IGS

ANALYSIS CENTER REPORTS

1998 Analysis Coordinator Report

J. Kouba and Y. Mireault

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

T.A. Springer

Astronomical Institute
University of Bern, Switzerland

Introduction

This report complements the 1998 Analysis Coordinator Report found in Volume I of the 1998 IGS Annual Report (Kouba, 1999a). Changes, enhancements and new products implemented during 1998 as well as the combination statistics of orbits, clocks and Earth Rotation Parameters (ERP) are reviewed. The most important change occurred towards the end of 1998 when the IGS orbits, clocks and ERP combination activities were officially transferred to the University of Bern (CODE AC). Also, on January 1 1999, Tim Springer from CODE was appointed as the new AC Coordinator of IGS, officially replacing Jan Kouba.

Changes, Enhancements and New Products in 1998

This section deals with the changes and enhancements that occurred during 1998. A short description is given for the most important ones while all changes and enhancements are chronologically summarized in Table 1.

Clock Solution Combinations

First of all, IGS users should be reminded that the IGS clock combination strategy was changed in December 1997. Non-SA based AC clock alignment and weighting were abandoned for a more reliable method using one reference AC aligned to all broadcast satellites. The absolute deviation of the aligned AC clock solutions with respect to an unweighted mean of the aligned AC clock solutions are now used to derive AC clock weighting. This resulted in more appropriate AC clock weights and consequently more precise and consistent IGS combined clock corrections. To further improve the consistency of IGS orbits and clocks, a new alignment correction to AC clocks, based on the difference in the radial component between AC and IGS combined orbits, was implemented in late December 1997/early January 1998. The above changes were already discussed in (Kouba and Mireault, 1998).

Table 1. Summary of changes and enhancements in 1998.

Wk/Day	Products	Changes
938/0 940/1	Final Rapid	New alignment correction to AC clocks based on the difference in the radial component between AC and IGS combined orbits.
941/0	Final Rapid	IGS/IGR accumulated ERP files submitted to CDDIS.
942/6	---	PRN13, launched on Jul. 23, 1997 at 03:43 UT (Wk 915/3) was set usable on this day at 00:57 UT.
947/0	Final Rapid	Change of reference frame from ITRF94 to ITRF96.
960/0 ++	Final Only	All AC orbits, ERP, station positions and clock solutions should be based on minimum (rotational) constraints only.
960/0 962/0	Final Rapid	Use of the most recent IERS Bulletin A daily or weekly pole file updates for AC LOD calibrations.
964/0	Final Only	Started to apply small rotations to NGS orbits and ERP values to align them to ITRF96 following NGS first unconstrained submission.
966/0	Final Rapid	New IGS ERP format (version 2) adopted.
986/0	Final Rapid	All IGS clock products reflect the use of the following antenna phase center offsets (satellite fixed reference frame): • Block II & IIA: dx=0.279m; dy=0.000m; dz=1.023m • Block IIR: dx=0.000m; dy=0.000m; dz=0.000m
986/0	Rapid Only	AC submission deadline set to 16:00 UT and 17:00 UT for IGR combined products.
988/4	All	Transfer of IGS orbit, clock and ERP combination activities to the CODE AC (University of Bern).
990/5	All	Tim Springer officially appointed as the new AC Coordinator.

IGR/IGS Accumulated ERP files

Following some demand for accumulated IGR and IGS ERP files, it was decided on January 18, 1998 (Wk 941) to start generating these files on a regular basis. Both files, igs96p02.erp and igs95p02.erp reside at CDDIS in the products directory and are overwritten on a daily (Rapid) and weekly (Final) basis, respectively. They both start at June 30, 1998 (Wk 860/0 or MJD 50264.5) and are generated at the same time the IGS combinations are performed.

Change of Reference Frame

Up to February 28, 1998 (Wk 946) all the IGS and AC solutions and the IGS ITRF realization were based on the ITRF94 positions and velocities of the same 13 stations that were also used for previous IGS ITRF realizations. Since March 1, 1998 (Wk 947) all the IGS products are nominally in ITRF96 and are based on up to 47 ITRF96 station positions and velocities *(ftp://igscb.jpl.nasa/gov//igscb/station/coord/ITRF96_IGS_RS47.SNX.Z)*. Comparisons of the IGS Final PM with independent PM series and analyses of the IGS orbit orientations (i.e. shifts of the daily mean positions at test stations WILL, BRUS and USUD) indicated that the March 1 shift of the IGS Final PM_y series was about half of the expected value of .2 milliarcsecond (mas) (*IGS Mail message #2105*). The remaining rotations ($RY=PM_x$ and RZ) as well as the scale changes were found to be in good agreement with the expected values, as estimated from the 13 ITRF94 and ITRF96 station positions (see *IGS MAIL message # 1838*). On March 1, 1998, the transformations found in Table 2 should be applied to the IGS Final products derived series (orbits, ERP) to remove apparent discontinuities, especially for higher accuracy applications. For more information on the IGS ITRF94/96 change, see *IGS Mail message # 2105.* For more information on the past IGS realizations of ITRF, including estimated transformations, see *IGS Mail message #1838*.

Table 2. Transformation Parameters IGS(ITRF94)-IGS(ITRF96).

Epoch 1998.16 (March 1, 1998; Wk 947; MJD 50873);
Confirmed by independent ERP series and IGS Final orbit precise point navigation.

IGS Orbits/ERP	TX (cm)	TY (cm)	TZ (cm)	RX (mas) (PM_y)	RY (mas) (PM_x)	RZ (mas) (-dUT)	SCL (ppb)
Parameter	0.0	0.1	-0.1	0.10	0.1	0.22	0.4
Sigma	0.3	0.3	0.3	0.05	0.5	0.10	0.4
Rates (/yr)	-0.02	0.09	-0.02	0.02	-0.01	-0.01	0.07
Sigma	0.06	0.06	0.06	0.03	0.02	0.03	0.09

Note: The transformation parameters above are consistent with the IERS conventions.

Minimum Datum Constraint

As recommended by the Darmstadt AC workshop and in preparation for the new IGS realization of ITRF (Kouba, Ray and Watkins, 1998), all the AC orbit, ERP, station positions and clock Final solutions should be consistent and based on minimum (rotational) constraints only. The proposed deadline was set to May 31, 1998 (Wk 960) and all ACs complied to this new strategy during the course of 1998. Following the first NGS minimum constraint submission on June 28, 1998 (Wk 964), small rotations were noticed and removed from NGS orbits/ERP solutions prior to the combinations. The rotations were estimated from the transformations of stations common to NGS SINEX and the ITRF96 IGS RS_47 SINEX files.

New IGS ERP Format (version 2)

To accommodate an increased resolution in the current IGS ERP format, an enhanced resolution format for all IGS combined products (i.e. the IGS, IGR and IGP ERP files) was agreed upon by all ACs on July 12, 1998 (Wk 966). After discussions amongst ACs and both services of the IERS (the Central Bureau and the Rapid Service), the format was modified primarily for the sake of meaningful (unscaled) formal solution sigmas which in some cases were reduced down to 1 or 2 of the .01 mas units of the old IGS ERP format. The new format (version 2) is almost identical to the current IGS ERP format, the only difference being the increased resolutions for the Polar Motion coordinates (.001 mas), their rates (.001 mas/d) and UT/LOD (.0001 ms) and their respective sigmas. The new IGS ERP format must be identified by the string "version 2" on the first line, starting in column 1. Note that this increased resolution does not imply any precision of GPS solutions which in fact, even for the current best GPS solutions, is much worse then the new format resolution of .001mas/.0001 ms.

Satellite Antenna Offset Problem

Three ACs, namely CODE, GFZ and JPL, puzzled by the results and uncharacteristic behaviour of the new PRN 13, (the first of the new Block IIR type of GPS satellites), investigated and tried to estimate the individual satellite antenna offsets. Despite of the geometrically weak solutions, satellite antenna offsets of all satellites, except for the new PRN 13, have agreed with the nominal (Block II) satellite radial antenna offset within a few dm. Station and orbit global solutions were found to be quite insensitive to changes of satellite antenna offsets. However, the clock solutions fully reflected, or compensated for, different satellite antenna offsets used as can be seen for example in Figure 31. JPL were submitting clock corrections for PRN13 but the antenna offset used for that PRN differed by ~1.5m from the other ACs. As soon as the irregularity was found (May 10, 1998 (Wk 957) for the Final and May 20, 1998 (Wk 958/3) for the Rapid combinations), JPL's PRN13 solutions, when provided, were excluded from both IGS combinations (see Figures 30 and 31). The combined satellite clocks were overall better served when the JPL PRN13 clock values were not used in the clock combination process. This way, IGS combined clocks were not affected or compromised. However, JPL's RMS values were underestimating the actual clock solution quality as the excluded clock solutions are always retained in the RMS computation. The clock alignments do not use excluded satellites and were therefore correct.

The antenna offset solution of the new PRN13 satellite tended to be close to 0 m and differed from the rest of the GPS satellites by almost 1.5 m (as well as its nominal value). The corresponding PRN13 satellite clock solutions were offset from the clock solutions based on the nominal satellite antenna offset by almost 5 ns. This is why ACs have agreed to use a nominal (conventional) set of satellite antenna offsets for all AC and IGS clock solutions. Since the satellite clock solutions fully reflect the adopted (fixed) satellite (radial) antenna offsets, all ACs agreed, as a temporary measure until better values are obtained or determined, to adopt the following set of satellite offset for all AC and IGS satellite clock solutions:

Block II & IIA dx=0.279m dy=0.000m and dz=1.023m
Block IIR dx=0.000m dy=0.000m and dz=0.000m

Note that the ACs are free to use any value of satellite antenna offsets they consider the best for their orbit solutions, as orbit and station solutions are largely insensitive to any change of satellite antenna offsets. However, their submitted satellite clock solutions must refer to the above adopted satellite antenna offsets. This is not the case for station antenna offsets that map directly into both station coordinate and clock solutions!

New Rapid Submission Deadline

Starting on November 29, 1998 (Wk 986), the AC submission deadline for the Rapid products was changed from 21:00 UT to 16:00 UT. This change was necessary to assure that the combination could be done during "office hours" at Bern. ACs were consulted prior to the change but no major concerns were raised. The IGS Rapid combination submission deadline was also shortened, i.e. from 22:00 UT to 17:00 UT. IGS Rapid combinations did not suffer from the shorter delivery time. The AC prediction submission deadline remained as before, i.e. at 23:00 UT.

Analysis Center Coordination Transfer

Starting from January 1, 1999, Tim Springer of the CODE AC was appointed as the new AC Coordinator of IGS. This significant change concluded the first five years of IGS AC coordination and successful generation of IGS combined products and necessitated a timely transfer of all IGS orbit/clock and ERP combinations from NRCan to CODE AC. The smooth and seamless transition occurred on December 17, 1998 (Wk 988/4), well ahead of schedule. This smooth transition is a tribute to dedication of two IGS AC colleagues, namely Yves Mireault of NRCan and Tim Springer. Yves Mireault who single-handedly produced IGS combined orbits for most of the past five years has prepared and documented the vast suite of combination software and scripts for this transfer. Tim Springer, the new AC Coordinator, visited NRCan in the summer of 1998 and managed to transfer and implement the IGS combination system on CODE computer systems with a significant help of Yves Mireault who, visited CODE AC in October 1998. Jan Kouba has also spent almost half a year, as a guest visiting scientist at the Astronomical Institute of University of Bern/CODE, to aid this transfer process. This is a major achievement, which should not be overlooked due to its seamless implementation.

Orbit and Clock Evaluations

As in previous years, the Long Arc (LA) orbit evaluation was performed for all AC Final products including IGS Final and Rapid orbits. LA was described in more detail in the

IGS 1994 Annual Report (Kouba, Mireault and Lahaye, 1995). LA RMS are presented in Figure 28.

From January 1996 until March 1998, the IGS combined orbits/clocks as well as all AC solutions which contain both the orbit and clock corrections data, were further evaluated by an independent single point positioning program (navigation mode) developed at NRCan (GPSPACE or GPS Positioning from Active Control System (ACS) Clocks and Ephemerides). This is done to verify clock solution precision and orbit/clock consistency for both the Rapid and Final orbit/clock products. Pseudorange data from three stations (BRUS, USUD and WILL) were used daily and their corresponding position RMS (with respect to ITRF) were summarized in the Rapid/Final summary reports. Tables 3a and 4a summarize the point positioning results obtained from both the Rapid and Final orbit/clock products for the first semester of 1998, i.e. from December 28, 1997 to March 1998, when NRCan's GPSPACE software was used.

Starting March 8, 1998 (Wk 948) for the Finals and March 22, 1998 (Wk 950) for the Rapids, the daily precise navigation statistics found in the IGS reports were now based on phase data using JPL's GIPSY-OASIS II point positioning capability installed at NRCan in 1998. The same stations are processed and the same statistics are summarized in the Rapid/Final summary reports. Tables 3b and 4b summarize the phase point positioning results for the rest of the 1998 for both the Rapid and Final products. RMS results went from a few dm to a few cm! For the best station/AC, RMS results are at the 4-5 cm level for the horizontal components while they are at the 6-7 cm level for the vertical components. Figure 1 shows the 3D RMS for the IGS Rapid and Final. Major improvements are clearly noticed when the switch was made from pseudorange- to phase-based point positioning software.

IGS Prediction, Rapid and Final Combination Results in 1998

In this section, results for the fifth year of IGS service, i.e. December 28, 1997 to January 2, 1999 (Wks 938-990), are presented.

Tables 5 and 6 show the Prediction and Rapid product statistics of the translation, the rotation, and the scale parameters from the daily Helmert transformations with respect to the IGS Rapid (IGR) orbits. Similarly, Table 7 shows the Final product statistics of the same parameters but this time with respect to the IGS Final orbits. A complete series in each table would have 371 days. Note also that rotations (RX, RY and RZ) greater than 50 mas in Table 5 and greater than 5 mas in Table 6 were excluded from the AC means and standard deviations for more meaningful AC overall statistics.

Figures 2-9 (Broadcast and Prediction products) and Figures 10-17 (Rapid products) display, for each AC, the daily translations, rotations and scales of the X, Y and Z satellite coordinates with respect to the IGS Rapid orbits (IGR). Broadcast results (Figure 2) are included for comparison only and do not contribute to the IGS orbit and clock combinations except for the AC Rapid clock alignment. In Figure 2, each translation and rotation series are offset by 1.0 m and 20 mas respectively for visibility. In Figures 3-9, each translation and rotation series are offset by 0.2 m and 10 mas respectively. Finally, in Figures 10-17, the translation series are offset by 0.1 m and each rotation/pole difference series are offset by 2 mas respectively.

Table 3. 1998 IGS Rapid Combination Point Positioning RMS for ACs providing orbit/clock solutions

b) using NRCan`s GPSPACE software (pseudorange data - navigation mode).
Period covered: GPS Wks 938-949 (Dec.28/1997-Mar.21/1998)

	BRUS				USUD				WILL			
ACs	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
emr	43	29	92	61	43	36	91	62	28	19	50	35
esa	58	64	111	82	51	55	126	85	39	45	69	53
gfz	45	30	94	63	49	37	102	69	34	22	57	40
igr	44	29	92	61	44	35	93	63	27	19	49	34
jpl	48	31	96	64	44	34	92	62	29	21	54	37
usn	47	31	93	63	43	36	93	63	28	18	50	35

b) using JPL`s GIPSY-OASIS II software (phase data – navigation mode).
Period covered: GPS Wks 950-990 (Mar.22/1998-Jan.2/1999)

	BRUS				USUD				WILL			
ACs	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
emr	7	4	9	7	20	11	31	22	5	5	9	7
esa	49	50	75	59	86	75	137	103	31	46	71	52
gfz	5	3	10	7	4	4	10	7	4	4	7	5
igr	6	4	9	6	6	5	15	10	4	4	7	5
jpl	12	8	17	13	22	22	22	22	4	4	6	5
usn	6	4	10	7	6	6	13	9	4	4	7	5

Units: centimeters (cm)
RMS ≥ 999 cm were excluded from the RMS computations

Figures 18-25 show the Final results for the same daily transformation parameters but this time with respect to the Final IGS orbits. IGR results (Figure 25) are included for comparison only and do not contribute to the IGS orbit and clock combinations. Again for visibility, the same offsets, i.e. 0.1 m for the translation series and 2 mas for the rotation/pole difference series were used. Figures 10-25 (middle plots) display, in addition to the rotations in X, Y and Z, the PM differences with respect to IGR/IGS. This was added to monitor AC orbit/EOP consistency and performance. PM differences in y/x should correspond to orbital X/Y rotations respectively. The correlation coefficients of each AC X/Y rotations versus AC PM differences in y/x are also shown on Figures 10-25. As in 1997, the AC Rapid correlations show a slightly more consistent orbit/EOP series than the Final. The mandatory minimum rotational constraints implemented after Wk 960 is clearly noticeable in XYZ orbit translations for some ACs in Figures 18 to 25.

Table 4. 1998 IGS Final Combination Point Positioning RMS for ACs providing orbit/clock solutions

a) using NRCan`s GPSPACE software (pseudorange data - navigation mode).
Period covered: GPS Wks 938-947 (Dec.28/1997-Mar.7/1998)

	BRUS				USUD				WILL			
ACs	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
cod	42	29	94	62	40	32	88	59	26	16	46	32
emr	44	28	96	63	43	33	87	59	27	17	48	33
esa	48	38	104	70	55	40	104	72	49	37	85	61
gfz	44	30	93	62	45	35	96	65	31	21	54	38
igs	43	28	96	63	41	33	88	59	26	17	47	33
jpl	45	29	95	63	43	32	86	58	26	16	47	32

b) using JPL`s GIPSY-OASIS II software (phase data – navigation mode).
Period covered: GPS Wks 948-990 (Mar.8/1998-Jan.2/1999)

	BRUS				USUD				WILL			
ACs	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
cod	13	15	20	16	17	14	33	23	8	8	14	10
emr	5	4	9	6	7	6	19	12	4	4	6	5
esa	37	34	55	43	38	41	100	66	26	25	43	32
gfz	5	4	9	6	4	5	19	11	4	4	6	5
igs	4	4	8	6	5	5	11	8	4	4	7	5
jpl	5	4	9	6	4	4	10	7	3	3	6	4

Units: centimeters (cm)
RMS ≥ 999 cm were excluded from the RMS computations

Figure 26 shows the orbit coordinate RMS of all AC Prediction submissions (and Broadcast orbit) with respect to the IGS Rapid (IGR) combinations. Two types of RMS are displayed: the combination RMS median (i.e. the median of all AC satellite combination RMS) and the weighted combination RMS (WRMS). Similarly, Figure 27 shows orbit coordinate RMS of all AC Rapid submissions with respect to the IGR combinations. Finally, Figure 28 shows the AC Final submission orbit RMS results where the combination RMS median was replaced by the 7-day Long Arc RMS. Figures 29-30 show the AC Prediction (including broadcast) and Rapid clock RMS respectively with respect to IGR and Figure 31 displays AC Final clock RMS with respect to the IGS Final clocks.

Table 5. IGS Prediction Combination - GPS Wks 938-990 (performed directly in the ITRF 94/96 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY (m)	DZ	RX	RY (mas)	RZ	SCL (ppb)	DAYS
brd	μ	0.01	0.01	0.05	-0.53	0.04	4.44	-4.1	371
	σ	0.11	0.11	0.17	2.57	3.87	5.83	2.2	
cop	μ	0.00	0.01	-0.02	-0.27	-0.11	-0.01	-0.2	369
	σ	0.01	0.01	0.03	0.90	1.13	2.71	0.4	
emp	μ	0.00	0.01	-0.01	0.01	-0.07	-0.18	-0.1	368
	σ	0.01	0.01	0.03	1.03	1.34	2.19	0.8	
esp	μ	0.00	0.01	0.00	-0.50	-0.08	0.39	0.1	360
	σ	0.01	0.01	0.07	1.12	1.47	3.70	0.6	
gfp	μ	0.00	0.01	0.01	0.10	0.07	-0.19	-0.2	368
	σ	0.01	0.01	0.03	1.28	1.29	1.87	0.4	
jpp	μ	0.00	0.01	0.00	-0.08	-0.40	-0.11	0.0	336
	σ	0.01	0.01	0.03	2.31	2.55	4.18	0.6	
sip	μ	0.00	0.01	-0.05	-0.27	-0.09	-1.34	0.2	348
	σ	0.03	0.02	0.05	1.18	1.12	7.68	0.9	
igp	μ	0.00	0.01	-0.01	-0.12	-0.07	-0.23	-0.1	371
	σ	0.01	0.01	0.02	0.88	0.95	2.08	0.4	

Note that Rotations (RX,RY,RZ) greater than 50.0 mas were not included in AC means and standard deviations for more meaningful annual statistics. Number of outliers: esp:3; other ACs: 0.

The predicted broadcast clocks (IGP) are provided by COD (COP). BRD and IGR clocks/orbits are always used for comparison purposes only. Note that COD (Rapid) and NGS (Rapid and Final) clocks correspond to broadcast clocks as provided by the satellite navigation message (therefore not included in the clock combination) and that SIO (Rapid and Final) does not provide any clock corrections. As mentioned in previous Annual Reports, erroneous satellite orbit and clock solutions are excluded from the combination if they bias the IGS combined solution but are always included in the RMS computation.

Table 6. IGS Rapid Combination - GPS Wks 938-990 (performed directly in the ITRF 94/96 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY	DZ	RX	RY	RZ	SCL	DAYS
			(m)			(mas)		(ppb)	
cod	μ	0.00	0.01	-0.01	-0.26	-0.06	0.02	-0.2	367
	σ	0.01	0.01	0.01	0.32	0.22	0.21	0.1	
emr	μ	0.00	-0.01	0.00	0.29	-0.06	0.27	-0.1	355
	σ	0.01	0.01	0.01	0.25	0.19	0.31	0.2	
esa	μ	0.00	0.01	0.01	-0.06	0.01	-0.02	0.1	303
	σ	0.01	0.01	0.01	0.27	0.21	0.38	0.2	
gfz	μ	0.00	-0.01	0.01	0.05	0.11	-0.12	-0.1	355
	σ	0.01	0.02	0.01	0.40	0.26	0.31	0.2	
jpl	μ	0.00	0.01	0.00	0.00	-0.07	-0.03	0.1	266
	σ	0.01	0.01	0.01	0.24	0.24	0.27	0.2	
ngs	μ	0.00	-0.02	0.00	0.08	0.11	0.02	-0.3	321
	_	0.02	0.03	0.03	0.45	0.41	0.27	0.6	
sio	_	0.00	0.01	-0.02	-0.16	0.02	0.00	0.7	319
	_	0.01	0.01	0.02	0.47	0.46	1.46	0.5	
usn	_	-0.01	0.01	0.00	0.21	0.00	0.03	0.2	331
	_	0.01	0.01	0.01	0.34	0.59	0.30	0.2	

Note that Rotations (RX,RY,RZ) greater than 5.0 mas were not included in AC means and standard deviations for more meaningful annual statistics. Number of outliers: gfz:1; ngs:1; sio:12; usn:3.

All exclusions are reported in the IGS weekly/daily combination reports. IGS predicted clocks (IGP) are at the same precision level as the broadcast clocks but with more outliers. IGS Rapid and Final clock results have reached the 0.2 ns precision level (and sometimes better!) with the Final combination results being slightly more consistent. The predicted orbit precision (IGP) has reached the ~35 cm RMS median level which is considerably better than the ~200 cm for the broadcast orbits. As expected, predicted orbits have occasional outliers caused by unpredictable satellite events. Rapid orbit position precision is close to the 5 cm level while the Final is generally below the 5 cm level which is quite remarkable. Again, the Rapid results are slightly noisier than the Final results mostly due to the very short delivery time which causes occasional lack of tracking data and or AC submissions (new submission deadline of 16 hours).

IGS ERP (PM, PM rates, LOD and UT) results will not be extensively studied in this report. However, the reader is referred to (Mireault, Kouba and Ray, 1999) for a more thorough analysis and discussion on past and present IGS ERP performance and results.

Here, comparisons between IGS and IERS Bulletin A, IERS C04 and Atmospheric Angular Momentum (AAM) are shown and analyzed. At the end of 1998, it was estimated that IGS PM precision was at or below the 0.1 mas, IGS Final rates were somewhat noisier at the 0.2 mas/day, IGS Final LOD was at the 30 μs level and IGS Final UT was below the 50 μs level. Comparisons with AAM showed correlation above the 0.6, 0.7 and 0.9 level for χ_1, χ_2 and χ_3, respectively.

Table 7. IGS Final Combination - GPS Wks 938-990 (performed directly in the ITRF 94/96 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY (m)	DZ	RX	RY (mas)	RZ	SCL (ppb)	DAYS
cod	μ	0.00	0.01	-0.01	-0.08	0.02	0.03	-0.2	371
	σ	0.00	0.01	0.01	0.15	0.09	0.16	0.1	
emr	μ	0.00	-0.02	0.02	0.22	-0.10	0.31	0.0	364
	σ	0.01	0.02	0.04	0.21	0.20	0.30	0.2	
esa	μ	0.00	0.01	0.00	0.04	-0.03	-0.07	0.2	348
	σ	0.01	0.01	0.01	0.18	0.16	0.24	0.1	
gfz	μ	0.00	0.00	0.00	-0.01	0.05	-0.08	-0.1	371
	σ	0.00	0.01	0.01	0.10	0.09	0.15	0.1	
igr	μ	0.00	-0.01	0.00	0.12	0.00	-0.06	0.0	371
	σ	0.01	0.01	0.01	0.18	0.14	0.22	0.1	
jpl	μ	0.00	0.01	0.00	-0.05	-0.04	0.01	0.3	371
	σ	0.01	0.01	0.01	0.10	0.10	0.09	0.1	
ngs	μ	0.00	-0.03	0.02	0.16	0.08	-0.04	-0.4	371
	σ	0.02	0.03	0.04	0.41	0.37	0.29	1.1	
sio	μ	0.00	0.01	-0.01	0.03	0.01	0.01	0.1	371
	σ	0.01	0.01	0.01	0.28	0.16	0.33	0.2	

1999 and Future Improvement

During 1999, most of the AC effort has been directed towards improved precision and consistency. On August 1, 1999 (Wk 1021), a new ITRF 97 realization is to be adopted by IGS which should result in some precision and consistency improvements of all IGS products and solutions. The final aim is a new IGS ITRF realization based on a new IGS SINEX station/ERP products that are currently produced by the Reference Frame Working Group (Ferland, 1999). The new IGS SINEX station/ERP is expected to become an official IGS product in the near future. The new IGS ITRF realization should be more consistent than is currently the case and should allow exact transformations for future ITRF changes (Kouba, Ray and Watkins, 1998).

A new satellite/station clock combination, reported at the 1999 AC workshop (Kouba, 1999b) is to be implemented and soon will replace the current IGS satellite clock combinations. It allows satellite/station clock combination consistent with the IGS combined orbits, SINEX stations and should result into new IGS station clock products as well. Tests reported in (Kouba, 1999b) indicated that the new clock combination maintained orbit/clock/station/ERP consistency at a mm level and allowed precise point positioning at a precision level comparable to the best AC orbit/clock precise point positioning.

Perhaps the greatest challenge for all ACs and IGS during 1999 will be the new ultra rapid product testing which is to start on October 3, 1999 (Wk 1030) on a voluntary participation basis. The new ultra rapid IGS orbit/clock/ERP product (IGU) is to support LEO and other applications requiring near real time GPS solutions and is to be made available within less than 3 hours, several times a day (Gendt, Fang and Zumberge, 1999). IGU may potentially replace the current IGP/IGR orbit/clock/ERP products.

Summary

As in previous years, ACs have again improved the reliability and precision of their products or at least maintained their quality level which in itself is quite remarkable. By the end of 1998, the best AC orbit solutions were below the 5 cm level for the Final solutions (down to 3 cm!) and close to 5 cm for the Rapid solutions. Prediction orbit precision had a RMS median of ~35 cm compared to ~200 cm for the broadcast orbit. Better AC clock corrections resulted in combined clock correction precision reaching the 0.2 ns level (and as precise as 0.1 ns on some occasions!) for both the Rapid and Final solutions.

Several changes, enhancements and new products were introduced in 1998. Namely, a new IGR/IGS accumulated ERP file was initiated, ITRF96 reference frame superseded ITRF94 and Final AC solutions based on minimum (rotational) constraints were introduced. A new IGS ERP format to increase the ERP resolution was implemented and finally, AC Rapid combination submission deadline was advanced by 5 hours, i.e. from 22 to 17 hours UTC.

1998 was a transition year for the IGS coordination team. All combination scripts and programs were successfully transferred from NRCan to CODE. The operation went very well resulting in a seamless transition of all IGS combinations on December 17, 1998. As of January 1, 1999, Tim Springer from CODE was officially appointed as the new AC Coordinator replacing Jan Kouba.

References

Ferland R., 1999, Densification of ITRF Reference Frame Working Group, in *International GPS Service for Geodynamics*, 1998 Technical Reports, Jet Propulsion Laboratory, Pasadena, California, this volume.

Gendt G., Fang P. and J.F. Zumberge, 1999, Moving IGS Products Towards Real-time, 1999 AC Workshop Proceeding, Scripps Institution of Oceanography, La Jolla, USA, June 8-11, in preparation.

Kouba J., 1999a, 1998 Analysis Coordinator Report, in *International GPS Service for Geodynamics*, 1998 Annual Report, Volume I, Jet Propulsion Laboratory, Pasadena, in preparation.

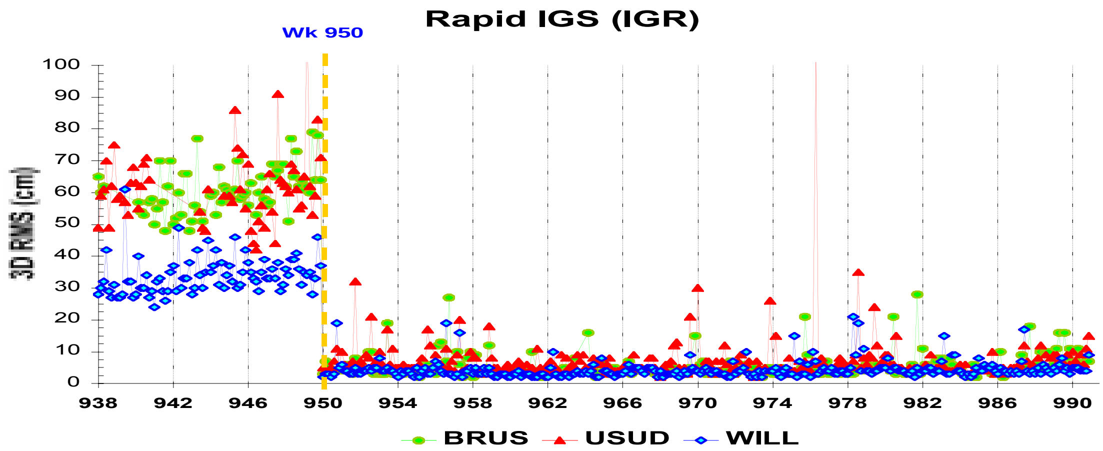
Kouba J., 1999b, New IGS Station and Satellite Clock Combination, 1999 AC Workshop Proceeding, Scripps Institution of Oceanography, La Jolla, USA, June 8-11, in preparation.

Kouba J. and Y. Mireault, 1998, 1997 Analysis Coordinator Report, in *International GPS Service for Geodynamics*, 1997 Technical Reports, Jet Propulsion Laboratory, Pasadena, California, pp. 23-69.

Kouba J., Mireault Y. and F. Lahaye, 1995, Appendix to the Analysis Coordinator Report, in *International GPS Service for Geodynamics*, 1994 Annual Report, Jet Propulsion Laboratory, Pasadena, California, pp. 70-94.

Kouba J., Ray, J.R. and M.M. Watkins, 1998, IGS Reference Frame Realization, 1998 AC Workshop Proceeding, Darmstadt, Germany, Feb. 9-11, pp. 139-172.

Mireault Y., Kouba J. and J.R. Ray, 1999, IGS Earth Rotation Parameters, GPS Solutions, to be published.



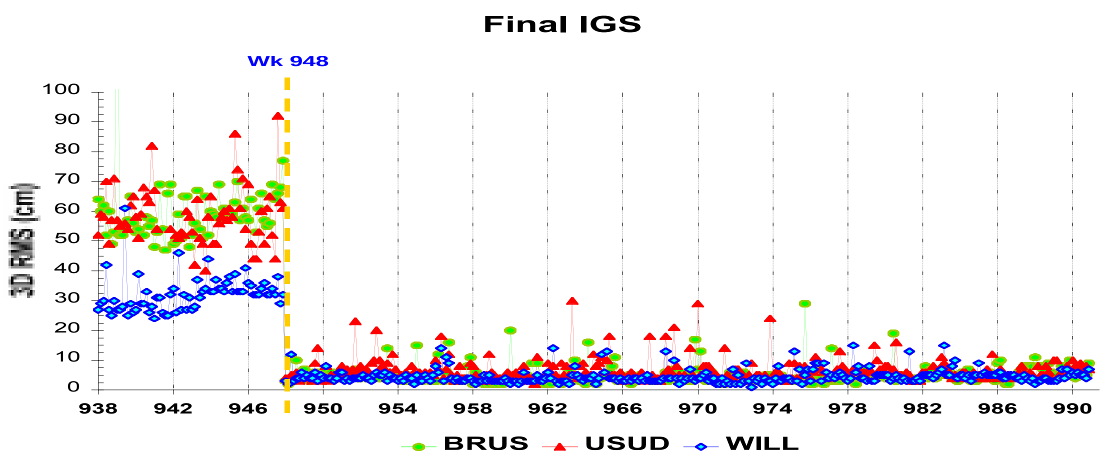
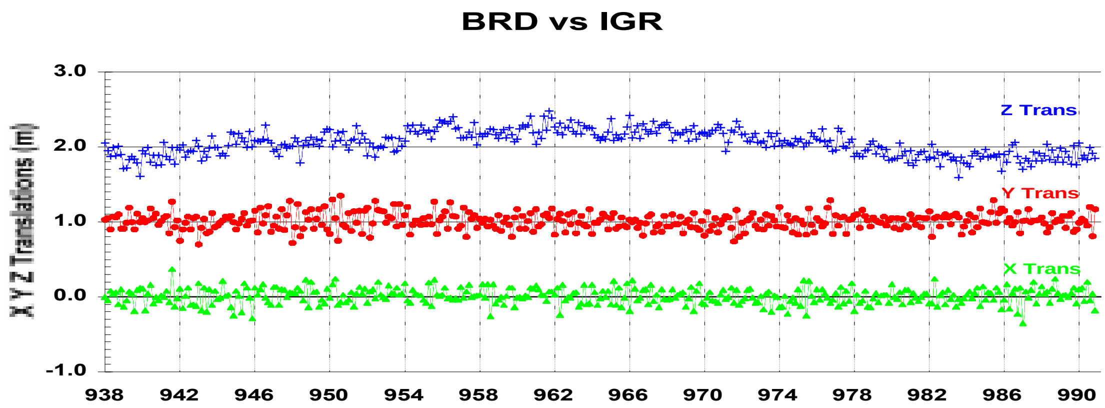
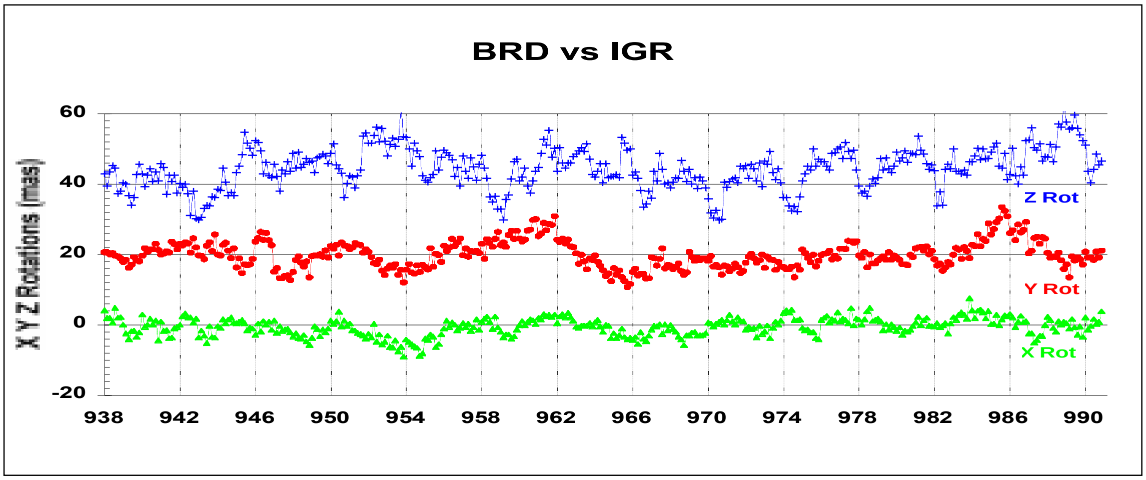


Figure 1: Precise Point Positioning (navigation mode). The top graphic shows the 3D-RMS for the Rapid IGS (IGR) while the bottom one shows the 3D-RMS for the Final IGS. NRCan's GPSPACE software (pseudorange data) was used for the Rapid and the Final IGS for GPS Wks 938 to 949 and GPS Wks 938 to 947 respectively. JPL's GIPSY-OASIS II software (phase data) was used for the Rapid and the Final IGS from GPS Wk 950 and GPS Wk 948 respectively.





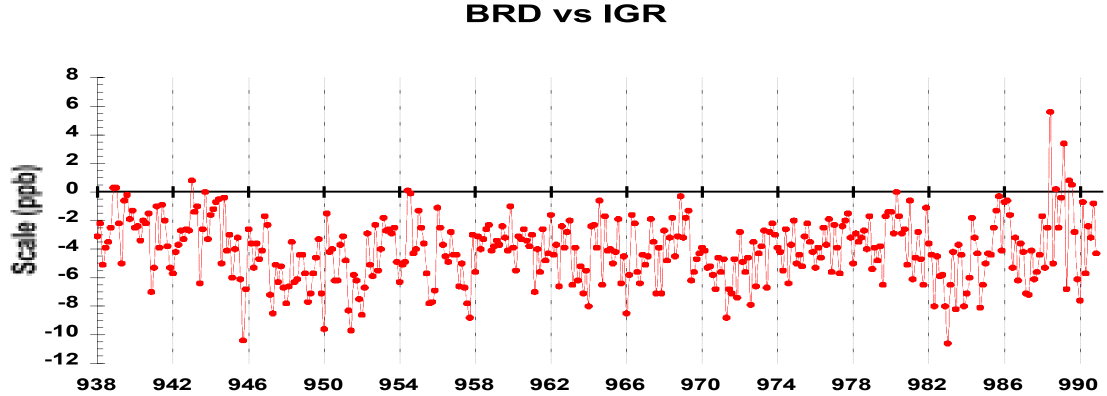
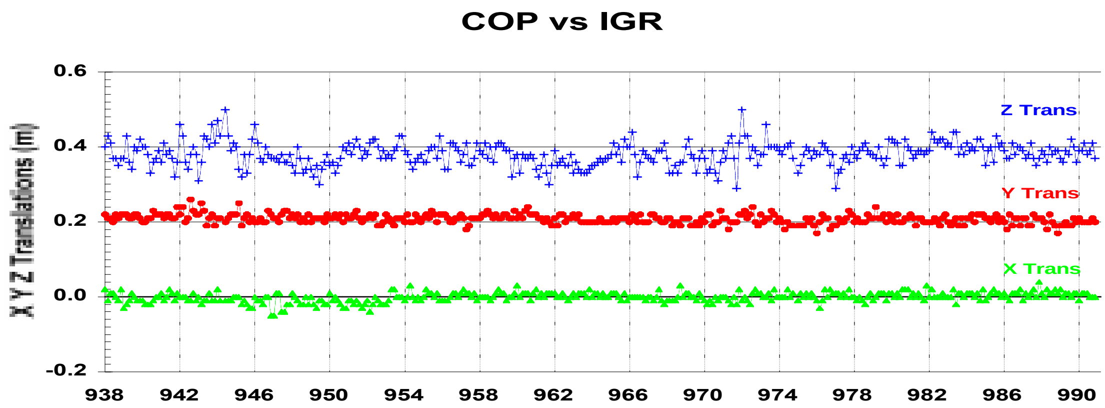
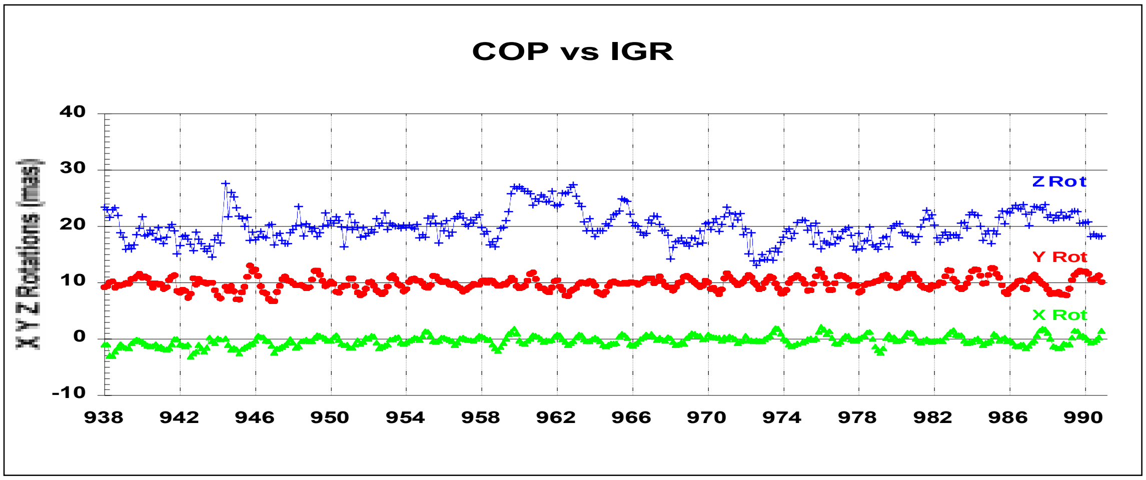


Figure 2: BRD 1998: Daily seven-parameter Helmert transformations transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 20 mas)





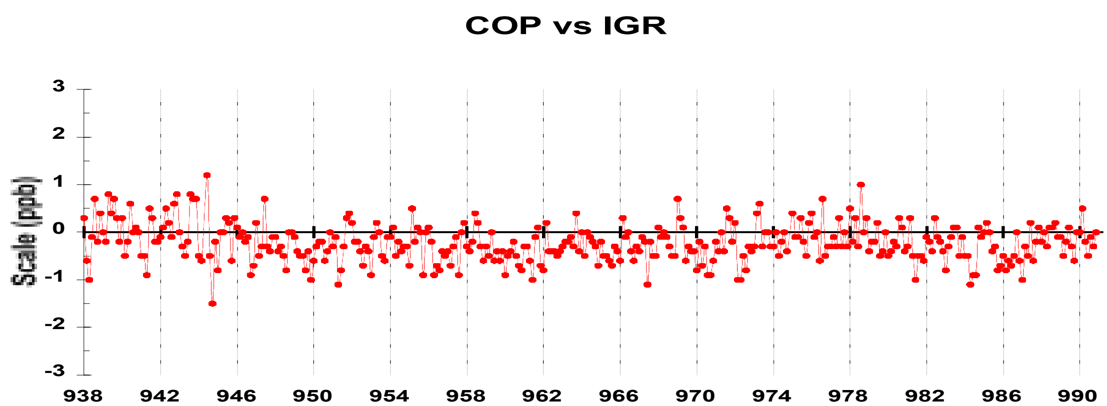
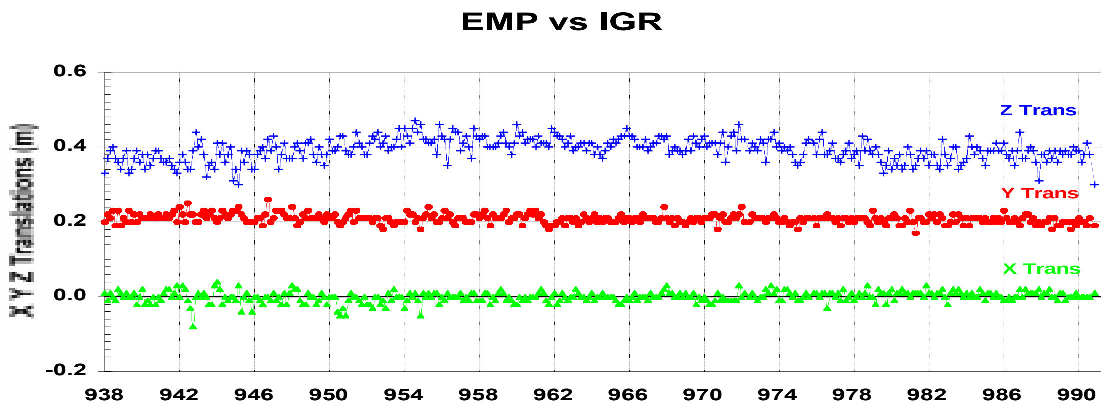
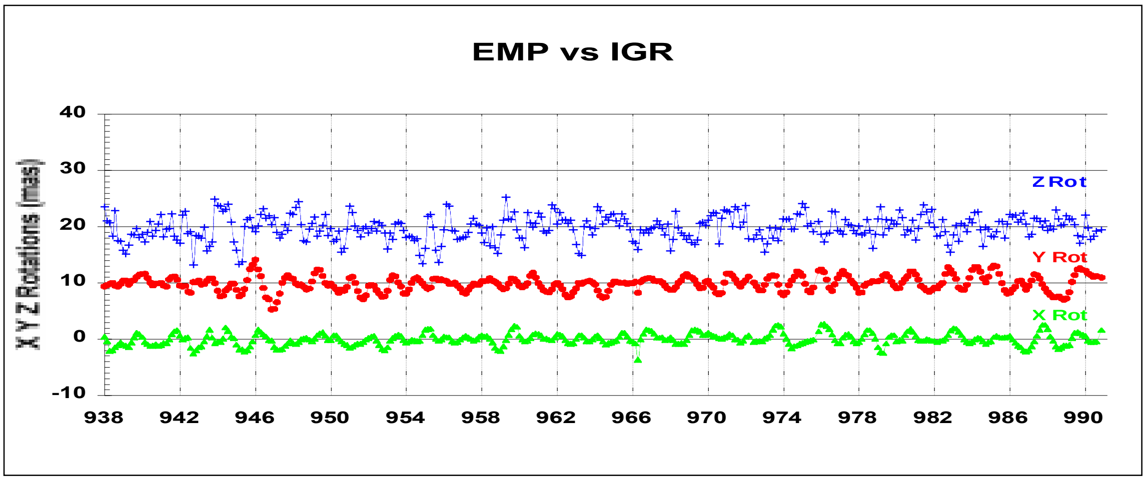


Figure 3: COP 1998: Prediction daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)





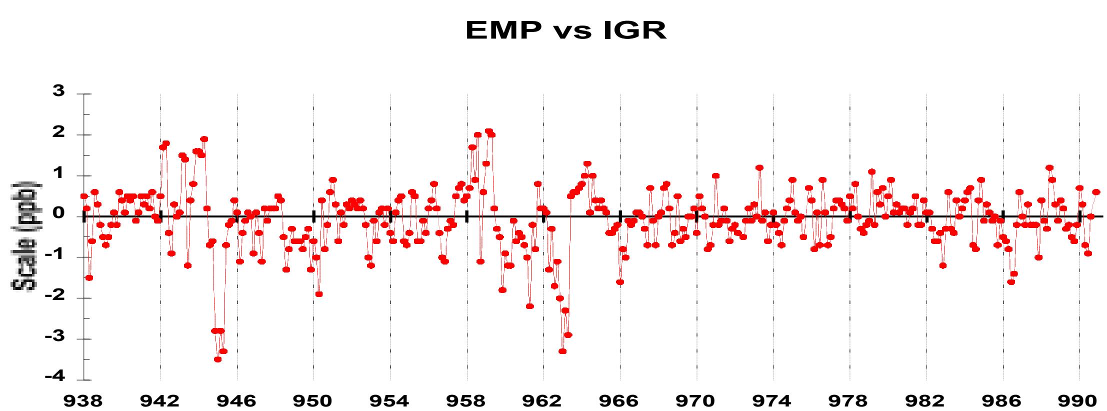
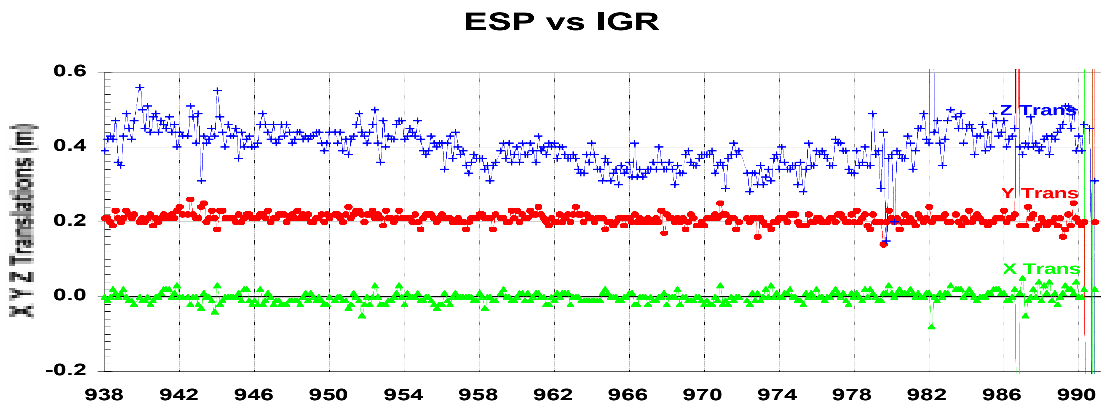
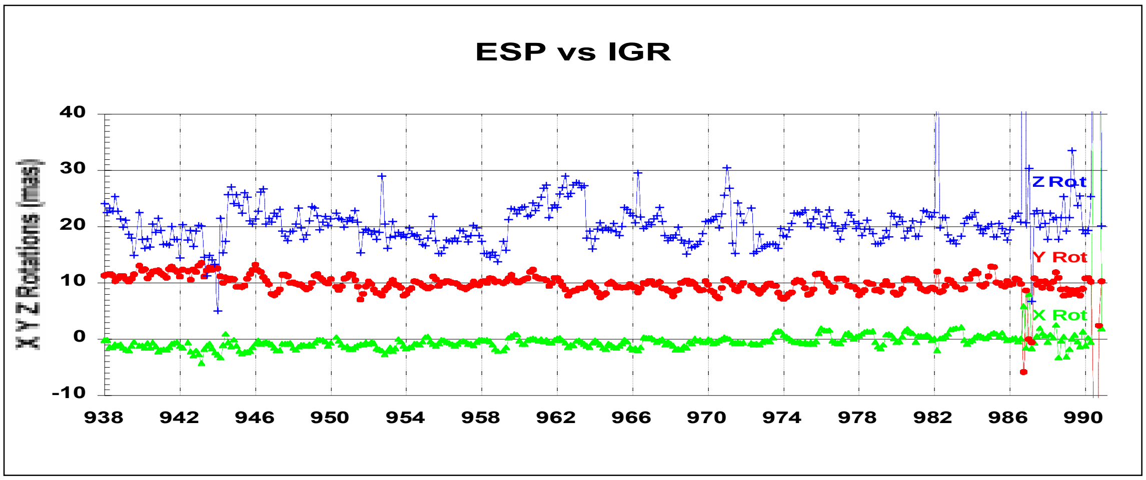


Figure 4: EMP 1998: Prediction daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)





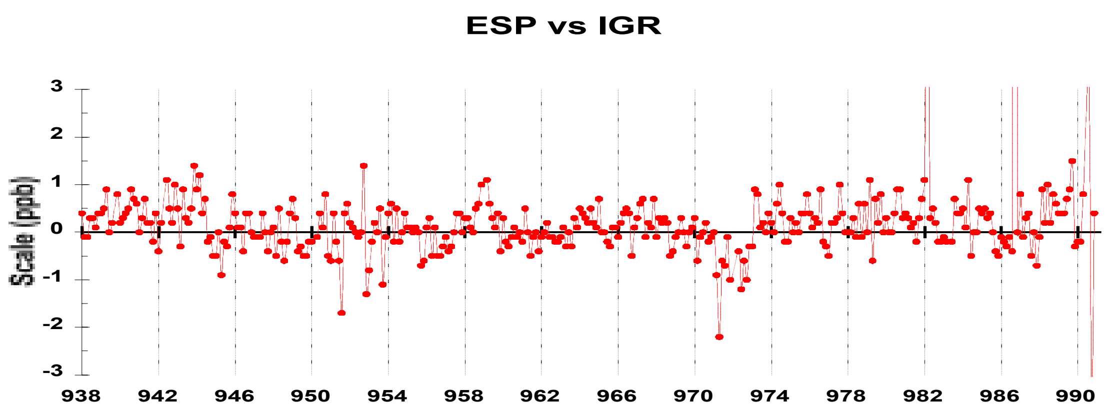
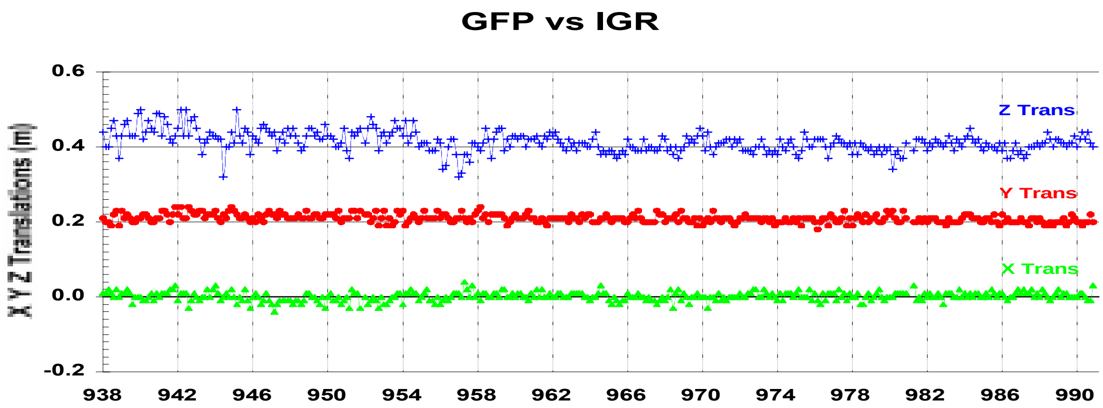
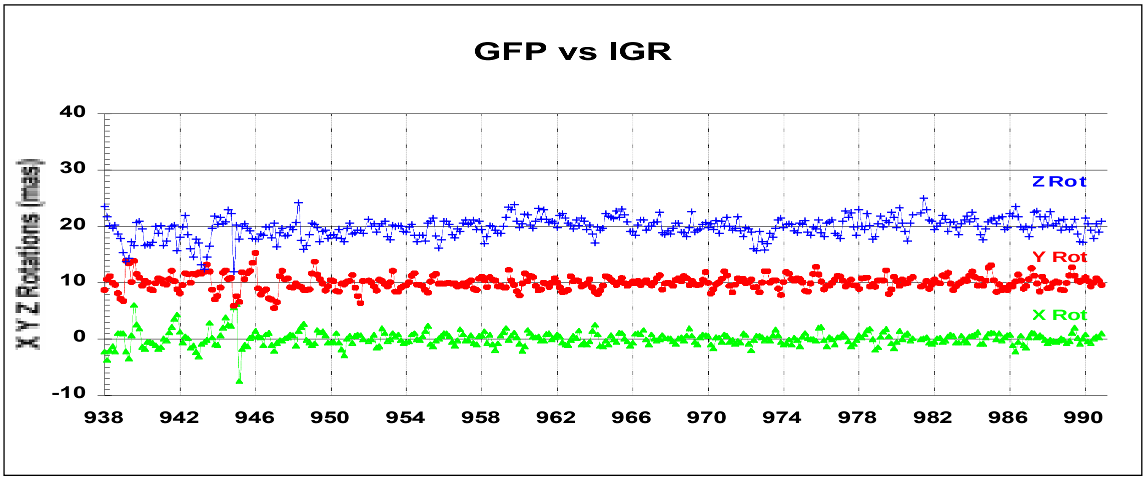


Figure 5: ESP 1998: Prediction daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)





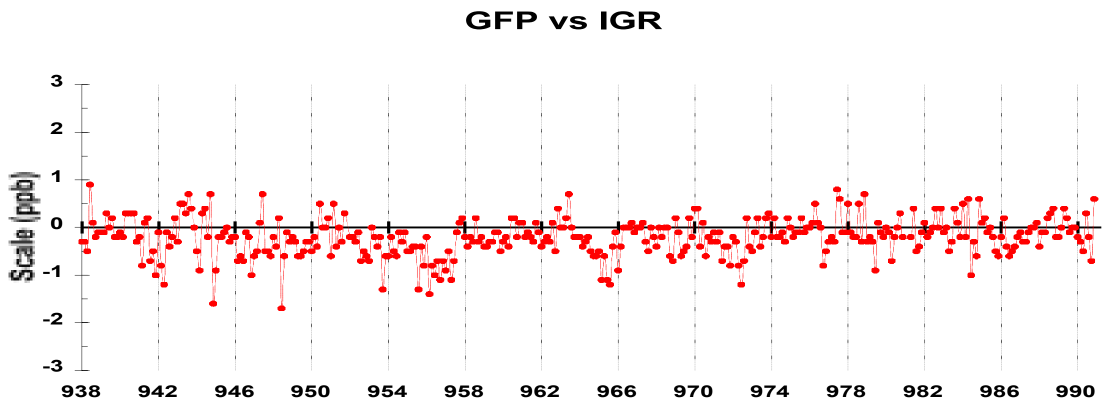


Figure 6: GFP 1998: Prediction daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

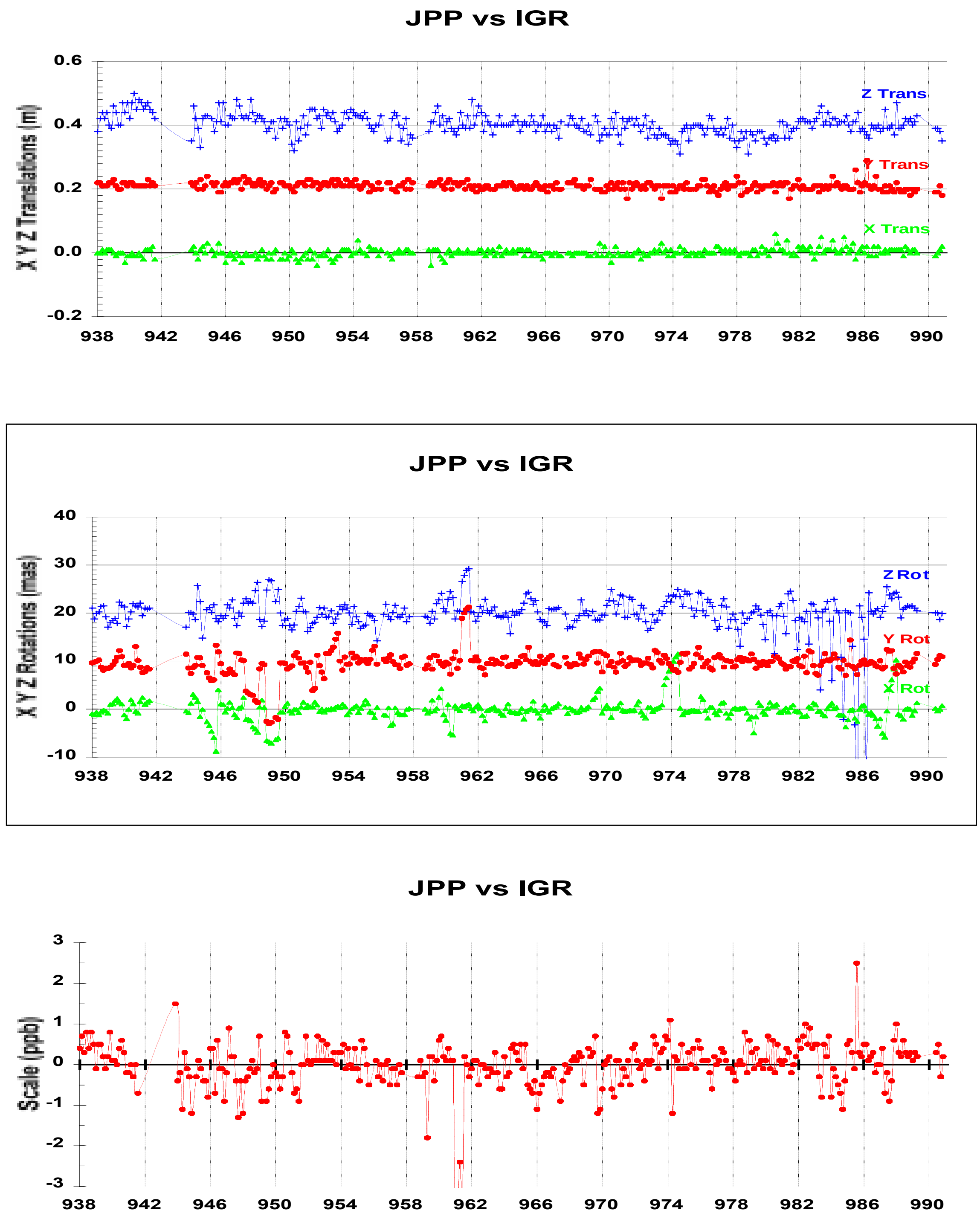
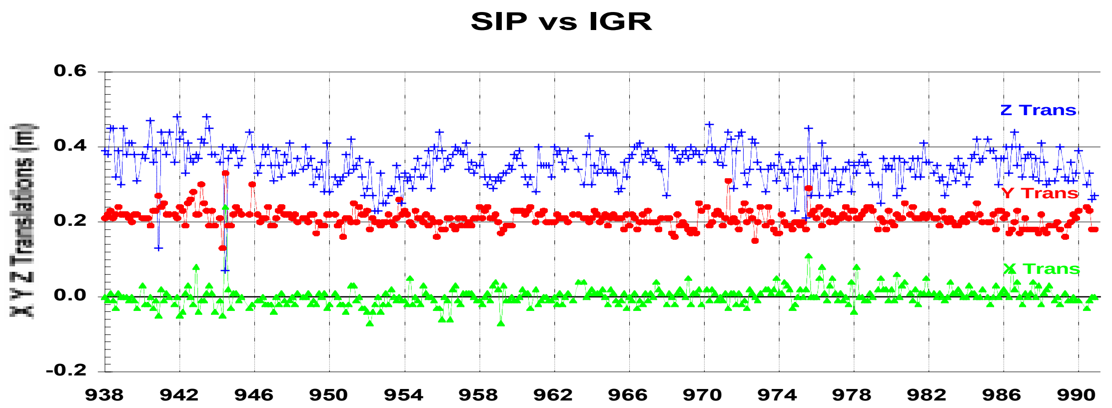
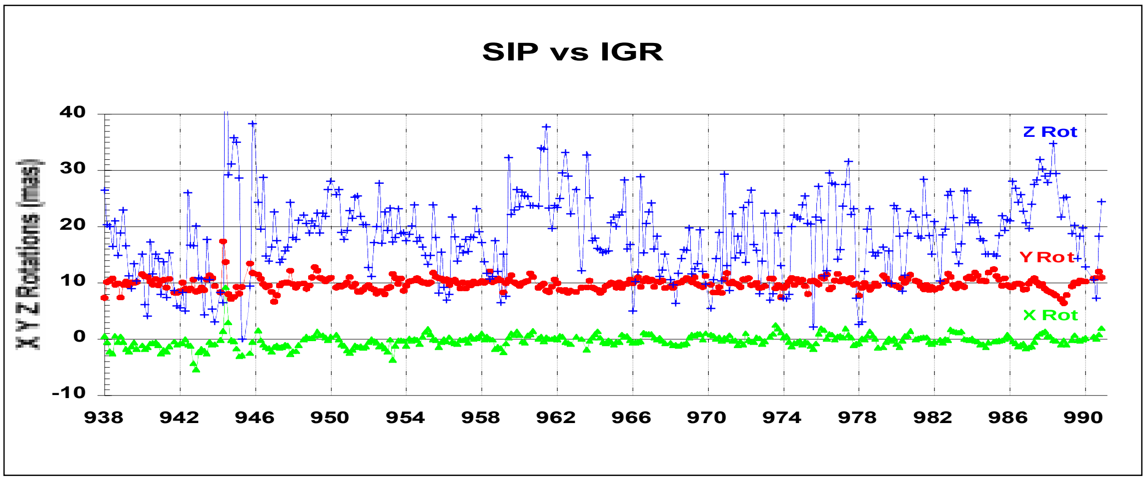


Figure 7: JPP 1998: Prediction daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)





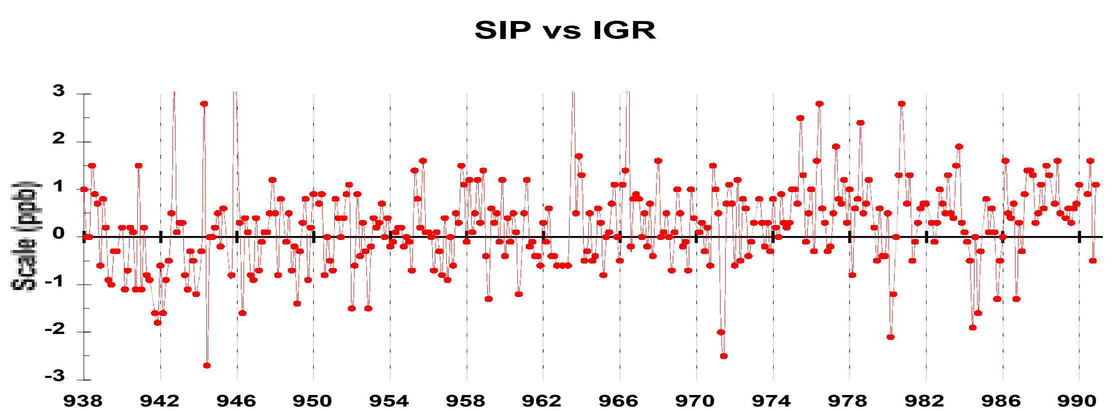
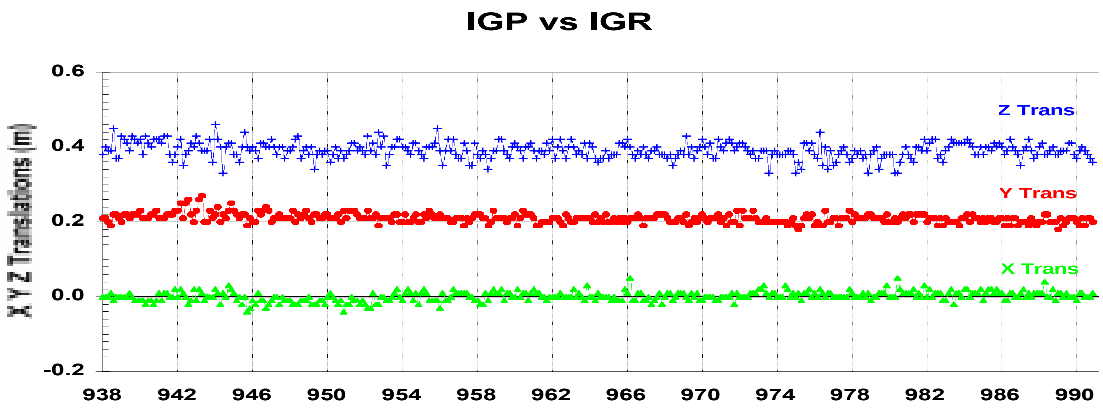
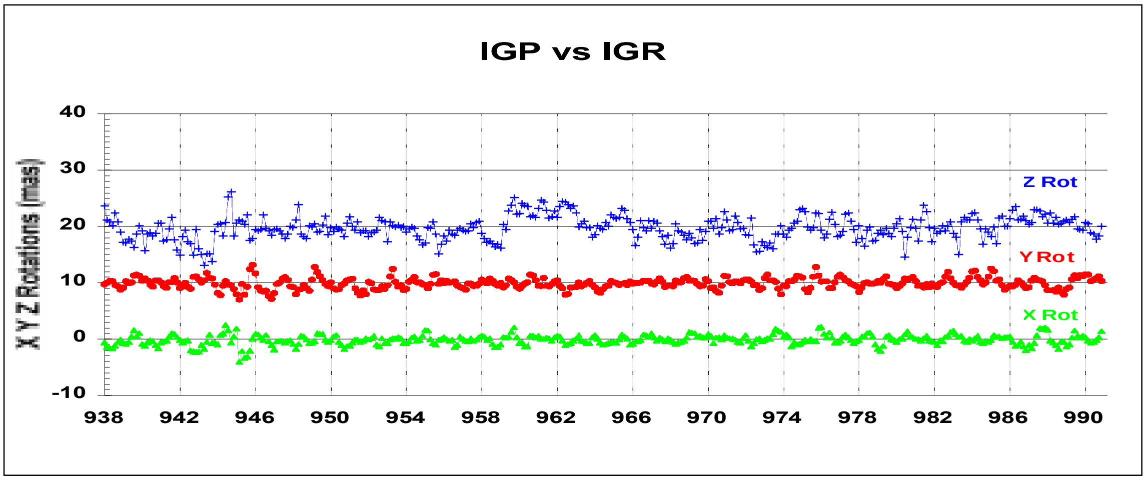


Figure 8: SIP 1998: Prediction daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)





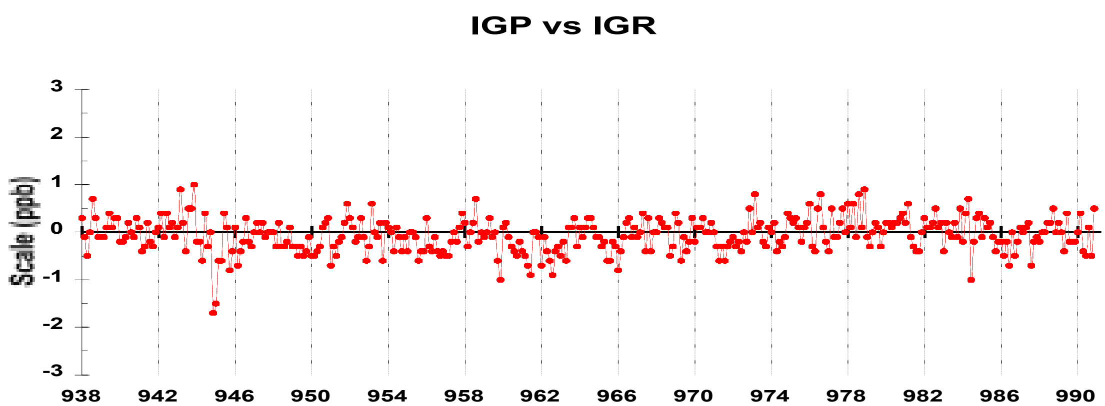


Figure 9: IGP 1998: Prediction daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)