GLONASS Data Analysis for IGS

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Abstract

The Federal Agency for Cartography and Geodesy analyses combined GPS/GLONASS data of a global network of observing stations since the beginning of the IGEX experiment in 1998. Significant milestones in the geometry of the tracking network, development of GLONASS receivers, constellation of GLONASS satellites and improvements of the analysis strategy became visible during that period of 6 years. The weekly analysis products include precise GLONASS satellite orbits, station coordinates, transformation parameters between PZ-90 and ITRF and the difference of the GPS- and GLONASS system time. The system time differences could be compared to the results of other analysis centres, e.g. ESA, and to the publications of the BIPM. The precise knowledge of such numbers is a prerequisite for a complete combination of GNSS systems (GPS, GLONASS or GALILEO), e.g., if the analysis procedure solves for phase ambiguities between satellites of different systems. Recent results are not precise enough for the latter application. In our approach we solve for GLONASS satellite orbits but use orbits from IGS for the GPS satellites. We have demonstrated, that we could use the IGS rapid orbits in our analysis without significant impact on our products. This allows to submit our weekly GLONASS orbits before the generation of the IGS final orbits. We plan to continue with the analysis of GLONASS data, to expand our products by satellite clock estimates and to observe the possibility to add GALILEO observations to the analysis.

Introduction

The Federal Agency for Cartography and Geodesy (BKG) analysis combined GPS/GLONASS observations of global tracking stations since October 1998. Weekly analysis reports are submitted by the former IGEX- and nowadays IGLOS- Mail exploder. The following products are publicly available:

- Improved orbits for GLONASS satellites,
- daily transformation parameters between the GLONASS reference frame (PZ90) and ITRF,
- receiver-specific estimates of the system time difference between GPS and GLONASS, and
- station coordinates (SINEX files).

Analysis Procedure

We use the Bernese GPS software for the analysis of combined GPS/GLONASS observations by considering the satellite specific signal frequencies and different realizations of reference frames and system time. There is no attempt to improve the GPS satellite orbits within the analysis procedure, but we use IGS orbits, and solve for GLONASS satellite positions. GPS system time and the ITRF are used as reference for both, GPS and GLONASS. Figure 1 shows the corresponding data flow. Transformation parameters between PZ90 and ITRF are calculated by Helmert transformations between (1) GLONASS satellite positions resulting from the orbit improvement (in the ITRF) and (2) GLONASS broadcast satellite positions (in PZ90). Thus, the accuracy of the transformation parameters is determined by the broadcast messages (uncertainty of about some m), if we assume an accuracy of some dm for the improved GLONASS orbits.

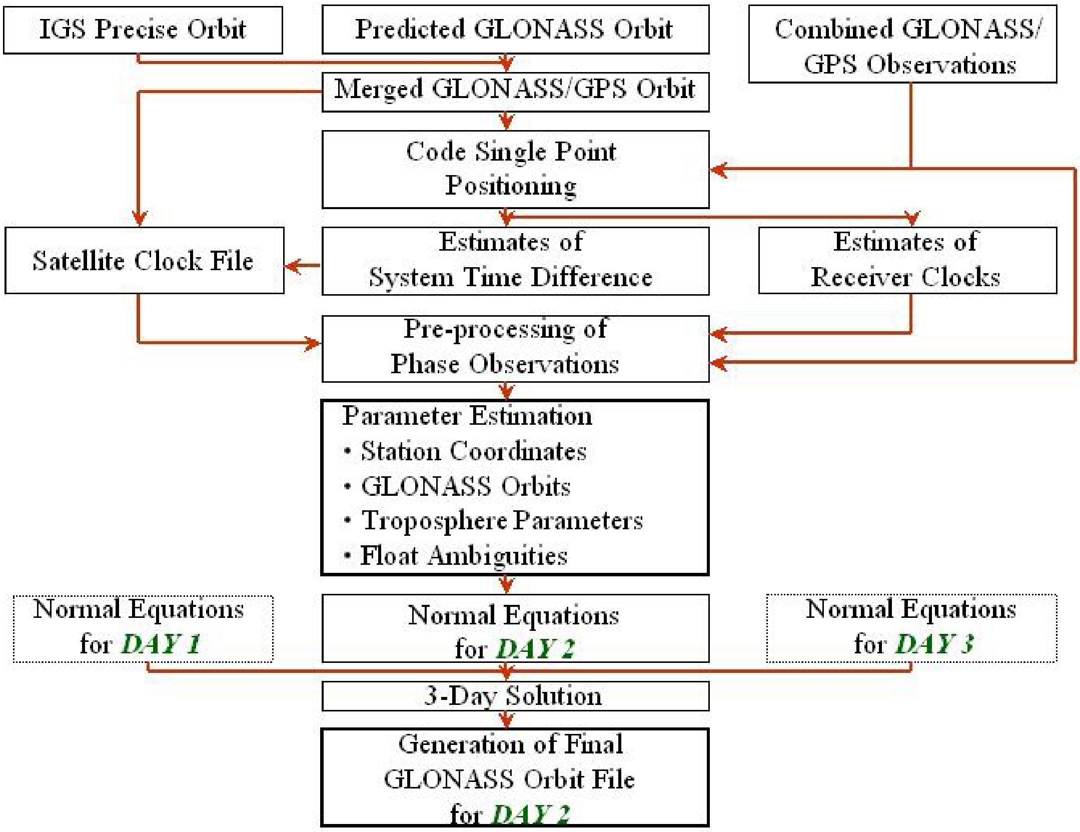


Figure 1: Data flow

Network

Figure 2 shows the distribution of global IGLOS tracking stations as at the beginning of year 2004. There is a poor global coverage compared to the IGS tracking network and ,e.g., no station in Africa. But it exists a dense GLONASS tracking network in Europe. The number of analysed stations rapidly increased since week 1246, after a careful enquiry about worldwide available tracking data. The number of analysed GLONASS satellites dropped down from 17 to 6 during the period shown, before recent satellite launches increased the number again.

Orbit Residuals

We use the residuals which result from a comparison of 3-day arcs for each day of the week and a 7-day arc for the whole week to indicate the quality of the estimated GLONASS orbits. The residuals are today typically smaller than 10 cm. The development of those orbit residuals since the beginning of the GLONASS processing is given in Figure 3. For satellite 118 (GLONASS slot number 18) we observed significant larger residuals for the recent weeks. The trend line decreases from 22 cm at week 980 to below 10 cm at week 1250. This line was derived from all satellites and is affected by bad performing satellites. The majority of the GLONASS satellites show numbers smaller than the trend.

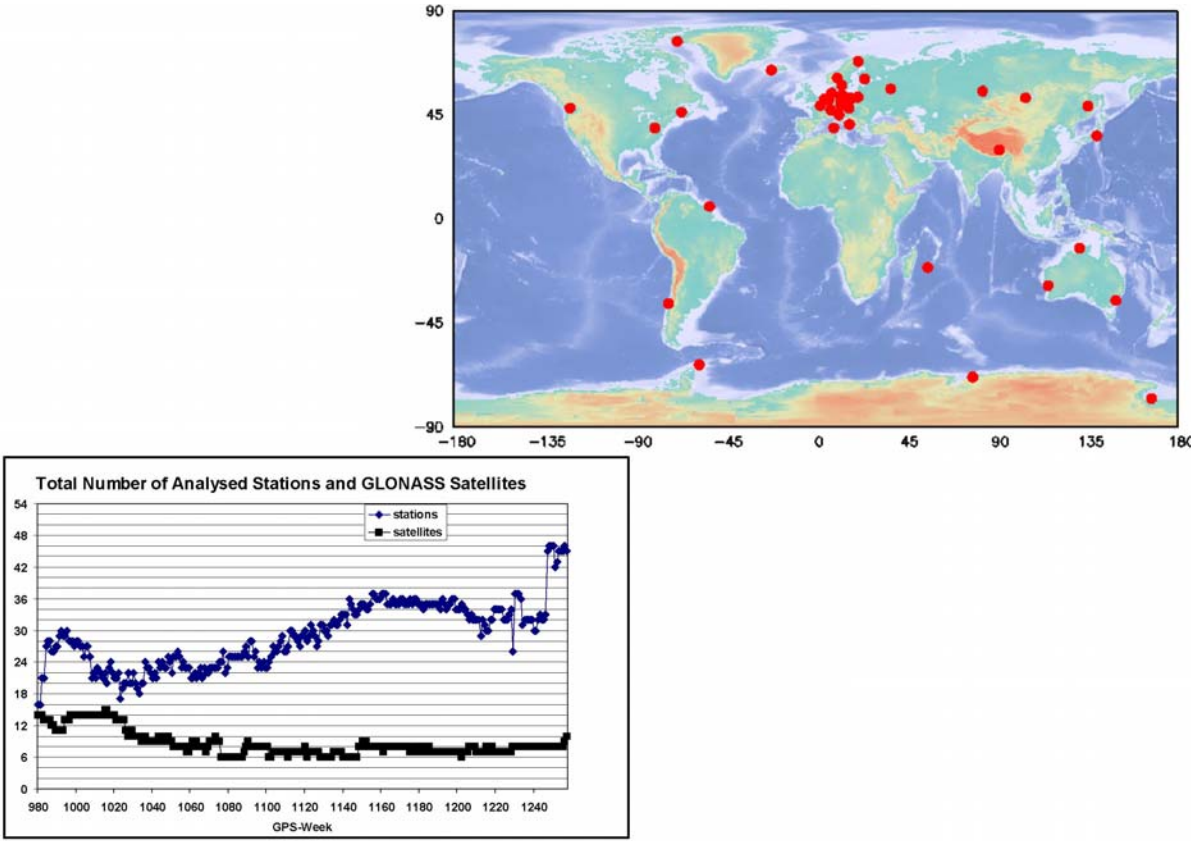


Figure 2: Network

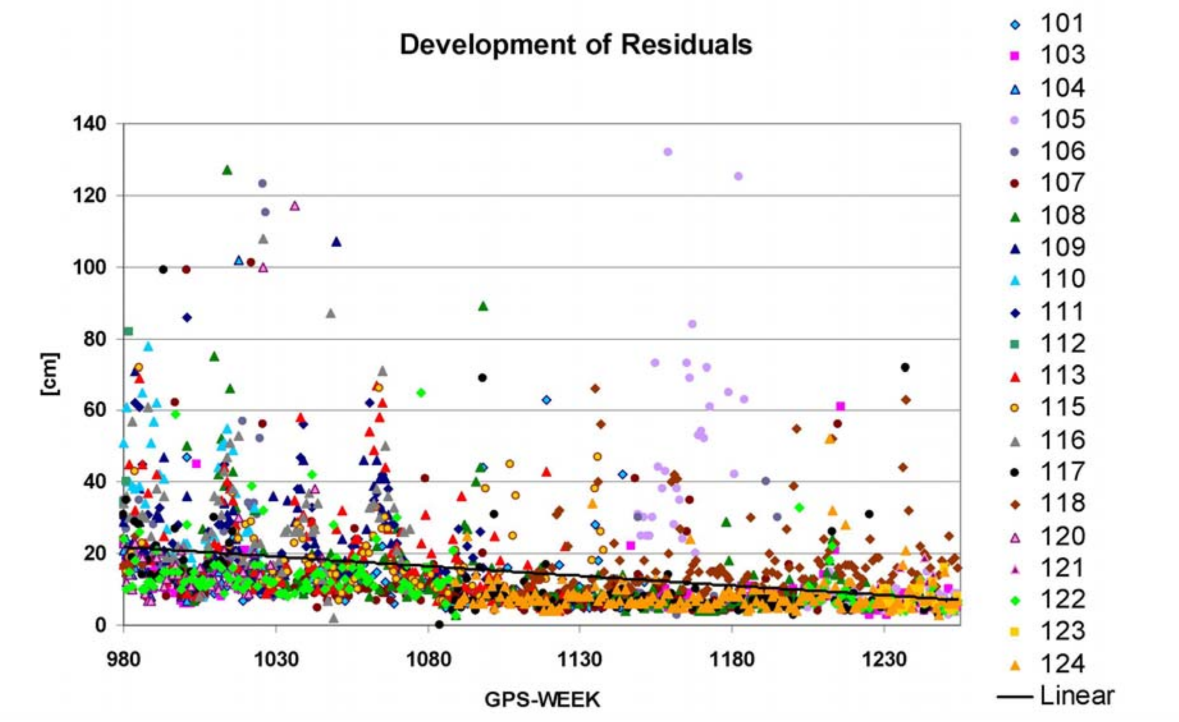


Figure 3: GLONASS Orbit Residuals

Transformation Parameter

Figure 4 shows 3 plots of the series of the transformation parameters grouped into translation (DX,DY,DZ), rotation (RX,RY,RZ) and scale (SC). There is no significant translation. The mean value of –0.6 m for DZ (shift in Z direction) has an RMS of 0.9 m. The most significant parameter is a rotation around the Z-axis with a mean value of –358 mas. We observed a jump in the estimates of the scale parameter, that occurred on June 28, 2003. That jump was also determined by the analysis of ESA/ESOC. The scale doesn't change in the coordinates of the ground station network. Therefore we assume a change in the PZ90. Colleagues from the Russian Aviation and Space Agency (S. Revnivykh and V. Mitrikas) pointed out, that such jump may be explained by a change of the satellite antenna phase centre offset. The plot of the RMS may be interpreted as a measure of the accuracy of the GLONASS broadcast ephemerides as already mentioned in the Analysis Procedure section.

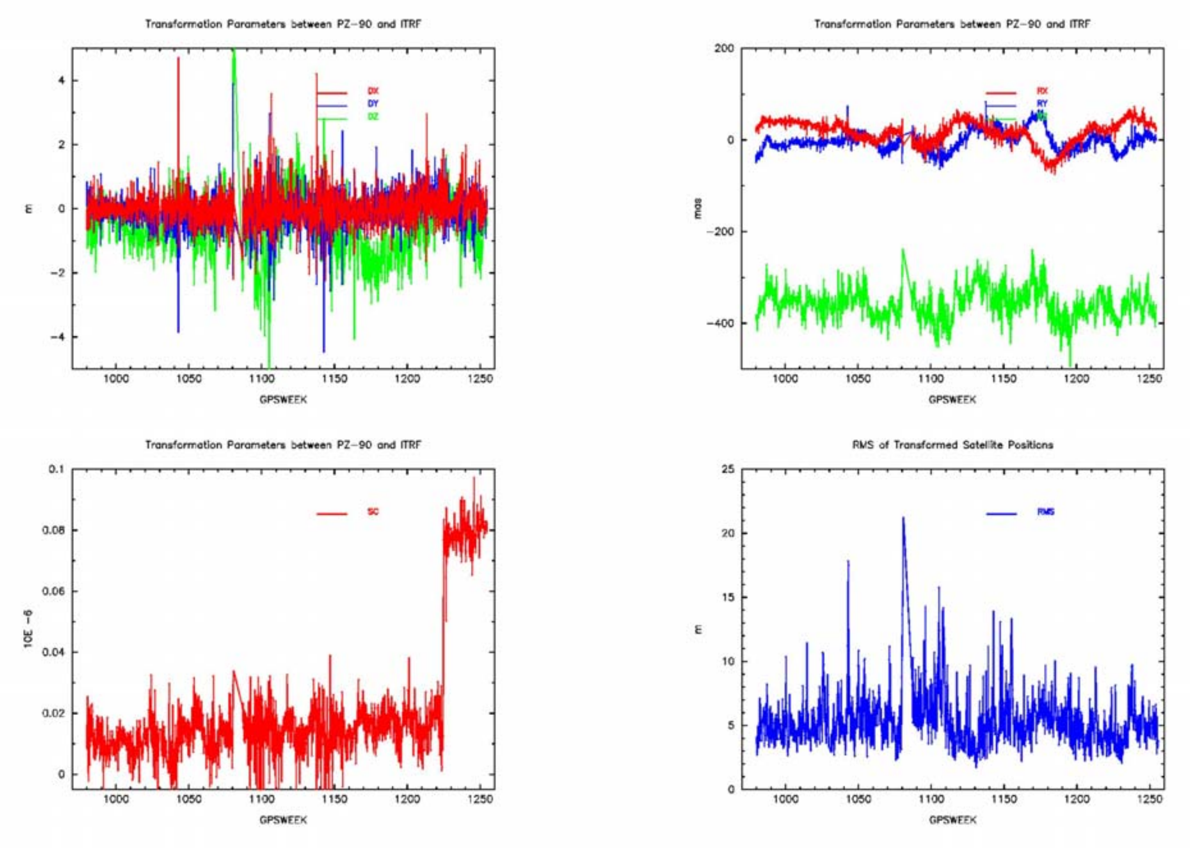


Figure 4: Transformation Parameter

System Time Difference

Three basic assumptions have to be observed during the processing: (1) The epochs of observations and ephemerides must refer to a unique time scale (either UTC or GPS time). (2) The clocks of all receivers have to be synchronized to a unique time scale to within some milliseconds. (3) GLONASS and GPS observations of a specific receiver have to be performed simultaneously (within some 10^{-12} sec) or with a known delay. The third principle is required to solve the double difference ambiguity of a GLONASS/GPS satellite pair or to use a common reference receiver clock in case of zero-difference processing.

We account for the system time in the code observation equation as follows:

$$P_k^i = c \cdot \tau_k^i + c \cdot \Delta t_k - c \cdot \Delta t^i + c \cdot \Delta t^s$$

,where $\Delta t^s = 0$ for GPS and $\Delta t^s \neq 0$ for GLONASS satellites (notation see Habrich, 1999). Such estimates are given in the upper left plot of Figure 5. They change with time (system part) and depend on the individual receivers (receiver part). The lower left figure shows the corresponding numbers as calculated and published by the ESA/ESOC in Darmstadt, Germany (Reduced by some mean value by ESA).

The upper right figure shows the differences of the estimates between two receivers, where any system parts are eliminated. The relative estimate for the ZIMJ-ZIMZ receiver pair shows a jump after a firmware update around week 1075.

The lower right figure shows the epoch wise differences of the estimates of two successive days. It shows mainly the changes of the system part, where constant receiver parts are eliminated. We used the numbers from all receivers to compute epoch wise mean values. The accumulation of such mean values is given in the black curve may be interpreted as mean variation of the system part.

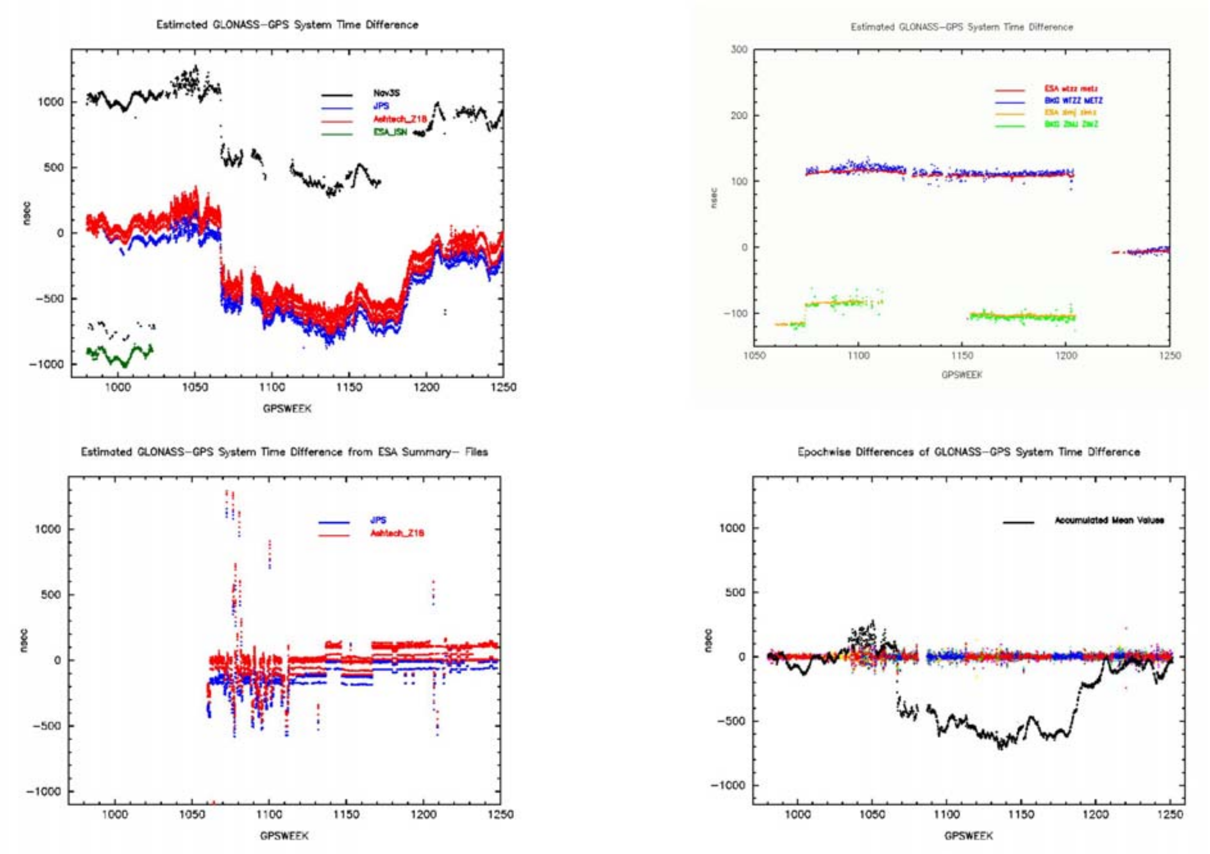


Figure 5: System Time Difference from Code Observation

Phase observations have to be processed to allow a precise determination of the system time difference Δt^s. We see from the code observations, that there exist two parts from Δt^s:

$$\Delta t^s = \Delta t^v + \Delta t_w$$

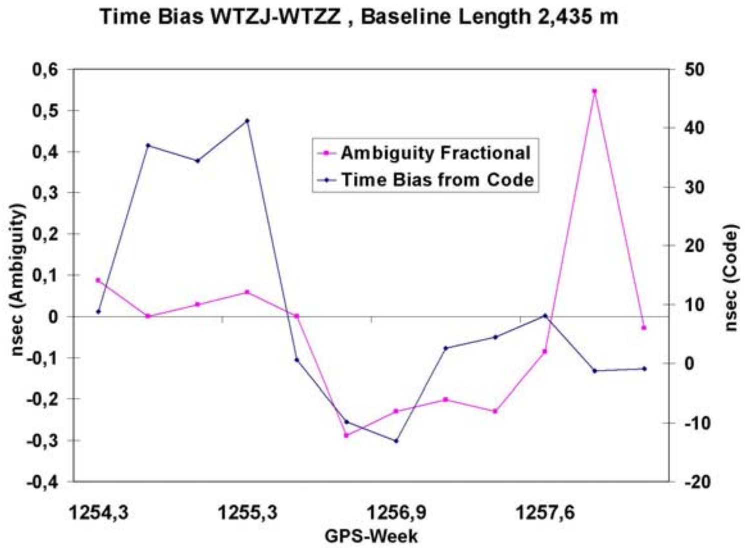
,where Δt^v is determined by the GLONASS satellite system and Δt_w by the specific receiver. We obtain for the double difference phase observation

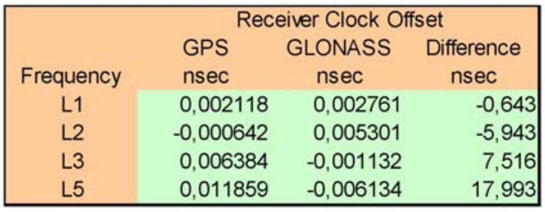
$$\Psi_{kl}^{ij} = c \cdot \Delta\Delta\tau_{kl}^{ij} + N_{kl}^{ij} \cdot \lambda^i + N_{kl}^{j} \cdot \Delta\lambda^{ij} + c \cdot \Delta t_{wkl}$$

, for the satellites i, j and the receivers k,l, (notation see Habrich, 1999). The system part Δt^v cancels out. Two systematic biases corrupt the integer nature of the double difference ambiguity N_{kl}^{ij} :

(1) The single difference bias term $N_{kl}^{j} \cdot \Delta\lambda^{ij}$ and (2) the relative system time difference $c \cdot \Delta t_{wkl}$.

In the following we assume only 2 single difference ambiguities to be unresolved, one ambiguity for a GLONASS and one for a GPS satellite. A priori numbers of these two ambiguities are known within +/- 0.2 cycles. In that case the single difference bias term (1) may be neglected and the fractional part of the double difference ambiguity may be interpreted as an estimate of the bias (2). The upper plot of Figure 6 shows such fractionals where the unit of cycles had been converted to the unit nsec. This is the pink line in the figure and the corresponding axis at the left side. It is an attempt to verify the assumptions above. The estimates from code observations have been added for comparison. This is the blue line and the corresponding axis at the right side. The fractionals are obviously biased by full wavelength cycles (ambiguities) and could not be used to determine the time bias directly. As an alternative approach to determine the time bias from phase observations we processed GPS and GLONASS observations separately and estimated two receiver clock offsets respectively. The difference of the two clock offsets may result in the unknown time bias. The corresponding results are given in the table above for L1, L2, L3 (ionosphere-free) and L5 (wide-lane) frequencies. The calculated differences change according to the used frequency. Further studies, e.g., sub-daily estimates, seem necessary.





	Receiver Clock Offset		
	GPS	GLONASS	Difference
Frequency	nsec	nsec	nsec
L1	0,002118	0,002761	-0,643
L2	-0,000642	0,005301	-5,943
L3	0,006384	-0,001132	7,516
L5	0,011859	-0,006134	17,993

Figure 6: System Time Difference from Phase Observation

Orbit Availability

We use IGS-Rapid instead of IGS-Final GPS orbits since week 1246 in order to enable the processing with smaller delay to the end of observation. Before that change GLONASS orbits resulting from both approaches had been compared. The corresponding differences are given in upper left of Figure 7. We had concluded, that this change of GPS orbits will not degrade our results. As consequence BKG is now able to submit the GLONASS orbits with a delay of 2 to 6 days. Therefore there might exist the possibility to introduce the BKG GLONASS orbits into the final IGS combination, as illustrated lower right of Figure 7.

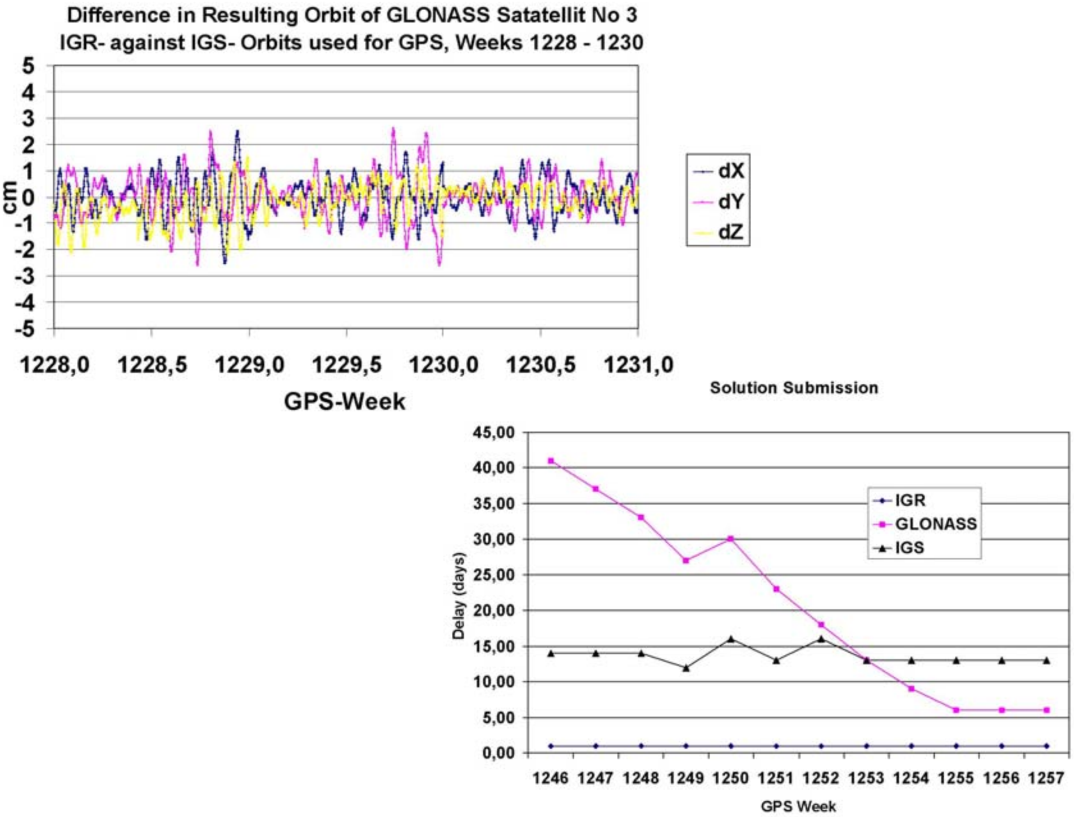


Figure 7: Orbit Availability

Ambiguity Resolution

Double difference ambiguity resolution is performed between stations with distances shorter than 800 km, but the solved ambiguities are currently not yet introduced into the final parameter estimation. Figure 8 shows the success of the ambiguity resolution depending on baseline length. This topic is currently topic of investigation.

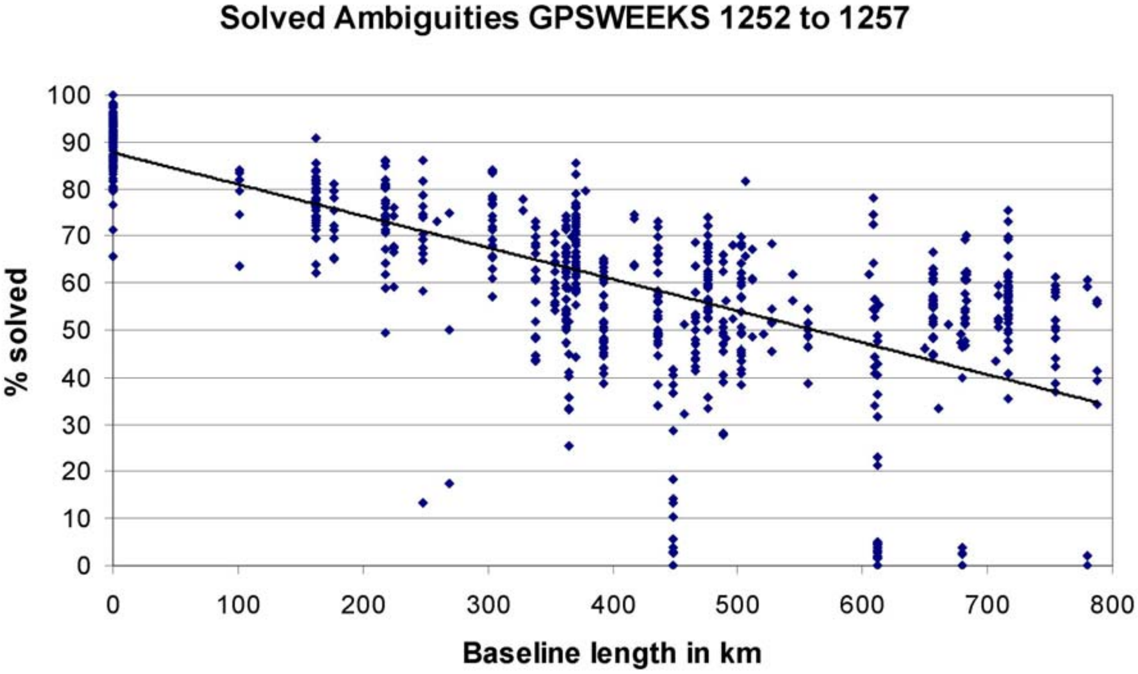


Figure 8: Ambiguity Resolution

Conclusions

The long history of GLONASS orbit determination since 1998 demonstrates the possibility to generate orbits from a global GPS/GLONASS tracking network on a stable level. The differences between GPS and GLONASS in the signal frequencies, the reference systems and the system time have been accounted for and the corresponding strategies may be applied to combine GPS/GLONASS and also the new GALILEO. We plan to improve our analysis procedure with the introduction of the resolved ambiguities and the estimation of satellite clocks, and to optimize the automation of the analyses as well. However currently it seems worthwhile to wait for the new release 5.0 of the Bernese Software before implementing extensive changes. We will continue to investigate some unresolved problems which show up in the combination of various GNSS systems, e.g., the system time difference prevents the full ambiguity resolution. New GLONASS satellites are scheduled to be launched until the end of 2004 (see IGSMAIL 4816).This is an encouraging signal for our GLONASS activities.

Reference

Habrich H. (1999): *Geodetic Applications of the Global Navigation Satellite System (GLONASS) and of GLONASS/GPS Combinations*, Dissertation Universität Bern, Switzerland, 1999, published in “Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 15,” ISBN 3-88648-099-2, Frankfurt, Germany, 2000