1999 Analysis Coordinator Report

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1 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.

2 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.

2.1 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.

2.2 IGS ITRF realization

The plans for the new and improved IGS ITRF (IGSRF) realization, as proposed during the 1997 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.

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

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.

3 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 et al.*, 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 correlations 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 et al.*, 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).

4 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

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A Tables and Figures

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 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	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

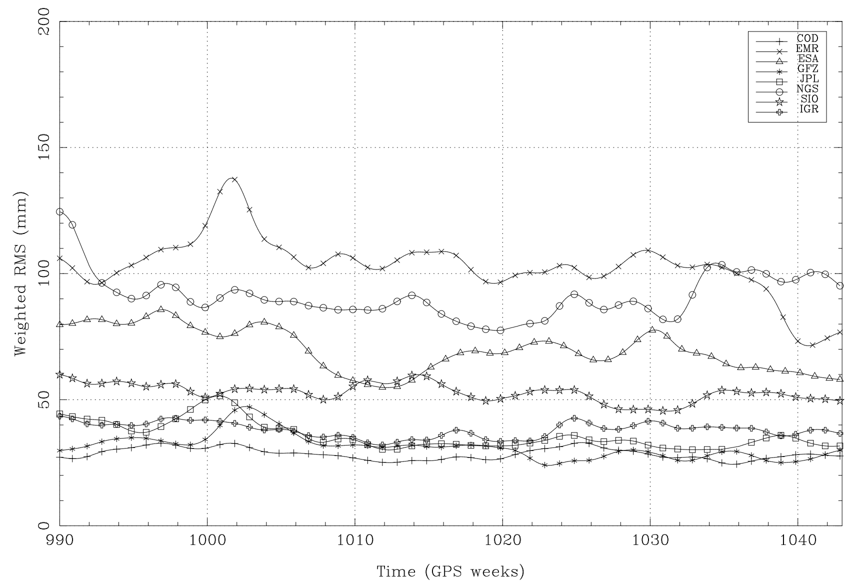
Table 3: IGS Rapid Combination mean (μ) and standard deviations (σ) of the daily transformation parameters, weighted orbit RMS, and Clock RMS. Based on GPS week 990 day 5 to GPS week 1042 day 5 (365 days).

AC		Days	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	Scale (ppb)	WRMS (mm)	CRMS (ns)
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

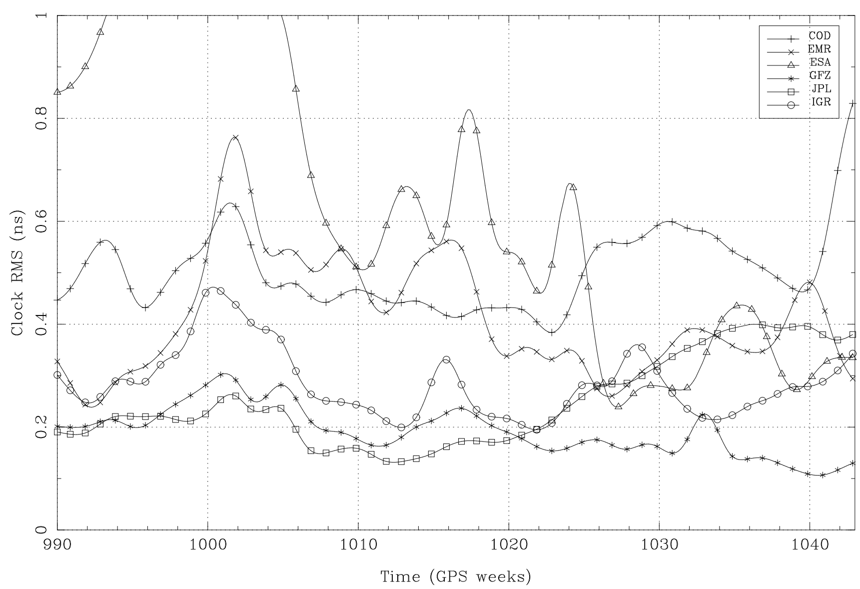
Table 4: IGS Prediction Comparison mean (μ) and standard deviations (σ) of the daily transformation parameters, weighted orbit RMS, and Clock RMS. Based on GPS week 990 day 5 to GPS week 1042 day 5 (365 days). USP joined the IGS predictions in June 1999.

AC	Days	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

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.

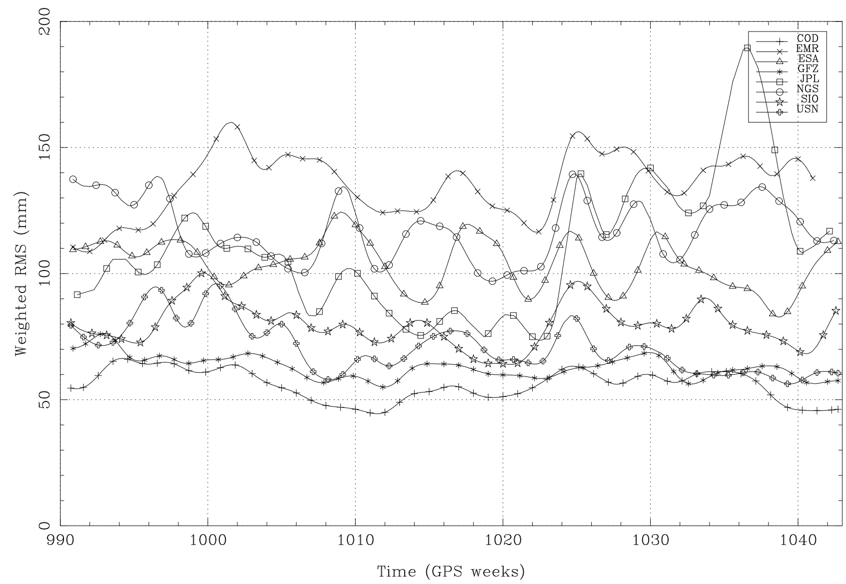


(a) Final Weighted Orbit RMS (mm)

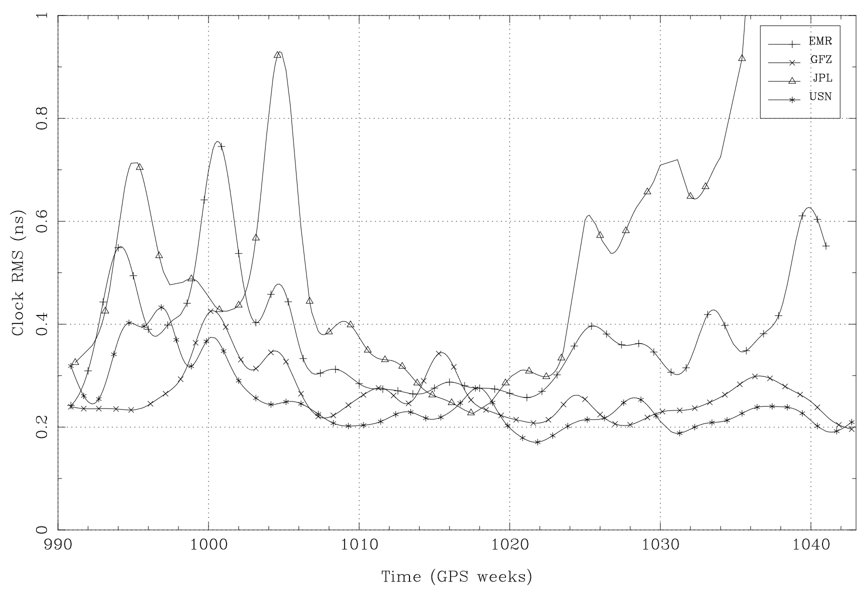


(b) Final Clock RMS (ns)

Figure 1: Final Weighted orbit RMS (mm) and Clock RMS (ns) of the AC and IGS Rapid (IGR) 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.

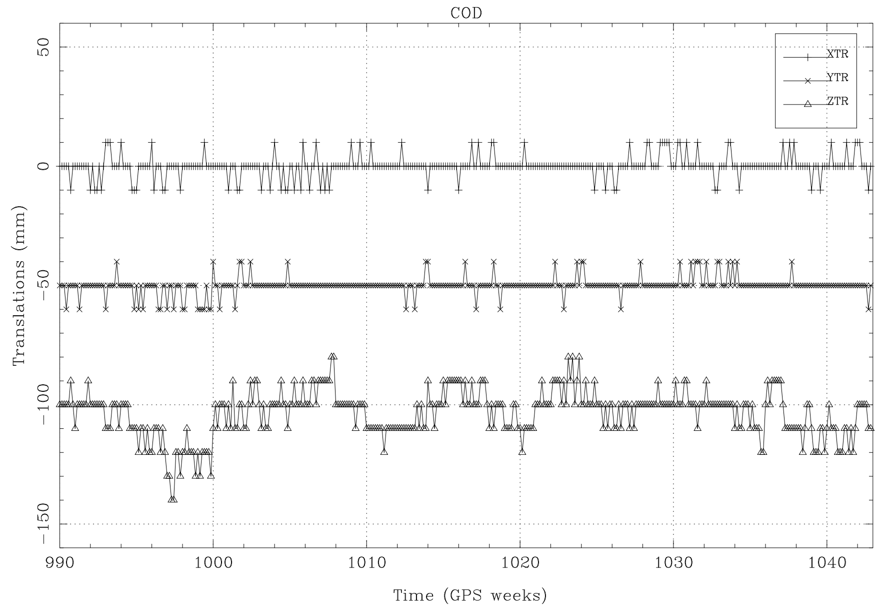


(a) Rapid Weighted Orbit RMS (mm)

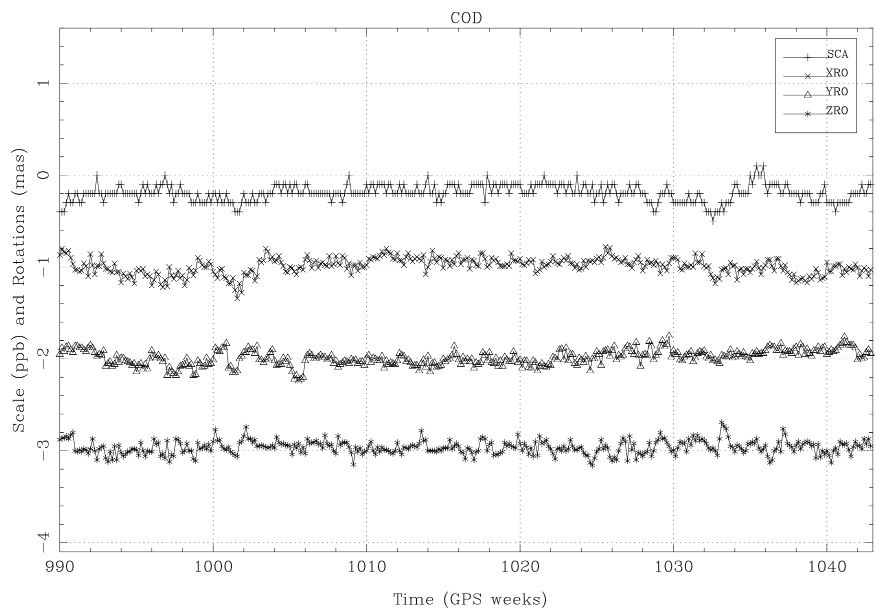


(b) Rapid Clock RMS (ns)

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.

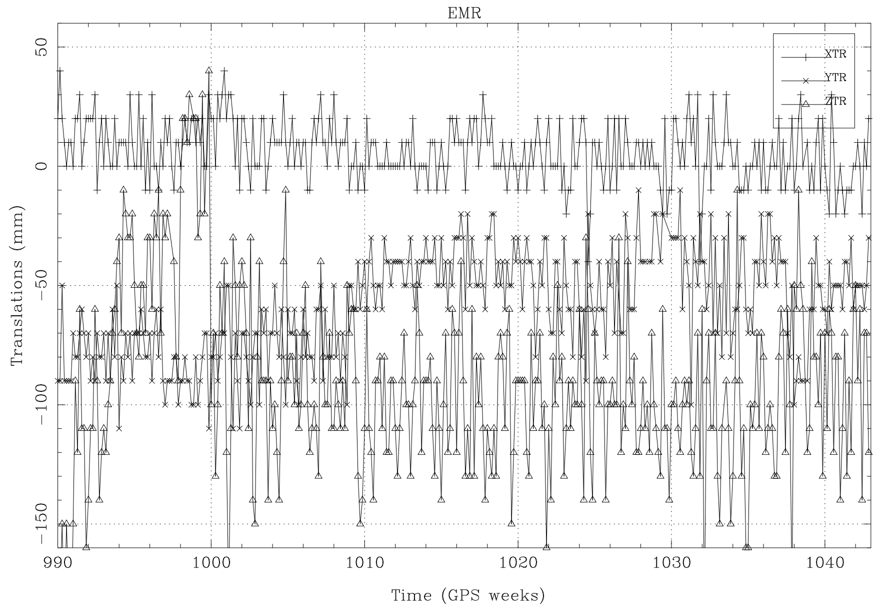


(a) Translations (X, Y, and Z)

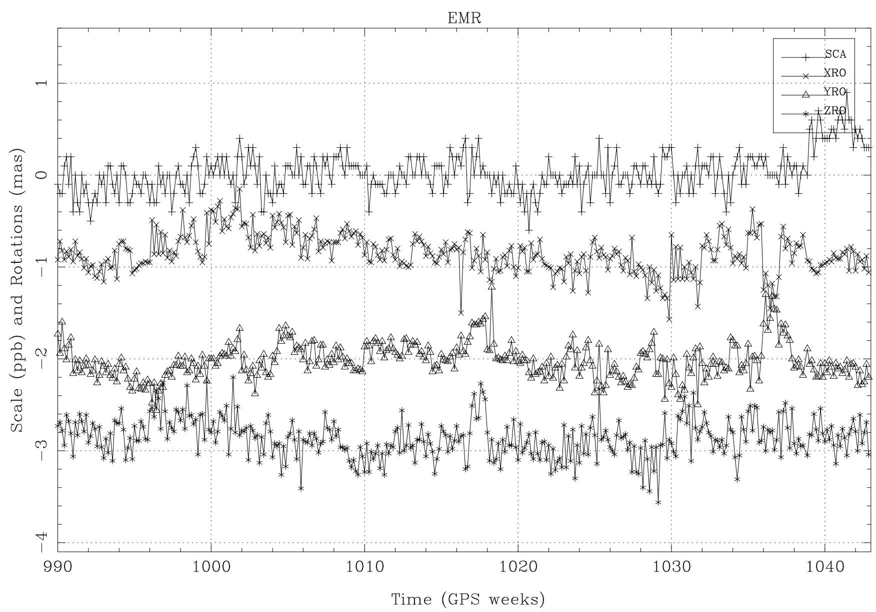


(b) Scale and Rotations (X, Y, and Z)

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.

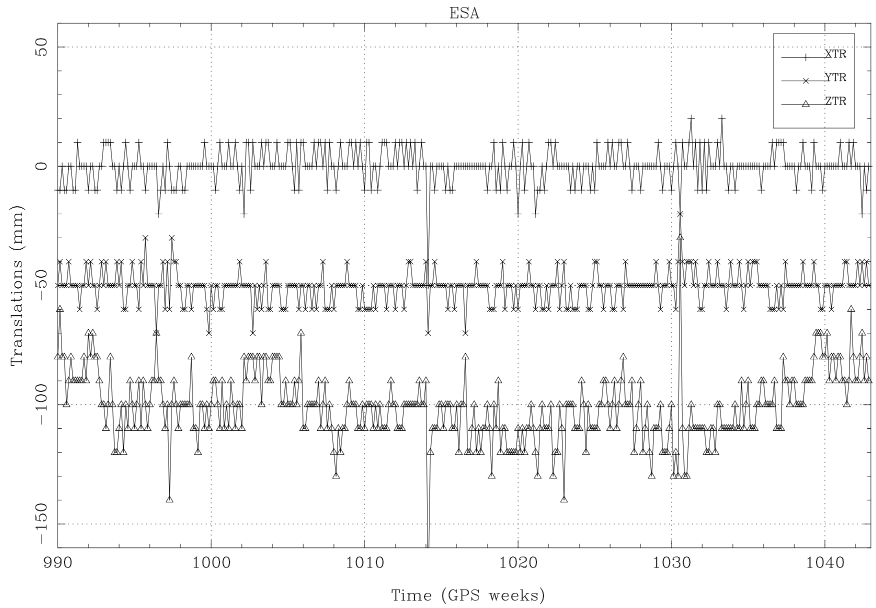


(a) Translations (X, Y, and Z)

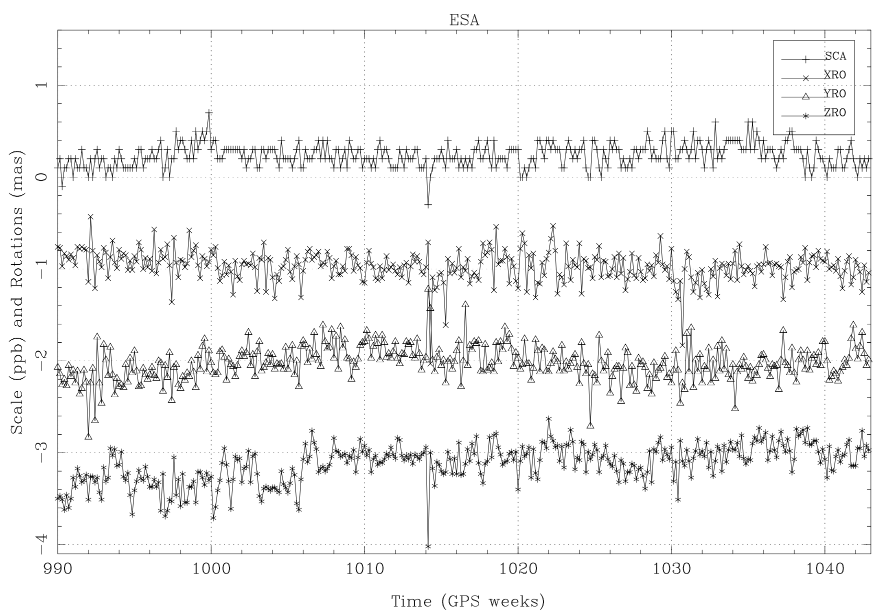


(b) Scale and Rotations (X, Y, and Z)

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.

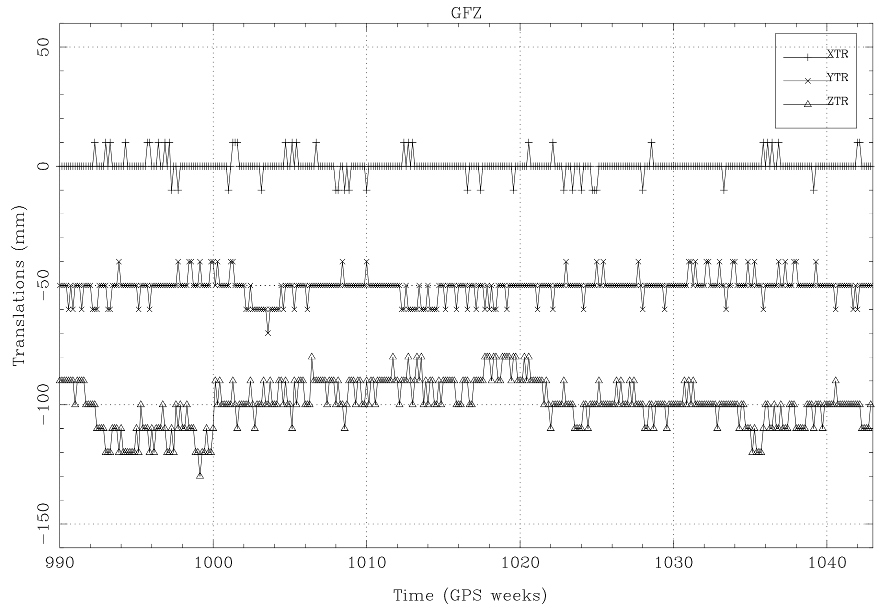


(a) Translations (X, Y, and Z)

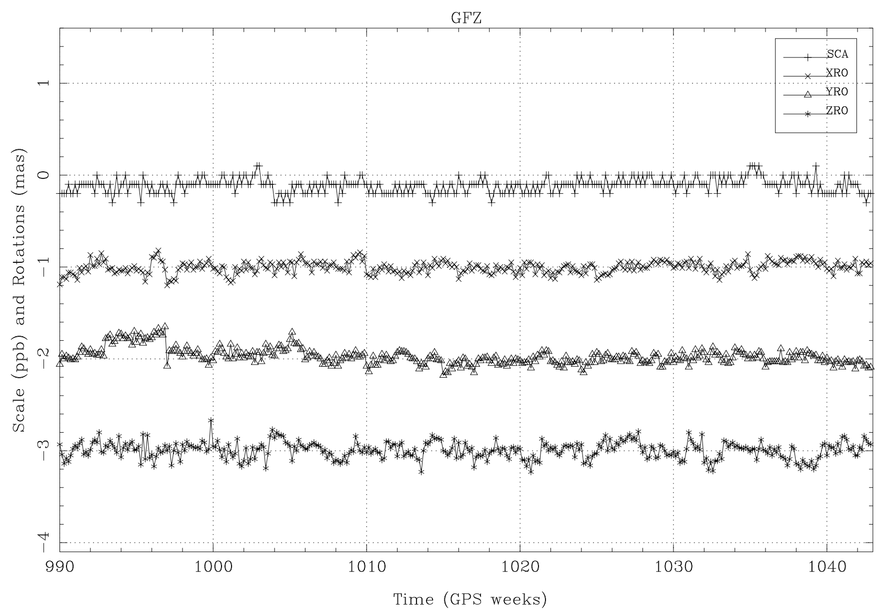


(b) Scale and Rotations (X, Y, and Z)

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.

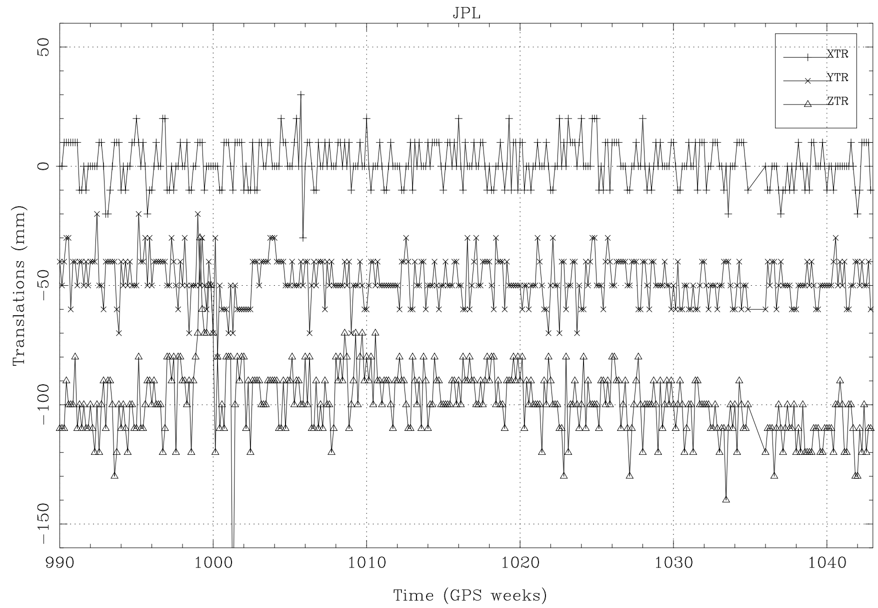


(a) Translations (X, Y, and Z)

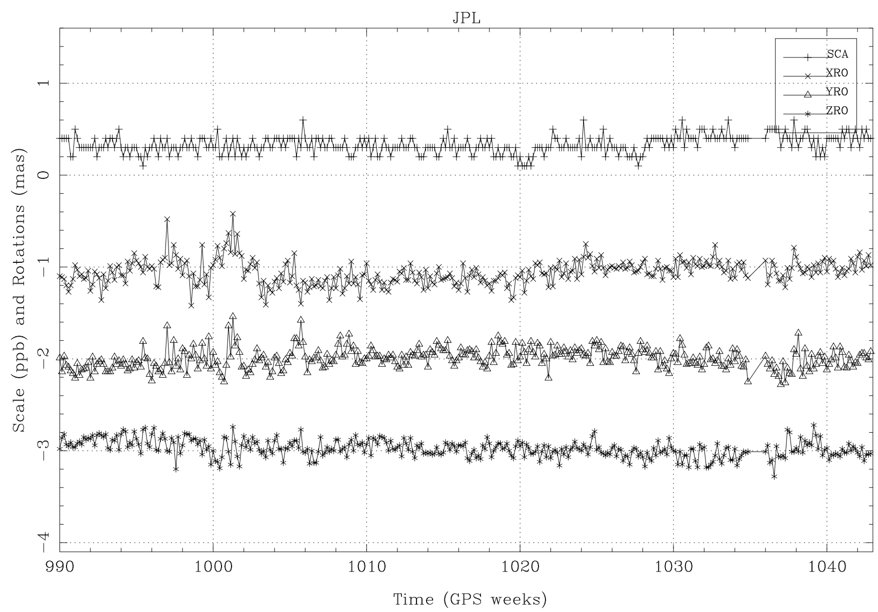


(b) Scale and Rotations (X, Y, and Z)

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.

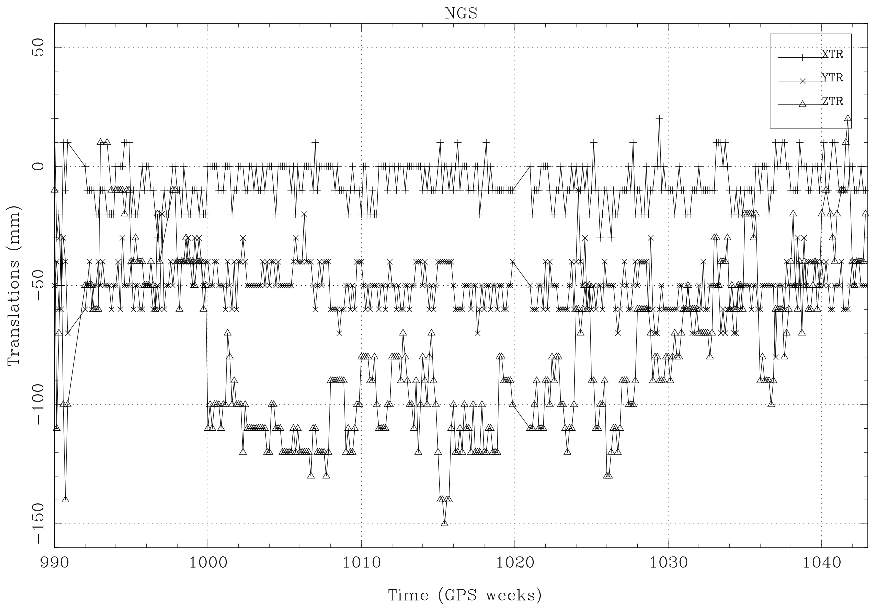


(a) Translations (X, Y, and Z)

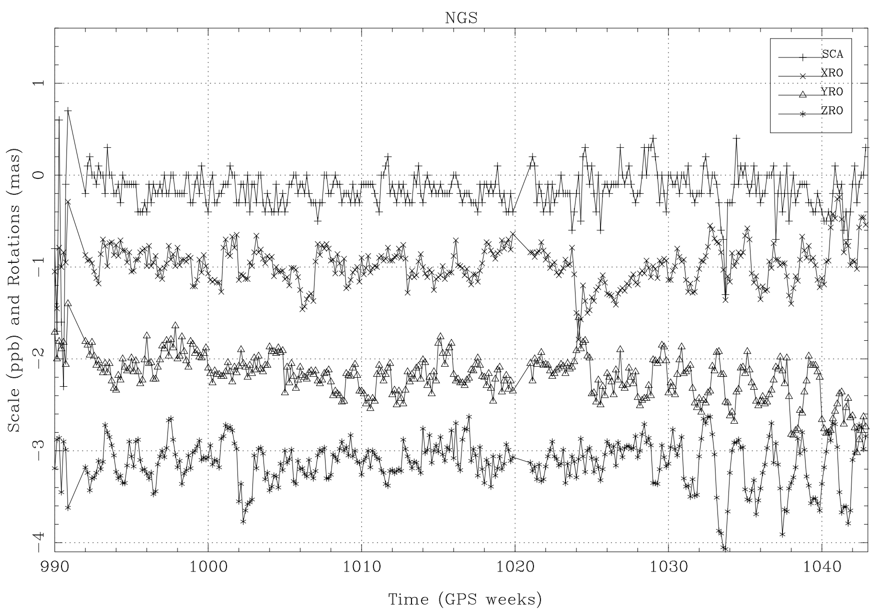


(b) Scale and Rotations (X, Y, and Z)

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.

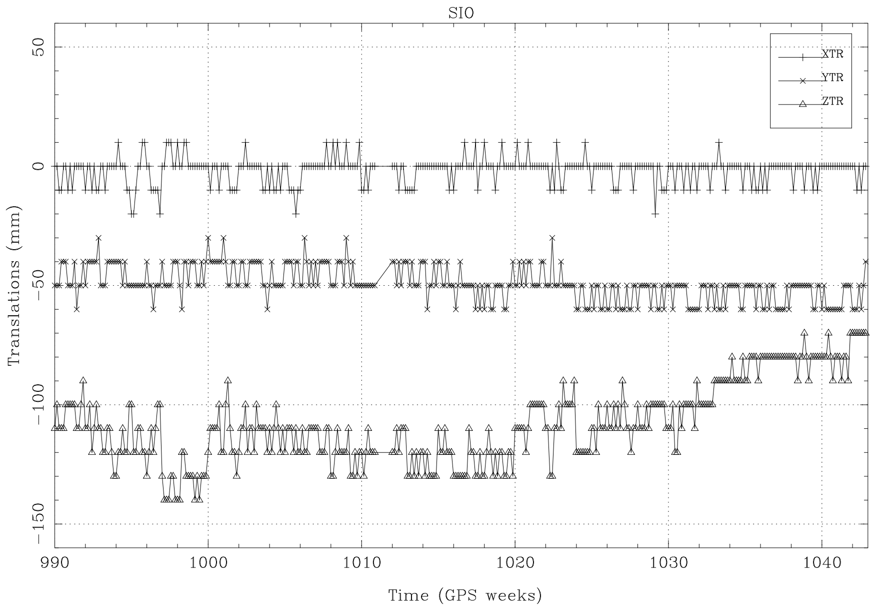


(a) Translations (X, Y, and Z)

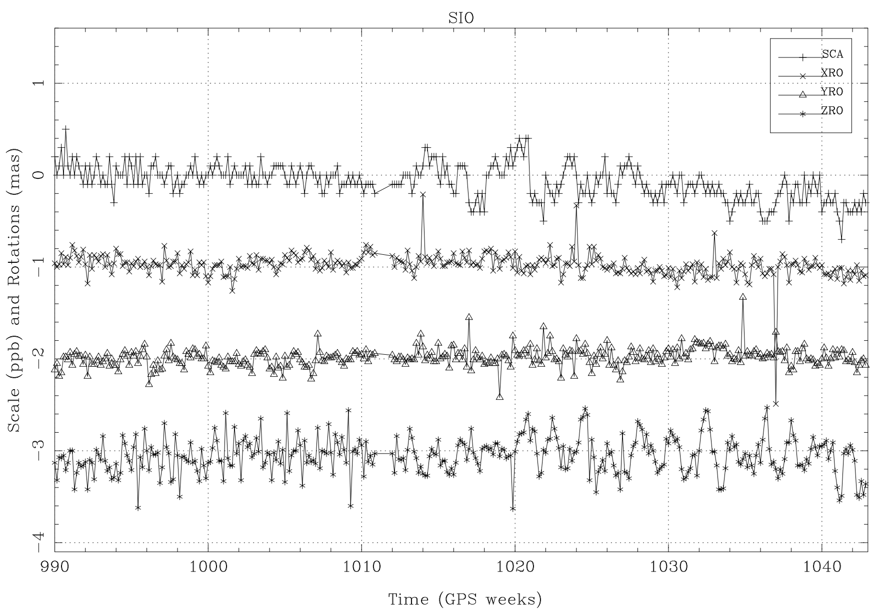


(b) Scale and Rotations (X, Y, and Z)

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.

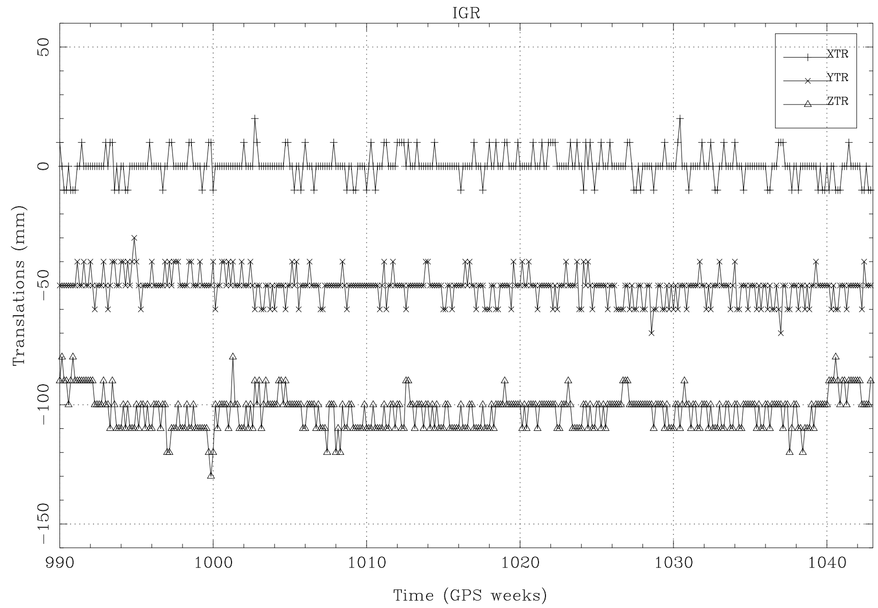


(a) Translations (X, Y, and Z)

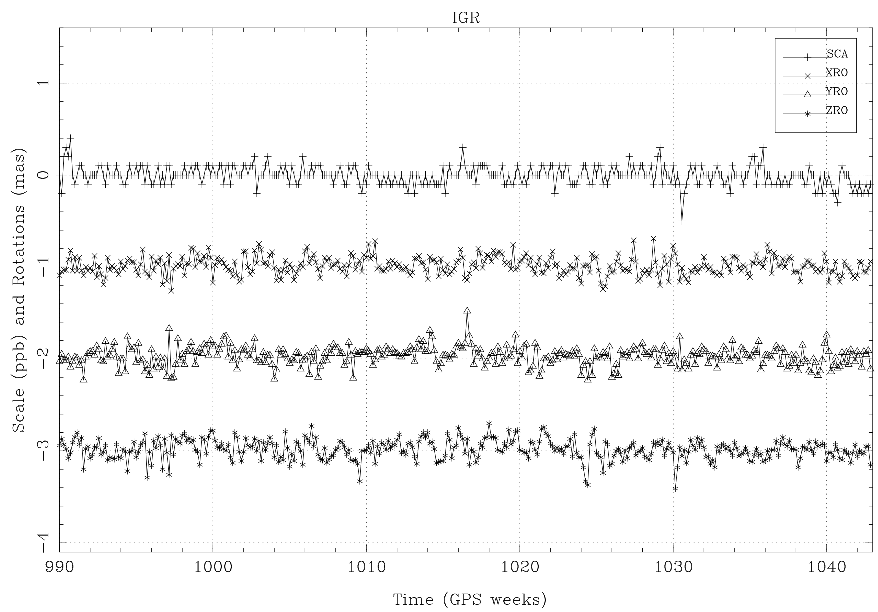


(b) Scale and Rotations (X, Y, and Z)

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

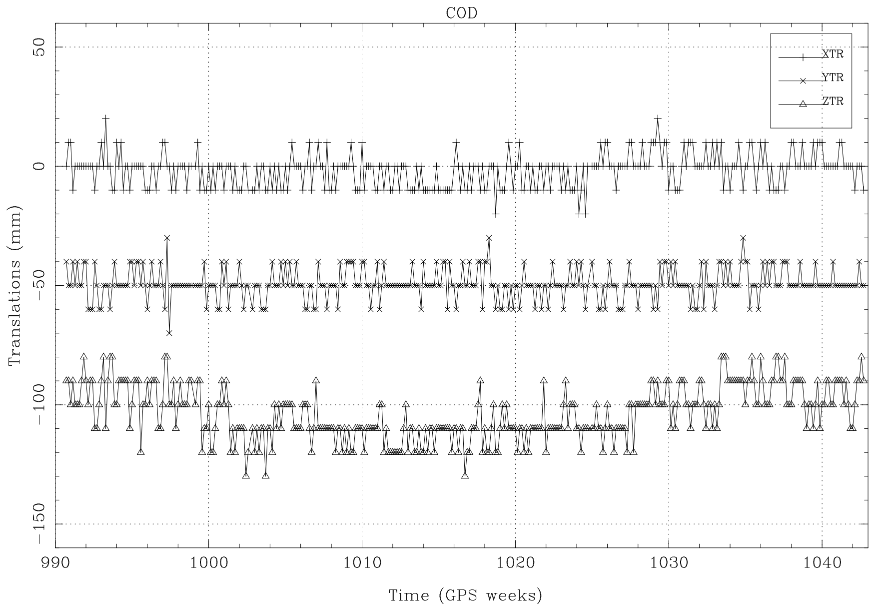


(a) Translations (X, Y, and Z)

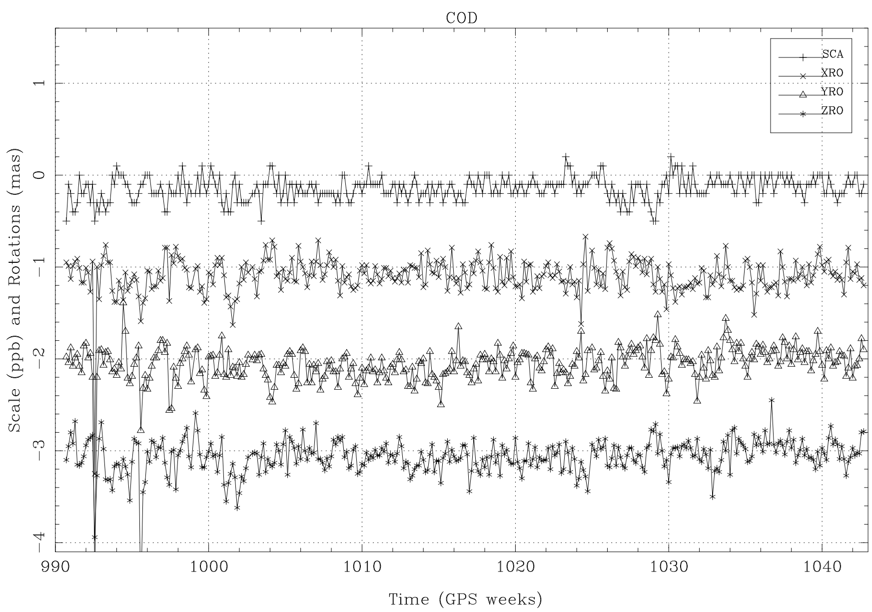


(b) Scale and Rotations (X, Y, and Z)

Figure 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.

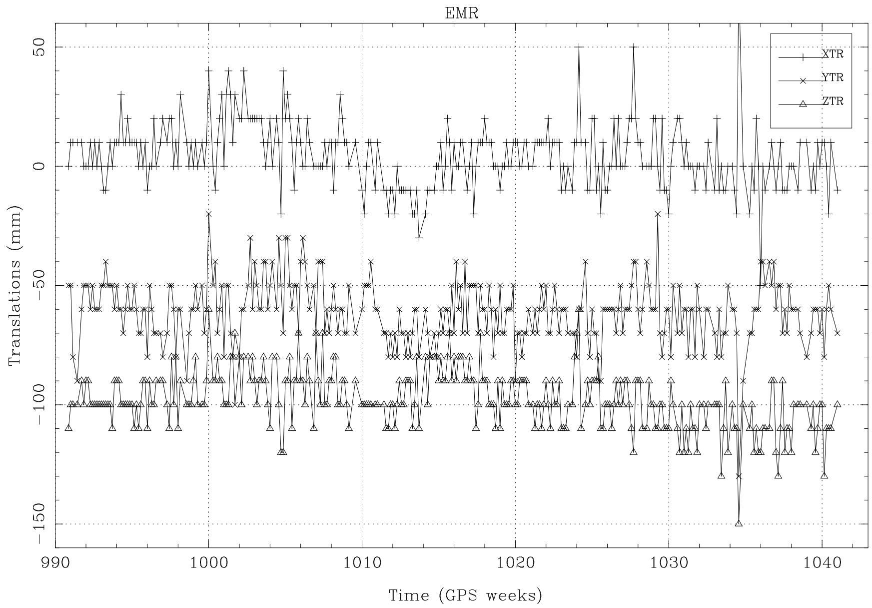


(a) Translations (X, Y, and Z)

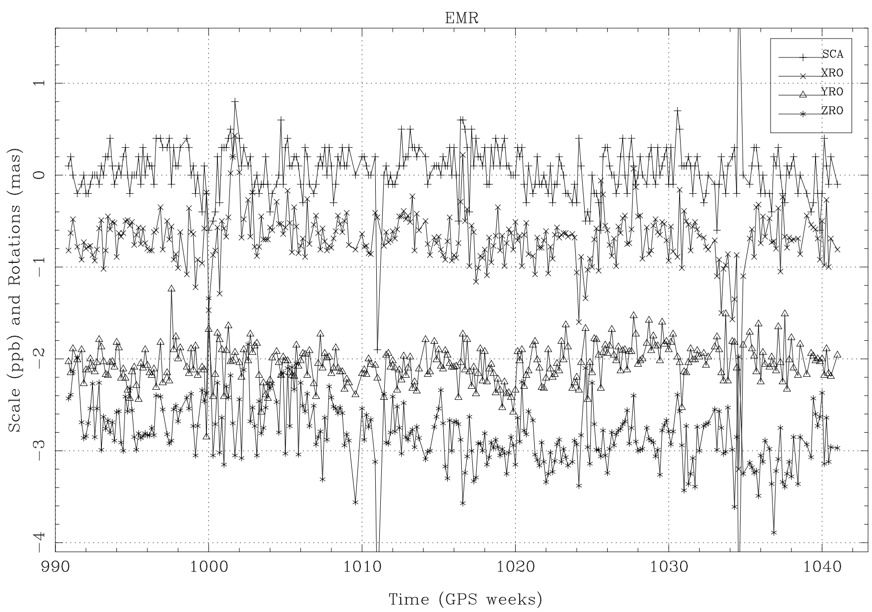


(b) Scale and Rotations (X, Y, and Z)

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

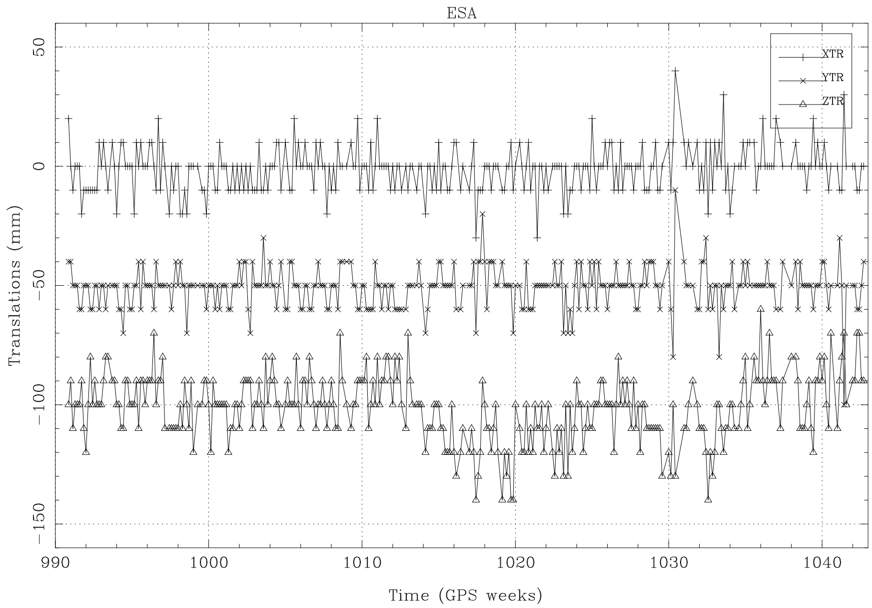


(a) Translations (X, Y, and Z)

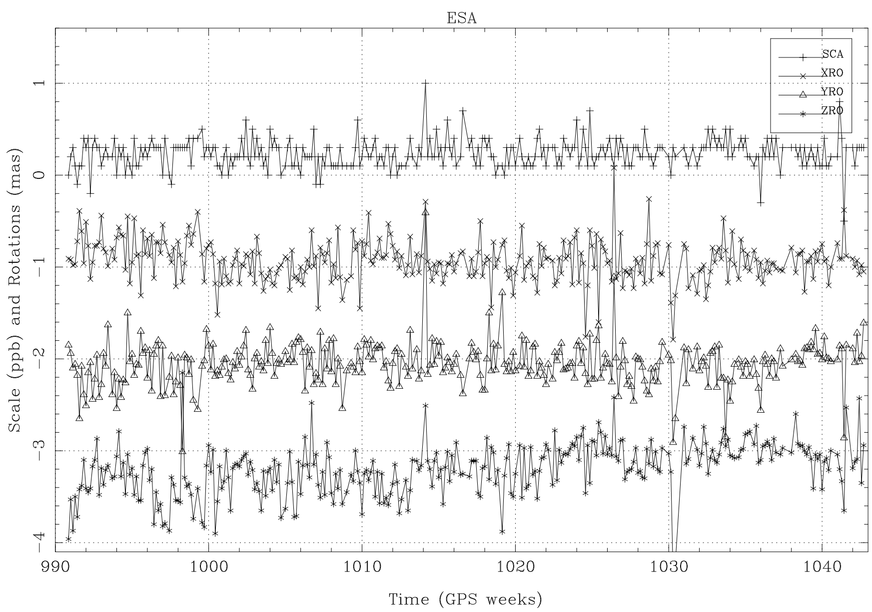


(b) Scale and Rotations (X, Y, and Z)

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

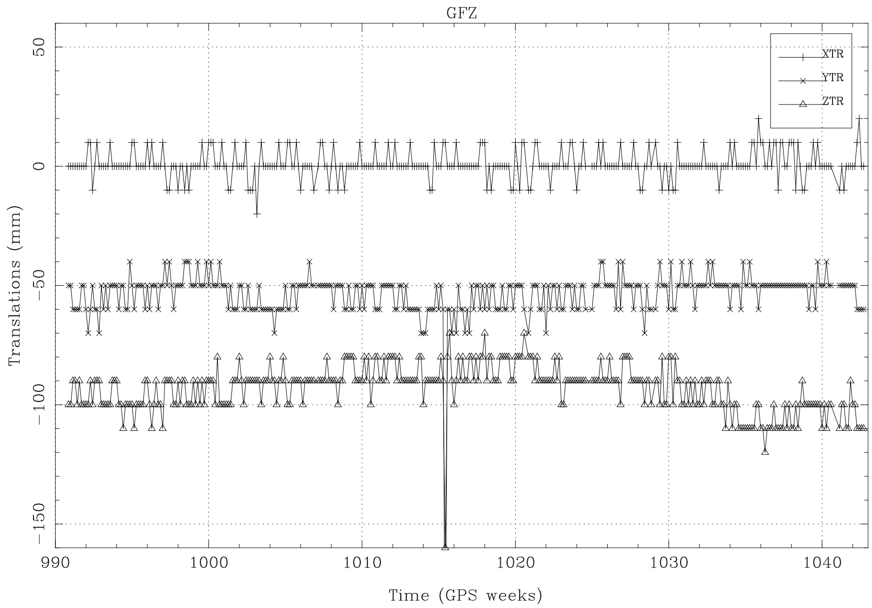


(a) Translations (X, Y, and Z)

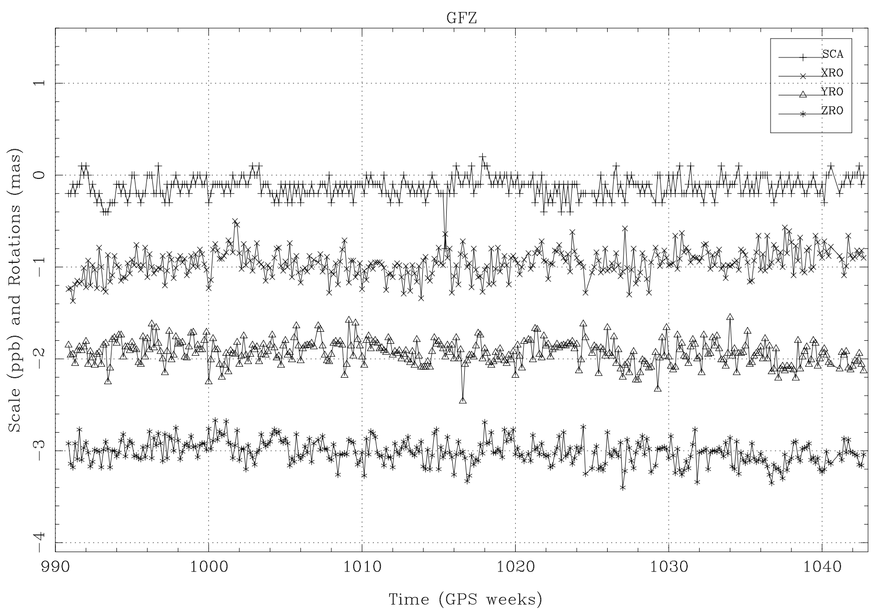


(b) Scale and Rotations (X, Y, and Z)

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

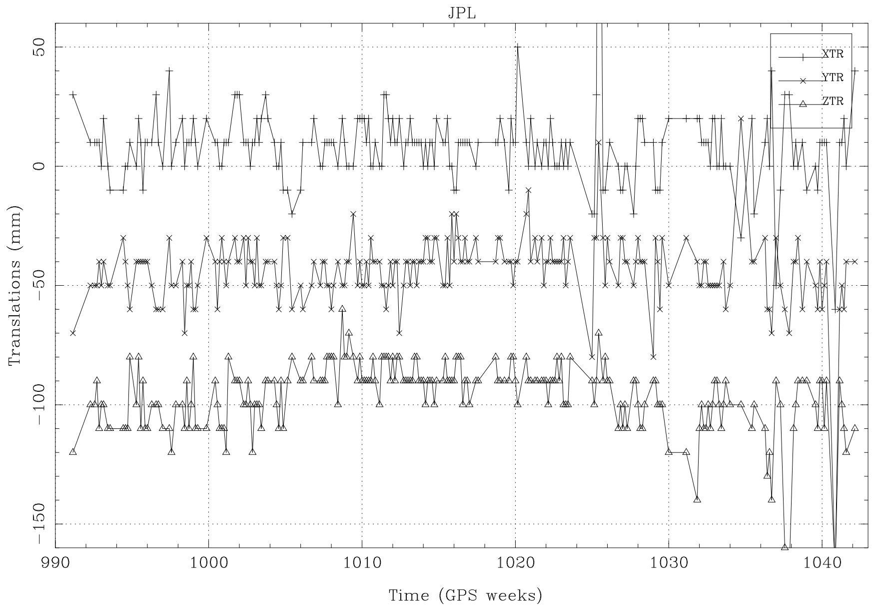


(a) Translations (X, Y, and Z)

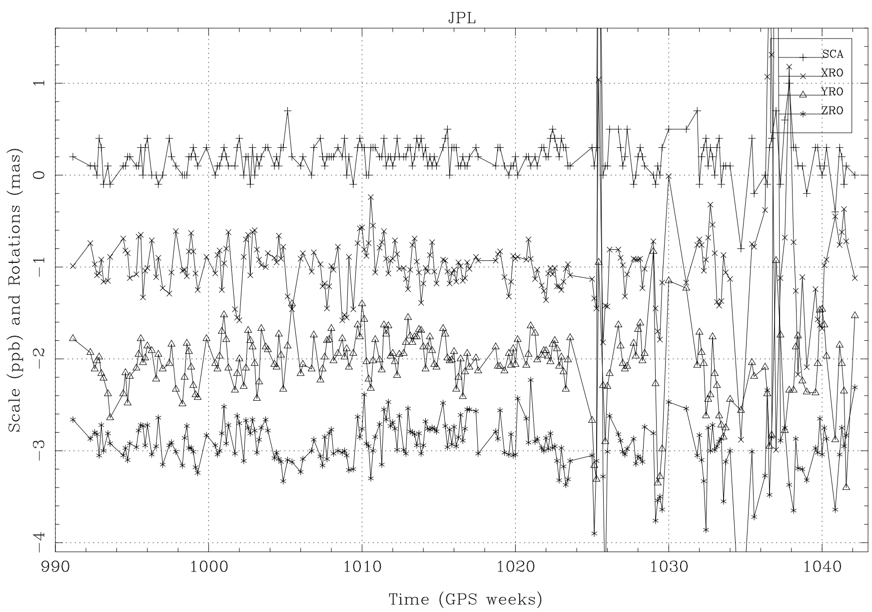


(b) Scale and Rotations (X, Y, and Z)

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

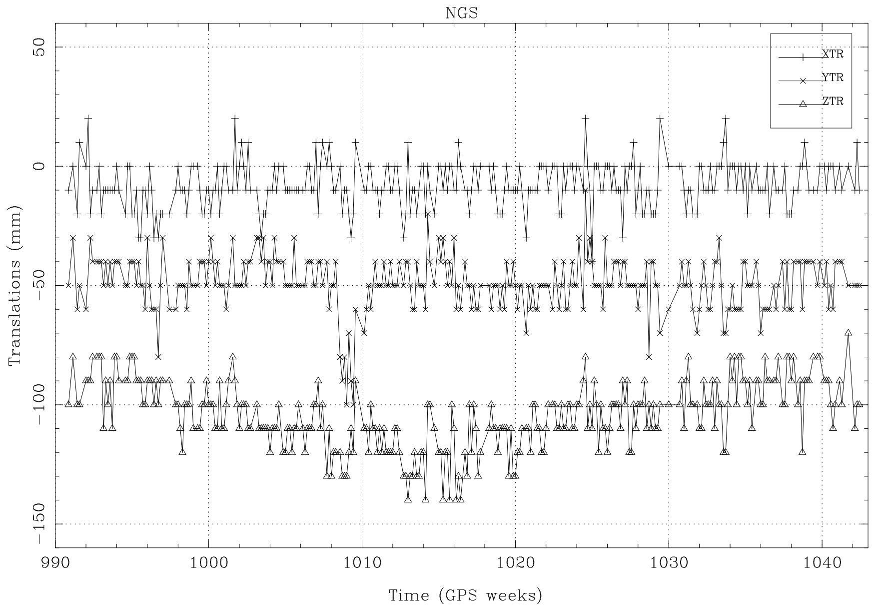


(a) Translations (X, Y, and Z)

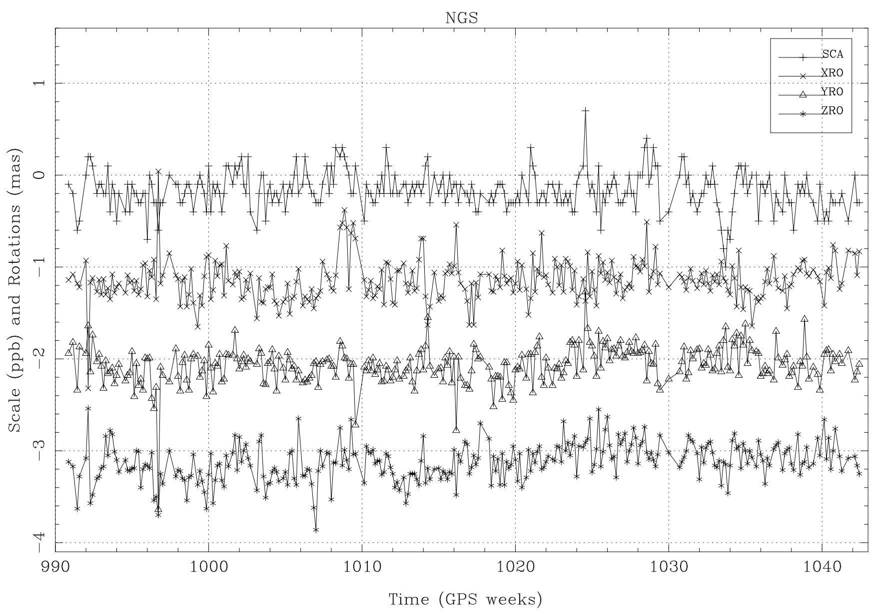


(b) Scale and Rotations (X, Y, and Z)

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

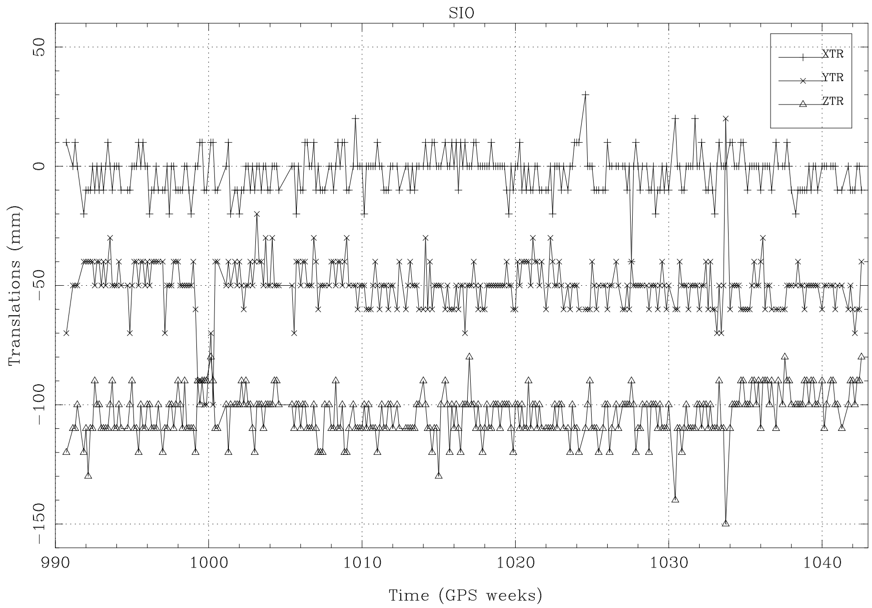


(a) Translations (X, Y, and Z)

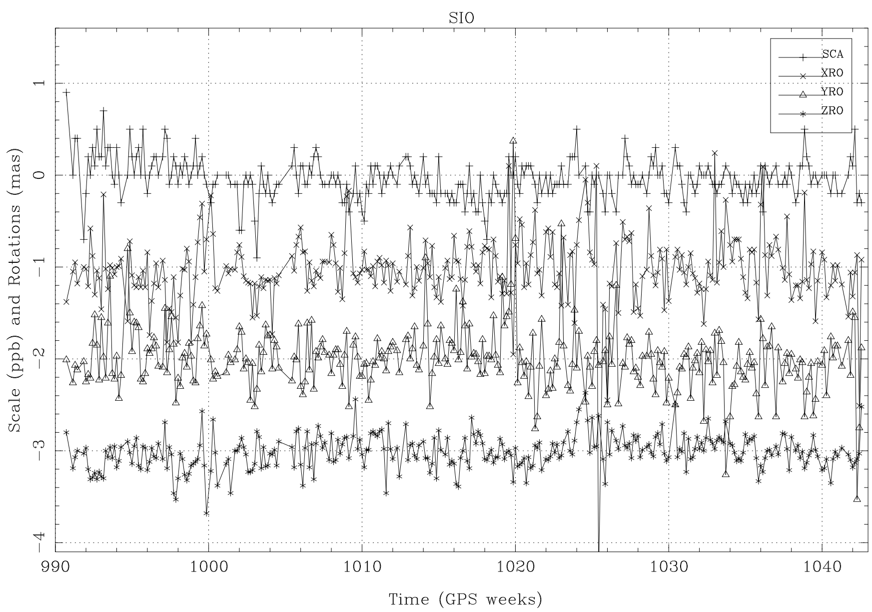


(b) Scale and Rotations (X, Y, and Z)

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

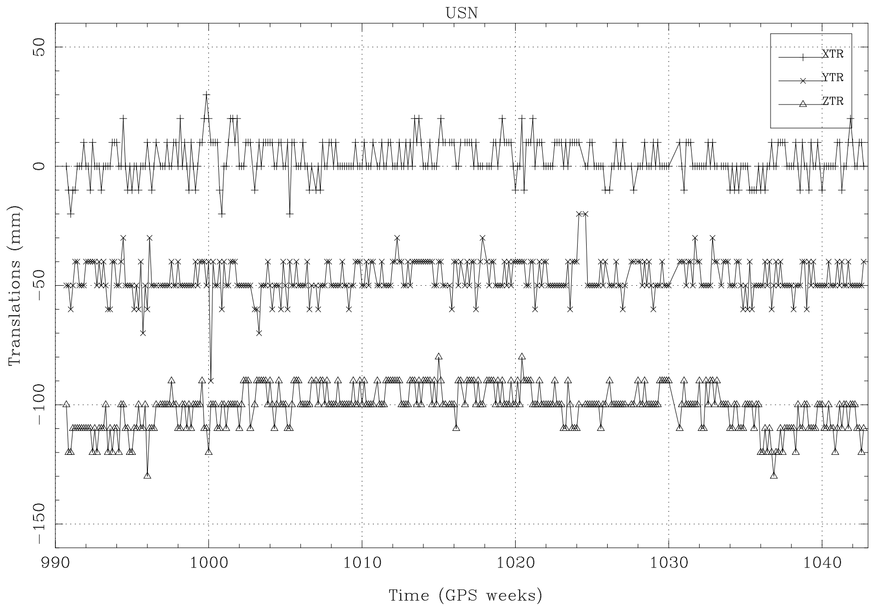


(a) Translations (X, Y, and Z)

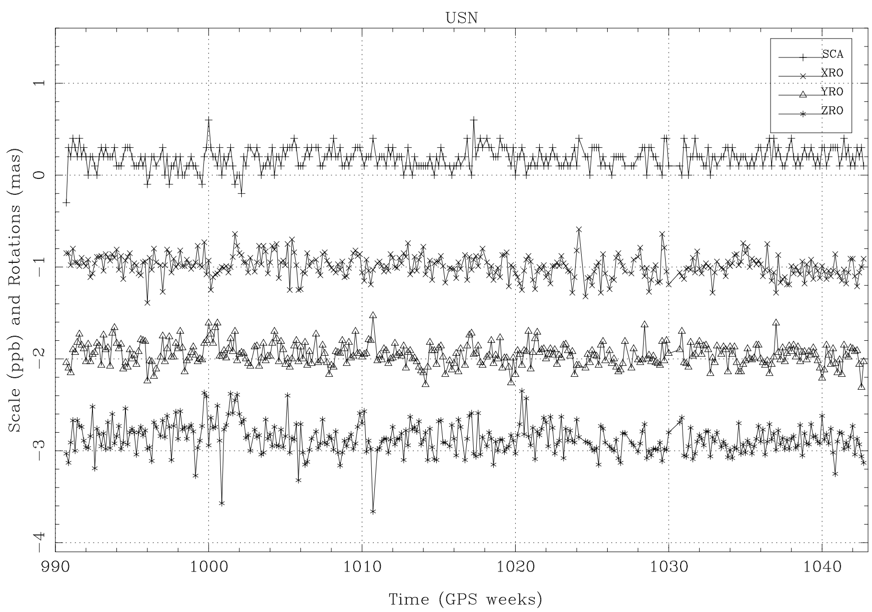


(b) Scale and Rotations (X, Y, and Z)

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

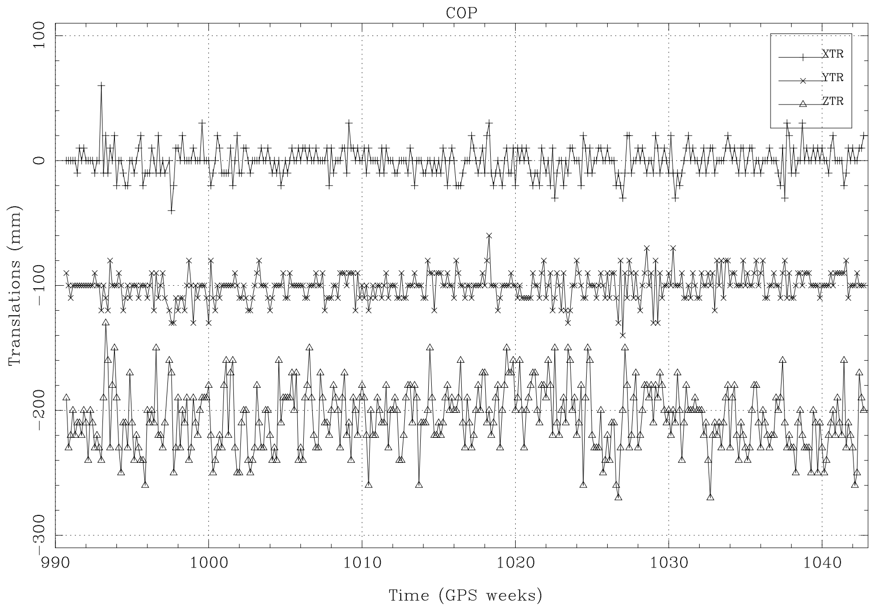


(a) Translations (X, Y, and Z)

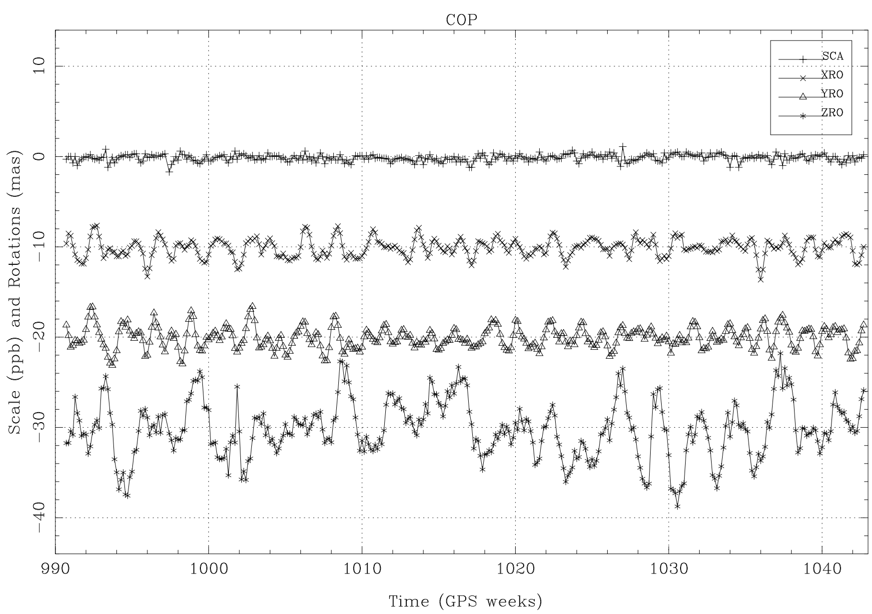


(b) Scale and Rotations (X, Y, and Z)

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

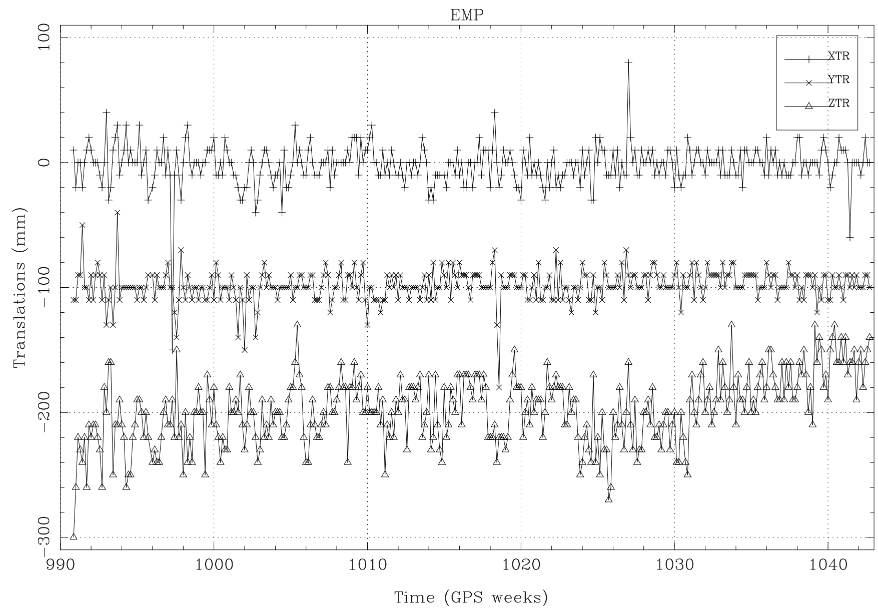


(a) Translations (X, Y, and Z)

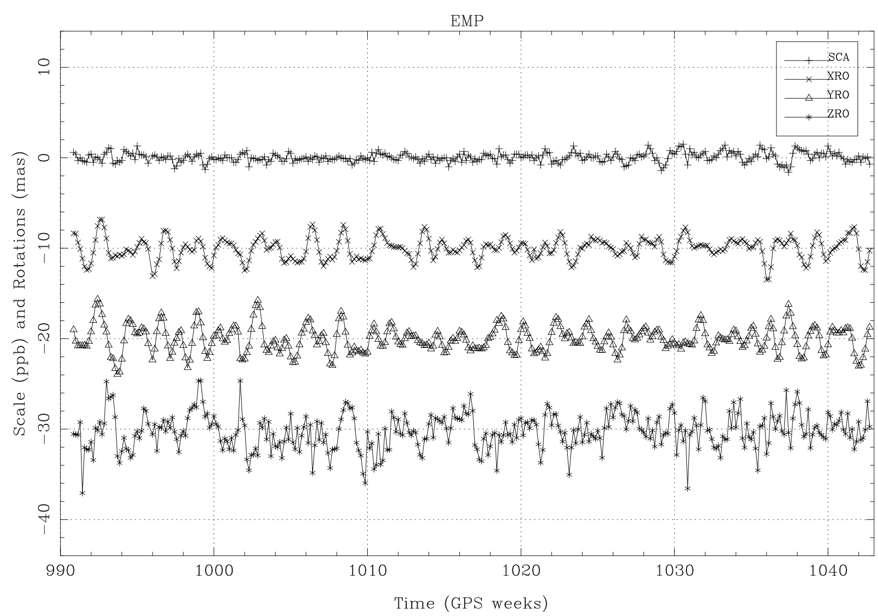


(b) Scale and Rotations (X, Y, and Z)

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.

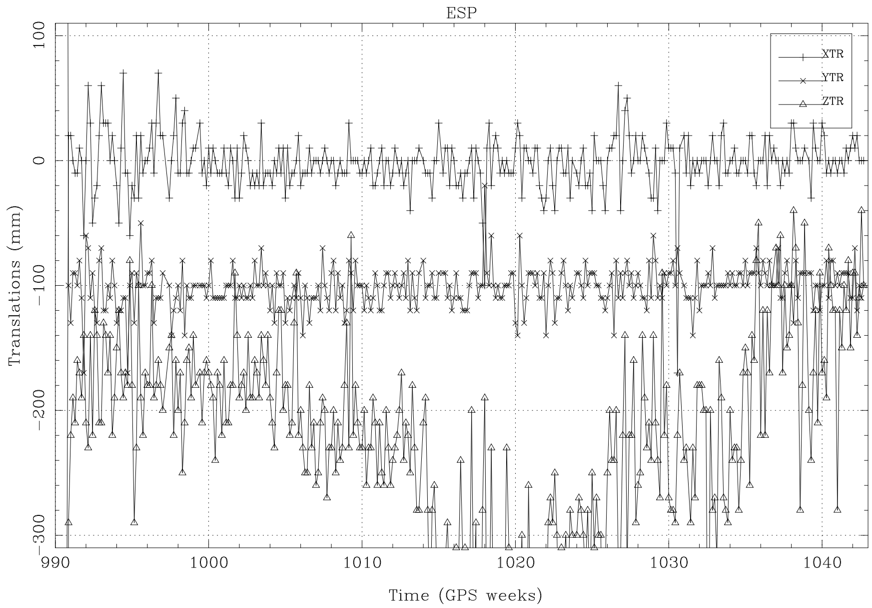


(a) Translations (X, Y, and Z)

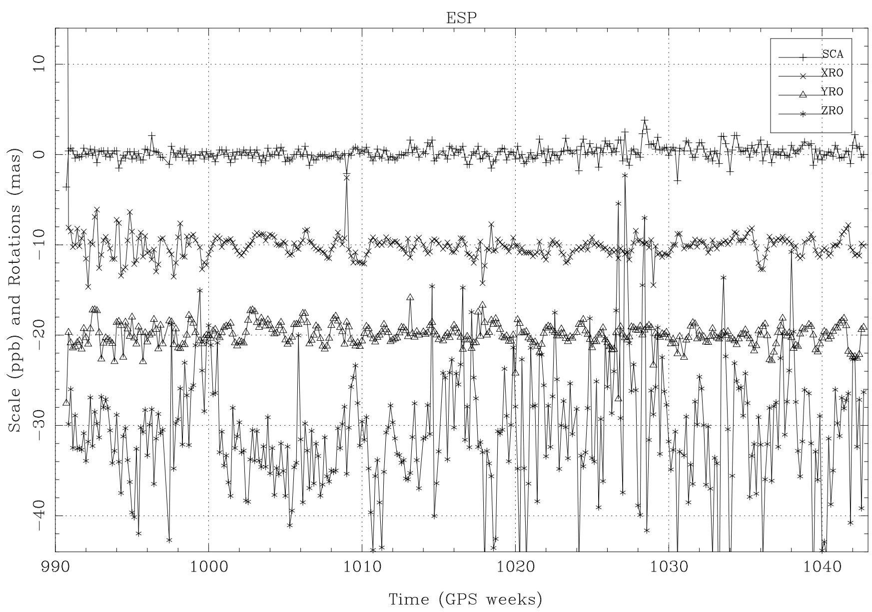


(b) Scale and Rotations (X, Y, and Z)

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.

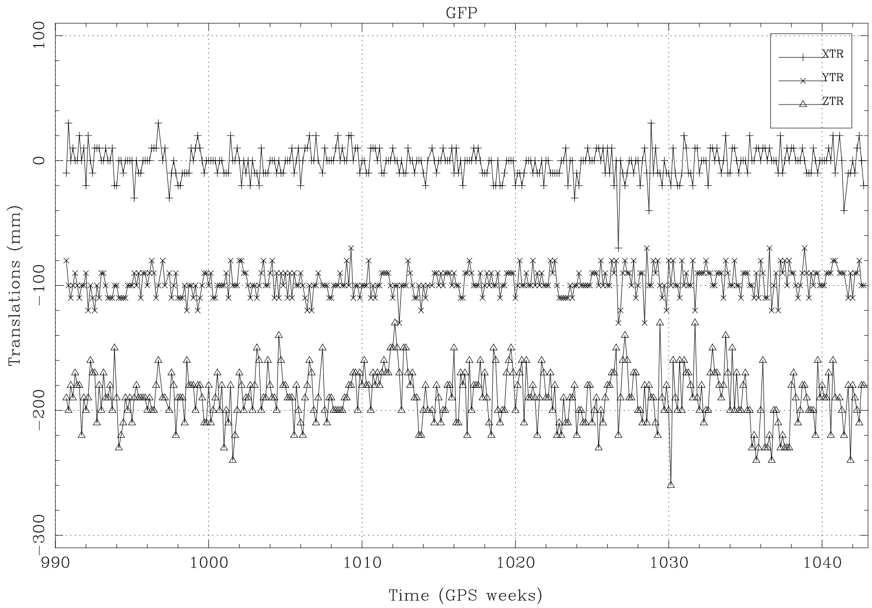


(a) Translations (X, Y, and Z)

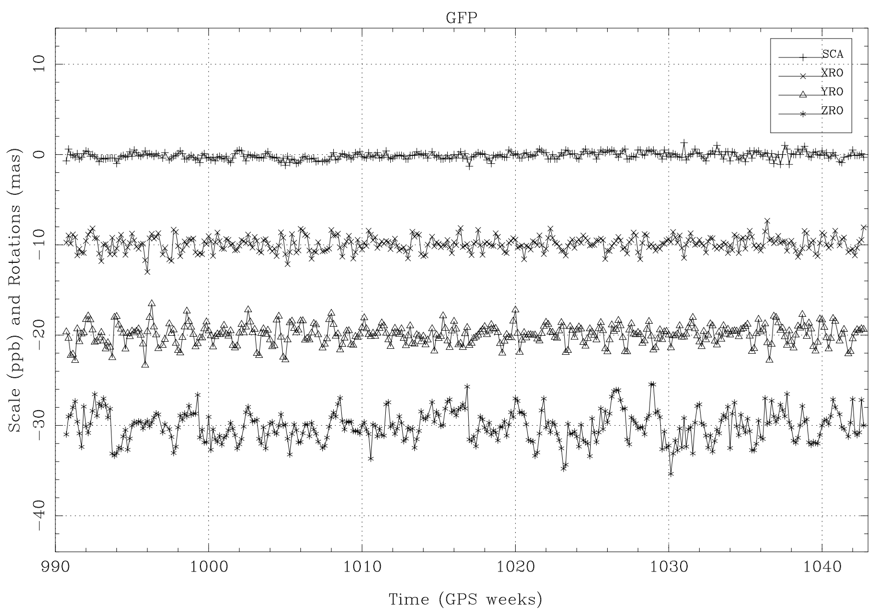


(b) Scale and Rotations (X, Y, and Z)

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.

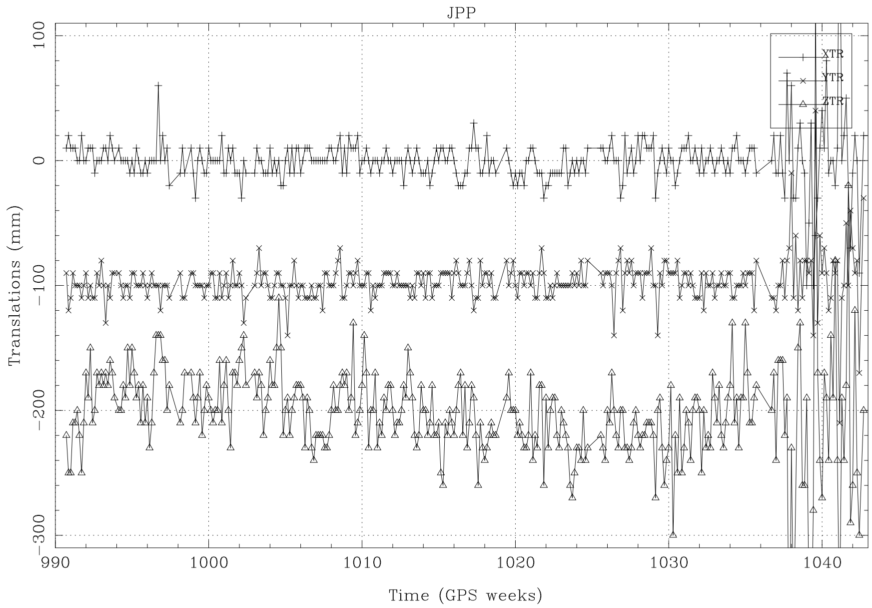


(a) Translations (X, Y, and Z)

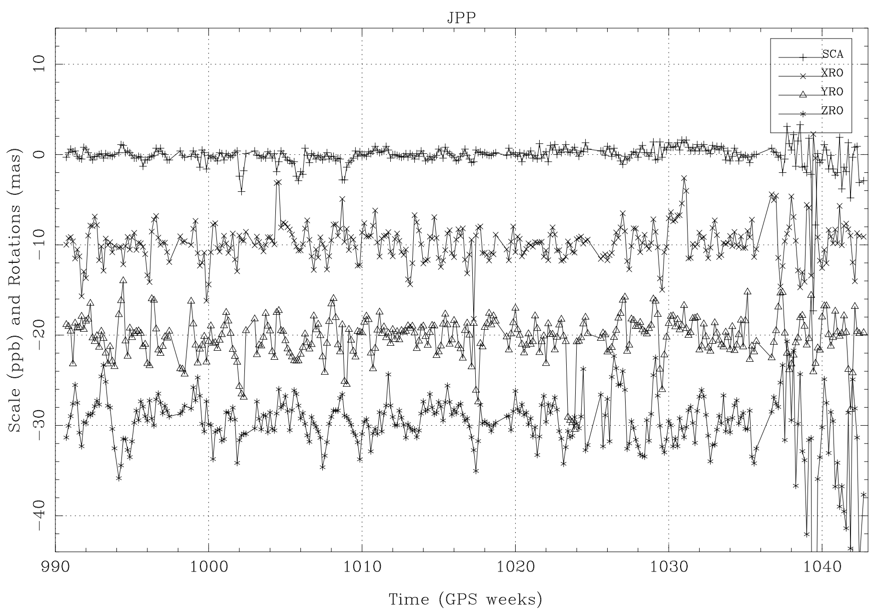


(b) Scale and Rotations (X, Y, and Z)

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.

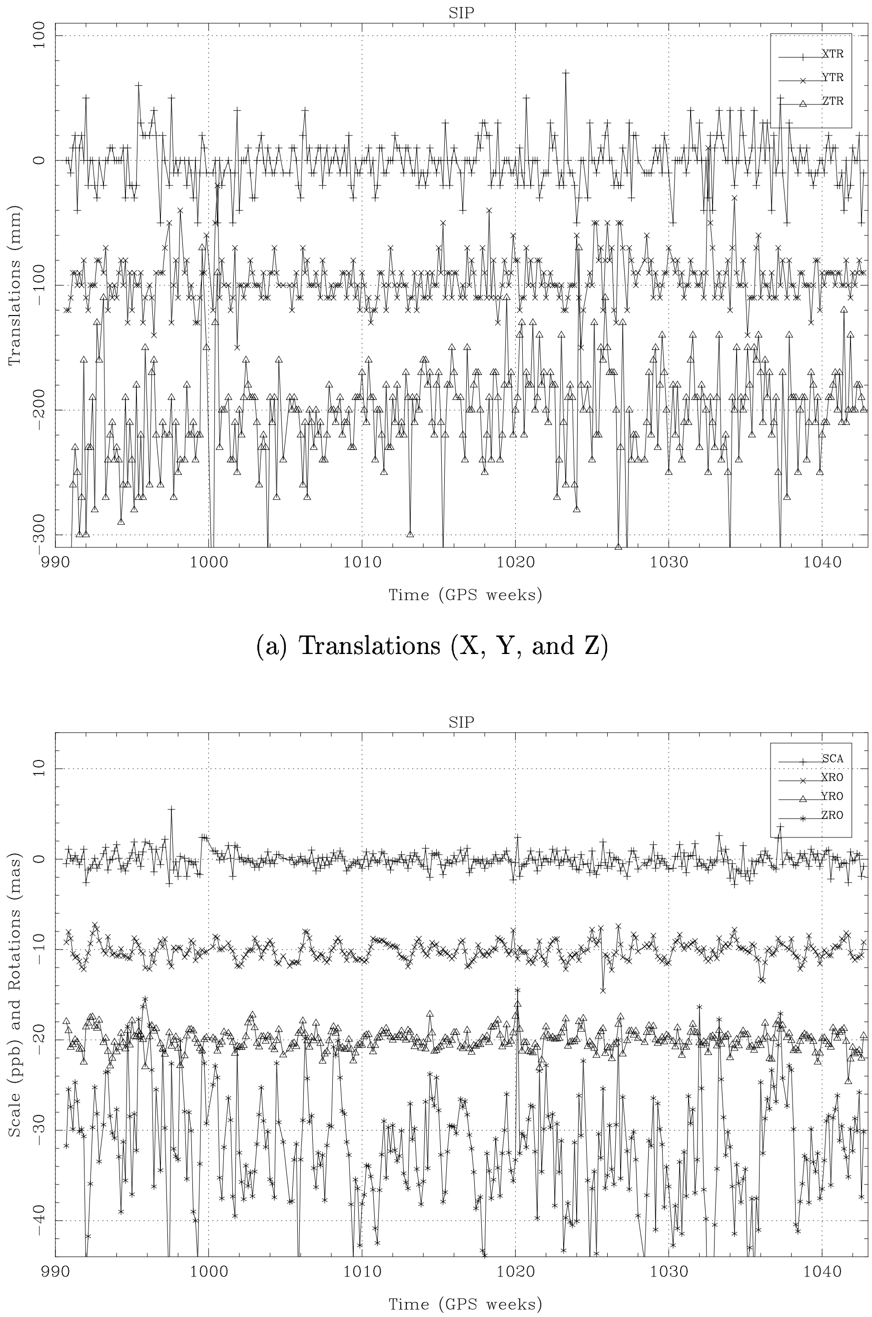


(a) Translations (X, Y, and Z)



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

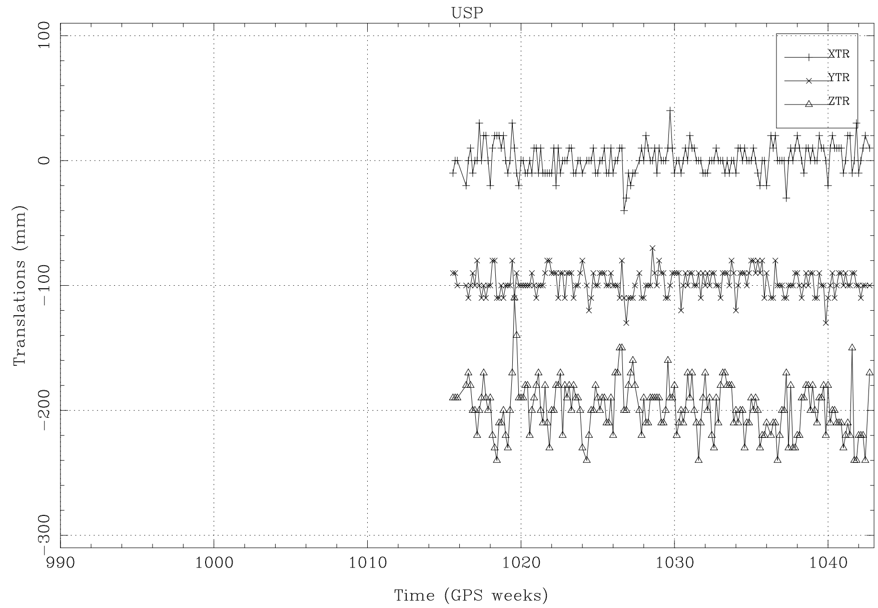
Figure 23: Daily Transformation parameters of the AC Predicted orbits with respect to IGS Rapid orbits. Translations are shifted by 100 mm, rotations are shifted by 10 mas.



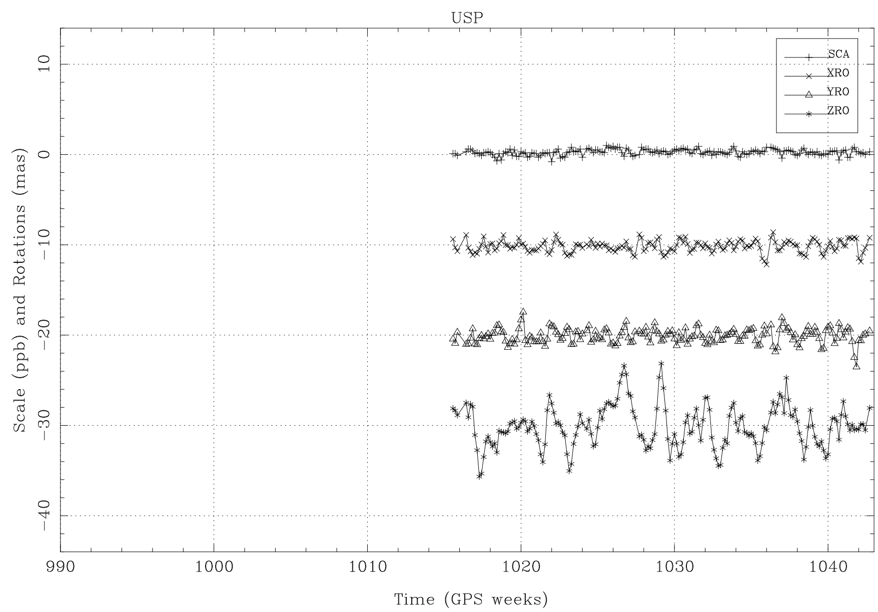
(a) Translations (X, Y, and Z)

(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.

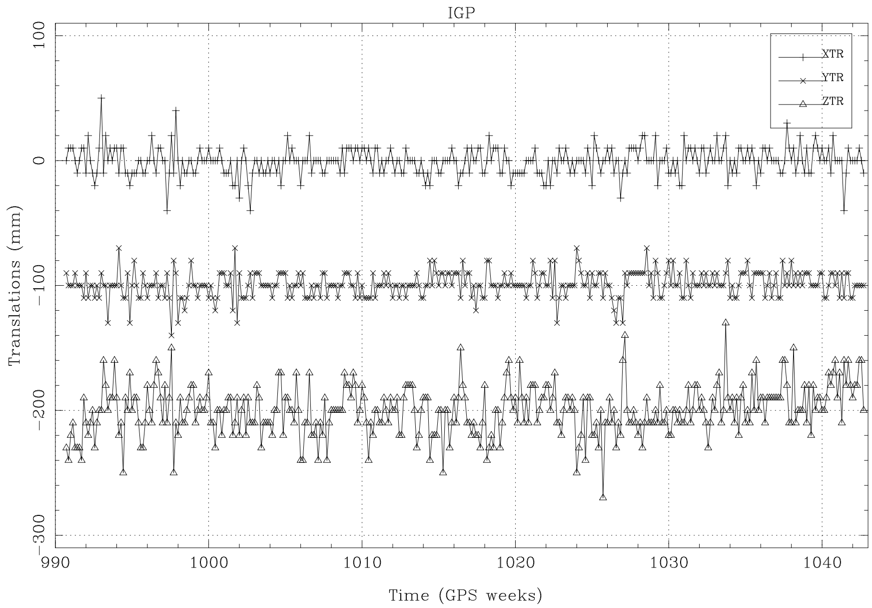


(a) Translations (X, Y, and Z)

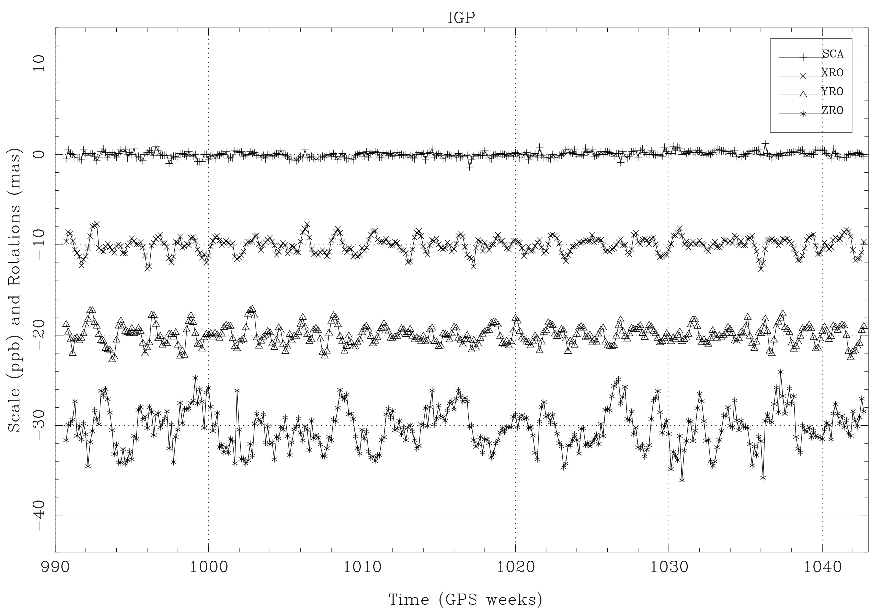


(b) Scale and Rotations (X, Y, and Z)

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.

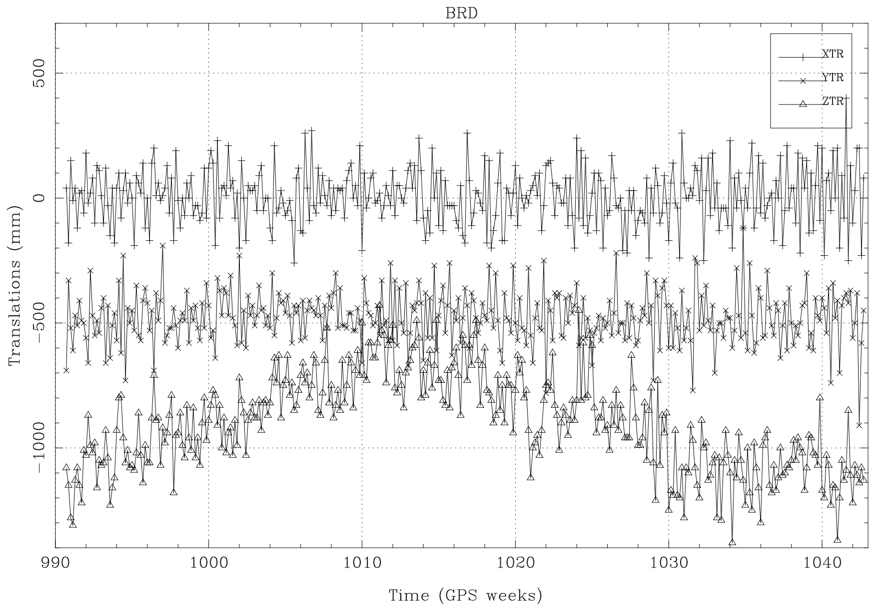


(a) Translations (X, Y, and Z)

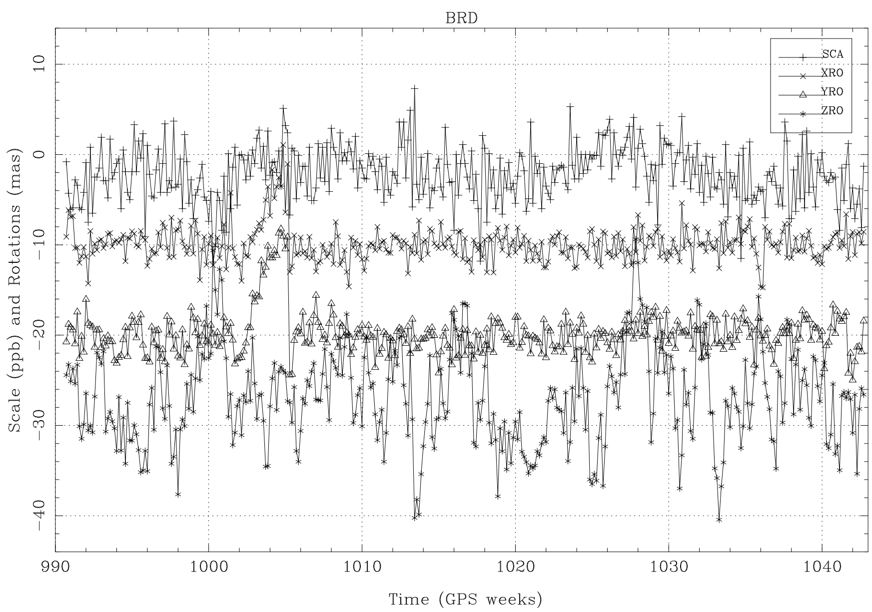


(b) Scale and Rotations (X, Y, and Z)

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.

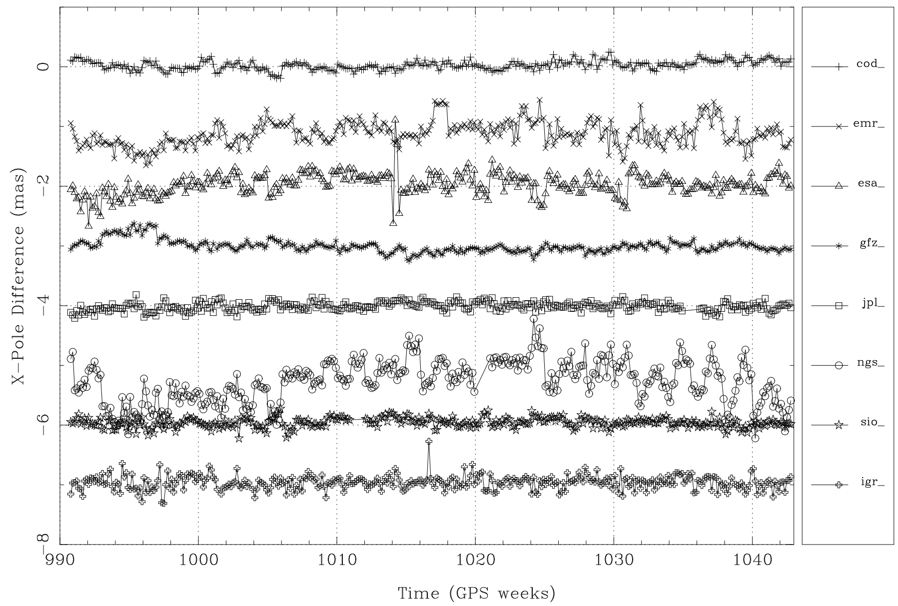


(a) Translations (X, Y, and Z)

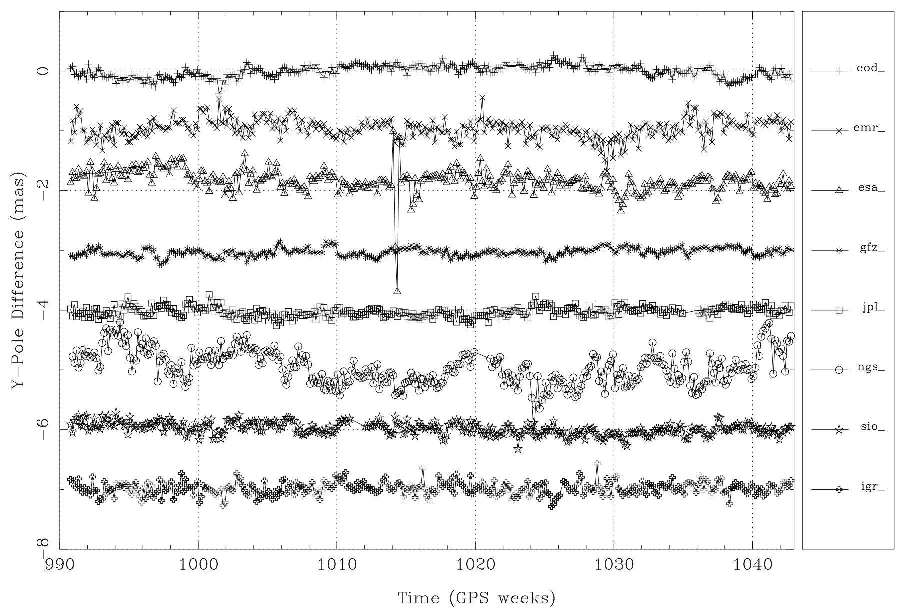


(b) Scale and Rotations (X, Y, and Z)

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.

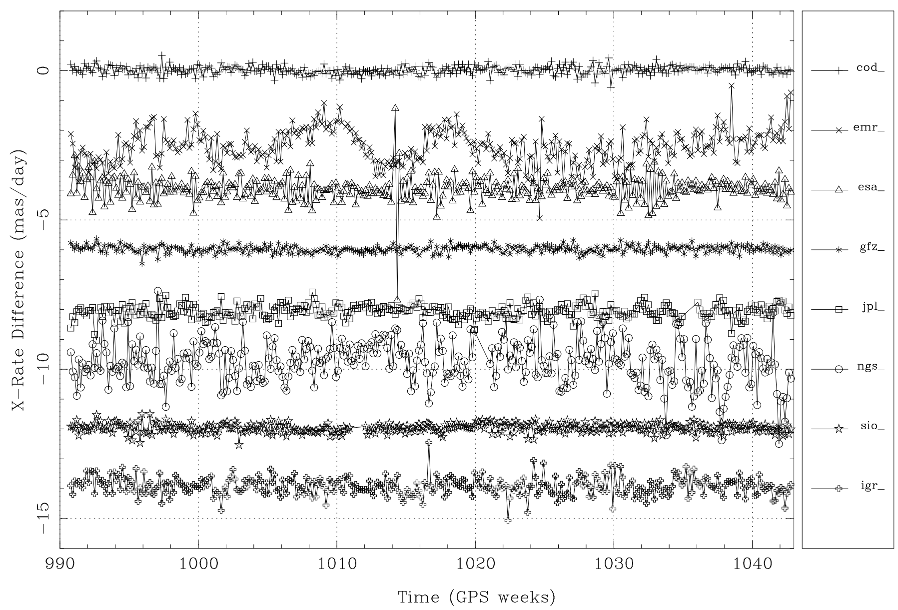


(a) X-Pole

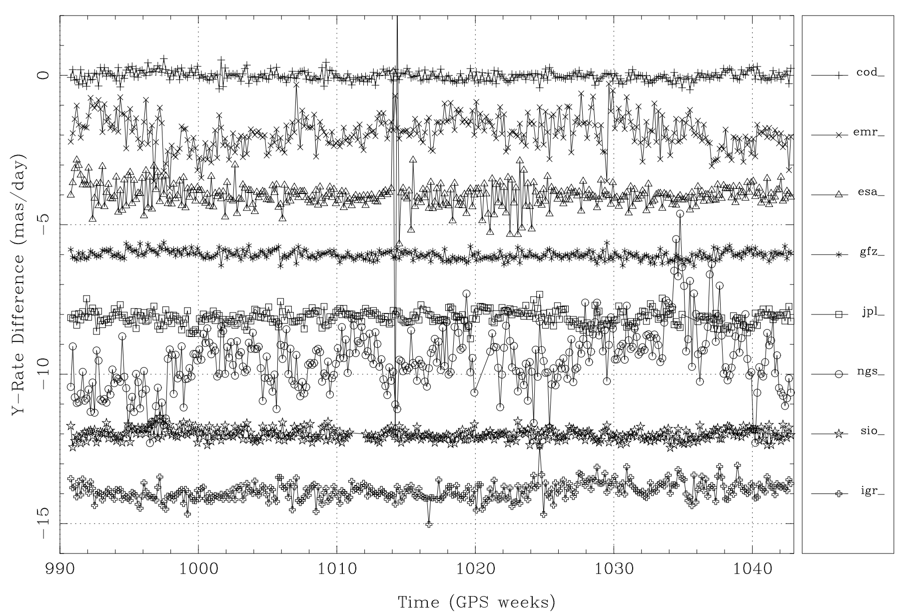


(b) Y-Pole

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

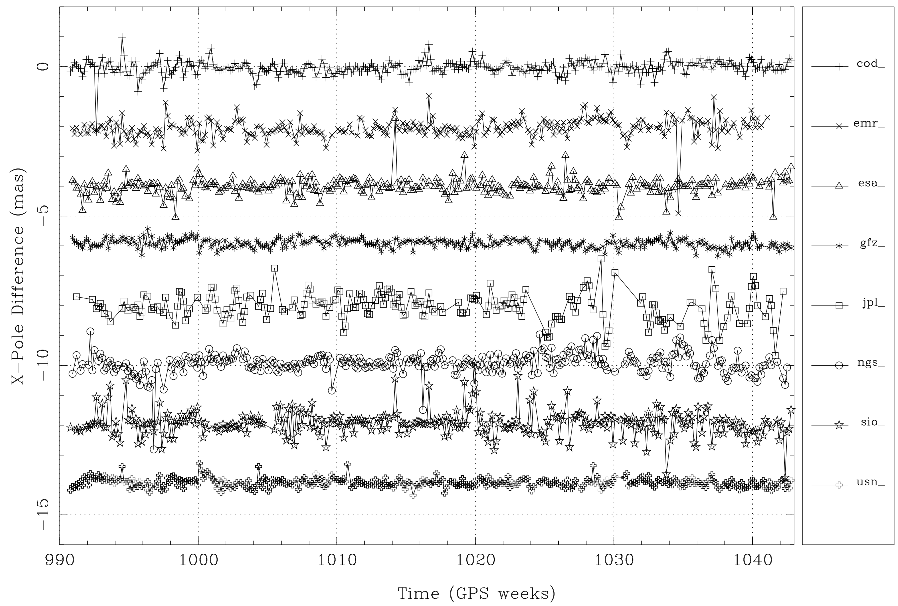


(a) X-Rate

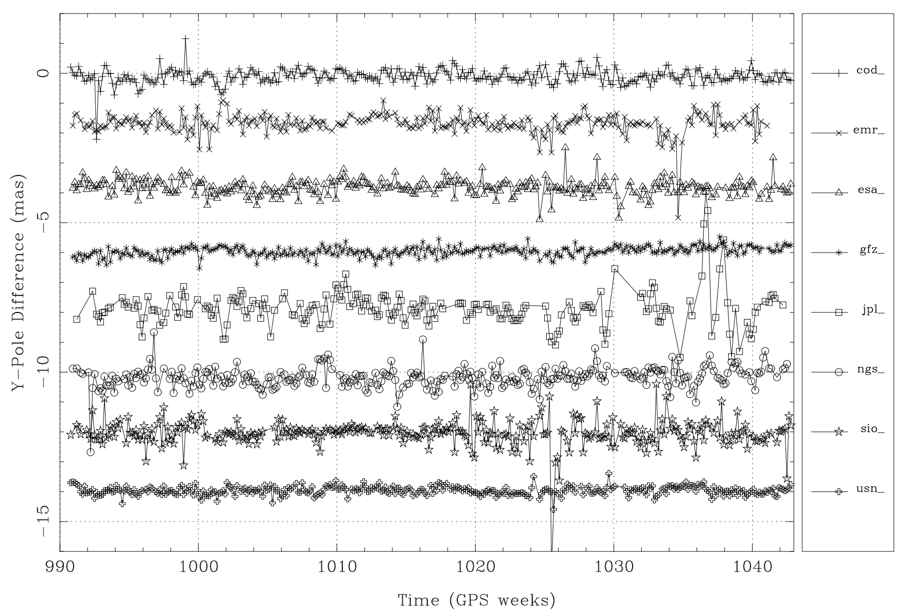


(b) Y-Rate

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

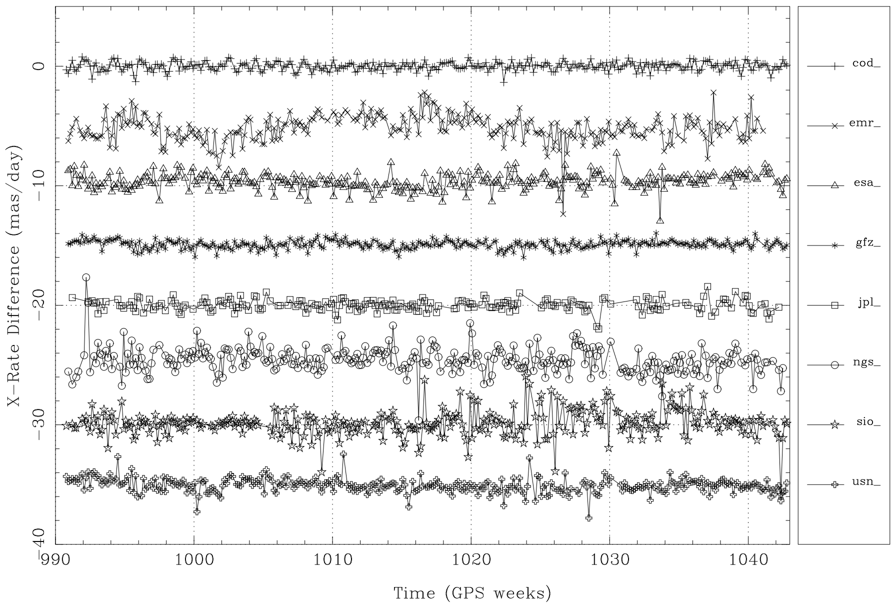


(a) X-Pole

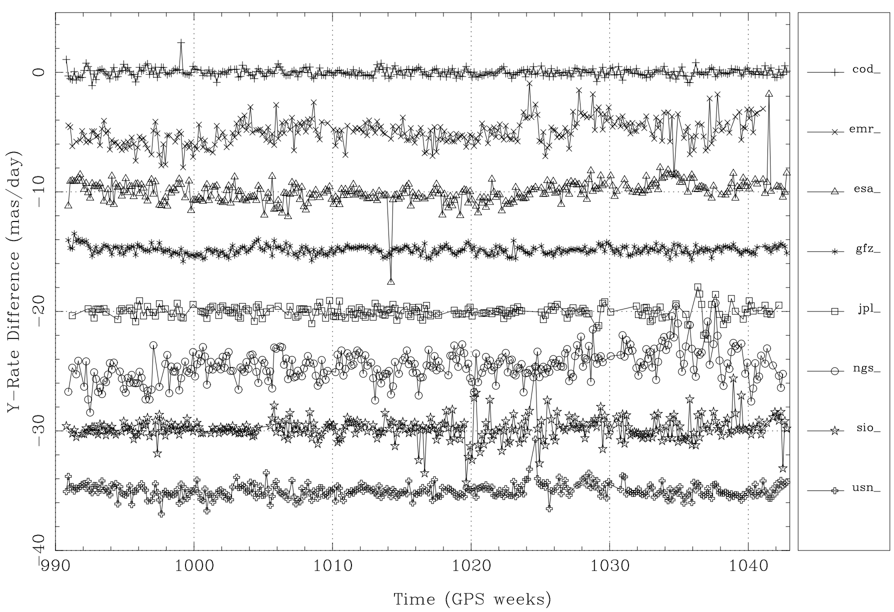


(b) Y-Pole

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

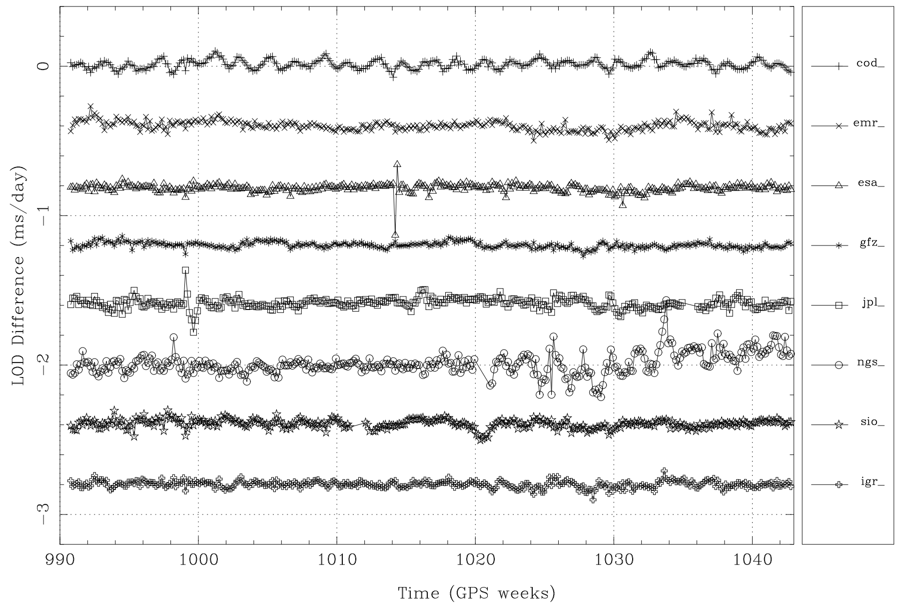


(a) X-Rate

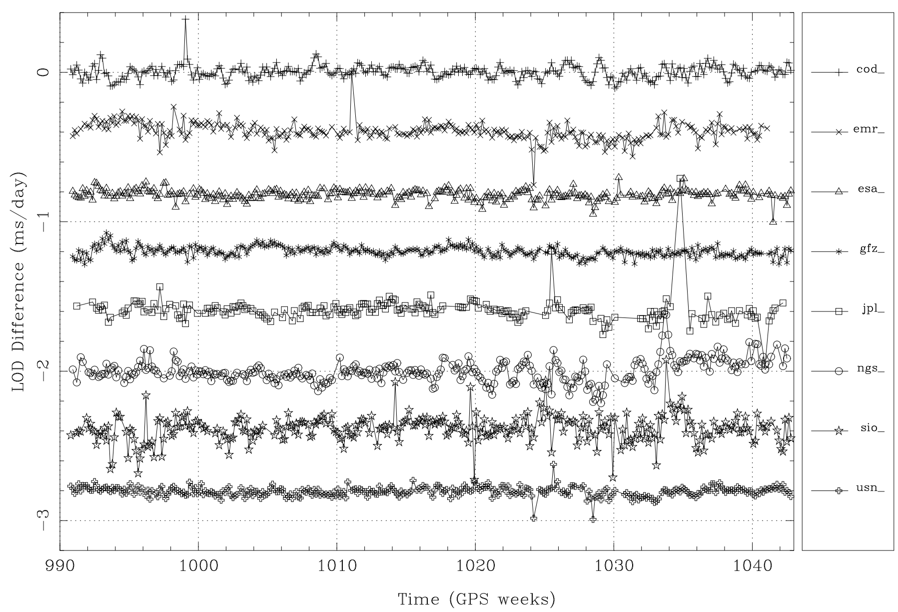


(b) Y-Rate

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.