GNSS scale determination using chamber calibrated ground and space antenna pattern

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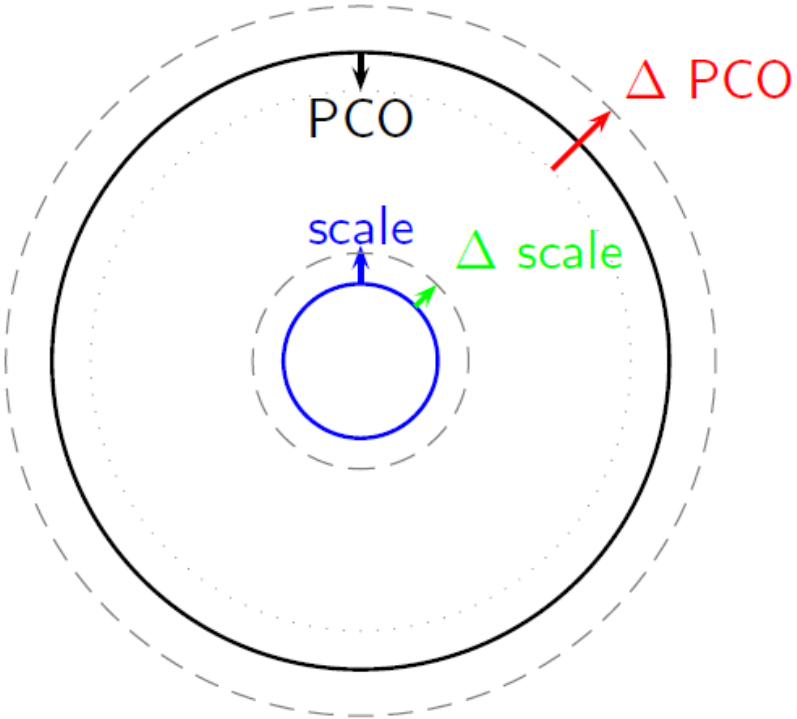
Relation PCO and scale determination

Why do we need calibrated antennas?



- PCO to Scale:
  [Zhu et al. 2002]
  1m ≙ -7.8 ppb
  1 ppb ≙ -0.13 m
- PCO's: -4 m Δ PCO
- Stations: 20 cm offset

Current status of antenna calibrations

Overview

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

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

unknown	estimated	calibrated	guess

Rob. : roboter calibrations

Current status of antenna calibrations

Overview

- IGS14.ATX:
  - GPS: Estimated PCO / Nadir dependent PV
  - Galileo and QZSS pre-launch satellite calibrated antenna pattern
  - Receiver antennas:
    - Mostly robot calibrations provided by Geo++
    - L1/L2 for GPS and GLONASS (missing E5 for Galileo)
- Chamber calibrations
  - Calibrations for all frequencies available
  - Compatibility with robot calibrations?
  - **GNSS based scale determination possible?**

Chamber calibrated receiver antennas

TRF scale contribution from GNSS?

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- 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
- Based on >90 stations (using robot or chamber calibrated antennas only)

Chamber vs. robot calibrations

Comparison: IF GPS PCO

Antenna	Radome	# Chm	#Rob	North	East	Up
ASH700936C_M	NONE	5	7	-1.02	-0.04	-3.19
JAVRINGANT_DM	NONE	6	9	0.62	-1.14	1.31
LEIAR10	NONE	5	24	-1.14	0.69	0.21
LEIAR20	LEIM	34	82	-1.15	-0.87	-6.1
LEIAR25.R3	LEIT	13	28	0.07	-0.18	-1.56
LEIAR25.R4	LEIT	47	35	0.53	0.14	-1.03
LEIAR25.R4	NONE	7	18	0.15	-0.44	**4.11**
TRM55971.00	TZGD	5	8	-0.47	-0.63	2.6
TRM57971.00	N[illegible]	5	13	-2.74	2.06	0.28
TRM57971.00	[illegible]GD	53	6	-0.66	0.28	0.63
TRM59800.0[illegible]	NONE	10	28	-1.77	-0.49	-2.52
TRM59800.00	SCIS	8	40	-0.01	-0.93	-4.15
TRM59900.00	NONE	7	5	0.3	-0.31	**-6.27**
TRM59900.00	SCIS	38	5	0.11	-0.38	2.51

COORDINATES

IGS14
L1/L2

Chamber:
L1/L2

→ ~ -1mm

[mm]

Chamber vs. robot calibrations

Comparison: IF Galileo PCO

Antenna	Radome	# Chm	#Rob	North	East	Up
ASH700936C_M	NONE	5	7	-0.56	0.57	-6.42
JAVRINGANT_DM	NONE	6	9	0.21	-1.57	-3.26
LEIAR10	NONE	5	24	-1.33	0.58	-2.51
LEIAR20	LEIM	34	82	-0.72	-1.17	**-14.76**
LEIAR25.R3	LEIT	13	28	0.01	-0.36	-3.61
LEIAR25.R4	LEIT	47	35	0.36	-0.2	-3.82
LEIAR25.R4	NONE	7	18	-0.04	-0.63	-0.27
TRM55971.00	TZGD	5	8	-0.66	0.36	-2.87
TRM57971.00	NONE	5	13	-2.98	3.17	-4.94
TRM57971.00	TZGD	53	6	-1.08	1.51	-3.44
TRM59800.00	NONE	10	28	-1.83	-0.69	-4.46
TRM59800.00	SCIS	8	40	0	-0.83	-7.32
TRM59900.00	NONE	7	5	0.1	0.69	-9.31
TRM59900.00	SCIS	38	5	-0.21	0.62	**0.79**

IGS14:
L1/L2

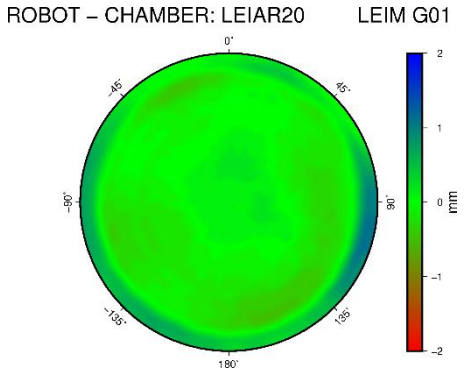
Chamber:
E1/E5

→ ~ -5mm

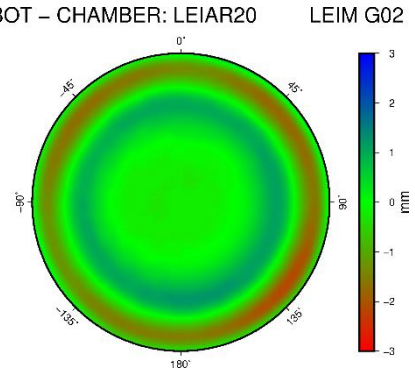
[mm]

Chamber vs. IGS 14 calibrations

Comparison: GPS PV: Robot – IGS14



2mm



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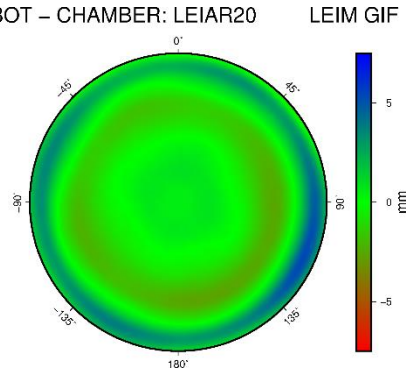
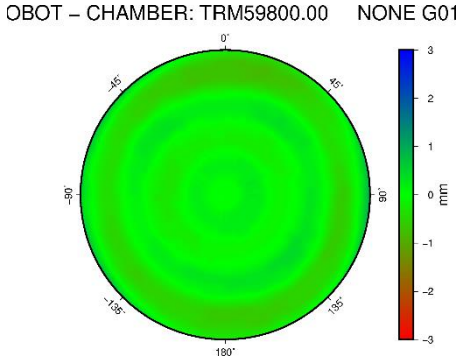
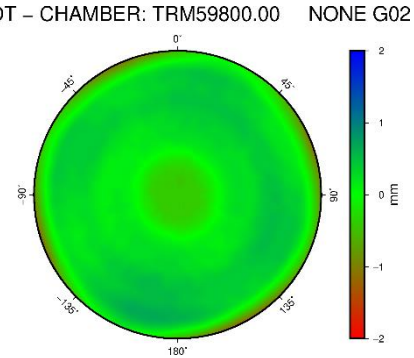


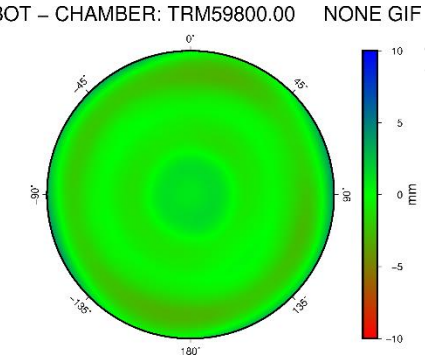
5mm



3mm



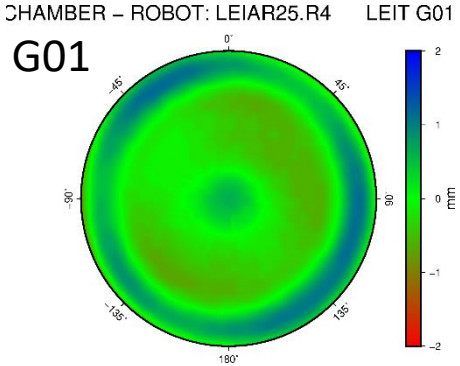
2mm

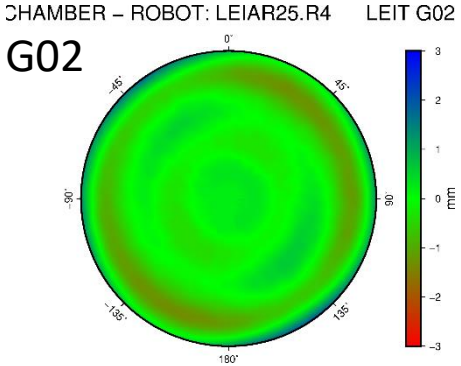


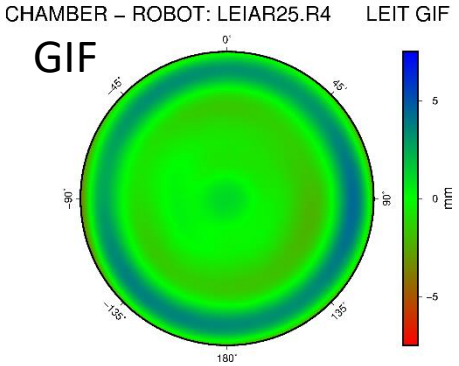
10mm

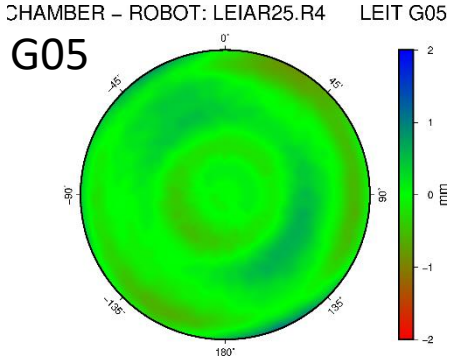
Chamber vs. robot calibrations

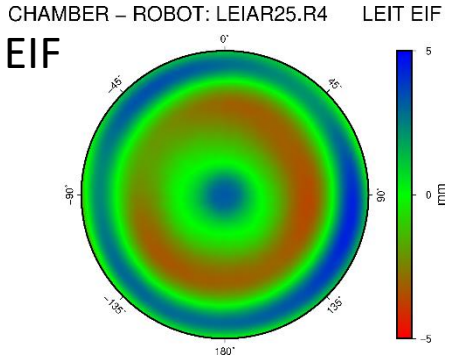
Comparison: GPS PV: BONN – Geo++











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

Local network solution

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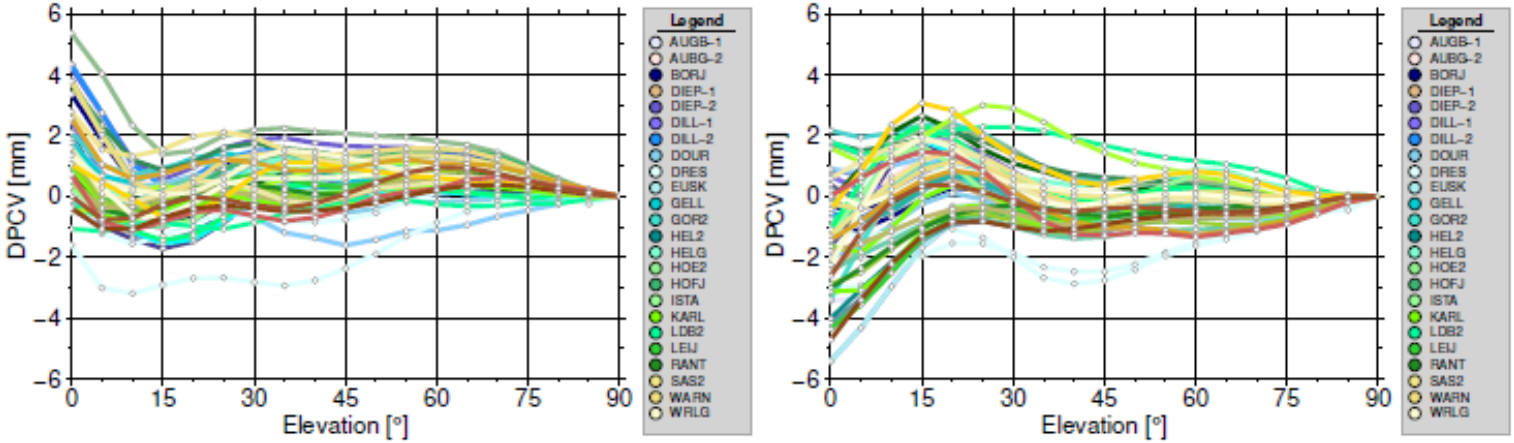
Small test provided bei Tobias Kersten,

Leibniz University Hannover, Institut für Erdmessung (IfU)

- Network solution (star-baseline), 17 stations
- LEIAR25, Rev. 3&4, w/o radome LEIT
- Pure chamber / Robot calibration solutions show consistent results
- Mixed solution shows differences (70% robot, 30% chamber)

Differences Geo++ / chamber

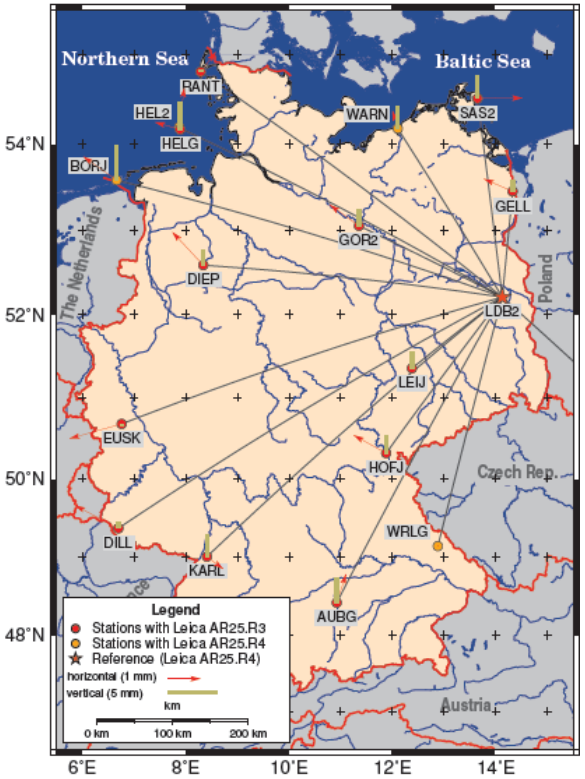


(a) (b)

Abbildung 1: Variationen zwischen Kalibrierergebnissen für Antennen aus verschiedenen Kalibriermethoden (Referenz Roboter, Abweichungen zu Kammer), gelistet für die Frequenzen GPS/GLONASS L1 (a) und GPS/GLONASS L2 (b).

[Kersten, 2019]

Mixed network test

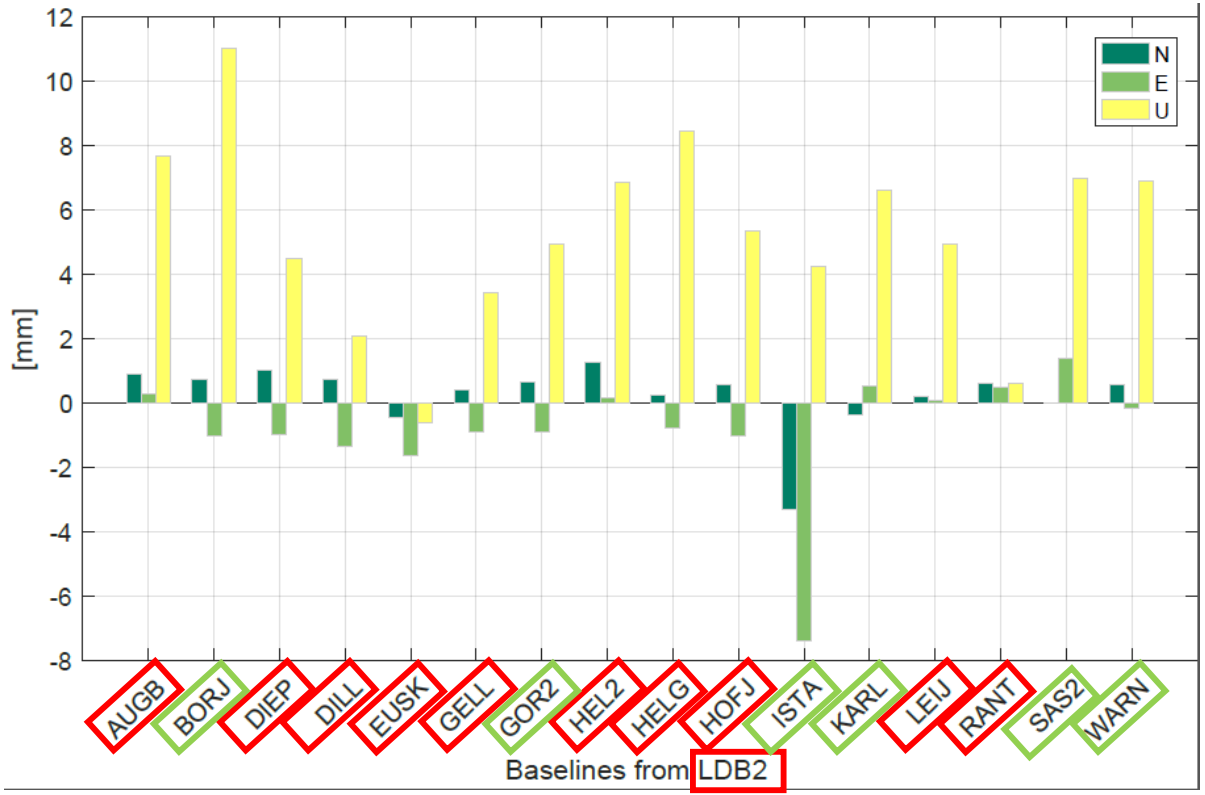


[Kersten 2019]

Mixed network solution

Baseline solution (star, LDB2, robot)

Robot
Chamber



[Kersten, 2019]

GPS/Galileo scale analyzes

Processing strategy

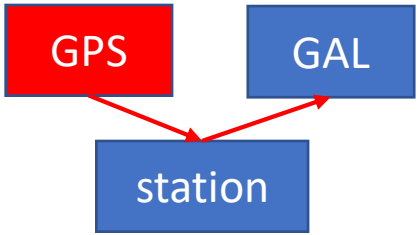
Based on CODE MGEX Solution:

- GPS/Galileo only
- Double difference solution
- Only stations with chamber calibrated pattern used
- Identical station selection for IGS14 and chamber calibrated antenna pattern used
- Estimation of (not complete):
  - Orbit, **satellite PCO**
  - ERP, TRP
  - Station coordinates → **scale**
  - Inter-system translation biases

Network (January 1., 2017)

Scale study (2017-2018)

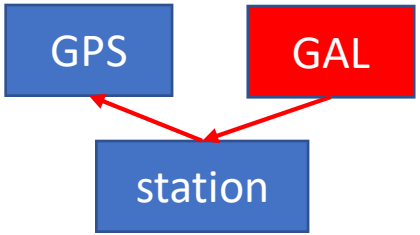
PCO (system-wise, Z-component)



	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)

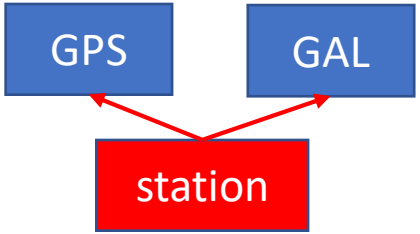
PCO (system-wise, Z-component)



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

Scale study (2017-2018)

PCO (system-wise, Z-component)



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

PCO (Z-component) system-wise estimated

ITRF 2014 scale fixed

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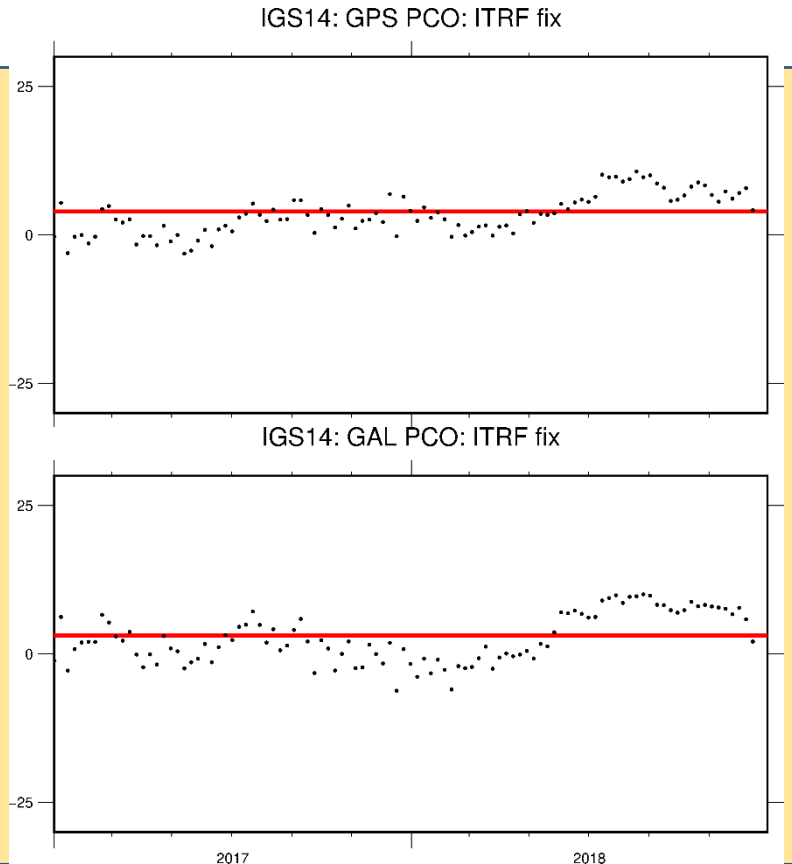
IGS14 ANTEX

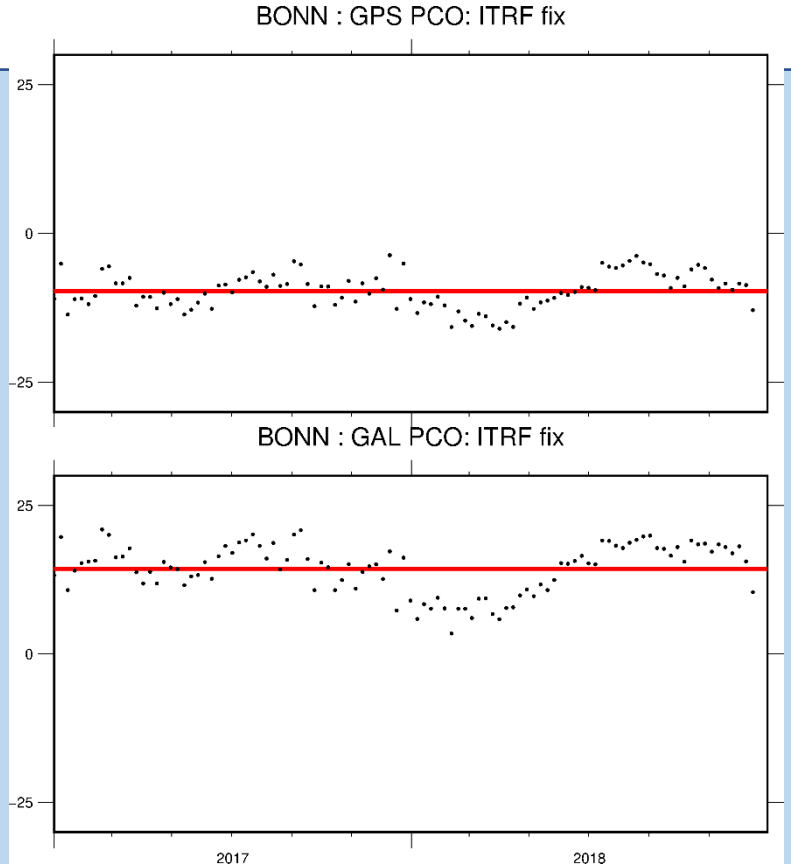


25 cm

-25 cm

25 cm

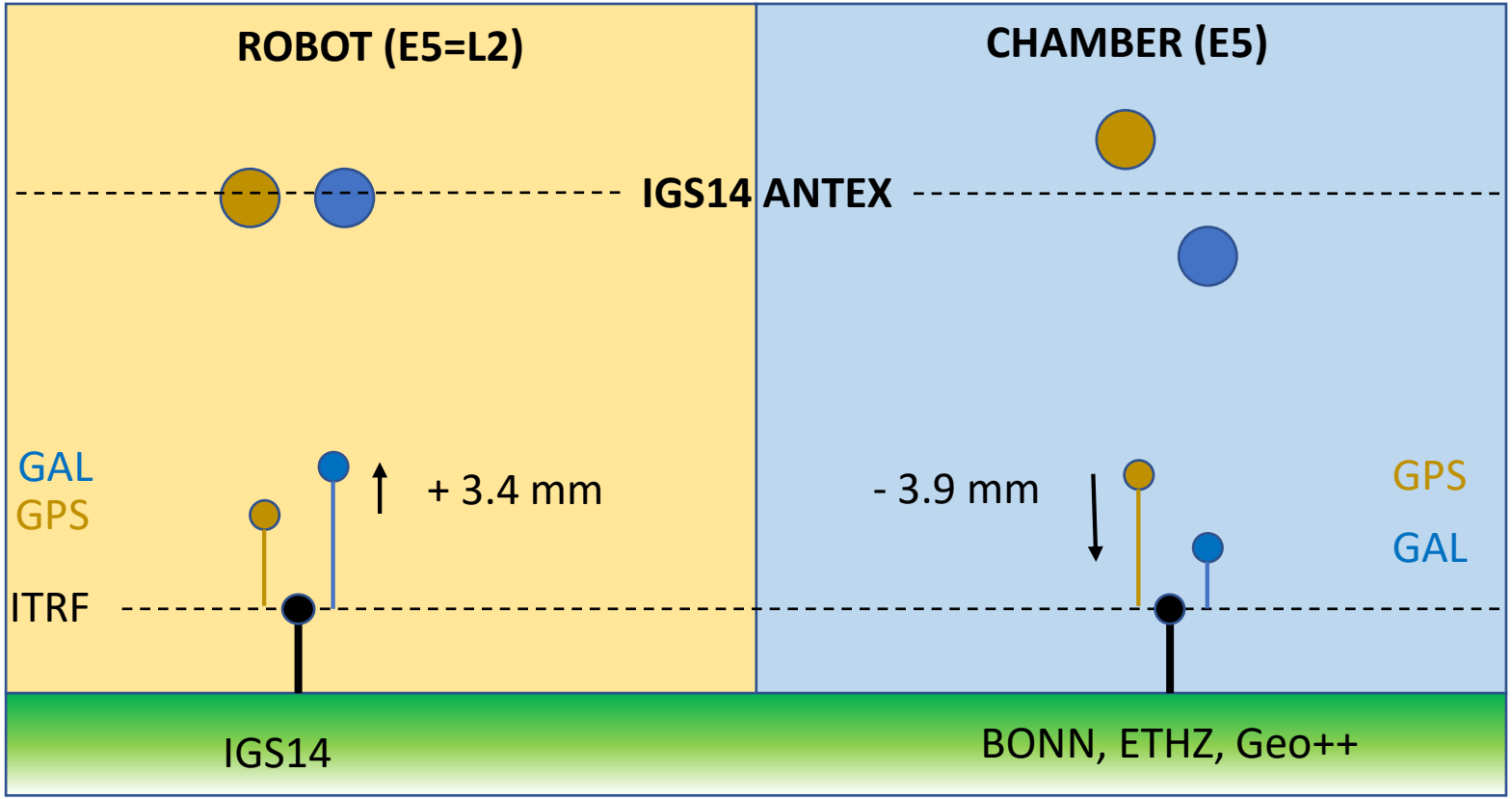
-25 cm



Chamber

Scale study (2017-2018)

Impact of IF-PCO values



Comparison receiver antenna PCOs

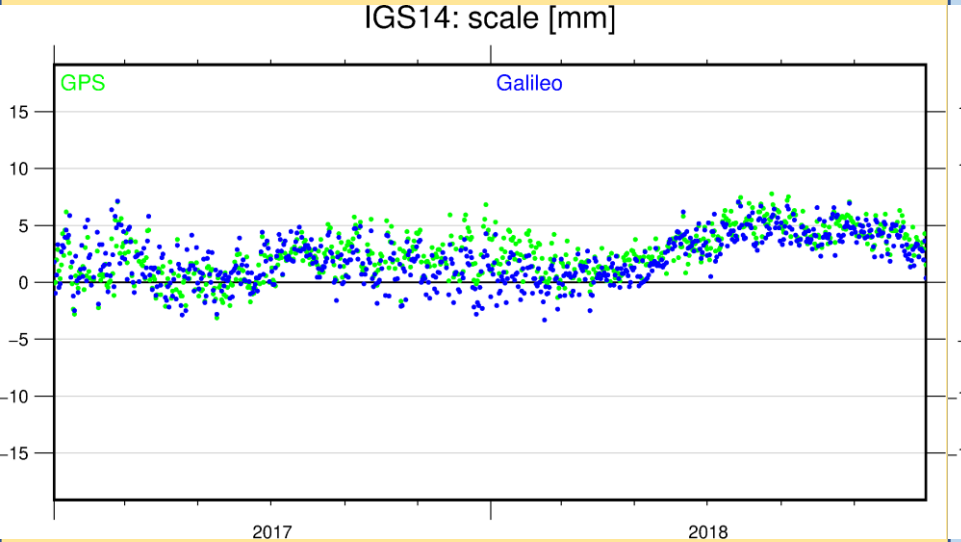
IF Galileo - GPS (PCO up [mm])

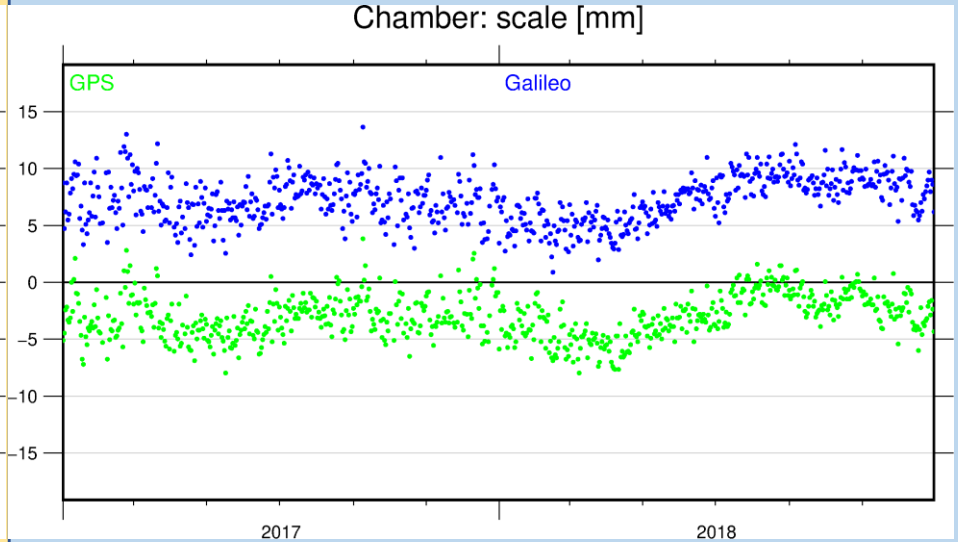
		ETH Zürich[1]	IGS14 (L1/L2)	BONN
JAV_GRANT-G37	NONE	6.7	-1.3	
JAV_RINGANT_G3T	NONE	-10.6	+1.2	-7.6
SEPCHOKE_B3E6	SPKE	-8.0	+4.7	
TRM57971.00	NONE	-2.94	-1.7	-5.2
		Geo++	**IGS14 (L1/L2)**	**BONN**
LEIAR25.R4	LEIT	-3.6	1.09	-2.45

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

Scale study (2017-2018)

Scale: solution = scale x ITRF2014





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 $\cong 6.4\ mm$

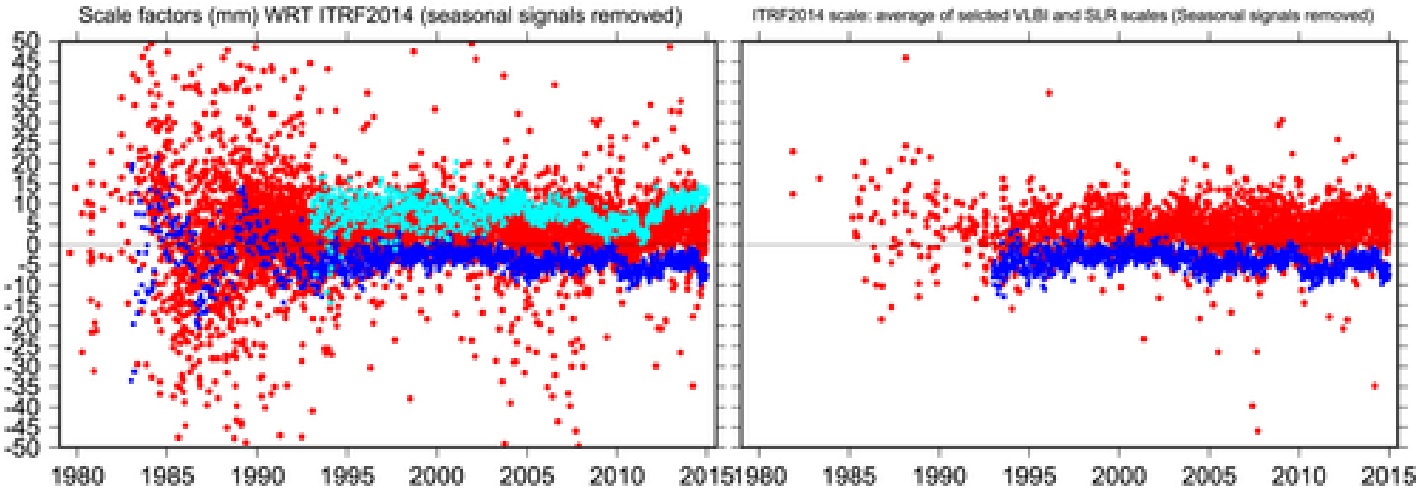
→ **Chamber calibrations: scale of +4.7 mm (+7.3 with a priori value 0)**

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

Scale study (2017-2018)

ITRF Scale (GPS / GAL PCO)

ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions



Journal of Geophysical Research: Solid Earth, Volume: 121, Issue: 8, Pages: 6109-6131, First published: 18 July 2016, DOI: (10.1002/2016JB013098)

Scale study (2017-2018)
Conclusion

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- Can we use Galileo for GNSS scale determination?
  - Yes, if ground antennas are calibrated
  - Galileo scale between +4.7 and +7.3 mm w.r.t. ITRF2014 (VLBI +4.4 mm)

- Why do L1/L2 robot calibrations for Galileo fit better?
  - Coincidence? Presumably, once robot calibrations are available we will now …
  - Robot calibrations from ETH Zurich indicate so