Investigation on systematic offsets between different Swarm orbit solutions

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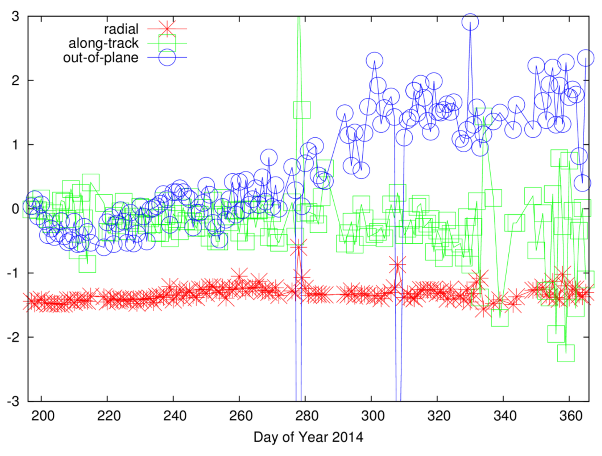
Motivation and Background

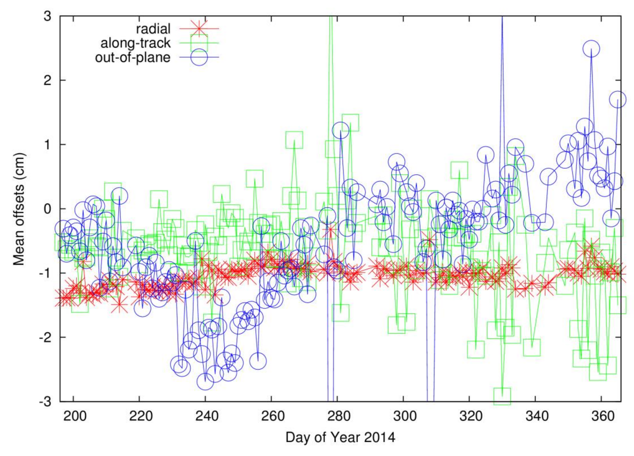
AIUB ⇔ TUD

Swarm A



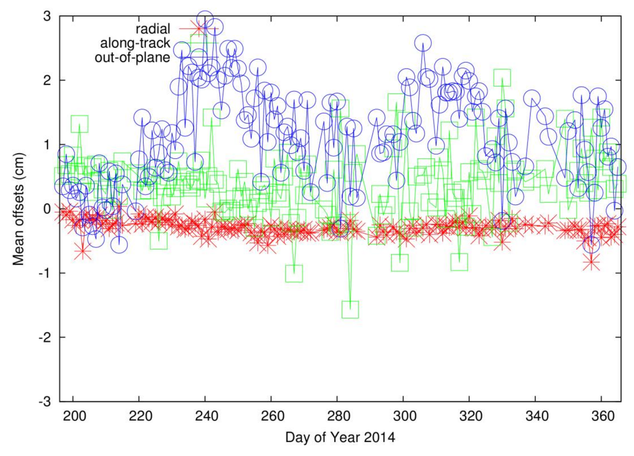
	Mean
rad	-1.42
alo	0.20
cro	1.08

AIUB ⇔ PTIM



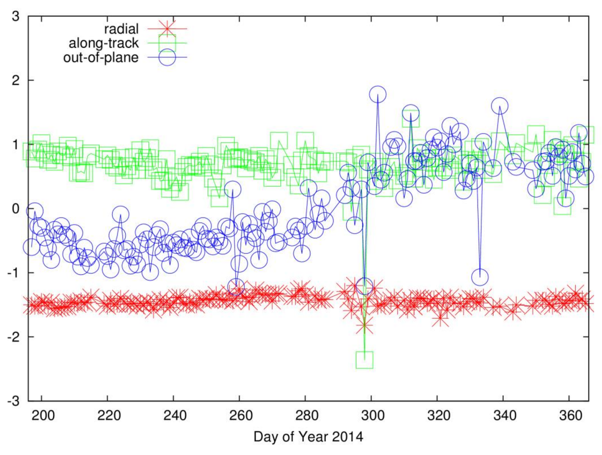
	Mean
rad	-1.13
alo	-0.18
cro	-0.09

TUD ⇔ PTIM

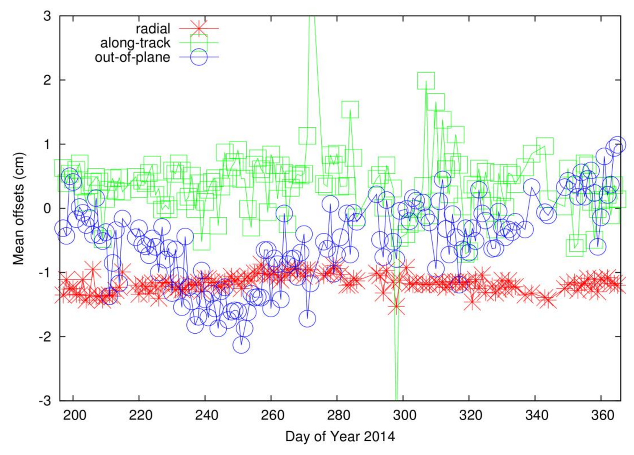


	Mean
rad	-0.29
alo	0.38
cro	1.16

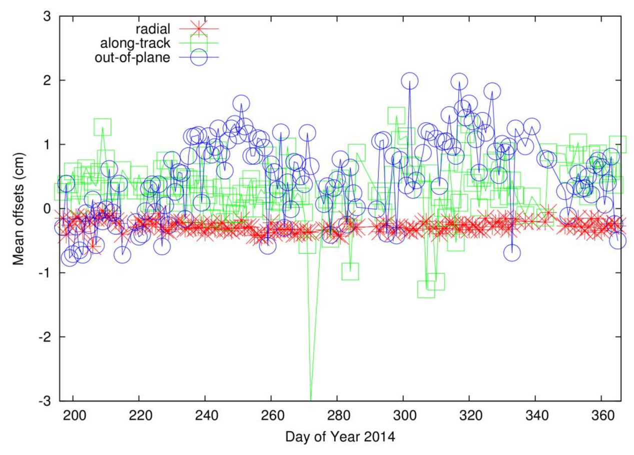
Swarm B



	Mean
rad	-1.49
alo	0.83
cro	0.25

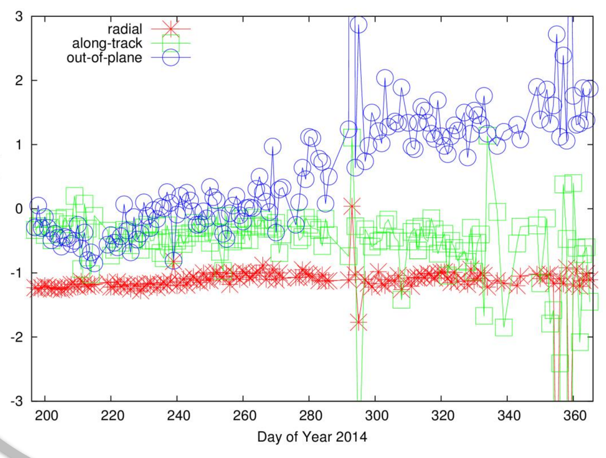


	Mean
rad	-1.22
alo	0.51
cro	-0.28

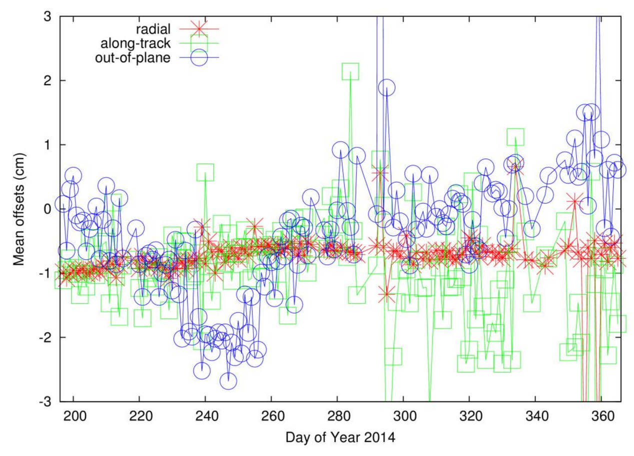


	Mean
rad	-0.28
alo	0.33
cro	0.52

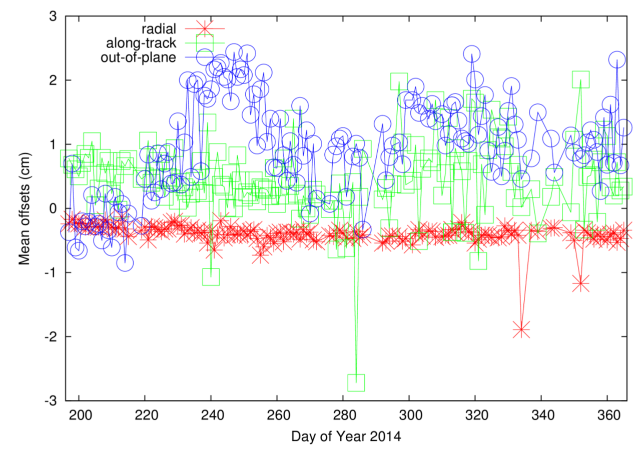
Swarm C



	Mean
rad	-1.21
alo	0.00
cro	1.18



	Mean
rad	-0.82
alo	-0.46
cro	0.21



	Mean
rad	-0.39
alo	0.46
cro	0.97

In addition to the official **Swarm orbit solutions** from TU Delft (**TUD**) the Astronomical Institute of the University of Bern (**AIUB**) and PosiTim (**PTIM**) are computing orbits for the Swarm satellites. Orbit comparisons reveal **systematic mean offsets (cm)** between the solutions.

The focus is in particular on the radial component, because systematic offsets may hint to erroneous information about the satellite geometry (e.g., position of the center of mass or antenna reference point). Additionally, the radial offsets are very consistent between the three solutions and similar for all three satellites.

The use of different software packages at TUD (GHOST), AIUB (Bernese GNSS Software) and PosiTim (NAPEOS) offers the chance to investigate the inconsistencies.

Induced radial orbit offsets by PCVs

The orbit models and parameterization in NAPEOS are following dynamical models to a large extent. Only few empirical parameters in along-track and out-of-plane directions allow for absorption of mismodelled accelerations. Mainly in radial direction, discrepancies between models and observations are, therefore, absorbed by the observation residuals.

The phase observation residuals, however, are used to estimate the antenna phase center variations (PCVs), which are applied in the final orbit determination process.

If an erroneous information in the satellite geometry exists, this mismatch is mapped into the PCVs (not to the full extent) generated by NAPEOS.

The PCVs can easily be tested for induced radial offsets by performing a simple least squares adjustment:

Using the vectors **Δr =(E, N, U)** and **e =(sin α*sin z,cos α*sin z, cos z)** the PCVs can be expressed with the following equation

PCV = -sin α*sin z*E - cos α*sin z*N - cos z*U + ΔΦ

A simple least square adjustment is set up for this purpose. The parameters **E, N** and **U** and **ΔΦ** may then be estimated from a set of PCVs.

We are mainly interested in the radial direction corresponding to the parameter U (Up direction). The following table summarizes, which radial offsets are induced by a set of PCVs when applying a priori a specific Up value for the PCOs (the original PCO Up value is 0.0 mm).

E: East, N: North, U: Up, α: azimuth, z: zenith distance, ΔΦ: arbitrary phase offset

PCVs based on updated PCO Up value

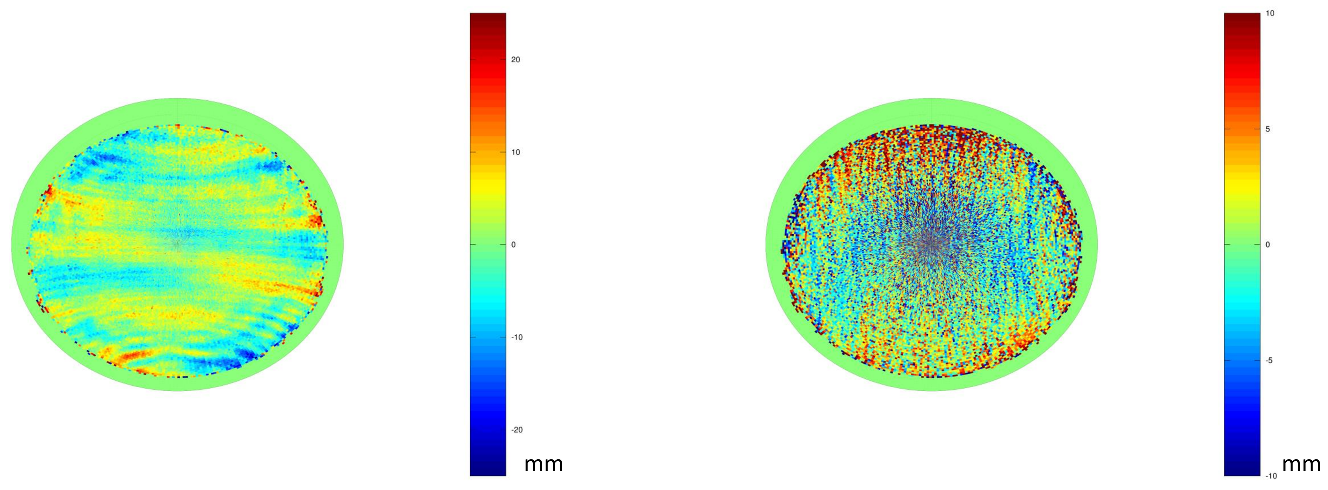
	Induced radial offset of resulting PCVs		
PCO Up value (mm)	Swarm A	Swarm B	Swarm C
-12.0	1.0	2.0	2.6
-10.0	**-0.3**	**0.7**	**1.3**
-9.5	0.5	0.8	2.2

Values obtained after 3 iterations

➡ Values obtained after 1 iteration only, but values are getting larger from iteration to iteration. Therefore, -9.5mm is no option.

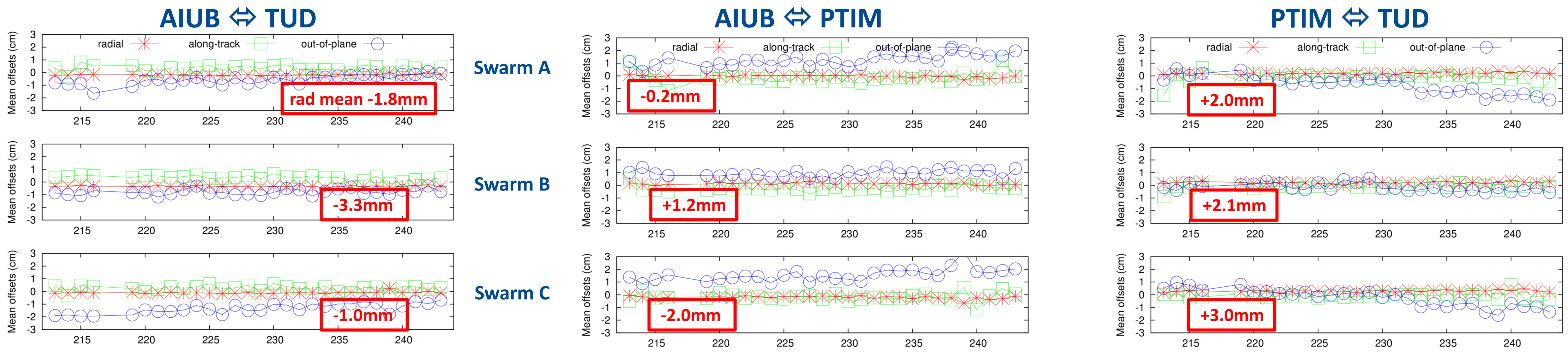
A new PCO Up value of -10.0 mm is selected for all three satellites and new sets of PCVs are computed for Swarm-A, -B and –C.

Updated PCVs for Swarm-A based on data from Aug – Dec 2014 (left). Differences between original PCVs for Swarm-A and new PCVs (right).



New orbit solutions – PCO Up value modified from 0.00 mm => -10.00 mm

AIUB ⇔ TUD **AIUB ⇔ PTIM** **PTIM ⇔ TUD**



	Swarm	Original Mean (cm)	solutions STD (cm)	New Mean (cm)	solutions STD (cm)
	A	0.51	1.92	0.37	2.03
TUD	B	-0.02	1.95	-0.01	1.97
	C	0.18	1.91	0.06	2.18
	A	1.15	2.21	0.56	2.18
AIUB	B	0.72	1.98	0.09	1.98
	C	0.72	2.12	0.13	2.11
	A	0.36	2.43	0.28	2.53
PTIM	B	0.18	1.99	0.14	1.98
	C	0.06	2.18	0.02	2.38

Note: The SLR validation is done without applying the azimuth-elevation dependent retro-reflector corrections.

New orbit solutions are computed by AIUB, PTIM and TUD applying the modified PCO Up value of -10.0 mm for all three satellites.

The systematic radial offsets can significantly be reduced with the new orbit solutions. The remaining radial offsets are within -3 …+3 mm.

The SLR validation (Table on the left) of the new orbits indicates reduced mean values for all orbit solutions (marked in green), however, the standard deviations increase in most cases.

Summary and Outlook

Systematic radial offsets of up to 1.5 cm are present between different Swarm orbit solutions.

When applying modified phase center offset values in the Up direction of -10.00 mm instead of 0.00 mm the systematic radial offsets can be significantly reduced below 3 mm.

In terms of the mean values the SLR validation confirms that the modified PCO value improves the orbits. However, the standard deviations of the statistics do not confirm the improvement.

Further investigations on the systematic radial orbit offsets are necessary to confirm the improvement of the orbit products based on all possible measures (orbit comparisons, SLR validation).

The out-of-plane offsets have to be investigated as well. The improvement of the modelling of the non-gravitational forces acting in out-of-plane direction are in focus for this.

Poster compiled by H. Peter, May 2016
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