IGS

SESSION 1:

REVIEW OF THE IGS ANALYSIS PRODUCTS

REVIEW OF IGS ANALYSIS PRODUCTS

Robert Weber, University of Technology, Vienna
Jim Ray, U.S. Naval Observatory, Washington
Jan Kouba, Natural Resources Canada, Ottawa

A) Final Combined Products

The IGS Final Products are the definitive set of GPS results provided for the general user community. They are designed to be fully self-consistent, within the noise level, and also consistent with International Terrestrial Reference Frame (ITRF) and the Conventions of the International Earth Rotation Service (IERS). Below is a summary of their current status.

Summary of Current Status of IGS Final Products

Final Product	Update Latency	Update Interval	Sample Interval	Accuracy
GPS ephem.	~13 days	weekly	15 min	<5 cm
GLONASS ephem.	~4 weeks	weekly	15 min	30 cm
sat & sta clocks	~13 days	weekly	5 min	0.1 ns *
coords: horizontal	12 days	weekly	weekly	3 mm
vertical				6 mm
veloc: horizontal	12 days	weekly	weekly	2 mm/yr
vertical				3 mm/yr
polar motion	~13 days	weekly	daily	0.1 mas
polar motion rates	~13 days	weekly	daily	0.2 mas/d
length-of-day	~13 days	weekly	daily	0.020 ms $
zenith troposphere	<4 weeks	weekly	2 hours	4 mm
iono TEC grid		(under development)		

* w.r.t. IGS timescale which is linearly aligned to GPS time each day
$ VLBI results are used to calibrate long-term behaviour of LOD estimates

Issues/questions to consider:

*** Orbit accuracy** -- While the internal consistency of the IGS orbits is at about the 2-cm level, the agreement with SLR is around 5 cm (radial). Are there any new results or changes in this area? Have we reached the accuracy/consistency limit, more or less?

*** Orbit modelling** -- Are there any innovations or improvements to report related to modelling GPS orbits? What about for Block IIR spacecraft?

*** Long-term product consistency** -- Users would prefer to get products from the IGS that are fully self-consistent, over long times as well as for any particular epoch. The occasional changes in TRF realization and other such changes can cause discontinuities. Should/how can the IGS provide long-term consistency?

Several approaches could be considered:

- reanalyse/recombine the full history of GPS data -- huge burden but would give the best possible results (who will do this, e.g. SIO, TU-Munich?)
- recombine the previous solutions using ITRF2000, etc -- nearly equivalent to next approach but more work
- transform existing products to be consistent with ITRF2000 -- relatively simple to do although it is not fully effective

The IGS needs to consider this challenge and determine the best approach that is also realistic. Probably, the most feasible option is for all orbit, ERP, and station products to always be transformed into the official ITRF realization, whenever it is changed, starting with the ITRF2000 change. The original solution files could be moved into subdirectories ITRFxx, where ITRFxx is the ITRF realization used originally. The regular product directory WWWW would thus contain only the IGS combined products in the current ITRF. This way everything would be available and the readily visible products will be always in the currently official ITRF.

In order not to duplicate too much information another approach, also worthwhile to consider, should be mentioned:

- label and separate clearly products based on different TRF realization within the public wwww and ftp directories; provide in addition a PC- and UNIX software tool which easily enables the user to transform orbits, ERPs and station coordinates between the TRF realizations.

*** ERP series** -- Effectively two Final ERP series are available, one from the SINEX combination and one from the orbit/ERP combination. The latter is available for a much longer span. As with the long-term consistency item above, these series should be unified into a single long-term (consistent) time series for users.

This has been done by the NRCanada group. The accumulated ERP file igs00p02.erp (from the Final SINEX-based ERP file starting with GPS week 1013) has been augmented with the longer igs95p02 series (old Finals from the orbit combination process), after applying transformations to the current ITRF2000 realization. The only other official IGS ERP series is igs96p02 from the Rapid combination, which is to be used for the most recent epochs.

*** AC model changes** -- Changes in an AC data analysis strategy can have major unintended consequences for the IGS product combinations. Even though ACs generally test their changes thoroughly before implementing them operationally it is not always easy to detect certain types of problem. For this reason, ACs are strongly encouraged to submit a full suite of test products to the AC Coordinator (as well as coordinators for specific product lines) for evaluation before operational implementation. At least a brief information on the planned change should be forwarded to the ACC per email one day before the change becomes effective. Also, AC Analysis Strategy Summaries should be updated at the Central Bureau at least annually.

*** ITRF2000** -- [See also the separate ITRF session and position paper]. The Reference Frame working group recommended that the IGS change from the IGS97 realization of ITRF97 using a set of 51 RF sites to:

- IGS2000 realization of ITRF2000 using a set of 54 RF sites
- change already performed on 02 December 2001 (start of GPS week 1143)
- change the RS51 set of sites to RS54 by:
  - drop BRAZ,AREQ
  - add ASC1, CEDU, DGAR, LPGS, and RIOG
- for sp3 files, the alias for "IGS2000" is "IGS00"
- the transformation from IGS97/RS51 to IGS2000/RS54 (using those stations in common) were computed by Remi Ferland and reported in IGS Mail #3605.
- the only significant shifts were the T_z component of the origin and the scale, part of which is due to the general relativistic effect of changing from TCG (geocentric) time in ITRF97 to TDT/TT (terrestrial time) in ITRF 2000.

*** IGS geocenter & solution constraints**-- Remi Ferland has shown that the IGS combined geocenter estimates are rather consistent with long-term geocenter of ITRF2000 (but not consistent with the Z component of ITRF97); the mean offsets are 3.9, 0.0, and 5.3 mm for X, Y, and Z, respectively. Significant systematic variations remain (e.g., annual oscillations in Z), the reality of which needs to be investigated. Nonetheless, the prospects of GPS contributing usefully to monitoring variations in the geocenter (motion of the Earth's center-of-mass viewed from the ITRF) appear bright.

ACs are reminded that all constraints to the parameters in a SINEX file must be included in the "APRIORI" blocks. Currently, the geocenter estimates from GFZ are not used in the IGS combination due to strong constraints applied in their analysis. Even though the geocenter estimates of the other ACs are included, evidence exists that subtle analysis constraints may continue to influence the IGS combination. These effects needs to be studied more closely and resolved, not just for geocenter estimates but for all parameters.

*** IGS TRF scale** -- Compared to VLBI and SLR, the GPS frame scale is complicated by the effects of: partly understood non-hemispherical phase patterns for the tracking antennas; much less understood satellite transmit antennas (Blocks II,IIA,IIR, and in the future IIF); very easy and sometime frequent changes in antenna equipment/heights; and important but usually neglected effects due to multipath and other phenomena involving the antenna environments. What are the prospects for overcoming these difficulties/limitations to the level of VLBI and SLR (~0.5 ppb or better)? [This relates closely with the separate session on antenna calibration.]

*** Station coordinate residuals** -- Time series of station coordinate residuals from the weekly SINEX combination can be very useful for many users. These are available in weekly files at the IGS Data Centres. Continuously updated, station-based files would be more useful for most users. A service of this type is already provided by Tom Herring at his Web-site http://bowie.mit.edu/~fresh/index2.html . IGS should consider providing on official IGS service of this type, advantageously located at the IGS Reference Frame Coordinator Web-Site.

EUREF, for example, provides besides the 'Standard Time Series' so-called 'Time Series for Geokinematics' which are improved coordinate series, where the jumps, outlier periods

are corrected and eliminated. Should IGS provide such a kind of product ? [This relates to the separate TRF session and results from Remi Ferland.]

*** Clock time scale** -- The new realigned clocks from Ken Senior are now available. It is recommended that these be adopted officially by the IGS to replace the previous clock products. The questions are when and how to do this, and whether to replace the prior clock files in the GLOBAL DATA Centers with the new product files.

*** Clock solution densification** -- What is the status of AC efforts to "densify" their clock submissions? It is really necessary to have at least two ACs do this on a reliable basis for a comprehensive set of tracking stations, but more ACs would be better. The current IGS coverage is not adequate to ensure that all stations with high-quality frequency standards and all BIPM timing labs are included.

*** High-rate satellite clocks** -- It has been suggested that high-rate satellite clocks (sampling at 30-s intervals rather than the current 5-min) might be needed to support LEO missions. This would place a heavy burden on the ACs. However, study of the actual random walk behaviour of the Cs and Rb clocks aboard the satellites shows that error from linear interpolation of 5-min clocks to the middle 2.5-min epochs is very close to the accuracy of the IGS clocks, namely ~0.11 ns. Rb clocks are somewhat better while Cs clocks are worse. There does not appear to be sufficient support now to justify recommending higher rate clock products.

*** Troposphere** -- What about "densifying" tropo solutions by asking the ACs to use precise point positioning for their tropo-products (in addition to densified clocks)?

*** Ionosphere** -- Based on the Ionosphere Working Group workshop, held during 17-18 January 2002, it is expected that combined IGS TEC maps can be produced as a routine product beginning in the near future. It is likely that the temporal resolution will be improved from 2 hours to 1 hour. When can this service begin? What about other ionospheric products, such as corrections for higher order effects?

*** Updated <P1-C1> biases** -- Given that the satellite biases vary significantly with time, these should probably be updated at least annually. The most recent set of biases was implemented on January 20th,2002. What is the proper update cycle for the future? This maintenance issue could be largely removed if the old cross-correlation receivers in the IGS network were replaced. Problems remain with some modern receivers that report C1 instead of P1 and with small inter-receiver biases.

*** Extended SP3 format** – Steve Hilla has drafted several proposals for adding new data type to the sp3 orbit files. Position and velocity errors would be possible each satellite and at each epoch, rather than the current single accuracy codes for each satellite. Clock errors would be entirely new, and various possible flags are suggested for specific types of orbit and clock events (e.g. manoeuvres and clock resets). The ACs should consider the options and prepare to adopt one of the extended formats in Ottawa.

B) Rapid Combined Products

The IGS Rapid Products are intended as a near-definitive set of products for users unable to wait for the Final Products. Generally, the accuracy is about 50% poorer than the Finals, but the difference is usually very small in absolute terms. Below is a summary of their current status.

Summary of Current Status of IGS Rapid Products

Rapid Product	Update Latency	Update Interval	Sample Interval	Accuracy
GPS ephemerides	17 hours	daily	15 min	5 cm
sat & sta clocks	17 hours	daily	5 min	0.2 ns *
polar motion	17 hours	daily	daily	0.2 mas
polar motion rates	17 hours	daily	daily	0.4 mas/d
length-of-day	17 hours	daily	daily	0.030 ms $

* w.r.t. IGS timescale which is linearly aligned to GPS time each day
$ VLBI results are used to calibrate long-term behaviour of LOD estimates

Issues/questions to consider

*** User requirements** -- Are rapid service user requirements being satisfied adequately, in terms of accuracy and product availability? What about the need of rapid tropo & iono products? Should these be considered?

*** Clock time scale & densification**—The issues for the IGS Rapids are the same as discussed above for the Final products.

C) Ultra-Rapid Combined Products

The IGS Ultra-Rapid Products are intended as a set of GPS products for high-accuracy real-time users. They are forward extrapolations using the latest and best observational results available. The goal is an orbit accuracy better than 30 cm, preferably better than 20 cm. Below is a summary of their current status (predicted part only).

Summary of Current Status of IGS Ultra-Rapid Products

Ultra-Rapid Product	Update Latency	Update Interval	Sample Interval	Accuracy
GPS ephemerides	real time	twice daily	15 min	~25 cm
sat clocks	real time	twice daily	15 min	~5 ns
zenith troposphere		(under development)		

Issues/questions to consider

* **User requirements** -- Are real-time user requirements being satisfied adequately, in terms of accuracy and product availability? Are more frequent updates needed? Robert Weber and his colleagues now provide diagnostic information on the Ultra-rapid combinations at their Web-site http://luna.tuwien.ac.at/forschung/satellitenverfahren/igs/html .

* **Integrity info** -- Should the IGS consider monitoring the real-time integrity of its Ultra-rapid products and start providing integrity alerts to users? [This relates to the separate session on real-time products and user needs.]

* **Near real-time troposphere** -- Gerd Gendt has proposed adding troposphere estimates for the observed half of the Ultra-rapids and to increase the update frequency to every 3 hours. This is under development. Is it adequate? Should these be "densified" using precise point positioning?

* **Predicted clocks** -- Are these worth providing? Not much effort is involved but they will probably never be at the 1 ns level, at least not until the entire constellation is replaced with Block IIR spacecraft or unless more frequent updates are made.

* **Clock time scale** -- When a satellite clock is reset, the current clock combination is corrupted. The algorithm should be changed (similarly to the IGS Rapid combination) to detect clock breaks and reject them from the time scale alignment. He combination could probably also be improved by identifying and rejecting poor submissions.

* **Missing satellites** – The Ultra-Rapid Orbit Combination usually suffers from a remarkable number of satellites missing in the AC-submissions (about 10-15%). How can we tackle that problem.

D) New IERS Conventions

The "IERS Conventions 2000" is near the final stages of preparation (for details see http://maia.usno.navy.mil/conv2000.html). As usual, ACs are encouraged to follow the Conventions to the greatest extent possible. Departures and innovations are should be noted in AC Analysis Strategy Summaries and should not compromise product quality. Based on the current draft, we can anticipate a number of areas of changes which will probably affect the IGS.

* **New celestial pole and nutation model** -- The 24th General Assembly of the IAU (2000) adopted a set of new definitions for the celestial pole and the ephemeris origin using a "non-rotating origin" no longer directly tied to the vernal equinox. In addition, a new nutation model was adopted. However, realization of the final version of the nutation model has been delayed many times and implementation of the new celestial formalism awaits appropriate user software and documentation. It is likely that GPS analyses will be only very slightly influenced by these model changes. Note that the IERS is planning a workshop on 18-20 April 2002 to focus on this topic and to consider plans for implementation.

* **New geopotential** -- This has been a very controversial area of the new Conventions. EGM96 is now recommended over JGM-3, but the high GPS orbits are probably not very sensitive to modest differences in these models.With data now coming from the CHAMP mission, we can expect other improved gravity fields (such as EIGEN-CH).

* **New solid Earth tide model** -- The model has been extensively modified but it is unclear what the practical effect is in terms of displacement accuracy. Further information is needed. ACs are encouraged to study this model and share their experiences.

* **New ocean loading service** -- Loading coefficients can be accessed at http://www.oso.chalmers.se/~loading/ which is associated with the new IERS Special Bureau for Loading, within the Global Geophysical Fluids Center. Again, ACs are encouraged to try this service and share their experiences.

* **New EOP tidal model for periods >5 d** -- The previous model from Yoder et al. (1981) for periods greater than 5 days has been updated to account for mantle anelasticity and ocean effects. For users of tidally corrected EOP values, great care should be taken to describe precisely which tidal model has been used. To avoid such problems, ACs are urged to deliver products to the IGS with the long-period tides fully restored.

* **New subdaily EOP tidal model** -- A new subroutine is available to compute the effects of subdaily (near 12 and 24 hr periods) EOP tidal variations. The tidal model itself is unchanged from 1996 and the coefficients of the 8 main tidal constituents are nominally the same. However, a frequency- dependent admittance function is now used to account for a total of 71 diurnal and semidiurnal terms. Comparison of the 2000 and 1996 models for year 1997 shows peak differences of 0.1 mas for PM-x, more than 0.08 mas for PM-y, and about 0.012 ms for UT1. The RMS differences are 0.033 mas, 0.030 mas, and 0.0041 ms, respectively. These differences are large enough to justify adoption of the new model by the IGS.

E) Summary of Recommendations

IGS Reference System

* Long-term product consistency -- For user convenience, past orbit and ERP products of the IGS will be transformed into the official ITRF realization, whenever it is changed, starting with the ITRF2000 change. The original solution files will be moved into subdirectories ITRFxx, where ITRFxx is the ITRF realization used originally. The regular product directory WWWW will thus contain only the IGS combined products in the current ITRF.

The igs00p02.erp file (the Final SINEX-based ERP file) has been augmented with the longer igs95p02 series (old Finals from the orbit combination process) and transformed to the current ITRF. The Reference Frame coordinator (Remi Ferland) has kindly taken care of this.

* *IGS geocenter & parameter constraints*-- ACs are encouraged to work with the Reference Frame coordinator (Remi Ferland) to resolve outstanding questions concerning subtle constraints in their SINEX submissions. It is very desirable that all AC SINEX

submissions be usable for the IGS geocenter combination and that these be free of all over-constraints.

* *AC model changes* -- ACs should provide test solutions before making operational changes and should update their Analysis Strategy Summary annually.

New IGS Products

* *Ionosphere* -- What/when will Iono-products be offered? This relates to the separate Iono session. A summary of their product recommendations will be available after the Workshop.

* *Near real-time troposphere* -- The Troposphere Working Group chair (Gerd Gendt) has begun a trial service providing near real-time zenith troposphere estimates as part of the Ultra-rapid products. These have 3-hr latency and are updated every 3 hr. All ACs are encouraged to support this new product.

* *Integrity info* -- Should the IGS consider monitoring the real-time ? This relates to the separate real-time session. A summary of their product recommendations will be available after the Workshop.

* *Clock time scale* – The adoption of the new clock time scale at least for IGS Final products should take place end of 2002.

* *Extended SP3 Format* – The adoption of a new extended SP3-Format should take place not later than end of 2002.

IGS Analysis Products — Clock and IERS Convention Issues - J. Ray

- **Densification of station clock solutions**
  - IGS clock combination requires at least 2 AC submissions for each clock
  - highly desirable to include all stable clocks (~40 H-masers, ~25 Cs, ~15 Rb) & all timing labs (~18 now)
  - allows IGS clock products to be used for time transfer, including by the BIPM for TAI/UTC
  - improves the stability of the IGS internal time scale
  - can be done most efficiently using PPP method by each AC to densify own clock submission
  - currently done by CODE & USNO ($\gtrsim$100 stations each)
  - *need more ACs to participate*
- **High-rate satellite clocks ?**
  - previously suggested that 30-s satellite clocks needed for LEO applications, rather than IGS standard of 5 min
  - however, current Cs & Rb satellite clocks show interpolation errors near IGS accuracy (~0.11 ns)
  - *currently, no need seen for high-rate clock*
- **Maintenance of <P1-C1> biases ?**
  - *recommend continued updates based on CODE solutions, at least annually*
  - *eliminate cross-correlator receivers from IGS network*
  - *work with receiver makers to supply P1 instead of C1*

- **IGS internal time scale**

  - to overcome short-term instability due to GPS time
  - developed by K. Senior using dynamically weighted ensemble algorithm
  - *propose to implement officially ~30 June 2002, provided:*

    * letter of institutional support/commitment submitted
    * approval by Governing Board
    * AC Coordinator is satisfied
    * IGS Mail to be sent beforehand

  - *suggest replacing all old clock files in IGS Data Centers*

- **Future of IGS/BIPM Pilot Project**

  - *recommend end of pilot phase on 31 Dec 2002*
  - *propose permanent liaison between IGS & BIPM starting in 2003*

IGS Analysis Products — New IERS Conventions

- **Website:** http://maia.usno.navy.mil/conv2000.html

- **Implementation of new IAU Resolutions**
  - new ICRS celestial system, time scale transformations, nutation-precession model, & origin for intermediate geocentric frame
  - IERS Workshop on implementation issues being held 18-19 April at Paris Observatory
  - IERS publication will be prepared based on workshop
  - expect mostly tiny effects for GPS analyses
  - *propose no AC changes at this time*

- **Geopotential model**
  - EGM96 now recommended but newer/better models coming quickly
  - differences probably not significant for GPS altitude
  - *ACs encouraged to investigate and share results*

- **New solid Earth tide model**
  - extensive changes from earlier versions
  - no information on practical consequences or magnitude of differences
  - supposed to be accurate to 1 mm
  - *ACs encouraged to investigate and share results*

- **New zontal UT1 tidal model**

  - updates Yoder *et al.* (1981) using Defraigne & Smits (1999) Earth model with inelastic mantle
  - for periods longer than 5.64 d
  - *recommend ACs not apply tidal corrections to output products to avoid ambiguities*

- **New subdaily EOP tidal model**

  - extends previous model for 8 main tides to 71 diurnal & semidiurnal terms
  - differences at about accuracy level
  - if uncorrected, will affect EOP rates and alias into GPS orbits, mostly
  - *recommend ACs adopt IERS subroutine for routine processing as soon as possible*
  - *set date for uniform conversion ?*

IGS Analysis Products - Combination Issues

Robert Weber

Introduction

This paper reflects the summary of a talk given at the IGS Workshop in Ottawa in April 2002. The text is meant to be complementary to the position paper 'Review of IGS Analysis Products' presented by (Weber, Ray, Kouba) prior to the IGS Workshop.

IGS Final Products

The IGS Final Products are the definitive set of GPS results provided for the general user community. They are designed to be fully self-consistent, within the noise level, and also consistent with International Terrestrial Reference Frame (ITRF) and the Conventions of the International Earth Rotation Service (IERS).

The graphics below show the status of orbit and clock consistency of the submitted AC solutions covering (approximately) the past 60 weeks. Both graphics are regularly updated and can be obtained from the IGS-ACC web page at http://www.aiub.unibe.ch/acc.html

The WRMS-figure (Fig.1) shows the Weighted RMS (mm) of the individual AC solutions with respect to the IGS Final orbit. The CRMS-figure (Fig.2) shows the Clock RMS (ns) of the individual AC solutions with respect to the IGS Final clocks. For display purposes the values of the Final Combination summaries are shown after smoothing using a sliding 7 day window.

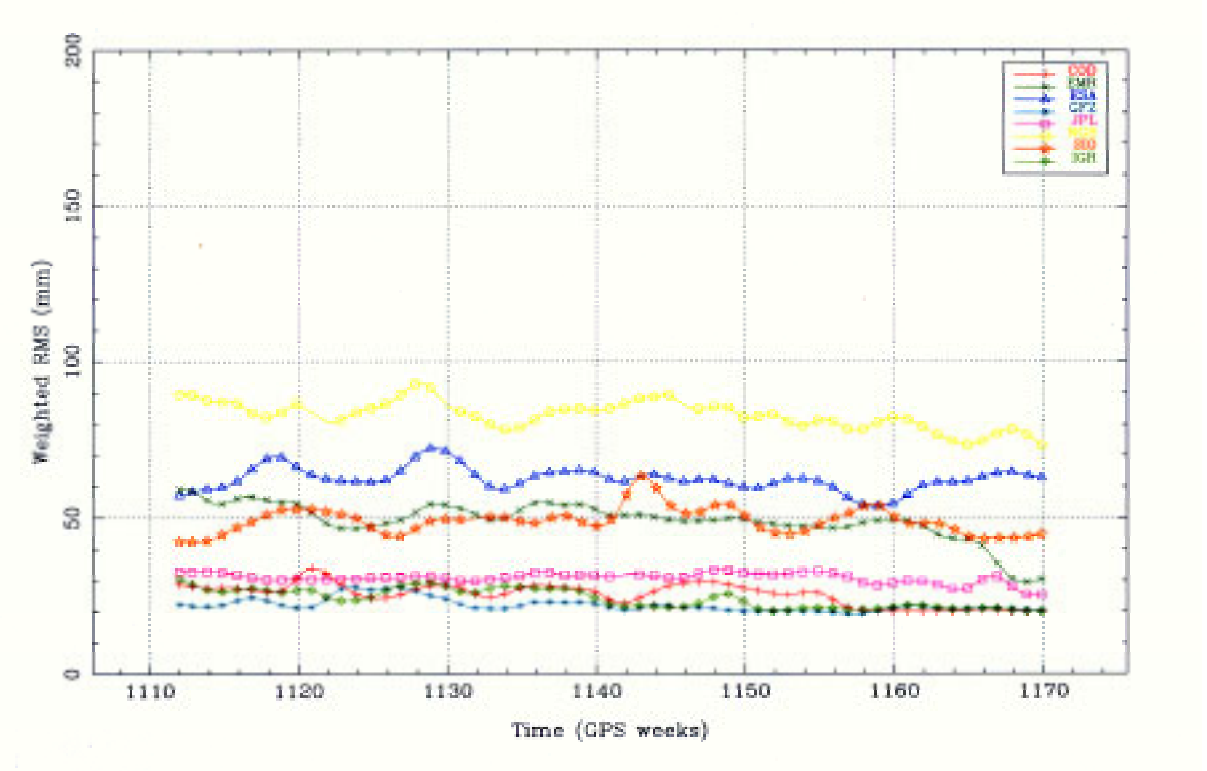

Figure 1

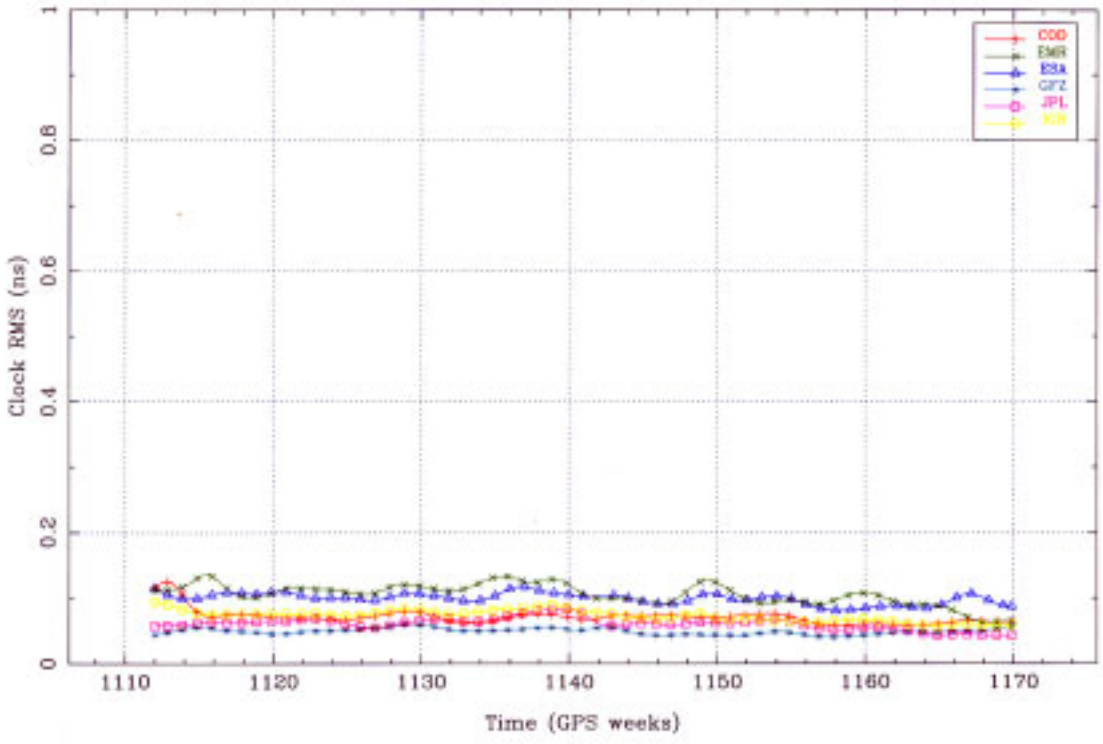

Figure 2

Both graphics show a quite satisfactory consistency of the submissions, below the 5cm level for the orbits and well below the 0.1ns level for the clocks.

A number of questions related to the igs-products were raised from individuals within the IGS and listed in various chapters of the position paper. In the sequence some of them should be discussed briefly. Comments reflect the discussion in Ottawa and are in accordance with the official list of workshop recommendations.

Questions related to IGS Final products

Question: Have we reached the accuracy limit for the orbits?
Answer: While the overall consistency of the IGS orbits is at the 2-cm level, the agreement with SLR is around 5 cm (radial). The consistency is very much dependent on the number of quite good orbit submissions. Up to 7 AC submissions are available and required each week to achieve this level of consistency. The bias between GPS and SLR observations has been investigated during the past 2 years by various groups without providing a satisfactory explanation. Another attempt will be made this summer in cooperation with SLR Analysis groups.

Question: Is 30s satellite clock sampling required for LEO mission support ?
Answer: Although there is no clear evidence that clock interpolation between 5 minutes time stamps is not sufficient, the IGS products will move towards providing 30 sec clocks. This will lay a huge computational burden on several ACs. Currently JPL is providing 30s clocks for the final product. LEO mission support usually asks for a low latency and therefore for 30s satellite clocks within the IGS Rapid and IGS Ultra Rapid (observed part) submissions.

Question: The new realigned clocks from Ken Senior are now available.
Adopt the new clock time scale to serve BIPM?

Answer: It is recommended that these realigned clocks should be adopted officially by the IGS to replace the previous clock products. The questions, when (Jan. 2003 might be appropriate) and how to do this still remain. Another question is whether to replace the prior clock files in the GLOBAL DATA Centers with the new product files?

Question: What is the status of AC efforts to "densify" their clock submissions?

Answer: It is really necessary to have at least two ACs do this on a reliable basis for a comprehensive set of tracking stations, but more ACs would be better. The current IGS coverage is not adequate to ensure that all stations with high-quality frequency standards and all BIPM timing labs are included.

The current latency of about *14 days* in delivering the IGS Final products seems to be well accepted. Studying the delivery-time of the particular AC submissions shows a very heterogeneous picture ranging from 5 to 12 days. Thus, decreasing the latency of the IGS final combination seems to be feasible, but is currently not really requested by the community.

IGS Rapid Products

The WRMS-figure (Fig.3) shows the Weighted RMS (mm) of the individual AC solutions with respect to the IGS Rapid orbit. Figure 4 shows the Clock RMS (ns) of the individual AC solutions with respect to the IGS Rapid clocks. For display purposes the values of the Rapid Combination summaries are shown after smoothing using a sliding 7 day window.

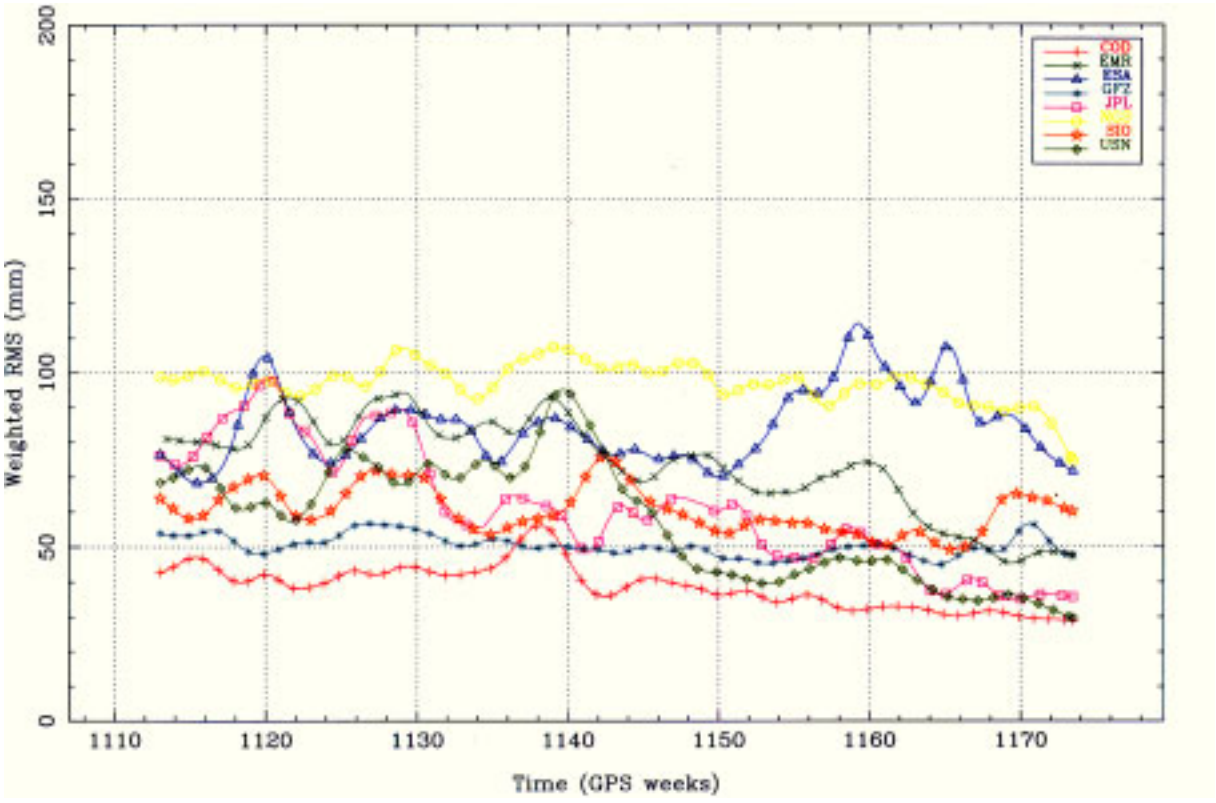

Figure 3

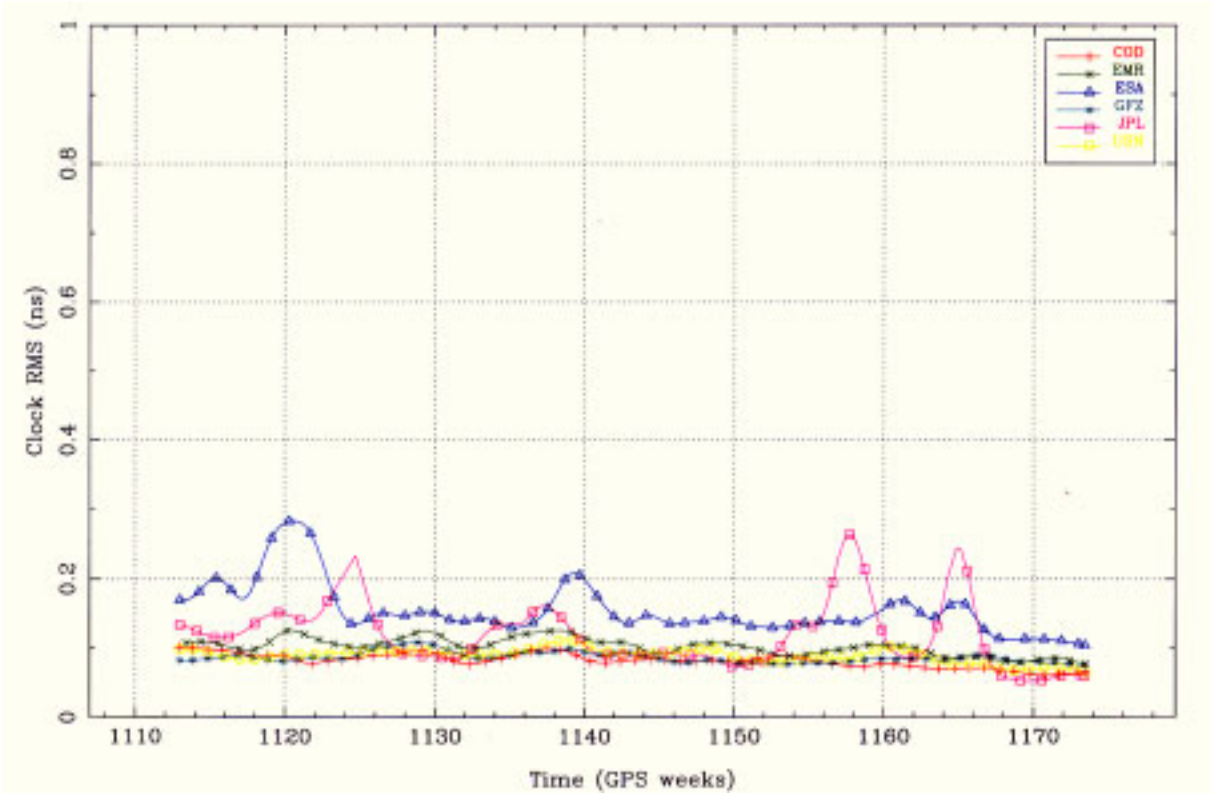

Figure 4

The next two figures show the difference between individual AC Rapid X-pole rate and Y-pole rate ERP solutions and the IGS Final ERP series. The individual series are shifted by 3 mas/day.

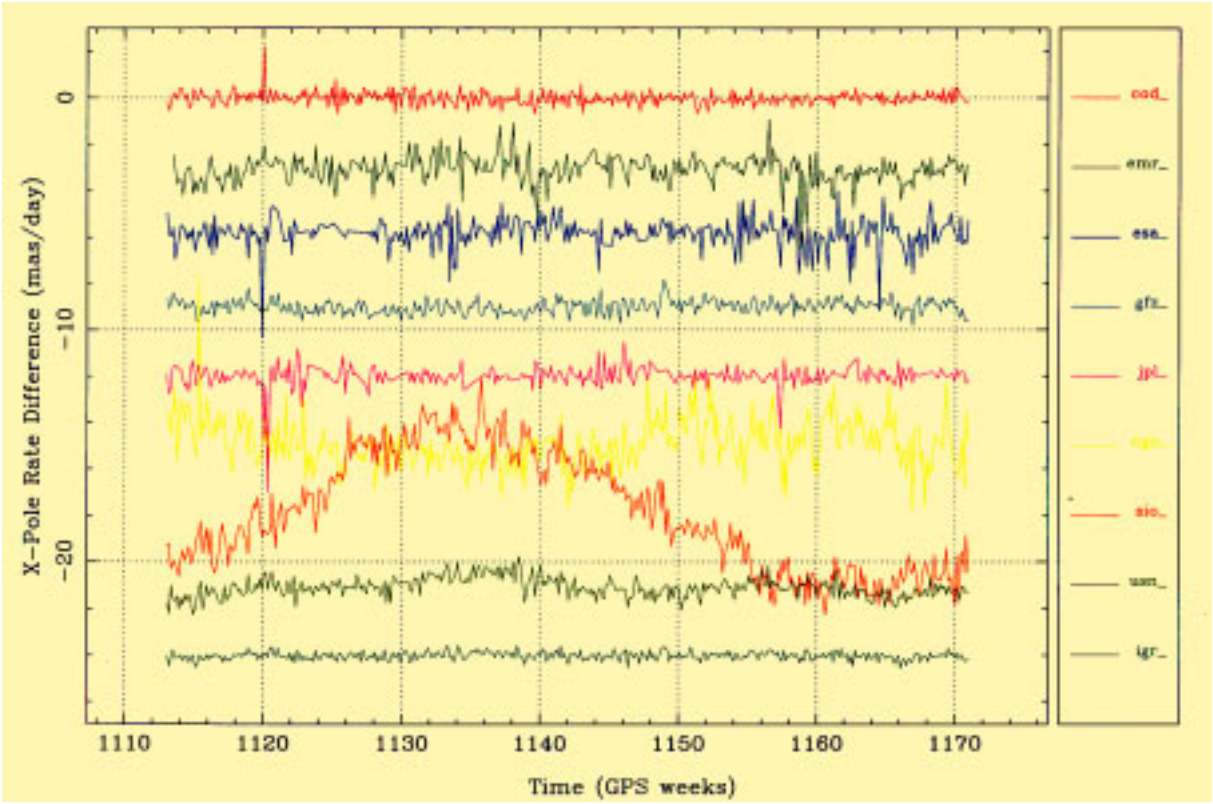

Figure 5

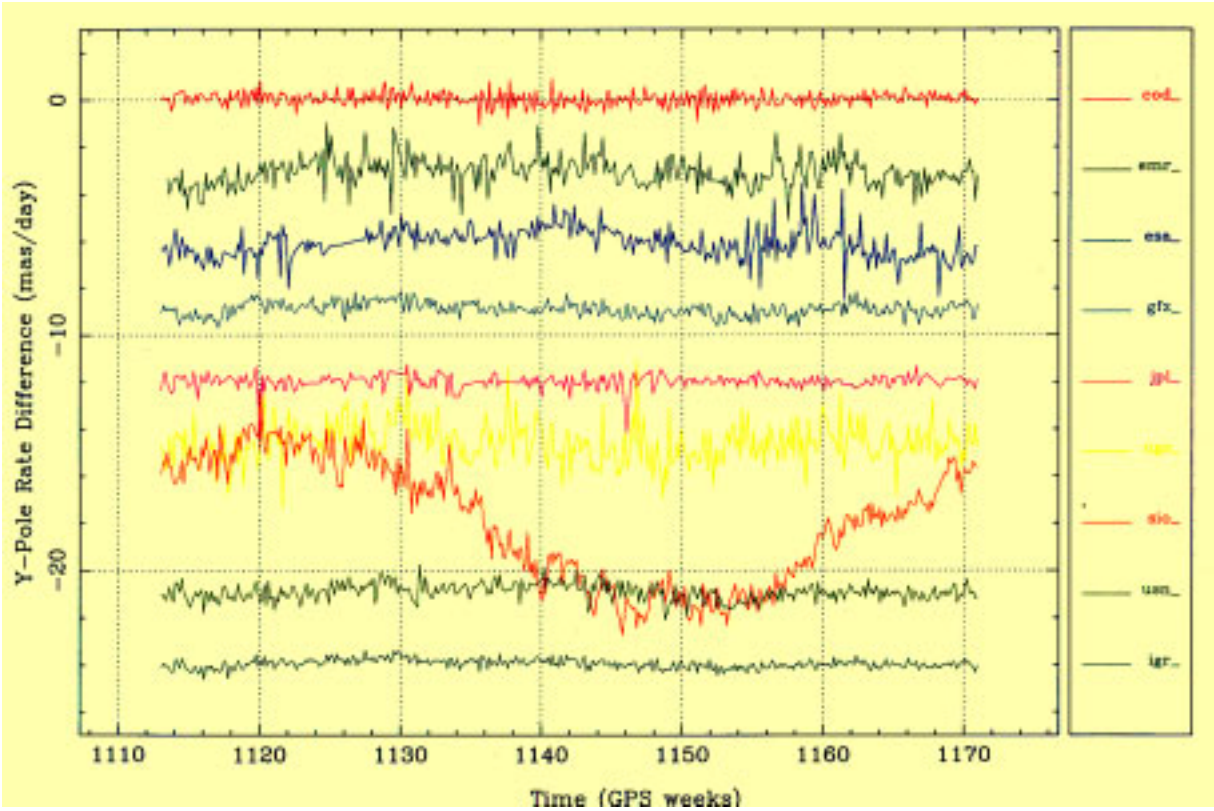

Figure 6

Please note the huge annual signal dominating the sio PM-rates. This signal has to be eliminated as soon as possible.

Questions related to IGS Rapid products

Question: Clock time scale & densification?
Answer: The issues for the IGS Rapids are the same as discussed above for the Final products.

The current latency of about *17 hours* in delivering the IGS Rapid products seems to be appropriate. Submissions to the IGS Rapid Combination are delivered by the ACs usually between 8 UTC and 17 UTC. Again decreasing the latency of the IGS Rapid combination seems to be feasible, but is currently not really requested by the community. People would prefer more frequent updates of the IGS Ultra-rapid combination, which will be discussed later.

IGS Glonass Products

Between January 1 and May 31, 2002, there have been 7-8 healthy, operational GLONASS satellites. They are all in the planes 1 and 3 of the constellation. The first new GLONASS-M satellite, GLONASS No. 711 in Plane 1/Slot 5, has not yet been designated as operational. It is not clear, if any problems may have been encountered after launch.

Microwave Technique / Tracking Status
The number of "permanent" IGLOS microwave tracking stations has grown slightly since December 2001. There are now 50 stations in the network, continuously tracking the GLONASS satellites and transmitting their data to the IGS Data Centers. Forty-five or more of these stations have been sending data to the data centers each week. Most of the receivers are Ashtech Z18 or JPS Legacy models. New stations that came on-line during the last three months include Frankfurt, Germany (FFMJ), Kourou, French Guyana (KOU1), and Zimmerwald, Switzerland (ZIMZ).

Orbit Determination
BKG, ESA and the Russian Mission Control Center (MCC) continue to compute and make available GLONASS orbits on a routine basis. The MCC orbits are based on SLR data. Figure 7 below demonstrates the daily coordinate rms. of the center submissions with respect to the combined orbit (1998.8-2002.2). The consistency among all contributed orbit submissions is at the 20cm level, regardless of the basic observable. MCC orbit rms. numbers are of course somewhat noisier, caused by the low number of satellites tracked by ILRS. The visible bump in summer 2001 is related to a mis-modelling of radiation pressure for satellite slot 8. Just after fixing that problem the rms. numbers decreased below the 20cm level.

In May 2002 the IGS-CB integrated all combined GPS/GLONASS tracking sites within their official data site pool, which was a long lasting request of the IGLOS-Pilot Project. This step should encourage all IGS Analysis Centers to make increased use of the GLONASS data in their processing schemes and come up with a number of new or improved products. In the first place precise GLONASS orbits with an increased orbit accuracy of 1-3 cm in the radial direction should be sufficient to study in detail the reason of the remaining bias of a few centimetres between microwave and laser tracking observations. Moreover, in case of a new GLONASS launch to plane II (elevation of sun above the orbital plane up to 88 degree) we are looking forward to learn more about reliable radiation pressure models for the GLONASS satellites.

Questions related to IGS Glonass orbits

Question: How many contributing ACs are necessary to provide a stable and reliable GLONASS orbit solution (orbit combination)?
Answer: The current number of 2 ACs calculating GLONASS orbits based on microwave observation data is far too small. We urgently need at least 2 more centers (or associated ACs) to provide a reliable solution !

Question: Why not providing combined GPS/GLONASS SP3 files?
Answer: That's of course the goal to reach. But in fact the number of IGS-AC currently able to provide this product is only one (ESA). So, again, we urgently need more ACs to calculate precise GLONASS orbits.

The current latency of about *4-10 weeks* in delivering the IGS GLONASS orbits seems to be too long. We have to keep in mind that IGS-ACs usually align the GLONASS orbits to their center specific GPS orbit solutions. IGS-AACs solely calculating GLONASS orbits are forced to wait for the IGS final combination for this alignment. Thus, about 14 days are currently the shortest conceivable period for delivering precise GLONASS orbits, respectively a combined GLONASS orbit solution.

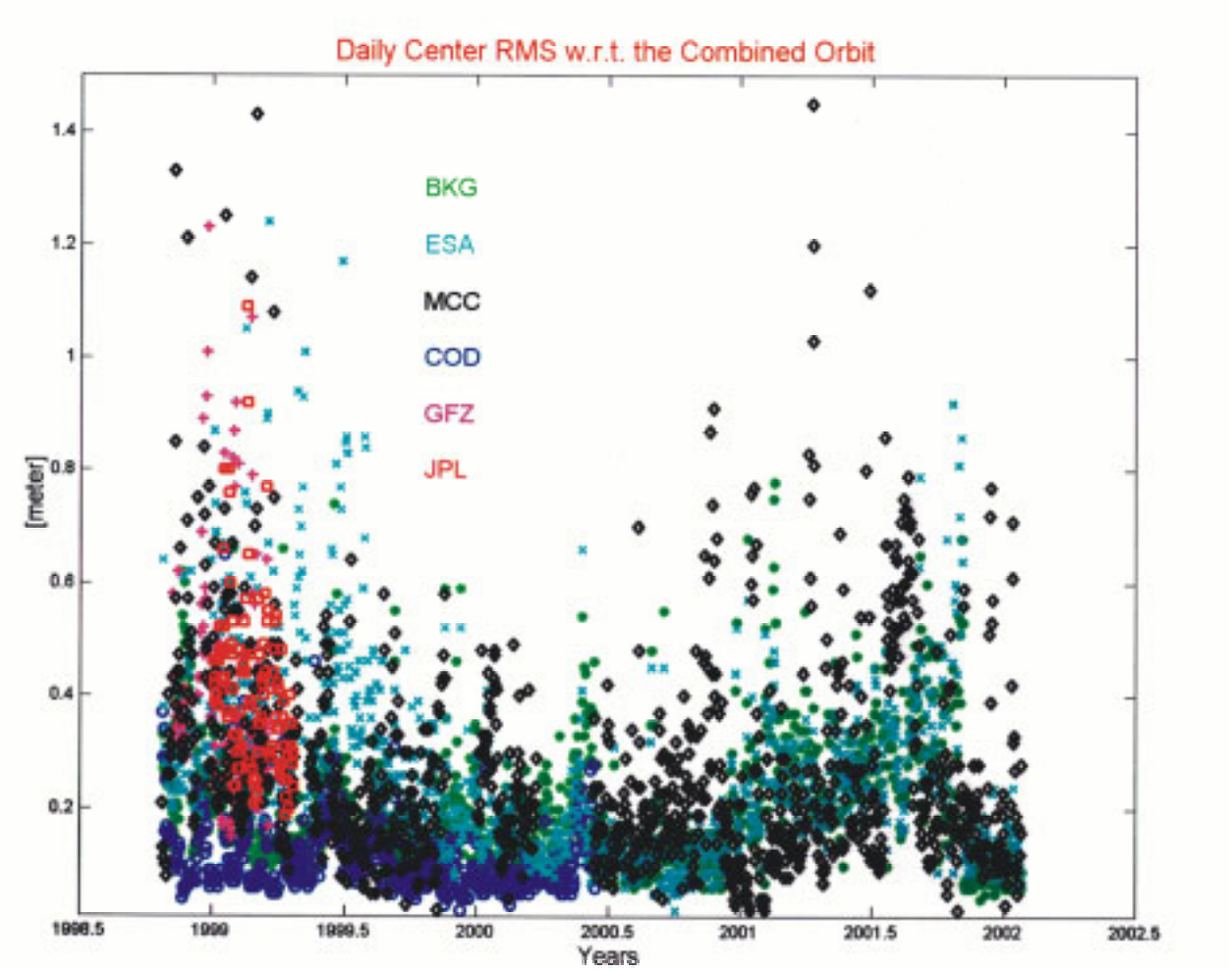

Figure 7

IGS Ultra Rapid Products

Figure 8 shows the Weighted RMS (mm) of the individual AC solutions with respect to the IGS Ultra Rapid orbits. For display purposes the values of the Ultra Rapid Combination summaries are shown after smoothing using a sliding 7 day window. The graphic shows a consistency of the submissions at the 20cm level. This number is quite comparable to the rms-differences between the Ultra Rapid combined orbit and the IGS Rapid orbit combination.

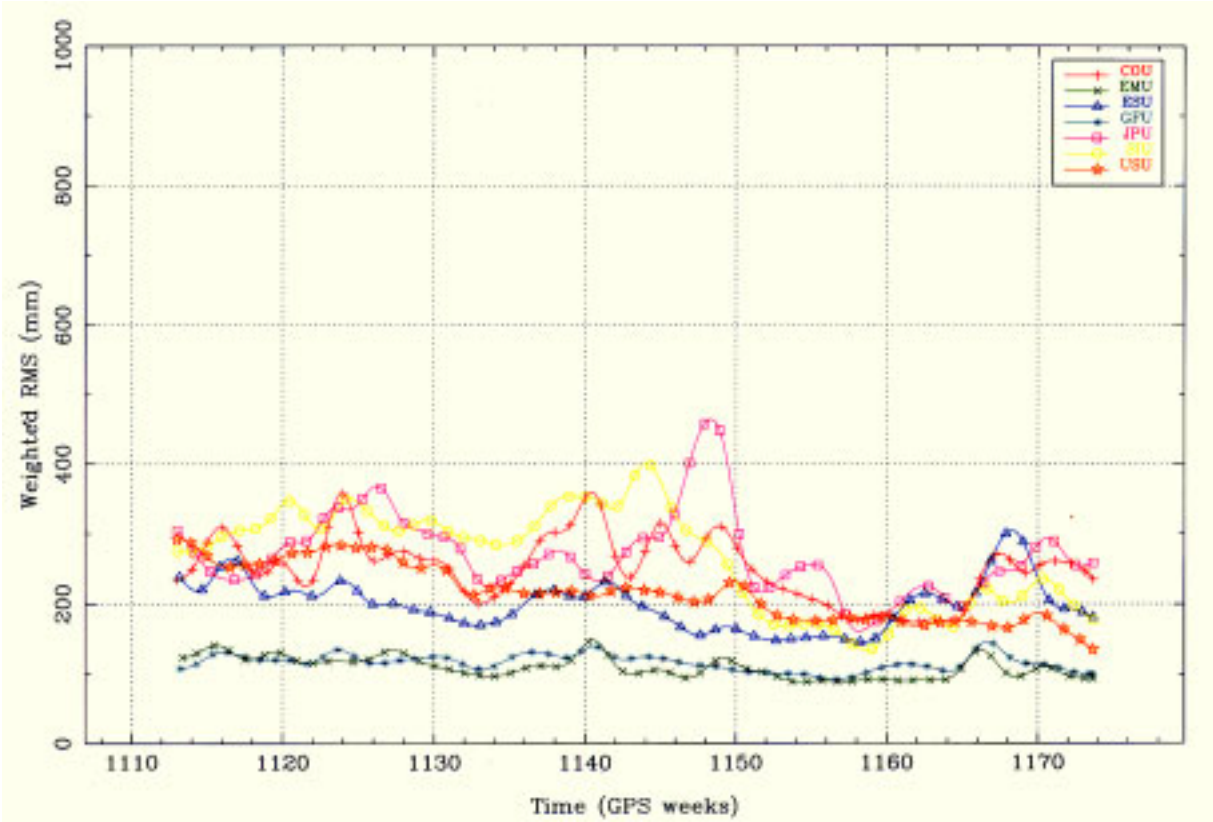

Figure 8

Questions related to IGS Ultra Rapid Products

Question: The IGS Ultra Rapid orbits are updated twice a day. Does the user community ask for more frequent updates? Which application may be served with more frequent updates?

Answer: Application which obviously would benefit from more frequent IGU updates are Near Real Time Troposphere Monitoring and LEO missions. This has been expressed in the relevant PROD4 recommendation of the Ottawa workshop, which is given below:

'In view of upcoming NRT-needs explore and implement a more frequent update of the IGU-Ultra Rapid Products. An update cycle of 3 hours for IGU products is envisaged. Investigate the option of different update cycles for orbits (6 hours) and clocks (3 hours). In addition explore the possibility of decreasing the latency of IGU products from currently 3 hours to 2.5 hours as well as the submission of 5-minutes rinex-clock files'.

In addition, Gerd Gendt has proposed to deliver troposphere estimates for the observed half of the Ultra-rapids and to increase the update frequency to every 3 hours. This is under development.

Question: The Ultra-Rapid Orbit Combination usually suffers from a remarkable number of satellites missing in the AC-submissions (about 10-15%; see also figures 12a,b). How can we tackle that problem?

Answer: ACs are asked to provide as much as possible satellites in their submissions. Make a more intensive use of accuracy codes to identify bad satellite position records (needs an SP3 format update) instead of removing satellites completely from the orbit file.

Question: Do we need clock-RINEX files (sampling 5 minutes or 30 seconds) complementary to the ultra rapid orbit files?

Answer: An adequate clock-interpolation asks for at least 5 minutes sampling. This holds especially for the observed 24 hours. Predictions are usually based on more or less simple analytical representations. A 5 minutes sampling is therefore not a must for the predictions. The whole issue has not decided up to now but there is another pro for providing clock rinex files: When a satellite clock is reset, the current clock combination is corrupted. The combination algorithm, based on clock rinex files, can (similarly to the IGS Rapid combination) detect clock breaks and reject them from the time scale alignment. The combination could probably also be improved by identifying and rejecting poor submissions.

Ultra Rapid Clock Comparisons

Since Wk 1151 a regularly updated Web-site

http://luna.tuwien.ac.at/forschung/satellitenverfahren/igs_ultrarapids_products.htm

provides weekly comparisons of the submitted ultra-rapid clock solutions, both for the observed and the predicted 24 hours. The plots are grouped per day and AC and show basically raw clock differences per satellite to the IGS Rapid clock solution as well as the offset and trend reduced clock-rms again with respect to the IGS Rapid clock solution. As a nice additional feature the clock rms numbers for the predictions are available for 3,6,9,12 and 24 hours time slots after start of the prediction.

A number of examples (3) is given below:

Example 1 (Figures 9a-d):
GFU-IGR , week 1156, day 3 observed, day 4 predicted

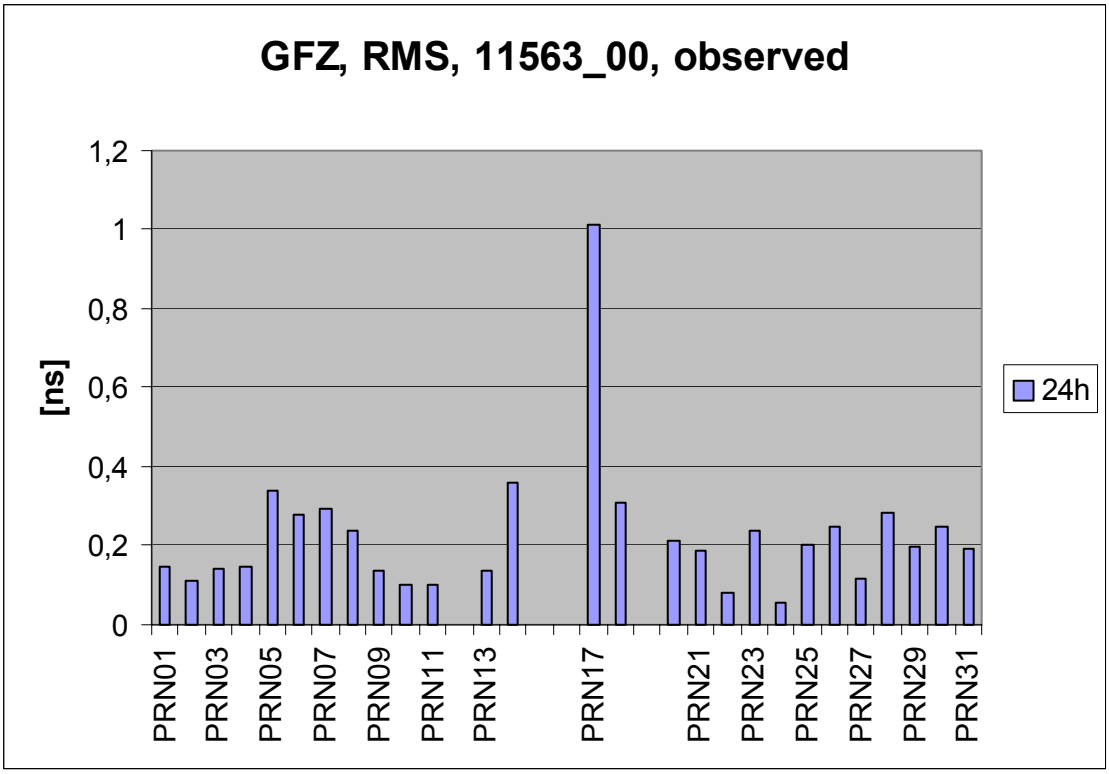

Figure 9a: clock-rms, day 3 , 00 UTC; offset+trend reduced

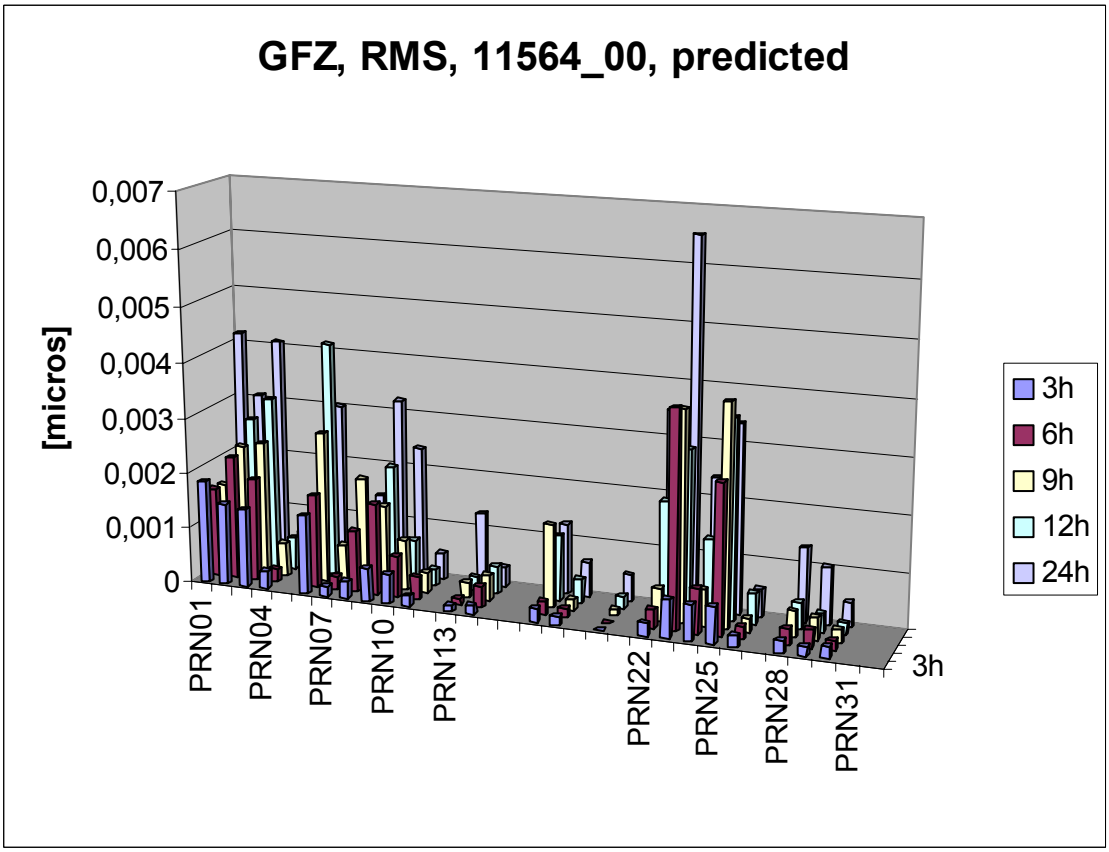

Figure 9b: clock-rms, day 4 , 00 UTC; offset+trend reduced; 5 time slots

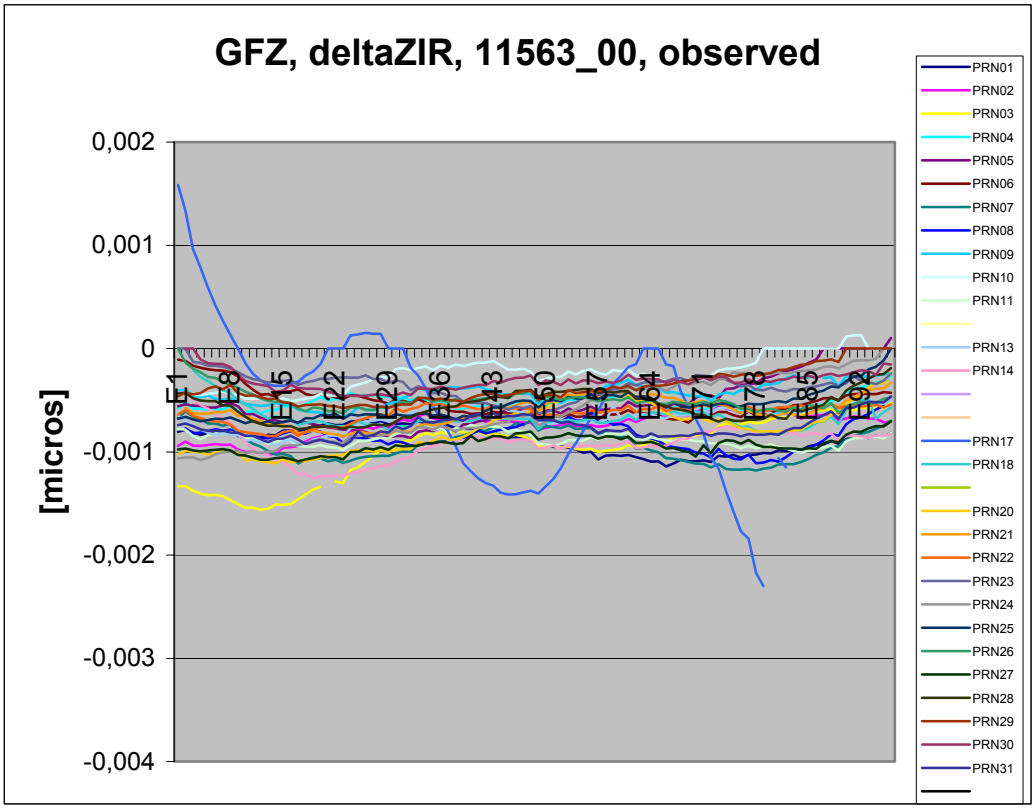

Figure 9c: raw clock difference, day 3 , 00 UTC

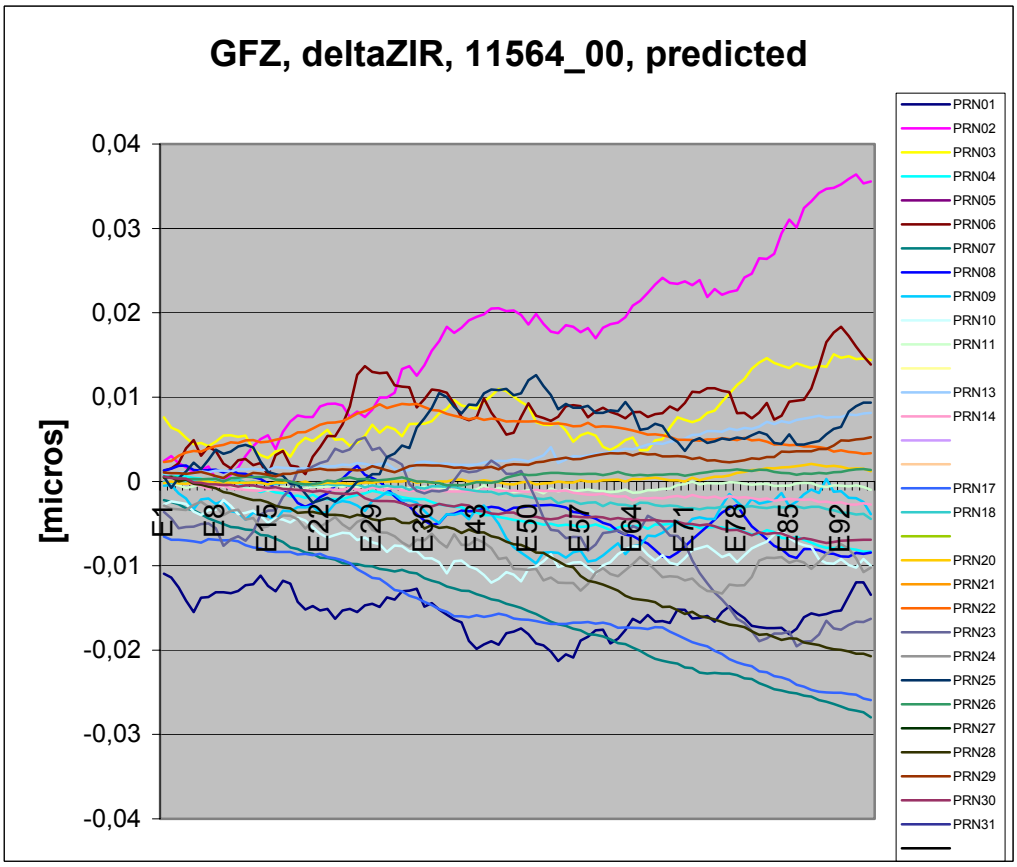

Figure 9d: raw clock difference, day 4 , 00 UTC

Example 2 (Figures 10a-d):
USU-IGR , week 1156, day 3 observed, day 4 predicted

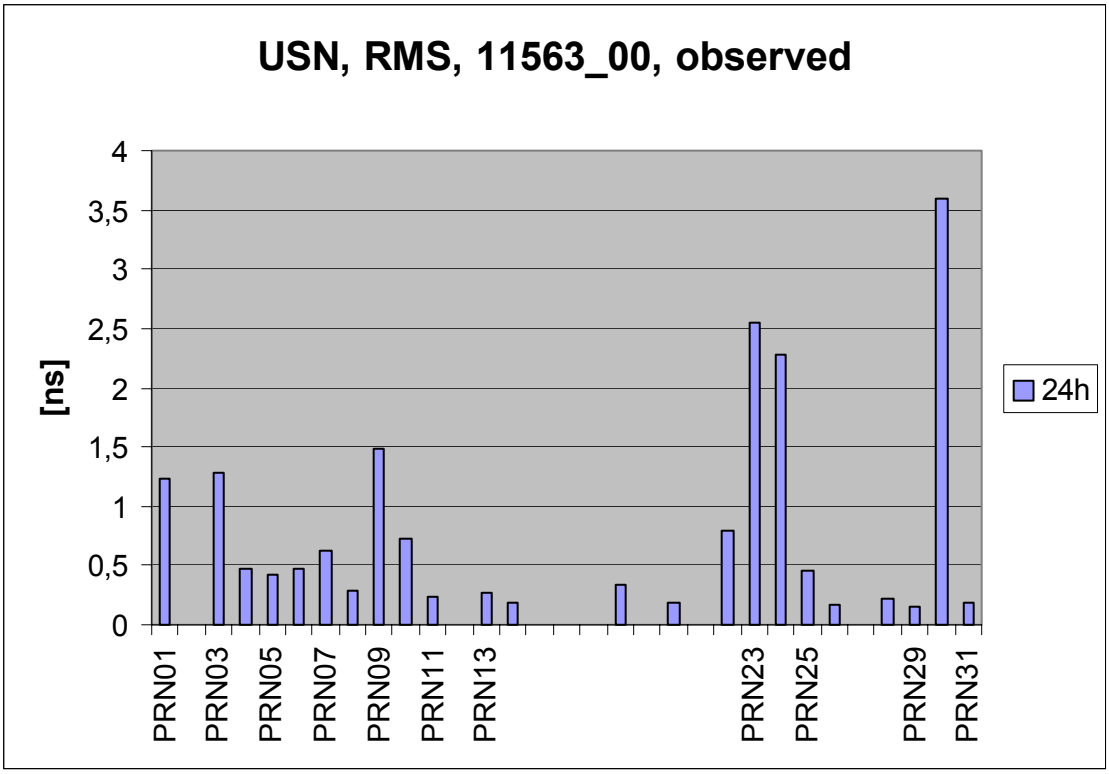

Figure 10a: clock-rms, day 3 , 00 UTC; offset+trend reduced

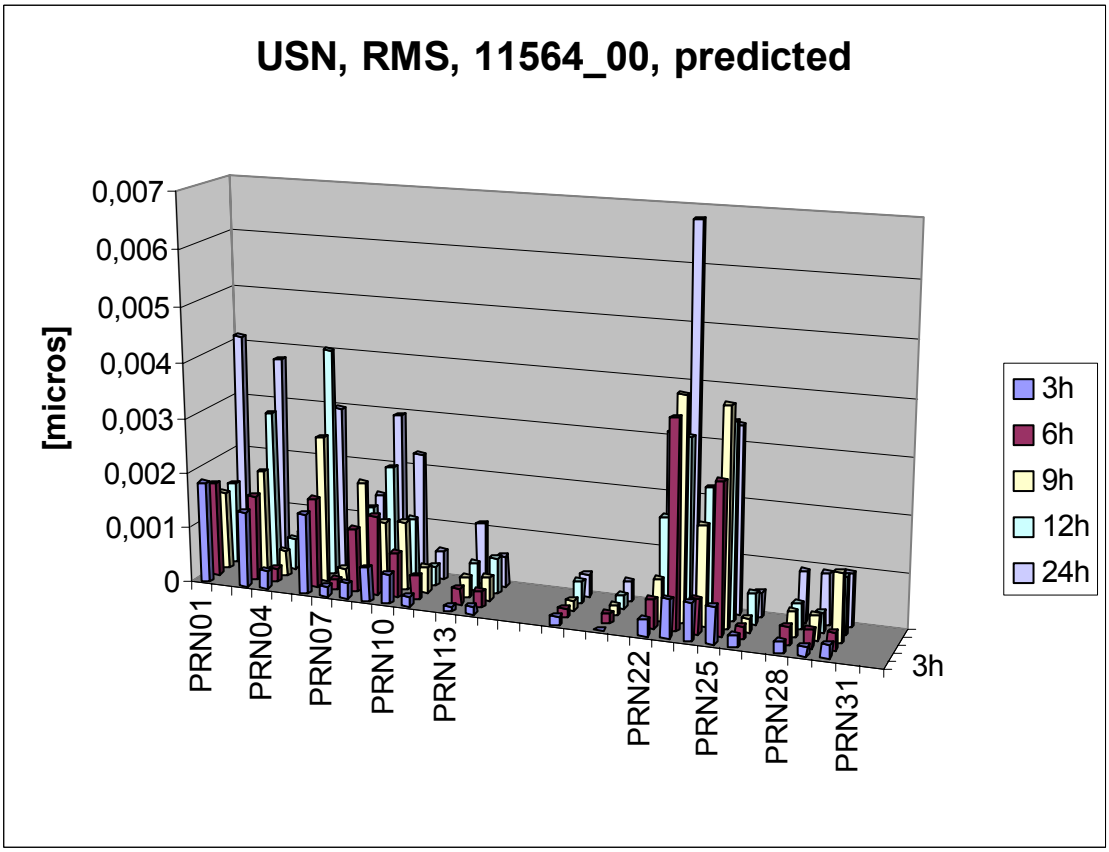

Figure 10b: clock-rms, day 4 , 00 UTC; offset+trend reduced; 5 time slots

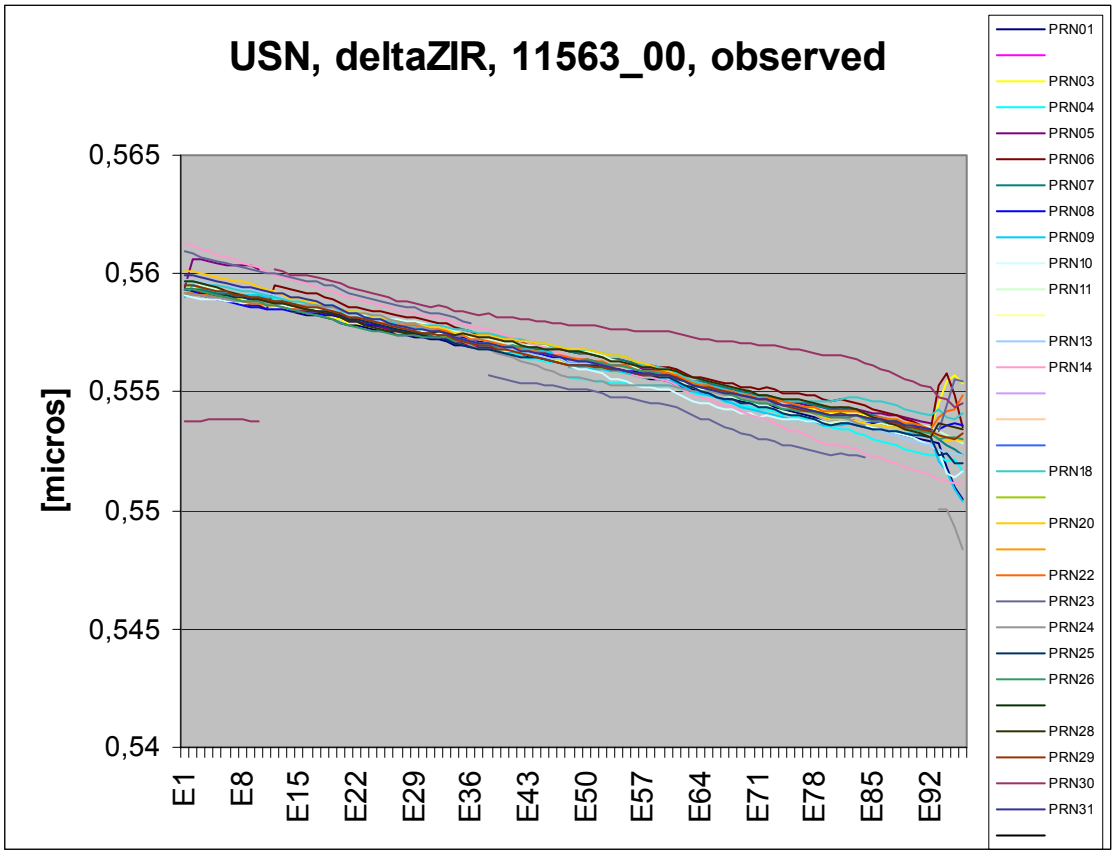

Figure 10c: raw clock difference, day 3 , 00 UTC

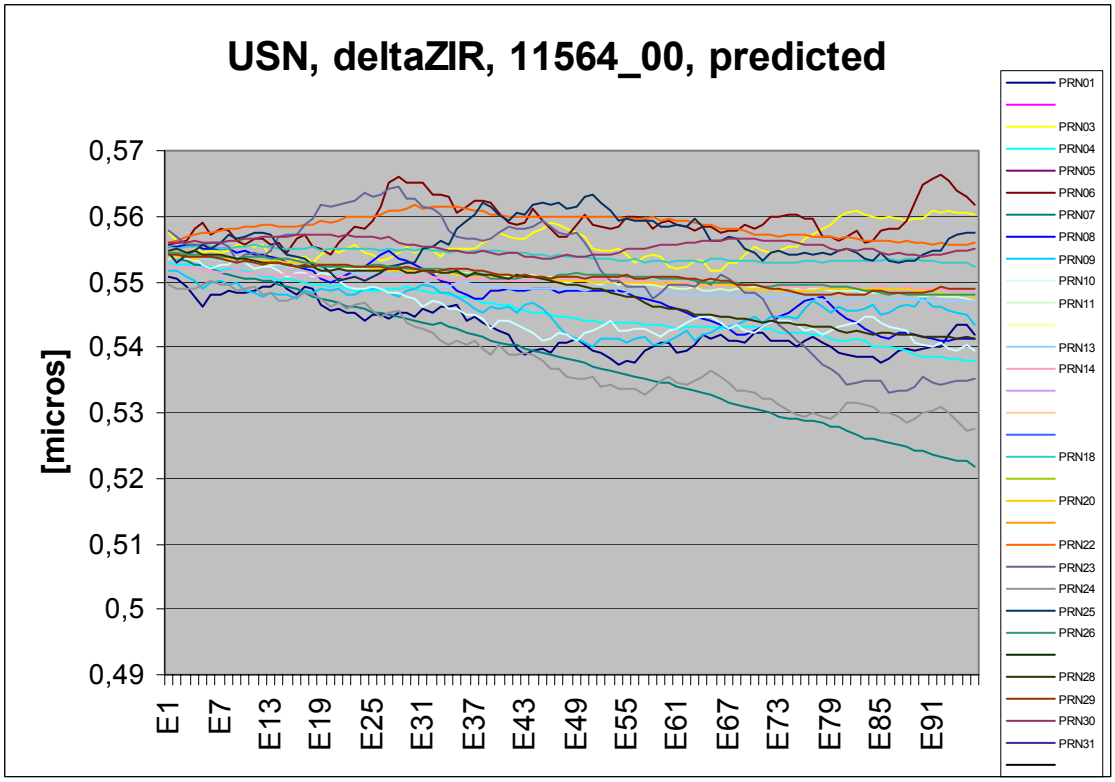

Figure 10d: raw clock difference, day 4 , 00 UTC

Example 3 is in principle related to the IGS Rapid Combination. The same software as described above has been used to show the raw clock differences per satellite between the IGS Rapid Combination (Wk 1159, day 3) and the accompanying JPL submission. This graph should demonstrate a number of missing clock epochs in the JPL clock RINEX file. While offset and drift of the solution w.r.t. the combination is unproblematic, these gaps pretend frequent reference clock jumps, which causes the combination software to reject the JPL- solution although the submitted clock values are in principle fine.

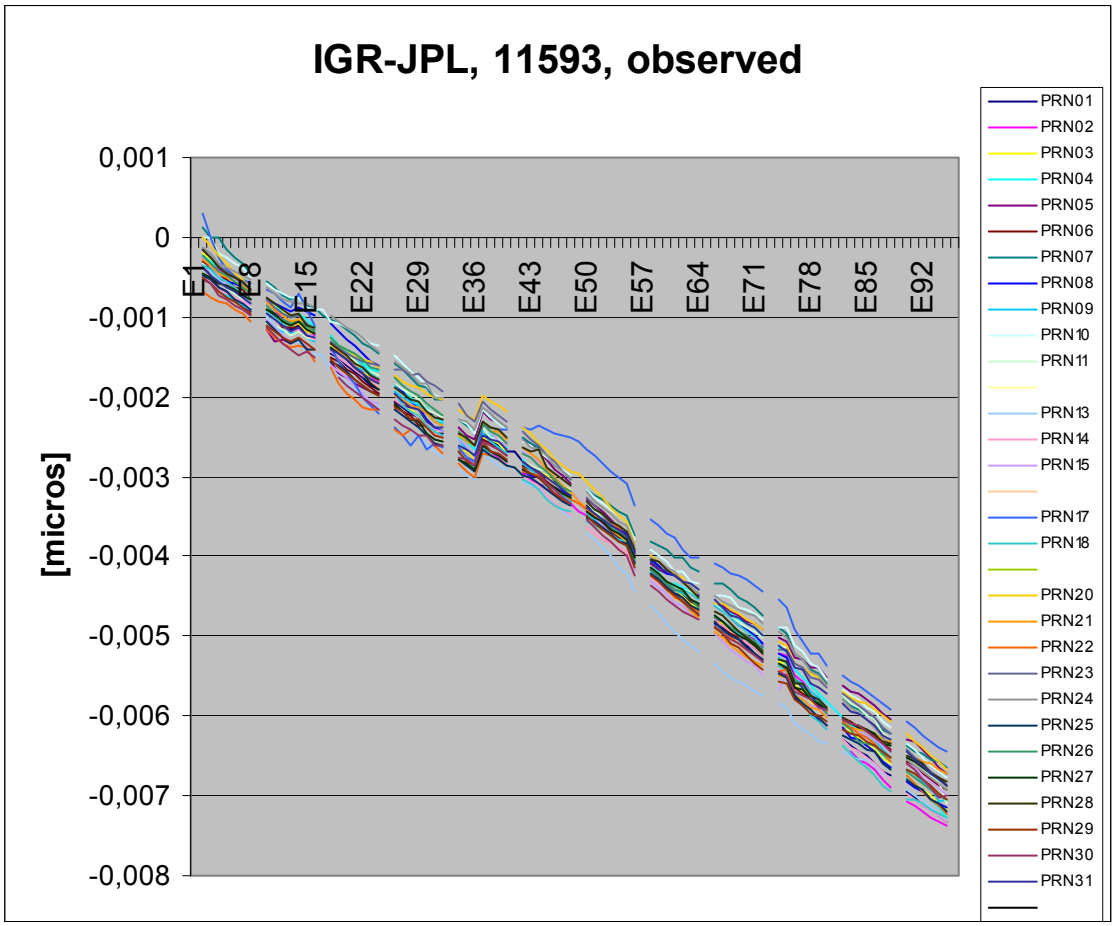

Figure 11: raw clock difference; IGS Rapid Combination-JPL

IGU / Percentage of Missing Satellites per AC

As mentioned above the Ultra-Rapid Orbit Combination usually suffers from a remarkable number of satellites missing in the AC-submissions (about 10-15%). The situation is illustrated in figures 12a and 12b. The figures are based on ultra-rapid comparison logs issued twice daily. Submitting 100% of the satellites would stand for all tracked satellites *times 2 (2 updates per day)*times 7 days *times the number of weeks. Missing full submissions as well as missing satellites within a submission reduce this score; satellites which are forwarded by less than 3 centers (and are therefore rejected from the combination) increase the score of the submitting AC.

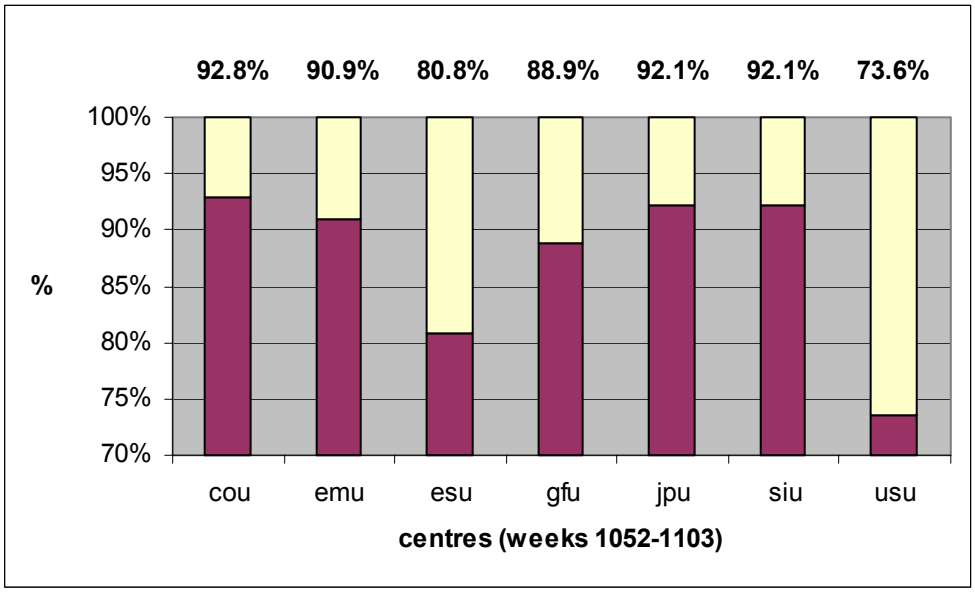

Figure 12a : since start of IGU experimental phase

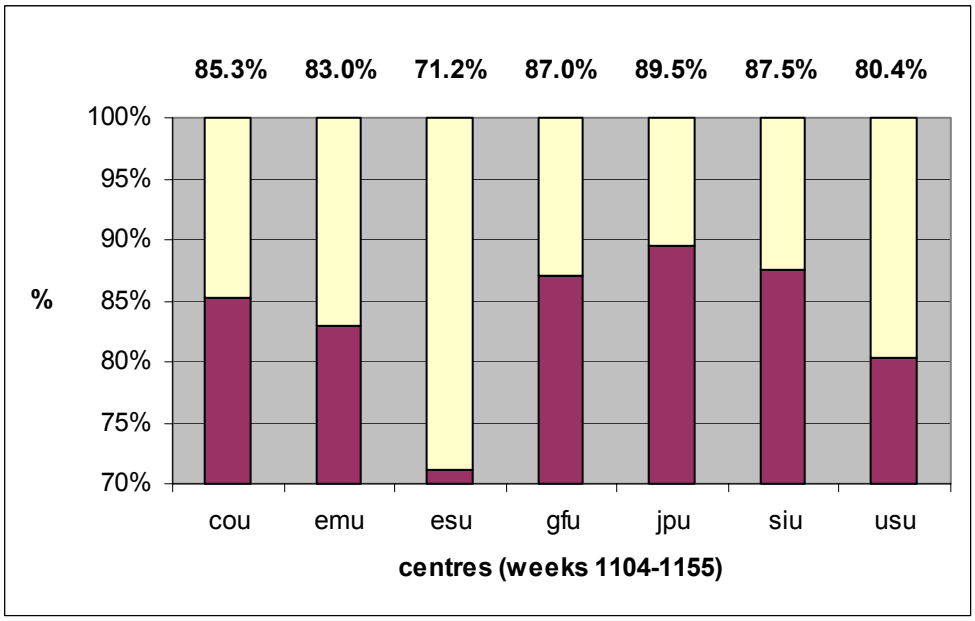

Figure 12b

The CODE submission (COU) has to be discussed explicitly. CODE provides full predictions (48 hours) instead of 24 hours orbit and clock estimates and 24 hours predictions. So, the CODE submission cannot be used for the combination process but will be included in the logfiles for comparisons. On the other hand the CODE column represents the true percentage of satellites passing successfully the combination process. In detail, within the period March 2000-Feb 2001 the IGU orbits covered about 93% of the satellites, while during the next year only about 85% passed the combination (about 4 missing satellites (out of 28) per IGU update). It has to stated that the accuracy of the submitted satellite orbits has been increased considerable over time. Nevertheless, the number of satellites included in the IGU orbits has to be enhanced again as soon as possible.

In this context figures 13a and 13b show the number of satellites with less than 3 AC-submissions (the combination software rejects that satellite from the IGU orbit file) over the past 1.4 years (in week 1087 the first official IGU products were issued). In case the COU solution (which is almost always available) would serve as the third missing solution this diagram shows, how often the COU prediction was better than 150 cm (quite better than broadcast) and how often worse than 150cm. The statement is quite clear: the predicted orbit cannot replace a regular orbit submission, based on 24 hours of observation. We urgently need all satellites in the AC submissions and we urgently need the COU orbit to be based on observations.

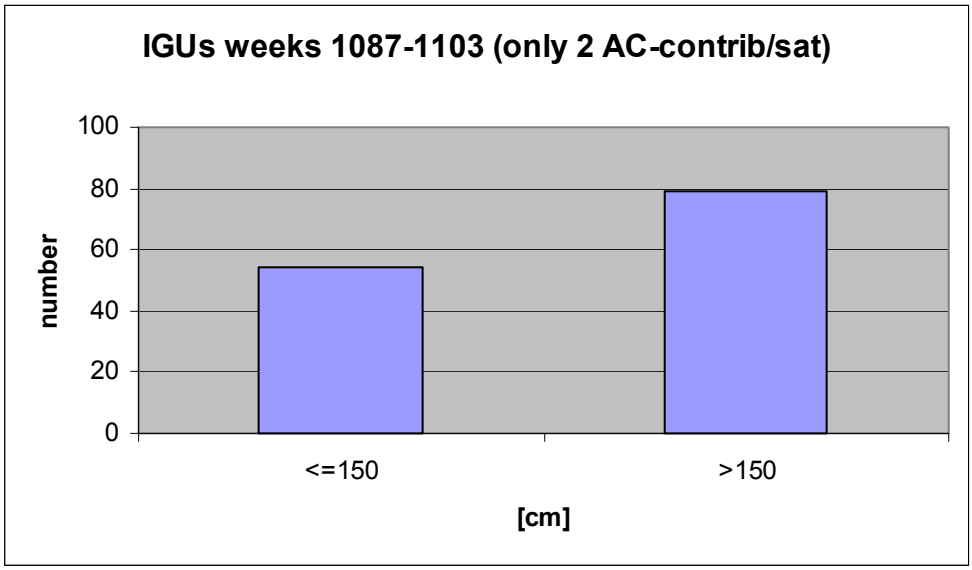

Figure 13a

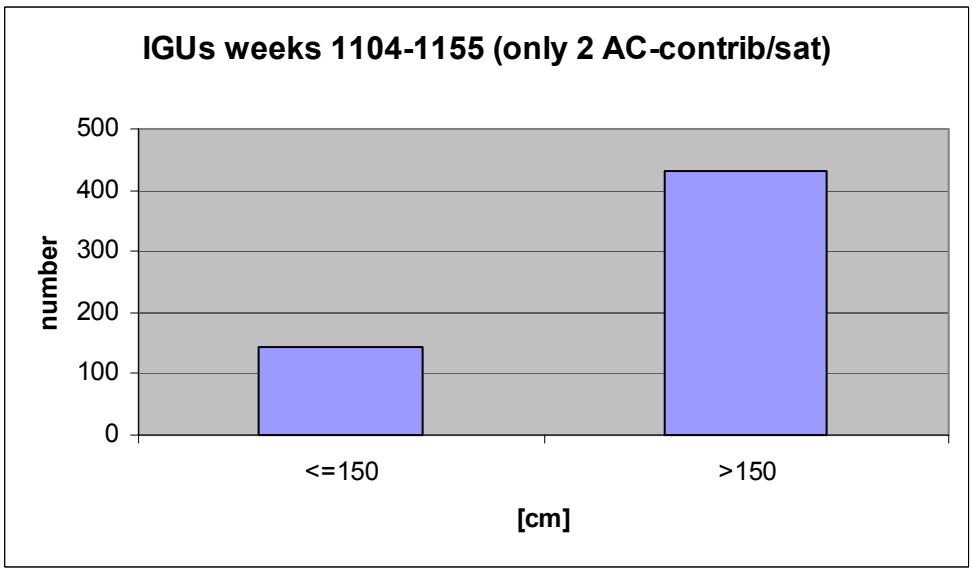

Figure 13b

Acknowledgements

The author wishes to thank Veronika Bröderbauer for the preparation of the Ultra-Rapid Comparison Plots and Elisabeth Fragner for her invaluable help in operating the IGS product combination software and for providing the GLONASS Orbit Combination Graphic.

References

IGS Workshop 2002 Recommendations
http://www2.geod.nrcan.gc.ca/~pierre/workshop_reco_website.htm

Review of IGS Analysis Products
R.Weber, J. Ray, J. Kouba
http://www2.geod.nrcan.gc.ca/~pierre/position_papers.htm

International GLONASS Pilot Project
J. Slater
Workshop Proceedings

Testing of the Proposed IERS 2000 Convention Sub-Daily Earth Rotation Parameter Model

J. Kouba
Natural Resources Canada, Geodetic Survey Division, 615 Booth Street, Ottawa, Canada K1A 0E9
email: kouba@geod.nrcan.gc.ca

Abstract

The differences between the proposed International Earth Rotation Service (IERS) 2000 and the conventional IERS 1996 sub-daily Earth rotation parameters (ERP) models can reach 0.1 mas and 0.1 mas/day. The largest differences are seen for the beat periods of 14.2 and 360 days, which correspond to the diurnal tidal waves of *O1* and *(K1, P1*), respectively. Precise independent polar motion (PM) rate solutions effectively doubles the sampling rate and allows for effective testing of sub-daily ERP models and other periodical effects at the diurnal and semi-diurnal frequency bands. The JPL independent daily PM rate solutions, which on November 12, 2000 have switched to the conventional IERS 1996 sub-daily ERP model from the older model of Herring and Dog (1994), now show no, or greatly reduced 14.2 day amplitude (*O1*) peaks. This has confirmed that the anomalistic amplitudes at the 14.2 day period, seen for JPL PM solutions prior November 12, 2000, was largely due to the use of the older sub-daily ERP model. The new IERS 2000 sub-daily ERP model is expected to perform equally well, or slightly better than the conventional IERS 1996 model, as indicated by the JPL PM rate solutions, corrected for the IERS 1996 and 2000 model differences (see Figure 1).

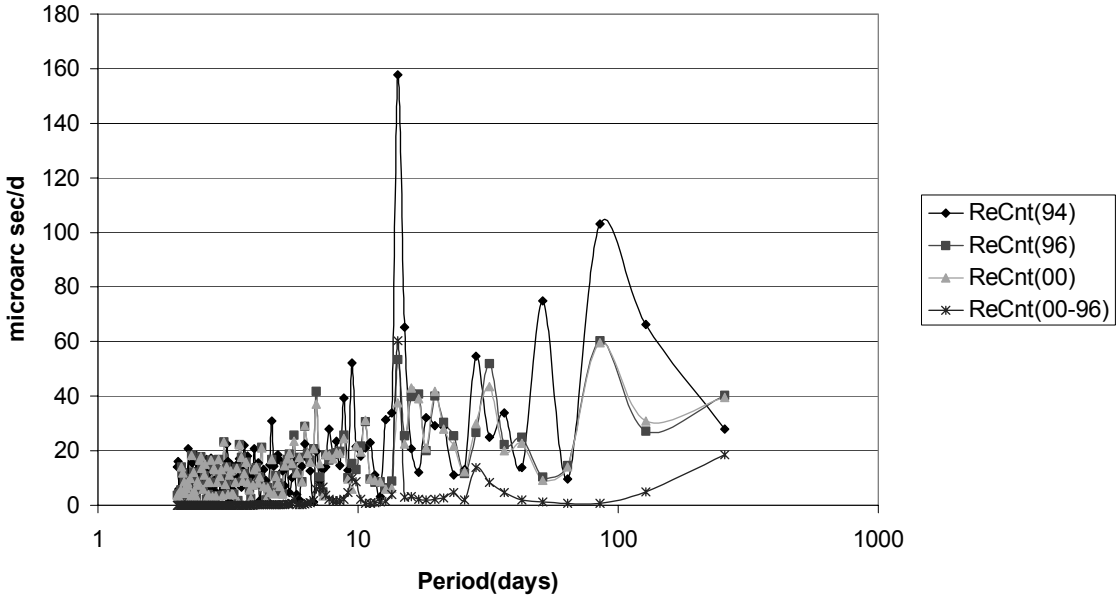

Figure 1: Spectra of JPL retrograde (negative) PM rate solution discontinuity tests (*ReCnt*) during February 2000 to July 2001. (Sub-daily ERP models: Herring and Dong 1994 (94) used prior November 12, 2000; IERS 1996 (96) and IERS 2000 (00) after November 12, 2000)

The analyses of noisier, but also independent EMR PM rate solution series did not produce any such indication. However, this continuity testing is not possible for the currently official IGS Final ERP series and the most of the AC ERP rate solutions, for which ERP rate continuities are enforced during each week. (For a complete report, refer to the electronic version of the workshop proceedings)

Reference:

Herring, T. A. and D. Dong, 1994, Measurement of diurnal and semidiurnal rotational variations and tidal parameters of Earth, *Jour. Geoph. Res., Vol. 99*, No. B9, September, pp. 18051-18071.

Long-Term Consistency of IGS Products

T. P. Yunck
Jet Propulsion Laboratory
California Institute of Technology
tpy@jpl.nasa.gov

The long-term consistency of IGS products is a pre-eminent concern for all of us. As the record of our products lenthens, our ability to tap that record for its potential science value depends critically on preserving strict consistency over the full history, despite inevitable changes in equipment and periodic updates of the ITRF. At present, to my knowledge, there are no uniformly accepted standards or procedures across the IGS for achieving such consistency, or any strict guidelines as to what constitutes long-term consistency. A number of strategies are now in use. When the ITRF is updated, some centers are able to reprocess their entire archive of data and redetermine all past solutions in the new frame. Other centers, owing to the computational burden of their processing approach, simply compute transformations to bring past solutions into the new frames. While the first approach is most desirable, it can present some serious challenges, particularly as the data record expands and expert analyst intervention remains a factor. Other intermediate options are also possible. Further discussion is provided in the position paper, "Review of IGS Analysis Products," prepared by Ray and Weber for this workshop. We recommend that the IGS take up the general question of long-term consistency and seek a workable strategy for maintaining the internal consistency of official IGS products over the full archival history, despite differences in approaches at individual analysis centers. One goal should be to define a careful and rigorous transition procedure, with standards for each analysis center to follow and a certification process to assure compliance, when converting our products to each new ITRF release.

Extending the Standard Product 3 (SP3) Orbit Format

Steve Hilla
National Geodetic Survey, NOAA
1315 East-West Hwy, Silver Spring, Maryland 20910
email: steve.hilla@noaa.gov

Abstract

At the last IGS Analysis Center Workshop at USNO, it was suggested that a new SP4 orbit format be developed so that orbit files distributed by the IGS could include some type of clock accuracy information, and so that separate accuracy codes would be available for the observed versus predicted parts of the Ultra-rapid orbit files. Since modifications for adding these accuracy codes are relatively minor, they could be made in such a way as to be mostly backwards compatible; in which case the new format could be considered version C of the current SP3 format (SP3-c).

Previously, W. Gurtner and M. Rothacher have defined an SP3-b format for combined GPS/GLONASS orbits (see IGEX Mail 0042, 27-Oct-1998). This format is backwards compatible with the original Standard Product 3 format (SP3-a), with the exception of the satellite ID labels which were changed from an I3 field to a A1,I2 field to accommodate both GPS and GLONASS identifiers in a manner similar to RINEX files. Also, the orbit group at the National Imagery and Mapping Agency (NIMA) has added an "E" flag in column 75 of the SP3 Position and Clock Record, to denote a clock event (for instance, when a clock swap occurs on a satellite). The IGS can easily utilize both of these previous modifications for the new format. It has also been suggested to add "orbit event" flags as well: to denote when a satellite is in eclipse, when a portion of an orbit is predicted rather than observed, and/or when a satellite is undergoing some specific type of maneuver or change in status.