Recent developments within the IGS and at the CODE analysis center

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and the Satellite geodesy research group at AIUB

Astronomical Institute, University of Bern, Switzerland

EUREF Analysis Centres Workshop
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EUREF-AC-MAIL: #2492

CODE is providing as the first of the IGS analysis centers a combined

GPS+GLONASS+Galileo

orbit and clock product

in its legacy rapid and ultra-rapid processing chains
since September 23rd, 2019.

Overview

Processing of Galileo Data at CODE

Situation Regarding Antenna Calibrations

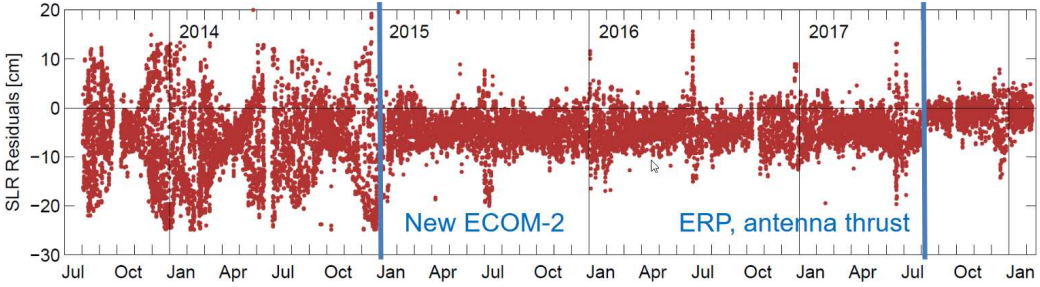
Summary

Processing of Galileo Data at CODE

- Galileo observations are processed at CODE since 2012 in the frame of the IGS MGEX project.

Processing of Galileo Data at CODE

- Galileo observations are processed at CODE since 2012 in the frame of the IGS MGEX project.
- In that time several improvements have been introduced:



SLR residuals to satellite SVN E102 in the CODE MGEX solution

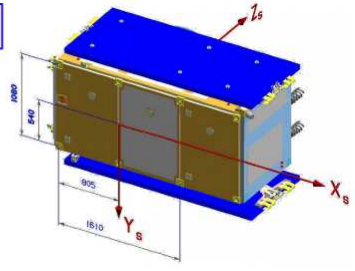
Montenbruck, O., R. Dach, P. Steigenberger; 2018: New Constellations for Geodesy: The IGS Multi-GNSS Pilot Project (MGEX). EUREF 2018 Symposium, Amsterdam, Netherlands, 30 May – 01 June, 2018.

Processing of Galileo Data at CODE

- Thermal radiation modelled since June 2019 in the CODE MGEX solution
- Radiators at Galileo satellites are installed on
  - IOV satellites: $+X$, $+Y$, $-Y$
  - FOC satellites: $+X$, $+Y$, $-Y$, and $-Z$

IOV

FOC

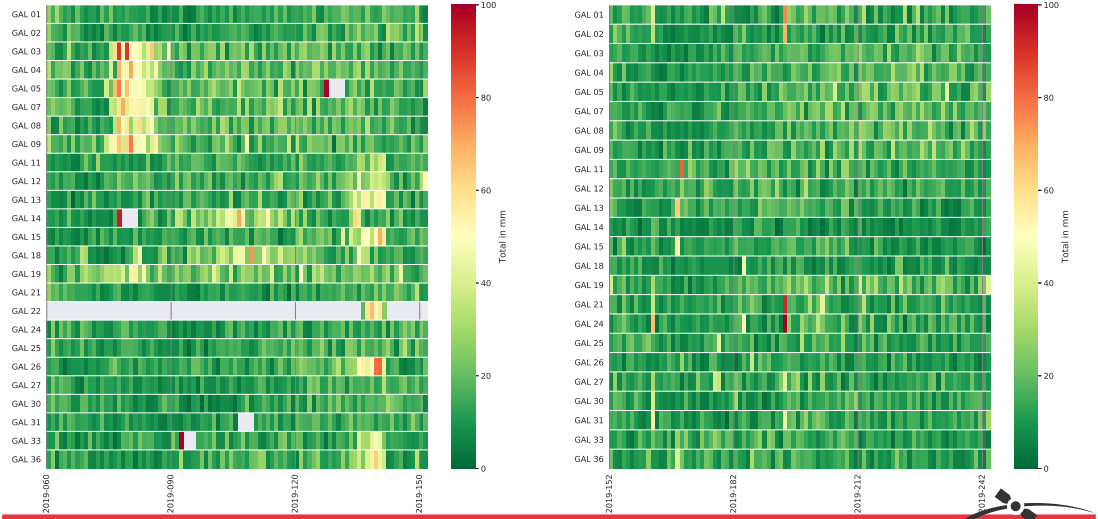


Galileo satellites (Galileo Satellite Metadata, URL: `https://www.gsceuropa.eu`).

D. Sidorov, R. Dach, L. Prange, A. Jäggi; 2018: Improved Orbit Modelling of Galileo Satellites During Eclipse Seasons. Presented at IGS workshop, Wuhan, China, 29 October - 02 November, 2018.

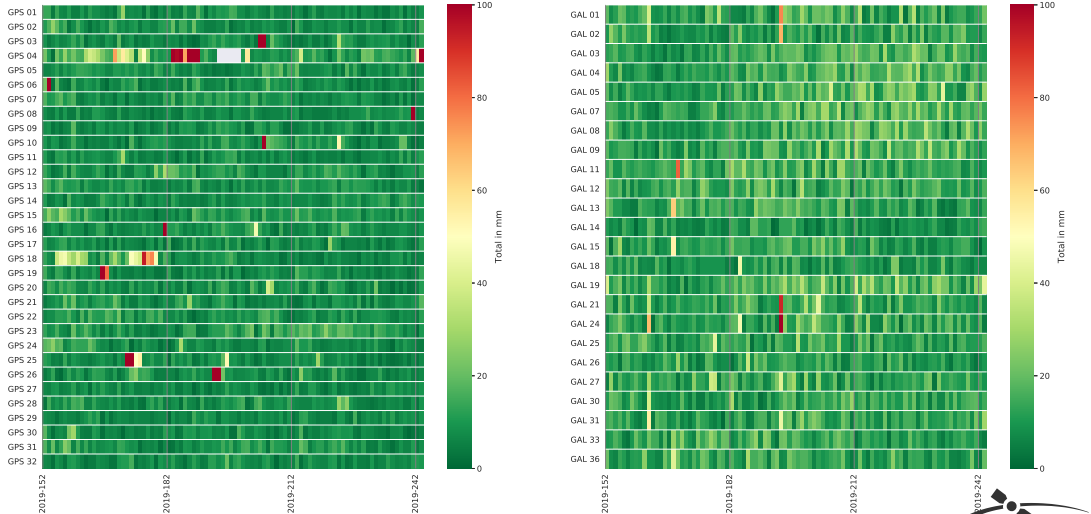
Processing of Galileo Data at CODE

Orbit misclosures from 3-day solutions (before and after mode change)

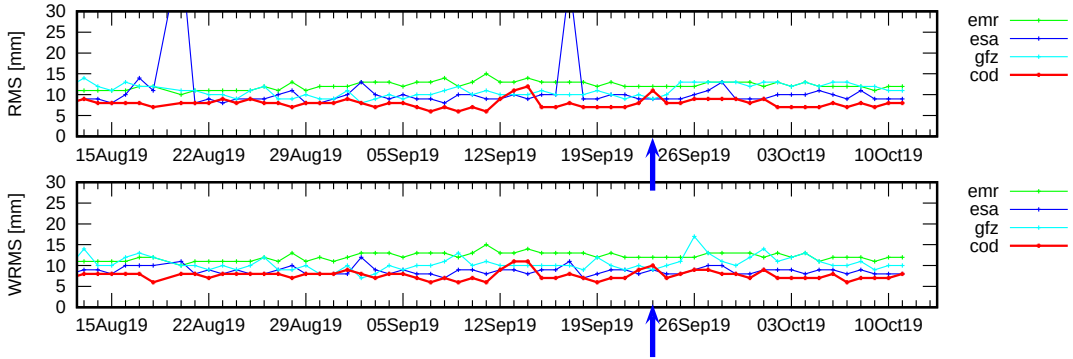


Processing of Galileo Data at CODE

Orbit misclosures from 3-day solutions (GPS and Galileo satellites)

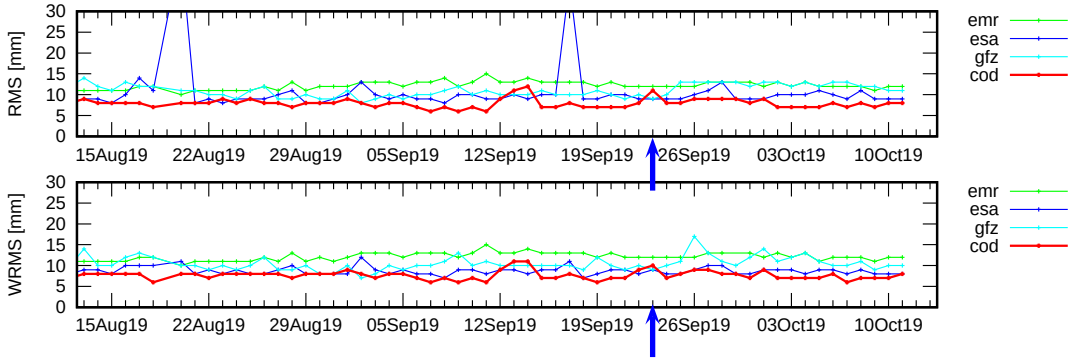


Consequences in the IGS Combination



Extract from the ACC combination protocols: IGS rapid (GPS)

Consequences in the IGS Combination



Extract from the ACC combination protocols: IGS rapid (GPS)

- No effect on the RMS (quality) of the GPS orbit product

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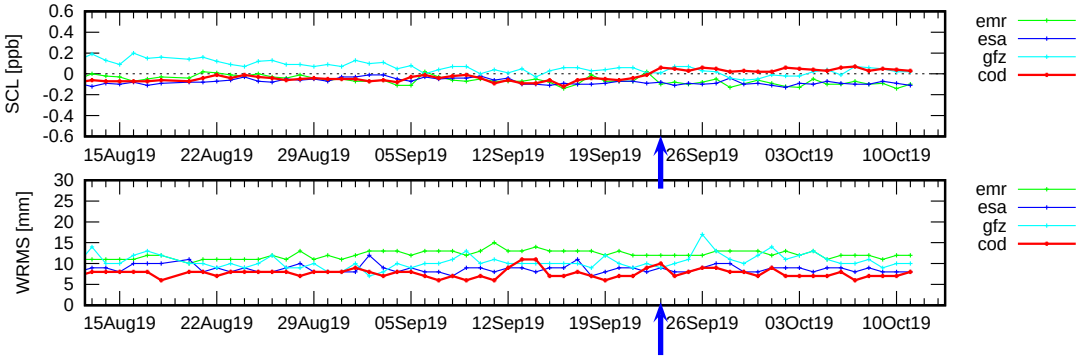
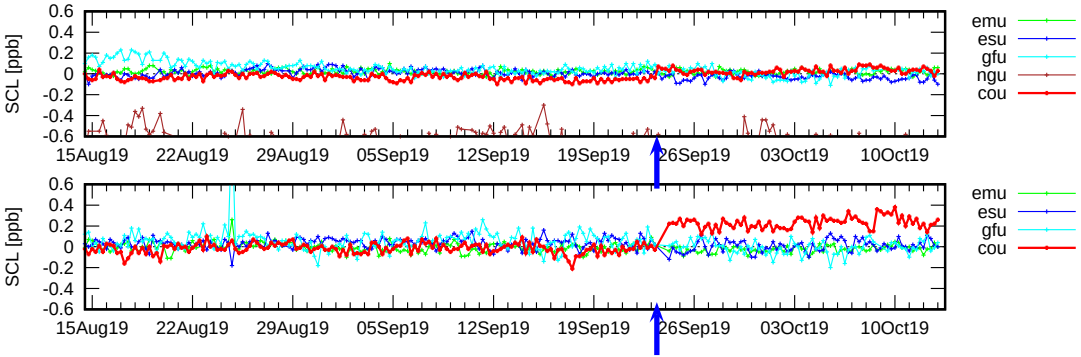


Extract from the ACC combination protocols: IGS rapid (GPS)

- No effect on the RMS (quality) of the GPS orbit product
- No effect on the transformation parameters apart from the scale!

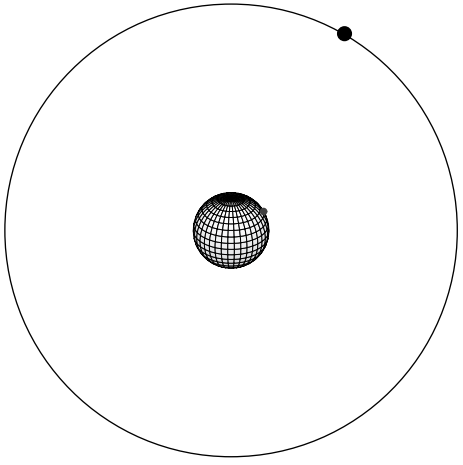
Consequences in the IGS Combination



Extract from the ACC combination protocols: IGS ultra-rapid (GPS and GLONASS)

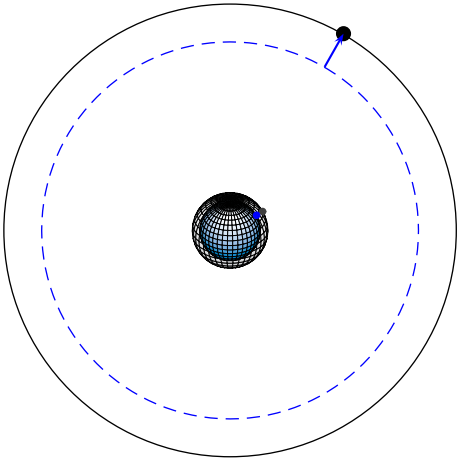
- No effect on the RMS (quality) of the GPS orbit product
- No effect on the transformation parameters apart from the scale!
  More pronnounced for GLONASS in the ultra-rapid combination

Lecture in Satellite Geodesy



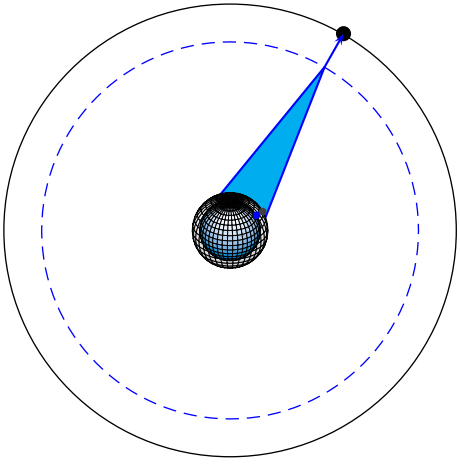
- The radius of the GNSS satellite orbits is well defined.

Lecture in Satellite Geodesy



- The radius of the GNSS satellite orbits is well defined.
- If the location of the satellite antenna is the reference point of the measurements.

Lecture in Satellite Geodesy



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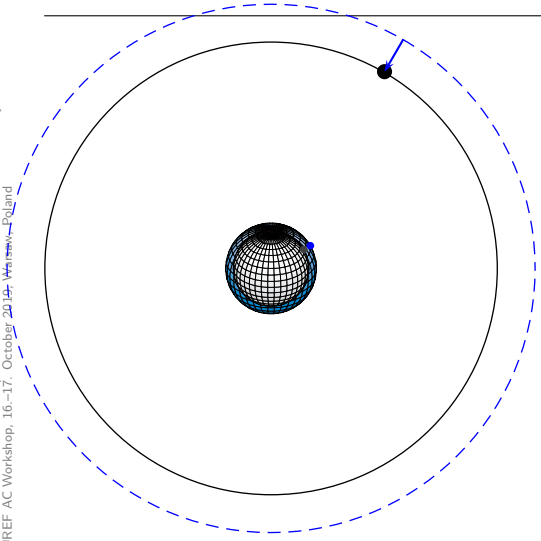
- It cannot reliably be determined from the data.



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- It cannot reliably be determined from the data.

Development Regarding Antenna Calibrations

IGS14.ATX

Signal		Satellite	Receiver
GPS	L1	est.	robot
	L2	est.	robot
	L5		
GLO	G1	est.	robot
	G2	est.	robot
	G3		
GAL	E1		
	E5a		
	E5b		
	E5		
	E6		

Remarks:

- est.: adjusted to the scale of ITRF2014 (average between VLBI and SLR)
- robot: type mean values

Development Regarding Antenna Calibrations

EPN14.ATX

Signal		Satellite	Receiver
GPS	L1	est.	robot
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	G2	est.	robot
	G3		
GAL	E1		
	E5a		
	E5b		
	E5		
	E6		

Remarks:

- est.: adjusted to the scale of ITRF2014 (average between VLBI and SLR)
- robot: individually calibrations completed by type mean values

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EPN14.ATX

Signal		Satellite	Receiver
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	E5a		
	E5b		
	E5		
	E6		

Remarks:

- est.: adjusted to the scale of ITRF2014 (average between VLBI and SLR)
- robot: individually calibrations completed by type mean values

- Fully consistent between GNSS and with the ITRF2014/IGS14.

Development Regarding Antenna Calibrations

EPN14.ATX with Galileo

Signal		Satellite	Receiver
GPS	L1	est.	robot
	L2	est.	robot
	L5		
GLO	G1	est.	robot
	G2	est.	robot
	G3		
GAL	E1	GSA	L1
	E5a	GSA	L2
	E5b		
	E5		
	E6		

Remarks:

- est.: adjusted to the scale of ITRF2014 (average between VLBI and SLR)
  GSA: pre-launch calibrations
- robot: individually calibrations completed by type mean values

Current Situation Regarding Antenna Calibrations

EPN14.ATX with Galileo

Signal		Satellite	Receiver	
GPS	L1	est.	robot	cham.
	L2	est.	robot	cham.
	L5			
GLO	G1	est.	robot	cham.
	G2	est.	robot	cham.
	G3			
GAL	E1	GSA	L1	cham.
	E5a	GSA	L2	cham.
	E5b			
	E5			
	E6			

Remarks:

- est.: adjusted to the scale of ITRF2014 (average between VLBI and SLR)
  GSA: pre-launch calibrations
- cham.: individual, multi-GNSS chamber calibrations as far as available
  robot: individually calibrations completed by type mean values

Current Situation Regarding Antenna Calibrations

Related questions:

Current Situation Regarding Antenna Calibrations

Related questions:

- What is the impact when using GPS(L2) robot calibrations for Galileo(E5) measurements?

Current Situation Regarding Antenna Calibrations

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- What is the impact when using GPS(L2) robot calibrations for Galileo(E5) measurements?
- How compatible are chamber and robot receiver antenna calibrations?

Current Situation Regarding Antenna Calibrations

Related questions:

- What is the impact when using GPS(L2) robot calibrations for Galileo(E5) measurements?
- How compatible are chamber and robot receiver antenna calibrations?
- Is there a discrepancy between the satellite antenna offsets based on ITRF2014 for GPS/GLONASS and the values for Galileo from GSA?

Current Situation Regarding Antenna Calibrations

Chamber versus robot calibrations (GPS):

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	NONE	5	13	-2.74	2.06	0.28
TRM57971.00	TZGD	53	6	-0.66	0.28	0.63
TRM59800.00	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

Current Situation Regarding Antenna Calibrations

Chamber versus robot calibrations (GPS): Mean difference $\approx 1\,\mathrm{mm}$

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**
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TRM57971.00	NONE	5	13	-2.74	2.06	0.28
TRM57971.00	TZGD	53	6	-0.66	0.28	0.63
TRM59800.00	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

Current Situation Regarding Antenna Calibrations

Chamber versus robot calibrations (Galileo):

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**

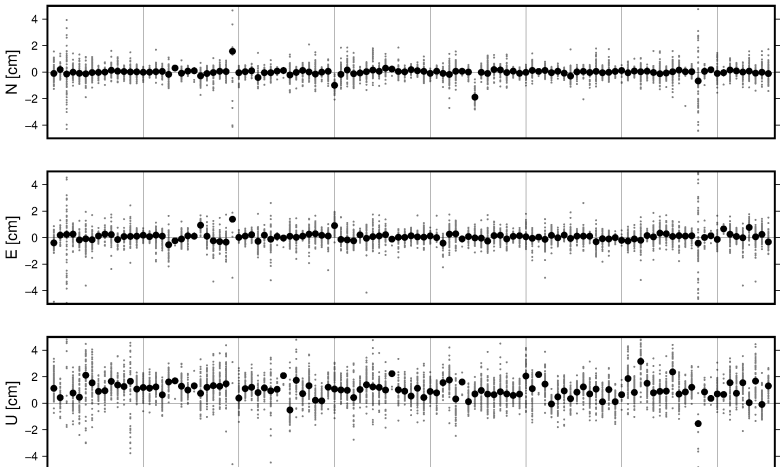
Current Situation Regarding Antenna Calibrations

Chamber versus robot calibrations (Galileo): Mean difference $\approx -5\,\mathrm{mm}$

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**

Current Situation Regarding Antenna Calibrations

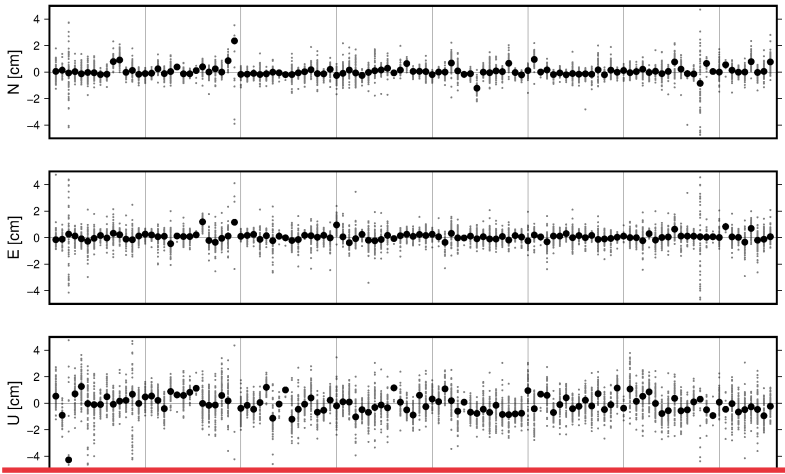
Galileo-GPS coordinate differences (GTRA):



- Satellite antenna: est. for GPS and GLONASS; GSA for Galileo
- Receiver antenna: chamber type mean

Current Situation Regarding Antenna Calibrations

Galileo-GPS coordinate differences (GTRA):



- Satellite antenna: est. for GPS and GLONASS; GSA for Galileo
- Receiver antenna: robot type mean; GPS(L2) for Galileo(E5)

Situation Regarding Antenna Calibrations for IGS repro3

`IGS14r3.ATX` for multi-GNSS (expected to be ≈`IGS20.ATX`)

Signal		Satellite	Receiver
GPS	L1	est.	robot
	L2	est.	robot
	L5		
GLO	G1	est.	robot
	G2	est.	robot
	G3		
GAL	E1	GSA	robot
	E5a	GSA	robot
	E5b		
	E5		
	E6		

Remarks:

- GSA: pre-launch calibrations
  est: adjusted scale to Galileo (SAO corrected by about $20\,\mathrm{cm}$)
- robot: new type mean multi-GNSS values

Situation Regarding Antenna Calibrations for IGS repro3

`IGS14r3.ATX` for multi-GNSS (expected to be ≈`IGS20.ATX`)

Signal		Satellite	Receiver
GPS	L1	est.	robot
	L2	est.	robot
	L5		
GLO	G1	est.	robot
	G2	est.	robot
	G3		
GAL	E1	GSA	robot
	E5a	GSA	robot
	E5b		
	E5		
	E6		

Remarks:

- GSA: pre-launch calibrations
  est: adjusted scale to Galileo (SAO corrected by about $20\,\mathrm{cm}$)
- robot: new type mean multi-GNSS values
- Do not use a system if no calibrations are available!

Situation Regarding Antenna Calibrations for IGS repro3

`IGS14r3.ATX` for multi-GNSS (expected to be ≈`IGS20.ATX`)

Signal		Satellite	Receiver
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	L2	est.	robot
	L5		
GLO	G1	est.	robot
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GAL	E1	GSA	robot
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Remarks:

- GSA: pre-launch calibrations
  est: adjusted scale to Galileo (SAO corrected by about $20\,\mathrm{cm}$)
- robot: new type mean multi-GNSS values
- Do not use a system if no calibrations are available!
- Intensively tested by IGS in preparation to repro3.

Summary

Available products:

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1. GPS+GLONASS with IGS14.ATX without Galileo
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2. GPS+GLONASS+Galileo with IGS14.ATX
   - robot calibrations (GAL(E5)=GPS(L2)) and mix GSA with estimated GPS/GLO offsets
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3. New self-consistent antenna calibration set (IGS14r3.ATX)
   - new multi-GNSS robot calibration together with GSA and re-adjusted GPS/GLO offsets
   - scale not consistent to IGS14 frame; likely close to ITRF2020 frame
   - CODE will use this ANTEX-file for its MGEX products as soon as possible.

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   - scale not consistent to IGS14 frame; likely close to ITRF2020 frame
   - CODE will use this ANTEX-file for its MGEX products as soon as possible.

Summary

Available products:

1. GPS+GLONASS with IGS14.ATX without Galileo
   - calibrations are self-consistent with reference frame ITRF2014/IGS14
   - recommended for reference frame products: IGS final (and CODE's EPN contribution)
2. GPS+GLONASS+Galileo with IGS14.ATX
   - robot calibrations (GAL(E5)=GPS(L2)) and mix GSA with estimated GPS/GLO offsets
   - these two inconsistencies seem to compensate each other
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THANK YOU

for your attention

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