Preliminary tests regarding the inclusion of Galileo in IGS repro3

Paul Rebischung

based on data provided by
Florian Dilssner (ESA), Arturo Villiger (AIUB), Andreas Brack (GFZ)

Questions

- **Ideally, we'd like repro3:**
  - to include Galileo
    (which currently implies switching from robot to chamber calibrations for ground antennas)
  - to have its terrestrial scale based on Galileo satellite antenna calibrations
    (which implies re-estimating GPS satellite z-PCOs based on Galileo satellite z-PCOs)
  - not to upset Zuheir
    (or other users of IGS station position time series)

- **So we need to wonder:**
  - What's the impact of switching from robot to chamber calibrations on station positions?
  - What's the impact of including Galileo on station positions?
  - Can we reliably re-estimate GPS satellite z-PCOs based on Galileo satellite z-PCOs?

Test dataset

- **2017-2018 reprocessing by ESA (thanks!) including the following daily solutions:**

	GPS-only		Galileo-only				GPS+Galileo			
	Gr	Gc	E5r	E5c	E7r	E7c	GE5r	GE5c	GE7r	GE7c
GPS	L1+L2	L1+L2	-	-	-	-	L1+L2	L1+L2	L1+L2	L1+L2
Galileo	-	-	E1+E5a	E1+E5a	E1+E5b	E1+E5b	E1+E5a	E1+E5a	E1+E5b	E1+E5b
ground calib.	robot	cham.	robot	cham.	robot	cham.	robot	cham.	robot	cham.

- **A priori satellite z-PCOs from igs14.atx, i.e.:**
  - ITRF2014-scale-based for GPS satellites
  - from GSA calibrations for Galileo satellites

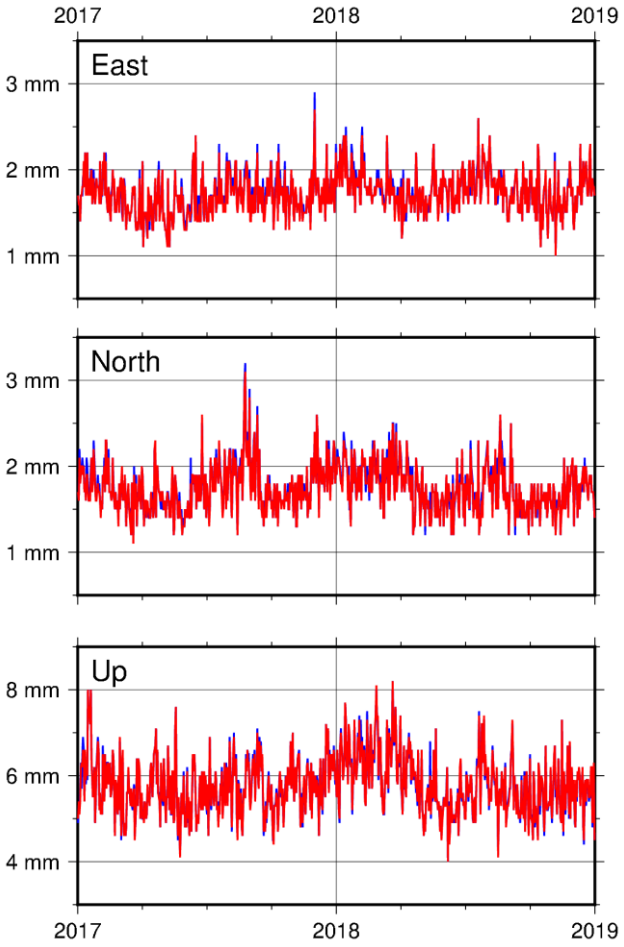
  - but satellite z-PCOs included in SINEX files, hence re-estimable

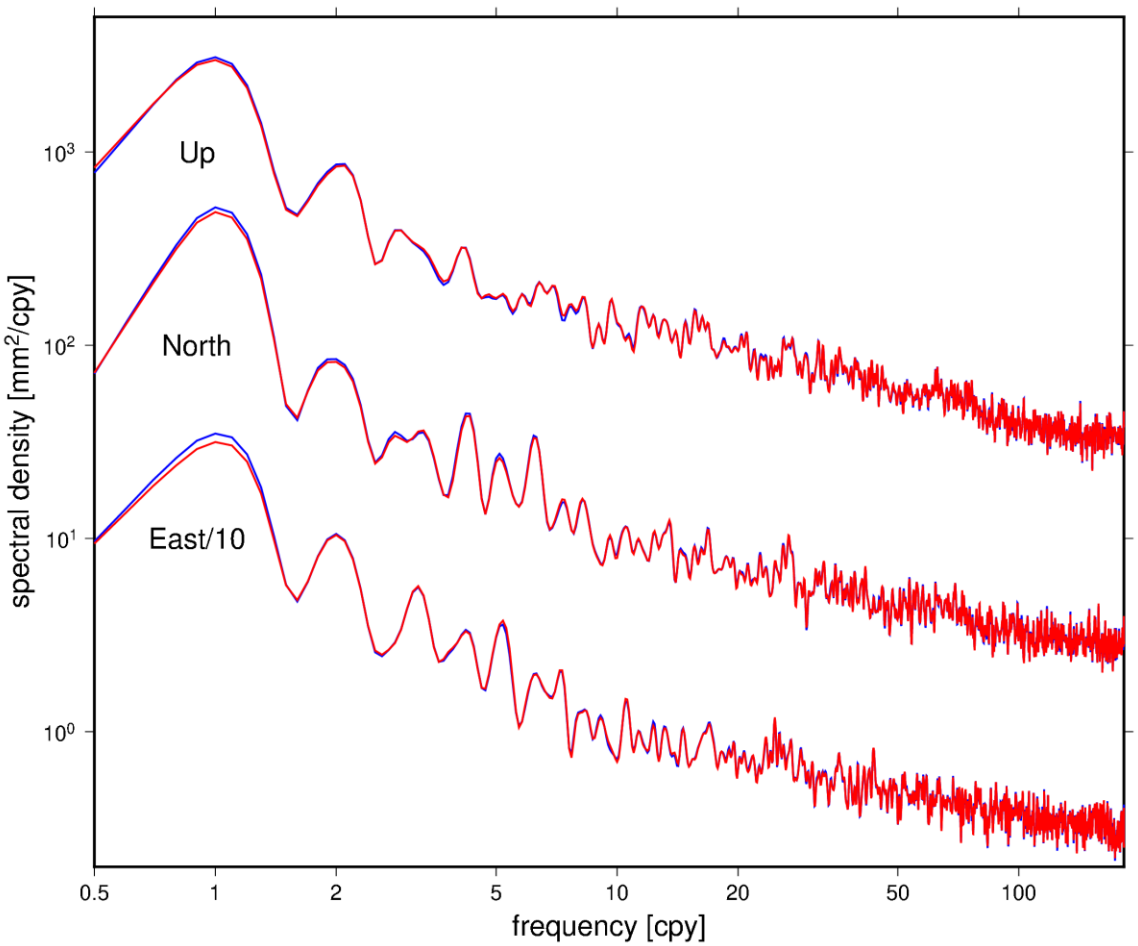
- **Thanks as well to CODE and GFZ for their efforts!**
  - Did not have time to look at CODE's 2017-2018 repro in detail yet, but will!
  - Some unresolved issues with GFZ's 2-week sample

Part 1:

Impact of robot → chamber calibration changes on GPS-only station positions

Gc vs. Gr: long-term stacking residuals



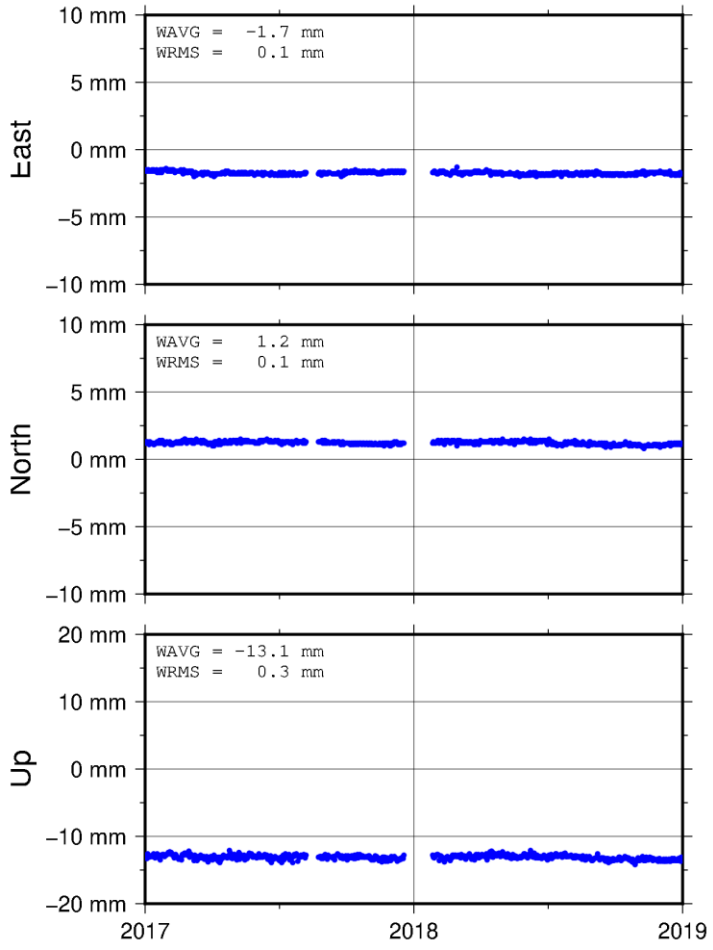


WRMS of the residuals from long-term stackings of the:
- **Gr solutions**
- **Gc solutions**

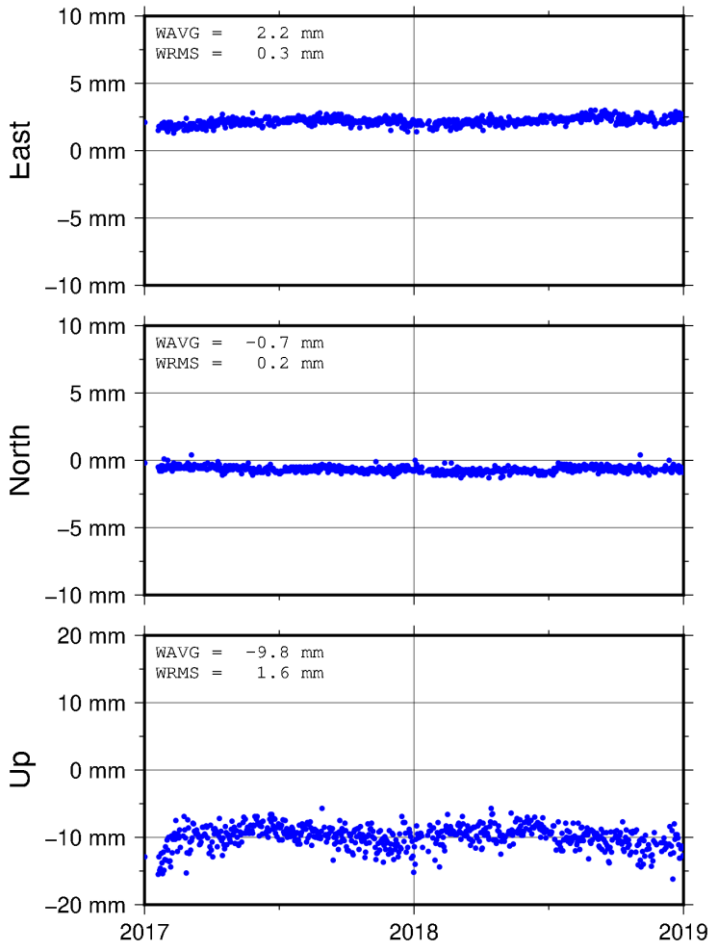
Average Lomb-Scargle periodograms of the residuals from long-term stackings of the:
- **Gr solutions**
- **Gc solutions**

Gc vs. Gr: station position differences

Typical case: AUCK (TRM57971.00 NONE)

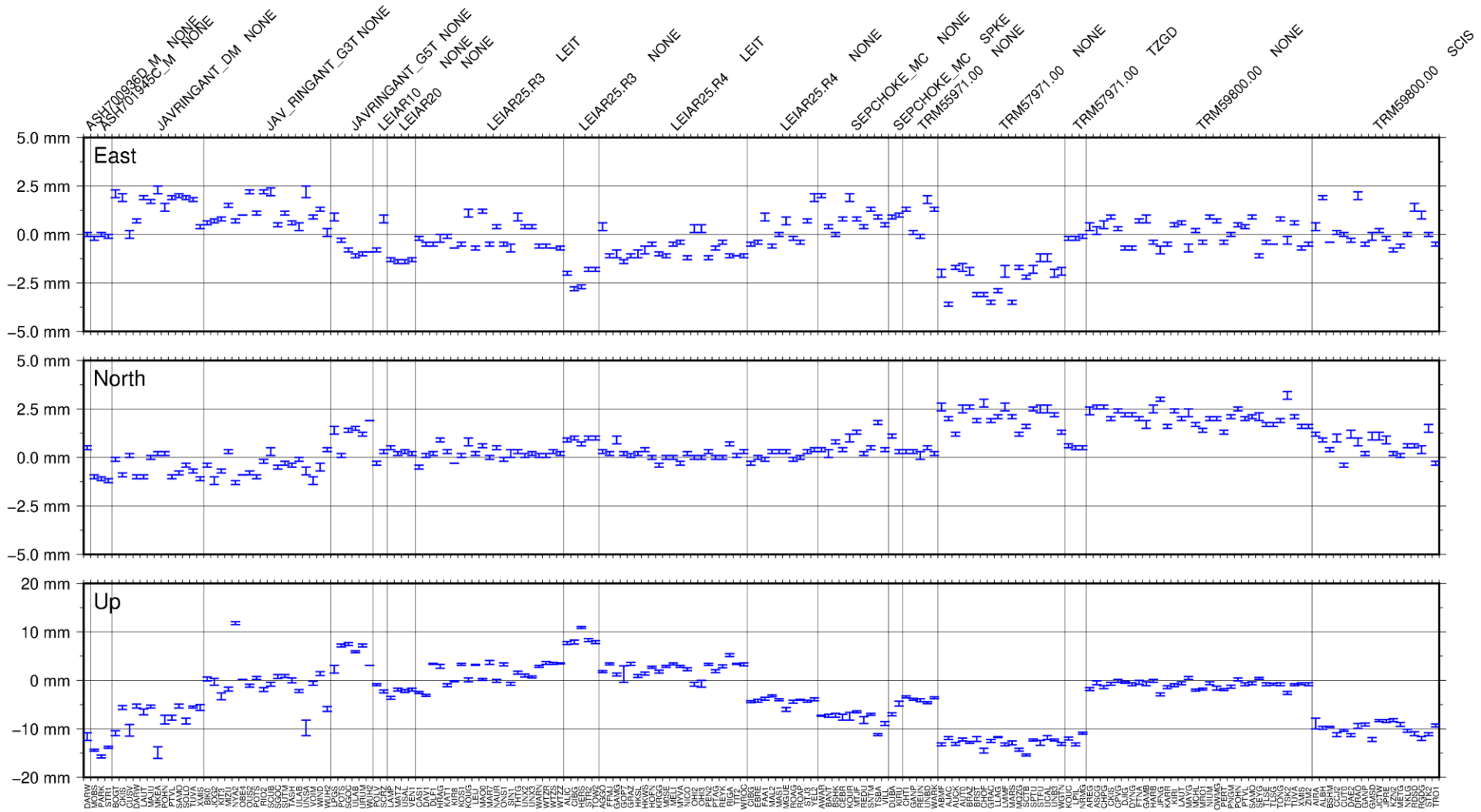


Worst case: UNSA (JAV_RINGANT_G3T NONE)



NB: The Gc and Gr solutions were differenced after having brought them to a common origin and orientation. Station position differences are thus shown up to an unknown global translation and rotation.

Gc vs. Gr: station position differences



NB: The Gc and Gr solutions were differenced after having brought them to a common origin and orientation. Station position differences are thus shown up to an unknown global translation and rotation.

Gc vs. Gr: summary

- **Robot → chamber calibration changes induce:**
  - large station+antenna-dependent position offsets,
  - but small time variations.
  - Similar situation as with usual robot → robot updates

- **If repro3 uses chamber calibrations for ground antennas, a specific Reference Frame (IGc14) will need to be defined.**
  1) Finalize ground antenna part of repro3 ANTEX
  2) Compute station+antenna-specific position offsets for IGS14 stations
  3) IGc14 = IGS14 + position offsets due to robot → chamber calibration changes

- **Subsidiary question: Which is best? Robot or chamber?**
  - Are position discontinuities due to antenna changes reduced? Amplified?
  - Are local tie residuals in ITRF combination reduced? Amplified?
  - To be investigated…

Part 2:

Can we reliably re-estimate GPS satellite z-PCOs based on Galileo satellite z-PCOs?

Re-estimation of GPS satellite z-PCOs

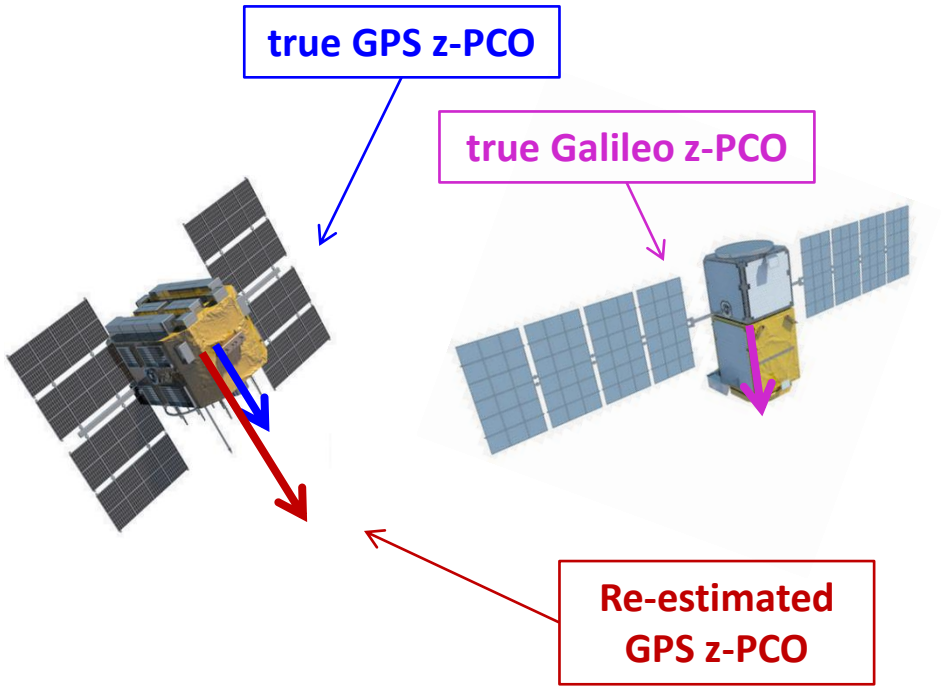
- **Can we technically re-estimate GPS satellite z-PCOs based on Galileo satellite z-PCOs?**

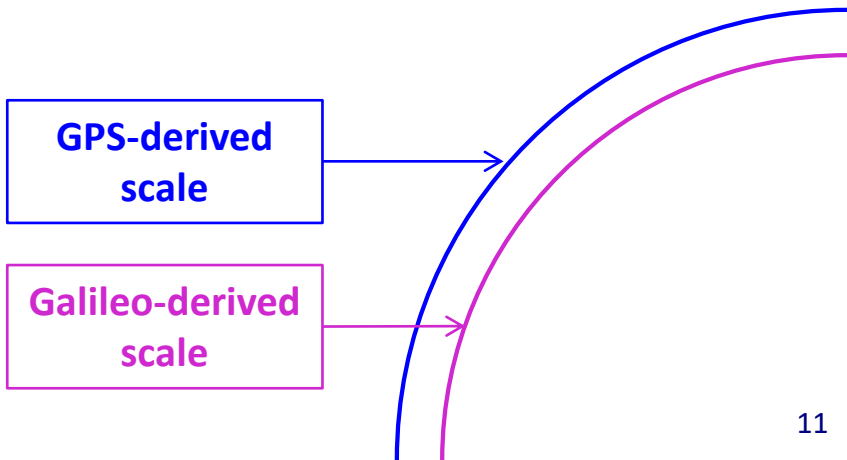
- **Yes:**
  - **Take a GPS+Galileo normal equation,**
  - **Fix Galileo satellite z-PCOs, hence the terrestrial scale,**
  - **GPS satellite z-PCOs can be solved for.**

- **But doing so, we implicitly assume that the scale difference between GPS-only and Galileo-only solutions is entirely due to satellite z-PCO inconsistencies.**

Re-estimation of GPS satellite z-PCOs

- **Assume we know the true satellite z-PCOs.**
- **Yet, GPS-only and Galileo-only solutions yield different terrestrial scales, due to, e.g.:**
  - **Ground antenna calibration errors**
  - **Orbit modeling errors**
  - **…**
- **Re-estimating GPS z-PCOs based on Galileo z-PCOs will:**
  - **Adjust GPS z-PCOs to the Galileo scale**
  - **Yield wrong GPS z-PCOs**





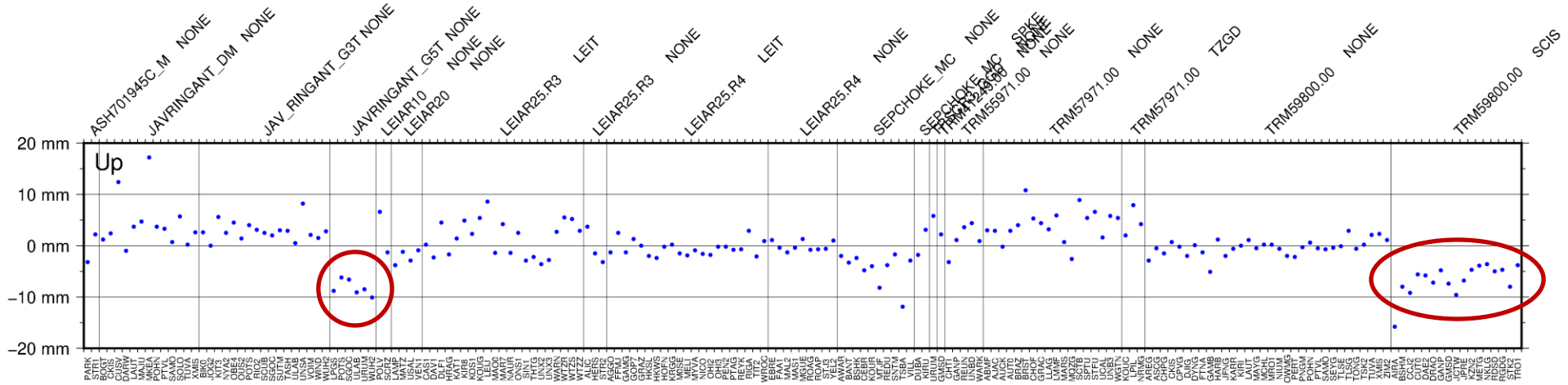
Re-estimation of GPS satellite z-PCOs

- **Can we accurately re-estimate GPS satellite z-PCOs based on Galileo satellite z-PCOs?**

- **It all depends on whether there is no GPS/Galileo scale difference due to anything else but satellite z-PCOs, like:**
  - **Ground antenna calibration errors**
  - **Orbit modeling errors**
  - **…**

- **How can we know?**
  - **Direct verification impossible: scale differences due to either satellite z-PCO inconsistencies or other causes cannot be separated**
  - **Look for indirect clues**

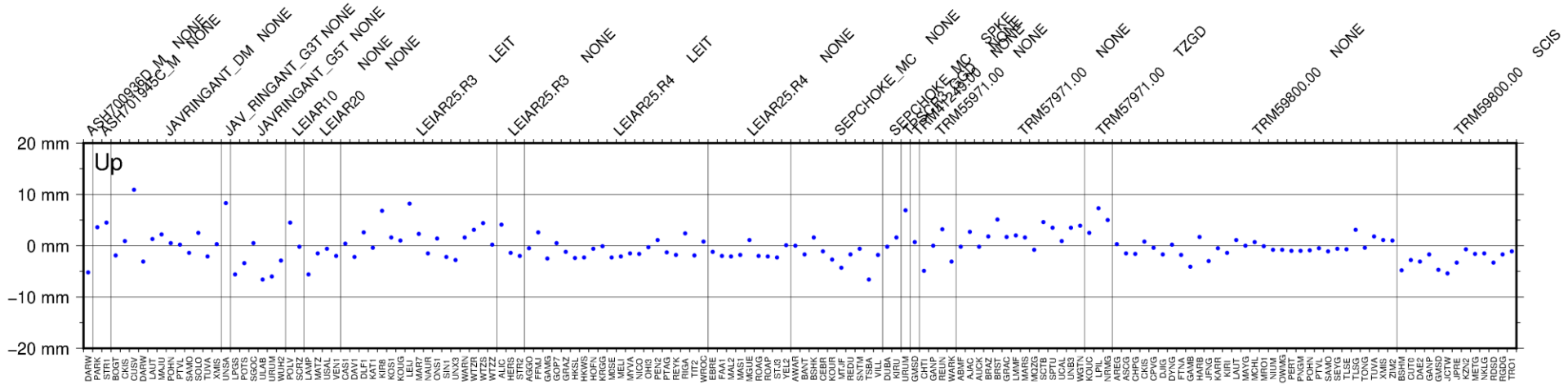
E5c vs. Gc: station height differences



NB: The E5c and Gc solutions were differenced after having brought them to a common origin, orientation and scale. Station position differences are thus shown up to an unknown global translation, rotation and scale factor.

- **Using chamber calibrations and E1+E5a, there are systematic biases between GPS- and Galileo-derived station heights.**
  - **This likely indicates frequency-dependent errors in the chamber calibrations of some antenna types.**
  - **This can be an issue for the re-estimation of GPS satellite z-PCOs: there's no reason that those station height biases average to zero.**
  - **This is also an issue for station positions themselves!**

E7c vs. Gc: station height differences

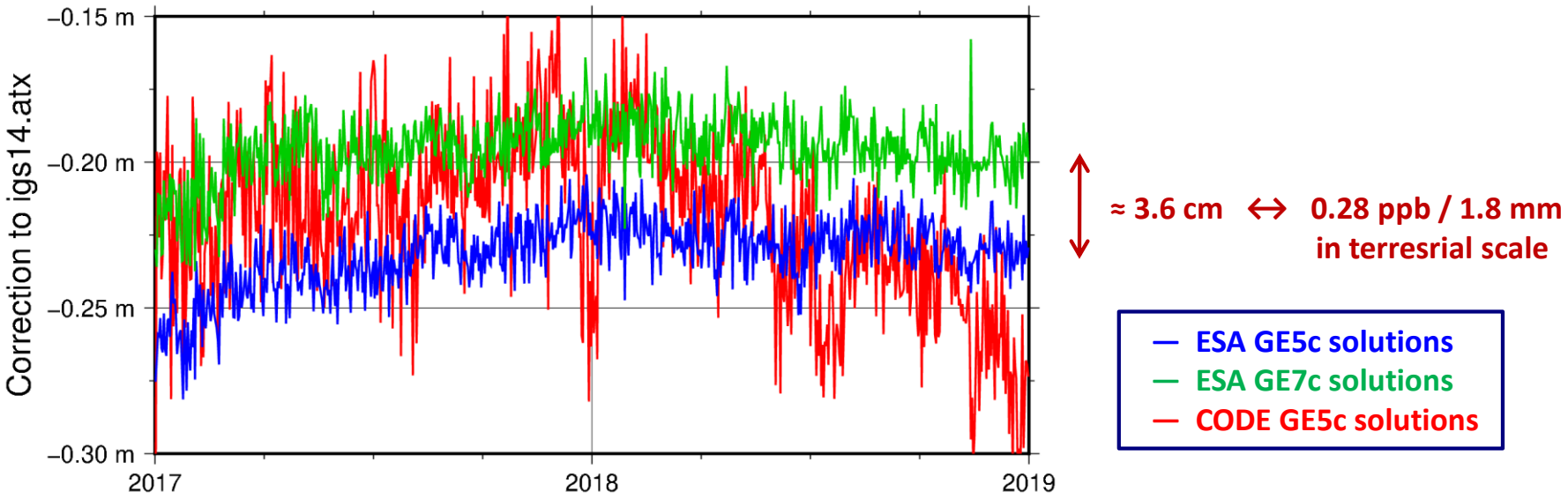


NB: The E7c and Gc solutions were differenced after having brought them to a common origin, orientation and scale. Station position differences are thus shown up to an unknown global translation, rotation and scale factor.

- **The situation seems a bit better when using chamber calibrations and E1+E5b.**
  - **Likely because E5b is closer to L2 than E5a.**
  - **Remaining systematic biases between GPS- and Galileo-derived station heights can however not be excluded.**

Re-estimation of GPS satellite z-PCOs: results

- **From ESA & CODE GPS+Galileo solutions:**
  - Fix Galileo satellite z-PCOs; solve for an average correction to igs14.atx GPS satellite z-PCOs



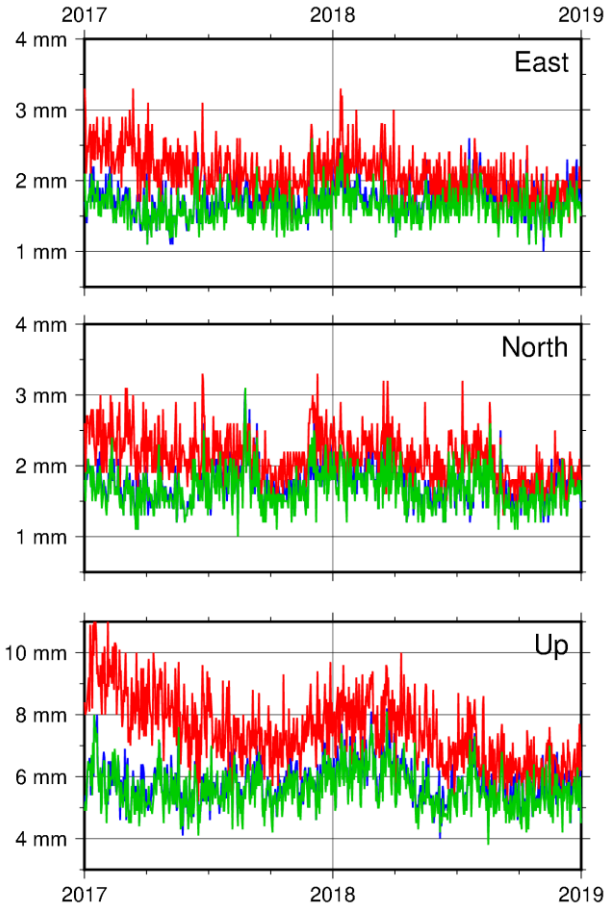
  - Part (all?) of the difference between ESA E1+E5a / E1+E5b results must come from ground antenna calibration issues (see previous slides).
  - Time variations (esp. in CODE results) need further investigation.

- **Can we accurately re-estimate GPS satellite z-PCOs?**
  - Not at better than several cm (↔ several mm in terrestrial scale), for now

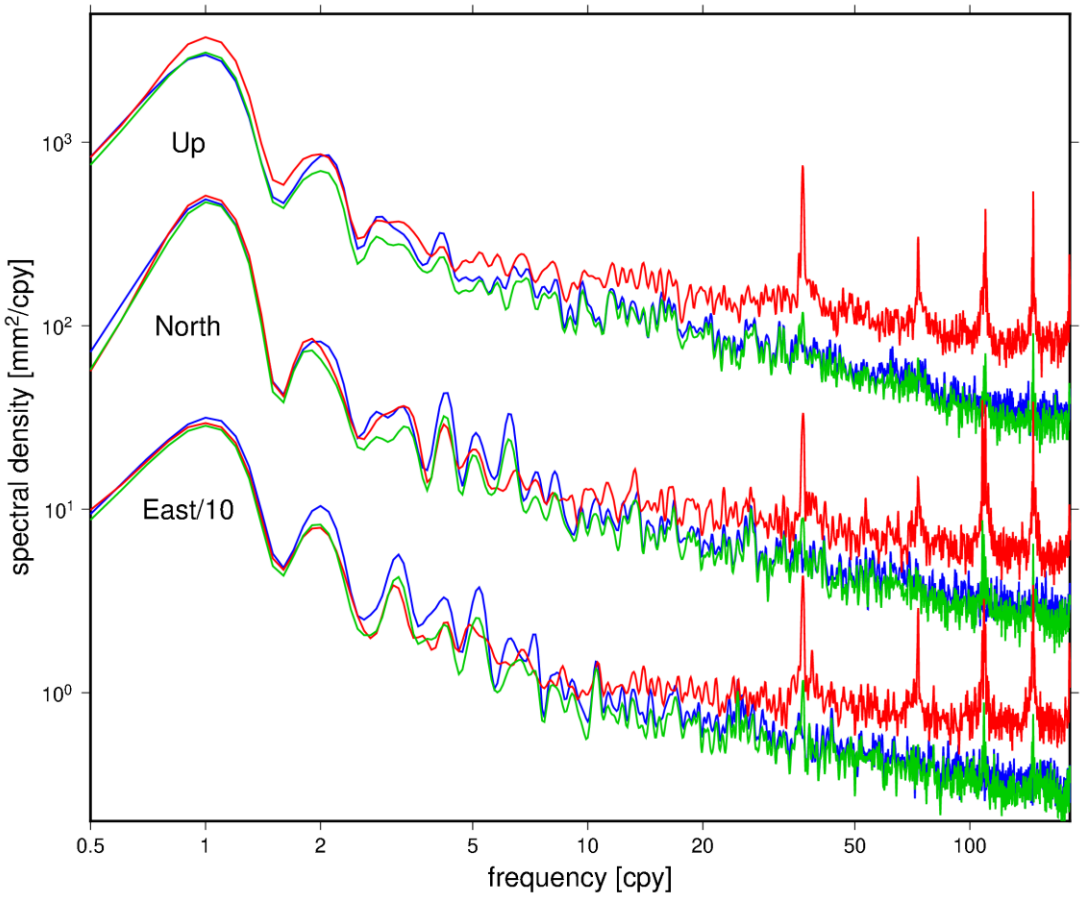
Part 3:

Impact of including Galileo on station positions

Gc / E5c / GE5c long-term stacking residuals



WRMS of the residuals from long-term stackings of the:
- **Gc solutions**
- **E5c solutions**
- **GE5c solutions**



Average Lomb-Scargle periodograms of the residuals from long-term stackings of the:
- **Gc solutions**
- **E5c solutions**
- **GE5c solutions**

NB: In the GE5c solutions, GPS satellite z-PCOs were fixed to igs14.atx values + previously derived average correction, so that consistent GPS & Galileo satellite z-PCOs were used.

Summary

- **Impact of switching from robot to chamber calibrations on GPS-only station positions:**
  - Large station+antenna-dependent position offsets, but small time variations
  - No problem for repro3/ITRF2020, except that a specific RF (IGc14) would have to be defined if chamber calibrations are adopted.
  - Still need to check impact on discontinuities due to antenna changes / local tie residuals

- **Impact of including Galileo on station positions:**
  - Background noise (and possibly GPS draconitics) slightly reduced
  - Periodic errors introduced at harmonics of Galileo ground repeat period
  - For some antenna types, systematic biases remain between GPS-derived and Galileo(E1+E5a)-derived station positions, even with chamber calibrations.

- **Can we reliably re-estimate GPS satellite z-PCOs based on Galileo satellite z-PCOs?**
  - Not at better than several cm (↔ several mm in terrestrial scale), for now