Bundesamt für
Kartographie und Geodäsie

GLONASS Data Analysis for IGS

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Introduction

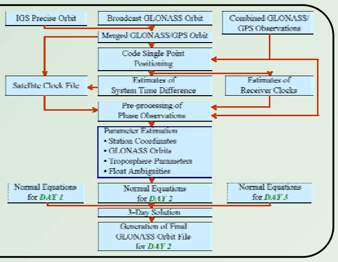
The Federal Agency for Cartography and Geodesy (BKG) analysis combined GPS/GLONASS observations of global tracking stations since the beginning of the International GLONASS Experiment IGEX-98 in October 1998. Weekly analysis reports are submitted by the former IGEX- and nowadays IGLOS- Mail exploder. 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
- Station coordinates (SINEX files)

Analysis Procedure

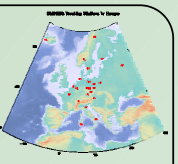
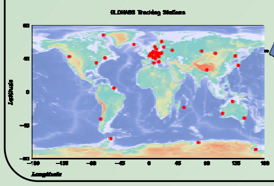
We use the Bernese GPS software for the analysis of combined GPS/GLONASS observations by considering the satellite specific signal frequencies and different realizations of reference frames and system time. There is no attempt to improve the GPS satellite orbits within the analysis procedure, but we use IGS orbits, and solve for GLONASS satellite positions. GPS system time and the ITRF are used as reference for both, GPS and GLONASS. 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, if we assume an accuracy of some dm for the improved GLONASS orbits.

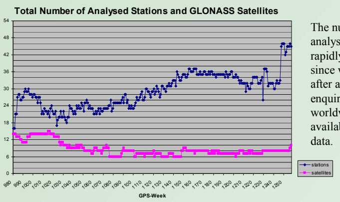
Data Flow


IGS Precise Orbit
Broadcast GLONASS Orbit
Combined GLONASS/GPS Observations
Merged GLONASS/GPS Orbit
Code Single Point Positioning
Satellite Clock File
Estimates of System Time Difference
Estimates of Receiver Clocks
Pre-processing of Phase Observations
Parameter Estimation
- Station Coordinates
- GLONASS Orbits
- Troposphere Parameters
- Float Ambiguities

Normal Equations for *DAY 1*
Normal Equations for *DAY 2*
Normal Equations for *DAY 3*
3-Day Solution
Generation of Final GLONASS Orbit File for *DAY 2*

Network

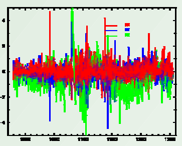
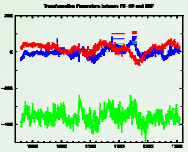
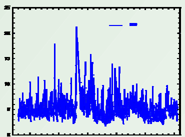
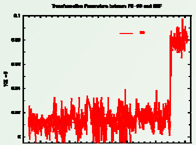





The number of analysed stations rapidly increased since week 1246, after a careful enquiry about worldwide available tracking data.

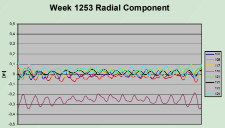
Transformation Parameter

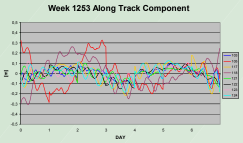
The 3 plots on the right show time series of the transformation parameters grouped into translation, rotation and scale.
There is no significant translation. The mean value of –0.6 m for DZ (shift in Z direction) has an RMS of 0.9 m. The most significant parameter is a rotation around the Z-axis with 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.
The plot of the RMS may be interpreted as a measure of the accuracy of the GLONASS broadcast ephemerides (see Analysis Proc.).

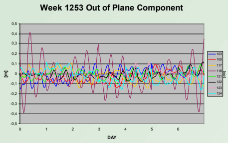





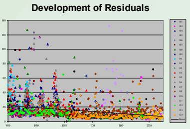
Orbit Residuals

The first three plots below beginning from the left show residuals for GLONASS satellite orbits for the radial, along track, and out of plane component. The residuals result from a comparison of 3-day arcs for each day of the week and a 7-day arc for the whole week. The residuals are typically smaller than 10 cm. For satellite 118 (GLONASS slot number 18) we observed significant larger residuals for the recent weeks. The development of those orbit residuals since the beginning of the GLONASS processing is given in the plot on the right. 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.





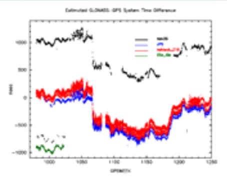
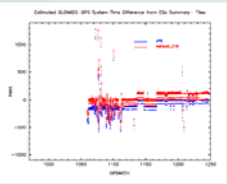




System Time Difference

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.

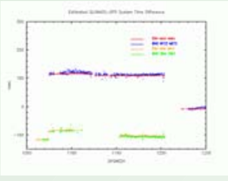
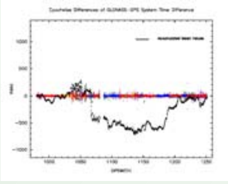
Code Observation

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.
Such estimates are given in the upper left figure. 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 (mean system change).

Phase Observation

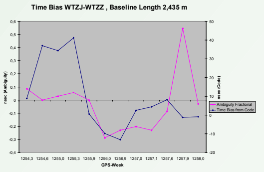
Phase observations have to be processed to allow a precise determination of the system time difference Δts. We see from the code observations, that there exist two parts from Δ ts:

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

,where Δtv is determined by the GLONASS satellite system and Δtw by the specific receiver. We obtain for the double difference phase observation

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

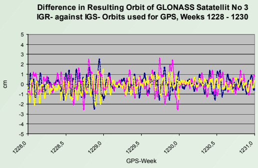
, for the satellites i, j and the receivers k,l. The system part Δtv cancels out. Two systematic biases corrupt the integer nature of the double difference ambiguity N_{kl}^{ij} :
(1) The single difference bias term $N_{kl}^{j}\cdot\Delta\lambda^{ij}$ and (2) the relative system time difference $c\cdot\Delta t_{wkl}$.
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 to the right 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 alternatively 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. Further studies, e.g., sub-daily estimates, seem necessary.



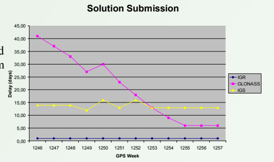
Receiver Clock Offset

Frequency	GPS nsec	GLONASS nsec	Difference 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

Orbit Availability

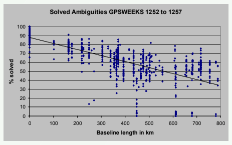


We use IGS-Rapid instead of IGS-Final GPS orbits since week 1246 in order to enable the processing with smaller delay to the end of observation. Before that change GLONASS orbits resulting from both approaches had been compared. The corresponding differences are given on the left. We had concluded, that 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. With it there might exist the possibility to introduce the BKG GLONASS orbits into the final IGS combination, as illustrated on the right.



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. The plot on the right shows the success of the ambiguity resolution depending on baseline length.



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 system, 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.

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