GNSS Satellite Clock Estimation at CODE

IGS Workshop, ESOC, Darmstadt, Germany, May 8-12, 2006

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Summary

Since May 2003 the Center for Orbit Determination in Europe (CODE) provides consistent orbits for GPS and GLONASS satellite from a combined analysis. For that purpose data of about 30 GPS/GLONASS as well as many GPS-only IGS stations are analyzed together.
GLONASS satellites emit their signals on individual frequencies leading to frequency-dependent code biases in the receivers. These biases are not only receiver-type specific but they differ also between individual receivers. Of course, they have to be considered in a combined analysis of GPS and GLONASS code data. For phase observations the corresponding biases are absorbed by the ambiguity parameters (affecting also the ambiguity resolution).
Each IGS analysis center providing GLONASS satellite clock corrections independently estimates the frequency-dependent code biases. This requires additional degrees of freedom for the combination of GLONASS satellite clock contributions from different ACs. Alternatively, conventional values for all GNSS receivers within the IGS network may be defined and maintained. The ACs have to introduce them when estimating GLONASS clock corrections (in analogy to the differential code biases).
In any case, these biases must be considered when using GLONASS satellite clocks in an analysis (e.g., for a PPP using also code data).
One additional intersystem time bias for each receiver is expected when including GALILEO as third GNSS to a combined analysis.

Description of the combined GNSS analysis

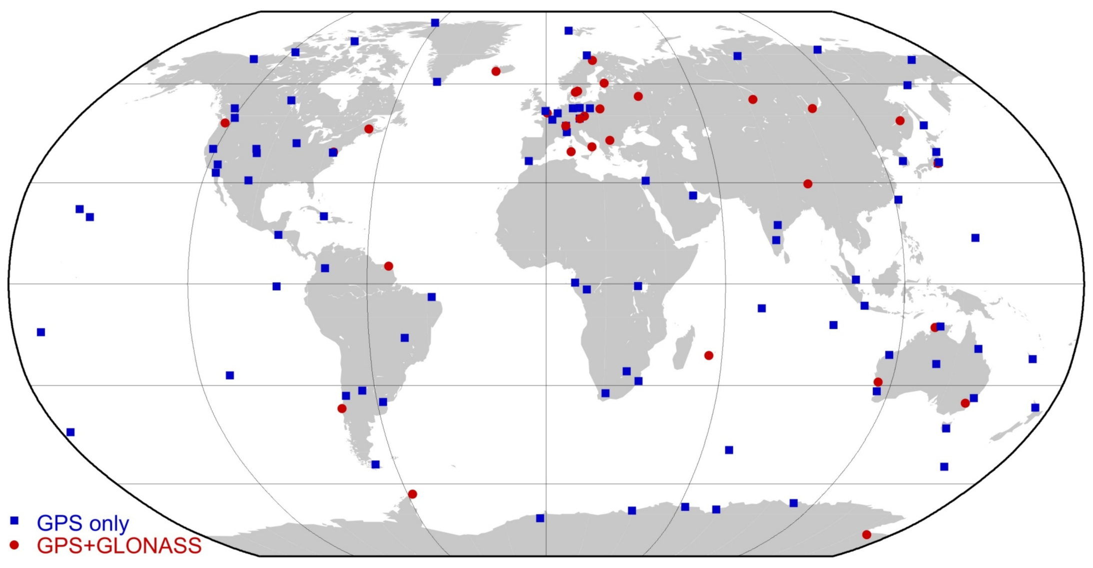

Figure 1: Location of the IGS stations used for the GNSS clock estimation by CODE.

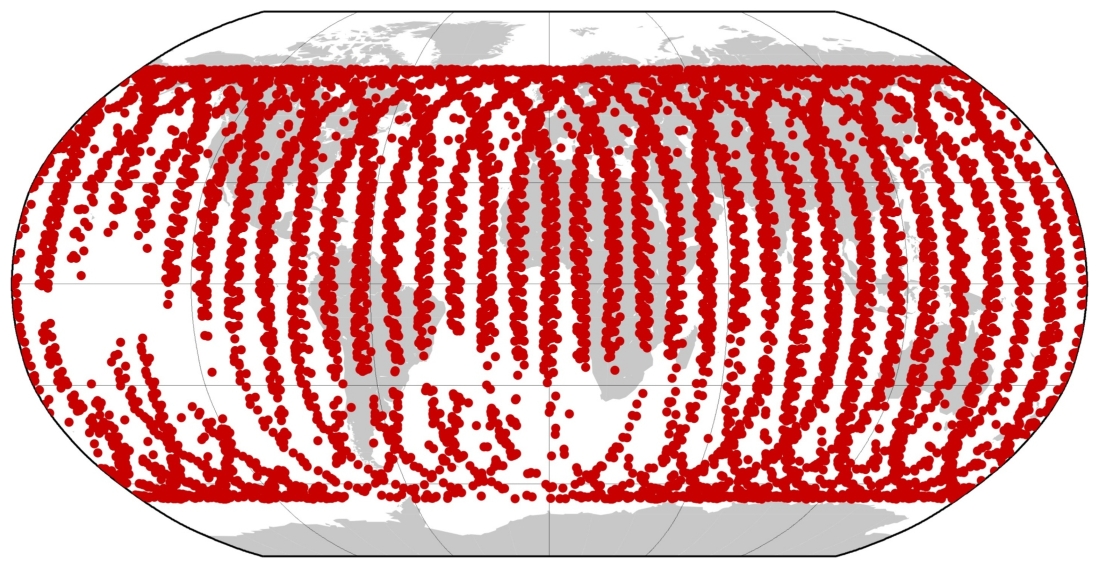

Figure 2: Availability of GLONASS satellite clocks along satellite ground tracks during 10 days in January 2006.

The GPS satellite clock corrections are computed using a subset of 90 stations for the rapid and 120 stations for the final products of the IGS tracking network. The stations are processed in three global clusters. Their (satellite) clock results are combined to a daily clock solution.
For the production of the GNSS clock corrections a 4th cluster with all available combined GPS/GLONASS receivers is added. Currently, the IGS network contains about 30 of such stations mainly located in Europe (see Figure 1). Unfortunately the coverage in other regions is very sparse.
Except for Europe no redundancy is available to cope with data outages or late submissions. For most GLONASS satellites it is not possible to provide clock corrections for all epochs (usually only about 90%) if a minimum number of three contributing stations is requested for the estimation. Regions without GLONASS satellite clock corrections are the Pacific ocean and the Southern part of the Atlantic ocean as well as South Africa (see Figure 2).
The GPS clock corrections are usually computed from data of at least ten stations observing the satellite simultaniously. On the other hand, the GLONASS satellites are possibly not observed by any of the GNSS receivers in the IGS network for short periods during the day (e.g., if they cross the Pacific ocean). As a consequence, one obtains independent parts in the resulting GLONASS satellite clock correction series which are not connected by phase data. Discontinuities analogous to the day boundary discontinuities for station clocks have to be expected.

GNSS satellite clocks

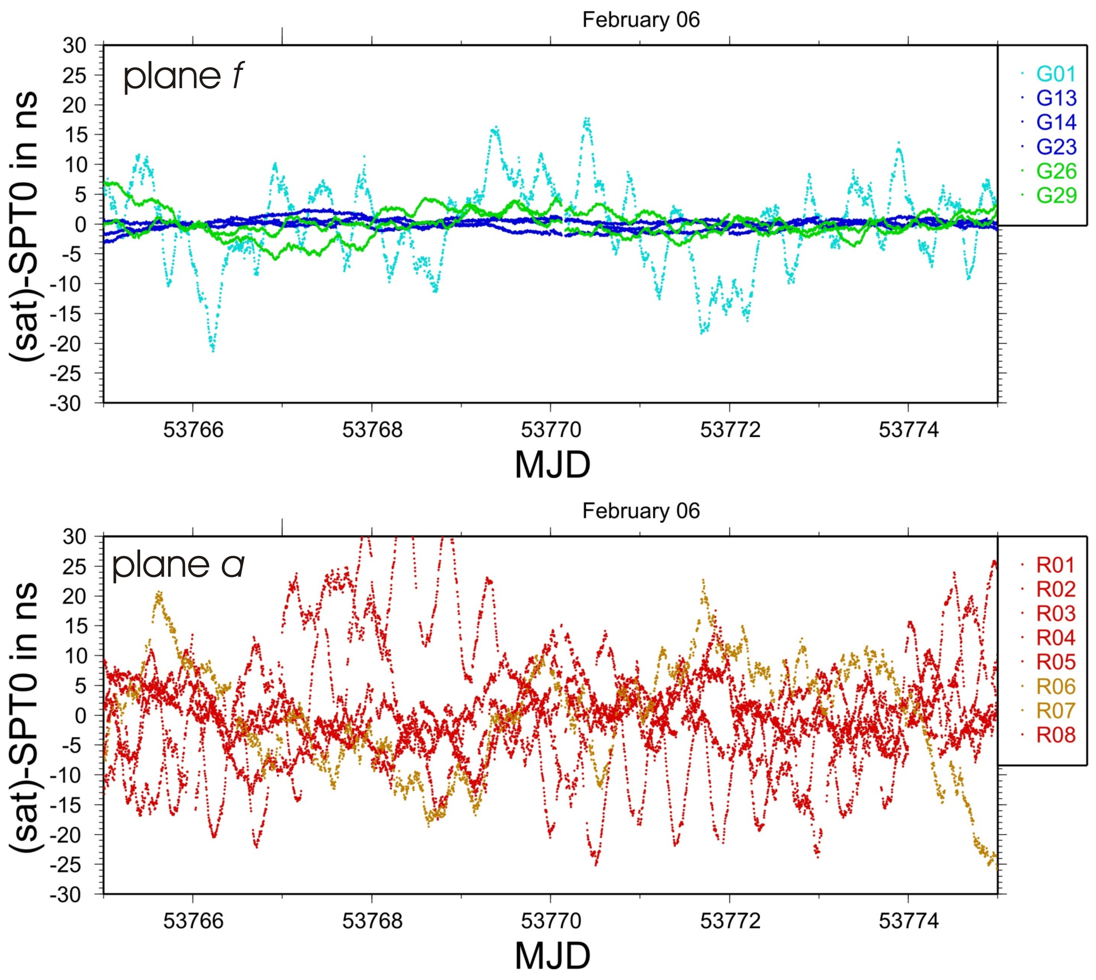

Figure 3: Estimated GPS (top) and GLONASS (bottom) satellite clocks for 10 days in February 2006 (for color codes see Figure 4).
The satellite clock corrections are plotted relative to the receiver clock corrections at station SPT0.

Figure 3 displays the estimated satellite clock corrections for selected GPS and GLONASS satellites. All GPS block II/IIA satellites driven by Cesium clocks and about half of the GLONASS satellites show a periodic signal (once-per-rev). Similar figures result for other planes resp. intervals.
Figure 4 shows the Allan deviation of the GPS and GLONASS satellite clocks. The performance of the GLONASS satellite clocks is comparable with the GPS block II/IIA Cesium clocks. No improvement for clocks onboard the new generation of GLONASS-M satellites with respect to the older GLONASS satellites can be found in the Allan deviation.
Remark: For a better comparability both, the GPS and GLONASS satellite clock corrections, for Figures 3 and 4 are computed using the same set of about thirty GNSS stations in the IGS network.

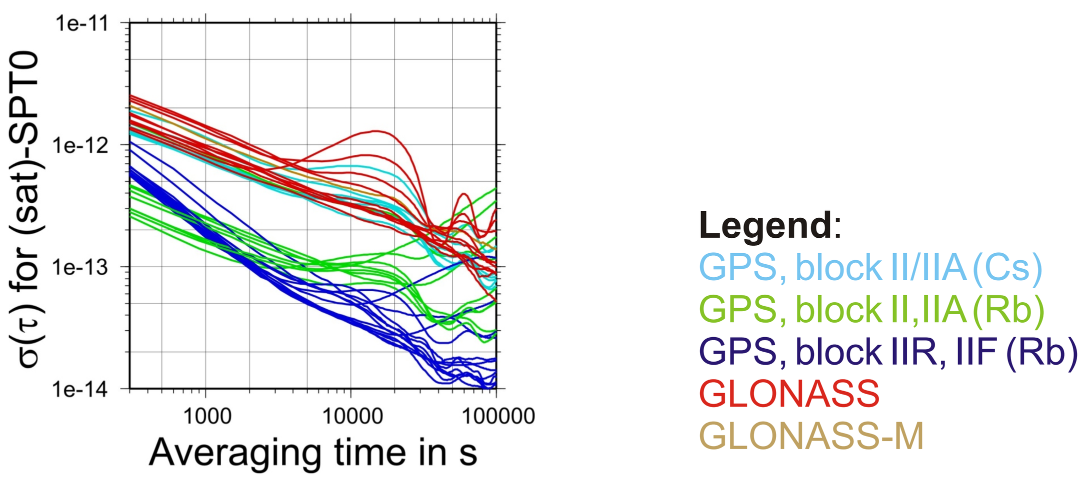

Figure 4: Allan deviation of GNSS satellite clock corrections computed for 10 days in February 2006.

Receiver-specific interfrequency code biases

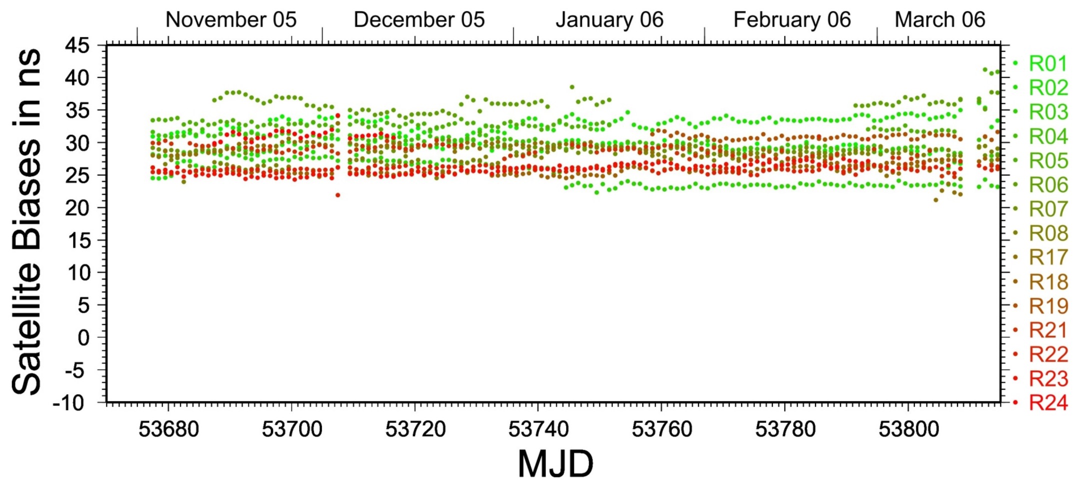

Figure 5: Time series of the receiver-specific GLONASS satellite code biases relative to the GPS biases for station ONSA.

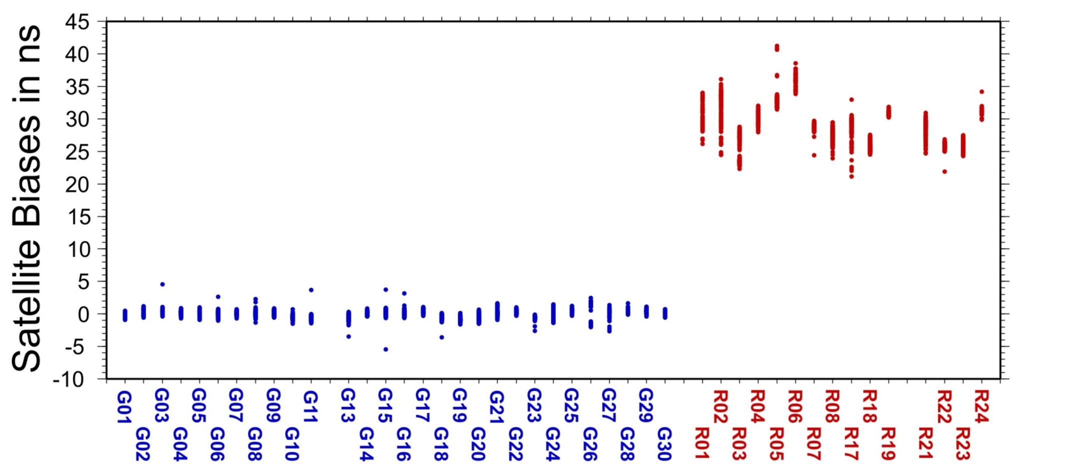

Figure 6: Repeatability of the receiver-specific satellite code biases for the station ONSA.

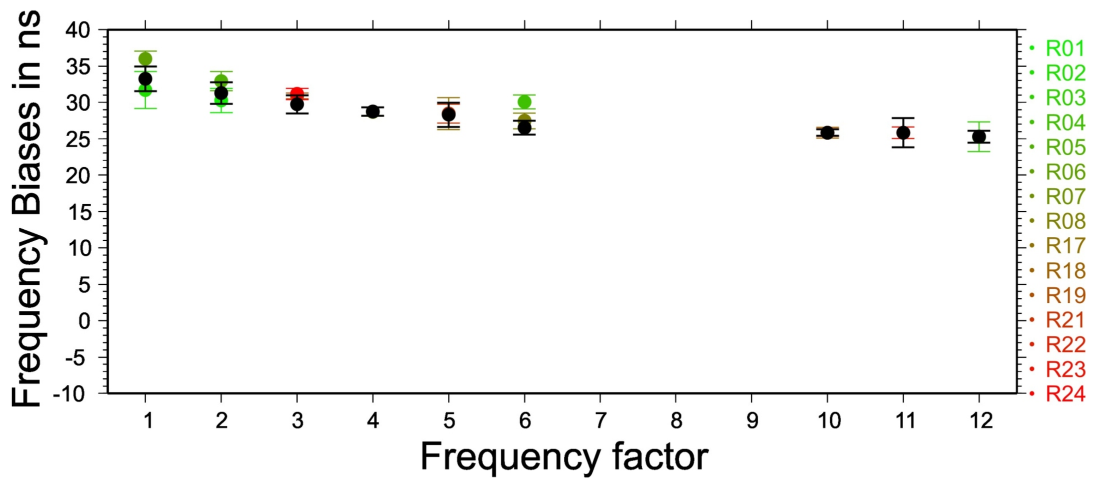

Figure 7: Receiver-specific GLONASS interfrequency code biases relative to the GPS frequency bias for station ONSA.

As the GLONASS satellites emit their signal on individual frequencies, not only receiver intersystem but also receiver interfrequency biases may be expected. One bias for the code measurements of each satellite (GPS and GLONASS) was estimated for each station.
Because the receiver and satellites clocks are also computed, two singularities have to be regularized by introducing zero mean conditions over all estimated code biases:

- The sum of all estimated GPS satellites biases of each individual station is zero (one condition per station).
- The sum of the biases of all stations for one and the same satellite is zero (one condition per satellite).

The satellite biases are stable for all stations over the analyzed time interval of more than four months (see results for station ONSA as an example in Figure 5). The repeatability of the satellite biases differs for individual stations - but it is consistent with the mean noise level of the code data that may be extracted from the residuals. The use of one value for each satellite and receiver seems to be reasonable.
Figure 6 shows that all GPS satellite biases are zero within the uncertainty level. For the GLONASS satellites a receiver-specific mean (intersystem) bias w.r.t. the GPS satellites of about 30 ns is found for ONSA.
A significant variation between the individual GLONASS satellite biases remains depending on the signals frequency - as shown in Figure 7. For the receiver in ONSA, as well as for the other stations no significant difference of the mean satellite biases can be found if two satellites are emitting their signal on the same frequency. This result justify to replace satellite by interfrequency code biases.
Figure 8 shows the mean interfrequency biases for two GNSS receiver types operated by different IGS stations (November 2005 to March 2006). ASHTECH Z18 receivers have negative intersystem biases (GLONASS relative to GPS) whereas the JAVAD receivers show positive biases. Obiously, this is caused by the imposed zero mean conditions and it allows no conclusions on the receiver performance.
It is furthermore noteworthy that the interfrequency code biases depend not only on the receiver type but they also differ for individual stations using the same receiver type (see, e.g., station MTKA for the ASHTECH Z18 receiver, or station SPT0 for the JPS LEGACY receiver).

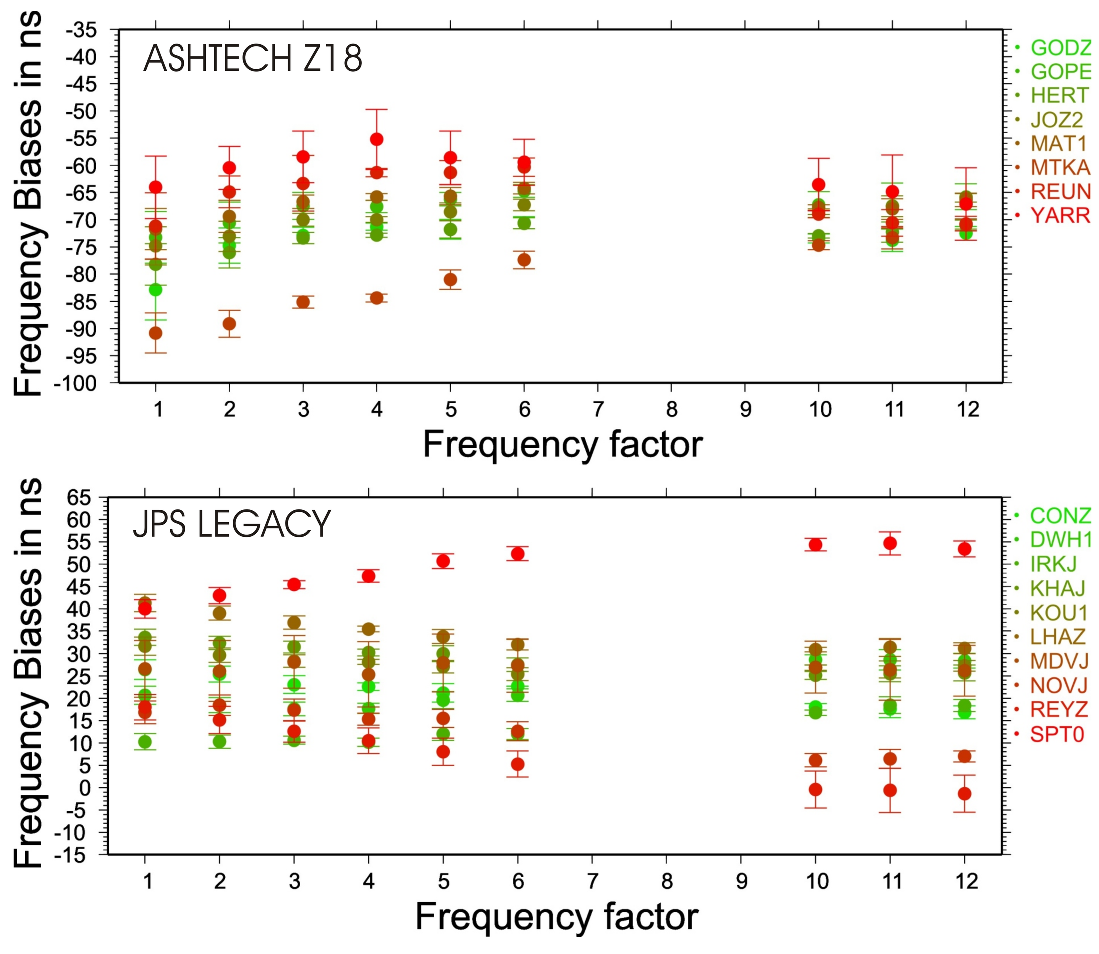

Figure 8: Receiver-specific GLONASS interfrequency code biases for different receiver types used within the IGS network (relative to the GPS frequency bias).

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