

Potential for a GNSS-based Determination of the Terrestrial Scale

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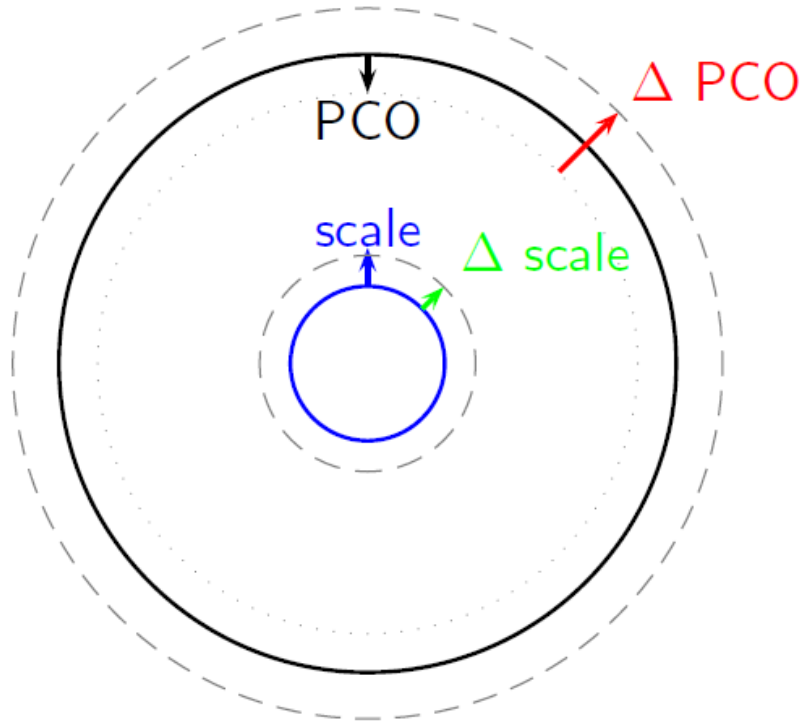
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Scale determination

Why do we need calibrated antennas?



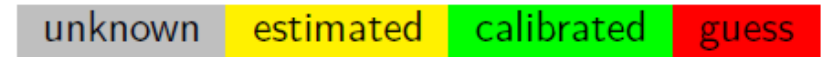
- PCO to Scale:
[Zhu et al. 2002]
 $1\text{m} \hat{=} -7.8 \text{ ppb}$
 $1 \text{ ppb} \hat{=} -0.13 \text{ m}$
- PCO's: $-4 \text{ m } \Delta \text{ PCO}$
- Stations: 20 cm offset

Current status of antenna calibrations

Overview IGS14

GNSS	Frq	Sat.	Rob.
GPS	L1	estimated	calibrated
	L2	estimated	calibrated
	L5	unknown	unknown
GLO	G1	estimated	calibrated
	G2	estimated	calibrated
	G3	unknown	unknown
GAL	E1	calibrated	guess
	E5a	calibrated	guess
	E5b	calibrated	guess
	E5	calibrated	unknown
	E6	calibrated	unknown

GNSS	Frq	Sat.	Rob.
BDS	B1	unknown	guess
	B2	unknown	guess
	B3	unknown	unknown
QZSS	L1	calibrated	calibrated
	L2	calibrated	calibrated
	L5	calibrated	unknown



Rob. : roboter calibrations

Current status of antenna calibrations

Overview chamber calibrations

GNSS	Frq	Sat.	Rob.	Cha.
GPS	L1	estimated	calibrated	Used for this study
	L2	estimated	calibrated	
	L5	unknown	unknown	
GLO	G1	estimated	calibrated	Used for this study
	G2	estimated	calibrated	
	G3	unknown	unknown	
GAL	E1	calibrated	L1	Used for this study
	E5a	calibrated	L2	
	E5b	calibrated	unknown	
	E5	calibrated	unknown	
	E6	calibrated	unknown	

GNSS	Frq	Sat.	Rob.	Cha.
BDS	B1	approx.	L1	Used for this study
	B2		L2	
	B3		unknown	
QZSS	L1	calibrated	unknown	Used for this study
	L2		unknown	
	L5		unknown	

unknown estimated calibrated approx.

Rob. : roboter receiver antenna calibrations
 Cha. : chamber receiver antenna calibrations

Reprocessing 3: will include multi-GNSS calibrations from roboter calibrations

- In June 2019 GSA released the chamber calibrated PV and PCO for the last 8 Galileo FOC satellites
 - **full constellation with calibrated PV and PCOs available!**
- Galileo shall be included into IGS reprocessing effort for the next ITRF solution:
 - What about the receiver antenna calibrations?
 - Are the estimated PCO for GPS and GLONASS compatible with the Galileo PCOs?
 - If not, how can we address this issue?
 - **Can we use Galileo to define a GNSS scale?**

Dedicated test campaigns

Overview

- For the IGS AC Workshop 2019 dedicated test solutions were created to address those issues
- Based on:
 - **Chamber calibrated receiver antennas**
 - The final reprocessing will be based mainly on robot calibration provided by Geo++ and extended by chamber calibrations (they were not available at the time of the test solution)
- **Test solutions:**
 - **COD: 2017 / 2018 (GE, G, E)**
 - **ESA: 2017 / 2018 (GE, G, E)**

Chamber calibrated receiver antennas

TRF scale contribution from GNSS?

- Creation of type-mean antenna pattern from chamber calibrations (more than 250 individual calibrations) → 37 type-mean calibrations (covering ~49% of the IGS network)
- Differences between robot and chamber calibrations?
- Comparison of satellite PCO and scale determination using robot or chamber calibrated ground antennas

Case study:

- Study on the scale determination using data from 2017-2018
- GPS/Galileo solution (COD / ESA)

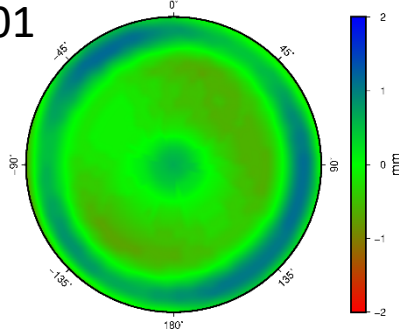
Chamber vs. robot calibrations

Comparison: GPS PV: BONN – Geo++

CHAMBER – ROBOT: LEIAR25.R4

LEIT G01

G01

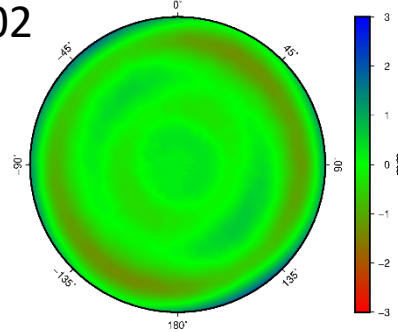


2mm

CHAMBER – ROBOT: LEIAR25.R4

LEIT G02

G02

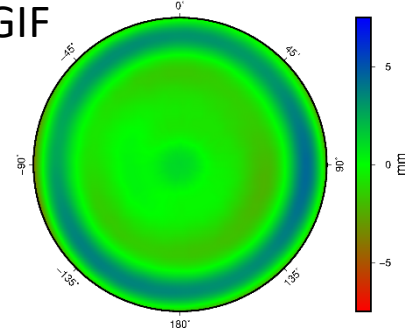


3mm

CHAMBER – ROBOT: LEIAR25.R4

LEIT GIF

GIF

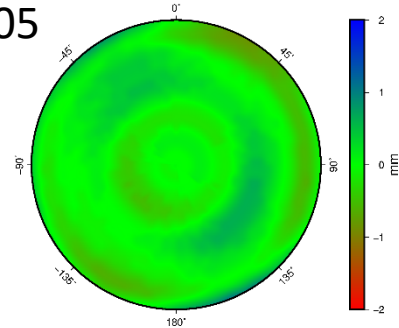


5mm

CHAMBER – ROBOT: LEIAR25.R4

LEIT G05

G05

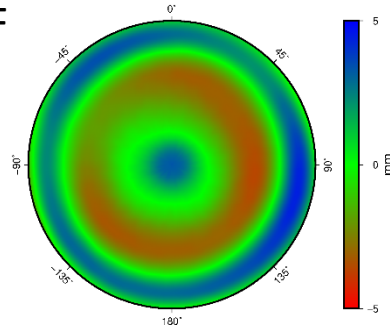


2mm

CHAMBER – ROBOT: LEIAR25.R4

LEIT EIF

EIF



5mm

PCO IF	IGS14	Geo++	BONN
GPS	150.96	150.07	150.77
GAL	152.05	146.47	148.31

Comparison receiver antenna PCOs

IF Galileo - GPS (PCO up [mm])

		ETH Zürich ¹	IGS14 (L1/L2)	BONN
JAV_GRANT-G37	NONE	6.7	-1.3	
JAV_RINGANT_G3T	NONE	-10.6	+1.2	-7.6
SEPCHOKE_B3E6	SPKE	-8.0	+4.7	
TRM57971.00	NONE	-2.94	-1.7	-5.2
		Geo++	IGS14 (L1/L2)	BONN
LEIAR25.R4	LEIT	-3.6	1.09	-2.45

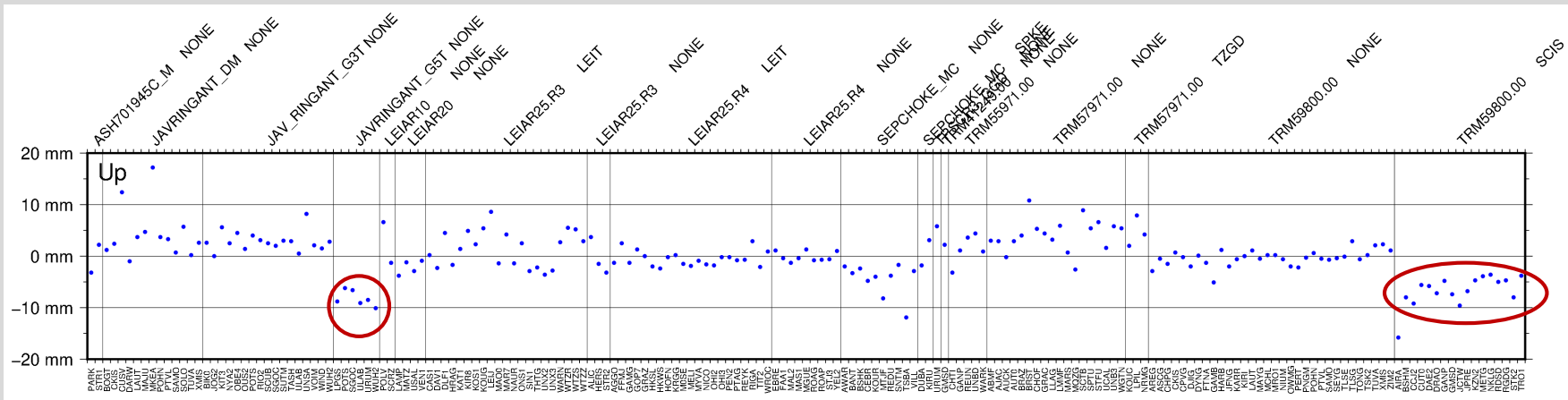
¹ [Willi et al. 2019, open access, <https://doi.org/10.3929/ethz-b-000332282>]

Consistency of antenna calibrations

Based on ESA solutions

Systematic errors between GPS and Galileo (E1/E5a) only solutions:

- Systematic differences for some receivers
- Robot calibrations have to be tested and, if needed, to be adjusted!



NB: The solutions were differenced after having brought them to a common origin, orientation and scale.

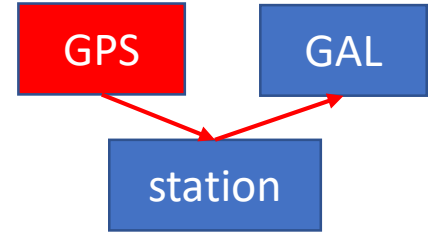
Station position differences are thus shown up to an unknown global translation, rotation and scale factor.

Scale study CODE (2017-2018)

PCO (system-wise, Z-component)

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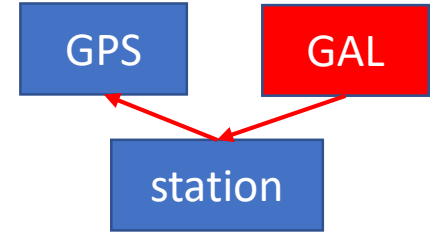
	Robot calibrations [cm]		Chamber calibrations [cm]	
	GPS	Galileo	GPS	Galileo
GPS PCO fixed	-	-0.2 ± 1.8	-	+24.7 ± 1.3

Scale study (2017-2018)

PCO (system-wise, Z-component)

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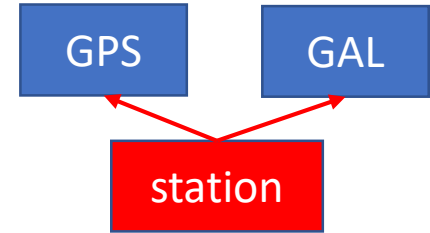
	Robot Calibration [cm]		Chamber Calibration [cm]	
	GPS	Galileo	GPS	Galileo
GPS PDO fixed	-	-0.2 ± 1.8	-	$+24.7 \pm 1.3$
Gal PCO fixed	-0.6 ± 2.5	-	-22.0 ± 2.1	-

Scale study (2017-2018)

PCO (system-wise, Z-component)

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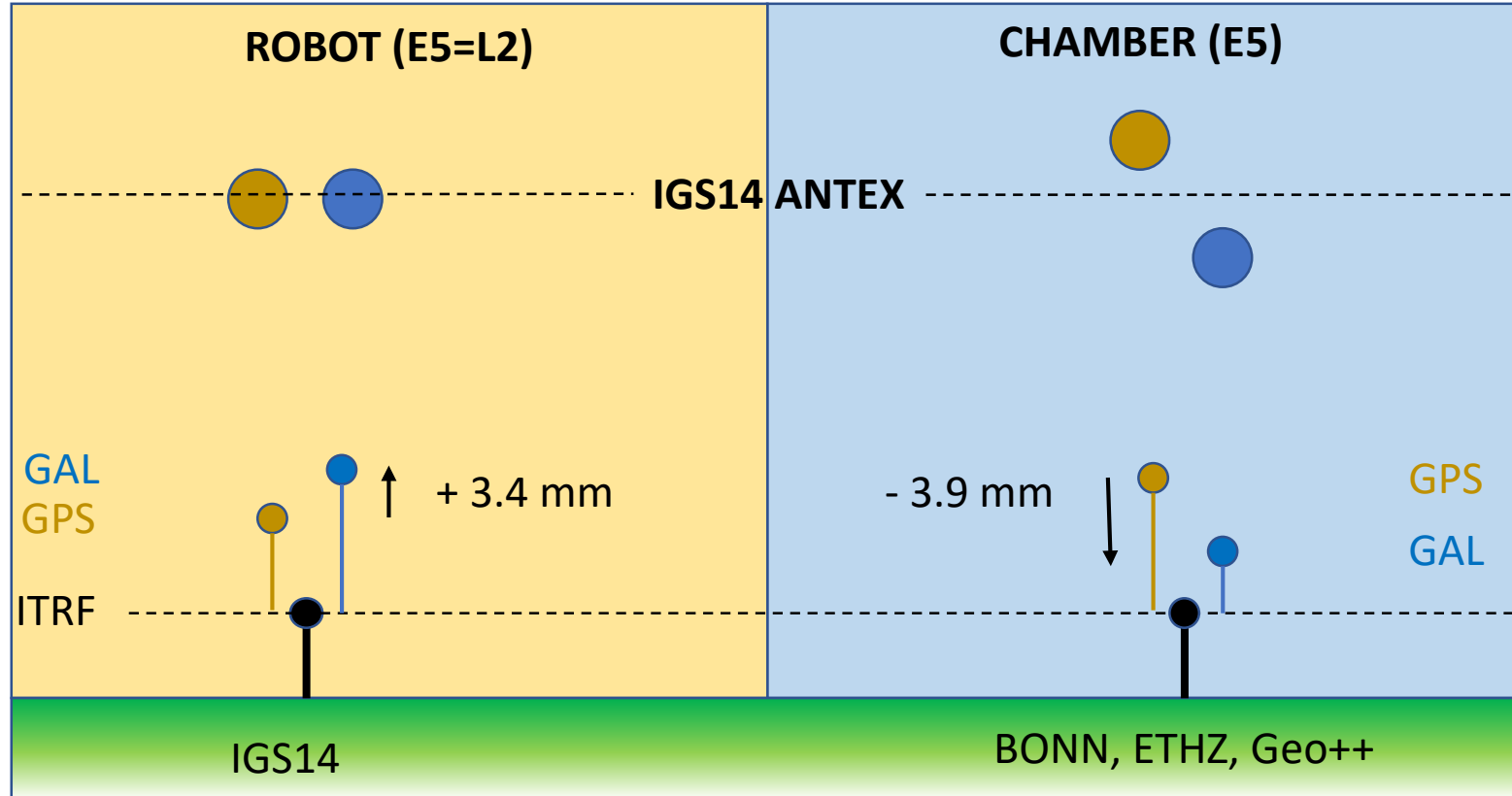
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	Robot Calibration [cm]		Chamber Calibration [cm]	
	GPS	Galileo	GPS	Galileo
GPS PCO fixed	-	-0.2 ± 1.8	-	$+24.7 \pm 1.3$
Gal PCO fixed	-0.6 ± 2.5	-	-22.0 ± 2.1	-
ITRF 2014 fixed	$+1.4 \pm 3.6$	$+1.9 \pm 4.7$	-10.9 ± 3.4	$+12.7 \pm 4.6$

Scale study (2017-2018)

Impact of IF-PCO values



Scale study (2017-2018)

Scale w.r.t ITRF 2014 – GAL/GPS fixed

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Solution	IGS14 ANTEX	Chamber
GPS PCO fixed	2.58 mm	-3.00 mm
GALILEO PCO fixed	2.09 mm	7.27 mm
Difference GAL-GPS	+0.49 mm	+10.27 mm
	VLBI	SLR
ITRF 2014 ¹	+4.4 mm	-4.4 mm

1 ppb \cong 6.4 mm

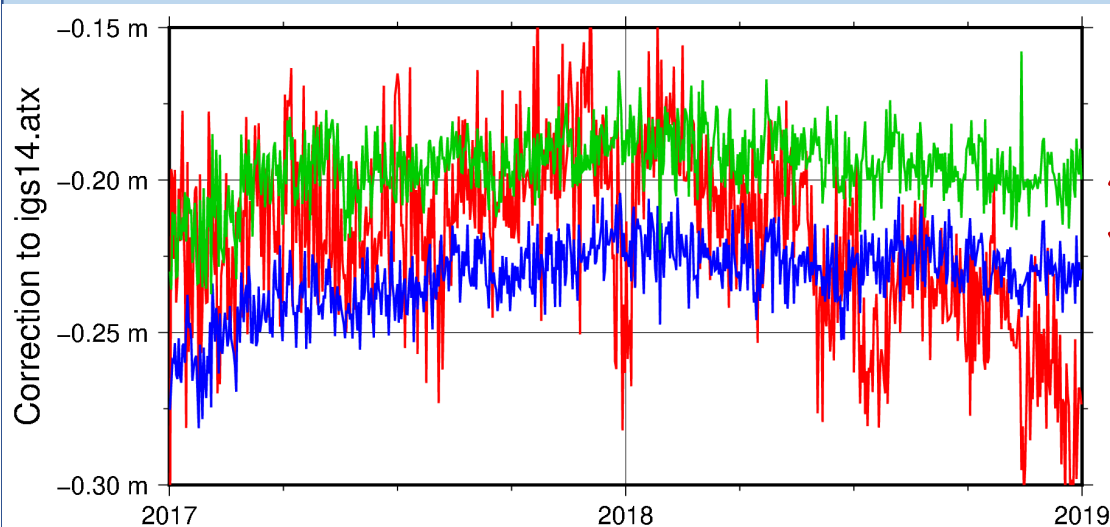
→ Chamber calibrations: scale of +4.7 mm (+7.3 with a priori value 0)

¹ [Altamimi et al. 2016, J. Geophys. Res.]

SINEX combination

ESA / COD (2017 & 2018)

Fix Galileo satellite z-PCOs; solve for an average correction to igs14.atx GPS satellite z-PCOs



$\approx 3.6 \text{ cm} \leftrightarrow 0.28 \text{ ppb} / 1.8 \text{ mm}$
in terrestrial scale

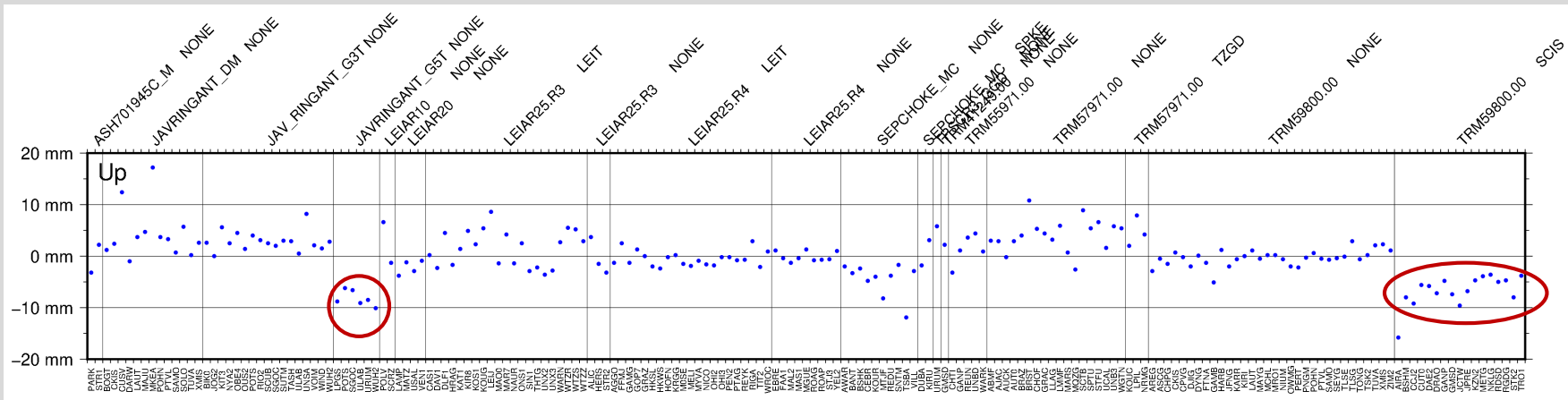
— ESA GE5c solutions
— ESA GE7c solutions
— CODE GE5c solutions

Consistency of antenna calibrations

Based on ESA solution

Systematic errors between GPS and Galileo (E1/E5a) only solutions:

- Systematic differences for some receivers
- Robot calibrations have to be tested and, if needed, to be adjusted!



NB: The 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.

Calibrations:

- Reprocessing will be based mainly on robot calibrations
- Including E1/E5 calibrations
- Chamber calibrations for Galileo

Satellite PCO

- GPS/GLO PCO (z-component) rescaled to Galileo
- Based on SINEX combination from various AC contributions

Receiver PCO

- Comparison of GPS and Galileo only solutions
- Adjustment of PCO (z-component) if needed for Galileo