SESSION 8

POSTER PAPERS

Static Positioning with GPS/GLONASS

Naoki Arai
Electronic Navigation Research Institute
6-38-1 Shinkawa, Mitaka Tokyo, Japan

Abstract

ENRI (Electronic Navigation Research Institute) has a GPS/GLONASS observation network including one IGEX station and five GPS stations in Japan. We combined the following solutions using GLOBK (Global Kalman filter VLBI and GPS analysis program: MIT/SIO) software.

1. ENRI local network solution
2. IGS global network solution by ESA
3. IGEX network solution by ESA

This paper presents the calculation of the combined solution and variations in the baseline's length.

GLONASS Orbit Validation by Short-Arc Technique

Francois Barlier, Christine Berger, Pascal Bonnefond, Pierre Exertier, Oliver Laurain, Jean-Francois Mangin and Jean-Marie Torre
Observatoire de la Côte d'Azur
Avenue Copernic, 06130 Grasse, France

Introduction

During the IGEX campaign some GLONASS and GPS satellites were tracked by laser telemetry in order to estimate the laser capability for qualifying the GPS/GLONASS radiotracking orbitography. In this frame our contribution was :

- to determine the laser residuals from orbits computed by analysis centers (in the present case University of Berne) and from laser data given by the International Laser Ranging Service network (ILRS). Data are taken from the CDDIS and EUROLAS data banks.
- to exhibit different features of the laser residual curves which can occur arc by arc. The arcs are a part of the dynamical trajectory with a duration of a fraction of the orbiting period (4 hours typically).

The statistical analysis of the laser residuals was performed as a validation of the GLONASS orbits. It evidenced some biases as already detected by several authors (Zhu et al., 1997 ; Springer et al., 1999a ; Springer et al., 1999b). Prospects for the future are given.

Method

It is based on the short-arc orbit technique developed by (Bonnefond et al, 1995) for the altimetry calibration. The purpose is to estimate arc by arc, at a given time, a translation vector of this arc of trajectory (R (radial) ,T (tangential), N (normal) components with possibly their time derivatives). The laser residuals are fitted by a least squares procedure. The components to be determined are automatically selected by a sensitivity coefficient analysis. The required correction models (tropospheric time delay, laser retroreflectors with respect to the center of mass of satellites, attitude of satellites) are taken into account.

An example is given in Figure 1 which shows the laser residuals observed by several stations before and after fitting a translation vector of the arcs of trajectory. Systematic effects can be removed at the level of a few centimeters. Some linear trends are due to the error of the position of the satellite along the orbit.

Results

The histograms of radial corrections are given for three different GLONASS satellites together, each one located in a basic orbital plane, separated by 120° in longitude, and for the two GPS satellites (Figure 2). The GPS orbits appear to be of a better quality. But, we have to keep in mind that the GLONASS orbits are based on the GPS ones in the orbitography process. Therefore, the sets of orbits are not completely independent. If the three GLONASS satellites are considered separately, it can be observed that the quality varies from one satellite to another. GLONASS 71 has the best orbit quality.

Titre:
Créé par:
Date de création:

Titre:
Créé par:
Date de création:

Figure 1. Laser residuals before and after fitting a translation vector of the arcs of trajectory.

Titre:
Créé par:
Date de création:

Titre:
Créé par:
Date de création:

Figure 2. Radial corrections for GLONASS and GPS satellites.

The different mean values of the different components are given in the Table 1.

Table 1. Orbit Corrections

		Number of Data	Mean	Dispersion (1 sigma)
GLONASS				
· Radial (R)	cm	543	-2.9 ± 0.7	16
· Along-Track (T)	cm	94	6.5 ± 4.3	42
· Normal (N)	cm	23	-9.0 ± 10.2	49
· Velocity (Tp)	cm/s	42	(-6.9 ± 0.6) 10^{-3}	3.6 10^{-3}
GPS				
· Radial (R)	cm	131	-7.0 ± 0.5	6

The tangential and normal corrections are generally speaking greater than the radial corrections by a factor of about 2 or 3. The number of cases for which R,T,N can be determined is markedly smaller than for R alone.

The GPS orbits are better than the GLONASS ones. The dispersion of the radial corrections is greater by a factor of about 2 or 3 for the GLONASS satellites than for the GPS ones.

A bias of the radial component R is confirmed for GPS and GLONASS from 7 cm to 3-4 cm, respectively. At the level of the obtained precision (a few cm), no very significant biases have been found for the two other components T and N, but more precise studies are required. The time derivative of T (Tp, fictitious velocity) appears significant and, in fact, too large for explaining a systematic error which would be generated by the obtained radial bias through the third Kepler law.

In the international community, the origin of the radial bias is being discussed. The origin of Tp can be due to the geometrical distribution of the retroreflectors on the array: at low elevation the measured distance is statistically too short.

It is important to emphasize the problem of the signature of satellites on the laser data. Figure 3 shows an example of laser residuals as obtained during the tracking of the GLONASS (on the left) and GPS (on the right) satellites by the Lunar Laser Ranging station in Grasse (duration 10mn, elevation 30°). Two laser pulses precisely separated by 2.9 ns, are emitted. By this way, the scale of the ordinate axis can be given. For each pulse, two lines of residuals, separated by about 1 ns, can be identified, one being stronger than the other one for GLONASS satellites only. This is due to the distribution of the reflectors on the array, the diameter of which being of about 1 m. This fact can introduce a bias in the laser residuals of a few decimeters mainly at low elevation. It can also induce some systematic effects from one laser station to another. On the opposite, the specific behavior of GLONASS residuals does not appear for GPS. The location of the retroreflectors is quite different. In the future, the signature of satellites on the residuals will have to be taken into account.

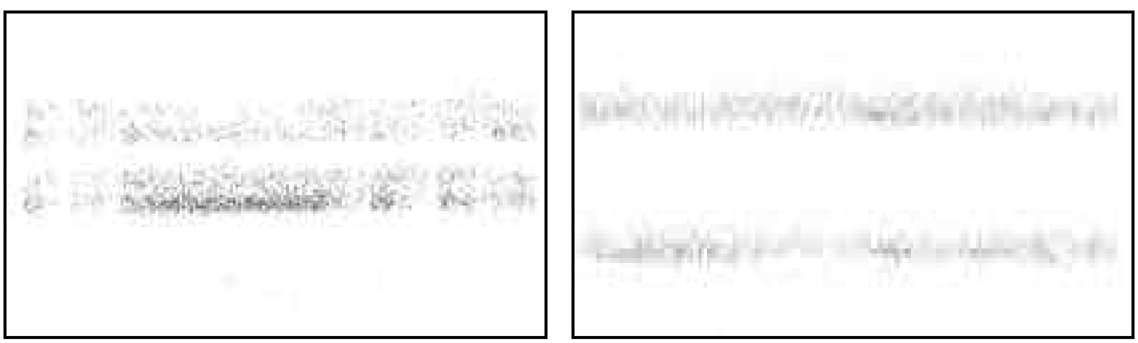


Figure 3. Laser residuals for GLONASS (left) and GPS (right) observed by the Lunar Lasar Ranging station in Grasse from two laser pulses.

Conclusion

- The ILRS network has the capability to test the radiotracking orbits of GPS and GLONASS at the level of a few centimeters.
- The contribution of the LLR at Grasse has been satisfactory especially during daytime conditions.
- The orbits can be improved locally, depending on the availability of laser data. Before fitting a translation vector, the laser residuals present some systematic

effects ranging from a few centimeters to 50 cm. They are reduced to the level of a few centimeters after the fitting.

In the future the objectives will be:

- to extend the study to all the GLONASS satellites taking part in the IGEX campaign.
- to compare the orbits of the different analysis centers.
- to get more information about the models of the location of the laser retroreflectors with respect to the center of mass of the satellites and about the models of the attitude of the satellites.
- to compute a dynamical solution based on laser data.

References

Zhu, S.Y., C. Reigber, Z. Kang (1997). Apropos Laser Tracking to GPS Satellites, *J.of Geodesy*, Vol. 17, No.7, pp. 411-431.

Springer, T.A., G. Beutler, M. Rothacher (1999a). Improving the Orbit Estimates of GPS Satellites, *J. of Geodesy*, Vol. 73, pp. 147-157.

Springer, T.A., D. Ineichen, M. Rothacher, G. Beutler (1999b). Modeling the Orbits of the GLONASS Satellites, EGS, The Hague, April 1999.

Bonnefond, P., P. Exertier, P. Schaeffer, S. Bruinsma, F. Barlier (1995). Satellite Altimetry from a Short Arc Technique: Application to the Mediterranean, *J. Geophys.Res*., Vol. 100, No. C12, pp. 25365-25382.

IGEX Activities in Sweden

Jörgen Börjesson, Jan Johansson
Onsala Space Observatory
Chalmers University of Technology, SE-439 92 Onsala, Sweden

Anders Frisk, Gunnar Hedling and Bo Jonsson
National Land Survey of Sweden
SE-801 82 Gävle, Sweden

Introduction

The IGEX experiment was the start signal for a lot of GLONASS interest in Sweden. Main issues were how the existing infrastructure of the Swedish permanent reference network could be upgraded to include GLONASS hardware, how the communications to the centralized data center should be handled, testing of GLONASS processing software together with interpretation of the results, and how to possibly include them in other ongoing projects.

We have also been examining how GLONASS receivers and the GLONASS system itself have been operating.

IGEX and SWEPOS

Despite the depleted satellite constellation GLONASS is useful, providing the user with the combined GPS / GLONASS constellations yielding more available satellites - which is particularly good for sites with high horizon masks and a lot of sky blockage. An example for this is urban areas, with buildings that can block the signal.

Another GLONASS advantage is generated by the higher orbital inclination compared to GPS, leaving higher latitude sites with a lesser uncovered part of the sky.

This plays right into the hands of Sweden, being a northern country which has already put in a lot of investments in satellite navigation infrastructure by building up a national reference station network, SWEPOS; see Figure 1.

SWEPOS has been in continuous operation since August 1993. Today, in 1999, the network consists of 24 stations of which 4 have collocated GPS/GLONASS receivers, the rest having only GPS receivers. The average station separation is approximately 200 km and covers a region from latitude 55 to 69 degrees north.

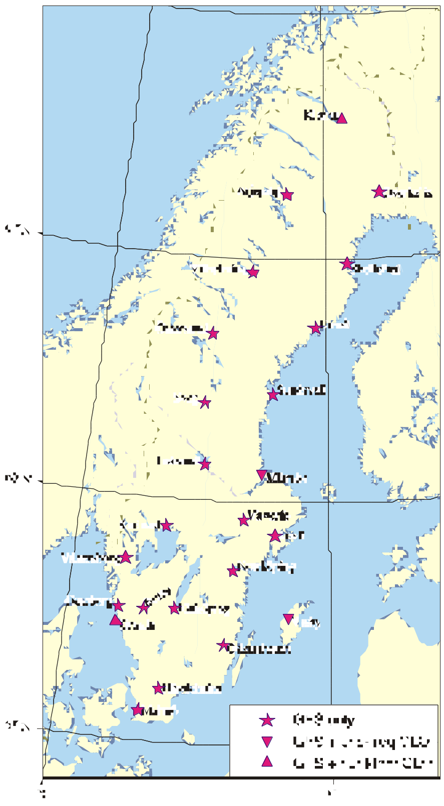


Figure 1. The Permanent Swedish Reference Network; SWEPOS.

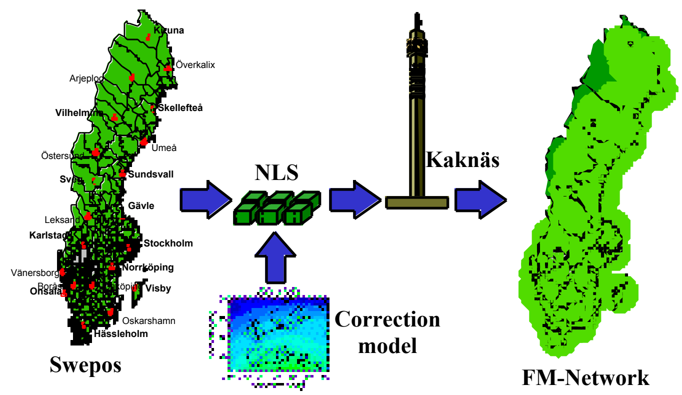


Figure 2. The NeW-RTK data flow.

The communication between the SWEPOS stations and the Network Control Center (NCC) is managed via 64 kbit/s TCP/IP lines. The NCC is located in Gävle at the National Land Survey of Sweden (NLS). The data are available both in real-time and for post-processing purposes.

With SWEPOS as a backbone several interesting areas for scientific studies, both for real-time and post-processing are underway. Two of the areas which could benefit most from the combined usage of GPS and GLONASS are atmospheric studies, both on the longer time-scale and for a shorter time scale with a possible inclusion of measurements within weather forecasting, and the NeW-RTK project.

The NeW-RTK project, a cooperation between Onsala Space Observatory, the NLS and Teracom AB, is a concept for RTK positioning based on a network of permanent GPS reference stations providing a nation-wide error correction model. The goal of the project is to establish a service which yields an accuracy on the centimeter level to the end users. So far NeW-RTK has been focused on GPS-only techniques but, as mentioned above, GLONASS could help improve satellite availability for the user, especially for urban areas and areas with a lot of high vegetation.

A simplified image of the data flow for the project can be seen in Figure 2.

Tracking Statistics

A plot over the tracking statistics for the Onsala site is seen in Figure 3. The percentage of possible observations is a quotient between the actual number of observations for a single day and the maximum expected number.

For the period shown the main causes for data loss have been power failures at the site and logging software malfunctions. The software and firmware of the receiver have been upgraded several times during the campaign, and the days with higher data loss have become more and more scarce.

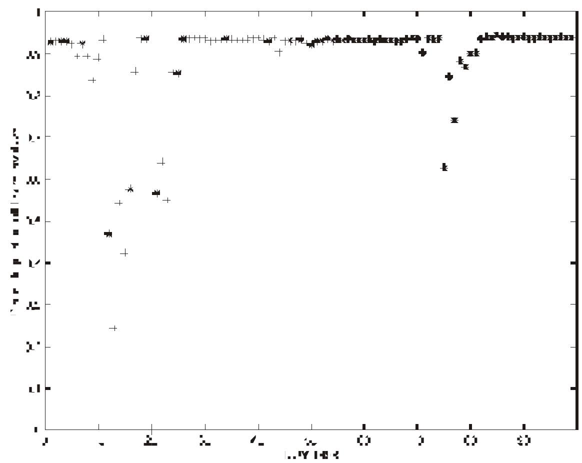


Figure 3: Tracking statistics for the Onsala site.

Processing and Strategies

Onsala Space Observatory volunteered as one of the data processing facilities within IGEX-98. The actual data analysis did not start until summer 1999 and the results have not yet been evaluated or released.

The Onsala IGEX analysis center mainly turns its attention to station coordinate repeatability for the stations that are processed. Atmospheric remote sensing using combined GPS/GLONASS measurements is also of interest in the processing.

Processed Network

For our processing for IGEX we choose to utilize a subset of the global IGEX tracking network. The selection criteria were

- Mainly high quality dual-frequency GPS/GLONASS receivers with good antennas.
- Good ties with existing GPS network.

Bernese Software

For the processing we use the Bernese software, a geodetic university software for GPS and GLONASS data, developed by the University of Berne, Switzerland.

This program processes and analyzes both carrier-phase and code data with a least-squares approach. The ionosphere-free linear combination of the two carrier frequencies is used in the final processing step.

Strategy

The existing global network and GPS/GLONASS orbit determination results from the International GPS Services (IGS) and IGEX. In our analysis we include combined GPS and GLONASS data.

Measurement Models

Preprocessing Model	Phase preprocessing in a baseline by baseline mode using triple-differences. In most cases cycle slips are fixed looking simultaneously at different linear combinations of L1 and L2. If a cycle slip cannot be fixed reliably, bad data points are removed or new ambiguities are set up. The a posteriori residuals of the observations are checked for outliers, too. These observations are marked for the final parameter adjustment.
Basic Observable	Carrier phase only, elevation angle cutoff 15 degrees, sampling rate 180 sec.
Modeled Observable	Double-differences, ionosphere-free linear combination.
Ground Antenna Center	Elevation-dependent antenna phase center corrections are applied to model the differences between different calibrations antenna types (e.g. Rogue and Trimble). We use the IGS_01 model.
Troposphere	Saastamoinen a priori model, estimating zenith delays in 2 hour intervals for each station, mapping function: 1/cos(zenith angle).
Ionosphere	Ionosphere model estimated from L2 - L1 double-difference observations

Estimated Parameters (Apriori Values And Sigmas)

Adjustment	Least-squares adjustment
Rejection Criteria	The described two-step preprocessing method eliminates outliers. Rejection Criterion of L3 outliers: 0.03 m.
Stations	Global IGS stations such as Onsala, Wetzell and Metsähovi are heavily constrained (1 mm).
Troposphere	Absolute constraints 0.1m, Relative constraints 5.0m.
Ionosphere	Cancels out in the ionosphere-free linear combination.
Ambiguity	Not possible to resolve GLONASS ambiguities in our software version.
Satellite Clock Bias	Satellite clock biases are not estimated but eliminated by forming double-differences.
Receiver Clock Bias	Receiver clock corrections are estimated during the pre-processing using code measurements.

Preliminary Results

For a time period of three months (Jan-March 1999) data from a subset of the IGEX stations have been analyzed on a daily basis using the strategy described above. Basically, we have concentrated our analysis on some of the European sites. Here, we present results obtained from analysis of the two Swedish IGEX sites (Onsala and Kiruna) that were equipped with dual-frequency GPS/GLONASS receivers.

Figures 4 and 5 show scatter plots of the horizontal components for Onsala and Kiruna, respectively.

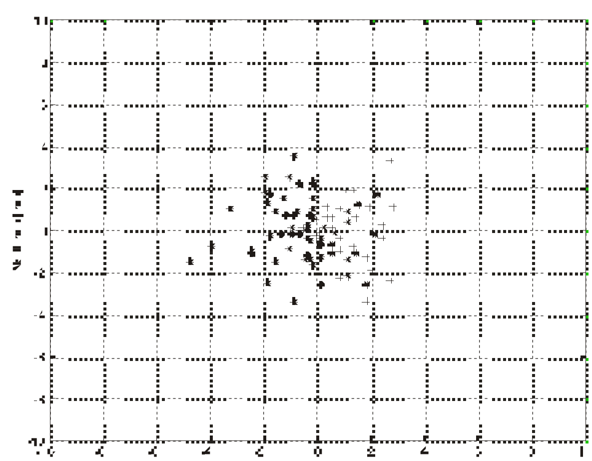


Figure 4. Onsala scatter repeatability for first quarter of 1999.

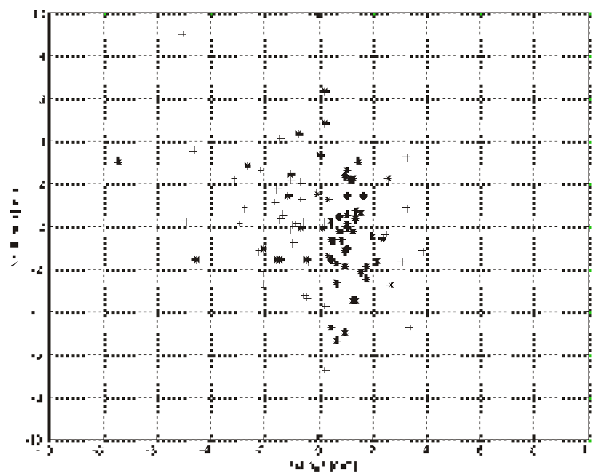


Figure 5. Kiruna scatter repeatability for first quarter of 1999.

In a similar way Figure 6 and 7 show the vertical component for the two stations. Please note that the Kiruna time series are much noisier compared to Onsala. However, this is explained by the fact that Onsala is actually used in the transformation from a free-network solution to the ITRF96. Furthermore, the Kiruna station is located in the far north with a lot of snow during the winter period. Results from the EUREF and BIFROST data processing have demonstrated the problem of snow accumulating on top of the radome covering the GPS/GLONASS antenna. The result of such snow accumulation is clearly visible in Figure 7.

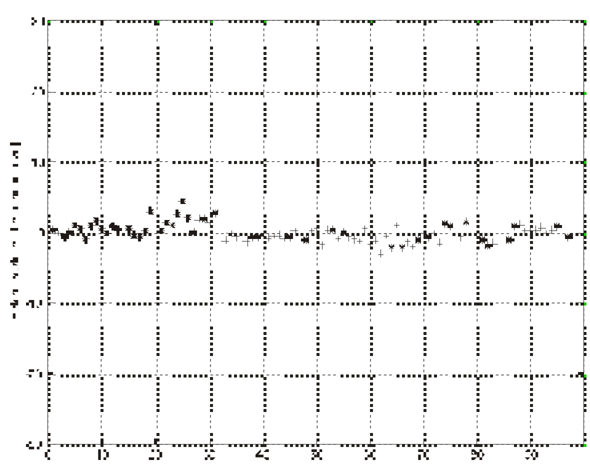


Figure 6. Onsala vertical repeatability for first quarter of 1999.

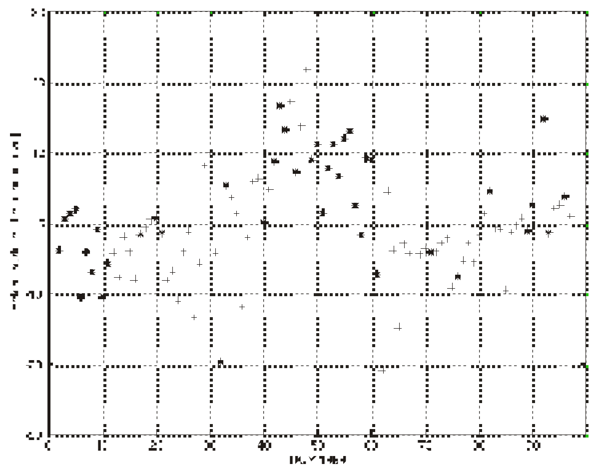


Figure 7. Kiruna vertical repeatability for first quarter of 1999.

Finally in Figure 8, we have plotted the total zenith tropospheric propagation delay for the two sites. The Onsala site is located near the ocean on the Swedish west coast with fairly wet winters while Kiruna is located at high altitude and has much colder and dryer winter climate.

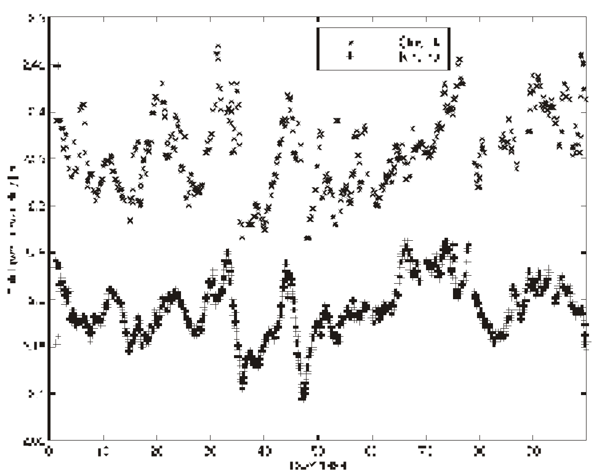


Figure 8. Onsala and Kiruna total tropospheric delay for first quarter, 1999.

Conclusions and Future Work

The results from the IGEX campaign and related tests of GPS/GLONASS equipment have laid a good foundation for future work.

The receiver operation, data collection, and data handling have been fully automated. Some problems occurred during the IGEX campaign period but were solved by installation of new receiver firmware and data collection software.

The Ashtech Z18 GPS/GLONASS receiver has now been fully integrated in SWEPOS operations. Following the recent announcement of a new firmware version for the Ashtech Z18 with RTK/RTCM capability, the possibility to replace the Ashtech Z12 receivers currently in use in Sweden could be carried out.

Furthermore, Javad receivers have become available on the market with the same capability as Ashtech Z18s.

At the moment the Javad receivers are being installed at Onsala, Borås, and possibly Mårtsbo while Ashtech Z18s will remain in Kiruna and Göteborg. The question concerning a continued operation of the Ashtech GG24 receivers has not yet been addressed.

This means that the GPS/GLONASS program will continue in Sweden together with SWEPOS.

The engagement to process combined GPS/GLONASS data for the benefit of IGEX, the Nordic Commission of Geodesy (NKG), and other scientific projects will continue over an extensive period.

The present infrastructure with the real-time GPS/GLONASS data flow from 5 SWEPOS stations will also contribute to the ongoing NeW-RTK project. Especially, the three-station network, including Onsala-Borås-Göteborg, with baseline lengths stretching from 40 to 65 kilometers will be used as a test bed for the implementation of GPS/GLONASS in an RTK-service in Sweden.

During the IGEX campaign also the post processing capabilities were tested. The post processing has been based on the Bernese Software. Our work with automatic routines was not finished until spring 1999. Up until now we have processed periods of GPS/GLONASS data. Unfortunately, we had no possibilities to make a detailed comparison of the results obtained from the IGEX data analysis and results obtained from processing of GPS data within the NKG/EUREF and BIFROST projects. This will be conducted during fall 1999 for the results prior to August 1999. For newer results such comparisons are planned to be performed in a fully automated manner.

Acknowledgements

Many thanks to Markus Rothacher and Daniel Ineichen at the Astronomical Institute, University of Berne, Switzerland for providing us with a software capable of handling GLONASS data and for their kind assistance in order to make it run on our computers.

Geodetic GPS/GLONASS Antenna Measurements

Bruce R. Schupler
Allied Signal Technical Services Corporation
7515 Mission Drive, Lanham, Maryland 20706 USA

Thomas A. Clark
Code 920.3, NASA Goddard Space Flight Center
Greenbelt, Maryland 20771 USA

Abstract

The IGEX campaign was intended to compare GPS and GLONASS performance and examine the utility of combination solutions. So far, most analysis centers have assumed that the phase centers of the antennas at tracking stations are coincident.

We have used the anechoic chamber at GSFC to characterize a number of samples of choke ring style geodetic quality antennas at GPS L1 and L2 frequency ranges. We have now extended these measurements to include the GLONASS L1 and L2 and the proposed GPS L5 frequency bands and report on detailed measurements made on one sample of the standard Dorne-Margolin choke ring antenna.

On average, over the entire 1200-1600 MHz L2-to-L1 range, the phase center of these antennas shows frequency-dependent variations with a slope ~-72 microns/MHz (the - sign implying that the phase center at L2 is above that at L1). At the low frequency end covering the GPS and GLONASS L2 frequencies, a slope ~-157 microns/MHz is seen, while around the upper L1 frequency, the slope is ~-48 microns/MHz. This slope results in an L2-to-L1 phase center offset of ~26 mm with the GLONASS phase center ~4 mm below GPS at L2 and ~2 mm below GPS at L1.

Rationale for Measurements

Past measurements using the anechoic chamber of the Goddard Space Flight Center (Schupler, Allshouse, and Clark, 1998) have shown the dependence of the vertical component of the phase center position of the choke ring style antennas typically used for GPS and GLONASS measurements on frequency. While the offset in phase center position between the GPS L1 and L2 vertical components has been known for quite some time, the realization that this effect changes continuously with frequency is a recent occurrence. Given that the GLONASS frequencies are not the same as GPS, this continuous shift in phase center vertical position with frequency results in an offset between the reference point used for GPS measurements and that used for GLONASS. (While this effect will also produce a different vertical position of the phase center for each GLONASS frequency, our measurements show that this is not yet significant at the GLONASS L1 band (0.6 mm between the highest and lowest GLONASS L1 frequency currently in use) and is only marginally significant at the GLONASS L2 band (1.5 mm).) Our most recent series of antenna measurements was designed to characterize the

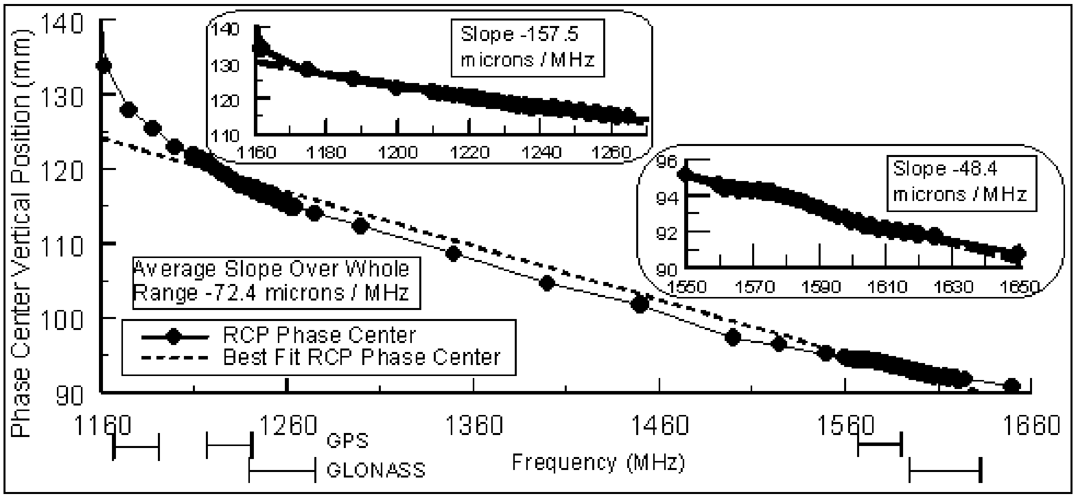


Figure 1. The shift in phase center vertical position of the Dorne-Margolin T choke ring antenna from 1160 to 1660 MHz.

performance of the choke ring style GPS / GLONASS antenna both within the composite L1 and L2 bands and between the L1, L2, and proposed L5 bands.

Results

Figure 1 illustrates the smooth nature of the movement of the vertical component of the phase center from 1160 to 1660MHz. The frequency ranges covered by the GPS and GLONASS transmissions are indicated by the lines at the bottom of the figure while the inset graphs show more detail in the main frequency regions of interest. The phase center movement can be well characterized by a downward motion of 72.4 microns for each MHz of frequency change over the entire range. Fitting the data from 1160 to 1260 MHz only results in a downward movement of 157.5 microns/MHz while the motion from 1550 to 1650 MHz is 48.4 microns/MHz.

Conclusions

The vertical position of the phase center for the choke ring style antennas typically used for high precision GPS and GLONASS measurements is a systematic function of frequency. The use of the same antenna reference point for both GPS and GLONASS processing will introduce a systematic bias in the results. More detailed results from our anechoic chamber measurements are available from the authors upon request.

References

Schupler, B.R., T.A. Clark, R.L. Allshouse (1998). Characterization of GPS Antennas Over a Wide Frequency Range in the New Goddard Anechoic Chamber, *EOS*, Vol. 79.

Repeatability of Continental Baselines Within the IGEX Network

Elisabeth Fragner and Robert Weber
Institute of Geodesy and Geophysics, University of Technology, Vienna
Gusshausstrasse 27-29, A-1040 Vienna, Austria

Currently daily orbit solutions, based both on microwave and laser tracking data, are available from six IGEX Analysis Centers (IGEX-AC). These ephemerides are input to the orbit combination process and therefore form the basis of a robust and reliable IGEX product. These precise GLONASS orbits were used to process continental baselines in Europe and North America in order to test the repeatability over a period of two weeks. Additionally similar calculations were based on combined GPS/GLONASS ephemerides, and finally solely on the available GLONASS broadcast information.

Because of the large number of active satellites (n = 15) we selected the GPS weeks 0999 and 1000. The investigated baselines Kiruna – Zimmerwald (~2450 km) and Lexington - Thule Airbase (~3750 km), shown in Fig. 1, are equipped with combined dual-frequency receivers.

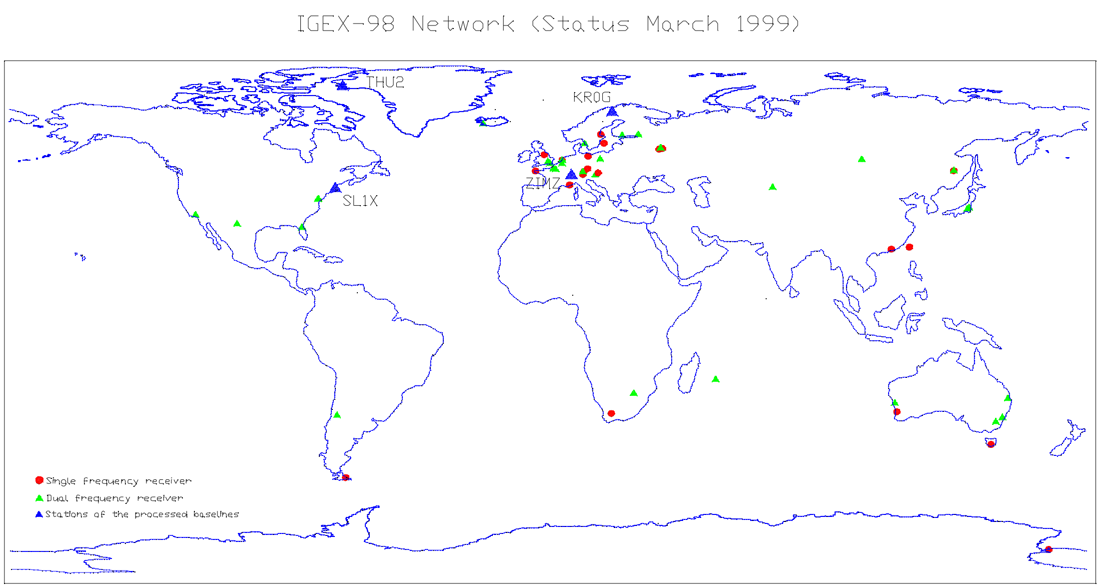


Figure 1. IGEX-98 network.

The calculations were performed with the Bernese GPS - Software. We estimated the coordinates of Kiruna and Lexington, while Zimmerwald and Thule Airbase were kept fixed. Due to the fact that the baseline error is essentially proportional to the baseline - length and the orbit error, remarkable coordinate variations are expected over large distances. This is quite well outlined in the rough rule of thumb by Bauersima, giving the error $\Delta\rho_{bas}$ of a baseline of length l as a function of an orbit error $\Delta\rho_{orbit}$:

$$\Delta\rho_{bas} \approx \frac{l}{d}\ \Delta\rho_{orbit} \qquad (1)$$

where d is the approximate distance between survey area and the used GPS satellites (20000 – 25000 km).

In the first experiment the data were processed using the combined GPS/GLONASS ephemerides (for the baseline Kiruna – Zimmerwald, see Figure 2), in the second experiment the calculations are based on precise GLONASS orbits (IGEX – combination; see Figure 3) and finally on the available broadcast information (see Figure 4).

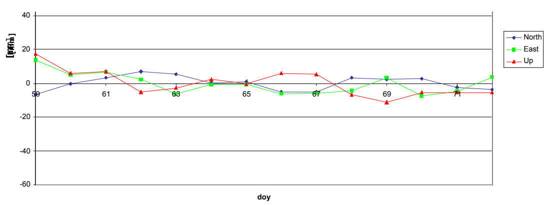


Figure 2. Daily repeatabilities of the coordinate components of the baseline Kiruna – Zimmerwald using precise GPS/GLONASS ephemerides.

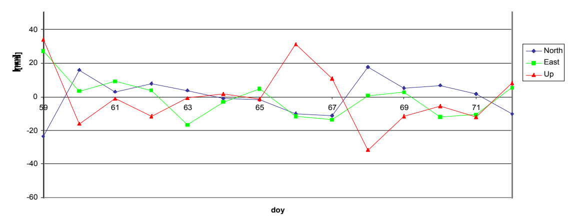


Figure 3. Daily repeatabilities of the coordinate components of the baseline Kiruna – Zimmerwald using precise GLONASS orbits.

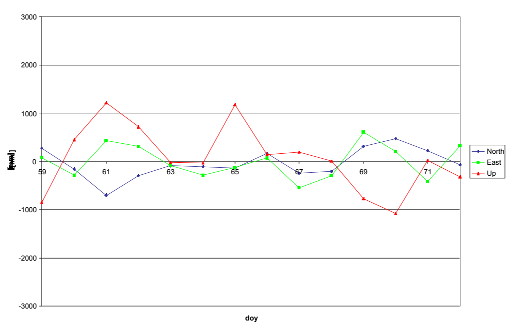


Figure 4. Daily repeatabilities of the coordinate componentsof the baseline Kiruna – Zimmerwald using GLONASS broadcast information.

Table 1. RMS of the Coordinate Components [in cm]

KR0G	GPS/ GLONASS	Precise GLONASS ephemerides	GLONASS broadcast
North	0.4	1.1	30.4
East	0.6	1.2	34.8
Up	0.8	1.8	68.8
Length	1.1	2.4	82.8

SL1X	GPS/ GLONASS	Precise GLONASS ephemerides	GLONASS broadcast
North	0.7	1.2	61.6
East	1.0	1.6	67.1
Up	1.0	3.9	96.8
Length	1.5	4.7	152.4

As expected, the rms per coordinate decreases from several decimeters (broadcast orbits) to 0.5 - 2 centimeters by using precise orbit information. The final line gives the length errors in centimeters for both baselines and the three different orbit qualities. These numbers confirm quite well formula (1) under the assumption of $\Delta\rho_{orbit} \approx$ 10 cm / 25 cm / 8 m.

References

Bauersima, I., (1983). NAVSTAR/Global Positioning System (GPS III*)*. Mitteilungen der Satellitenbeobachtungsstation Zimmerwald, No. 10, Astronomical Institute, University of Berne, Switzerland.

Weber, R., (1999). Report of the Status of the International GLONASS Experiment (IGEX), *Proceedings of the IGS – Analysis Center Workshop*, La Jolla.

GLONASS/GPS Monitoring in MCC: Experience and Future

Alexander Moodruck and Vladimir Glotov
Russian Mission Control Center
2 Pionerskaya Street, Korolyov of Moscow Region, Russian Federation

Introduction

The order of the President of Russian Federation #38-RP from February 18, 1999 and Decision of Government of Russian Federation #346 from March 29, 1999 assigned GLONASS the status of a dual-purpose system and determined problems of a civil segment of GLONASS maintenance development.

One of the main problems of GLONASS civil usage is independent civil monitoring. The Information and Analysis Center of Coordinate and Time Supply (IAC CTS) of MCC organized such a service of GLONASS and GPS real-time monitoring in May 1999. The service works continuously in a real-time mode. It performs real-time GNSS monitoring and more in-depth GNSS functioning study at a stage of a posteriori processing of satellite measurements. The service estimates local GNSS performance characteristics and controls GNSS satellites using an all-in-view strategy.

This paper presents the overview of GNSS monitoring in IAC CTS, current results of monitoring and prospects of IAC CTS activities in the field of monitoring of existing and future satellite navigation systems.

GNSS Monitoring

The goal of the monitoring is an independent analysis of GNSS performance and user notification on failures. The service deals with the Standard Positioning Service (SPS) only. The technique of monitoring provides the possibility to monitor any navigation satellite system.

GNSS monitoring is subdivided on time of realization into

- real-time monitoring
- a posteriori analysis of GNSS performance (or a posteriori monitoring)

In the *real-time* mode the following GNSS and separate satellite characteristics are supervised:

- navigation message integrity
- position accuracy
- time transfer accuracy
- PDOP, GDOP, HDOP, VDOP
- URE

In the *a posteriori* mode the following characteristics are supervised:

- navigation message integrity
- availability
- potential reliability
- actual reliability
- position accuracy
- time transfer accuracy
- GPS - GLONASS time difference
- C/A-code RMS
- mean URE
- mean URE module

The service now uses a single tracking point with the following hardware:

- specially equipped and fixed site, on which the satellite antenna is mounted. Site position 55 deg 55 min north lat., 37 deg 49 min east longt.
- 24-channel dual-system single-frequency receiver GG-24 (Ashtech).

Measurement collection interval – 30 sec, elevation mask – 10 deg

- frequency standard: Rb-standard with 1-day instability about $7x10^{-13}$
- means of information transfer, processing and storage

The essence of monitoring consists of navigation service performance estimation and comparison of results with values defined using GNSS ICD, ICAO and IMO requirements etc. The satellite measurements are processed with the help of the original software developed by the IAC CTS experts.

IAC CTS experts have developed a special set of GNSS performance characteristics allows one to study GNSS performance and its variations. The quality of a satellite navigation signal is estimated by direct comparison of the simulated pseudo-range to its measured value. To provide an accurate simulation the monitoring service maintains a stable mathematical time scale. The functioning of GLONASS and GPS is supervised separately.

The service estimates only local GNSS performance and now is unable to eliminate receiver failures due to lack of equipment.

The Results of GNSS Monitoring

Real-Time Monitoring

Real-time monitoring data are available online via the Internet (http://www.mcc.rsa.ru/iackvo). The information is placed in real-time on the IAC CTS web-site and updated every 30 sec. The following information is presented on the real-time monitoring web-page:

- satellites in view
- estimated position
- URE for satellites in view

In case real-time data are absent, the last received data are presented on the page. The GLONASS page is demonstrated in Figure 1.

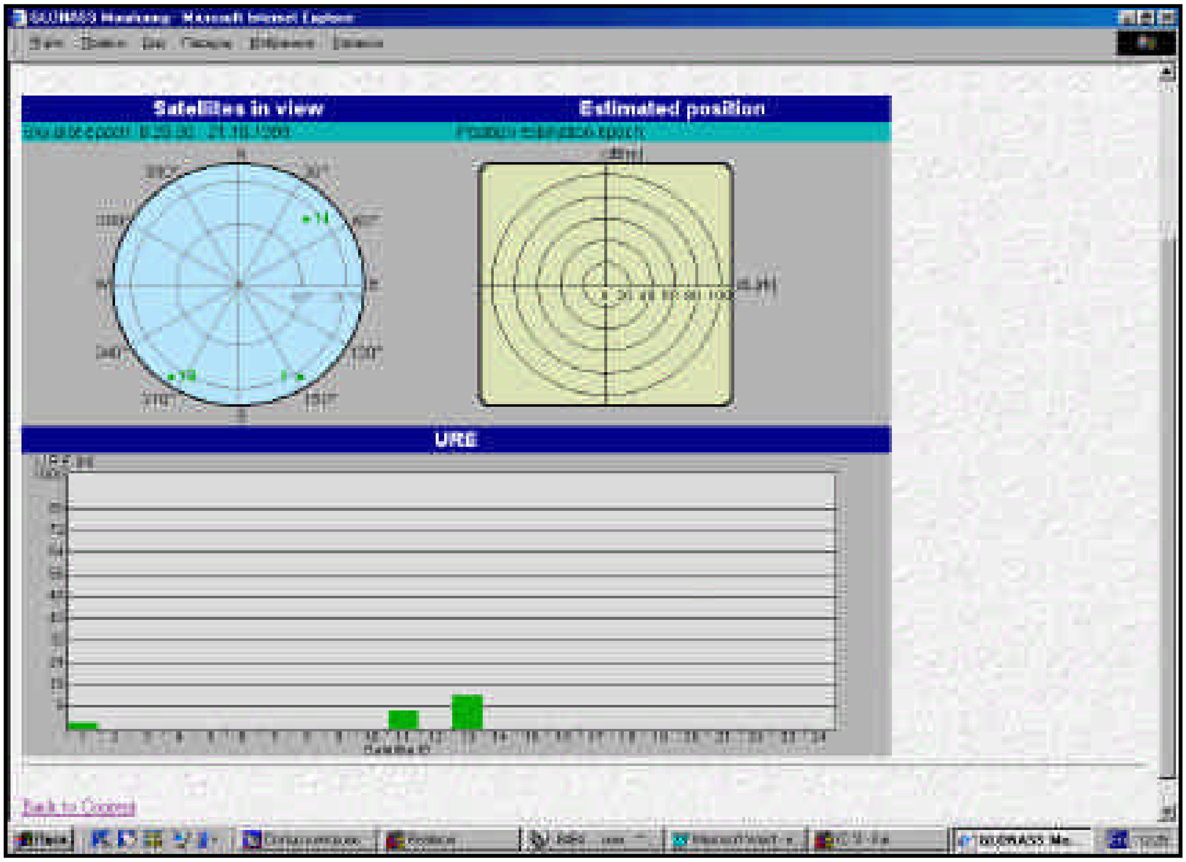


Figure 1. GLONASS real-time monitoring web-page.

A Posteriori Monitoring

Monthly reports of the monitoring service document the results formulated from the data collected at the tracking site. All characteristics are averaged on one day and one month intervals. As an example, GLONASS and GPS performance characteristics for May 1999 are presented below.

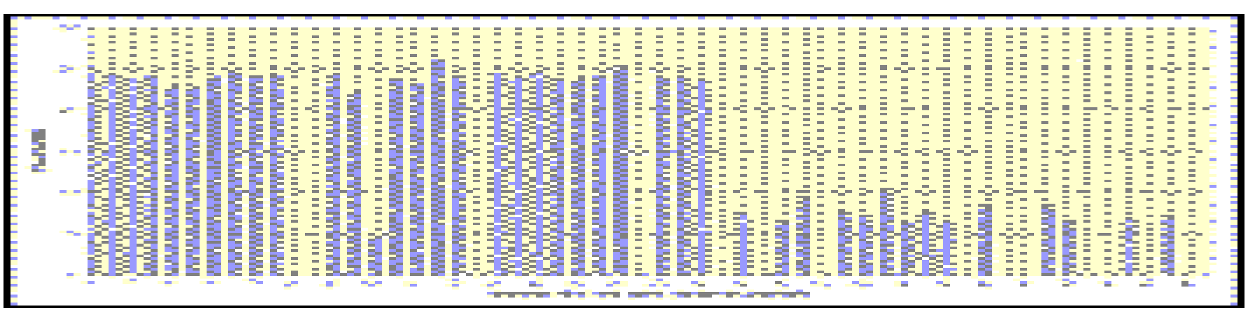


Figure 2. C/A-code RMS for GPS and GLONASS.

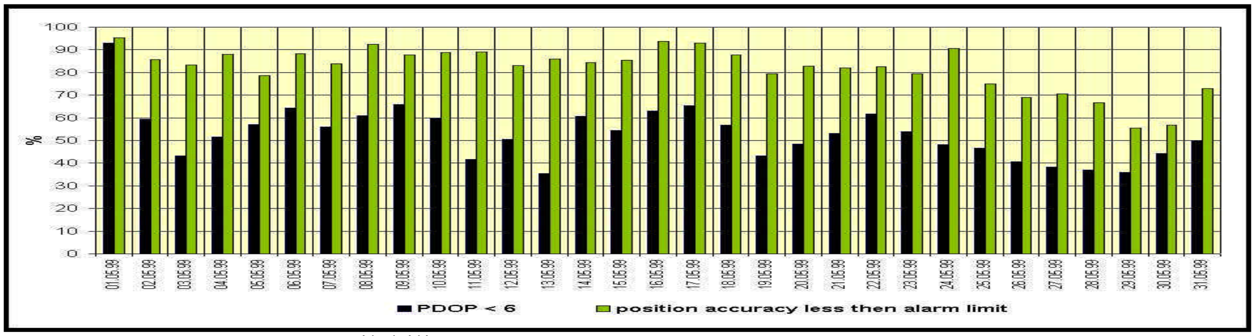


Figure 3. GLONASS availability.

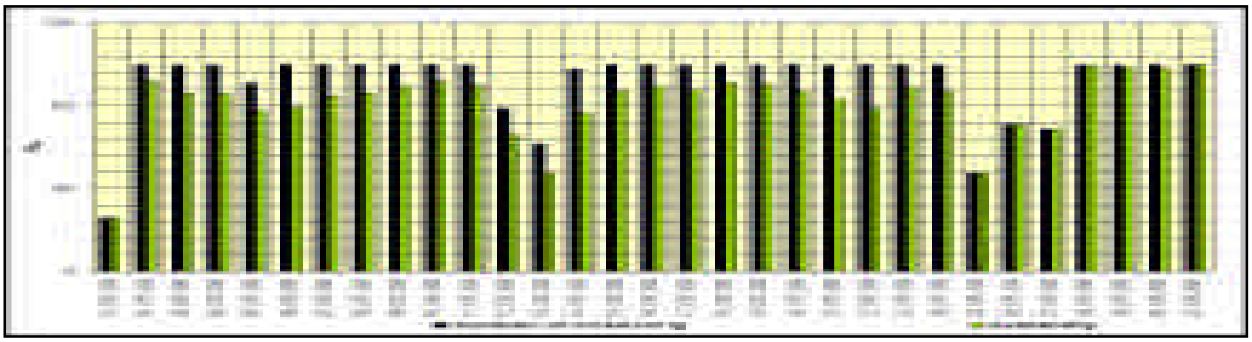


Figure 4. GLONASS reliability.

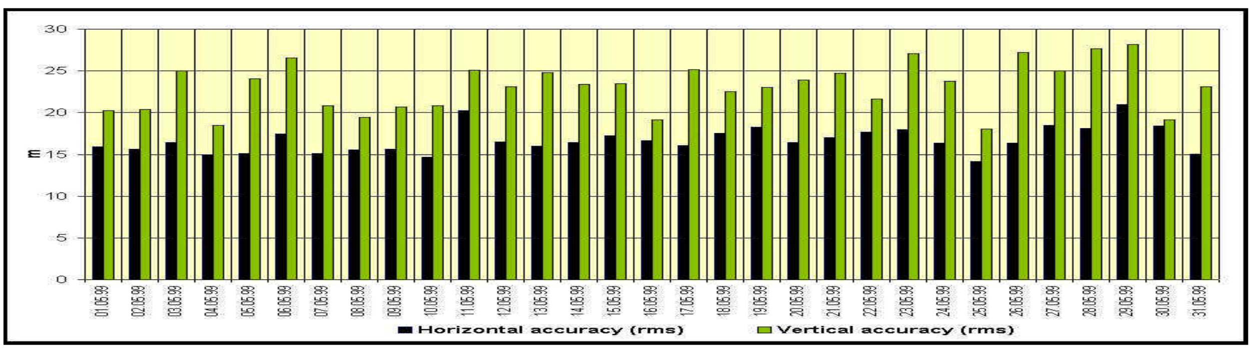


Figure 5. GLONASS position accuracy.

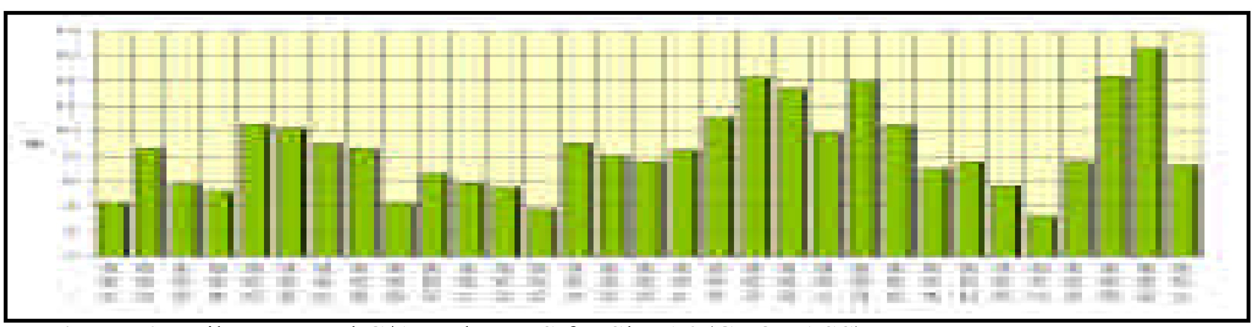


Figure 6. Daily averaged C/A-code RMS for Slot 16 (GLONASS).

Table 1. GLONASS and GPS Performance (for actual constellations) (September 1999).

	GLONASS	**GPS**
Number of active satellites	13	27
Availability (4 satellites in view)	64.34%	100.00%
Reliability (position accuracy meets requirements)	69.84%	99.49%
Horizontal position RMS	17.49 m	29.33 m
Vertical position RMS	22.87 m	44.86 m
C/A-code RMS	6.99 m	21.25 m
Mean URE	- 0.29 m	- 0.19 m
Mean URE module	3.24 m	2.84 m

The data in Table 1 show that GLONASS C/A-code rms is 3 times less than that of GPS due to Selective Availability in GPS. But GLONASS availability is much worse because the satellite constellation of the system was not complete (13 satellites vs. 27). The same reason caused bad visibility conditions for GLONASS (bad DOP), so the position accuracy for GLONASS users meets defined requirements (100 m horizontal accuracy, 150 m vertical accuracy) only 69.8% of time. The way to solve the problem is to complete the GLONASS satellite constellation.

IAC CTS Future Activities

1) The creation of a regional network of monitoring stations (Moscow, Irkutsk, Khabarovsk, etc.)
2) To perform the processing of the data from IGEX stations in a posteriori mode. We have already performed successful experiments with Wettzel (Germany) and Yaragadee (Australia) sites.
3) The development of new software:
   - to perform more in-depth analyses
   - to maintain a high-stability time scale
   - to create a database of monitoring results
   - to provide a possibility to access the database via Internet
   - to process data from the tracking network
4) To control a GNSS coordinate supply with the help of SLR (Satellite Laser Ranging)
5) Scientific supply of new receiver development
6) To take part in the development of a future GNSS:
   - to optimize the GNSS satellite constellation
   - to determine orbitography and synchronization methods
   - to organize GNSS monitoring
   - to develop methods of GNSS operation

ILRS System Performance in Support of IGEX

Van Husson
AlliedSignal Technical Services Corporation
7515 Mission Drive, Lanham, Maryland 20706, USA

Tim Springer
Astronomical Institute, University of Berne
Sidlerstrasse 5, CH-3012 Berne, Switzerland

Abstract

The ILRS IGEX-98 tracking campaign began on 19 October 1998 and ended 19 April 1999. Since the end of the campaign, GLONASS tracking has continued open-ended into the future, but in a reduced scope (i.e., only three GLONASS satellites are on the ILRS tracking priority list now versus nine GLONASS satellites during IGEX). The single shot precision ranging to the GLONASS satellites is dependent on the ILRS system configuration and the orientation of the satellite array. The only problem in the ILRS support of the IGEX was and still is the numerous GLONASS numbering schemes (i.e., western GLONASS numbers, COSPAR IDs, slot numbers, Russian COSMOS numbers, etc.). In the rest of this paper we will discuss the different tracking phases of the IGEX campaign and ILRS data issues.

The ILRS tracking support of IGEX-98 was very robust with satellite laser ranging (SLR) data obtained on 18 different GLONASS satellites (62, 64, 65, 66, 67, 68, 69, 70, 71, 72, 74, 75, 76, 77, 79, 80, 81, 82) in both day and night, from more than 30 different ILRS stations. The ILRS IGEX-98 tracking campaign began on 19 October 1998, and was scheduled to end 19 January 1999, but was extended three months until 19 April 1999 by the ILRS Governing Board. The IGEX-98 campaign extension was granted due to the 30 December 1998 launch of GLONASS 80, 81, and 82. GLONASS 80, 81, and 82 were added to this ILRS priority list as of 22 February 1999. During the campaign, SLR tracking of GLONASS-65 was discontinued due to problems on-board the spacecraft. Since 19 April 1999, the ILRS has recommended only three GLONASS satellites (70, 72, 79) be continued to be supported on an indefinite basis.

Satellite laser ranging to the GLONASS satellites has been relatively easier compared to tracking GPS-35 and GPS-36, which have a much smaller retro-reflector array (24 x 19 centimeter array with 32 cube corners versus the GLONASS 120 x 120 centimeter array with 396 cube corners). The return signal strength from GLONASS is comparable to LAGEOS' return signal strength, which enables daylight laser ranging capability. However, the relative large size and shape of the GLONASS retro-reflector array coupled with the NADIR pointing of the spacecraft does present some challenges in determining the proper SLR center of mass correction.

The SLR signal shot precision to GLONASS is dependent upon the attitude of the retro-reflector array relative to the ILRS ground station and the ILRS system configuration (detection scheme). Within the ILRS, there are basically two types of detectors, photo-multiplier tubes (PMT) and the single photon avalanche diode (SPAD).

The PMT systems' single shot GLONASS RMSs vary from 50 to 200 picoseconds at ranges of 127 to 152 milliseconds, respectively. In contrast, the SPAD systems' single shot GLONASS RMSs vary from 120 to 500 picoseconds at ranges of 127 to 152 milliseconds, respectively. In addition, based on analysis of Center for Orbit Determination (CODE) IGEX Precision Orbit Determination, the mean range bias between the GLONASS-determined orbit and the SLR data is detector dependent. The mean range bias of SLR PMT and SLR SPAD systems relative to the GLONASS orbits is -63 and -26 millimeters, respectively. So PMT SLR systems measure 37 millimeter shorter, on the average, versus the SPAD SLR systems to the GLONASS satellite.

There are various numbering schemes for the GLONASS constellation, which has led to some confusion when comparing results between microwave and SLR analysis centers. The primary causes of this problem are related to the fact that the GLONASS satellites are usually launched in triplets and that the Russians, NORAD, and the ILRS use different naming schemes for the satellites. Currently, ILRS GLONASS 77 is really NORAD GLONASS 79 and vice versa. Also, ILRS GLONASS 80 is really NORAD GLONASS 82 and vice versa.

GLONASS and GPS have very similar arrays and orbits, but the large size of the GLONASS retroreflector array relative to the GPS retroreflector array makes GLONASS a much easier target for SLR acquisition. However, the large size of the GLONASS planar array does cause some very noticeable detector dependent target signatures. An algorithm of SLR GLONASS target signatures needs to be developed in order to enhance the future synergies of SLR and GLONASS by resolving centimeter level systematic differences between these two space geodetic techniques.

The IGEX Data Center at the CDDIS

Carey E. Noll
NASA Goddard Space Flight Center
Code 920.1, Greenbelt, MD 20771, USA

Maurice P. Dube
Raytheon Information Technology and Scientific Services
Code 922, Greenbelt, MD 20771, USA

Abstract

The Crustal Dynamics Data Information System (CDDIS) serves as a global data center for the IGEX-98. This paper will present information about the archive and data holdings. Complete listings of data holdings, latency figures, as well as problems encountered during the campaign will also be presented.

Introduction

The Crustal Dynamics Data Information System (CDDIS) was established in 1982 as a dedicated data bank to archive and distribute all Crustal Dynamics Project-acquired data and information about these data. Today, the CDDIS continues to serve as the NASA archive and distribution center for space geodesy data, particularly GPS, GLONASS, laser, DORIS and VLBI data. The CDDIS has served as a global data center for the International GPS Service (IGS) since its start in June 1992, providing on-line access to GPS data from nearly 160 sites on a daily basis as well as the products derived by the IGS Analysis Centers from these data. The CDDIS also serves as a data center for GPS and DORIS in support of the International Earth Rotation Service (IERS). Furthermore, the CDDIS provides an on-line archive of TOPEX/Poseidon (SLR and DORIS) and ERS-1 and -2 (SLR) data for near real-time access by precision orbit determination (POD) analysis centers. Selected data sets are accessible to scientists through ftp and the World Wide Web (WWW); general information about all data is accessible via the WWW. The CDDIS staff issues a bimonthly bulletin to apprise the user community of new data sets and changes to the archive.

In 1998, the CDDIS was selected to serve as a global data center for the International GLONASS Experiment (IGEX-98), as well as a data center for the International Laser Ranging Service (ILRS) and the International VLBI Service for Geodesy and Astrometry (IVS). In its capacity as an IGEX data center, the CDDIS established an on-line archive of GLONASS data and products; all data and products since August 1998 are available through the CDDIS.

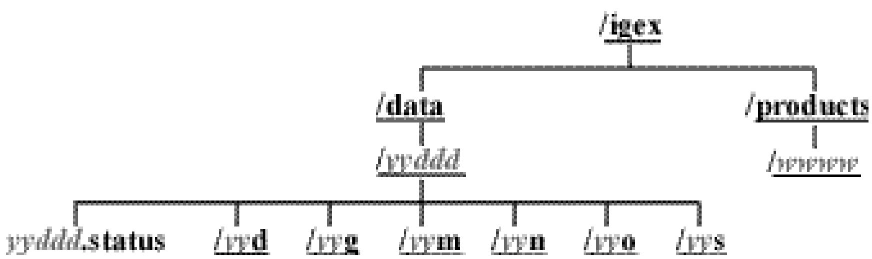
Computer System

A new computer system for the CDDIS, a DEC AlphaServer 4000 running the UNIX operating system, host name *cddisa.gsfc.nasa.gov*, was recently installed. The system is currently equipped with over 210 Gbytes of on-line magnetic disk storage; approximately 100 Gbytes of storage are devoted to the storage of GPS and GLONASS data and products. A 600-platter CD-ROM jukebox, primarily for GPS data, is also part of this computer facility.

The on-line archive of the CDDIS consists of an ORACLE data base and GPS, GLONASS, laser, DORIS, and VLBI data sets (over 100 Gbytes on-line, many Gbytes near-line). The off-line archive consists of GPS, laser, DORIS and VLBI data on CD-ROM, magneto-optical disks, and magnetic tapes. The CDDIS utilizes the ORACLE data base management system to provide flexibility for storing and accessing these diverse data sets, particularly meta-data, or information about these data.

Support of IGEX-98

The GLONASS data available through the CDDIS consists of daily files (from 00:00:00 through 23:59:30 GPS time) of observation data sampled at 30 seconds. These data are stored in compressed, compact RINEX format using UNIX compression on Hatanaka-compacted files. In addition, GPS and GLONASS navigation and meteorological data (also in RINEX format) are available. Ideally, data are transmitted from the GLONASS station to the global data center within 48 hours after then end of the UTC day. The directory structure for the CDDIS GLONASS data archive is shown in Figure 1.



yy = year
ddd = day of year
wwww = GPS week

d = Hatanaka compressed files
g = GLONASS broadcast ephemeris files
m = meteorological data
n = GPS broadcast ephemeris files
o = compressed observation files
s = teqc summary files

Figure 1. Directory structure of CDDIS GLONASS data holdings.

Table 1 lists the data holdings for the IGEX campaign (19-Oct-1998 through 19-Apr-1999). Over 8300 station days of data were archived from 74 receivers located at 62 globally distributed sites.

Table 1. IGEX-98 GLONASS Data Holdings of the CDDIS (19-Oct-98 through 19-Apr-99)

Mon. Name	Site Name	Country	Receiver Type	Start Date	End Date	No. Days	
BELR	Bellevue	Australia	Ashtech GG24C	23-Nov-98	19-Jan-99	27	
BETR	Bellevue	Australia	Ashtech Z-12 (GPS only)	09-Nov-98	19-Jan-99	15	
BISZ	Bishkek	Kyrgyzstan	MAN NR-R124	16-Nov-98	19-Apr-99	147	
BORG	Borowiec	Poland	3S Navigation R100/30T	19-Oct-98	19-Apr-99	167	*
BRST/G	Brest	France	Ashtech GG24 (Martec)	19-Oct-98	16-Apr-99	156	
SUNM	Brisbane	Australia	Javad Legacy GGD	24-Dec-98	03-Apr-99	90	*
BRUG	Brussels	Belgium	3S Navigation R100/30T	19-Oct-98	19-Apr-99	154	*
DLFT	Delft	The Netherlands	Ashtech GG24C	19-Oct-98	16-Feb-99	120	
			Javad Legacy GGD	23-Feb-99	19-Apr-99	53	*
VSLD	Delft	The Netherlands	3S Navigation R100/40T	21-Oct-98	15-Apr-99	165	*
EKAT	Ekaterinburg	Russia	Javad Legacy	13-Jan-99	04-Feb-99	8	
GATR	Gainesville	USA	Javad Legacy GGD	19-Oct-98	03-Apr-99	120	*
GRAC	Grasse	France	Ashtech GG24C	29-Nov-98	19-Apr-99	119	
GRAB	Graz	Austria	Ashtech Z-18	23-Nov-98	19-Apr-99	115	
GTY1	Great Yarmouth	United Kingdom	Trimble 4000SSI (GPS only)	19-Oct-98	30-Jan-99	97	
GTY2	Great Yarmouth	United Kingdom	Ashtech GG24	19-Oct-98	28-Jan-99	74	
GODZ	Greenbelt	USA	Ashtech Z-18	19-Oct-98	19-Apr-99	170	*
HERP	Herstmonceux	United Kingdom	3S Navigation R100/40	03-Nov-98	19-Apr-99	151	*
HOBR	Hobart	Australia	Ashtech GG24C	18-Nov-98	30-Nov-98	3	
HKPU	Hong Kong	China	Ashtech GG24C	20-Oct-98	29-Oct-98	4	
IBK1	Innsbruck	Austria	Ashtech GG24	19-Oct-98	19-Apr-99	120	
IRKG	Irkutsk	Russia	Trimble 4000SGL	19-Oct-98	10-Apr-99	169	*
IRKZ	Irkutsk	Russia	Ashtech Z-18	19-Oct-98	19-Apr-99	174	*
3SNA	Irvine	USA	3S Navigation R100/40T	19-Oct-98	19-Apr-99	139	
KHAB	Khabarovsk	Russia	Ashtech Z-18	19-Oct-98	20-Mar-99	150	*
KR0G	Kiruna	Sweden	Ashtech Z-18	19-Oct-98	19-Apr-99	170	*
CSN1	Korolev	Russia	Ashtech Z-12 (GPS only)	25-Oct-98	25-Oct-98	1	
REUN	La Reunion	La Reunion	Ashtech Z-18	15-Dec-98	19-Apr-99	64	
LDS1	Leeds	United Kingdom	ESA/ISN GNSS	19-Oct-98	19-Apr-99	181	
LDS2	Leeds	United Kingdom	Trimble 4000SSE (GPS only)	20-Oct-98	19-Apr-99	178	
LDS3	Leeds	United Kingdom	Ashtech GG24EC	19-Oct-98	19-Apr-99	180	
SL1X	Lexington	USA	Ashtech Z-18	19-Oct-98	18-Apr-99	172	
LINR	Lindfield	Australia	3S Navigation R100/30T	19-Oct-98	19-Apr-99	90	*
MR6G	Maartsbo	Sweden	Ashtech GG24C	19-Oct-98	19-Apr-99	177	*
MAGD	Magadan	Russia	Javad Legacy	13-Jan-99	10-Mar-99	54	
MTBG	Mattersburg	Austria	Ashtech GG24C	05-Nov-98	17-Apr-99	137	*
MDOA	McDonald	USA	Javad Legacy	20-Nov-98	19-Apr-99	138	
CRAR	McMurdo	Antarctica	Javad Legacy GGD	26-Dec-98	06-Feb-99	43	
MDVG	Mendeleevo	Russia	Trimble 4000SGL	19-Oct-98	14-Feb-99	118	
MDVZ	Mendeleevo	Russia	Ashtech Z-18	19-Oct-98	19-Apr-99	181	*
METZ	Metsahovi	Finland	Ashtech Z-18	19-Oct-98	19-Apr-99	137	*
MTKA	Mitaka	Japan	Ashtech Z-18	27-Oct-98	19-Apr-99	127	*
STRR	Mt. Stromlo	Australia	Ashtech Z-18	07-Nov-98	19-Apr-99	123	*
NKLG	N'Koltang	Gabon	Ashtech Z-18	13-Feb-99	19-Apr-99	37	
BLVA	Neubiberg	Germany	3S Navigation R100/R101	19-Oct-98	21-Dec-98	10	
NTZ1	Neustrelitz	Germany	3S Navigation R101	19-Oct-98	19-Apr-99	183	*
NTZ3	Neustrelitz	Germany	Rogue SNR-8100 (GPS only)	19-Oct-98	19-Apr-99	183	*
NPLI	New Delhi	India	3S Navigation GNSS-300T	16-Nov-98	26-Nov-98	2	
DLRA	Oberpfaffenhofen	Germany	3S Navigation R100/40T	19-Oct-98	19-Apr-99	132	
OS0G	Onsala	Sweden	Ashtech Z-18	22-Oct-98	18-Apr-99	163	*
PKST	Petropavlovsk-Kamchatskiy	Russia	Javad Legacy	16-Jan-99	14-Feb-99	28	
CSIR	Pretoria	South Africa	3S Navigation R100/30T	19-Oct-98	19-Apr-99	165	*
REYZ	Reykjavik	Iceland	Ashtech Z-18	19-Oct-98	18-Apr-99	85	*
RIOZ	Rio Grande	Argentina	MAN NR-R124	11-Nov-98	19-Apr-99	141	
SANG	Santiago	Chile	3S Navigation R100/40	05-Nov-98	19-Apr-99	156	
BIPD	Sèvres	France	3S Navigation R100/30T	25-Oct-98	18-Apr-99	144	*
SUTG	Sutherland	South Africa	MAN NR-R124	03-Dec-98	19-Apr-99	136	
SVT3	Svetloe	Russia	Javad Legacy GGD	05-Jan-99	07-Feb-99	34	
CK02	Taiwan	Taiwan	Ashtech Z-12 (GPS only)	20-Oct-98	19-Apr-99	125	
NCKU	Taiwan	Taiwan	Ashtech GG24	20-Oct-98	17-Apr-99	117	
NPLB	Teddington	United Kingdom	Ashtech Z-12	27-Nov-98	30-Nov-98	4	
NPLC	Teddington	United Kingdom	3S Navigation R100/40T	21-Oct-98	19-Apr-99	131	
THU2	Thule	Greenland	Ashtech Z-18	10-Nov-98	19-Apr-99	112	*
TSKA	Tsukuba	Japan	Ashtech Z-18	19-Nov-98	19-Apr-99	136	
LRBA	Vernon	France	Ashtech Z-18	21-Oct-98	19-Apr-99	138	
VS0G	Visby	Sweden	Ashtech GG24C	19-Oct-98	19-Apr-99	169	*
USNX	Washington, DC	USA	3S Navigation R100/30T	22-Oct-98	19-Apr-99	166	*
WTZG	Wettzell	Germany	3S Navigation R100/R101	19-Oct-98	19-Apr-99	123	*
WTZZ	Wettzell	Germany	Ashtech Z-18	07-Feb-99	19-Apr-99	68	*
YAKT	Yakutsk	Russia	Javad Legacy	12-Jan-99	07-Mar-99	52	
YARR	Yaragadee	Australia	Ashtech Z-18	20-Oct-98	19-Apr-99	137	*
ZIMJ	Zimmerwald	Switzerland	Javad Legacy GGD	14-Feb-99	19-Apr-99	48	*
ZIMZ	Zimmerwald	Switzerland	Ashtech Z-18	19-Oct-98	19-Apr-99	172	*
ZWEG	Zvenigorod	Russia	Ashtech GG24	28-Oct-98	02-Feb-99	79	
Totals:	74 receivers at 62 sites				station days:	8,354	

Notes: * denotes site that continues in operation
47 dual frequency, 20 single frequency, and 7 GPS-only receivers

Figure 2 shows the average latency of data transmitted from the stations to the CDDIS; nearly 30 percent of the data were received in 24 hours.

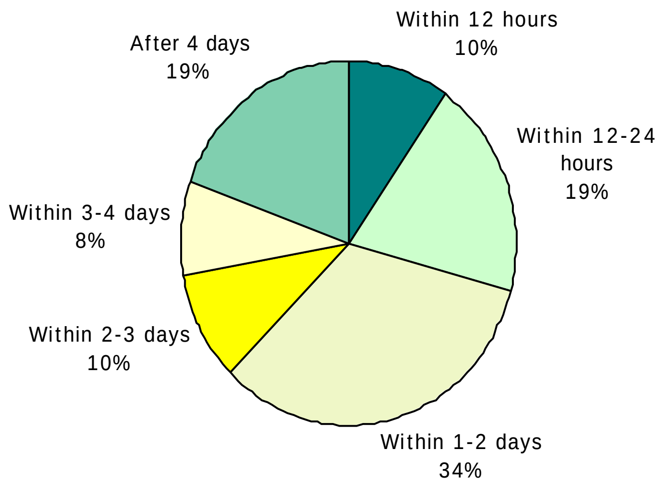


Figure 2. Average latency of data transmitted from IGEX-98 stations to the CDDIS.

The CDDIS also archived the satellite laser ranging (SLR) data from the ILRS stations tracking the retro-reflector-equipped GLONASS satellites. These data holdings are shown in Table 2. A total of thirty SLR stations tracked eighteen GLONASS satellites during the official campaign, generating over 6600 passes containing over 36K normal points.

Table 2. IGEX-98 SLR Data Holdings of the CDDIS (19-Oct-98 through 19-Apr-99)

Site Name	Country	Sta.	Number of Passes																		
			GL-62*	GL-64	GL-65*	GL-66*	GL-67	GL-68*	GL-69*	GL-70*	GL-71*	GL-72*	GL-74	GL-75	GL-76	GL-77	GL-79*	GL-80*	GL-81*	GL-82*	Totals
Beijing	China	7249	7	0	0	3	0	6	6	7	6	4	0	0	0	0	0	0	0	0	39
Borowiec	Poland	7811	2	0	0	3	0	1	4	5	5	3	0	0	0	0	3	0	0	0	26
Changchun	China	7237	45	23	8	15	11	37	40	34	36	35	14	20	22	18	27	0	0	1	386
Grasse	France	7835	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Grasse (LLR)	France	7845	66	0	8	77	0	47	60	65	127	82	0	0	0	0	76	0	0	0	608
Graz	Austria	7839	70	8	8	50	0	56	54	64	65	68	4	30	37	43	44	0	0	0	601
Greenbelt	USA	7105	34	0	10	37	0	56	47	49	39	38	0	0	0	0	31	2	13	4	360
Haleakala	USA	7210	29	0	3	44	0	43	18	26	43	18	0	0	0	0	1	0	0	0	225
Herstmonceux	United Kingdom	7840	45	5	5	37	39	50	48	53	48	42	0	0	0	0	41	0	0	0	413
Kashima	Japan	7335	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	4
Koganei	Japan	7328	2	0	0	0	0	2	1	4	6	1	0	0	0	0	1	0	0	0	17
Komsomolsk-na-Amure	Russia	1868	0	0	0	14	0	0	0	0	19	0	0	0	0	0	0	0	0	0	33
Kunming	China	7820	2	1	0	2	0	1	7	5	6	9	0	0	0	1	1	0	0	0	35
Maidanak	Uzbekistan	1864	1	0	0	8	0	8	8	8	12	1	0	1	0	0	5	0	0	0	52
McDonald	USA	7080	27	0	6	39	1	25	27	28	39	22	0	0	0	0	28	0	3	0	245
Metsahovi	Finland	7806	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Miura	Japan	7337	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Monument Peak	USA	7110	112	0	12	88	0	108	123	117	119	110	0	0	0	0	77	4	15	11	896
Mount Stromlo	Australia	7849	68	0	8	72	0	65	63	68	62	68	0	0	0	0	56	1	4	0	535
Orroral	Australia	7843	7	6	5	7	0	5	9	3	8	0	2	10	7	0	9	0	0	0	78
Potsdam	Germany	7836	11	0	1	9	0	12	19	12	12	17	0	0	0	0	8	0	0	0	101
Shanghai	China	7837	22	0	1	11	5	24	22	22	14	28	0	3	2	2	13	0	0	0	169
Simeiz	Ukraine	1873	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2
Simosato	Japan	7838	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	3
Tahiti	French Polynesia	7124	8	0	0	4	0	4	6	6	3	9	0	0	0	0	1	0	1	0	42
Tateyama	Japan	7339	4	0	0	1	0	5	1	4	2	1	0	0	0	0	1	0	0	0	19
Wettzell	Germany	8834	61	18	3	19	12	49	42	34	42	27	7	25	25	30	23	0	0	0	417
Wuhan	China	7236	2	2	1	0	1	4	3	4	6	1	0	0	0	0	2	0	0	0	26
Yarragadee	Australia	7090	157	0	22	148	0	114	102	121	139	154	0	0	0	0	104	0	12	0	1,073
Zimmerwald	Switzerland	7810	27	0	5	20	0	27	30	34	31	31	0	0	0	0	25	0	0	0	230
Totals:		30	810	63	106	709	69	752	742	775	892	770	27	89	93	94	577	7	48	16	6,639

Site Name	Country	Sta.	Number of Normal Points																		
			GL-62*	GL-64	GL-65*	GL-66*	GL-67	GL-68*	GL-69*	GL-70*	GL-71*	GL-72*	GL-74	GL-75	GL-76	GL-77	GL-79*	GL-80*	GL-81*	GL-82*	Totals
Beijing	China	7249	89	0	0	29	0	46	56	68	67	31	0	0	0	0	0	0	0	0	386
Borowiec	Poland	7811	5	0	0	9	0	3	13	20	18	7	0	0	0	0	9	0	0	0	84
Changchun	China	7237	335	153	35	71	55	258	294	236	275	233	69	131	136	93	154	0	0	4	2,532
Grasse	France	7835	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	10
Grasse (LLR)	France	7845	228	0	23	266	0	161	216	218	466	304	0	0	0	0	258	0	0	0	2,140
Graz	Austria	7839	640	66	64	358	0	446	466	595	562	557	47	217	274	316	364	0	0	0	4,972
Greenbelt	USA	7105	174	0	50	215	0	270	264	243	234	249	0	0	0	0	128	12	66	19	1,924
Haleakala	USA	7210	174	0	30	370	0	331	155	177	360	198	0	0	0	0	2	0	0	0	1,797
Herstmonceux	United Kingdom	7840	249	37	12	148	158	235	241	265	249	239	0	0	0	0	191	0	0	0	2,024
Kashima	Japan	7335	0	0	0	0	0	0	3	10	3	0	0	0	0	0	0	0	0	0	16
Koganei	Japan	7328	14	0	0	0	0	7	6	30	40	4	0	0	0	0	9	0	0	0	110
Komsomolsk-na-Amure	Russia	1868	0	0	0	28	0	0	0	0	118	0	0	0	0	0	0	0	0	0	146
Kunming	China	7820	13	5	0	9	0	4	49	22	35	51	0	0	0	6	5	0	0	0	199
Maidanak	Uzbekistan	1864	3	0	0	21	0	17	15	15	81	1	0	3	0	0	13	0	0	0	169
McDonald	USA	7080	139	0	20	181	3	111	120	110	189	114	0	0	0	0	109	0	12	0	1,108
Metsahovi	Finland	7806	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	7
Miura	Japan	7337	4	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	9
Monument Peak	USA	7110	569	0	46	447	0	611	800	697	681	715	0	0	0	0	398	8	73	60	5,105
Mount Stromlo	Australia	7849	315	0	37	316	0	312	277	291	297	322	0	0	0	0	251	4	24	0	2,446
Orroral	Australia	7843	21	18	19	36	0	18	23	8	25	0	6	42	20	0	22	0	0	0	258
Potsdam	Germany	7836	49	0	5	35	0	67	91	51	66	69	0	0	0	0	36	0	0	0	469
Shanghai	China	7837	196	0	9	93	19	152	220	193	94	282	0	24	19	11	101	0	0	0	1,413
Simeiz	Ukraine	1873	0	0	0	0	0	0	0	0	4	23	0	0	0	0	0	0	0	0	27
Simosato	Japan	7838	0	0	0	7	0	0	7	0	7	0	0	0	0	0	0	0	0	0	21
Tahiti	French Polynesia	7124	37	0	0	19	0	17	31	22	11	39	0	0	0	0	2	0	2	0	180
Tateyama	Japan	7339	19	0	0	4	0	25	4	19	9	8	0	0	0	0	3	0	0	0	91
Wettzell	Germany	8834	249	72	13	81	46	258	177	159	168	153	27	108	98	131	101	0	0	0	1,841
Wuhan	China	7236	21	13	6	0	12	53	30	61	67	8	0	0	0	0	15	0	0	0	286
Yarragadee	Australia	7090	775	0	70	586	0	456	442	506	678	773	0	0	0	0	399	0	60	0	4,745
Zimmerwald	Switzerland	7810	300	0	28	127	0	220	262	225	196	282	0	0	0	0	175	0	0	0	1,815
Totals:		30	4,618	364	467	3,456	293	4,100	4,262	4,241	5,000	4,662	149	525	547	557	2,745	24	237	83	36,330

Notes:
* indicates GLONASS satellites specifically requested for SLR tracking
GLONASS-65 failed in December 1998
GLONASS-80, -81, -82 launched December 30, 1998

The CDDIS also archived the products generated by IGEX analysis centers from the GLONASS data sets. These products consisted of precise orbits of the GLONASS satellites and station positions of the tracking network. Orbit files were made available in SP3 format; station position files in the Software Independent Exchange (SINEX) format. Table 3 lists the analysis centers contributing products to the data centers.

Table 3. IGEX-98 Analysis Centers Supplying Results to the CDDIS

Acronym	Source	Time Period
BKG	Bundesamt für Kartographie und Geodäsie (BKG), Germany	Weeks 0980 through present
COX	Center for Orbit Determination (CODE), AIUB, Switzerland	Weeks 0979 through present
ESX	European Space Agency Space Operations Center (ESA/ESOC), Germany	Weeks 0980 through present
GFX	GeoForschungsZentrum Potsdam (GFZ), Germany	Weeks 0983 through 1001
JPX	Jet Propulsion Laboratory (JPL), USA	Weeks 0991 through present
MCC	Mission Control Center (MCC), Russia	Weeks 0980 through present
IGX	Combined IGEX Solution, University of Technology, Vienna, Austria	Weeks 0981 through 0989

Problems Encountered

It was soon apparent that the data processing for GLONASS would not be as routine as that experienced by the CDDIS in support of the IGS. A list of typical problems encountered can be found in (Noll, 1999).

Future Plans

The CDDIS plans to continue the archive and distribution of GLONASS data and products as part of a future service, the International GLONASS Experiment Pilot Service (IGEX-PS), within the auspices of the IGS.

Contact Information

To obtain more information about the CDDIS, contact:

Ms. Carey E. Noll	Phone: (301) 614-6542
Manager, CDDIS	FAX: (301) 614-5970
Code 920.1	E-mail: *noll@cddis.gsfc.nasa.gov*
NASA GSFC	WWW: *http://cddisa.gsfc.nasa.gov*
Greenbelt, MD 20771	
USA	

References

Noll, C. (1999). Data Flow for the IGEX-98, *Proceedings IGEX-98 Workshop*, Nashville, Sept. 13-14, 1999, JPL.

Altimetric Ionospheric Correction Using DORIS And GLONASS Data

Nicolas Picot and Philippe Escudier
Centre National d'Etudes Spatiales
18 avenue Edouard Belin, 31401 Toulouse Cedex 4, France

Sylvie Labroue
Collecte et Localisation par Satellite
8-10 rue Hermès, Parc Technologique du Canal, 31526 Ramonville, France

Abstract

The DORIS precise positioning system (Dorrer et al., 1991) provides dual-frequency Doppler measurements over a global network of about 50 transmitting beacons. These measurements are used to estimate a global map of the vertical Total Electronic Content in the ionosphere at the satellite local time (Escudier et al., 1993). In this article, we present the technique applied to the measurements obtained with the DORIS receiver flying on board the TOPEX/Poseidon satellite. It is used on an operational basis for the ionospheric correction to be applied to the Poseidon single-frequency altimeter and for the calibration of the ionospheric content derived from the TOPEX dual-frequency radar altimeter. Comparisons between the corrections from TOPEX and the DORIS data set are given to assess the model quality. New developments of the assimilation chain will allow us to use the GLONASS data to obtain a better coverage and time sampling.

Technique for the Estimation of the DORIS Ionospheric Correction

At each frequency f_i (2 GHz and 400 MHz), DORIS measures a Doppler count. Assuming that Doppler measurements at both frequencies are equal, except for the ionospheric delay, one can deduce the ionospheric correction *m* to be applied to the 2 GHz Doppler measurement. The ionospheric delay is inversely proportional to the frequency squared, this approximation being good enough as the higher order terms are very small and can be neglected. We use a model in which the ionosphere is represented as a single layer and we assume that the electronic content is slowly variable along the ray path. Thus the aim is to determine the TEC at the sub-ionospheric point, belonging to the beacon-satellite direction and at the altitude close to the maximum of the electron density. Following the sub-ionospheric assumption which states that the measurement *m* is related to the slant ionospheric content along the ray path, *m* can be related to the vertical TEC at the sub-ionospheric position with a good accuracy.

The measurements are spread all over the world in the visibility circles of each beacon. The beacons network provides a good but not full coverage of the Earth. For example, one can note a gap of data over the equatorial Pacific Ocean. To achieve the goal of an ionospheric determination at each location of the satellite, we must employ an inversion technique to fill these gaps.

The model used to represent the TEC is an interpolation over a geomagnetic latitude by geographic longitude grid. The grid steps in latitude and longitude are parameters that can be adjusted depending on the required resolution and on the measurement density. The interpolation scheme uses cubic polynomials in both latitude and longitude. The TEC values at each grid point are estimated using a least squares fit over the whole set of measurements. Two days of DORIS data are presently used for each fit. The DORIS measurements are weighted according to measurement quality as computed by pre-processing of the data.

Comparison of DORIS and TOPEX Ionospheric Corrections

To validate this assimilation technique, we use the TOPEX determination of the TEC. We have now more than 7 years of data (from 1992 to mid-1999) over the oceans, covering –66 degrees to 66 degrees, all local time and a solar activity index from medium (beginning of the mission) to low (mid 1996-mid 1997). This tremendous data set gives us really good information on the ability of our model to recover the TEC information from the DORIS measurements.

Over the whole mission, the mean of the difference TOPEX-DORIS appears to be very stable: we have a mean value of 1 cm with some slight evolutions due to the local time effect. The root mean square is below 1.5 cm. Most of the 1 cm value is believed to be due to a miscalibration of the two bands of the altimeter. The model performs a really good fit for the latitudes above 30 degrees north (or below 30 degrees south). The lack of DORIS beacons is also well illustrated in the equatorial Atlantic and in the west Pacific. The fit is less accurate where the TEC values are higher and where we have less information to constrain the model (the equatorial region).

Improvement of the Model Using GPS and GLONASS Data

The DORIS derived ionospheric correction provided to the single-frequency radar altimeter is useful stuff. However, we have noticed that, during high solar activity periods the accuracy is not as good as required. One of the limitations of the model is the coverage of the network. Even if the satellite is visible from a DORIS beacon more than 90% of a day, there is still a lack of data in some regions. The coverage can be improved using another source of information. This is the reason for recent studies regarding to the ingestion of GPS and GLONASS data in the present model. These data will offer additional coverage to that of DORIS.

Conclusion

The DORIS-based ionospheric correction provides the altimetric community with a useful tool to correct single-frequency radar measurements. Further improvements of the model are to be done using combined GPS and GLONASS data. The DORIS-based ionospheric correction is also used to monitor the quality of the dual frequency ionospheric correction and it is a backup solution in case of any problem on the C-band of the TOPEX altimeter. Furthermore, it is a good estimate of the ionospheric content where the C-band cannot be used (over ice, land, small lakes or near the coast). Another application is the monitoring of the ionospheric content in order to survey the solar activity (Space Weather activities). This model will be used on an operational basis for the upcoming Jason and Envisat missions.

References

Dorrer, M., P. Deschamps, B. Laborde (1991). DORIS (Doppler Orbitography and Radiopositionning Integrated from Space): System assessment results with DORIS on SPOT 2, *Acta Astronautica*, Vol. 25, No. 8/9, pp. 497-504.

Escudier, P., N. Picot, O.Z. Zanife (1993). Altimetric Ionospheric Correction Using DORIS Doppler Data, in *Environmental Effects on Spacecraft Positioning and Trajectories*, IUGG 1993, Vol. 13, pp. 61-71.

Benefits From a Combined GPS / GLONASS Analysis for Earth Rotation Studies

Markus Rothacher
Forschungseinrichtung Satellitengeodäsie, Technical University of Munich
Arcistrasse 21, D-80333 Munich, Germany

Robert Weber
Institute of Geodesy and Geophysics, University of Technology, Vienna
Gusshausstrasse 27-29, A-1040 Vienna, Austria

The IGEX began October 1998 to study the impact of the GLONASS on space geodetic work. Primary goals of this campaign were to establish a global GLONASS tracking network, to produce precise satellite orbits and to serve the timing and frequency community. Other topics to be investigated in this study include whether and how the use of GLONASS can help to improve Earth Rotation Parameters (ERPs). Moreover, the fact that the revolution period is not in a 2:1 resonance with the Earth´s rotation has to be considered and might be advantageous.

In October 1998, the Center for Orbit Determination in Europe (CODE) started to process the GLONASS and GPS data provided by the tracking stations of IGEX. Usually the GLONASS orbits are derived by first fixing the GPS orbits and the ERPs to the final CODE GPS solutions (Ineichen et al.,1999). To establish a rigorous IGS+IGEX combination, this study processed simultaneously data from around 110 IGS and 30 IGEX sites.

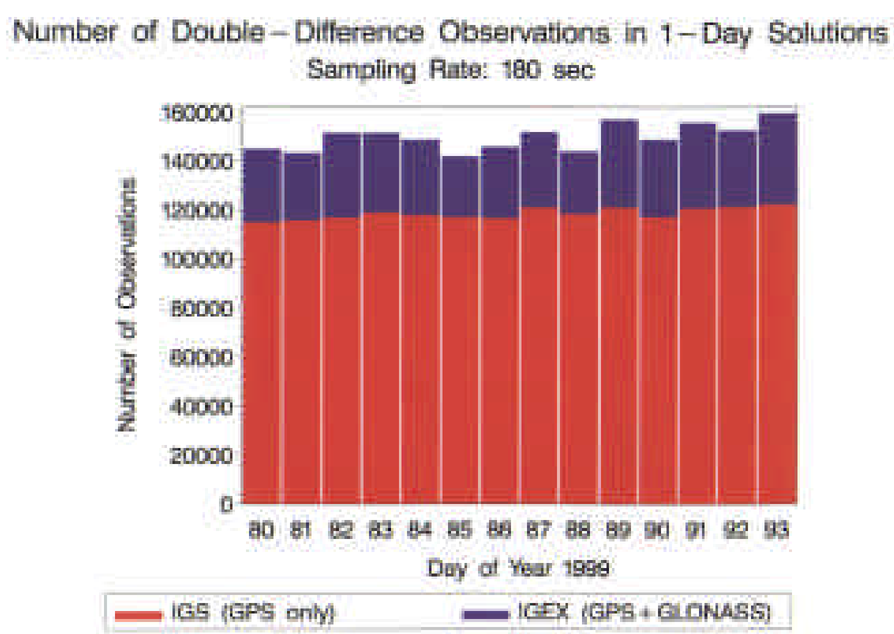


Figure 1. Contribution of GLONASS observations to double-differences in 1-day solutions.

The reference frame was realized by fixing 43 sites to their ITRF96 coordinates in the combined solution (37 IGS + 6 IGS/IGEX). Unfortunately the IGEX network is rather sparse and the distribution of tracking stations is inhomogeneous. This causes a quite modest share of additional observations in the combined IGS+IGEX network compared to the GPS-only (IGS-only) solution. Figure 1 shows the increase of double-difference observations during the chosen test period of two weeks in March 1999. The amount of involved GLONASS data is less than 10%.

Orbit modelling errors are limiting factors for the determination of diurnal and semi-diurnal tidal terms with GPS. Periods close to 12 and 24 hours (see Figure 2) are particularly critical because orbit errors typically vary periodically with the revolution period. The GLONASS with a revolution period of about 11^h15^m could contribute significantly to the determination of tidal terms near one sideral day (e.g. S1, ψ1).

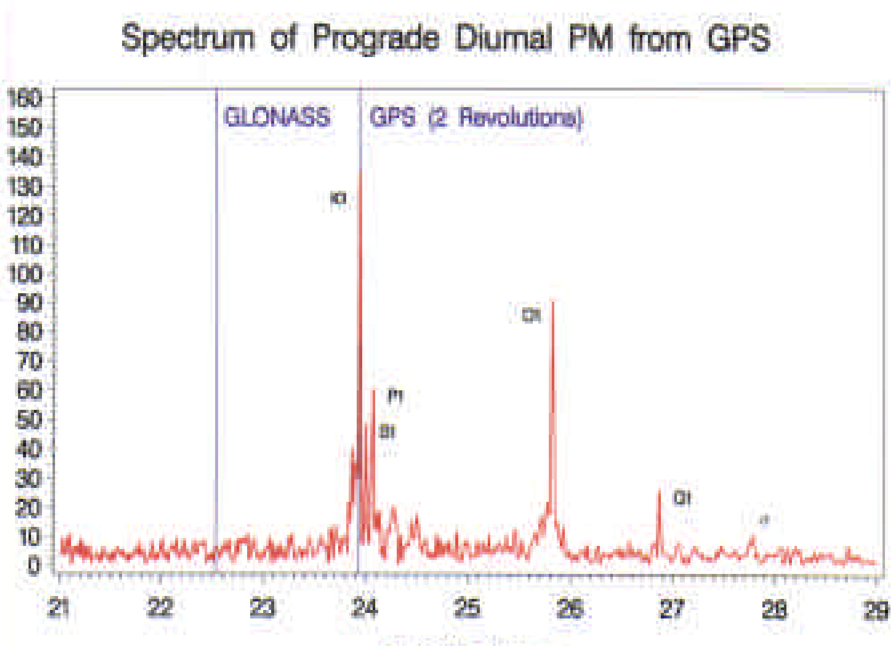


Figure 2. Spectrum of diurnal polar motion from GPS.

Moreover the estimation of LOD should benefit from the larger inclination of the GLONASS orbits. First test computations confirm this assumption. LOD estimates show modest improvements in the full combination and their formal a posteriori errors decrease by about 25%. Further studies will test the effectivity of the full integration of GLONASS data.

References

Ineichen, D., M. Rothacher, T. Springer, G. Beutler (1999). Results of CODE as an Analysis Center of the IGEX-98 Campaign, *Proceedings IGEX-98 Workshop,* Nashville, Sept. 13-14, 1999, JPL.

LRBA as an Observation Center
Difficulties and Positive Aspects

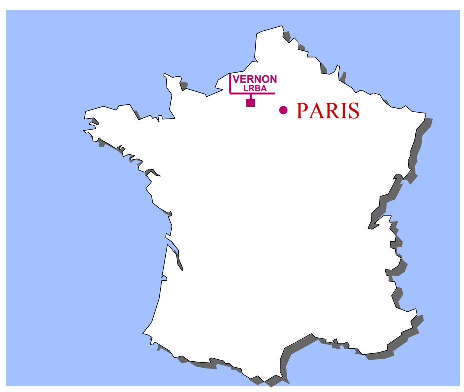
Christelle Vigneau
Ballistics and Aerodynamics Research Laboratory
PoB 914, 27207 Vernon, France

Abstract

The Ballistics and Aerodynamics Research Laboratory (LRBA) was an observation station during the IGEX campaign. The poster deals with the difficulties and positive aspects of being a tracking station. Difficulties were encountered about data transfer tests during the validation phase and the use of provided software (Hatanaka). The receiver failures have also interrupted the continuous providing of data. Positive aspects were the efficiency of the centralized organization, the support from the international IGEX network, and the ability of a French MOD principal technical center to serve the scientific community.

Presentation of the LRBA

The LRBA is a laboratory of the French MOD and the expert center in satellite radionavigation for the Ministry of Defense.



Difficulties (1): Validation Phase-Data Transfer Tests

During the validation phase, the LRBA had difficulties joining its data center. The main consequence was that, in the beginning, the LRBA files were not taken into account and without contact, we had no way to fix the problem.

Difficulties (2): Use of Provided Software [Hatanaka]

At first, there was incompatibility between the PC operating system (WIN 95 or NT) and the instruction « GOTO » in the Hatanaka software. The LRBA succeeded in finding a solution by installing WIN 98, but this wasted valuable time until the origin of the failure was discovered.

A second incompatibility was between the Z18 receiver software and the Hatanaka utility. The Z18 software codes the ambiguity on 11 bits; the Hatanaka utility only accepts 10 bits. This problem was solved by an ON/OFF operation on the receiver twice a week (very constraining).

Difficulties (3): Z18 Failures

First, since the beginning of the campaign (in October 1998), the receiver has announced random failures. The first solution used was a RESET of the receiver. Along the campaign, the RESET action was less and less efficient and at the end inefficient . So the receiver became unavailable.

Second was manufacturer support; the LRBA received low support from the manufacturer. Although they often have been called upon for support through their French representative, and appeared interested in solving the problems, the failures were not solved. The result was a disaster for the campaign: more than 15 days without data.

Positive Aspects (1): Efficiency of the Centralized Organization

The provided guidelines were well done and the members of the steering committee were always available.

Positive Aspects (2): Support from the International IGEX Network

The scientific community immediately answered when the LRBA was in trouble
(i.e., message from W. Gurtner about Hatanaka problems)

Positive Aspects (3) : Ability of a French MOD Principal Technical Center to Serve the Scientific Community

The IGEX campaign was a challenge for the LRBA because of combined security and administrative problems. Today we are proud of having succeeded in participating and so having served the scientific community.

We are ready to start again!