Status of the TUM MGEX orbit and clock products

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Abstract

- The Technical University of Munich as member of the Center of Orbit Determination in Europe (CODE) is providing Multi-GNSS orbits and clocks for the MGEX Pilot Project [1] since doy 295 of 2012. The orbits are generated using zero-difference phase and code observations.
- First, GPS CODE rapid orbits and clocks are used in an initial PPP to estimate the receiver coordinates and clocks as well as troposphere parameters.
- In the second step these parameters are fixed and the Galileo, QZSS or BeiDou orbits and clocks are estimated for a one-day arc
- The GNSS daily normal equations are combined to 3-day long-arc solutions
- The final orbits are validated using orbit overlaps, orbit cross-comparisons and Satellite Laser Ranging residuals

Parameter	Setting
Software	Bernese 5.3
Observations	Zero-difference phase- and pseudorange observations
Ambiguities	Float
Elevations	Cut-off angle 5°, elevation dependent weighting with $\cos(z)^2$
Troposphere	GMF, wet delay estimated every 2h, daily horizontal gradients
Ionosphere	No a priori model, Ionosphere-free LC
Sampling	300 sec
Arc-length	3 days

Table 1: *General processing settings*

Timeline

Since tum19251.sp3:

- [2] Inclusion of an a priori box-wing model for Galileo [3], attitude models [4], increase of station network

Since tum20130.sp3:

- Inclusion of BeiDou-2 MEO and IGSO orbits into the TUM MGEX product

Since tum20221.sp3:

- Improved radiation pressure modelling was achieved for non-cubic satellites such as Galileo and QZSS by using a priori box-wing models from published or estimated optical properties
- Arc length set from 5 days to 3-days for Galileo orbits
- Consideration of Earth Albedo
- Consideration of antenna thrust

Radiation pressure modelling

Considering solar radiation pressure modelling optical properties for use in a priori box-wing models were estimated for the Galileo IOV and FOC, QZSS and BeiDou satellites [5] (SLR see table 5). The results were validated using the available metadata for Galileo and most recently QZS-2 - QZS-4 metadata. The metadata box-wing model was adopted for Galileo and QZSS where large orbit improvements could be achieved compared to a solution without box-wing model due to their non-cubic shapes, whereas the BeiDou MEO and IGSO satellites did not seem to benefit from the estimated a priori model. BeiDou GEO improve, but are not yet included to the tum product.

GNSS	RPR
Galileo	Galileo: A priori box-wing model using metadata properties + ECOM (D0, Y0, B0, BC, BS)
QZSS	QZSS: A priori box-wing model (estimated optical properties [3]) + ECOM (D0, Y0, B0, BC, BS)
BeiDou	No a priori model, ECOM (D0, Y0, B0, BC, BS)

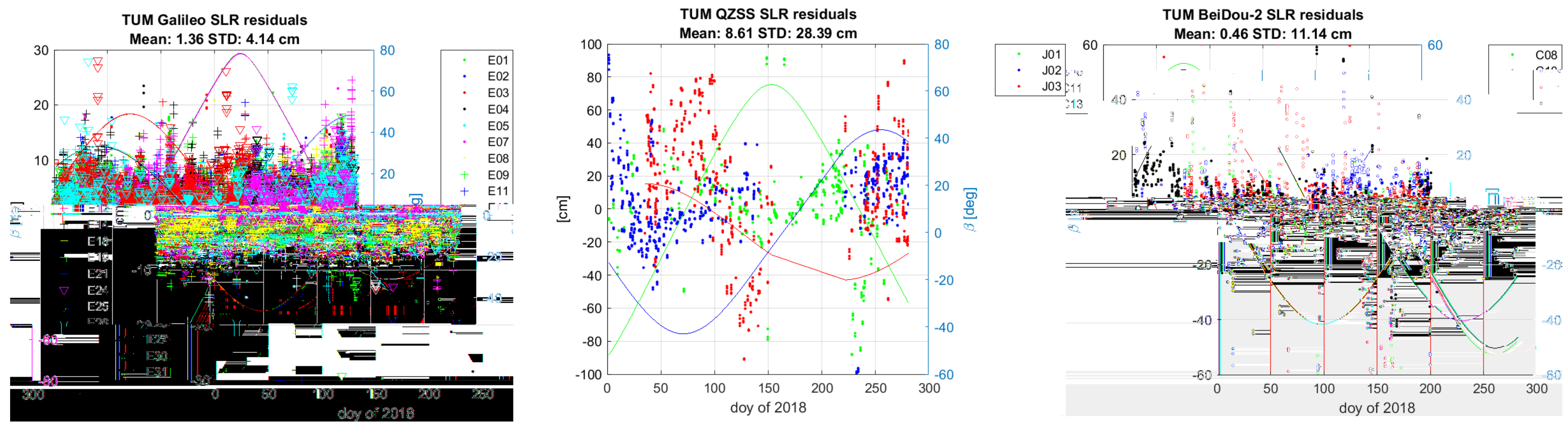
Table 2: *Radiation pressure modelling*

Earth Albedo

The Radiation pressure stemming from Earth was applied using an analytical model. It has however a minor impact on the orbits of mm-level.

Orbit and clock analysis for 2018

SLR residuals in 2018:

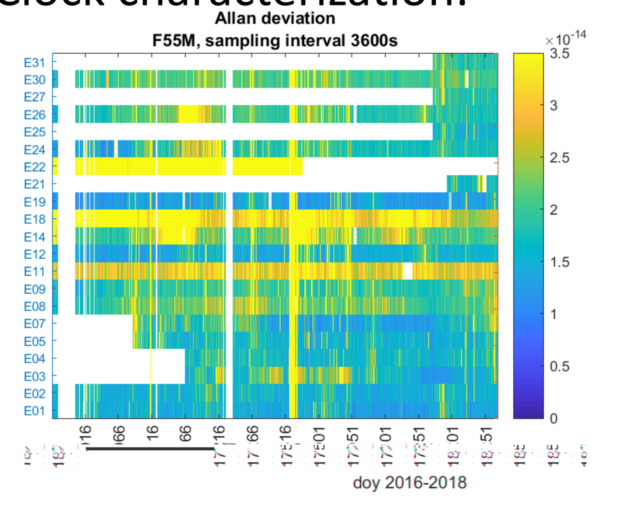


Orbit comparisons with other analysis centers for doy 001 – 275 of 2018 (Mean ± Standard deviation [cm], threshold 50 cm for Galileo and BeiDou-MEO, 1m for BDS-IGSO, 2m for QZSS):

		COM	GBM	GRM			COM	GBM
Galileo	Radial	-0.91 ±3.04	-0.57±2.70	-1.92±3.64	QZS-IGSO	Radial	17.0±45.51	-4.59±34.78
	Along	0.93±8.74	0.23±8.81	0.97±10.08		Along	-20.46±77.65	3.31±68.62
	Across	-0.06±6.34	-0.24±6.67	-0.28±8.17		Across	-9.95±68.90	−6.05 ±53.62
BDS-MEO	Radial	-0.71±25.08	1.15±30.63	-	BDS-IGSO	Radial	-0.71±25.08	1.15 ±30.63
	Along	-1.61±41.14	-2.61±47.8	-		Along	-1.61±41.14	-2.61±47.80
	Across	0.48±32.31	1.61±40.41	-		Across	0.48±32.31	1.61±40.41

Table 4: *Orbit comparisons*

Clock characterization:



Influence of box-wing models on SLR residuals standard deviation (Yaw steering | orbit normal) mode [cm]:

GNSS	ECOM	ECOM+BW	Improvement
Galileo	8.2	4.2	48.8 %
QZS-1	19.9 | 33.7	4.8 |10.5	75.9 % | 68.8 %
QZS-2	27.0	19.1	29.2 %
BeiDou-MEO	12.2 | 16.4	13.1 | 17.4	-7.4 % | -6.1 %
BeiDou-IGSO	10.0 | 12.3	10.8 | 12.3	-8.0 % | 0.0 %

Table 5: *Summary of SLR-results for estimated box-wing models*

Antenna thrust

The antenna thrust has an impact on the radial direction of up to a few cm, depending on the satellite's mass and transmit power. Official values for the transmit power have been published for GPS and QZSS, the remaining values stem from estimates of Steigenberger et al. [6].

Satellite type	Satellite mass	Transmit power	Radial Change
Galileo E101/E102	700 kg	130 W	-1.34 cm
Galileo E103	700 kg	100 W	-1.03 cm
Galileo E104	700 kg	155 W	-1.60 cm
Galileo FOC	700 kg	260 W	-2.68 cm
QZS-1	2300 kg	250 W	-2.3 cm
QZS-2	2300 kg	500 W	-4.4 cm
QZS-3	2800 kg	550 W	-4.2 cm
QZS-4	2400 kg	500 W	-4.5 cm
BeiDou 2M	2200 kg	130 W	-0.36 cm
BeiDou 2I/2G	2200 kg	180 W	-0.50 cm

Table 3: *Influence of antenna thrust*

Use of Metadata

The published metadata for Galileo and QZSS was largely included. The a priori box-wing models for Galileo and QZS-2 - 4 use the published optical and geometrical data. For QZS-1 optical parameters are not yet available and were therefore estimated. The antenna phase center variations are now included in the IGS ANTEX files which are also used in the TUM processing. The official antenna thrust values were adopted where available. The published attitude laws are not yet fully implemented.

Conclusions and outlook

The TUM orbit product now includes BeiDou-2 IGSO and MEO satellites. The orbit modelling was improved particularly for QZSS by using an a priori box-wing model. Furthermore, effects of Earth Albedo and antenna thrust are now considered.
QZSS and BeiDou-2 geostationary as well as BeiDou-3 satellites are not yet included into the official product. Also, the existing BeiDou-2 MEO/IGSO orbits should be improved. Furthermore, the attitude modes as well as a ambiguity-fixing will be investigated in the future.

[1] Montenbruck O., Steigenberger P., Khachikyan R., Weber G., Langley R.B., Mervart L.,Hugentobler U., "IGS-MGEX:Preparing the Ground for Multi-Constellation GNSS Science", Inside GNSS 9(1):42-49 (2014); **[2]** Selmke I., Hugentobler U., "Multi-GNSS orbit determination using 2-step PPP approach", poster at IGS Workshop 2017, Paris.; **[3]** Montenbruck O., Steigenberger P., Hugentobler U. (2014) "Enhanced solar radiation pressure modeling for Galileo satellites", J Geod (2015) 89:283-297, doi: 10.1007/s00190-014-0774-0; **[4]** Ebert K., Oesterlin W.; Astrium GmbH. Dynamic yaw steering method for spacecraft. European patent specification EP 1 526 072 B1. 2008; **[5]** Duan B., Hugentobler U., Selmke I., Hofacker M., "Adjusted Optical Properties for Galileo, BDS and QZSS Satellites from Precise Orbit Determination", presentation at EGU 2018, Wien; **[6]** Steigenberger P., Thölert S., Montenbruck O., "Measuring GNSS Satellite Transmit Power", presentation at IGS Workshop 2017, Paris

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