Comparison of robot and chamber based receiver calibrated antenna pattern for TRF scale determination

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Motivation

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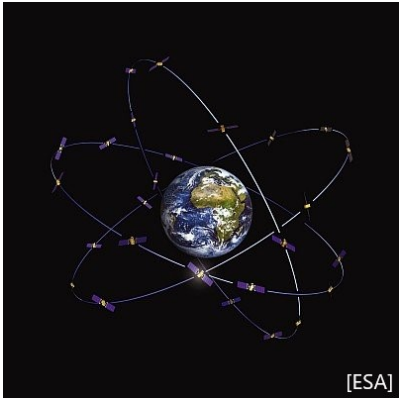
- The IGS contributes with dedicated GNSS reprocessings to the realizations of the International Terrestrial Reference Frame
- The IGS14, the IGS reference frame aligned to the ITRF2014, is based on GPS and GLONASS
- The IGS will contribute to the realization of the next ITRF

Motivation

Why should we include Galileo?

- Galileo is the third GNSS which reached the full constellation
- Currently 24 Galileo satellites are active (more satellites for the user $\rightarrow$ better coverage)
- GSA disclosed as the first Global GNSS System provider metadata, including macromodel, mass history, and the **antenna calibrations**

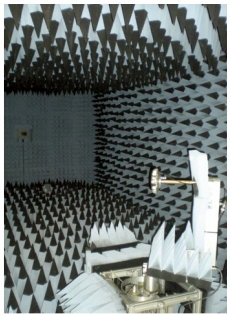


Introduction - Receiver antenna calibrations

What is needed to use the Galileo satellite antenna calibrations?

- The antenna calibrations of the current IGS 14 covers GPS and Galileo
- For the full benefit of the satellite antenna calibrations Galileo pattern for the ground segment are needed

Antenna calibration methods:



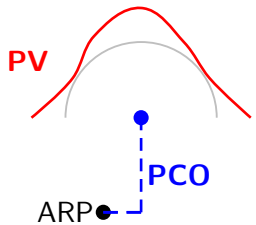
Haasdyk and Janssen Position, 2011

http://www.geopp.de/robot-site-selection

Antenna Phase Center Offset and Phase Variations

Antenna calibrations describe the phase variations (PV) and phase center offset (PCO) according to an antenna reference point:

- Receiver antenna: A well defined point on the antenna.
- Satellite antenna: Currently the center of mass



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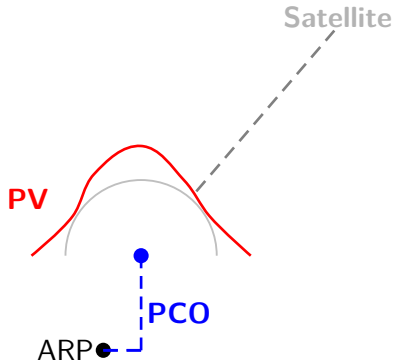

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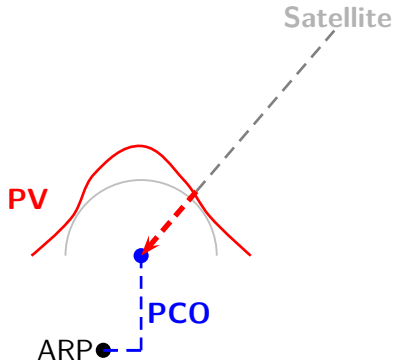

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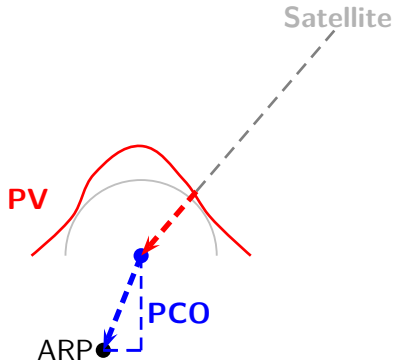
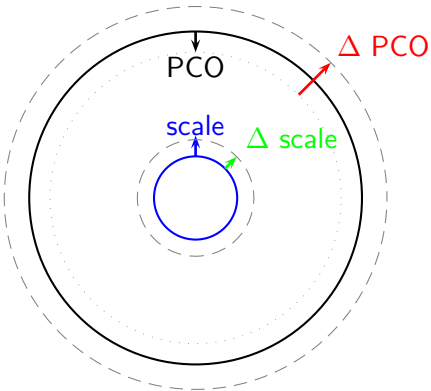


Relation: Scale - Satellite and receiver antenna calibrations



- 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

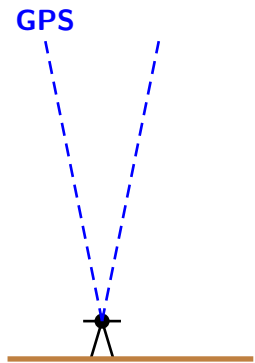
Comparison between robot and chamber calibrations

Table: Difference of the Z-PCO of between robot and chamber calibrations (IF, GPS: L1/L2, GLONASS: L1/L2, Galileo: E1/E5a) in mm. Datum: Zero-mean condition over PV and constant term removed. ROB: Robot calibrations, CHA: chamber calibrations

Antenna		GPS	GLONASS	Galileo
ASH701945C_M	NONE	5.28	-2.32	**6.86**
JAVRINGANT_DM	NONE	-2.63	-3.31	-1.46
..				
LEIAR20	LEIM	5.04	**5.49**	3.69
LEIAR20	NONE	3.41	4.92	3.32
LEIAR25.R3	LEIT	**9.03**	3.20	6.03
TRM55971.00	TZGD	-2.55	-4.95	-2.63
TRM59800.00	NONE	1.88	1.55	-0.85
Mean value		**0.53**	**-0.65**	**0.43**

Multi-GNSS antenna calibration patterns: consistency

Inter-System Translation Bias Parameter (ISTP):
Offset between GPS and Galileo phase center at the ground station



Current situation (IGS14.atx)

- GPS and GLONASS estimated according to IGS14 ("ITRF2014" compatible)
- Galileo: chamber calibrated patterns

Adjusted "Galileo-scale" satellite antenna PCOs

- GPS and GLONASS adjusted to fit Galileo
- Galileo: chamber calibrated patterns

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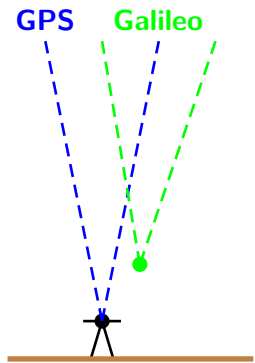

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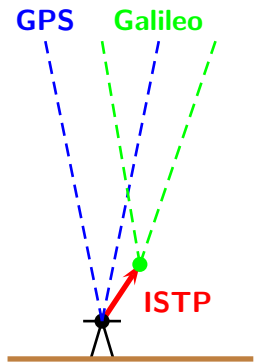

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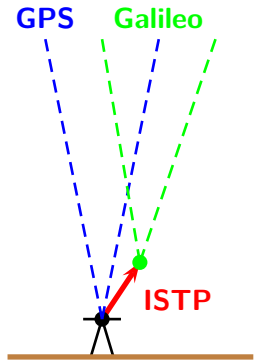
Consistency test: average ISTP values (up-component)

Current situation (IGS14.atx)

Method	GPS-GLO	GPS - GAL
Chamber	-3.15 mm	8.40 mm
Robot	-1.07 mm	6.63 mm

Adjsuted "Galileo-scale" satellite antenna PCOs

Method	GPS-GLO	GPS - GAL
Chamber	-1.11 mm	0.19 mm
Robot	-1.07 mm	0.05 mm

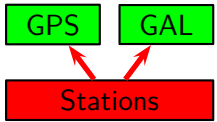


Consistency between GPS and Galileo

Inter-system Translation Bias (ISTP) and elevation dependent offset. Median value over a two year period.

Antenna		CHA			ROB		
		#	Up	Trp	#	Up	Trp
JAVRINGANT_DM	NONE	15	8.50	-0.00	15	3.34	0.66
JAVRINGANT_DM	SCIS	1	0.82	1.39	1	-7.92	3.68
JAVRINGANT_G5T	NONE	6	-8.50	2.22	6	-1.80	1.49
LEIAR10	NONE	4	2.14	-0.07	4	3.27	0.35
LEIAR25.R4	NONE	7	0.57	0.45	7	0.43	0.64
LEIAT504	NONE				1	1.96	0.42
SEPCHOKE_B3E6	NONE				1	-2.07	1.46
TRM57971.00	NONE	17	1.64	-0.86	17	-0.13	-0.86
TRM59800.00	NONE	29	2.62	-0.72	31	0.60	-0.06
TRM59800.00	SCIS	14	-5.10	0.70	14	-2.31	0.38

PCO estimation: ITRF 2014 scale



- GPS
- GLONASS
- Galileo

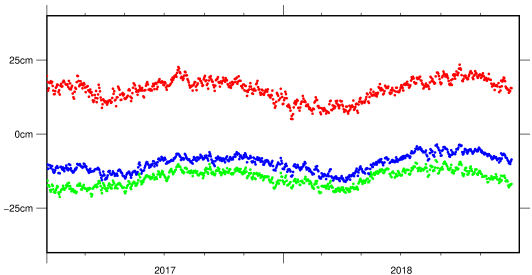


Figure: Chamber calibrations: Scale fixed to ITRF 2014.

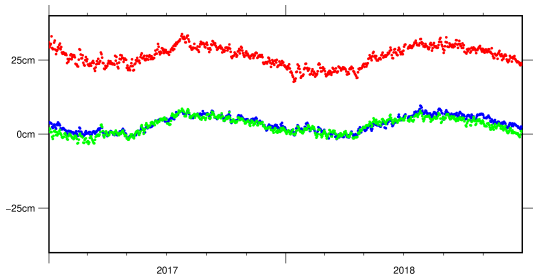


Figure: Robot calibrations: Scale fixed to ITRF 2014.

PCO estimation: GPS scale

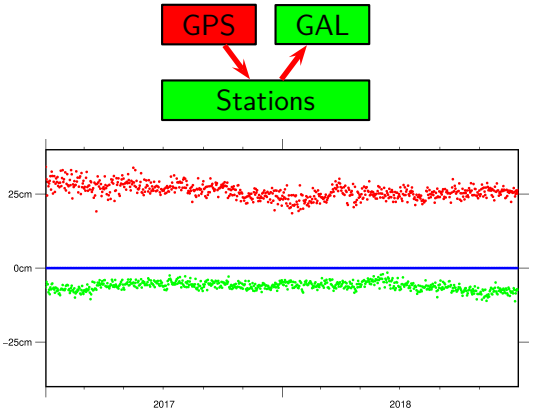
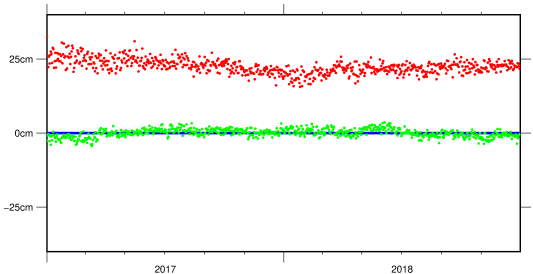


Figure: Chamber calibrations: Scale realized by introducing GPS satellite PCOs.

- GPS
- GLONASS
- Galileo



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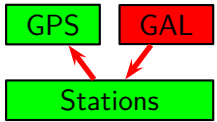
PCO estimation: Galileo scale



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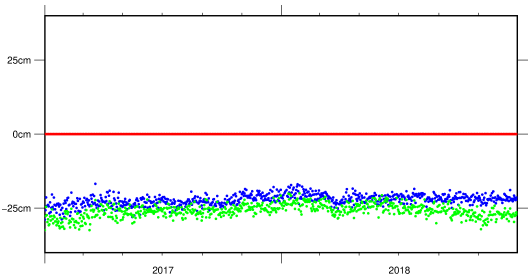

Figure: Chamber calibrations: Scale realized by introducing Galileo satellite PCOs.

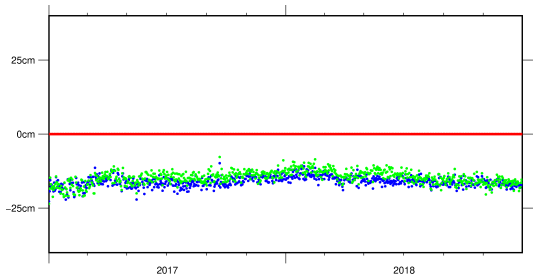

Figure: Robot calibrations: Scale realized by introducing Galileo satellite PCOs.

Comparison of different scale estimations

System-wise PCO offset estimates in cm constraining different PCOs.
Two years of NEQs were stacked (2017-2018).

		scale		
		GPS	GLO	GAL
chamber	GPS	-	4.0	-22.1
	GLO	-6.1	-	-25.8
	GAL	25.8	31.6	-
robot	GPS	-	5.4	-16.2
	GLO	-3.5	-	-15.3
	GAL	22.5	23.1	-

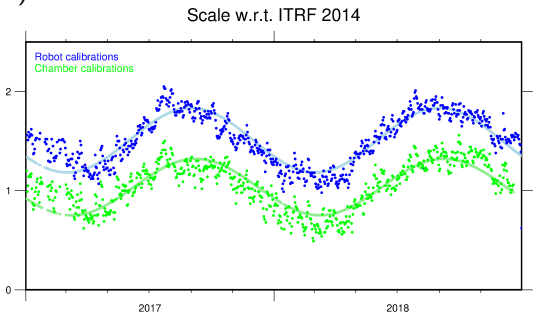

Figure: Scale in ppb.

GNSS scale based on Galileo w.r.t. ITRF 2014

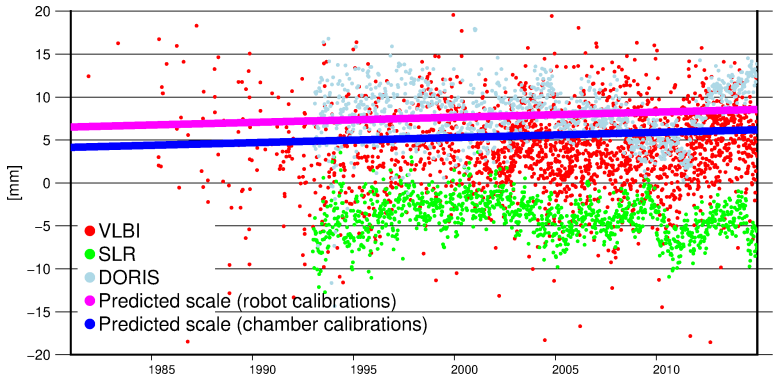

Figure: Scale w.r.t. ITRF 2014

VLBI, SLR, and DORIS scale from Altamimi et al. J. Geophys. Res. Solid Earth, 2016

Conclusion

Antenna consistency

- Robot and chamber receiver antenna calibrations provide Galileo patterns
- Both methods show a good agreement between GPS and Galileo pattern
- Differences between the two methods $\rightarrow$ **the next IGS ITRF contribution relies on robot calibrations**

Scale determination

- The GNSS scale w.r.t. ITRF 2014 lies between **1.03 ppb (chamber calibrations) and 1.41 ppb (robot calibrations)**
- The backward compatibility (back to 1994) will be studied based on the ongoing IGS reprocessing effort