Update of the IGS antenna phase center model: new GLONASS satellite antenna corrections from CODE and ESOC

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Abstract

Within the scope of the upcoming realization of the new terrestrial reference frame ITRF2008/IGS08, an update of the current IGS antenna phase center model ("igs05.atx") is foreseen. In order to derive a new set of satellite-specific z-offsets for the GPS constellation, results from the first IGS reprocessing campaign ("repro1") will be adopted. Since GLONASS observations were not considered for repro1 at all, it will thus be necessary to prepare an additional GLONASS solution. The increased global availability of GLONASS-capable ground stations within the IGS network as well as the fact that the majority of GLONASS satellites involved in the processing for the igs05.atx model has been decommissioned and replaced meanwhile by the latest generation of GLONASS-M spacecraft underline this demand.

In order to provide up-to-date sets of consistent satellite-specific antenna phase center offsets (PCOs) and variations (PCVs) for the GLONASS constellation, the IGS analysis centers (ACs) at the European Space Operations Centre (ESOC) and the Center for Orbit Determination in Europe (CODE) have recently reprocessed several years of multi-GNSS data. The solutions were generated according to a rigorously combined multi-system processing scheme ensuring full consistency between the GPS and the GLONASS results. The key results of this effort will be presented. The agreement between the two AC solutions estimated by independent multi-GNSS software packages using different analysis strategies will be discussed. Moreover, the significant differences occurring between the new correction values and the igs05.atx model values will be addressed.

Background

Since 2003, the GLONASS space segment has slowly but surely been rebuilt, leading to the current (May 2010) constellation of 21 operational satellites of the modernized GLONASS-M series and two more in-orbit spares. The space segment thereby consists of the largest number of viable satellites since 1996/97 when it was fully populated for the first time. With the advent of a new generation of combined GPS/GLONASS receivers in 2006/07, the number of GLONASS-capable tracking stations in the IGS network started to increase as well. By the end of 2008, the IGS offered data from more than 100 continuously operating GPS/GLONASS stations with reasonable global coverage (Dach et al. 2010).

Since March 2010, the igs05.atx model comprises phase center corrections for 13 first-generation GLONASS satellites and 25 second-generation GLONASS-M satellites. The antenna parameters for all 13 GLONASS and 4 GLONASS-M satellites were estimated in August 2006 using 15 months of observation data of a relatively sparse GLONASS tracking network (~30 stations) with the majority of sites being located in Europe. The estimates for two GLONASS-M satellites, space vehicle number (SVN) 713 and 714, are based on about three months of data only. In order to keep the number of additional model parameters low, only one mean nadir-dependent phase center pattern for all satellites was estimated. In a second step, this pattern was fixed to derive a consistent set of satellite-specific z-offsets. The horizontal antenna PCOs were fixed to the nominal values provided by the satellite manufacturer (Table 1). The 21 GLONASS-M space vehicles (SVN 715-735) launched since December 2006 have been added step-by-step to the igs05.atx with block-specific phase center pattern, the nominal horizontal PCOs and a rounded block-mean z-offset value of 230.0 cm.

Another important reason for updating the igs05.atx model values is related to the fact that the solution has been aligned with IGb00, the IGS implementation of ITRF2000. The IGb00 station positions and velocities, however, were derived using relative receiver antenna phase center corrections. Moreover, the near-field impact of radome constructions on the antenna phase center characteristics was ignored, since hardly any calibrations for antenna/radome combinations were available at that time.

Table 1 Nominal phase center offsets for the GLONASS and GLONASS-M satellite antennas.

Satellite block	x (cm)	y (cm)	z (cm)
GLONASS	0.0	0.0	162.0
GLONASS-M	-54.5	0.0	218.3

Reprocessing strategies

CODE and ESOC have recently reprocessed 7.0 and 2.5 years, respectively, of GPS/GLONASS measurements in order to derive an up-to-date set of satellite-specific phase center corrections for all 25 GLONASS-M satellites and 14/3 (CODE/ESOC) original GLONASS satellites. Both AC solutions can be considered as "real multi-GNSS solutions" as the measurements from each system contribute to all relevant parameters to the same extent.

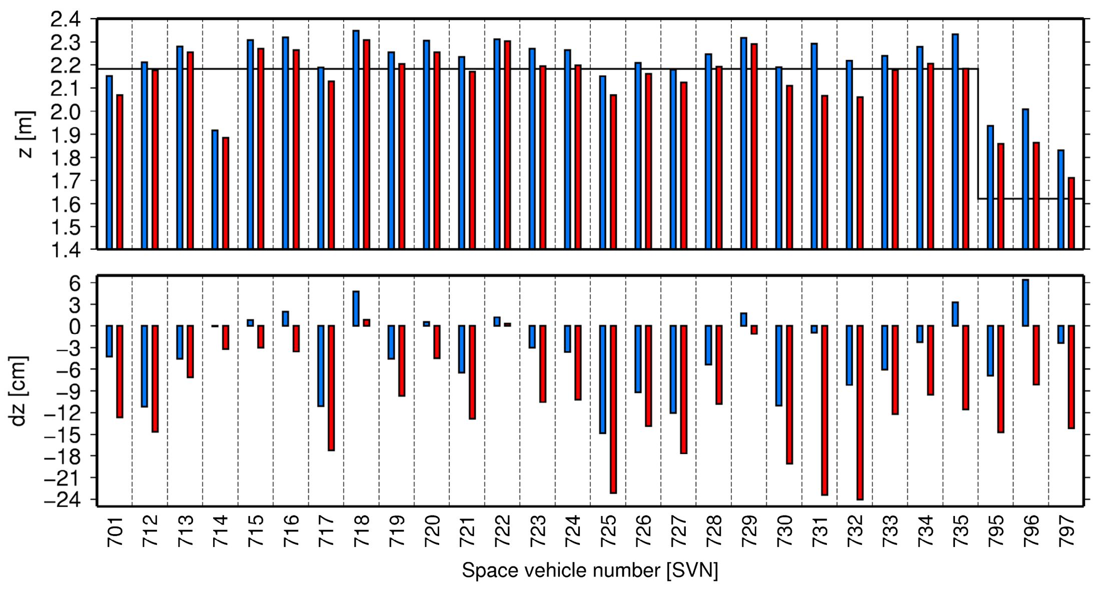
The z-offsets and PCVs of the GLONASS satellite antennas are estimated together with several other geodetic parameters usually set up in global analyses. The maximum nadir angle for the modelling of the GLONASS PCVs was extended from 14° to 15°, since more than 10% of all GLONASS observations are tracked beyond 14° (Dilssner et al. 2010). The z-offsets and PCVs of the GPS Block IIR-M satellites (SVN 48-50, 52-53, 55, 57-58) and of the recently launched first GPS IIF satellite (SVN 62) were estimated as well, since no or only a very limited amount of data (< 1 year) contributed to their igs05.atx values. The antenna parameters of all other GPS satellites were fixed to their igs05.atx values for consistency reasons. Further details about the individual reprocessing strategies applied by the two ACs can be found in Table 2.

Because of the high correlations between z-offsets and nadir-dependent PCVs, we estimate the z-offsets first while keeping the PCVs fixed. In the subsequent step, the new z-offsets are kept fixed and consistent PCVs are estimated. The final multi-year solutions are generated by "stacking" all single normal equations (NEQs) together. The solutions are aligned with ITRF2005/IGS05. Once the new ITRF2008/IGS08, along with a consistent set of new GPS satellite antenna z-offsets, is available, the NEQs will be transformed to the new datum. Due to the terrestrial scale difference of around -0.94 ppb to be expected between ITRF2005 and ITRF2008, the z-offsets will increase by about +12 cm on average.

Table 2 Reprocessing strategies of CODE and ESOC.

	CODE	ESOC
Number of GLONASS stations	30 to 40 in 2003, mainly in Europe; global coverage during 2007; 100 station in 2008, 120 in 2010	
GLONASS SVNs	701, 711-735, 783-784, 787-789, 791-798	701, 712-735, 795-797
Time interval	08 June 2003 - 13 June 2010	20 January 2008 - 19 June 2010
Software	Bernese Version 5.1 (modified)	NAPEOS Version 3.4.1 (modified)
Data	double-difference GPS/GLONASS carrier-phase observations	zero-difference GPS/GLONASS carrier-phase and code pseudo-range observations
Sampling rate	3 minutes	5 minutes
Elevation cut-off angle	3°	5°
Weighting	elevation-dependent (weight $w = \cos^2 z$ with zenith angle z)	
Ambiguity fixing	only GPS (85 - 90% per day)	only GPS (68 - 80% per day)
Interfrequency biases	implicit with the assumption of constant value per day for each station/satellite	estimated weekly for each station/satellite
Station coordinates	no-net-rotation condition for ITRF2005/IGS05 stations; coordinate/velocity solution introduced for both satellite antenna PCO/PCV estimation steps	no-net-scale and no-net-rotation condition for ITRF2005/IGS05 stations
Orbits	72-hour orbital arcs; 6 initial osculating elements, 3 constant plus 2 once-per-revolution radiation pressure parameters and pseudo-stochastic pulses at 12 UT for each satellite estimated	24-hour orbital arcs; initial orbit positions and velocities, 3 constant plus 2 once-per-revolution radiation pressure parameters and 3 tightly constrained along-track parameters for each satellite estimated; Earth albedo and infrared radiation force model
Earth rotation	piece-wise linear modelling with a resolution of one day for ERPs	daily pole coordinates and drifts, UT1 and LOD are estimated
Ionospheric refraction	first-order effect eliminated by forming ionosphere-free linear combination; higher-order effects not corrected for	
Tropospheric refraction	a priori tropospheric zenith path delays (ZPDs) computed with formula of Saastamoinen using Global Pressure and Temperature (GPT) model; ZPDs are mapped into slant delays using hydrostatic Global Mapping Function (GMF); ZPDs at 2-h intervals are estimated as continuous piece-wise linear functions using wet GMF; horizontal gradients estimated with 24-h resolution (only CODE)	
Satellite antenna PCOs	satellite-specific estimation for GPS Block IIR-M/IIF and GLONASS satellites; a priori values from igs05_1585.atx; fixed when estimating PCVs; fixed to igs05_1585.atx values for all other GPS satellites	
Satellite antenna PCVs	satellite-specific, nadir-dependent estimation for GPS Block IIR-M/IIF and GLONASS satellites ; Φ_{max} = 14° for GPS, Φ_{max} = 15° for GLONASS; piece-wise linear modelling with 1°-resolution; sum condition to prevent the NEQ system from becoming singular; constrained to zero when estimating PCOs; fixed to igs05_1585.atx values for all other GPS satellites	
Receiver antenna PCOs/PCVs	fixed to igs05_1570.atx values	fixed to igs05_1585.atx values

Fig. 1 Satellite-specific z-offset solutions from CODE (*red*) and ESOC (*blue*) together with the nominal z-offset values (*black line*). The estimates with respect to the igs05.atx a priori values are shown in the lower part of the figure.

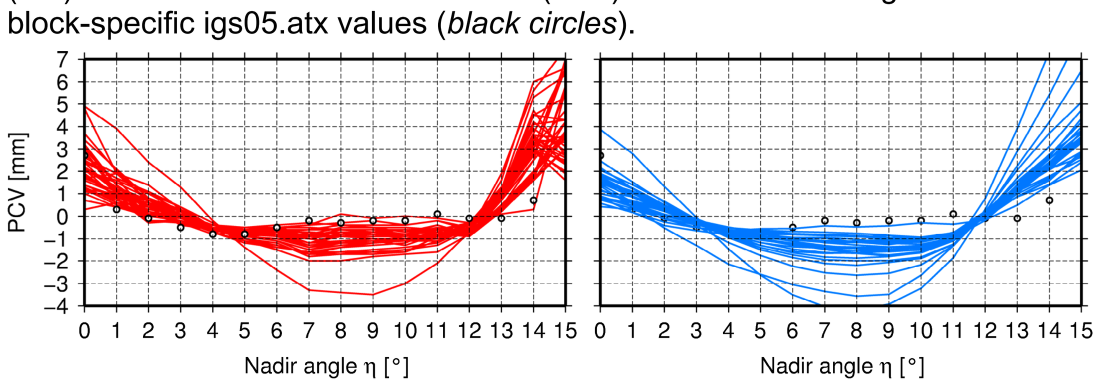


Estimated phase center z-offsets

We notice a common bias between the two AC z-offset solutions of 7.3 cm. The reason for this bias is not yet fully understood. The well-known orbit scale difference of +0.5 ppb between CODE and ESOC due to different handling of the albedo/infrared radiation forces can only explain a small part of this discrepancy (1.3 cm). The agreement between the bias-reduced z-offset values is ±4.7 cm (RMS). The largest deviations (> 10 cm) occur for three satellites launched in March 2010 (SVN 731-732, 735) and for two first-generation space vehicles (SVN 796-797) for which ESOC only processed 104 and 148 days, respectively, of data at the beginning of 2008.

Bearing in mind that the majority of GLONASS-M z-offsets contained in the igs05.atx model are rounded block-mean values derived from a completely different satellite constellation, it can be stated that the agreement between the new z-offsets and the igs05.atx values is surprisingly good. However, we clearly notice that the recomputed z-offsets of the two ACs tend to be systematically smaller than the corresponding igs05.atx values. A common bias of this size (CODE: -11.1 cm, ESOC: -3.8 cm) has a perceptible effect on the station heights and the scale of the global terrestrial reference frame. A comparison between GPS-only and GLONASS-only PPP solutions based on the igs05.atx model has nicely shown that the station heights determined with GLONASS are systematically 0.6 cm (1.0 ppb) higher than the station heights determined with GPS (Dilssner et al. 2010).

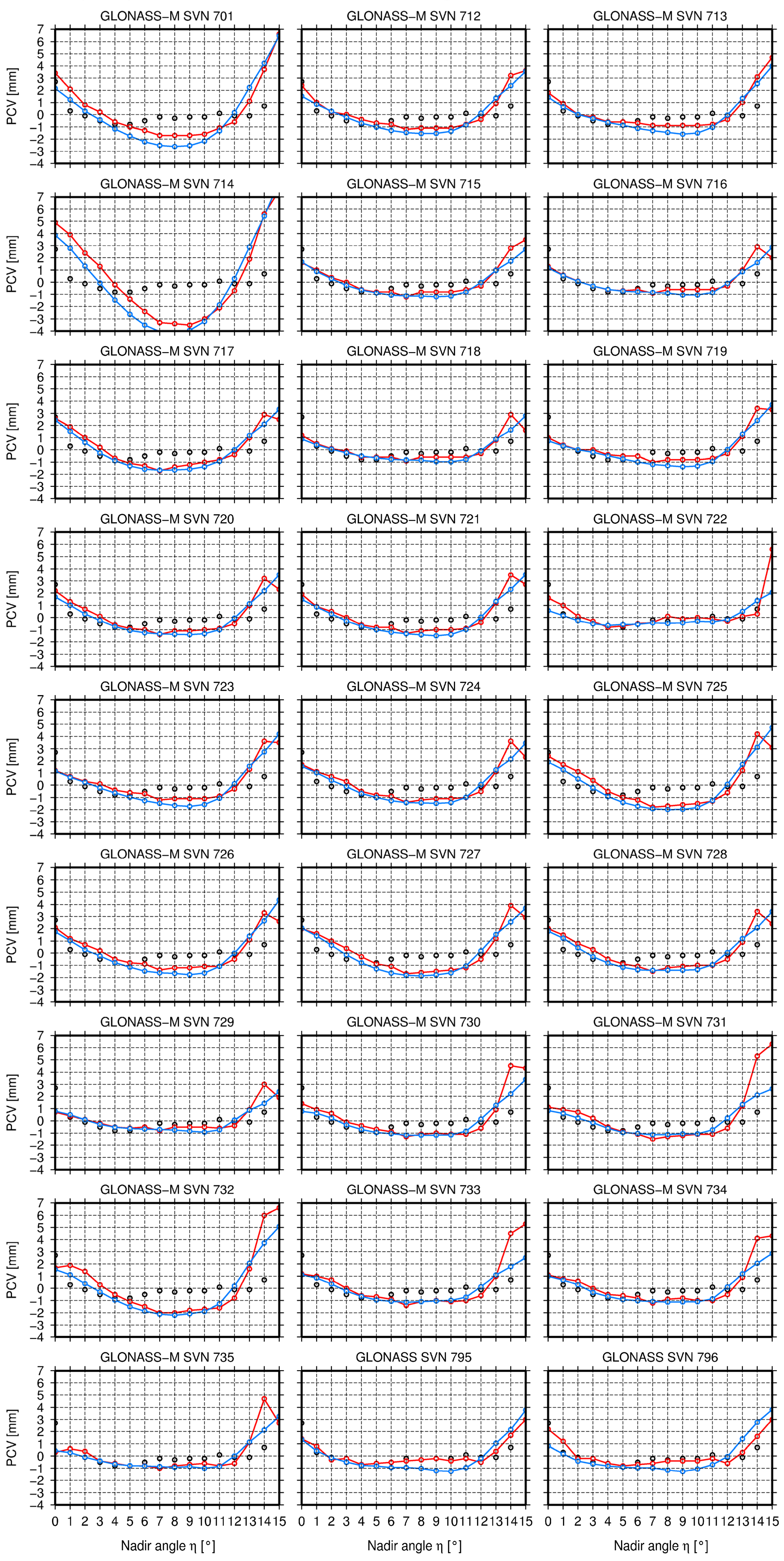
Fig. 2 Satellite-specific GLONASS/GLONASS-M PCV solutions from CODE (*red*) for 39 satellites and from ESOC (*blue*) for 28 satellites together with the block-specific igs05.atx values (*black circles*).



Estimated phase center variations

We found that the majority of GLONASS/GLONASS-M satellite antennas shows a quite similar phase pattern (Fig. 2). The agreement between the solutions of the two ACs is better than ±1 mm (Fig. 3). The exceptional PCVs found for SVN 714 are related to anomalies in the L2 signal (Dilssner et al. 2010). Since the new PCVs differ by up to a few mm from the block-specific igs05.atx pattern, we strongly recommend updating the igs05.atx model values.

Fig. 3 Satellite-specific comparison between the PCVs from CODE (*red*) and ESOC (*blue*). The *black circles* indicate the igs05.atx PCV values.



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