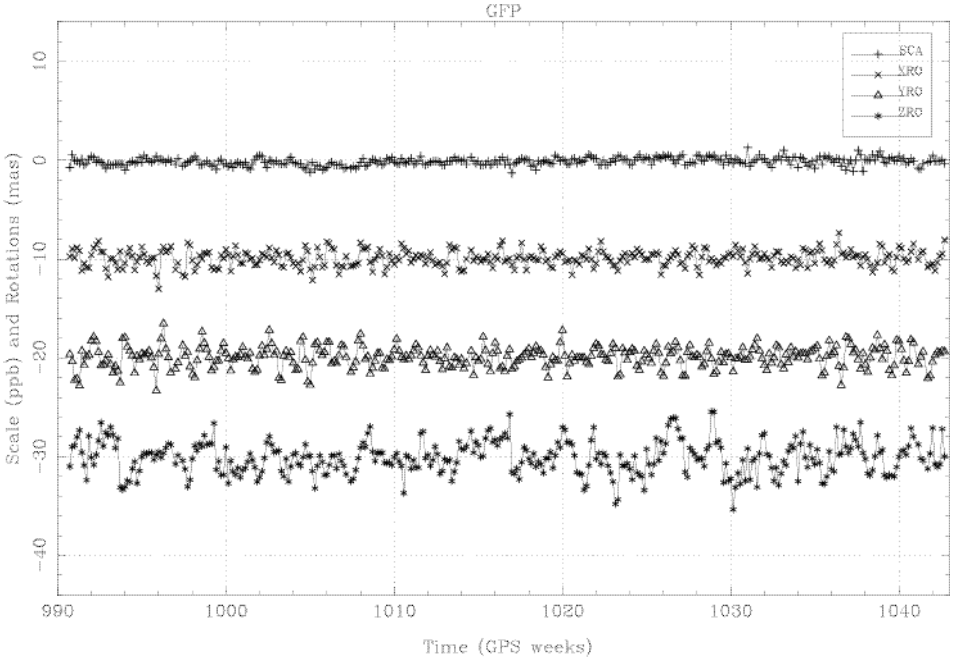


(b) Scale and Rotations (X, Y, and Z)

Figure 21: Daily Transformation parameters of the AC Predicted orbits with respect to IGS Rapid orbits. Translations are shifted by 100 mm, rotations are shifted by 10 mas.

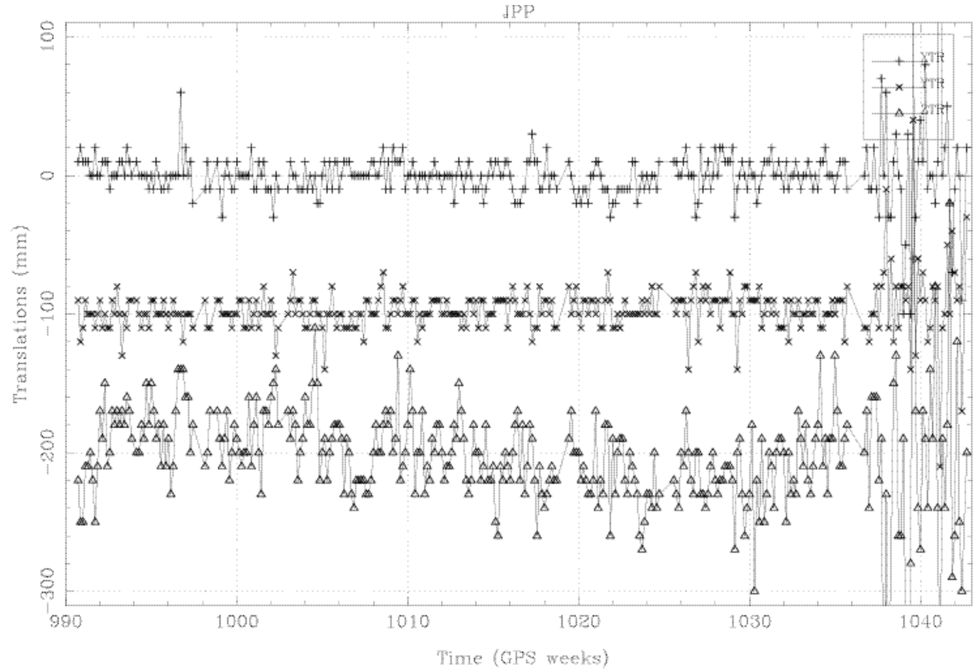


(a) Translations (X, Y, and Z)

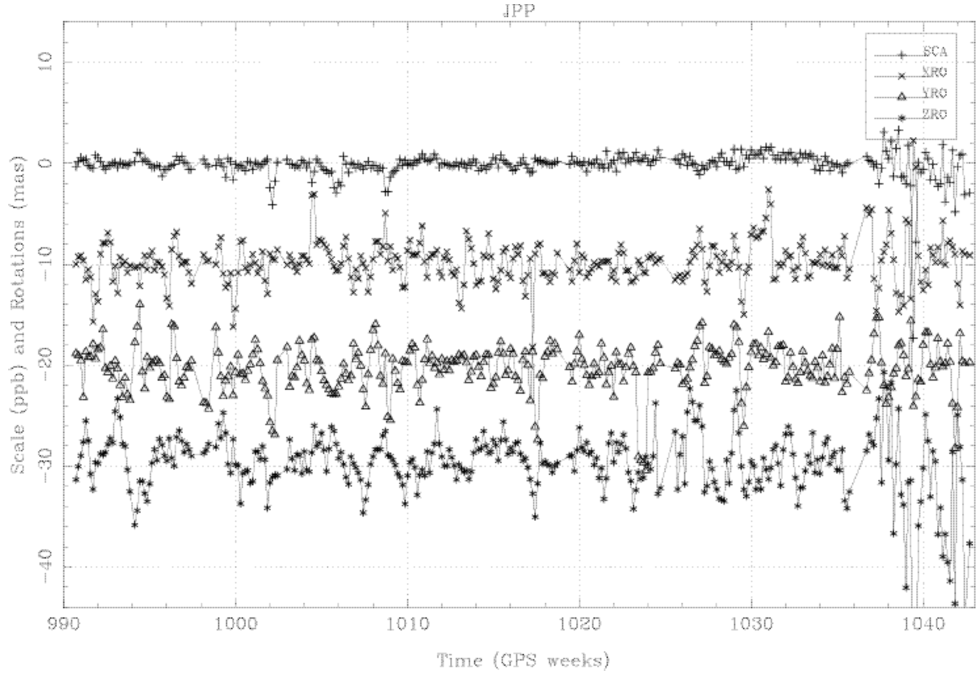


(b) Scale and Rotations (X, Y, and Z)

Figure 22: Daily Transformation parameters of the AC Predicted orbits with respect to IGS Rapid orbits. Translations are shifted by 100 mm, rotations are shifted by 10 mas.

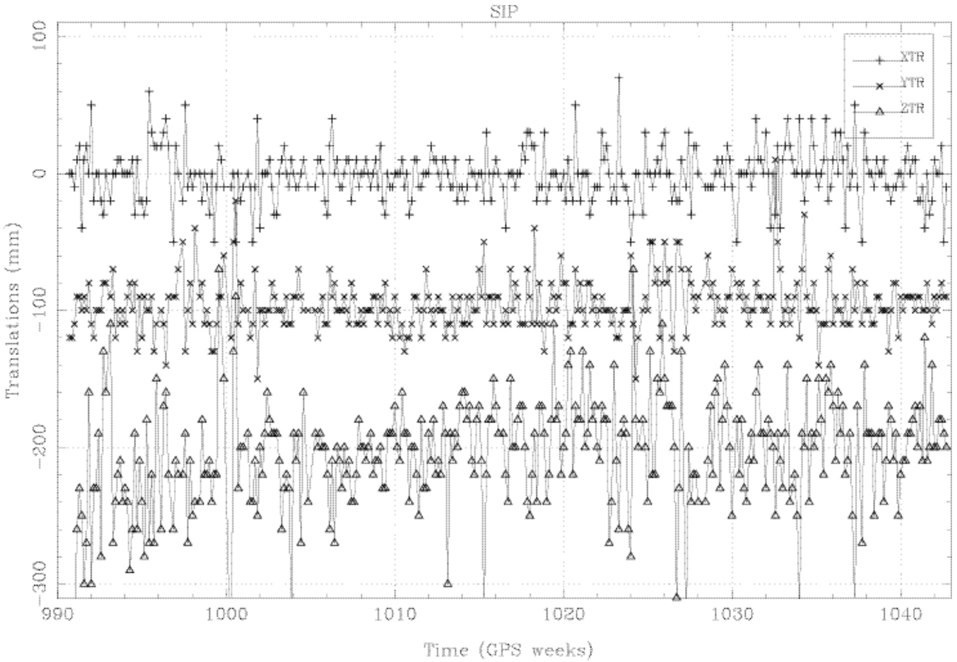


(a) Translations (X, Y, and Z)

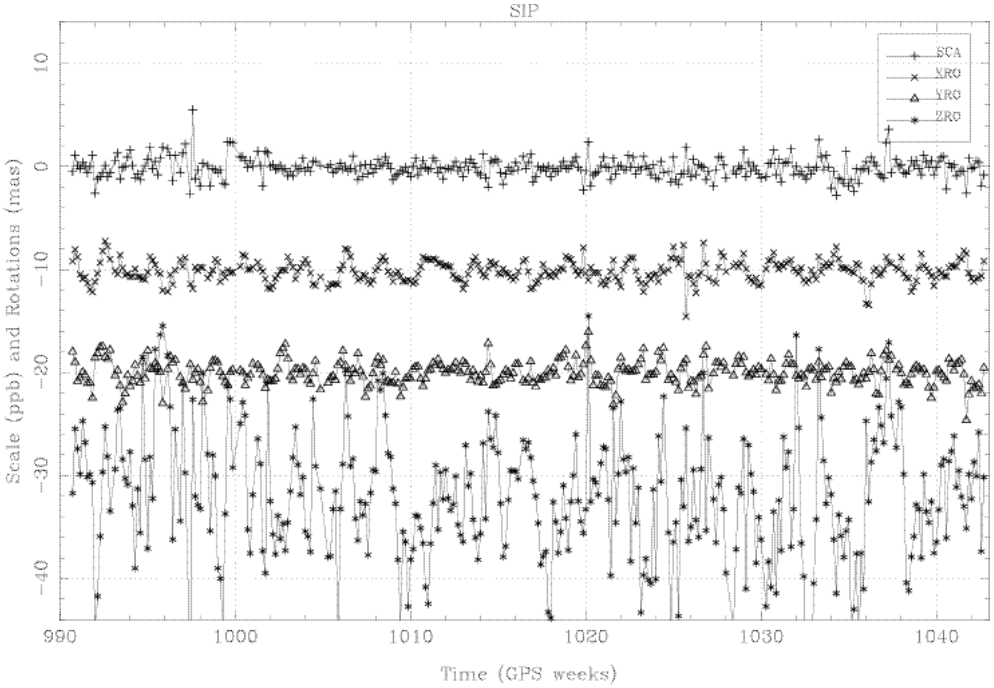


(b) Scale and Rotations (X, Y, and Z)

Figure 23: Daily Transformation parameters of the AC Predicted orbits
with respect to IGS Rapid orbits.
Translations are shifted by 100 mm, rotations are shifted by 10 mas.

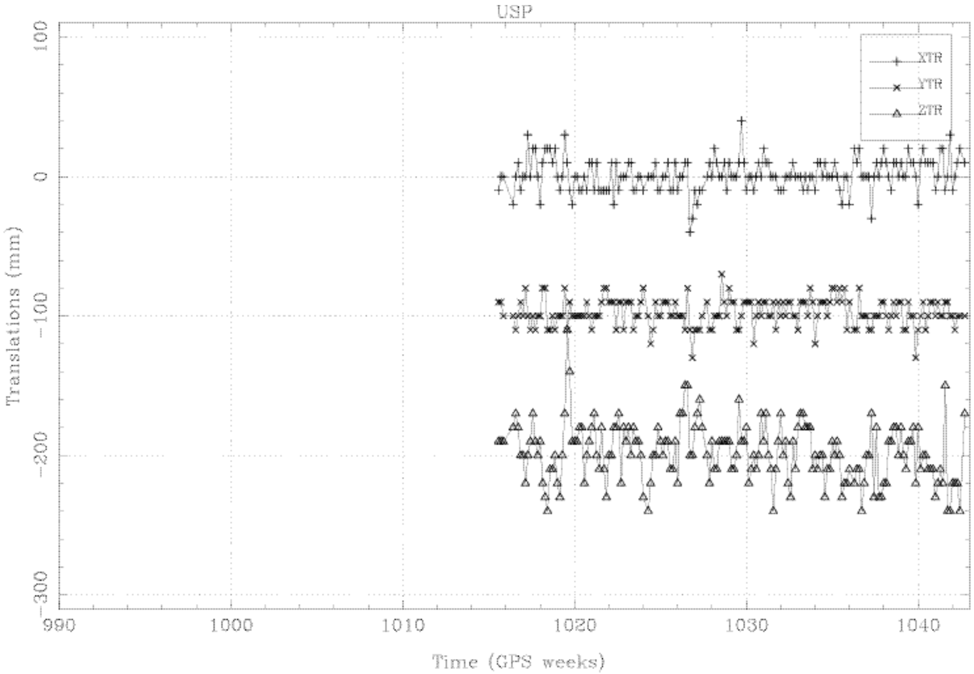


(a) Translations (X, Y, and Z)

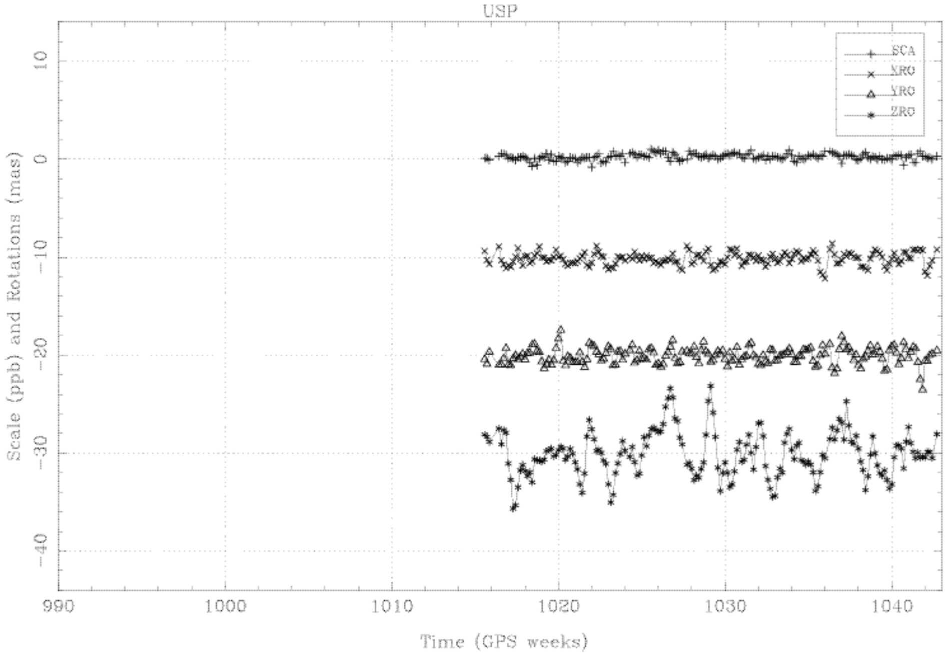


(b) Scale and Rotations (X, Y, and Z)

Figure 24: Daily Transformation parameters of the AC Predicted orbits
with respect to IGS Rapid orbits.
Translations are shifted by 100 mm, rotations are shifted by 10 mas.

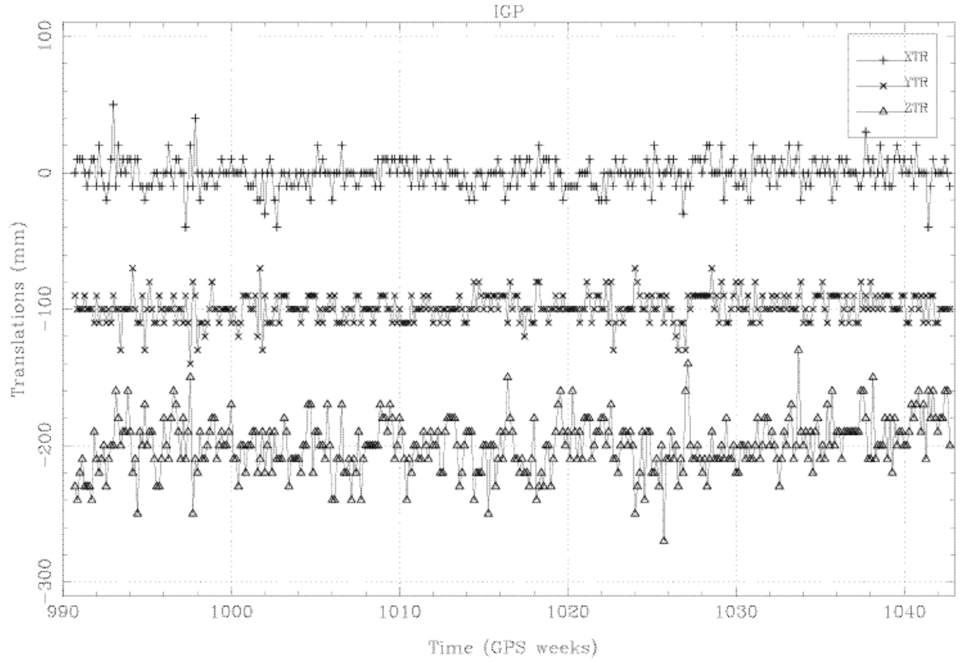


(a) Translations (X, Y, and Z)

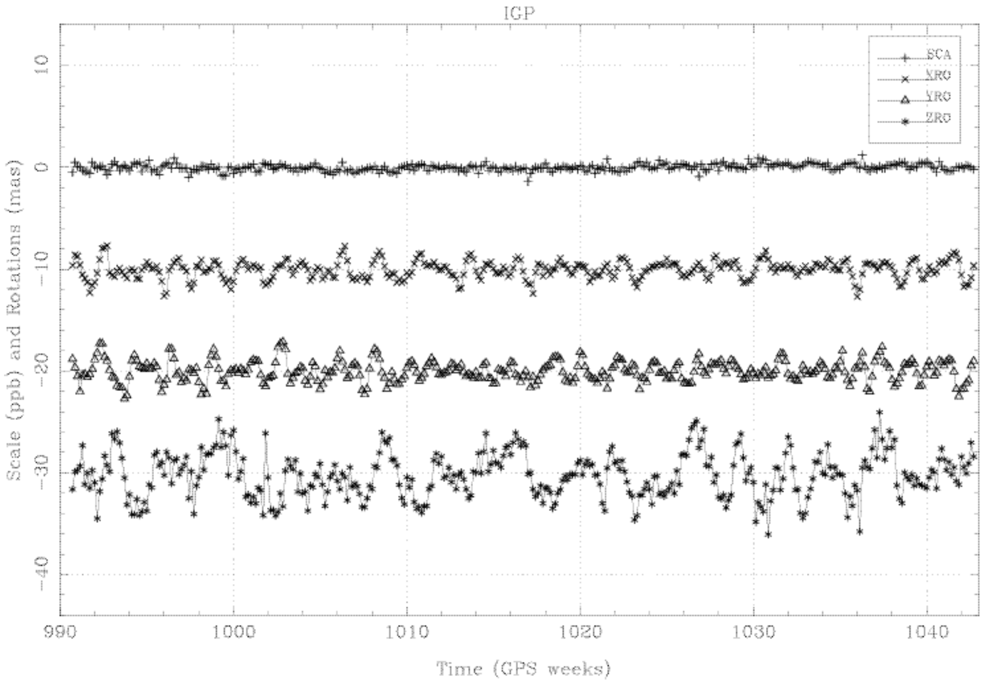


(b) Scale and Rotations (X, Y, and Z)

Figure 25: Daily Transformation parameters of the AC Predicted orbits with respect to IGS Rapid orbits. Translations are shifted by 100 mm, rotations are shifted by 10 mas.

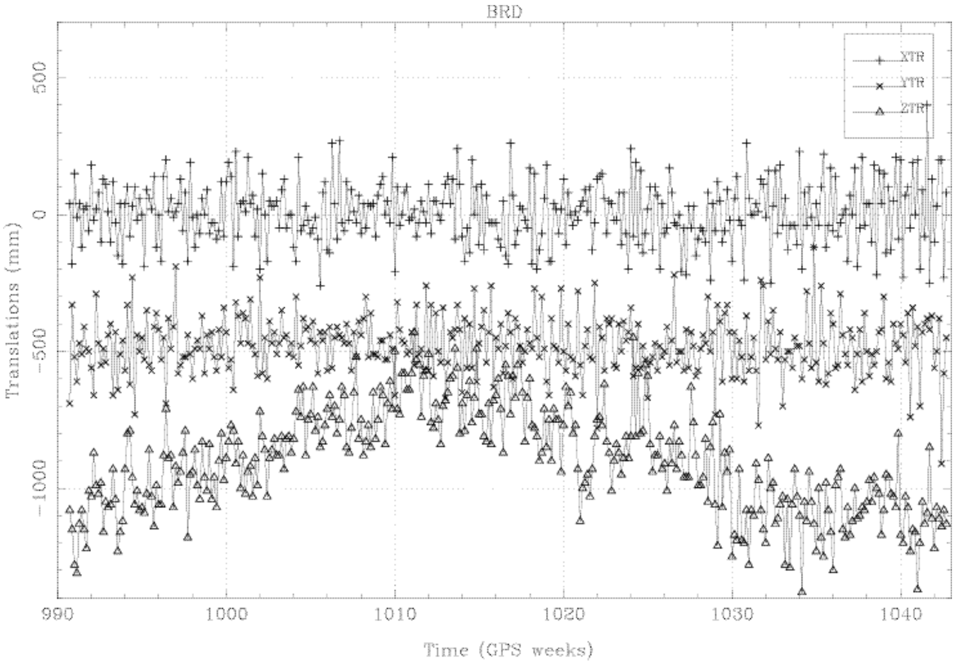


(a) Translations (X, Y, and Z)

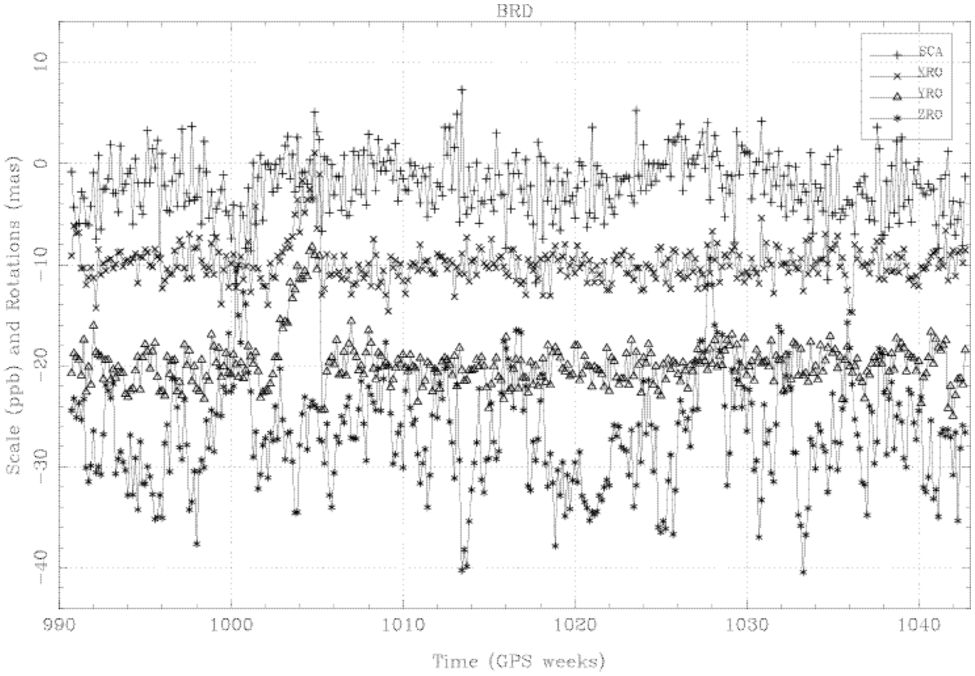


(b) Scale and Rotations (X, Y, and Z)

Figure 26: Daily Transformation parameters of the IGS Predicted orbits with respect to IGS Rapid orbits. Translations are shifted by 100 mm, rotations are shifted by 10 mas.

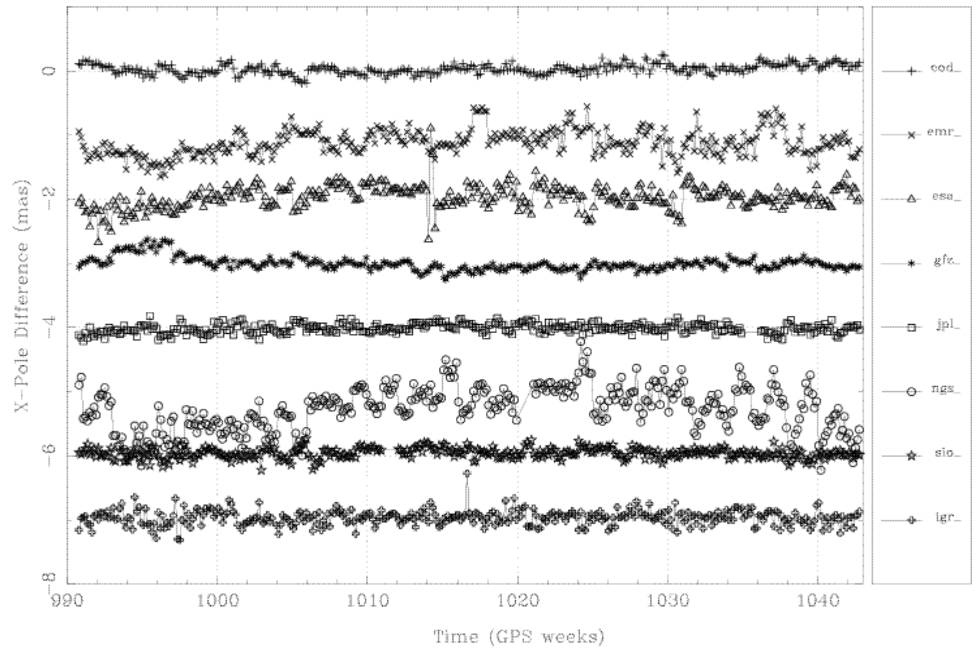


(a) Translations (X, Y, and Z)

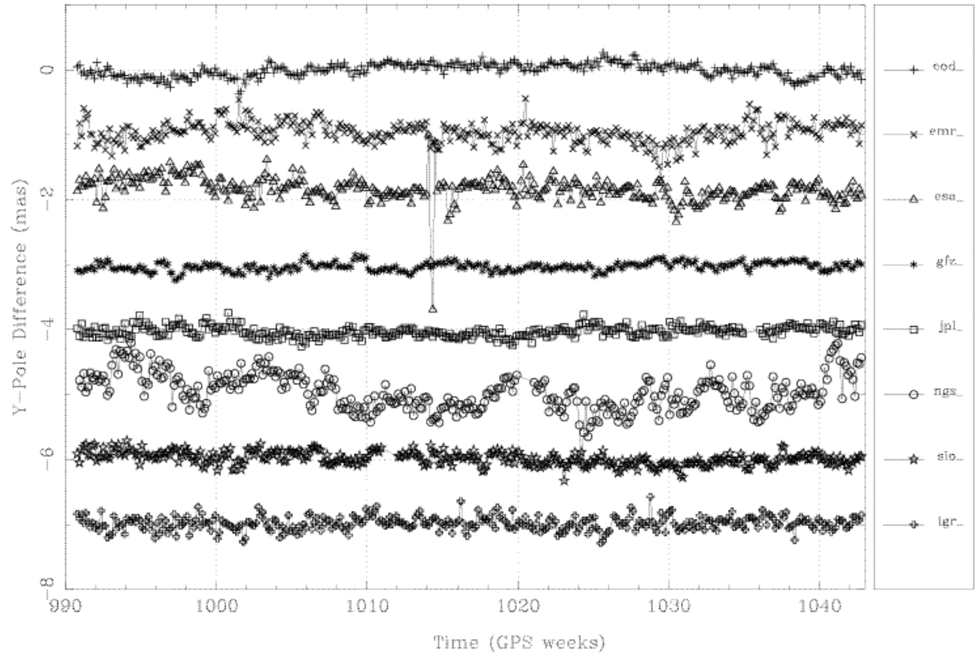


(b) Scale and Rotations (X, Y, and Z)

Figure 27: Daily Transformation parameters of the broadcast orbits
with respect to IGS Rapid orbits.
Translations are shifted by 500 mm, rotations are shifted by 10 mas.

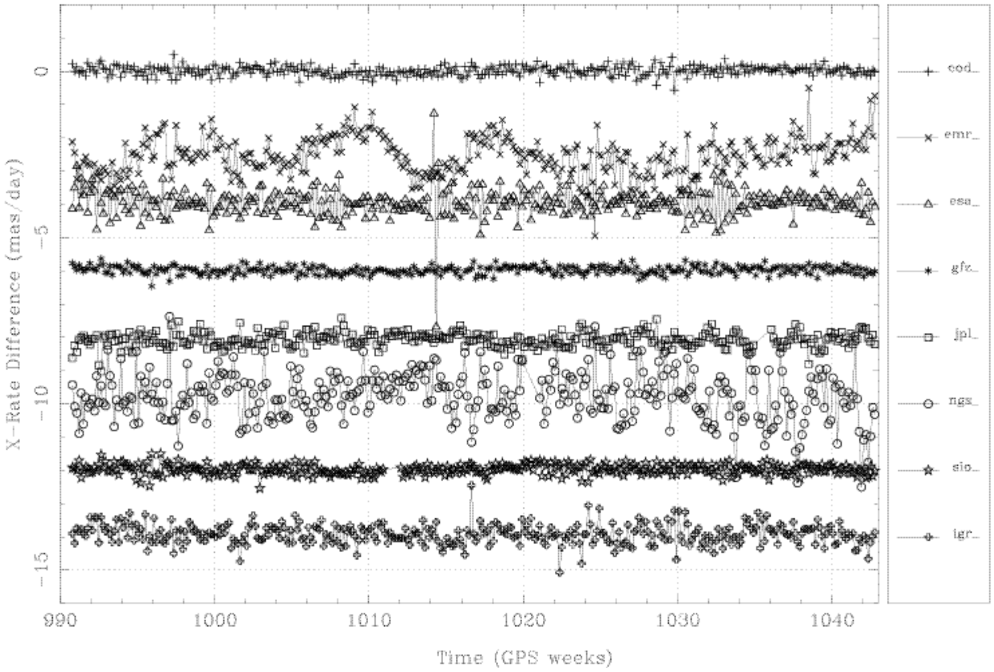


(a) X-Pole

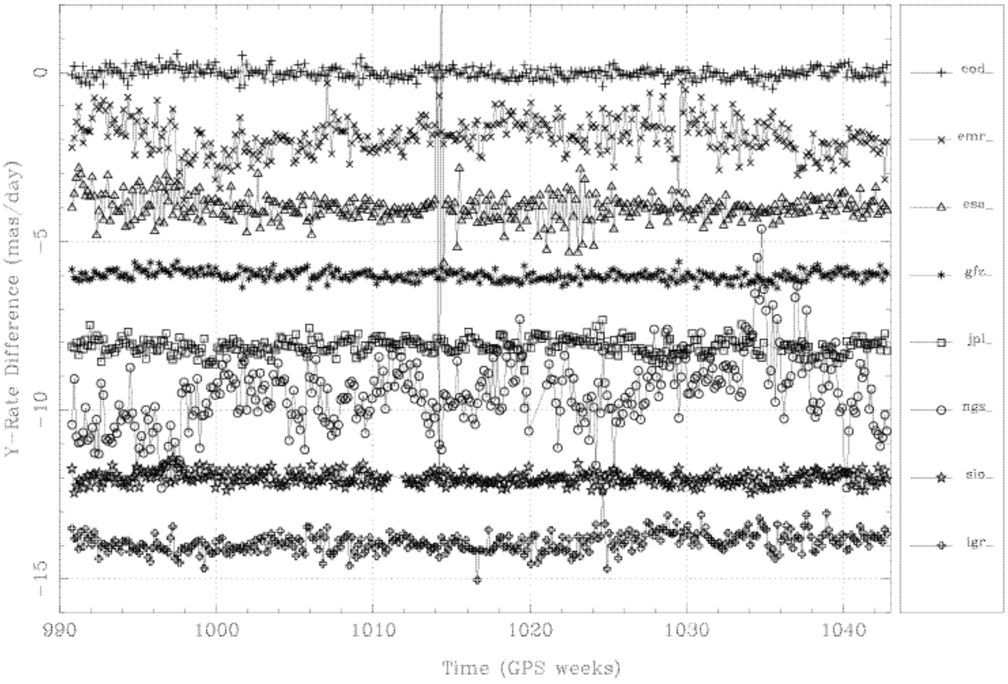


(b) Y-Pole

Figure 28: Daily AC Final Pole differences with respect to IGS Final pole.
ACs are shifted by 1 mas.

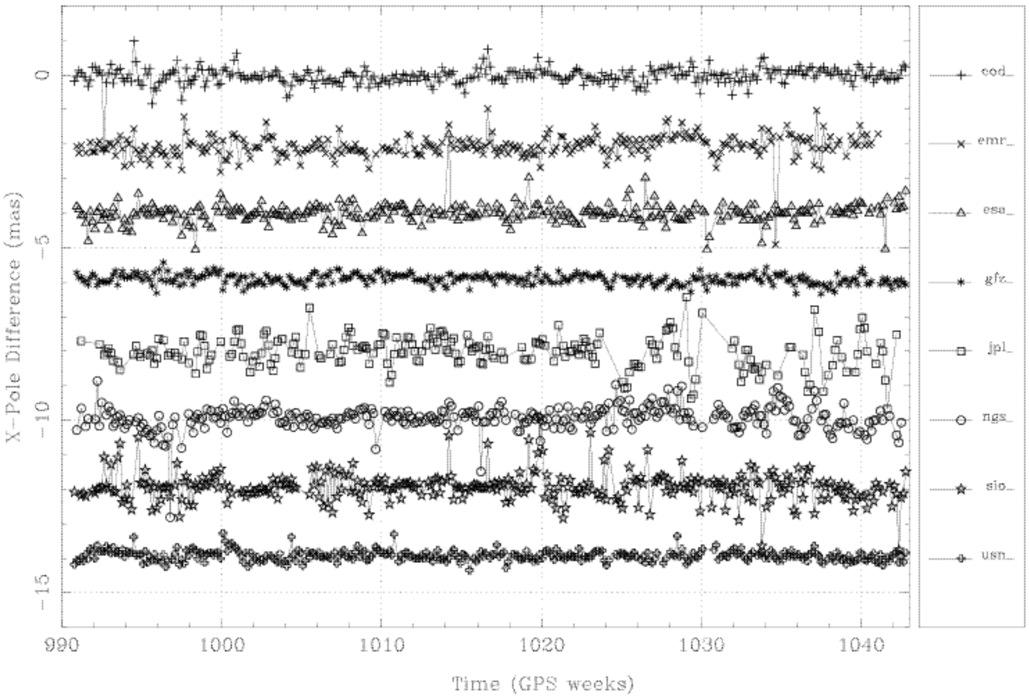


(a) X-Rate

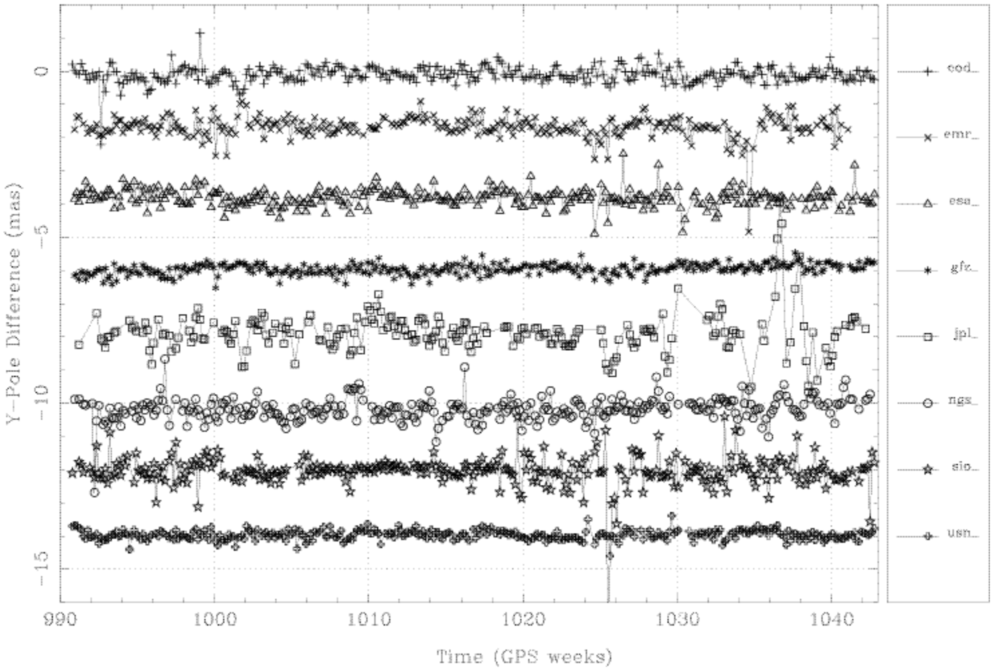


(b) Y-Rate

Figure 29: Daily AC Final Pole-rate differences with respect to IGS Final pole.
ACs are shifted by 2 mas/day.

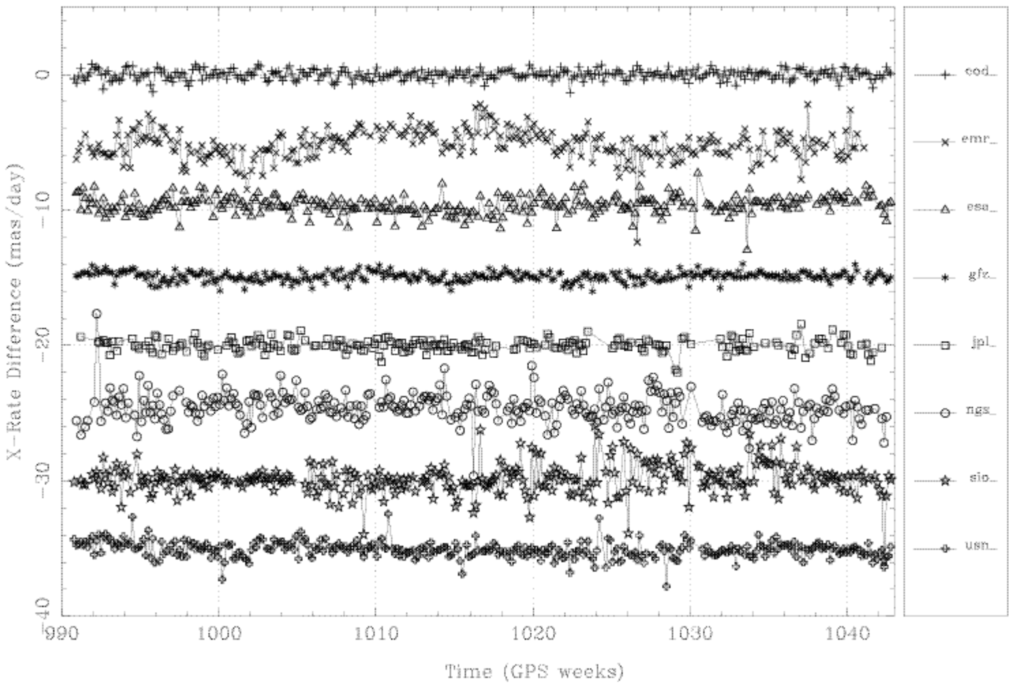


(a) X-Pole

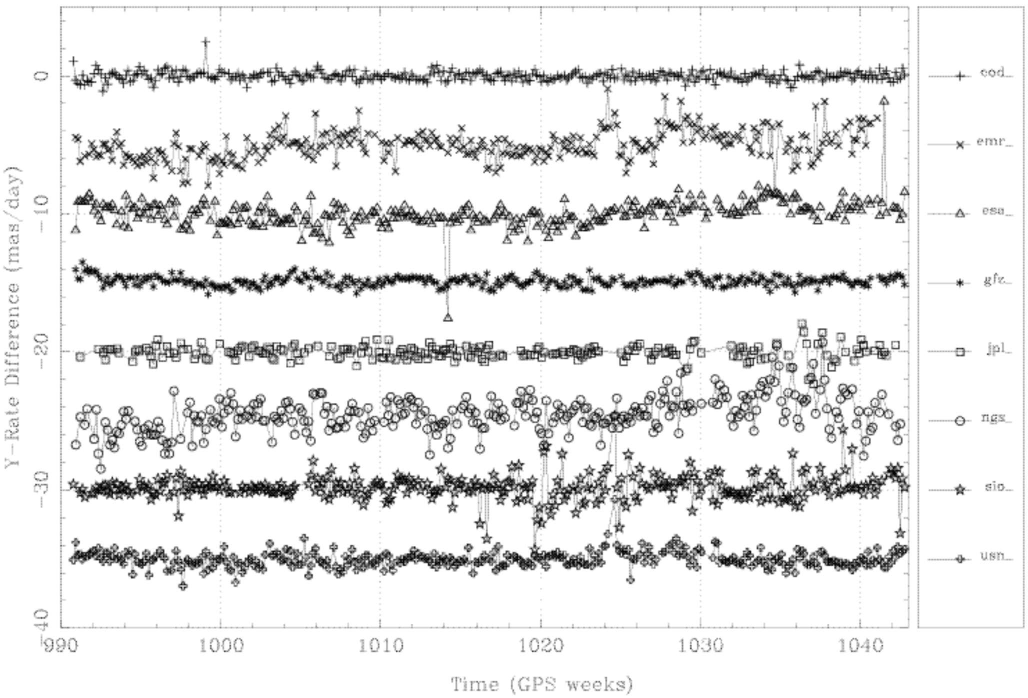


(b) Y-Pole

Figure 30: Daily AC Rapid Pole differences with respect to IGS Final pole. ACs are shifted by 2 mas.

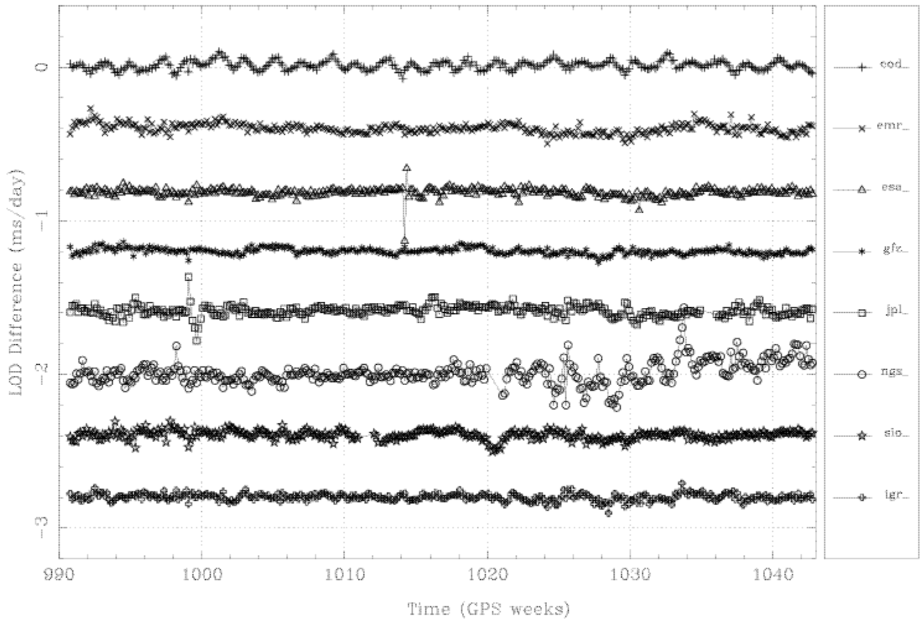


(a) X-Rate

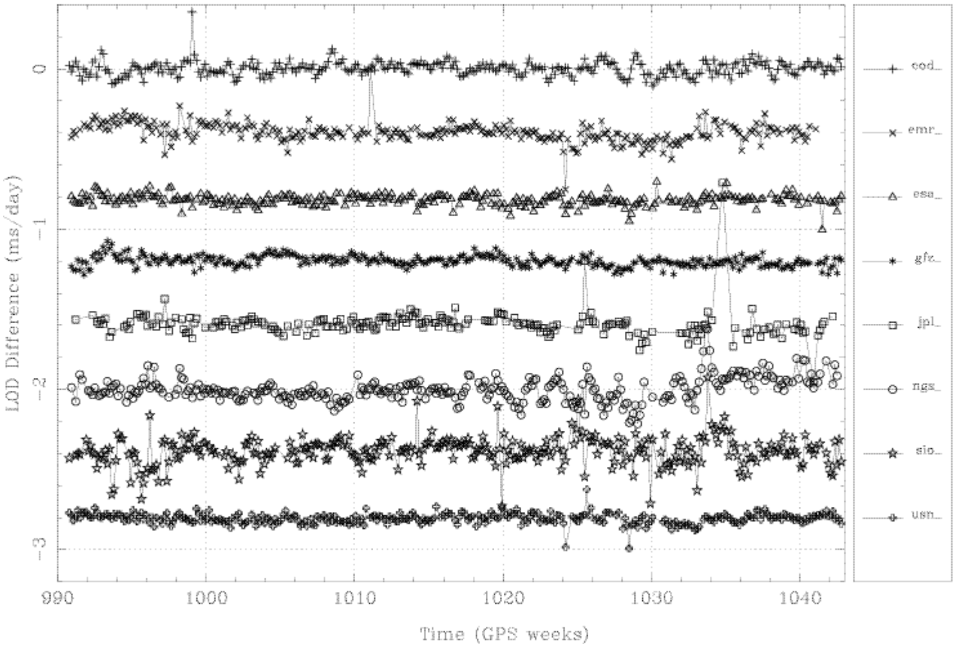


(b) Y-Rate

Figure 31: Daily AC Rapid Pole-rate differences with respect to IGS Final pole.
ACs are shifted by 5 mas/day.



(a) Final LOD



(b) Rapid LOD

Figure 32: Daily AC LOD differences with respect to IGS Final pole.
ACs are shifted by 0.4 ms/d.

IGS

ANALYSIS CENTERS

CODE IGS Analysis Center Technical Report 1999

U. Hugentobler, T. Springer, S. Schaer, G. Beutler, H. Bock,
R. Dach, D. Ineichen, L. Mervart, M. Rothacher[1]
Astronomical Institute, University of Bern

U. Wild, A. Wiget, E. Brockmann
Federal Office of Topography, Wabern

G. Weber, H. Habrich
Bundesamt für Kartographie und Geodäsie, Frankfurt

C. Boucher
Institut Géographique National, Paris

Introduction

CODE, the Center for Orbit Determination in Europe, is a joint venture of the following four institutions:

- the Federal Office of Topography (L+T), Wabern, Switzerland,
- the Federal Agency of Cartography and Geodesy (BKG), Frankfurt, Germany,
- the Institut Géographique National (IGN), Paris, France, and
- the Astronomical Institute of the University of Berne (AIUB), Berne, Switzerland.

CODE is located at the AIUB. Special emphasis lays on Europe, as reflected by the following facts:

- About one third of the sites included in the global CODE solutions are European sites. This should guarantee that the CODE orbits are of best possible quality over Europe.
- Separately a network of about 40 European sites is processed on a daily basis since day 204 (July 23), 1995, using different processing options. CODE is significantly contributing to the establishment and maintenance of the European Reference Frame (EUREF).

This report covers the time period from January to December 1999. It focuses on the major changes in the routine processing during this period and shows the new developments and products generated at CODE. The processing strategies used till December 1998 are described in the CODE annual reports of previous years [Rothacher et al., 1995, 1996, 1997, 1998, 1999].

Solutions Generated at CODE

All solutions and results are produced with the latest version of the Bernese GPS Software [Rothacher and Mervart, 1996] (currently version 4.3). Three major processing procedures are running every day: (1) the normal IGS processing to generate the CODE

---

[1] At the Technical University of Munich, Germany, since September 1999.

final products, (2) the rapid orbit solution, and (3) the computation of an European solution [Springer, 1999]. The procedures are running on the VMS alpha cluster of the computing services of the University of Bern.

The routine processing for the final products at CODE is performed as follows:

- In a first step the observations are downloaded from the global data center at IGN and the regional data center at BKG. If necessary, additional data files are transformed from CDDIS or SIO. For the solutions (except the ionosphere solution) the number of stations is limited to 100. If more stations are available, those with the maximum number of observations are selected.

- The data files are checked for outliers. Code single point positioning is performed for each station in order to synchronize the station clocks to GPS time. If available, the rapid orbits are used as a priori information for the final processing. For the rapid processing broadcast orbits are used.

- A first 1-day ambiguity-free solution (called G1) is generated. The solution is used to clean the double difference phase data.

- The procedure for the 3-day solutions starts with the computation of the global ionosphere models which are used for fixing the ambiguities in the subsequent step. Ambiguities are fixed on baselines shorter than 2000 km using the QIF strategy [Mervart, 1995]. On the average about 70% of the ambiguities can be fixed to integer values. This relatively low percentage is caused by the low elevation cut-off angle of 10 deg.

- After ambiguity fixing a new 1-day solution (called Q1) is generated. The global network is split up into three regions (clusters). Within each cluster the mathematical correlations of all simultaneous double difference observations are treated correctly. The results for the three regions are combined to the global solution. The normal equation systems (NEQs) from this Q1-solution are saved for later use in the 3-day solution. The NEQs contain orbit parameters, station coordinates, 2-hourly ERPs, nutation drifts, geocenter offsets, tropospheric zenith delays, and satellite antenna offsets.

- Two additional 1-day solutions are generated, S1 to get the “best possible” 1-day orbits that will be compared to the 3-day orbits, and S1N for the study of coordinate time series.

- Five 3-day solutions are generated based on the NEQs from three successive days [Beutler et al., 1996]. They are labeled S3, R3, X3, Y3, Z3. S3 is used to generate station coordinate time series, the other four series differ by the set of estimated orbit model parameters.

- In the final clock solution satellite and station clock corrections are computed based on undifferenced smoothed code. All relevant parameters (orbits, ERPs, station coordinates, tropospheric zenith delays) are taken from the 3-day solution which ensures the compatibility of the clock estimates with the other products.

The official final product generated at CODE stems from the middle day of the 3-day solution. It is based on the extended radiation pressure model [Springer et al., 1999a] with five estimated parameters and stochastic terms. The elevation cut-off angle is set to 10 deg and the Niell mapping function [Niell, 1996] is used for mapping the dry atmosphere. No troposphere gradients are estimated. The observations are weighted using $\cos^2 z$, z being the zenith angle. The ocean loading coefficients from [Scherneck, 1991] are used.

The rapid solution is computed within 17 hours after the observations. It is generated along the same lines as the final products, but only one 1-day and one 3-day solution are generated. Minor differences in the processing allow to speed up the processing in order to guarantee a rapid submission of results. The same elevation cut-off angle and mapping function are used as in the final solution.

Special emphasis is put on the computation of solutions for an European network which is used to test and study different processing strategies. Currently eight solutions are generated each day:

- EG_: Full network solution without ambiguity fixing. An elevation cut-off angle of 15 deg is used and 12 tropospheric zenith delays are estimated per day and station. The Saastamoinen model [Saastamoinen, 1972] is used as a priori model. The mapping function $\cos^{-1} z$ is used to estimate the tropospheric zenith delay corrections to the a priori model.

- EQB: Same as EG_ but with ambiguities fixed to their integer values. 24 instead of 12 tropospheric delays are estimated per station. On the average 80-90% of all ambiguities are resolved using the QIF strategy.

- NMF: Same as EQB but using the Niell mapping function to estimate the total tropospheric zenith delays. No a priori correction is applied. With an elevation cut-off angle of 15 deg no significant differences to EQB are expected for the coordinate repeatability. The different mapping function, however, causes the scale to change by about 2 ppm [Rothacher, 1997].

- NMW: Same as NMF but using elevation dependent weighting. The function $\cos^2 z$ is used as weight for the undifferenced observations at zenith angle z.

- EQ_: Same as NMW but using an elevation cut-off angle of 10 deg. Lower elevation cut-off should give better decorrelation of station heights and tropospheric delays. On the other hand the observations show more cycle slips and multipath effects.

- ET_: Same as EQ_ but using tropospheric delay estimates from the CODE global solution for stations which are common to both, the global and the European networks. This approach should reduce the effects from the fact that absolute tropospheric delays are correlated for regional networks.

- NM5: Same as EQ_ but using an elevation cut-off angle of 5 deg.
- NMG: Same as NM5 but solving in addition for one set of tropospheric gradients for each station and day.

CODE is acting as an Analysis Center for the EUREF (European Reference Frame). The solution EQB described above is submitted to the EUREF ACC located at BKG.

Changes in the Routine Processing

The major changes implemented in the CODE routine analysis for the year 1999 are listed in Table 1. During the time period covered by the report the models used remained essentially unchanged. A number of new stations were included into the processing, the new IGS receiver and antenna names were implemented, and the terrestrial reference system was switched to the ITRF97.

Table 1. Modification of the processing scheme at the CODE Analysis Center from January 1999 to December 1999.

Date	Day/Year	Description of Change, Impact
20-Mar-99	079/99	Zero-difference GIMs addressed as official CODE TEC product. New TEC product submitted to CDDIS.
05-Apr-99	095/99	Rapid ionosphere product (including DCB estimates) is derived from zero differences. Station-specific TEC models based on double differences are generated to improve QIF ambiguity resolution.
11-Apr-99	101/99	All available stations are used to derive the final ionosphere product (Z1 solution). For the station-specific TEC maps and DCBs (Z1N solution), up to 100 station are used. For this reason, the maximum degree of the spherical harmonics expansion was reduced from 4 to 3.
04-Jul-99	185/99	New receiver and antenna names used.
01-Aug-99	213/99	Switch to ITRF97. The new set of reference stations consists of about 50 stations. The complete ERP time series, going back to day 200 of 1993, was recomputed using ITRF97 coordinates and velocities (see IGS mail 2422).
24-Aug-99	236/99	Download also GZ RINEX observation files from JPL data archive if necessary.
26-Sep-99	269/99	12 new sites added: ARTU, BAKO, CORD, DAEJ, KUNM, PIMO, RIOG, RIOP, SYOG, URUM, YKRO, YSSK.
09-Oct-99	282/99	New site added: BILI.
04-Nov-99	308/99	The DCB solution from the final ionosphere run (Z1 solution) is now included in official CODE IONEX files. Validation studies showed that the quality of the estimates is comparable to those from the previously included separate solution (Z1N).

Date	Day/Year	Description of Change, Impact
24-Dec-99	358/99	Upper limit of the number of stations to be processed in final solution (temporarily) reduced from 100 to 98 in order to be able to successfully analyze the 28th satellite, PRN 11, which is active since day 355.

Product Quality and Results

Ionosphere

CODE is generating global ionosphere maps (GIMs) for each day [Schaer, 1999]. The long-time series of global TEC parameters available at CODE covers more than 4.5 years by now. Daily updated ionosphere maps as well as 1-day and 2-day predictions may be found on the WWW page http://www.aiub.unibe.ch/ionosphere.html.

GLONASS Processing

In the context of the International GLONASS Experiment (IGEX) CODE is computing precise orbits for all active GLONASS satellites since October 19, 1998. The orbits delivered are stemming from the middle day of a 5-day arc computed with the Bernese extended orbit model (Beutler et al., 1994) without setting stochastic pulses. Nine radiation pressure coefficients are estimated for each satellite and arc: A constant as well as two once-per-revolution terms in the direction of the direct radiation pressure (D-direction, Sun-satellite direction), in the direction of the solar panel axis (Y-direction, 'Y-bias'), and in the direction orthogonal to the previous two directions (X-direction).

To evaluate an improved orbit model for the GLONASS satellites a number of solutions were generated for which different sets of the total of nine radiation pressure coefficients were estimated [Ineichen et al., 2000]. The observations from 25 sites equipped with dual-frequency GPS/GLONASS receivers were processed together with the data from 135 IGS sites for a time span of three weeks (GPS weeks 998-1000). For comparison purposes GPS-only solutions were computed in order to evaluate the impact of a combined processing. Finally the solutions were compared to CODE's official IGEX solution.

To evaluate the quality of the various solution types orbit overlaps at the arc boundaries, the accuracy of the estimated ERP and the coordinate repeatabilities were studied. The tests showed that in order to get good results at least periodic terms in the X-direction have to be estimated in addition to the constant terms in all three directions.

The orbit overlap results are degraded by at least one order of magnitude for the GLONASS as well as for the GPS orbits, if no periodic radiation pressure coefficients or periodic terms only in the D-direction are estimated. On the other hand, the RMS of the orbit overlaps improves if not all nine radiation pressure coefficients are estimated.

Further studies showed that the RMS values of the ERP are increased for all solutions where the periodic radiation pressure coefficient in the D-direction are estimated. The

RMS values are lower for the solutions based on 3-day arcs than for the solutions based on 5-day arcs.

The results of the study urge CODE to switch the parameterization of its GLONASS IGEX orbits from estimating all nine parameters to a solution which uses the same parameterization as used for CODE's official IGS GPS orbit products, i.e., constant radiation pressure coefficients in the D-, Y-, and X-direction, once-per-revolution periodic terms in X-direction, and stochastic pulses. The results show furthermore that a combined processing of the IGS and IGEX network to estimate all parameters in one step significantly improves the GLONASS results and does not compromise the quality of the products generated for IGS. A full GLONASS constellation *would* significantly contribute to the stability of the IGS products.

Earth Rotation Parameters

The combination of GPS and GLONASS data may help to improve the Earth Rotation Parameters (ERPs) because the revolution period of the GLONASS satellites is not in deep 2:1-resonance with the Earth's rotation as it is the case for the GPS satellites. Furthermore the different inclinations of the two satellite systems should lead to a better decorrelation of orbit and ERP estimates. The GLONASS, with a revolution period of 11h15m, could contribute significantly to the determination of tidal terms near one sidereal day (e.g., K_1, S_1, Psi_1) [Rothacher et al., 2000].

Tests were carried out using two weeks of simultaneous observations from 110 IGS and 30 IGEX sites in March 1999. The amount of GLONASS data is, however, below 10% of the total number of GPS and GLONASS observations. The reference frame was realized by fixing 43 sites to their ITRF96 coordinates in the combined solution.

Table 2 gives the RMS difference between the 2-hour ERP estimates of different solution types and the Rapid ERP Series from IERS Bulletin A. For the comparison the ERP subdaily terms according to the Ray model were added to the Bulletin A series. The LOD values show a significant improvement from solutions E3 to C3 (in view of and despite the small amount of GLONASS data involved). The formal a posteriori LOD error decreased by about 25% from E3 to C3 whereas those of polar motion remain almost identical. This result is caused by the different orbit inclinations of the two satellite systems [Rothacher et al., 1999].

Table 2. RMS differences between the 2-hour ERP estimates of different solution types and the IERS Bulletin A Series (with subdaily terms from the Ray model added).

Solution	X-Pole [mas]	Y-Pole [mas]	LOD [ms]
R3: GLONASS only	0.490	0.538	0.250
E3: GPS only	0.241	0.239	0.158
C3: GPS and GLONASS fully combined	0.230	0.228	0.148

Antenna Phase Center Offsets and GPS Scale

The locations and the elevation dependence of the satellite and receiver antenna phase centers are a problem in GPS data processing. The major part of the satellite antenna offset in the Earth-pointing direction is absorbed by clock correction parameters or removed by forming single differences. The remaining effect has an elevation dependent signature. An elevation dependent variation of the satellite and receiver antenna offset correlates through the estimated tropospheric delays with the station heights and, as a result, with the terrestrial scale. A number of test solutions were generated [Springer, 1999] to study the dependence between antenna phase center offsets, phase center variations, the tropospheric zenith delay, and the terrestrial scale based on a dataset of one week in 1998. The following processing options were modified:

- Terrestrial scale is defined by constraining the coordinates of 37 reference stations to 1 mm or let free by only applying three rotational constraints.
- The satellite phase center offset (Z-offset) is either fixed, artificially changed by 1 m, or estimated for each satellite.
- Either relative receiver antenna phase center variations relative to the Dorne Margolin antennas [Rothacher et al., 1996] or absolute variations from the anechoic phase chamber calibrations [Rocken et al., 1996] are used.
- Different elevation cut-off angles (10, 15, 20 deg) with elevation dependent weighting are used.

Table 3 lists the differences of the generated solutions with respect to the reference solution which was computed with the terrestrial scale left free, an elevation cut-off angle of 10 deg with elevation dependent weighting, relative phase center variations introduced, and no satellite Z-offset estimated.

No significant scale change is observed for the solutions with fixed and free scales and varying cut-off angle whereas the scale changes by more than 8 ppb if the satellite antenna offset is artificially changed by 1 m. Estimating the antenna phase center offsets leads to a scale change of up to 23 ppb if the scale is left free. The formal errors of the station heights (3-6 mm) and for the tropospheric zenith delays (1-2 mm), on the other hand, barely change. This behaviour underlines the correlation between satellite antenna offset, troposphere delays, and station heights. It is, therefore, not possible to solve for the satellite antenna offsets in an absolute sense. The estimation of relative offsets between satellites of different blocks is, however, possible [Bar-Sever, 1998].

The introduction of absolute antenna phase center variations for the receivers change the terrestrial scale by about 14 ppb and a significant difference in the tropospheric zenith delay is observed. Even for the solution with the scale constrained the change of the scale is as large as 8 ppb! If the satellite antenna offsets are estimated, the free solution shows a scale change of 30 ppb. The results show that we are not yet in a position to use the absolute phase center variations.

Table 3. Influence of processing changes on the terrestrial scale, tropospheric delay, and satellite antenna offsets. Differences w.r.t. the reference solution and RMS of the one-way L1 phase observations.

Solution Description	Scale [ppb]	Tropos. [mm ZPD]	Z-off [m]	RMS [mm]
Scale fixed	0.1	0	–	1.46
Scale free, 15 deg cut-off	–0.3	1	–	1.40
Scale free, 20 deg cut-off	–1.0	4	–	1.36
Scale free, Z-offset + 1 meter	–8.3	5	(+1.0)	1.46
Scale fixed, Z-offset estimated	1.5	–1	–0.2	1.44
Scale free, Z-offset estimated	13.2	–7	–1.6	1.44
Scale free, Z-offset est., 15° cut-off	17.0	–12	–2.0	1.39
Scale free, Z-offset est., 20° cut-off	22.8	–18	–2.5	1.34
Scale fixed, abs. phase center var.	8.5	–10	–	1.57
Scale free, abs. phase center var.	14.3	–18	–	1.53
Scale fix., abs. p. c. var., Z-off. est.	–1.4	–9	2.1	1.49
Scale free, abs. p. c. var., Z-off. est.	–29.7	9	5.5	1.46

Summary and Outlook

During the year 1999 several important events occurred at CODE, the most important being the loss of Markus Rothacher who became a Professor at the Technical University of Munich, Germany, in September 1999. He was succeeded by Urs Hugentobler. The two other major events were the preparation and release of a new version of the Bernese GPS Software, and the start of the migration of the entire IGS routine processing from the VMS cluster to a Unix cluster which was installed at the university's computing department.

A number of problems remain to be studied and model improvements need to be implemented. The GPS scale problem and the shift of the geocenter which seems to be caused by orbit parametrization need to be addressed in more detail. A more appropriate GLONASS radiation pressure model has been identified and will be implemented into the CODE IGEX processing. The advantages of the combination of GPS and GLONASS processing could be demonstrated. The implementation of a combined GPS/GLONASS routine processing will be the next step. The introduction of satellite specific weights may further stabilize the processing results.

Potential for improvements was identified in our modeling of the troposphere. Estimation of troposphere gradients, setting up of continuous troposhere zenith delay parameters, introduction of the dry Niell mapping function and estimation of the wet component of the Niell mapping are planned for the near future.

References

Bar-Sever, Y. E. (1998), Estimation of the GPS Transmit Antenna Phase Center Offset, EOS Transactions, 79(45), 183.

Beutler, G., E. Brockmann, W. Gurtner, U. Hugentobler, L. Mervart, M. Rothacher, A. Vernun (1994), Extended orbit modeling techniques at the CODE processing center of the international GPS service for geodynamics (IGS): theory and initial results, Manuscripta Geodetica, 19, 367-386.

Beutler, G., E. Brockmann, U. Hugentobler, L. Mervart, M. Rothacher, R. Weber (1996), Combining Consecutive Short Arcs into Long Arcs for Precise and Efficient GPS Orbit Determination, Journal of Geodesy, 70, 287-299.

Habrich, H. (1999), Geodetic Applications of the Global Navigation Satellite System (GLONASS) and of GLONASS/GPS Combinations, Ph.D. Thesis, Universität Bern.

Ineichen D., M. Rothacher, T. Springer, G. Beutler (1999), Computation of Precise GLONASS Orbits for IGEX-98, in Geodesy Beyond 2000, the Challenges of the First Decade, IAG Symposia Vol 121, edited by K.-P. Schwarz, IAG General Assembly, Birmingham, July 19-30, 1999, pp. 26-31.

Ineichen, D., T. Springer, G. Beutler (2000), Combined Processing of the IGS- and the IGEX-Network, submitted to Journal of Geodesy.

Mervart, L (1995), Ambiguity Resolution Techniques in Geodetic and Geodynamic Applications of the Global Positioning System, Geodäisch-geophysikalische Arbeiten in der Schweiz, Vol. 53, Schweizerische Geodäische Kommission, Institut für Geodäsie und Photogrammetrie, Eidg. Technische Hochschule Zürich, Zürich.

Niell, A. E. (1996), Global Mapping Functions for the Atmosphere Delay at Radio-Wavelengths, JGR, 101(B2), pp. 3227-3246.

Rocken, C., C. Meertens, B. Stephens, J. Braun, T. VanHove, S. Perry, O. Ruud, M. McCallum, J. Richardson (1996), Receiver and Antenna Test Report, UNAVCO Academic Research Infrastructure (ARI).

Rothacher, M., G. Beutler, E. Brockmann, L. Mervart, R. Weber, U. Wild, A. Wiget, H. Seeger, S. Botton, C. Boucher (1995), Annual Report 1994 of the CODE Processing Center of the IGS, in IGS 1994 Annual Report, edited by J. F. Zumberge et al., pp. 139-162, IGS Central Bureau, JPL, Pasadena, CA.

Rothacher, M., G. Beutler, E. Brockmann, L. Mervart, S. Schaer, T. A. Springer, U. Wild, A. Wiget, H. Seeger, C. Boucher (1996), Annual Report 1995 of the CODE Processing Center of the IGS, in IGS 1995 Annual Report, edited by J. F. Zumberge et al., pp. 151-174, IGS Central Bureau, JPL, Pasadena, CA.

Rothacher, M., L. Mervart (Eds.) (1996), The Bernese GPS Software Version 4.0, Astronomical Institute, University of Berne, September, 1996.

Rothacher, M., W, Gurtner, S. Schaer, R. Weber, H. O. Hase (1996), Azimuth- and Elevation-Dependent Phase Center Corrections for Geodetic GPS Antennas Estimated from GPS Calibration Campaigns, in IAG Symposium No. 115, edited by W. Torge, pp. 335-339, Springer-Verlag.

Rothacher, M., T. A. Springer, S. Schaer, G. Beutler, E. Brockmann, U. Wild, A. Wiget, C. Boucher, S. Botton, H. Seeger, (1997), Annual Report 1996 of the CODE Processing Center of the IGS, in IGS 1996 Annual Report, edited by J. F. Zumberge et al., pp. 201-219, IGS Central Bureau, JPL, Pasadena, CA.

Rothacher, M., T. A. Springer, S. Schaer, G. Beutler, D. Ineichen, U. Wild, A. Wiget, C. Boucher, S. Botton, H. Seeger, (1998), Annual Report 1997 of the CODE Processing Center of the IGS, in IGS 1997 Technical Reports, edited by I. Mueller et al., pp. 73-87, IGS Central Bureau, JPL, Pasadena, CA.

Rothacher, M., T. A. Springer, G. Beutler, R. Dach, U. Hugentobler, D. Ineichen, S. Schaer, U. Wild, A. Wiget, E. Brockmann, C. Boucher, E. Reinhart, H. Habrich (1999), Annual Report 1998 of the CODE Processing Center of the IGS, in IGS 1998 Technical Reports, edited by K. Gowey et al., pp. 61-73, IGS Central Bureau, JPL, Pasadena, CA.

Rothacher, M, T. Springer, S. Schaer, G. Beutler (1997), Processing Strategies for Regional GPS Networks, Proceedings of the IAG General Assembly, Rio, Brasil, September 3–9, 1997.

Rothacher, M., R. Weber (1999), Benefits from a Combined GPS/GLONASS Analysis for Earth Rotation Studies, in Proceedings of the ION GPS-99, Nashville, Tennessee, September 14-17, 1999.

Rothacher, M, G. Beutler, R. Weber, J. Hefty (2000), High-Frequency Earth Rotation Variations from Three Years of Global Positioning System Data, submitted to JGR.

Saastamoinen, J. (1972), Atmospheric correction for the troposphere and stratosphere in radio ranging of satellites, in The Use of Artificial Satellites for Geodesy, Geophysical Monograph Series.

Schaer, S. (1999), Mapping and Predicting the Earth's Ionosphere using the Global Positioning System, Geodätische-geophysikalische Arbeiten in der Schweiz, Schweizerische Geodätische Kommission, Vol. 59, Institut für Geodäsie und Photogrammetrie, Eidg. Technische Hochschule Zürich, Zürich.

Scherneck, H.-G. (1991), A parametrized solid earth tide model and ocean tide loading effects for global geodetic baseline measurements, Geophys. J. Int., 106, pp. 677-694.

Springer, T. (1999), Modeling and Validating Orbits and Clocks Using the GPS, Ph.D. Thesis, Druckerei der Universität Bern, Bern.

Springer, T., G. Beutler, M. Rothacher (1999a), Improving the Orbit Estimates of GPS Satellites, Journal of Geodesy, 73, pp. 147-157.

Springer, T., G. Beutler, M. Rothacher (1999b), A new Solar Radiation Pressure Model for GPS, Adv. Space Res., 23, No. 4, pp 673-679.

The ESA/ESOC IGS Analysis Centre

J.M. Dow, J. Feltens, C. Garcia, I. Romero, R. Kahle

ESA/European Space Operations Centre
Darmstadt, Germany

Summary

1999 was a very active year with various changes and activities in the ESOC Analysis Centre.

The main implementation was the use of undifferenced observables replacing the double-difference approach that had been use since the beginning of our activities in 1992.

The use of our IGS products for the data processing of satellites carrying GPS receivers was continued with the analysis of the Automated Rendezvous Pre-development (ARP). The analysis of the fourth Flight Demonstration was issued in September 1999.

Many recommendations followed the Analysis Centre Workshop hosted by IGPP/SIO in La Jolla. Their implementation was carried out in coordination with other Analysis Centres.

The development of the Ultra-rapid products took place during the last months of 1999. The first distributions and combinations had to wait until the beginning of the year 2000.

Several tests and preparations by the end of the year to avoid Y2K problems made possible a smooth transition to the year 2000.

ESOC GPS/GLONASS Web Pages

Information on our activities can be found at our web pages:

http://nng.esoc.esa.de

ESOC IGS Analysis

Information on the models and estimated/used parameters in our routine processing is located at:

http://igscb.jpl.nasa.gov/igscb/center/analysis/esa.acn

The following products have been made available during 1999:

- Final Orbits
- Rapid orbits
- Daily rapid EOP file
- Daily predicted EOP file
- Weekly final EOP file
- Weekly final processing summaries
- Weekly free network solution in SINEX format
- Daily final tropospheric files
- Daily rapid RINEX clock files with 5 minutes sampling
- Daily final RINEX clock files with 5 minutes sampling

ESOC Analysis Centre major changes in 1999

- 17-Jan-1999 Inclusion of EOP rates in SINEX file
- 18-Apr-1999 use of undifferenced observations for final orbits and clocks
- 2-Jun-1999 final clock biases in RINEX format
- 8-Jun-1999 use of undifferenced observations for rapid orbits and clocks
- 4-Jul-1999 new IGS standard receiver and antenna names
- 1-Aug-1999 ITRF'97 adopted for final and rapid products
- 2-Aug-1999 submission of predicted eop file
- 3-Aug-1999 noncc2cc implemented to filter non cross-correlation RINEX
- 2-Sep-1999 single station reference for clock biases replaces composite
- Dec-1999 rapid clock biases in RINEX format

Processing of Undifferenced Data

This development was done for the processing of IGEX GLONASS data. After some tests it was confirmed that the IGS clock estimations could benefit from this approach.

The batch least squares package BAHN was modified for the estimation of time dependent parameters. The preprocessing program GPSOBS was updated accordingly.

The undifferenced data can be directly processed and satellite and receiver clock biases are estimated along with the orbits and the geodetic parameters. Due to computer limitations observations are decimated to 5 minutes sampling. Time dependent parameters like clocks can only be estimated at the observation times.

Unlike the previous processing strategy where the clock information was eliminated with the double differenced combinations and estimated in a different step, with the undifferenced processing clock estimates are fully consistent with the orbits. The accuracy has also been improved.

The limitation of using only observations which can be combined in a double difference disappears.

Ultra Rapid Development

Starting in October of 1999 a dedicated effort has been made to prepare the new Ultra-Rapid IGS product. As described in the final recommendations of the 1999 IGS Workshop this product is a twice daily GPS orbit fit plus prediction spanning 48 hours with a 12 hour sliding window.

The implementation of this new product in our processing involves borrowing techniques used for our processing of the Predicted and Rapid products. A variable number of full or half days of RINEX observables can be included as well as a number of Earth fixed positions taken from the Rapid IGS solutions. This ensures that the Ultra-Rapid product benefits from having a long enough arc of observations for the orbit fit and a long enough arc of Earth fixed positions for the prediction.

At the end of 1999 most of the Ultra-Rapid processing implementation had been completed in our computer systems, and preliminary runs were being performed for internal testing and debugging.

Regular submissions of the ESA Ultra-Rapid product and the IGS Ultra-Rapid Combinations began in early 2000.

Clock Reference Selection

Before September '99 the reference clock for clock biases estimations was a composite made up every day with the most stable station masers. This presented several problems:

1. A composite clock is very prone to have problems due to unreported changes in the individual IGS reference stations.
2. The rest of the Analysis Centres which produce clock biases use a single station reference. The reference of our solution was sometimes drifting from the others but the navigation solution was of the same accuracy. To produce a solution more useful for the IGS combinations we decided to use a single station reference.

The reference is selected every day in the preprocessing. It has to be present at all the epochs. The bias and the drift must be within a given threshold and contain no resets.

IGEX Processing

In 1999 the ESOC IGEX contributions have been continued. Unfortunately six satellites became unhealthy so that at the end of the year only nine Glonass satellites remained for the processing.

Usually about 25 to 30 IGEX stations have been available from the IGEX data holding centers, only dual-frequency receivers with GPS time tags have been considered (mainly GPS-Glonass receivers and a couple of Glonass-only receivers).

Our IGEX products (Final Orbits, Weekly final processing summaries, Weekly free network solution in SINEX format) have been delivered with one to six months delay. In year 2000 they will be available within two or three weeks.

We plan to continue our IGEX processing as long as there are enough stations and satellites.

Ionosphere Processing

Routine processing of ionosphere Total Electron Content (TEC) maps and satellite/receiver differential code biases (DCBs) continued during 1999. In order to reduce the timeline, the separated processing in final and in rapid mode were merged in such a way that now generally the rapid orbits are used, but the amount of GPS observations data corresponds to those of the final orbits.

The ionosphere processing in rapid mode was formally abandoned on 5 May 1999, and processing in final mode continued - but now with the rapid orbits. Also the routine fitting of 2-d single layer TEC maps with Gauss-Type Exponential (GE) functions was stopped at the end of 1999 and replaced by a 3rd variant of a 3-d Chapman profile fit (fit number 4) in the list below). The number of ground stations used was increased from about 60 to about 120. The 24 hours time resolution with which the TEC maps are produced, could not be increased yet. The daily routine ionosphere processing is now as follows:

- A nighttime TEC data fit is made to obtain a set of reference DCB values for that day. The nighttime TEC itself is absorbed in this fit with a low degree and order spherical harmonic. In the other fits 2) - 4) these DCBs are then introduced as constraints.

- A Chapman profile model is fitted to the TEC data of that day, where the layer of maximum electron density N0 and its height h0 are estimated as surface functions of geomagnetic latitude and local time. h0 is restricted to have values within a predefined range only, currently 350 km =< h0 =< 450 km.

- A Chapman profile model is fitted to the TEC data, where h0 is estimated as a global constant.
- A Chapman profile model is fitted to the TEC data, where h0 is kept fixed as global constant at a height of 450 km, and the influence of the solar zenith angle is not accounted for. This run is made for test reasons and theoretical studies.

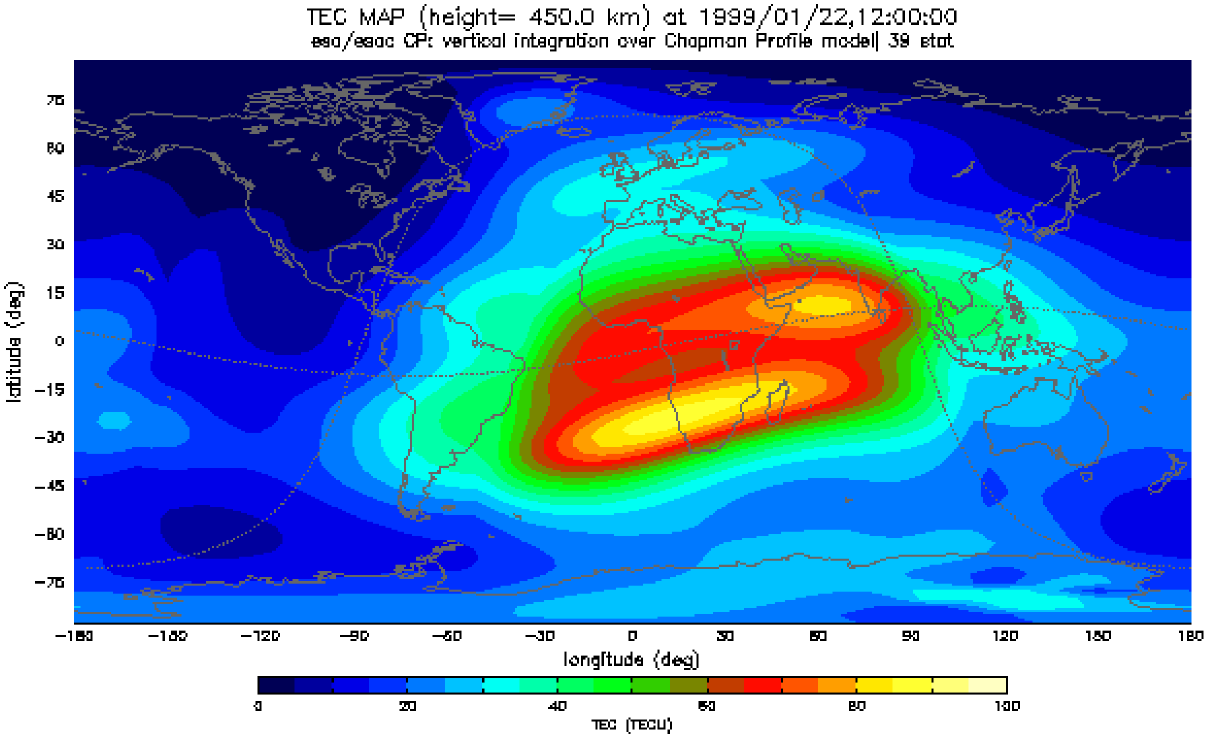


Figure 1: Global TEC map obtained from a fit of type 2) for 22 January 1999.

Beyond the routine processing of our own TEC maps, ESOC is also chairing the IGS Ionosphere Working Group (Iono_WG) and thus responsible for the weekly comparisons of Iono_WG products and for the coordination of the activities of this working group.

References

The ESA/ESOC IGS Analysis Centre. 1997 Technical Reports. October 1998. IGS Central Bureau.

The ESA/ESOC IGS Analysis Centre. 1998 Technical Reports. IGS Central Bureau.

1998 Analysis Centre Workshop proceedings, 9-11 February 1998. ESA/ESOC, Darmstadt, Germany.

GFZ Analysis Center of IGS – Annual Report for 1999

Gerd Gendt, Galina Dick, Wolfgang Söhne
GeoForschungsZentrum Potsdam (GFZ)
Telegrafenberg, 14473 Potsdam
Division Kinematics & Dynamics of the Earth

Summary

In 1999 only a few changes concerning the classical IGS/IGR products were introduced. Activities concentrated on the development of software and technologies as well as routine data analysis for the topics:

- Ultra-rapid products,
- GLONASS Pilot Experiment (IGEX).

Changes in the Routine Analysis

Up to 1999 for a number of sites the ocean loading effects were not applied because of missing coefficients in the official tables. To avoid distortions between sites with applied loading effects to those where they were not applied it was decided to use S. Pagiatakis' freely available software to compute a homogeneous set of coefficients for all sites. The model based on the ocean tidal model FES95_2 was introduced at GPS week 999.

Table 1. Changes in the analysis strategy

Week	Date	Description
999	1999-02-28	Ocean loading for all sites, use of software by Pagiatakis
1021	1999-08-01	Introduction of ITRF97 with 51 core sites
1023	1999-08-15	Introduction of once-per-revolution term for x-bias

Starting with week 1021 the ITRF96 frame with 47 core sites was replaced by the ITRF97 frame using 51 core sites (ITRF97_IGS_RS51). The Helmert transformation between these two frames which were shifted to 1999.5 gives (rotx, roty, rotz= -0.18± 0.02, 0.26± 0.02, 0.04± 0.02 mas). Checking the influence of this transition onto the ERP results we analyzed 7 weeks using both frames. During the generation of the weekly SINEX products and hence for the ERP product a free network adjustment is applied. The alignment to the ITRF is realized by introduction of inner constraints (the sum of rotations to IRTF is minimized) for a defined set of stations. The alignment is realized on a weekly basis (for 7 NEQs containing 3 days of data each, i.e. 9 days in total). In Figure 1, the differences in pole position switching from ITRF96 to 97 are given. One can see the fluctuations from week to week depending on the number of sites available for the inner constraints (tests were performed with two different sets of sites). The fluctuations of the order of 0.01 to 0.04 mas are small compared to the overall quality of the ERP results (~0.1 mas). The mean differences are dx_p= -0.204 ± 0.009, dy_p= 0.186± 0.011, which is consistent with the Helmert transformation.

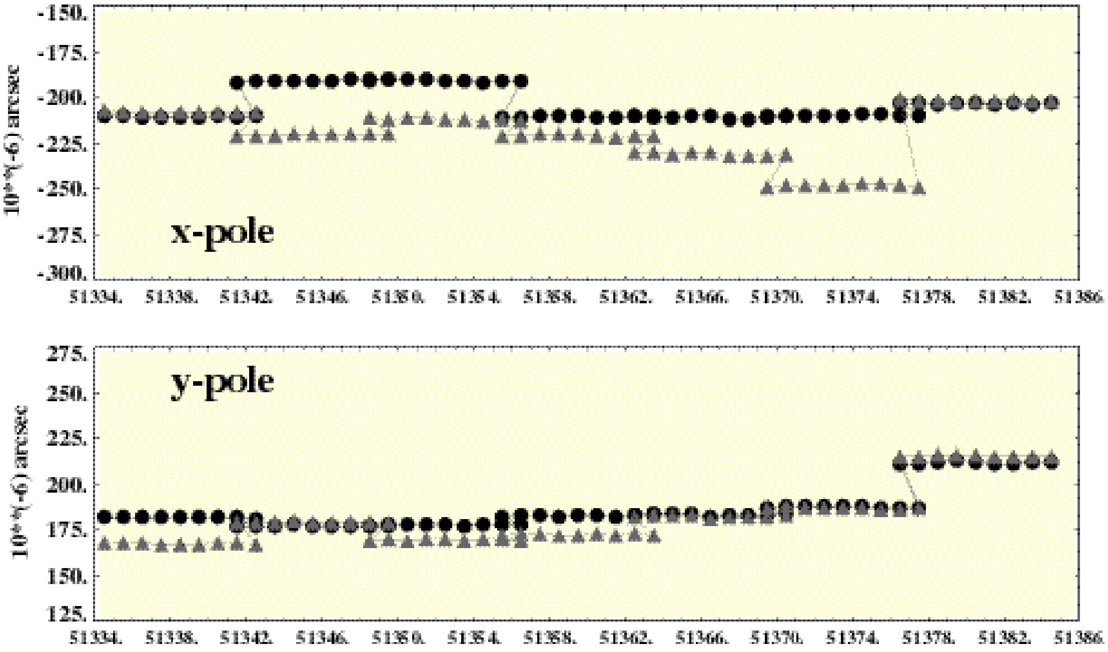
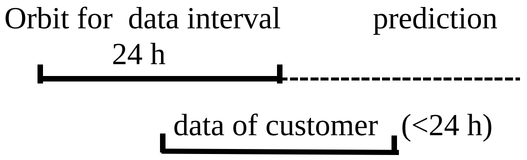


Figure 1. Differences in pole position between ITRF96 and ITRF97. Two different sets of stations were used to realize the reference frame by inner constraints (minimal sum of rotations).

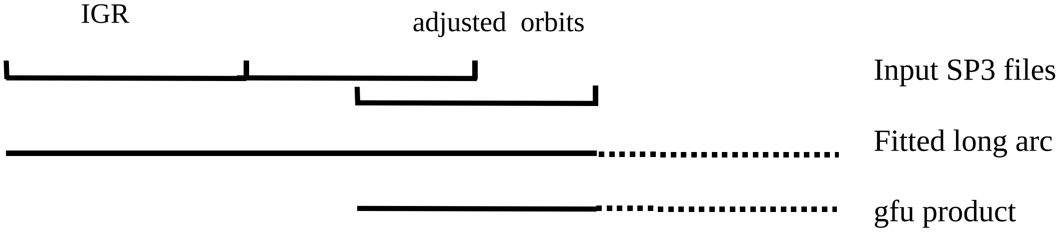
To further improve the quality of the orbits in addition to the stochastic impulses and the y-bias a once-per-revolution term for the x-bias (in the satellite frame) was introduced.

3 Ultra-Rapid Products - First Results

The quality of the classical IGS orbit predictions (IGP) which are based on daily RINEX-files and predicted over an interval of 24 to 48 hours is not sufficient for many upcoming applications, e.g. water vapor monitoring. Many stations started to transmit hourly RINEX files and their number is permanently growing. At the last workshop in La Jolla the IGS decided to use the hourly data for more rapid products, so-called ultra-rapid (name: igu), which should be generated several times a day (Gendt, et al. 1999). In a first step the ACs should produce ultra-rapid products twice a day and submit them shortly before 3 UT and 15 UT. Up to now the IGS rapid products and predictions are provided in separate files containing information for exactly one day each. For the igu-product this principle will not be appropriate any longer because the customer usually is uses the rapid and the predicted part at the same time.



Therefore the ultra-rapid product should be a continuous orbit containing both the interval for the last data and the predictions (for convenience it was defined to include the interval of the last 24 hours with data and a prediction for the next 24 hours). The product file will be named with the day the prediction starts.



At GFZ the generation of the new product was started in October 1999 (name: gfu; available at ftp.gfz-potsdam.de/pub/igsprod/igu). The data are analyzed in 24-hour sliding windows shifted by 12 hours (the software is capable to use arbitrary windows and shifts). The last two adjusted orbits and the last official rapid product are used as a basis for a long orbital arc (about two days in length), which is fitted through all input orbit positions and predicted for another 24-hour interval. The ultra-rapid orbit is taken from the fitted long arc. This way an orbit without any jump between the data part and the predicted part is obtained. As maneuvers cannot be predicted the application is left with the problem to decide which satellites have sufficient quality to be included into the analysis. Here a tool is necessary which inspects the sp3 files with the help of the data to be analyzed.

The quality of the gfu-orbits for 8 weeks in October/November 1999 can be seen in Figure 2. The distribution of sites with hourly data retrieval is not yet sufficient, especially in the southern hemisphere. But also in Asia and Africa additional sites are necessary (Fig. 3.). Most critical was the missing redundancy, so that problems in sub-networks would directly be seen in the quality of the ultra-rapid products. Nevertheless, a high quality was already gained for the 12-hour predictions. The median in the range of 10 to 15 cm is significantly better than in the classical predictions (~30-40 cm). Our technology will of course not give optimal results for the data part. However, the quality at the level of 10 cm or below is sufficient compared to the quality of the prediction part to get a homogeneous accuracy for the whole interval.

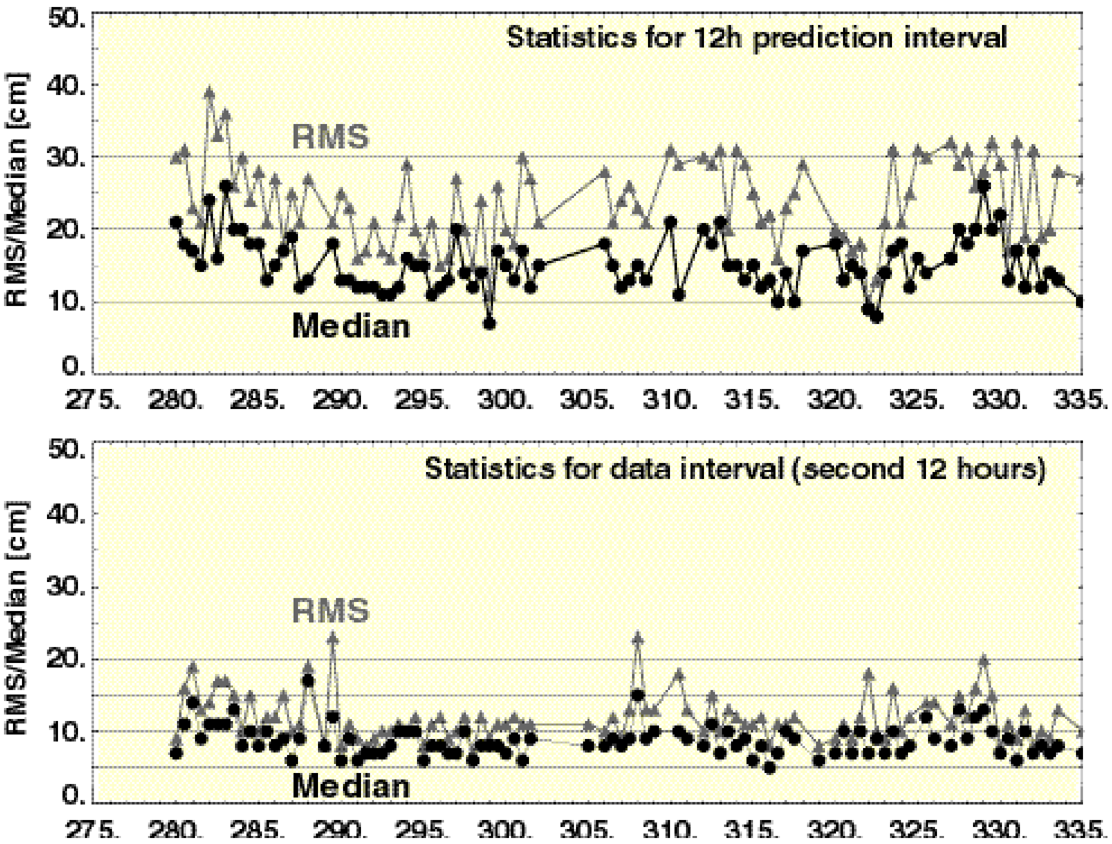


Figure 2. Quality of ultra-rapid products for the first 12 hours of predictions (top) and the last 12 hours of data interval (bottom)

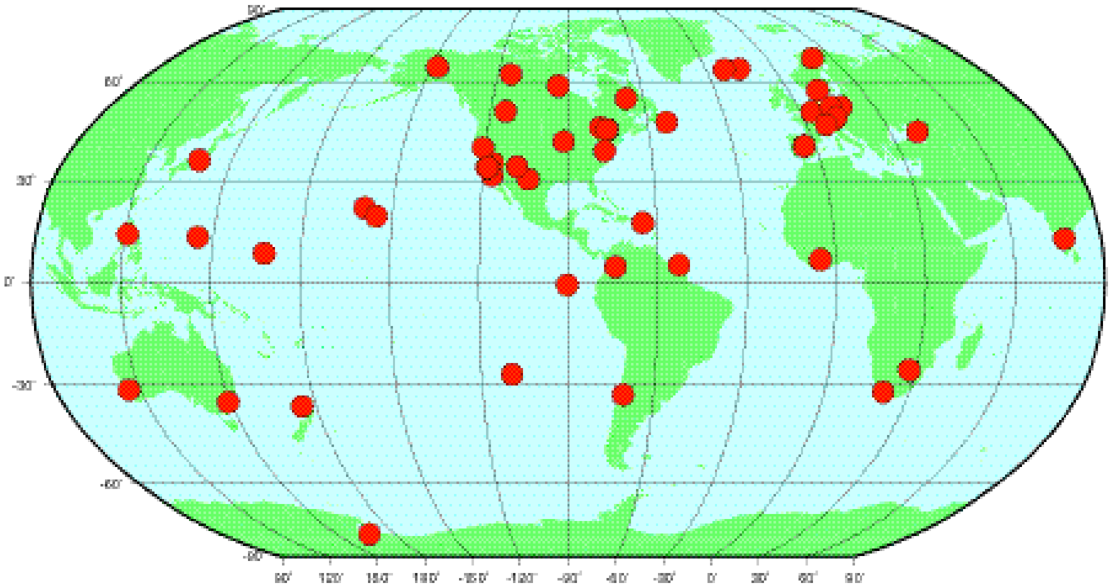


Figure 3. Network of IGS sites with hourly data retrieval

With the upcoming improvements in the global network (e.g. high-rate sites established for the CHAMP and GRACE projects) and the generation of combined ultra-rapid products (as soon as at least three ACs will contribute) a further significant improvement can be expected.

This new product is a basic element of the strategic project "GPS Atmosphere Sounding" (GASP) of the Helmholtz Society (Dick et al. 1999) which is going to use ground-based and space-based GPS techniques for applications in numerical weather predictions, climate research and space weather monitoring.

Contribution to IGEX

On October 19, 1998 the International GLONASS Experiment IGEX-98 started. The aim of the campaign was to demonstrate the processing of precise GLONASS orbits in a (nearly) routine way. The primarily proposed date for the end of the campaign, January 19, 1999, was extended by another three months. This was mainly due to a better satellite configuration after the start of three new satellites in late December 1999, a higher number of stations and a growing number of analysis centers. Observations and analyses are still being continued at some sites and by some analysis centers.

Changes and modifications of the software

In general, for the combined GPS/GLONASS adjustment the same software as for the IGS analysis was used. Modifications started in early 1998 but only few tests could be made due to the small amount of GLONASS observation data available at that time. In September 1998 the first two-frequency GPS/GLONASS data were available at the global data centers. The new software should be able to process standalone GLONASS as well as combined GPS+GLONASS.

A lot of modifications and extensions had to be introduced into the software due to the higher number of satellites, the two different types of phase observations (i.e. same frequency for all satellites using GPS and different frequency for each satellite using GLONASS) and the different navigation messages.

For the GPS/GLONASS antennas no correction models existed so far but this deficiency was negligible at the recent accuracy level.

Adjusted Parameters

General

In principle for the combined GPS+GLONASS analysis the same parameter set as for the GPS standalone analysis is taken. This is given in our summary files (available at ftp: cddisa.gsfc.nasa.gov/products). The main differences to the IGS analysis are that the orbits for the GPS satellites and the ERP were fixed (see below) and only very few station coordinates were constraint to their ITRF values.

Clocks

Using GPS alone one clock for each station and for each satellite has to be solved for every epoch. The singularity problem usually is solved by taking one (good) station clock as a reference. Using standalone GLONASS it can be handled in the same way. Using GPS and GLONASS together in one analysis two station clocks and one clock per satellite for both systems have to be estimated. The clocks of both systems are nearly independent from each other. Coupling takes place only through station coordinates and earth rotation parameters which are weakly stabilized. There are two ways to adjust for the receiver clock. The first one is to adjust one bias between the GPS and the GLONASS receiver clock per day and station. This seems to be just a sub-optimal solution due to the fact that the difference between the two clocks is not constant over the day. The second one is to adjust two independent receiver clocks per epoch. Additionally to the fixed GPS reference station clock a GLONASS station clock (not necessarily at the same reference) had to be fixed to avoid the singularity problem.

The bias between the GPS and the GLONASS receiver clock depends on the receiver type. For the 3S receiver it is typically one microsecond ± 100 nanoseconds. For the full two-frequency receivers it is in the range of ± 100 nanoseconds except for the ESA receiver at site LDS1 where it is about -950 nanoseconds. The differences between the biases estimated by BKG and those estimated by GFZ are often in the range of 50 nanoseconds and above. But these differences include all other effects which are not modeled. Figure 4 shows the estimated biases for 5 Ashtech Z-18 receivers installed on European sites. The biases vary from day to day but in the same way for all receivers. The day-today variations seem to included other effects, e.g. different satelite constellations. The receivers themselves seem to have a receiver-dependent bias.

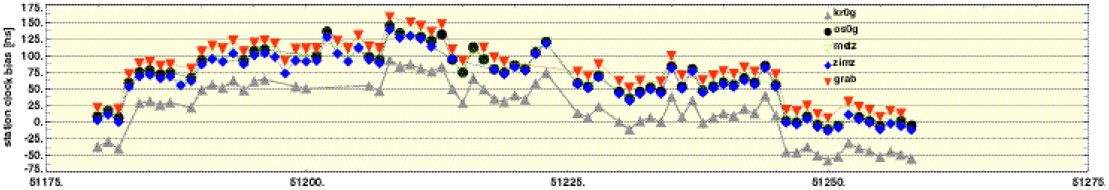


Figure 4. Daily GPS-GLONASS station clock bias for 5 European stations equipped with Ashtech Z-18 receiver

Single Frequency Data

A lot of sites within IGEX were equipped with single frequency receivers. From two points of view it seemed necessary to us to include data of some single frequency receivers: a) improving the global station distribution, especially in the southern part of the world; b) using our own GFZ stations which were equipped with single frequency receivers. So the decision was to include the three GFZ receivers in Bishkek, Sutherland

and Rio Grande. For a global solution the data of single frequency receivers could not be used directly. The residuals were too large and most of the data would be eliminated. Therefore the data had to be corrected for ionospheric influence using one of the following possibilities:

- ionospheric corrections are calculated using a nearby two-frequency receiver. Therefore for the IGEX campaign it was proposed to collocate the GLONASS single frequency receiver with a GPS two-frequency receiver, ideally an IGS station
- use of a model.

Correcting the GPS L1 data by an ionospheric correction term calculated with the data of a nearby two-frequency receiver works well since the line of sight is nearly identical. However, the directions to the GLONASS satellites are completely different, in general. Therefore we decided to work with the adoption of a ionospheric map. We used the daily CODE ionospheric maps of TEC values with a spatial resolution of 5 and 2.5 degree in longitude and latitude and a temporal resolution of two hours to interpolate within gridded data. The coordinate repeatability is better for Bishkek (670 mm) than for Rio Grande (1675 mm) and Sutherland (1240 mm). There are two possible explanations: The two southern stations are in regions which are more affected by ionospheric disturbations. Here the model correction does not work well. Bishkek is in a region with more stations around, Rio Grande and Sutherland are poorly controlled by other stations. Rio Grande degrades the single other station in South America, Santiago. Large cycle slips and outliers were found in the corrected data but at the end some 'virtual' cycle slips were detected when the satellite constellation changed. Therefore the elevation mask for the single frequency receivers was increased from 15 to 25 degree to reduce this error source.

Results from IGEX campaign

After some weeks of testing GFZ produced a routine solution starting with GPS week 991 and ending with GPS week 1001. Satisfying results could be obtained by fixing the GPS orbits and ERPs to the IGS final solution. The mean difference over all satellites between the IGX final solution and the GFX solution calculated for the weeks 991-1001 was 24.9 cm (Figure 5). The differences between the GFX solution and solutions of other ACs were in the same range. The repeatabilities of the weekly coordinate solution were well below the 2 cm level for the GPS/GLONASS two frequency stations in Europe and Asia and slightly worse for North America (Figure 6). The stations where only the GLONASS data were used showed larger values especially for the height component due to the much lower number of observations. The repeatability for the GLONASS L1-only stations was on a high decimeter or even meter level.

The GLONASS satellite 10 (gv-71, 1995-009A) which was healthy during the complete campaign was problematic; its data were rather bad and our software detected a large number of cycle slips. Most of its observations were eliminated during the analysis. Therefore this satellite was excluded from the orbit solution during most of the days.

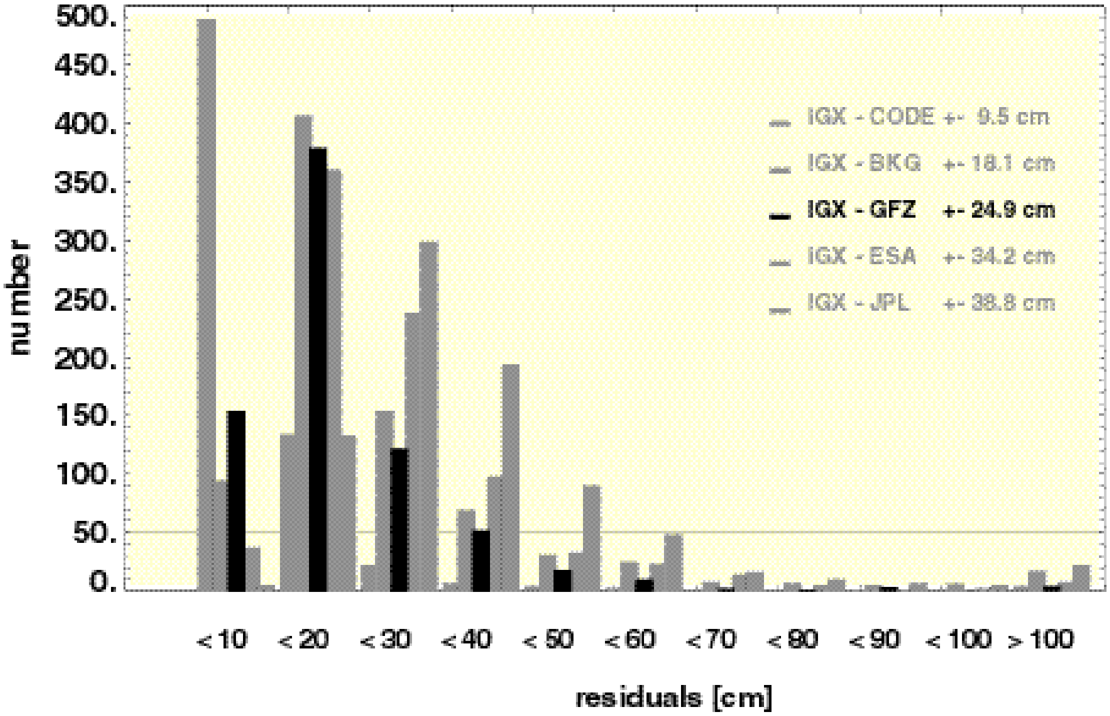


Figure 5. Histogram of Orbit accuracy fore all GLONASS satellites (GPS weeks 991 – 1000)

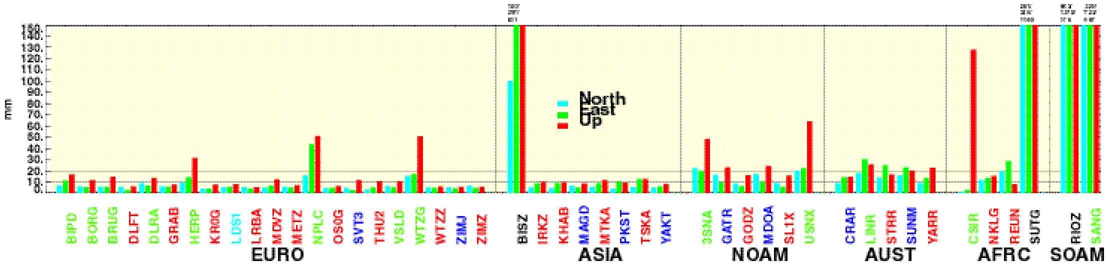


Figure 6. Repeatability of weekly station coordinate solution for IGEX stations (GPS weeks 991 – 1001)

References

Gendt, G, P Fang, J F Zumberge (1999): Moving IGS towards real-time. Proceedings IGS Analysis Center Workshop, 8-10 June 1999, La Jolla, CA, USA, in print

Dick, G, G Gendt, Ch Reigber (1999): Operational water vapor estimation in a dense German network. Proceedings XXII General Assembly IUGG, July 18-30, 1999, Birminham, UK

JPL IGS Analysis Center Report, 1999

D. C. Jefferson, Y. E. Bar-Sever, M. B. Heflin,
F. H. Webb, and J. F. Zumberge

Jet Propulsion Laboratory/California Institute of Technology
Pasadena, California 91109 USA

Summary

JPL activities as an IGS Analysis Center continued throughout 1999; regular deliveries of rapid, precise, and high-rate GPS orbits and clocks, Earth orientation parameters, and free-network ground station coordinates were maintained. A new product was made available in 1999: daily satellite and station clock estimates in RINEX format (GPS-time alignment of all clock products began early in the year). Also, in 1999 we began aligning our analysis products with 1TRF97.

Evolution in 1999

Material relating to JPL participation as an IGS analysis center, beginning in 1992, can be found in [1] and references therein. [2] describes JPL activities as a GNAAC (Global Network Associate Analysis Center). Table 1 indicates the evolution of our activities during 1999.

Table 1: 1999 Analysis evolution

Action	Date
Exclude stations within 25 degrees of equator	Feb 14
Align satellite and station clocks to GPS time	Feb 21
Stop exclusion of equatorial sites	Mar 14
Create and submit RINEX-formatted clock files	May 16
Increase global analysis station set from 37 to 39 sites	May 23
Exclude MAD2 as a core site for ITRF alignment	Jun 15
Exclude non-Dorne-Margolin antenna stations	Jun 27
Use ITRF97 coordinates and velocities for 20+ subset of 51 IGS core sites	Aug 1
Increase global analysis station set from 39 to 40 sites	Sep 5
Increase global analysis station set from 40 to 41 sites	Sep 12
Increase global analysis station set from 41 to 42 sites	Sep 26

Product Summary

Tables 2 and 3 summarize the regular products that result from JPL IGS AC activities. Newly added products are the daily GPS satellite and station clock solutions in RINEX format. These are described in section 6 of this report. Table 4 contains addresses of World Wide Web pages with related information.

Table 2: Regular products from the JPL IGS Analysis Center, at ftp://sideshow.jpl.nasa.gov/pub/jpligsac

Example File	Contents
1021/jpl1021.sum.Z	narrative summary for GPS week 1021
1021/jpl1021[0-6].sp3.Z	free-network precise orbits for days 0-6 (Sun through Sat) of GPS week 1021
1021/jpl1021[0-6].yaw.Z	free-network yaw-rate data for eclipsing satellites, days 0-6, GPS week 1021
1021/jpl10217.erp.Z	free-network Earth orientation parameters for GPS week 1021 (fixed-network prior to week 947)
1021/jpl10217.snx.Z	free-network station coordinates for GPS week 1021 (7-parameter transformation to ITRF beginning wk 947) (3-parameter rotation to ITRF beginning wk 964)
1021/jpl1021[0-6].tro.Z	free-network troposphere solutions, days 0-6, GPS week 1021 (fixed-network prior to week 949)
1021/jpl1021[0-6].clk.Z	free-network 30-sec GPS and 5-min station clocks, days 0-6, GPS week 1021, in RINEX clock format
hirate/JPL1021[0-6].sp3.Z	fixed-network 30-s GPS orbits and clocks, days 0-6, GPS week 1021
1999.eng.Z	engineering data for 1999, sites in global solution
1999_p.eng.Z	engineering data for 1999, point-positioned sites
ytd.eng	year-to-date engineering data, sites in global solution
ytd_p.eng	year-to-date engineering data, point-positioned sites

Table 3: Other products at ftp://sideshow.jpl.nasa.gov/pub/gipsy_products

Example File	Contents
RapidService/orbits/jpl1021[0-6].sp3.Z	quick-look fixed-network precise orbits for days 0-6 (Sun through Sat) of GPS week 1021
RapidService/orbits/jpl1021[0-6]_pred.sp3.Z	quick-look fixed-network 3-day predicted orbits for days 0-6, GPS week 1021
RapidService/orbits/1999-01-01.*	daily quick-look and predicted fixed-network files use in GIPSY
1999/clocks/1999-01-01.*	1999 daily free- and fixed-network clocks and yaw-rates for use in GIPSY
1999/orbits/1999-01-01.*	1999 daily free- and fixed-network precise orbits, polar motion, shadow-events data for use in GIPSY
hrclocks/1999-01-01.*	high-rate free- and fixed-network clocks (in TDP format) for use in GIPSY
IERSB/*	IERS Bulletin-B information

Table 4: Addresses of relevant web pages

Address	Contents
http://sideshow.jpl.nasa.gov/mbh/series.html	graphical time-series of site coordinates
http://sideshow.jpl.nasa.gov/mbh/all/table.txt	table of site coordinates and velocities
http://milhouse.jpl.nasa.gov/eng/jpl_hp2.html	summaries and plots of station and satellite performance

Use of ITRF97 and Site Selection UPDATE

At the outset of the year, station coordinates and GPS orbits were aligned with ITRF96. Beginning with GPS week 1021 (August 1, 1999), monument coordinates and velocities are taken from ftp://igscb.jpl.nasa.gov/igscb/station/general/ITRF97_IGS_RS51.SNX, and antenna heights from ftp://igscb/igscb/station/general/igs.snx. (Antenna reference point to L1 and L2 phase centers are from ftp://igscb/igscb/station/general/igs_01.pcv.) As we use only 42 stations in our daily processing, we select a subset of the 51 sites designated by the IGS as core sites to be used for alignment with ITRF97. Our total site selection procedure is as follows:

- Choose a reference clock station (usually USNO as of week 955).

- Use 24-hour rapid-service processing results to make a separate list of stations with highly stable clocks. Although these are usually sites with H-masers, in general, these are any stations for which there are at least 250 5-minute clock solutions (out of a maximum of 288) that are smooth at the 4-cm level on timescales of 5 minutes.

- Based on isolation, choose the next 8 most isolated sites from the list of stable clock sites. These will aid in post-processed high-rate clock production.

- Add any sites not yet selected that are core sites and use pseudorange observations.

  Note that as of GPS week 1021, the list of sites for ITRF aligment is a predetermined, well-distributed 20-station subset of the 51 sites designated as IGS core sites (see IGS Mail Message No. 2373).

- Again based on isolation, choose a number of well-distributed stations using pseudorange, accounting for other core sites and desired isolated stations not using pseudorange.

- Choose the remaining most isolated stations to complete the 42 total. Ensure that any of these that are of the 51-site IGS core set will be constrained during the fixed-network portion of the processing.

The site selection algorithm was modified a bit in early 1999 in an initial effort to circumvent the effects of the TurboRogue L2 Tracking anomaly. IGS Mail Message Nos. 2071, 2190, and others describe the problem encountered at ground stations employing TurboRogue receivers during periods of increased ionospheric activity. This effect is most pronounced at sites in the equatorial region of the Earth. After a preliminary positive study, it was decided to exclude stations at low latitudes, specifically those within +/- 25 degrees of the equator. Implemented over a period of four weeks (mid-Feb to mid-Mar '99), this strategy change actually had an adverse effect on JPL's solutions (primarily due to degraded global coverage), and we subsequently reverted to our previous methods, removing equatorial proximity as a criterion for exclusion from global processing. (Further discussion of the progress in resolving this tracking issue can be found in IGS Mail Message Nos. 2240, 2336, etc.)

Clock Solution Update

Starting with products for GPS week 998, all of our reported GPS satellite and station clocks are synchronized with GPS time. This is accomplished by using the JPL Rapid solution (which uses broadcast clocks to align itself with GPS time) to initialize the clock offset and drift of the clock at the chosen reference station at an epoch of 00:00 UTC each day.

Also, beginning with GPS week 1010 (May 16, 1999), JPL began to submit a contribution to the IGS combined clock product. These files contain our daily high-rate (30-sec) estimates of the GPS clocks and 5-min estimates of ground station clocks (5-min) for each satellite and station used in the free-network global solution (the free-network station position estimates are also included in the file headers). The file format is the RINEX clock format as described at http://maia.usno.navy.mil/gpst/clock-format. We acknowledge Rob Liu of Raytheon Systems Company for providing the conversion software that produces these files, and also the software, that creates SINEX files, based on information from the igs.snx database file at the IGS Central Bureau.

Results and Performance

Figure 1 chronicles the progression of orbit quality since 1995. As in the past, our metric for orbit quality is the day-to-day consistency of the solutions (i.e., the degree to which estimates from adjacent days agree near the midnight boundaries). Contributing factors to improvement are the continuing expansion of the global network, the use of global phase ambiguity resolution (implemented in April 1996), and the estimation of tropospheric gradients (implemented in August 1997).

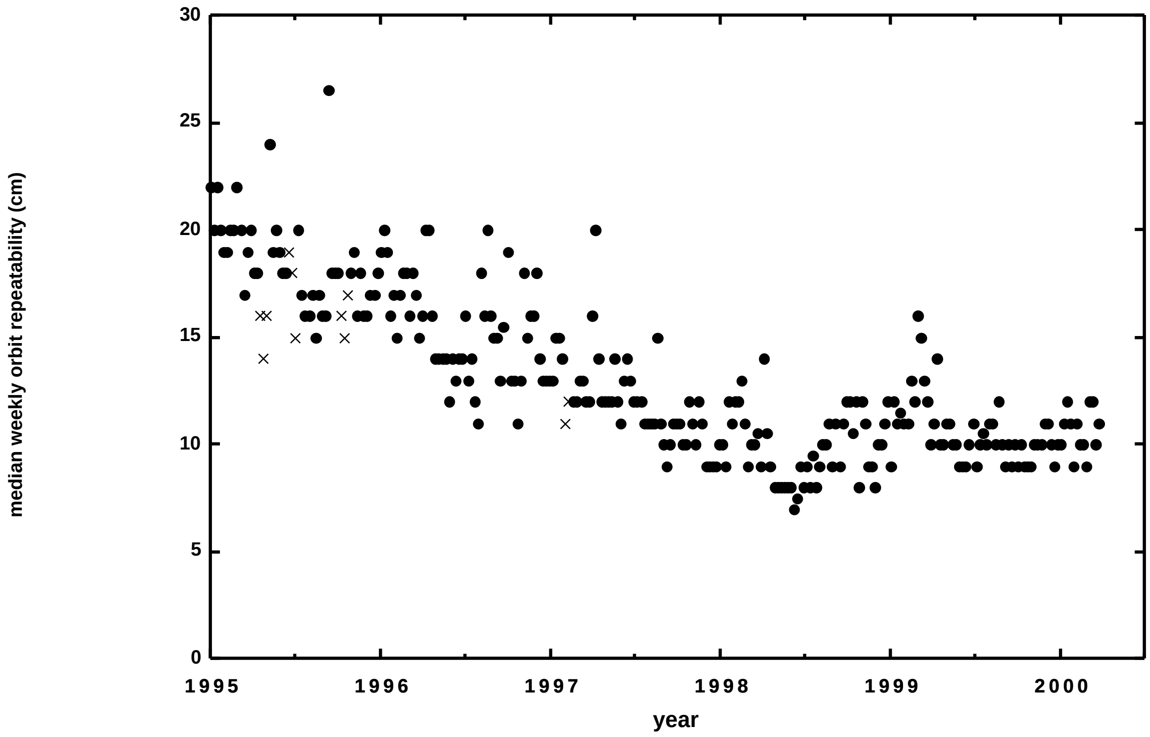


Figure 1: JPL orbit repeatability (3drms) since 1995. Each data point indicates the median over all satellites and days for a particular GPS week. (The daily number for a given satellite indicates the degree to which the precise orbit agrees with those of adjacent days near the midnight boundary.) Weeks during which AS was off are marked with an 'X'.

Another measure of performance is how well the JPL GPS solutions for station coordinates and velocities compare with other those from other geodetic techniques. The first two columns in Table

6 below shows the level of agreement between JPL derived station velocities and those independently realized from Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR). The last column shows dependent agreement with ITRF97. (More details on our velocity estimates can be found in [3].)

Table 6: Geodetic Velocity Comparisons

	JPLGPS-VLBI	JPLGPS-SLR	JPLGPS-ITRF97
N (mm/yr)	1.0	1.5	1.2
E (mm/yr)	1.0	2.0	1.0
V (mm/yr)	2.0	2.6	2.1
No. common sites	33	17	44
GPS years	6.3	5.5	6.1

Acknowledgment

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

[1] J. F. Zumberge, M. B. Heflin, D. C. Jefferson, M. M. Watkins, and F. H. Webb, Jet Propulsion Laboratory IGS Analysis Center 1994 Annual Report, in *IGS 1994 Annual Report*, edited by J. Zumberge, R. Liu and R. E. Neilan, IGS Central Bureau, Jet Propulsion Laboratory, Pasadena CA, 1995, JPL Publication 95-18

[2] M. B. Heflin, D. C. Jefferson, M. M. Watkins, F. H. Webb, and J. F. Zumberge (Jet Propulsion Laboratory), R. F. Meyer and R. Liu (Raytheon), GNAAC Coordinate Comparisons at JPL for GPS Weeks 813-1054, in *IGS 1999 Technical Reports*, editors TBD.

[3] M. Heflin, D. Argus, K. Hurst, D. Jefferson, F. Webb, J. Zumberge, Long Term Reference Frame Stability for Geodetic Velocity Estimates, submitted to Journal of Geophysical Research, May, 2000.

GPS Orbit and Earth Orientation Parameter Production at NOAA for the International GPS Service for 1999

National Geodetic Survey
National Ocean Service
National Oceanic and Atmospheric Administration
Silver Spring, MD USA

Spatial Reference System Division
William G. Kass, Robert L. Dulaney III, Robert B. Leonard Jr.

Geosciences Research Division
Gerald L. Mader, Mark S. Schenewerk, William H. Dillinger

Introduction

The GPS orbit and Earth Orientation Parameter (EOP) solutions submitted to the IGS by the National Geodetic Survey (NGS) are a joint effort between the Spatial Reference System Division (SRSD) and the Geosciences Research Division (GRD). The GRD is responsible for the development of the processing software and techniques while the SRSD is responsible for the operational production. SRSD and GRD are both divisions within NGS which is part of the National Ocean Service (NOS) of NOAA (National Oceanic and Atmospheric Administration). A detailed description of the techniques and models can be found in the Analysis Strategy Summary located at http://www.ngs.noaa.gov/GPS/noaa_acn.html .

Station Network

NGS used an average of about 65 tracking stations which are submitted to the IGS for the GPS orbit and EOP production. This list is not static but changes occasionally to include new stations that offer a more favorable geometry or new geographical coverage. If new stations are added in a region where the tracking network density is greater or redundant, other stations are dropped thereby keeping the total number at less than or equal to 75. This number appears adequate to provide overall tracking network stability that is relatively insensitive to daily tracking site drop outs within the global network. Included tracking sites are listed in the weekly summary available at the Crustal Dynamics Data Information System (CDDIS) at ftp://cddisa.gsfc.nasa.gov .

Software Changes

No major software enhancements were made during 1999. PAGES/GPSCOM, both developed at NGS, remain the software tools used for orbit production. In August, the IERS (Ray, et al. 1994, Ray 1995, McCarthy 1996) model for diurnal and subdiurnal tidal variations in Earth orientation parameters was substituted for the Herring and Dong (1994) model. The ability to estimate model parameters for deformations driven by ocean tidal loading was installed but not activated for production processing. All NGS software had been made insensitive to the GPS week and Y2K rollovers early in 1999; however, a subtle error affecting only the use of the orbit integrator was detected just before the new year. As a result, submissions for the last two weeks of 1999 were delayed while the problem was corrected.

Product Evaluation

The Figure 1 shows the daily RMS differences between the NGS and IGS final ephemerides for 1999 after a "best fit" seven parameter transformation has been applied to the NGS ephemeris, along with the values of the associated seven parameter transformations.

The subplots are: (left column, top to bottom) RMS of fit in meters, X translation in meters, Y translation in meters, Z translation in meters; (right column, top to bottom) Scale factor in parts per billion, X rotation in mas, Y rotation in mas and Z rotation in mas. All available GPS satellites were included and universally outlying points seen in the plots are caused by a single poorly estimated satellite within a day. On average over all 1999, NGS EOP solutions match the National Earth Orientation Service Bulletin A values at: X pole 0.222 +/- 0.281 mas and Y pole 0.022 +/- 0.287 mas. The NGS software uses double differences as an observable, therefore, a true UT1 time series is not available.

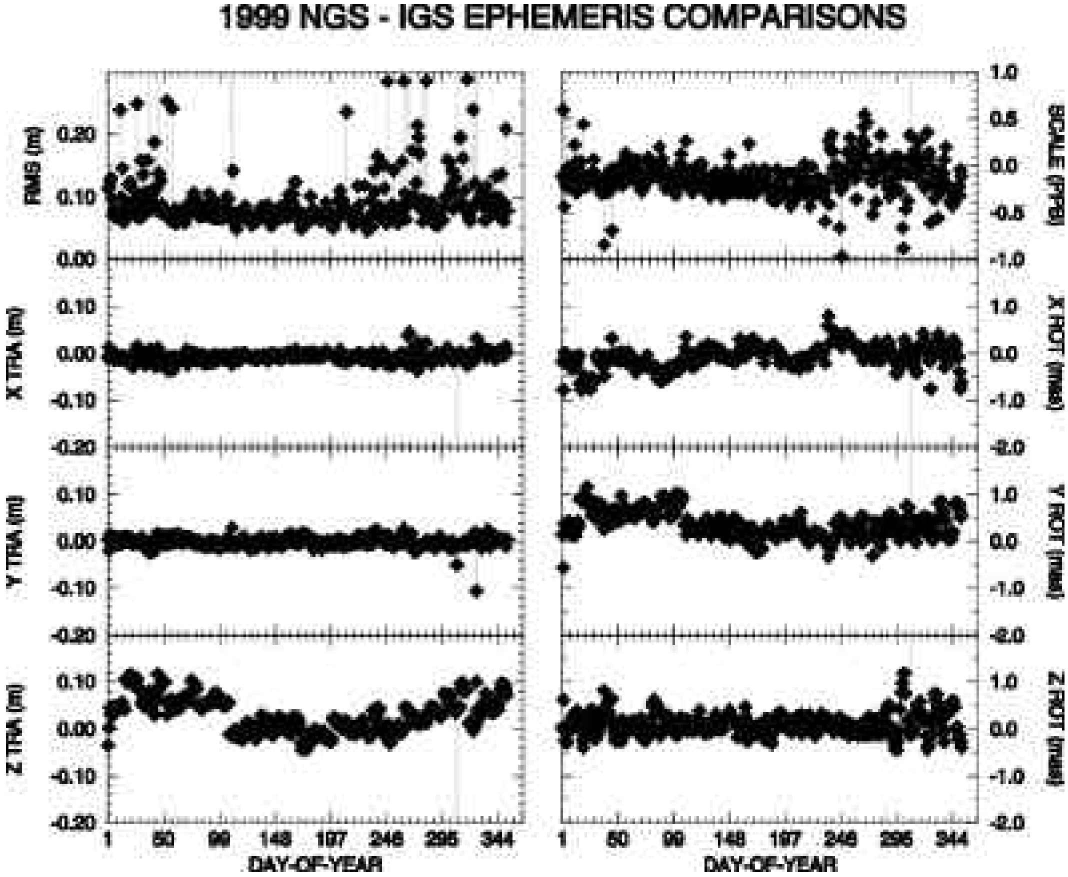


Figure 1. Daily RMS differences between the NGS and IGS final ephemerides for 1999.

NGS Orbit Products

I. Constrained Precise GPS Orbit: Up to 65 constrained IGS fiducial tracking sites in the IGS97, epoch 1997.0 reference frame
available - 3 to 6 days from date of observation
contact - http://www.navcen.uscg.mil/gps/precise/default.htm
accuracy - approximately 5-10 centimeters

II. Minimally Constrained Precise GPS Orbit: A consistent minimally constrained weekly solution in the IGS97, epoch 1997.0 reference frame
available - 4 to 10 days from date of observation
contact - ftp://gracie.grdl.noaa.gov/dist/cignet/Ngsorbits
accuracy - approximately 5-10 centimeters
III. Rapid GPS Orbit: Up to 50 constrained IGS fiducial tracking sites in the IGS97, epoch 1997.0 reference frame
available - 16 hours from last observation
contact - ftp://www.ngs.noaa.gov/cors/orbits/rapid
accuracy - approximately 8-12 centimeters

IV. Ultra-Rapid GPS Orbit: A constrained estimated/predicted solution in the IGS97, epoch 1997.0 reference frame
available - within 2 to 3 hours from last observation
contact - under development
accuracy - approximately 20-60 centimeters

V. Earth Rotational Parameters: Rapid and precise polar motion values
available - 16 hours from date of last observation
recipient - Bureau International de L'Heure (BIH)
United States Naval Observatory(USNO)
International GPS Service (IGS)
accuracy - approximately 0.25 milli-arcseconds

VI. Troposheric estimates for the zenith path delay
available - 4 to 10 days from date of observation
recipient - GeoForschungsZentrum, Potsdam, Germany
International GPS Service (IGS)

Note: NGS, along with the other contributing IGS agencies, switched from the ITRF97 reference frame to the IGS realization of the ITRF97 reference frame on June 4th, 2000.

References

Herring, T. A., and Dong D., 1994, “Measurement of Diurnal and Semidiurnal Rotational Variations and Tidal Parameters of Earth”, J. Geophys. Res., 99(B9), pp. 18051-18071.

McCarthy, D. D. (ed.), 1996, “IERS Conventions (1996)”, IERS Technical Note 21, Observatoire de Paris, pp. 72-77.

Ray, R.D., Steinberg, D.J., Chao, B. F., and Cartwright, D.E., 1994, “Diurnal and Semidiurnal Variations in the Earth’s Rotation Rate Induced by Oceanic Tides”, Science, 264, pp. 830-832.

Ray, R.D., 1995, Personal Communication.

NRCan IGS Analysis Centre Report for 1999

P. Tétreault, C. Huot, Y Mireault, P. Héroux, D. Hutchison, R. Ferland

Geodetic Survey Division
Geomatics Canada, Natural Resources Canada
Ottawa, Canada

Summary

During 1999 NRCan continued its contribution to IGS with submission of final, rapid and predicted GPS derived products including station and satellite clock corrections, station tropospheric zenith delay and daily global ionospheric grids. All recommendations made at the 1999 IGS Analysis Centre Workshop [IGS Mail # 2359, 1999] were implemented in NRCan processing. Preparation for the Y2K rollover, including an upgrade of JPL's GIPSY-OASIS software to version 2.5, was a major activity in 1999.

Estimation Strategy

In 1999 two software upgrades were performed. In December, JPL's GIPSY-OASIS, used for NRCan estimation of rapid and final products, was upgraded to version 2.5. The Bernese software, used for NRCan predicted products, was upgraded to version 4.0 in August and to version 4.2 in December. The basic NRCan estimation strategies remained mostly unchanged for 1999; see [Tétreault et al., 1998 and 1997] for more detail. Table 1 lists all products contributed to IGS in 1999.

Table 1: NRCan Products Contributed to the IGS for GPS Week/Day wwww/d

File Name	Frequency	Content
emrwwwwd.sp3	daily + weekly	estimated GPS satellite positions and clock corrections at 15 minute interval
empwwwwd.sp3	daily	predicted (48 hours) GPS satellite positions at 15 minute interval
emrwwwwd.erp	daily + weekly	EOP parameters and their rate of change at 12 (noon)
emrwwwwd.snx	weekly	station coordinates, EOP's along with their estimated variance-covariance matrix
emrwwwwd.clk	weekly	station and satellite clock corrections with respect to a reference clock (one file per day)

Table 1 (cont'd)

File Name	Frequency	Content
emrwwwwd.tro	daily	daily station tropospheric zenith delays at 2 hour interval
emrwwwwd.yyi	daily	global ionospheric grid in IONEX format

By July 1999, several stations of the IGS global network had been equipped with newer generation GPS receivers, such as the AOA ACT and Ashtech Z-XII. Since pseudorange observations from those newer receivers have satellite dependent biases compared to the AOA TurboRogue's pseudoranges, it was recommended by IGS [IGS Mail 2320, June 1999] that ACT and Z-XII pseudoranges be converted into synthesized "cross-correlated" type pseudoranges. This was necessary in order to mitigate the degradation of the IGS combined clock estimates. This was implemented in NRCan processing for GPS Week 1017.

ITRF97 station coordinates and velocities were adopted, at the beginning of GPS Week 1021, for all NRCan GPS products contributed to the IGS. The resulting discontinuities in NRCan products have been estimated by processing Wk 1021 with station coordinates and velocities from subsets of both the ITRF96 IGS 47 station reference frame and ITRF97 IGS 51 station reference frame. The discontinuities are listed in Table 2.

Table 2: ITRF96 to ITRF97 Discontinuities in NRCan Final Products

Solution	**RX(mas) PMy**	**RY(mas) PMx**	**RZ(mas) - DUT**	**Sc(ppb)**	**TX(cm)**	**TY(cm)**	**TZ(cm)**
Orbits	-0.12	0.22	0.01	0.01	0.09	-0.10	0.85
Sigmas	0.02	0.03	0.01	0.00	0.04	0.03	0.12
Stations	-0.12	0.23	0.01	-1.33	-0.06	0.00	1.20
Sigmas	0.02	0.03	0.01	0.15	0.02	0.02	0.15
EOP	-0.13	0.23	0.09				
Sigmas	0.02	0.03	0.09				

The NRCan 2-day orbit prediction (EMP) processing strategy was revised in 1999. High RMS values for some eclipsing satellites were decreased with the installation of a newer version of the Bernese software (4.0). More realistic RMS were obtained for eclipsing satellites which improved the EMP contribution to the IGS 2-day prediction (IGP).

At the same time and using the newer version 4.0, it was decided to revisit the strategy used to produce EMP. Until then, the last four IGS Rapid orbits (igr) were used to predict two days in the future (4igr+2). The following strategies were tested: [n]igr+2 with n=1,2,…,6. As expected, n=1,5,6 did not give better results than n=4. However, n=3 and even n=2 gave excellent results when compared to n=4. A more thorough analysis indicated that n=2 and n=3 were very close to each other but better results overall were obtained with n=2. Starting with GPS Wk 1023 day 5 (August 20,1999), EMP orbits have been generated using Bernese 4.0 and based on the two last available days of IGS rapid orbits!

A new release of Bernese (version 4.2), Y2K compatible, was installed, tested and used for production starting on GPS Wk 1040 day 6 (December 18, 1999). Only minor improvements were noticed when the switch to version 4.2 happened.

Implementation of GIPSY-OASIS Version 2.5

As part of NRCan preparation plan for the Y2K rollover was an upgrade to version 2.5 of GIPSY. During 1999 new software was developed to implement the NRCan estimation strategy for GIPSY version 2.5. Namely, the STRETCH software [Ferland], which is used to properly propagate the variance-covariance matrix in time, was modified and additional software was required to make use of NRCan estimated orbits for day (n-1) as properly constrained a priori for day (n), thus making possible to estimate UT and LOD separately.

GIPSY-OASIS version 2.5 was implemented on GPS Week 1039 for final products estimation and on Week 1041 for rapid products. Early results are encouraging with a reduction of 4cm in average orbit RMS with respect to the combined IGS orbits. NRCan final products translation in Y and Z were also decreased from about 5cm to about 2cm. Development is currently underway to further improve the quality of NRCan products contributed to IGS.

Acknowledgment

We thank JPL for making available to NRCan their GIPSY-OASIS software and in particular Ken Hurst for his help in getting us started. We also thank our colleagues of the Active Control System Operations and Orbit Processing Team for their assistance.

References

Ferland, R., STRETCH (Stochastic Results Change) Program Description (Draft)

Tétreault, P., C. Huot, R. Ferland, Y. Mireault, P. Héroux, D. Hutchison and J. Kouba (1998). *NRCan IGS Analysis Centre Report, 1997*, in International GPS Service for Geodynamics, 1997 Technical Reports, Jet Propulsion Laboratory, Pasadena, California, pp. 117-122.

Tétreault, P., C. Huot, R. Ferland, D. Hutchison, J. Kouba and J. Popelar (1997*). NRCan Analysis Centre Annual Report for 1996*, in International GPS Service for Geodynamics, 1996 Technical Reports, Jet Propulsion Laboratory, Pasadena, California, pp. 221-232.

IGS Mail # 2320 (1999) Handling mixed receiver types

IGS Mail #2359, (1999) IGS Workshop Summary, by T. Springer and Y. Bock

Scripps Orbit and Permanent Array Center
1999 Global Analysis Center Report

Peng Fang, Matthijs van Domselaar, and Yehuda Bock

Cecil H. and Ida M. Green
Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
University of California San Diego
La Jolla, CA 92037
http://lox.ucsd.edu

Introduction

The Scripps Institution of Oceanography's Orbit and Permanent Array Center (SOPAC) at the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP), has served as a Global Analysis Data Center and Global Data Center since the inception of the IGS. SOPAC is responsible for the collection, archiving, processing and publishing of high-precision continuous GPS data to support the global GPS community. Here we present a chronology of significant analysis changes that occurred at SOPAC in 1998-1999. We describe new products (the hourly and ultra-rapid orbit/EOP solutions) and new Web-based user applications (SOPAC's Coordinate Generator and Site Velocity Generator).

SOPAC also provides analysis support for the Southern California Integrated GPS Network (SCIGN), NOAA's Forecast Systems Laboratory (FSL), and the California Spatial Reference Center (CSRC).

Brent Gilmore, Paul Jamason, and Michael Scharber at SOPAC perform data archiving tasks for the IGS which are described in our Global Data Center report.

Changes in the Routine Analysis of Rapid and Final Products

Our basic processing strategies for 1989-1999 followed the general approach described in the SIO 1997 annual report (Fang et al. 1998). The table below outlines significant changes in our analysis strategy during this two-year period.

Table 1. Significant changes in SOPAC's Analysis (1998-1999)

98 053	Switched from ITRF94 to ITRF96.
98 060	Moved to GAMIT software version 9.69.
98 144	Excluded PRN13 until 150 98 (week 0959).
98 151	Switched to GAMIT version 9.70 to deal with PRN13 mis-modeling problem.

Table 1. Significant changes in SOPAC's Analysis (1998-1999) (cont'd)

98 170	Implemented new UT prediction scheme to cope with Z-rotation in rapid analysis.
98 186	Changed EOP-format to IGS standard (version 2) from GPS Week 0965.
98 193	Moved to the final ITRF96. Core station's coordinates and velocities changed to official values using IGSCB itrf.snx ITRF96_IGS_RS47.SNX. Previous version was a pre-release.
98 219	Changed rapid from 2 day overlap for current day .sp3, to just one day GLOBK. Prediction still uses two day GLOBK solution. Solution accuracy increased significantly and Z-rotation problem eliminated.
98 333	Changed satellites' mass and yaw parameters to reflect IGS specifications. Biggest changes for Block IIR satellites.
99 010	Tightened constraints for all core ITRF sites.
99 020	Rapid solutions switched to GAMIT version 9.72, but still use version 9.70 orbit integrator (ARC).
99 024	Rapid solutions switched from Sun to PC workstations.
99 031	Rapid solution uses new GAMIT yaw table to deal with PRN13. Use the IGS predicted orbit as prior orbit for rapid solutions instead of SIO predicted orbit.
99 031	Final solutions switched to GAMIT version 9.72.
99 063	Relative humidity in input values in GAMIT changed from 0 to 50%.
99 087	Solved unconstraining problem in SOLVE. GAMIT/GLOBK h-files are now really loose.
99 101	Switched to GAMIT version 9.80. GLOBK version 4.17 unchanged (EOP problem not solved yet).
99 115	Cutoff elevation changed from 7 to 15 degrees.
99 157	Switched from GLOBK 4.17 to 5.01 (compatible with 9.80 GAMIT).
99 208	GAMIT solutions switched to ITRF97. Weekly GLOBK solutions still use ITRF96.
99 213	GLOBK solutions switched to ITRF97.
99 220	Switched to GAMIT 9.82, start of degradation in east and vertical components (mainly regional) due to decrease in number of resolved phase ambiguities.
99 220	GPS Week 1022 solutions had multiple problems due to corrupted data caused by SOPAC archive's raid crash.
99 275	Problem with ambiguity resolution found (AUTCLN apply_phs_clk 1 entry), GAMIT 9.82 runs now use 9.80 AUTCLN with apply_phs_clk turned OFF, until problem solved. Repeatabilities return to normal after this change.
99 283	Elevation dependent weighting turned on in GAMIT solutions.
99 289	Hector Mine earthquake in southern California.

Table 1. Significant changes in SOPAC's Analysis (1998-1999) (cont'd)

99 332	All regional solutions are analyzed in postfit editing mode, with 30 s data used in cleaning, decimated to 120 seconds in final SOLVE. Elevation dependent weighting in final solution uses dynamic, site specific model based on values computed in post-fit edit run. Utilizes GLOBK N-file. Started estimating horizontal tropospheric gradients. Elevation cutoff lowered from 15 to 10 degrees.
99 336	Started using station metadata (GAMIT's station.info file) generated by the SOPAC's Oracle database. Wrong codes in old station.info could induce jumps in some time series, particularly when antenna heights changed. Made patch to translate unsupported antenna/receiver codes with supported ones (station.info.db.patch).
99 353	Switched to GAMIT version 9.92.
99 363	Completed transition to full use of SOPAC's Oracle database for site metadata.
99 365	Started estimating troposphere gradients parameters in global solutions and elevation cutoff lowered to 10 degrees.

In the period 1998-1999, SIO final solutions started to include more global as well as regional sites (Figure 1a). The total number of stations used in our rapid solutions remained unchanged (Figure 1b) but the latency of SIO rapid products was lowered from 17 hours to 8 hours (Figure 1c). The performance of SIO final solutions in terms of coordinate estimates with respect to ACs combined and ITRF definition is shown in Figure 2. By the end of this period, the RMS difference between SIO and ACs Combined was at about the 3 mm level and the RMS difference between SIO and ITRF was at about the 4.5 mm level. The performance of SIO tropospheric products in 1998-1999 is shown in Figure 3. The RMS difference between SIO and ACs Combined remained constant at about the 3.5 mm level in total zenith delay and the bias with respect to ACs Combined was reduced considerably over this period.

Introduction of Hourly Products and Participation in IGS Ultra-Rapid Activity

In late 1998 to early 1999, SOPAC started experimenting with hourly orbit generation and its application to ground based GPS meteorology using hourly and 30 minute GPS data from CDDIS/IGN and NOAA/FSL. The processing scheme was implemented in a sliding window fashion, which computed and updated both the estimated and predicted GPS orbits/EOP every hour using a group of hourly data collected within the most recent 24 hour window. For the tropospheric solutions, only last 6-8 hours of data were used. Very encouraging initial results were presented at the EGS XXIII meeting in Nice (Fang and Bock, 1998). From April 1999, SIO started prototype production for selected users. Since August 1999, hourly products are posted for public access. At the 1999 IGS AC workshop in La Jolla, ultra-rapid products were proposed (Gendt et al., 1999) and SOPAC decided to participate by contributing its 0th -hourly and 12th-hourly solutions.

The hourly solutions implement SIO's traditional distributed processing approach by dividing the entire global network into two hemispherical sub-networks with a few (3-4) sites in common. The two sub-networks are processed simultaneously with GAMIT on a dual-CPU PC workstation and then combined with a Kalman Filter procedure using the GLOBK software. To avoid poorly behaved satellites contaminate the solution, only selected satellites are included. The selection is carried out through an orbit overlapping checking procedure, which rejects any satellite that has overlapping rms > 40 cm, from a solution that uses all the satellites. The all-satellite solution is running in parallel on a separate dual-CPU PC workstation and has the identical setup as the hourly solution. The data sampling interval is 120 s. The major parameters solved for are the tropospheric zenith delays at 2 hour intervals and two tropospheric delay gradients at 12-hour intervals. The total processing time is about 40 minutes. Two separate data retrieving processes, usually taking 5-10 minutes to complete, run at 30 minute interval acquiring hourly RINEX files from CDDIS and IGN.

Web-Based Analysis Tools

We have developed several Web-based user applications. The Web pages are provided dynamically with near-real time access to SOPAC's Oracle RDBMS. The Site Information Manager (SIM) provides an easy method for managing permanent GPS site information such as site log management, site problem tracking, and site maintenance. See SOPAC's Data Global Data Center report for an overview of our RDBMS and the SIM.

New analysis tools include a Site Coordinate Generator and a Velocity Map Generator and. The Coordinates Generator (http://lox.ucsd.edu/cgi-bin/Pythagoras.cgi) based on the GAMIT software automatically provides the user baseline estimates relative to the nearest three continuous GPS stations, using precise orbits and integer-cycle phase ambiguity resolution (Figure 4a-d). Coordinates, coordinate uncertainties and a site location map are mailed to the user within about 15 minutes of submission of RINEX data files and relevant site information. The Velocity Map Generator (http://lox.ucsd.edu/cgi-bin/Vortex.cgi) allows the user to produce and manipulate site velocity maps, based on SOPAC-generated coordinate time series, in a variety of user-specified reference frames (Figures 5a-b).

General Information

Current SOPAC Analysis Team:

Peng Fang (pfang@ucsd.edu)
Matthijs van Domselaar (matthijs@josh.ucsd.edu)
Linette Prawirodirdjo (linette@josh.ucsd.edu)
Rosanne Nikolaidis (niko@josh.ucsd.edu)

Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
8785 Biological Grade
La Jolla, CA 92037

References

Fang, P, Y Bock (1998): A Sliding Window Procedure for Super Rapid Near Realtime Continuous GPS Water Vapor Estimation Using Predicted Orbits, Annales Geophysicae, Supplement to Volume 16, ppC376.

Fang, P, M V Domselaar, Y Bock (1998): Scripps Orbit and Permanent Array Center 1997 Analysis Center Report, IGS 1997 Technical Reports, IGS Central Bureau, pp123-129.

Gendt, G, P Fang, J F Zumberge (1999): Moving IGS towards real-time. Proceedings IGS Analysis Center Workshop, 8-10 June 1999, La Jolla, CA, USA, in press.

Acknowledgments

Funding for SOPAC analysis activities is provided by the Southern California Earthquake Center (SCEC) through grants from the William M. Keck Foundation, National Science Foundation, and U.S. Geological Survey, NOAA's Forecast Systems Laboratory, and the California Spatial Reference Center (CSRC). Support from our colleagues at MIT (Tom Herring, Bob King, and Simon McClusky) is greatly appreciated.

Figure 1 (a, b, c). SIO analysis statistics for the period 1998-1999. During this period the number of stations in our final solutions increased to 90-100 while the number of sites in our rapid solutions remained constant at about 50 but with a reduction of latency from about 17 to 8 hours.

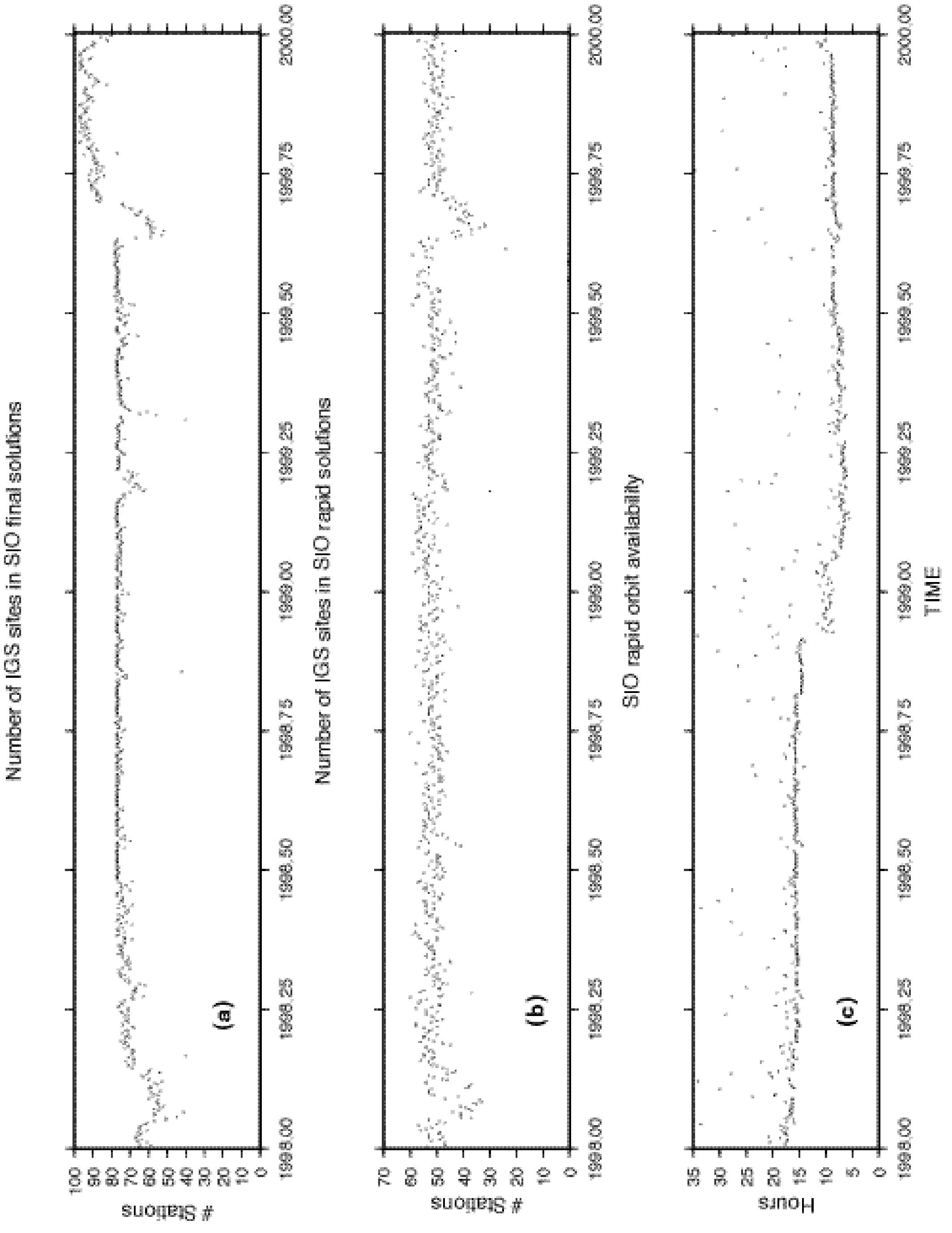


Figure 2. SIO analysis statistics for the period 1998-1999. During this period there was a steady improvement in the precision and reliability of SOPAC's global coordinate solutions.

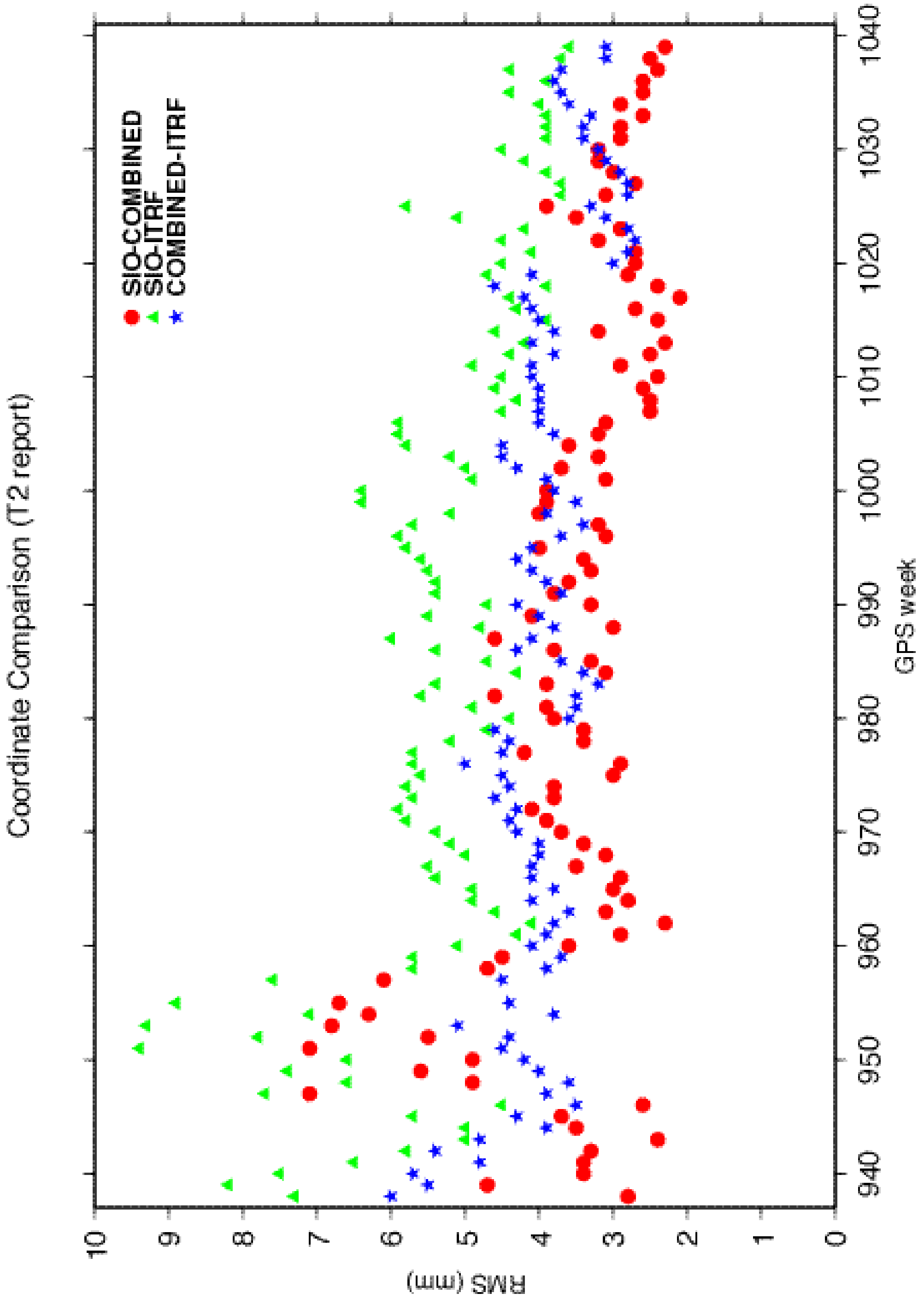


Figure 3. SIO analysis statistics for the period 1998-1999. During this period SOPAC produced tropospheric parameter estimates. The precision of our solutions remained about the same (3-4 mm in zenith delay), but the accuracy (bias) relative to the other IGS centers improved.

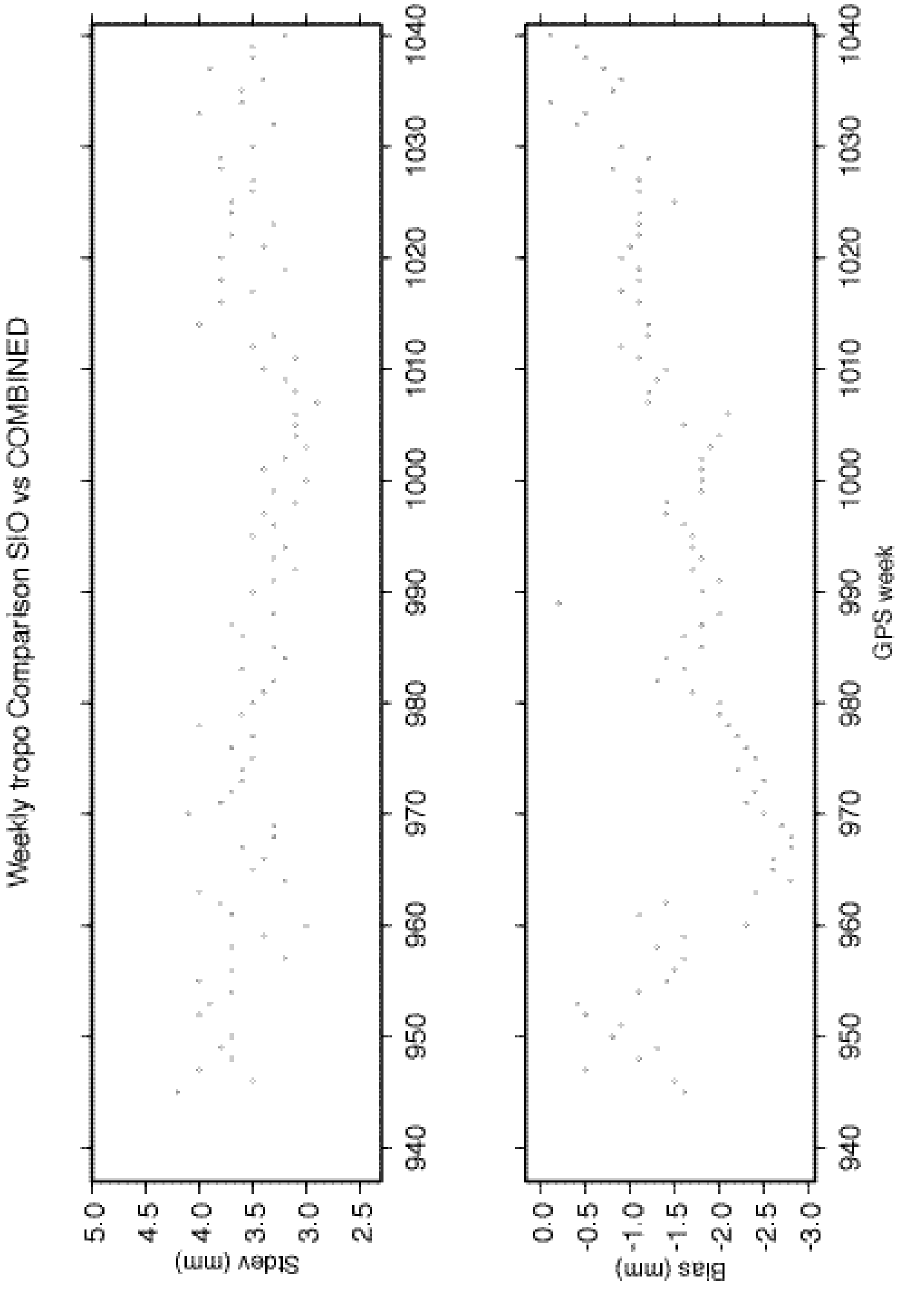
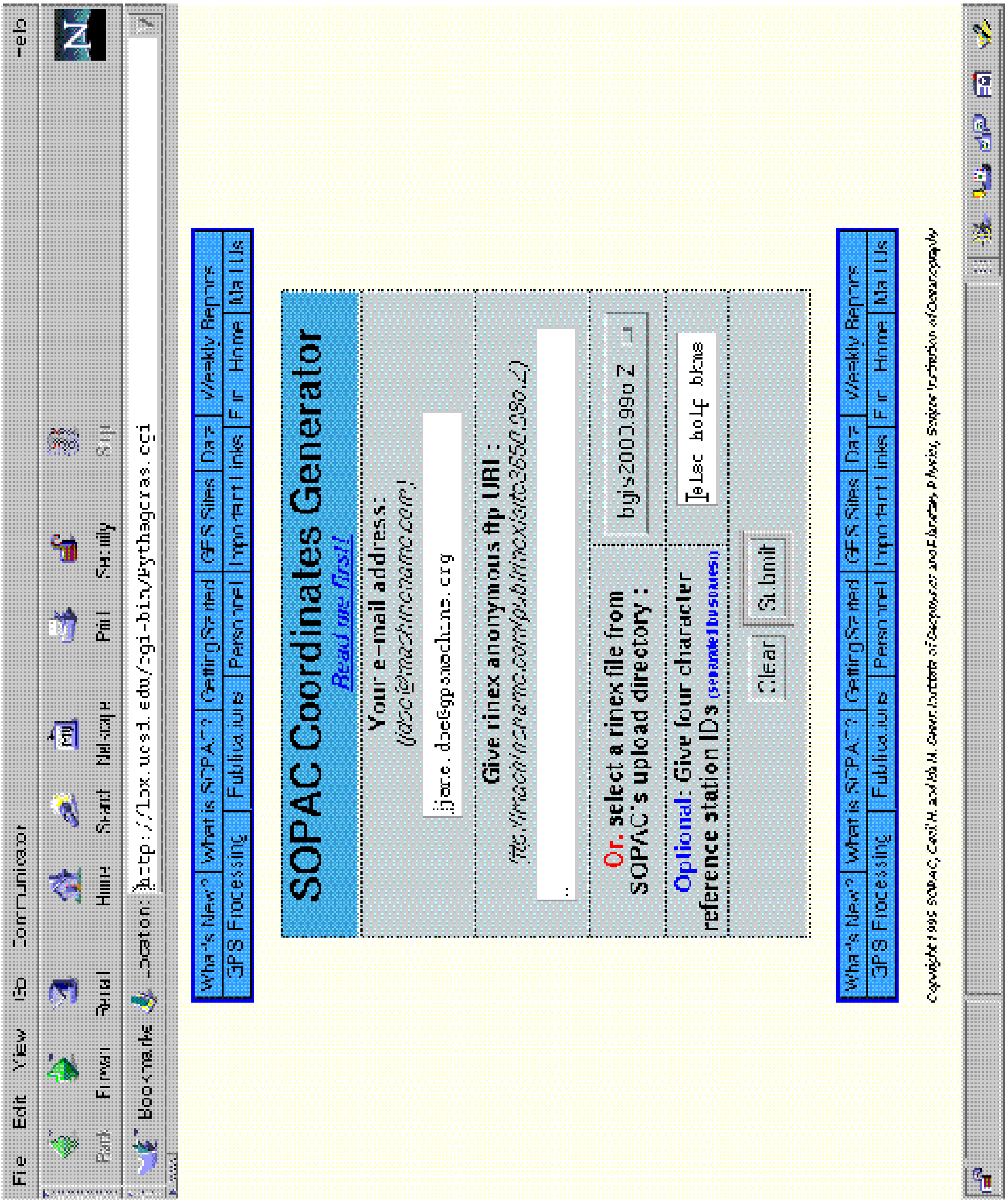


Figure 4a. SOPAC Coordinates Generator: Home panel



Location: http://lox.ucsd.edu/cgi-bin/pythagoras.cgi

SOPAC Coordinates Generator

Read me first!

Your e-mail address:
(jdoe@machinename.com)
jane.doe@gpsmachine.org

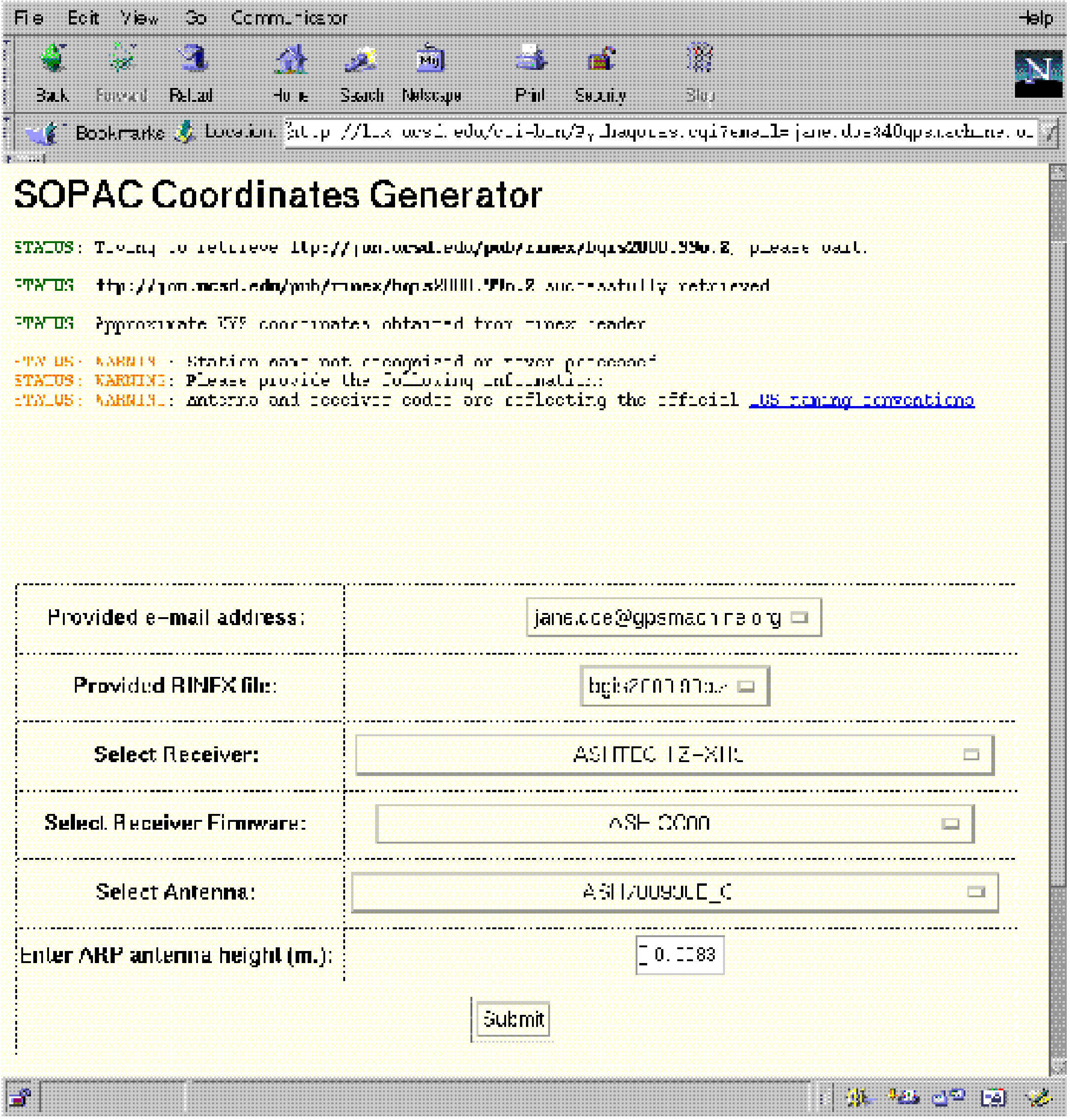
Give rinex anonymous ftp URL :
(ftp://machinename.com/pub/rinex/site3650.98o.Z)

Or, select a rinex file from SOPAC's upload directory :

Optional: Give four character reference station IDs (separated by spaces)

Copyright 1999 SOPAC, Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography

Figure 4b. SOPAC Coordinates Generator: Verification that RINEX dara were successfully retrieved from user's ftp directory and prompting for site-specific metadata.



SOPAC Coordinates Generator

STATUS: Trying to retrieve ftp://gpn.ucsd.edu/pub/rinex/bgis2000.00o.Z, please wait.

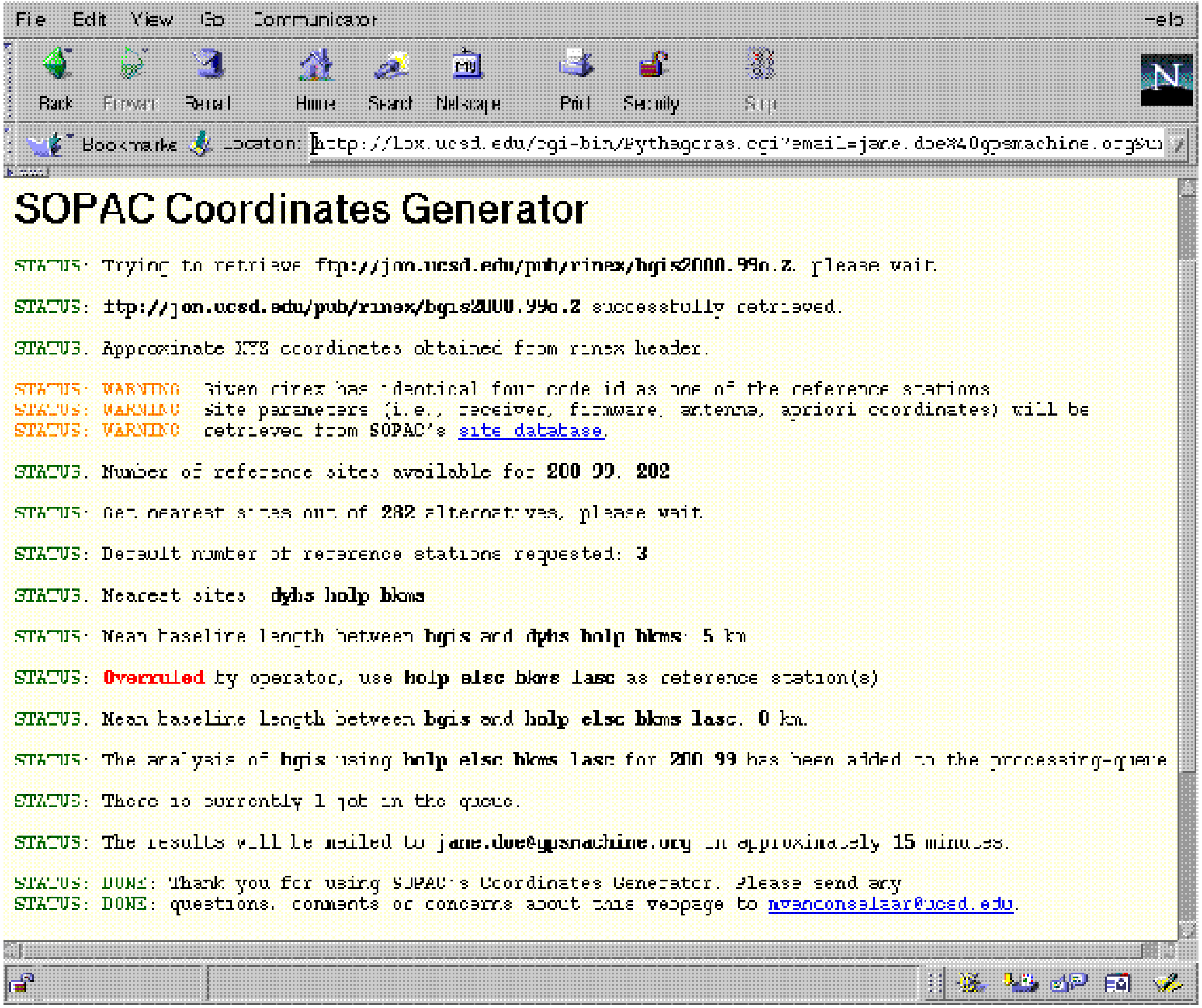
STATUS: ftp://gpn.ucsd.edu/pub/rinex/bgis2000.00o.Z successfully retrieved

STATUS: Approximate XYZ coordinates obtained from rinex header

STATUS: WARNING: Station code not recognized or never processed
STATUS: WARNING: Please provide the following information:
STATUS: WARNING: antenna and receiver codes are reflecting the official IGS naming conventions

Provided e-mail address:	jane.doe@gpsmachine.org
Provided RINEX file:	bgis2000.00o.Z
Select Receiver:	ASHTECH Z-XII3
Select Receiver Firmware:	ASH 2000
Select Antenna:	ASH700936E_C
Enter ARP antenna height (m.):	0.0083

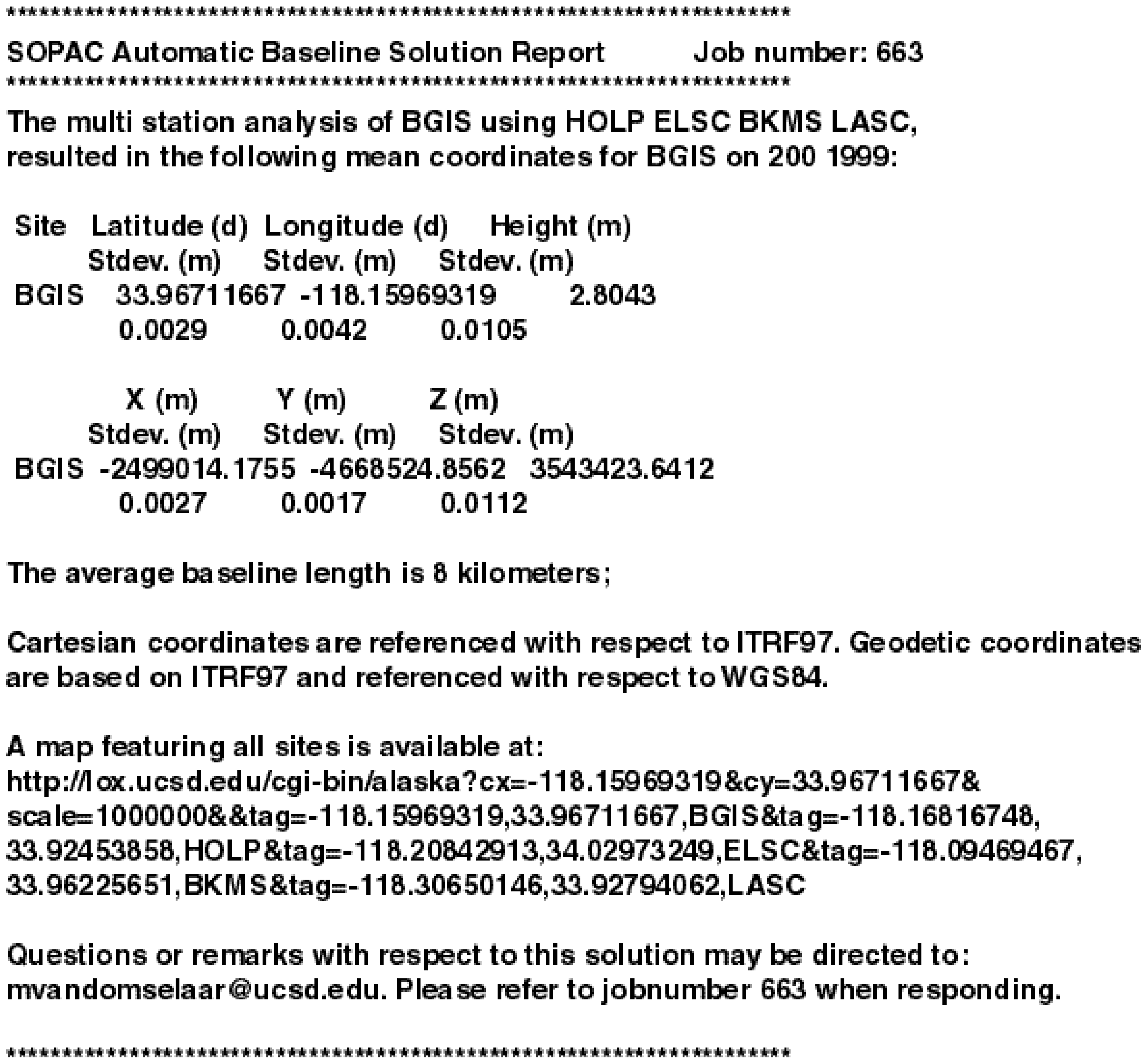
Figure 4c. SOPAC Coordinates Generator: Acknowledments to user and notification that process has been submitted.



SOPAC Coordinates Generator

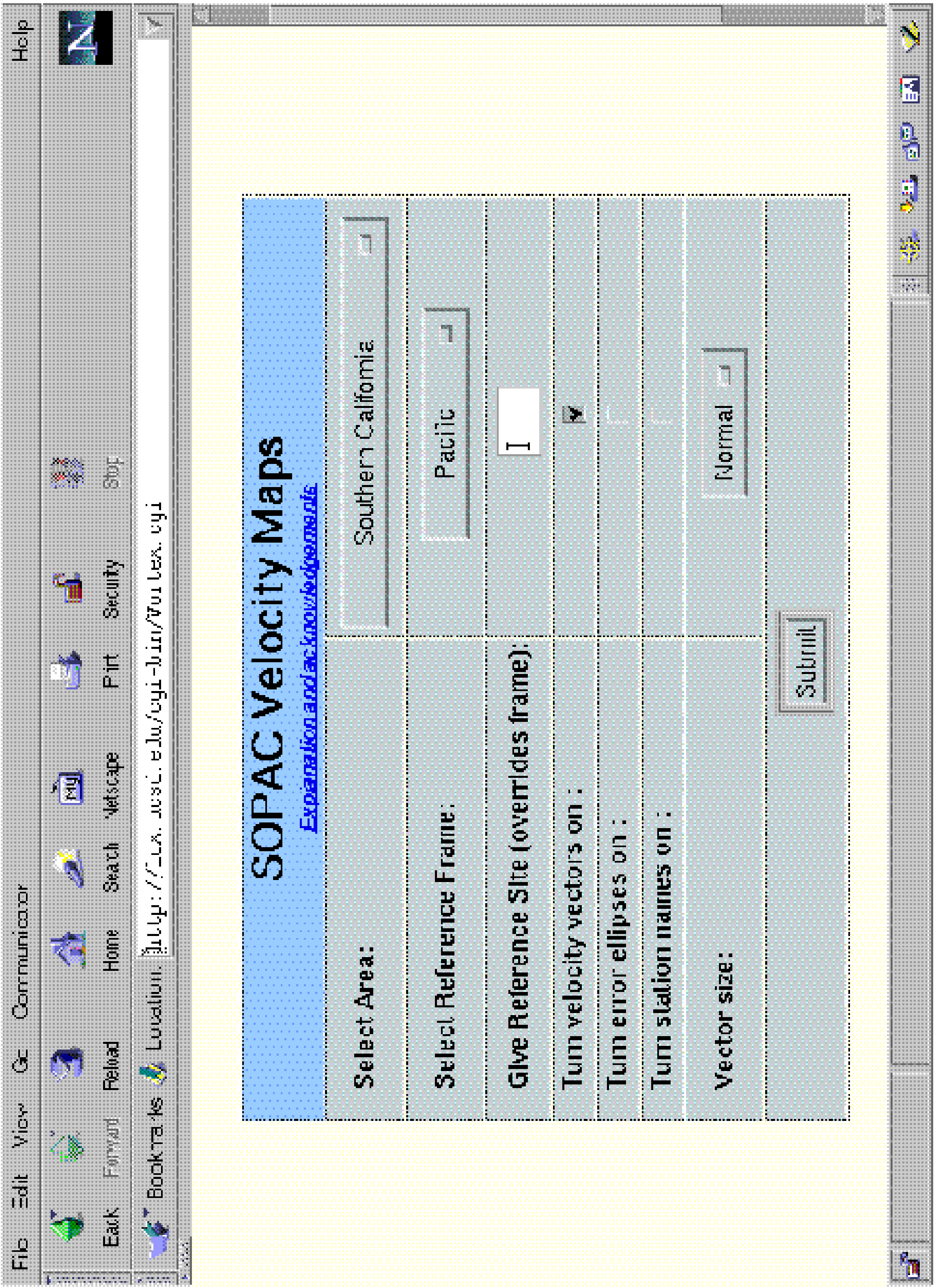
```
STATUS: Trying to retrieve ftp://jon.ucsd.edu/pub/rinex/bgis2000.99o.Z, please wait.

STATUS: ftp://jon.ucsd.edu/pub/rinex/bgis2000.99o.Z successfully retrieved.

STATUS: Approximate XYZ coordinates obtained from rinex header.

STATUS: WARNING  Given rinex has identical four code id as one of the reference stations
STATUS: WARNING  site parameters (i.e., receiver, firmware, antenna, apriori coordinates) will be
STATUS: WARNING  retrieved from SOPAC's site database.

STATUS: Number of reference sites available for 200 99: 202

STATUS: Get nearest sites out of 202 alternatives, please wait.

STATUS: Default number of reference stations requested: 3

STATUS: Nearest sites:  dyhs holp blms

STATUS: Mean baseline length between bgis and dyhs holp blms: 5 km

STATUS: Overruled by operator, use holp elsc blms lasc as reference station(s)

STATUS: Mean baseline length between bgis and holp elsc blms lasc: 0 km.

STATUS: The analysis of bgis using holp elsc blms lasc for 200 99 has been added to the processing-queue

STATUS: There is currently 1 job in the queue.

STATUS: The results will be mailed to jane.doe@gpsmachine.org in approximately 15 minutes.

STATUS: DONE: Thank you for using SOPAC's Coordinates Generator. Please send any
STATUS: DONE: questions, comments or concerns about this webpage to mvandomselaar@ucsd.edu.
```

Figure 4d. Output of SOPAC Coordinates Generator: The estimated station coordinated are provided in Cartesian (XYZ) and geodetic (WGS84) coordinates.



```
*****************************************************************************
SOPAC Automatic Baseline Solution Report          Job number: 663
*****************************************************************************
The multi station analysis of BGIS using HOLP ELSC BKMS LASC,
resulted in the following mean coordinates for BGIS on 200 1999:

 Site   Latitude (d)  Longitude (d)     Height (m)
        Stdev. (m)     Stdev. (m)     Stdev. (m)
 BGIS    33.96711667  -118.15969319         2.8043
            0.0029         0.0042         0.0105

             X (m)          Y (m)          Z (m)
        Stdev. (m)     Stdev. (m)     Stdev. (m)
 BGIS  -2499014.1755  -4668524.8562   3543423.6412
            0.0027         0.0017         0.0112

The average baseline length is 8 kilometers;

Cartesian coordinates are referenced with respect to ITRF97. Geodetic coordinates
are based on ITRF97 and referenced with respect to WGS84.

A map featuring all sites is available at:
http://lox.ucsd.edu/cgi-bin/alaska?cx=-118.15969319&cy=33.96711667&
scale=1000000&&tag=-118.15969319,33.96711667,BGIS&tag=-118.16816748,
33.92453858,HOLP&tag=-118.20842913,34.02973249,ELSC&tag=-118.09469467,
33.96225651,BKMS&tag=-118.30650146,33.92794062,LASC

Questions or remarks with respect to this solution may be directed to:
mvandomselaar@ucsd.edu. Please refer to jobnumber 663 when responding.

*****************************************************************************
```

Figure 5a. SOPAC Velocity Map Generator: Selection panel

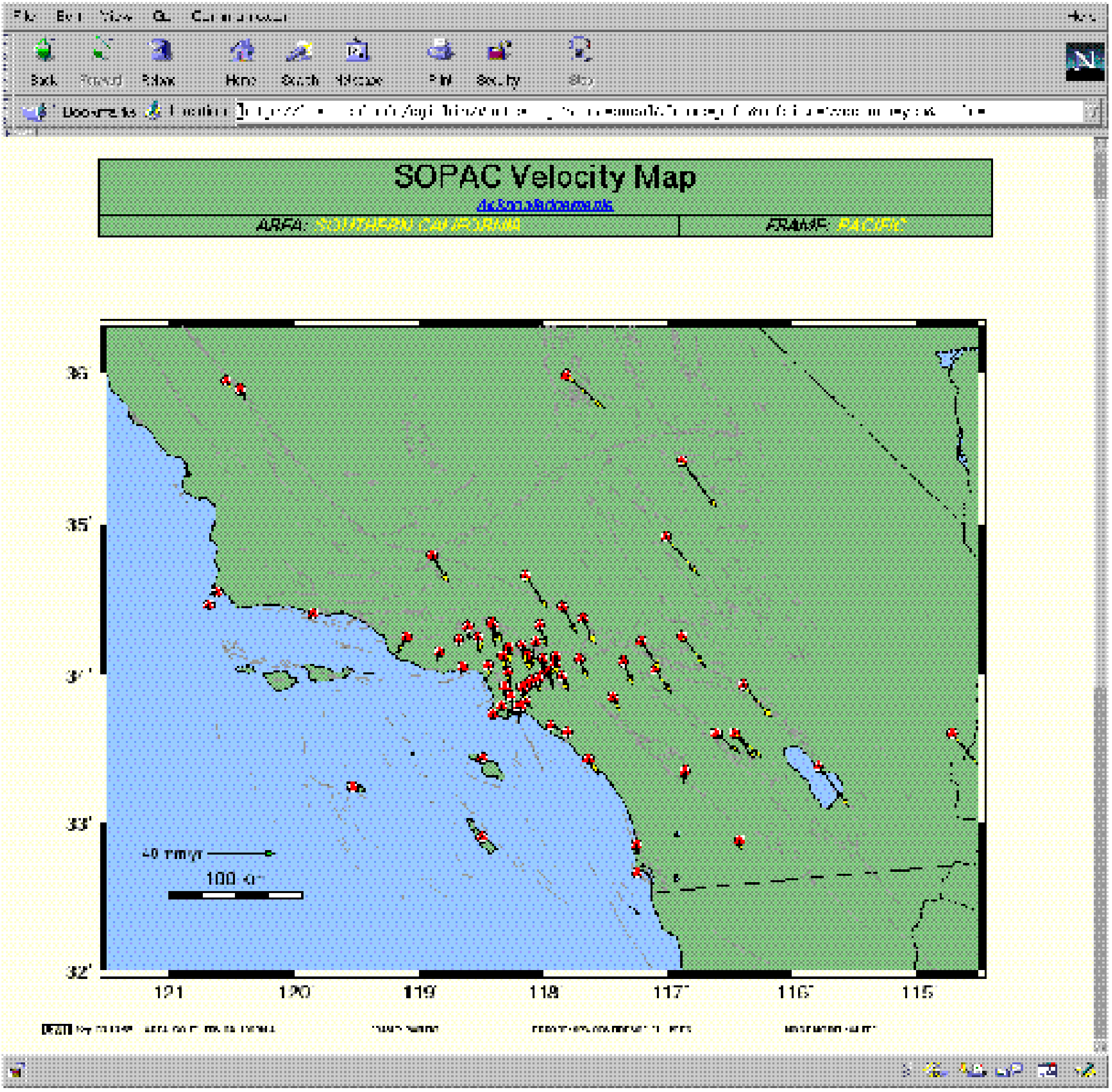


SOPAC Velocity Maps

Explanation and acknowledgements

Select Area:	Southern California
Select Reference Frame:	Pacific
Give Reference Site (overrides frame):	I
Turn velocity vectors on :	☑
Turn error ellipses on :	☐
Turn station names on :	☐
Vector size:	Normal

Figure 5b. SOPAC Velocity Map Generator: Velocity map for the southern California region witrh respect to the NUVEL-1A Pacific plate pole of rotation, based on data collected by the Southern California Integrated GPS Network (SCIGN) and analyzed by SOPAC for SCIGN.



SOPAC Velocity Map

AREA: SOUTHERN CALIFORNIA

FRAME: PACIFIC

IGS

ASSOCIATE ANALYSIS CENTERS

IGS

RAPID SERVICE AND PREDICTION

U.S. Naval Observatory: Center for Rapid Service and Predictions

J. R. Ray, J. R. Rohde, P. C. Kammeyer, B. J. Luzum,
M. S. Carter, V. J. Slabinski, F. J. Josties, A. E. Myers, and H. B. Iz
Earth Orientation Department, U.S. Naval Observatory
Washington, DC 20392 USA

Introduction

The mission of the U.S. Naval Observatory (USNO) includes determining the positions and motions of celestial bodies, measuring the Earth's rotation and orientation, maintaining the master clock for the U.S, and disseminating precise time. The Earth Orientation (EO) Department contributes to this mission by collecting suitable observations and performing data analyses to determine and predict the time-varying orientation of the terrestrial reference frame within the quasi-inertial celestial reference frame. The key parameters determined and disseminated are polar motion coordinates, universal time (UT1), precession, and nutation. The user community is very broadly based with the primary applications being high-accuracy navigation and positioning, particularly for real-time uses.

In order to accomplish these objectives, USNO collaborates closely with a large number of other groups and organizations, and uses a combination of results from a variety of techniques. Very long baseline interferometry (VLBI) is essential in order to maintain accurate knowledge of UT1, the celestial pole, and the celestial reference frame, which is realized by the positions of about 600 extragalactic radio sources. GPS is vitally important also, for its high accuracy, continuous data, and rapid product availability. This report summarizes the status and progress of USNO activities involving the IGS and GPS during 1999.

IERS Sub-Bureau for Rapid Service and Predictions

The IERS Sub-bureau for Rapid Service and Predictions of Earth orientation parameters (EOPs) is hosted by the EO Dept. at USNO. EOP results contributed by many analysis centers derived from observations by VLBI, satellite laser ranging to LAGEOS, lunar laser ranging, and GPS are combined into a homogeneous daily time series which is updated daily and distributed by e-mail twice weekly as *IERS Bulletin A*. Combined EOP values for the recent past are published together with predictions extending a year into the future. The "final" EOP values are published monthly in *IERS Bulletin B*, which is prepared by the IERS Central Bureau at the Observatoire de Paris. The major changes affecting *IERS Bulletin A* during 1999 are summarized in Table 1.

In recent years, the *Bulletin A* polar motion combination has been dominated by the highly precise IGS Final products, with the Rapid series being used for the most recent epochs. The Rapid determinations are quite important for *Bulletin A* by providing timely (delivered daily by 17:00 UTC), high-quality results which are most significant for the polar motion predictions needed by real-time users. In February, the directly observed Rapid polar motion rates were added for the latest epoch to improve the performance of the *Bulletin A* fit at the end of the observational data and hence improve the near-term predictions. The IGS change on 01 August from 47 sites aligned to ITRF96 to 51 ITRF97 sites produced small discontinuities of -0.263 mas in polar motion x and +0.159 mas in y (Springer, 1999). Fortunately, the effects of the frame change were very accurately known thanks to the efforts of the IGS Reference Frame Pilot Project (Ferland, 1999), and corrections have been applied in the *Bulletin A* combination.

Table 1. *IERS Bulletin A* changes during 1999.

02 February	add new analysis of daily VLBI UT1 sessions from St. Petersburg University
11 February	use IGS polar motion rates for latest epoch to improve near-term predictions
06 May	assimilate NEOS VLBI analysis as 3 sub-series to attenuate network-related systematic errors
02 June	new method to assimilate USNO GPS-based UT series in its entirety (not just most recent 22 days)
04 June	inconsistency in weighting SLR polar motion corrected
01 August	IGS switch from ITRF96 to ITRF97
10 August	add new VLBI analysis series from Institute of Applied Astronomy

IERS Bulletin A continues to grow increasingly reliant on IGS estimates of length of day (LOD) and UT1-like variations. In June, the method used to assimilate the GPS-based series from USNO (Kammeyer, 2000) was changed to incorporate the full series beginning 08 July 1998. A calibration trend is computed and applied based on a smoothing of low-frequency differences compared with VLBI. The high-frequency UT1 residuals are about 25 _s. Calibration of the most recent GPS results, after the end of the latest VLBI data, is now based on an ARIMA model extrapolation of the earlier low-frequency trend. No change was made for the GPS-based series from the EMR Analysis Center (Natural Resources Canada) or the integrated IGS LOD series, which continue to be included only for the most recent period.

The new approach provides better UT1 values in the historic *Bulletin A* series where gaps in VLBI data occur and it provides improved rapid service performance by enhancing the stability of the recent GPS calibration.

Errors in predicted EOP values are a significant source of systematic error in the IGS Predicted orbits. An EOP error of 1 mas corresponds to a net rotation of the GPS constellation by up to ~13 cm at altitude. Martín Mur *et al.* (1998) have stressed the need for improved EOP predictions for predicted GPS orbits, which in turn can be used for such real-time applications as atmospheric sounding. We estimate that during 1999 the maximum *Bulletin A* prediction errors that a user of our daily updates would experience were about 0.9 mas for each component of polar motion and about 2.25 mas (or 0.15 ms) for UT1.

All *IERS Bulletin A* information, including plots of the performance of each IGS Analysis Center, is available at <http://maia.usno.navy.mil/>

IGS Rapid Service Associate Analysis Center

During 1999, USNO continued to contribute to the IGS Rapid products and began submitting results for the IGS Predicted orbits in June. Rapid submissions were successfully made for 347 of the 365 days (95.1%). Four days were missed due to corrupt RINEX files from the JPL network; the remaining omissions were caused by data problems at other sites, bugs in the processing scripts, ftp interruptions, and operator errors. The average RMS, weighted RMS, and median of the USNO Rapid orbit residuals for the year were 8.4 cm, 7.1 cm, and 6.3 cm, respectively, a considerable improvement over our 1998 performance. This can be attributed to a refined orbit modelling strategy, mostly completed in early 1999, together with adoption of GIPSY version 5.2 in January. A two-stage process is employed with a first solution using 30 sites followed by a second solution using 33 sites. The results of the first solution are used to adjust satellite-dependent data weights and stochastic acceleration sigmas for the orbit parameterizations in the second solution. In this way, the sometimes erratic behavior of certain satellites can be accommodated better in the solutions submitted to the IGS. Strengthening checks of data quality and site/satellite rejection has been an ongoing process necessitated by the continuous emergence of new types of data problems and configuration changes at the stations. Significant changes in the USNO Rapid analysis strategy during 1999 are summarized in Table 2. Other notable events surrounded the GPS week 1000 rollover on 07 March, the week 1023 rollover on 21 August, and the Y2k New Year, each of which brought mostly minor disruptions.

Table 2. USNO analysis changes during 1999.

05 January	GIPSY/OASIS-II version 5.2 adopted operationally
05 January	begin using IGS satellite antenna phase center offsets
14 April	stochastic acceleration parameters given larger steady-state sigmas for satellites with poor fits in 1st solution
18 May	start using noncc2cc to synthesize cross-correlation pseudoranges from non-TurboRogue receivers
22 June	satellite data deweighting algorithm modified for poorly behaved satellites
28 June	apply *a priori* deweighting (x2) to satellite data for PRNs 14, 16, 18, 19, & 23
01 August	IGS switch from ITRF96 to ITRF97
20 December	GIPSY/OASIS-II version 5.5 adopted operationally
20 December	operations moved from HP J2240 to HP J5000 workstation

The data analysis software used at USNO continues to be the GIPSY/OASIS-II package, which was developed and maintained by JPL. The version was upgraded from 4.8 to 5.2 then to 5.5.

USNO began submitting contributions for the IGS Predicted orbits on 24 June; they were used in the combination beginning 08 July and for 174 of the 177 remaining days (98.3%). Compared to the IGS Rapid combination, the average RMS, weighted RMS, and median of the USNO orbit prediction residuals for the year were 464 cm, 230 cm, and 31.9 cm, respectively. Improved algorithms were implemented in September (see below), which greatly reduced the RMS and weighted RMS residuals after that time by better accounting for problem satellites (particularly those subject to regular thrusting events for attitude control). The average RMS residual improved from 635 to 329 cm while the average WRMS residual fell from 354 to 133 cm due to these changes.

In forming the USNO predictions, each satellite orbit is fit to past observed positions from the IGS Rapid products using standard gravitational models, the CODE extended solar radiation pressure model (Springer *et al*., 1999), and a "constant" along-track acceleration correction estimated for each spacecraft. The nominal fitting arc is six days, except during eclipse season when four days are used. The 3D RMS of the fit is computed. Starting in September, no predictions are produced for a satellite when the RMS exceeds 40 cm, indicating a problem satellite. This change reduced the number of extreme prediction RMS values. A second improvement made that month allowed for a slow linear change in the "constant" along-track acceleration correction as a function of sun angle from the orbit plane. This change contributed to the decrease in average RMS values starting in September. In addition, satellites in eclipse season, or subject to frequent thruster firings, were given poorer accuracy codes starting the same month, a change which subsequently yielded lower WRMS values.

Work began on developing a new process of Ultra-Rapid solutions, twice daily with only 2.75 hours turnaround time, as recommended at the IGS Analysis Center Workshop held in La Jolla in June. Operational implementation is expected in early 2000.

H. Baki Iz joined our staff in mid-1999 to assist with operational activities and to investigate methods for improved orbit modelling.

GPS Time Transfer Activities

A growing interest at USNO is the use of geodetic GPS techniques for precise time transfer. Besides full participation in the IGS/BIPM timing project (Ray, 1999), USNO supports this effort in a variety of other ways. In particular, two geodetic GPS receivers are operated and supplied with 5 MHz reference signals from ultra-stable, steered H-masers, one at USNO in Washington, DC (connected to Master Clock 3) and the other at Schriever Air Force Base in Colorado Springs, CO (connected to the Alternate Master Clock). During 1999, both receivers were upgraded from AOA model TurboRogue SNR-12 RM to SNR-12 ACT models. While the new receivers provide much better pseudorange observables, especially at the L2 frequency, they have an undiagnosed problem with the data offload process which can cause them to fail rather frequently. This is operationally very annoying and highly detrimental for timing applications because continuous data spans are now usually limited to a week or less. Efforts to circumvent this problem are underway.

USNO continues to post plots of clock analysis results from our Rapid solutions as well as from our “Final” clock solutions. The latter set use a larger network consisting of many sites equipped with high-quality frequency standards, and the IGS Final orbits and EOP values are fixed without adjustment. Plots and data files are distributed for the Final clock solutions. These results are available at the Web site <http://maia.usno.navy.mil/gpsclocks/index.html>.

GPS Determinations of Universal Time

As before, Kammeyer’s (2000) operational procedures continue to determine UT1-like variations by comparing observed, Earth-fixed GPS satellite ephemerides to numerically propagated models of their orbit planes. The modelled orbit planes are propagated using empirical models for the orbit-normal component of the radiation pressure acceleration. These models are expressed in terms of the angle from the orbital angular momentum to the Sun direction and the angle from the projection of the Sun direction onto the orbit plane to the position vector of the satellite. For each satellite and each time, there is a unique axial rotation angle which brings the observed Earth-fixed positions into alignment with the propagated orbit plane. The difference between the ascending node of the modelled orbit plane and that of the actual orbit plane for each satellite causes this rotation angle to differ by an offset from Greenwich apparent sidereal time. Adding to the rotation angle an estimate of this offset gives a single-satellite estimate of sidereal time and equivalently of UT. Taking the median of these estimates for the 12 satellites modelled gives the UT estimate reported to *IERS Bulletin A*.

During 1999, significant changes were made in the operational use of Kammeyer's series in the *IERS Bulletin A* combination. The new methodology has been described above. This change has benefitted the *Bulletin A* UT1 performance considerably by providing much better "interpolation" through VLBI data gaps and by permitting more accurate "extrapolation" after the latest VLBI epoch. Efforts are underway to implement further improvements, such as by including more GPS satellites. In addition, investigations have begun into the sources of the residual nodal motions, which could include mass redistributions within geophysical fluids as well as errors in the modelling of radiation pressure effects.

References

Ferland, R., IGS Reference Frame Pilot Project, in *IGS 1998 Annual Report*, Jet Propulsion Laboratory Publication 400-839, Pasadena, California, 28-30, 1999.

Kammeyer, P., Determining a UT1-like quantity by comparing observed GPS orbits to numerically-propagated models of orbit planes, submitted to *Celestial Mechanics and Dynamical Astronomy*, 2000.

Martín Mur, T.J., T. Springer, and Y. Bar-Sever, Orbit predictions and rapid products, in *1998 IGS Analysis Center Workshop Proceedings*, European Space Operations Centre, Darmstadt, Germany, 73-88, 1998.

Ray, J.R., IGS/BIPM time transfer project, *GPS Solutions*, **2**(3), 37-40, 1999.

Springer, T., ITRF96/97 IGS product change, IGS Electronic Mail #2432, 20 Aug. 1999.

Springer, T., G. Beutler, and M. Rothacher, A new solar radiation pressure model for GPS satellites, *GPS Solutions*, **2**(3), 50-62, 1999.

IGS

GLOBAL NETWORK ASSOCIATE ANALYSIS CENTERS

The Newcastle GNAAC Annual Report for 1998-1999

Konstantin Nurutdinov, David Lavallee, Peter Clarke and Geoffrey Blewitt[*]

Department of Geomatics
University of Newcastle upon Tyne
NE1 7RU, UK
[*] *Also at Nevada Bureau of Mines, University of Nevada at Reno, USA*

1999 saw the continuation of Newcastle GNAAC activities with submissions of a weekly G-network and P-network SINEX files and associated summary files. The analysis procedure outlined previously (Kawar et al., 1997, 1998., Davies 1995, 1996.) remained unchanged throughout the years 1998 and 1999. Starting GPS week 1021 the ITRF-97 (51 stations) is used instead of ITRF-96 (47 stations) to constrain the solution. Most of the software has been moved from HP-UX machine to SUN Spark station in the end of 1999.

G-network Results

A-network SINEX data from all seven global analysis centres (COD, EMR, ESA, GFZ, JPL, NGS, SIO) were processed in the years 1998 and 1999, the appearance of a station in a minimum of 3 solutions defining a global station and inclusion in the NCL G-network (Figure 1). Any remaining stations and RNAAC (AUS, EUR, SIR) stations (Figure 2) are defined as regional stations and are included in P-network along with global stations. During 1999 an average of 90 global and 54 regional stations appeared in weekly P-network, this contrasts with 89 and 49 during 1998 and 68 and 36 during 1997 respectively.

Figure 3 shows the RMS of residuals for each weekly loose G-network solution after Helmert transformation to the weekly mapped kinematic solution for all weeks since the project began. A steady improvement with time can be clearly seen, the RMS values for north, east and up-components are 2.1, 3.6, 4.2 mm respectively during the year 1998 and 1.9, 3.4, 3.9 during first 32 weeks of the year 1999. These values describe repeatability of the G-network estimates.

The loose G-network solution is estimated from block of normal equations composed of each deconstrained A-network. The corresponding covariance matrix is augmented to remove Helmert rotation parameter constraints. This solution is constrained later to the CORE 51 stations of ITRF-97 for second half of the year 1999 (47 stations of ITRF-96 for the year 1998 and first half of the year 1999) producing constrained G-network.

Figures 4 through 8 show the translation (for X, Y, Z coordinates) and scale parameters for 7-parameter Helmert transformation from deconstrained AC and loose NCL G-network (GNET) solutions to ITRF-96 and ITRF-97 on corresponding time intervals. These figures demonstrate that Helmert parameters for NGS and EMR are the most unstable. This is because of nonglobal distribution of stations (mainly in west hemisphere) and (for EMR) relatively small number of stations. The parameters for NCL look more smooth and low-value compared to AC values.

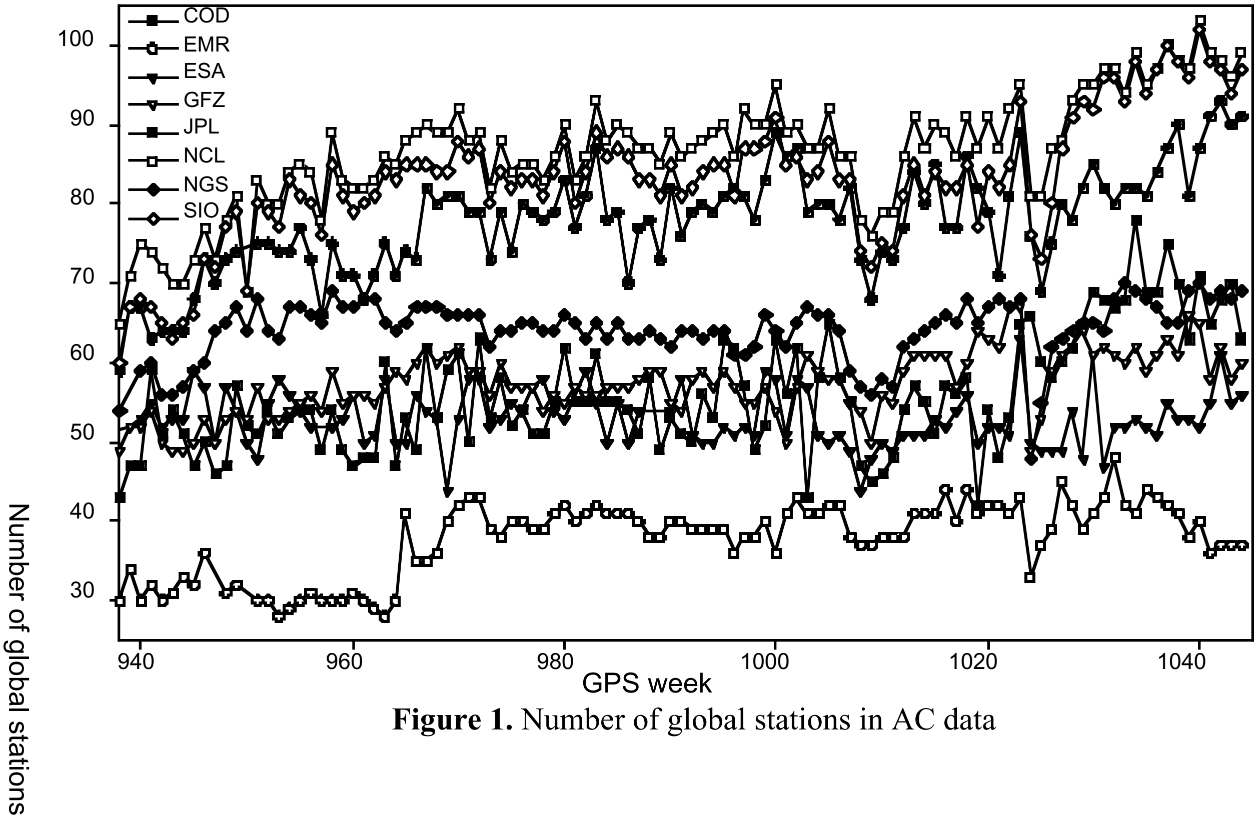


Figure 1. Number of global stations in AC data

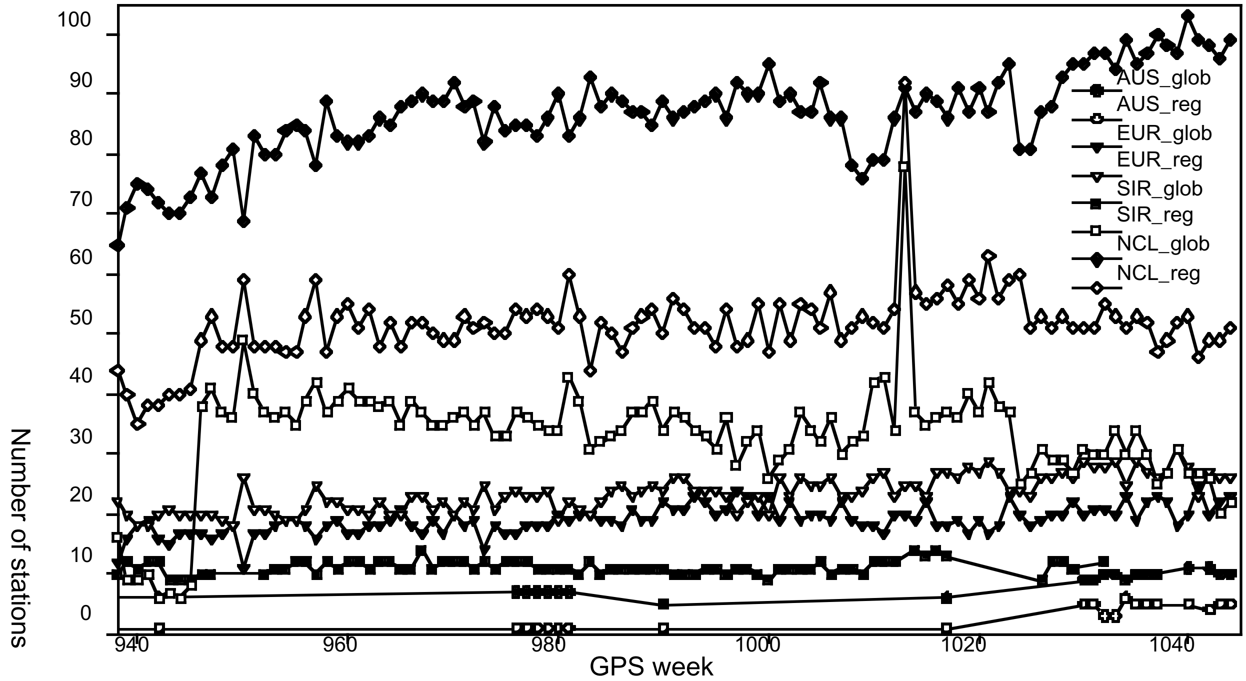


Figure 2. Number of global and regional stations in RNAAC and P-network solutions

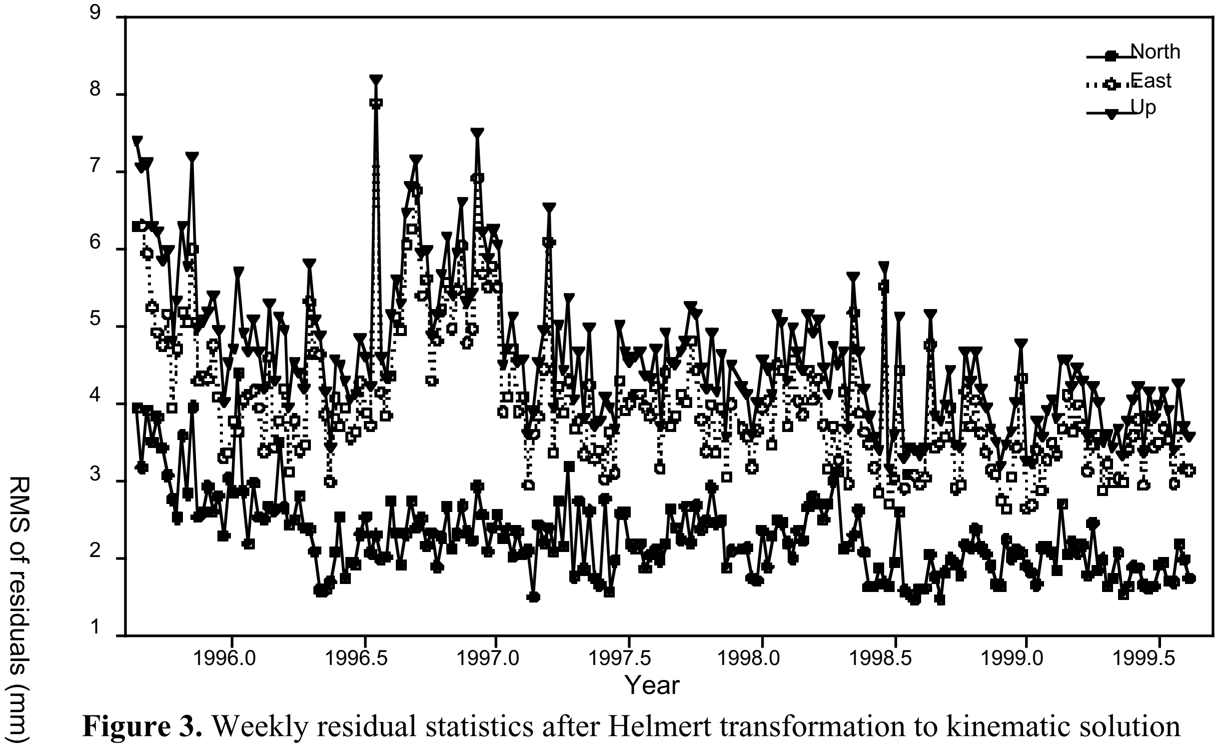


Figure 3. Weekly residual statistics after Helmert transformation to kinematic solution

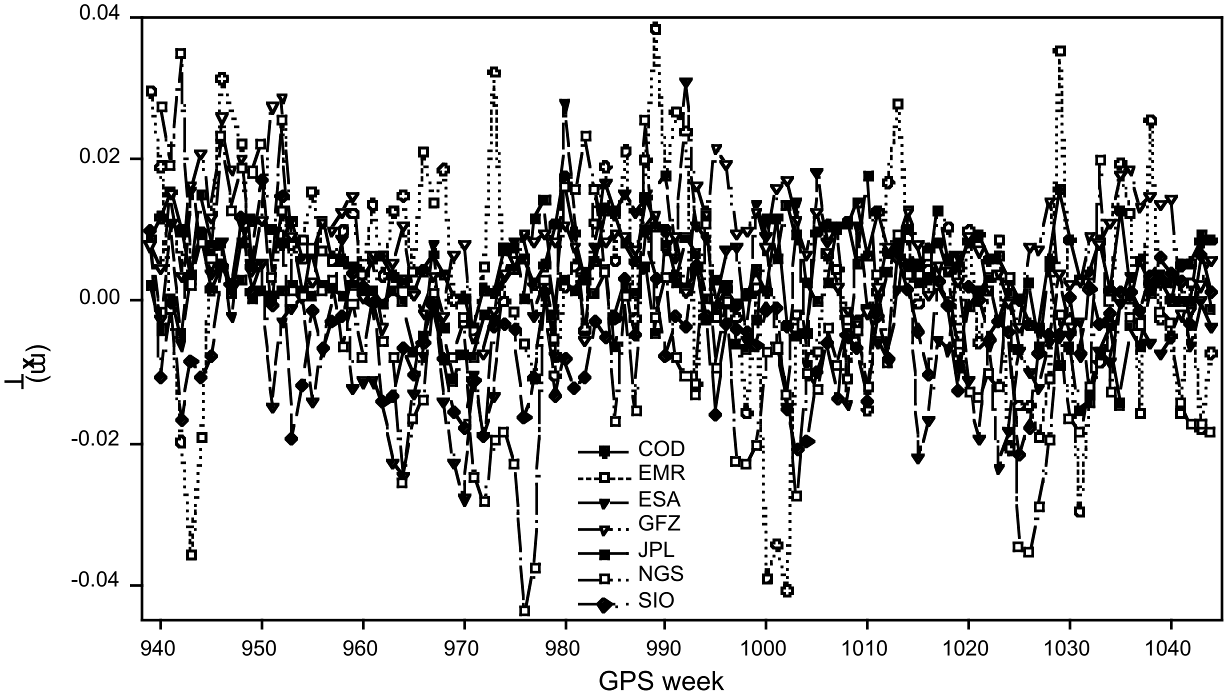


Figure 4. Time series of T_x transformation parameter for the ACs to ITRF

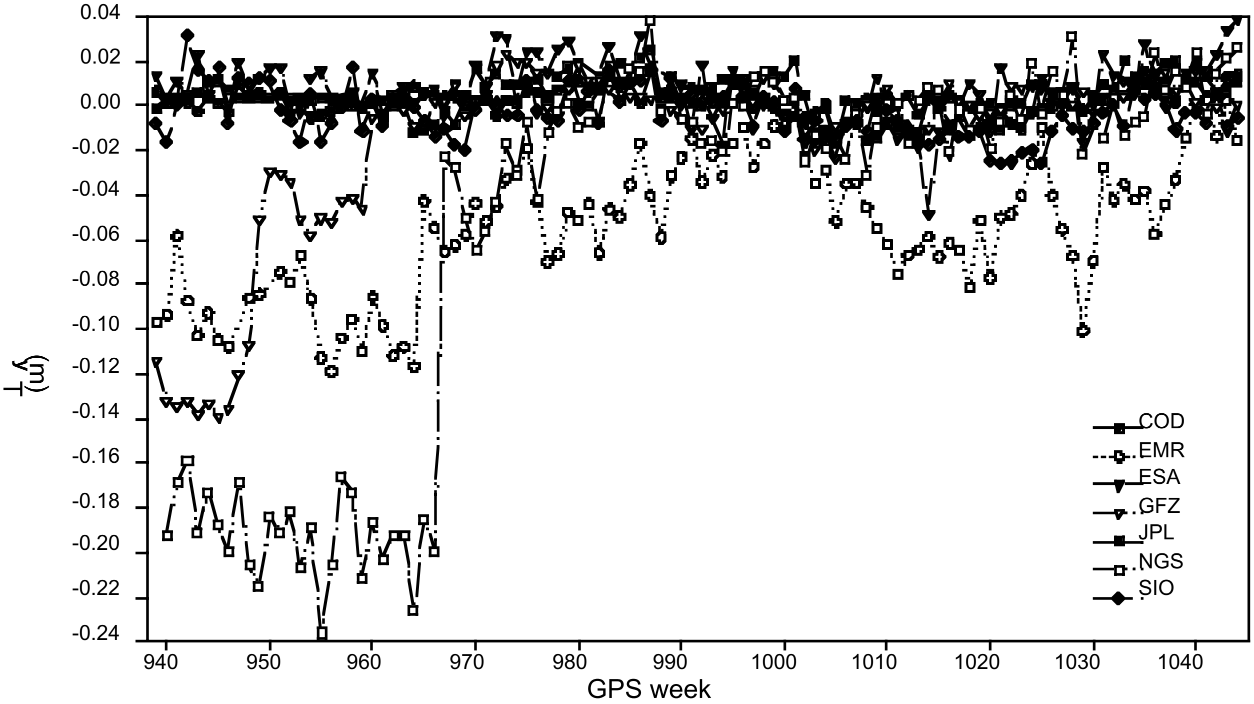


Figure 5. Time series of T_y transformation parameter for the ACs to ITRF

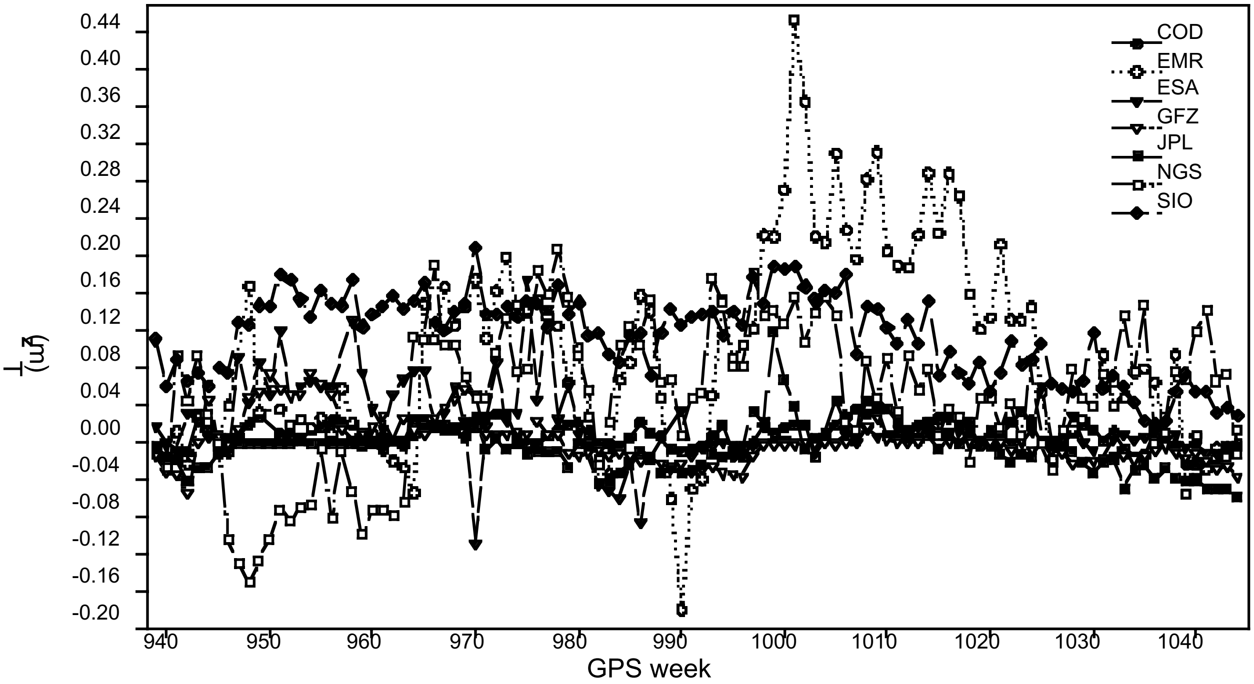


Figure 6. Time series of T_z transformation parameter for the ACs to ITRF

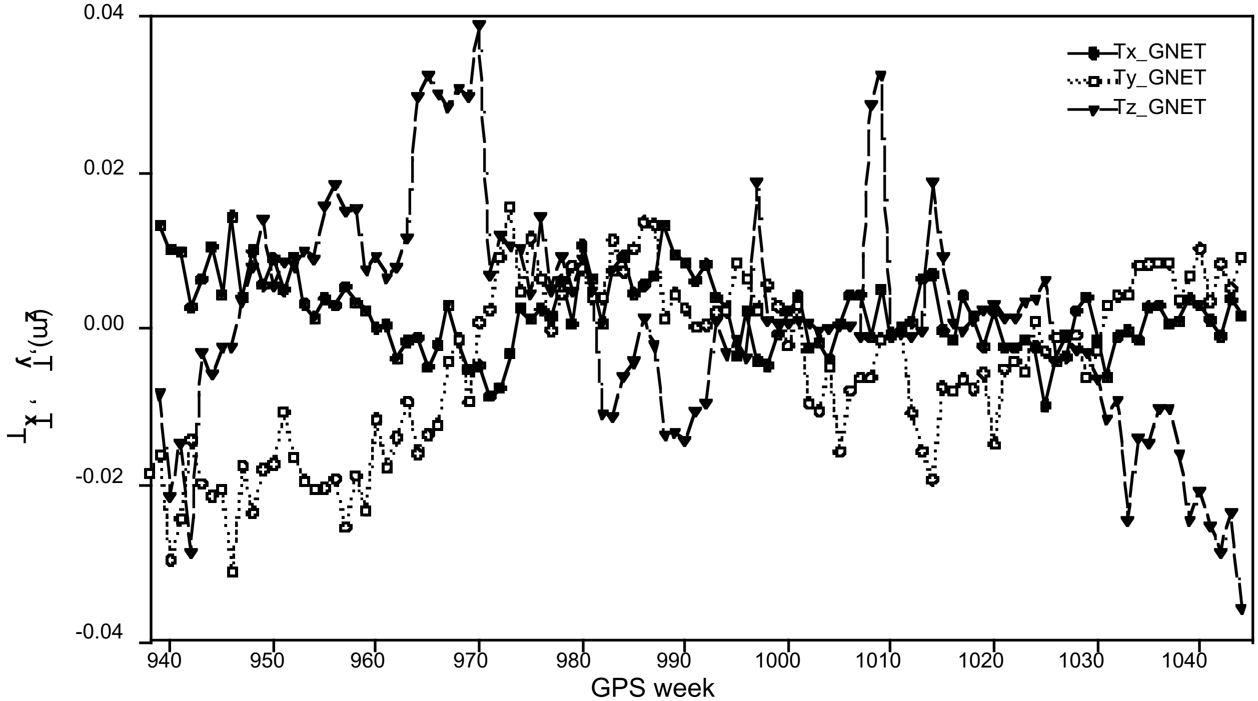


Figure 7. Time series of T_x , T_y , T_z transformation parameters for the NCL GNET to ITRF

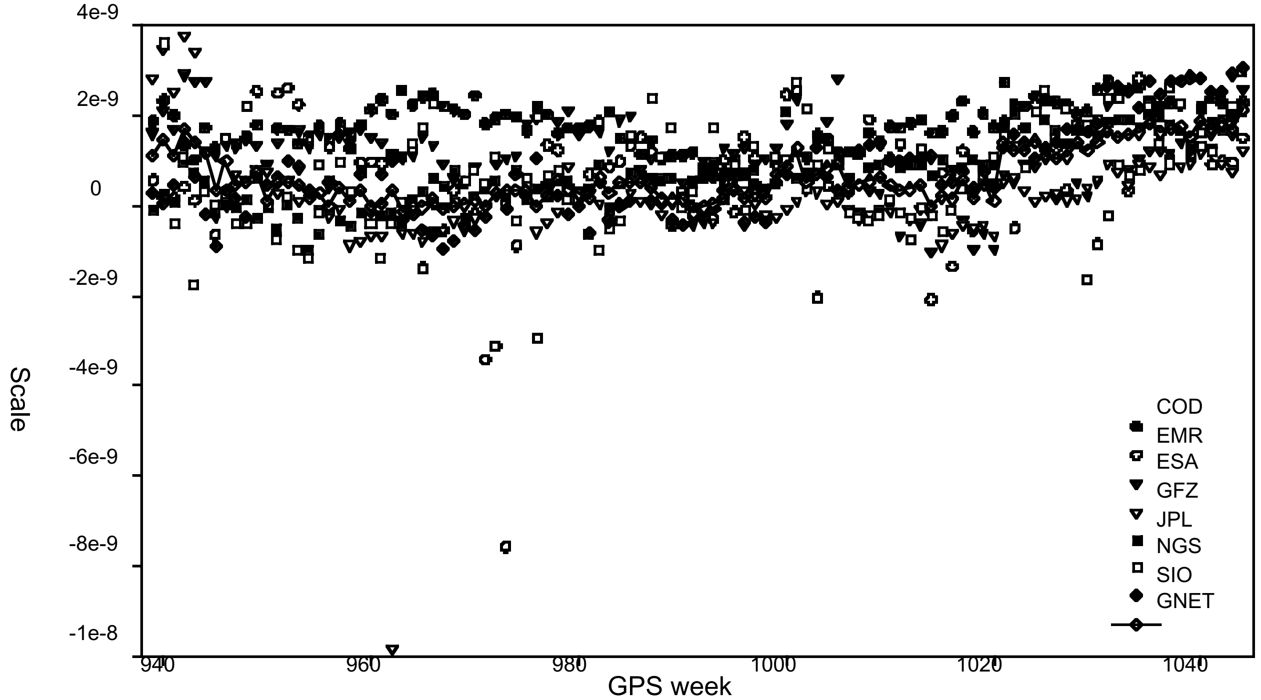


Figure 8. Time series of scale parameter for ACs and NCL GNET to ITRF

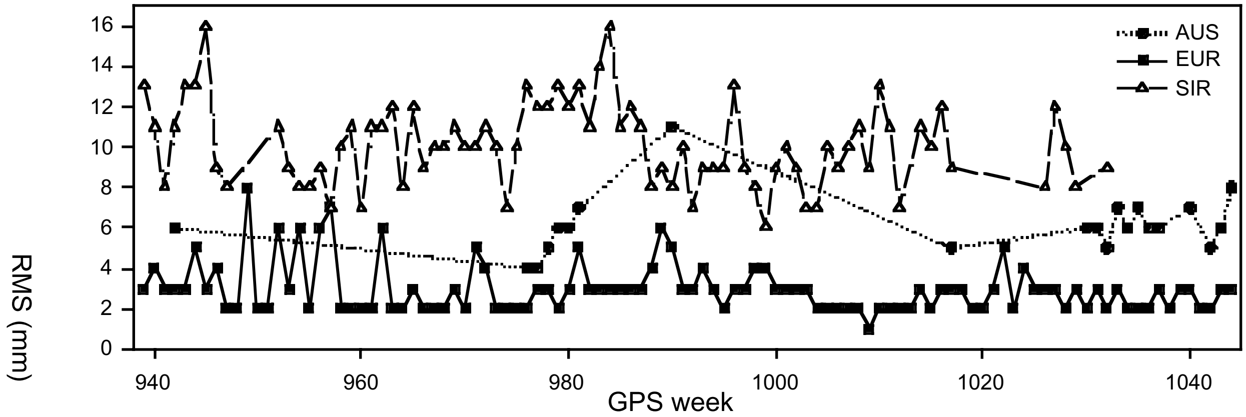


Figure 9. RMS of residuals for RNAAC R-network transformation to loose NCL G-network

P-network Results

Creation of P-network is based on G-network and the weekly input R-SINEXes from the RNAACs. A minimum of 3 global and 1 regional stations is required for inclusion of solution in the P-network. However this was not the case sometimes. More often, late submission (later than three weeks after the G-network process) of SINEX files by some RNAACs (AUS, SIR) was the main reason of why their solutions have not been included in P-network. From the RNAACs the solutions from EUR, SIR and AUS were included 52, 31, and 11 times respectively during 1999, contrasting with 52, 51 and 11 during 1998 and 52, 38 and 6 in 1997.

In the used attachment method of network combination the G-network is not allowed to be perturbed by the R-networks. Figure 9 shows time series of the RMS residuals after 7-parameter Helmert transformation of deconstrained R-network to the loose NCL G-network.

References

Kawar, R., Blewitt, G., Davies, P., The Newcastle Global Network Associate Analysis Centre. Proceedings of the IGS Analysis Centre Workshop, Darmstadt, February 9-11, 1998.

Kawar, R., Blewitt, G., Davies, P. The Newcastle Global Network Associate Analysis Center Annual Report. International GPS Service for Geodynamics (IGS) 1997 Annual Report, 139-147, 1998

Davies, P. B. H., Blewitt, G., The Newcastle Global Network Associate Analysis Center Annual Report 1996. International GPS Service for Geodynamics (IGS) 1996 Annual Report, 237-252, 1997.

Davies, P. B. H., Blewitt, G., The Newcastle Global Network Associate Analysis Center Annual Report 1995. International GPS Service for Geodynamics (IGS) 1995 Annual Report, 189-200, 1996.

MIT T2 Associate Analysis Center Report

Thomas A. Herring
Department of Earth, Atmospheric, and Planetary Sciences,
Massachusetts Institute of Technology, Cambridge, MA 02139

Abstract

We discuss the analysis of the 1999 combined solutions generated from the SINEX files submitted by the IGS analysis centers. We highlight the changes to the analysis procedures reported in previous annual reports. Analysis of our combined solutions shows mean fits to the up to 43, and on average 41, ITRF97 reference sites of 3.7 mm. For the G-SINEX combinations the median root-mean-square (RMS) repeatability in north, east, and height are 1.9, 2.4 and 5.6 mm, respectively for 173 sites. For the P-SINEX combinations, the median RMS repeatabilities are 1.9, 2.1, and 5.9 mm, respectively for 230 sites. Estimates of daily pole position and length-of-day (LOD), now included in our G-SINEX analysis, deviate from IERS Bulletin A with RMS scatters of 0.16 and 0.19 milli-arc-seconds (mas) in X- and Y-pole position, and 0.023 milliseconds (ms) in LOD.

Analysis Procedure Changes

As reported previously [*Herring*, 1996,1997], two analyses are performed each week. One of these analyses uses the IGS Analysis Center (AC) weekly A-SINEX files to generate a combined G-SINEX file, and the other uses the Regional Analysis Center (RAC) R-SINEX files combined with the G-SINEX file to generate weekly P-SINEX files. In 1999, the G-SINEX files contain 173 sites that were used more than 10 times during the year and 65 sites that were used every week. The corresponding values for the P-SINEX files are 230 and 94 sites, respectively. The G- and P-SINEX analyses are performed 3 and 7 weeks delays.

The basic procedures we use are documented in the weekly summary files submitted with the combined SINEX files. The two changes of note are associated with (a) deconstraining SINEX files, and (b) incorporation of Earth rotation parameters in the weekly analyses. Also starting at the beginning of 1999 we began applying the pole-tide correction to the ESA, NGS and SIO SINEX files (the other analysis center already appear to be applying these corrections). We also adopted an automatic correction feature that reads the igs.snx file, and applies corrections to the analysis center SINEX files if there are differences. If the antenna type is correct, then this procedure should generate the same result as if the analysis center had used the correct information in the original processing. The corrections applied are reported each week in the summary file. Corrections were still needed even by the end of 1999 and into 2000. Typically, 3-4 station heights and 1-2 antenna phase offsets need correction per week.

Deconstraining AC SINEX Files

All of the IGS analysis centers now submit either loosely constrained SINEX files (JPL, SIO) or SINEX files with minimum constraints applied (EMR, GFZ, NGS, COD and ESA). For this latter group of analysis centers we add to their covariance matrix a rotational deconstraint with variance of (10 mas)^2. This additional matrix is generated by computing the full covariance between station coordinates and Earth orientation parameters for rotations about each axis with (10 mas)^2 variance. Two analysis centers (ESA and GFZ) are applying constraints to the center of mass position. We are currently not removing these constraints because we have not implemented in our software the necessary algorithms to undo these types of constraints. As a result, our estimates of center mass motion can not be considered reliable indicators of true center of mass motions or of the quality of the GPS determinations.

Earth rotation parameter estimation

We now carry forward into the SINEX combinations the estimates of Earth rotation parameters. In our combination we allocate elements in the Kalman filter state vector for the Earth orientation parameters (value and rate of change) for each day of the week centered at 12:00 UTC. The stochastic variations in these parameters are treated as a combination of a random walk (process variance 1 mas^2/day for pole position, and 0.066 ms^2/d of UT1) and integrated random walk (0.1 mas^2/day^3) for pole position and 0.007 ms^2/day^3 for UT1). The initial values at the start of the week are assumed to have variances of (100 mas)^2 for pole position, (10 mas/day)^2 for polar motion rate, (6.7 ms)^2 for UT1 and (0.67 ms)^2 for length of day. We ignore the values of UT1 given in the input SINEX files, i.e. the estimates of UT1 in our combined SINEX files are the IERS Bulletin A values at the start of week and integration of LOD for later days in the week.

We apply corrections to the submitted SINEX for some centers. For JPL, prior to January 1, 2000, we treat the input LOD as being regularized even through it is not given as LODR. For all dates, we reverse the sign of LOD since the submitted values appear to be the time derivative of UT1. For GFZ, we reverse the sign of UT1 since it appears to be given as UTC-UT1. (This latter change has little effect because we do not use the UT1 values).

Analysis of Combined Solutions

Our analysis of 1999 combined SINEX files examines the internal consistency of these combinations and their agreement with ITRF97. In Figure 1, for each weekly combination in 1999, the RMS agreement between theITRF97 reference sites is shown (list of sites given in weekly summary files and the number of sites used in the realization). This RMS is computed from the combination of the north, east, and height differences after a translation, rotation, and scale are removed from the weekly combination. In computing the RMS, the height is down-weighted by a factor of 3 (i.e., we construct a weight matrix with the heights given one-tenth the weight of the horizontal components).

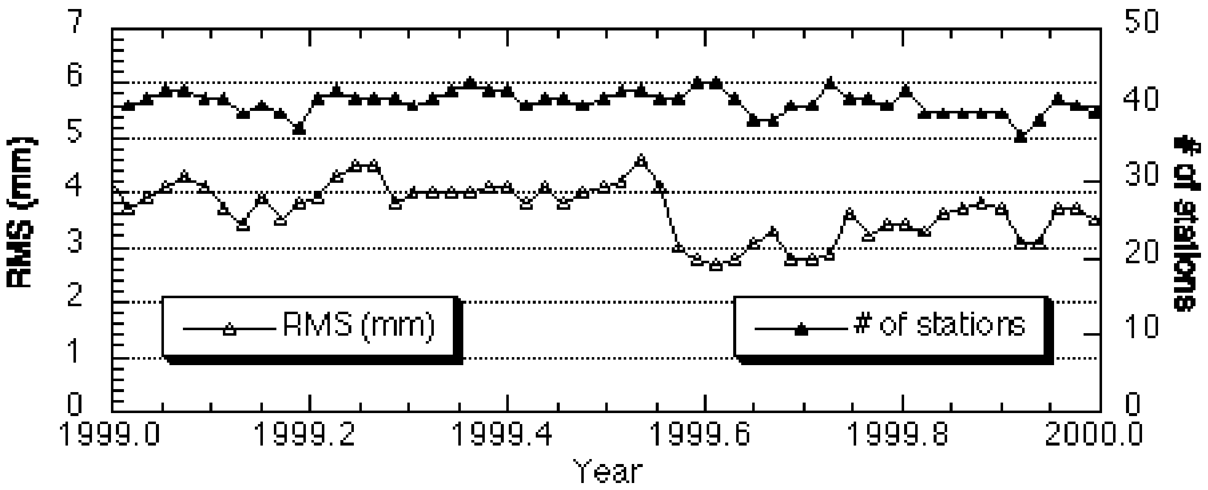


Figure 1. RMS fit of the weekly combinations to the up to 43 ITRF97 reference sites. The mean RMS fit is 3.7 mm with a median of 41 stations form the reference site list used.

In Figure 2, we show the estimates of the differences between the G-SINEX estimates of pole position and LOD. Some of the systematic differences seen in the pole position differences arise from errors in the treatment of EOP parameters and changes in the analysis center data that were being used in the combination. Near the end of 1999 and continuing into 2000 the differences between our pole position estimates and IERS Bulletin-A are considerably reduced. From December 1999 forward, the RMS scatters of the pole position differences reduce to about 0.05 mas. The behavior of LOD remains unchanged in the latter part of the time series and this may be because we are not yet correctly fixing the problems in the analysis center EOP estimates (or the analysis center has fixed a previous problem but we are not aware that the change has been made). Overall the RMS scatter of the LOD differences are small compared to the magnitude of LOD variations (RMS 0.41 ms for the variations compared to 0.02 ms for the differences). For reasons that are not clear, the combination appears to underestimate the uncertainties of the EOP parameters by a much larger factor than station positions.

In Figure 3, we show the histograms for the repeatabilities of the sites in the G- and P-combinations. Although the RMS scatters are small, they are typically three-times larger than the standard deviations of the estimates. The time series of the position estimates also show systematic variations (see http://www-gpsg.mit.edu/~fresh/MIT_IGS_AAC.html). The median RMS scatters for the G- and P-SINEX solutions are similar with the P-SINEX being a little smaller in the East component suggesting that bias fixing in the P-SINEX files (which tend to contain sites with shorter intersite distances) may improve the East repeatability. The ratio of the scatter of the position estimates to their uncertainties is 10% larger for the P-SINEX files suggesting that the errors are underestimated by a larger factor than the G-SINEX files. Despite rescaling of the covariance matrices of individual centers to make χ^2-per-degree of freedom (χ^2/f) near unity, the scatter of the position estimates is 2-3 times larger than the error bars would suggest. Interestingly, the height errors appear closer to the scatter (ratio 2) than the errors horizontal errors do (ratio 3). Analysis of the power spectra of the site position residuals shows these spectra have red-noise characteristics which is consistent with χ^2/f being larger than unity.

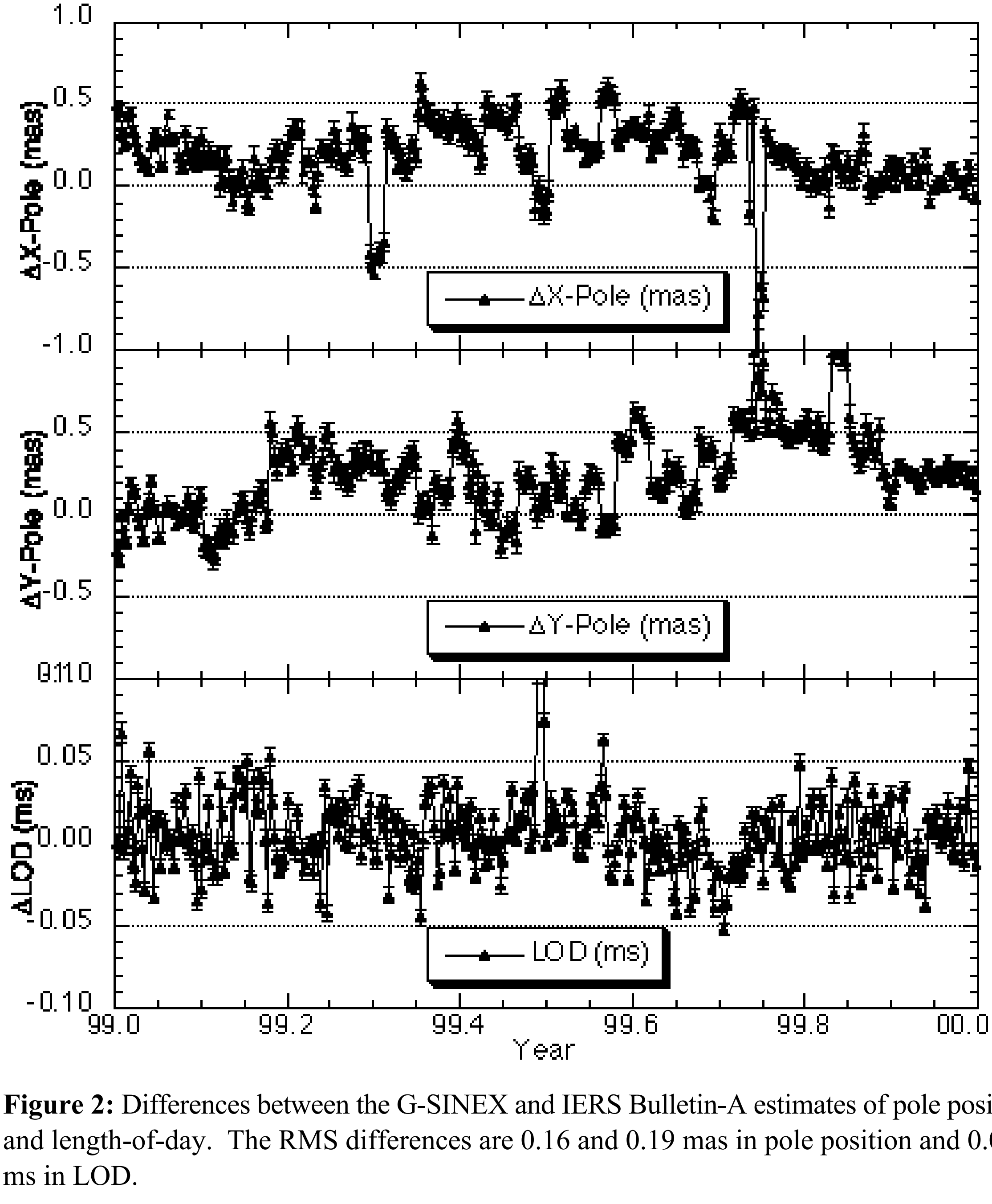


Figure 2: Differences between the G-SINEX and IERS Bulletin-A estimates of pole position and length-of-day. The RMS differences are 0.16 and 0.19 mas in pole position and 0.023 ms in LOD.

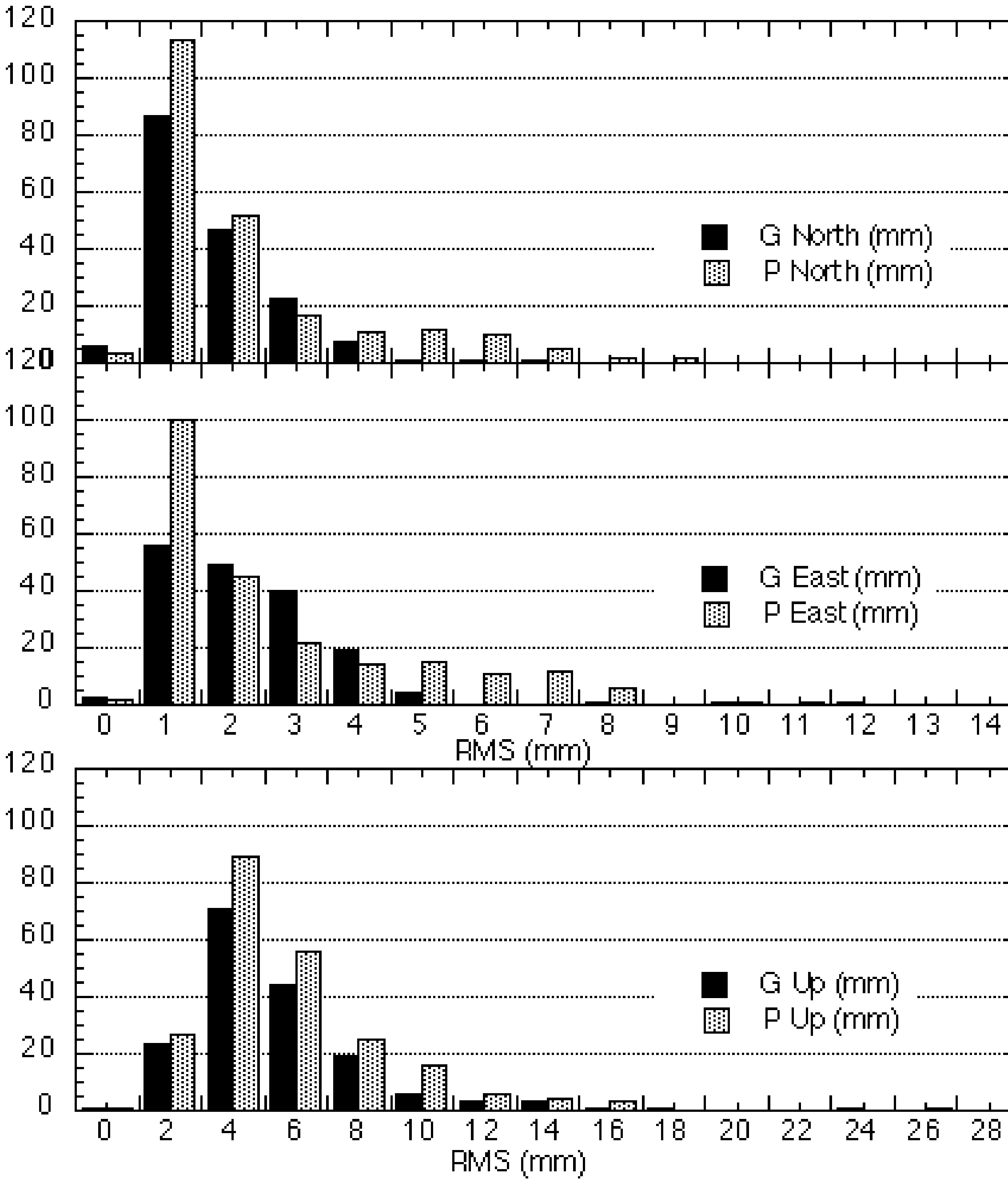


Figure 3: Histogram of the repeatabilities from the G- and P-SINEX combinations. The median values are 1.9, 2.4, and 5.6 mm for the north, east and height in the G-SINEX combinations and 1.9, 2.1, and 5.9 mm in the P-SINEX combinations. For horizontal components, the P-SINEX solutions have median ratios of the scatter to the standard deviations from the combination of 3.2 compared to 2.8 for the G-SINEX. For heights, the ratio medians are about 1.8 and 2.0 for the G- and P-SINEX files.

References

Herring, T. A., MIT Global Network Associate Analysis Center Report, *International GPS Service for Geodynamics (IGS) 1995 Annual Report*, pp. 203-207, 1996.

Herring, T. A., MIT T2 Associate Analysis Center, *International GPS Service for Geodynamics (IGS) 1996 Annual Report*, pp. 255-267, 1997.

GNAAC Coordinate Comparisons at JPL for GPS Weeks 813-1054

M. B. Heflin, D. C. Jefferson, M. M. Watkins, F. H. Webb, and J. F. Zumberge
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA 91109 USA

R. F. Meyer and R. Liu
Raytheon
Pasadena, CA 91109 USA

Global Network Associate Analysis Center (GNAAC) activities began at JPL starting with GPS week 813 (95Aug06). Constraint removal was implemented on week 821 (95Oct01) and a combination was computed starting with week 837 (96Jan21). Sinex 1.0 format was implemented on week 890 (97Jan26). New sinex software was implemented starting week 1013 (99Jun06) for the GNAAC combination which excludes sites without an official IGS log file. GNAAC processing was contracted to Raytheon starting week 1041(99Dec19).

Solutions from COD, EMR, ESA, GFZ, JPL, NGS, and SIO are obtained from the CDDIS, IGN, or SIO archives each week. Apriori constraints are removed to the level of about 10 meters if necessary. Each possible pair of solutions is compared after application of internal constraints and estimation of three rotations, three translations, and one scale. Transformation parameters for each pair are given in the report along with the WRMS of residuals. Tables 1 and 2 summarize the transformation parameters with respect to JPL for all weeks and the most recent 52 weeks respectively. The x-component of geocenter location continues to agree at the level of 1 cm or better for all centers. The y-component agreement is also better than 1 cm for COD, EMR, GFZ, and NGS relative to JPL. The z-component remains more difficult although COD, JPL, EMR, and GFZ are all within 2 cm. Scale agreement remains at the level of 1.2 parts per billion or better.

Table 1. Mean Geocenter and Scale with respect to JPL for GPS weeks 837-1054.

Center	TX cm	TY cm	TZ cm	Scale ppb
COD	0.7	-0.2	0.8	0.5
ESA	0.1	-8.4	9.0	-0.2
EMR	-0.0	1.2	2.3	0.9
GFZ	-0.2	-3.8	1.8	-0.3
NGS	-0.2	-11.7	9.1	-1.1
SIO	-0.2	-0.5	8.3	-0.3

Table 2. Mean Geocenter and Scale with respect to JPL for GPS weeks 1003-1054.

Center	TX cm	TY cm	TZ cm	Scale ppb
COD	0.5	-0.1	1.6	0.4
ESA	-0.3	-3.8	10.1	-0.7
EMR	-0.7	0.5	1.7	-0.9
GFZ	-0.0	-0.3	1.1	-1.2
NGS	-1.0	0.2	7.5	-0.4
SIO	-0.2	-1.1	8.9	0.1

A full combination is computed and submitted to the CDDIS along with the summary report. Sites common to all solutions are used to compare individual solutions with the combination each week. The WRMS coordinate residuals are tabulated in the report. Tables 3 and 4 summarize the WRMS residuals for each center for all weeks and for the most recent 52 weeks. Significant improvements can be seen over time at several centers. Recent comparisons show weekly coordinate agreement at the level of roughly 2 mm N, 2 mm E, and 5-8 mm V for COD, GFZ, and JPL over the last year.

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, and Raytheon under contract with the National Aeronautics and Space Administration.

Table 3. Mean Coordinate WRMS for GPS weeks 837-1054.

Center	North mm	East mm	Vertical mm
COD	2.2	2.5	8.2
EMR	5.1	8.3	11.4
ESA	4.4	7.0	18.8
GFZ	2.5	5.0	8.8
JPL	2.0	2.2	6.4
NGS	8.1	11.4	11.9
SIO	2.9	3.8	8.1

Table 4. Mean Coordinate WRMS for GPS weeks 1003-1054.

Center	North mm	East mm	Vertical mm
COD	1.7	1.9	7.7
EMR	4.9	6.9	10.7
ESA	4.2	4.9	10.1
GFZ	2.0	1.7	5.8
JPL	2.1	1.9	4.8
NGS	4.3	5.7	8.5
SIO	2.5	3.2	6.3

REGIONAL NETWORK ASSOCIATE ANALYSIS CENTERS

The EUREF RNAAC: 1999 Bi-Annual Report

Matthias Becker
Federal Agency of Cartography and Geodesy
D-60598 Frankfurt am Main, Germany

Carine Bruyninx
Royal Observatory of Belgium
B-1180 Brussels, Belgium

Daniel Ineichen
Astronomical Institute, University of Berne
CH-3012 Berne, Switzerland

Introduction

Since the beginning of 1996, the EUREF network has evolved from about 30 permanent tracking sites and 4 analysis centers to close to 100 stations and twelve analysis centers delivering weekly solutions.

Although the primary purpose of establishing the Permanent EUREF Network was the maintenance of the ETRS89 (the European Terrestrial Reference System), its data, structure and results have become valuable for a wide variety of scientific investigations. This was formally endorsed by the EUREF sub-commission at its ninth Symposium in Prague (Czech Republic) in June 1999.

Network Status and Developments

Tracking Network

At the end of 1999, nearly 100 stations were listed as part of the EUREF network (Figure 1), half of them belonging also to the IGS. In 1998, 12 new stations joined the network ; in 1999, 21 new stations registered including a lot of new stations in the Eastern, less densified, part of Europe.

Data from most of the EUREF stations are available within a 24-hour delay. Hourly data uploads have been initiated in October 1998; one third of the EUREF stations (32) presently provide hourly data.

Since mid 1999, tracking stations not fulfilling the IGS/EUREF standards for more than three months receive the label *"inactive"* with as direct consequence that EUREF stops its engagement to monitor and process the station data and auxiliary information. Four permanent tracking stations fall presently within this category.

Responding to a general request, EUREF accepts since June 1998 stations from outside Europe (North Africa, Middle-East) into its the network. These stations are known as "*Associated EUREF stations"* and their inclusion in the EUREF network should allow to better assess the motion of the European plate with respect to the neighboring continental plates. Examples of *Associated EUREF stations* are Yerevan (Armenia) and Mitzpe Ramon (Israel).

Data Centers

During the years 1998 and 1999, all EUREF local data centers switched to the use of the Hatanaka compression. Since October 1998, a few of these data centers started to make available hourly data.

In addition to this, all data centers started to make available standard data holding files. These files are retrieved by the EUREF CB and merged together in order to have a complete overview of the data availability within the EUREF network.

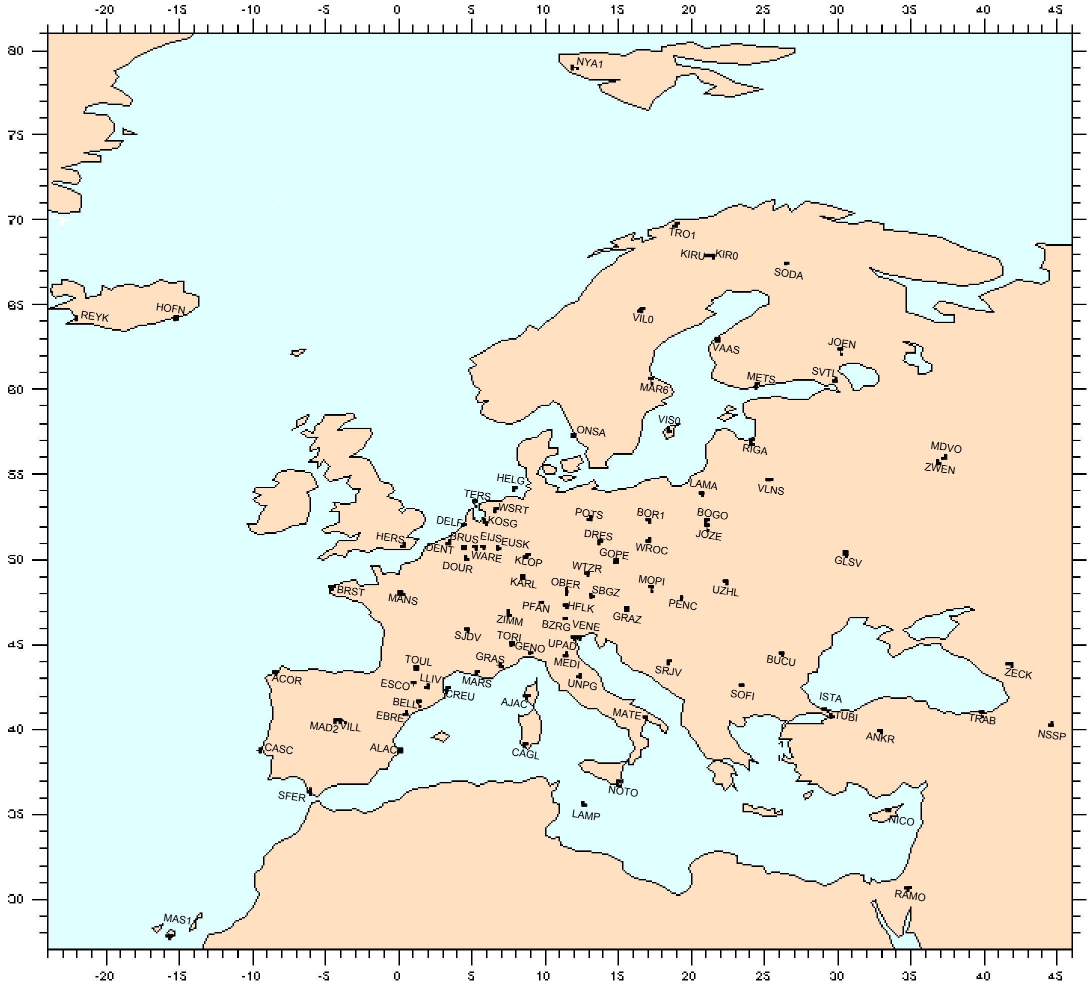


Figure 1. **Network of EUREF tracking stations, as of January 1, 2000**

Data Analysis

The EUREF data analysis is based on the distributed processing approach where 12 Local Analysis Centers (AC) each processes a sub-network of the EUREF network. Two of these analysis centers recently started to submit solutions to EUREF:

- Institut Géographique National (Marne-la-Vallée, France), submitting solutions since November 1998
- University of Padova (Padova, Italy), submitting solutions since December 1998

Until July 25 1999, the individual sub-network solutions were combined into one unique EUREF solution by the CODE analysis center. From July 1999, after a six month transition period, the Bundesamt für Kartographie und Geodäsie (BKG, in Frankfurt am Main, Germany) took over this responsibility and became the new EUREF combination center.

Activities of the EUREF Central Bureau

The EUREF Central Bureau, managed by the EUREF network coordinator, has been actively working towards a near-real time upgrading of its ftp-site and web-pages which contain all fundamental information for the EUREF network. As a result, in December 1998, a completely re-managed EUREF web-site (http://homepage.oma.be/euref/) including clickable maps, reviewed guidelines for the network components, etc… was presented to the EUREF community. As part of this effort, individual site information pages have been created. In addition to the site description logs, these pages also contain additional information about the availability of e.g. meteorological data, site pictures, collocation with tide gauges,.. . The intention is to prepare EUREF for multi-disciplinary applications and foster the integrated monitoring of the environmental change.

The Central Bureau also organized an EUREF Analysis Centers Workshop: "Towards Multi-disciplinary EUREF products" at Marne la Vallée, France in September 1999. This workshop addressed issues such as the creation of a future troposphere product. One of the outcome of the workshop was a endorsement of the strength of the multi-centers data analysis (at least three analysis centers for each EUREF station) and a formal engagement of the EUREF AC's to extend their sub-networks in order to guarantee this principle. As a result, at the end of 1999, 90 % of the EUREF stations were processed by 3 AC's, 8 % by 4 AC's and 2 % of the stations is only processed by two AC's. Minutes of the workshop are available at the EUREF Web site.

The IGS Central Bureau initiated on April 9 1999 the switch to new receiver and antennae equipment names. The EUREF Central Bureau performed the role of liaison between the IGS and the EUREF tracking stations and coordinated this switch at the EUREF level. The new equipment names became active on May 26, 1999 simultaneously with the IGS. At the analysis level, starting on July 4, all EUREF analysis centers delivered SINEX files using the new naming conventions. The switch at the analysis level was again done simultaneously with the IGS analysis centers avoiding discrepancies at the GNAAC's combination level.

Additionally, following IGS recommendations, from July 4 on, the 4-char site identification used for the RINEX files and log files has been adopted as the unique site name accepted in the SINEX files.

EUREF Data Processing

The distributed processing at the twelve analysis centers still follows the guidelines published in the 1997 IGS Technical Report (Bruyninx et al., 1997). For the combination step changes were made in the generation of the solution fixed in the ITRF. Due to the increased number of sites and the distribution of sites amongst the different analysis centers the following anchor sites in the ITRF96 and ITRF97 were used respectively:

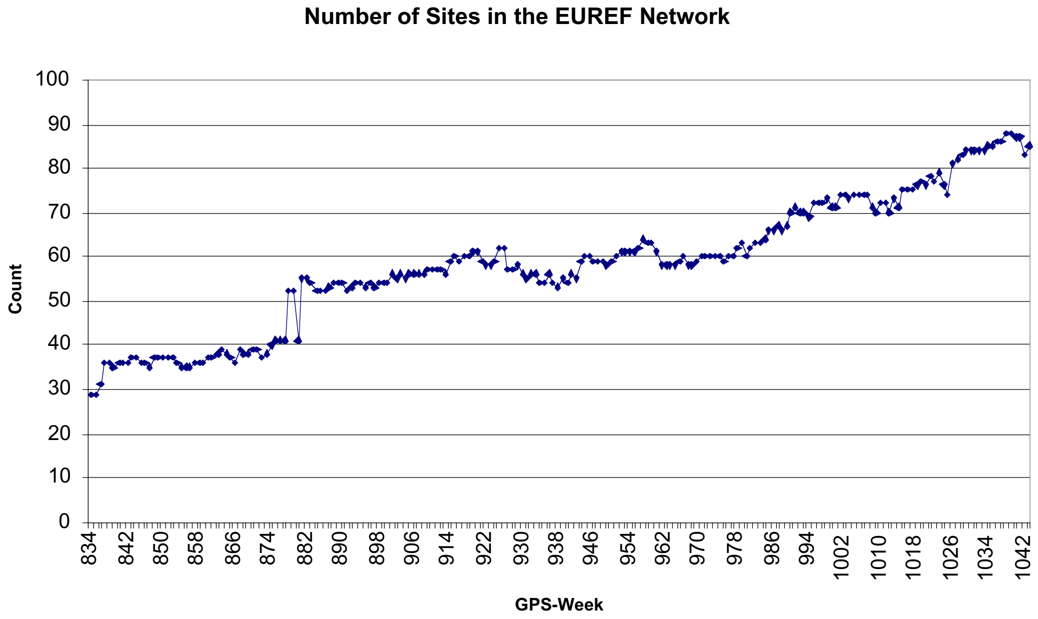


Figure 2. Number of active sites used in the weekly EUREF combination.

For the realization of the ITRF96 reference frame the following sites are used from GPS week 0947 - 0981:

BOR1, GRAZ, KOSG, MATE, ONSA, POTS, REYK, WTZR, ZIMM, ZWEN, VILL

From GPS week 0982 — 1020:

BOR1, GRAZ, KOSG, MATE, ONSA, POTS, REYK, WTZR, ZIMM, ZWEN, VILL, GRAS

For the realization of the ITRF97 reference frame the following sites are used from GPS week 1021 onwards:

BOR1, GRAZ, KOSG, MATE, ONSA, POTS, REYK, WTZR, ZWEN, VILL, GRAS NYA1, TRO1, THU1.

The quality of the combined solution is shown by the combination of the loosely constrained weekly solutions into a multi year combined solution. Figure 2 shows the number of sites active in the EUREF network from GPS week 843 to 1043. The distribution of the rms values of the residuals of weekly solutions versus the combination solution for these sites is shown in Figure 3. The average of the residual s rms is 1.60, 1.68 and 4.86 mm for the North, East and Up components respectively.

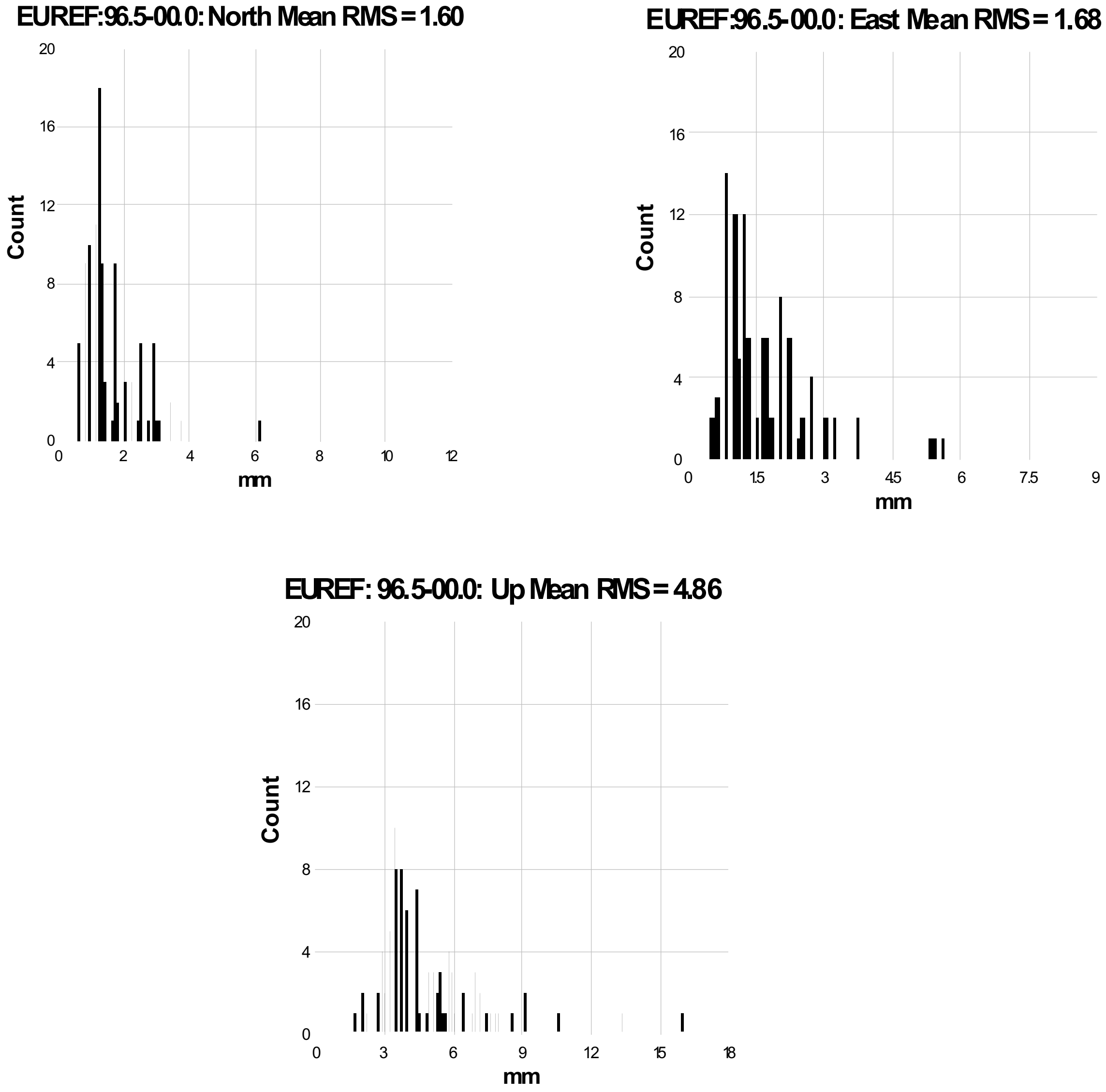


Figure 3. Histogram of rms values of site residuals of weekly EUREF combinations versus multi year solution.

The histograms in Figure 3 show a few outliers which result from systematic differences between the three solutions submitted. This indicates sites with problems and possible modelling imperfections which call for further improvement in the standardization and the guidelines, see the section entitled “Outlook.”

EUREF Contribution to the ITRF2000

The EUREF - RNAAC computed a multi year combination of the weekly EUREF solutions as regional densification of the ITRF. In order to avoid the problems in the transition from ITRF93 to ITRF94 at GPS week 860 (June 30th, 1996), the weeks 834 to 859 were not used in the combination. Because of the long time series now available and due to the fact that for most of the sites the noise in this leading week is higher as in recent times, this seems to be justified. The combination was based on the SINEX files of the weekly solutions and was computed by use of the program ADDNEQ2 of the Bernese Software Vers.4.3. (Mervart, pers. comm. March 2000). The solution is summarized in Table 1.

The so-called STACRUX-file containing all information on site changes, antenna changes etc. of EUREF which is available at the Central Bureau was used assure the generation of consistent coordinates and velocities. In addition < 15 outliers of single sites were eliminated. At some sites discontinuities in one of the coordinate components occured which could not be associated to logged changes eccentricities or antennas. These sites are listed in Table 2 and for them one velocity but two sets of coordinates for different time periods were estimated. In addition , sites which a recording history shorter than 6 months were constrained to their NUVEL 1A NNR velocities.

Table 1. Summary of EUREF contribution to ITRF2000.

Observation-Interval:	Week 0860 – 1042
Time period	June, 30, 1996 – January 1, 2000
Number of GPS weeks used	183
Number of weeks neglected	26
Number of stations	95
Additional coordinates of identical sites	5
Number of sites with velocity estimation	82
A posteriori RMS	0.0036 m

Table 2. Sites with offsets in the time series modelled as two independent sets of coordinates.

Station Name	Start Epoch of Second Coordinate Solution
	YYYY MM DD HH MM SS
ANKR 20805M002	1999 08 15 00 00 00
HERS 13212M007	1999 04 25 00 00 00
PFAN 11005S002	1999 10 31 00 00 00
TRO1 10302M006	1998 12 27 00 00 00
ZIMM 14001M004	1998 11 08 00 00 00

Two version of the solution are generated, a loosely constrained solution and a solution constrained to the ITRF97 coordinates and velocities of the following core sites: MATE, ONSA, POTS, WTZR, ZWEN. For geophysical investigations and interpretations of site velocities other strategies may be used in future.

For a first assessment of the accuracy of the EUREF contribution the solution was compared to the ITRF2000 contribution of CODE (Springer, pers. comm.). The rms of the differences of the 38 sites in common are .9, 2.7 and 4.9 mm in North, East and Up components at a central epoch respectively. The agreement is excellent and is rather consistent with the internal precision of the weekly solutions.

Outlook

The continuous extension of the EUREF network, both through its components as its applications, urges for a reorganization of the coordination tasks. The charter for this reorganization will be set up by the EUREF Technical Working Group and it will focus on a the development of a full service supporting a wide range of applications, such as:

- geodynamics : almost 4 years of EUREF solutions are available now
- sea level monitoring : one out of three EUREF stations is installed near a tide gauge
- meteorology : one out of three EUREF stations is submitting hourly data

In addition, it will allow the network to flexibly adapt to future demands and applications.

The analysis guidelines, adopted in April 1997 by the EUREF AC's to guarantee the homogeneity of the EUREF solution have aged. New analysis guidelines will be developed and implemented in 2000. This may help in reducing the systematic differences between

AC's, e.g. by consistently modelling ocean tidal loading, improving the tropospheric zenith delay estimation (mapping function and elevation cutoff) and more.

One important point which is not sufficiently clarified till now is the use of a consistent set of antenna phase-center calibration tables. A number of antenna types used in the EUREF network is not adequately modelled and included in the IGS tables. There is a urgent need for a generally accepted update of the IGS antenna phase-center correction tables.

References

Bruyninx, C., D. Ineichen and T. Springer (1997), "The EUREF RNAAC: 1997 Annual Report ", in International GPS Service for Geodynamics, 1997 Annual Report, Jet Propulsion Laboratory, Pasadena, California

Acknowledgements

Without the labor and the commitment of the responsible agencies, their representatives at the observation sites, the data centers and the analysis centers, the EUREF network would not be the success that is it today. The authors would like to acknowledge especially the responsibles of the EUREF analysis centers. Special thanks to Leos Mervart and Tim Springer of CODE for the assistance in the ITRF2000 computation.

.

AUSLIG RNAAC – 1999 Annual Report

Geoff Luton

Australian Surveying and Land Information Group (AUSLIG)
Canberra, Australia

Introduction

AUSLIG continued processing all sites in the Australian Regional GPS Network (ARGN) during 1999. The weekly combined SINEX result files were submitted to the Crustal Dynamics Data Information System (CDDIS) as AUSLIG's role as an IGS type 2 Associate Analysis Centre.

Station Network

The station network processed by the AUSLIG RNAAC is shown in Figure 1. Twelve of the sixteen stations in this network are operated by AUSLIG. DST1, PERT TID2 and YAR1 are owned and operated by non-Australian agencies. A new AUSLIG site STR1 located at the new Mount Stromlo Satellite Laser Ranging observatory near Canberra was added to the network commencing GPS week 1016.

Data Analysis and Results

The Bernese GPS Software version 4.0 (Rothacher and Mervart 1996) is used for the GPS data processing. Daily solutions are computed using the following strategy:

- L3 double differenced phase observable.
- No resolution of integer ambiguities.
- Elevation cut-off angle of 20°.
- Estimation of tropospheric zenith delay parameters at 2 hourly intervals.
- IGS antenna phase centre variation model applied.
- IGS final orbits and EOPs held fixed.
- Site coordinates for a single site constrained (either TID2 or YAR1).

Seven daily solutions are combined at the normal equation level to obtain the weekly solution output in SINEX format submitted to the CDDIS. These solutions were tightly constrained to the ITRF coordinates at the following ITRF96 reference sites; DAV1, HOB2, MAC1, PERT, TID2 and YAR1 and the following ITRF97 reference sites; CAS1, DAV1, HOB2, MAC1, PERT, TID2 and YAR1. Solutions up to and including GPS week 1020 are in the ITRF96 system. Solutions from and including GPS week 1021 are in the ITRF97 system.

The AUSLIG RNAAC weekly SINEX solution files were included in the Type 2 GNAAC combination generated by the Massachusetts Institute of Technology (MIT) and the University of Newcastle upon Tyne GNAAC Polyhedron solutions.

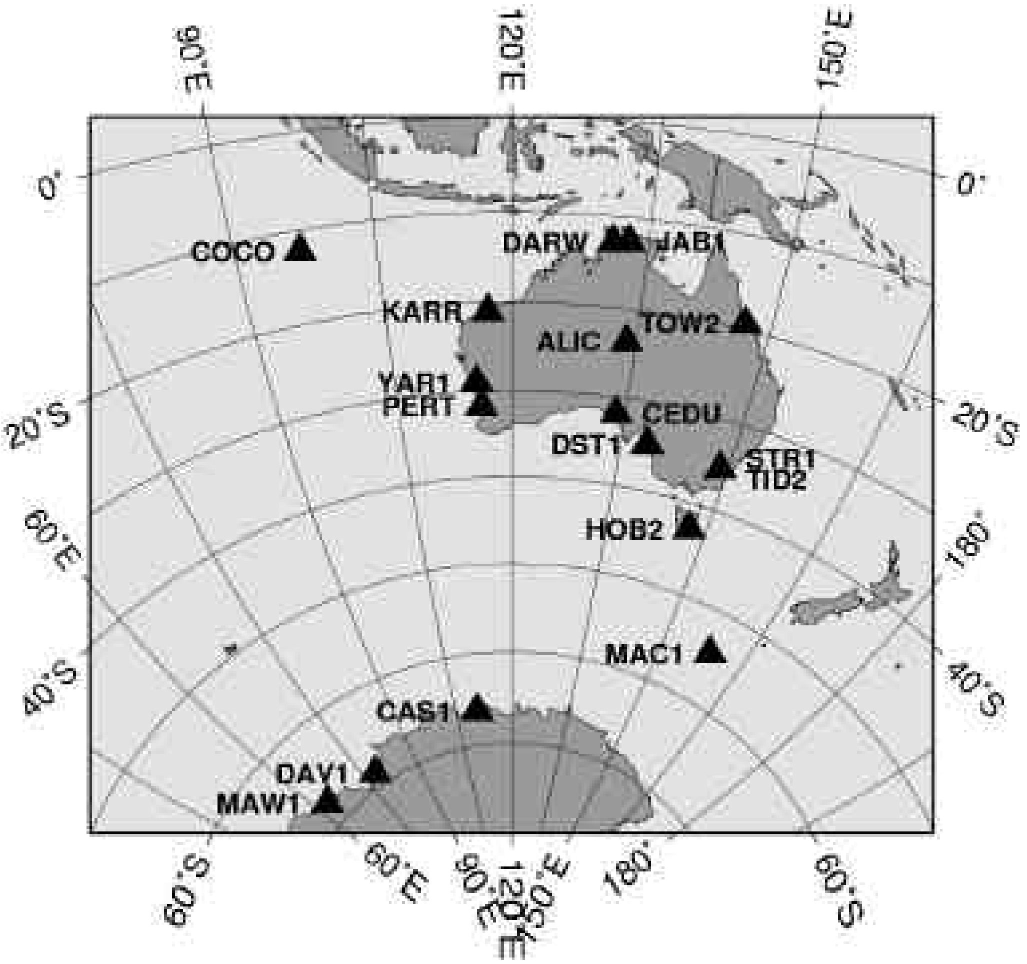


Figure 1. AUSLIG RNAAC station network as of 31 December 1999

Future Plans

AUSLIG plans to participate as an IGS Associate Analysis Centre (AAC) in support of Low Earth Orbiter (LEO) Missions.

References

Rothacher, M. and L. Mervart (eds.), Bernese GPS Software Version 4.0, Astronomical Institute, University of Berne, 1996.

GSI RNAAC Technical Report 1999

A. Yamagiwa

Geodetic Observation Center
Geographical Survey Institute, Japan

Introduction

Geographical Survey Institute (GSI)'s contribution to International GPS Service (IGS) as a Regional Network Associate Analysis Center (RNAAC) started in 1996, and since then, GSI has been playing a important role in IGS network.

Outline of Processing

7 domestic GPS sites, as well as 10 IGS global sites, are selected for this regional analysis (Figure 1a, 1b). Daily coordinate solutions are generated using GAMIT version 9.74 and they are combined with GLOBK version 4.24 to generate weekly constraint solutions.

Characterizing features of the performed solutions are as follows:

Final IGS orbits and Earth orientation parameters are applied.
Measurement elevation angle cut off 20 degrees, sampling interval
60 secs for single-day adjustments.
Tropospheric zenith delays are estimated every 3 hours.
Orbit relaxation strategy is used.

Station coordinates estimated in the International Terrestrial Reference Frame (ITRF), applying a priori sigma of ~10.

Estimated parameters are obtained as Software/Solutions Independent Exchangeable (SINEX) format and submitted to Crustal Dynamics Data Information System (CDDIS).

Present State of GSI RNAAC

Our fiducial IGS site TSKB had suffered from GPS End of Week Rollover Problem since 1024 GPS week, which caused fatal trouble in GAMIT/GLOBK analysis. This problem was solved using patch program and we are now trying to catch up with our regular works.

As to data reliability, our solution keeps stable precision constantly. (See Figure 2.)

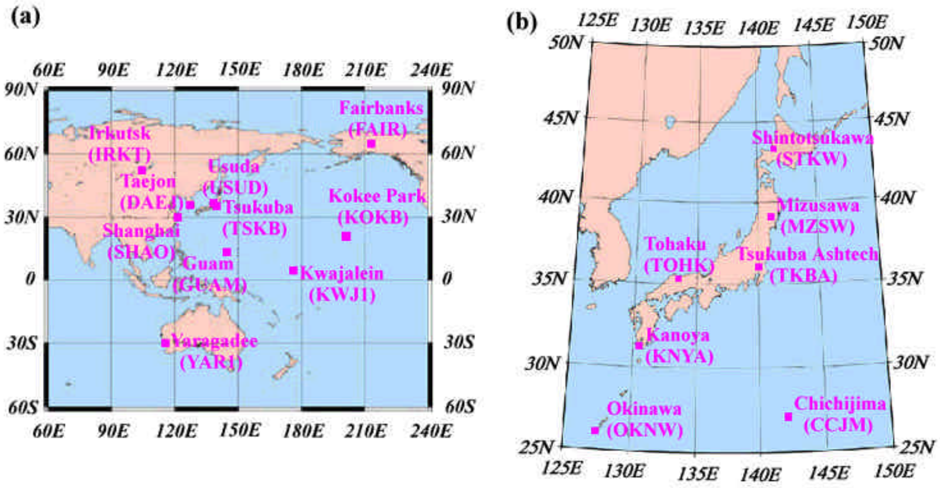


Figure 1. GPS observation sites for GSI RNAAC analysis
(a) IGS global sites (b) domestic sites

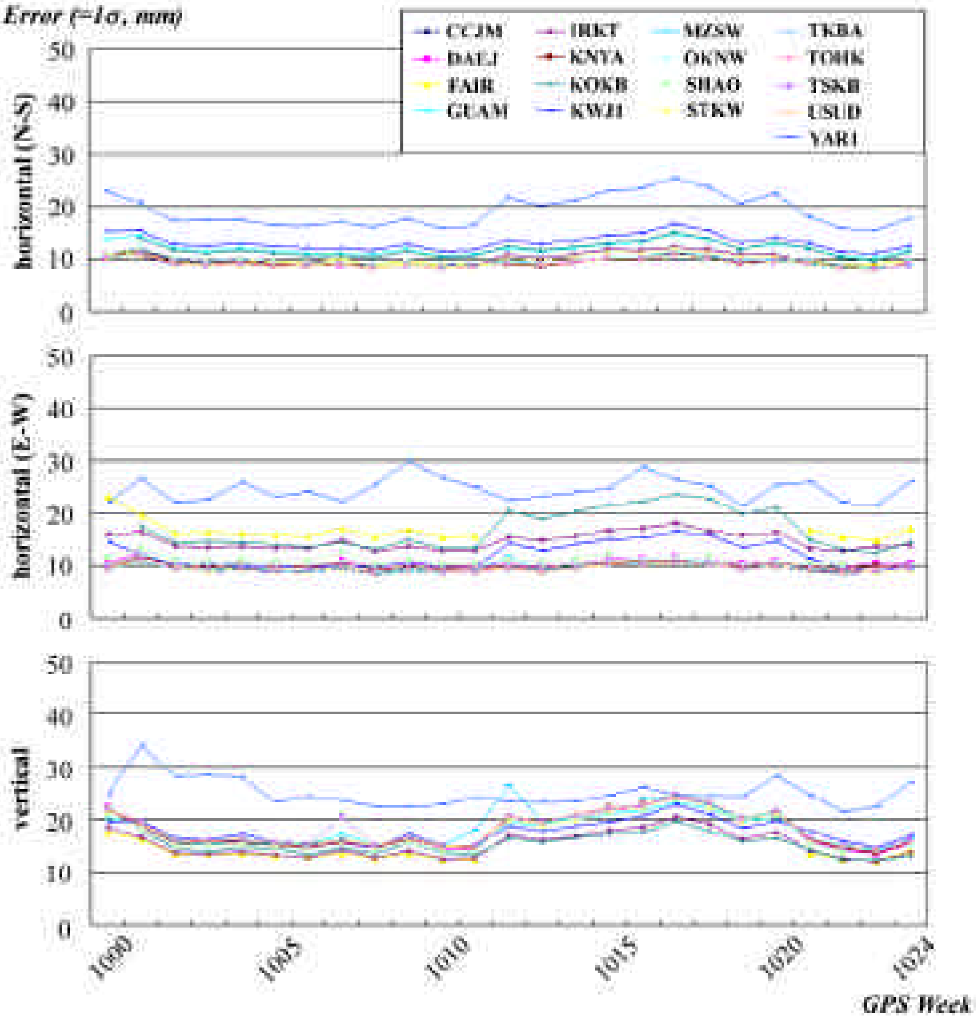


Figure 2. Weekly solution reliability on GSI RNAAC analysis.

Annual Report 1999 of RNAAC SIRGAS

Wolfgang Seemüller and Hermann Drewes

Deutsches Geodätisches Forschungsinstitut
München, Germany

Introduction

The IGS RNAAC SIR has processed the observations of the permanent GPS stations of the South American network (SIRGAS) since July 1996. The Bernese processing Engine (BPE) version 4.0 is used until the beginning of the year 2000. The weekly solutions were sent regularly to the IGS Global Data Centers, and are included in the weekly global polyhedron solutions of the GNAAC MIT and NCL.

Station Network

At the end of 1999 the regional network SIRGAS consists of 36 stations, with 22 IGS stations, as well as 10 Brazilian, 3 Argentinean and one Venezuelan stations processed by IGS RNAAC SIR only (see fig. 1). New IGS stations included in 1999 are Jamaica and Cordoba, new regional stations are Rawson/Argentine and Porto Allegre/Brazil. Most recently (at the beginning of 2000) two more stations in Colombia were added to the network, one of them (BOGA) is located about 190 m from the IGS station Bogotá (BOGT).

Solutions

The three and a half years of weekly solutions allow to derive velocities besides of station coordinates for all those stations which have at least one year of observations. Figure 1 shows the ITRF97 velocities compared with the movements derived by DGFI. The solution is based on weekly SINEX files generated by DGFI as the IGS RNAAC for South America. IGS combined orbits and Earth orientation parameters were held fixed. The solution is referred to ITRF by introducing positions at the reference epoch (1998, day 119) and velocities of CRO1, FORT and SANT as fictitious observations. The weight applied to these „observations" is set such as to still allow the positions and velocities of these fiducial stations to deviate from their ITRF97 values by some mm and mm/10 per year respectively. The formerly included IGS stations Richmond and Bermuda were processed again for that purpose.

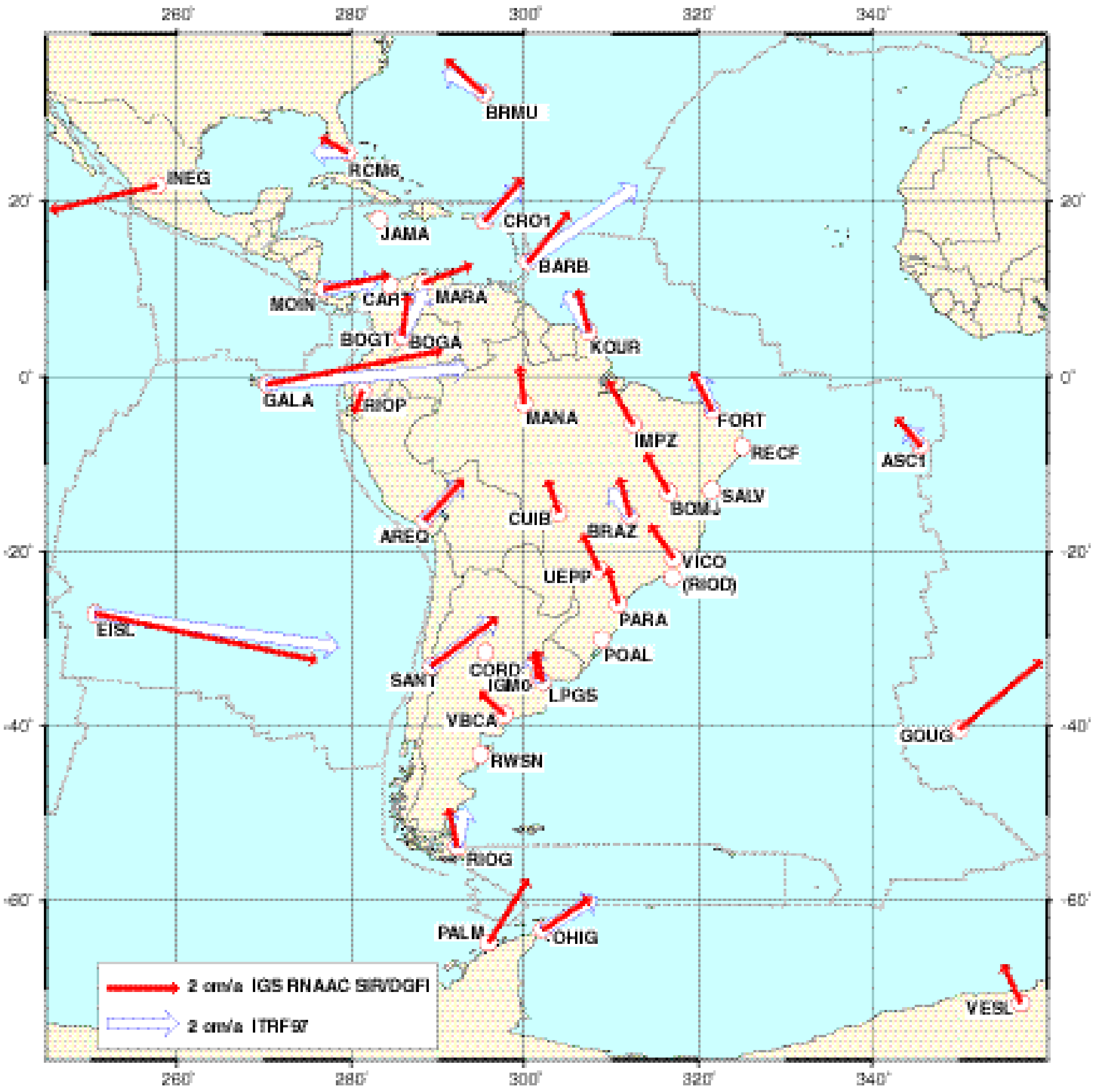


Figure 1: Comparison of ITRF97 and IGS RNAAC SIR/DGFI velocities

Conclusion

Most of the velocities shown in fig. 1 are in good agreement, only some stations (e.g., Barbados and Rio Grande) have significant differences to the ITRF97 solution. The reason for the differences at Barbados and Rio Grande may be the short observation periods of both stations (BARB 81 weeks, RIOG 48 weeks).

Step by step the number of regional stations will increase and densify the network. New IGS stations on the South American continent and in the surrounding area will be added to the IGS RNAAC SIR network and should strengthen the regional reference frame.

References

Rothacher, M. and L. Mervat (eds): Bernese GPS software version 4.0. Astronomical Institute, University of Berne, 1996

Seemüller W. and H. Drewes Annual Report 1997 of the RNAAC SIRGAS, IGS 1997

Seemüller W. and H. Drewes Annual Report 1998 of RNAAC SIRGAS, IGS 1998 Technical Reports

IGS

IERS CONTRIBUTIONS

The International Terrestrial Reference Frame

Zuheir Altamimi
Institut Geógraphique National / ENSG/LAREG
6-8 Avenue Blaise Pascal
Cite Descartes, Champs-sur-Marne
77455 Marne-la-Vallee, FRANCE

Introduction

Following its Terms of Reference, IGS works in close cooperation with the International Earth Rotation Service (IERS). The Central Bureau of IERS is operated jointly by Institut Géographique National (IGN), in charge of the primary realization of the International Terrestrial Reference System (ITRS) through the International Terrestrial Reference Frame (ITRF), and the Paris Observatory, in charge of the International Celestial Reference Frame (ICRF) and the Earth's rotation determination.

The ITRF Section of the IERS Central Bureau (ITFS) cooperates very closely with the different IGS participants (Central Bureau, Analysis Centers, Tracking Stations) for ITRF station coordinates, analysis of solutions provided by IGS analysis centers as well as site information and local ties of collocation sites.

For more information: http://lareg.ensg.ign.fr/ITRF

ITRF and IGS Relationship

Since the beginning of the IGS preliminary test activities in 1992, the IGS analysis centers have used ITRF coordinates for some subset of stations in their orbit computations. Moreover, the combined IGS ephemerides are expressed in ITRS because the coordinates used by the IGS are based on ITRF91 from the beginning until the end of 1993; ITRF92 during 1994; ITRF93 during 1995 until mid-1996; ITRF94 since mid-1996 until the end of April 1998; ITRF96 starting on March 1, 1998; and ITRF97 since August 1, 1999.

IGS supports the continuous improvement of the ITRF by contributing to the extension of the ITRF network, providing new collocations or by improving position accuracy. The IGS analysis centers contribute greatly to ITRF by providing IGS/GPS solutions which are included in the ITRF combinations.

IGS also provides very efficient method to densify the ITRF network: one can now obtain millimetric positions directly expressed in ITRS by processing suitable GPS data together with IGS products.

ITRF and the IGS Reference Stations

Starting on March 1, 1998, IGS uses ITRF96 positions and velocities of a set of 47 reference stations. The IGS selection of these stations is the result of criteria tests including primarily the quality of their ITRF96 coordinates. For this latter criterion, the ITFS has performed a specific quality analysis based on ITRF96 position and velocity residuals. The analysis was repeated in the light of the ITRF97 results upon the original 52 stations proposed by the IGS Analysis Centers. The main result of this quality analysis is that the ITRF97 position quality (at 97.0 epoch) is better than 1 cm for 47 stations and better than 2 cm for the remaining 5 stations. Moreover, the velocity quality is better than 5 mm/y for 37 stations, and better than 10 mm/y for the remaining 13 stations. The 52 selected ITRF97 reference stations are used by IGS since August 1, 1999.

Figure 1 shows the coverage of the ITRF97 sites, underlying the 52 IGS reference stations.

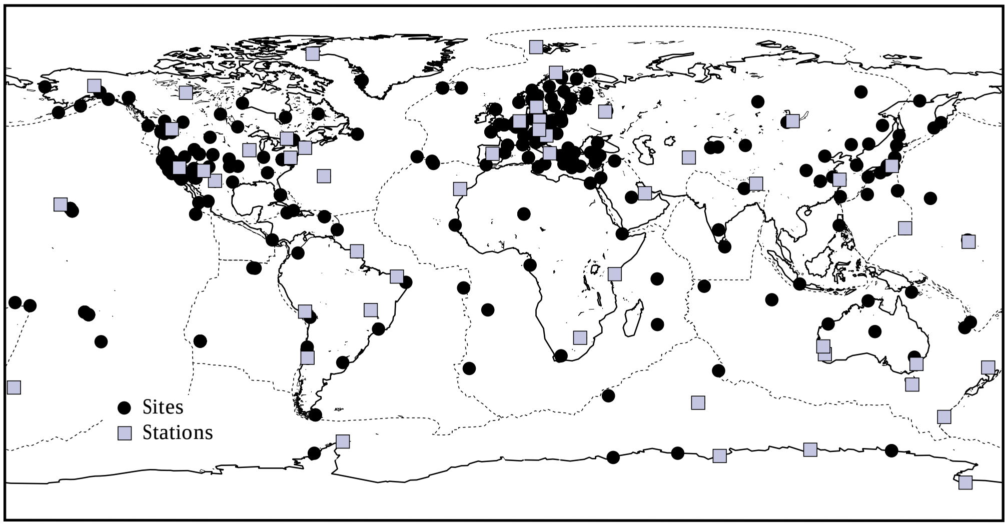


Figure 1. ITRF97 Sites and the 52 IGS Stations

ITRF2000

One of the year 2000 major trends of the International Earth Rotation Service (IERS) is the establishment of the ITRF2000. This Global reference is to be considered as a standard solution for a wide user community (geodesy, geophysics, astronomy, etc.). The ITRF2000 comprises on one hand primary core stations observed by VLBI, LLR, GPS, SLR and DORIS techniques and, on the other hand, significant extension provided by regional GPS networks for densifications as well as other useful geodetic markers tied to the space geodetic ones. The current ITRF2000 network is illustrated in Figure 2. It is expected to publish the ITRF2000 at the end of year 2000 or early 2001.

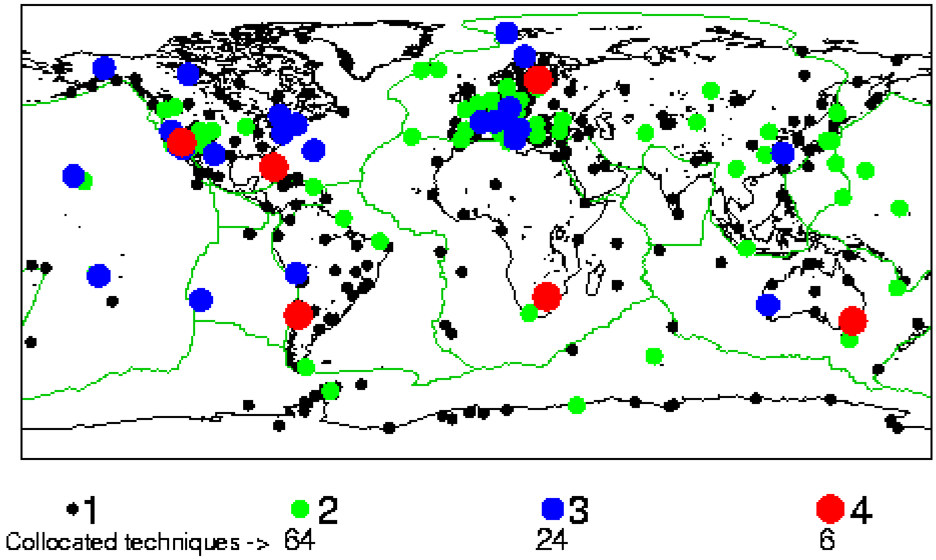


Figure 2. ITRF2000 sites and collocated techniques

References

Altamimi, Z., 1998, IGS reference stations classification based on ITRF96 residual analysis, in J.M. Dow, J. Kouba and T. Springer (eds), Proceedings of the IGS 1998 Analysis Center Workshop, Darmstadt,
February 9-11, 1998.

Atamimi, Z., Boucher, C. and P. Sillard 1999, ITRF97 and quality of IGS reference stations, Proceedings of the IGS 1999 Analysis Center Workshop, SIO, La Jolla, CA, USA, 8-11 June 1999

Boucher C., Z. Altamimi, and P. Sillard, 1999, The 1997 International Terrestrial Reference Frame (ITRF97), IERS Technical Note 27, Observatoire de Paris.