

Assessment of COSMIC–2 reduced–dynamic and kinematic orbit determination

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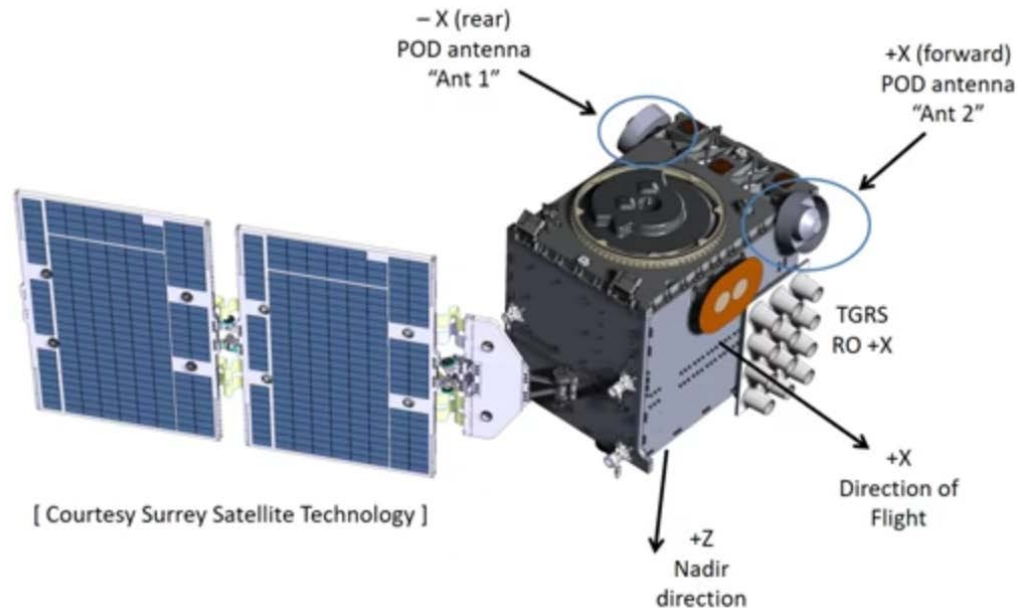
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COSMIC-2 satellites



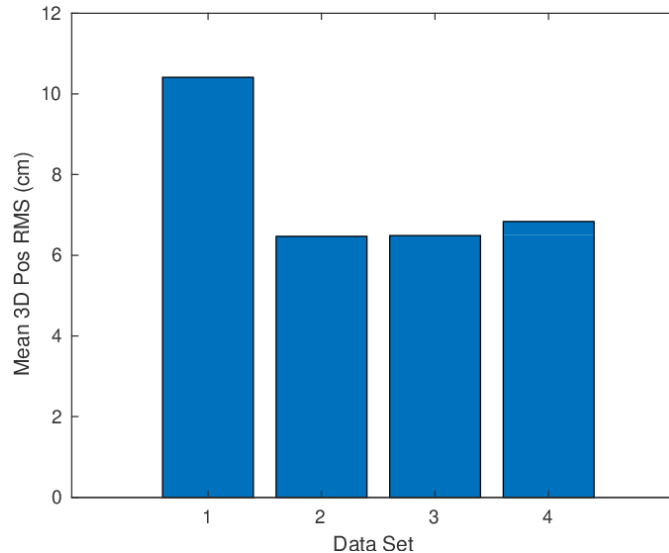
- Six satellite constellation around the equator (24° inclination, 520 km altitude).
- Main mission purposes are radio occultation sounding for improved numerical weather prediction, space weather monitoring, trending of climate change.
- Equipped with two POD antennas tilted 75° from zenith to allow for ionospheric profiling. GPS and Glonass are tracked by the POD antennas.
- Rear antenna ("Ant 1") normally used for POD since more observations are scheduled.

Orbit solutions

- **Reduced-dynamic solutions**
 - **Antenna 1 or Antenna 2 used**
 - Ambiguity float
 - Ambiguity fixed
 - **Antennas 1 and 2 combined**
 - Ambiguity float
 - Ambiguity fixed
- **Kinematic solutions**
 - **Antenna 1 or Antenna 2 used**
 - Ambiguity float
 - Ambiguity fixed
 - **Antennas 1 and 2 combined**
 - Ambiguity float
 - Ambiguity fixed

Separate receiver clocks are estimated for the two antennas.

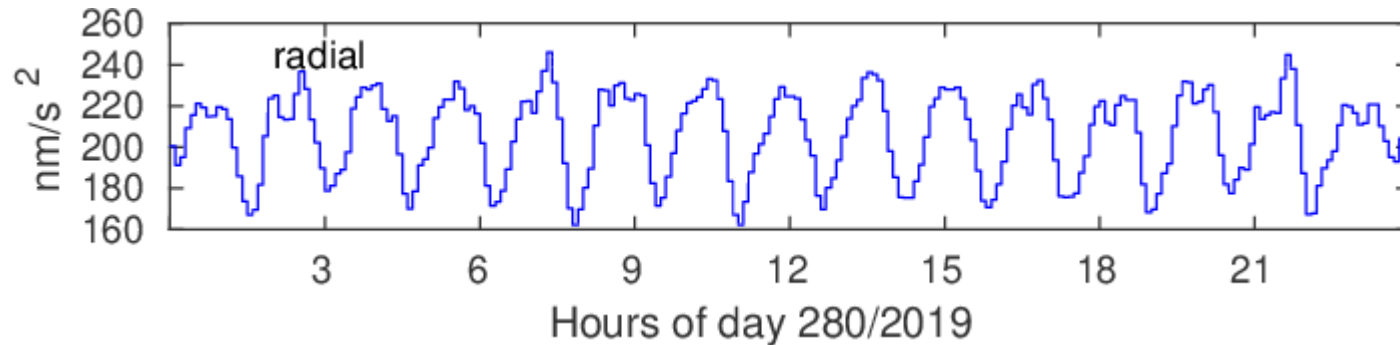
Overlaps of reduced-dynamic float solutions



Overlaps are based on one single overlapping point of 24 h arcs. It is a pessimistic measure to assess orbit precision.

- **Data Set 1 (initial flight s/w): Oct. 2019, FM-1, POD-1 used, GPS only used**
=> Data based on the initial flight s/w are used in the following slides
- **Data Set 2 (latest flight s/w): Oct. 2019, FM-1, POD-1 used, GPS only used**
=> Better overlaps compared to data set 1
- **Data Set 3 (latest flight s/w): Oct. 2019, FM-1, POD-1 used, GPS & Glonass used**
=> No significant changes due to the inclusion of the (low volume) of Glonass data
- **Data Set 4 (latest flight s/w): Nov. 2020, FM-1, POD-1 used, GPS only used**
=> Results in line with those shown in Weiss et al. (2021)

Estimated accelerations

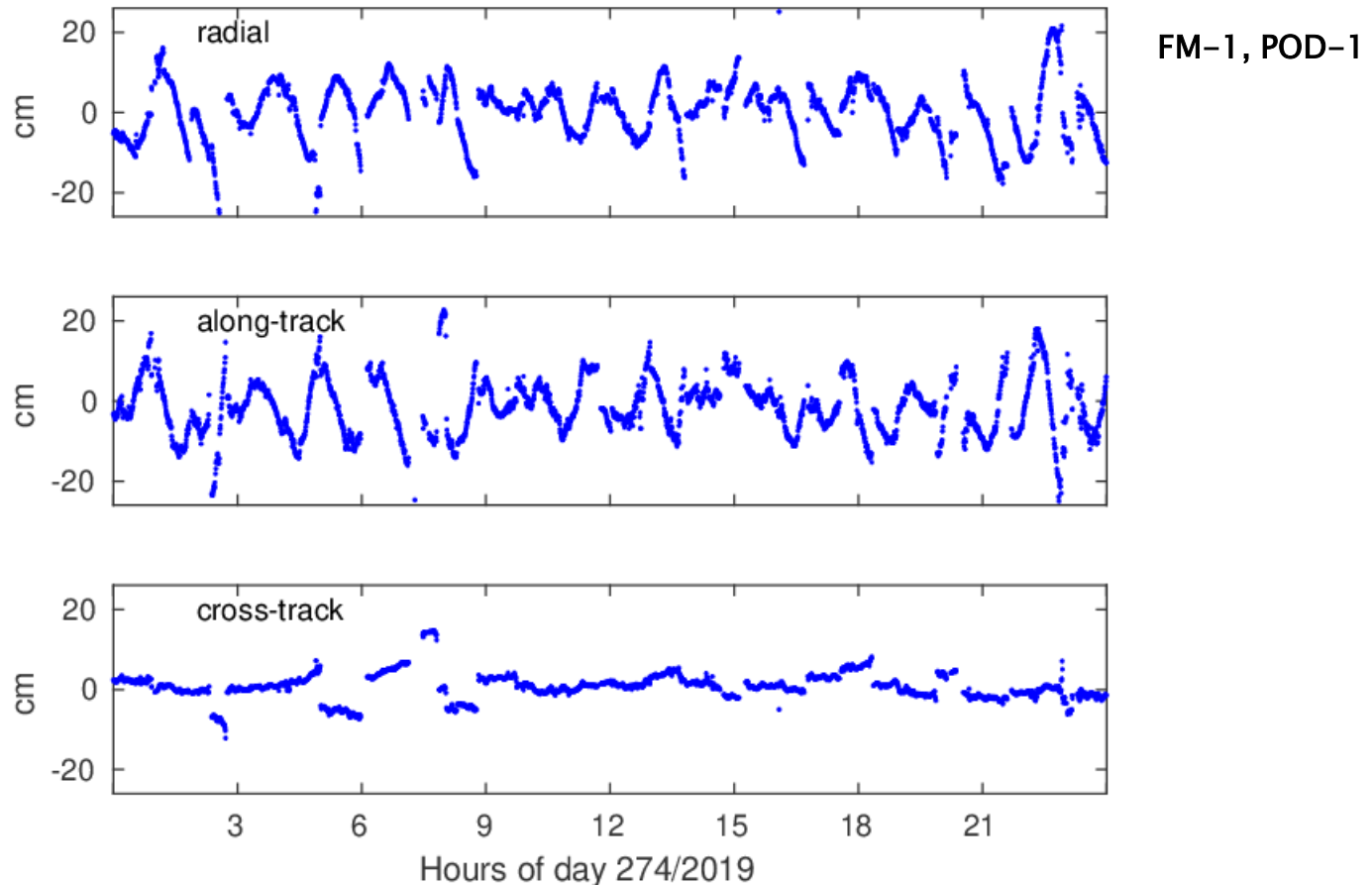


The levelling of the computed reduced-dynamic solutions is similar to a “kinematic” solution due to the estimation of a free mean offset of the piecewise constant accelerations in the radial, along-track, and cross-track directions.

A large mean offset of about **204 nm/s²** is observed in the radial direction. If the entire effect of the observed mean acceleration would be of artificial nature (erroneous GPS antenna offset, CoM position), this would correspond to a wrong leveling as large as 5.5 cm.

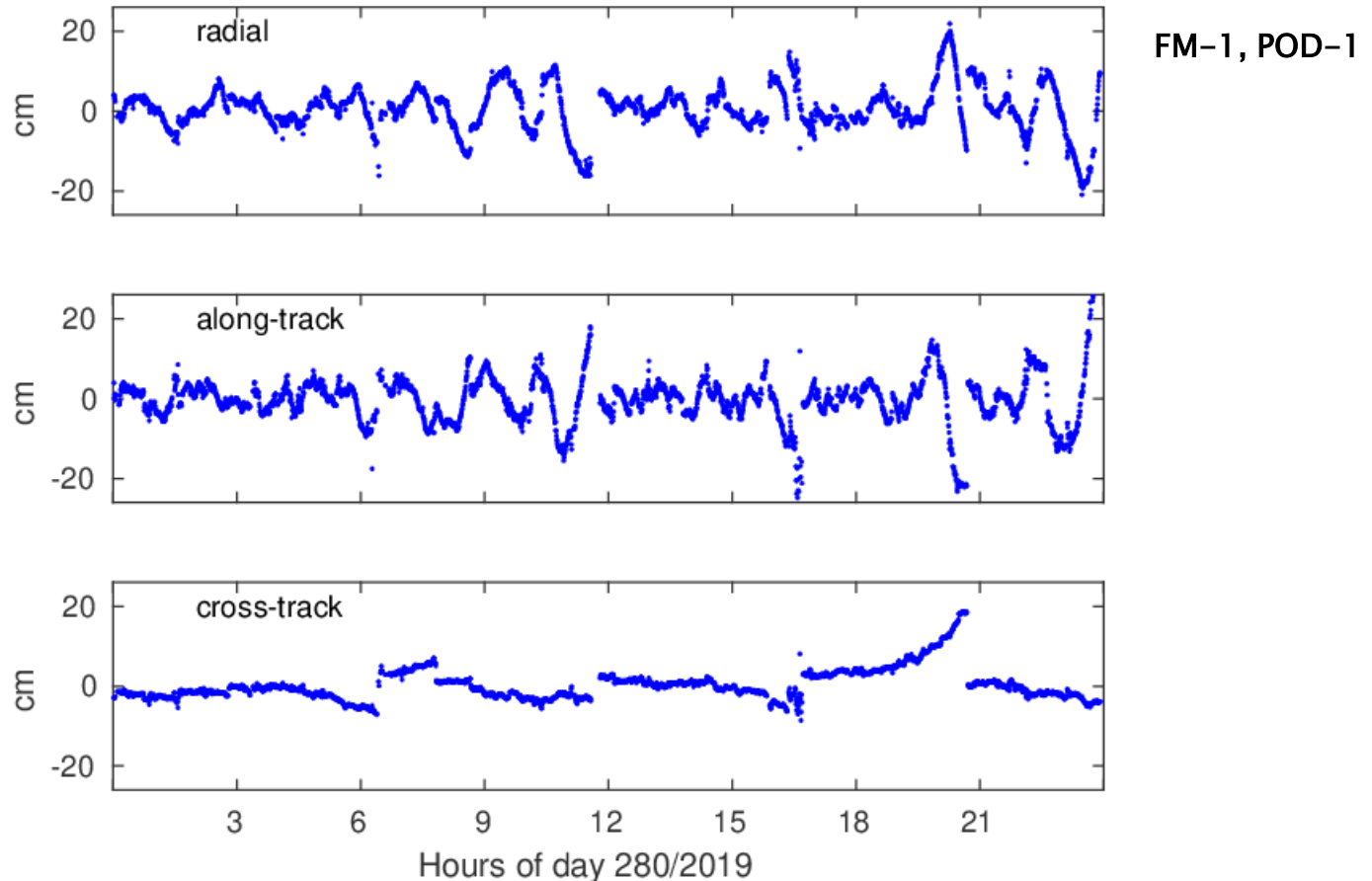
Comparisons to dynamic solutions (based on macro-models) will allow to better quantify the magnitude of potentially erroneous instrument offsets.

Float kinematic orbits using a single antenna



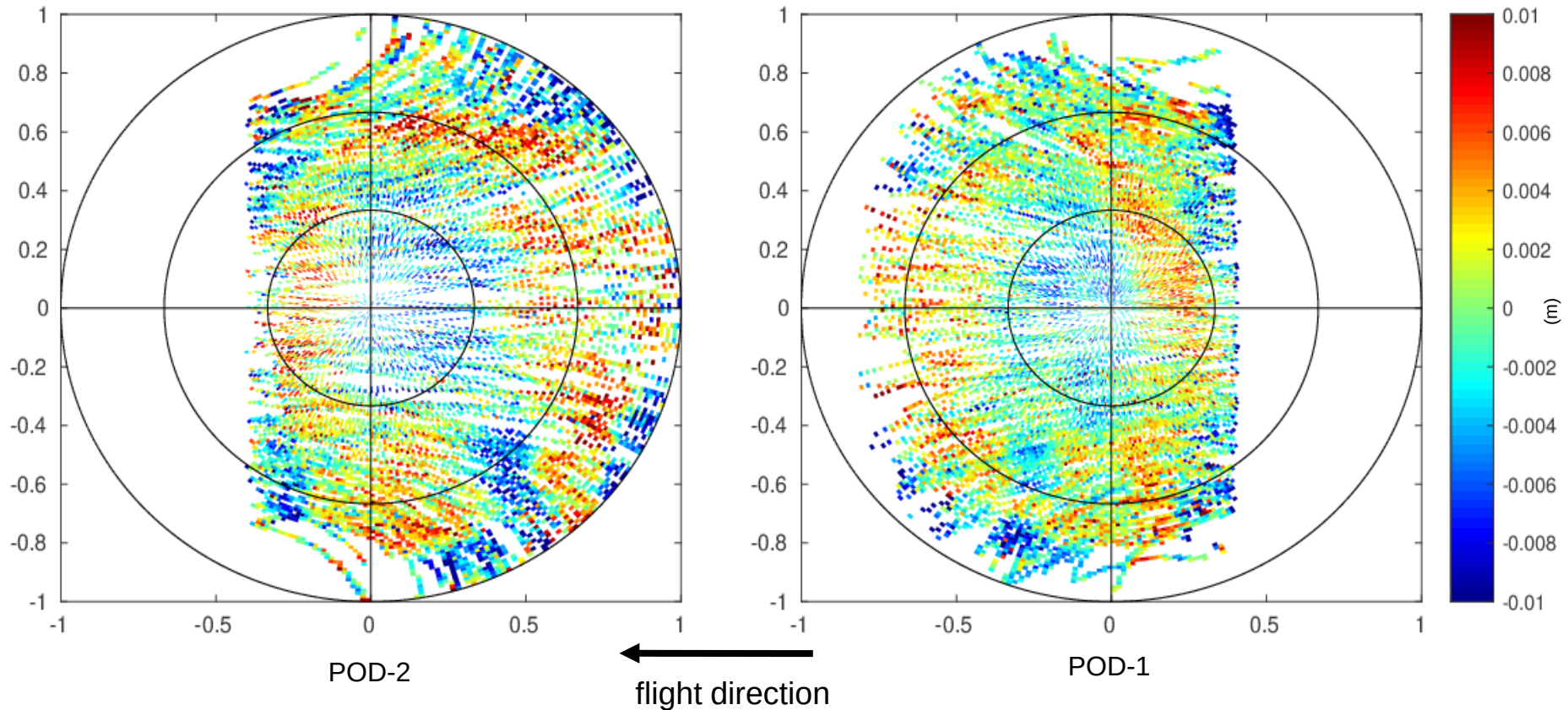
Comparison of kinematic and reduced-dynamic orbits. Due to the bad geometry of single antenna solutions, a larger number of ambiguities will lead to significant deviations of the kinematic orbit wrt the reduced-dynamic orbit.

Float kinematic orbits using a single antenna



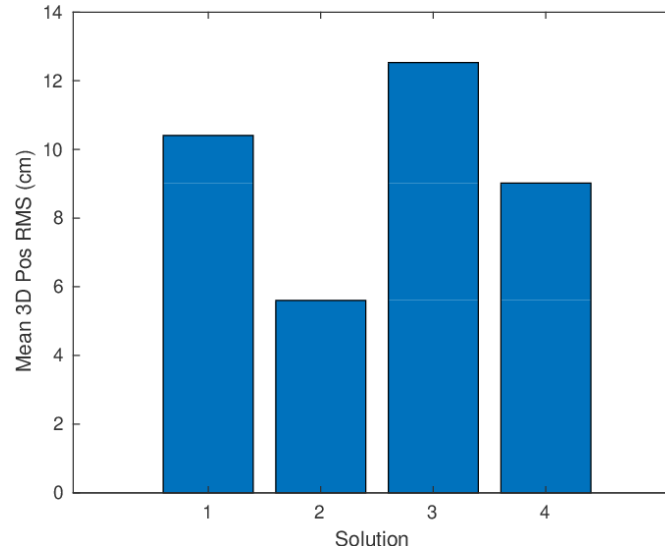
In case the number of ambiguities is smaller, as it is the case on this day, e.g., because there are less interruptions in the GNSS carrier phase data, slightly more stable kinematic orbits may be obtained also from single antenna data. Of course, the geometry remains weak ...

COSMIC-2 POD antennas



Due to the 75° tilted POD antennas, only a part of the sky is covered by a single POD antenna.

Overlaps of red.-dyn. float/fixed solutions



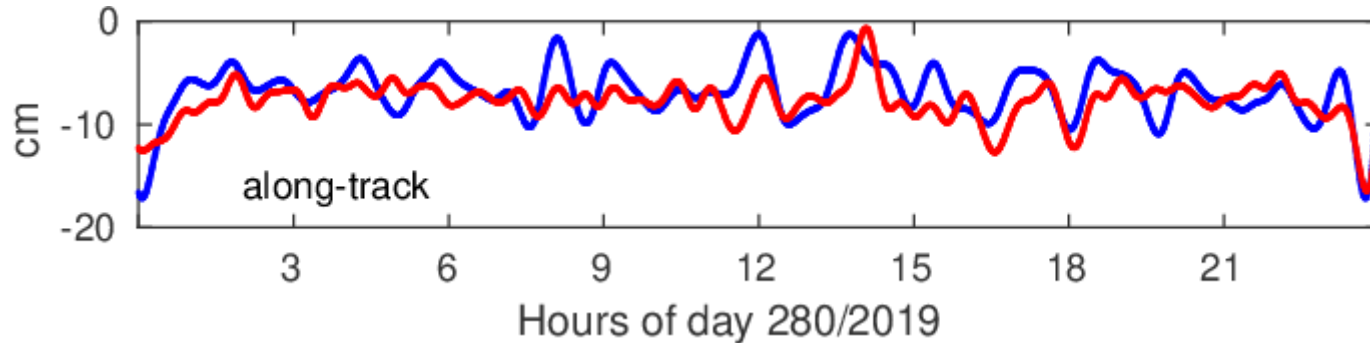
- **Solution 1: FM-1, POD-1, GPS-only, ambiguity float**
- **Solution 2: FM-1, POD-1, GPS-only, ambiguity fixed**

=> Significantly improved overlaps due to ambiguity fixing. Note that GPS L1 C/A, L2P, L2C are tracked, which needs to be taken into account for the ambiguity fixing (Schaer et al., 2021)

- **Solution 3: FM-1, POD-2, GPS-only, ambiguity float**
- **Solution 4: FM-1, POD-2, GPS-only, ambiguity fixed**

=> Improvement may also be observed, but the smaller data amount challenges the POD quality

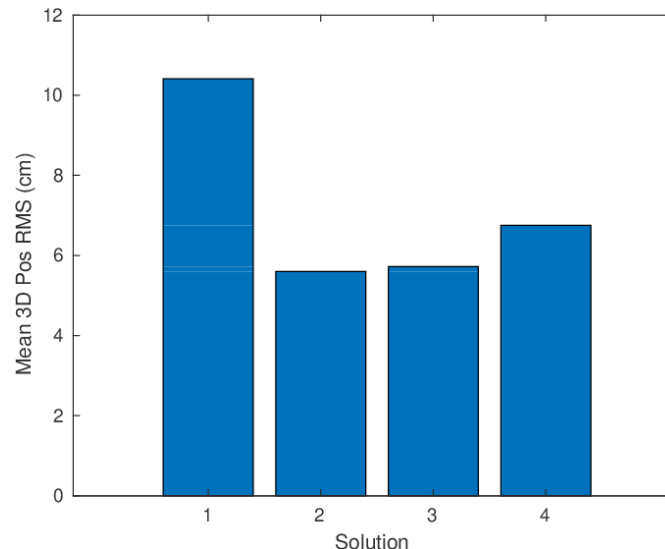
Along-track shifts of single-antenna solutions



- **FM-1, Along-track difference between POD-1 and POD-2, GPS-only, ambiguity float**
- **FM-1, Along-track difference between POD-1 and POD-2, GPS-only, ambiguity fixed**

Single-antenna solutions are significantly shifted in along-track with respect to each other. Mean offsets over the analyzed time period are **-6.3 cm** and **-7.1 cm**.

Overlaps of red.-dyn. one/two antenna solutions



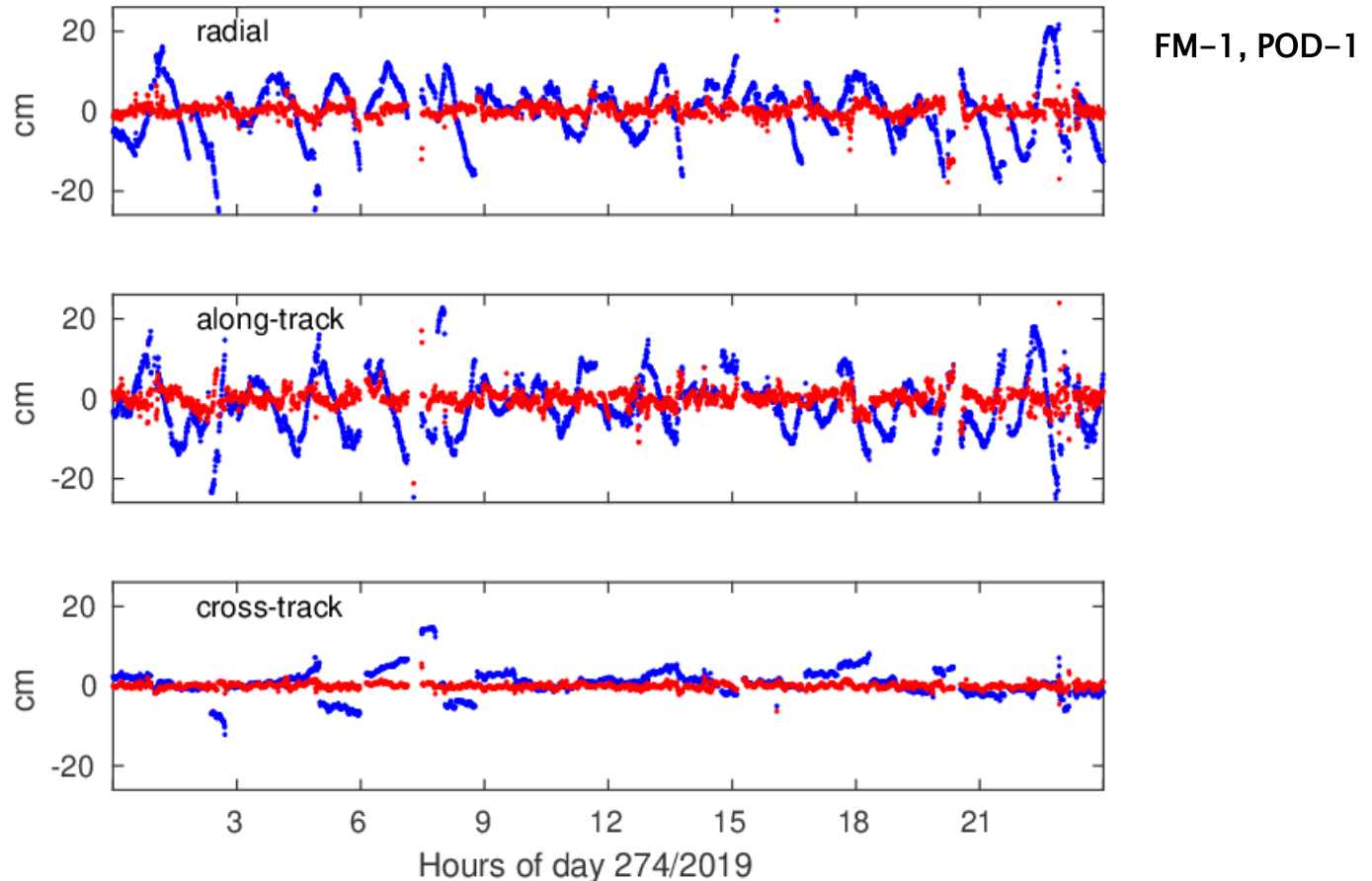
- Solution 1: FM-1, POD-1, GPS-only, Ambiguity float
- Solution 2: FM-1, POD-1, GPS-only, Ambiguity fixed

=> Same solutions as on slide 10, shown here just for comparison

- Solution 3: FM-1, POD-1 & POD-2, GPS-only, Ambiguity float
- Solution 4: FM-1, POD-1 & POD-2, GPS-only, Ambiguity fixed

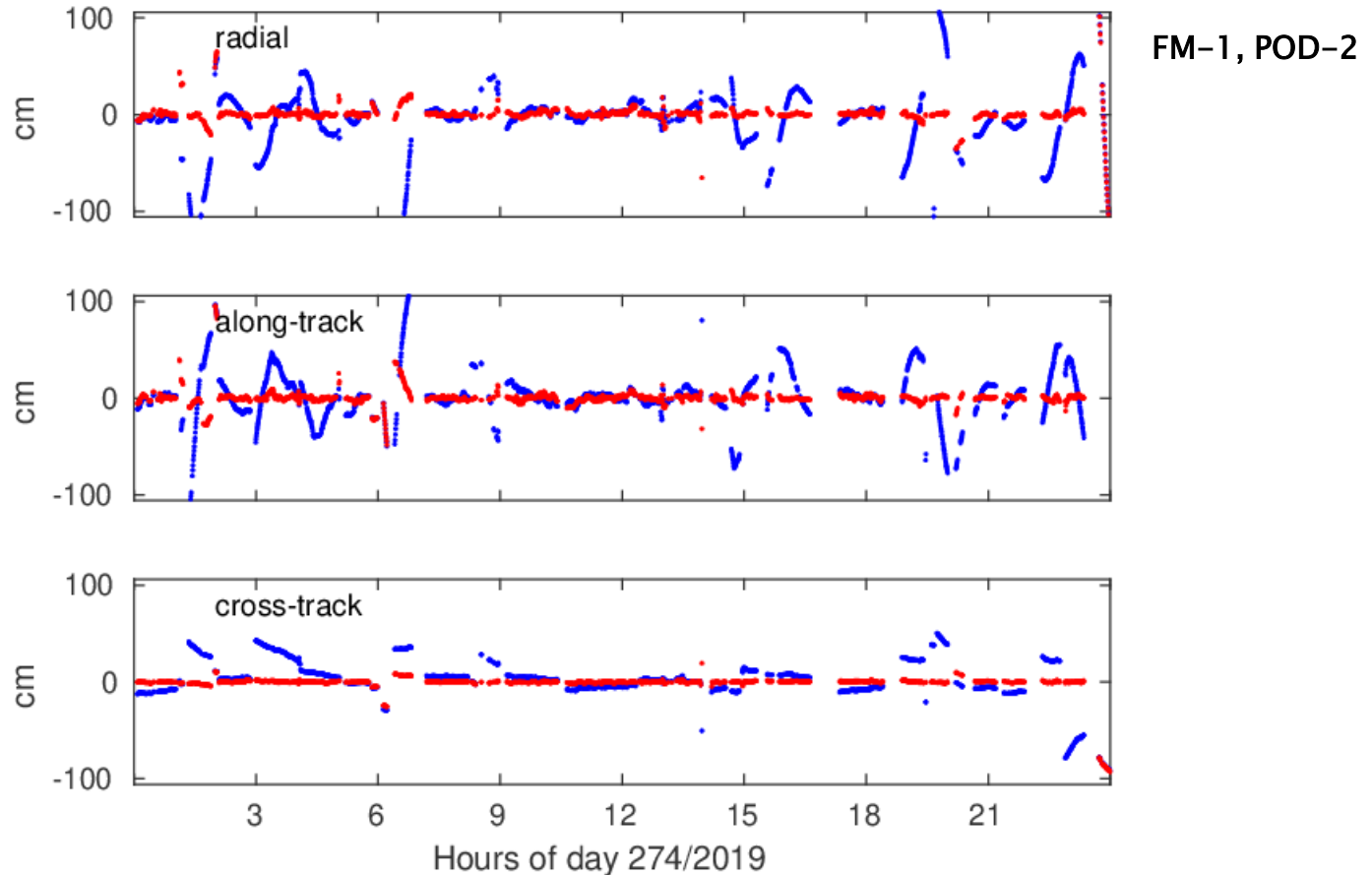
=> Significant improvement for 2-antenna solution even if no ambiguity fixing is performed.
Degradation for fixed solution based on two antennas, needs to be further investigated.

Fixed kinematic orbits using a single antenna



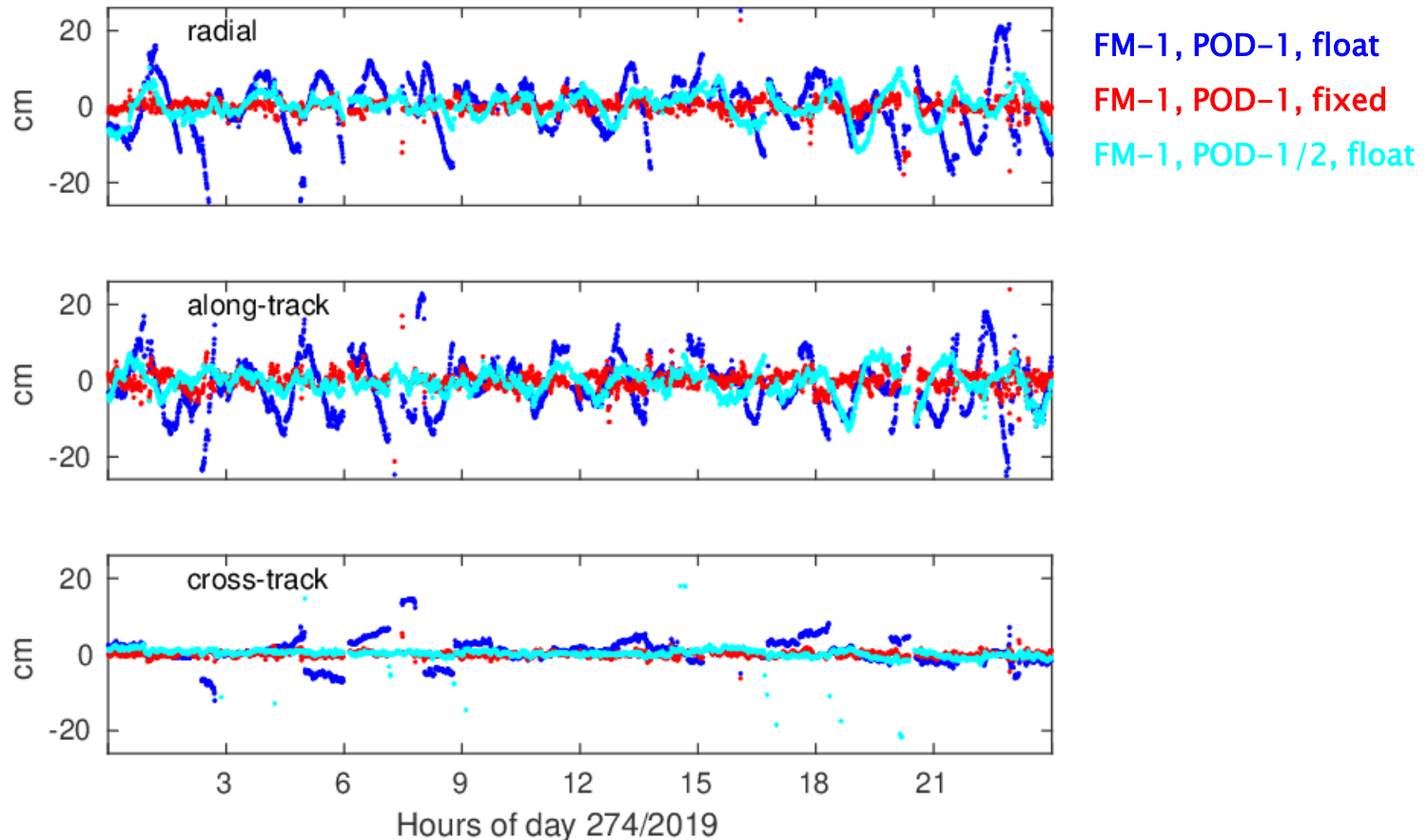
Comparison of **ambiguity-float** solutions and **ambiguity-fixed** solution. Even in the case with many interruptions a considerable stabilization of the solution can be observed.

Fixed kinematic orbits using a single antenna



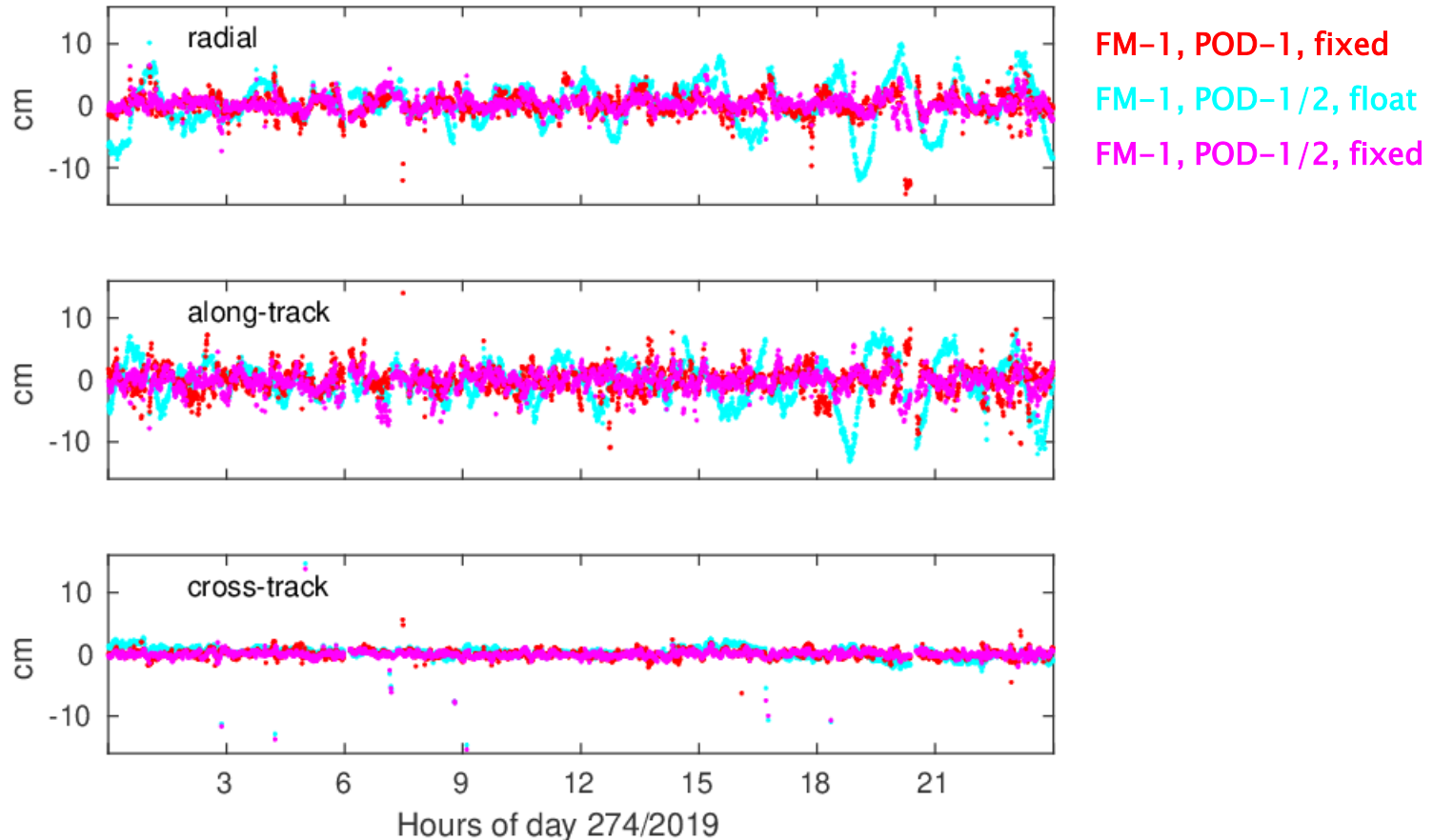
Comparison of **ambiguity-float** solutions and **ambiguity-fixed** solution. In particular for the much weaker kinematic orbits based on the data of the POD-2 antenna the ambiguity fixing is crucial to obtain (more) reasonable solutions.

Float kinematic orbits using both antennas



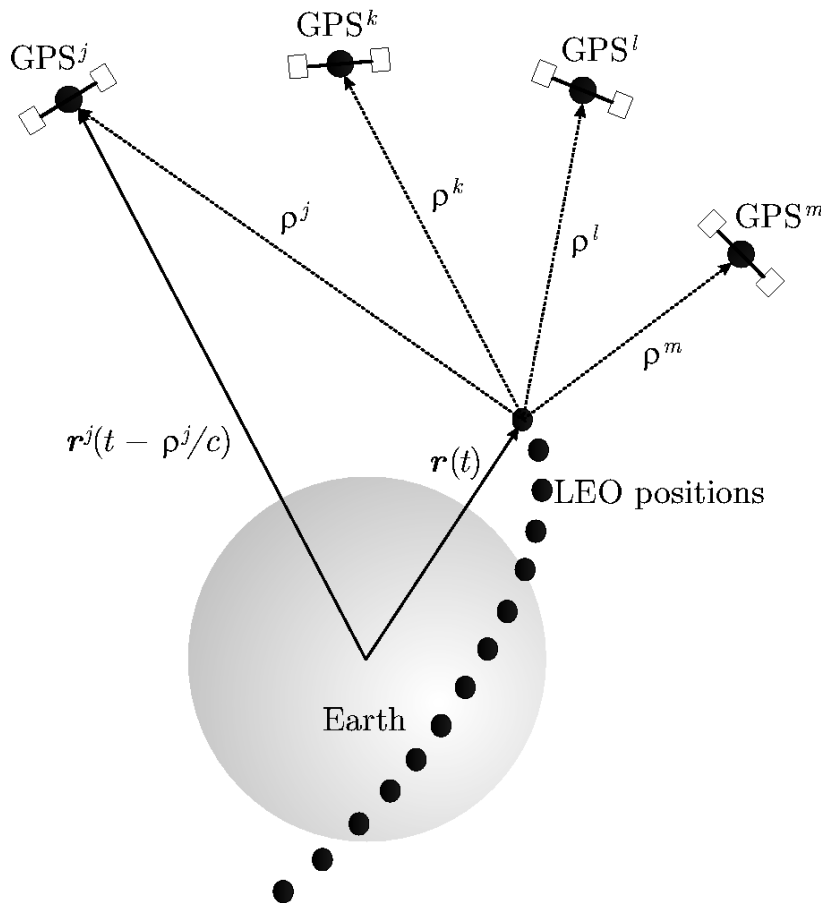
Comparison of **ambiguity-float** solutions and **ambiguity-fixed** solution based on the data of the POD-1 antenna, and **ambiguity-float** solution based on the data of the **POD-1 & POD-2** antenna. A significant improvement may be observed when combining the data from the two antennas even if no ambiguity fixing is performed.

Fixed kinematic orbits using both antennas



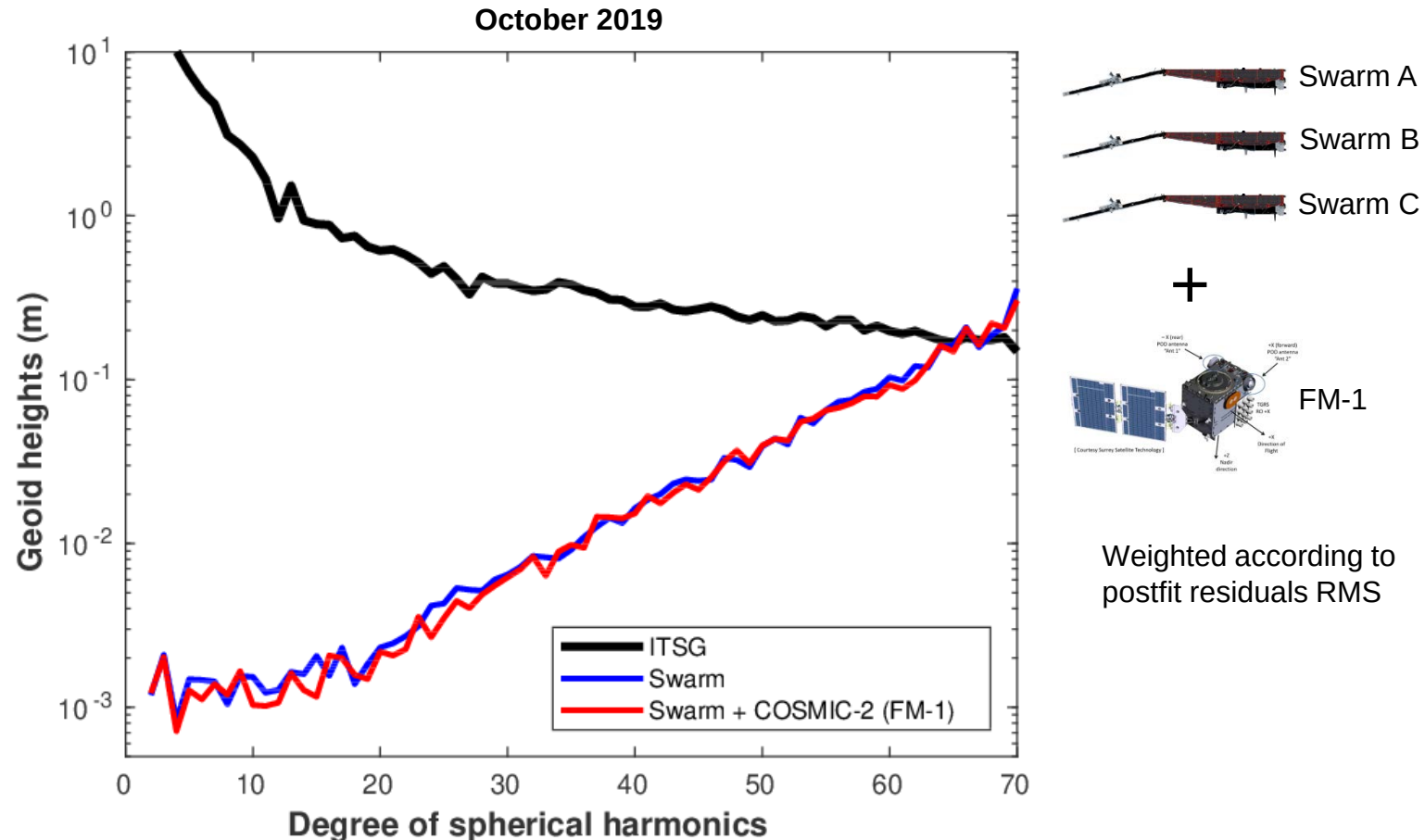
Comparison of **ambiguity-float** solutions based on the data of the **POD-1 & POD-2** antennas with **ambiguity-fixed** solutions based on the data of the **POD-1** antenna and **ambiguity-fixed** solutions based on the data of the **POD-1 & POD-2** antennas. Technical issues in the kinematic two-antenna solutions are causing the observed outliers.

Gravity field recovery from orbital positions



- Kinematic COSMIC-2 positions contain independent information about the long-wavelength part of the Earth's gravity field
- Kinematic positions serve as pseudo-observations together with covariance information to set-up a generalized orbit determination problem, which also includes gravity field parameters
- Due to the very low inclination of 24° , normal equations from COSMIC-2 kinematic positions are combined with normal equations from Swarm kinematic positions to avoid a huge polar gap.
- Gravity field coefficients are solved without applying any regularization

Gravity field recovery from orbital positions

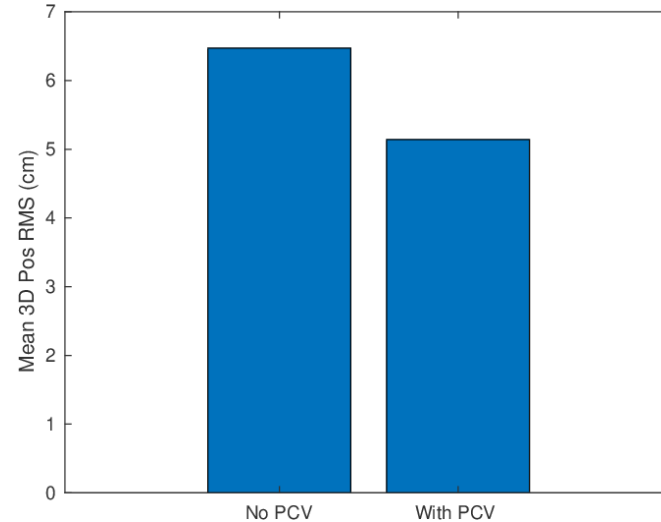
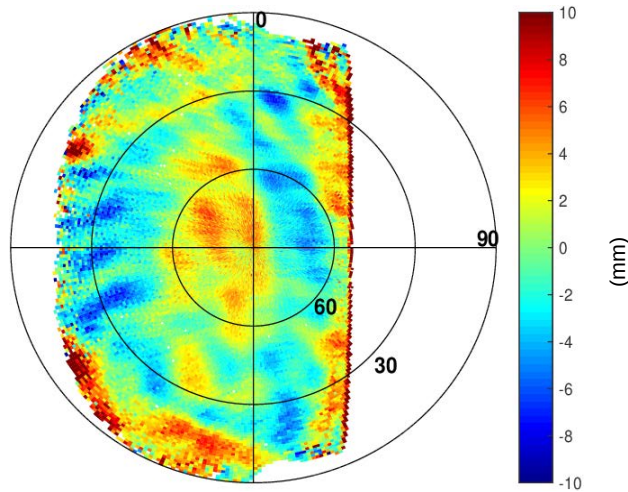


Monthly gravity field solutions from **Swarm** and from **Swarm combined with COSMIC-2 (FM-1)** compared to the monthly ITSG-GRACE solutions. Small improvements might be seen due to the addition of the COSMIC-2 kinematic positions (two-antenna solutions, ambiguity float).

Summary

- **POD antennas tilted 75° from zenith pose a challenge to POD due to a very weak geometry when using data from only a single antenna.**
- **This becomes most obvious when analyzing kinematic orbits, but also when comparing orbit solutions from the two antennas, revealing along-track errors.**
- **A considerable stabilization can be achieved when adopting single-receiver ambiguity resolution techniques. It needs to be taken into account that GPS signals tracked on the second frequency (L2P or L2C) depend on the block-type of the GPS satellites.**
- **Dual-antenna solutions cure the weak geometry of single antenna solutions. When analyzing kinematic solutions an almost similar stabilization can be observed for float solutions as for ambiguity fixed single-antenna solutions.**
- **Some technical issues need to be resolved for kinematic dual-antenna solutions when observations are present for only one antenna.**
- **COSMIC-2 orbit solutions may considered to be used for applications beyond the main mission purposes: in this presentation tests made with monthly gravity field solutions show that COSMIC-2 data, despite the low inclination of 24° of the constellation, might have the potential to slightly improve monthly gravity field solutions derived from Swarm GPS data in a combined solution.**

Outlook



- All solutions shown so far were computed without PCV maps. Further improvements, in particular of the ambiguity float solutions, will be achieved by using empirically derived PCV maps from post-fit residuals, as it is shown in the above plot in terms of overlap statistics for data set 2 (latest flight s/w, Oct 2019, FM-1, POD-1 used, GPS only used).

References

- Schaer, S., A. Villiger, D. Arnold, R. Dach, L. Prange, A. Jäggi (2021): The CODE ambiguity-fixed clock and phase bias analysis products and their properties and performance. *Journal of Geodesy*, under revision.
- Weiss, J., D. Hunt, W. Schreiner, T. VanHove, D. Arnold, A. Jäggi (2021): Recent Precise Orbit Determination Results for the COSMIC-2 Mission. Presented at 43rd COSPAR Scientific Assembly 2021.