The IGS Analysis Products and the Consistency of the Combined Solutions *

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Abstract

The basic IGS analysis products (orbits, Earth orientation parameters, station coordinates, and clocks) are of very high quality, and should in general be more reliable and at least as accurate (if not more so) than the solutions obtained by the individual analysis centers (ACs). This position paper focuses on the current combination procedures, reporting and feedback. Possible enhancements in precision, consistency, robustness, presentation and feedback of the results are discussed. Furthermore, it addresses a need for additional products in order to meet the needs of IGS users.

1 Introduction

Many different combination activities are going on within the IGS. Ideally every AC would provide just one single file each day containing all estimated parameters, including orbit, Earth orientation parameters (EOPs), clocks, coordinates, and troposphere estimates together with their full covariance matrix. These solutions could than be rigorously combined in one single combination scheme! Of course this is not feasible for many reasons at this time; one obvious reason being the different models which are used. Another is that results from different ACs are not likely to be independent, since they are based on datasets which are largely common.

Therefore different combination activities were initiated by the IGS over the last years. The orbit combination, the first and most well known IGS combination, has played a major part in the improvement of the IGS products and has been the key to the overall success of the IGS. Based on its success other combinations have been initiated including the EOP, clock, and station coordinate combinations by the GNAACs (in the framework of the densification project), and the troposphere combinations by Gerd Gendt at GFZ. Currently others are planned like combination of station clock estimates, (in the framework of the time-transfer project), and ionosphere estimates.

Due to the diversity of the combination activities and consequently the different methods used, the consistency between all these IGS combined products is not (automatically) guaranteed.

* IGS Analysis Center Workshop, Darmstadt, February 9--11, 1998

The complete decoupling of the orbit- and coordinate-combinations can lead to some problems. The resulting IGS-coordinates, which essentially represent the IGS reference frame, are not necessarily compatible with the IGS-orbits and EOPs. Furthermore the feedback to the AC's and other users of IGS products, coming from the different combinations, has very different levels of quality and usefulness. Some reports are very good and extensive whereas others give practically no information. The different combinations and resulting products also make it very difficult for ''outsiders'' to get and keep a good overview of the IGS activities and developments. It is even hard for those within the IGS to keep track of all activities and to find the necessary information!

In this position paper we critically review all different combination activities which are currently performed within the IGS. We review the:

- combination procedures which are currently used,
- consistency of the products within a combination (e.g. orbits, EOPs, and clocks),
- consistency of the products between different combinations (e.g. orbits, EOPs, clocks, and Sinex),
- feedback from the different combinations, and
- ways of improving any of the above.

One other aspect of the IGS which is discussed here will be the quality control of the data from all the IGS stations! Although the observational data in the Rinex format is one of the most important IGS products, if not **the** most important, the IGS has not been very successful in setting up and maintaining a standard for IGS stations.

2 IGS Combination Activities

Currently the following combination activities are performed within the IGS:

- Combinations by the IGS Analysis Center Coordinator for the Final, Rapid and Predicted results:
  - Orbit combination
  - EOP combination
  - Clock combination
- Station Coordinate combination
  - JPL, Michael Heflin,
  - MIT, Tom Herring,
  - NCL, Phil Davies, and
- Troposphere Combination at GFZ, Gerd Gendt.

As mentioned before ideally every AC would provide just one single product file each day containing all currently available products. Because this is not possible for obvious reasons we have the different IGS combinations listed above. This means that the resulting combined IGS products are not necessarily consistent at the required level of accuracy.

Another issue which we have to address is the extent to which the products of the individual ACs are internally consistent. For instance some ACs provide satellite clock estimates although they use double difference observations for their orbit estimates. We have to know and understand to what extend the orbits, EOPs and clocks of these ACs are consistent. Other possible inconsistencies exist, for instance high rotations sometimes observed in the orbit combinations indicate that for some ACs the orbit and pole estimates are inconsistent.

So besides the consistency of the IGS combined products we should also look for possible inconsistencies within the individual AC products. All inconsistencies, if any, should be detected and corrected, or reduced to an acceptable level, as soon as possible.

2.1 Review of ACC Combination

The IGS orbit combination was originally developed in 1993, [*Beutler et al.*, 1995]. Since then many improvements and additions have been made by the Analysis Center Coordinator (ACC) and his colleagues at NRCan, [*Kouba*, 1995; *Kouba and Mireault*, 1996]. However, the basic method of the combination, the L1-norm, was not changed.

It is our impression that the IGS final orbits, EOPs and clocks are of very high quality and are in general more accurate and reliable than the solutions obtained by the individual ACs. Nevertheless, there are possibly a few improvements which can be made. First of all the consistency between the combined orbits and the combined clocks can, and should, be improved, especially with respect to those users who want to perform precise point positioning [*Zumberge et al.*, 1997*a*]. A second improvement may be found, as envisioned during the initial development in 1993, in the use of a priori weights for the individual satellites.

2.1.1 Consistency between the IGS orbits and clocks

The quality of the satellite clock estimates provided by the ACs has improved dramatically over the 1996--1997 timeframe. Thanks to the increased accuracy of the AC satellite clocks and the growing number of people interested in using precise point positioning (using precise orbits *and* satellite clocks) it became clear that the IGS orbits and clocks were inconsistent at the 200 mm level. To improve the consistency between the combined IGS orbits and the combined IGS clocks two changes were made recently to the clock combination algorithm.

The two new features are:

- an improved clock weighting scheme, using the clock estimates from one AC as reference instead of the satellites without Selective Availability (SA, only 1 remaining), and
- correcting the AC clocks, before the combination, based on the difference in the radial component between the AC orbit and the IGS combined orbit.

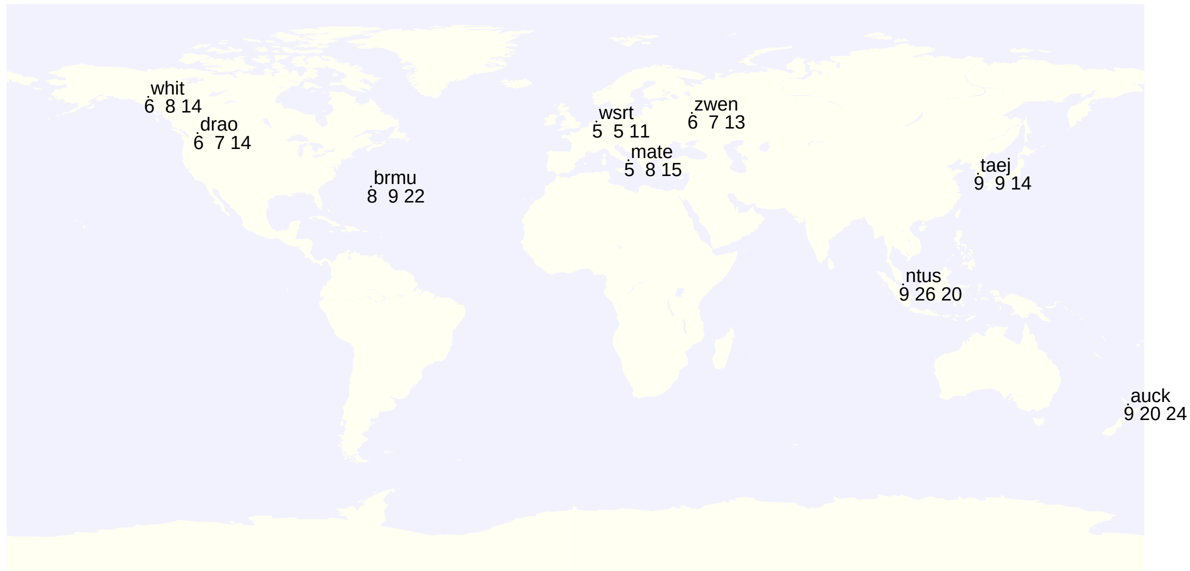

Figure 1: Sites used. The numbers indicate the observed daily repeatability for site coordinates in the North, East, and Vertical dimensions, using the latest clock combination technique, for the period December 7 -- December 27, 1997.

Different ACs use different reference clocks. Therefore the AC clocks have to be aligned before the combination to correct for the differences between the different reference clocks. For this purpose the satellites without SA were used, because their clocks can be accurately modeled fitting only an offset and a drift. At the same time the RMS of this fit was used for the clock weighting. Because only one satellite remains without SA the alignment has become unreliable. Therefore the alignment was changed by using one of the ACs as reference.

Providing the orbits and the clocks of the individual ACs are consistent then orbit differences between the ACs should show up in the clocks as well. In a first order approximation only the radial differences are important. Therefore an attempt to improve the consistency between the orbit and clocks, by correcting the AC clocks based on the radial AC orbit differences, was made **and** coded almost 3 years ago! It was only implemented recently due to other more urgent combination improvements/enhancements and because 3 years ago no improvement was found!

One way to evaluate the IGS clock/orbit product is to use it in precise point positioning [*Zumberge et al.*, 1997*a*] to analyze data from a single receiver. We have selected nine sites (Figure 1) and the 6-week period beginning November 16, 1997 to perform such an evaluation. The sites were selected to give reasonable global coverage. To ensure that the results using the JPL product wouldn't look artificially good, it was decided to exclude sites that were used by JPL for its IGS contribution during the test period.

The SP3 product contains both orbits and clock information for each satellite, once every 15 minutes. SA results in large and rapid fluctuations in the GPS clock correction. Thus only data that are on the even quarter hour in a daily Rinex file can be modeled to the sub-centimeter level for phase and half-meter for pseudorange, given a precise orbit/clock product. For each day and

Product	*period*	*North (mm)*	*East (mm)*	*Vertical (mm)*
IGS0	Nov 16 -- Dec 06	11	17	24
IGS1	Dec 07 -- Dec 27	8	10	16
NEW	Dec 07 -- Dec 27	6	8	14
JPL	Nov 16 -- Dec 06	4	4	7
JPL	Dec 07 -- Dec 27	4	6	8

Table 1: Median daily repeatabilities as a function of time and orbit/clock product. The table contains the median value of the nine sites. A change in the clock weighting scheme was implemented on Dec 7, and a proposed improvement using radial variations in contributed orbits was also evaluated (*NEW*). The JPL results, using the same timeframes and sites, are shown for comparison.

site, the data are used to estimate site coordinates, with satellite parameters -- orbits and clocks -- held fixed at their values in the SP3 file. For eclipsing satellites, the yaw angle was fixed at its value as estimated in JPL's contribution to the IGS. Gipsy/Oasis-II was used for all processing. On a given day, only satellites that are in both SP3 product files were kept. The JPL product contains only satellites which JPL considered usable, so this criterion attempts to exclude poorly modeled satellites.

Shown in Table 1 is the median of the daily repeatabilities of site coordinates as a function of orbit product and time window (the numbers indicate only fluctuations, and do not include any average offset). The product labelled ‘‘IGS0’’ used the original clock combinations. For the product labelled ‘‘IGS1’’ the improved weighting scheme was used and for the ‘‘NEW’’ product the radial corrections were applied in addition to the improved weighting scheme. For reference the results using the JPL orbits and clocks using the same timespan and sites are also given. Note that the solutions ‘‘IGS0’’ and ‘‘IGS1’’ are based on the official IGS products for those timeframes whereas the the ‘‘NEW’’ product represents the now operational (current state of the art) IGS clock combination (active since GPS-week 0938, day 0 for IGS and GPS-week 0940, day 1 for IGR).

With the latest implementations regarding the IGS satellite clock combination we find typical daily repeatabilities of 10 mm horizontal and 14 mm vertical for stationary site coordinates. These are approximately a factor of two better than before these improvements were implemented and are approaching the individual AC consistency. This is quite an achievement in view of the very inhomogeneous input for the clock combination: not all ACs submit clocks, the quality of the clocks are very different and one AC provides clocks only every 30 minutes. However, the results using JPL's SP3 product indicate that there is still some additional room for improvement for the IGS product.

One feature of the results that is not well understood are significant variation among sites in the repeatabilities, which are indicated in Figure 1. An extreme case is Auckland, New Zealand, where the repeatabilities are approximately a factor of two larger than the median (this is not observed when the JPL product is used). Further enhancements may be necessary to reduce these significant site-to-site variations.

One possibility to further improve the consistency of the combined IGS clocks may be found in the alignment of the AC clocks. Currently the alignment of the AC clocks is achieved by estimating one offset and drift per AC with respect to a chosen reference AC. In order to do proper clock alignment amongst ACs, i.e. to remove the effects of a single reference station, we need AC station clock solutions (e.g. also at 15 min sampling), or at least a subset of consistent AC station clock solutions. The station clock solutions are also essential to the time transfer pilot project [*Ray*, 1998]. Furthermore an important quality control could be realized by analyses of the stable hydrogen maser clock subnet of stations.

Note that there are some significant hurdles in the clock combination. The quality of the individual AC clock solutions are very different. Only three ACs (EMR, GFZ, and JPL) provide satellite clocks based on processing undifferenced phase (and code) data. Of these, GFZ has a sampling rate of only 30-minutes with respect to the nominal 15-minutes sampling. This may cause problems in the combination, something which will have to be studied.

The clock estimates of two other ACs (CODE and ESA) are based on (phase-)smoothed code observations and may be noisier than the true ‘‘phase-clocks’’. This may have some negative influence on the combined IGS clocks as well. It should also be investigated to what extent the clocks of these ACs are consistent with their other products, because for both ACs the primary products (orbit, EOP and coordinates) are based on double difference processing!

Clearly it would be very advantageous if all ACs would provide satellite and station clock estimates at least as frequently as every 15-minutes. Preferably the clocks should be of similar quality, comparable to the quality of the orbits.

2.1.2 Use of a priori satellite weights

One limiting factor in the orbit combination scheme is the fact that there is no (a priori) information about the quality of the individual satellites! Although the orbit exchange format (SP3) allows for the inclusion of (meaningful) accuracy codes for each individual satellite this option is not used by many ACs. In the combination scheme this information is only used, when available, a posteriori to compute the weighted RMS.

During the original development of the orbit combination software, using the L2-norm (least squares instead of the L1-norm) it was envisioned that at some stage a priori weights would be used for each satellite and possibly also for the ACs [*Springer and Beutler*, 1993]. Because satellite specific weights were not readily available in 1993 it was decided to switch to the L1-norm, a much more robust estimator than the L2-norm, to be less sensitive to bad satellites and therefore make the use of satellite specific weights obsolete.

However, looking at recent orbit combination reports several ACs exclude supposedly ‘‘bad’’ satellites from their orbit solutions. In many cases the bad satellites, however, were used in the actual data analysis and only removed from the final (SP3) product. The reason behind this is to ensure that users do not by mistake use these bad satellites. If all ACs would remove all, and the same, bad satellites there would be no problem except that we would lose (based on recent combinations) about 2 satellites each day! Because not all IGS users are interested in the highest precision this would be disadvantageous for several users. It is our conclusion that also ‘‘bad’’ satellites are to be considered IGS products, and therefore should be included in all AC submissions.

Another reason for this is that the omission of bad satellites in some, but not all, of the AC solutions could distort the combination. To avoid any distortions from missing satellites the combination, and its statistics, should be based on the common satellites only! The satellites submitted by only a few ACs can be combined a posteriori using the estimated transformation parameters and weights.

Of course the inclusion of bad satellites in the combination could, despite the robustness of the L1-norm, distort the combination. It would therefore be sensible to start using a priori satellite weights. The weights would, ideally, be based on the accuracy codes found in the SP3-header. However they could also be based on the 7-day arc fit which is performed in the orbit combination. In this way the bad satellites can easily be detected and downweighted in the combination. In any case the IGS should put more emphasis on the availability and the usefulness of the accuracy codes in the orbit files and request the ACs to submit solutions for **all** satellites, with the possible exception of satellite manoeuvres and exceptionally large modeling problems.

2.2 Review of GNAAC Combination

The combination methods of the three different GNAACs are described in detail in the IGS Annual Reports. The coordinate combination, based on the weekly SINEX files, has one very large advantage over the orbit combination. It has access to the full covariance matrix of the coordinate estimates. Therefore the combination method is both easier and more accurate than the orbit combination where we have no statistical information whatsoever.

It has been shown in several publications, [*Davies and Blewitt*, 1997] that the GNAAC combinations are better than most if not all AC solutions. We therefore conclude that the GNAAC combinations are in very good shape and can not significantly be improved. However, there are some persisting problems with site names, site ties, antenna types etc. etc. which have to be sorted out once and for all **soon**. Because these inconsistencies are a more generic IGS problem they are discussed in a later section.

The only ‘‘problem’’ with the GNAAC activities is that there is not yet an official IGS product! There is no official IGS combined solution and therefore no IGS reference frame. This is confusing for many of the IGS users and also quite illogical. Essentially we need only one GNAAC but redundancy may be useful. Therefore the easiest, and politically correct, decision would be that a combined IGS solution is based on a combination of the three GNAAC combinations, the ‘‘super’’ combination.

One planned addition to the Sinex submissions is the inclusion of the EOP parameters. This will facilitate and improve the IGS EOP combination. This improved combined IGS EOP can than be used in the orbit combination. In this way the IGS combined orbit will be consistent with the IGS reference frame, [*Kouba et al.*, 1998]. However, this requires that the GNAAC combinations are done prior to the orbit combination, e.g. before or on the second Wednesday (10 days) after the end of the GPS-week.

2.3 Review of Troposphere Combination

For several months the tropospheric zenith delay estimates of most ACs, as provided in the (pseudo-)Sinex format, have been combined [*Gendt*, 1998]. For this combination it is essential that the differences in the zenith delays, caused by differences in the station coordinates, are corrected prior to the combination. This is very similar to the correction of the satellite clocks based on the radial orbit differences. Clearly a consistent IGS coordinate (and velocity) set, the IGS reference frame, is helpful, if not essential, for the troposphere combination. The individual AC troposphere solutions can then be made consistent with this official IGS reference frame prior to their combination. In this way the troposphere estimates would be related to the ‘‘true’’ and constant reference frame.

One aspect that should be mentioned here is that in small networks there is a large advantage if a global station is included together with its estimated tropospheric delay. In a small network (few 100 km) it is difficult to estimated the absolute tropospheric delay. The inclusion of one ‘‘global’’ station with its estimated tropospheric delay solves this problem. This may be very important for future meteorological investigations. Here similar consistency problems, as encountered in the case of precise point positioning between the orbit and the clocks, may be encountered between the IGS combined tropospheric zenith delays and the IGS combined station coordinates.

One additional problem in the troposphere combination is the use of different mapping functions by the different ACs. The effect different mapping functions have on the zenith delay estimates should be studied. It should also be investigated how an IGS user can use the combined zenith delay, e.g. which mapping function he should use. Analogous to how the clocks are adjusted based on different reference clocks the zenith delay estimates should be corrected, calibrated, to account for the usage of different mapping functions.

Finally it is very likely that future troposphere estimates will included tropospheric gradients; at this time gradients are already routinely estimated at CODE and JPL. The current tropospheric Sinex format currently does not allow for the inclusion of tropospheric gradients.

2.4 Consistency between the Combinations

It is essential that **all** submitted AC products be either consistent, or sufficient info is included (e.g. EOP) that they can be made consistent before IGS combinations. This applies to all products, i.e. orbit, EOP, clock, Sinex, and troposphere.

Therefore the inclusion of the EOP parameters in the AC Sinex submissions and GNAAC combinations is absolutely essential in order to make the IGS orbits, EOPs and clocks consistent with the IGS reference frame [*Kouba et al.*, 1998]. All ACs therefore **must** included EOPs in their Sinex solutions **as soon as possible**. A nice benefit from this will be the (much) improved quality of the combined IGS EOP because it will be done using the full covariance matrix.

3 Review of feedback

In general all the results and combinations produced in the framework of the IGS are unique in the (scientific) world. However, there is always room for improvement! Therefore here it is tried to identify in what way all the information from the different IGS activities can be improved, enhanced, streamlined, and so on.

Because the troposphere combination is in its pilot phase it is not considered here. However, we would like to state that it already looks to be in good shape and the reports should soon become official and distributed using the IGSREPORT e-mail system.

In our opinion there is one central problem with respect to the feedback. The information is coming from very different sources and in very different formats. Therefore it is suggested that all interesting results are gathered and made available at a central place. The information should be made available both numerically and graphically, and automatically updated. The most likely way of providing this kind of service is by using the World-Wide-Web (WWW). Essentially all kind of routinely produced information should be made available. Besides feedback and results from all different combinations the site should also provide documents describing the IGS, its products and how to access and use the different IGS products.

Some items which this WWW (feedback) site could contain are:

- time series of the transformation parameters coming from the orbit combination,
- time series of station positions,
- time series of network/station performance,
- access to the EOP plots and statistics as provided by USNO,
- documents describing different facets of the IGS,
- documents describing access to the IGS products,
- documents describing usage of IGS products,
- and many many more.

Some of these features are already available at the IGS Central Bureau (CB), and others have been proposed by CODE when it assumes the role of Analysis Center Coordinator (ACC). We expect cooperation and coordination between the CB and ACC to provide improved feedback.

3.1 ACC Final and Rapid Combination Feedback

The feedback as provided by the (final) IGS orbit combination is one of the most valuable within the IGS. It is clear that it provides excellent information. One point which can be improved is the navigation solution. Currently smoothed code observations are used which are not really capable of showing the quality of the orbits and clocks. Therefore it should be enhanced by using the carrier phase measurements. In this way it will automatically provide feedback about the consistency between the orbits and the clocks.

The feedback from the rapid orbit combination is also quite good, although the long arc test is not included here because, the rapid combination is done on a daily rather than a weekly basis. Therefore the feedback about the rapid orbits may be improved by performing a weekly comparison in the same way as is being done for the final orbits. In this weekly comparison the long arc test would than be included. One other positive effect of this is that it will give the rapid orbits more visibility and thus create some more awareness about the availability of these products.

The predicted orbit combination provides good feedback for all participants. However, if the combined IGS predicted orbit would be included in the proposed weekly rapid comparison, in the same way as they rapid orbit is included in the final combination, then the visibility and awareness of the prediction products and efforts is also guaranteed.

One upcoming problem for the rapid and predicted orbit is the change of time-zone which will take place when the ACC activities change from EMR to CODE (sometime in 1998). The deadline for the rapid products will have to be adjusted to allow the combination to be performed during ‘‘normal’’ office hours. Assuming that the rapid combination should be performed before 19:00 MET (e.g. 17:00 or 18:00 UTC depending on daylight saving time), this would mean a effective deadline around 16:00 hours UTC! In view of the increasing demands for real-time products (especially troposphere) this would be a (small) step in the right direction. It should be investigated if an earlier deadline is feasible (12:00 hours UTC?).

3.2 GNAAC Combination Feedback

The feedback of the individual GNAACs is very different. Thanks to the fact of having three different GNAACs the total feedback is sufficient. The recent addition, by the MIT GNAAC, of providing station coordinates residual file is valued highly. Nevertheless there are some problems with the GNAAC combinations.

Most importantly, and most disturbing, are the problems with station names, receiver and antenna types, and antenna heights and phase center variations. These are well known IGS problems which are not caused by the GNAACs. These station inconsistencies encountered in the GNAAC activities underline the bad situation of the IGS global network. Furthermore, the persistence of these problems, despite the GNAAC combinations, shows that the GNAACs are not very well embedded in the IGS structure. This situation should be *much* improved before any form of IGS reference frame realization can based on the GNAAC results. Hopefully the ‘‘super combination’’ will help to close the gap between the GNAACs and the ACs.

One other confusing part of the GNAAC feedback is the time at which the different GNAAC combinations are performed. The delay is usually much larger than that of the orbit combination an on several occasions a GNAAC center has provided several weeks at one time. For successful and timely realization of the IGS reference frame the GNAAC combinations will have to be performed both more regularly and more timely. The proposed implementation of the EOPs in Sinex and the use of the combined EOP in the orbit combination implies that the deadline for all GNAAC combinations will be 10 days after the end of the GPS-week. This will solve this problem.

3.3 Feedback to Data Centers and Station Managers

The IGS has not been very successful in controlling the quality of the stations, their data, their Rinex files and the resulting coordinate estimates despite several different checks which are being performed routinely, including:

- JPL network reports,
- CDDIS Rinex checking,
- IGSCB station log and Rinex checking.
- CODE Rinex checking,
- several GNAAC checks, and
- coordinate residuals from the MIT GNAAC.

Little action is taken based on all the available information. All different information pieces should be gathered at a central place (IGSCB, DCs, or ACC) and erroneous stations should be informed of their errors and their data files flagged by the IGS *automatically*.

The (still unexplained !!) problems with the station of Madrid, throughout 1997, showed that the way station problems are currently handled within the IGS is completely insufficient. Many IGS customers used the station as fiducial for their local network which resulted in severe problems (due to the several cm apparent shift of the station). Also the list of discrepancies in antenna heights, antenna types between station logs and Rinex files, and consequently between ACs and GNAACS, is (still) almost endless.

Despite all the checks being performed the situation has not really improved over the last two years. Therefore it is time to specify some (strict) guidelines on what the *minimal* requirements are to become and to remain an IGS station. In our opinion the absolute minimal requirement is the availability of a complete station log file at the IGSCB and Rinex files which contain information corresponding to the station log. The IGS should aim to provide *only* data from official IGS stations. This should take effect as soon as possible but no later than July 1998. Data from non-IGS sites may be made available but it should be clearly flagged. by either putting the data in a separate directory at the DCs or by (re)naming the file.

The Rinex ‘‘file sequence number’’ may be abused for flagging files in the following way:

- XXXX0010.98O_Z -- normal name for an IGS station
- XXXX001Z.98O_Z -- for an non-IGS station

Flagging non-IGS files in addition to improved and automatic feedback to the Data Centers (DC) and station managers is the **only** way to improve the current (bad) situation of the global network. It is the key to ensure and maintain a high quality global network! The details on how exactly to define a non-conforming station need to be worked out.

4 Future Products

It is very difficult to predict the future and especially the future of the IGS which is still developing rapidly. Nevertheless, we can reasonably anticipate some future demands and, consequently, products.

Combined troposphere and ionosphere estimates will possibly become official IGS products. A combined troposphere solution is already being generated routinely and may soon become official. For the ionosphere the situation is less clear but already an exchange format has been defined (IONEX) and at least one AC (CODE) already routinely produces ionosphere "maps". So the generation of combined ionosphere solutions could be started very soon if enough participants are found. One ‘‘problem’’ with the ionosphere is that it is not a (by-)product of the normal processing algorithms, which use the ionosphere-free linear combination of the two carrier phase observations.

One large future ‘‘customer’’ of IGS products will be the Low Earth orbiter (LEO) missions. At the moment it seems that at a large amount, if not all, of the LEO data will be processed using precise point positioning. For most of the LEO missions it will be mandatory to have satellite clock estimates with a higher rate than the current 15 minutes. For the meteorological LEO missions (e.g. tomography) it will be mandatory to have access to satellite clock estimates with a 30 second sampling rate (assuming precise point positioning is used). If higher sampling rates are required than also a subset of the ground network stations will have to sample the observations at a higher rate. This poses no real problems because there is already a large number of sites with higher sampling rates. Only the data are not made available as official IGS data. If satellite clocks are provided with a sampling of 30-seconds people might also become interested in obtaining 30-second station clock estimates. This would especially be interesting in the framework of the time transfer project. However 30-second station clock estimates might be much more difficult to do than 30-second satellite clock estimates.

Finally, as discussed during the 1996 IGS AC workshop, there should be a ‘‘short’’ SINEX file format; a SINEX file without the covariance matrix. This would enable users to study time series of station coordinate solutions more easily. It might be wise to generate only a short SINEX file from the official IGS reference frame solution rather then generating short SINEX files for **all** available SINEX files, which could very easily confuse the IGS users!

Summarizing we foresee the following future IGS products:

- Troposphere and Ionosphere
- 30 sec satellite clocks

- 30 sec station clocks
- Short Sinex file, only for the official IGS ‘‘super combination’’

One other product might be estimates of the Earth’s Center of Mass, which could be included in the Sinex files. These estimates may also be useful for the orbit combination.

Furthermore the upcoming GLONASS test campaign (end of 1998) should be mentioned. Although not organized by the IGS, it may lead to some new products like, GLONASS orbits, the time difference between GLONASS and UTC and others.

Other, more distant, products may include:

- Earth’s center of mass estimates (included in Sinex)
- EOPs with a higher time resolution (hourly?) to verify and possibly improve sub-daily polar motion models.
- Estimation of nutation drifts. This has similar problems as the estimation of LOD (UTC drifts).
- Station coordinate solutions with a higher time resolution (hourly?) to verify and possibly improve Earth tide models.
- GLONASS products.
- ...
- and probably many many more!

4.1 Generation of accurate high rate Satellite clocks

One drawback to the clock portion of the IGS combined orbit/clock product is that precise clock solutions are available only once every 15 minutes. Unlike the orbits, which vary smoothly with time, one cannot interpolate precise GPS clocks that are computed only four times an hour (due to SA). Thus only low rate data -- 4 measurements per hour -- can be analyzed with the precise point positioning technique. To apply this technique to upcoming missions with low-Earth-orbiting (LEO) satellites carrying GPS receivers, one will need nearly continuous knowledge of the GPS clocks. They must be determined frequently enough, therefore, that interpolation is feasible.

Zumberge et al. [1997*b*] describe a computationally efficient method for determining precise GPS clocks at the full rate of the ground network; the JPL AC computes such solutions operationally. The method exploits the globally distributed subset of the IGS network which has precise frequency references. The JPL high-rate solutions, and potential similar ones from other ACs, could be used to augment the existing IGS combined clock solution in a simple way.

5 Recommendations

Recommendation 1: Inclusion of **all** satellites with meaningful accuracy codes in the orbit products from all individual ACs. Use of these accuracy codes, or accuracy measures from the long-arc analysis, to identify and consequently downweight ‘‘bad’’ satellites in the orbit combination. In addition the IGS users should be made aware of the availability and importance of the accuracy codes in the SP3 files (see also Recommendation 5).

Recommendation 2: Enhancement of clock products. All ACs which submit clocks **must** also submit clock estimates from a, yet to be determined, subset of ‘‘core time stations’’! All ACs are **urged** to submit clock estimates. Furthermore the ACs are **encouraged** to increase the sampling rate the of the clock products to 30 seconds.

Recommendation 3: Inclusion of Earth Orientation Parameters in Sinex **as soon as possible**!

Recommendation 4: Clear deadline for GNAAC combinations in compliance with the orbit combination; 10 days after the end of the GPS-week.

Recommendation 5: Improved and automatic feedback to Data Centers (DC) and station managers in case there are discrepancies between Rinex files and station log's, data problems and unexpected problems (jumps) in the station coordinate solutions.

Recommendation 6: Create a central place (WWW) for feedback and information about the IGS products and their use.

Recommendation 7: Definition of minimal requirements for becoming an IGS AC. Any AC must produce **all** core products, i.e. orbits, EOPs, and Sinex, both on time and with sufficient (high) quality.

add 1: To achieve the highest consistency of the orbit and clock combination it is mandatory that all ACs provide estimates for all satellites. Bad satellites should be flagged by inclusion of meaningful accuracy codes in the orbit files. This will allow a priori weighting of the satellites in the orbit combination which should improve the combination and its consistency. At the same time the users of the IGS products can, and should, use these accuracy codes to weight or remove bad satellites. The IGS should put some effort into increasing the user awareness of the availability and importance of the accuracy codes in the SP3 files. To avoid any distortions from missing satellites, in some of the AC solutions, the combination, and its statistics, should be based on the common satellites only!

add 2: ‘‘Core clock stations’’ are necessary to improve the AC clock alignment. An higher clock sampling rate is necessary, or at least very advantageous, for several future missions but also for the precise point positioning users.

add 3: To make the combined IGS orbit and coordinates, essentially the IGS reference frame, consistent we need to include the Earth Orientation Parameters in the Sinex files. The inclusion of these parameters will allow to obtain combined IGS EOPs which are consistent with the IGS reference frame. The AC orbits can then easily be made consistent with this reference frame. At the same time the accuracy of the combined IGS EOPs should improve!

add 4: To be able to use the EOPs based on the Sinex solutions (see recommendation 3) it is mandatory for the, AC SINEX, the GNAAC combination SINEX (and the ‘‘super combination’’) to be available at the time of the orbit combination; e.g. by the second Wednesday (10 days) after the end of the GPS-week.

add 5: Stations which are performing poorly or have incorrect/inconsistent documentation should be identified in a timely fashion. A file containing a list of such stations as a function of time, should be maintained and accessible by anonymous ftp from the Central Bureau. In addition the DCs should flag the Rinex data files.

add 6: To enable a better overview of all IGS activities, products, combinations, and feedback a central WWW-site should be developed. This (feedback) site should contain descriptions of all the IGS activities. It should also contain documentation on how to use the IGS products. The information can either be at this site or provided using ‘‘links’’. (This recommendation was part of the CODE ACC proposal).

add 7: At present there are no (clear) guidelines about what an IGS AC is required to do nor how to become one. Therefore a list with the **minimal** requirements to be and to become an IGS AC should be generated.

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