Antenna calibrations for TRF scale determination and their influence on coordinate estimation

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Motivation

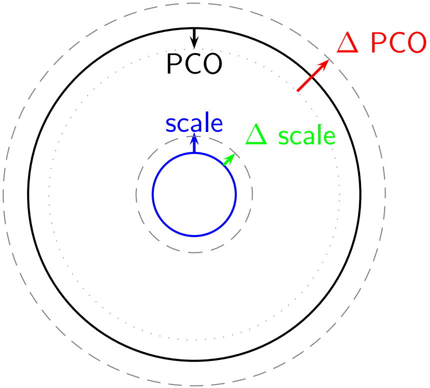
IGS antenna patterns before the release of Galileo and QZSS calibrations:

- 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)?

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

IGS antenna pattern: before Galileo and QZSS disclosure

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

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

unknown	estimated	calibrated	guess

Rob. : roboter 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	guess

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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			

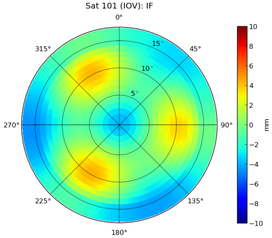
unknown estimated calibrated guess

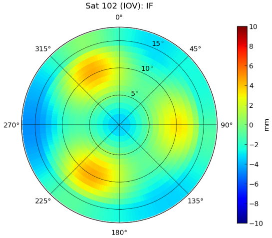
Rob. : roboter calibrations
Cha. : chamber calibrations

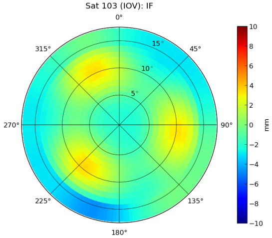
Galileo IOV/FOC Pattern

- Officially disclosed by GSA
(IOV: December 2016, FOC: October 2017)
- Chamber calibrated PCO and PCV for all active FOC/IOV satellites
- Difference between calibrated PCO's
and estimated PCO's *[Steigenberger et al., 2016,J. Geod]*:

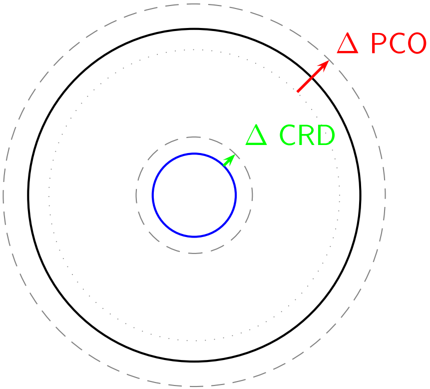
  X: up to 1 cm
  Y: up to 1 cm
  Z: IOV: ca. 0 – 10 cm, FOC 17 – 34 cm







Relation between satellite and receiver antenna PCO's



What atenna offset would cause this difference?

ΔPCO	$\rightarrow$	ΔCRD
-4m		20 cm
-20 cm		**1 cm**

→ ΔPCO for ionosphere free linear combination: -1 cm

Evaluation of the IOV/FOC patterns

- Orbit comparison between IGS PCO and released IOV/FOC PCOs and PCVs
- Introducing station-wise inter-system translation biases (GTRA)
- Solutions based on MGEX (140 stations) for doy 60 to 120 in 2017

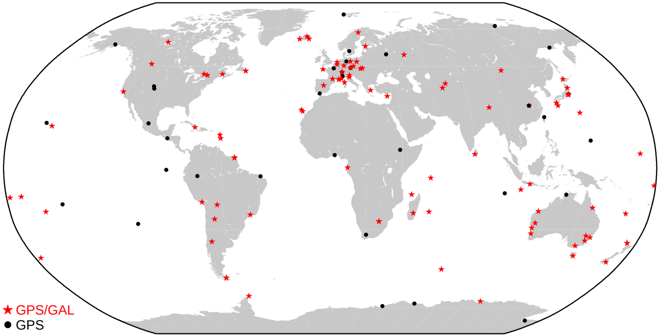
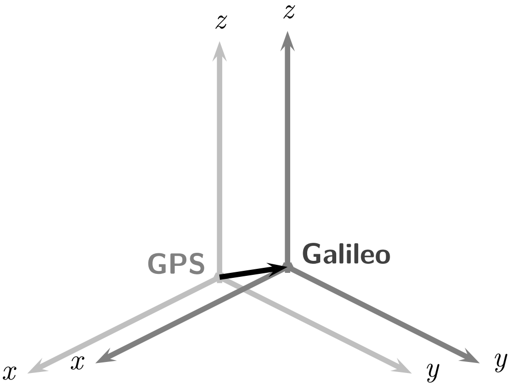


Figure: Used MGEX network for day 2017-060

Inter-system translation biases (GTRA)

- Orbit-Solution (double-difference): Zero mean condition applied: translation and rotation
- PPP-Solutions: No constraints applied



- Station coordinates from GPS-only
- Station coordinates from Galileo–only
- **Vector between GPS– and Galileo–coordinates**

Orbit comparison (NNR and NNT)

GAL: calibrated PCO, IGS: estimated PCO [Steigenberger et al., 2016, J. Geod]

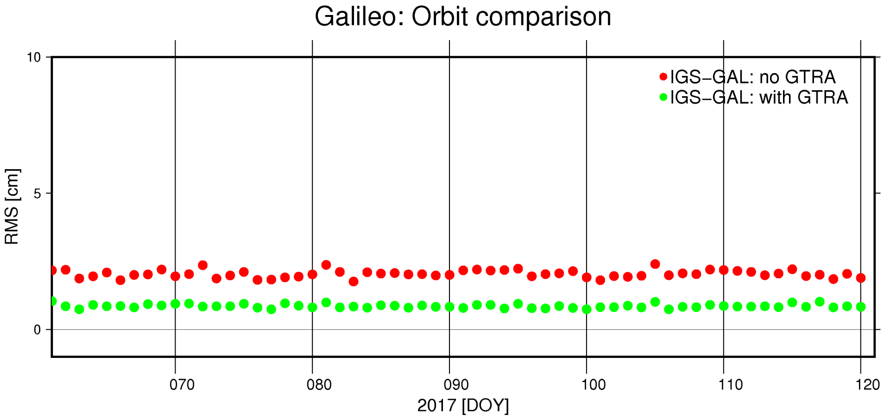


Figure: Difference between Galileo orbits using IGS and GAL PCO's without GTRA

GNSS inter-system translation biases comparison

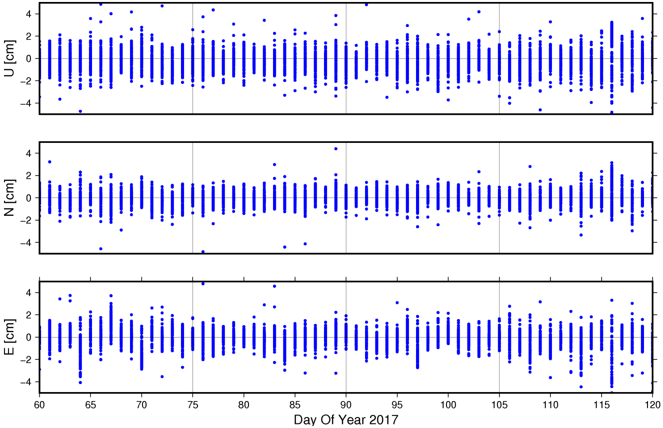


Figure: GTRA: Galileo; IGS stallite PCO's , GTRA: Galileo

GNSS inter-system translation biases comparison

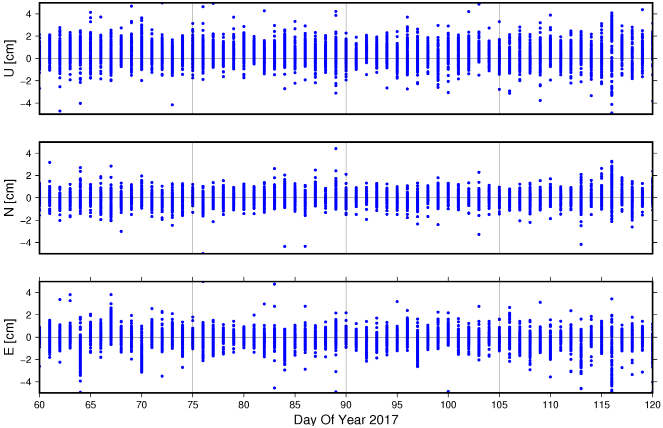


Figure: GTRA: Galileo; GAL satellite PCO's , GTRA: Galileo

Summary

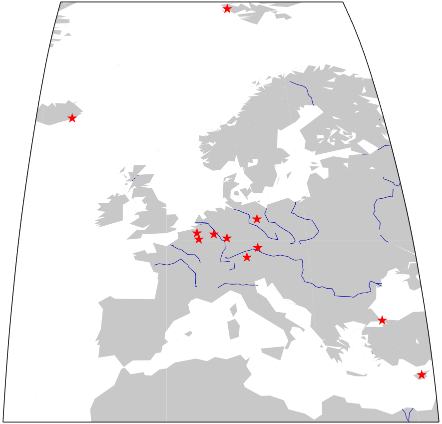
→ Mean difference in U: -9.6 mm

Calibrated Galileo pattern:

- no orbit improvement or degradation
- Mean difference between L1/L2 and E1/E5 PCO is ca. 1 cm
- This is no longer the case for calibrated pattern
- → inter-system translation biases can solve the lack of calibrations
- → creating a GPS and a Galileo coordinate ...

Chamber calibrated receiver stations

- Individual calibrated EUREF sites with chamber calibrated antennas with frequency E5 (12 sites used)
- Impact of using E5 antenna pattern instead of L2
- Estimation of Inter-System Translation Bias for Galileo FOC and IOV satellites using either L1/L2 or E1/E5 pattern.



Chamber calibrated antenna patterns

Ionosphere-Free Linear Combination

- Galileo: IGS is using L1/L2 patterns (taken from GPS)
- No Galileo patterns available
- EUREF: 12 chamber calibrated antenna patterns
- Difference of L1/L2 and E1/E5 PCOs between -1 and -10 mm

STA	Antenna type	PCO (IF) L1 / L2 ind. [mm]	PCO (IF) L1 / L5 ind. [mm]	Δ PCO ind. [mm]
BRUX	JAVRINGANT_DM NONE	65.19	56.62	-8.56
POTS	JAV_RINGANT_G3T NONE	48.97	39.75	-9.22
OBE4	JAV_RINGANT_G3T NONE	49.18	39.28	-9.90
NYA2	JAV_RINGANT_G3T NONE	50.40	41.17	-9.23
BADH	LEIAR10 NONE	96.22	94.74	-1.49
WRLG	LEIAR25.R3 LEIT	151.72	148.89	-2.84
DOUR	LEIAR25.R3 NONE	146.59	143.55	-3.04
REYK	LEIAR25.R4 LEIT	149.68	145.31	-4.36
HOFN	LEIAR25.R4 LEIT	149.12	144.92	-4.20
NICO	LEIAR25.R4 LEIT	148.09	143.56	-4.54
EUSK	LEIAR25.R4 LEIT	149.52	145.20	-4.32
ISTA	LEIAR25.R4 LEIT	155.77	149.24	-6.53

Chamber calibrated antenna patterns

Ionosphere-Free Linear Combination

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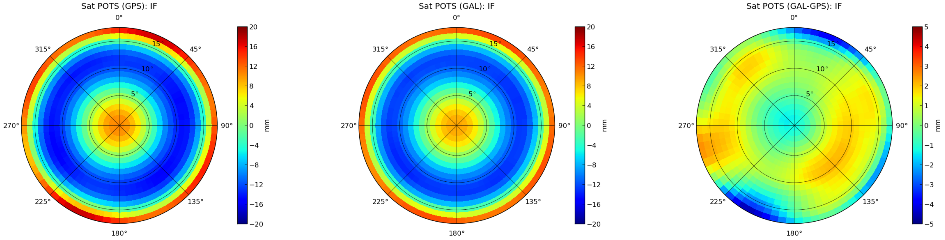

Galileo inter-system translation biases

STA	Antenna type	GTRA			
	Used PCO and PCV:	L1/L2 [mm]	E1/E5 [mm]	Δ GTRA [mm]	Δ PCO [mm]
BRUX	JAVRINGANT_DM NONE	-4.3	7.1	-11.4	-8.56
POTS	JAV_RINGANT_G3T NONE	-5.4	5.3	-10.7	-9.22
OBE4	JAV_RINGANT_G3T NONE	-3.6	7.7	-11.3	-9.90
NYA2	JAV_RINGANT_G3T NONE	3.7	11.1	-7.4	-9.23
BADH	LEIAR10 NONE	4.8	8.0	-3.2	-1.49
WRLG	LEIAR25.R3 LEIT	0.9	9.2	-8.3	-2.84
REYK	LEIAR25.R4 LEIT	0.3	8.0	-7.3	-4.36
HOFN	LEIAR25.R4 LEIT	1.0	7.9	-6.9	-4.20
NICO	LEIAR25.R4 LEIT	-6.6	1.0	-7.6	-4.54
EUSK	LEIAR25.R4 LEIT	2.0	10.4	-8.4	-4.32
ISTA	LEIAR25.R4 LEIT	-3.0	5.5	-8.5	-6.53

Table: Galileo GTRA: median over 60 days, CODE MGEX orbit and clock products used (IGS PCO and no GTRA)

Outlook

Assessment of chamber calibrations

- Collecting as many chamber calibration as possible
  - Station manager
  - Network operators
- Potential analyses:
  - Creation of "type-mean" chamber calibrations
  - MGEX POD solution using "type-mean" chamber calibrations
  - Comparison of GPS/GLONASS POD using robot and chamber calibrations
- Next step: results of this study shall be presented at the IGS Workshop 2018

Proposal for a resolution

The IAG Reference Frame Sub-commission for Europe (EUREF)

- recognising Galileo is developing towards the third fully deployed global navigation satellite system and the effort within the IGS MGEX working group to significantly improve the quality of the orbits in an operational scheme
- noting the effort that was invested into the EPN infrastructure to install multi-GNSS stations and to establish the related RINEX3 dataflow
- encouraging the analysis centers to build the capability to process the Galileo observations
- supporting the IGS antenna working group to develop a strategy to overcome the missing receiver antenna calibrations for Galileo signals (e.g., by providing chamber calibrations for scientific purposes).