2001/2002 Analysis Coordinator Report

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Introduction

This report complements the Analysis Activities Report given in the IGS Annual Report 2001/2002 (Weber, 2003). A summary of the most important model changes and IGS Analysis Activities in 2001/2002 will be presented.

IGS product quality

The primary objective of the IGS is to provide a Reference System for a wide variety of GPS applications. To fulfil this role the IGS produces a large number of different combined products which constitute the practical realization of the IGS Reference System. Table 1 shows the estimated quality of the provided data sets at the end of year 2002.

Table 1: Quality of the IGS products as of December 2002
(for details see http://igscb.jpl.nasa.gov/components/prods.html)

Products / Delay	Ultra-Rapid/ Real Time	Rapid/ 17 hours	Final/ 13 days	Units
Orbit (GPS)	15.0	5.0	3.0	cm
Satellite Clocks	5.0 (predicted)	0.1	0.05	ns
Station Clocks		0.1	0.05	ns
Orbit (GLONASS)	----	----	25.0	cm
Polar Motion		30.0	0.05	mas
LOD			20.0	µs/d
Stations h/v			3.0/6.0	mm
Troposphere			4.0	mm ZPD

IGS Final Orbits

Figure 1 shows the weighted orbit RMS (WRMS) of the Final Analysis Centre solutions with respect to the combined IGS final orbit products from 1994 until end of 2002. The graphic nicely demonstrates past and still ongoing improvements in modelling satellite orbits. Most Analysis Centres and also the IGS rapid orbits (IGR) have reached the 3-6 centimeter precision level (Table 2). Similar levels of accuracy are indicated by the IGS 7-day arc orbit analysis and by comparisons with satellite laser ranging measurements to the GPS satellites PRN 5 and PRN 6.

Table 2: Yearly average weighted orbit RMS (cm) of the Final Analysis Center orbit submissions and the IGS Rapid (IGR) orbit solution with respect to the IGS final orbits

Year	COD	EMR	ESA	GFZ	JPL	NGS	SIO	IGR
Final 2002	2	4	6	2	3	8	5	2

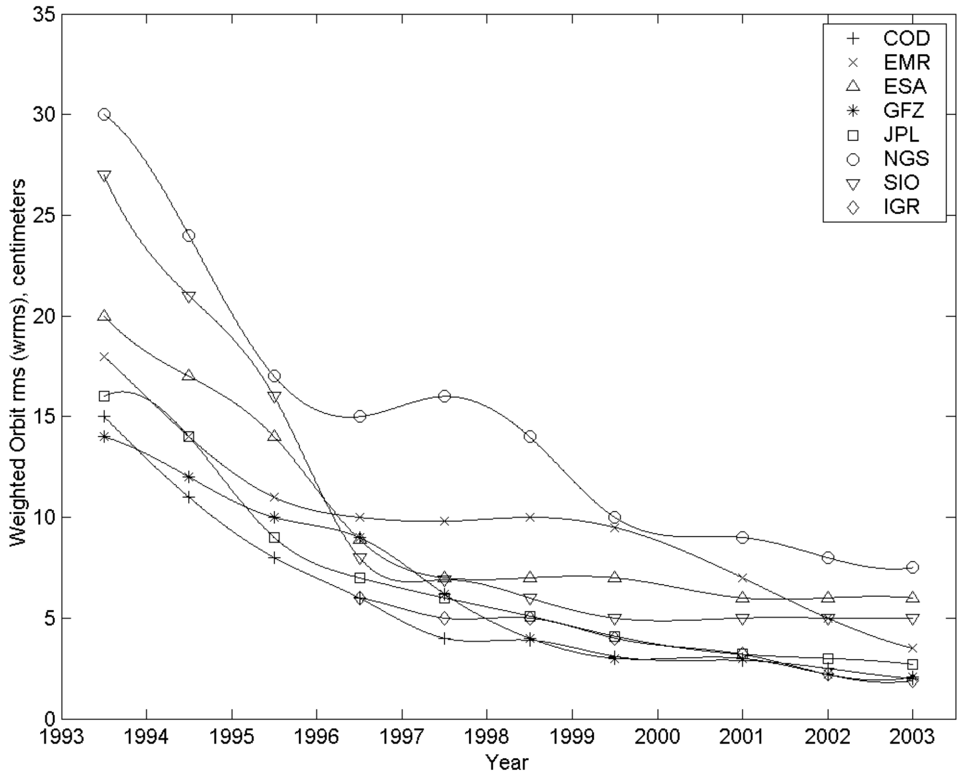

Figure 1: Weighted orbit RMS (WRMS) of the Analysis Center and the IGS Rapid (IGR) orbit solutions with respect to the IGS final orbits; WRMS values were smoothed for graphical representation

Detailed Information concerning quality and availability of Precise Glonass orbits is provided in the report of the International GLONASS Service – Pilot Project (this Volume).

IGS Rapid Orbits

The IGR-orbit is routinely compared to the IGS orbit. Although not entering with any weight in the Finals orbit combination the IGR orbit turns out to be as close to the IGS orbit as the best final AC solutions or even closer (1-2cm; see Table 2).

Table 3: Yearly average weighted orbit RMS (cm) of the Rapid Analysis Center submissions with respect to the IGS Rapid orbit combination.

Year	COD	EMR	ESA	GFZ	JPL	NGS	SIO	USN
Rapid 2002	3	5	8	5	4	8	6	3

Table 3, along with Figure 2, show the weighted RMS (mm) of the individual AC solutions with respect to the IGS Rapid orbit in 2002. For display purposes the values of the Rapid Combination summaries are smoothed using a sliding 7 day window. The orbit consistency ranges between 3-8 cm, which are quite small numbers having in mind the latency of only 17 hours causing a relatively low amount of available tracking data.

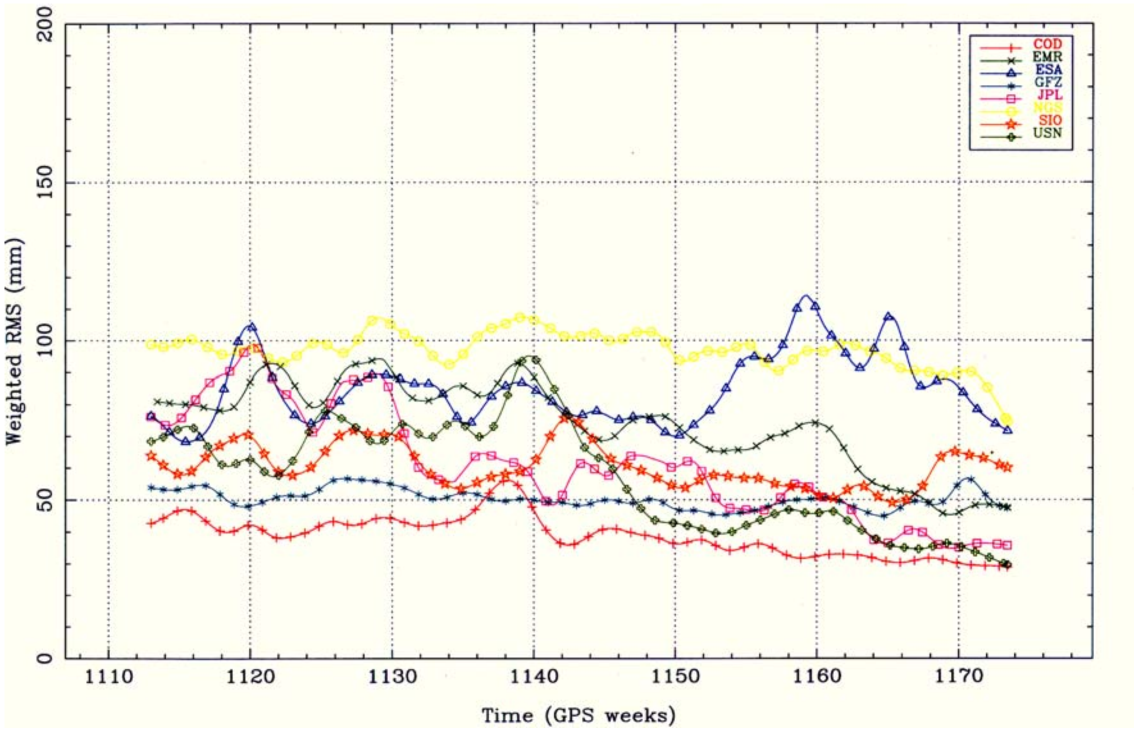

Figure 2: Weighted orbit RMS (WRMS) of the Analysis Center Rapid orbit solutions and the IGR orbit solutions with respect to the IGS final orbits (mid 2001 until mid 2002)

IGS Clock Combination

The consistency of the final AC clock solutions is at the 0.05 ns level, the consistency of the rapid clock solutions slightly better than 0.1 ns (see Figure 3). The combined final and rapid solutions provide satellite and station clock information with a temporal spacing of 5 minutes. An even higher resolution (30 seconds) is recommended, and foreseen to be provided in the near future. This will put a remarkable additional computation load at the ACs.

The basic clock combination proofed to be a very robust process. After combination the IGS combined clock products are aligned to GPS time (broadcast satellite clock corrections) on a daily basis. This procedure sometimes fails due to jumps of the reference clock of individual AC's. Moreover the alignment introduces significant daily discontinuity errors up to a few nanoseconds. To mitigate the problem the IGS clock products will be aligned to the UTC time scale in the near future (see Senior et al., 2001)

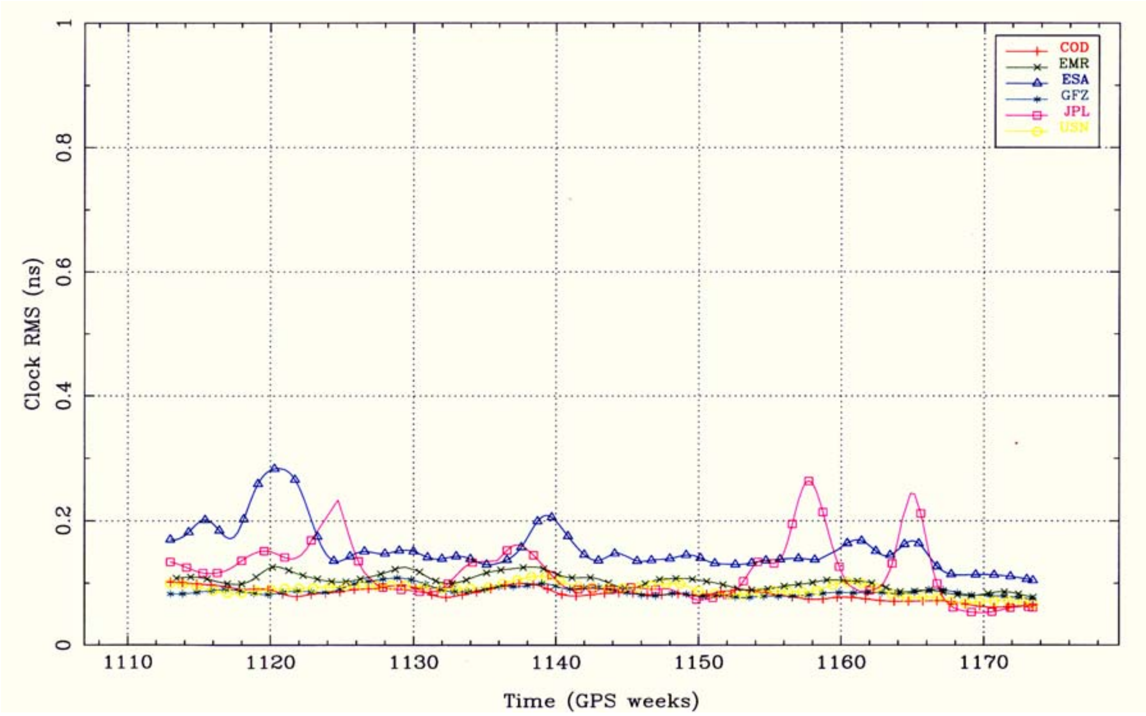

Figure 3: Clock RMS (ns) of the individual AC satellite clock solutions with respect to the IGS Rapid clocks (mid 2001 until mid 2002).

Reference Frame

Since December 2001 (GPS-Week 1143) all IGS products are based consistently on the IGS Reference Frame realization (IGS00) of the ITRF2000. To perform this task the unconstrained weekly combined IGS-SINEX solution of station coordinates/velocities and ERP's is aligned by minimum datum constraints to IGS00, based on a list of 54 reference stations with high quality positions/velocities in ITRF2000. Previous to the combination also the individual orbit solutions are rotated by means of a spatial similarity transformation to this common frame. IGS reference frame products are available in SINEX format and issued by the IGS Reference Frame Coordinator on a weekly basis. Detailed information can be obtained from (Ferland, 2001) or from the weekly IGS SINEX Combination Reports (e.g. Ferland, Hutchison, 2001).

Earth Rotation Parameters

Although the IGS final combination establishes another weighted erp-file based on orbit quality, the 'official' IGS pole series stem from the weekly SINEX combination performed at NRCan. IERS comparisons show an agreement between IGS and IVS solutions at the 0.1mas level for polar motion (PM) and 0.1ms for Length of Day (LOD). It has to be stated that Bulletin B erp-series are dominated by VLBI although there are differences at the same level (0.1mas,0.1ms) between IVS solutions using different observation networks. IGR erp-series be given a heavy weight in the Bulletin A combination and are therefore close (0.05mas PM, 0.1ms LOD) to the Bulletin series. An IERS recommendation, passed at the IERS Workshop in Munich (November 2002), encourages all IGS AC's to provide in addition to polar motion and LOD also nutation rate series.

Atmosphere Sounding Products

Detailed Information concerning quality and availability of IGS Atmosphere Sounding Products is provided in the reports of the relevant Working Groups (this Volume).

IGS Ultra Rapid Products

In October 1999 the GFZ Analysis Centre provided the first ultra rapid products. These products, delivered every 12 hours (two times per 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 generation of a combined 'ultra-rapid' product (IGU) has started in March 2000 based on contributions from up-to six different Analysis Centres. Currently IGU orbits are used in an increasing number of applications, e.g. for the derivation of ground-based GPS meteorological parameters used in numerical weather prediction or in regional GNSS Reference Network solutions used for RTK surveying.

IGU Orbits

The orbit consistency level, characterized by the weighted orbit RMS (WRMS) of the observed part of ultra rapid Analysis Center solutions with respect to (w.r.t.) the combined IGS Ultra-Rapid Orbit (IGU) ranges from 10-25 centimetres (see Figure 4). The predicted part of the IGU compares to the IGR orbit at the 30 cm level.

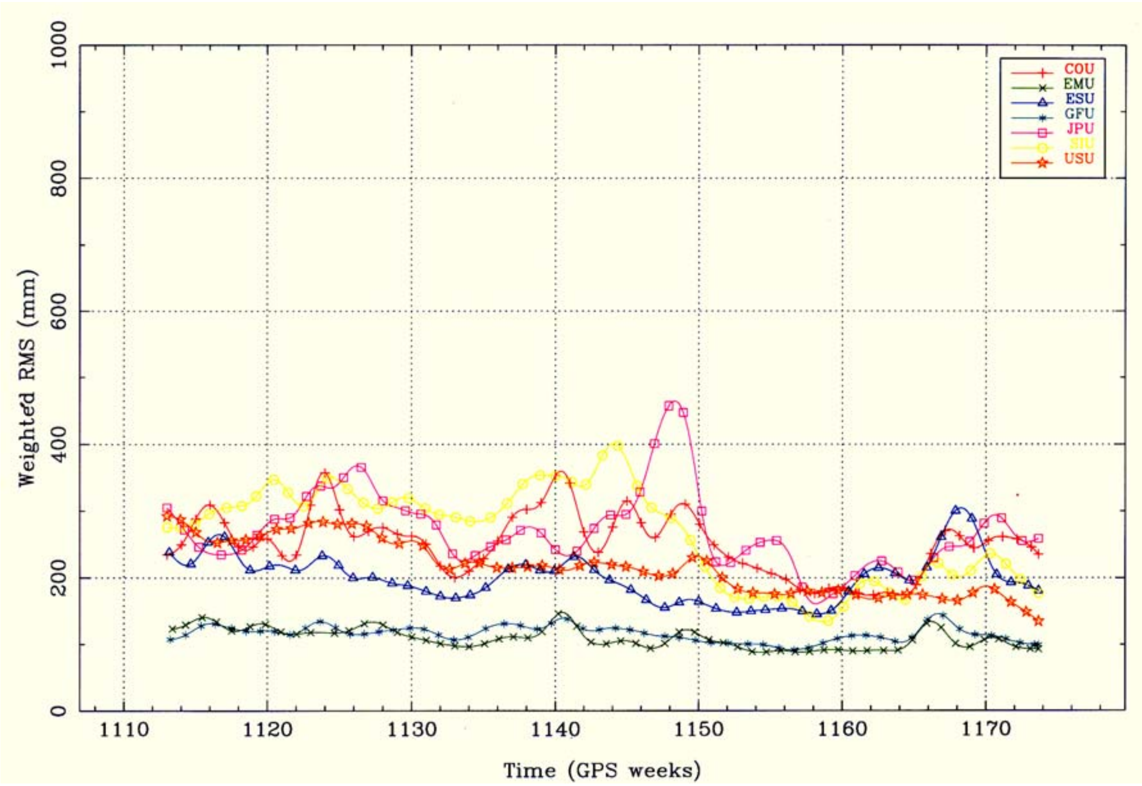

Figure 4: Weighted orbit RMS (WRMS) of the Analysis Center Ultra Rapid orbit solutions with respect to the IGS Rapid orbits (mid 2001 until mid 2002)

IGU Satellite Clock Corrections

As mentioned above, the IGU orbits and clock corrections are the result of a weighted averaging process, currently based on individual submissions of 6 IGS Analysis Centres. Most of these solutions contain 24 hours of observed clock corrections consistent with the provided orbits and 24 hours of clock extrapolation. We were interested in a rough estimate of the overall quality of the individual AC clock submissions. A raw comparison of the observed and the predicted clock-offsets w.r.t. the combined IGS Rapid clock solution is given in Figures 5 and 7. The calculations are based on the clock information given in the sp3-product files with a time resolution of 15 minutes. Thus the time axis in these diagrams cover 96 epochs over a day (E1-E96).

Raw clock differences usually reflect the clock offset and the clock drift of clock 2 w.r.t. reference clock 1. In contrast to the combined IGS Rapid clock product (linearly aligned to GPS-time) the reference clocks used in AC solutions are steered to a very stable clock at one of the tracking sites or to a weighted assembly of hydrogen masers located in timing laboratories around the world. A clock-offset and the clock-drift are common to all reported satellite clocks. In addition clock-differences may reflect radial orbit differences (per satellite) of the corresponding ephemeris, which propagate into the clock solutions. For the observed 24 hours part these differences induced by the orbits usually range up to a few tenth of a nanosecond (1 ns = 30 cm).

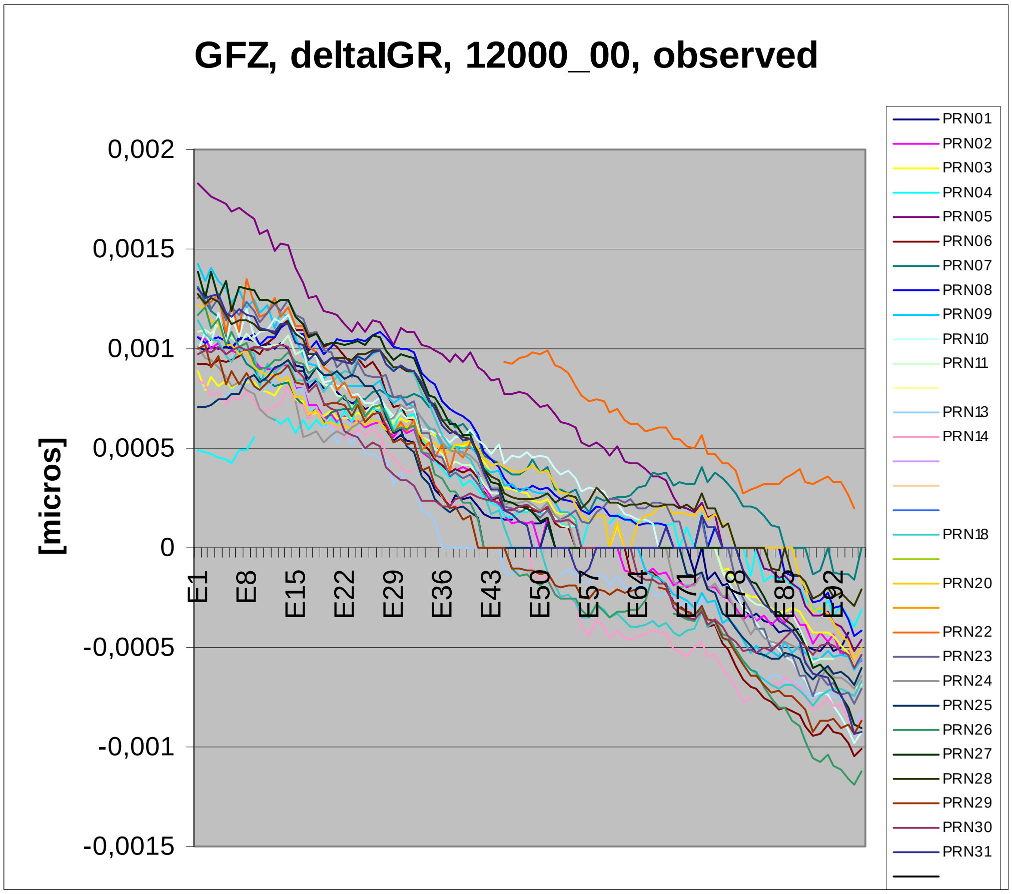

Figure 5: observed 24 hours of GFZ ultra rapid satellite clock solution w.r.t. combined IGS Rapid clocks / GPS-week 1200, day 0.

In a second step the rms of the offset and drift reduced clock differences was calculated. These differences reflect solely high order polynomial or periodical deviations.

As demonstrated in figures 5 and 6 the rms of observed satellite clocks typically range from 0.1 ns to about 0.4 ns. This result might be a little disappointing when compared to IGS Final or IGS Rapid clocks which are of a higher quality by a factor of 2-3. However, we should keep in mind that Ultra Rapid products are based on a relatively small quantity of immediately available tracking data.

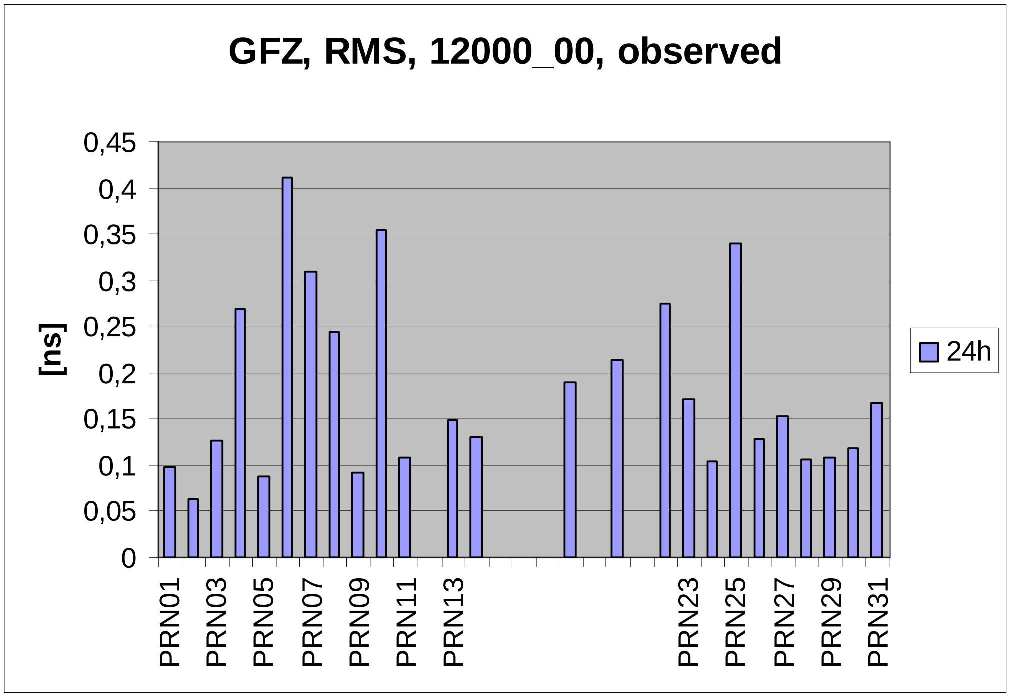

Figure 6: Satellite clock rms of GFZ observed Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1200, day 0.

When inspecting the 24 hours period of clock prediction we find a complete different scenario. While the clock-differences of the observed part normally populate a small band of 1-2 ns, the values within the predicted part diverge substantially (see Figure 7). Another outcome of the diagram is, that obviously some satellite clocks are more difficult to predict then others. Usually clock predictions over 12 hours are good to ±3-4 ns, depending on the stability of the satellite clock (type of clock) and the prediction model. Unfortunately extrapolations of 12 hours or more are sometimes wrong by 10 –20 ns.

For the predicted part, the clock rms is calculated in different intervals as shown in figures 8a-d. The intervals start at 0.00 GPST with the first predicted clock offset and last for 3, 6, 9, and 12 hours, respectively. Again the clock differences have been reduced for an offset and a drift in advance. As expected the rms-values increase in most cases with the length of the interval. A series of steady growing bars reflect a significant quadratic or periodic behaviour of the satellite clock. The satellite specific clock rms for the predicted interval of 3 hours is typically at the +/-1ns level growing up to +/-2 ns for the 6 hours interval. At the end of an 12 hours interval the rms of worse behaving clocks may reach +/-10ns or more. For comparison the AC-solutions from CODE, EMR, ESA and GFZ presented in figures 8a-d coincide in time but not in scale.

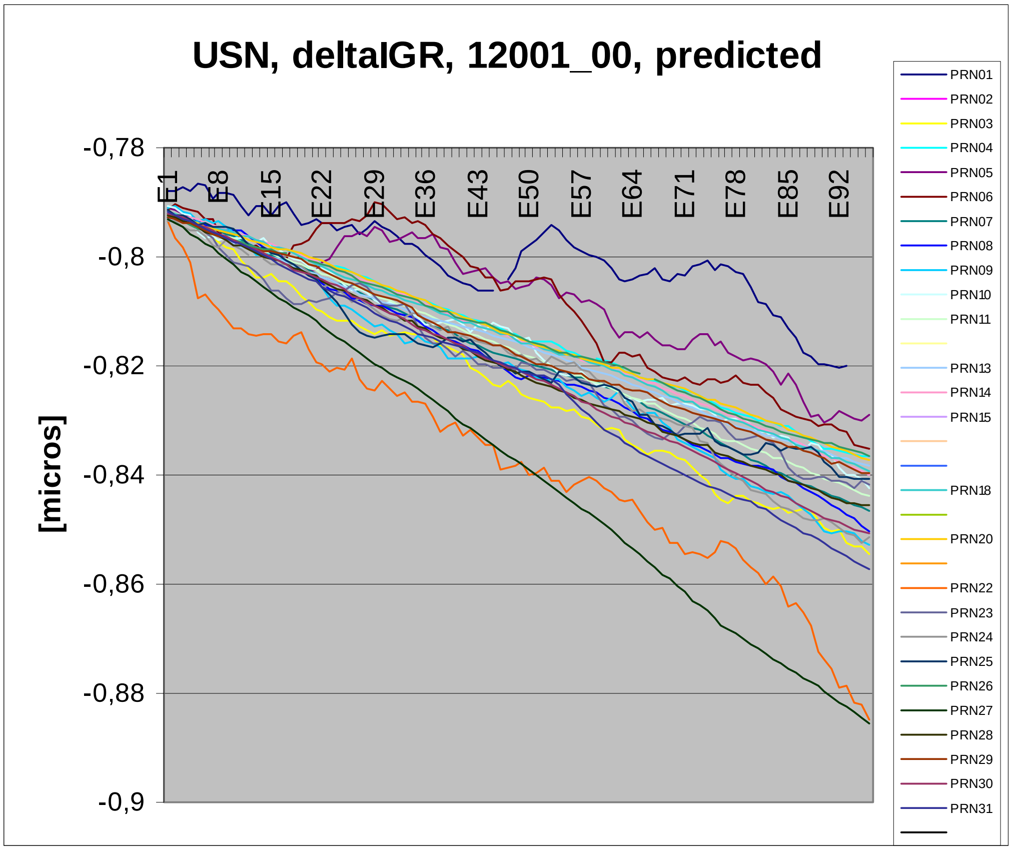

Figure 7: predicted 24 hours of USNO ultra rapid satellite clock solution w.r.t. combined IGS Rapid clocks / GPS-week 1200, day 1.

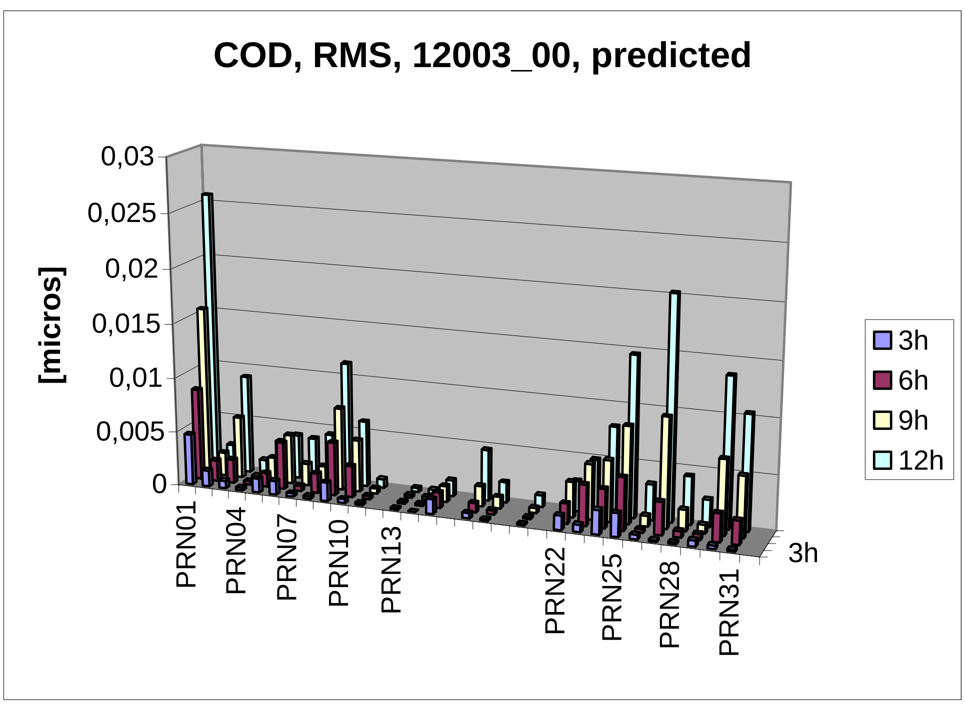

Figure 8a: Satellite clock rms of COD predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

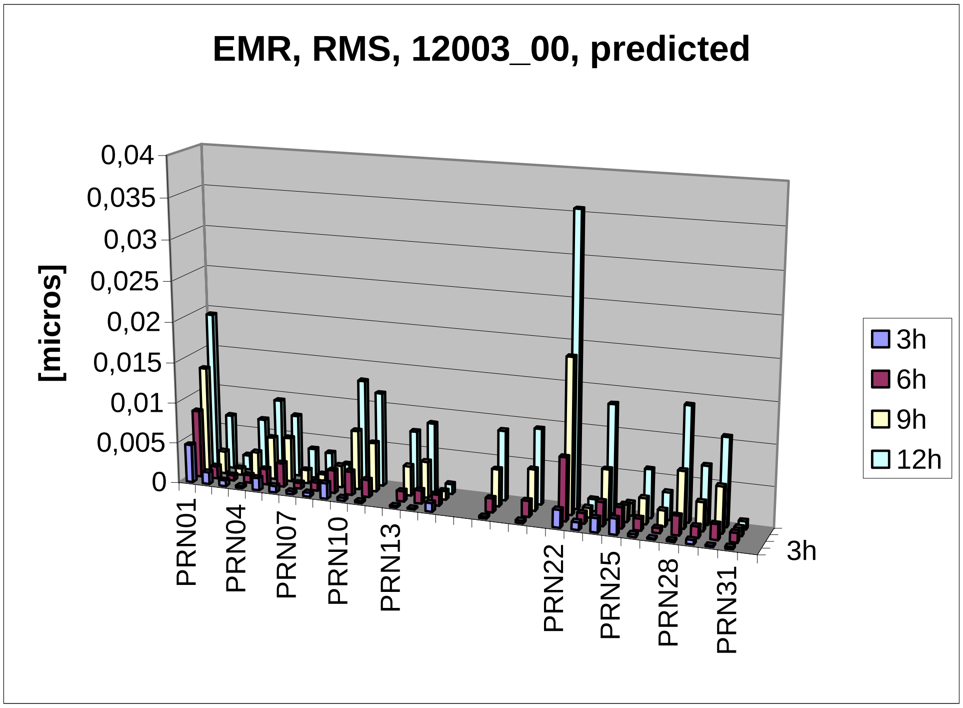

Figure 8b: Satellite clock rms of EMR predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

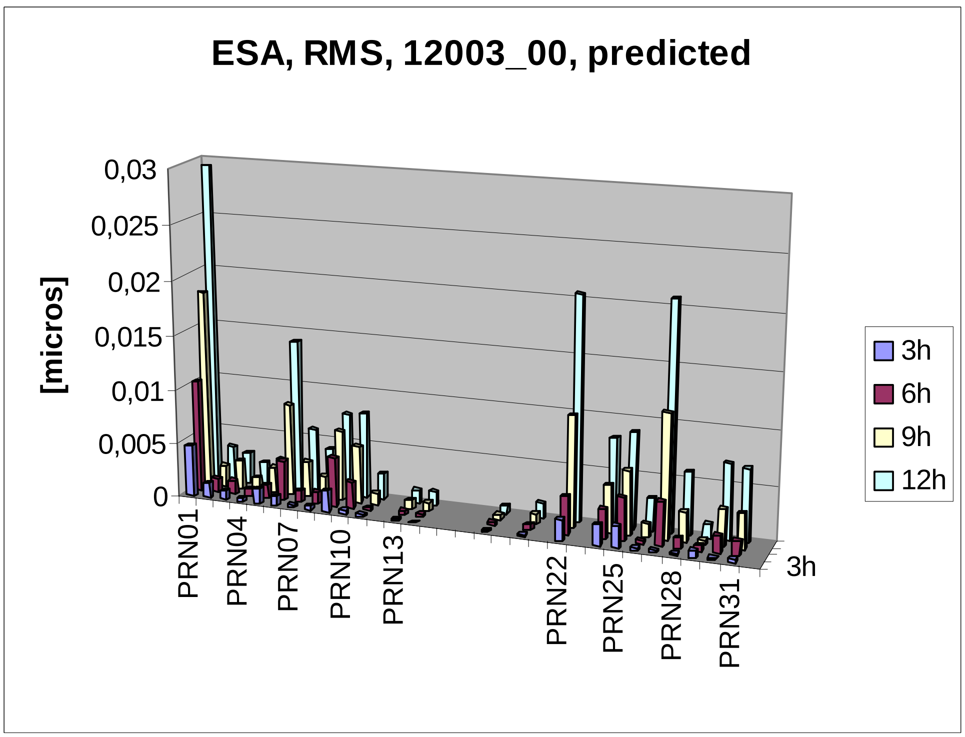

Figure 8c: Satellite clock rms of ESA predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

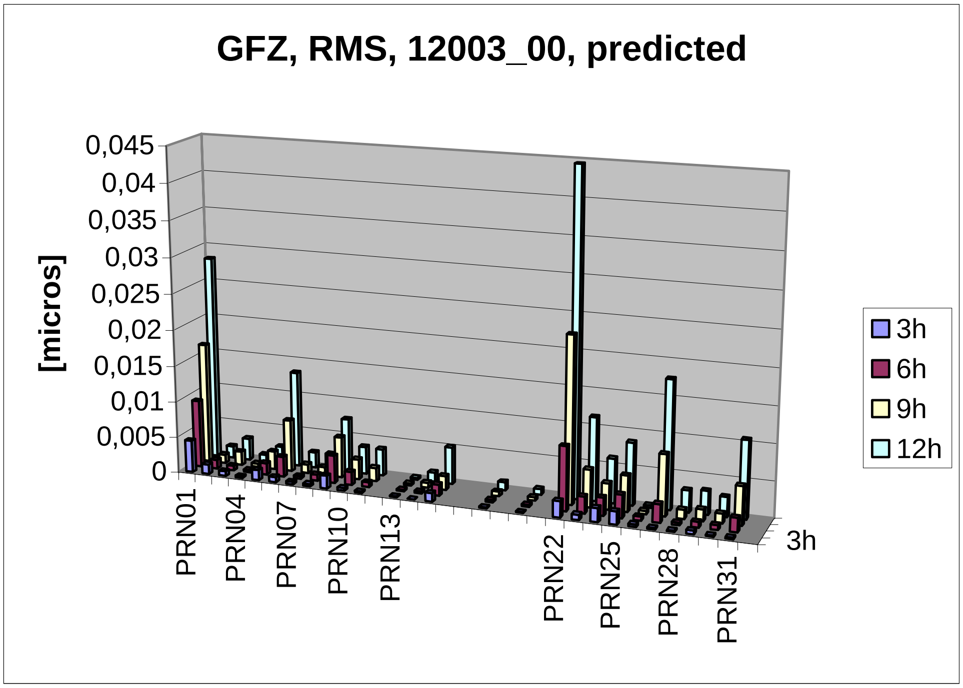

Figure 8d: Satellite clock rms of GFZ predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

The presented comparisons are carried out routinely since GPS Week 1151 (February 2002). Graphics and statistics are posted regularly at http://www.hg.tuwien.ac.at/forschung/satellitenverfahren/igs.htm

Unfortunately the Ultra-Rapid Orbit Combination suffers frequently from a remarkable number of satellites missing in the AC – submissions (about 10-15%) due to modelling

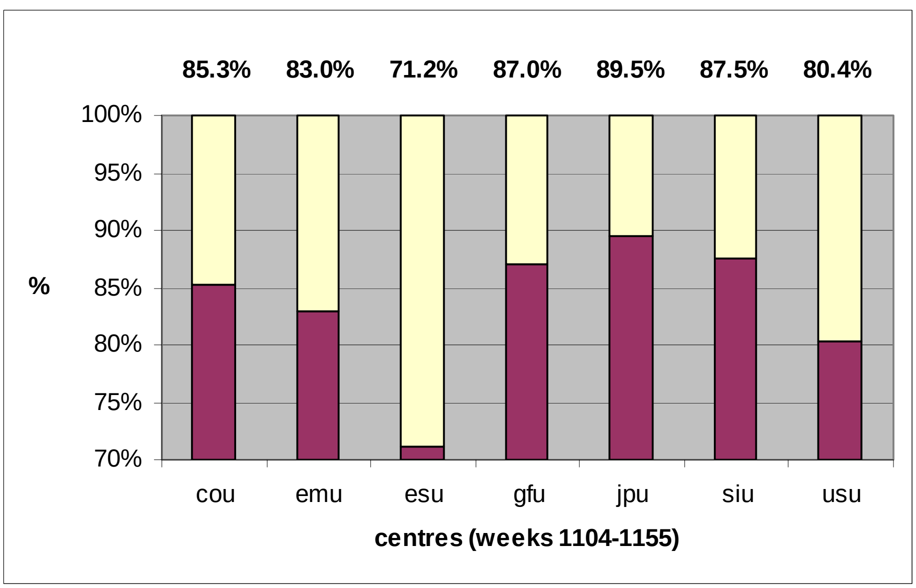

Figure 9: Percentage of satellites submitted within the AC's Ultra Rapid Orbit File (March 2001 until March 2002)

problems. The situation is illustrated in figure 9 covering the period from March 2001 until March 2002. The figure is based on ultra-rapid comparison log-files issued twice daily. Submitting 100% of the satellites would stand for submitting all tracked satellites. The scheme might be too pessimistic cause missing full submissions due to time or internet restrictions also reduce the score. On the other hand satellites which are forwarded by less than 3 centers (and are therefore rejected from the combination) increase the score of the submitting AC. Within the period March 2001-March 2002 about 85% of the tracked satellites passed the combination (about 3-4 missing satellites (out of 28) per IGU update). In the second half of 2002 the situation improved and the number of satellites excluded in the IGU orbits went down to 1-2 satellites per submission. The average percentage of satellites provided in the IGU-orbits with an accuracy better than 20cm could be enhanced to over 90% end of 2002. Satellite orbits with reduced accuracy were still rejected from the combination.

In April 2002 the IGS Analysis and Network Workshop 'Towards Real Time' took place in Ottawa. A number of recommendations were passed aiming at short- and medium-term improvements of the IGS products. Concerning the Ultra Rapid Products it is envisaged to shorten the prediction periods and thus to improve the orbit and clock quality significantly due to more frequent updates (e.g. 3 or 6 hourly updates). A more comprehensive report of this successful meeting comprising the official list of workshop recommendations has been made available via http://igscb.jpl.nasa.gov/mail/igsmail/2002/msg00183.html .

SP3- Format update

It has been demonstrated that the old SP3 standard format for exchange of satellite orbits and clock corrections lacks of flexibility e.g. to characterize sufficiently the variable accuracy of the given data points within the IGU-orbits or to discriminate between observed and predicted data points. Therefore a new format update, labelled SP3c, has been developed under the direction of Steve Hilla from NGS (Hilla, 2003). Data exchange in SP3c format among AC's started on Dec,1st, 2002, the start of distribution of IGS Combined SP3c files will be early in 2003. A comprehensive description of the new format can be obtained via ftp://igscb.jpl.nasa.gov/igscb/data/format/sp3c.txt .

Summary and Outlook

Early in 2003 Gerd Gendt from GFZ Potsdam started his term as the new IGS Analysis Coordinator. Within a few months the IGS combination software package has been successfully installed at GFZ Potsdam. Although some Analysis problems could be solved in 2002 there are still a number of open questions to tackle.

So future activities will certainly focus on

- the implementation of more frequent updates of IGS Near Realtime products (IGU's)
- the real time dissemination of IGS data and products
- the implementation of the new IAU 2000 Resolutions comprising an updated nutation and precession model as well as the paradigm of the non rotating origin
- the implementation of new IERS Conventions, (e.g. subdaily ERP model, see Kouba, 2003a)

- the adoption of a new realigned (UTC) clock time scale
- the full integration of GLONASS data and products within the IGS product lines
- the stabilization of the varying IGS TRF scale e.g. by introducing new antenna calibrations
- the delivery of a really unconstrained GNSS 'technique-specific' combined coordinate solution to IERS

Finally, I want to wish the new IGS ACC Gerd Gendt and his team all the best for the upcoming years.

Acknowledgements

I want thank all people within the IGS and all components of the IGS for their support and cooperation over the past two years. My special thanks have to go to Remi Ferland, Jim Ray and Jan Kouba for a large number of email-discussions and their invaluable scientific support in questions concerning the reference frame and the clock products. Moreover I have to thank the CODE IGS team in Berne, in special Urs Hugentobler, Stefan Schaer and Rolf Dach, for a lot of discussions concerning improvements in the combination software, for maintaining the operating system and for looking after the combination during a huge number of weekends.

Moreover the author wishes to thank Veronika Bröderbauer for the preparation of the Ultra-Rapid Clock Comparisons and for the maintenance of the related Web-Site. Last but not least, I am very much indebted to my colleague, Elisabeth Fragner for her invaluable help. During the past two years she spent countless hours at my side in operating the IGS product combination software.

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