

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

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EGU 2018, 11. April 2018

# Motivation

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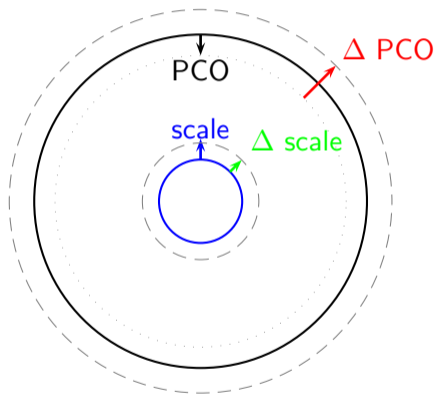
IGS antenna patterns before the release of Galileo and QZSS calibrations:

- 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]*  
 $1\text{m} \hat{=} -7.8 \text{ ppb}$   
 $1 \text{ ppb} \hat{=} -0.13 \text{ m}$
- PCO's:  $-4 \text{ m } \Delta \text{ PCO}$
- Stations:  $20 \text{ cm offset}$

# IGS antenna pattern: before Galileo and QZSS disclosure

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	estimated	L1
	E5a	estimated	L2
	E5b	unknown	unknown
	E5	unknown	unknown
	E6	unknown	unknown

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

unknown    estimated    calibrated    guess

Rob. : roboter calibrations

# IGS antenna pattern: after Galileo and QZSS disclosure

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GPS	L1	estimated	calibrated
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	L5	unknown	unknown
GLO	G1	estimated	calibrated
	G2	estimated	calibrated
	G3	unknown	unknown
GAL	E1	calibrated	L1 unknown
	E5a	calibrated	L2 unknown
	E5b	calibrated	unknown
	E5	calibrated	unknown
	E6	calibrated	unknown

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

unknown    estimated    calibrated    guess

Rob. : rotoer calibrations

# IGS antenna pattern: after Galileo and QZSS disclosure

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

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

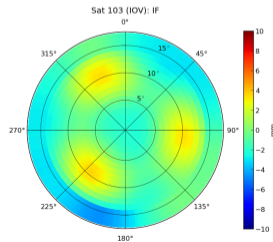
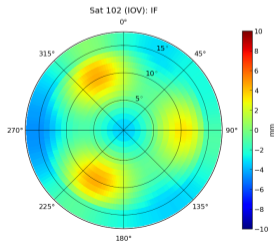
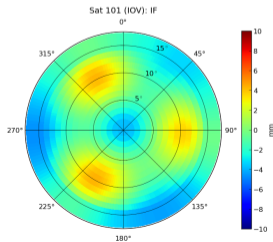
unknown    estimated    calibrated    guess

Rob. : roboter calibrations

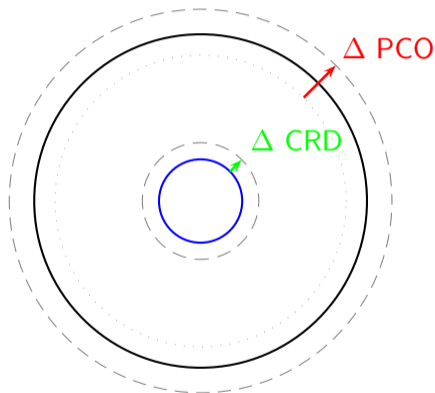
Cha. : chamber calibrations

# 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 antenna offset would cause this difference?

$$\frac{\Delta PCO}{-4\text{m}} \rightarrow \frac{\Delta CRD}{20\text{ cm}}$$

**-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 day 60 to 120 in 2017

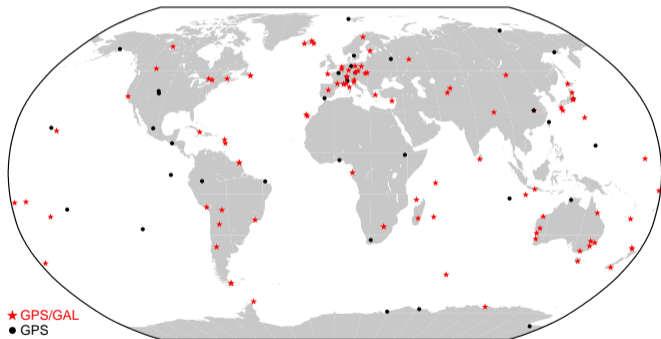
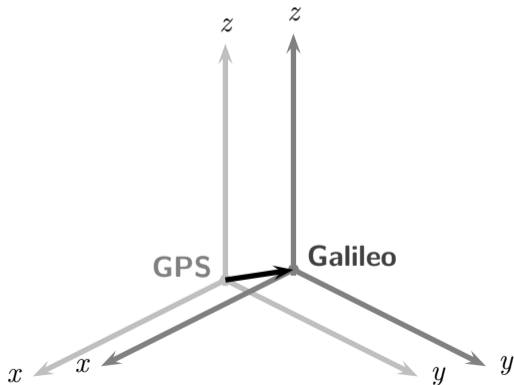


Figure: Used MGEX network for day 2017-060

# 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]

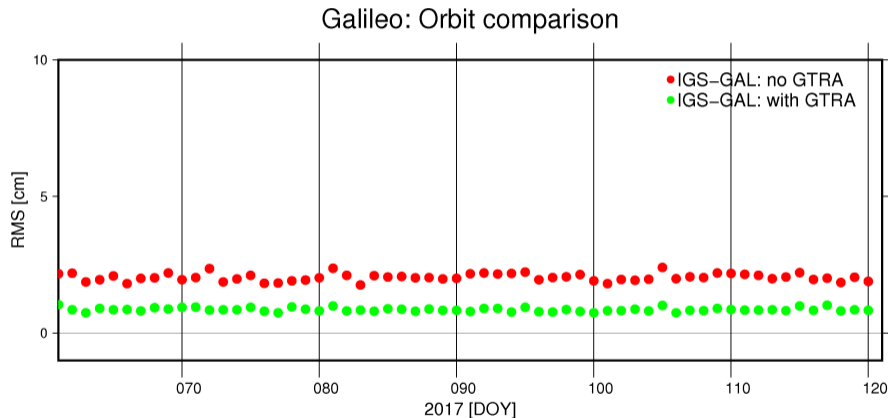


Figure: Difference between Galileo orbits using IGS and GAL PCO's without GTRA

# GNSS inter-system translation biases comparison

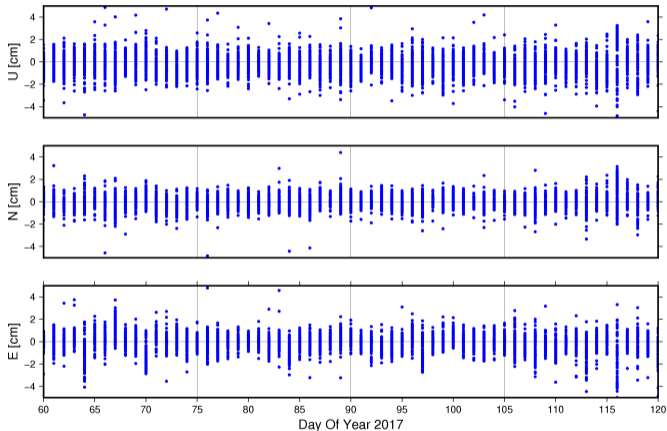


Figure: GTRA: Galileo; IGS stallite PCO's , GTRA: Galileo

# GNSS inter-system translation biases comparison

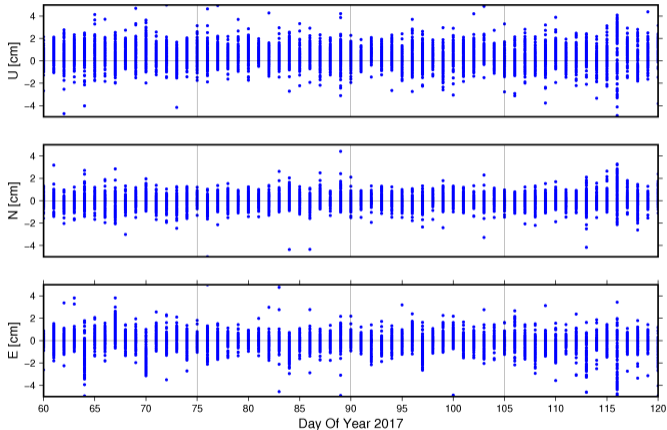


Figure: GTRA: Galileo; GAL satellite PCO's , GTRA: Galileo

# Summary

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→ 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

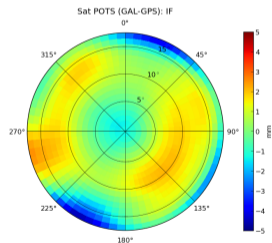
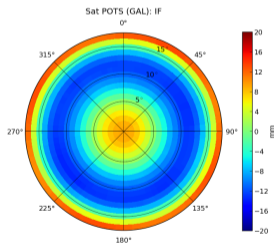
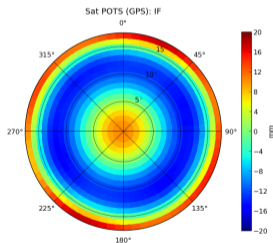
STA	Antenna type	PCO (IF)		$\Delta$ PCO ind. [mm]
		L1 / L2 ind. [mm]	L1 / L5 ind. [mm]	
BRUX	JAVRINGANT_DM NONE	65.19	56.62	-8.56
POTS	JAV_RINGANT_G3T NONE	48.97	39.75	-9.22
OBE4	JAV_RINGANT_G3T NONE	49.18	39.28	-9.90
NYA2	JAV_RINGANT_G3T NONE	50.40	41.17	-9.23
BADH	LEIAR10 NONE	96.22	94.74	-1.49
WRLG	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

- 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



# Galileo inter-system translation biases

STA	Antenna type <i>Used PCO and PCV:</i>	GTRA			$\Delta$ PCO [mm]
		L1/L2 [mm]	E1/E5 [mm]	$\Delta$ GTRA [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)

## Assessment of chamber calibrations

- Collecting as many chamber calibration as possible (call by the IGS Antenna Working Group in preparation)
  - 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