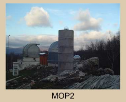

MOP2

GANP

OBSA

Effects of non-modeled signal biases in multi-GNSS Precise Point Positioning

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INTRODUCTION

Precise Point Positioning (PPP) which is based on processing of un-differenced GNSS phase and code observations using the precise satellites orbits and satellites clocks is challenge for autonomous high quality geocentric coordinate determination without necessity of terrestrial reference sites. Increase of number of broadcasted signals of individual satellite navigation systems as well as the combination of more GNSS in common adjustment model emphasizes the importance of consideration of intra-system and inter-system biases.

The complexity of proper bias modeling is emphasized by the fact that origin of signal biases is both in satellites and receivers. Part of the GNSS signal delays are included in global network solutions products modeling predominantly the satellite dependent biases. The multi-GNSS receiver's biases could be evaluated within the individual independent site's PPP processing by addition of parameters related to receiver dependent inter-system, inter-code and inter-channel biases.

We present PPP-based estimates of non-modeled signal biases for several sites with different GNSS instrumentation for GPS, GLONASS and Galileo GIOVE satellites.

OBSERVATION EQUATIONS FOR PSEUDORANGE CODE *P* AND PHASE *L* OBSERVABLES IN MULTI-GNSS PPP

For combination of various GNSS is essential to consider the inter-system bias parameters *S* related to GNSS hardware, inter-channel biases *H*, *h* and the differential code biases *D*.

$$P^j_{Af} = \rho^j_A + c\delta_A - c\delta^j + I^j_{Af} + T^j_A + S^j_A + H_{Af} + D^j_{AC} + \varepsilon^j_{PAf}$$
$$L^j_{Af} = \rho^j_A + c\delta_A - c\delta^j - I^j_{Af} + T^j_A + h_{Af} + \lambda_f N^j_{Af} + \varepsilon^j_{LAf}$$

These biases can be receiver dependent (*A*), satellite dependent (*j*), frequency dependent (*f*) and code combination dependent (*C*).

In the PPP solution strategy some of these biases are adopted along with satellite orbits and satellite clocks from the global network solutions (e. g. satellite DCBs). Some of the biases are included in the real-valued ambiguity parameter estimates *N* and only part of biases (or their combination) is estimable from single site PPP solution.

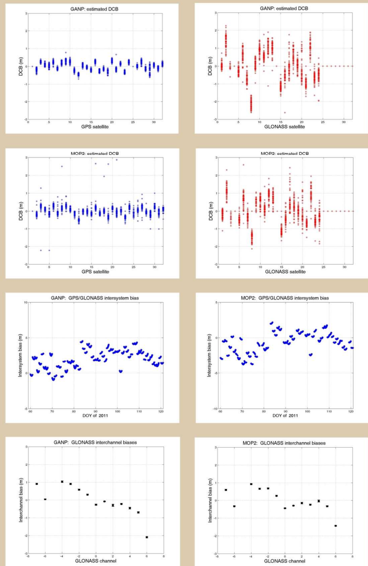
PROCESSING STRATEGY

- Pre-processing of dual frequency phase and code GNSS observations separately for each satellite and for each continuous observing interval resulting in the iono-free pseudoranges and approximate values of phase ambiguities.
- Reduction of observed ranges for systematic phenomena according to the relevant models and computation of o-c (observed minus calculated) values using the precise satellite orbits and clocks information.
- Forming of adjustment model and least-square estimation of parameters: site coordinates, receiver clocks, real-valued corrections to ambiguities, troposphere zenith delays and other optional parameters.
- Processing starts with separate GPS and GLONASS adjustment as well as with o-c evaluation for Galileo GIOVE satellites. Next, the combination of GPS/GLONASS and GPS/Galileo is performed by adding the inter-system biases, differential code biases and inter-channel parameters (for GLONASS only).
- Parameters estimated in this study: site coordinates, troposphere induced ZTD, satellite clocks and real-valued ambiguities. Additional parameters related to non-modelled signal biases: inter-system biases GPS/GLONASS, GPS/Galileo, inter-channel biases (GLONASS), and receiver dependent part of differential code biases (GPS, GLONASS, Galileo). All the estimated biases are expensed in length units.
- Satellite orbits and clocks are taken from global network solutions: IGS – ESOC (GPS and GLONASS), CONGO – DLR (GPS, GLONASS and Galileo GIOVE satellites).
- All the analyses are examined by using the software package ABSOLUTE developed for the PPP multi-GNSS processing at the Slovak University of Technology in Bratislava. The results presented are resulting from processing of 24-hour observing intervals.

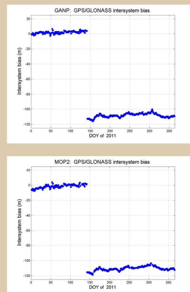
GNSS OBSERVATIONS ANALYZED

Site	Receiver / Antenna	GNSS observed	Observation interval analzyed DOY, year	Satellite orbits and clocks
GANP Gánovce Slovakia	TRIMBLE NETR8 TRM55971.00 NONE	GPS, GLONASS	129 – 142, 2011	IGS - ESOC
MOP2 Modra-Piesok Slovakia	TRIMBLE NETR5 TRM55971.00 TZGD	GPS, GLONASS	129 – 142, 2011	IGS - ESOC

Site	Receiver / Antenna	GNSS observed	Observation interval analzyed DOY, year	Satellite orbits and clocks
CUT0 Curtin University Bentley Australia	TRIMBLE NETR9 TRM59800.00 SCIS	GPS, GLONASS, Galileo	053 – 063, 2012	IGS – ESOC DLR – CONGO
GRA2 Graz_B Austria	LEICA GRX1200+GNSS LEIAR25.R4 LEIT	GPS, GLONASS, Galileo	053 – 063, 2012	IGS – ESOC DLR – CONGO
HARB Hartebeesthoek South Africa	TRIMBLE NETR9 TRM59800.00 NONE	GPS, GLONASS, Galileo	053 – 063, 2012	IGS – ESOC DLR – CONGO
OBSA SUT Bratislava Slovakia	TRIMBLE R9 TRM_GNSS3 NONE	GPS, GLONASS, Galileo	318 – 330, 2011 053 – 063, 2012	IGS – ESOC DLR – CONGO
POTS Potsdam Germany	JAVAD TRE_G3TH DELTA JAV_RINGANT_G3T NONE	GPS, GLONASS, Galileo	318 – 330, 2011	IGS – ESOC DLR – CONGO

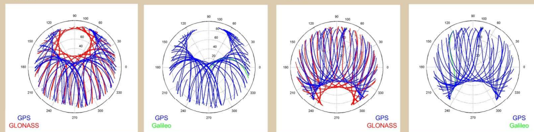


Evolution of GPS/GLONASS intersystem biases during March-April 2011, estimated DCB biases from daily 24-solutions and estimated GLONASS inter-channel biases. The general pattern of all biases is similar for MOP2 and GANP, however receiver/site related specificities are distinguishable.



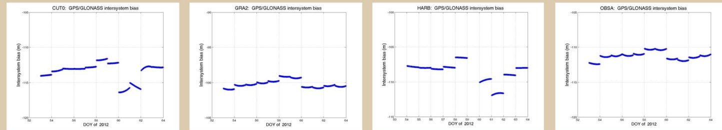
Evolution of GPS/GLONASS intersystem biases in 2011. The significant shift after DOY 142 is related probably to change of strategy of GLONASS satellite clock modeling at ESOC.

GRA2 CUT0

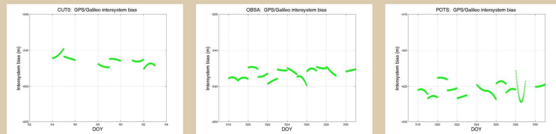


Sky plots for GPS+GLONASS and GPS+GIOVE satellites observed during 24 hours at CUT0 and GRA2 (DOY 057 of 2012)

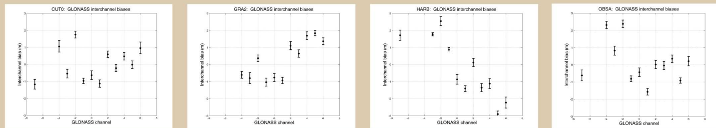
EXAMPLES OF SIGNAL BIASES ESTIMATED FROM MULTI-GNSS PPP



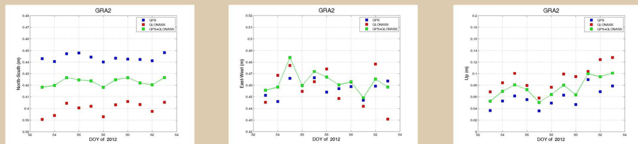
The estimated GPS/GLONASS intersystem biases show similar pattern for various receivers, however they are systematically shifted.



GPS/Galileo intersystem biases estimated from DLR orbits and clocks products.



GLONASS inter-channel biases for different GNSS receivers estimated from 10 days PPP solutions. The receiver/site specificities are significant.



Local coordinates evolution from GPS-only, GLONASS-only and GPS+GLONASS combined solutions at GRA2 during 10 days. All three series show similar variations and stable shifts for N-S and up components.

CONCLUSIONS

- Combination of various GNSS using the PPP algorithms needs incorporation of inter-system, inter-channel and differential code biases. The receiver dependent part of these biases could be estimated from combination of code and phase observations within the PPP single site processing.
- Inter-channel biases for GLONASS frequency channels are strongly receiver/antenna dependent, however we found them as stable in time.
- The inter-system biases of GPS/GLONASS and GPS/Galileo combinations are receiver/antenna dependent but their time dependence is significant too.
- The receiver dependent part of differential code biases we found at ~ 1 m level for GLONASS P1-P2 bias and at 100 m level for GIOVE E1-E5a bias.
- The combination of GPS and GLONASS improves the internal consistency of coordinate adjustment; however do not improve the coordinate repeatability. The effect of inclusion of one Galileo satellite into GPS solution changed only negligibly the coordinate outputs.