Consideration of Station-Specific Intersystem Translation Parameters at CODE

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Abstract. At CODE, we recently started to consider an extra set of (3+1) parameters for each GLONASS observing station to characterize a GLONASS-GPS receiver antenna offset vector and a GLONASS-GPS ZPD troposphere bias.

We describe how these GLONASS-GPS bias parameters are treated. First results (with a main focus on the GNSS PCV model switch from IGS05 to IGS08) are presented.

We anticipate that consideration of station-specific intersystem translation parameters as introduced here will become common for highest-precision, “as-consistent-as-possible” multi-GNSS analysis (in particular for consistency monitoring purposes).

Keywords. GPS, GNSS, multi-GNSS, intersystem biases, antenna phase center models, consistency

1 Introduction

The Permanent Network Analysis Center (PNAC) at swisstopo has been generating GPS-only as well as GLONASS-only regional network analysis solutions already for several years—in addition to the regular GPS/GLONASS-combined analysis solutions (Schaer et al. 2007). It should be mentioned that the two single-GNSS analysis solutions are fairly compatible in terms of quality due to the fact that ambiguity resolution is performed not only for GPS but also most successfully for GLONASS.

Investigations made as part of (Schaer et al. 2010), however, revealed significant discrepancies between the two sets of single-GNSS station coordinate results (in case of stations actually observing both GPS and GLONASS). Furthermore, these discrepancies between pure GPS-based and pure GLONASS-based results proved to be reasonably reproducible in time. One main conclusion from this observation was that it would be a desirable feature to set up corresponding intersystem bias parameters in the regular GPS/GLONASS-combined analysis scheme—in order to detect inconsistencies between station results as seen by each GNSS observed by a particular station.

2 GLONASS-GPS Intersystem Translation Parameters

We decided to consider an extra set of (3+1) parameters for each GLONASS observing station to characterize

- a GLONASS-GPS receiver antenna vector and
- a GLONASS-GPS ZPD troposphere bias.

Fig. 1 shows the translation vector in a N/E/U coordinate frame (internally considered in the geocentric X/Y/Z frame) between the GPS-based and the GLONASS-based station coordinates. Note that “mixed RP” (reference point) indicates that point you would refer to in the GPS/GLONASS-combined case when neglecting the present intersystem translation vector. The “mixed RP” should correspond in fact to the weighted mean of the GPS and the GLONASS RP realization.

A second essential group of station-specific parameters is dedicated to the characterization of troposphere zenith path delay (ZPD) and associated gradient path delay. We believe that one additional

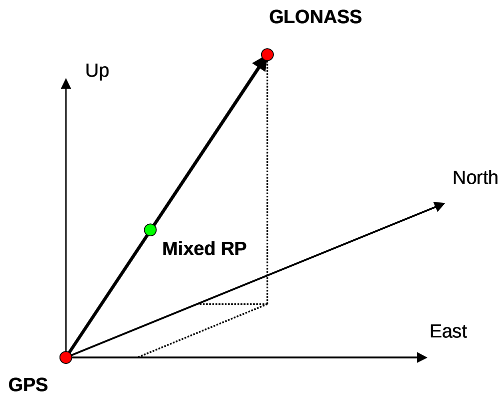

Fig. 1: GLONASS-GPS intersystem translation parameters with respect to station coordinates.

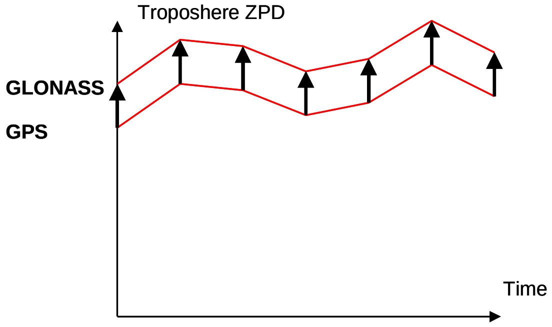

Fig. 2: GLONASS-GPS intersystem translation parameters with respect to troposphere zenith path delay (ZPD).

intersystem bias parameter with respect to the ZPD may compensate to a large extent for remaining elevation-dependent effects between GPS and GLONASS observations. Fig. 2 illustrates this troposphere bias to be set up for each dual-GNSS observing station. Ultimately, consideration should be extended to a corresponding set of intersystem biases responding to troposphere gradients.

From a physics point of view, any sort of troposphere parameters should not depend on a particular GNSS to be analyzed. Consequently, the introduced troposphere bias parameters may be seen as auxiliary parameters specifically absorbing potentially existing effects of intersystem receiver antenna phase center variations (PCV).

It is rather obvious that intersystem translation parameters with respect to station coordinates (as illustrated in Fig. 1) may be interpreted as station-specific receiver antenna phase center offsets (PCO) between two GNSS, or, to be more precise, PCO corrections that are superimposed to PCO values coming from the basic receiver antenna PCO/PCV model (IGS05, or IGS08).

Determination of station coordinates with respect to each observed GNSS would be in principle equivalent to the proposed parameterization. There are three major reasons, however, to pursue our proposal:

- Datum definition: PCO-like parameters are well suited to define no-net translation and no-net rotation conditions (to eliminate the singularities arising from the intersystem coordinate bias parameters additionally introduced).
- GPS as "master GNSS": Reference (and thus resulting) ITRF station coordinates and velocities are commonly referred to GPS(-only) results.
- Similarity to intersystem troposphere bias parameter handling: Just one common inter-system bias shall be compensated with respect to each (coordinate and troposphere) component.

It should be emphasized that that the third item implies an essential aspect: just a minimum number of additional bias parameters shall be set up and estimated in the (final) parameter adjustment in order to find an optimal trade-off between under-parameterization and over-parameterization.

3 Results

GLONASS-GPS intersystem translation parameters with respect to station coordinates and troposphere ZPD are regularly set up at CODE since GPS week 1615 for the EUREF regional analysis and since GPS week 1619 for the IGS final analysis (Schaer et al. 2011a). Starting with GPS week 1625, these GLONASS-GPS bias parameters (4 for each GNSS station) are determined on a weekly basis and subsequently used for generation of our daily IGS analysis results (Schaer et al. 2011b). A weekly set of estimated station coordinates, now supplemented by a weekly set of estimated intersystem translation parameters, is used for the associated daily resubstitution computations.

The definition used for the GLONASS-GPS receiver antenna offset vectors is similar to that used for station coordinates: no-net translation and, for global analysis, no-net rotation conditions with respect to all GLONASS observing stations are imposed. GLONASS-GPS ZPD troposphere biases are generally treated unconstrained. Consequently, CODE's weekly SINEX contribution to the IGS implicitly includes these GLONASS-GPS bias parameters (4 for each GNSS station).

Fig. 3 and Fig. 4 show the evolution in time of the (weekly) mean and median of the GLONASS-GPS troposphere ZPD biases for the CODE EUREF analysis and the CODE IGS analysis, respectively. They provide clear evidence that the switch from the IGS05 to the IGS08 ANTEX model is responsible for the significant reduction of the previously implied overall troposphere ZPD bias of about +1.5 mm between GLONASS and GPS.

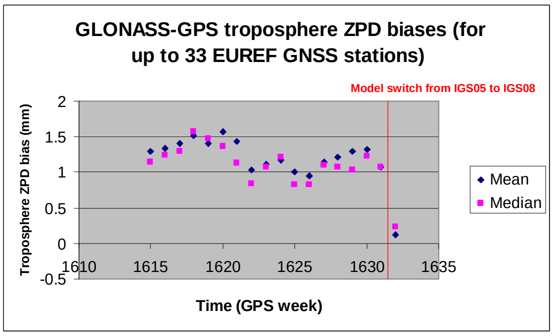

Fig. 3: Mean GLONASS-GPS troposphere ZPD biases, plotted for CODE EUREF (regional) weekly results.

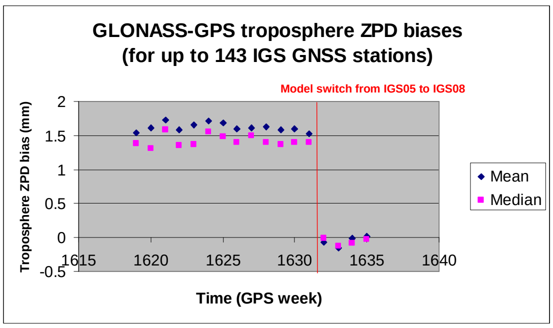

Fig. 4: Mean GLONASS-GPS troposphere ZPD biases, plotted for CODE IGS (global) weekly results.

The IGS08 ANTEX model update was stipulated to be adopted within the IGS community starting with GPS week 1633 (Schmid et al. 2011). It should be mentioned that the most recent update concerning the IGS08 ANTEX model included for the first time receiver antenna PCO/PCV correction values specific to GLONASS.

The impressive reduction of the global GLONASS-GPS (de facto GLONASS) troposphere ZPD bias—to an insignificant level—may primarily be attributed to the comprehensive update of the satellite antenna Z-PCO values for the complete GLONASS constellation (as provided by CODE and ESA/ESOC). The results shown in Fig. 3 and Fig. 4 confirm on the one hand considerably improved consistency for the latest IGS ANTEX model (IGS08) and, on the other hand, they demonstrate the advantage of considering such intersystem bias parameters for consistency monitoring purposes.

Fig. 5 and Fig. 6 show a “regional” and a “global” example for sets of weekly determined GLONASS-GPS translation parameters in North versus East (left) and in Up versus tropospheric ZPD (right). The approximate peak-to-peak values for N/E/U/ZPD are approximately: 10/5/15/3 mm for the EUREF regional and 15/20/30/10 mm for the IGS global receiver network analyzed at CODE.

Due to the intended datum definition, the center point concerning the plotted N/E points must be close to the origin (0/0). However, we use to maintain a list of “misbehaving” GNSS stations to be excluded for the corresponding datum definition. That list typically includes all stations equipped with Ashtech Z18 receivers (unable to sample zero and negative GLONASS frequency channels and therefore observing just half of the GLONASS constellation) or stations with receivers running with out-dated firmware (also disregarding substantial parts of the GLONASS constellation).

Fig. 7 finally shows a corresponding set of GLONASS-GPS translation parameters as retrieved from a 3-year combination of a dedicated “GNSS-only” time series (intentionally restricted to continuous observation data collected by a GPS/GLONASS-combined-only receiver network).

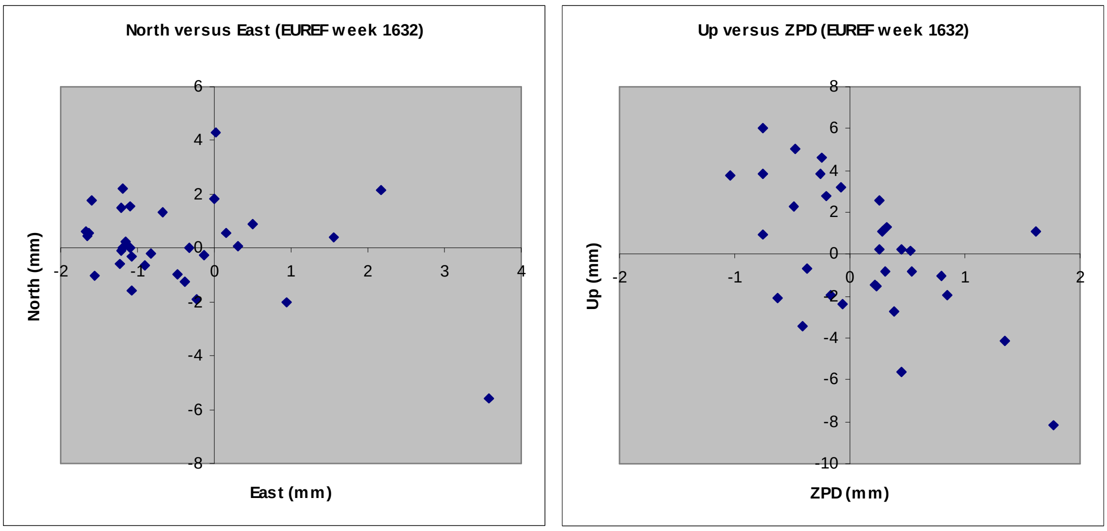

Fig. 5: GLONASS-GPS translation parameter results concerning N/E and U/ZPD, plotted for EUREF week 1632.

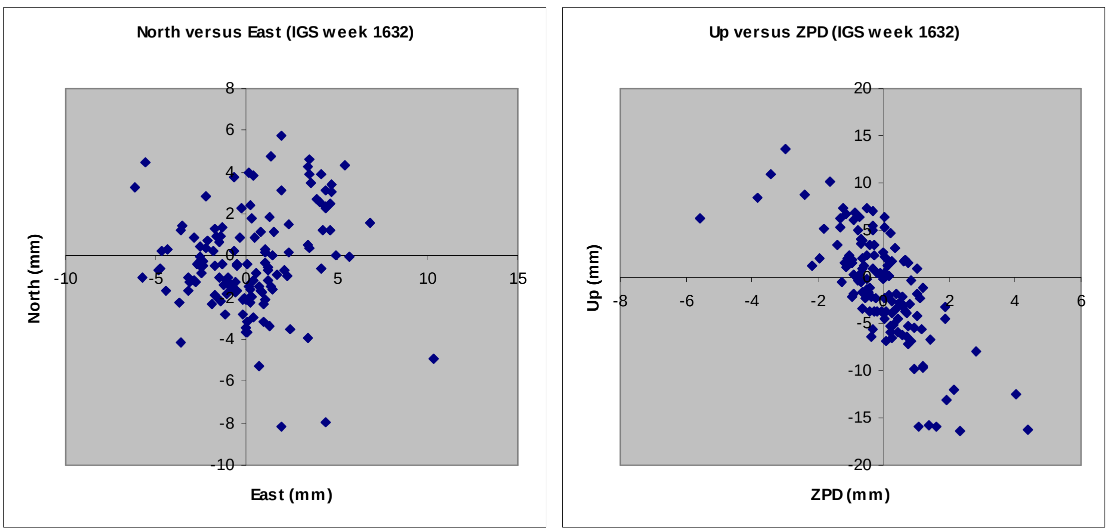

Fig. 6: GLONASS-GPS translation parameter results concerning N/E and U/ZPD, plotted IGS week 1632.

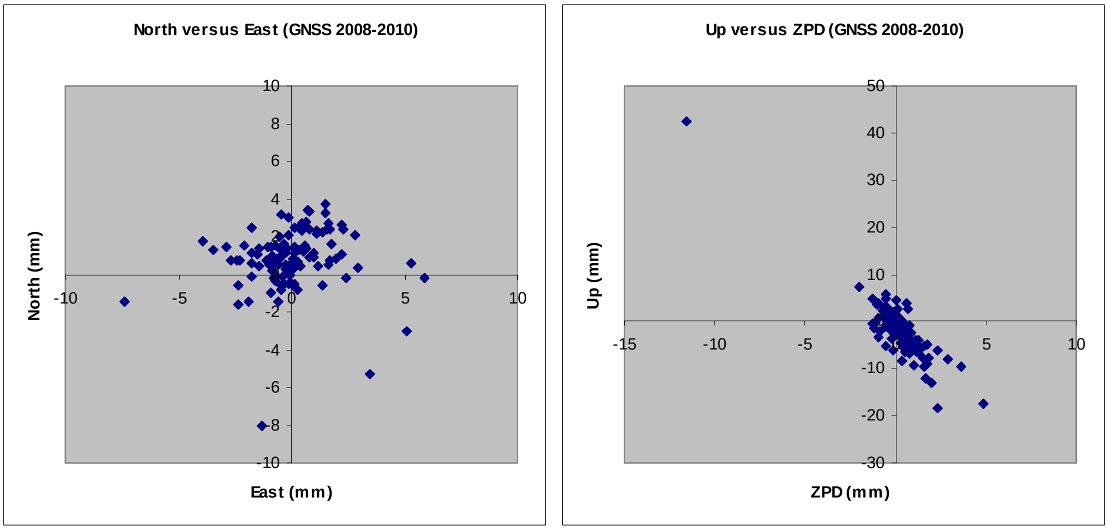

Fig. 7: GLONASS-GPS translation parameter results concerning N/E and U/ZPD, plotted for "GNSS-only" test analysis covering 3 years (2008–2010).

The peak-to-peak values for the horizontal position are, with 12 mm in North and 13 mm in East, comparable to the translation parameters results retrieved for a single week shown in Fig. 6. Such significant deviations (exceeding 10 mm) in a multi-year combination of GNSS station coordinate results clearly document the necessity for consideration of the dedicated intersystem bias parameters for highest-precision applications. With regard to Up and ZPD, Fig. 7 (right) is compatible with Fig. 6 (right), with the exception of the outlier corresponding to the station at REUN 97401M003 (ASHTECH Z18 connected to ASH701073.3 NONE).

4 Summary and Conclusions

We proposed consideration of GLONASS-GPS intersystem translation parameters specific to each station coordinate and each station troposphere zenith path delay (ZPD) component. The development version of the Bernese Software (Dach et al. 2007), as it is operationally employed at CODE, has been extended with the capability

- to set up intersystem bias parameters,
- to apply adequate datum definition conditions in particular for those bias parameters being directly coupled with the station coordinates, but also (optionally) for troposphere ZPD bias parameters, and
- to export and to import estimated bias values related to the presented intersystem differences.

It should be emphasized that the necessary datum definition is crucial for linking the GLONASS orbit information properly (as consistently as possible) to ITRF. To be more precise, we use to impose 3 no-net translation and 3 no-net rotation conditions with respect to all station coordinate translation parameters (allowing for a station exclusion list). Intersystem translation parameters concerning troposphere ZPD are treated completely unconstrained.

Corresponding sets of intersystem translation parameters have to be set up on a (daily) session basis. Session results are then stored in form of normal equations (NEQ). By combination at NEQ level, one is in the end free to define the desired validity time internals for the included intersystem translation parameters (eventually being subject to appropriate parameter transformations).

The advantage of the proposed intersystem translation parameters for consistency monitoring purposes could be demonstrated explicitly for the passed IGS ANTEX model switch from IGS05 to IGS08. After following the IGS08 ANTEX model, the *overall* GLONASS-GPS troposphere ZPD bias is reduced to an insignificant level. Based on this experience, we believe that it is indispensible to extend the set of (currently 3+1=4) intersystem translation parameters to troposphere gradients (finally leading to a total of 3+1+2=6 bias parameters for each dual-GNSS observing station).

Deviations (or "inconsistencies) between *individual* station coordinates and troposphere ZPD derived from GPS and GLONASS remain on a significant level—even when following the latest IGS08 ANTEX model. Our results revealed intersystem deviations of the order of ±5 mm for both horizontal and vertical positions and ±15 mm for troposphere ZPD. These deviations may be attributed to (a) station environmental effects and to (b) deficiencies in terms of receiver antenna PCO/PCV correction model. A first investigation confirmed that station environmental (particularly multipath) effects must be the dominating source for the recovered intersystem deviations. There seems to be a minor remaining part (common to identical GNSS antenna types) that could be used for validation and ultimately for improvement of

GNSS receiver antenna PCO/PCV correction models.

The accurately recovered GLONASS-GPS intersystem translation vectors clearly visualize the limitations in terms of (absolute) accuracy as achievable by GPS (or by any other GNSS observation technique). Moreover, comparisons of GNSS-derived baseline vectors with terrestrial reference measurements repeatedly show the limiting accuracy of GNSS station coordinate results in the absolute sense (Brockmann et al. 2009).

Let us finally point to an interesting feature of the resulting GNSS station coordinates when considering GLONASS-GPS station-specific intersystem translation parameters: these station coordinates are expected to be *unbiased* and consequently *GPS-referenced*. This means that station coordinates as obtained from such a consistently treated multi-GNSS analysis should be directly comparable with conventional GPS-only results (at least as long as GPS is used in the multi-GNSS analysis). This is definitively not true if the existing intersystem inconsistencies are ignored: the differences of accordingly computed GNSS-combined and GPS-only station coordinate results should correspond to a significant fraction of the ignored inconsistencies (cf. Fig. 1: difference vector is expected to result roughly in "Mixed RF"-minus-"GPS").

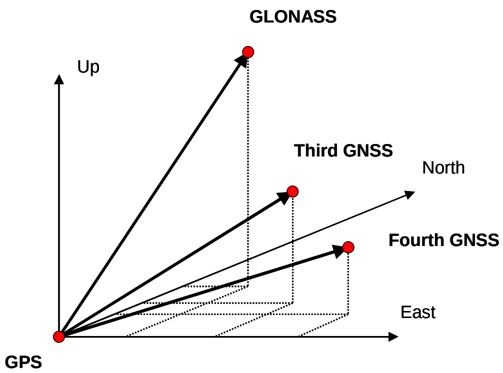

Fig. 8: Intersystem translation parameters with respect to each involved GNSS (here for a total of four observed GNSS).

It is important to note that such GPS-referenced, multi-GNSS station coordinate and troposphere ZPD results are far from being equivalent to GPS-only results. There is further no equivalence to results coming from a GNSS-separated analysis (where observation data is treated separately for GPS and for GLONASS).

The ultimate consequences of the presented developments on GNSS-based ITRF and thus on SINEX (potentially in addition on ANTEX) are not yet clear.

We believe that consideration of station-specific intersystem translation parameters for each additionally observed GNSS (as suggested in Fig. 8) is a logical step and will become standard for highest-precision, "as-consistent-as-possible" multi-GNSS analysis.

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