Consistency of antenna products in the MGEX environment

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Motivation

IGS antenna patterns before the release of Galileo and QZSS calibrations:

- Type-mean robot calibrations for receiver antennas
- Estimated satellite antenna offsets

In 2016 and 2017 Galileo and QZSS satellite antenna calibrations were disclosed by the GSA and CAO

- What is the impact when using the calibrated patterns?
- Only GPS and GLONASS L1/L2 receiver antenna patterns available.
  Influence using GPS pattern for Galileo?
  Alternatives (chamber calibrations)?

Collection of chamber calibrations

- Mid 2018 the AWG started a call for chamber calibrations (IGSMAIL #7639, EUREFMAIL #9309)
  - Goal: creation of type mean receiver antenna calibrations including E05
  - Great response from various institutions:
    Vermessungsamt Mecklenburg-Vorpommern, Germany
    Vermessung und Geoinforamtion Schleswig-Holstein, Germany

BKG	ESA
EUREF (publicly available)	GFZ
IGE	University of Bonn

  - Total of 267 antennas
- 37 antenna/radom types covered (with one or more individual calibrations)
- 49% of the IGS stations covered with the chamber calibrations

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- 49% of the IGS stations covered with the chamber calibrations

Global precise orbit determination possible!

Extracted antenna calibrations

AOADM.T	NONE	AOADM.T	SCIS	ASH700936A_M	NONE
ASH700936C	NONE	ASH700936C_M	NONE	ASH700936D_M	NONE
ASH701945B_M	NONE	ASH701945C_M	NONE	JAVRINGANT_DM	NONE
JAVRINGANT_G5T	NONE	JAV_RINGANT_G3T	NONE	JNSCR_C146-22-1	NONE
LEIAR10	NONE	LEIAR20	LEIM	LEIAR20	NONE
LEIAR25.R3	BEVA	LEIAR25.R3	LEIT	LEIAR25.R3	NONE
LEIAR25.R4	LEIT	LEIAR25.R4	NONE	LEIAR25R4	LEIT
LEIAS10	NONE	LEIAT502	NONE	LEIAX1202GG	NONE
NAX3G+C	NONE	SEPCHOKE_MC	NONE	SEPCHOKE_MC	SPKE
TPSCR.G5	NONE	TRM159900.00	SCIS	TRM55971.00	NONE
TRM55971.00	TZGD	TRM57971.00	NONE	TRM57971.00	TZGD
TRM59800.00	NONE	TRM59800.00	SCIS	TRM59900.00	NONE
TRM59900.00	SCIS				

IGS antenna pattern: before Galileo and QZSS disclosure

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	approx.

Rob. : roboter receiver antenna calibrations

IGS antenna pattern: after Galileo and QZSS disclosure

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 | approx.

Rob. : roboter receiver antenna calibrations

IGS antenna pattern: after Galileo and QZSS disclosure

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

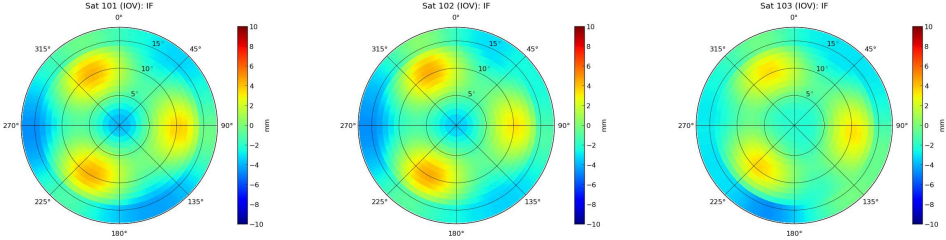
GNSS	Frq	Sat.	Rob.	Cha.
BDS	B1		L1	
	B2		L2	
	B3			
QZSS	L1			
	L2			
	L5			

unknown	estimated	calibrated	approx.

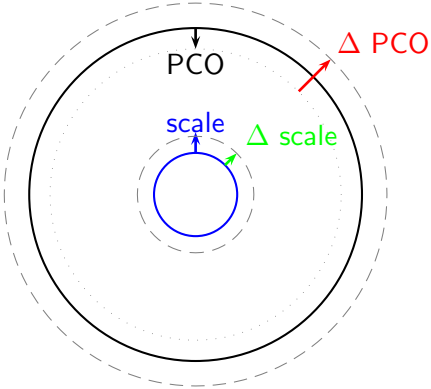
Rob. : roboter receiver antenna calibrations
Cha. : chamber receiver antenna calibrations

Galileo IOV/FOC Pattern

- Officially disclosed by GSA
  (IOV: December 2016, FOC: October 2017)
- GSA calibrations (PCO and PCV) for (all) active FOC/IOV satellites
- Difference between calibrated PCO's
  and estimated PCO's *[Steigenberger et al., 2016,J. Geod]*:
  - X: up to 1 cm
  - Y: up to 1 cm
  - Z: IOV: ca. 0 – 10 cm, FOC 17 – 34 cm

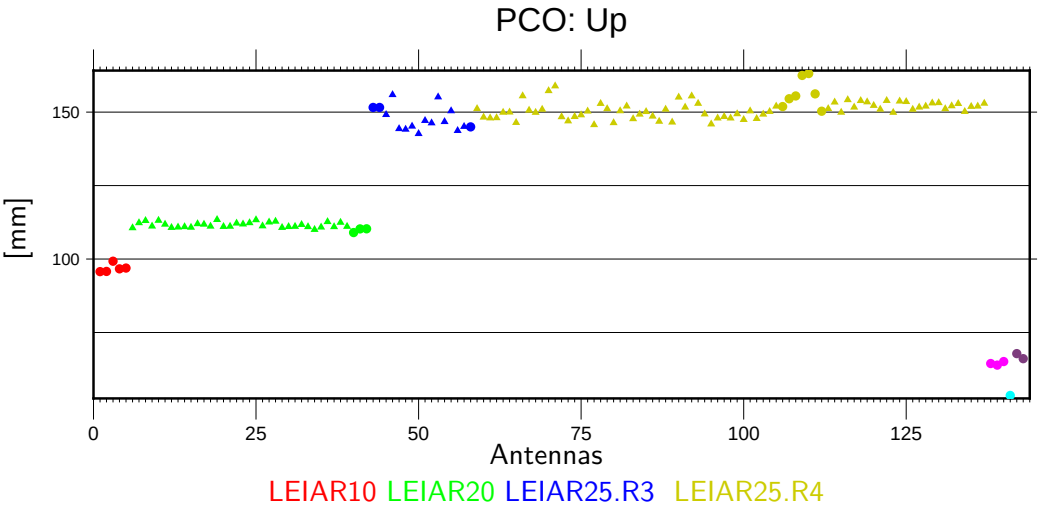


Relation between satellite PCO and scale

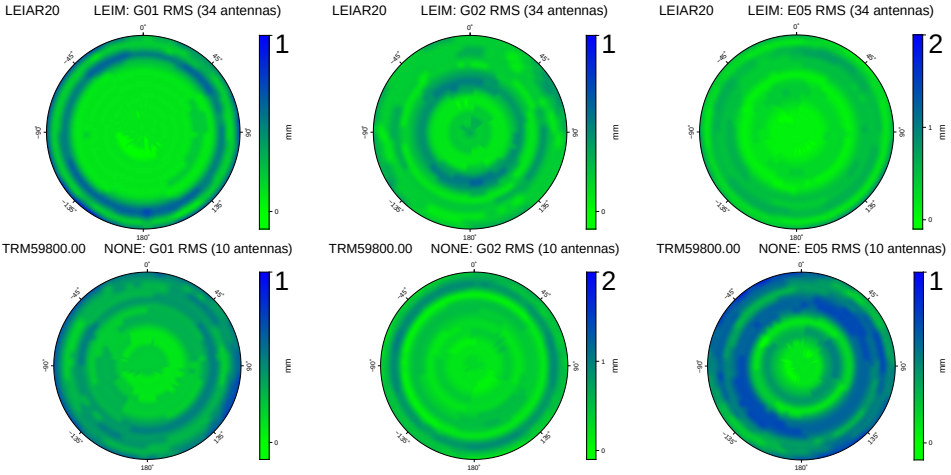


- PCO to Scale:
  [Zhu et al. 2002]
  1m $\hat{=}$ -7.8 ppb
  1 ppb $\hat{=}$ -0.13 m
- PCO's: -4 m Δ PCO
- Stations: 20 cm offset

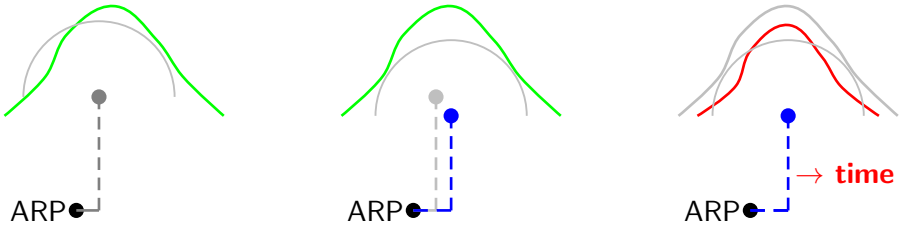
Creation of group mean values (IF)



RMS of chamber calibrations: PCV



Comparison chamber and robot calibration



Applied correction [mm]:

		chamber				robot			
Antenna		N	E	U	const	N	E	U	const
LEIAR20	LEIM	0.01	0.00	0.01	-0.01	-0.02	0.04	-5.24	2.47
TRM59800.00	NONE	0.03	0.00	0.00	-0.00	0.011	0.00	-11.07	4.90
JAVRINGANT_DM	NONE	0.03	0.00	-0.03	0.02	-0.04	0.05	-11.44	5.03

Comparison: PCO GPS (IF)

Antenna	Radom	# Chm.	# Rob.	North	East	Up	Org
ASH700936C_M	NONE	5	7	-1.02	-0.04	-3.19	14.16
JAVRINGANT_DM	NONE	6	9	0.62	-1.14	1.31	17.31
LEIAR10	NONE	5	24	-1.14	0.69	0.21	-1.61
LEIAR20	LEIM	34	82	-1.15	-0.87	-6.10	-2.43
LEIAR25.R3	LEIT	13	28	0.07	-0.18	-1.56	-20.18
LEIAR25.R4	LEIT	47	35	0.53	0.14	-1.03	-15.83
LEIAR25.R4	NONE	7	18	0.15	-0.44	4.11	-9.00
TRM55971.00	TZGD	5	8	-0.47	-0.63	2.60	6.04
TRM57971.00	NONE	5	13	-2.74	2.06	0.28	1.99
TRM57971.00	TZGD	53	6	-0.66	0.28	0.63	3.87
TRM59800.00	NONE	10	28	-1.77	-0.49	-2.52	13.62
TRM59800.00	SCIS	8	40	-0.01	-0.93	-4.15	15.92
TRM59900.00	NONE	7	5	0.30	-0.31	-6.27	2.88
TRM59900.00	SCIS	38	5	0.11	-0.38	2.51	14.66

Robot: L1/L2 Chamber: L1/L2

Comparison: PCO GPS (IF)

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ASH700936C_M	NONE	5	7	-1.02	-0.04	-3.19	14.16
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LEIAR20	LEIM	34	82	-1.15	-0.87	-6.10	-2.43
LEIAR25.R3	LEIT	13	28	0.07	0.38	1.56	-20.18
LEIAR25.R4	LEIT	47	35	0.5[illegible]	1.14	-1.03	-15.83
LEIAR25.R4	NONE	7	18	0.15	-0.44	4.11	-9.00
TRM55971.00	TZGD	5	8	-0.47	-0.63	2.60	6.04
TRM57971.00	NONE	5	13	-2.74	2.06	0.28	1.99
TRM57971.00	TZGD	3	6	-0.66	0.28	0.63	3.87
TRM59800.00	NONE	10	28	-1.77	-0.49	-2.52	13.62
TRM59800.00	SCIS	8	40	-0.01	-0.93	-4.15	15.92
TRM59900.00	NONE	7	5	0.30	-0.31	-6.27	2.88
TRM59900.00	SCIS	38	5	0.11	-0.38	2.51	14.66

Robot: L1/L2 Chamber: L1/L2

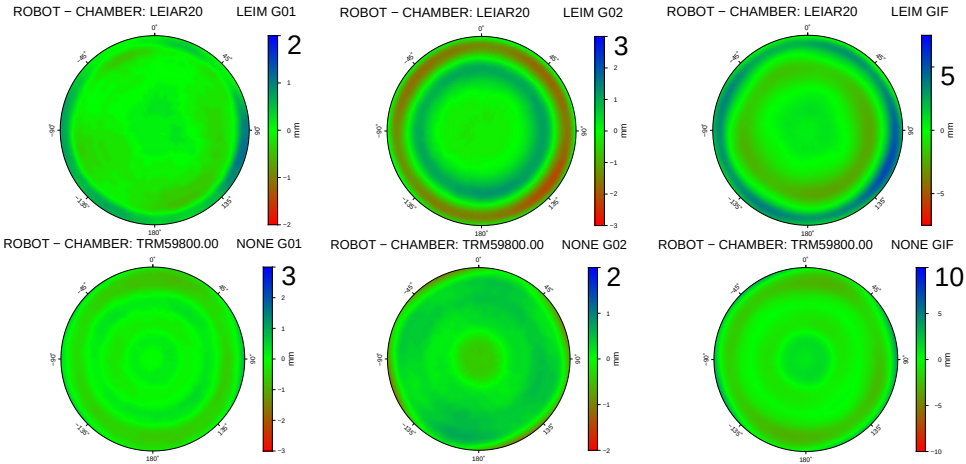
coordinates

Comparison: PCO Galileo (IF)

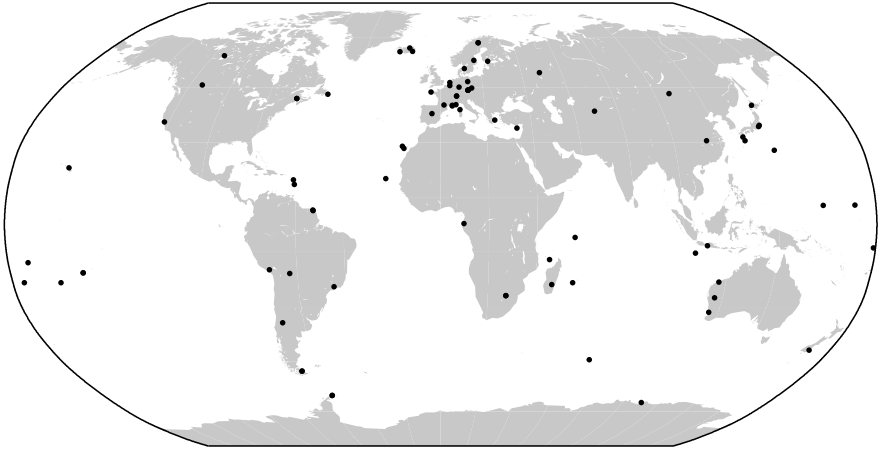
Antenna	Radom	# Chm.	# Rob.	North	East	Up	Diff
ASH700936C_M	NONE	5	7	-0.56	0.57	-6.42	-3.23
JAVRINGANT_DM	NONE	6	9	0.21	-1.57	-3.26	-4.57
LEIAR10	NONE	5	24	-1.33	0.58	-2.51	-2.72
LEIAR20	LEIM	34	82	-0.72	-1.17	-14.76	-8.66
LEIAR25.R3	LEIT	13	28	0.01	-0.36	-3.61	-2.05
LEIAR25.R4	LEIT	47	35	0.36	-0.20	-3.82	-2.79
LEIAR25.R4	NONE	7	18	-0.04	-0.63	-0.27	-4.38
TRM55971.00	TZGD	5	8	-0.66	0.36	-2.87	-5.47
TRM57971.00	NONE	5	13	-2.98	3.17	-4.94	-5.22
TRM57971.00	TZGD	53	6	-1.08	1.51	-3.44	-4.07
TRM59800.00	NONE	10	28	-1.83	-0.69	-4.46	-1.94
TRM59800.00	SCIS	8	40	-0.00	-0.83	-7.32	-3.17
TRM59900.00	NONE	7	5	0.10	0.69	-9.31	-3.04
TRM59900.00	SCIS	38	5	-0.21	0.62	0.79	-1.72

Robot: L1/L2 Chamber: E1/E5

Comparison chamber vs robot calibrations: PCV



Chamber calibrations: covered (used) network



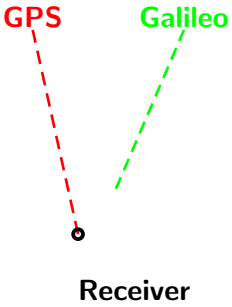
(Date: January 1, 2018)

What are GNSS translation biases (GTRA)?

- Offset between GPS and an other GNSS system
- One set per station (East, North, Up)
- In an ideal case they are zero
- → GPS coordinate is independents the used GNSS

What can cause non-zero GTRA?

- Missing / wrong receiver antenna pattern
- Missing / wrong satellite antenna pattern
- Inconsistent satellite PCOs between the different GNSS (→ different scale)
- ...



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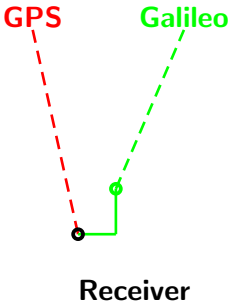
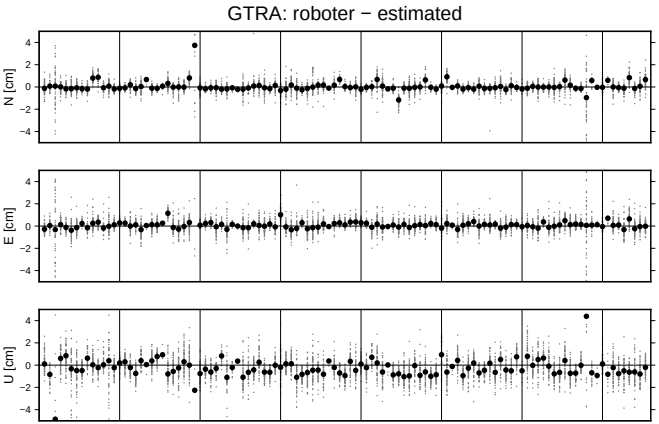


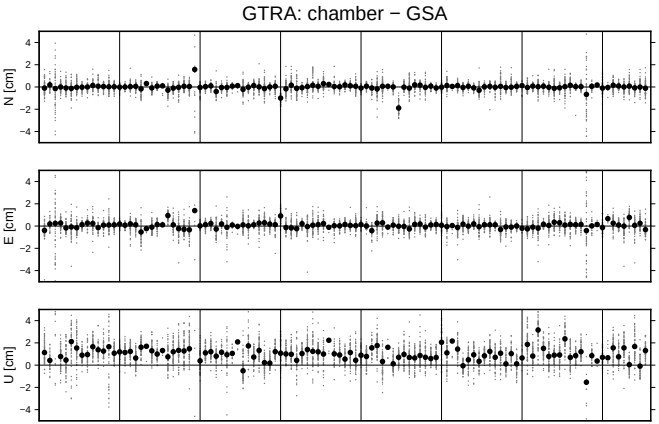
Galileo - GPS translation biases: roboter



Mean GTRA values [mm]:

North	0.2
East	0.5
Up	-2.6

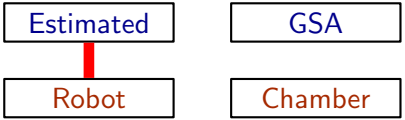
Galileo - GPS translation biases: chamber



Mean GTRA values [mm]:

North	-0.3
East	0.6
Up	9.4

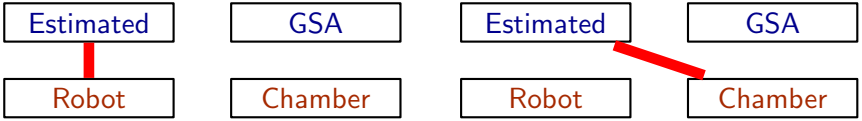
Comparison of inter-system GPS-Galileo biases



	N	E	U
GTRA [mm]	0.2	0.5	-2.6

Satellite
Receiver

Comparison of inter-system GPS-Galileo biases

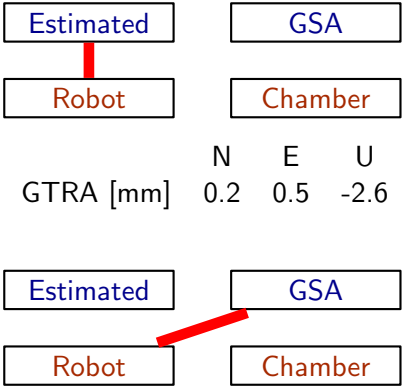


Satellite
Receiver

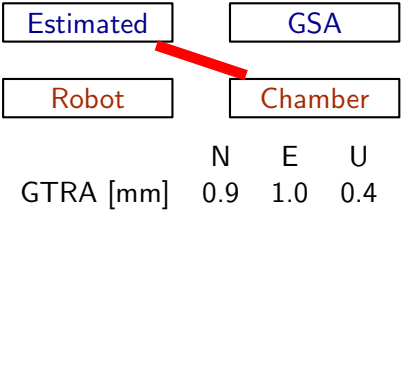
	N	E	U
GTRA [mm]	0.2	0.5	-2.6

	N	E	U
GTRA [mm]	0.9	1.0	0.4

Comparison of inter-system GPS-Galileo biases



	N	E	U
GTRA [mm]	0.2	0.5	-2.6

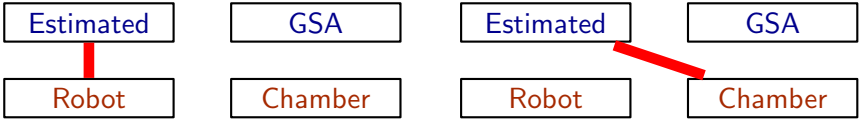


	N	E	U
GTRA [mm]	0.9	1.0	0.4

	N	E	U
GTRA [mm]	-0.7	0.5	7.3

Satellite
Receiver

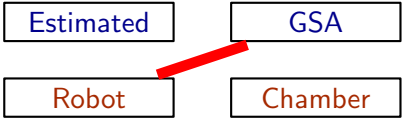
Comparison of inter-system GPS-Galileo biases



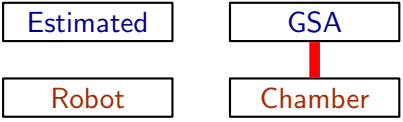
	N	E	U
GTRA [mm]	0.2	0.5	-2.6

	N	E	U
GTRA [mm]	0.9	1.0	0.4

Satellite
Receiver

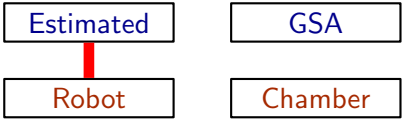


	N	E	U
GTRA [mm]	-0.7	0.5	7.3

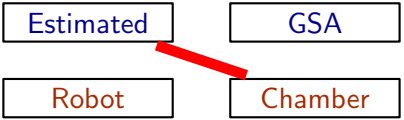


	N	E	U
GTRA [mm]	-0.3	0.6	9.4

SLR residuals

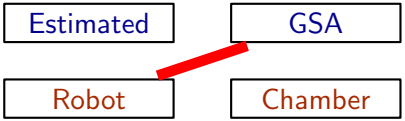


	Q50	Q75-Q25
[mm]	-2.1	31.6

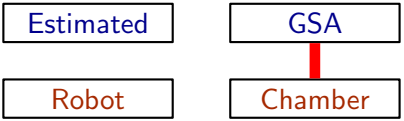


	Q50	Q75-Q25
[mm]	0.3	31.8

Satellite
Receiver



	Q50	Q75-Q25
[mm]	-2.1	33.3



	Q50	Q75 - Q25
[mm]	0.1	32.6

What does this means in terms of scale?

Estimating scale (of the ground network) using Galileo-Only solution!

- Reference stations: on average 35 sites (60-day period)
- Scale: -1.2 ± 0.0008ppb
- Daily standard deviation of scale estimation: 0.0002 ppb
- : On Earth: -8 mm
- : Satellite orbit: -36 mm

How can the scale difference between GPS / Galileo be solved?

- Introducing L5 calibrations (chamber)
- Estimating GPS PCO using scale derived from Galileo
- $\rightarrow$ leading to "GNSS" scale
- option for future ITRF solutions (keep consistency in current ITRF solution)

Summary/Conclusion

- Chamber calibrations show consistency at the level of 0 to 7 mm in the Z-PCO with robot calibrations
- Chamber calibrations are accepted by the IGS (resolution IGS Workshop 2010, Newcastle)
- GNSS-Scale derived from Galileo (and potential other GNSS if calibrated PCOs available)
- For future ITRF solutions one needs to think to prefer calibrations with complete frequencies
- Further test have to be be carried out
  - Estimation of GPS PCOs based on Galileo scale
  - Using at least one year of data
  - Extend the used network
  - Comparison of PCOs estimation with QZSS (available PCOs, regional)

Summary/Conclusion

- We are grateful to the participating institutions for providing a set of (Bonn) chamber receiver antennas calibrations!
- We hope that in the future we get more satellite chamber calibrations from other GNSS operators.