IGEX-98

IGS

SESSION 2

RECEIVER TECHNOLOGY

An Operational Evaluation of the JPS Legacy Receiver

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Abstract

Based on cost, performance specifications, and availability, the University of Florida (UF) selected the Javad Positioning System (JPS) Legacy GLONASS/GPS receiver to participate in the IGEX Experiment. The IGEX designation assigned the UF station is GATR. The JPS antenna was mounted on a 1.3 meter high by 0.1 meter diameter cast-iron pipe column, on the roof of Reed Laboratory, on the UF Gainesville campus. The column is one of three on the roof, all of which are within a few meters of station BOLT, a station in the National Geodetic Survey's GPS-based Florida High Accuracy Reference Network (HARN). Station Bolt has been used for several UF research programs within the past several years and accurate coordinates in the ITRF were already known before the IGEX experiment began. The antenna was connected by approximately 25-meter long coaxial cable to the receiver, which was in an environmentally controlled room one floor below. The observational data collected were transferred to a personal computer for storage and quality checking, and then sent in 24-hour blocks by FTP to the NASA CDDIS.

Installation of the JPS receiver took only minutes, and the system began collecting observations on all visible GPS and GLONASS satellites immediately. However, several problems materialized within the first few weeks of operation, requiring consultations with the manufacturer's technical staff, and the installation of several upgraded versions of the firmware. Since this initial shake down period, the receiver has worked reliably for almost one year of continuous operation in the hot, humid weather of central Florida. There have been no failures of the electronic components. Data collection protocol, operational difficulties, and explanations for specific gaps in the data will be presented. Based on computations performed by UF personnel and by others analyzing the IGEX data set, the data have been of acceptable quality.

University of Florida Geomatics Program

The University of Florida Geomatics Program consists of approximately 40 undergraduate and 25 graduate students. Students come to the program from many diverse backgrounds. Many come from the surveying practicing community while others have transferred into geomatics from other campus departments, such as geography, forestry, geology, computer science, or engineering. An increasing number of high school students are choosing studies in geographic information sciences. Student activities give further learning opportunities. Our student chapter carries on the learning process through community service projects, trips to state and national meetings, social events, regular meetings, and invited speakers. Students develop managerial and leadership abilities through these activities.

Areas of study in the Geomatics Program include:

- Geographic Information Systems (GIS)
- Integrated land studies
- Land development
- Environmental assessment
- Geographic information sciences
- Professional surveying and mapping
- Geodesy, surveying, global positioning systems (GPS), photogrammetry, cartography, mapping, remote sensing.

Degree programs in geographic information sciences are offered to prepare students for careers and continued study. An undergraduate program leads to the Bachelor of Science in Geomatics (BSGEO) degree. Graduate programs lead to Master of Science (M.Sc.) and Doctor of Philosophy (Ph.D.) with advanced emphasis in geographic information sciences and geomatics.

University of Florida's Involvement in IGEX-98

The University of Florida chose to participate in the IGEX-98 experiment for two primary reasons:

- We wanted to serve as a North American base station to improve the geometry of the world network.
- As an educational institution, we wanted to gain hands-on experience with a state-of-the-art GPS/GLONASS system to further our knowledge of technology that has great promise for the future.

Our Community's Need for GPS and GLONASS

Global positioning systems are playing an increasingly important role in the surveying profession. Accordingly, we are interested in any developments in the technology that can increase the accuracy of GPS measurements while simultaneously reducing the time and cost needed to obtain those measurements. The utilization of data from both the NAVSTAR GPS and GLONASS systems has the potential for realizing these objectives.

The additional satellites of a combined satellite constellation means:

- better geometry more of the time.
- more redundancy of measurements.
- shorter sessions.
- better measurements in so-called "urban canyons" during conventional ground surveying, i.e., obstructions are less of a constraint in mission planning.

- during banking and other attitude maneuvers, there is less of a chance of the loss of satellite lock for airborne GPS systems used for airborne laser swath mapping (ALSM) (Carter et al., 1997).

Why JPS?

The primary reason for purchasing our system from Javad Positioning Systems (JPS) was availability. The time from the placement of the order to receipt of the system was approximately two months.

The JPS Setup

UF's system consisted of a JPS Legacy dual-frequency GPS+GLONASS receiver, a JPS RegAnt choke-ring antenna, an IBM-compatible PC running Windows95 and JPS's PC-CDU data acquisition software (**Figure 1**). The system's electronic components were attached to an uninterruptable power supply (UPS) to maintain operation during short power outages. The antenna was attached to the receiver with a 25-meter RG-8/50 ohm coaxial cable and was mounted to a fixed pedestal on the roof of Reed Laboratory (**Figure 2**). Also on the roof of Reed Laboratory is reference point BOLT (**Figure 3**) which is part of the National Geodetic Survey's High Accuracy Reference System (HARN) network (PID# AR1943). The antenna reference point (ARP) relative to reference point BOLT was determined by conventional surveying methods (**Table 1**). The antenna's phase center is located 0.0731 meters above the ARP.

Figure 1. UF's JPS Legacy receiver system.

Figure 2. Antenna mount.

Figure 3. Reference point "Bolt."

Table 1. Coordinates of Antenna Reference Point

Earth-Centered Cartesian Coordinates (meters)			Geodetic Coordinates		
X	**Y**	**Z**	**Latitude**	**Longitude**	**Ellipsoid Height**
738692.3459	-5498293.3052	3136519.5303	29° 38’ 52.22299" N	82° 20’ 53.39555" W	25.0919 m

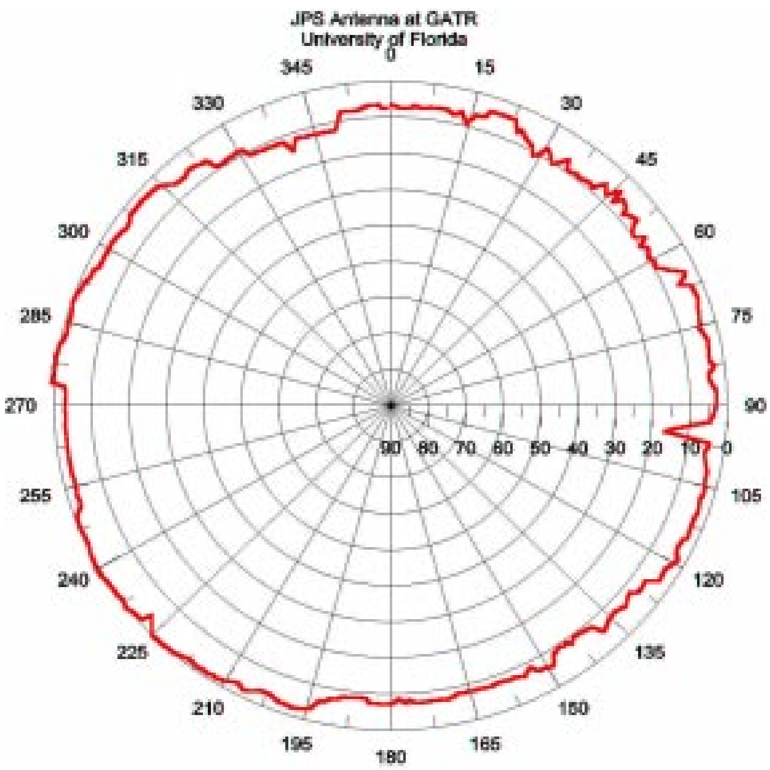

Figure 4. Obstruction diagram for site GATR.

An obstruction diagram for site GATR (**Figure 4**) was computer-generated from Northing/Easting/elevation data gathered by an airborne laser swath mapping (ALSM) system (Carter et al., 1998; Shrestha et al., 1999). The highest solid obstruction (10° to 15° elevation) lies between 330° and 350° azimuth and thus does not interfere with signals from GPS or GLONASS satellites. The obstruction at approximately 100° azimuth is an antenna structure at 73 meters from site GATR that, due to its tenuous nature, most likely has little, if any, effect on satellite signals.

Hardware

Over the year we have been operating the JPS system, the hardware (Figures 5, 6, and 7) has performed flawlessly. The antenna has been continuously stationed on the roof of our building, exposed to the hot and humid environment of North Central Florida. The receiver, located in our environmentally controlled laboratory, performed without a hitch.

Figure 5. JPL Legacy receiver.

Figure 6. JPL RegAnt antenna.

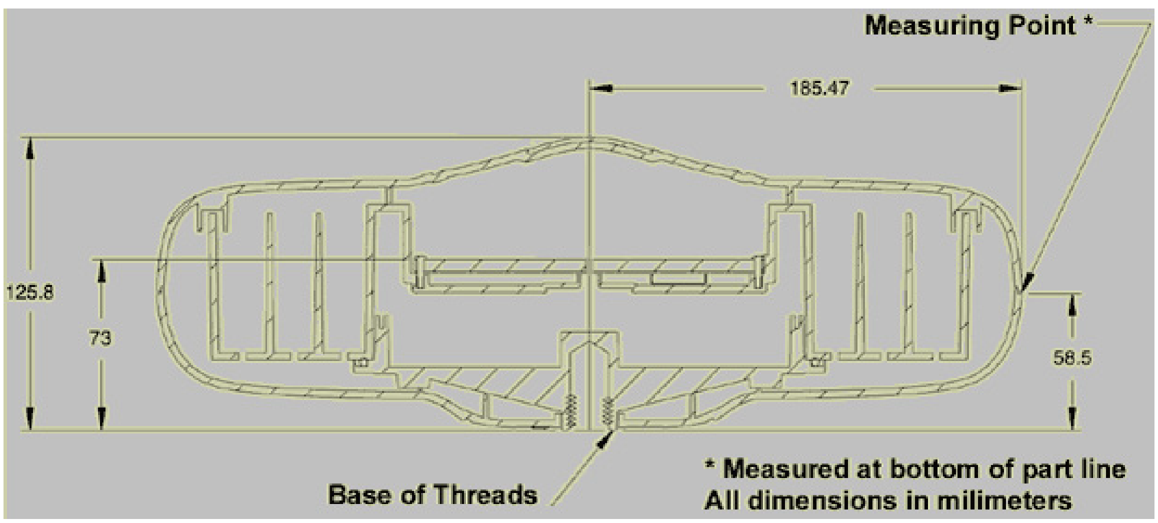

Figure 7. Antenna cross-section.

Software and Firmware

The JPS system came with their PC-CDU data management/satellite monitoring software. Throughout the past year, JPS has been enhancing and fine-tuning the software by adding features and conveniences not found in the initial "bare-bones" version and by fixing software bugs large and small.

During the year of operation, we downloaded and installed at least fifteen versions of receiver firmware. There were additional versions of firmware that, through no fault but our own, were not installed. After a while it became apparent that versions of receiver software and firmware had to be "synchronized" with problems arising if they were not. A discussion of some of these conflicts follows.

Chronicle of UF's Experiences During the IGEX-98 Experiment

The JPS system was originally set up in early October 1998, just before the official start of the IGEX-98 experiment on October 19, 1998. During the first two months of the campaign, we experienced a number of software and firmware related problems and inconveniences that resulted in sporadic data being submitted from the GATR site.

Initially, PC-CDU, JPS's data management/satellite monitoring software, did not allow for automatic conversion from the JPS proprietary format (*.jps files) to standard RINEX 2 format. This conversion had to be performed using a separate software package, JPS's Pinnacle data processing software, which proved to be an inconvenience. By mid-December, 1998, JPS had incorporated an automatic JPS-to-RINEX converter into PC-CDU, making the daily task of data preparation much more streamlined.

At the start of the experiment, UF was collecting 24-hour data blocks; however, the data did not start at the beginning of the GPS day (0:00:00 hours UTC). This was due to our unfamiliarity with the PC-CDU software. By recording a new file every "24 hours," PC-CDU started data collection from the instant data recording was initiated; by recording a new file every "1 day," data collection for each file started at 0:00:00 hours UTC. Once this difference was understood, the problem was corrected and data collected from November 9, 1998 forward started at the beginning of the GPS day.

A firmware problem in late October/early November 1998 relating to time synchronization at the end of the GPS week caused PC-CDU to spew out erroneous files after the changeover from Saturday to Sunday. This problem was corrected by JPS after a few days of investigation.

From November 2 through November 12, 1998, we were erroneously compressing the RINEX data before uploading them to the IGEX data center at CDDIS. Instead of first performing RINEX compression (using the Hatanaka compaction program, RNX2CRX) and then compressing the resulting compacted RINEX ASCII file into a binary UNIX file using the COMPRESS program, we proceeded in the reverse order, resulting in files that were not decompressable.

A very critical mistake was to delete the JPS proprietary data files (*.jps) after an apparently successful conversion to RINEX format. In some cases, due to software/firmware bugs or the incompatibility of software/firmware versions, the JPS proprietary files were not correctly converted. Had the JPS files been saved, they could have been successfully converted once the bugs or problems with the converter had been corrected. As an example, a huge block of data (from May 5, 1999 through June 29, 1999) was converted to RINEX format with only C/A-code and Doppler data (i.e., no carrier phase data). These files were essentially useless for analysis for the IGEX experiment. The problem was caused by a new version of receiver firmware that put out shorter messages for L1 and L2. The version of the RINEX converter being used did not recognize this shorter message length.

The RINEX files created by PC-CDU after collecting a GPS day of measurements were transferred over a local area network (LAN) from the base station computer to a processing computer. For most of the experiment, the Windows *Move* command was used for this operation. However, a block of files from August 27 through September 3, 1999 was lost when the *Move* command malfunctioned, removing the files from the source directory and not moving the files to the destination directory. Had we used the slightly less efficient two-step process of first copying the files from the source to destination directory and *then* deleting the source directory files, the data would not have been lost.

During the December 1998 holidays, the system went down (possibly a prolonged power outage). Nobody was in the office from December 23 through December 31, 1998; therefore, the data collection software was not restarted until January 1, 1999.

Starting on April 4, 1999, the receiver/PC-CDU software did not function correctly; the system would not lock onto any satellites. Coincidentally, April 4, 1999 was the start of daylight-saving time when, at 2:00 A.M. local time, clocks are advanced one hour. Whether this time offset caused the problem is not known. For the next few days, we attempted to get the system up and running with no success. Unfortunately, we neglected to follow up on this problem with JPS technical support until over a month later. After consulting with JPS, a newer version of receiver firmware was downloaded and installed, solving this problem.

This new firmware, version 1.6 PL2, turned out to be incompatible with the currently installed RINEX converter, causing the firmware/RINEX converter incompatibility problem previously described. This problem was detected by Daniel Ineichen of the Center for Orbit Determination in Europe (CODE) in late June 1999. The fact that there was a problem should have been recognized by the size of the compacted/compressed RINEX observation files: the files with the omitted data were just over one-third the size of the complete files.

In early May 1999, JPS, via e-mail, pointed out to its customers the importance of keeping their software and firmware current. Our less-than-satisfactory compliance to this advice was responsible for some large blocks of missing data during the spring of 1999.

In early June 1999, JPS technical support inaugurated an e-mailing list subscription for its registered customers. This system has greatly improved JPS's ability to distribute information regarding software and firmware upgrades and other news about its products. Since this system has been in place, we have found it much easier to keep our system's software and firmware up-to-date and "in synch." As a result, we have experienced much less downtime.

Processing Baselines

Initially, one of our goals was to process and analyze the baseline between UF's site GATR and the University of Texas/McDonald Observatory site MDOA (also with a JPS equipment) to evaluate the performance of the JPS system. Because of a late start and some problems with various post-processing software packages, we reached only preliminary conclusions. We would have liked to examine the effect of the GLONASS satellites in combination with GPS satellites in situations where a "borderline" dilution of precision existed.

Since site MDOA ceased data collection in late April 1999, we processed GLONASS and GPS observation and precise ephemeris data from January 1999 using JPS's Pinnacle post-processing software. After resolving some problems caused by the RINEX converter at the time of data collection, the baseline length (more than 2000 km) was calculated (float solution) by Pinnacle with an RMS error of about 1.4 to 1.5 meters. We processed the same baseline again without the GLONASS data with similar results. These errors seemed inordinately high, since GLONASS and GPS satellite intervisibility between the two sites was quite good.

Doug Hogarth of JPS, processed the same data (GPS only) with both Pinnacle and Trimble's GPSurvey software. As with our experience, Pinnacle yielded an RMS error of 1.4 meters; however, GPSurvey yielded an RMS error of 0.012 meters (greater than two orders of magnitude better) (Hogarth, 1999).

We then processed the same GPS data with Ashtech's Office Suite (AOS) software. AOS could not successfully solve for the baseline, giving an error message stating that it could not find four common satellites between the two sites.

Next, we used the National Geodetic Survey's Page 5 software to process the same data (again, GPS only). This fixed solution produced an RMS error of 0.0261 meters and agreed with GPSurvey's calculated baseline to within 0.020 meters (Schenewerk, 1999).

Clearly, certain software packages seem to do a better job at processing long baselines than do others. What factors cause these differences is not known; however, the raw data produced by the JPS system appear to be fine and not the cause of any processing problems. In fact, data from the JPS systems participating in the IGEX experiment have been used successfully by the various agencies working on GLONASS orbit determination.

Conclusions

The IGEX-98 experiment served as a learning experience for us. Although certain problems - some caused by software/firmware problems; others by our lapses in vigilance - arose during the year, we hoped that through our participation in the experiment we could provide the international community with useful data.

Javad Positioning Systems were extremely supportive and responsive from the experiment's onset; indeed, over the course of the year, they improved their existing product and added new methods of support to keep the customer informed about a continually evolving product. Through our involvement in IGEX-98, we hope that we were able to provide JPS with useful input regarding software/firmware problems as well as with suggestions about some of the software's user interfaces.

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ESA/ISN Dual-Frequency GPS/GLONASS Receiver

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Abstract

In this paper the architecture, configuration and performance of the ESA/ISN combined dual-frequency GPS/GLONASS receiver used in the IGEX-98 campaign are presented. The receiver is a high performance breadboard unit developed by the Institute of Satellite Navigation (ISN), University of Leeds, UK for the European Space Agency (ESA), and is the only European dual-frequency GPS/GLONASS receiver to have taken part in the campaign. The laboratory-based breadboard has operated on a near-continuous basis for the duration of IGEX-98 and beyond, collecting primarily dual-frequency GLONASS data, with dual-frequency GPS data collected on a secondary basis for comparative purposes. The IGEX campaign has been the final testing ground for the ESA/ISN receiver, providing the prefect opportunity to thoroughly validate the operation of its dual-frequency GLONASS carrier phase tracking. This opportunity has been timely as a radiation-tolerant ASIC largely based on the digital hardware designed and developed at the ISN has been produced by ESA and is planned to become available to the European GNSS community. The ASIC will be used in a number of future space missions by ESA dedicated to atmospheric sounding by radio occultation. The validation of the performance of the receiver prior to completion of the ASIC has been an essential part of the work carried out by the ISN for ESA during the last year. This validation is now considered to have been successfully concluded, a fact endorsed through the results of the data centers active during the IGEX-98 campaign that have processed the data produced by the ESA/ISN receiver. The ESA/ISN receiver has contributed high quality dual-frequency GLONASS carrier phase data to the IGEX campaign, a contribution that will aid the analysis of the GLONASS system.

This paper is split into two main sections: first, the receiver architecture is presented along with a description of the configuration that was employed during the campaign. The measurement precision and other salient parameters that have been achieved by the receiver during its development are presented. Secondly, the performance of the receiver as determined by the independent data processing centers that took part in the IGEX campaign is compiled and analyzed. These data indicate the accuracy and repeatability that have been achieved by the receiver in the configuration used for the campaign. Results to date from the

data processing centers indicate that the receiver has consistently performed to a high standard, its measurement accuracy being similar to other dual-frequency GPS/GLONASS units. Additional processing of the ESA/ISN receiver data was carried out by ESA at ESOC to gain further insight into the receiver performance and is included in the paper.

Overview

- History of the ISN GPS/GLONASS receiver development
- Description of the ESA/ISN receiver
- Configuration and data throughput of the receiver during IGEX
- Example of results obtained
- Conclusions

History of the ISN GPS/GLONASS Receiver Developments

- 1982- 1985 First University-built analogue GPS receiver
- 1985- 1988 First University-built digital GPS receiver
- 1985- 1988 GLONASS navigation receiver (C/A-code)
- 1990- 1993 GPS/GLONASS multi-channel navigation receiver
- 1990- 1993 GPS/GLONASS single-frequency survey receiver
- 1990- 1993 GLONASS navigation receiver (P-code)
- 1994 onward ESA/ISN combined dual-frequency GPS/GLONASS receiver

ESA/ISN Dual-Frequency GPS/GLONASS Receiver

- Two advanced bread-board receivers developed by the ISN for ESA
- Capable of high precision C/A-, P-, P(Y)- and RA-code and carrier tracking
    - Highly flexible architecture
- Developed for ESA for scientific applications
    - Radio occultation, ionospheric science, POD, sea surface monitoring
- Also for spacecraft support applications
    - Attitude determination, navigation, timing
- The only European dual-frequency GPS/GLONASS receiver in IGEX

Receiver Configuration for IGEX

- 8 full dual-frequency channels
- 15° elevation mask angle
- Receiver tracks all GLONASS satellites above the mask plus highest GPS above mask (channels permitting)
- 10 Hz L1 carrier bandwidth, 1 Hz L2 carrier, C/A- & P/P(Y)-code bandwidth
- Measurements at 1 Hz on UTC(LDS) 1 pps
    - L1 & L2 carrier phase; C/A-, P_{L1} & P_{L2} pseudorange
- Almost 60 MBytes of data per day
- Data resampled to 1/30 Hz, and sent to data centre (ESOC) in a RINEX format

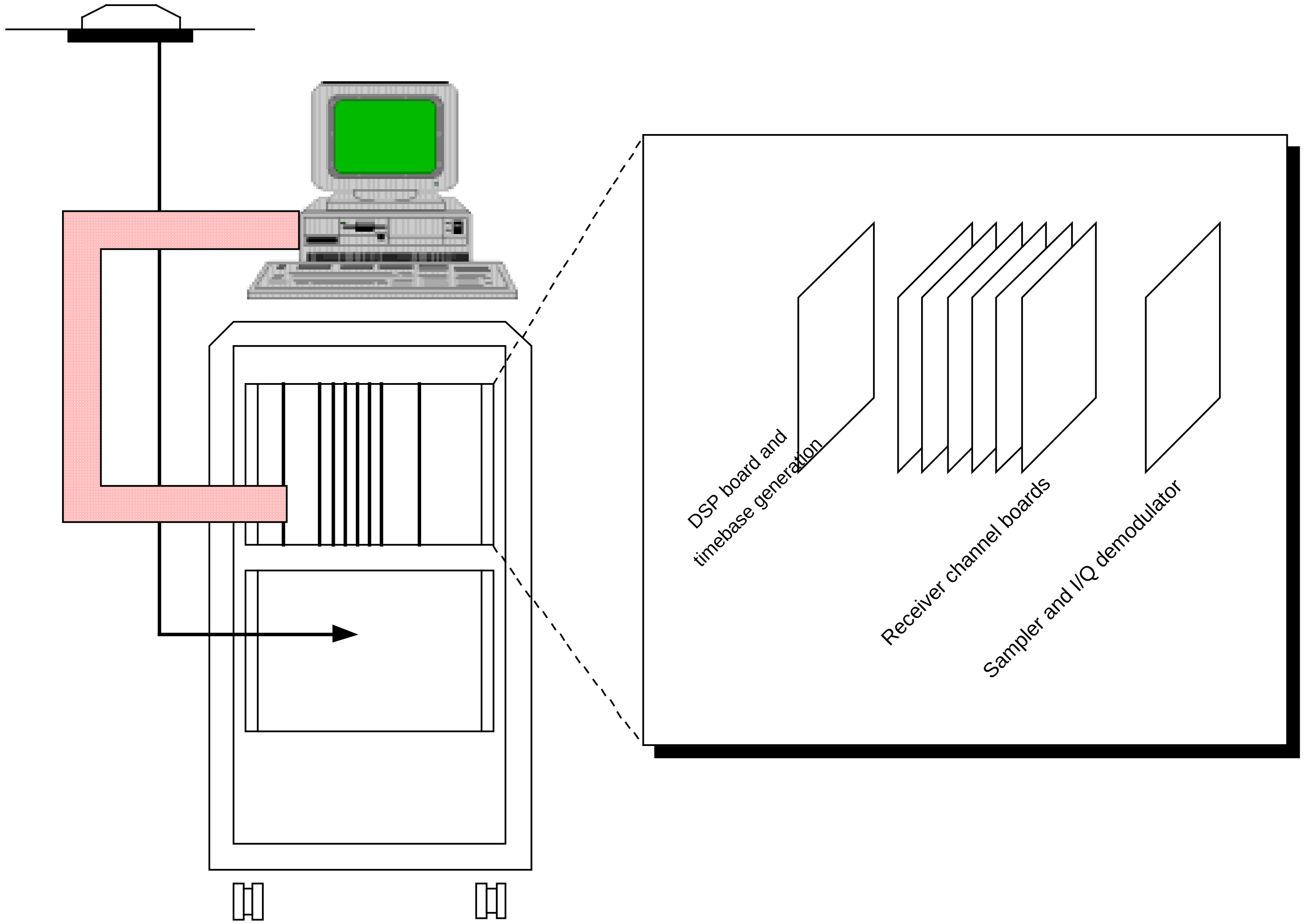

Figure 1. Receiver format.

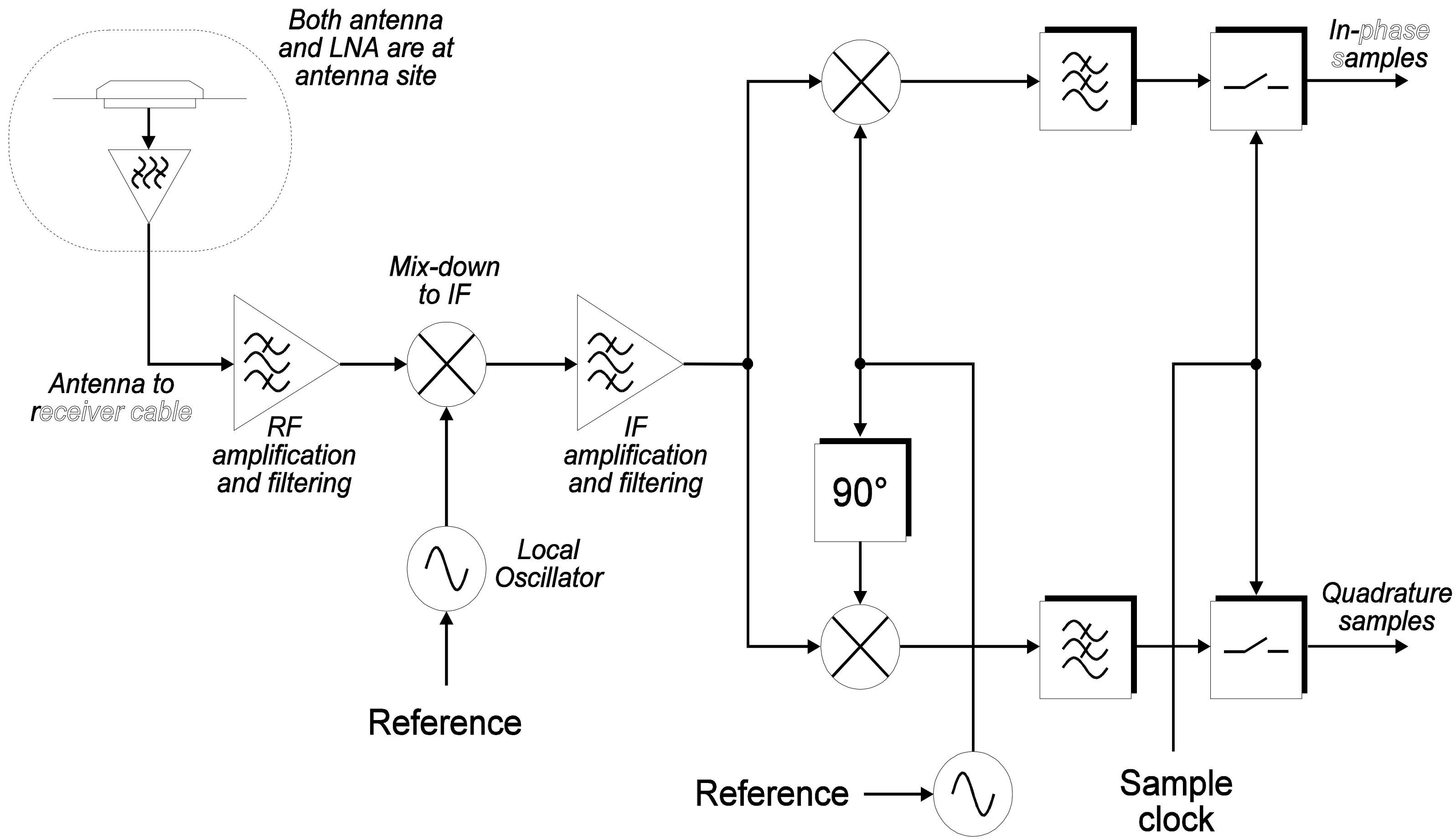

Figure 2. RF/IF processing.

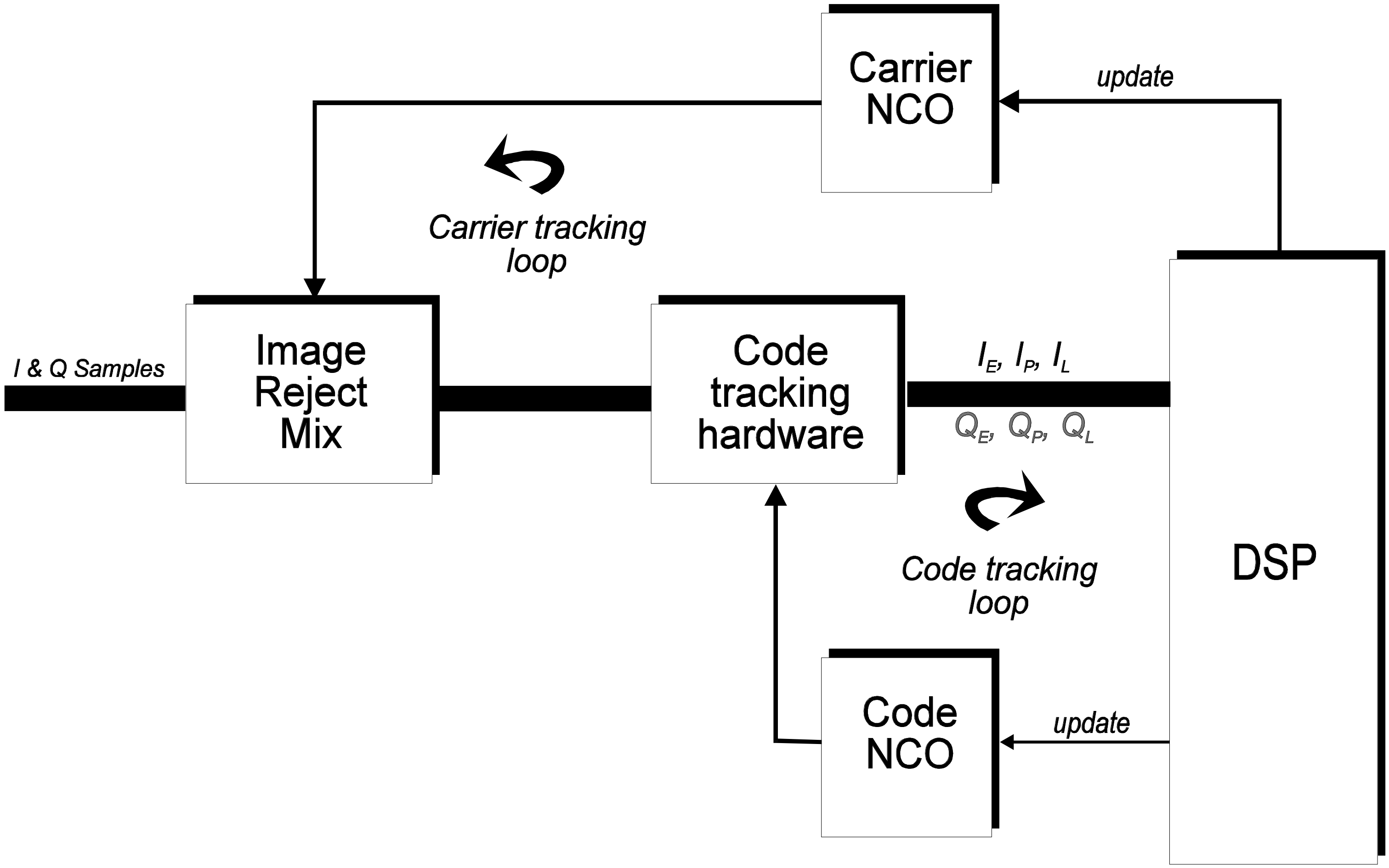

Figure 3. Tracking loops.

Receiver Reliability

- Receiver reliability validated by IGEX campaign
- Data obtained throughout campaign
  - results for a 22 week period shown
  - only 3 out of 154 days lost in real time, few outages mainly due to power and delays in data communication
- Detailed results for a 2 week period show observables available for over 99.7% of the time

Table 1. Receiver Reliability Over 2 Weeks

Day	No of epochs	Missing Epochs	Good Epochs	Down time (s)	% Epochs lost
99073	02880	18	2862	540	0.63
99074	02880	8	2872	240	0.28
99075	02880	8	2872	240	0.28
99076	02880	0	2880	0	0.00
99077	02880	6	2874	180	0.21
99078	02880	0	2880	0	0.00
99079	02880	26	2854	780	0.90
99080	02880	2	2878	60	0.07
99081	02880	19	2861	570	0.66
99082	02880	3	2877	90	0.10
99083	02880	4	2876	120	0.14
99084	02880	5	2875	150	0.17
99085	02880	4	2876	120	0.14
99086	02880	10	2870	300	0.35

Sample Results

The following results show sample data from the ESOC and BKG analysis centres.

Coordinate Repeatability

- Weekly position solutions for LDS1 provided by ESOC
- 24 weeks used in this analysis
- Range of coordinate solutions:

  X = 16.9 cm   Y = 15.6 cm   Z = 30.3 cm

- Range of standard errors of supplied coordinates

  X: 0.8 to 2.4 cm   Y: 0.5 to 1.5 cm   Z: 0.9 to 3.2 cm

- RMS from mean coordinate solution

  X = 3.8 cm   Y = 4.6 cm   Z = 6.5 cm

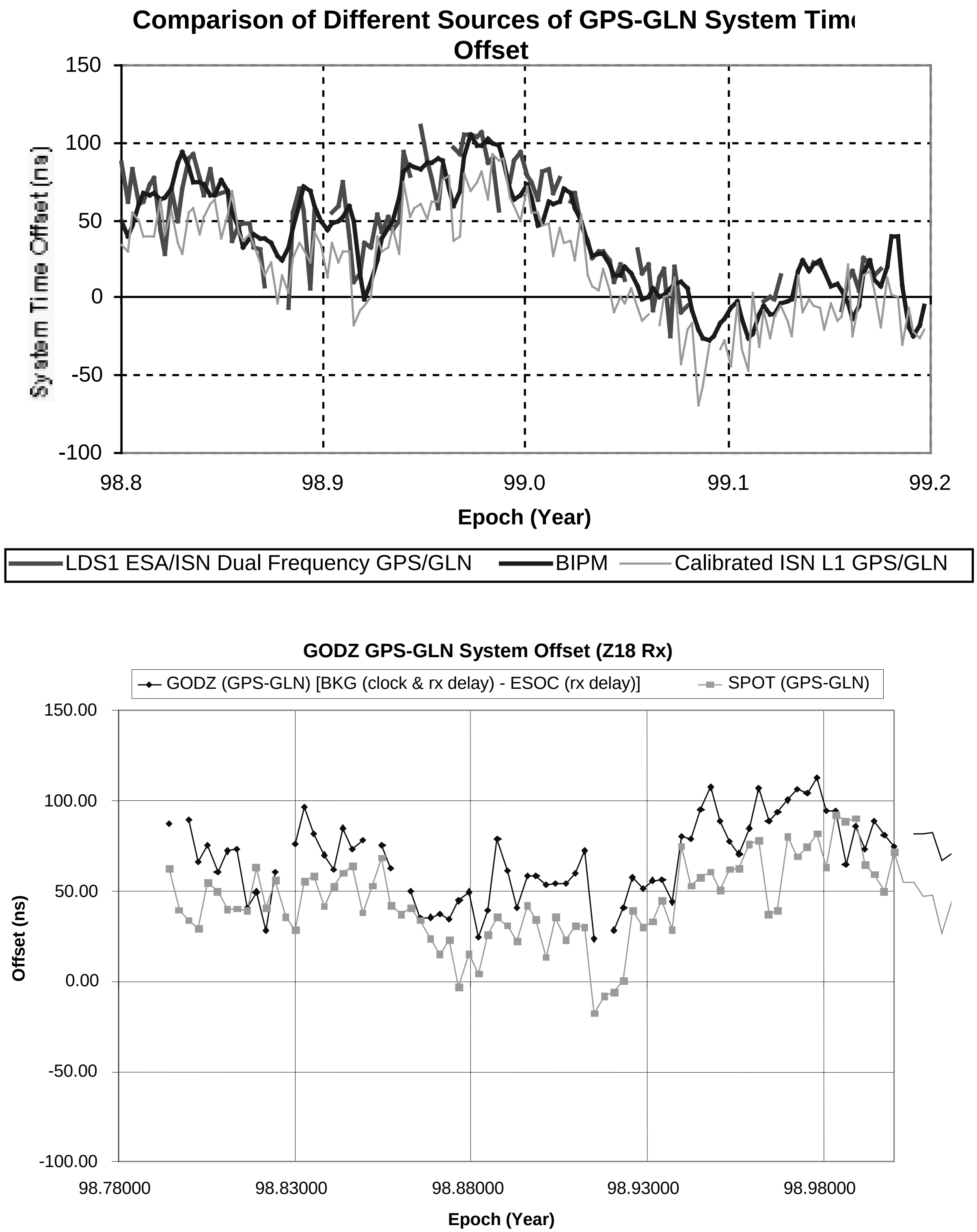

Figure 4. Comparison with other sources.

Conclusions

- The history of the ISN and its receivers has been presented, specifically the ESA/ISN dual-frequency GPS/GLONASS scientific test-bench
- Although not optimised for the IGEX campaign, the data quality from this receiver has been shown to be very good
    - The accuracy of the observables is comparable with other receiver types
    - Combination of solutions from different processing centres has yielded an estimate of the GPS-GLONASS system time offset that is comparable with other sources
    - The estimated coordinate solutions are extremely precise and repeatable

An Analysis of Dual-Frequency Receivers Used in the IGEX-98 Campaign

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Abstract

This paper presents an analysis of receivers that were used during the IGEX-98 campaign. Dual-frequency receivers with the capability of tracking both GPS and GLONASS are the primary focus. Data produced during the campaign are used for this analysis. Data from Bundesamt fuer Kartographie und Geodaesie (BKG) showing GLONASS/GPS time offset and data from GeoForschungsZentrum (GFZ) showing the bias and repeatability of station coordinates are analyzed. The GFZ data indicate that for computation of station coordinates, particular sites have a larger bias and rms. The User Range Error (URE) is calculated for 3S Navigation R100 receivers, and a discussion of the URE values is given. The URE computation for R100 receivers typically shows a value near ten meters. A report on the performance of the receiver at the Santiago, Chile, site is made.

Background

There were four types of dual-frequency receivers used in the IGEX campaign. These are the ESA/ISN GNSS, a prototype receiver constructed by the University of Leeds, Legacy manufactured by Javad Positioning Systems, R100 manufactured by 3S Navigation, and Z18 manufactured by Ashtech. The ESA/ISN GNSS receiver, which records dual-frequency GLONASS data, was used only at the University of Leeds' site LDS1. There were 7 Legacy receivers studied in this paper. This type of receiver records both dual-frequency GPS and GLONASS signals. This paper looks in depth at 13 sites that used the R100 receiver which collected dual-frequency GLONASS plus single-frequency GPS. There were 19 Z18 receivers studied. These receivers also collected dual-frequency GLONASS and GPS. The 3S Navigation receivers are all referred to as R100 in this paper although two of the sites studied operated somewhat different versions of the receiver.

Clock Analysis

Data from BKG (IGEXMail, 1998; 1999) reporting the GLONASS/GPS time offset bias and rms were selected for analysis. The data spanned GPS weeks 980 to 1001. Data with exceptionally large biases or rms values were excluded from the results in order to consider the overall performance of the receiver type. Figure 1 depicts the time offset bias per site, which shows that each receiver type has a characteristic time offset bias. WTZG, the site with an R100 receiver located at Wettzell, Germany, has a time offset bias of -716 ns while all other R100 receivers have a value near 1000 ns. It has been noted in campaign status reports and in the WTZG site log that the receiver is an older model named R101+R100. This explains this behavior.

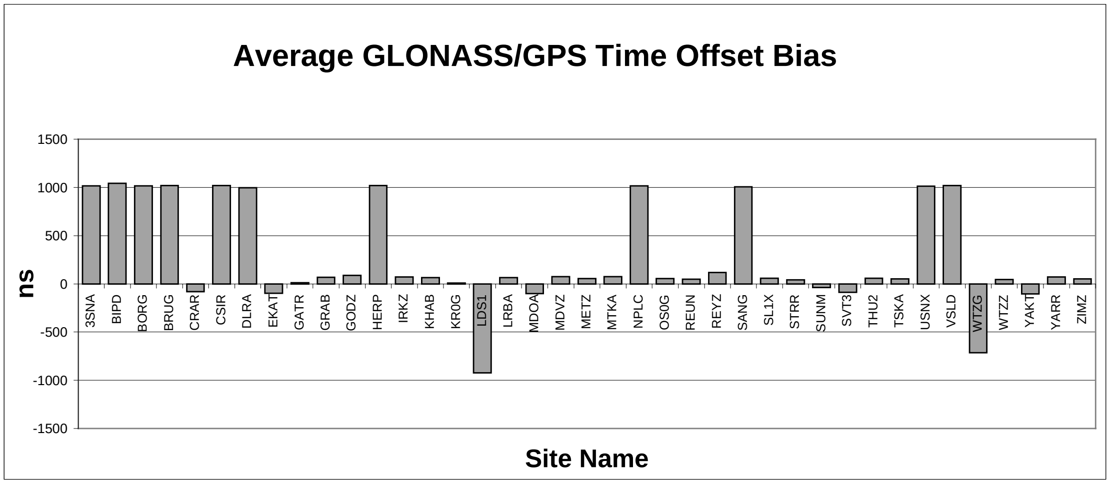

Figure 1. This figure shows the average of the daily GLONASS/GPS time offset bias for each site. The sites are listed alphabetically.

The time offset bias average and rms for each receiver type was determined from each site's average time offset bias. It will be shown that the time offset bias drifts over time. However, the average value is still informative. Table 1 shows these values by receiver type. Each receiver has a characteristic value for the time offset bias. WTZG was excluded from R100's values. The average value for the Legacy receiver is somewhat skewed. There are two instances of the time offset bias changing suddenly for a Legacy receiver. During the course of the campaign, the Legacy RINEX converter program was updated. This could have been the cause of the sudden changes. This also explains the somewhat higher rms value. During GPS week 1001, the time offset bias for Legacy receivers was near -120 ns. Sites that reported data for only a limited period of time also skewed the average due to the trend in the daily time offset bias.

Table 1. GLONASS/GPS Time Offset Bias and RMS by Receiver Type

GNSS	bias =	-925 ns	rms = N/A
Legacy	bias average =	-72 ns	rms = 42 ns
R100	bias average =	1012 ns	rms = 11 ns
Z18	bias average =	60 ns	rms = 22 ns

Table 2 shows the number of time offset bias and rms values excluded for each site. This was investigated to determine if any particular receiver showed a tendency to have erroneous values. For the time offset bias, outlier values were easy to determine because they were at least 10 times the typical value for that receiver type. All rms values exceeding 9 ns were excluded for all computations. This value was chosen because a break in the data occurred at this point. Generally, if a time offset bias was excluded, so was the rms for that day since they both tended to be outliers. However, this was not always the case. For instance, WTZG had 15 offset values that were outliers, but only one of them resulted in an outlier for the rms value. MDVZ's outliers were clustered with all occurring between days 058-066. This could indicate a problem that has since been resolved.

Table 2. Number of Values Excluded for Individual Sites

SITE	No. excluded for offset bias	No. excluded for offset rms	No. of days of data	Receiver type
BIPD	3	6	118	R100
CSIR	0	1	99	R100
GODZ	0	1	81	Z18
LDS1	0	2	139	GNSS
MDVZ	8	9	130	Z18
NPLC	1	1	114	R100
THU2	1	1	112	Z18
USNX	10	9	118	R100
WTZG	15	1	40	R100

Figure 2 shows the average GLONASS/GPS time offset rms per site. All outliers are excluded. The rms average is 1.02 with a standard deviation of 0.16. Most of the rms values for all types of receivers fall within one standard deviation of the overall average. There are three sites, GATR, LDS1, and REUN, that show somewhat higher rms values. GATR is a Legacy receiver, LDS1 is ESA/ISN GNSS, and REUN is a Z18 receiver. Although these rms values are somewhat higher, GATR and REUN had no outliers excluded and LDS1 had only 2 values out of 139 rms values excluded. Some other sites with better rms values had several outliers excluded. All receiver types show some outlying values. The time offset rms values are nearly the same for all of the different types of dual-frequency receivers.

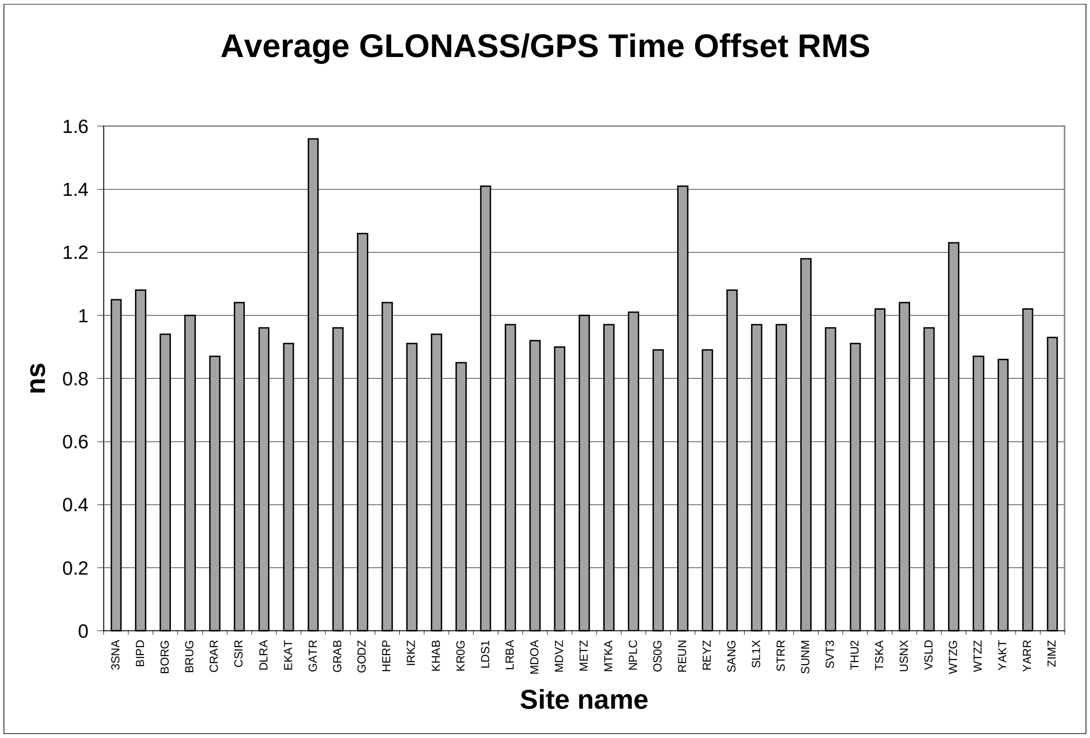

Figure 2. This figure shows the average of the daily GLONASS/GPS time offset rms for each site. The sites are listed alphabetically.

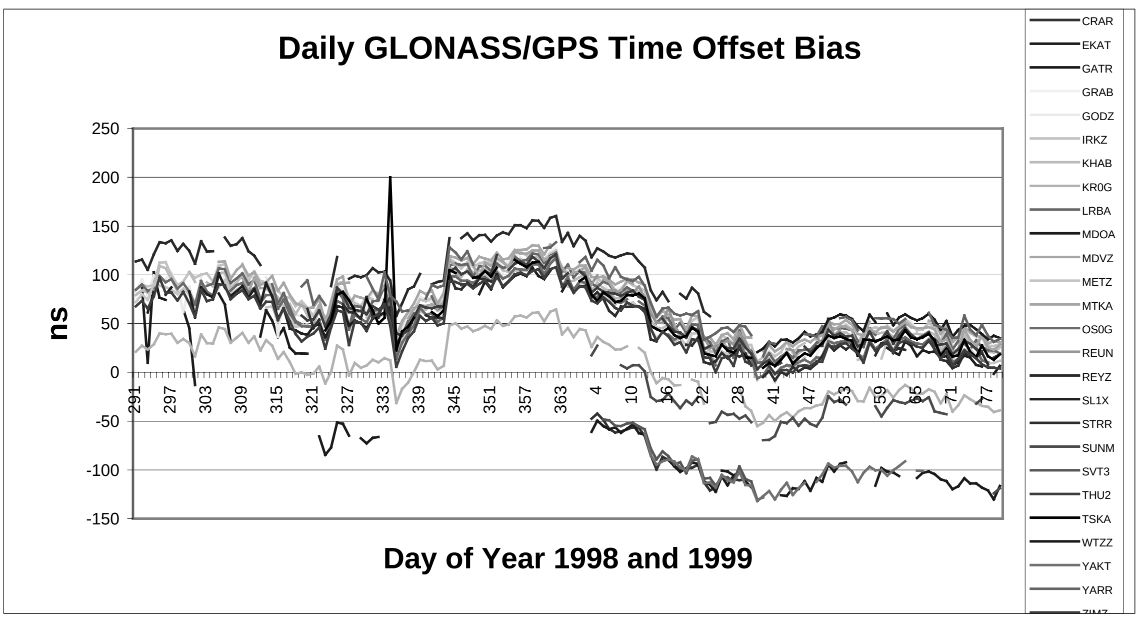

Figure 3. Daily GLONASS/GPS time offset bias for GPS weeks 980 through 1001. Only sites using Legacy or Z18 receivers are shown.

Figure 3 shows the daily GLONASS/GPS time offset bias for Legacy and Z18 receivers over the course of GPS weeks 980 to 1001. Only these two types of receivers are shown in this figure because their time offset biases are on the order of 100 ns. There is a trend in the data. The R100 receivers and the ESA/ISN GNSS receiver also show the same trend. For example, there is a 43 ns jump in the time offset bias on day 344 for all receivers. This figure is a depiction of the time system difference between GPS and GLONASS.

Bias and Repeatability of Station Coordinates.

The GFZ IGEX Analysis Reports (IGEXMail, 1998; 1999) included values for the bias and repeatability of station coordinates. Five sites show exceptionally large values for both of these. They are BISZ, RIOZ, SUTG, CSIR, and SANG. BISZ, RIOZ and SUTG all have GG24 receivers, manufactured by Ashtech, which are single-frequency only. These are the only single-frequency receivers included in the GFZ report. CSIR and SANG are both R100 dual-frequency GLONASS receivers. CSIR and SANG are both isolated sites with no other dual-frequency receiver close enough to be able to use the data for double differencing. Since double differencing is the method used by many of the analysis centers for orbit reduction, the data from these two sites are largely unusable. It is possible that the bias and repeatability errors associated with these two dual-frequency sites are due to their isolation rather than the quality of the data itself. The rms value of CSIR is lower than expected for this set of data indicating that its values are more stable. The last section of this paper discusses the SANG site and details problems with its data.

The weekly values of the bias and repeatability measures, which are given in differences in the Northing, Easting and Up directions, were root-sum-squared to give a total miss value. These values vary greatly among some sites, in particular the five sites listed in the previous paragraph. The average value for the repeatability is nearly the same as the standard deviation. Although this infers that the average of the station coordinate bias and repeatability may not be a reliable measure, it does give an indication as to the usability of the data. Many sites have values of less than 10 millimeters for both bias and repeatability. There were four sites that have repeatability values between 50-100 millimeters. They are 3SNA, GATR, MDOA, and SUNM. SUNM is in Brisbane, Australia while the remaining three are in the United States. There are not enough data to relate error with location of the receiver. Other sites in the U.S.A. and Australia have much smaller rms values. SUNM and GATR are Legacy receivers while 3SNA and MDOA are R100 receivers. There is also no pattern to the data to suggest that one particular type of receiver results in a less accurate station coordinate value.

URE for R100 Receivers

The User Range Error (URE) is calculated for all R100 receivers for days 013 through 019. Figure 4 shows the URE for each day for each site. The URE is the difference between the observed and computed pseudorange, taking into account the receiver clock bias and drift. The computed pseudorange is determined from the known positions of the user and of the satellites. In this case, the broadcast ephemeris is used for the positions of the satellites. The

URE is calculated in 5-minute increments and averaged. The URE residuals are also determined which are the differences between the measured pseudoranges and the averaged pseudoranges per satellite per epoch. Most sites have a URE value near 10 m for most days. WTZG shows a different trend with all of its values near 20 m. As previously noted, this site used an older model of the R100 receiver. Site 3SNA is excluded because of the large trend in its data (see Fgure 5). The analysis software used assumes that an atomic clock is the time reference. The clock error is modeled as a bias and linear drift. According to the 3SNA site log, a cesium clock is used but it is of poor quality. The analysis software does not properly model the 3SNA clock's behavior and depicts the results as error. Data from the USNX site is excluded because the analysis software used for URE computation had problems processing the data.

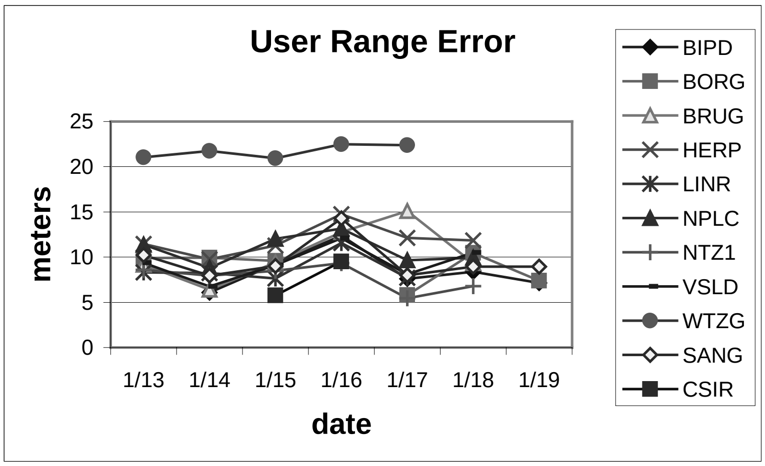

Figure 4. User Range Error for R100 receivers excluding 3SNA and USNX.

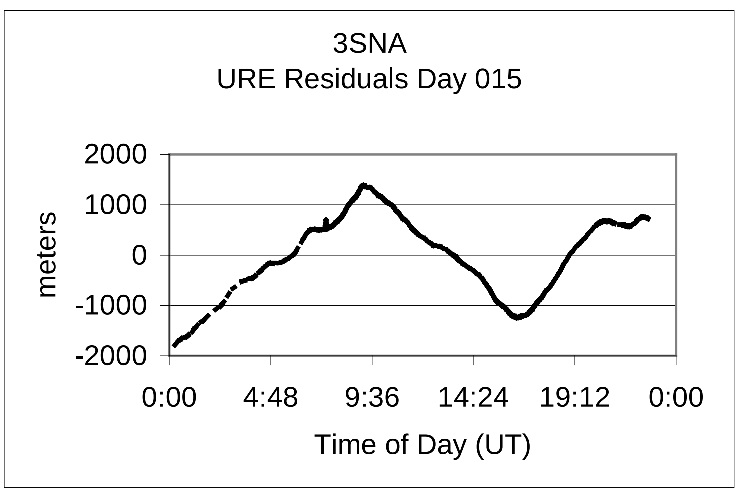

Figure 5. Site 3SNA URE residual errors for day 015 (Jan. 15, 1999). The analysis software produces the large errors because the clock behavior is not properly modeled.

SANG Site Analysis

The SANG site data was rarely used by Analysis Centers for orbit computation. There were two problems with the data that caused this. One problem is that this site is isolated from other dual-frequency sites. Some analysis centers used double differencing for orbit computation which required that a satellite be in view of two stations at the same time. This did not occur frequently for this site. SANG's receiver also experienced recurring problems with a loss of lock on one of the GLONASS frequencies. SANG did not have a problem losing lock on the GPS satellites that it tracked on a single frequency. The orbit reduction process required successive dual-frequency readings without cycle slips. Thus SANG's data would not have been usable for periods of time even if another station tracking dual-frequency GLONASS was located nearby. The problem with the loss of lock needs to be resolved.

The URE values were calculated for the Santiago site for the entire period of operation. The analysis software ignored loss of lock segments and based the URE only on the epochs that contained dual-frequency GLONASS data. The bias and drift of the clock was modeled. With this consideration, the URE values computed for SANG were quite good most of the time. The receiver experienced a period during February 1999 when the data appeared to get progressively worse. It was determined there was a hardware problem in the antenna cable. This period is easily identified in figure 6 which shows the URE values for the entire period of observation.

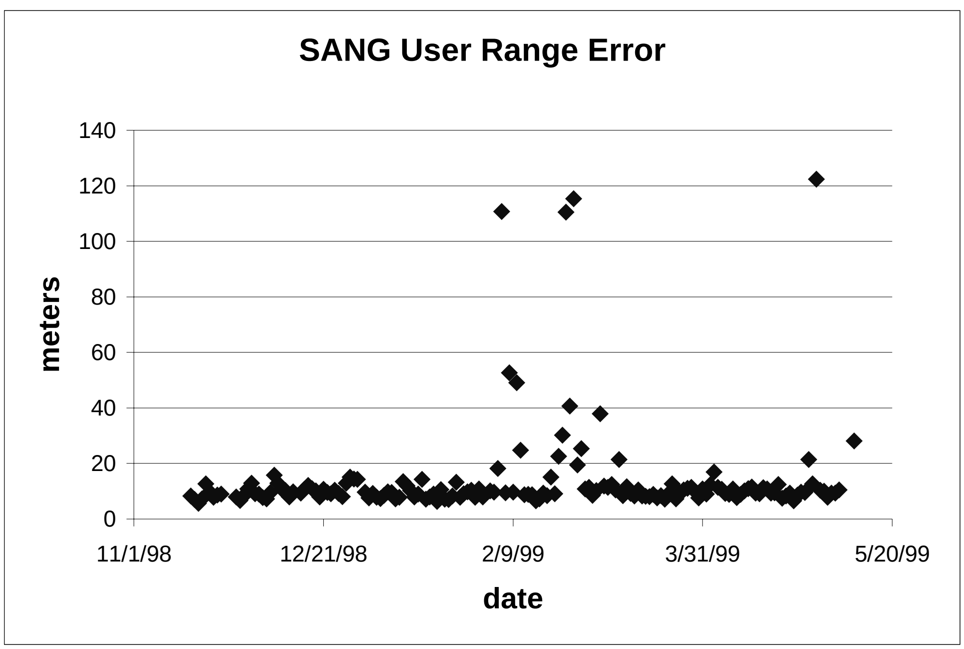

Figure 6. URE for SANG site for entire IGEX-98 Campaign.

The URE values generally returned to normal once repairs were made. Day 120 (April 30, 1999) is an exception; it has a URE of 122 m. Figure 7 shows the URE residuals for that day. The receiver restarted several times and the data showed large errors near 1000 hours UT.

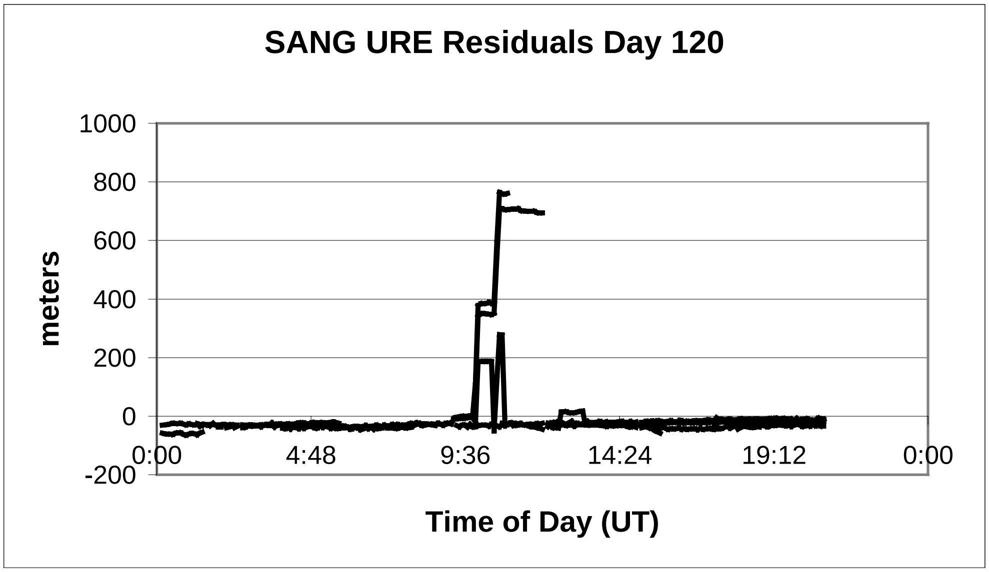

Figure 7. URE Residuals for SANG for day 120 (April 30, 1999). A problem occurred at approximately 1000 hours UT.

According to the IGEX Campaign requirements, all time tags had to be within 1ms of the even minute or 30 sec mark. SANG experienced a problem with exceeding this requirement. Out of 190 days of data submitted, 39 days had time tags exceeding the 1 ms requirement. Nearly half of these instances (17) occurred during two time spans (a total of 25 days). One of those time spans occurred when the site had problems with the antenna cable. Since the SANG site shut down daily for processing the RINEX output files, the amount of time that the time tag requirement was exceeded generally did not cover the entire day. A day was included in the count if even only one hour of data exceeded the requirement. Some other R100 receivers failed to meet the 1 ms time tag requirement also but not as often as SANG site did.

The operators shut down the receiver daily to convert and transfer data. Each restart caused a reset in the clock. Some of the analysis centers modeled only one clock bias and drift per day per station. Because of the method of operation used, the data from SANG site always had a discontinuity between the two sets of values for the clock bias and drift (or more if the receiver rebooted automatically due to any type of failure). For the URE computation, the data were processed using separate values for bias and drift for each continuous segment of data collection. This modeled the SANG receiver's behavior better.

Conclusion

The GLONASS/GPS time offset bias and rms indicate no difference in performance by receiver type. There is a definitive difference in the overall time offset bias but it is a consistent value within that type of receiver. The User Range Error for the R100 receivers is acceptable for those sites studied. The operations of the SANG site did not meet the Analysis Centers' requirements in several ways. First, it was an isolated site and the data were unusable by analysis methods that used double differencing. Second, there was a problem with the loss of lock on one of the GLONASS frequencies. This receiver experienced this problem often and this caused SANG's data to be unusable for those periods of time. Third, the SANG receiver did not meet the 1 ms time tag requirement 20% of the time although many of those values fell within a short period of time. The issues with the SANG receiver need to be resolved.

Reference

IGEXMail Service (1998;1999). Internet address http://lareg.ensg.ign.fr/IGEX.