Multi-GNSS orbit determination using 2-step PPP approach

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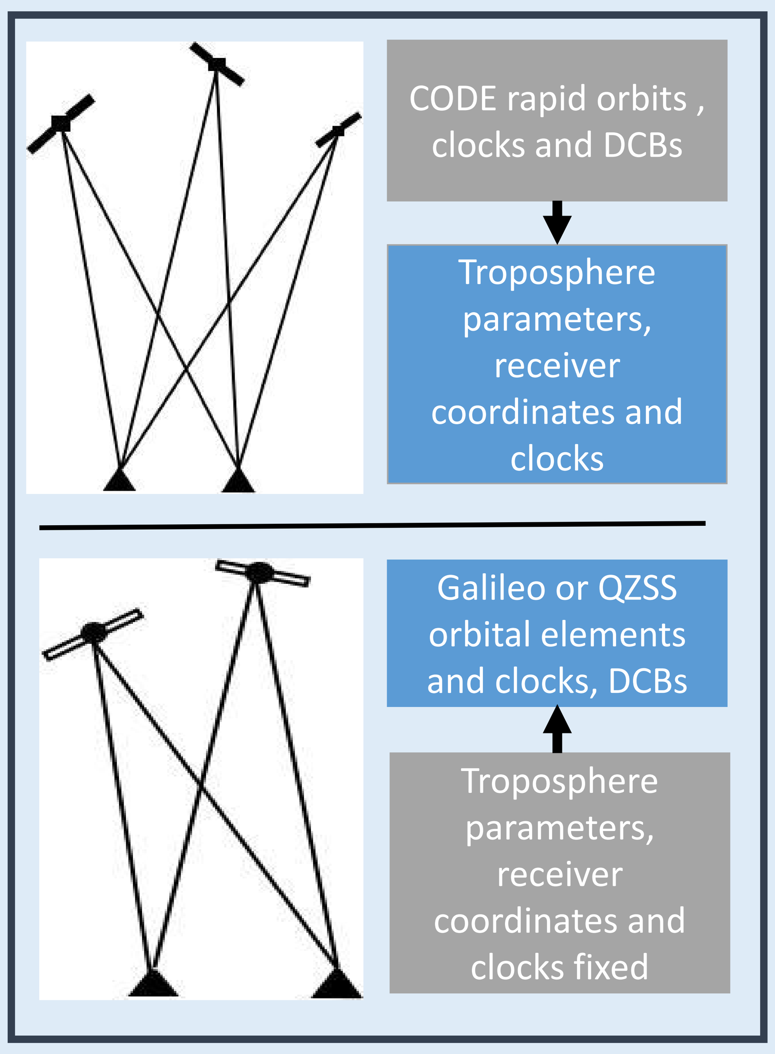
Outline

For the Multi-GNSS precise orbit determination within the MGEX Pilot Project [1] Technische Universität München as member of the CODE consortium is using a 2-step PPP (Precise Point Positioning) approach. In the first PPP step GPS CODE rapid orbits and clocks are used to estimate station coordinates, troposphere parameters and receiver clocks. These estimated parameters can then be fixed for the second PPP step where only the Galileo- and QZSS-specific parameters are estimated. These include the keplerian orbital elements, the satellite clock corrections and Differential Code Biases.

Processing switch on 30th November 2016 [2]:
Main improvement was the use of an a priori box-wing model for Galileo, but also the inclusion of additional stations and Galileo- and QZSS-specific attitude models.



Overview

Option	Settings
Software	Bernese GNSS Software (mod. Vers. 5.3)
Sampling	300 s
Elevations	Cutoff angle 5°, elevation dependent weighting with cos(z)**2
Troposphere	Global mapping function Wet part estimated every 2 hours Daily gradients: Chen&Herring
Stations	Ca. 70
Ambiguities	Float
Solar radiation pressure	A priori model: Box-wing ECOM-parameters: D0, Y0, B0, BC, BS
Arc length	Galileo: 5 days QZSS: 3 days

Table 1: *Parameter settings*

Long arc orbits

Orbit 1	Ref.	RMS	RMS Radial	RMS Along-Track	RMS Cross-Track
Orbit overlaps					
F1	F5	9.54	3.24	11.85	8.67
F1+1	F5	34.57	8.72	56.56	9.35
F1+2	F5	111.40	18.63	184.56	15.89
F5+1	F5	3.87	1.07	5.04	3.08
F5+2	F5	8.13	2.37	11.35	5.86
F3+1	F3	5.25	1.60	7.09	4.08
Orbit prediction					
R5+1	F5	23.14	4.99	36.17	9.12
R5+2	F5	53.92	9.71	87.14	12.99
R3+1	F5	15.69	4.11	23.94	7.16
R3+1	F3	15.41	3.79	23.33	7.17

Table 2: *Galileo orbit overlaps and predictions from 40 days in [cm]*

By combining the normal equations from the daily solutions a long arc can be formed for the final solution.

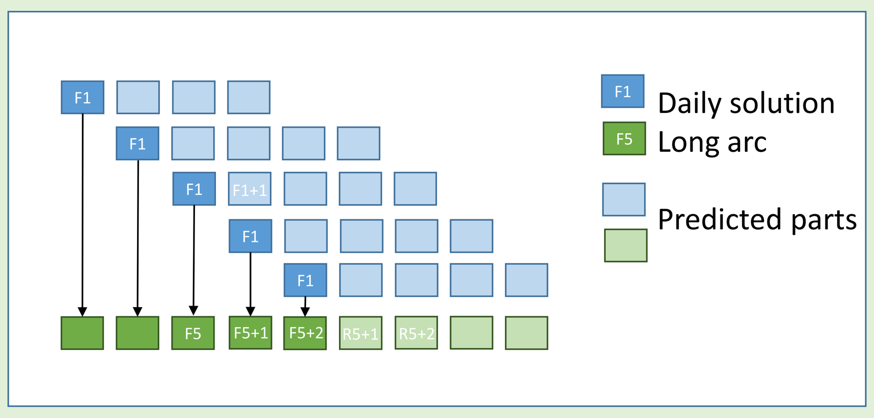


Figure 1: *5-day long arc combination*

The results from table 2 show in the first half orbit overlaps of the Galileo daily (F1), 3-day long arc (F3) and 5-day long arc (F5) solutions, indicating the consistency of the orbits. The second half compares the rapid products (predicted part of a long arc solution) using 3- or- 5-days with the final 5-day solution. The results indicate a better prediction for the 3-day (R3+1) than the 5-day rapid products (R5+1).

Satellite clocks

The allan deviation of the estimated Galileo satellite clocks shows the typical behavior of the high quality Passive Hydrogen Masers. Looking at the long-term values of the daily estimates for a particular averaging interval, the differences between the satellites become clearer.

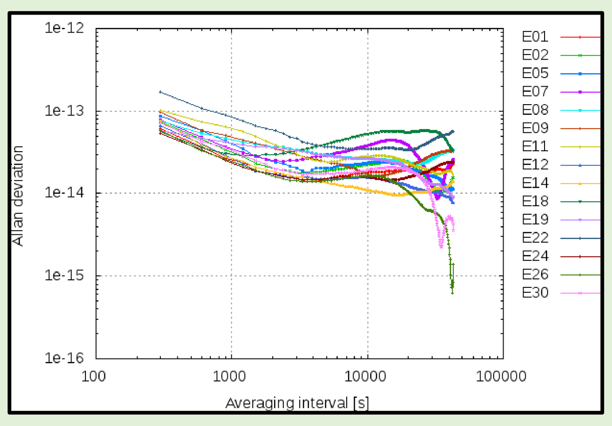


Figure 2: *Allan deviation of daily satellite clock estimates for 1st May 2017*

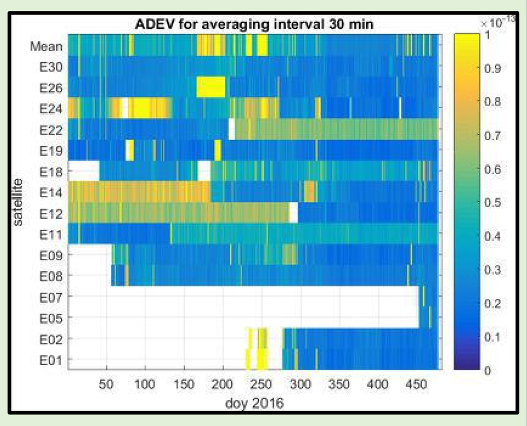


Figure 3: *Allan deviation for 30 min averaging interval over 480 days*

Orbit validation

The estimated orbits can be validated using e.g. normal points from satellite laser ranging as an independent measurement method. The SLR residuals for the different MGEX products show differences mainly due to the solar radiation pressure models used. For TUM [fig. 5, first row] since the version switch on 30th November 2016 an a priori box-wing model is used. The SLR residuals now are much less dependent on the sun elevation angle and generally smaller. For QZSS a nominal attitude model for low sun elevation angles was introduced in the new version.

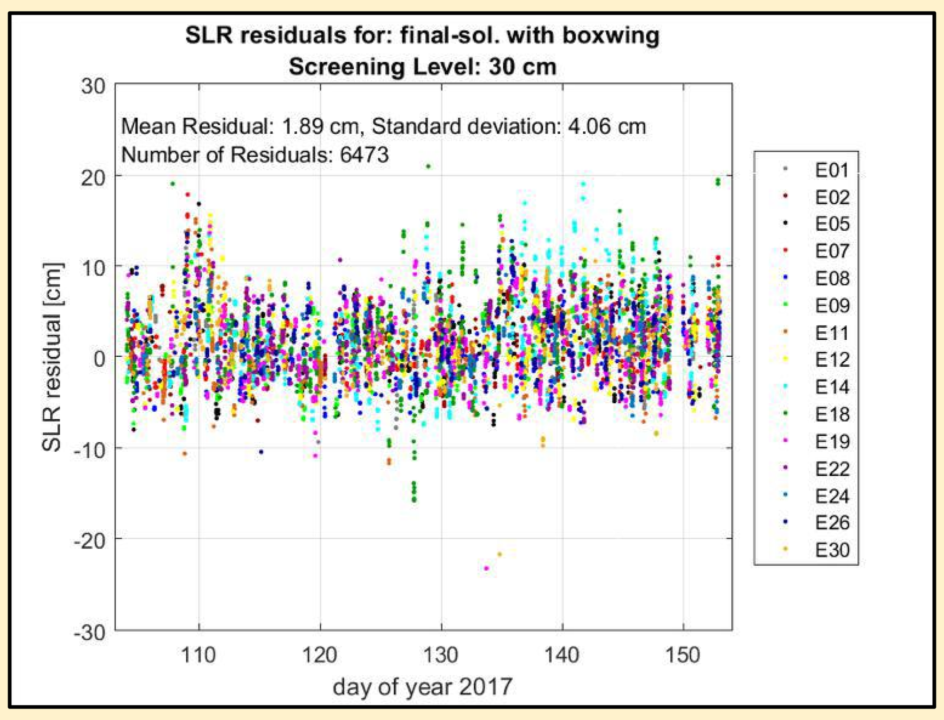


Figure 4: *Galileo SLR residuals for final solution*

	Mean			RMS		
	Radial	Along-Track	Cross-Track	Radial	Along-Track	Cross-Track
TUM-COM	0.01	0.03	0.01	0.06	0.03	0.18
TUM-GBM	0.02	0.03	0.00	0.09	0.25	0.18
COM-GBM	0.04	0.00	0.00	0.09	0.16	0.07
COM-GRM	0.04	0.00	0.00	0.07	0.19	0.09

Table 3: *Comparisons between MGEX Galileo orbits for orbits since 1st January 2016 [m]. Values from [3]*

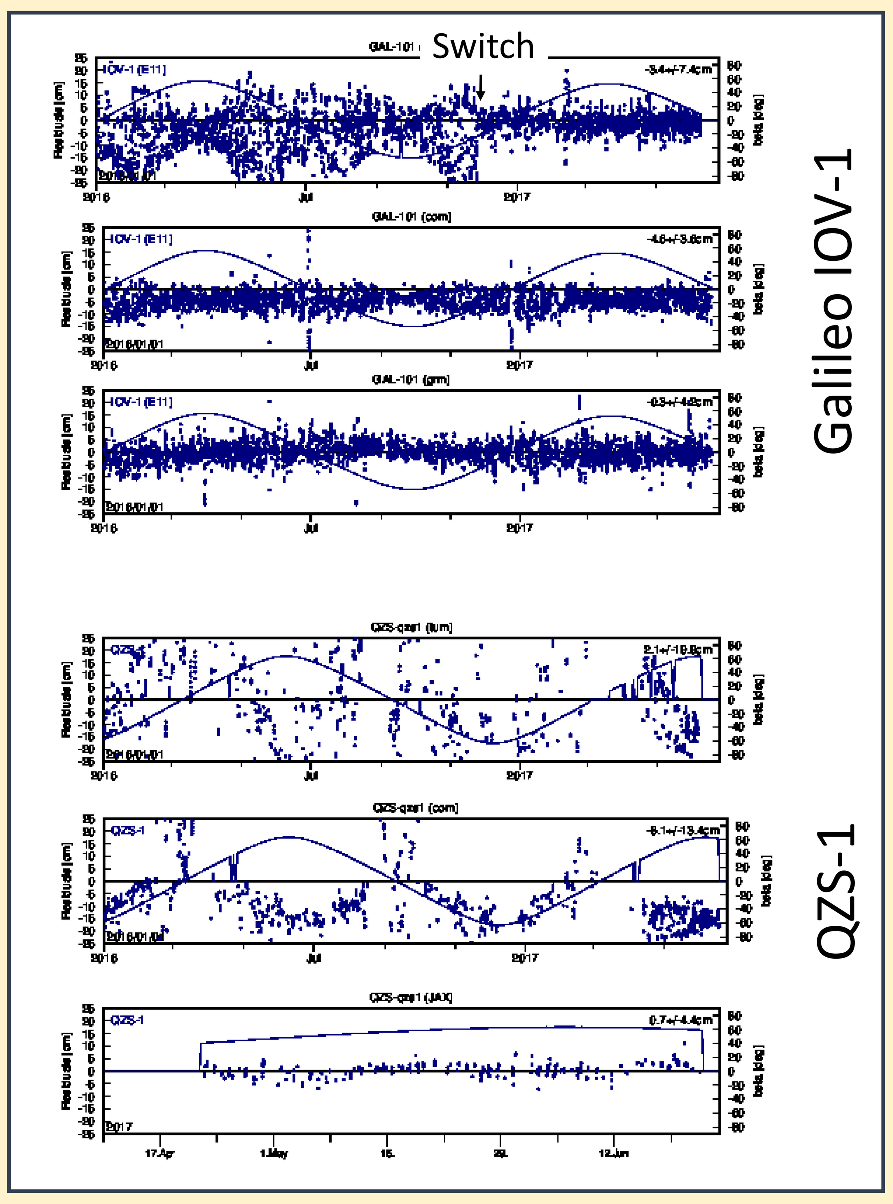


Figure 5: *Selection of SLR residuals [3] for different MGEX products*

Another validation method is of course the comparison with other MGEX products as shown in table 3.

[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", InsideGNSS 9(1):42-49 (2014). [2] IGSMAIL-7377: https://igscb.jpl.nasa.gov/pipermail/igsmail/2016/008567.html. [3] MGEX website: http://mgex.igs.org/analysis
[4] European GNSS Service Centre: https://www.gsc-europa.eu/support-to-developers/galileo-iov-satellite-metadata

IOV Metadata

In December 2016 metadata for the four Galileo IOV satellites were published [4]. The metadata includes e.g. a dynamical yaw-steering attitude model, satellite mass, satellite surface properties and antenna phase center offsets and variations. These data can serve to improve precise orbit determination. So far a similar dynamical yaw-steering model which was available before the declassification of the metadata is implemented and the new PCO values adopted.

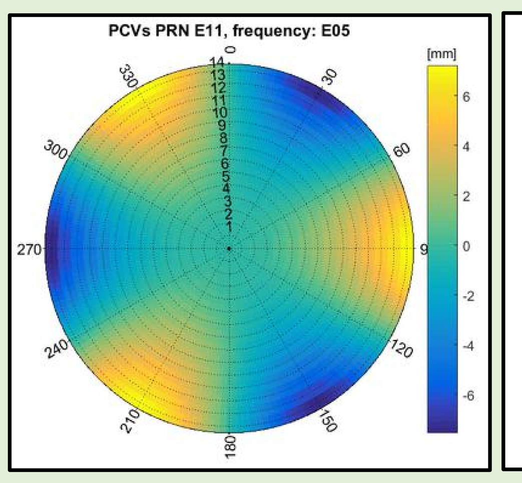


Figure 6: *Phase center variations for satellite E11 and frequency E05*

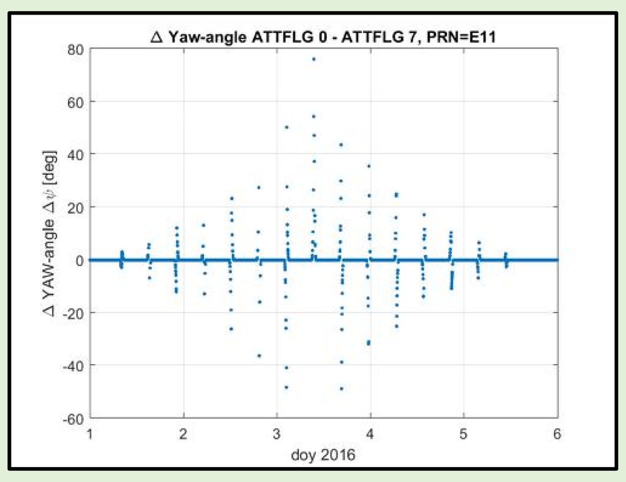


Figure 7: *Yaw-angle differences between nominal and IOV attitude model observed for low sun elevation angles*

Conclusions and outlook

The inclusion of the box-wing a priori model clearly improved the radial component of the Galileo orbits as visible in the SLR-residuals. However, the overall quality in comparison to other MGEX products may still be improved, e.g. by mean of better preprocessing. Next steps for the TUM MGEX product will also include the estimation of Beidou orbits and further analysis of the IOV metadata.

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