Initial results from the 2017-2018 multi-GNSS test reprocessing campaign

Paul Rebischung, based on inputs from CODE, ESA, GFZ, CNES/GRGS and TU Graz

1. E vs. GR: individual station position differences

Previous tests carried out using *chamber* calibrations had revealed antenna-type-dependent biases between GPS+GLONASS (GR) and Galileo-only (E) station position solutions. (See slide 13 in this presentation.) Those biases were likely due to frequency-dependent errors in the chamber calibrations of some antenna types and could reach nearly 1 cm in height. Such biases are obviously a concern for the formation of meaningful GPS+GLONASS+Galileo (GRE) solutions. A first question that the new 2017-2018 multi-GNSS test reprocessing campaign was intended to answer was therefore the following: do such station position biases remain between GR and E solutions when using the new multi-GNSS *robot* calibrations provided by Geo++?

To look into this question, I formed, for each AC, differences between pairs of daily GR and E solutions, after having brought each pair to a common origin, orientation and scale. Plots of the resulting "E – GR" station position difference time series can be found at ftp://igs-rf.ign.fr/pub/repro3_tests/plots/E-GR/sta/. The weighted average station position differences, grouped by antenna types, are additionally shown in these plots: ftp://igs-rf.ign.fr/pub/repro3_tests/plots/E-GR/ant/. Comments on those results follow.

- For antennas that have multi-GNSS calibrations in igsR3_2057.atx, and with the exception of three JAVAD antenna types (see next bullet), there doesn't seem to be such significant antenna-type-dependent biases as could be observed with chamber calibrations. There may be a small (≈ -3 mm) negative height bias for stations equipped with "LEIAR25.R3 LEIT" antennas, and a small (≈ +3 mm) positive height bias for stations equipped with "TRM115000.00 NONE" antennas, but the overall situation seems rather satisfying to me.

- The situation is much more chaotic however for stations equipped with "JAV_GRANT-G3T NONE", "JAV_RINGANT_G3T NONE" and "JAVRINGANT_G5T NONE" antennas, especially in the horizontal components. Here, large position biases can be observed (often > 5mm; sometimes > 1 cm, e.g., JOG2, NYA2, SUTM, ULAB…), that are highly dependent on the station and the AC. Still for the same antenna types, similar biases can also be observed, between GPS-only and GLONASS-only station position solutions (see Section 4). This raises a number of questions:
    - Does anyone have a clue why this happens? Are these antenna types known to have any particularities?
    - What can explain that the "E – GR" position biases of stations equipped with those antennas are so AC-dependent, particularly in the North component?
    - Should we take any measure about stations with those antenna types in repro3? Discard or downweight their GLONASS and Galileo observations? Estimate inter-system station position biases like CODE has done in the past (this would be my preference)? Or should we just live with these biases and provide average multi-GNSS station positions?

- While CODE, ESA, GRGS and TUG included in their Galileo solutions only antenna types that have multi-GNSS calibrations in igsR3_2057.atx, GFZ also used antenna types with legacy L1/L2 calibrations. While that was not originally planned in this test reprocessing campaign, this however gives us the opportunity to assess "E – GR" station position biases for some antenna types which do *not* have multi-GNSS calibrations in igsR3_2057.atx. The results are mixed, with some antenna types showing small or no biases (e.g., "AOAD/M_T NONE"), and others showing height biases of about 1 cm (e.g., "SEPCHOKE_MC NONE", "TRM55971.00 NONE"). We know anyway that using L2 antenna calibrations for E5a Galileo observations is usually not recommendable, hence the following question:
    - In repro3, should we forbid to use Galileo observations acquired by antennas which do not have multi-GNSS calibrations?

2. E vs. GR: terrestrial scale differences

To make the results of Section 3 more easily understandable, it is useful to first look at the terrestrial scale differences between the GPS+GLONASS (GR) and Galileo-only (E) solutions provided by the different ACs. Figure 1 thus shows scale factors estimated between pairs of daily E and GR solutions.

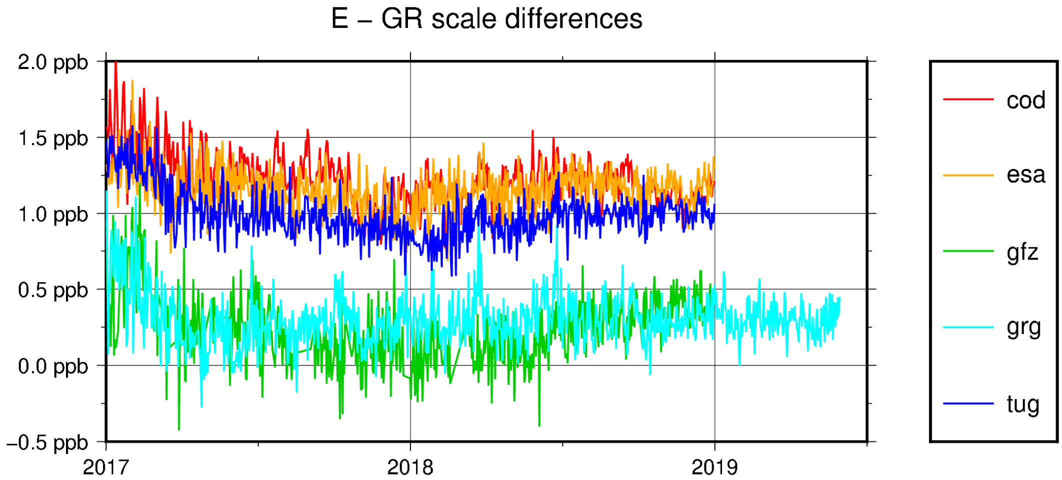

Figure 1: Time series of scale factors estimated between pairs of daily E and GR solutions

The GPS and GLONASS satellite z-PCOs in igsR3_2057.atx are conventionally aligned to the ITRF2014 scale at epoch 2010.0. On the other hand, the Galileo satellite z-PCOs in igsR3_2057.atx are those provided by GSA from pre-launch satellite calibrations. Unless the Galileo satellite z-PCOs provided by GSA coincidentally yield the same terrestrial scale as ITRF2014 at epoch 2010.0, scale differences are therefore expected between E and GR solutions based on igsR3_2057.atx. Figure 1 confirms the existence of such scale differences.

However, what's not expected in Figure 1 is that these "E – GR" scale differences largely depend on the AC. Two AC groups can in fact clearly be distinguished. On the one hand, CODE, ESA and TUG see an average "E – GR" scale difference of 1 – 1.2 ppb. On the other, GFZ and GRGS see an average scale difference of only ≈ 0.3 ppb. The "E – GR" scale differences do however not tell us which of the "E" or "GR" scale differs between the two groups of ACs. That's why "E" and "GR" inter-AC scale differences are shown in Figure 2, where CODE was arbitrarily chosen as reference.

It can be seen in Figure 2 that the scales of the GR solutions from the different ACs agree well with each other (like observed in the operational IGS SINEX combinations). However, the scales of the Galileo-only solutions from the different ACs greatly differ from each other. The average scale difference between GFZ and CODE Galileo-only solutions is for instance -1.37 ppb (-8.7 mm!). This is of course a serious issue for repro3…

- If we want Galileo included in repro3, then these scale differences between the Galileo-only solutions from the different ACs first need to be understood and resolved.

It is interesting to know that in previous test solutions provided by CODE, ESA and GFZ earlier this year, the same problem was already present. The scales of the Galileo-only solutions from CODE and ESA were in good agreement while GFZ was ≈ -1.5 ppb off. At that time, GFZ was "alone against the world", so I suspected that they had wrongly used the Galileo satellite z-PCOs from GSA, but I was assured that this wasn't the case. The issue was then not investigated further. Now, the situation is even trickier. TUG seems to have joined the CODE/ESA club, although their Galileo-only solutions have a small ≈ -0.2 ppb average scale offset with respect to CODE's (≈ -0.3 ppb with respect to ESA's); but at the same time, GFZ was joined by GRGS. If all ACs correctly used the Galileo satellite z-PCOs provided by GSA, then I don't know what can explain such large scale differences between their Galileo-only solutions…

- Could they be related to orbit modeling differences? Would it be worth comparing the orbits from the Galileo-only solutions of the different ACs?? (GFZ already provided their sp3 files. If the other ACs could do the same, then I could give a try to such orbit comparisons.)
- Does anybody have any other idea???

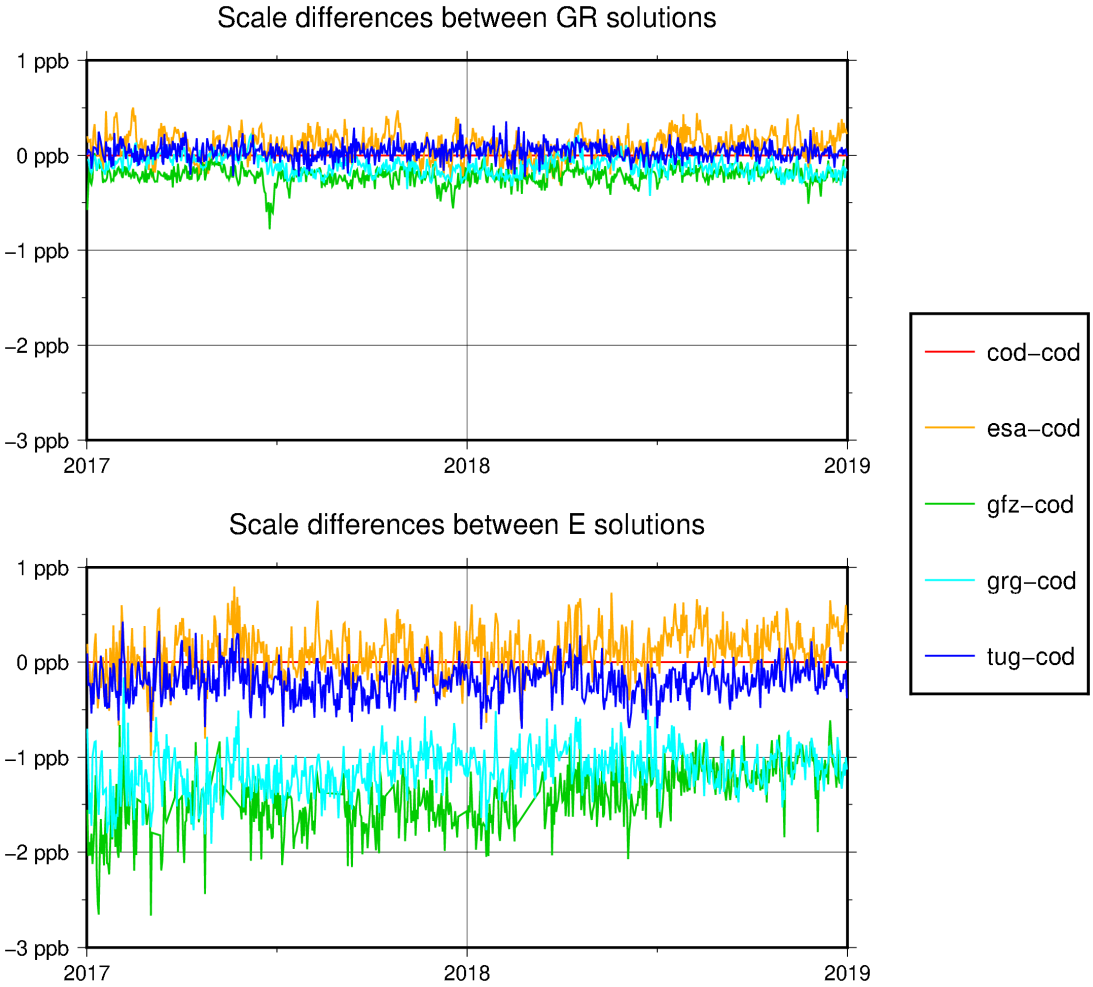

Figure 2: Time series of inter-AC scale differences between daily GR (top) and E (bottom) solutions

3. Re-evaluation of the GPS and GLONASS satellite z-PCOs

The second purpose of the 2017-2018 test reprocessing campaign was to re-estimate the GPS and GLONASS satellite z-PCOs based on the Galileo satellite z-PCOs provided by the GSA, with the ultimate goal of forming a final repro3 ANTEX file in which satellite z-PCOs would be consistent across the three systems and would yield an (ITRF-independent) intrinsic GNSS terrestrial scale. Given the results shown in Section 2, one can already expect difficulties with this re-evaluation, but I tried it nevertheless.

More precisely, from each daily GRE solution of each AC, I derived an average correction to the igs14.atx z-PCO values of all GPS and GLONASS satellites, after having fixed the Galileo satellite z-PCOs. (The x- and y-PCOs of all satellites were fixed. The origin and orientation of the terrestrial frame were constrained, but not its scale.) The obtained daily estimates of this average correction to the igs14.atx z-PCO values of all GPS and GLONASS satellites are shown in Figure 3.

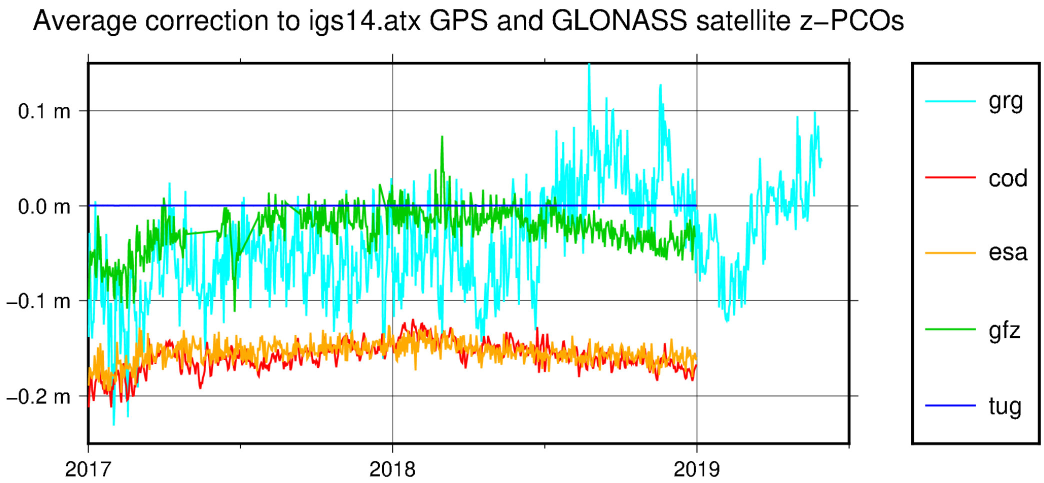

Figure 3: Estimates of the average correction to the igs14.atx GPS and GLONASS satellite z-PCOs obtained by fixing the Galileo satellite z-PCOs in the daily GRE AC solutions

Even if they are inconsistent with each other, the results obtained for CODE, ESA and GFZ are at least consistent with the scale results presented in Section 2. (According to Zhu et al. (2003)'s rule of thumb, the z-PCO corrections in Figure 3 should indeed be approximately -0.13 [m/ppb] times the scale differences shown in Figure 1.) Besides, it seems that once the scale difference issue described in Section 2 is understood and resolved, the z-PCO correction estimates from CODE, ESA and GFZ should nicely align with each other. Meanwhile, this scale difference issue however prevents us from deriving a single "universal" correction to the igs14.atx GPS and GLONASS satellite z-PCO values, hence from moving forward with the final repro3 ANTEX file.

- ➢ The scale difference issue described in Section 2 really needs to be understood and resolved!

On the other hand, the results obtained for GRGS and TUG are unexpectedly *not* related to the scale differences shown in Figure 1 via Zhu et al. (2003)'s rule of thumb. More issues to solve for these two ACs.

- For TUG first, the obtained z-PCO corrections are 0 ± a few µm. More generally, whatever I try to do with your SINEX files, I always get satellite z-PCO estimates that are the a priori values ± a few µm to a few 0.1 mm, even without applying any constraint neither to any satellite z-PCO nor to the terrestrial scale. Besides, when I compute the SVD of one of your normal matrices, I don't see the expected near-singularity involving the average of the satellite z-PCOs and the terrestrial scale. This makes me wonder whether correlations with all the reduced parameters (clocks, ZWDs, etc.) are correctly kept in your normal matrices.
  - ➢ Sebastian, could you please look into this?
- Then for GRG, the obtained z-PCO corrections are on the contrary highly variable, as if fixing the Galileo satellite z-PCOs was not enough to precisely solve for the GPS and GLONASS satellite z-PCOs, i.e. as if the satellite z-PCOs from the different systems were decoupled in your normal equations.
  - ➢ Sylvain, any idea about that? (I'll check the SVD of the normal matrices of your GRE solutions next week to see if my guess is correct, but even if it is, we'll still need to understand why and how to solve this.)

4. R vs. G: individual station position differences

Following Arturo's request in [IGS-ACS-1244], CODE, ESA and TUG provided GPS-only (G) and GLONASS-only (R) solutions with the purpose of identifying possible station position biases between both sets of solutions due to antenna calibration issues. I compared those G and R solutions in the same way as I compared the GR and E solutions in Section 1. The resulting "R – G" station position difference time series can be found at ftp://igs-rf.ign.fr/pub/repro3_tests/plots/R-G/sta/. The weighted average station position differences, grouped by antenna types, are additionally shown in these plots: ftp://igs-rf.ign.fr/pub/repro3_tests/plots/R-G/ant/. I quickly looked into those results and they seem generally OK to me except:

- for a few particular stations (BNDY, HRAO, FAIR…);
- for the same three JAVAD antenna types as mentioned in Section 1 (see comments there);
- for the "LEIAR25.R3 LEIT" antenna type which shows a clear ≈ 1 cm "R – G" height bias (should we do something about it?).