Current state of IGS Analysis: Quality Assessment

Thomas Herring 1) and Tim Springer2)

1) Massachusetts Institute of Technology,
77 Massachusetts Avenue,
Cambridge, MA 02139 USA
e-mail: tah@mit.edu

2) Astronomical Institute
University of Bern,
Sidlerstrasse 5
CH-3012 Bern / Switzerland
e-mail: tim.springer@aiub.unibe.ch

Abstract

In this paper we examine the current state of the IGS analysis of GPS data and the needs of users. Since the initial sessions of the meeting examine near real-time analysis issues, we will examine the conventional IGS products. We will examine the needs of users for knowing the quality of both IGS products, and more fundamentally the quality of individual satellites and stations in the IGS network. There already exists a number of methods that can be used to assess IGS quality and we will review the contents of these existing mail, ftp, and web sites. We will consider how best to report marginal satellites and sites to users particularly in the form of interactive web based tools that could be developed, and how to integrate the existing information into a coherent assessment tool for users.

Introduction

The International GPS Service generates products from the analysis of GPS data that are made available through international data centers. The primary IGS data center is located at the Goddard Space Flight Center in Greenbelt, Maryland (cddisa.gsfc.nasa.gov). The products are stored in directories, accessible with anonymous ftp, with names of the form gps/products/[WWWW] where [WWWW] is the GPS week number. The current IGS products are (a) orbits for the GPS satellites that are available in three forms: final orbits; rapid orbits; and predicted orbits, (b) Earth orientation parameters, (c) tropospheric delay estimates, and (d) combined terrestrial reference frame SINEX files, one for the week and the other an accumulation to the week. In addition to the products themselves there are many summary and log files that contain a wealth of information about the products if the correct files are examined. In addition to these official products, there are other products in development that are available but are not deposited in the standard IGS product areas. These include satellite and ground receiver clock estimates, ionospheric delay maps, and combined GPS/GLONASS analyses. In this paper, we will discuss mainly the quality of the official products.
Within the area of quality we will consider timeliness and accuracy. For accuracy, we need to consider not only the accuracy of the products but also the quality of the data input to the analyses. In the latter area, we consider not only the GPS stations and receivers but also the satellites. In addressing these issues we also consider the needs of the users. We start the discussion, with user needs and then consider timeliness and accuracy.

User Needs

There has not been a recent widespread survey of the users of the IGS products but based the activities of the research community the main uses of the IGS products are reasonably clear. Probably the most used IGS products are the orbit files, although for volume of data transferred, the RINEX files from the IGS stations are the largest. The Earth orientation parameter (EOP) files are also widely used by the International Earth Rotation Service (IERS) but because the IGS orbits are distributed in an Earth fixed frame, the EOP parameters are not necessarily needed for processing GPS data. As users become more aware of the availability of the new IGS combined SINEX files, their use should increase for tectonic studies. The ways the tropospheric delay files are used is not clear at the moment although most likely these are used to evaluate the utility of these types of data in meteorological forecasts. Since these files are currently only available about 4-weeks behind real-time, their latency is too large to be of use in forecasting. The clock estimates are being studied by the international timing community as a means of transferring time globally with sub-nanosecond accuracy. We will concentrate here on the needs of users for precise positioning using IGS products and data. We will also emphasize that the IGS supports the research community and because all of the major GPS analysis programs are used by the IGS analysis centers, the IGS provides a natural framework for making significant improvements to accuracy of GPS results. Such improvements are very evident when the evolution of quality of GPS results is examined over the last decade.

Timeliness

For many users, the timeliness of products is important. For groups working near real-time this is particular important. But also many geophysical researchers who operate continuous GPS networks want results to be available at known times so that they can be sure that their processing can be done in autonomous fashion. To evaluate the timeliness of the IGS orbit products we examined the difference between the product date and the time-stamp on the file at the cddisa.gsfc.nasa.gov data center. We did this for files from late 1998 to the current date. (We can’t use this technique to go back too far in time because the file time stamps may have been reset when files are moved between storage areas). The results are shown in Figure 1 for the IGS final, rapid and predicted orbits. The two large excursions in the results starting in late July 1999 and the beginning of 2000 corresponds to a large disk failure and a particularly difficult Y2K transition, respectively. Excluding these intervals, the delivery of the IGS final orbit has been very reliable and generally within 3-weeks of real-time. The rapid and predicted results are more erratic and some of the excursions here may be due to re-posting of results rather than date of original transmission. However, if results are re-posted then users working with these products, in near real-time, would not have the best product at the time.
Probably the most worrisome feature of Figure 1, is the “single-point” failure mode of the results. The loss of the cddisa data center caused large delays until the use of alternative data centers was implemented by the IGS analysis center. The IGS should develop more formal contingency plans for the loss of a data center, and encourage the organizations that fund the data centers to allocate greater resources to ensure redundancy within the data centers themselves.

**Figure 1**: Difference between product date and file stamp for the interval between Oct 18, 1998 and July 2, 2000 shown as a function of GPS week number. The IGS final orbit (black line) is posted once per week, which explains the saw-toothed structure of the results. The rapid (red curve) and predicted (green curve) are posted daily. For results prior to Week 1042, the time difference has 1-day resolution of due to the nature of the time stamps.

**Product quality**

There are a number of methods available for assessing the quality of the IGS products and the contributions of the individual analysis centers. The longest running product of the IGS is the final orbit of each satellite given in the SP3 format and these files have accuracy assessments each satellite. In addition, there are summary files that report the quality of each analysis center. Users can assess the accuracy of the products, if they know to look in the correct places in the files. However, what is not clear from these summaries is why a particular satellite is bad on a given day, and which parts of the orbits may be good to use for satellites that have thruster firings during the day. It is also not clear from these summaries, how individual analysis centers can improve their results for poorly behaved satellites. In particular, there are a group of
satellites whose momentum wheels have either partially or fully failed, and while the list of these satellites is given in some IGS reports, conveniently finding this information is not easy. Efforts to improve the overall quality of the IGS analysis centers should concentrate on sharing this type of information and making available likely causes of problems rather than simply reporting (through RMS scatters of results) that a problem exists. These types of studies are carried out and disseminated in IGS reports by individual centers but what seems to be needed in more directed access to these results.

The other major effect on the quality of the IGS products is the operation of the GPS receivers in the network. Problems with receivers and/or the configuration of the stations are probably one of the greatest issues facing the IGS. In this category there are many facets that effect both the IGS analysis centers and the users of IGS data. The overall quality of the IGS data set and position results is impressive. Shown in Figure 2 are histograms of the RMS scatters of the position estimates from the 67 weeks of the combined IGS SINEX files after linear trends are removed from the results. The median RMS scatter for the horizontal components is about 2 mm and for the vertical 6 mm.

The average statistics of the IGS position determinations does not reveal the important fact that there are failures of some stations that can dramatically effect users if they are using these stations as the primary link to the IGS reference frame. Also not revealed in the statistics are the temporal and spatial correlations with the results. Within the IGS community there are some well-known receiver failures such as the MADR/MAD2 where for almost 3-years the station returned data regularly but the position estimates showed multi-centimeter scatters. Similarly, near the end of 1996 the WETT site started to show anomalous position estimates although the RINEX data from the site was not obviously corrupt. As far as we know, the data from these sites can still be obtained during these intervals by anyone doing “historical data” processing, nor do the IGS log files make any mention of the problems with these data during these times.

There are web sites that can be accessed to see the time series either from the IGS analyses or individual analysis centers. The Jet Propulsion Laboratory site http://sideshow.jpl.nasa.gov/mbh/series.html shows results from the JPL analysis. The Scripps Institution of Oceanography (SIO) site http://lox.ucsd.edu shows results from the SIO analysis. Both of these analyses show daily position estimates. MIT maintains a site http://www-gpsg.mit.edu/~fresh/MIT_IGS_AAC.html that shows results from different IGS analysis centers and recently from the IGS combined SINEX file. The IGS combined results are now updated weekly. This latter site allows results from the combination and from thee different analysis centers to be overlaid pair-wise. In all these sites, a possible problem with assessing the quality of data from site is that times when results from are poor, the data is likely not be included in the time series plots. This is particularly the case when sites are trying to present geophysical results (such as velocity fields) in addition to the time series. For a user of IGS data, the problem arises that it is not always clear when results from a site are missing whether this is due to poor quality data or if, due to communication problems, the data were simply not available in a sufficiently timely fashion to be included in the IGS analyses. Currently, there is no easy way for a user to access this information.
In Figure 2, we show a recent example of the subtle failure of an IGS station and the way that this can effect IGS analysis (these results can be viewed and obtained from the MIT IGS web site). (On both the JPL and SIO web sites, the time series end near the beginning of 2000 although SIO continues to include the site their IGS submissions.) What has precisely happened at this site is not clear although all three components of the site position are affected. It is also that the data from the site is not obviously corrupt especially in early 2000 with the first northward motion where the error bars do not appreciably change size. (The most recent results have larger error bars suggesting that large portions of the data from the site are either not in the RINEX files or are being deleted during data analysis.) It is also clear that the COD analysis center stopped processing data from this site although the reason is not clear. Currently there is
no formal forum for analysis centers to exchange information about the problematic sites. A user of data from this site would also find it difficult to know that data from this site was problematic.

![Recent ZWEN position estimates](image)

**Figure 3:** Recent time series for the North component of the IGS site ZWEN. There clearly is some failure of the site although it continues to generate results that are sufficiently high quality to be included in some IGS analysis center submissions.

Examination of all the results from the IGS analyses and other regional analyses such as the SCIGN array in California show a variety of failure modes of GPS receivers whose precise origins are rarely clear. In some cases, the reason is known. A specific case is the IGS SELE in Central Asia. In early 1999, the horizontal coordinates of the site show erratic daily deviations with amplitudes of 10-20 mm although the quality of the phase data seemed largely unaffected. The reason for the problem was traced to a loose antenna mounting (the antenna was literally being blown around by the wind). Although many IGS analysis centers include this station, there was never any report to the station operator that there was a problem. For many IGS stations, it is not clear that the operators of the stations process their own data because one of the advantages of being an IGS station is that your data is processed by the IGS. Currently, there is no formal feedback mechanism to station operators from the IGS analysis centers. Various sites in the Southern California Integrated Geodetic Network (SCIGN) have shown failure modes which appear to be related to water entering antennas and cables. Again, these failure modes do not necessarily produce obviously corrupt phase data; just the position estimates can be erratic.
One other class of failure mode is weather related. A number of IGS stations are located in regions where snow can accumulate during the winter. Depending on the raydome configuration, the presence of snow near, in, and on the antenna can have a dramatic effect on the position estimates. One of the extreme cases is the Antarctic site CAS1 where the height changed nearly 100 mm over a six-month interval. A visit to the site showed that the raydome on the antenna had been damaged and it was replaced. However, careful examination of the raydome showed that the height of the site had returned to its nominal value about 1-month before the replacement. The implication is that the anomalous height changes were not due to damage to the raydome but rather due to snow entering the area through the hole in the raydome. This is a very remote site and so there were no direct observations of the sites at the time the height was anomalous. The effects of the presence of snow and other corrupting signals can be quantified using the signal-to-noise ratio (SNR) from the GPS receivers. Standalone software is available (http://www-gpsg.mit.edu/~tah/snrprog) that will read RINEX files with SNR included (e.g., by using the S1 and S2 observable types in the teqc program) and generates estimates of phase residuals to be expected from interfering signals. This analysis technique has been very successful at detecting the corrupting effects of the presence of snow. It can also show whether an anomalous change in station position is due to the receiver or to motion of the monument.

Some IGS sites show non-secular position variations whose origin is not clear. One very clear example is the permafrost site at Yakutsk. This site shows annual deviations in its north position with peak-to-peak variations of nearly 20 mm. The height shows even larger variations. Local measurements to a nearby site on a building have shown that these motions are due to the movement (most likely tilting) of the monument in the permafrost. Again, there is no easy way for a general user of IGS data to know that this site is problematic. Nearly all IGS sites show annual height variations whose cause is not directly known. In some cases, a portion of the movement could be due to atmospheric pressure loading and in other cases they could be due to ground water effects, either through loading and/or soil expansion and contraction. In many of the IGS log files, the precise configuration of geologic setting of a site is not given (in other cases, the descriptions can be quite expansive). As interest in interpreting non-secular motions of sites increases, there will need to be greater emphasis placed on the configurations of stations.

**Enhancement of IGS quality**

Fundamentally, the quality of IGS products is controlled by the quality of station and satellite data used in the analyses. Currently a number of IGS stations yield problematic data and the characteristics of a number of satellites is less than desirable. Correction of these problems or increased dissemination of information about the causes of problems would increase the quality of IGS analysis and aid users of both the products and data.

A subtler problem is the overall accuracy of the GPS results being currently obtained. This is a more difficult problem because of the uniqueness of GPS in its temporal resolution and the overall number of stations. The IGS is at the forefront of developing standards that allow combination of initially results from different IGS analysis centers but now also includes results from different techniques. These rigorous combination procedures are now being investigated by the IERS and possibly in the future the IERS will be the lead operational entity that makes the
combinations. Such studies are now in their infancy but in long run will hopefully provide improvements to all techniques in the same way that IGS analysis centers have all improved over the last few years. Some recent combination results of merging VLBI and GPS with internally consistent earth orientation parameters have suggested that the VLBI results may be degraded by the combination. In examining time series from both systems the indication is that some part of the annual signals seen in GPS results may be artifacts (possibly induced by orbit modeling errors that have an annual modulation due to the orbital period of the GPS satellites). However, the assessment is difficult due to the sparse temporal and spatial coverage of VLBI measurements. Satellite Laser Ranging (SLR) results are starting to become available and these data may help clarify the situation.

Conclusions and recommendations

While the overall quality and timeliness of IGS products is very high, we have some recommendations that should enhance these characteristics even more.

Timeliness:
The IGS is very dependent on its data centers and we recommend that
(a) Formal contingency plans be developed and tested that allow transition between data centers in the event of a failure of one the centers; and
(b) The funding agencies for the data centers be made aware of their importance and be encouraged to provide sufficient funds to make the data centers more robust.

Quality:
Since the IGS depends so much on the quality of the data from the IGS stations and the users of the products depend on these same data, we recommend that
(a) The IGS develop plans to have a more positive feedback between the site operators, the IGS analysis centers, and the IGS product and data users. Such plans, we imagine would include autonomous system to monitor station quality through both phase and position quality. When a station appears to be failing the IGS should be proactive in contacting the site operator to ascertain the problem and in informing users of the problems. A web site, maintained by the central bureau, could have a ranked list of sites that would be updated at frequent intervals. A historical ranked list should also be maintained for users that are processing older data.
(b) The IGS data centers should be encouraged to move data files for stations that were known to be corrupt from the main data areas to other areas where users will be aware that they use the data at their own risk.
(c) Station operators should be encouraged to make measurements to local reference sites at sites that are suspected of being unstable and that these local data be made available to the IGS data centers for anyone to process.
(d) The IGS encourage regional data centers to include the SNR in RINEX files. The impact on the size of the files is about a 10% increase in compressed files. These RINEX files can then be used as part of the monitoring system and provide a means of assessing quickly whether the degradation of site positions is receiver or monument related.