Impact of new background models on GNSS orbit determination

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- Overview of CODE MGEX solution
- Recent model changes in COM solution
- Experiment on impact of satellite meta data on POD
- Effect of IOV antenna calibrations
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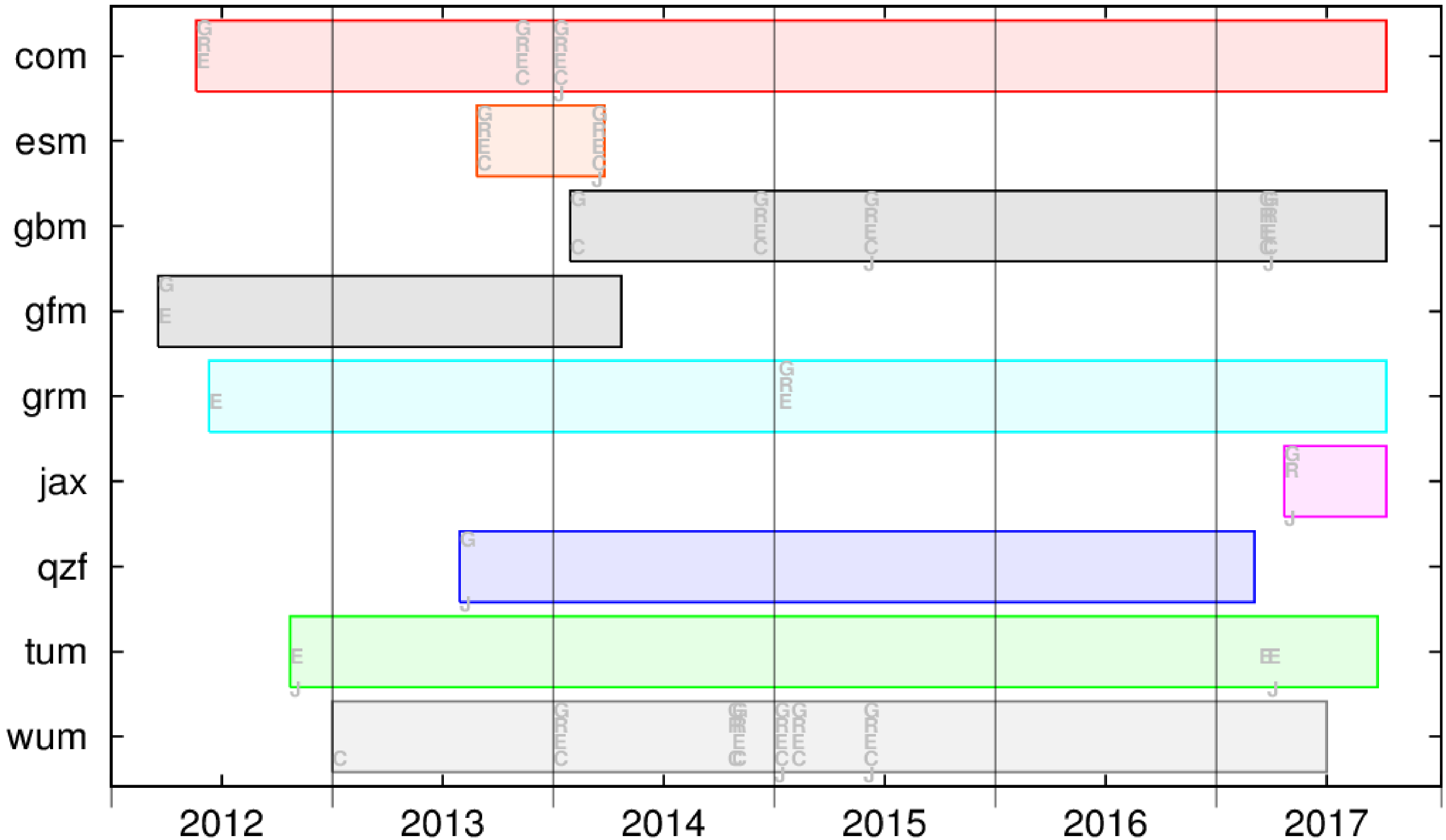
CODE MGEX orbit solution

GNSS considered:	**GPS + GLONASS + Galileo + BeiDou** (MEO+IGSO) + **QZSS** (>80 SV)
Processing mode:	Post-processing (≈2 weeks latency)
Timespan covered:	GPS-weeks 1689 - today
Number of stations:	140 (GPS), 125 (GLONASS), 95 (Galileo); 70 (BeiDou); 40 (QZSS)
Processing scheme:	**Double-difference** network processing (observable: phase double differences)
Signal frequencies:	L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) Galileo; B1 (L2) + B2 (L7) BeiDou
Orbit characteristic:	3-day long arcs; SRP: ECOM / ECOM2 (since 2015)
Reference frame:	IGb08 (until week 1934); IGS14 (since week 1934)
IERS conventions:	IERS2003 (until 1705); IERS2010 (since week 1706)
Product list:	Daily orbits (SP3; 900 => 300s since 1962) and ERPs
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/ and ftp://ftp.aiub.unibe.ch/CODE_MGEX/
Designator:	comwwwwd.???.Z => COD0MGXFIN_YYYYDDD...gz (since week 1962)

CODE MGEX clock solution

GNSS considered:	**GPS + GLONASS + Galileo + BeiDou** + **QZSS** (>80 SV)
Processing mode:	Post-processing (≈2 weeks latency)
Timespan covered:	GPS-weeks 1710 - today
Number of stations:	140 (GPS), 125 (GLO), 95 (Galileo); 70 (BeiDou); 40 (QZSS)
Processing scheme:	**Zero-difference** processing (observable: code+phase undifferenced)
Signal frequencies:	L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) Galileo; B1 (L2) + B2 (L7) BeiDou
A priori information:	Orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known
Reference frame:	IGb08 (until week 1934); IGS14 (since week 1934)
IERS conventions:	IERS2010
Product list:	Epoch-wise (30s) satellite and station clock corrections in daily clock RINEX files; daily inter-system biases for mixed stations in Bernese DCB-, BIAS-SINEX-, OSB-format
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/ and ftp://ftp.aiub.unibe.ch/aiub/CODE_MGEX/

MGEX products availability

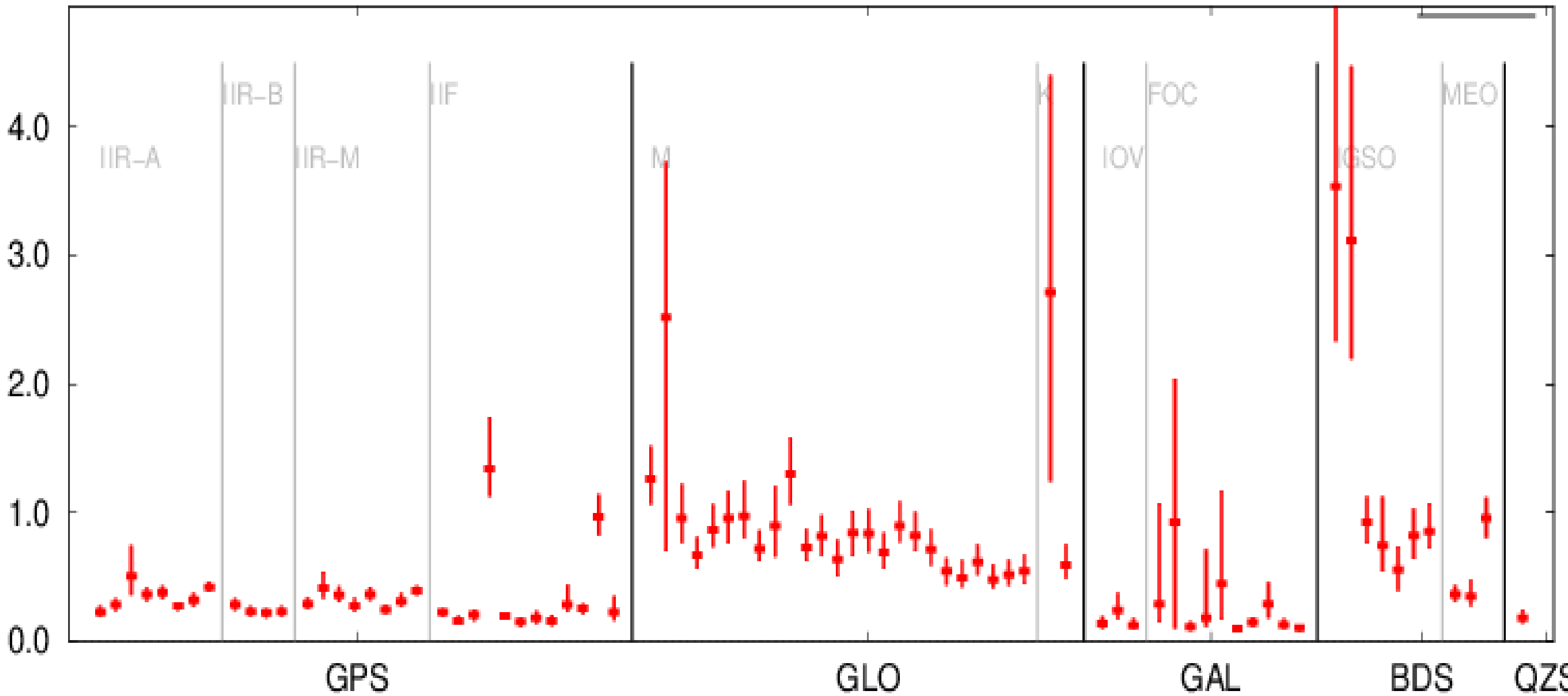


Status: October 2017

Satellite system IDs according to the content of the precise orbit files at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/

COM clock validation 2016: daily linear fit

(Median and IQR; satellites in eclipse or normal mode are not considered)



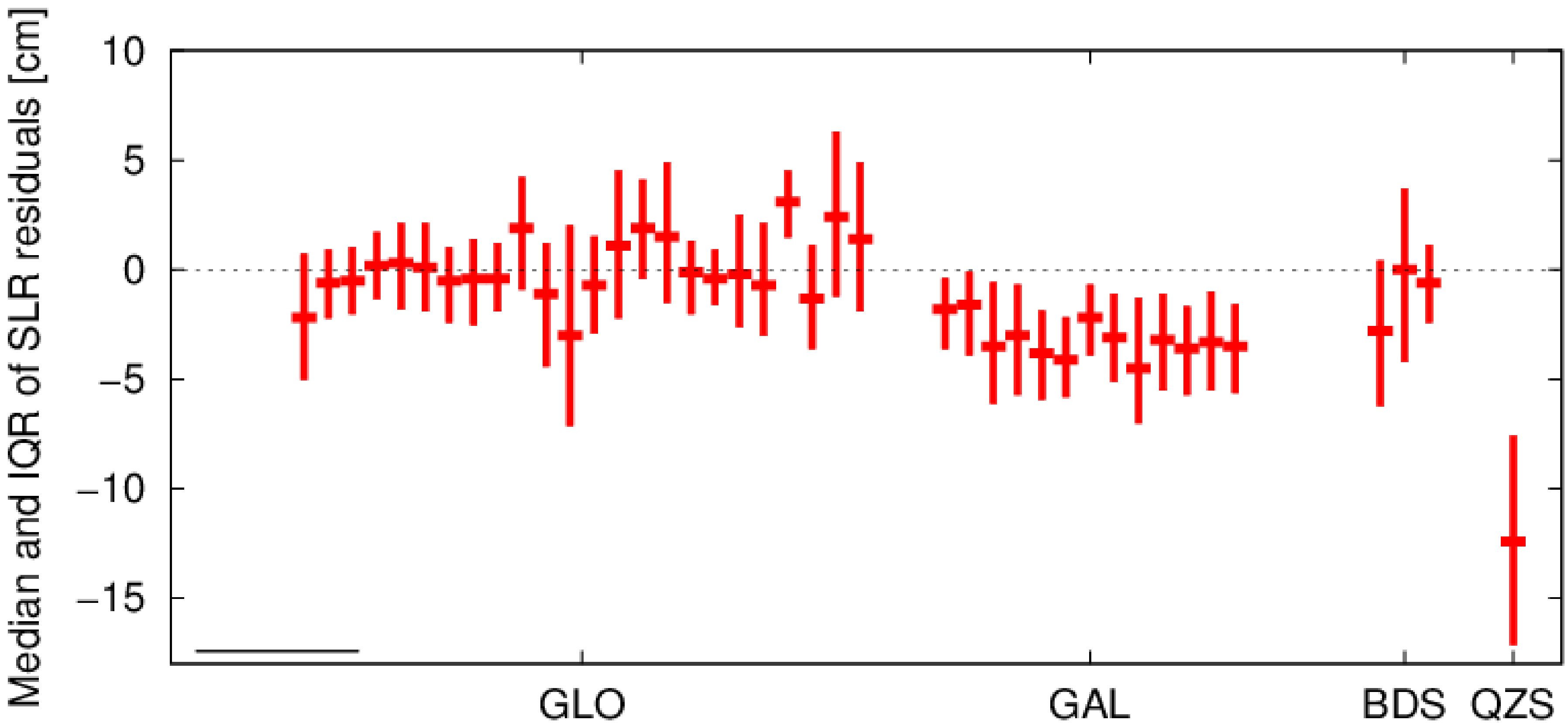
⇒ Galileo PHM, QZS-1, most GPS IIR and IIF: excellent clocks (even suited for orbit validation)

⇒ Some GPS IIF, GLONASS, Galileo RAFS: worse (RMS: 0.5 ns or bigger)

⇒ BeiDou: mixed performance

COM orbit validation 2016: SLR residuals

(Median and IQR; satellites in eclipse or normal mode are not considered)



⇒ Significant SLR offsets for Galileo and QZSS due to orbit model deficiencies with impact on radial orbit component (respectively scale)

⇒ Model improvements are needed (e.g., ANTEX, albedo, antenna thrust)

⇒ See doi 10.1007/s00190-016-0968-8 for more information

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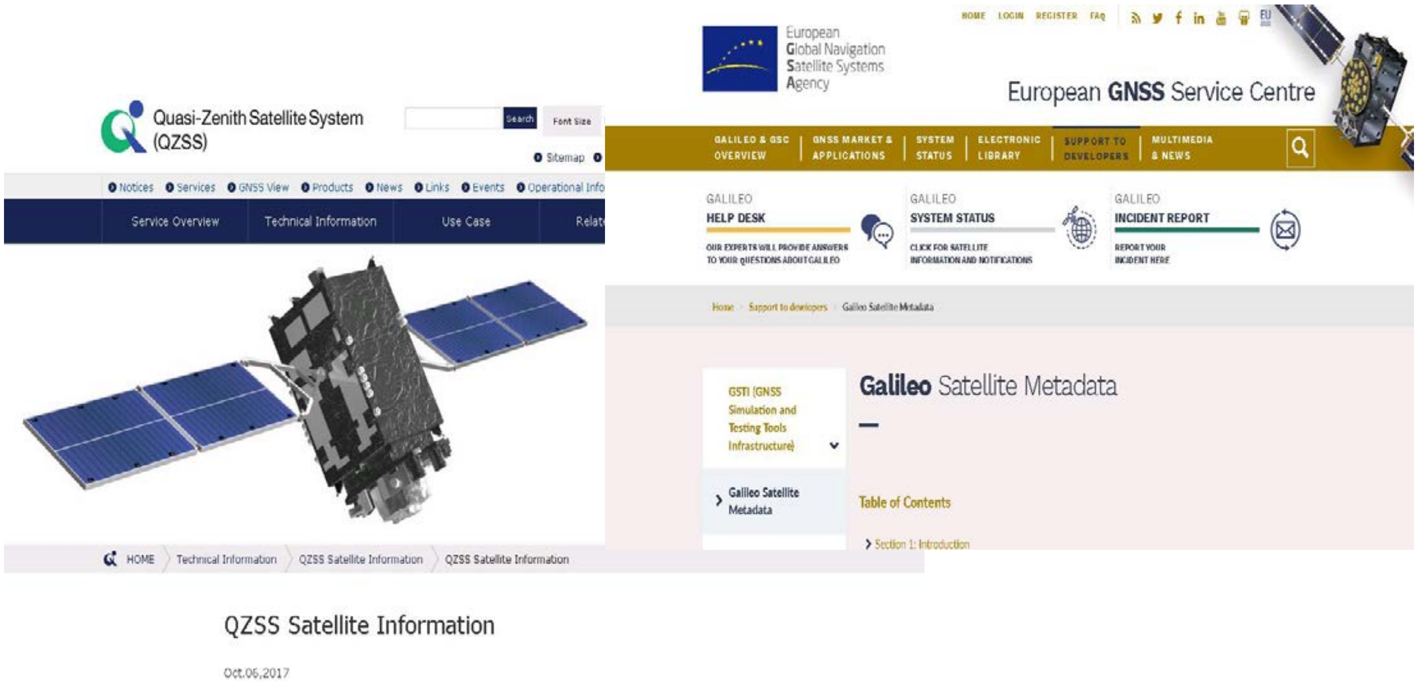
Release of satellite meta data …

- Missing satellite meta data is a limiting factor for accuracy of estimated orbits and clocks, therefore …



- Disclosure of Galileo IOV (Dec. 2016) and FOC (Oct. 2017) meta data by the GSA
- Disclosure of QZS-1 and QZS-2 information by JAXA in several steps in 2017

⇒ … are very appreciated!

… triggered some of the latest model changes

- Observation biases:
  - Change from differential code biases (DCB) to observable-specific biases (OSB) => mainly internal impact (e.g., on ambiguity resolution, multi-GNSS clock solution)

- Antenna calibrations:
  - Use of disclosed antenna phase center offset (PCO) for Galileo IOV and QZS-2
  - Values included or to be included in IGS14-ANTEX file
  - Impact of ANTEX changes analyzed for Galileo IOV (=> Villiger et al. at IGS Workshop 2017)

- Attitude models:
  - Use of disclosed Galileo IOV model for all Galileo SC

- Earth albedo and transmit antenna thrust:
  - Activated for Galileo and QZS-1 (see following slides)

Experiment: Impact of satellite meta data on POD

Information available/assumed for albedo and antenna thrust experiment (data base: MGEX data of first 2 months in 2017):

Galileo:
- Disclosed IOV meta data (satellite mass, size, and surface properties) => sufficient for simple box-wing model
- Later: updated solar panel properties
- Disclosed IOV attitude model
- Same models assumed for FOC (info meanwhile published)
- Estimated antenna transmit power for IOV and FOC provided by Steigenberger et al. at EGU and IGS WS 2017

QZS-1:
- Very coarse info about QZS-1 size provided (e.g., on MGEX website); assumption on surface properties => rough guess on simple box-wing (BW) model
- Wide range of possible SC masses (1800 - 4100 kg)
- Transmission power provided by Kogure et al. in: Springer Handbook of Global Navigation Satellite Systems
- Later: Updated BW model as assumed by Montenbruck et. al (2017)
- QZS-2: not yet considered in the experiment

Experiment: Impact of satellite meta data on POD

Test	Galileo					QZS-1		
Name	Al-bedo	Ant. Thr.	Atti-tude	Pulses	Median SLR [cm]	Albedo	Ant. Thr. (244 W)	Median SLR [cm]
OPER	-	-	-	-	-3.8 (-+4.5)	-	-	-7.8
ALB1	x	-	-	-	-2.0	m= 1800 kg	-	-2.6
AAT1	x	260 W	-	-	+0.6	m= 1800 kg	m= 1800 kg	+0.3
AAT2	x	130 W	-	-	-0.7	m= 3600 kg	m= 3600 kg	-3.7
EAT	x	200 W	x	-	0.0	m= 1950 kg	m= 1950 kg	-0.3
EATP	x	200 W	x	R, S, W; 12h	+0.6	m= 1950 kg	m= 1950 kg	-0.3
EATU (upd…)	x	I: 130 W F:200 W	X	-	-0.2 (-+4.6)	m= 2000 kg	m= 2000 kg	-1.8
EATUP (…BW)	x	I: 130 W F:200 W	X	R, S, W; 12h	+0.5 (-+3.5)	m= 2000 kg	m= 2000 kg	-1.6 (w. PLS)

Experiment: Impact of satellite meta data on POD

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ALB1	x				-2.0	m= 1800 kg	-	-2.6
AAT1	x	260 W	-	-	+0.6	m= 1800 kg	m= 1800 kg	+0.3
AAT2	x	1[illegible]			-0.7	m= [illegible]	m= [illegible]	-3.7
EAT	x	200 W	x	-	0.0			-0.3
EATP	x	200 W	x	R, S, W; 12h	+0.6	[illegible]	[illegible]	-0.3
EATU (upd...)	x	I: 130 W F:200 W	X	-	-0.2 (-+4.6)	m= 2000 kg	m= 2000 kg	-1.8
EATUP (...BW)	x	F:200 W		S, W; 12h	+0.5 (-+3.5)	m= 2000 kg	m= 2000 kg	-1.6 (w. PLS)

Impact albedo: +1.8 cm

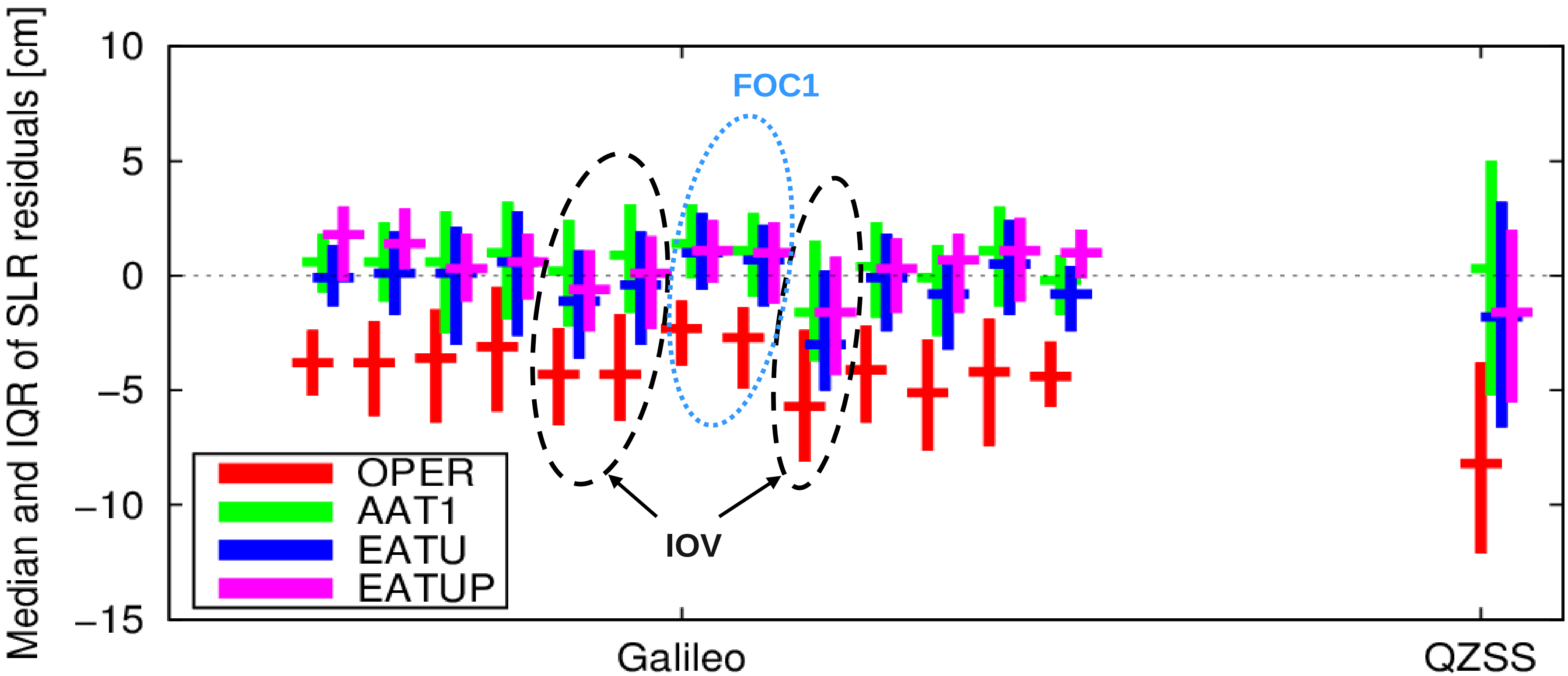
Impact antenna thrust: 1 cm/100 W

Impact SC mass: 2.2 cm/1000 kg

(macro model over-scaled)

Pulses might shift the SLR offset

Experiment: Impact of satellite meta data on POD



⇒ Consideration of albedo and antenna thrust reduces SLR offset

⇒ Uncertainties remain:

- Satellite macro model is rough and sometimes needs corrections (e.g., absorption of SP)
- True satellite mass and CoM not always known
- Uncertainties w.r.t. transmit power
- Antenna calibration also impacts orbit scale

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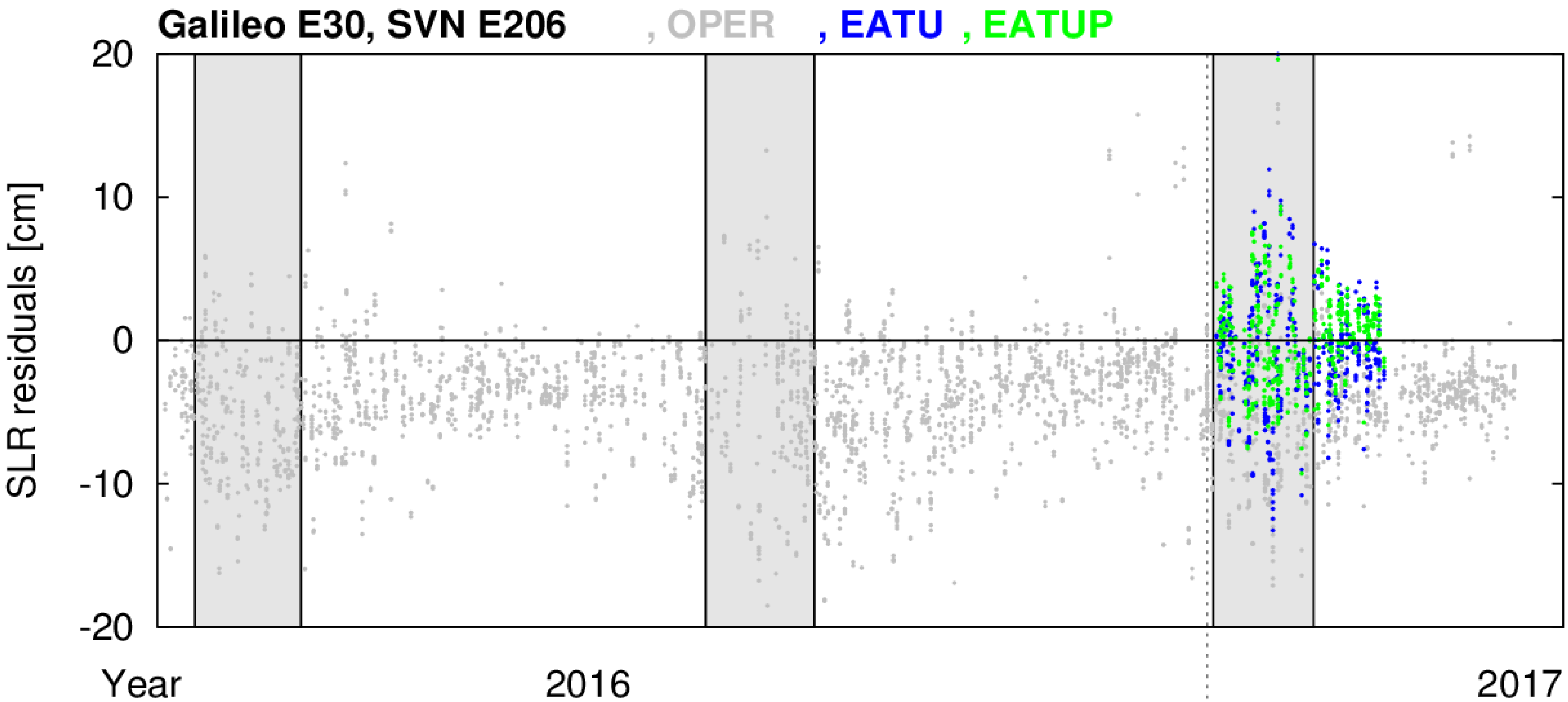
Experiment: Impact of satellite meta data on POD

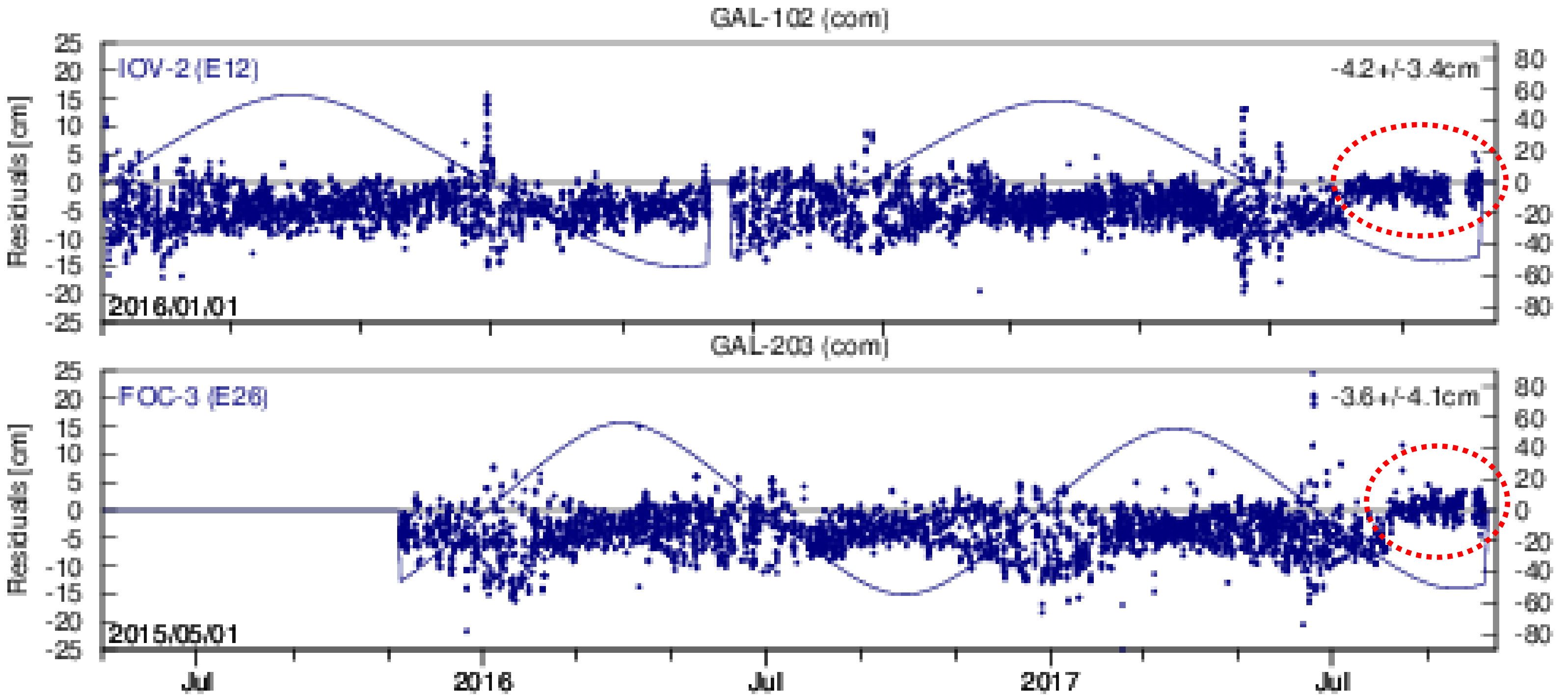


⇒ IOV attitude model (OPER vs. EATU): slight impr. during deep eclipse

⇒ Pulses in R, S, W (EATUP): IQR drops 4.6 → 3.5 cm
(expected future configuration)

⇒ Orbit errors remain increased during eclipses (unmodelled thermal re-radiation from spacecraft?)

Experiment: Impact of satellite meta data on POD



(SLR validation provided by the IGS MGEX: http://mgex.igs.org)

⇒ Model changes active in CODE MGEX solution since GPSWEEK 1962

⇒ Expected orbit improvement confirmed by external validation

Experiment: Effect of IOV antenna calibrations

Table: Average inter-system bias for IOV satellites (E11,E12,E19) in cm

Sol	East	North	Up	σ_{East}	σ_{North}	σ_{Up}
IGS	-2.19	-0.15	2.27	32.02	16.56	33.10
IOV	-0.96	-0.23	1.70	22.54	11.47	19.69

Consistency between GPS and Galileo improves (data base: IGS MGEX network)

STA	Antenna type *Used PCO and PCV:*	GTRA L1/L2 [mm]	GTRA L1/L5 [mm]	Δ GTRA [mm]	Δ PCO [mm]
BRUX	JAVRINGANT_DM NONE	3.7	15.0	-11.3	-8.56
POTS	JAV_RINGANT_G3T NONE	4.9	15.9	-11.0	-9.22
...	...	...	...	...	
ISTA	LEIAR25.R4 LEIT	6.5	14.6	-8.1	-6.53

≈

Remaining limiting factor: Adopting receiver antenna PCO+PCV from L1/L2 frequencies, might cause coordinate offsets with magnitude of PCO difference (data base: EUREF)

(source: **Villiger et al. (2017):** Consistency of antenna products in the MGEX environment. IGS Workshop 2017)

⇒ Impact of satellite antenna calibrations depends also on availability of corresponding **ground antenna calibrations** for all GNSS and frequencies (=> **IGS task**)

CODE MGEX: next steps

Galileo IOV:
- Use of transmit antenna PCV calibrations after inclusion in IGS ANTEX file (released on 23 Oct. 2017)

Galileo FOC: (meta data available since Oct. 2017)
- Update of box-wing model for albedo
- Use of antenna PCO and PCV calibrations (investigation of impact planned)
- Update of attitude model
- Update of antenna transmit power (as soon as data is disclosed)

QZS-1: (new info in Oct. 2017)
- Update of box-wing model for albedo
- Update of transmit power and satellite mass
- Normal attitude and related SRP model

QZS-2: (basic set of info provided in June 2017)
- Use of antenna PCO and PCV calibrations
- Set up box-wing model for albedo modelling and antenna thrust as soon as all neccessary data is provided

Summary and conclusions

- Lack of meta information about spacecraft properties results in poor performance of «precise» orbit determination (POD) - especially for new GNSS
- This limits the usefulness and acceptance of these GNSS for high precision geodetic applications (e.g., ITRF scale)
- Some system providers (namely GSA, JAXA) have recognized this and started to release meta data within the recent months
- Besides information gathered by the scientific community itself (e.g., antenna PCO estimations, antenna transmit power estimations) this information is starting to improve GNSS solutions
- The provision of meta data is therefore appreciated; release of further and more complete satellite meta data is encouraged

Thank you

for

your attention!