Sentinel orbit performance monitoring

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What we do for 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 (4.0) and use the latest state of the art models.
  - We provide both orbit solutions in NRT and in NTC mode (results presented here based on NTC products).

Data processed for Sentinel

- The following periods and Satellites have been processed so far:
  - Sentinel-1A 7th of April 2014 – current
  - Sentinel-1B 18th of June 2016 – current
  - Sentinel-2A 27th of June 2015 – current
  - Sentinel-2B 23rd of March 2017 – current
  - Sentinel-3A 16th of March 2016 – current
- Orbits are available on our own ftp server dgnl6.esoc.esa.int (login / password required) and on the COPPOD ftp server

Processing strategy

- NAPEOS version 4.0
- 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)
- For Sentinel-3A SLR data used for validation only

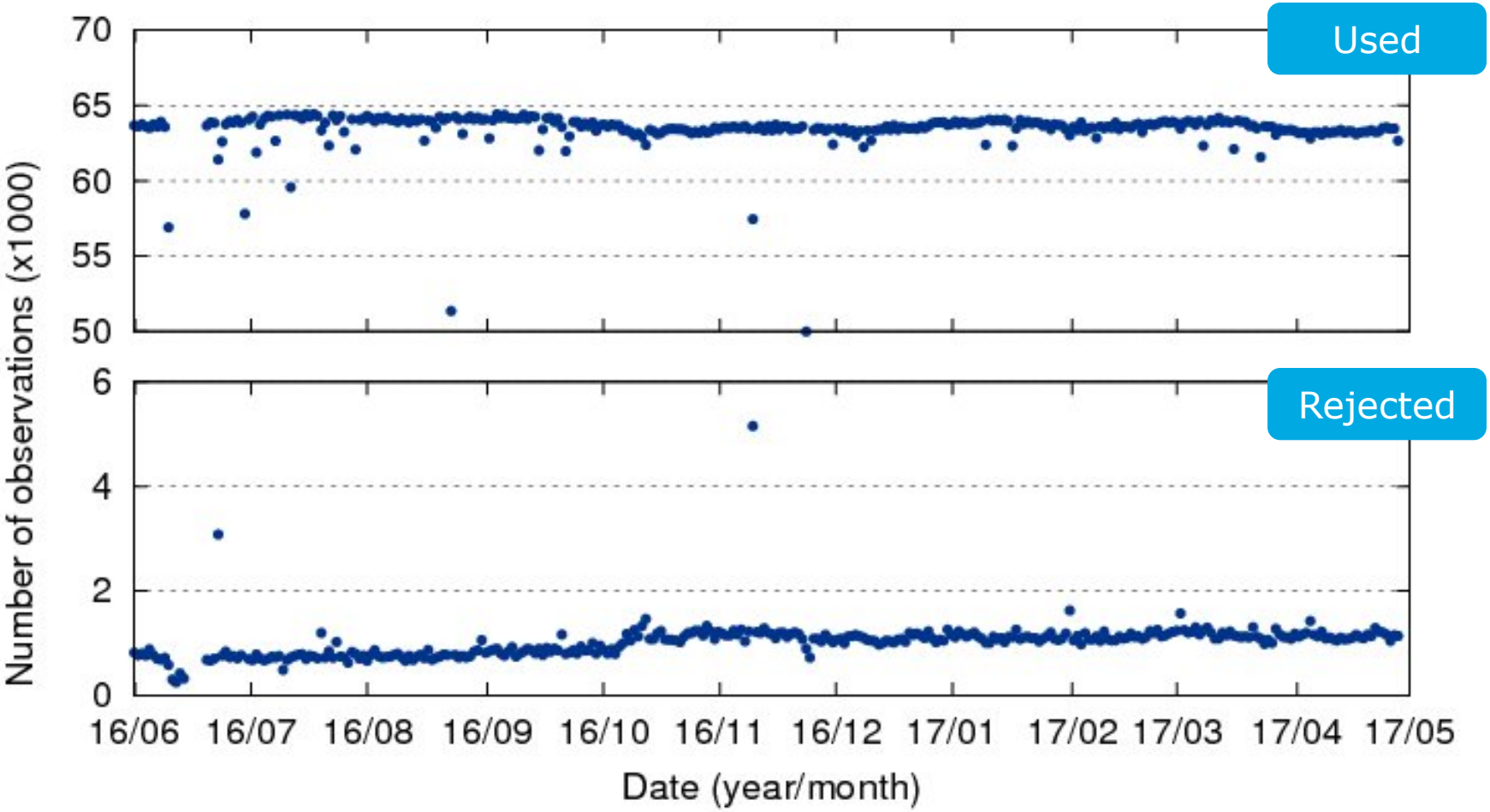
- Estimated parameters
  - Orbit parameter (1-day arcs)
    - SV
    - 6 CPRs (constant/sin/cos in along-track/cross-track) every 12h
    - 10 Drag parameters every 24h
  - GPS phase ambiguites (float)
  - Sentinel clock bias (10s)

Processing strategy

- Gravityfield
  - GRGS EIGEN.GRFS.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 (UPDATED for Sentinel-1 and Sentinel-3)
- GPS antenna phase centre modeling
  - values for Sentinel-1A are taken from: "GMV-GMESPOD-MEM-0004_v1.2"
  - values for Sentinel-2A are taken from: "GMV-GMESPOD-MEM-0007_v1.1"
  - values for Sentinel-3A are taken from: "GMV-GMESPOD-TN-0027_v1.1draft"
  - ANTEX corrections are based on the latest files from the COPPOD server
- Attitude modelling
  - Nominal attitude model for all satellites

Observation data Sentinel-1A

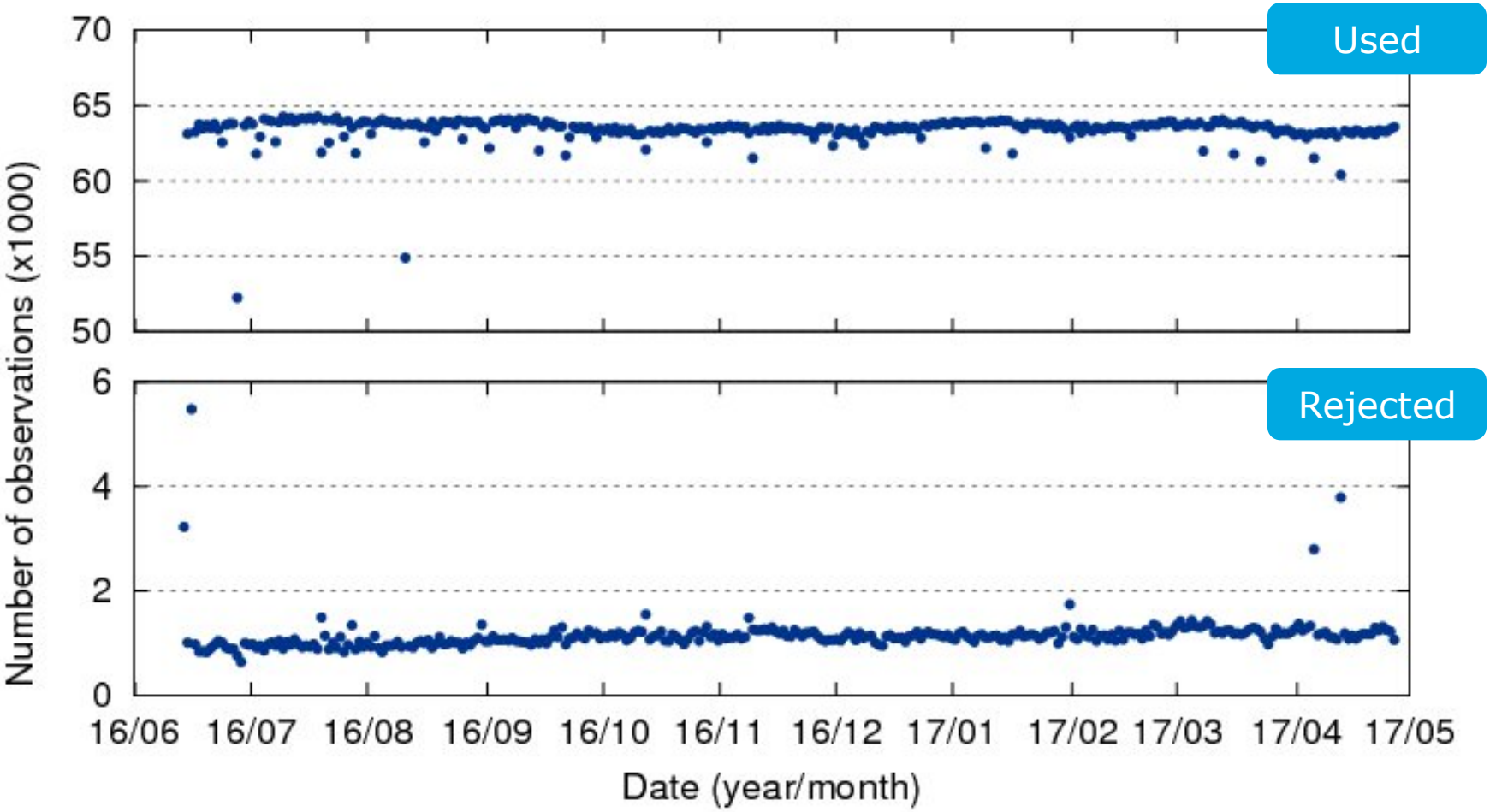
From 24 hour arcs (data since last QWG meeting)



Observation data Sentinel-1B

From 24 hour arcs (data since last QWG meeting)

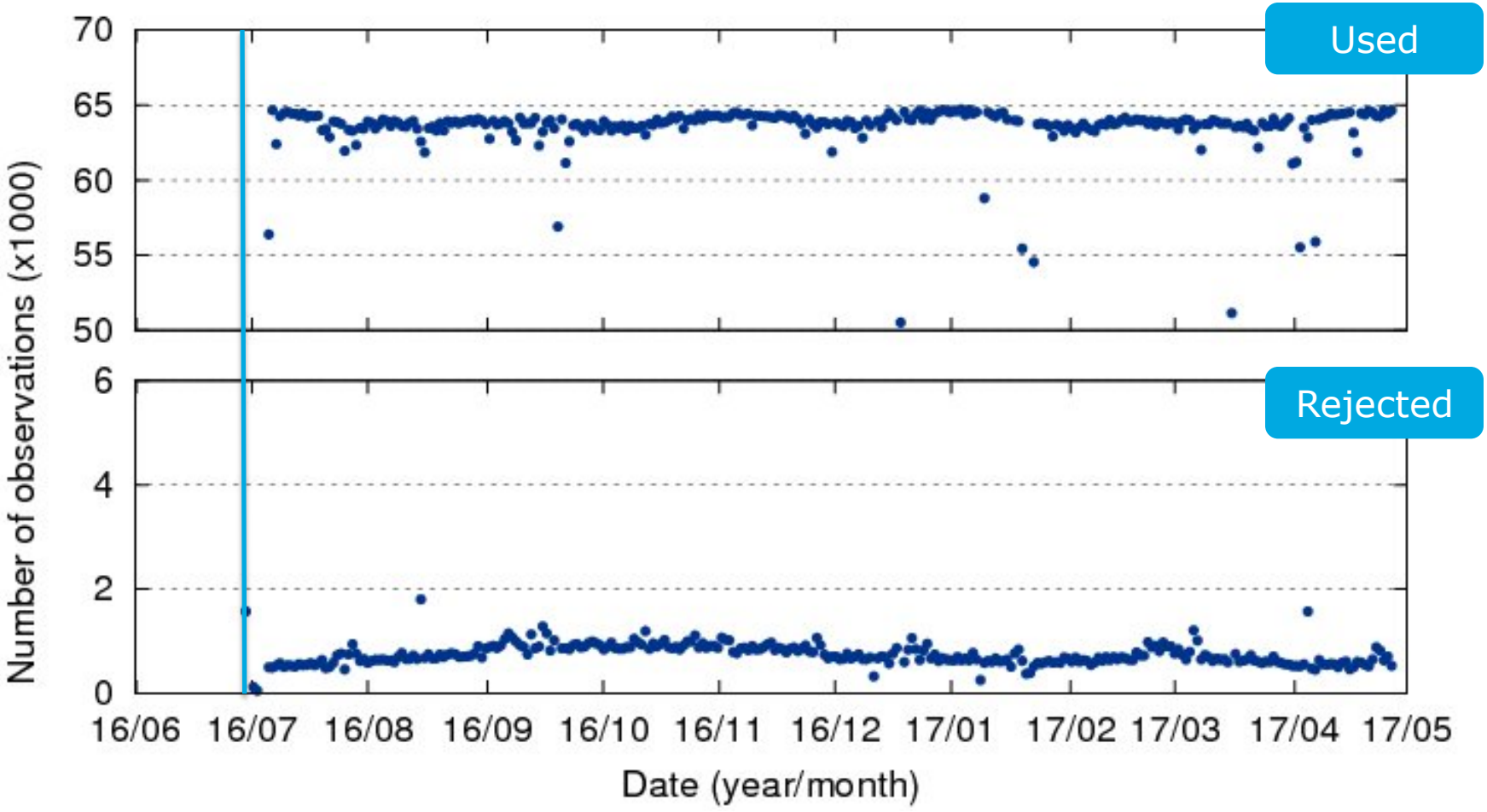
Sentinel-1B GPS observations (10 sec.) from 24hr arcs



Observation data Sentinel-2A

From 24 hour arcs

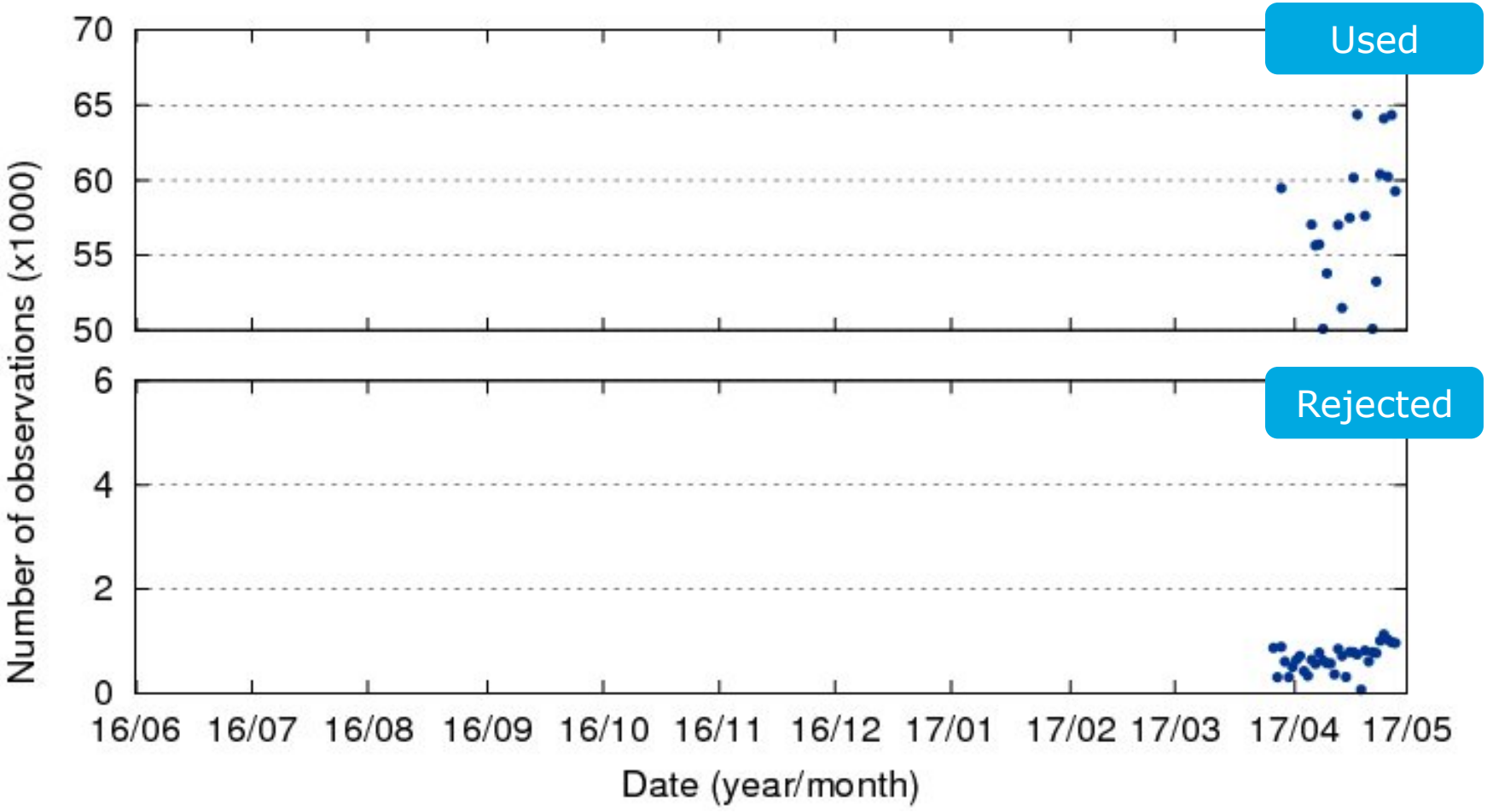
Sentinel-2A GPS observations (10 sec.) from 24hr arcs



Blue line marks start of delivery to ESOC of L0 data for S2-A

Observation data Sentinel-2B

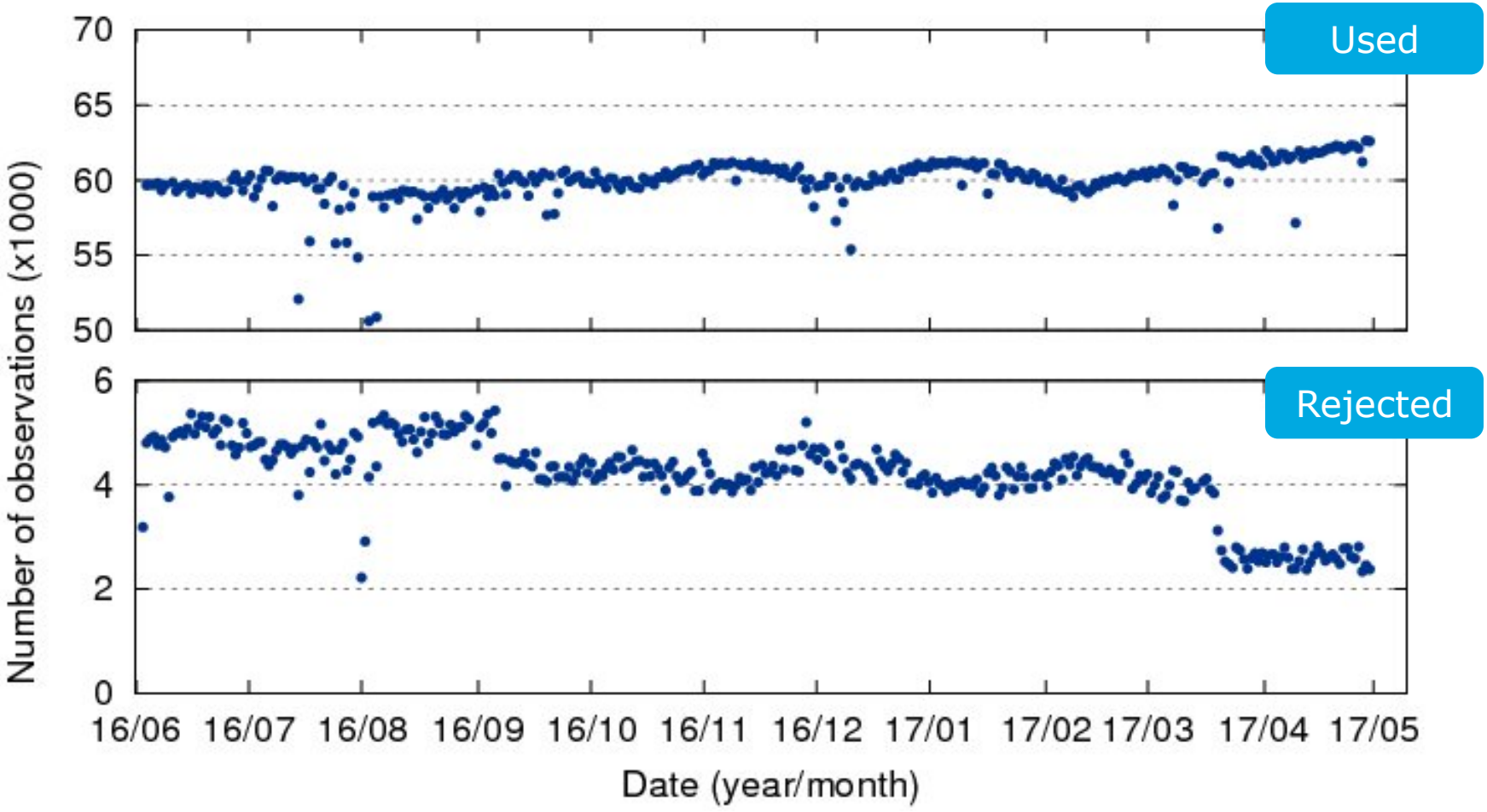
From 24 hour arcs



Still large gaps in Sentinel-2B data as delivered to us

Observation data Sentinel-3A

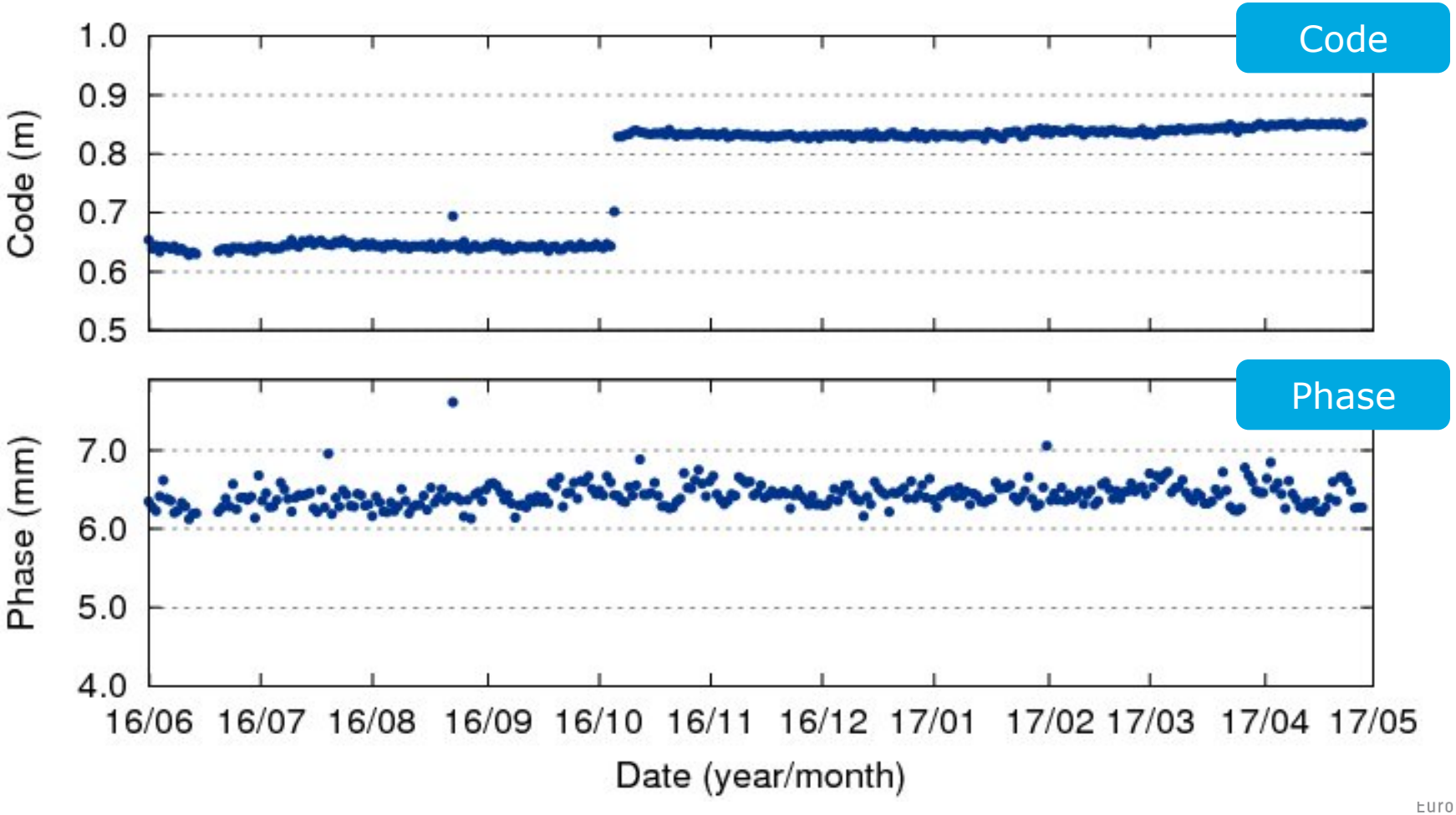
From 24 hour arcs



Observation data Sentinel-1A

From 24 hour arcs (data since last QWG meeting)

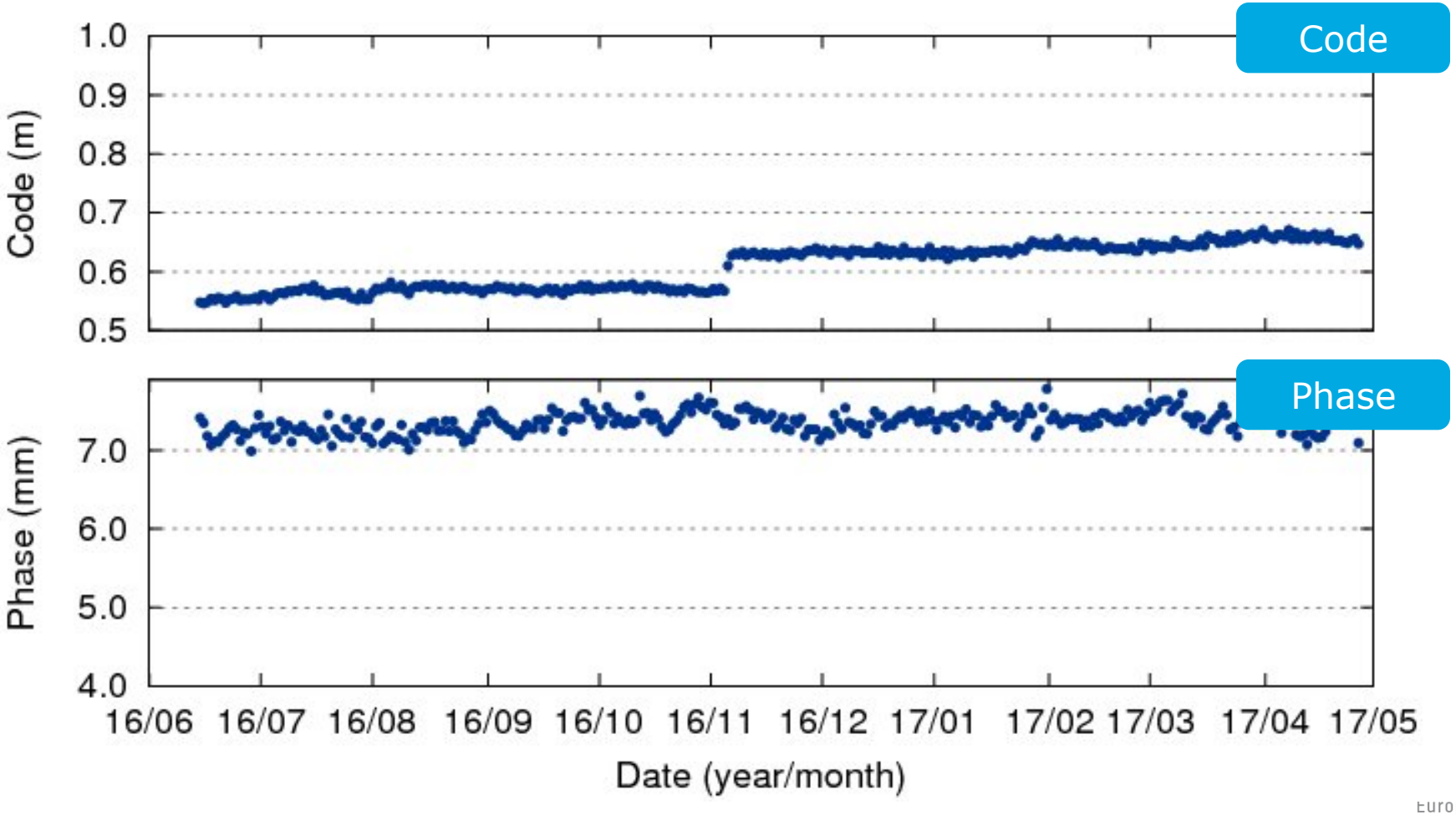
Sentinel-1A GPS observations (10 sec.) from 24hr arcs



Observation data Sentinel-1B

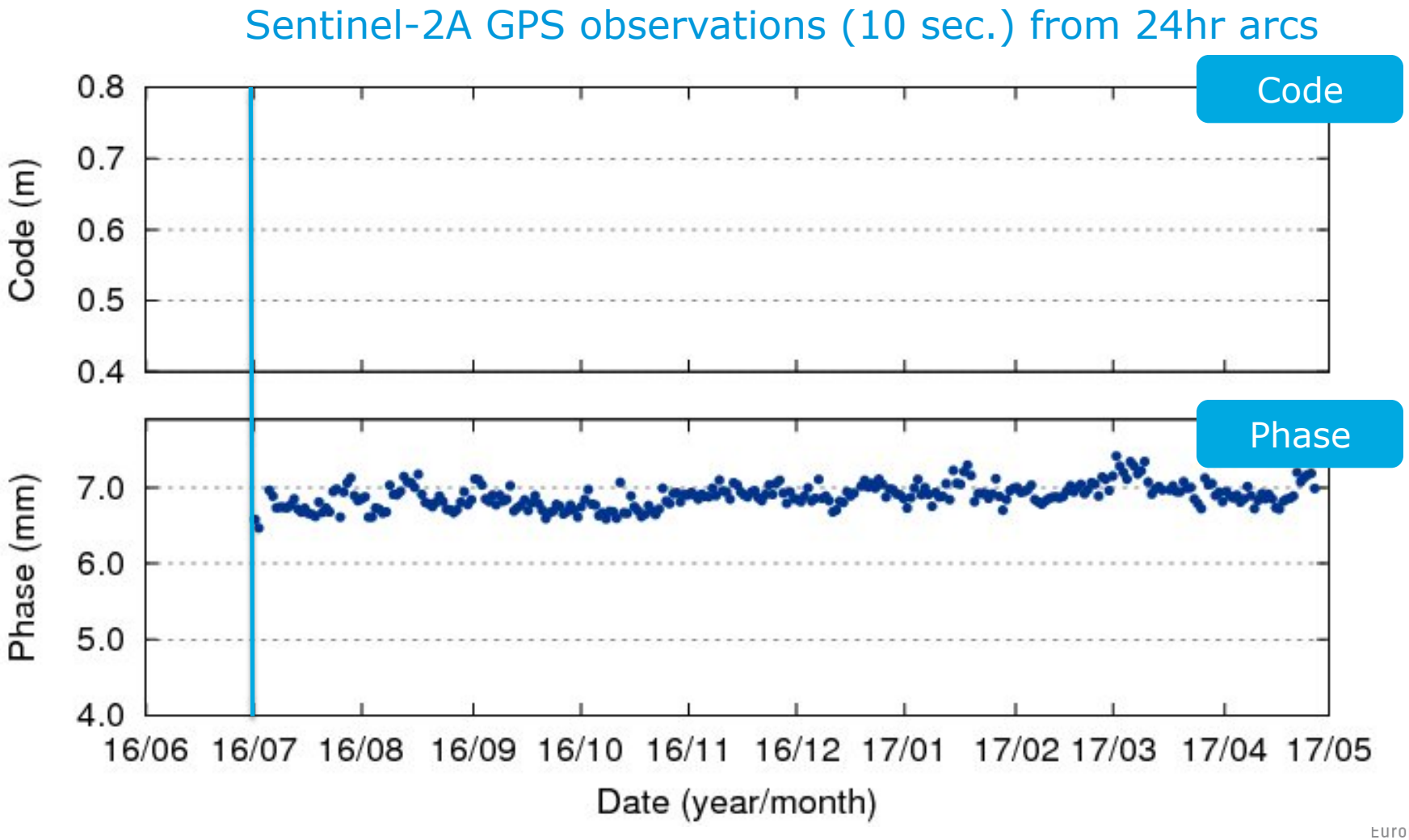
From 24 hour arcs (data since last QWG meeting)

Sentinel-1B GPS observations (10 sec.) from 24hr arcs



Observation data Sentinel-2A

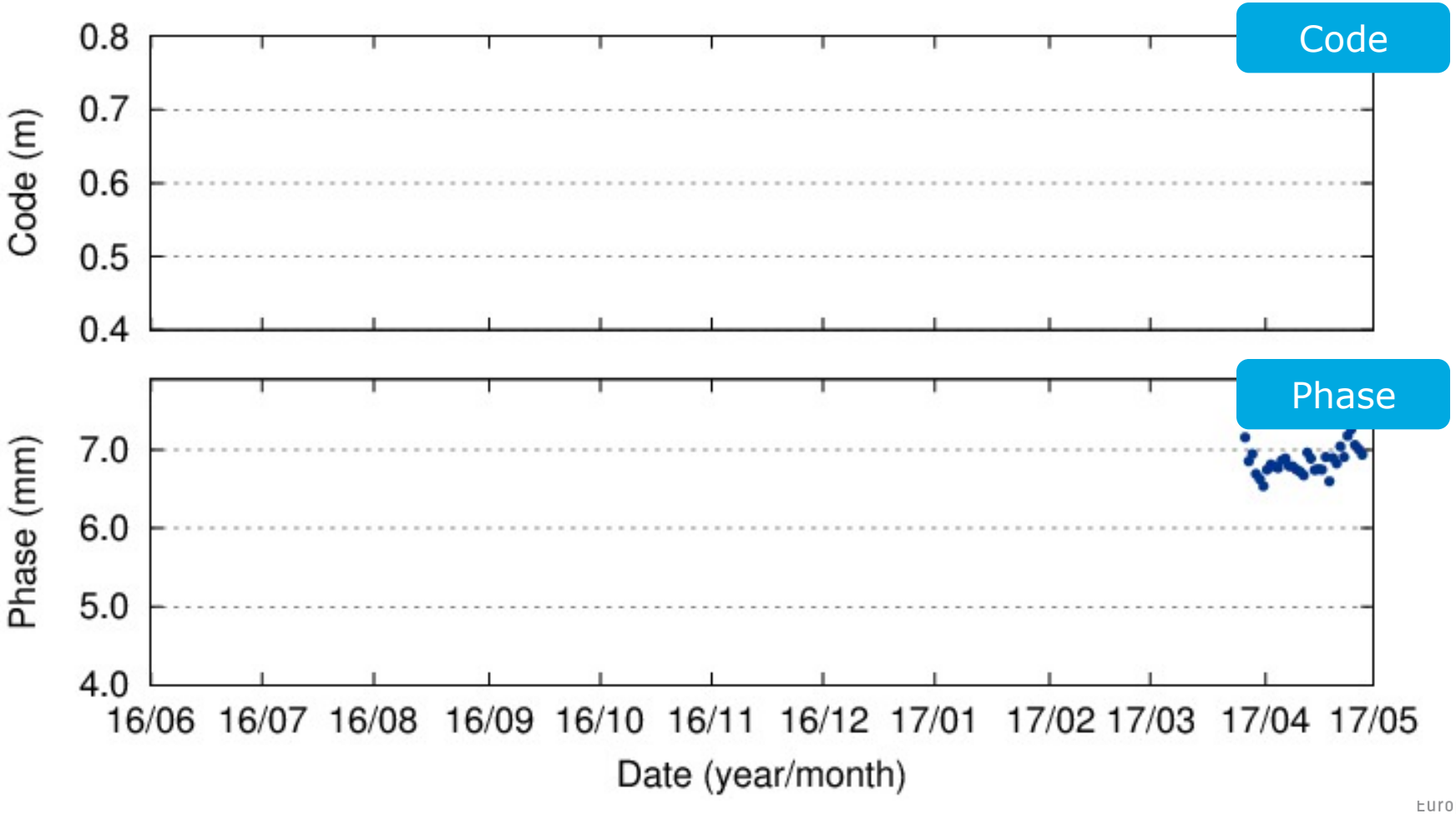
From 24 hour arcs



Bias exist between our code and phase data

Observation data Sentinel-2B

From 24 hour arcs

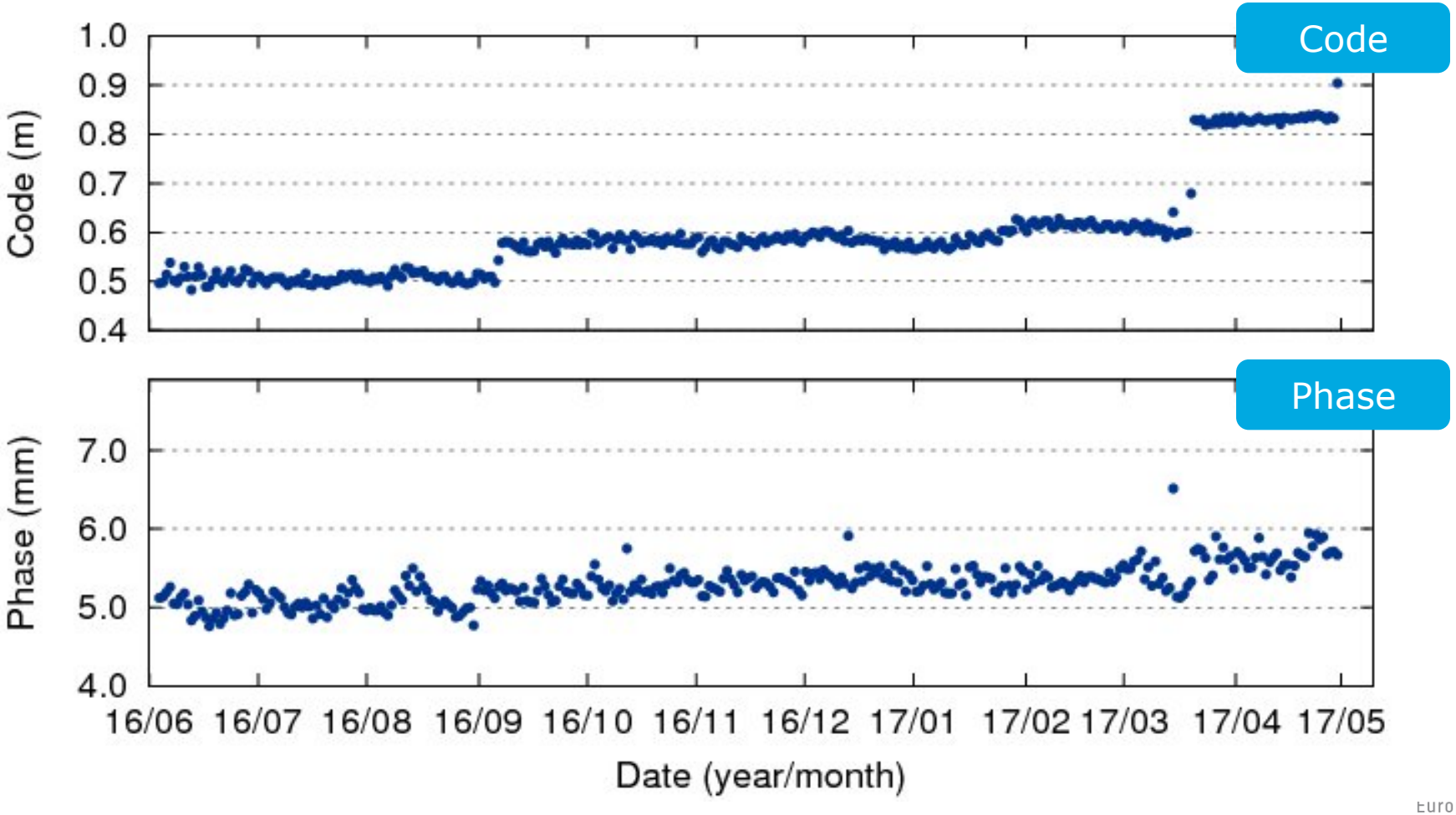


Bias exist between our code and phase data

Observation data Sentinel-3A

From 24 hour arcs

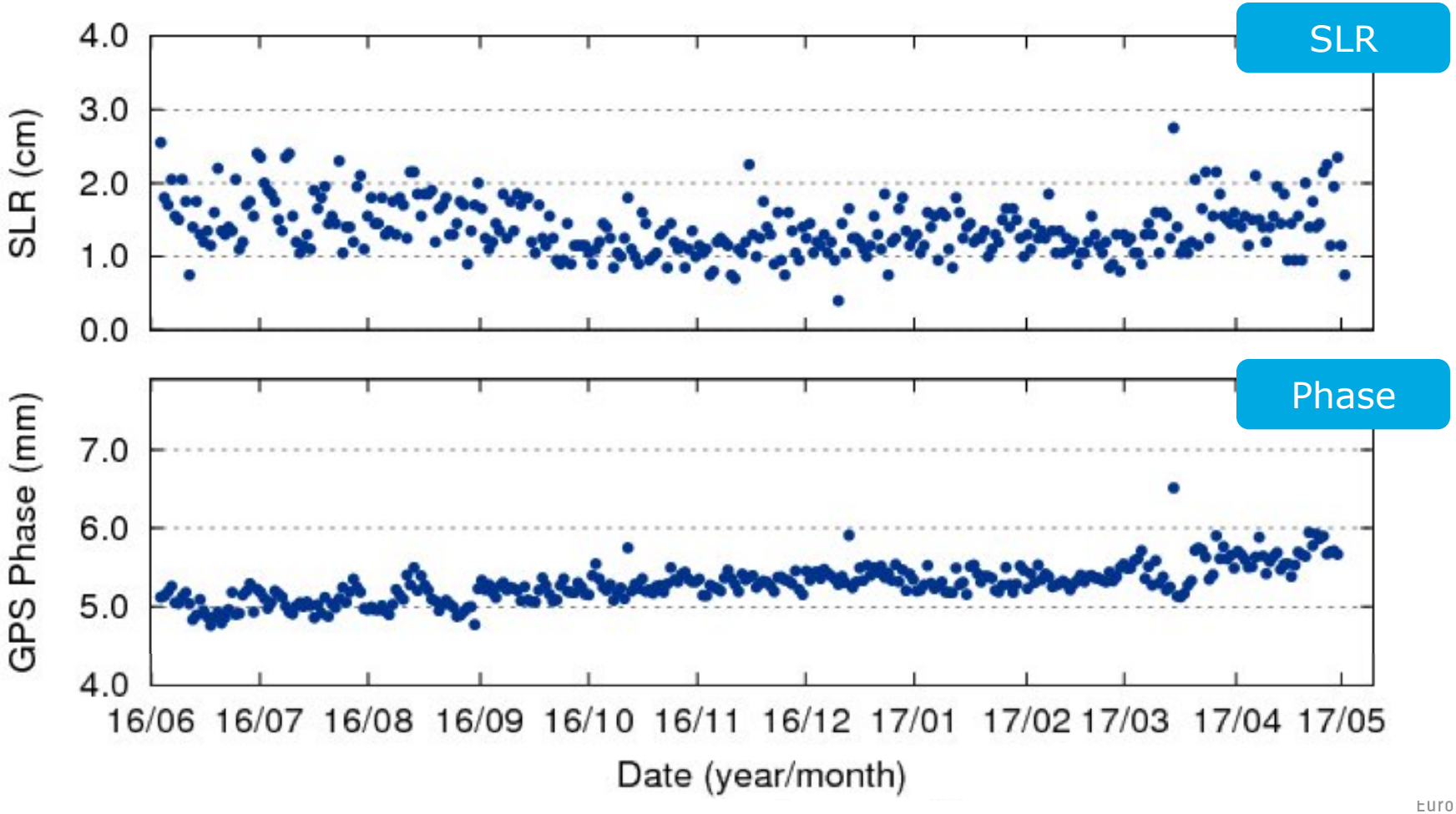
Sentinel-3A GPS observations (10 sec.) from 24hr arcs



Observation data Sentinel-3A

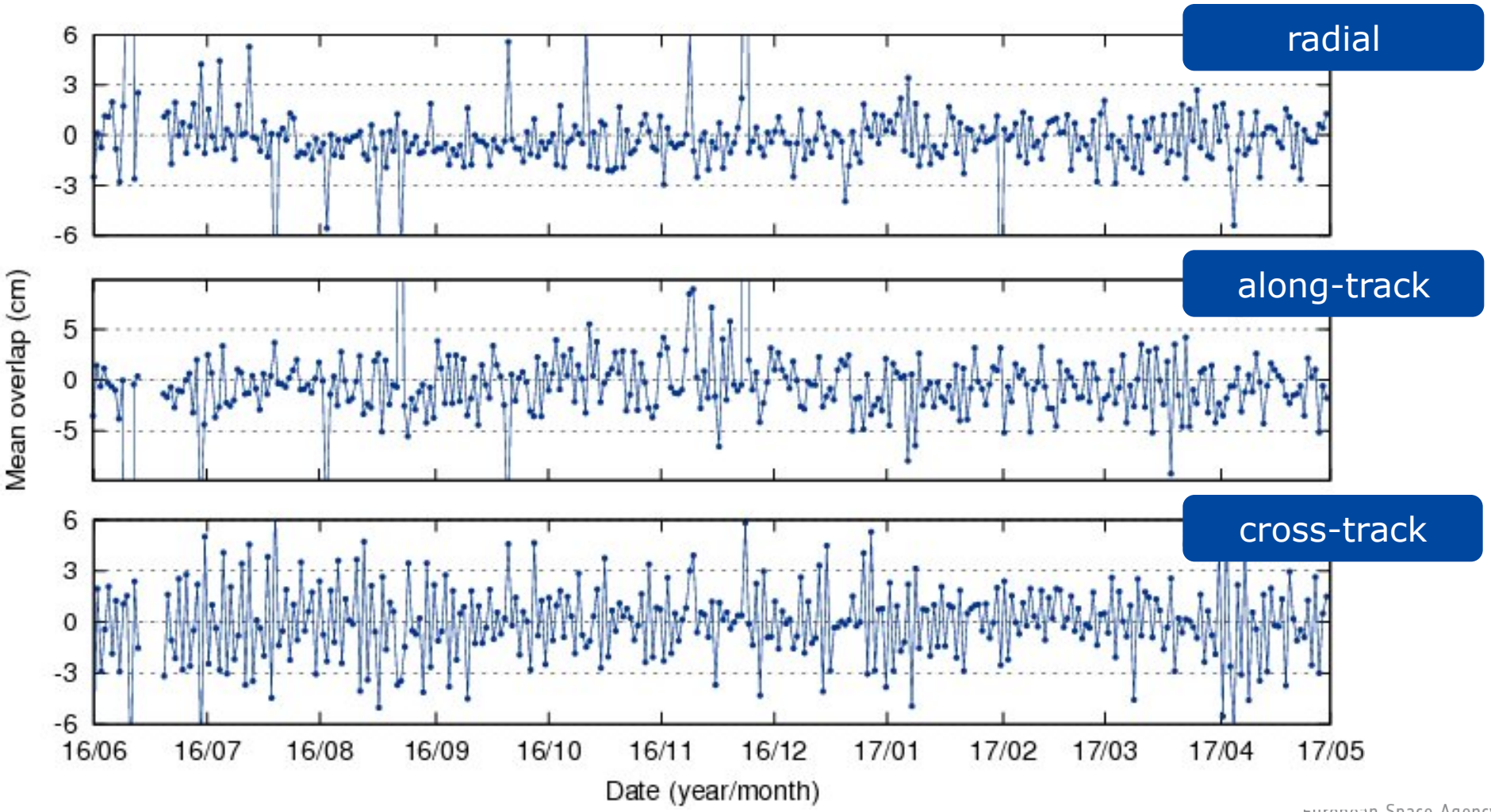
From 24 hour arcs

Sentinel-3A GPS observations (10 sec.) from 24hr arcs



Daily orbit overlap from ESOC solution

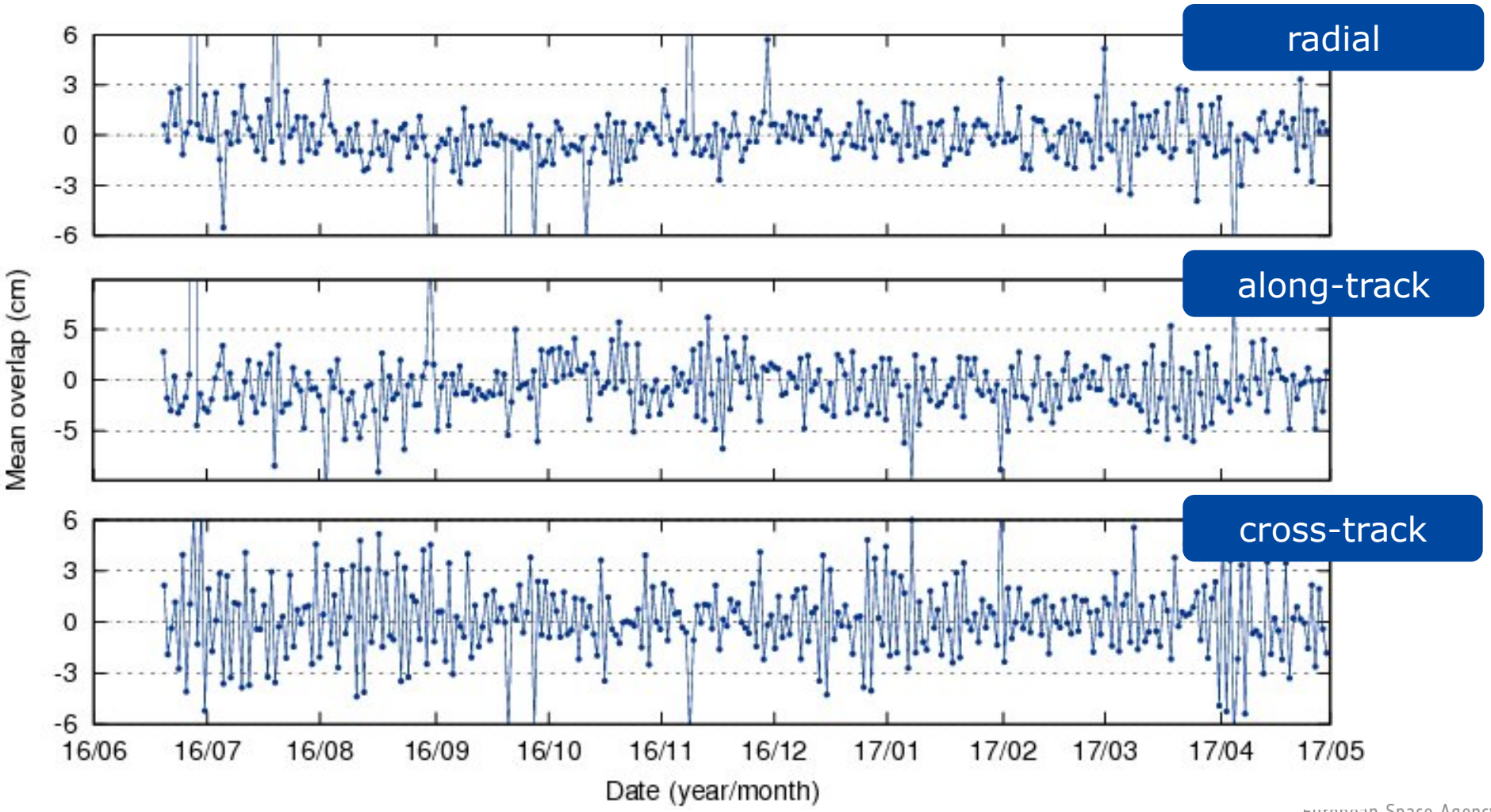
Sentinel-1A from 24 hour solution (single point)



rms values (radial, along and cross): 1.07, 2.08, 1.78 cm

Daily orbit overlap from ESOC solution

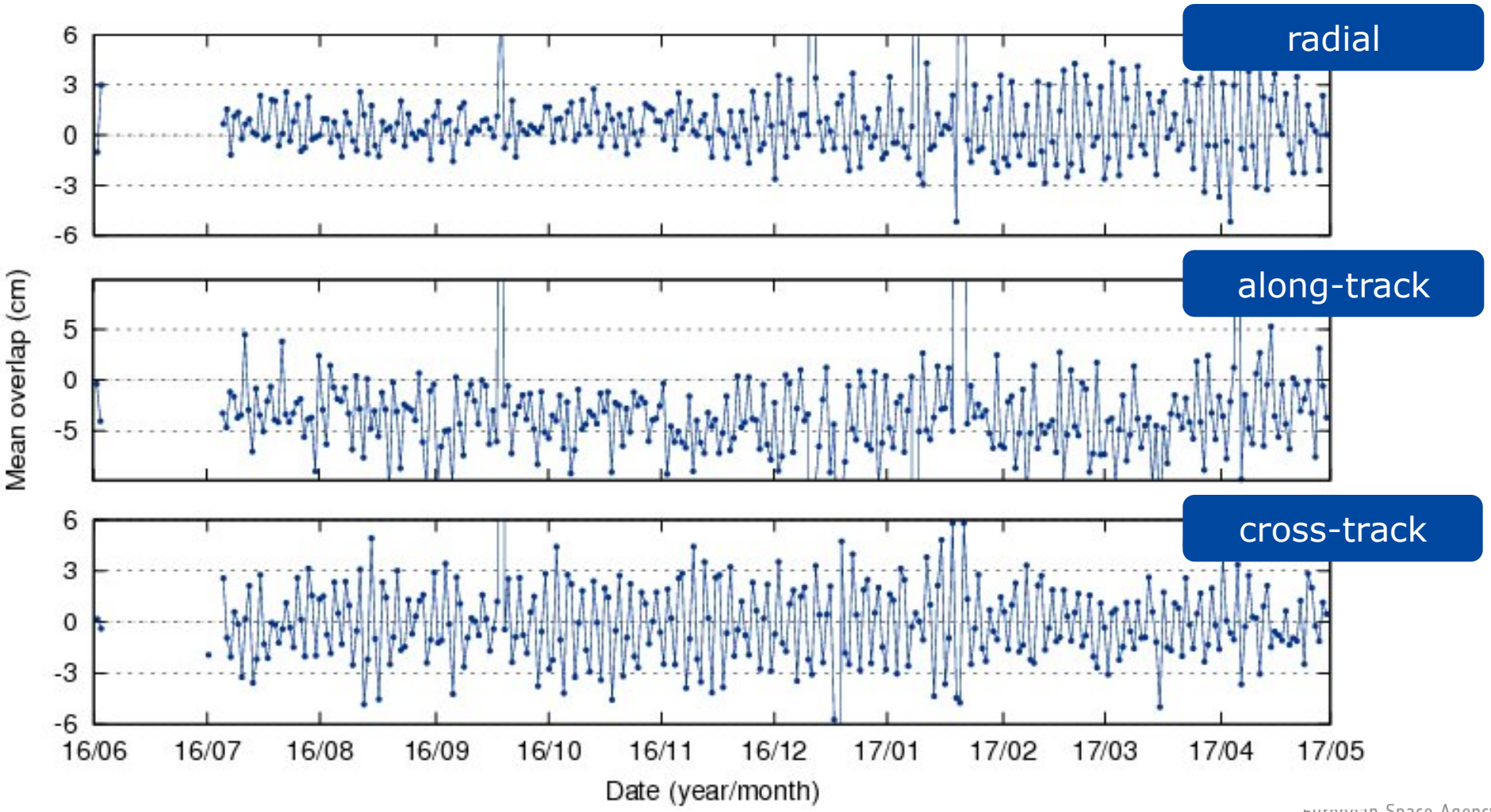
Sentinel-1B from 24 hour solution (single point)



rms values (radial, along and cross): 0.97, 2.03, 1.61 cm

Daily orbit overlap from ESOC solution

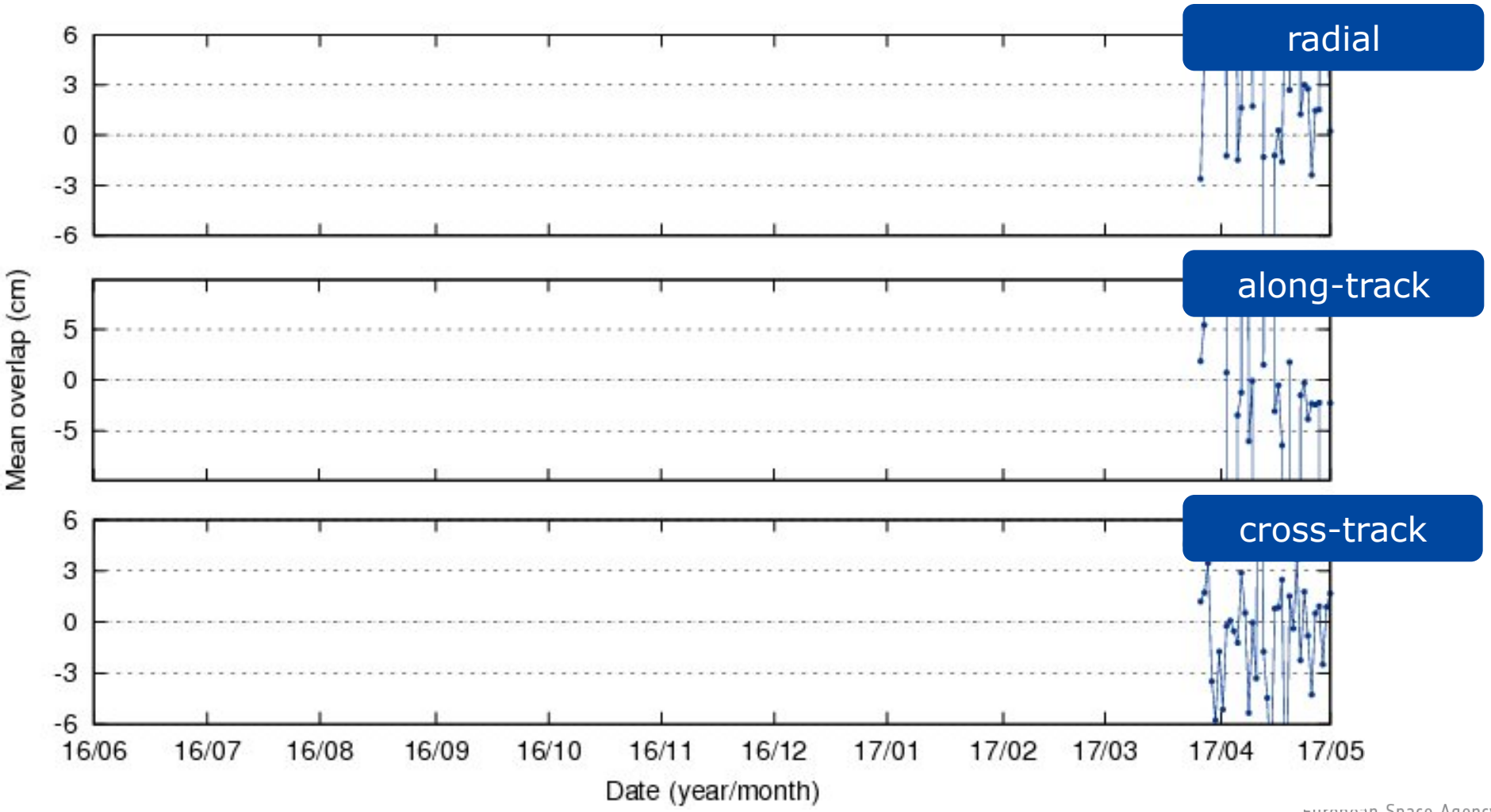
Sentinel-2A from 24 hour solution (single point)



rms values (radial, along and cross): 1.28, 3.42, 1.69 cm

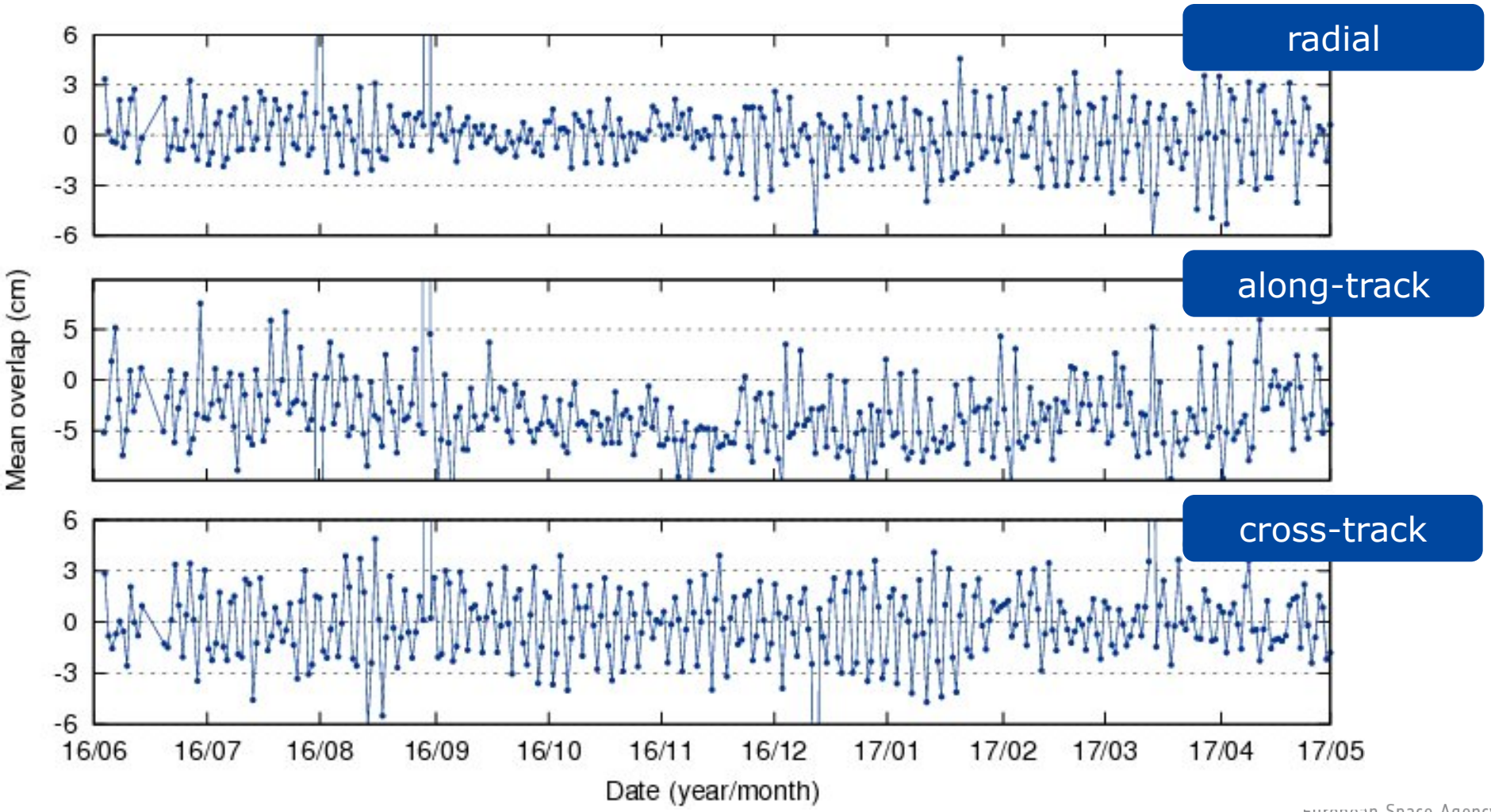
Daily orbit overlap from ESOC solution

Sentinel-2B from 24 hour solution (single point)



Daily orbit overlap from ESOC solution

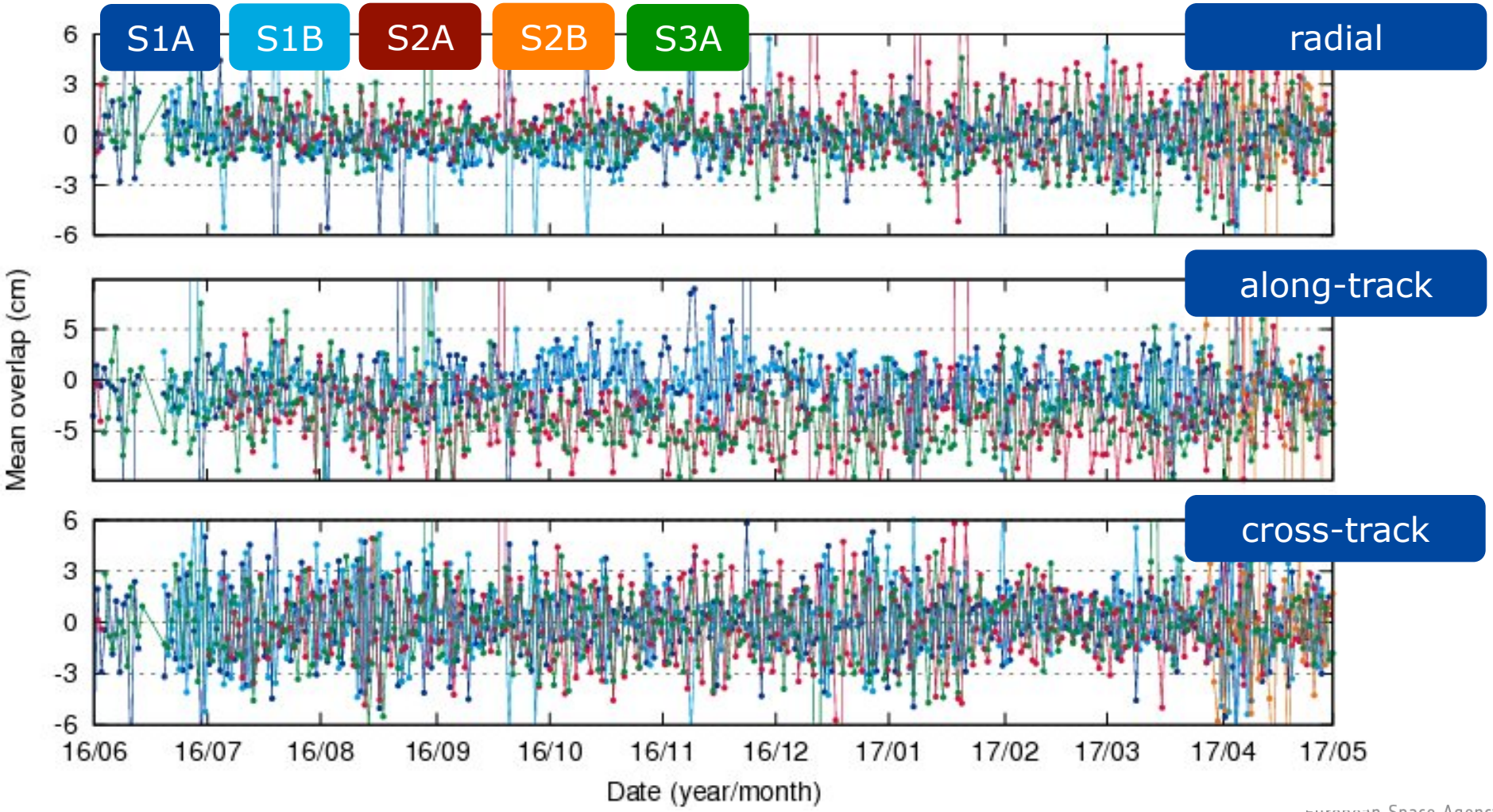
Sentinel-3A from 24 hour solution (single point)



rms values (radial, along and cross): 1.32, 3.61, 1.48cm

Daily orbit overlap from ESOC solution

Sentinel-1,2,3A from 24 hour solution (single point)



rms: (1.07, 2.08, 1.78) (0.97, 2.03, 1.61) (1.28, 3.42, 1.69) (1.32, 3.61, 1.48) cm

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.
- We used all (different) available RINEX files for Sentinel-3A: DLR, GMV original and GMV new (fit, gpst, imt)

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

Different RINEX files – Float Solution

Sentinel-3A

- At the float level all types of RINEX files perform the same. The Sentinel-3A phase residuals are around the 3.41mm level and the code residuals are 54,9cm.
- All types for RINEX files show large biases in the code for different satellites:

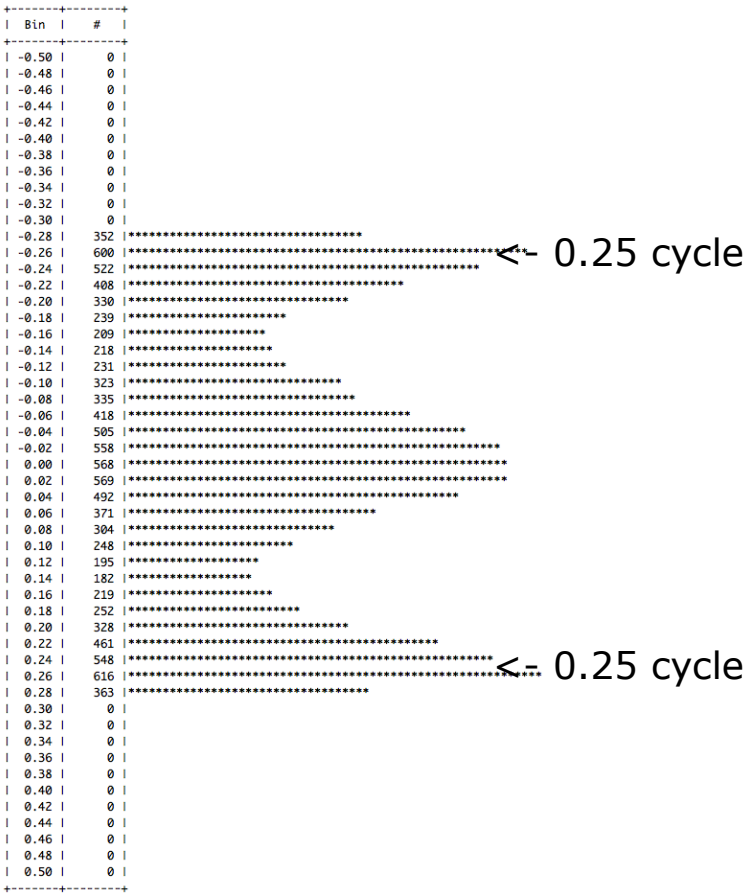
		SS-udPh (mm)				SS-udPr (m)			
SAT-ID	TRAN	#Obs	#Reject	Mean	RMS	#Obs	#Reject	Mean	RMS
SENT-3A	GPS1	10329	292	0.000	3.492	10329	292	0.000	0.559
GPS-44	G28	343	37	0.000	3.137	343	37	-0.306	0.711
GPS-47	G22	354	3	0.000	2.944	354	3	-0.205	0.518
GPS-61	G02	454	1	0.000	4.225	454	1	-0.207	0.508
GPS-62	G25	372	19	0.000	4.320	372	19	0.322	0.645
GPS-66	G27	142	4	0.000	2.839	142	4	0.231	0.504
GPS-70	G32	281	5	0.000	3.521	281	5	0.195	0.648

Selected residuals taken from DLR RINEX doy 249 (2016)

Ambiguity Fixing

Sentinel-3A

Narrowlane SD/DD histogram from Sentinel-3A



- 50% of all observations show a ±¼ cycle present in the Sentinel-3A Narrowlane histogram when resolving the integer ambiguities. But the Widelane (MelWub) looks fine.
- Systematic biases present in code observations.
- Suspect bias (1 WL?) in the L1 or L2 phase and code observations
- Present in all RINEX files

Orbit overlap and comparison

Sentinel-3A using GMV original RINEX files

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

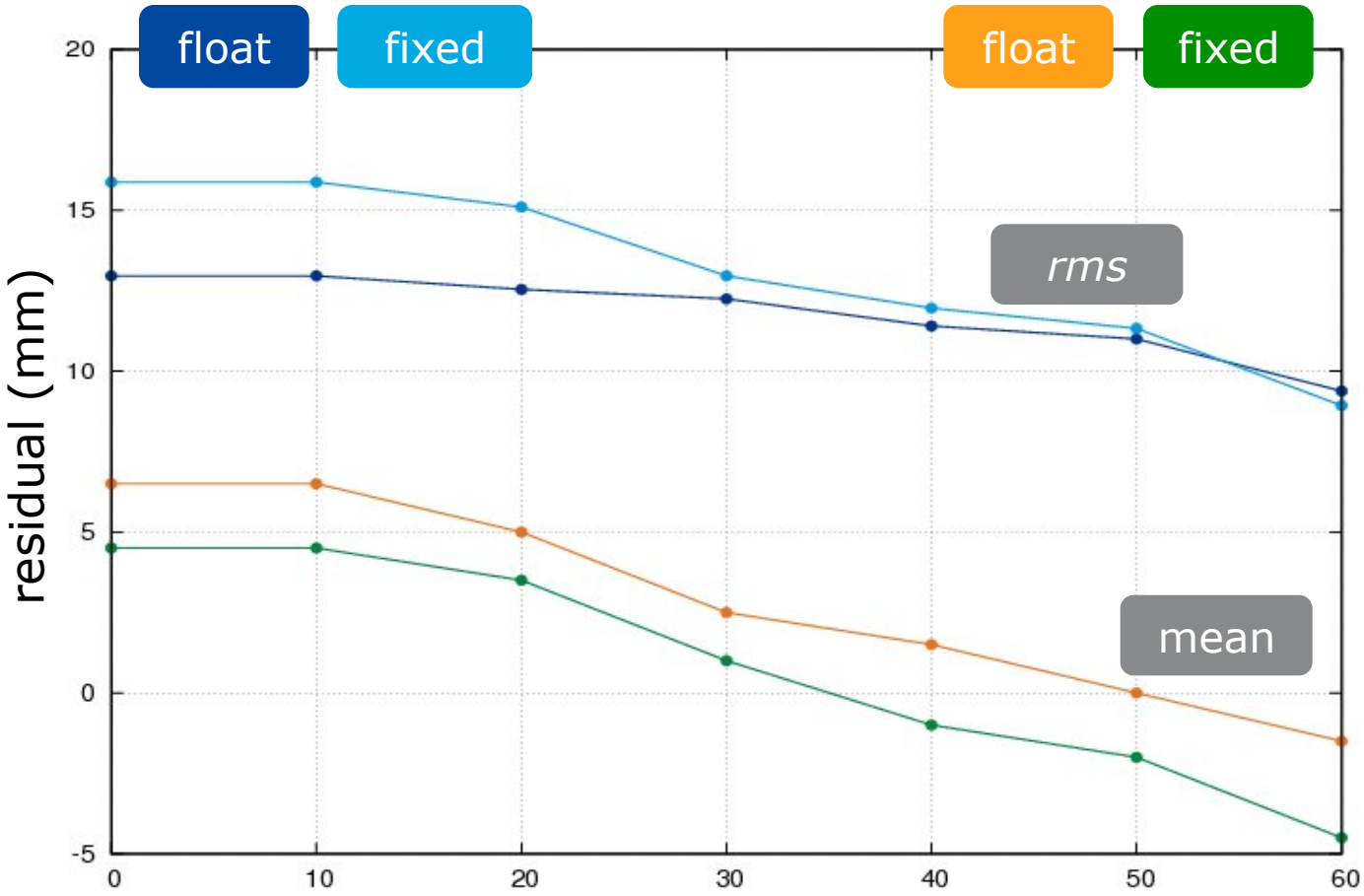
Solution	Radial	Along	Cross
Float	0.68	1.02	0.85
Fixed	0.73	1.16	0.74

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

SLR residual performance

Sentinel-3A using GMV original RINEX files

Sentinel-3A SLR residuals as function of elevation



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.

Summary (1)

- Integer ambiguity resolution for the Sentinel-3A still not possible
- Observations show a ±¼ cycle present in the Sentinel-3A Narrowlane histogram when resolving the integer ambiguities. But the Widelane (MelWub) looks fine.
- Suspect bias (1 WL?) in the L1 or L2 phase and code observations
- Present in all RINEX files
- Even with these ¼ cycles the integer fixed orbit have very similar performance as the float orbits (but should of course be better)

Summary (2)

- Processing strategy at ESOC of the Sentinel RINEX data show jumps in the code residuals for nearly all missions. Cause is under investigation probably caused by the difference between the house-keeping time and IMT/GPST and the way we handle this difference in our processing and reconstruct the GPS observation at the integer GPS second.

- Very good quality of all Sentinel orbits, with minor systematic errors visible (along-track bias for S2/S3).

- Still gaps in the Sentinel-2B L0 data delivered to us (for Sentinel-1/3 we retrieve the L0 data ourself)

Orbits available on COPPOD ftp server

Reprocessing

- With over three years since the launch of Sentinel-1A we recommend that a full reprocessing is considered for all NTC orbits. The reprocessing should at least take into consideration the following improvements:
  - ITRF2014 (homogeneous orbits for GPS as well!)
  - Recent gravity field model
  - updated ANTEX corrections based on all the available data
  - updated surface force models/properties based on more accurate information on the satellite properties

Thank you

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Backup – Sentinel-3A clock 60s