Analysis Centers

Analysis Center Coordinator

1997 Analysis Coordinator Report

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1 Introduction

This report is a complement to the 1997 Analysis Coordinator Report found in Volume I of the 1997 IGS Annual Report (Kouba, 1998). Changes, enhancements and new products implemented during 1997 as well as the combination and evaluation procedures and statistics of orbits, clocks and Earth Orientation Parameters (EOP) are reviewed. In 1997, three IGS combinations were routinely performed: the IGS Prediction (IGP/daily), Rapid (IGR/daily) and Final (IGS/weekly) combinations. The United States Naval Observatory (USNO), an Associate Analysis Centre (AAC) joined the Rapid IGS production group in April 1997 (Wk 902) but does not contribute to the Prediction or the Final IGS products.

2 Changes, Enhancements and New Products in 1997

In 1997, all IGS products continued to be oriented to ITRF94 which had been introduced, along with many other changes, on June 30, 1996 (Wk 860) (Kouba and Mireault, 1997). This year's changes and enhancements were mostly related to the IGS LOD/UT and clock correction combinations. The IGS Rapid solution deadline, to make IGS Rapid (IGR) orbits available to the Analysis Centres (AC) participating in the combined Prediction products, was advanced by two hours, from 24 to 22 hr UTC. The changes and enhancements are summarized in Table 1.

2.1 IGS Orbit Prediction Combination (IGP)

As mentioned in last year's Annual Report (Kouba and Mireault, 1997), the IGS orbit Prediction combination, a 2-day orbit prediction (i.e. 24 to 48h) was officially introduced on March 2, 1997 (GPS Wk 895). This year, more comprehensive statistics regarding AC and IGS orbit/clock prediction (IGP) performance have been incorporated (see section 5). The accuracy code found in the IGP sp3 file is based on the comparison with IGR, which is reported daily with a 2-day delay, as part of the IGR combinations. Predicted satellite orbits, with missing comparison information with respect to IGR, are assigned an accuracy code of 15 (i.e. precision of ~33 m) in the sp3 file for that day. Comparison RMS between IGR and IGP below 10 m are left with the accuracy codes estimated by the combination program. Accuracy codes for satellites with comparison RMS above 10 m are adjusted according to the RMS.

Table 1.

Wk/Day	Products	Changes
894/0 895/0	Final Rapid	IGS LOD combination/integration officially implemented using only the IERS Bulletin A UT1 values that included 24h VLBI data.
896/0 898/0	Final Rapid	IGS LOD combination/integration using observed IERS Bulletin A UT1 values.
902/0	Rapid only	IGS Rapid submission deadline shortened by two hours (from 24 to 22 hr UTC).
907/0 908/3	Final Rapid	IGS LOD combination/integration using up to five days prior to the most current observed IERS Bulletin A UT1 values.
917/0 919/0	Final Rapid	New EOP comparison table implemented.
929/0 931/0	Final Rapid	New IGS LOD weighting scheme based on the AC LOD RMS bias calibration ($1/RMS^2$) with respect to IERS Bulletin A.
933/0	Rapid only	Use of EMR UT-derived LOD values in the IGS Rapid LOD combination/integration.
935/0 936/1	Final Rapid	Non-SA based AC clock alignment and weighting abandoned for a more reliable method using one reference AC, all broadcast satellites and the absolute deviation of AC aligned clocks with respect to the unweighted mean for AC clock weighting.
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.

2.2 IGS LOD/UT Combination

IGS LOD/UT combination was briefly described in the 1996 IGS Annual Report (Kouba and Mireault, 1997) although officially implemented in 1997 only. The IGS Rapid and Final LOD/UT combinations were respectively implemented on Wks 895 and 894.

To summarize, IGS combined LODs are now based on a weighted average of AC LOD solutions that are first calibrated/aligned with respect to IERS Bulletin A over a 21 day period ending five days prior to the last observed (i.e. non-predicted) IERS Bulletin A UT1 value (also called the *anchor* point). The combined IGS LOD values are then integrated into IGS UT starting from the *anchor* point and up to the day required. The integration period is generally 6-10 days for the Rapid combinations and 1-4 days for the Final combinations. Figure 1 presents a schematic view of the LOD combination and integration procedure while section 4 describes in more detail the combination method used.

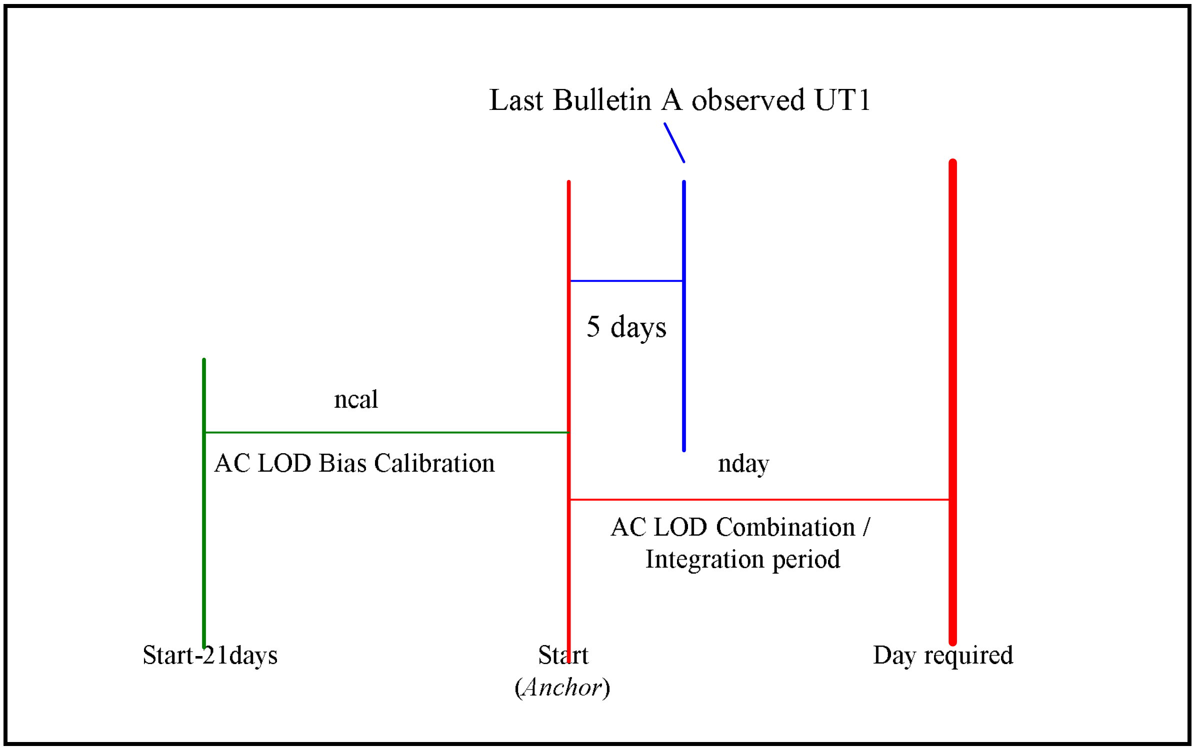

Figure 1.

Initially, only the IERS Bulletin A UT1 values containing 24h VLBI data were used for the LOD calibration and integration. The strategy was modified a few weeks later to also include all observed, i.e. non-predicted values. After extensive testing, it was shown that using IERS Bulletin A UT1 values ending five days prior to the last observed UT1 value would give more optimal and reliable results (Mireault et al., 1997).

At first, as in the IGS Polar Motion (PM) combinations, AC orbit weights were used for AC LOD weights. Other weighting strategies based on AC LOD calibration standard deviation ($1/\sigma^2$) and calibration RMS ($1/RMS^2$) were tested. The $1/RMS^2$ weighting scheme produced the best results overall (when compared to IERS Bulletin A) and was therefore implemented. Another improvement (as already noted by (Ray, 1996)) was realized when EMR UT-derived LOD values were used instead of its estimated LOD. Tests were conclusive and the new strategy was immediately implemented (strategy IGR-C-3* in Table 2). LOD strategy changes that occurred in 1997 are listed in Table 1 while Table 2 contains a sample of the results from some of the LOD tests performed.

Table 2. Comparison of strategies of IGS LOD/UT combination and IERS Bulletin A
Product tested: IGS Rapid (IGR)
Period covered: Wk 921/day 0 to Wk 937/day 6

Strategy used	UT Comparison wrt IERS Bulletin A RMS (μsec)	RMS Improvement (%)
IERS Bulletin A (originally)	377	---
IGR-A-1	162	57
IGR-B-1	158	58
IGR-C-1	137	64
IGR-C-2	127	66
IGR-C-3	121	68
IGR-C-3*	***96***	***75***

Description of IGR LOD combination/integration strategies used:

IERS Bulletin A (originally): UT values taken directly from IERS Bulletin A (at the time of the combination);

(A): IGR LOD combination with AC LOD bias calibration based on IERS Bulletin A UT1 values that included 24h VLBI data;
(B): IGR LOD combination with AC LOD bias calibration based on all observed (i.e. non predicted) IERS Bulletin A UT1;
(C): IGR LOD combination with AC LOD bias calibration based on IERS Bulletin A UT1 values ending five days prior to its last observed UT1 value;

(1): AC LOD weights from AC orbit combinations;
(2): AC LOD weights based on the standard deviation of AC LOD bias calibration wrt IERS Bulletion A ($1/\sigma^2$);
(3): AC LOD weights based on the RMS of AC LOD bias calibration with respect to IERS Bulletion A ($1/RMS^2$);

(*): Use of EMR UT-derived LOD and use of AC LOD for all others.

2.3 New EOP Comparison Table

In order to have a closer look at the AC EOP performance, a new EOP comparison table was introduced in the IGS/IGR summary reports (August, 1997). The new table shows the difference between IGS/IGR combined values and the AC individual contributions for the Earth Rotation Parameters (ERP: Xpole, Ypole, Xrt, Yrt) and Length Of Day (LOD). Table 3 shows an example of the new table (*Table 4.wwww.d*) for the IGS Rapid combination of GPS Wk 933 day 2. It includes a header describing the EOP involved, the units and some short explanatory comments on flags used. The table is divided into 3 sections: (1) AC names and flags used; (2) ERP (i.e. Xpole, Ypole, Xrt, Yrt) and LOD comparisons of IGR versus each AC (IGR-AC) and (3) LOD bias estimation summary with respect to IERS Bulletin A.

Table 3.

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Table 4: Earth Orientation Parameters daily summary.

         Daily Centre ERP, ERP Rates and LOD differences with respect to
         IGR combined values.

         Xpole,Xrt: x pole and x pole rate (10**-5")
         Ypole,Yrt: y pole and y pole rate (10**-5"/day)
         LOD: Length Of Day (µsec)

         AC LOD BIAS: 21-day mean LOD bias with respect to Bulletin A (us)
         AC LOD BIAS RMS: RMS of AC LOD BIAS (us)

         FLAG: "u" (used), "x" (excluded), "-" (no submission)
               for Xpole, Ypole, Xrt, Yrt and LOD

         A star ("*") beside the AC name indicates that AC LOD values were
         derived from AC UT1-UTC values.
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Table 4.0933.2 GPS week: 0933 Day: 2 MJD: 50777.5

CENT	FLAG	Xpole	Ypole	Xrt	Yrt	LOD	AC LOD BIAS	AC LOD BIAS RMS
cod	uuuuu	-30	44	-6	48	-27	-14	55
emr*	uuuuu	25	-48	102	-102	12	4	29
esa	uuuuu	-5	16	-90	-41	-9	3	61
gfz	uuuuu	-1	-5	11	13	-9	-1	32
jpl	uuuuu	59	-49	27	71	1	7	32
ngs	uuuuu	-81	-87	-148	-75	-15	28	56
sio	uuuuu	-54	76	-18	68	-29	-14	185
usn	uuuuu	34	-29	21	-70	24	12	48

For the Final combinations, one week of daily EOP Tables (*Table 7.wwww.d*) are generated preceded by a weekly summary Table (*Table 6.wwww.d*) compiling statistics for the whole week.

2.4 Clock Combinations

Almost from the beginning of the IGS, the AC clock weighting strategy has been based on the absolute deviation of AC initial clock alignment with respect to the broadcast satellites without Selective Availability (SA) (3 satellites at the beginning). Now, since only one non-SA satellite remains (PRN15) this clock weighting strategy has become unreliable.

Given the good performance of AC clock corrections during 1997, it was decided to change from the clock combination weighting strategy based on non-SA satellites, to the following one: a chosen reference AC is aligned to the broadcast GPS clocks using all satellites, then all other ACs are aligned to that reference AC. The clock weights are computed from the absolute deviation of the AC aligned clock corrections with respect to the unweighted mean. This strategy was used whenever the alignment using non-SA satellites gave inappropriate weights and unrealistic clock RMS. It was also used early in 1994 (Kouba et al., 1995) before the non-SA strategy weighting scheme was introduced. A strength of this method is that it does not really matter which AC is chosen for reference as long as it has a very high number of relatively good clock corrections and no clock resets. Its biggest advantage is that AC solutions showing poor performance are greatly down-weighted resulting in more precise and consistent IGS combined clock corrections without having to explicitly exclude any AC solutions, thus making the procedure easier and faster to execute. This strategy was reinstated in the Rapid and Final clock combinations starting Wk 936/day 1 and Wk 935/day 0 respectively.

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. A first attempt was made almost 3 years ago but no improvement was noticed at that time due to the then higher AC clock RMS (~1.0 ns then compared to ~0.3 ns now). Considering the above two changes, tests using precise point positioning (Springer et al., 1998) have shown a factor of two improvement over using the former non-SA satellite weighting method. With the latest implementations in the IGS satellite clock combination, typical repeatability of 10 mm horizontal and 14 mm vertical was found for stationary site coordinates (Springer et al., 1998). This strategy was implemented on Wk 938/day 0 and Wk 940/day 1 (late 1997 and early 1998) for both the Final and Rapid combinations respectively.

3 Orbit and Clock Evaluations

The Long Arc (LA) orbit evaluation was described in more detail in the IGS 1994 Annual Report (Kouba et al., 1995) and, therefore will not be described here. Note though, that LA evaluation is only performed for the Final orbit products that are generated on a weekly cycle. LA RMS are presented in Figure 29.

Between January 1996 and March 1998, the IGS combined orbits/clocks as well as all AC solutions which contain both the orbit and clock corrections data, have been 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 was 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 ITRF94) are summarized in the Rapid/Final summary reports. Tables 4a and 4b summarize the point positioning results obtained from both the Rapid and Final orbit/clock products for 1997. Note that the IGR orbits/clocks are included in the Final IGS summary reports for performance comparison, i.e. they are not used in the IGS Final combinations. For most ACs, both Rapid and Final 3D Navigation RMS ranged from ~30 cm to ~65 cm overall (depending on the station processed) with the height component being the least precise.

Starting March 1998, the daily precise navigation statistics found in the IGS reports are now based on receiver phase data using JPL's GISPY-OASIS II point positioning capability recently installed at NRCan. Section 6 gives more details.

Table 4a. 1997 IGS Rapid Combination Point Positioning RMS using GPSPACE (Pseudorange data - navigation mode) for ACs providing orbit/clock solutions

	BRUS				USUD				WILL			
ACs	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
emr	47	36	93	63	37	29	79	53	27	18	47	33
esa	88	55	126	94	61	52	138	92	37	30	70	49
gfz	52	37	101	69	53	32	87	62	31	20	54	38
igr	48	35	91	63	38	29	81	54	27	18	48	33
jpl	48	35	92	63	37	27	78	52	27	17	46	32
usn	48	38	98	67	41	31	89	59	29	19	50	35

Table 4b. 1997 IGS Final Combination Point Positioning RMS using GPSPACE (Pseudorange data - navigation mode) for ACs providing orbit/clock solutions

	BRUS				USUD				WILL			
ACs	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
cod	49	36	97	66	37	29	79	53	26	17	46	32
emr	50	36	99	67	37	29	79	53	27	18	48	33
esa	57	39	100	70	43	33	89	60	33	23	57	40
gfz	51	39	96	67	39	31	82	55	29	21	53	37
igs	48	36	96	65	37	29	80	53	27	17	48	33
jpl	49	36	98	66	36	28	79	53	27	16	46	32

Period covered: GPS Wks 886-937 (Dec.29/1996-Dec.27/1997)
Units: centimeters (cm)

RMS ≥

4 IGS Orbit, Clock and EOP Combinations by Weighted Average: Method Description

Table 5 summarizes the Prediction, Rapid and Final combination procedures for the orbit, clock and EOP products at the end of 1997. Changes that occurred during the year are listed in Table 1. A more detailed description including the formulas involved in the orbit/clock combinations can be found in the IGS 1994 Annual Report (Kouba et al., 1995). Two different procedures for the EOP combination are used, one for Xpole, Ypole, Xrt and Yrt (group I) and another for LOD/UT (group II).

Table 5. Orbit, clock and EOP combination/evaluation procedures at the end of 1997

1. Long Arc Ephemerides Evaluation for each AC: *Final Combination*: seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and RMS residuals are examined; *Prediction and Rapid Combinations*: none
2. Transformation to Common Reference: **(a) Orbit** *Prediction, Rapid and Final Combinations*: performed directly in the ITRF94 reference frame without EOP alignment; **(b) Clock** *Rapid and Final Combinations*: are aligned with respect to broadcast GPS clock corrections. First, a reference AC is aligned to the broadcast GPS clocks using all satellites and then each AC is aligned to the reference AC. *Prediction Combination*: none
3. Orbit and Clock Combinations: *Prediction, Rapid and Final Combinations*: AC orbit weights are computed from absolute deviations with respect to unweighted mean orbits; satellite ephemerides are then combined as weighted averages of AC solutions. *Rapid and Final Combinations*: AC clock weights are computed from the absolute deviation of the AC aligned clock corrections with respect to the unweighted mean; Satellite clock corrections are then combined as weighted averages of AC solutions. *Prediction Combination*: none (CODE's predicted clock corrections are used for IGP predicted clock corrections).
4. EOP Combination: *Rapid and Final Combinations*: PM x and y and PM rates are combined as weighted averages from available AC EOP values using orbit weights. *Rapid and Final Combinations*: AC LOD alignment is based on comparisons with the IERS Bulletin A during the three week period ending five days before the last observed Bulletin A daily value. AC LODs are then combined as weighted averages according to the AC LOD alignment RMS. IGS LODs are then integrated into IGS UTs. *Prediction Combination*: PM x and y, PM rates, LODs and UTs are taken directly from the most current IERS Bulletin A.
5. Long Arc Ephemerides Evaluation for the IGS Combined Orbits: *Final Combination*: seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and RMS residuals are examined. *Prediction and Rapid Combinations*: none.
6. Independent Point Positioning Evaluation (navigation mode): *Rapid and Final Combinations*: all AC solutions which contain orbits and clocks (including IGS/IGR combinations) are evaluated using the three IGS stations: BRUS, USUD and WILL. *Prediction Combination*: none.

Group I: ERP (Xpole, Ypole, Xrt, Yrt)

The parameters in the first group are combined as a straightforward weighted mean of AC (Cent) available values using AC orbit weights (eqn. 1).

$$\overline{ERP}_{Comb} = \sum_{Cent}^{Ncent} ERP_{Cent} \cdot W_{Cent}^{Orb} \tag{1}$$

where: W_{Cent}^{Orb} is the AC orbit weight (Kouba et al., 1995) and

$\overline{ERP}_{Comb}$ is the combined IGS value of one of the parameters of group I.

Group II: LOD/UT

Initially, each AC LOD series is calibrated with respect to the IERS Bulletin A. This is done by estimating a 21-day calibration (ncal) bias between IERS Bulletin A and each AC individually (eqn. 2). AC LOD values from day "Start" (or *anchor* point) and up to the day required (nday total) are then properly corrected (eqn. 3) before combining them to form IGS combined LOD values (eqn. 4). AC LOD weights are based on the bias calibration RMS from (eqn. 2) and given explicitly in (eqn. 5 and 6). Finally, IGS combined LODs from (eqn. 4) are integrated into IGS UTs (eqn. 7) from the *anchor* point up to the day required. All the equations are given below. Figure 1 illustrates the general procedure.

$$Bias_{Cent} = \frac{\sum_{ical}^{ncal} \left(LOD_{Bull.A} - LOD_{Cent} \right)}{ncal} \tag{2}$$

$$LOD'_{Cent_{iday}} = LOD_{Cent_{iday}} + Bias_{Cent} \qquad iday = 1, nday \tag{3}$$

$$\overline{LOD}_{comb_{iday}} = \sum_{Cent}^{Ncent} W_{LOD_{Cent}} \cdot LOD'_{Cent_{iday}} \qquad iday = 1, nday \tag{4}$$

where:

$$W_{LOD_{Cent}} = \frac{1}{RMS^2_{Bias_{Cent}}} \tag{5}$$

$$RMS_{Bias_{Cent}} = \sqrt{\frac{\sum_{ical}^{ncal} \left(LOD_{Bull.A} - LOD_{Cent} \right)^2}{ncal}} \tag{6}$$

Finally,

$$\overline{UT}_{comb_{iday}} = UT_{Bull.A_{Start}} - \sum_{i}^{iday} \overline{LOD}_{Comb_i} \qquad iday = 1, nday \qquad (7)$$

where:

"Start"	is 5 days prior to the IERS Bulletin A last observed UT1,
$LOD_{Bull.A}$	is IERS Bulletin A UT1-derived LOD,
LOD_{Cent}	is the AC LOD or AC UT-derived LOD (in the case of EMR),
$Bias_{Cent}$	is the AC LOD calibration bias,
LOD'_{Cent}	is the corrected AC LOD or AC UT-derived LOD (e.g. EMR),
$\overline{LOD}_{Comb}$	is the estimated IGS combined LOD,
"ncal"	is the number of calibration days (maximum 21),
"nday"	is the number of combination/integration days,
$UT_{Bull.A_{Start}}$	is the IERS Bulletin A UT1 starting or *anchor* value, and,
$\overline{UT}_{Comb}$	is the estimated IGS combined UT.

5 IGS Prediction, Rapid and Final Combination Results in 1997

In this section, results for the fourth year of IGS service, i.e. December 29, 1996 to December 27, 1997 (Wks 886-937), are presented.

Tables 6 and 7 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 8 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 364 days except for EMP (Table 6) which started on Wk 887 / day 5 (352 days), ESP (Table 6) which started on Wk 899 / day 3 (270 days) and USN (Table 7) which started its Rapid contribution on Wk 902 / day 3 (249 days). Note also that rotations (RX, RY and RZ) greater than 5 mas in Table 7 were excluded from the AC means and standard deviations for more meaningful AC overall statistics.

Figures 2-9 (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.

Table 6. IGS Prediction Combination - GPS Wks 886-937 (performed directly in the ITRF94 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	0.03	0.02	0.52	-0.50	4.36	-3.1	364
	σ	0.12	0.13	0.28	2.69	4.44	6.92	2.8	
cop	μ	0.00	0.02	-0.03	-0.52	0.11	0.15	-0.2	364
	σ	0.02	0.02	0.06	0.97	1.30	3.32	0.5	
emp	μ	0.00	0.02	-0.01	0.35	0.08	-0.04	-0.1	346(1)
	σ	0.02	0.02	0.04	1.16	1.75	7.09	0.7	
esp	μ	0.00	0.02	-0.01	0.67	0.21	0.66	0.2	256(2)
	σ	0.02	0.02	0.04	0.98	1.59	5.52	0.5	
gfp	μ	0.00	0.02	0.01	0.42	0.25	-0.45	-0.3	342
	σ	0.01	0.01	0.03	1.78	1.63	2.47	0.6	
jpp	μ	0.00	0.02	0.00	0.07	-0.44	-0.13	0.2	363
	σ	0.01	0.01	0.04	2.10	2.65	2.66	0.7	
sip	μ	0.00	0.02	0.00	-0.44	0.05	-2.21	-0.1	337
	σ	0.03	0.03	0.07	1.26	1.26	8.20	1.2	
igp	μ	0.00	0.02	0.00	0.02	0.00	-0.25	-0.1	364
	σ	0.01	0.01	0.03	0.92	1.13	2.57	0.4	

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(1): emp submissions started only on Wk 887 day 5 (Maximum 352 days)
(2): esp submissions started only on Wk 899 day 3 (Maximum 270 days)
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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.

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 10 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. A perfect correlation would be translated as a 1.0 value in Figure 26, which shows the correlation coefficient of each AC X/Y rotations versus AC PM differences in y/x for the same period as shown in Figures 10-25.

Table 7. IGS Rapid Combination - GPS Wks 886-937 (performed directly in the ITRF94 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	0.02	-0.01	-0.59	0.11	0.09	-0.2	363
	σ	0.01	0.01	0.01	0.35	0.29	0.29	0.2	
emr	μ	0.00	-0.01	0.00	0.36	-0.02	0.12	-0.1	325
	σ	0.01	0.02	0.01	0.47	0.39	0.44	0.2	
esa	μ	0.00	0.01	0.00	0.03	-0.20	0.19	0.2	334
	σ	0.01	0.02	0.01	0.35	0.38	0.38	0.2	
gfz	μ	0.00	-0.03	0.01	0.23	0.10	-0.33	-0.1	322
	σ	0.01	0.01	0.01	0.44	0.35	0.44	0.2	
jpl	μ	0.01	0.02	0.00	-0.06	-0.14	0.06	0.1	283
	σ	0.01	0.02	0.01	0.35	0.28	0.31	0.2	
ngs	μ	0.00	-0.04	-0.01	0.22	0.14	-0.06	-0.2	315
	σ	0.02	0.02	0.02	0.58	0.50	0.47	0.3	
sio	μ	0.00	0.02	0.00	-0.34	0.02	-0.44	0.2	311
	σ	0.01	0.02	0.02	0.67	0.40	1.90	0.5	
usn	μ	0.00	-0.03	0.00	0.34	0.00	0.22	0.2	219(1)
	σ	0.02	0.04	0.02	0.48	0.43	0.37	0.2	

(1): usn submissions started on Wk 902 day 3 (Maximum 249 days)

Note also 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: esa:2; gfz:1; jpl:3; sio:22; usn:4.

The AC Rapid correlations show a slightly more consistent orbit/EOP series than the Final. However, in almost all cases, the consistency improved between the first and second half of 1997.

Figure 27 shows the orbit coordinate RMS of all AC Prediction submissions 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 28 shows orbit coordinate RMS of all AC Rapid submissions with respect to the IGR combinations. Finally, Figure 29 shows the AC Final submission orbit RMS results where the combination RMS median was replaced by the 7-day Long Arc RMS. Figures 30-31 show the AC Prediction and Rapid clock RMS respectively with respect to IGR and Figure 32 displays AC Final clock RMS with respect to the IGS Final clocks.

Table 8. IGS Final Combination - GPS Wks 886-937 (performed directly in the ITRF94 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	-0.27	0.11	0.22	-0.2	364
	σ	0.00	0.01	0.01	0.18	0.13	0.22	0.1	
emr	μ	0.00	-0.01	-0.01	0.38	-0.07	0.43	-0.1	357
	σ	0.01	0.01	0.01	0.21	0.17	0.38	0.2	
esa	μ	0.00	0.00	0.00	0.05	-0.13	0.15	0.1	364
	σ	0.01	0.01	0.01	0.23	0.20	0.21	0.1	
gfz	μ	0.00	0.00	0.01	0.11	0.06	-0.21	-0.1	364
	σ	0.00	0.01	0.01	0.16	0.13	0.20	0.1	
jpl	μ	0.00	0.01	0.00	-0.04	-0.12	0.02	0.3	357
	σ	0.01	0.01	0.01	0.16	0.10	0.12	0.1	
ngs	μ	0.00	-0.05	0.00	0.20	0.25	-0.13	-0.1	364
	σ	0.01	0.01	0.02	0.45	0.30	0.36	0.2	
sio	μ	0.00	0.01	0.00	-0.01	0.17	-0.36	0.2	336
	σ	0.01	0.01	0.01	0.31	0.66	0.30	0.4	
igr	μ	0.00	-0.01	0.00	0.10	0.10	-0.03	0.0	364
	σ	0.01	0.01	0.01	0.23	0.21	0.25	0.1	

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.

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 0.2-0.3 ns precision level with the Final combination results being slightly more consistent. The predicted orbit precision (IGP) has reached the ~50 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 and Final orbit position precision are below the 10 cm and at, or below, the 5 cm level respectively. Again, the Rapid results are somewhat noisier than the Final results due mostly to the very short delivery time which causes occasional lack of tracking data (submission deadline of 21 hours).

6 1998 and Future Improvement

By the time this report is published, at least two new major enhancements will have already been implemented. Starting March 1, 1998 (Wk 947), the new ITRF96 reference system will be used for all IGS products. Also in March 1998, (Wks 948 and 950 for IGS Final and IGS Rapid respectively), a new precise point navigation program utilizing phase instead of pseudorange data, will have been implemented. A brief summary was already given in the Volume I of this year's Annual Report (Kouba, 1998) and a more thorough analysis will be presented in next year's Annual Report. Figure 33 shows an example of IGR and IGS performance using this point positioning approach. When fixing IGS orbits/clocks, navigation positioning precision of only a few cm is now possible anywhere in the world without the need for any base station data. Current IGS sp3 clock sampling of 15 minutes and SA limit navigation to 15 min intervals only. For higher sampling, more frequent IGS clocks are needed to allow precise interpolation of the SA clock effects.

6 Summary

1997 was again a very busy year for both the ACs and the IGS AC coordinator. ACs have again improved the reliability and precision of their products or at least maintained the quality level already reached in the past, which in itself is quite an accomplishment. By the end of 1997, the best AC orbit solutions were at or below the 5 cm level for the Final solutions and between 5-10 cm for the Rapid solutions. Prediction orbit precision, a new product made available in 1997, has a RMS median of ~50 cm or lower compared to ~200 cm for the broadcast orbit. Better AC clock corrections along with improved clock combination strategies resulted in combined clock correction precision reaching an unprecedented 0.2–0.3 ns level (and as precise as 0.1 ns on some occasions!) for both the Rapid and Final solutions. The IGS LOD combination and integration into IGS UT were also introduced in 1997. Several combination strategies were tested and implemented throughout the year resulting each time in a more precise and consistent IGS LOD/UT series when compared to IERS Bulletin A. A new EOP comparison table to monitor AC EOP performance was also added to the IGR/IGS summary reports. Finally, AC Rapid combination submission deadline was advanced by 2 hours, i.e. from 24 to 22 hours UTC, allowing ACs to use IGR in their orbit predictions.

7 References

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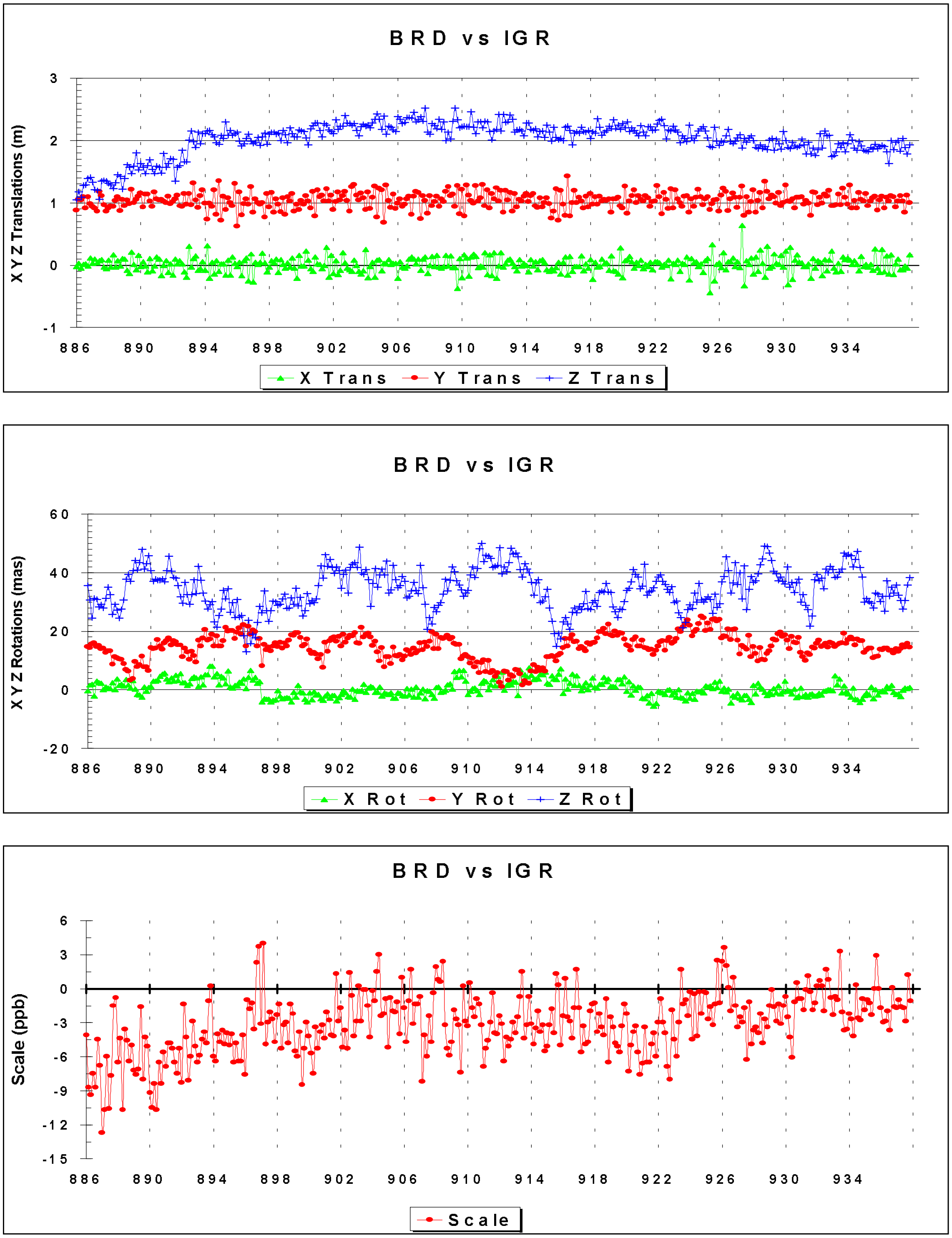


Figure 2. Daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 20 mas)

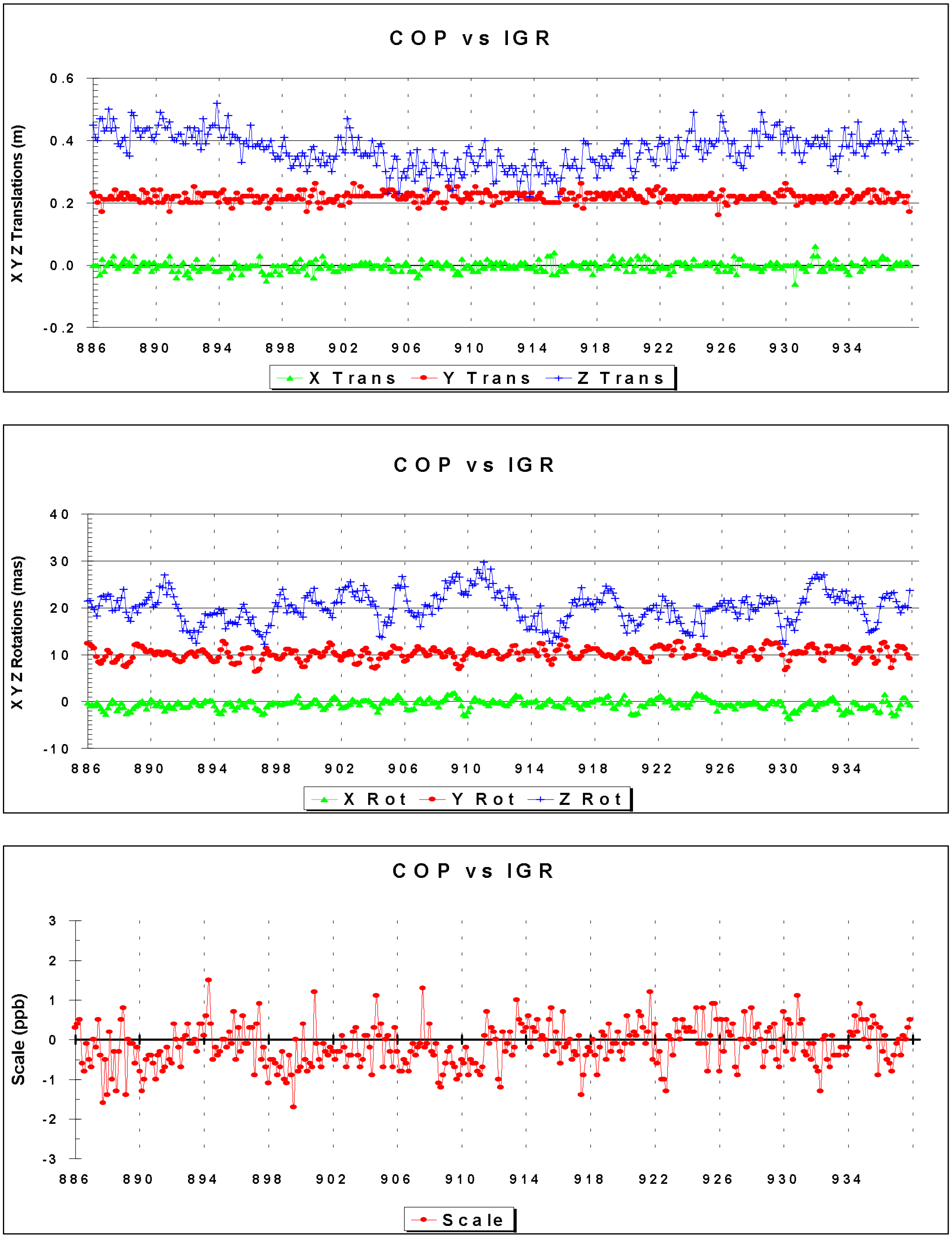
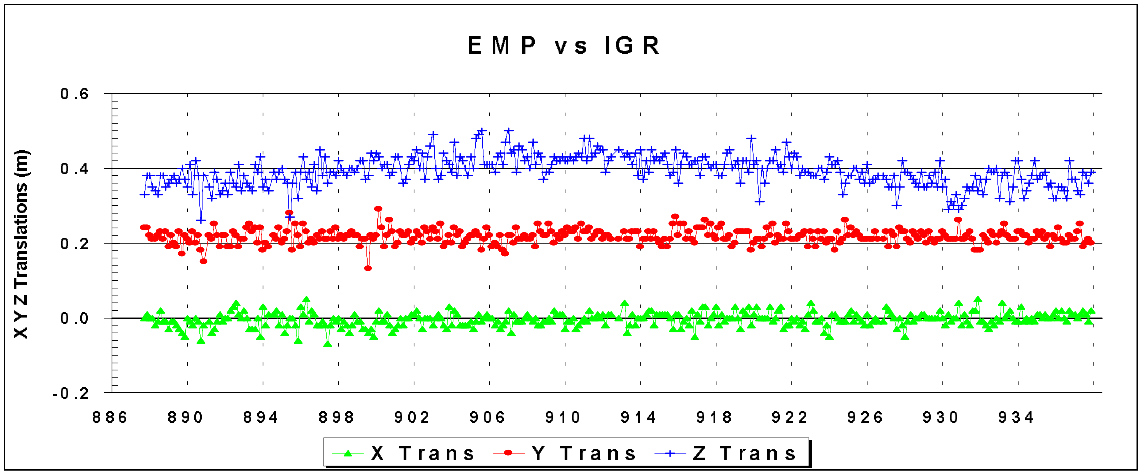
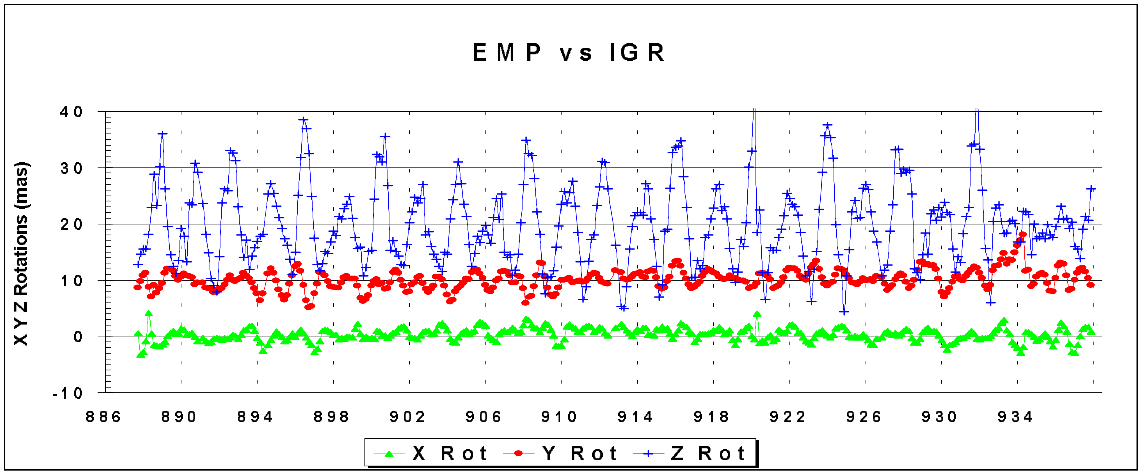


Figure 3. COP 1997: Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 0.2 metre; X, Y and Z Rotations are each offset by 10 mas)





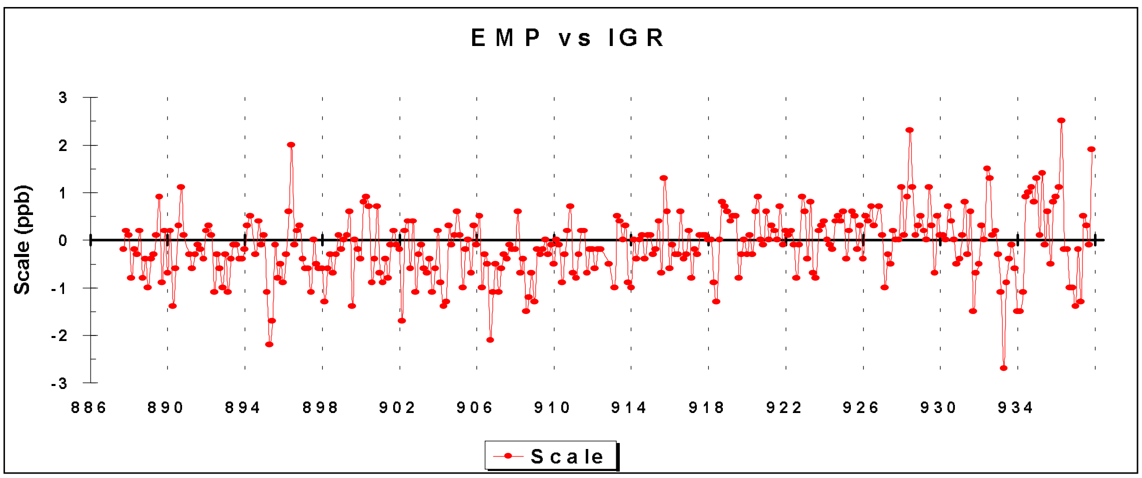


Figure 4. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

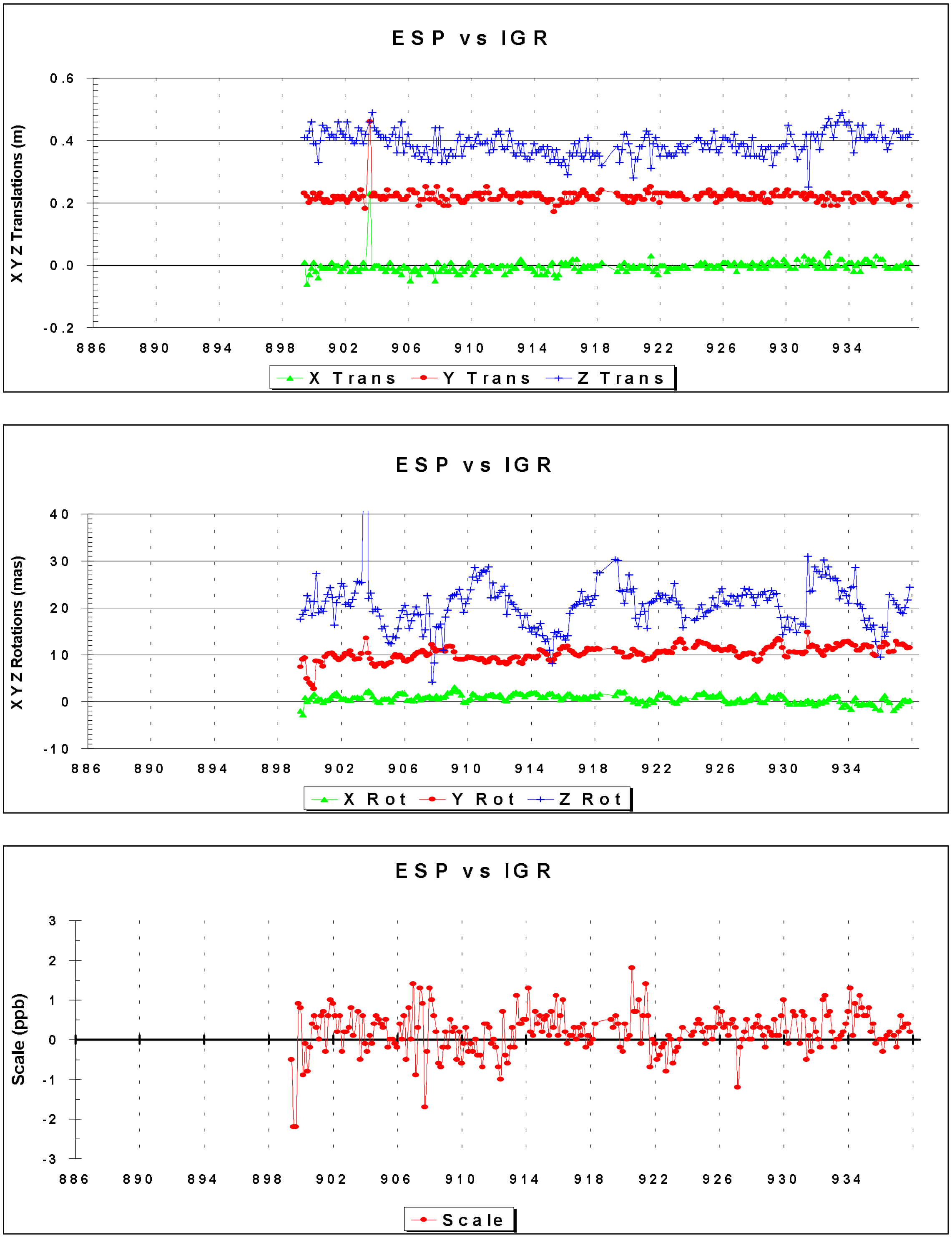
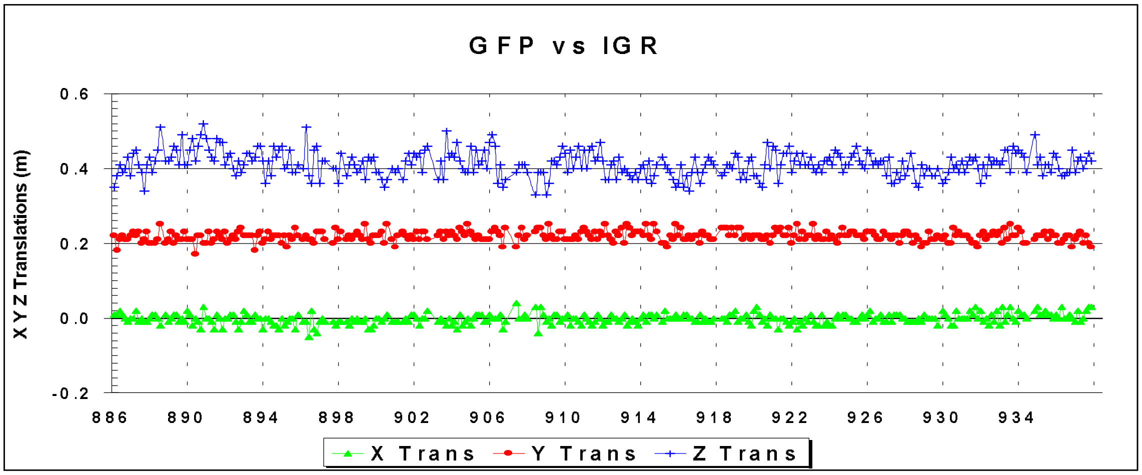
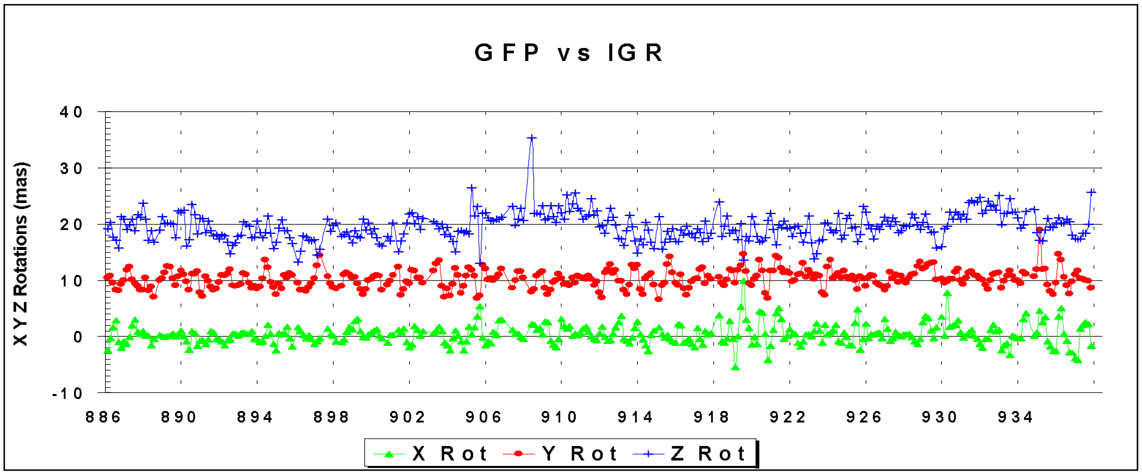


Figure 5. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)





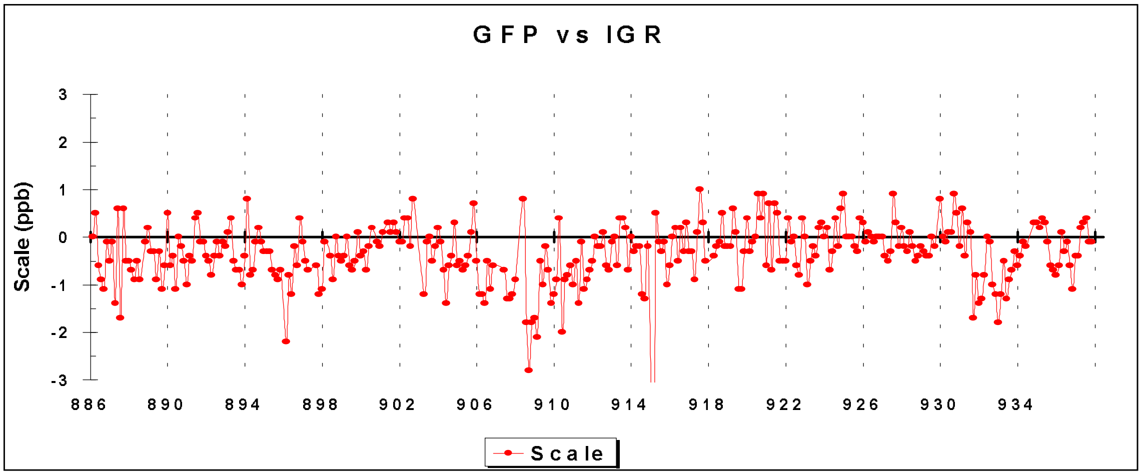


Figure 6. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

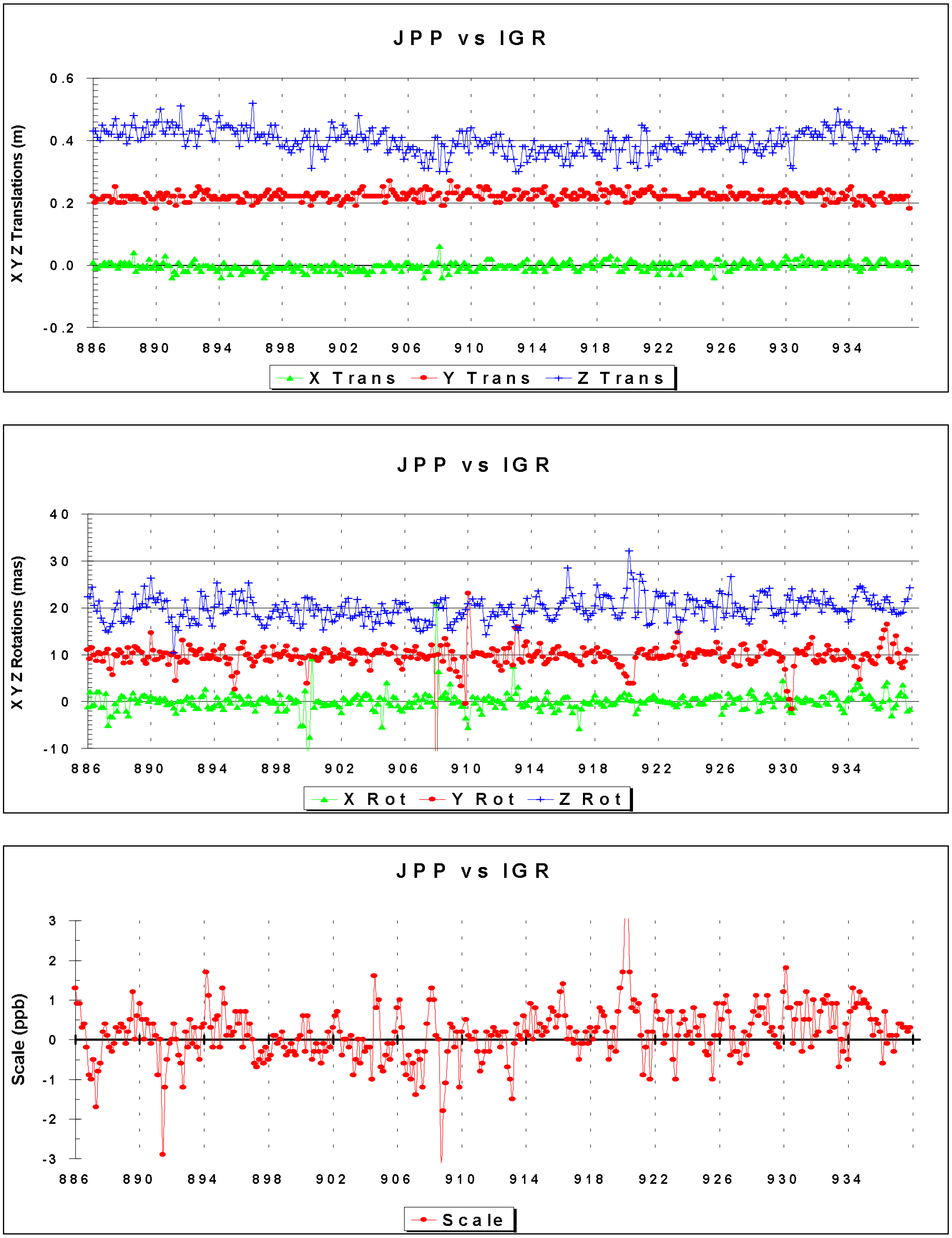


Figure 7. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

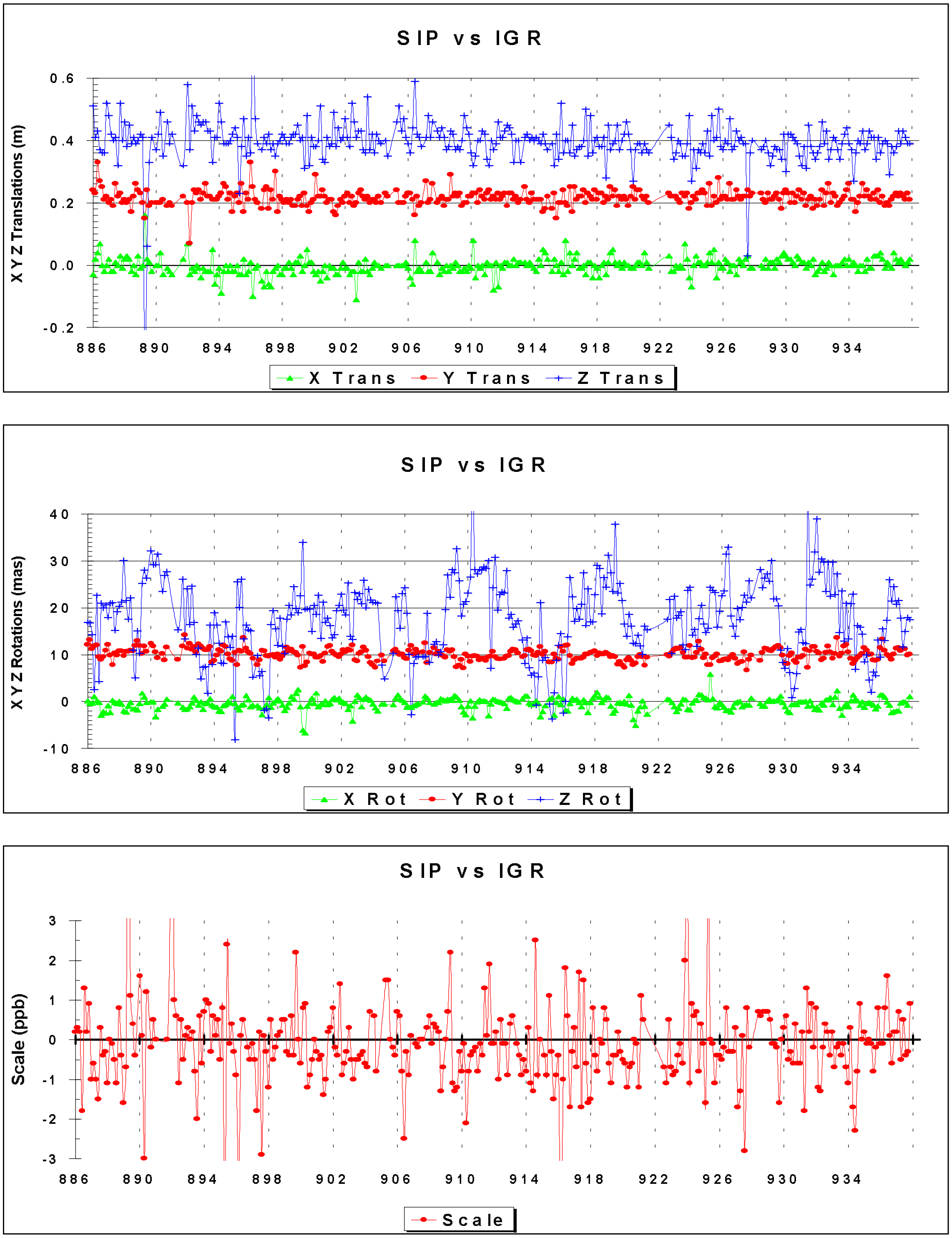


Figure 8. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

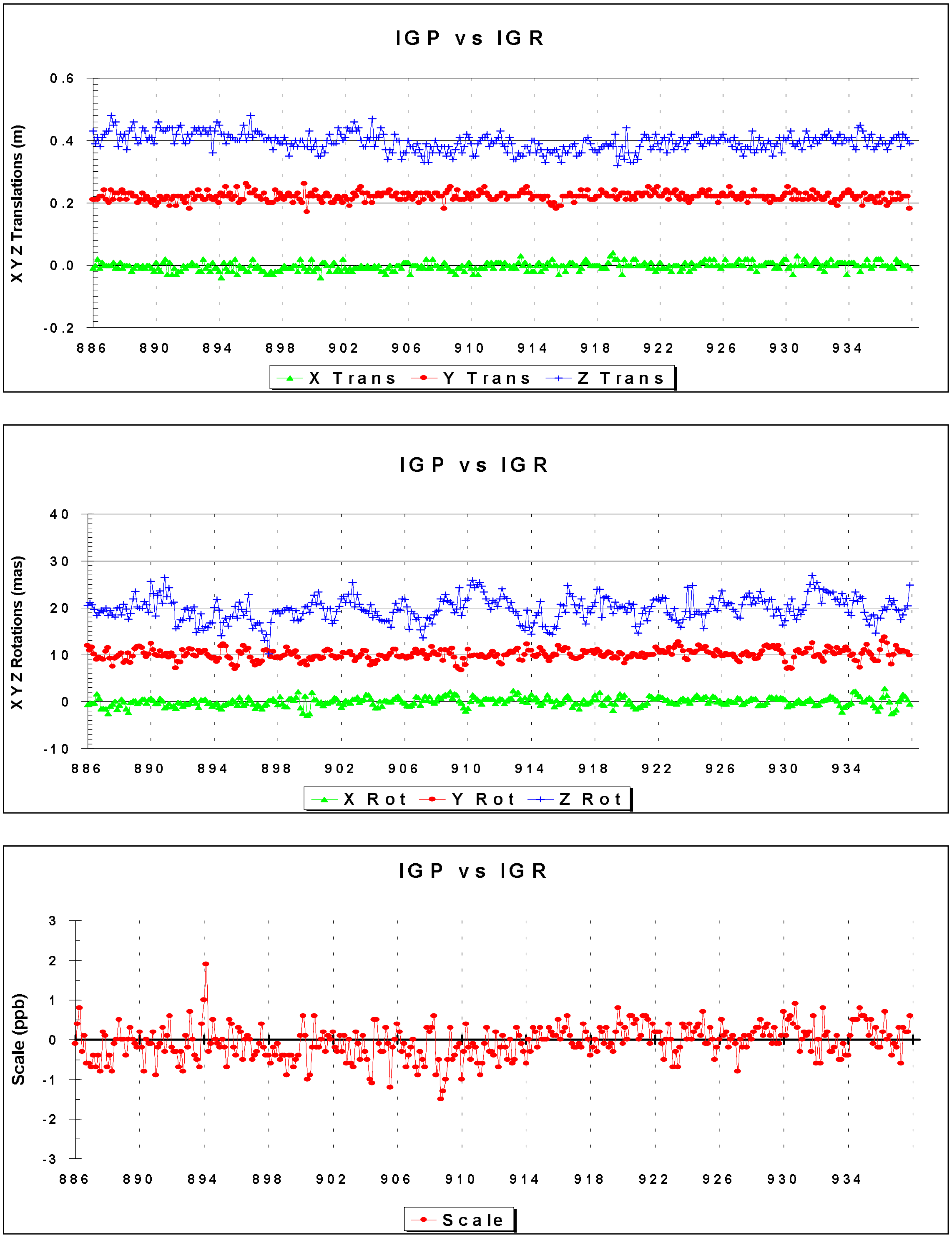
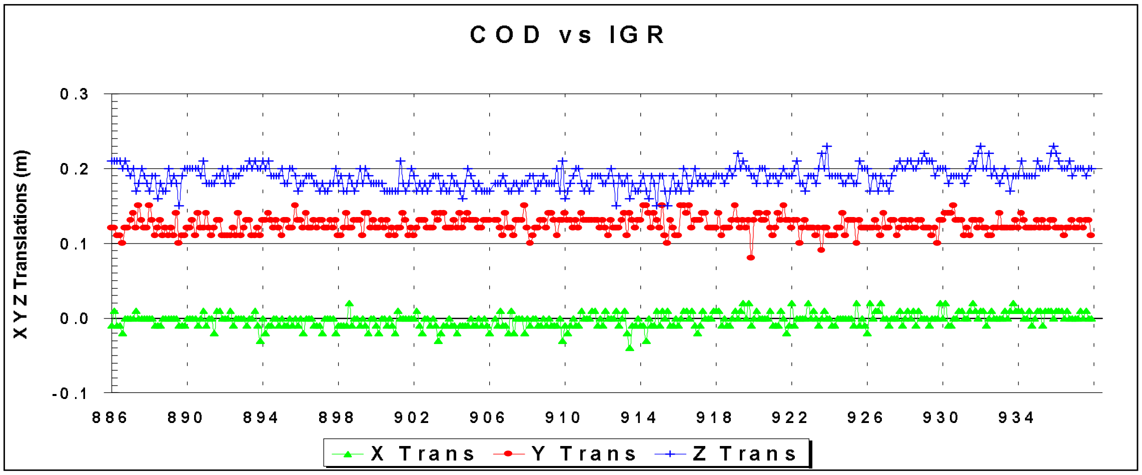
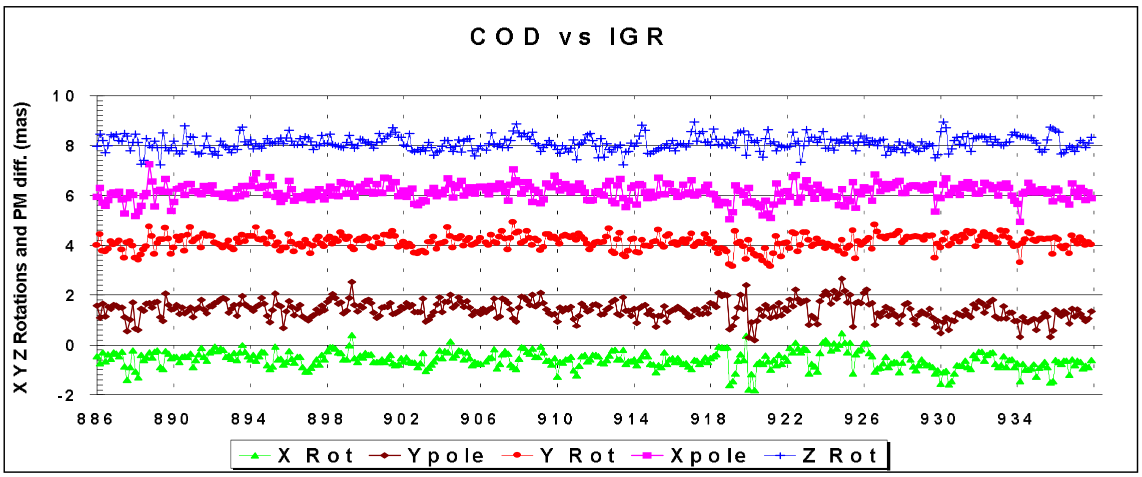


Figure 9. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)





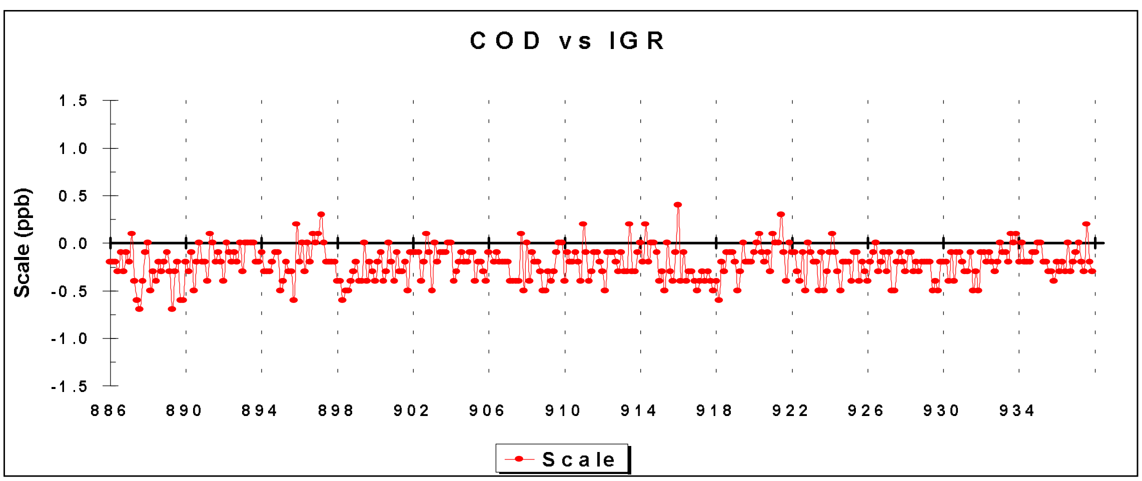
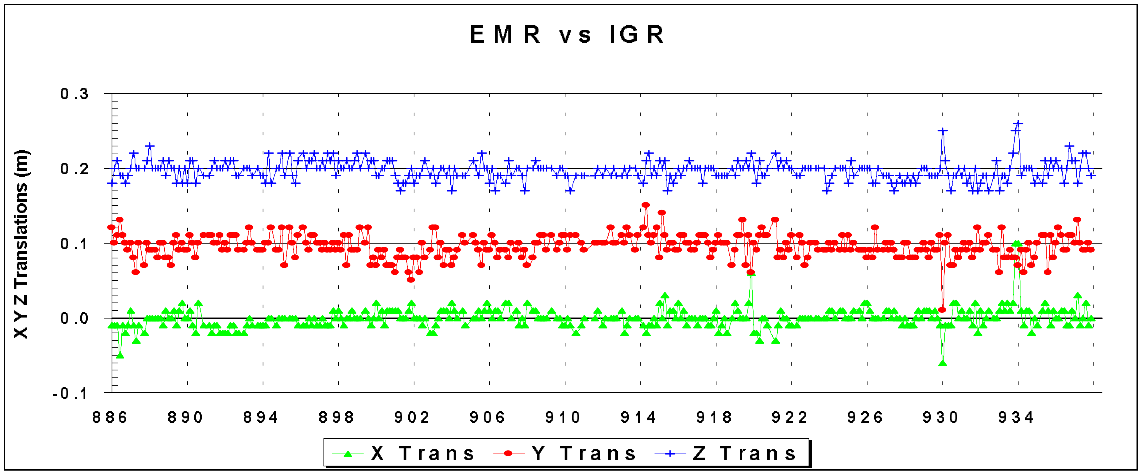
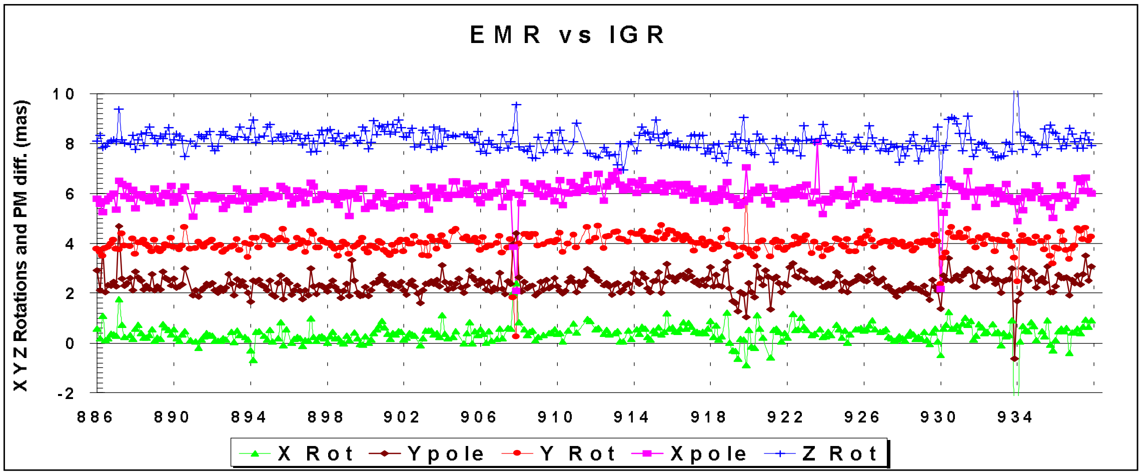


Figure 10. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)





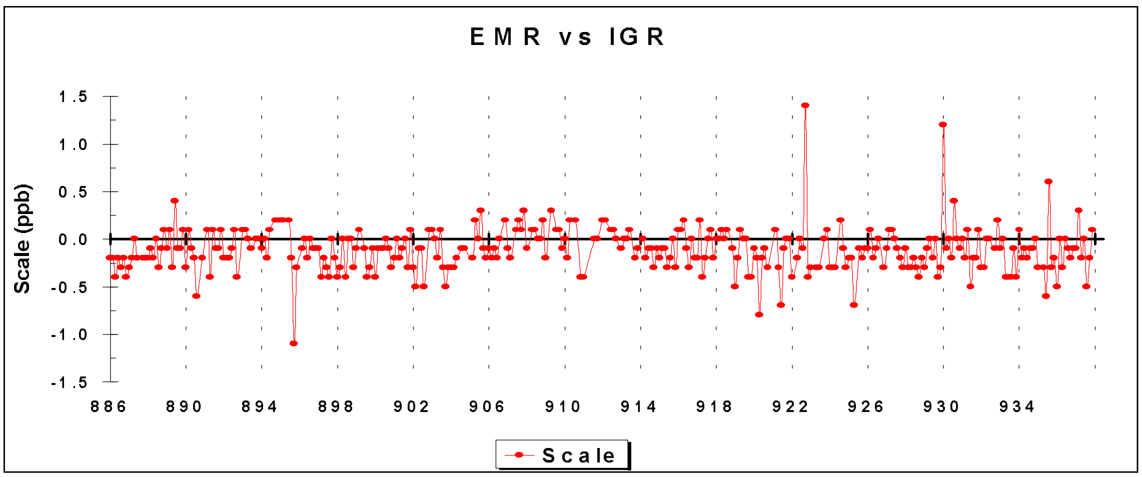


Figure 11. EMR 1997: Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

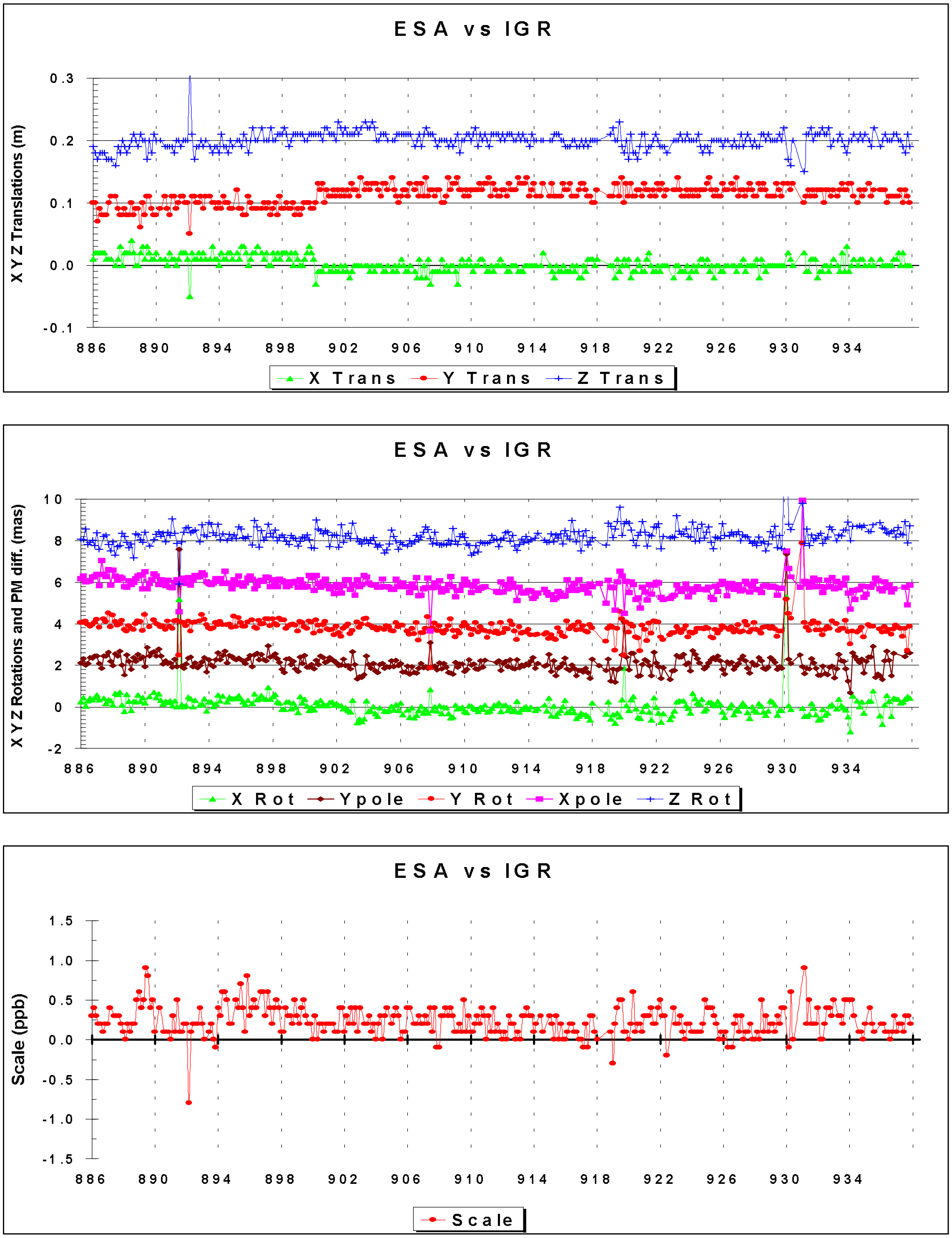


Figure 12. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

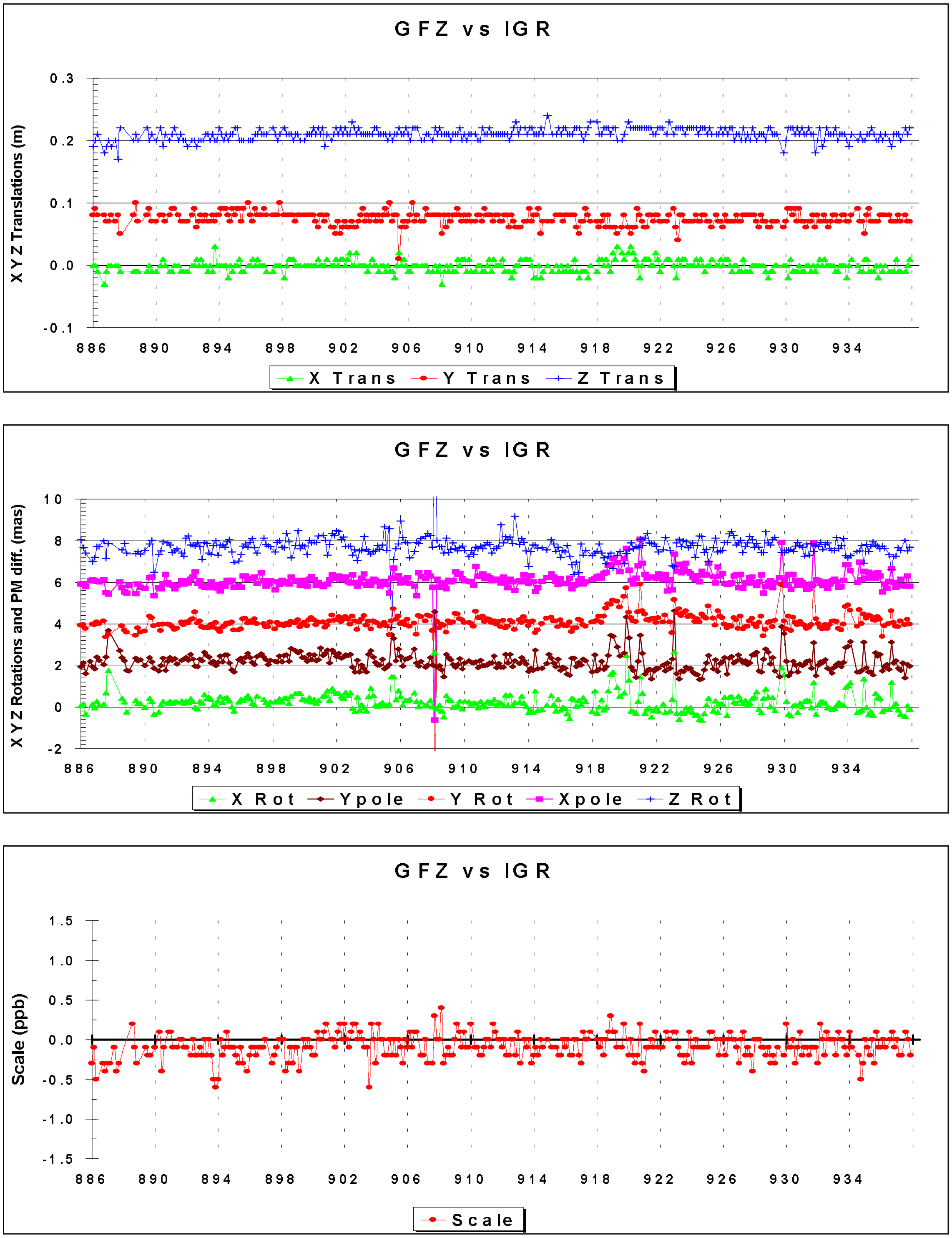


Figure 13. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

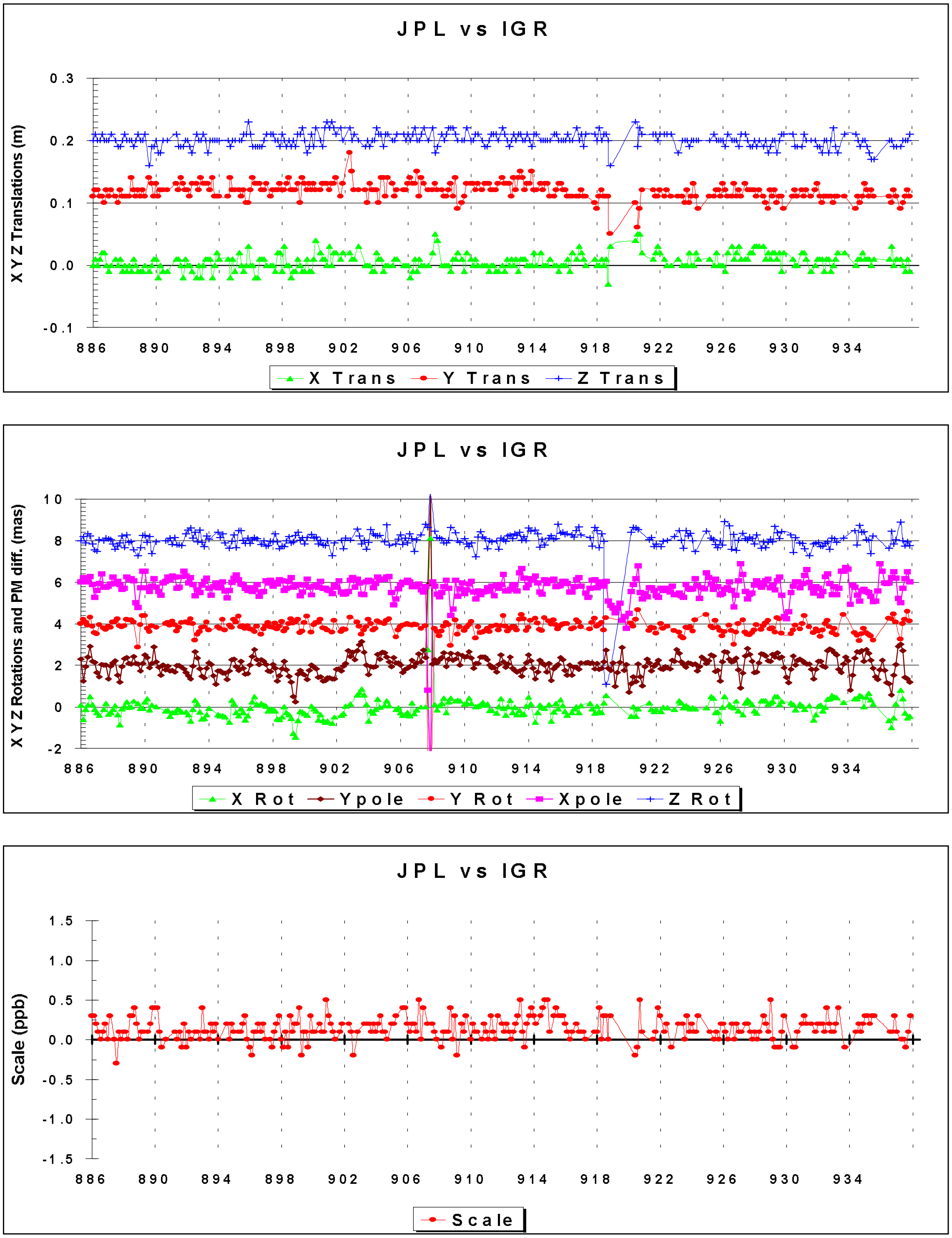


Figure 14. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

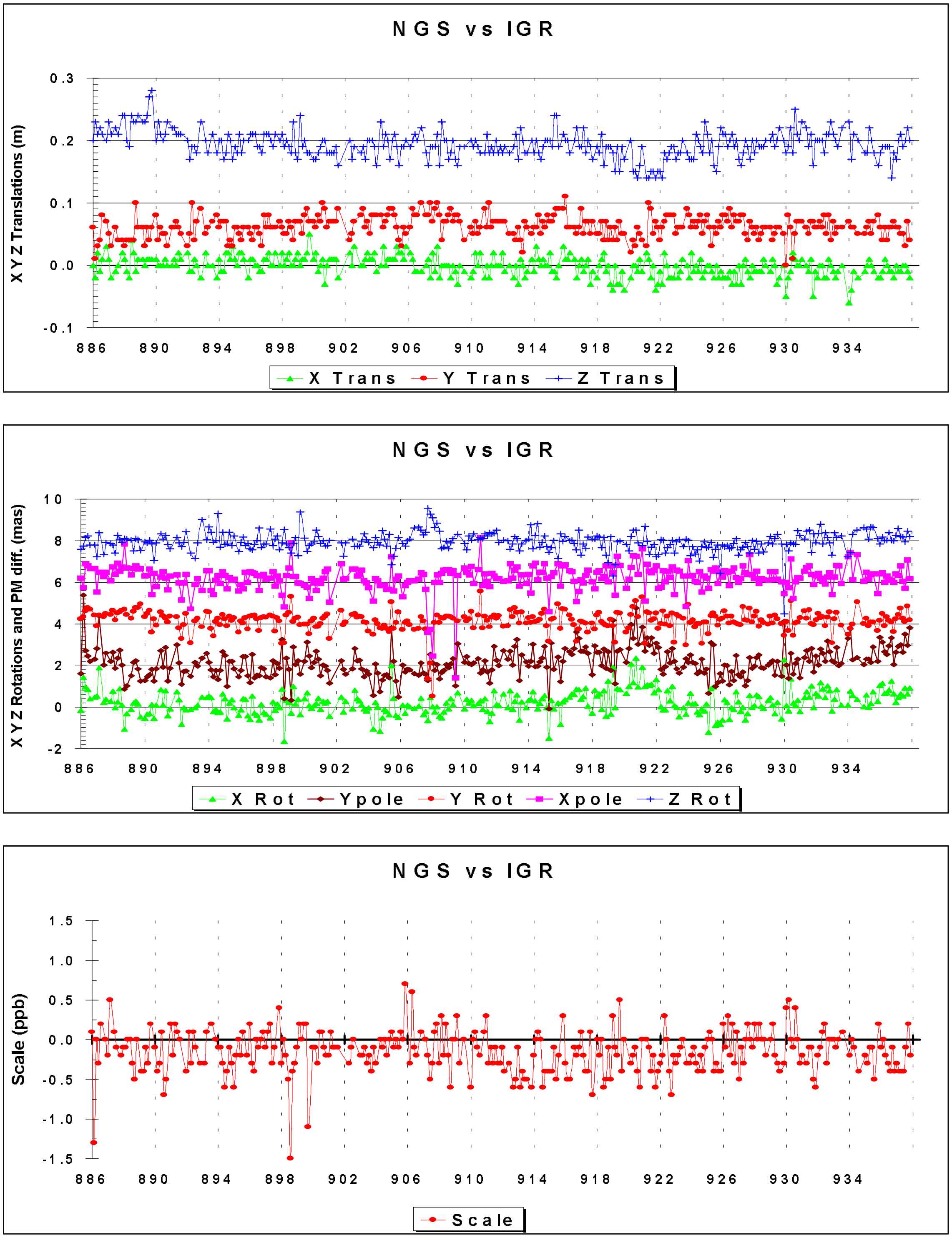


Figure 15. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

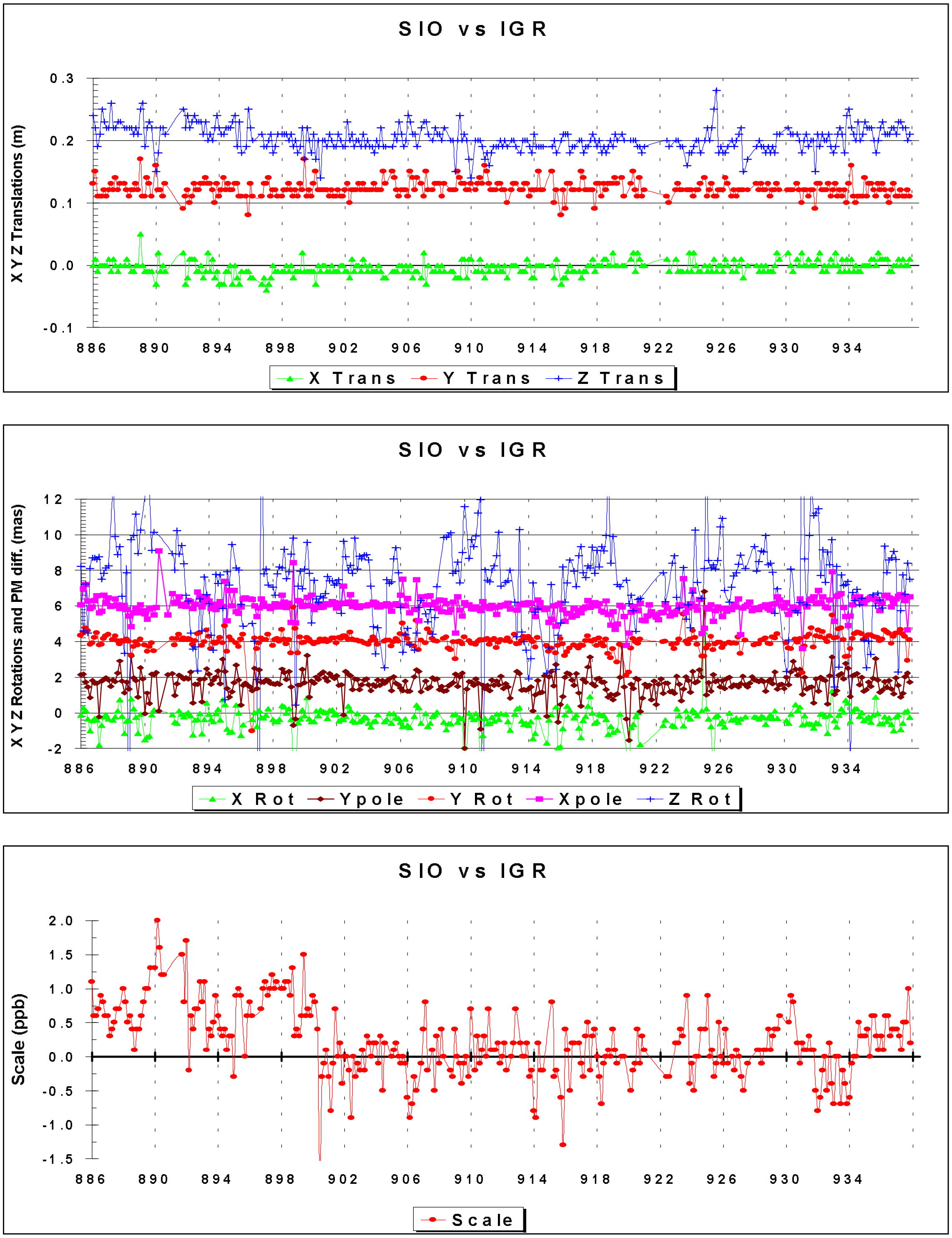
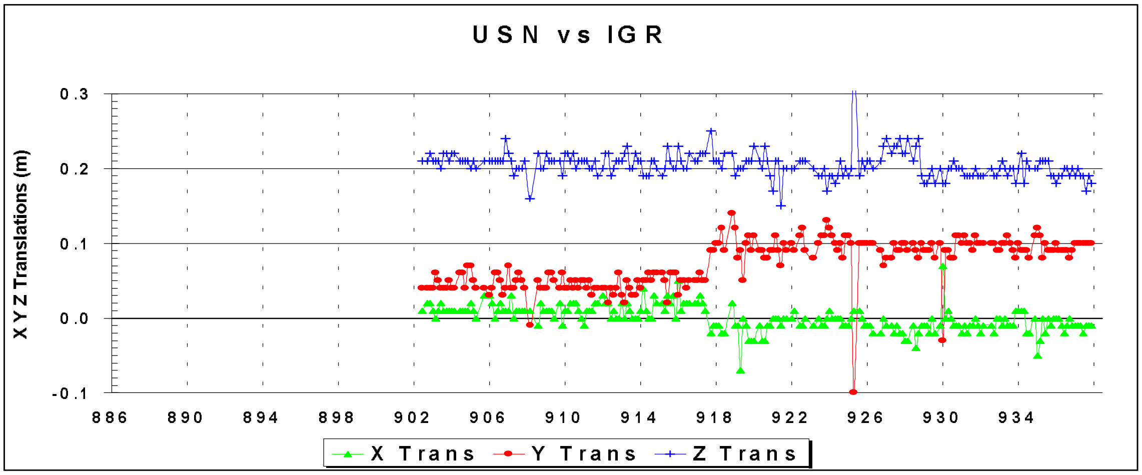
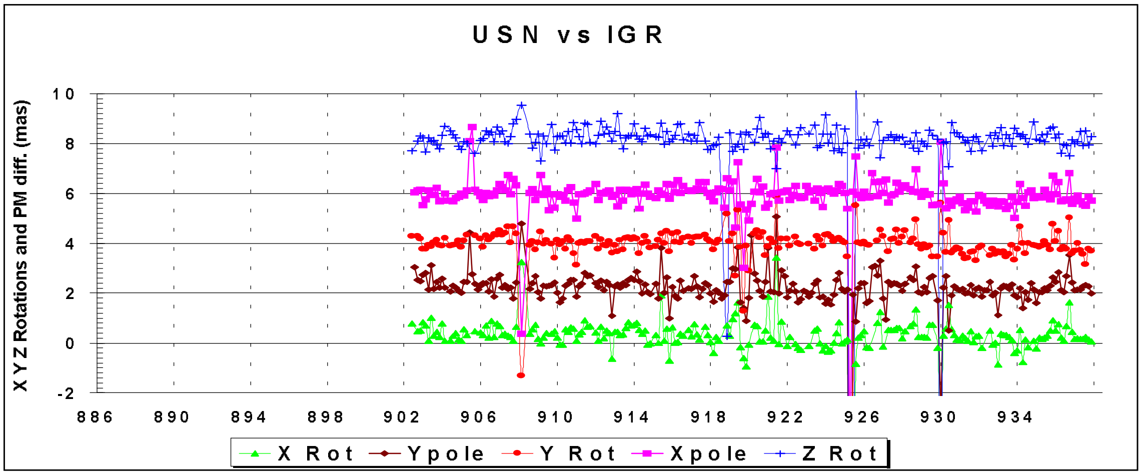


Figure 16. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)





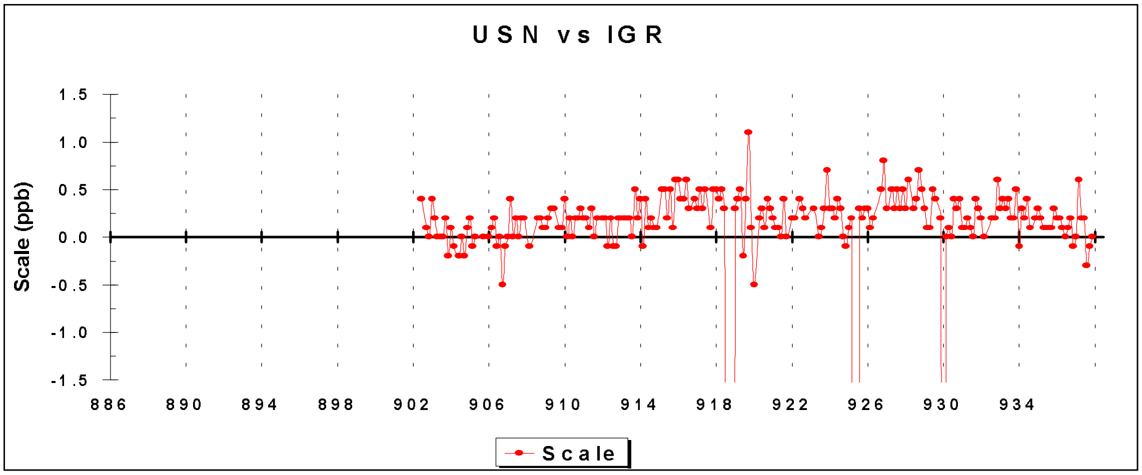


Figure 17. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

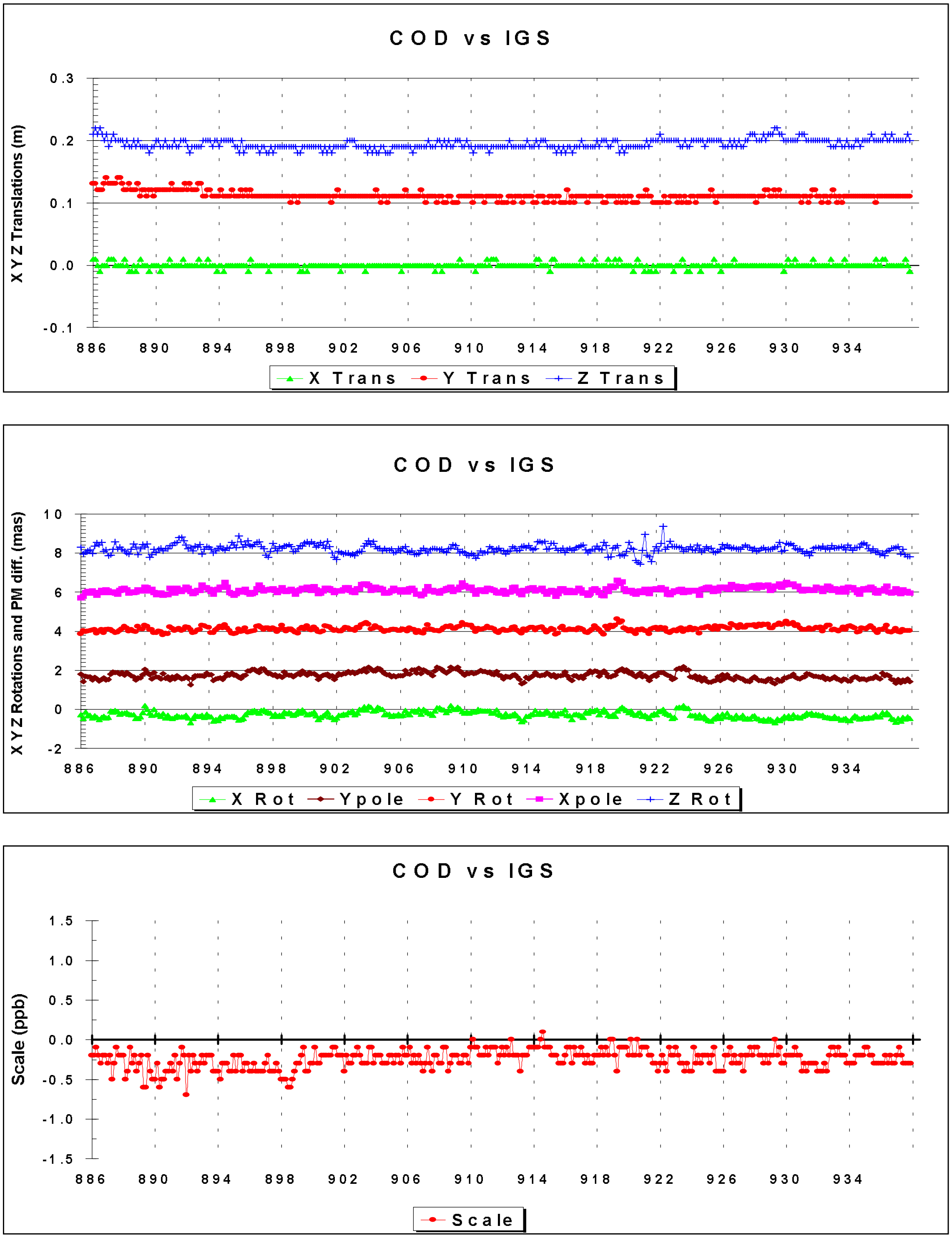


Figure 18. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

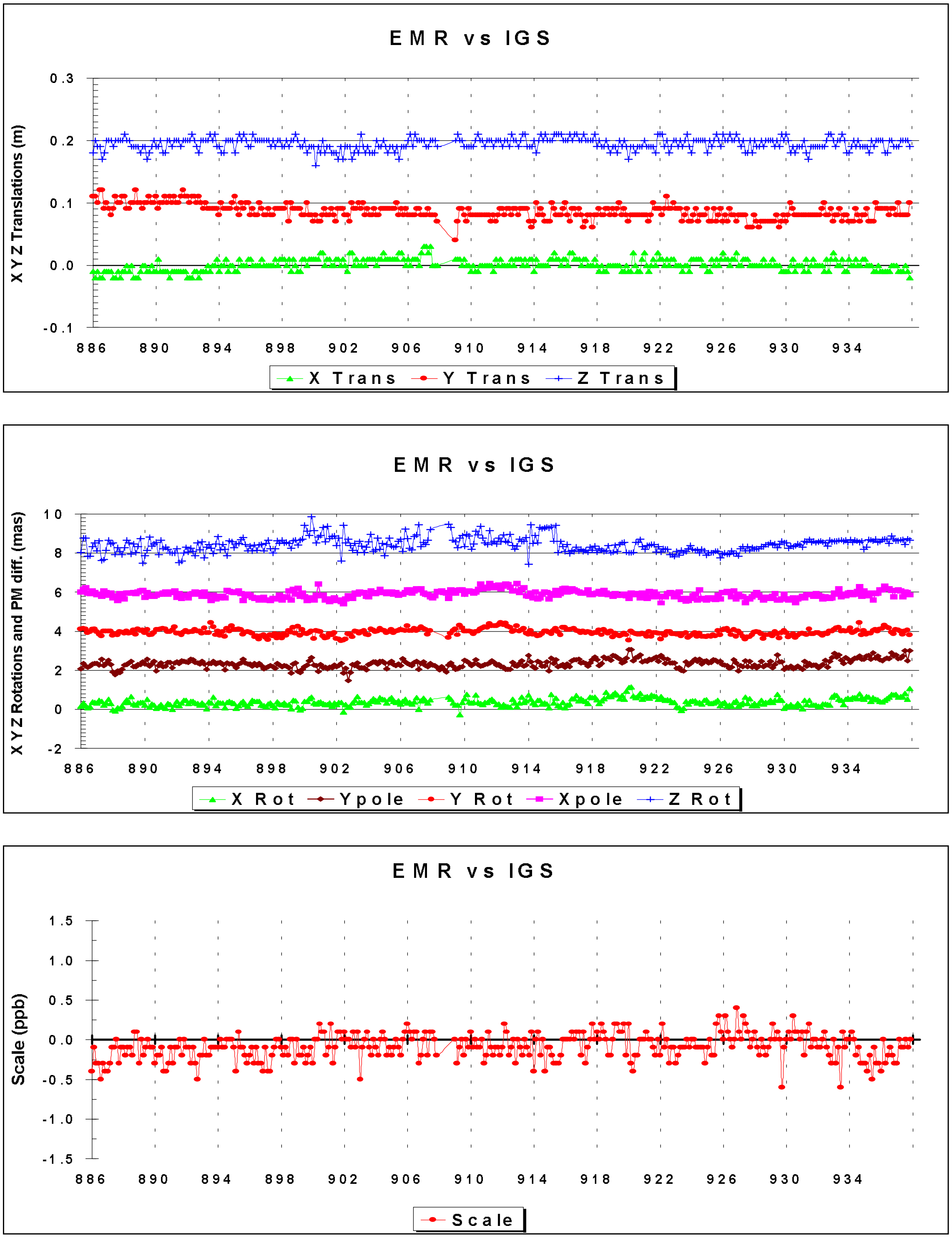


Figure 19. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

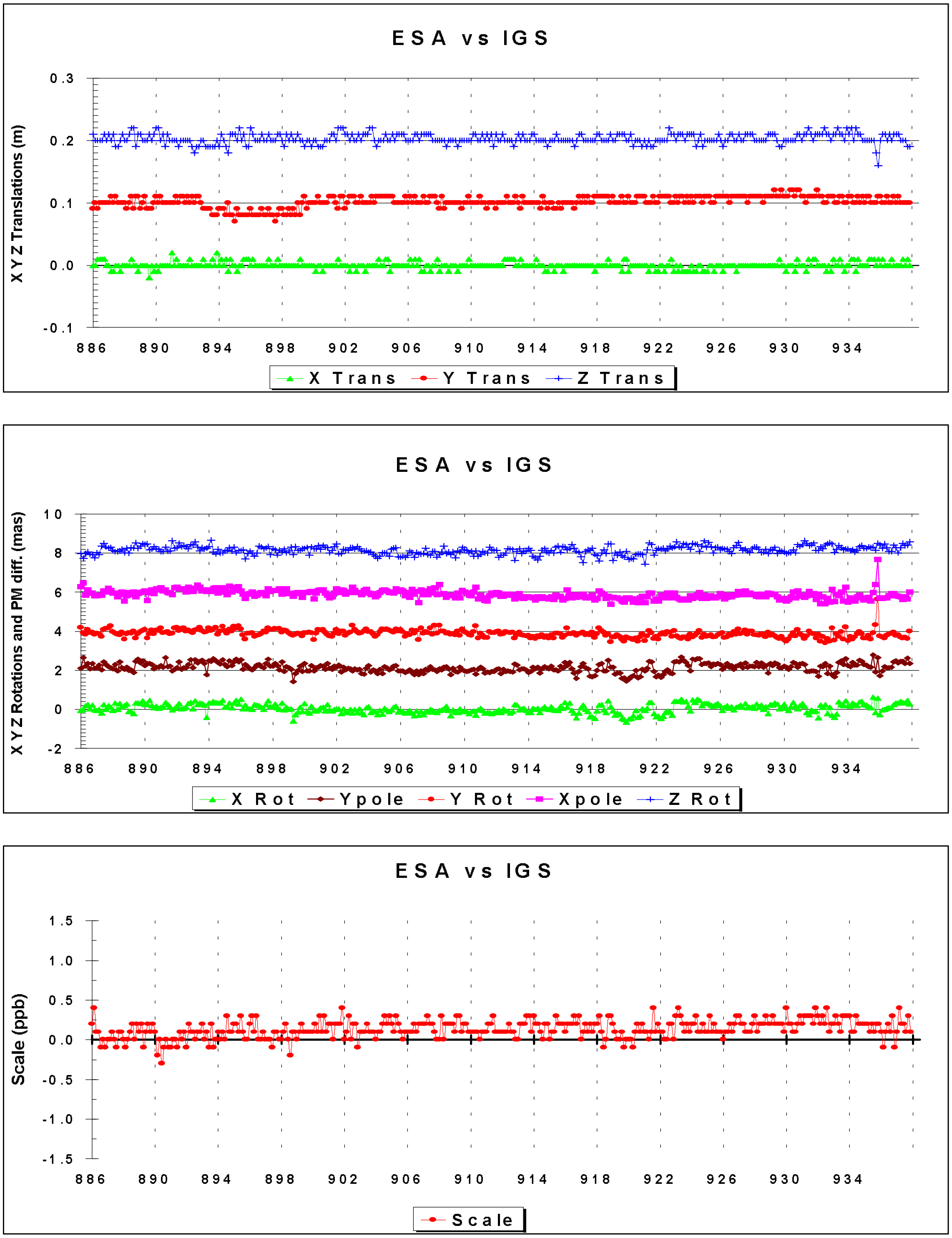
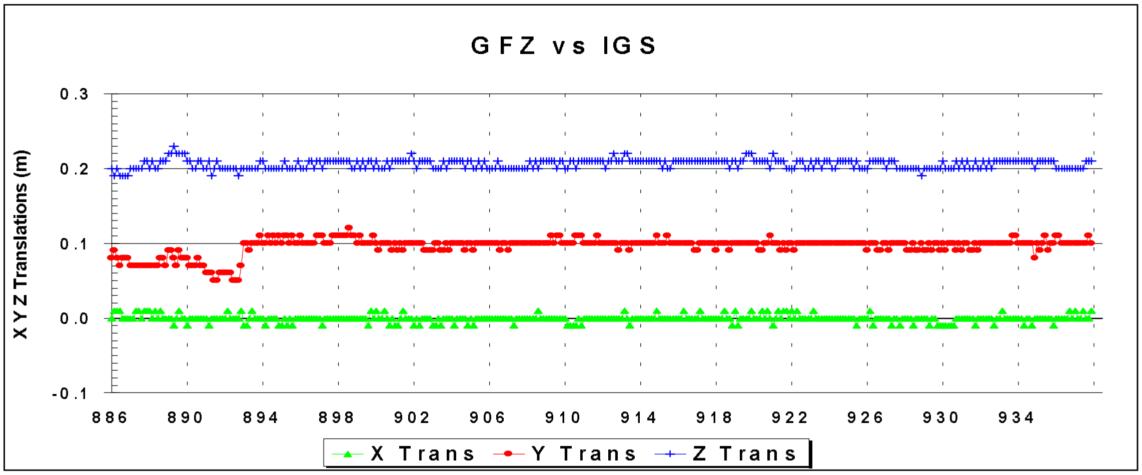
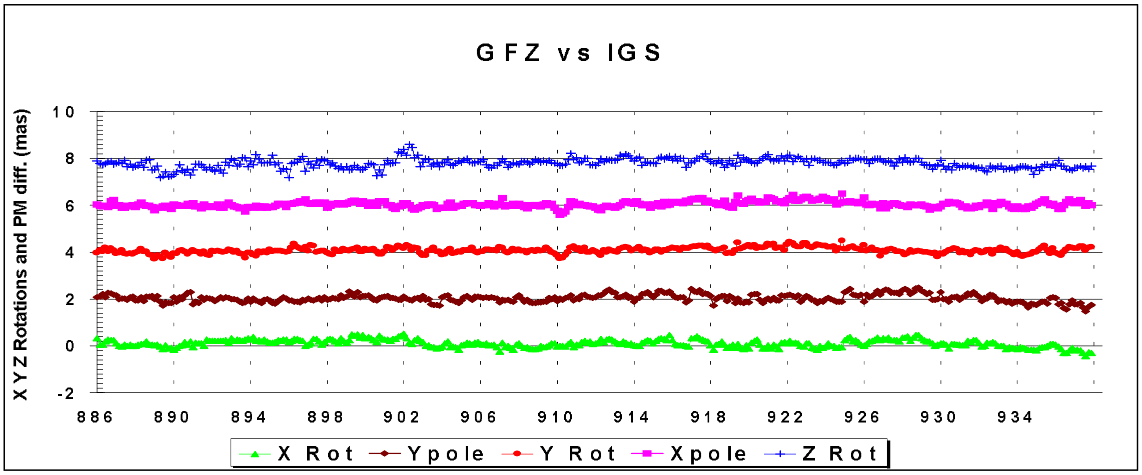


Figure 20. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)





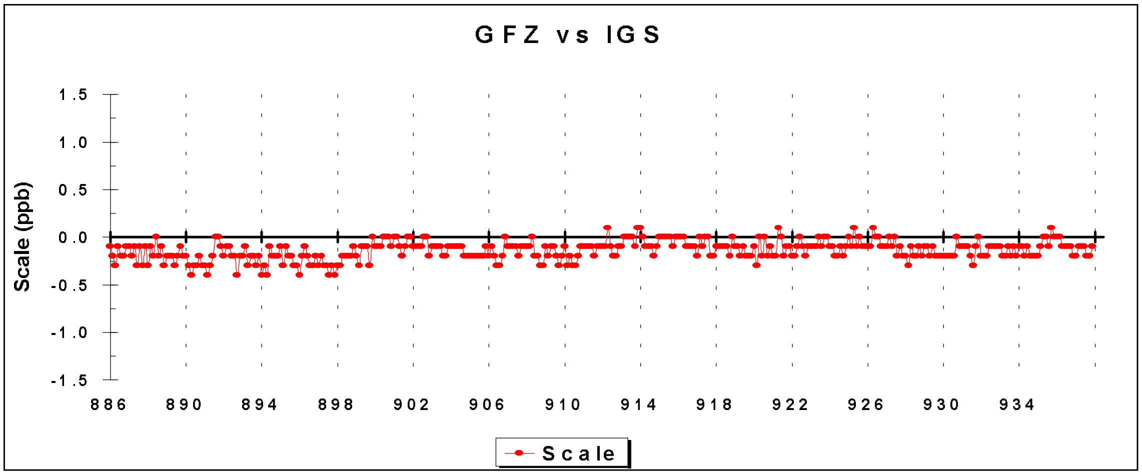


Figure 21. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

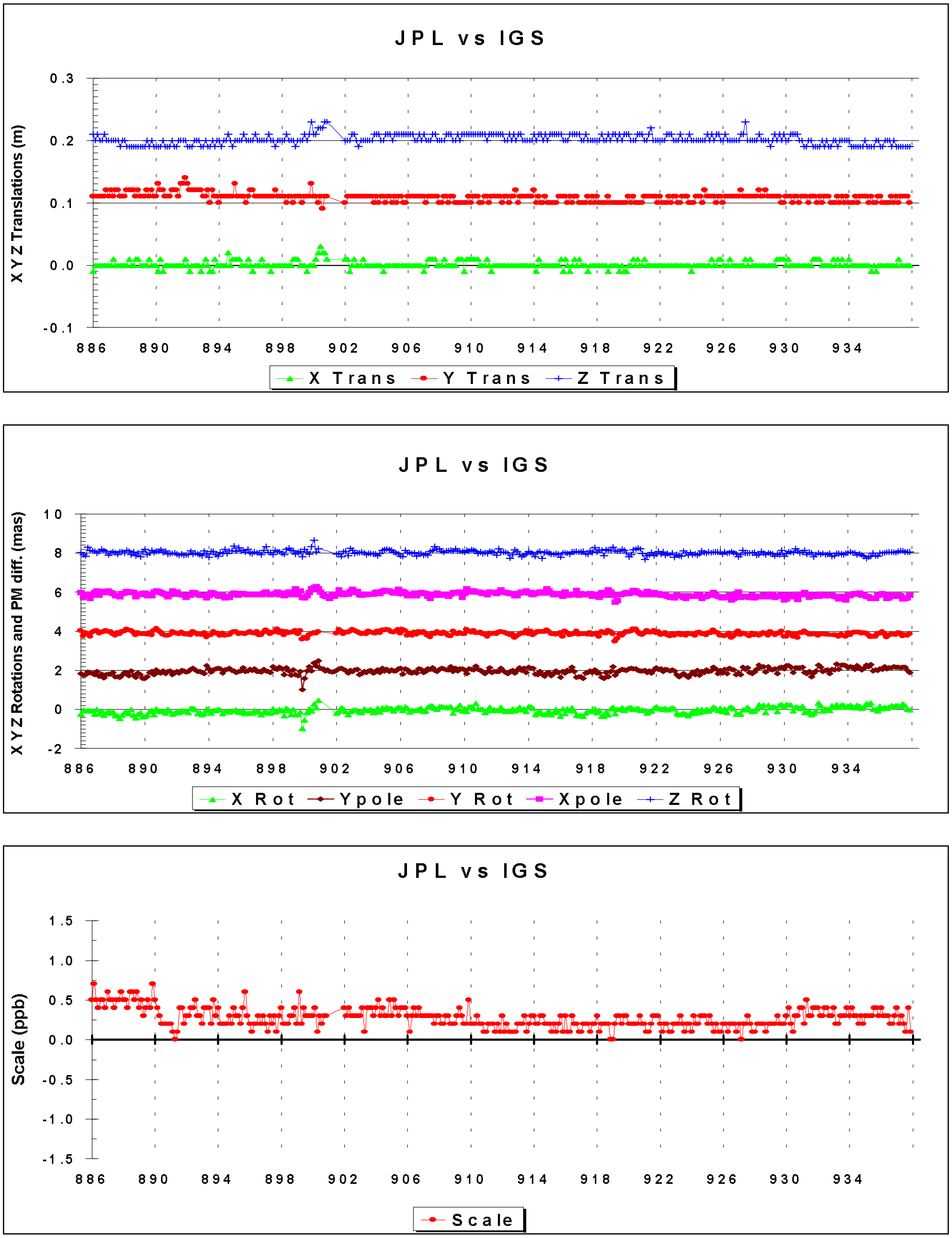


Figure 22. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

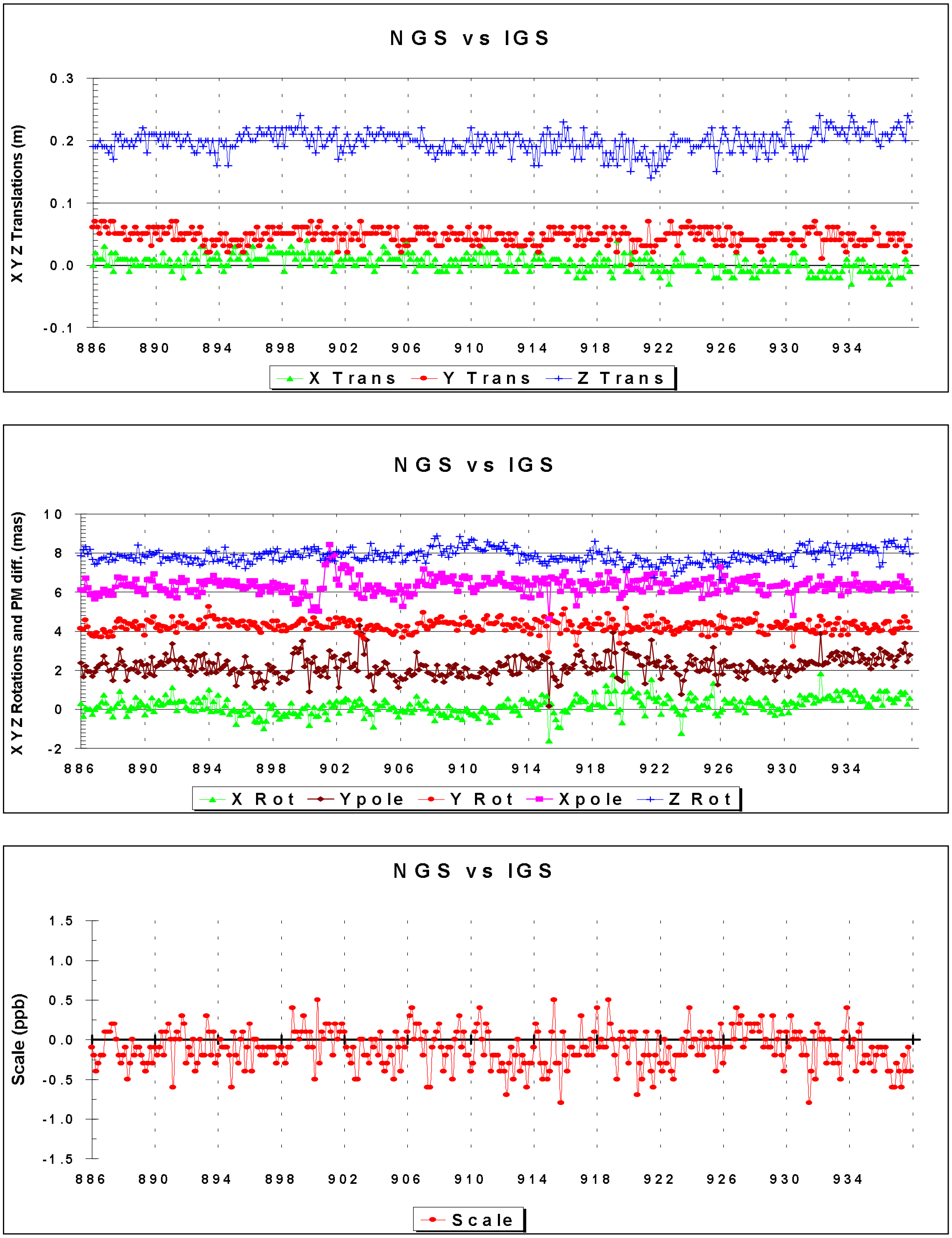
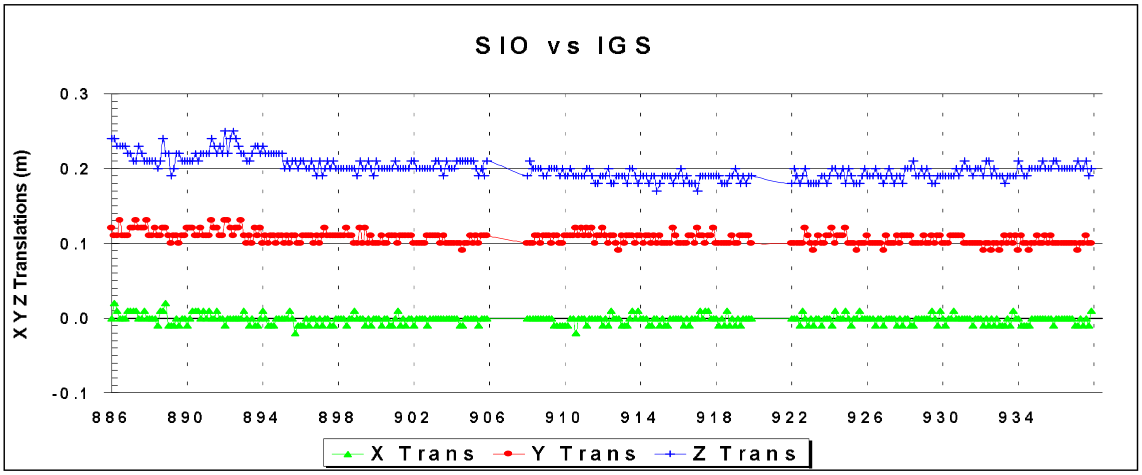
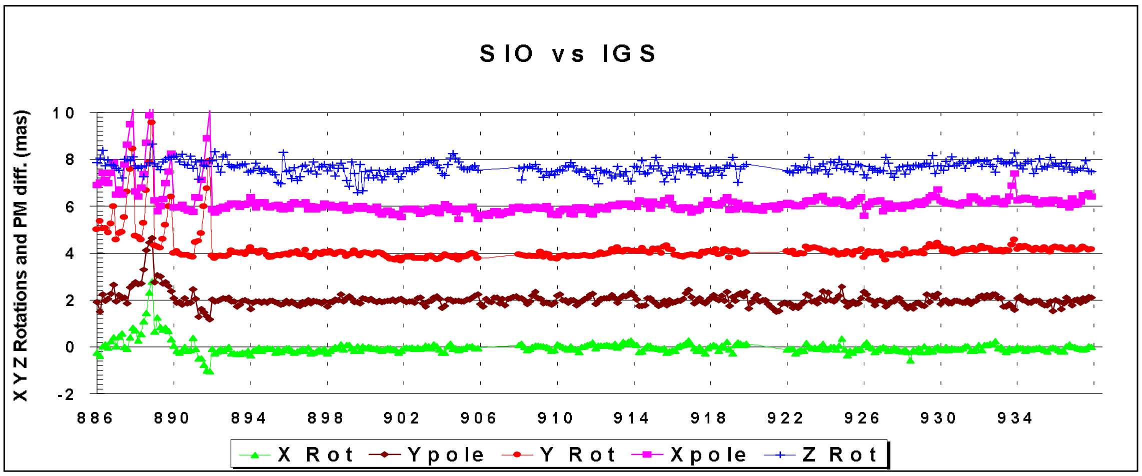


Figure 23. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)





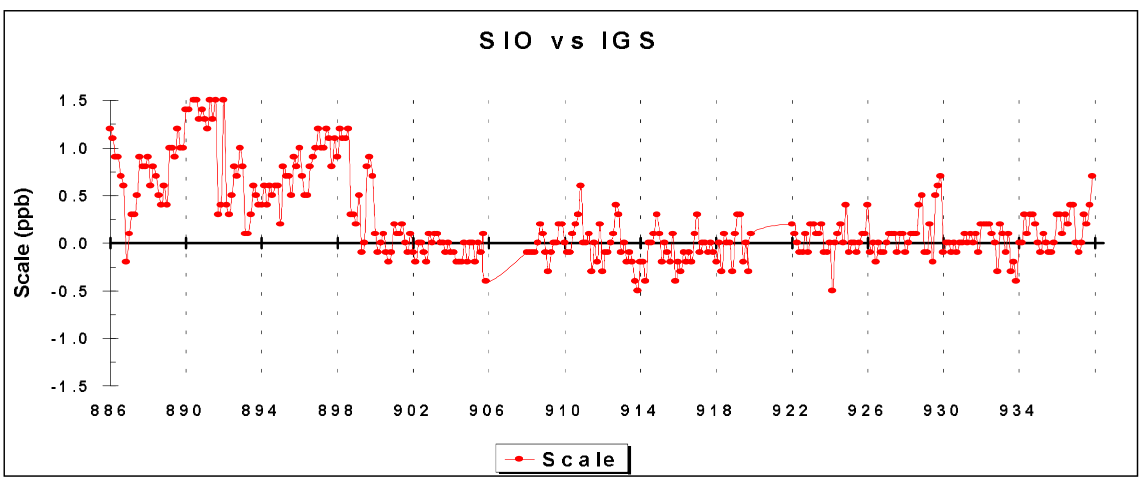


Figure 24. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

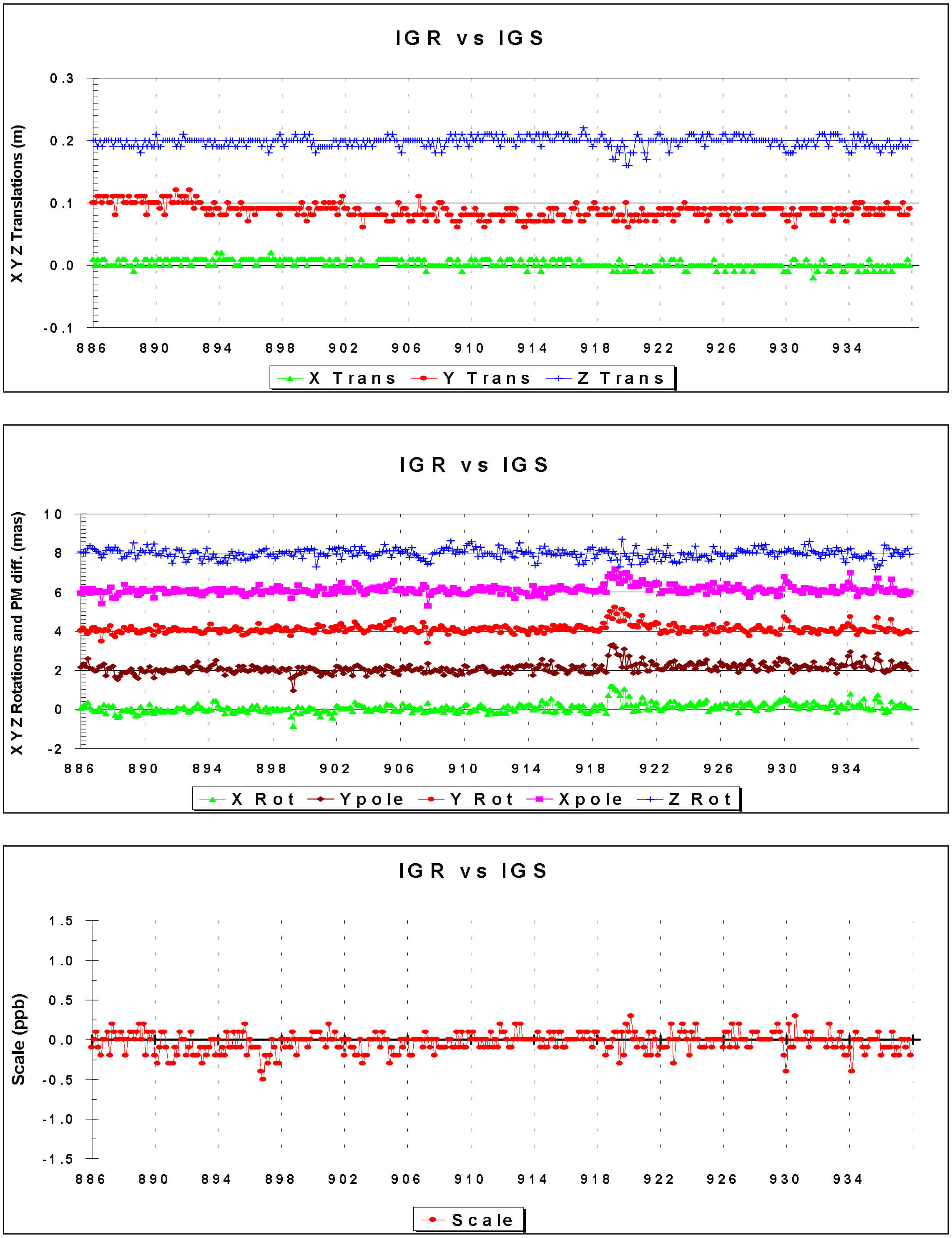


Figure 25. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

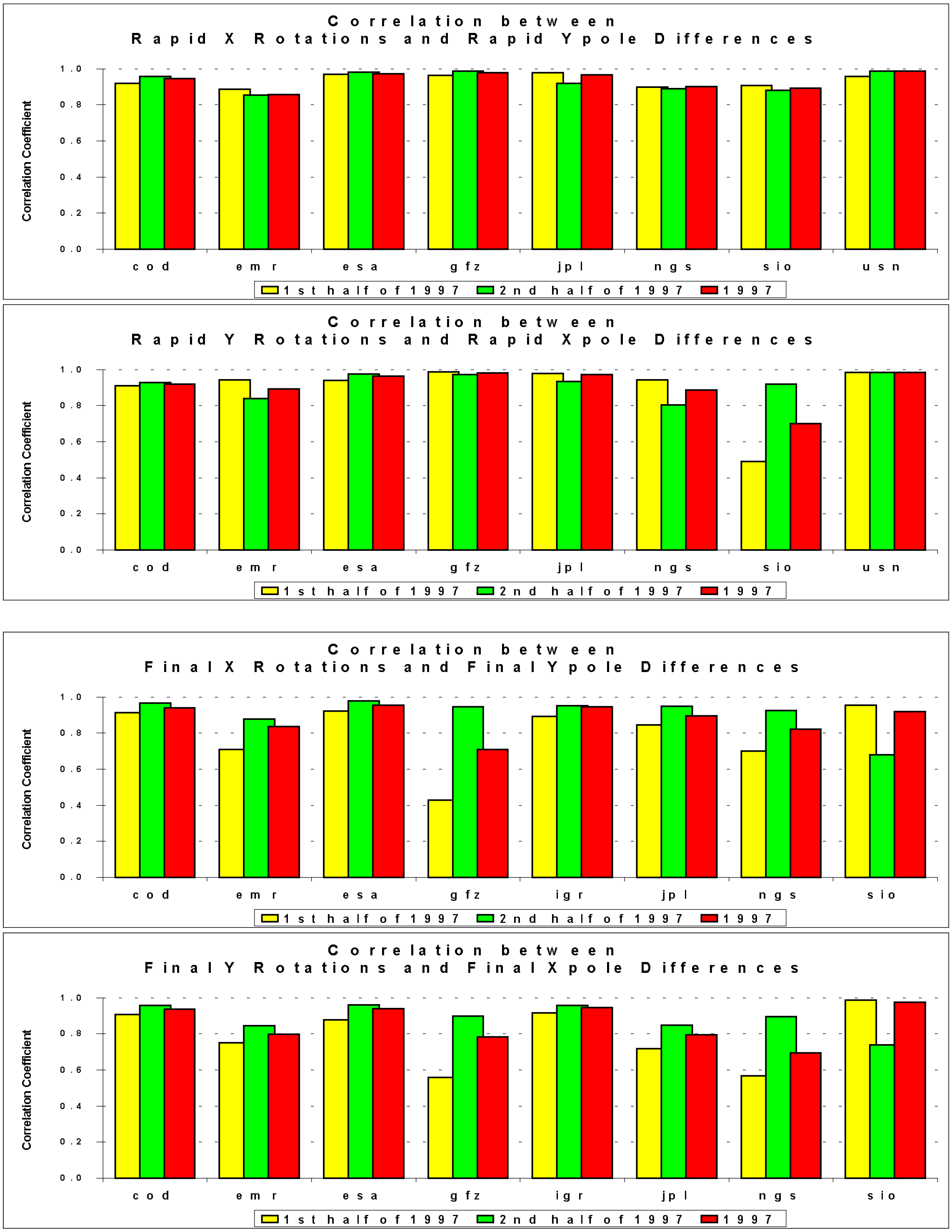
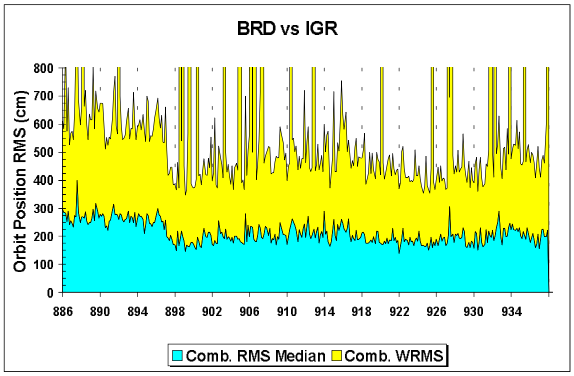
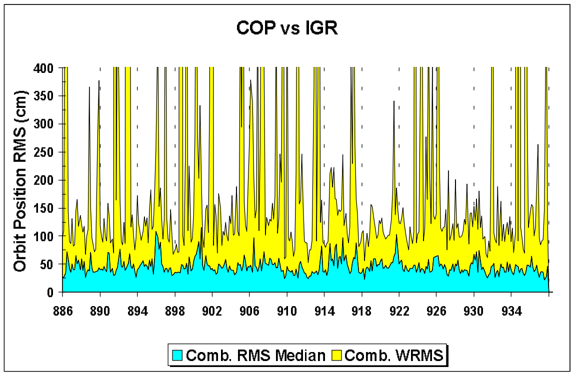
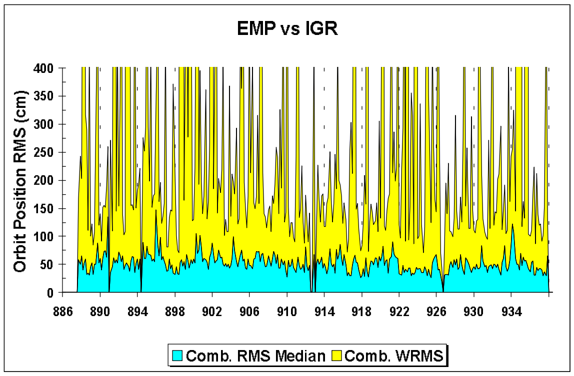
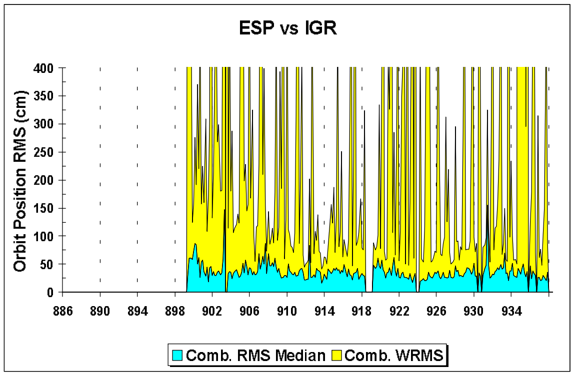


Figure 26. 1997 correlation coefficients between AC X/Y rotations and AC PM differences in y/x with respect to IGR/IGS.


BRD vs IGR
Orbit Position RMS (cm)
800
700
600
500
400
300
200
100
0
886
890
894
898
902
906
910
914
918
922
926
930
934
Comb. RMS Median
Comb. WRMS


COP vs IGR
Orbit Position RMS (cm)
400
350
300
250
200
150
100
50
0
886
890
894
898
902
906
910
914
918
922
926
930
934
Comb. RMS Median
Comb. WRMS


EMP vs IGR
Orbit Position RMS (cm)
400
350
300
250
200
150
100
50
0
886
890
894
898
902
906
910
914
918
922
926
930
934
Comb. RMS Median
Comb. WRMS


ESP vs IGR
Orbit Position RMS (cm)
400
350
300
250
200
150
100
50
0
886
890
894
898
902
906
910
914
918
922
926
930
934
Comb. RMS Median
Comb. WRMS

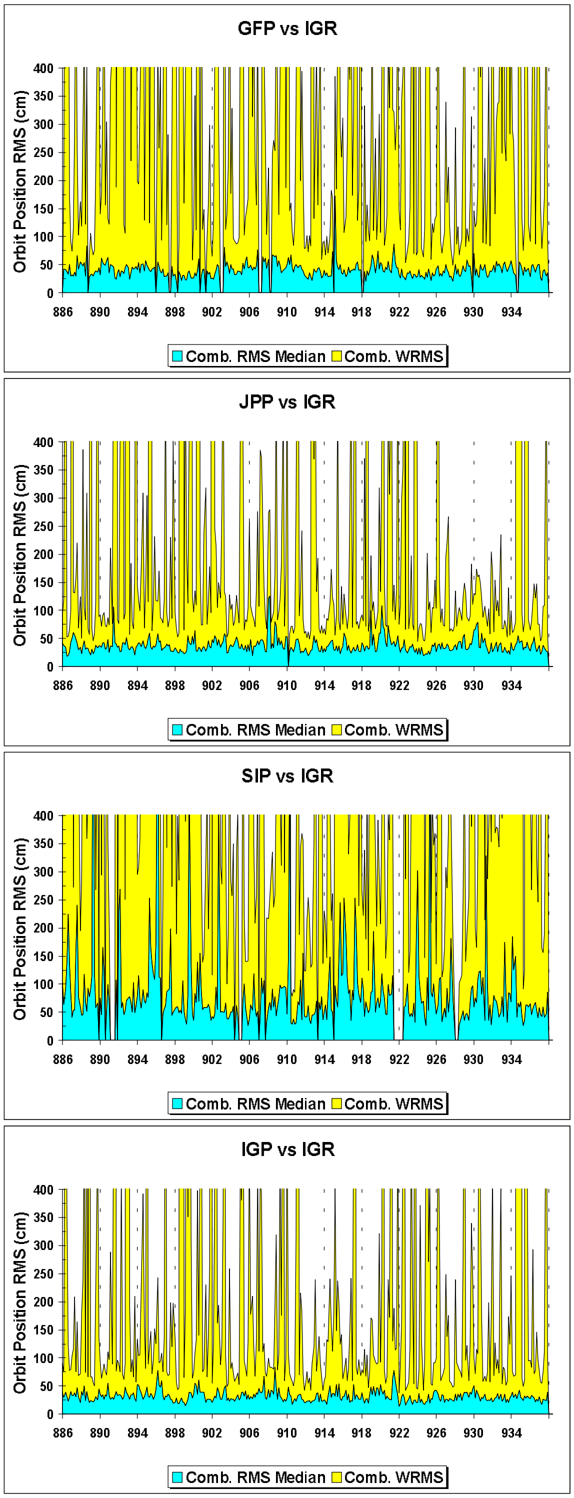

GFP vs IGR
JPP vs IGR
SIP vs IGR
IGP vs IGR
Orbit Position RMS (cm)
0
50
100
150
200
250
300
350
400
886
890
894
898
902
906
910
914
918
922
926
930
934
Comb. RMS Median
Comb. WRMS

Figure 27.

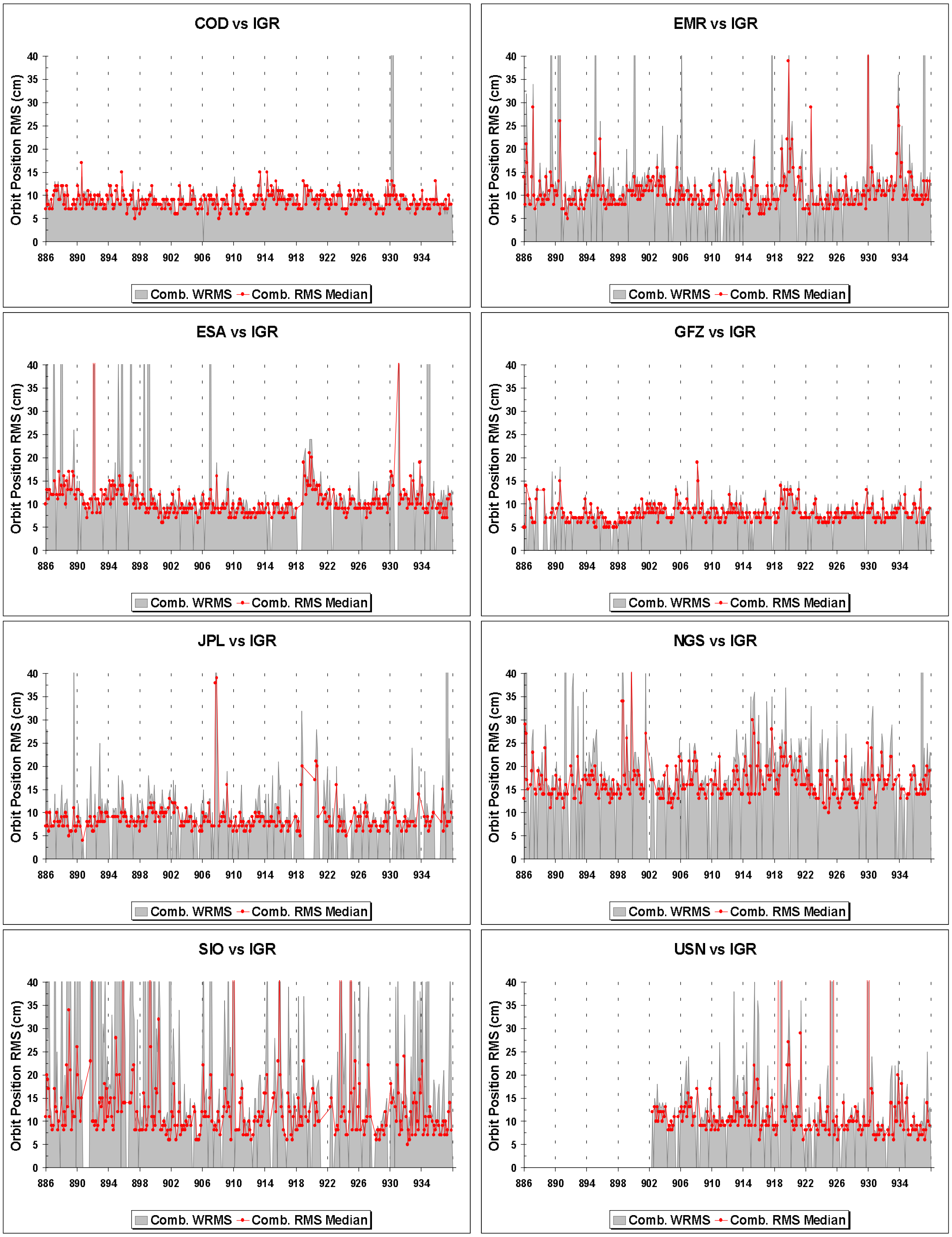

COD vs IGR
EMR vs IGR
ESA vs IGR
GFZ vs IGR
JPL vs IGR
NGS vs IGR
SIO vs IGR
USN vs IGR
Orbit Position RMS (cm)
0
5
10
15
20
25
30
35
40
886
890
894
898
902
906
910
914
918
922
926
930
934
Comb. WRMS
Comb. RMS Median

Figure 28.

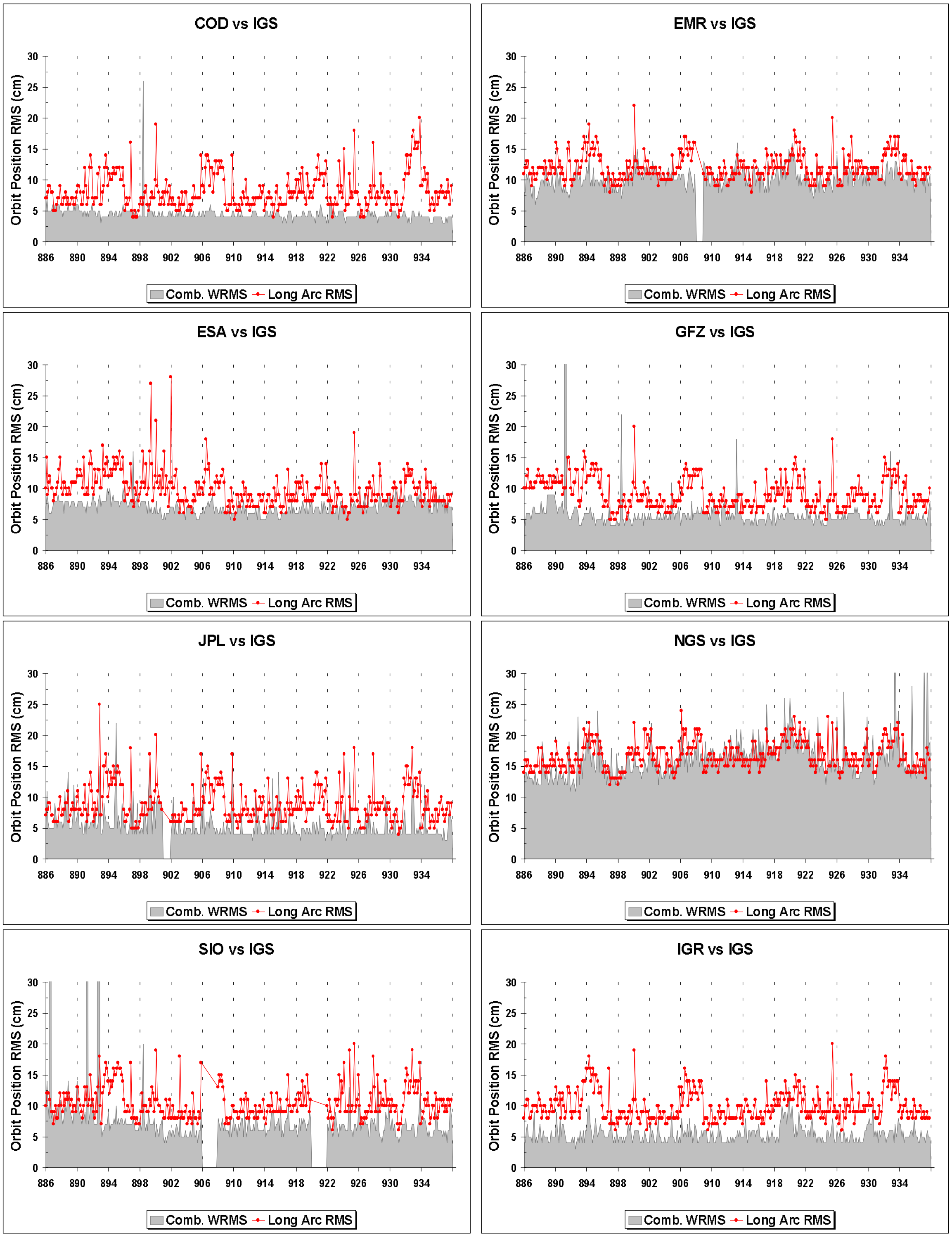

COD vs IGS
EMR vs IGS
ESA vs IGS
GFZ vs IGS
JPL vs IGS
NGS vs IGS
SIO vs IGS
IGR vs IGS
Orbit Position RMS (cm)
0
5
10
15
20
25
30
886
890
894
898
902
906
910
914
918
922
926
930
934
Comb. WRMS
Long Arc RMS

Figure 29.

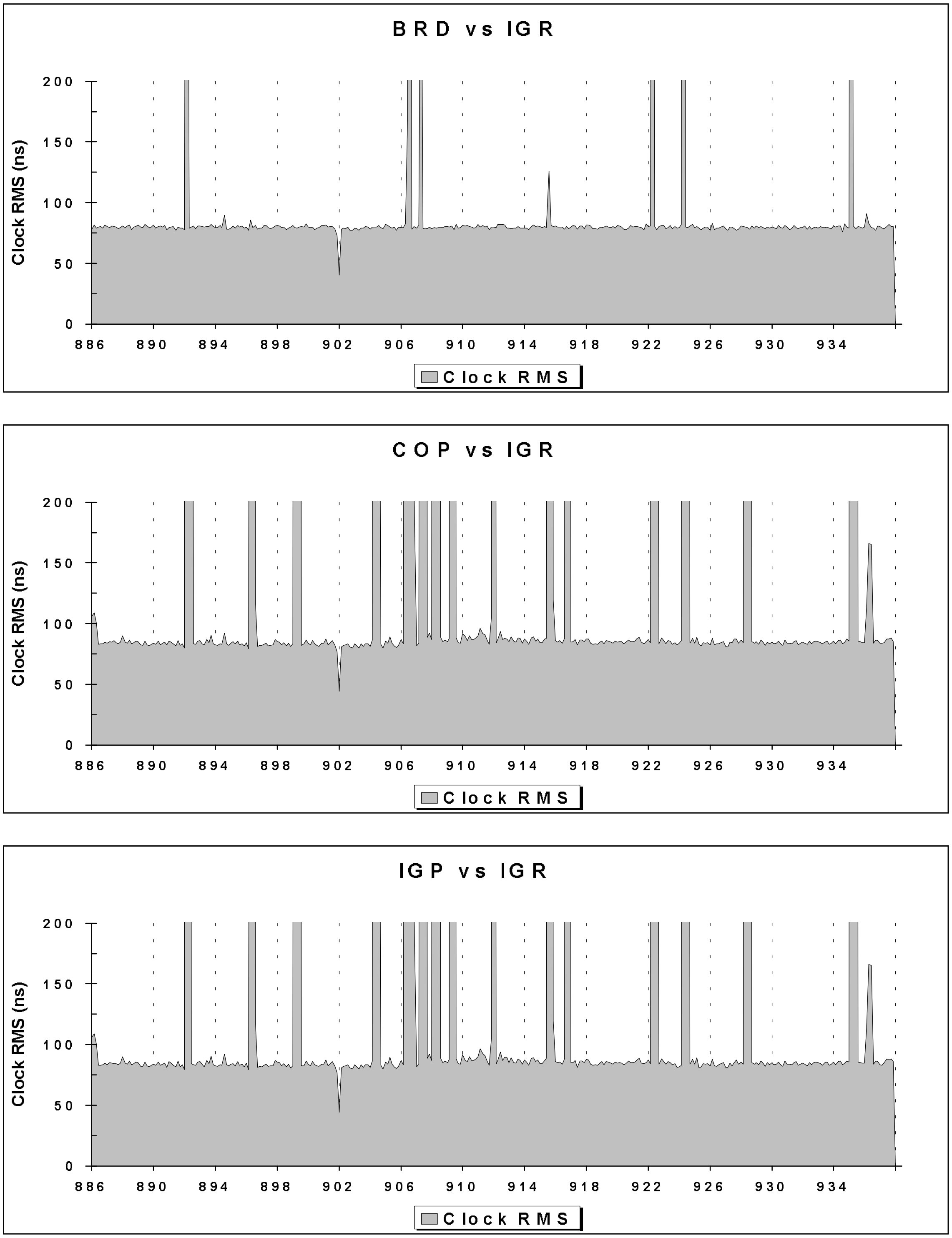
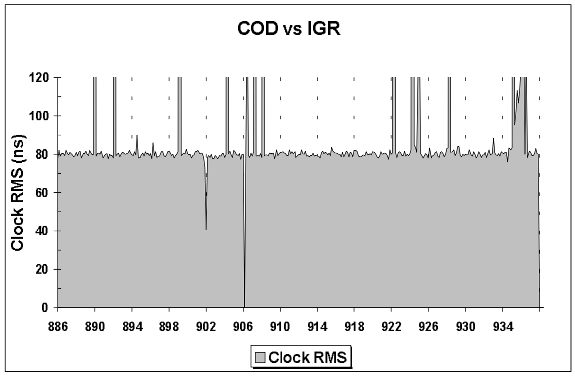
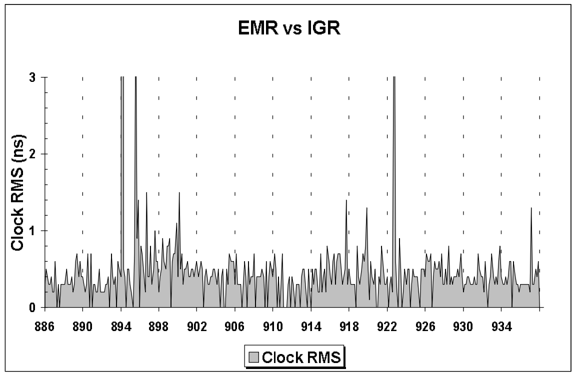
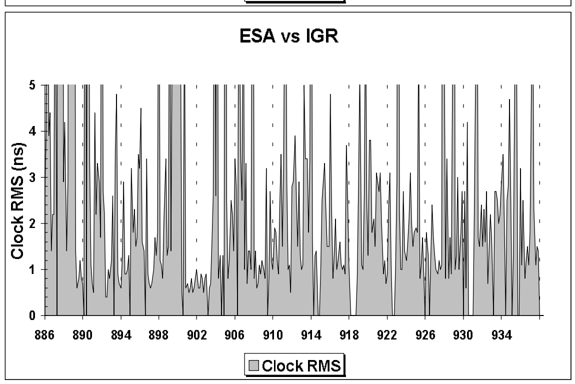
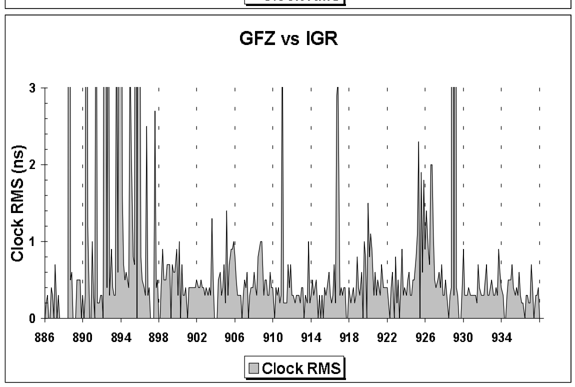

BRD vs IGR
Clock RMS (ns)
200
150
100
50
0
886
890
894
898
902
906
910
914
918
922
926
930
934
Clock RMS
COP vs IGR
Clock RMS (ns)
200
150
100
50
0
886
890
894
898
902
906
910
914
918
922
926
930
934
Clock RMS
IGP vs IGR
Clock RMS (ns)
200
150
100
50
0
886
890
894
898
902
906
910
914
918
922
926
930
934
Clock RMS

Figure 30.


COD vs IGR
Clock RMS (ns)
120
100
80
60
40
20
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS


EMR vs IGR
Clock RMS (ns)
3
2
1
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS


ESA vs IGR
Clock RMS (ns)
5
4
3
2
1
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS


GFZ vs IGR
Clock RMS (ns)
3
2
1
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS

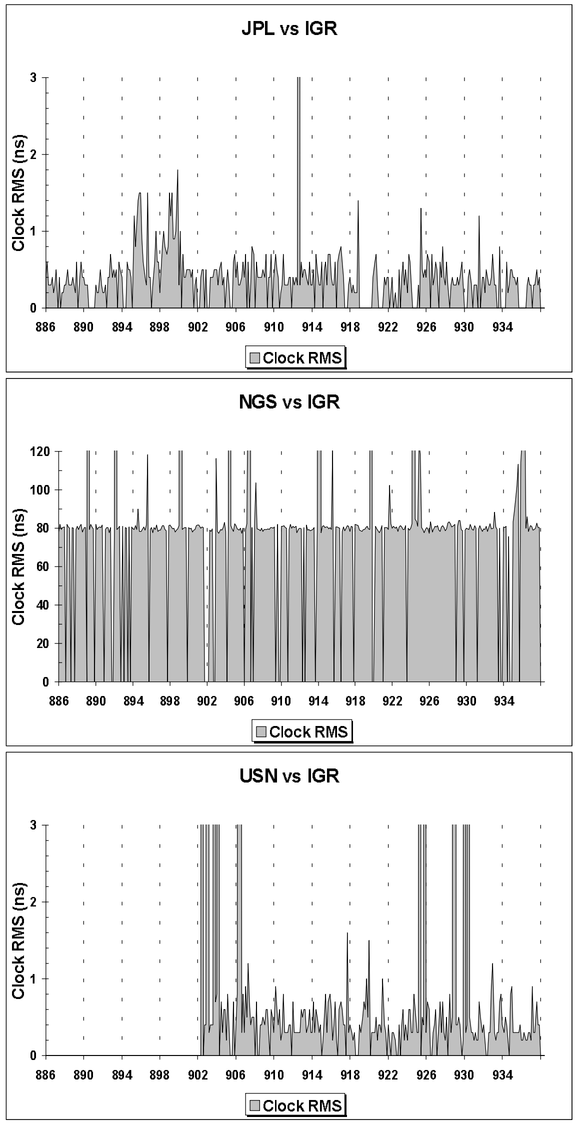
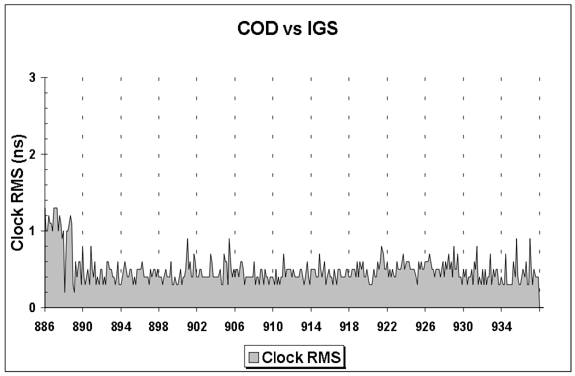
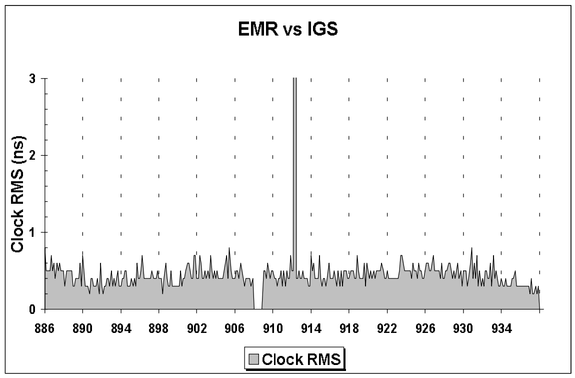
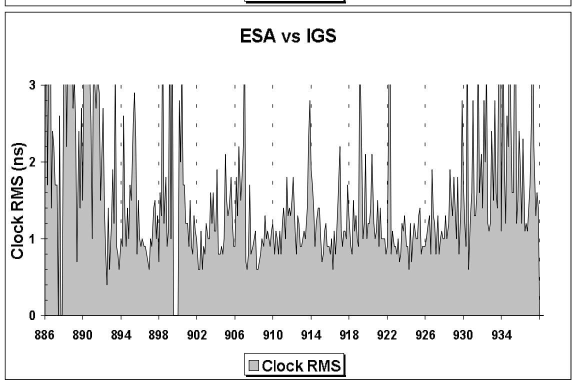
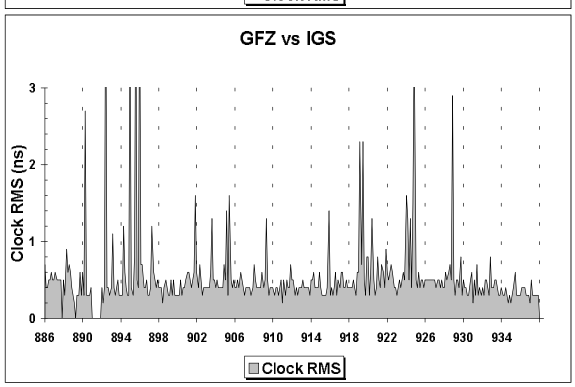

JPL vs IGR
Clock RMS (ns)
3
2
1
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS
NGS vs IGR
Clock RMS (ns)
120
100
80
60
40
20
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS
USN vs IGR
Clock RMS (ns)
3
2
1
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS

Figure 31.


COD vs IGS
Clock RMS (ns)
0
1
2
3
886
890
894
898
902
906
910
914
918
922
926
930
934
Clock RMS


EMR vs IGS
Clock RMS (ns)
0
1
2
3
886
890
894
898
902
906
910
914
918
922
926
930
934
Clock RMS


ESA vs IGS
Clock RMS (ns)
0
1
2
3
886
890
894
898
902
906
910
914
918
922
926
930
934
Clock RMS


GFZ vs IGS
Clock RMS (ns)
0
1
2
3
886
890
894
898
902
906
910
914
918
922
926
930
934
Clock RMS

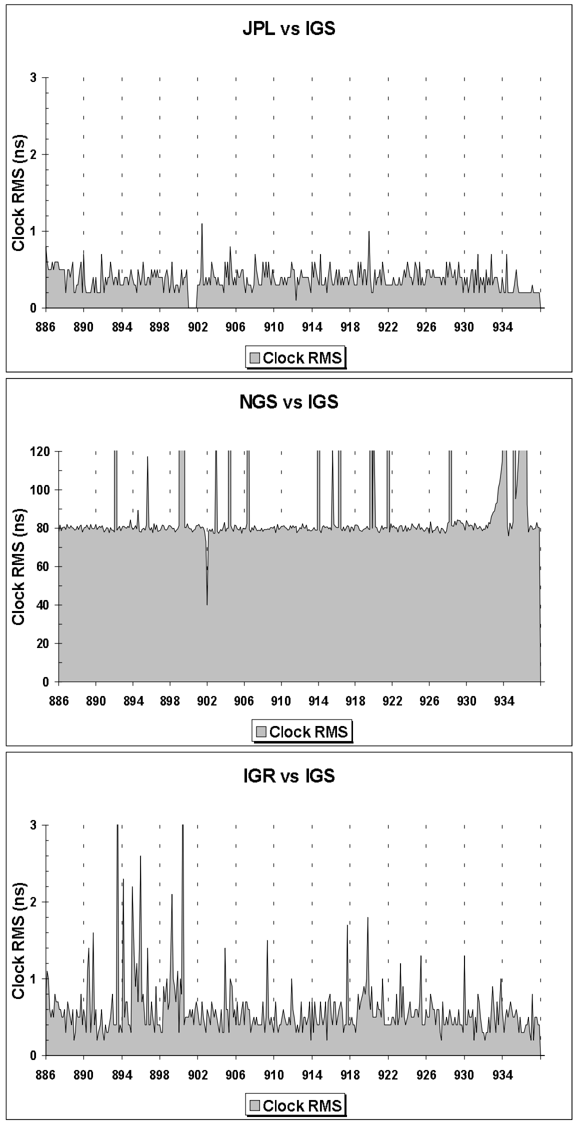
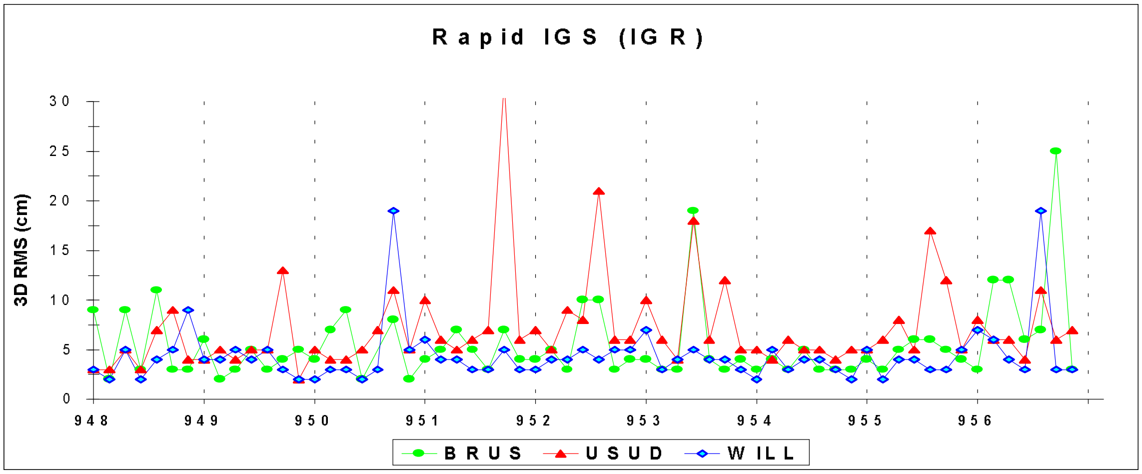

JPL vs IGS
Clock RMS (ns)
3
2
1
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS
NGS vs IGS
Clock RMS (ns)
120
100
80
60
40
20
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS
IGR vs IGS
Clock RMS (ns)
3
2
1
0
886 890 894 898 902 906 910 914 918 922 926 930 934
Clock RMS

Figure 32.



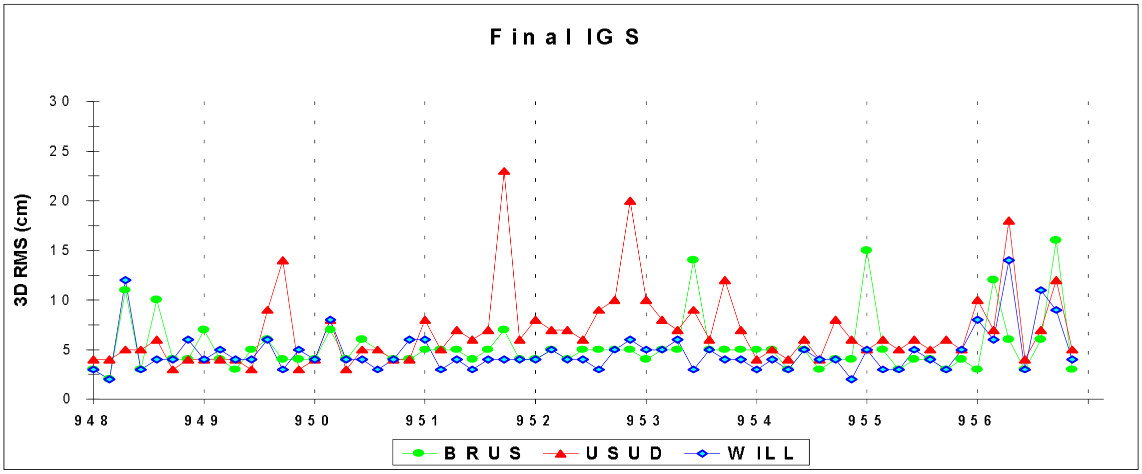


Figure 33. Precise Point Positioning (Navigation) using phase data and JPL's GIPSY-OASIS II software. The top graphic shows the 3D-RMS for the Rapid IGS (IGR) while the bottom one shows the 3D-RMS for the Final IGS.