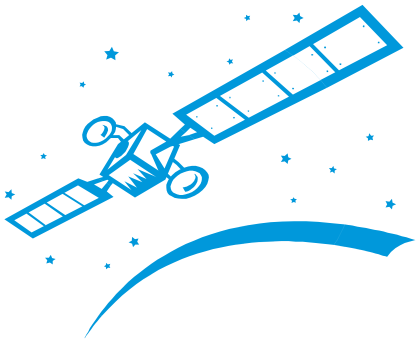

Precise and Homogeneous Orbits for Sentinel-3A

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What we do for the Sentinel missions

Sentinel-1,2 and 3

- The Navigation Support Office provides a complete independent solution for validation purposes:
  - We generate our own RINEX files from the Sentinel telemetry (L0 data).
  - We use our own (ESA) NRT/IGS GPS satellite orbits and clocks (30 seconds).
  - We generate the Sentinel orbits making use of the Navigation Support Office software package NAPEOS (3.9) and use the latest state of the art models.
  - We provide both orbit solutions in NRT and in NTC mode (currently only deliver NTC products).

Processing strategy

Sentinel-3A

- NAPEOS version 3.9
- Loosely based on to the CNES GDR-E standards
- Modeling according to latest standards (IERS2010)
- ESA IGS08/NRT GPS orbits and clocks (30s) introduced (kept fixed). Sentinel-3A 10s GPS data used.
- For Sentinel-3A SLR data used for validation, testing DORIS RINEX data
- Estimated parameters
  - Orbit parameter (1-day arcs)
    - SV
    - 6 CPRs (constant/sin/cos in along-track/cross-track) every 12h
    - 10 Drag parameters every 24h
  - GPS phase ambiguites (float)
  - Sentinel clock bias (10s)

Processing strategy

Sentinel-3A

- Gravityfield
  - GRGS EIGEN.GRGS.RL03.v2 (120x120) + linear drift, annual and semi annual variation up to degree and order 80
- Surface forces
  - box-wing model for Solar radiation, drag, Albedo and IR
- Station Coordinates
  - SLR ITRF2008
- GPS and SLR antenna phase centre modeling
  - GPS values for Sentinel-3A are taken from: "GMV-GMESPOD-TN-0027_v1.1draft"
  - SLR values are taken from DLR technical note: TN_1101_IPIE_LRA_v1.0
- Attitude modelling
  - Nominal attitude model for Sentinel-3A

GPS data sampling and SLR correction

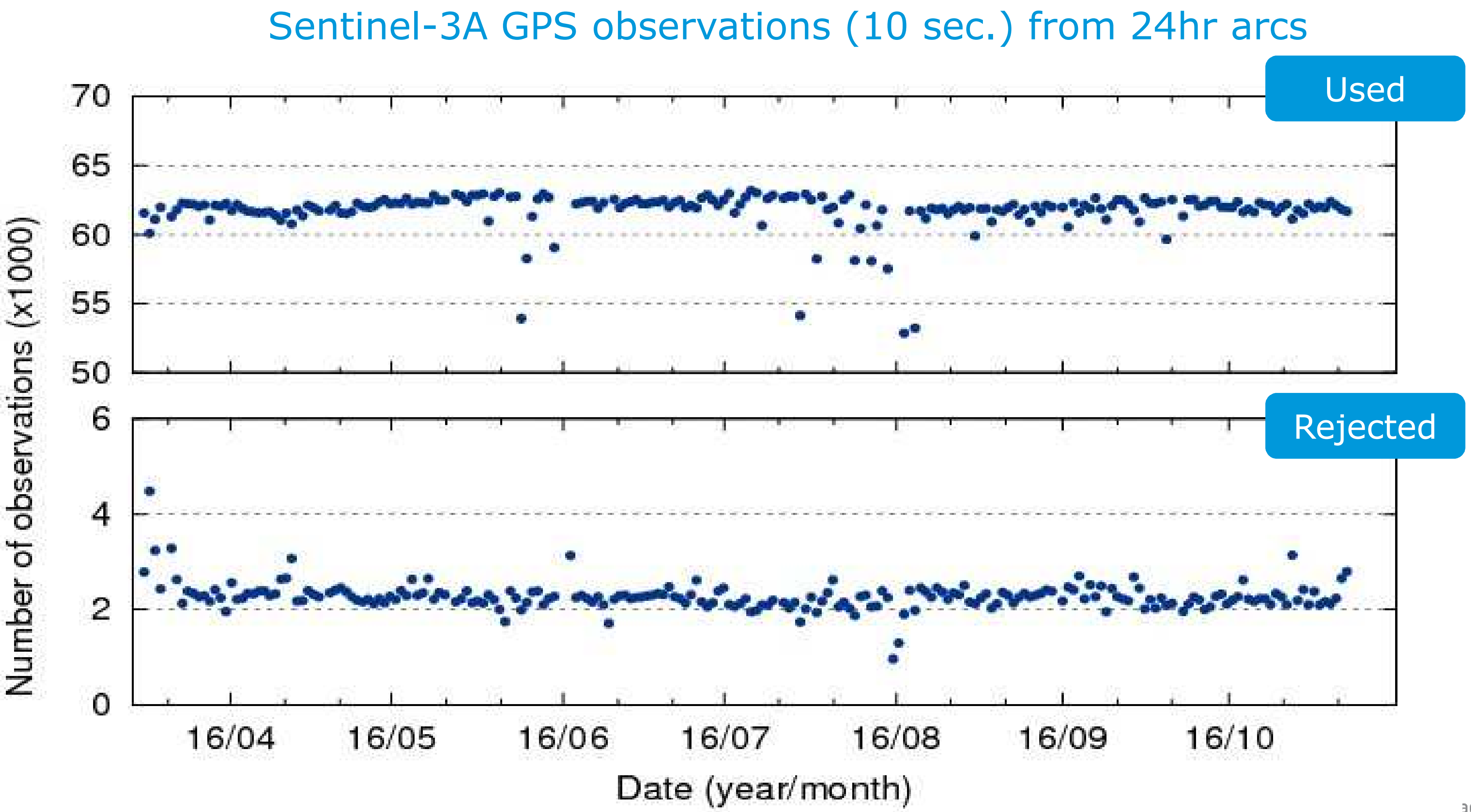
Sentinel-3A

- Sentinel-3A provides 1Hz GPS data we investigated the effect on the phase residuals as well as the orbit when interpolation the input clocks (30 seconds). Effect of interpolating the GPS clocks from 30 seconds to 10 seconds or 1 seconds gives (as expected) an increase in the GPS phase residuals (from 3.7mm up to 5.9mm) but the effect on the orbit in negligible (less the 1mm)

- Sentinel-3A is the first mission in which we use ANTEX like correction for the additional path delay of the SLR reflector. Effect of using the ANTEX correction instead of constant correction has a clear positive impact on the SLR mean residuals and a minor improvement on the RMS.

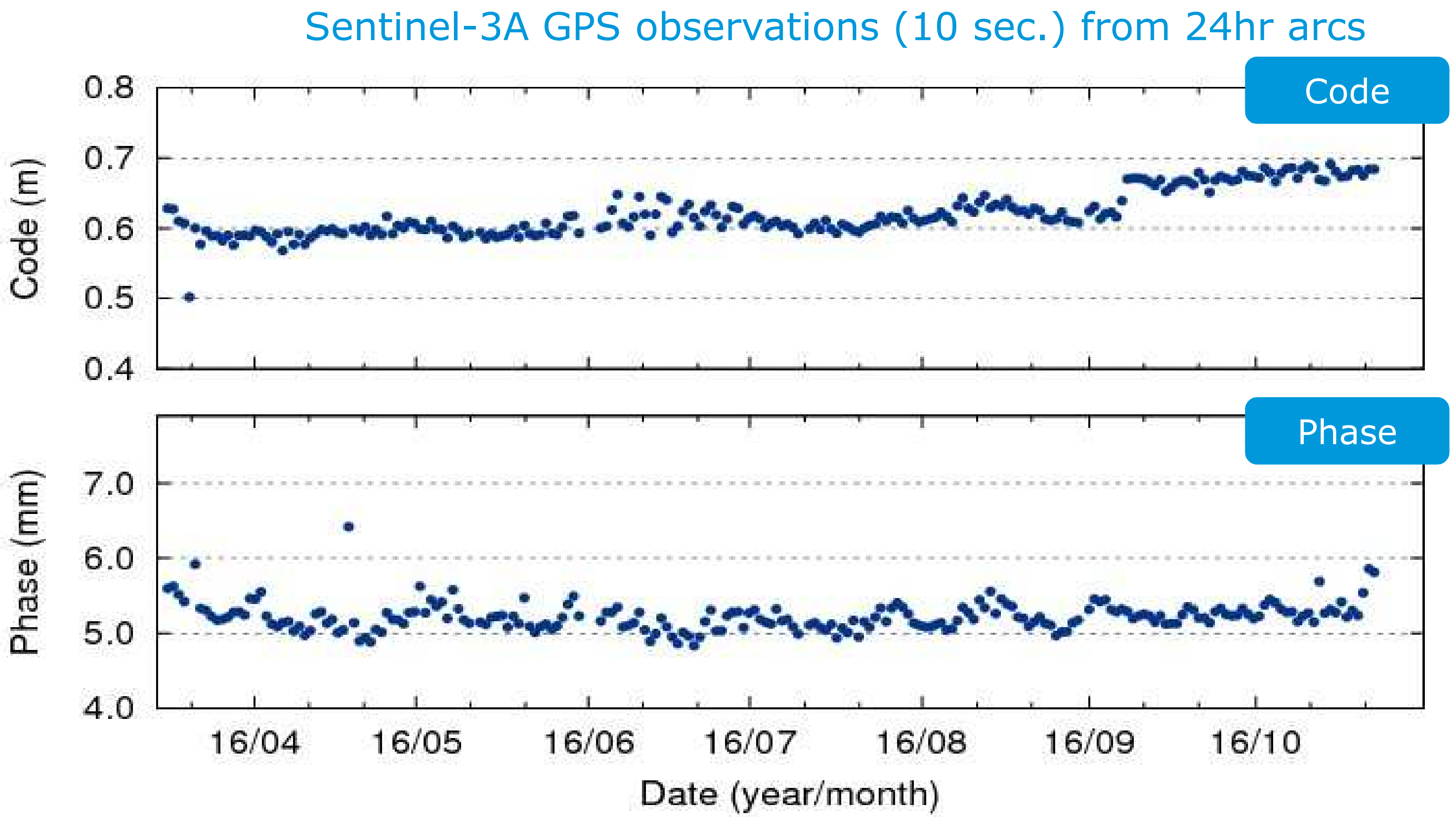
Observation data Sentinel-3A

From 24 hour arcs



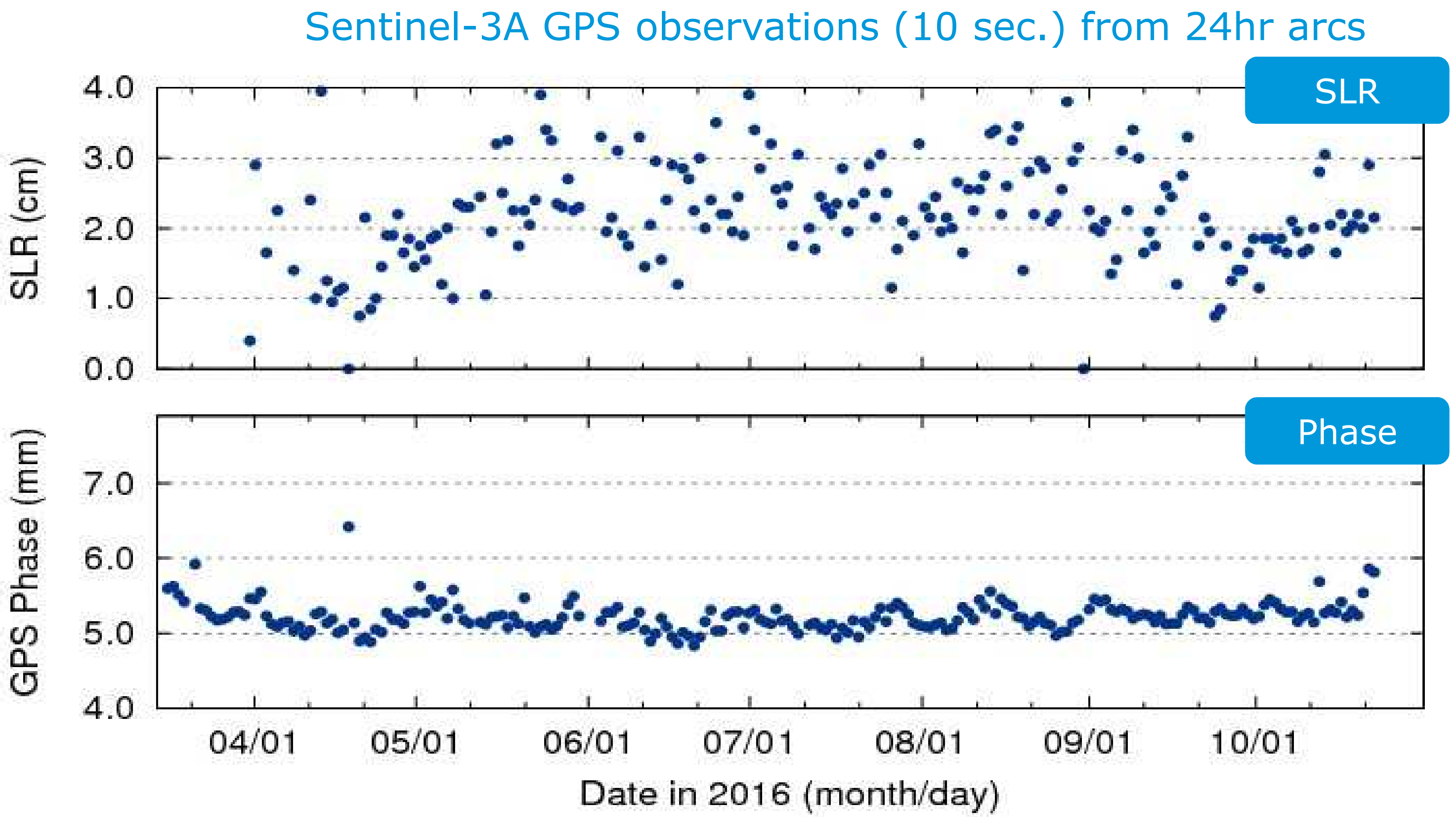
Observation data Sentinel-3A

From 24 hour arcs



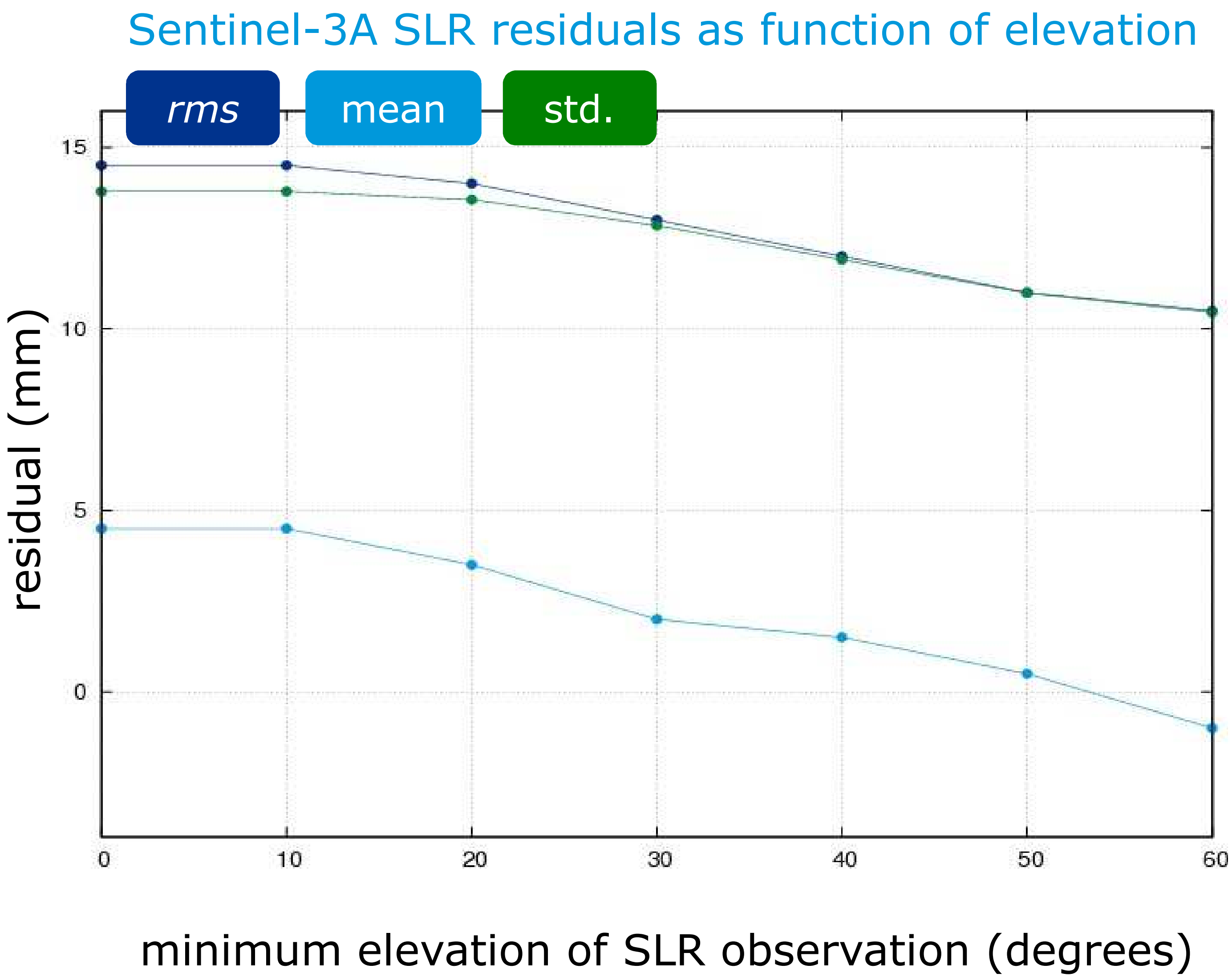
Observation data Sentinel-3A

From 24 hour arcs



Sentinel-3A SLR data

From 24 hour arcs

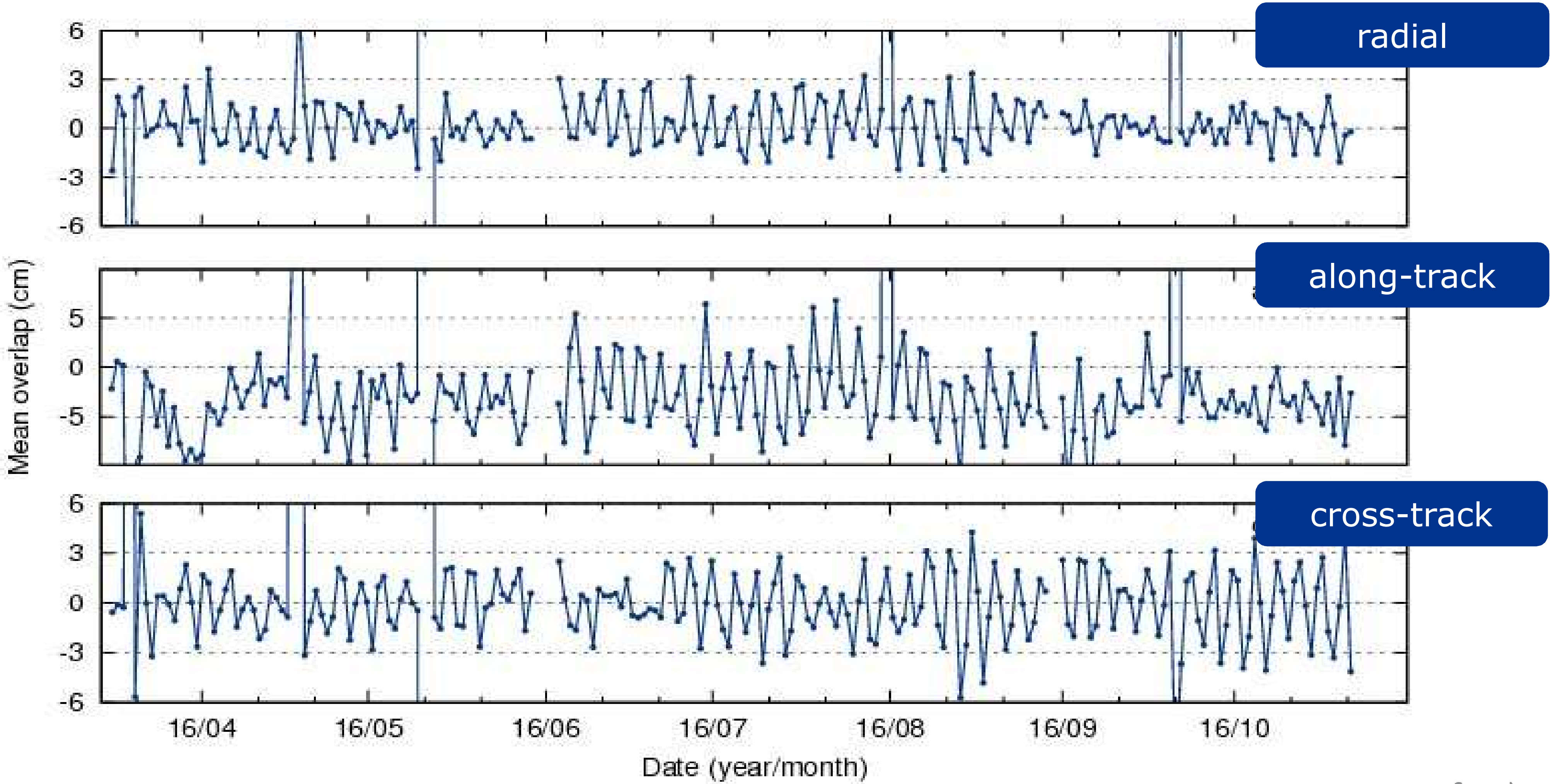


SLR residuals based on selected SLR network: (7090/7105/7119/7821 /7840/7841/7941/8834).

SLR ANTEX phase centre correction based on TN-1101-IPIE_LRA_v1.0 document.

Daily orbit overlap from ESOC solution

Sentinel-3A from 24 hour solution (single point)

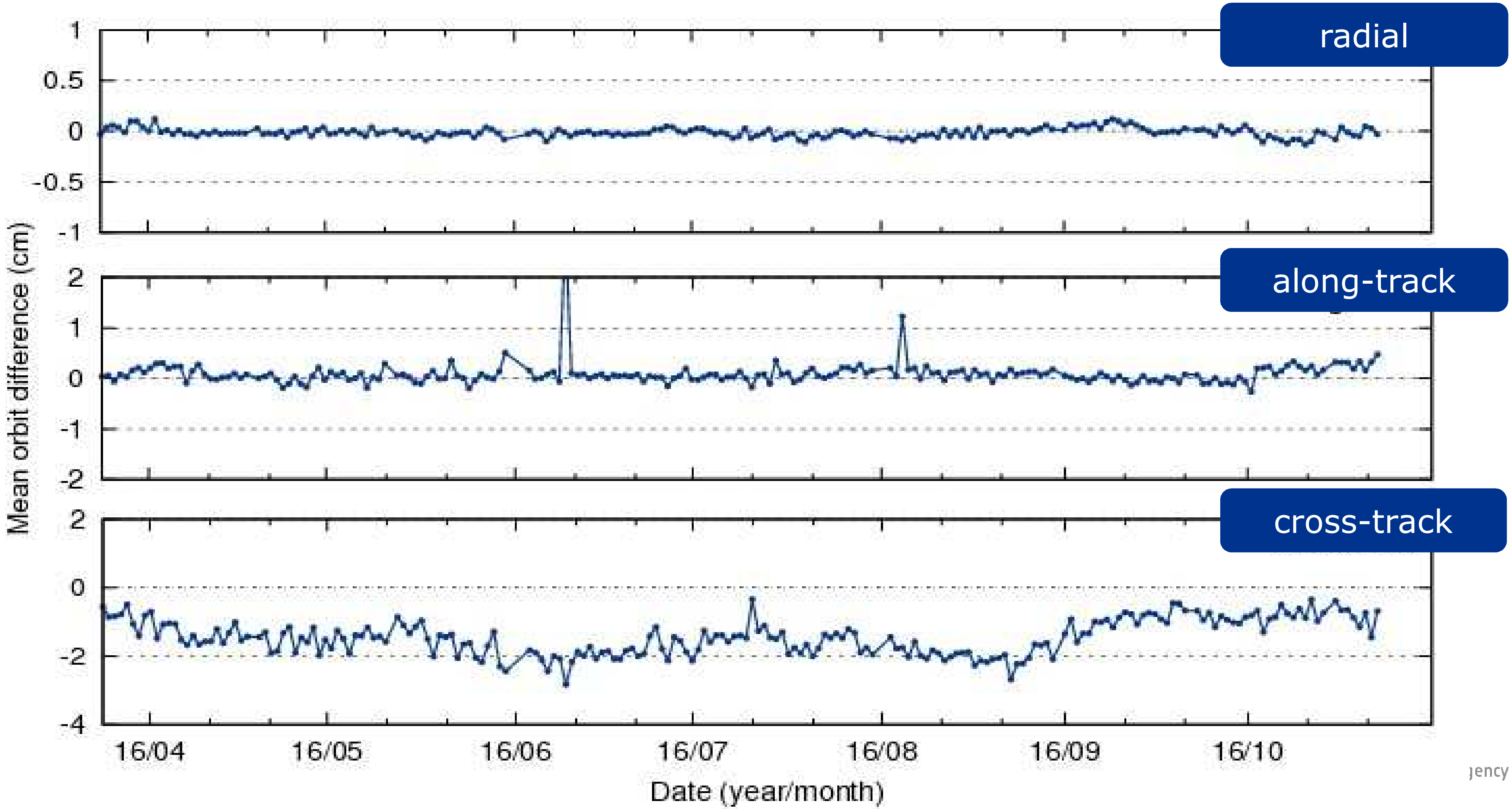


rms values (radial, along and cross): 1.01, 3.82, 1.46cm

Daily mean of orbit differences

Sentinel-3A

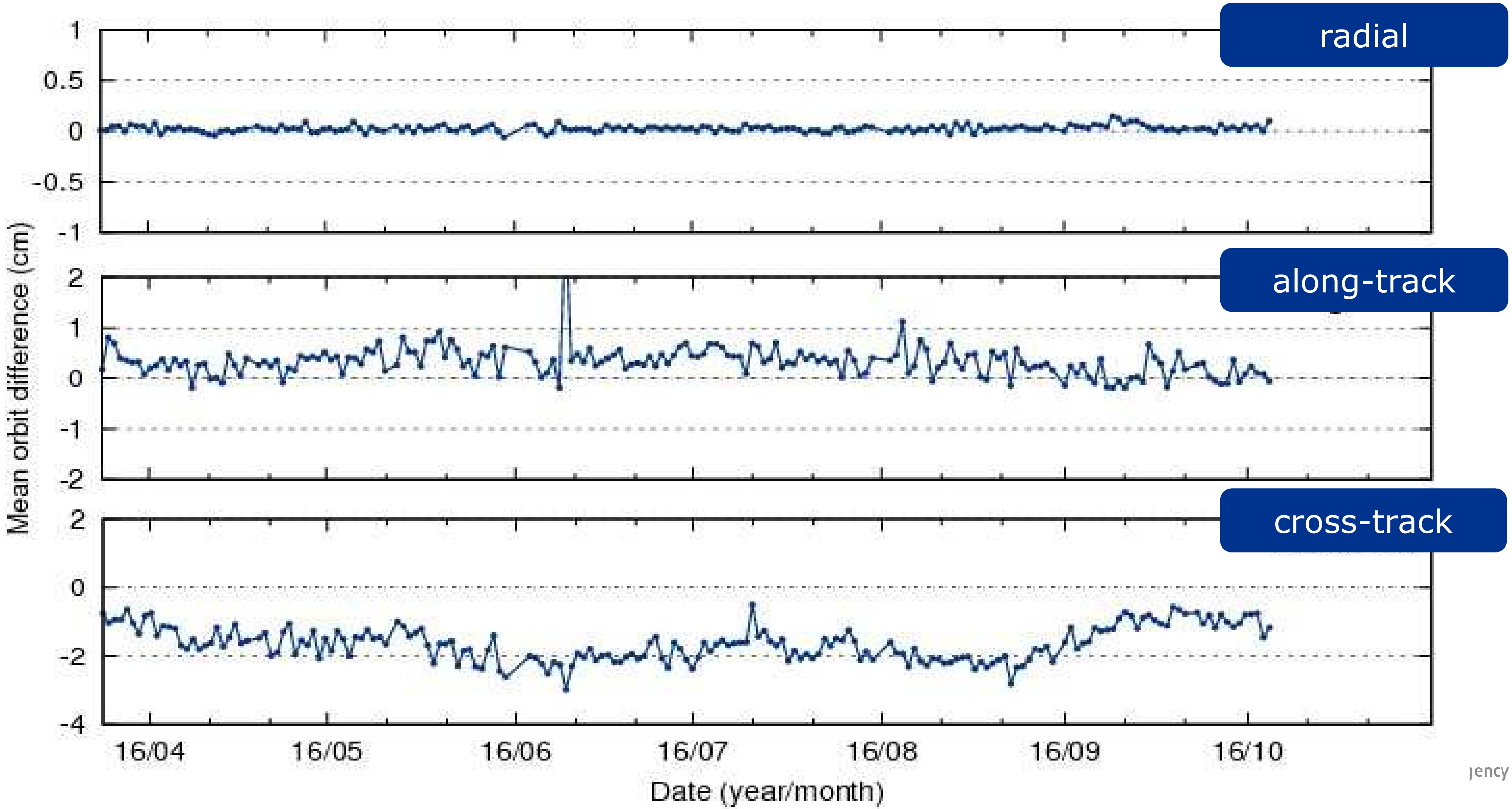
ESOC – CPOD (GMV)



Daily mean of orbit differences

Sentinel-3A

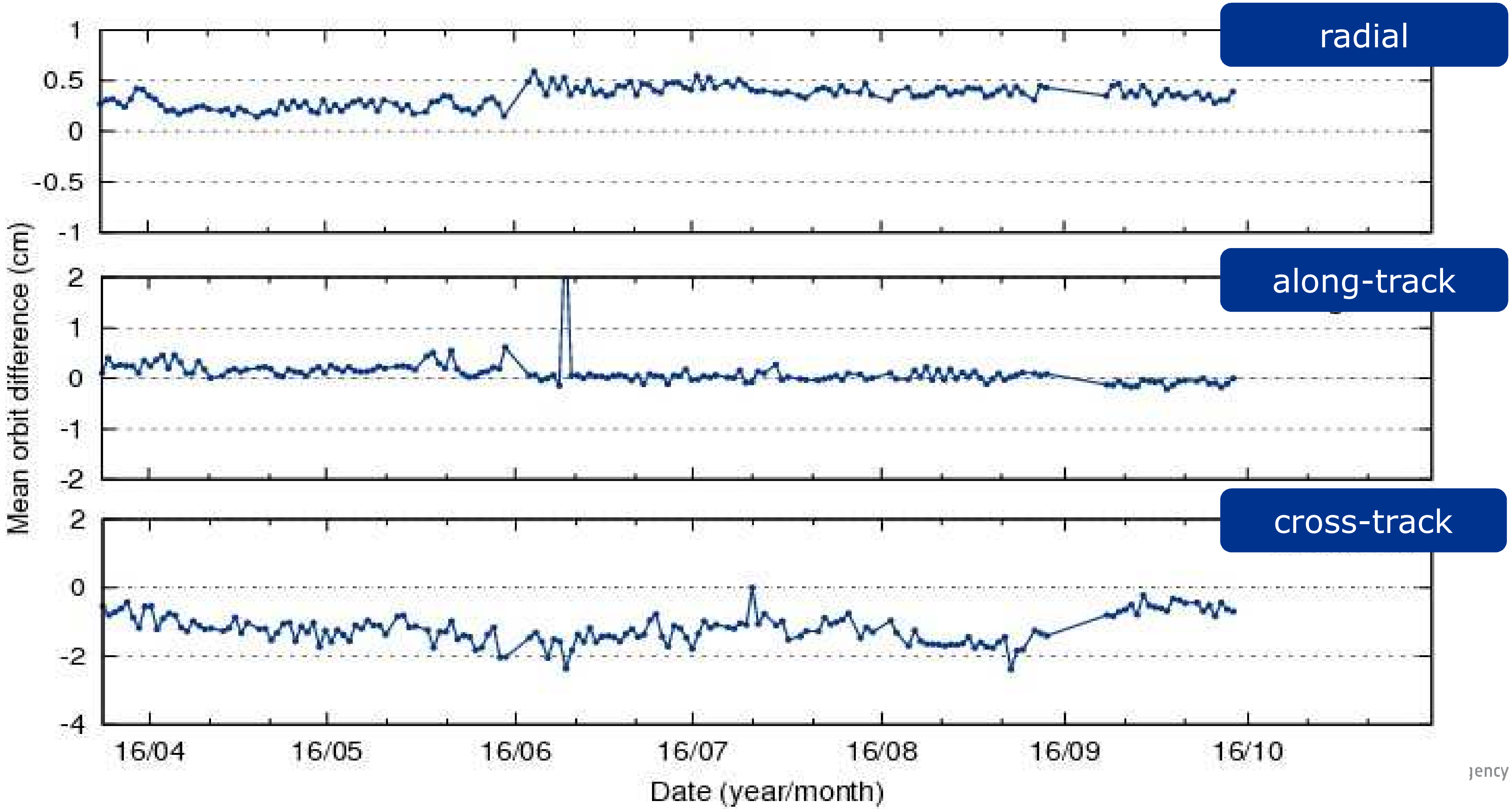
ESOC – CNES NTC



Daily mean of orbit differences

Sentinel-3A

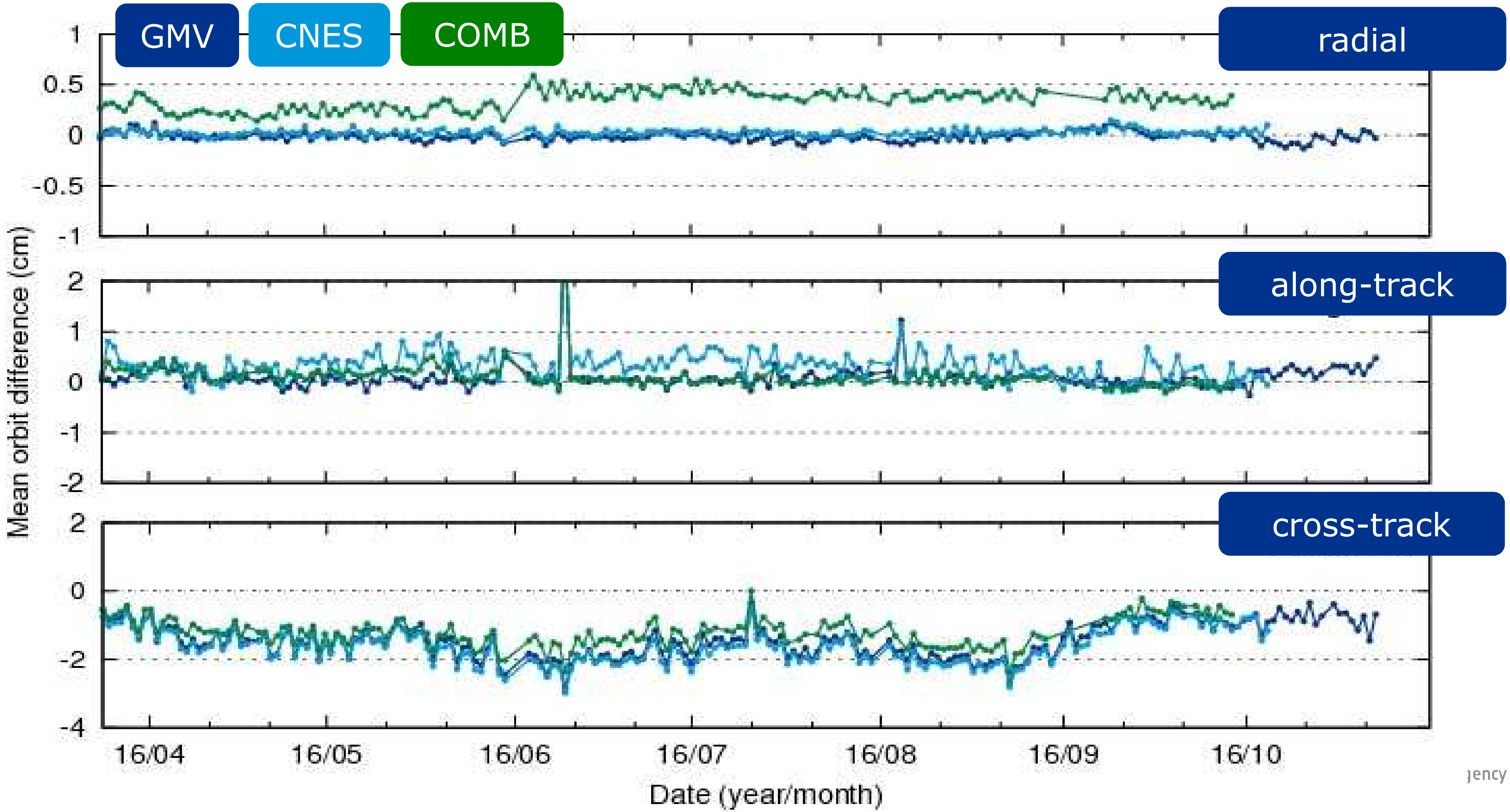
ESOC – Combined solution



Daily mean of orbit differences

Sentinel-3A

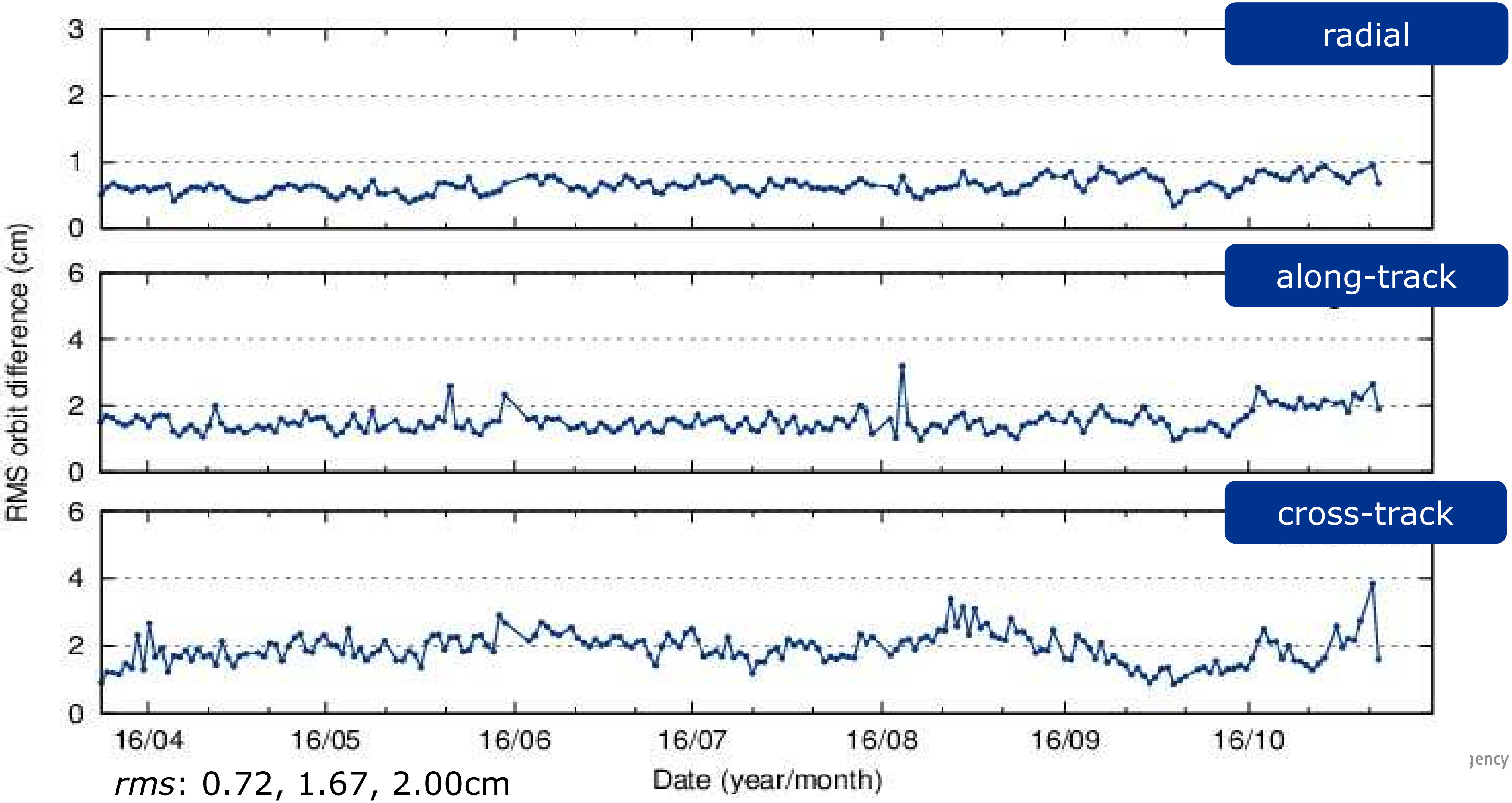
ESOC – all



Daily RMS of orbit differences

Sentinel-3A

ESOC – CPOD (GMV)

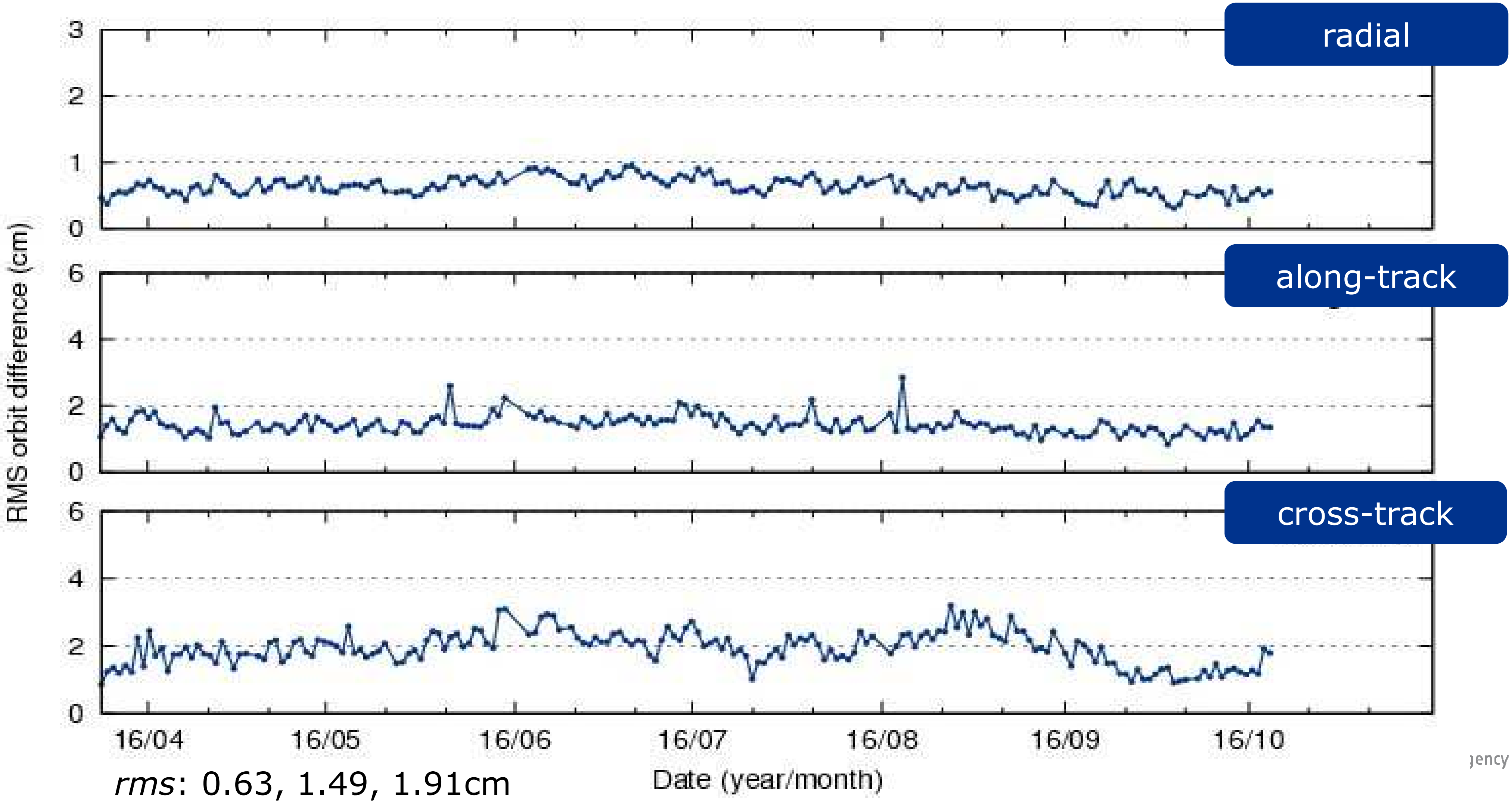


rms: 0.72, 1.67, 2.00cm

Daily RMS of orbit differences

Sentinel-3A

ESOC – CNES NTC

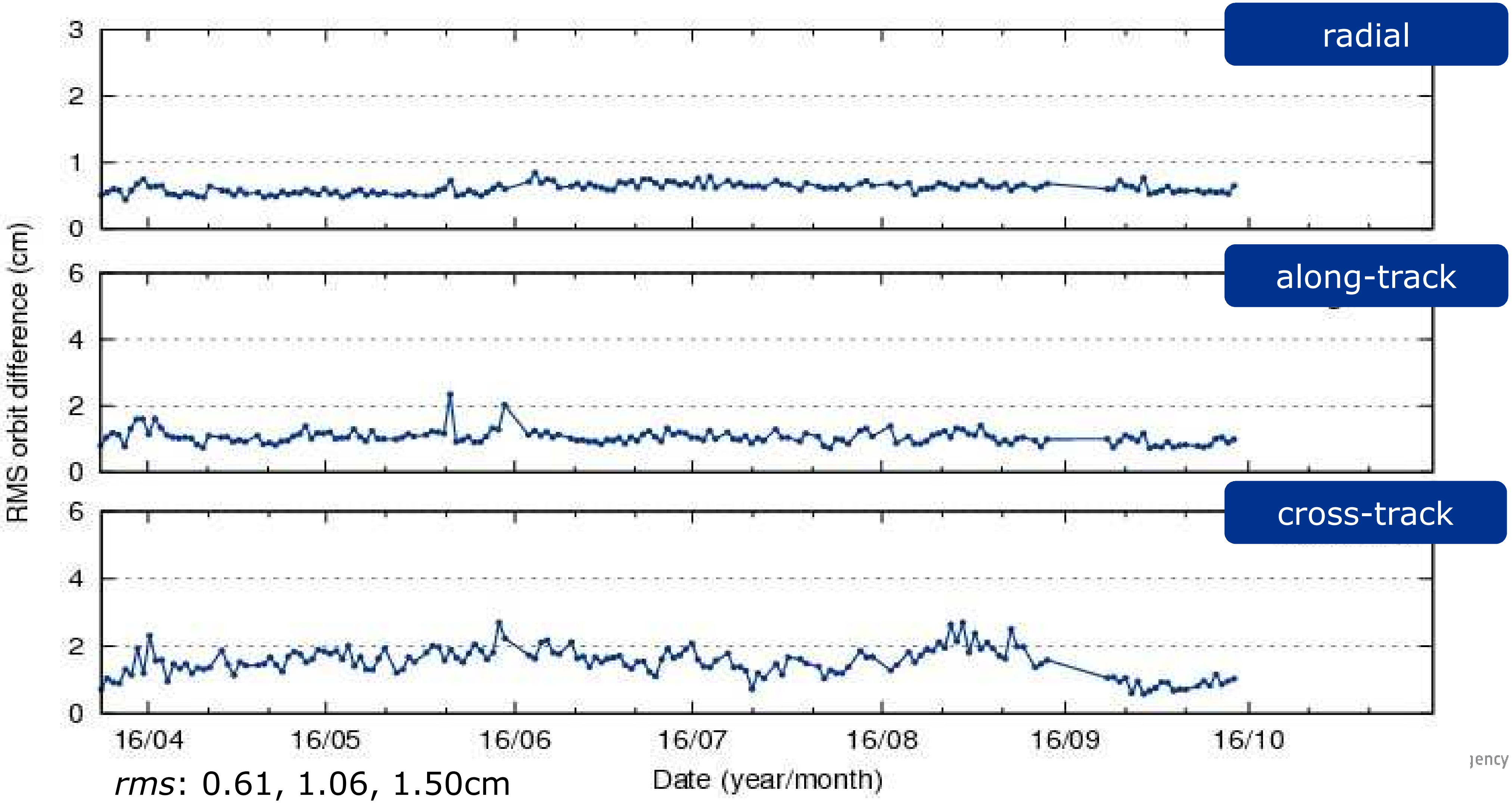


rms: 0.63, 1.49, 1.91cm

Daily RMS of orbit differences

Sentinel-3A

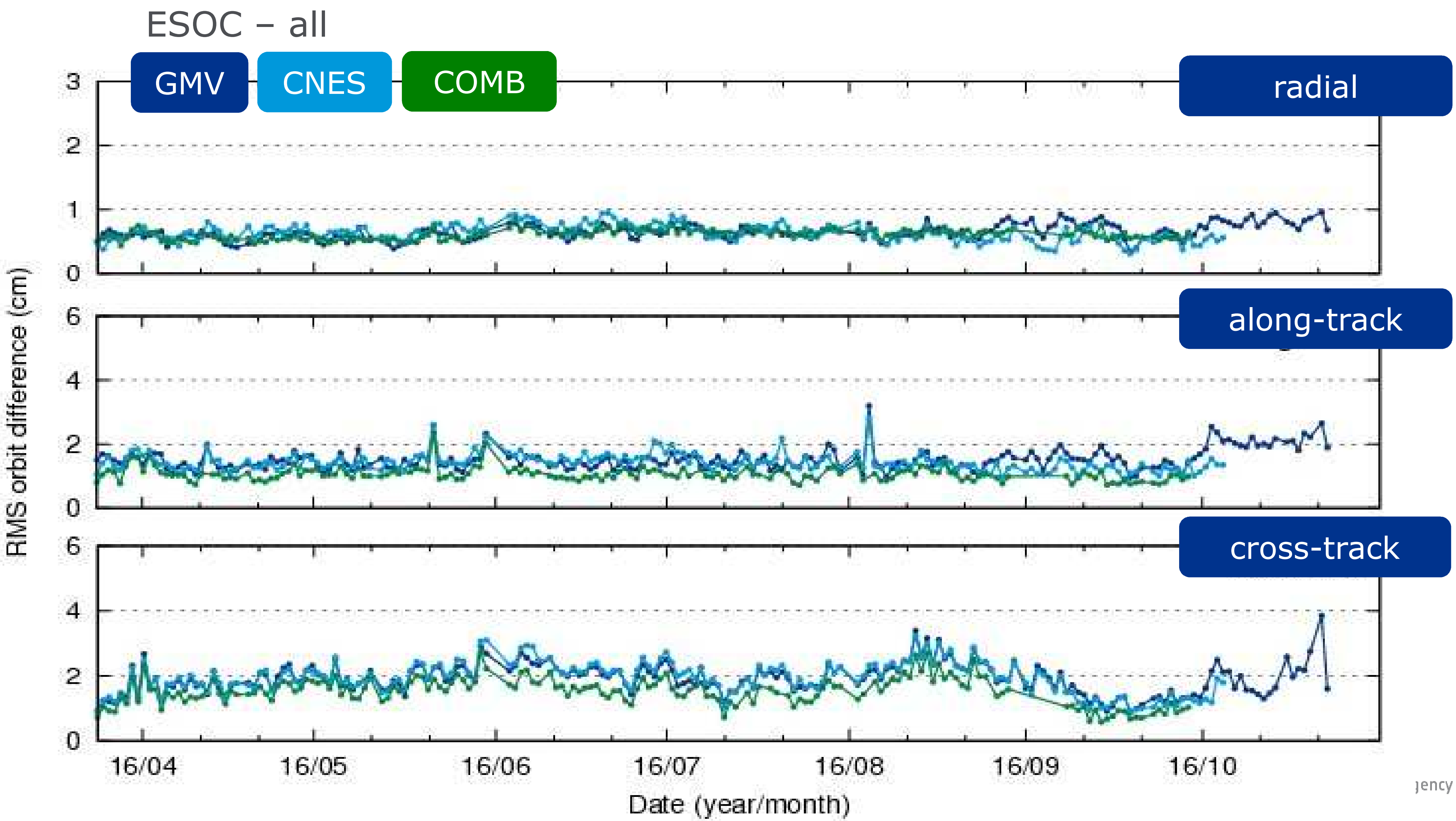
ESOC – Combined solution



rms: 0.61, 1.06, 1.50cm

Daily RMS of orbit differences

Sentinel-3A



Ambiguity Fixing – Two techniques

- Currently we have in our software (NAPEOS) two possible ways of fixing the ambiguities for the LEO satellites:

1. The integral approach in which the LEO is included into an IGS like scenario (including GPS station data) and the LEO is treated as another (although orbiting) station and the integer ambiguities are resolved at the double difference level together with the station ambiguities.
2. In the second approach the un-calibrated phase delays (UPD) are saved from our IGS runs and later reintroduced into the LEO ambiguity resolution processing. In this processing the UPDs are used together with two single differences to resolve the integer ambiguities of the LEO.

Processing strategy Ambiguity fixing

- This first method that we tested was the combined processing (method 1) and all results that will be shown are based on this method.
- For the test period we have used September 2016.
- We included 60 globally well distrusted stations.
- We used 60 second sampling for the ground stations and Sentinel-3A.
- We computed 24hr arcs without overlap.
- Estimate the same number of orbit parameters for Sentinel-3A as in the float solution.

Processing strategy Ambiguity fixing

- We first generate a solution in which all the ambiguities are estimated as float together with all the other parameters
- From this solution we then resolve for both the stations and Sentinel-3A the integer ambiguities at the double difference level
- We generate then again a new solution identical to the first step but now we keep all the ambiguities fixed that could be resolved in the previous step
- We do this last step to be able to edit out wrongly fixed ambiguities

Orbit overlap and comparison

Sentinel-3A

Solution	Radial	Along	Cross
Float	1.01	3.82	1.46
Fixed	0.86	5.62	1.98

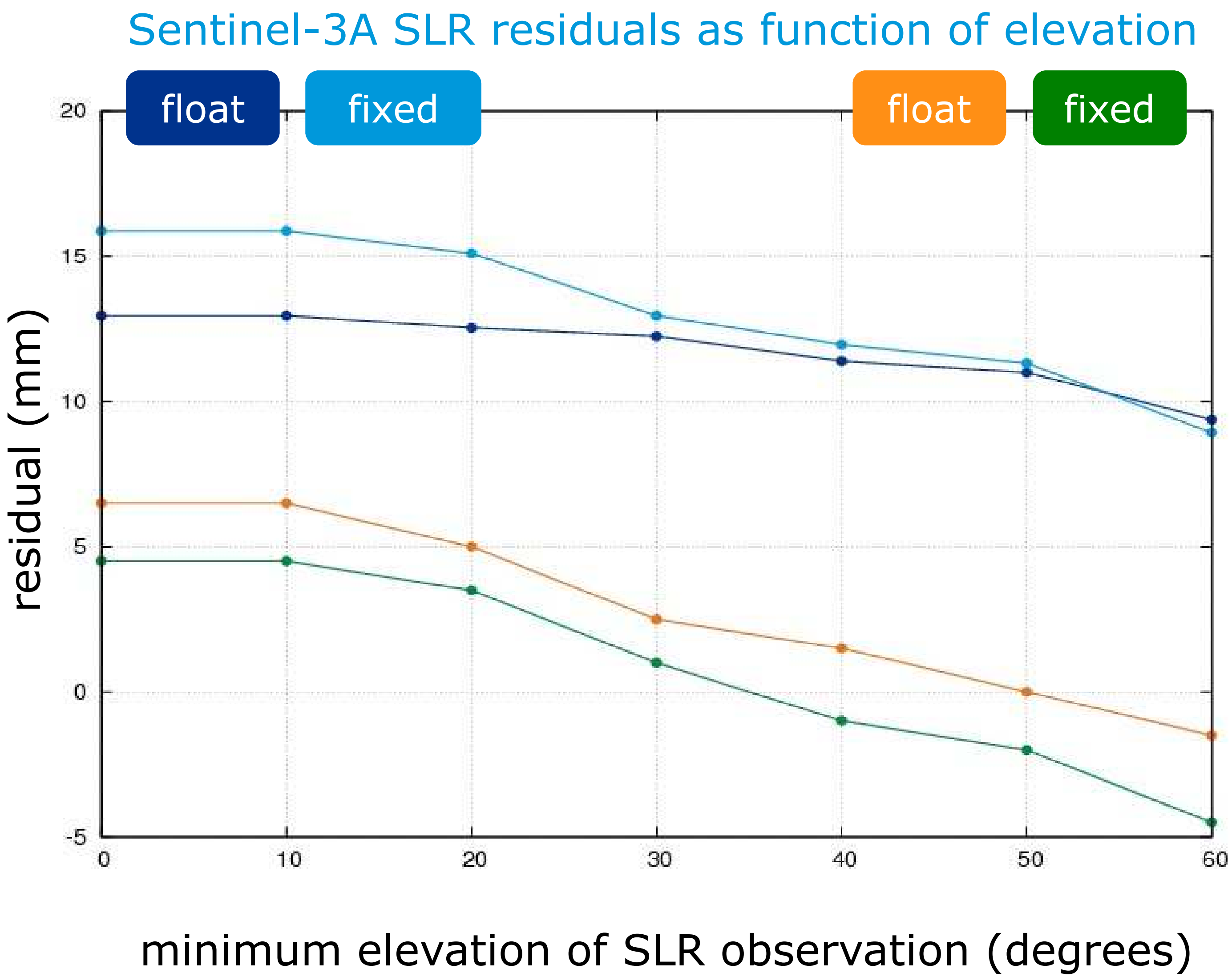
Sentinel-3A orbit overlap point from 24hr arc (cm) for September 2016

Solution	Radial	Along	Cross
Float	0.68	1.02	0.85
Fixed	0.73	1.16	0.74

Sentinel-3A orbit comparison against combination (cm) for September 2016

SLR residual performance

Sentinel-3A



SLR residuals based on selected SLR network: (7090/7105/7119/7821/7840/7841/7941/8834).

SLR ANTEX phase centre correction based on TN-1101-IPIE_LRA_v1.0 document.

¼ Cycle slips in data?

Sentinel-3A

Narrowlane SD/DD histogram from Sentinel-3A

```
+--------+---------+
|  Bin   |    #    |
+--------+---------+
| -0.50  |       0 |
| -0.48  |       0 |
| -0.46  |       0 |
| -0.44  |       0 |
| -0.42  |       0 |
| -0.40  |       0 |
| -0.38  |       0 |
| -0.36  |       0 |
| -0.34  |       0 |
| -0.32  |       0 |
| -0.30  |       0 |
| -0.28  |    1388 |***********      <- 0.25 cycle
| -0.26  |    1043 |********
| -0.24  |     796 |******
| -0.22  |     631 |*****
| -0.20  |     190 |*
| -0.18  |      91 |*
| -0.16  |     166 |*
| -0.14  |      98 |*
| -0.12  |      72 |*
| -0.10  |     128 |*
| -0.08  |     206 |**
| -0.06  |     227 |**
| -0.04  |      74 |*
| -0.02  |     177 |*
|  0.00  |    7618 |************************************************************
|  0.02  |     233 |**
|  0.04  |      72 |*
|  0.06  |     227 |**
|  0.08  |     206 |**
|  0.10  |     118 |*
|  0.12  |      62 |
|  0.14  |     117 |*
|  0.16  |     101 |*
|  0.18  |      93 |*
|  0.20  |     231 |**
|  0.22  |     503 |****
|  0.24  |     864 |*******
|  0.26  |    1118 |*********        <- 0.25 cycle
|  0.28  |    1264 |**********
|  0.30  |       0 |
|  0.32  |       0 |
|  0.34  |       0 |
|  0.36  |       0 |
|  0.38  |       0 |
|  0.40  |       0 |
|  0.42  |       0 |
|  0.44  |       0 |
|  0.46  |       0 |
|  0.48  |       0 |
|  0.50  |       0 |
+--------+---------+
```

Large number of ±¼ cycle present in the Sentinel-3A Narrowlane histogram when resolving the integer ambiguities. Cause is under investigation. Possible cause can be in the RINEX generation.

Still possible to resolve 90% of all ambiguities.

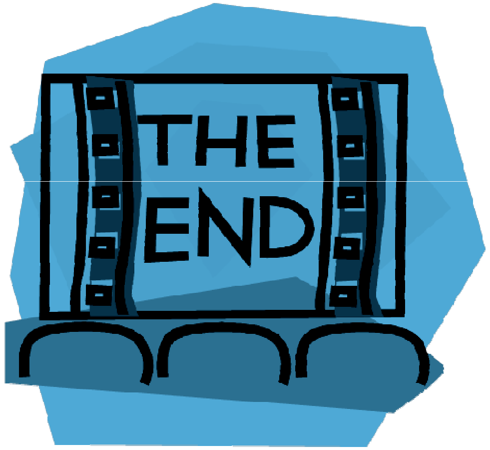
Summary (1)

- Very good quality of the Sentinel-3A GPS data, same level as for the other Sentinel missions.
- Orbit overlap statistics show a 1cm radial orbit error (at the day boundary).
- Very good performance of the different Sentinel-3A orbits. Radial orbit differences between the different solutions below the 1cm.
- Independent high elevation SLR residuals are 1cm. Indicating at a radial orbit accuracy of 1cm. Small along-track bias between the SLR data and the GPS orbits.
- First test with resolving integer ambiguities for the Sentinel-3A data indicate possible ¼ cycles present in the RINEX data. Cause of the ¼ cycles is under investigation. Potential cause can be caused

Summary (2)

- First test with resolving integer ambiguities for the Sentinel-3A data indicate possible ¼ cycles present in the RINEX data when construction the Narrowlane SD/DD. Cause of the ¼ cycles is under investigation. Potential cause can be how the L1C/L1W phase is written in the RINEX data (receiver squaring).
- Even with these ¼ cycles the integer fixed orbit have very similar performance as the float orbits (but should of course be better)
- Still to be performed is a detailed altimeter XO evaluation of our orbits.
- Orbits available on the COPPOD ftp server (login required)

Thank you



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