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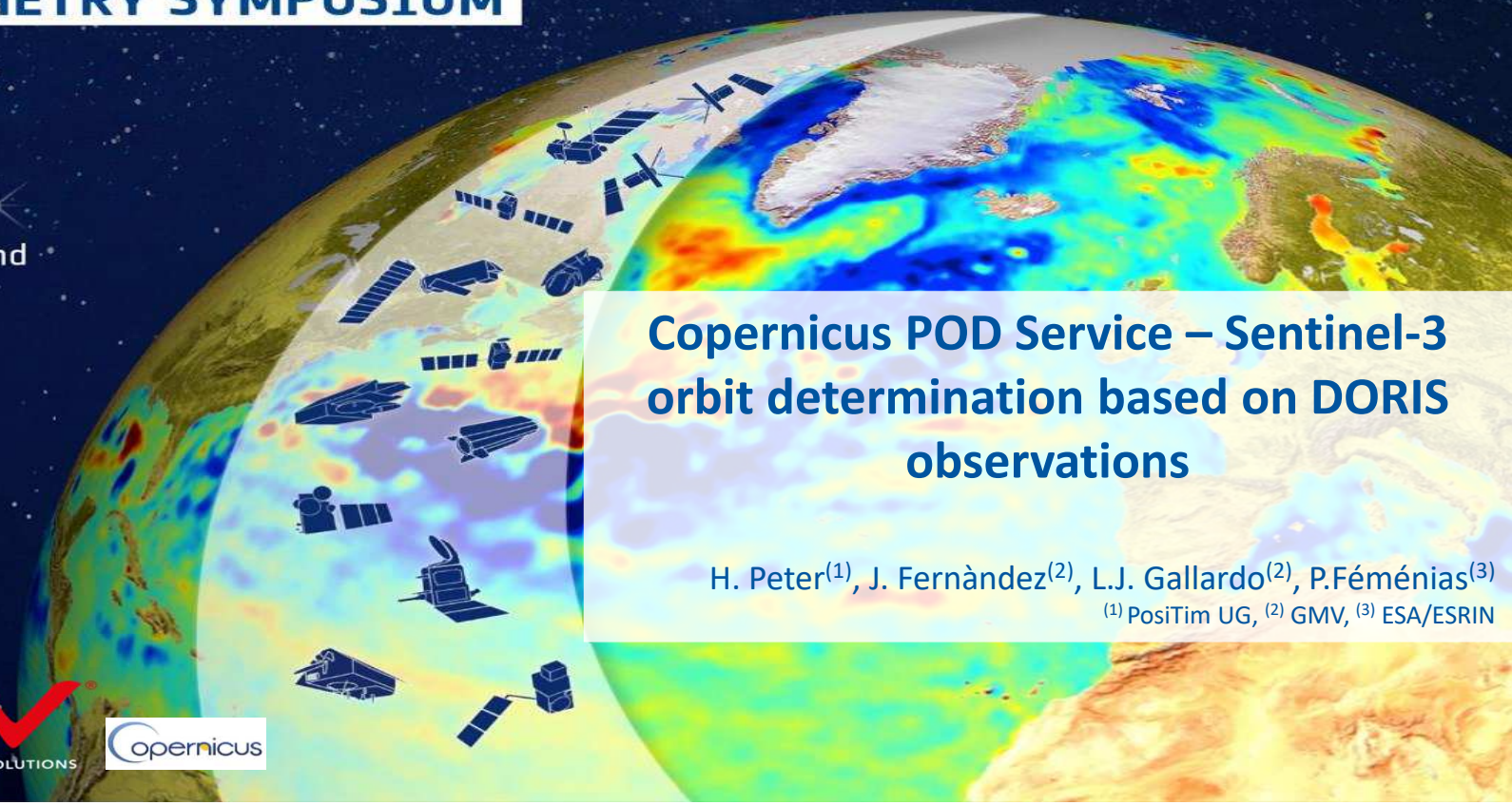
IDS WORKSHOP

24–29 September 2018
Ponta Delgada, São Miguel Island
Azores Archipelago, Portugal



# Copernicus POD Service – Sentinel-3 orbit determination based on DORIS observations

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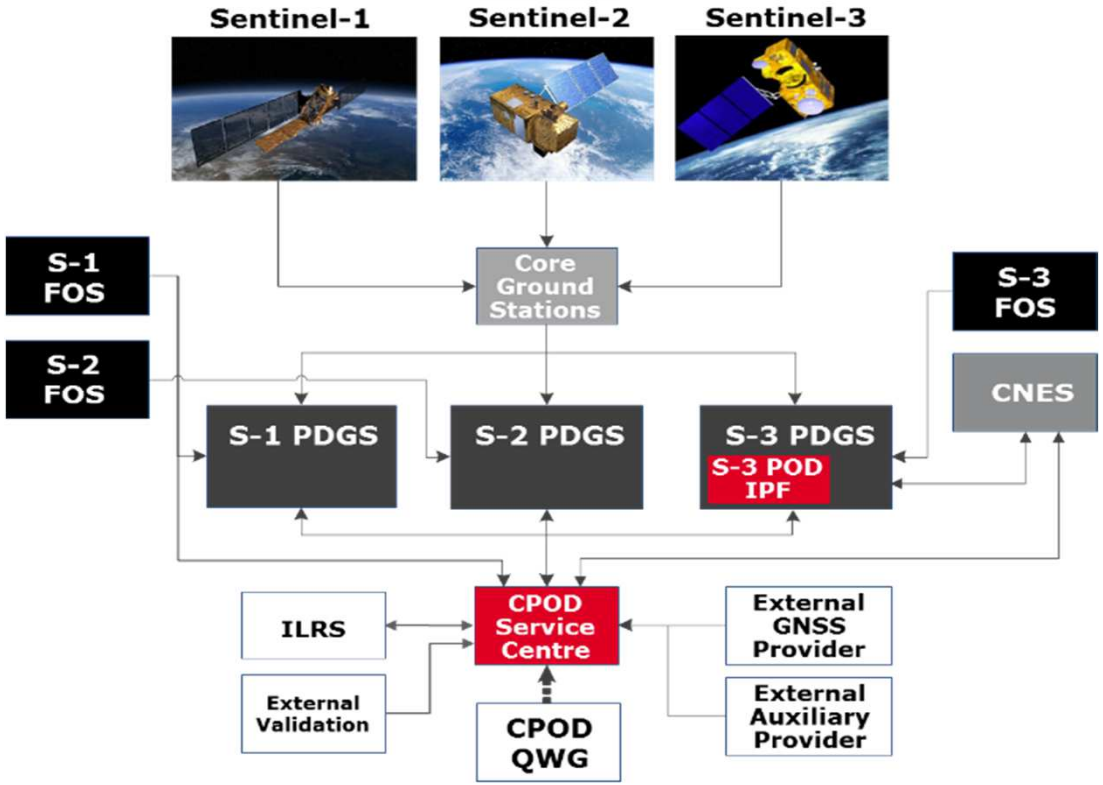
IDS
DLR POSITIM TUM AIUB TU Delft veripos
gmv INNOVATING SOLUTIONS
Copernicus

# Overview of Copernicus POD Service

- **Payload Data Ground Segment** (**PDGS**):
  - Processing the scientific data
  - Provider of GPS and attitude data to the CPOD Service
  - User of the orbits and platform files from the CPOD Service
- **Sentinels Flight Operations Segment (FOS):**
  - Orbits, manoeuvre and satellite mass evolution
  - ESOC for S1 and S2; EUMETSAT for S3
- **Centre National d'Études Spatiales (CNES):**
  - S-3 orbital and attitude products, DORIS data
- **ILRS - SLR data provider:**
  - International Laser Ranging Service –ILRS- centres
- **External Validation:**
  - AIUB, CNES, DLR, ESOC, TU Delft, TUM, EUM, CLS, (JPL)
  - provision of independent orbital products
- **External GNSS data Provider (EGP):**
  - VERIPOS; provider of high accurate GPS orbits and clocks products
  - ***magicGNSS***: in-house back-up GPS provider
- **External Auxiliary providers:**
  - Atmospheric gravity models, EOPS and leap seconds, etc.
- **CPOD Quality Working Group (CPOD QWG):**
  - Monitoring the quality of CPOD products
  - Definition of enhancements (algorithms, standards, etc.)




**S-3 POD IPF**
Marine Centre (EUMETSAT)
Land Centre (Svalbard/ESA)

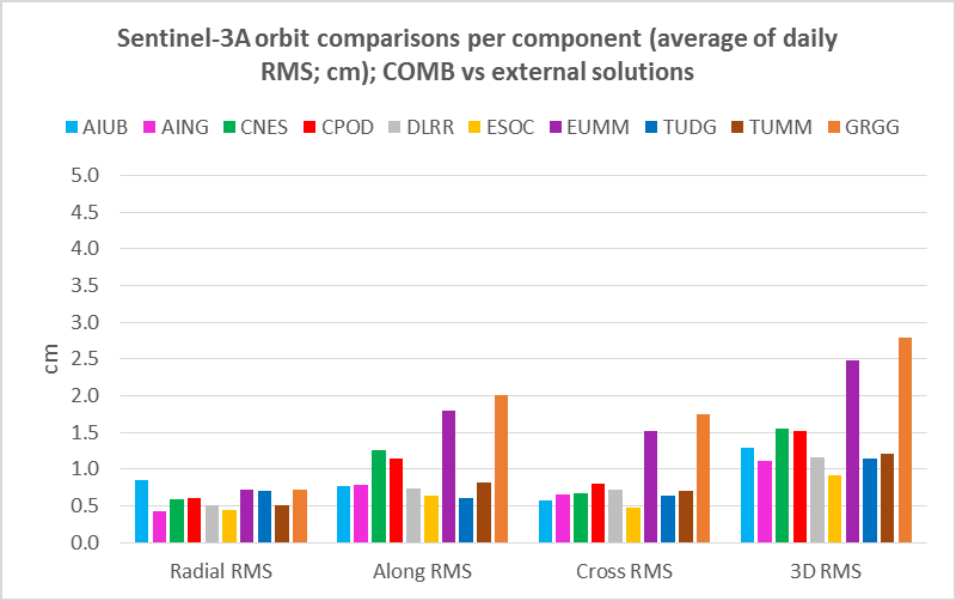
# Sentinel-3 orbit determination

| REQUIREMENTS OF POD PRODUCTS | | | |
|---|---|---|---|
| **Category** | **Latency** | **Orbit Accuracy** | **SOLUTIONS** |
| **RT** | RT | N/A | DORIS on-board Navigation solution<br>GPS on-board Navigation solution |
| **NRT** | 30 min | 10 cm radial RMS 1-sigma (target of 8 cm) | CPOD (@ Marine and Land PDGS) |
| **STC** | 1.5 days | 4 cm radial RMS 1-sigma (target of 3 cm) | CPOD (@ GMV)<br>CNES |
| **NTC** | 25 days | 3 cm radial RMS 1-sigma (target of 2 cm) | CPOD (@ GMV)<br>CNES |

- The official Sentinel-3 orbit products from the CPOD Service are all based on GPS observations only, SLR measurements are used for validation (NTC), no DORIS observations are used until now.
- Regular Service Reviews are done to compare the NTC orbit solutions against solutions from the POD QWG (AIUB, CNES, CLS/GRGS, DLR, ESOC, EUMETSAT, TUD, TUM).
- Except the solution from CLS/GRGS (DORIS-only) and CNES (GPS+DORIS combined) all other orbit solutions are GPS-only.

# Sentinel-3A orbit determination

## Comparison results from the last RSR#11 (Feb – May 2018)




| | Radial | Along-track | Cross-track | 3D |
|---|---|---|---|---|
| AIUB | 0.85 | 0.77 | 0.57 | 1.29 |
| AING | 0.43 | 0.78 | 0.65 | 1.10 |
| CNES | 0.59 | 1.26 | 0.67 | 1.56 |
| CPOD | 0.60 | 1.14 | 0.81 | 1.53 |
| DLR | 0.51 | 0.74 | 0.72 | 1.16 |
| ESOC | 0.44 | 0.64 | 0.47 | 0.91 |
| EUM | 0.72 | 1.80 | 1.52 | 2.48 |
| TUDG | 0.70 | 0.61 | 0.64 | 1.14 |
| TUM | 0.50 | 0.82 | 0.71 | 1.20 |
| GRG | 0.72 | 2.00 | 1.75 | 2.79 |

## SLR validation from the last RSR#11 (Feb – May 2018)

| | AING | AIUB | CNES | DLR | ESOC | EUM | GRGG | TUDG | TUM | CPOD | COMB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (cm) | 0.43 | -0.16 | 0.48 | 0.52 | 0.50 | 0.18 | 0.43 | -0.08 | 0.38 | 0.50 | 0.32 |
| Std Dev (cm) | 1.04 | 1.13 | 1.32 | 0.82 | 0.97 | 1.79 | 1.62 | 0.87 | 0.94 | 1.34 | 0.90 |
| RMS (cm) | 1.13 | 1.14 | 1.40 | 0.97 | 1.09 | 1.80 | 1.68 | 0.88 | 1.01 | 1.43 | 0.96 |

# DORIS processing @ CPOD Service

- A processing scheme for DORIS-based orbit determination is set up in parallel to the operational GPS-only S-3A/B orbit determination process.
- Until now, no regular/automatic quality control is set up.

- 10 sec DORIS phase observables are converted to range-rate observations, GPS-derived orbit is used as a-priori information.

The key data of the DORIS processing are:

- Three-day arc length (72 hours)
- Estimation of
  - 1 radiation pressure coefficient
  - 10/24h atmospheric drag scale factors
  - 2/24h sets of CPR along-track and cross-track sine+cosine parameters
- Elevation cut-off angle of $10^{o}$ for DORIS observations, no elevation-dependent weighting
- Tropospheric zenith delays per station pass
- Range-rate bias per station pass

# Orbit solutions based on DORIS

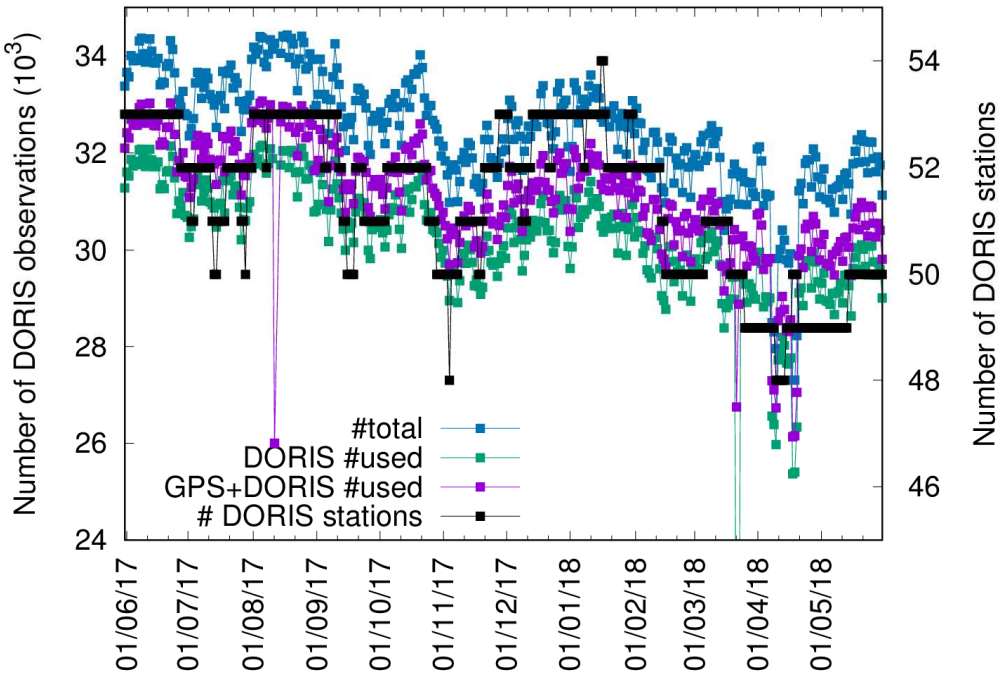
- **DORIS-only** solution, SLR is used for validation

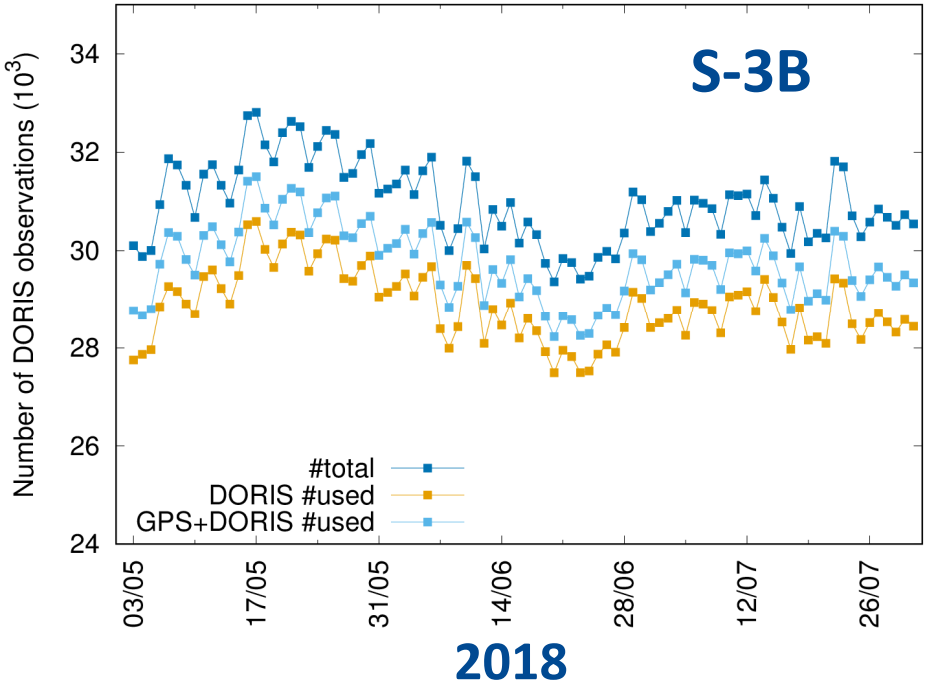
- **GPS** (30 sec)**+DORIS combined** solution, SLR is used for validation

- **Sentinel-3A:**
  - 1 June 2017 – 31 May 2018 (RSR#09 - #11)
  - Comparison to CLS/GRGS, CNES and combined (from QWG) orbits
  - SLR validation

- **Sentinel-3B:**
  - 1 May – 31 July 2018
  - Comparison to CPOD NTC GPS-only solution
  - Comparison to combined (from QWG) orbit, 8 -14 June 2018
  - SLR validation

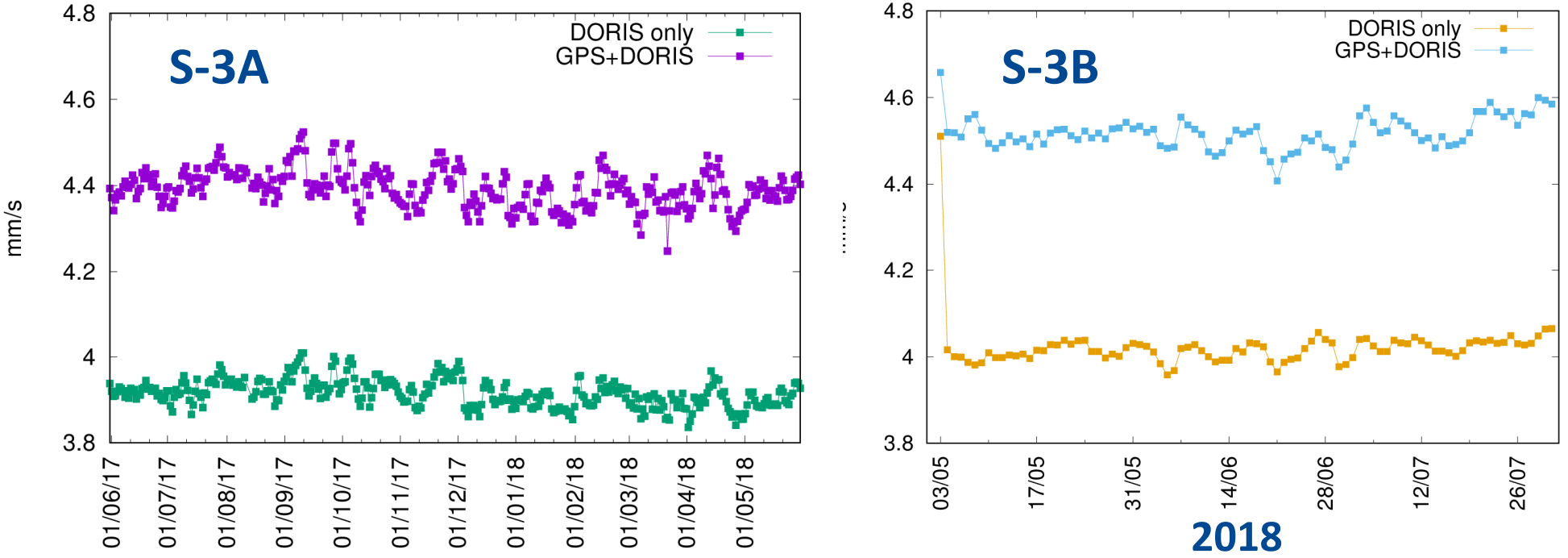
# DORIS processing: number of observations



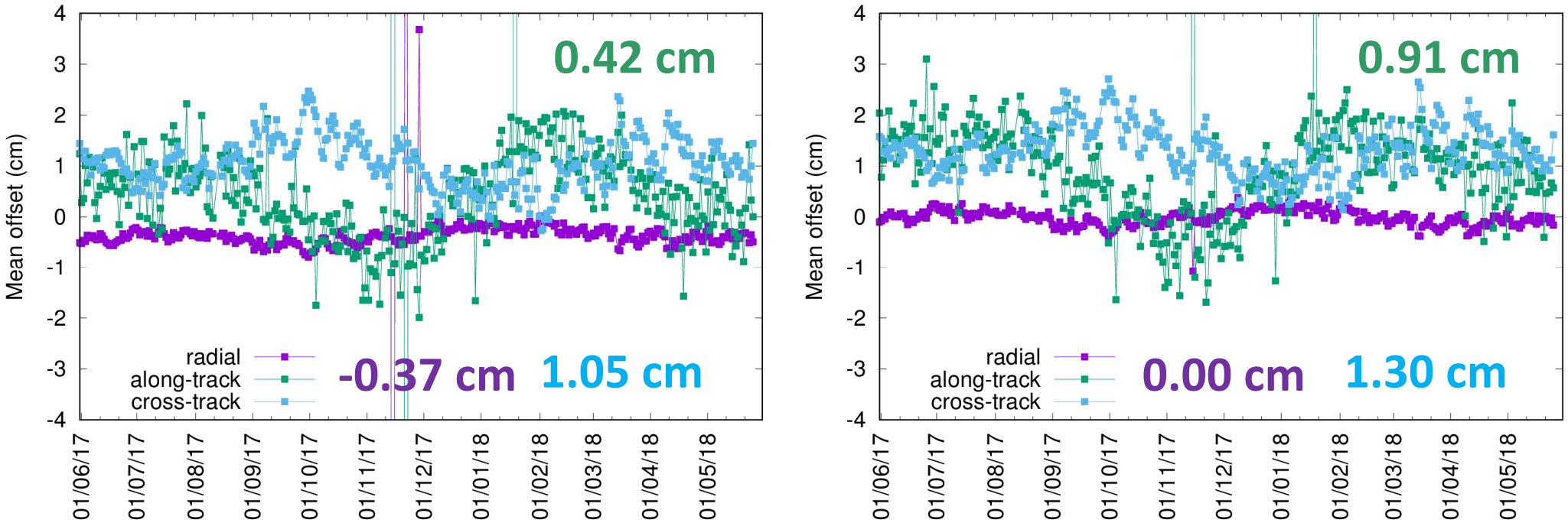

- Number of totally available and used DORIS observations for both orbit processing schemes for Sentinel-3A and -3B.
- Number of observations is (not surprisingly) correlated to number of tracking stations.

# DORIS processing: Range-rate RMS




- Range-rate RMS (mm/s) for Sentinel-3A and -3B shows similar performance.
- The values for S-3B are a bit larger than the values for S-3A.

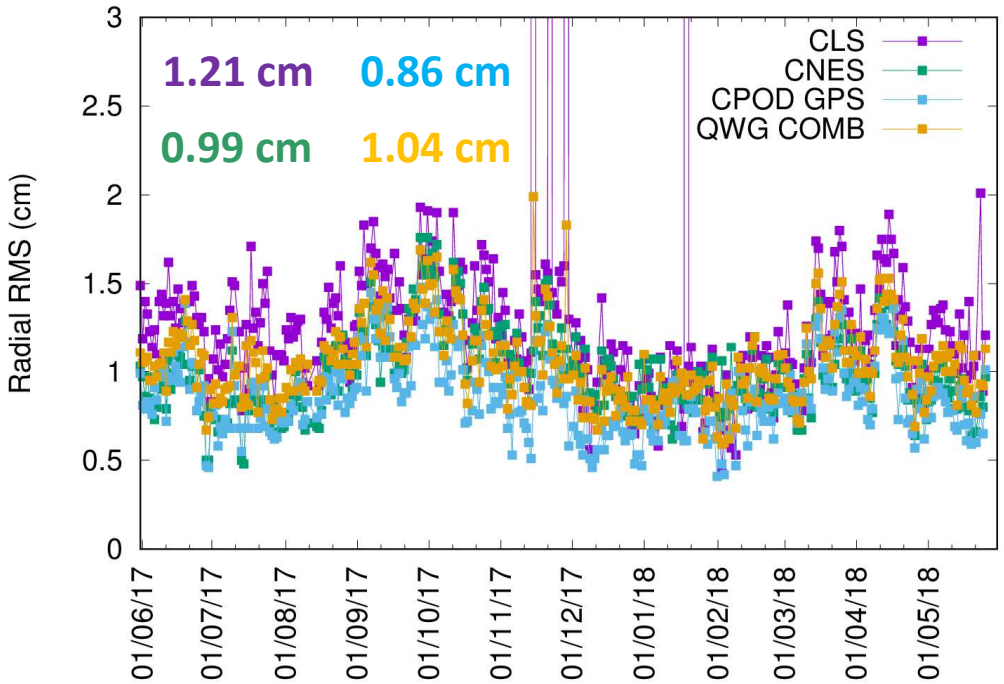
# S-3A DORIS orbits: Comparisons

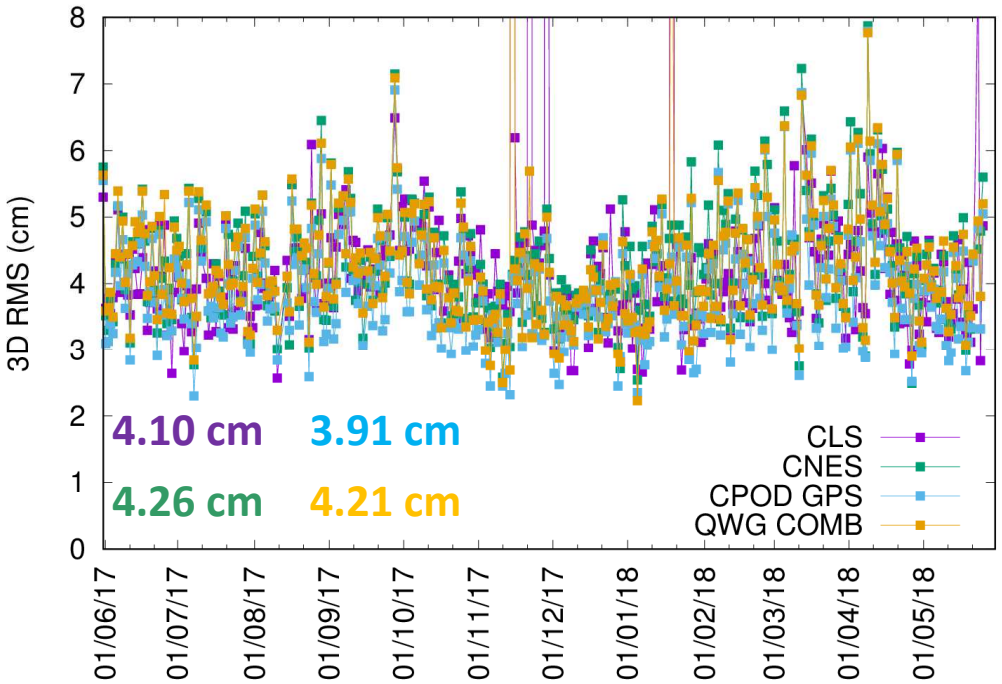



**Daily mean offsets (m) between S-3A DORIS orbits and CLS/GRGS orbits (left) and QWG combined orbits (right)**

- **Small radial offset between CLS/GRGS and CPOD DORIS orbits, variable along-track offsets, significant cross-track offsets**

# S-3A DORIS orbits: Comparisons

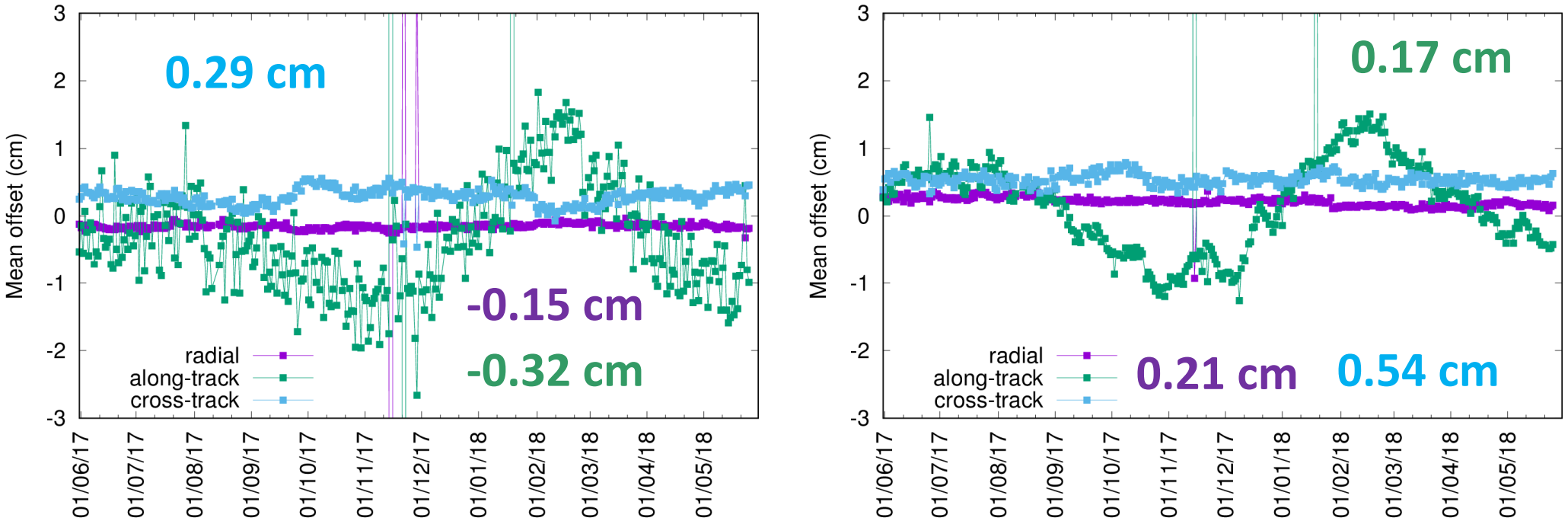



**Daily radial and 3D RMS (cm) of S-3A DORIS orbits w.r.t different orbit solutions**

- **All comparisons are similar**

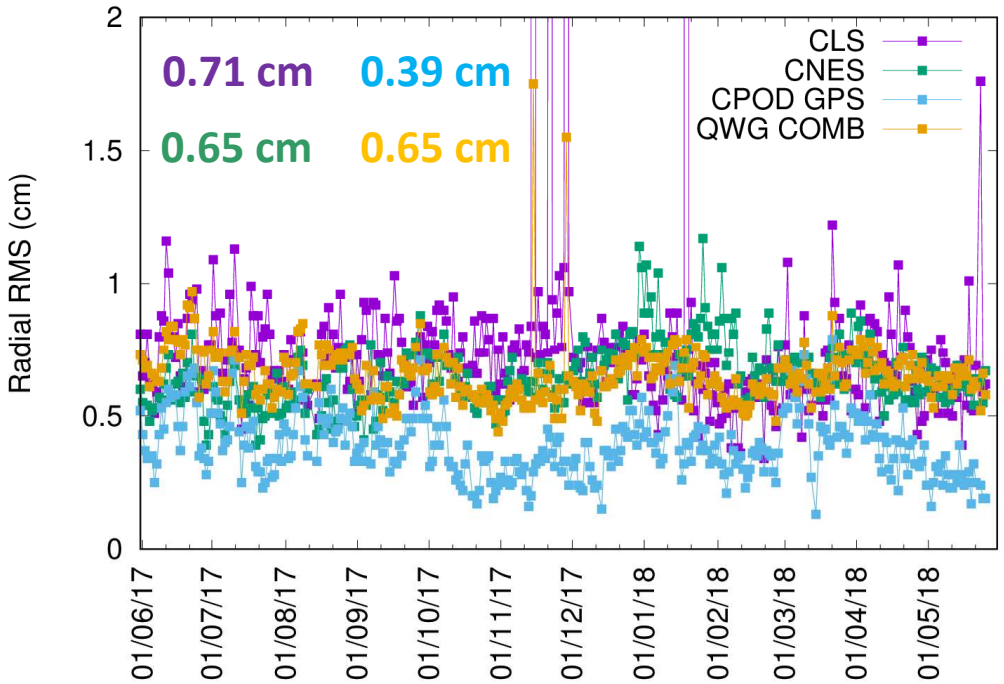
# S-3A DORIS+GPS orbits: Comparisons

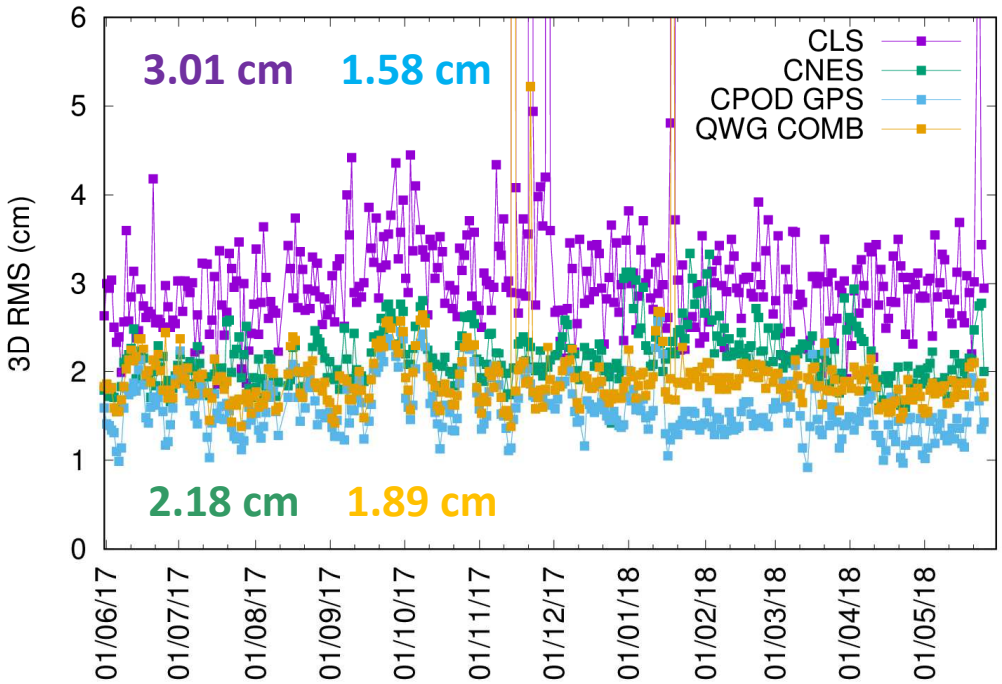



**Daily mean offsets (m) between S-3A DORIS+GPS orbits and CLS/GRGS orbits (left) and QWG combined orbits (right)**

- **Small offsets in all directions**
- **Radial and cross-track offsets constant over time, along-track offsets variable**

# S-3A GPS+DORIS orbits: Comparisons

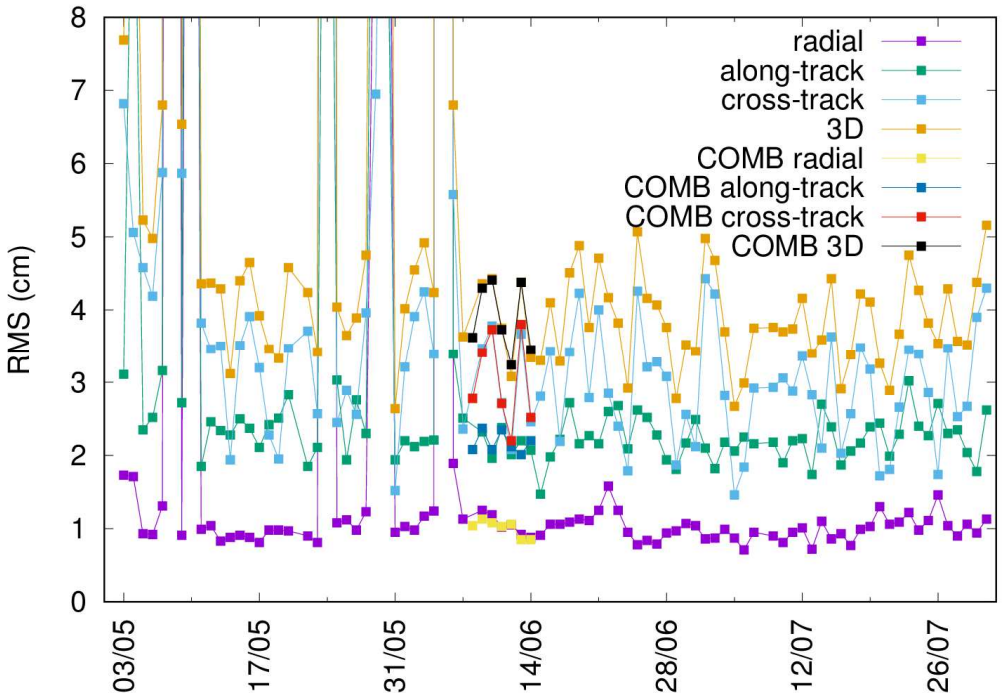


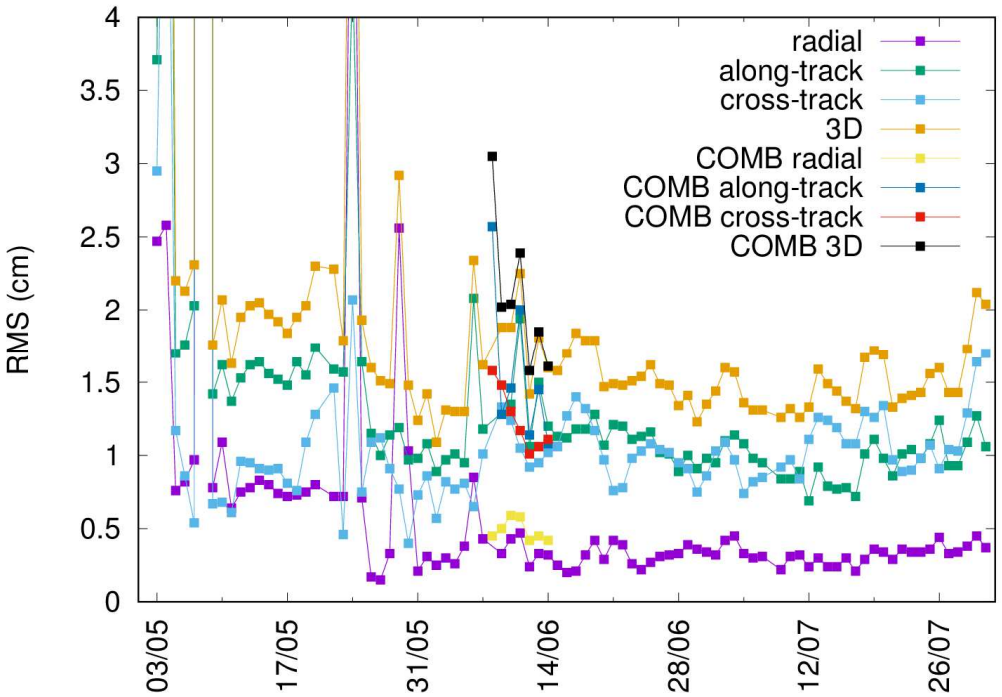




**Daily radial and 3D RMS (cm) of S-3A GPS+DORIS orbits w.r.t different orbit solutions**

- **RMS values much smaller than for CPOD DORIS orbits**
- **Comparison to DORIS-only orbits (CLS/GRGS) is worst**
- **Comparison to CPOD GPS-only orbits is best (not surprising)**

# S-3B DORIS and GPS+DORIS orbits: Comparisons

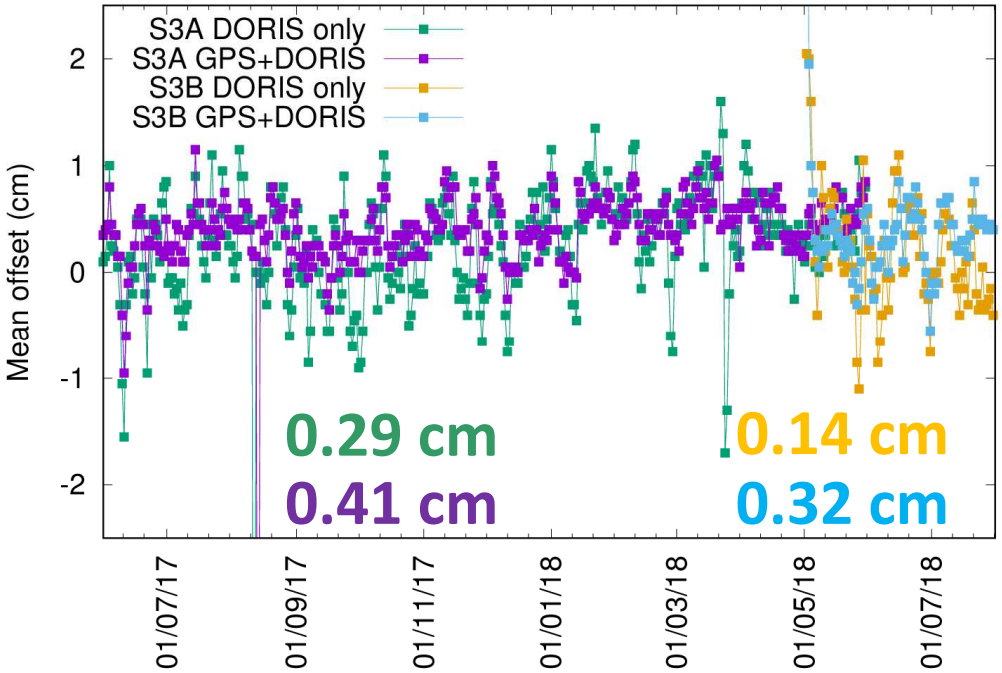


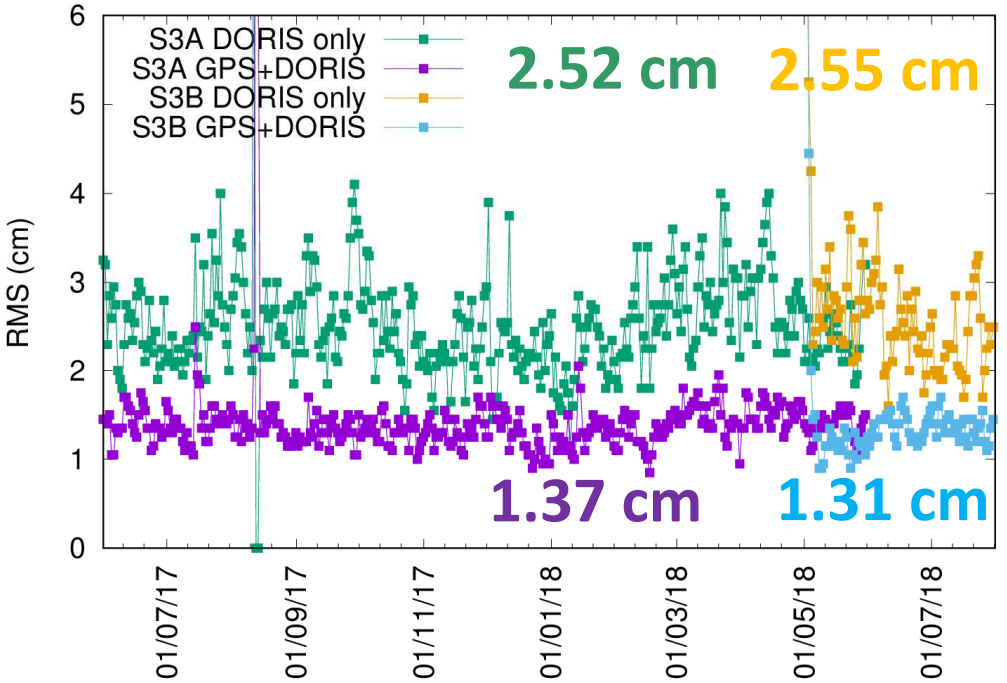




**Daily RMS values (cm) of S-3B DORIS (left) and S-3B GPS+DORIS (right) orbits w.r.t CPOD GPS orbits, one week of QWG combined orbits are available as well**

- **Larger differences in May due to many manoeuvres**
- **Differences are stable since tandem phase has been reached (6 June)**

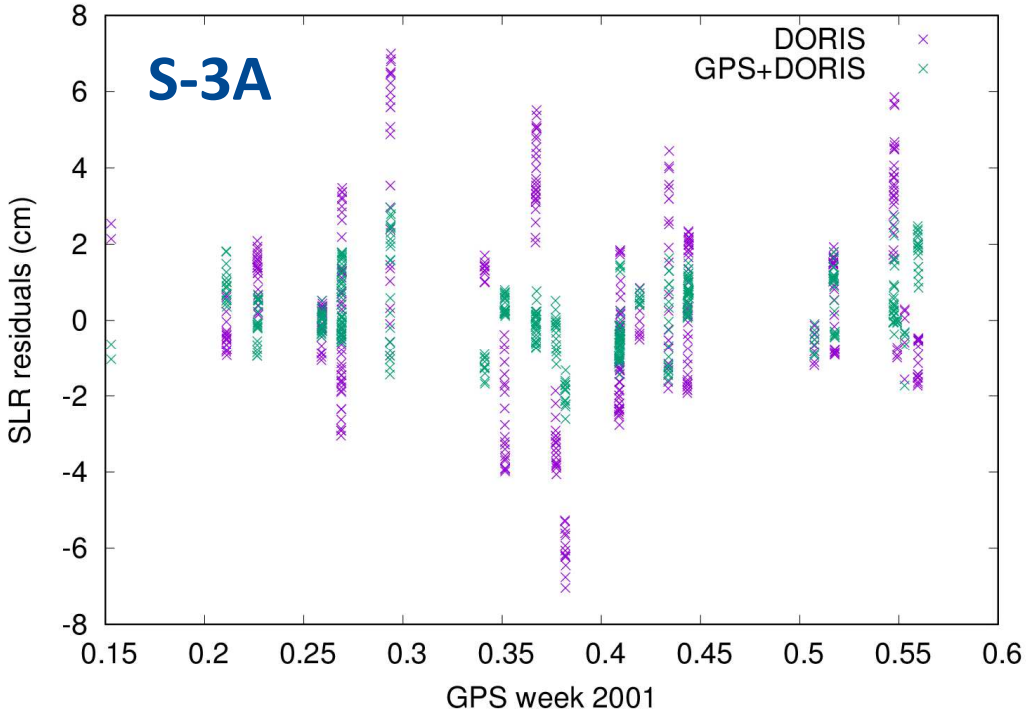
# Daily mean offsets (cm) and RMS (cm) of SLR validation

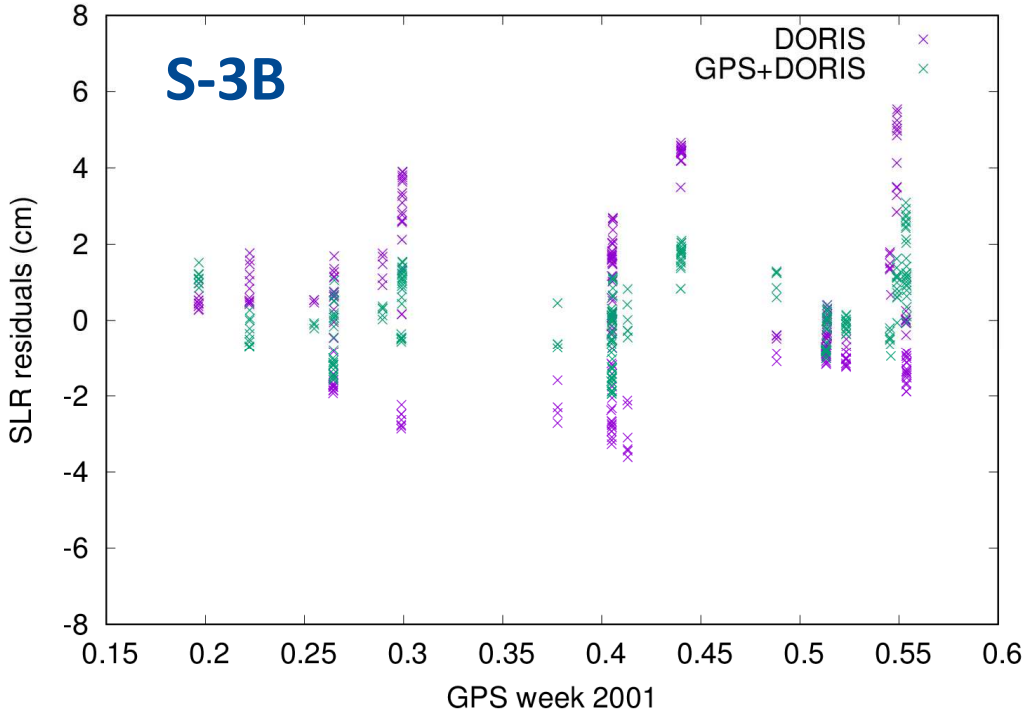



- Nine SLR stations used, station elevation cut-off angle at 10°
- Sentinel-3A and -3B orbits show similar performance.
- Mean offsets of DORIS-only orbits are smaller but with larger noise.
- RMS values of DORIS-only orbits are significantly larger than for the combined GPS+DORIS orbits

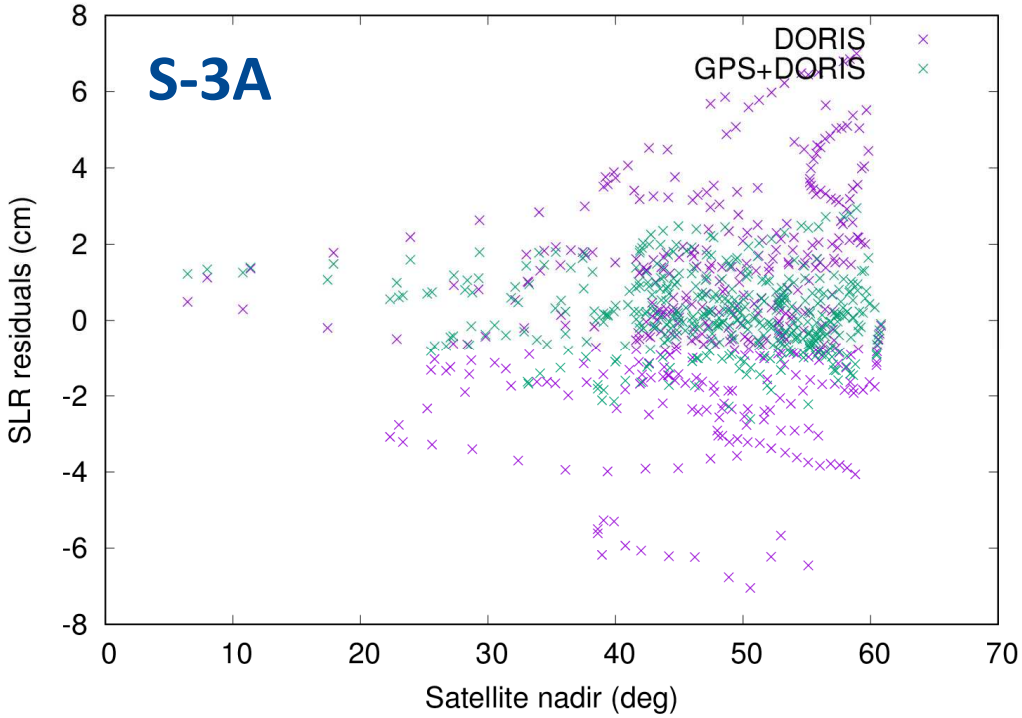
# SLR residuals for 15 May 2018

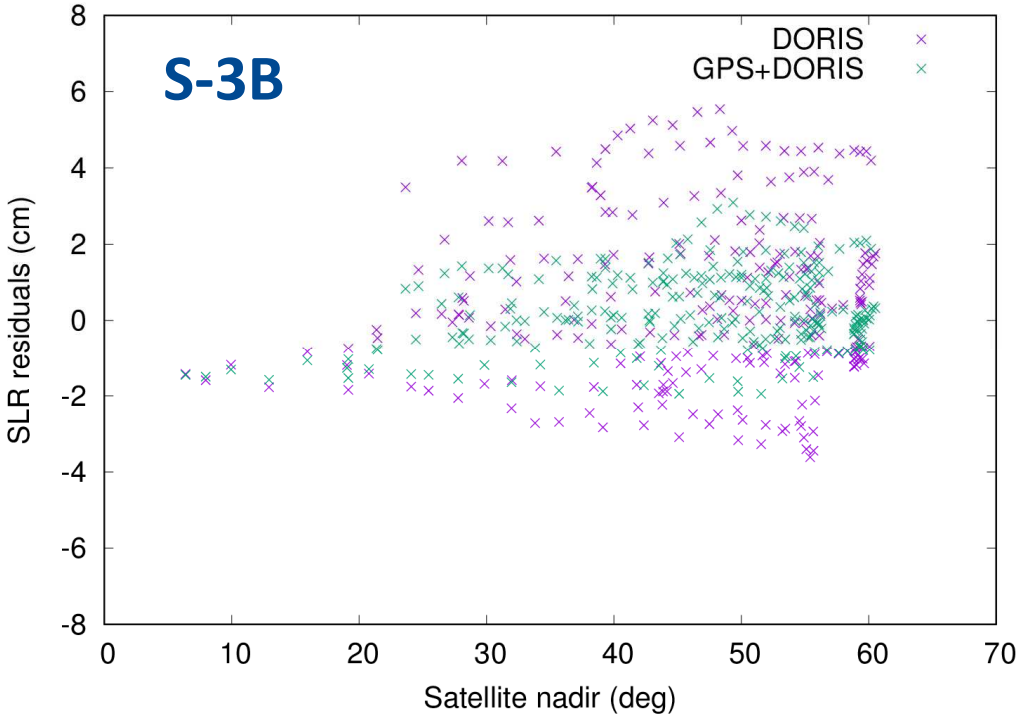



- **Differences between SLR residuals of DORIS orbits (purple) and of GPS+DORIS orbits (green) can clearly be seen.**

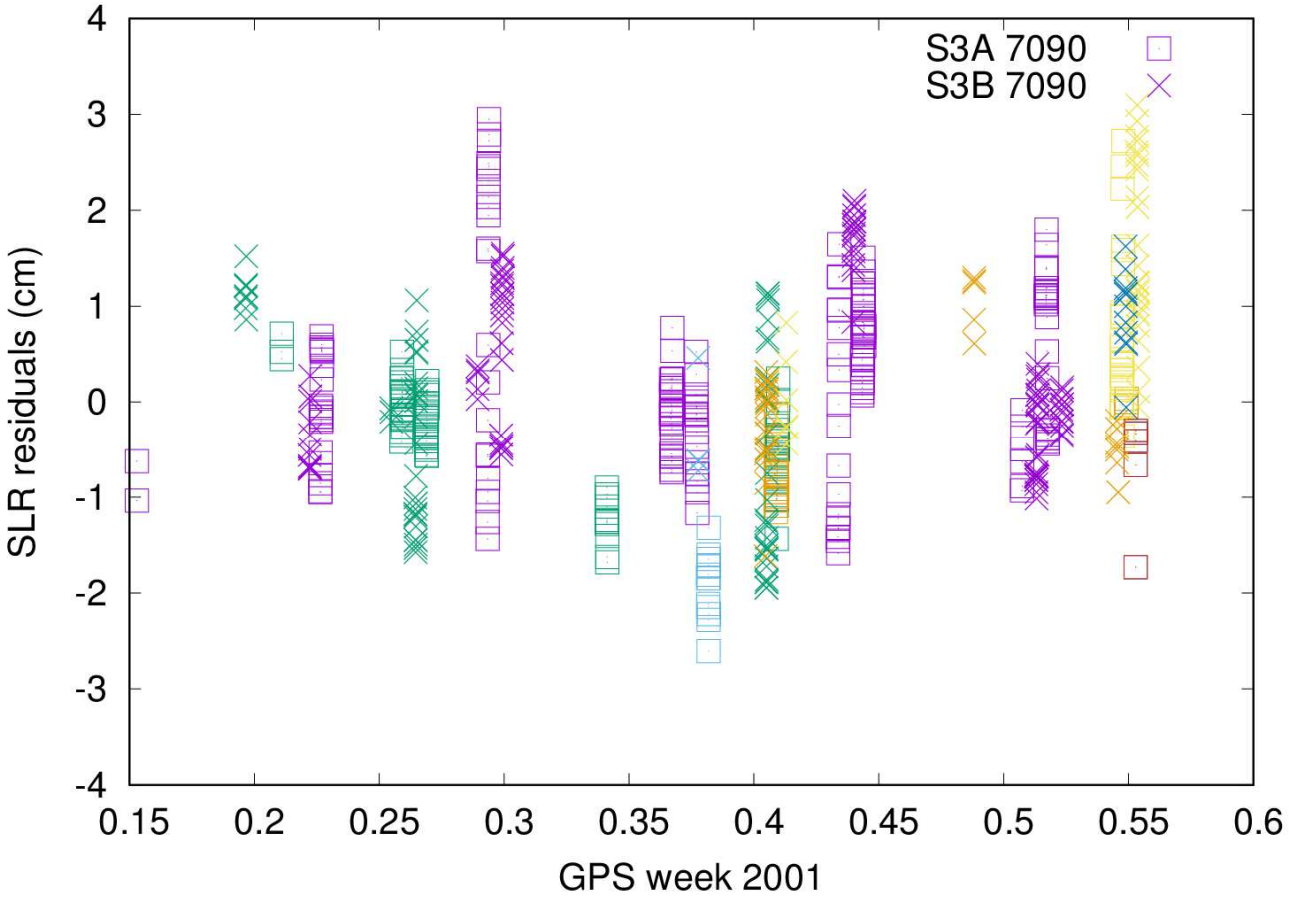
# SLR residuals for 15 May 2018




- **Differences between SLR residuals of DORIS orbits (purple) and of GPS+DORIS orbits (green) can clearly be seen.**

# SLR residuals for 15 May 2018 – GPS+DORIS orbits




- Different colors for different SLR stations
- Different markers for the two satellites
  - S3A: square
  - S3B: X
- Several stations track both satellites during the same passes (satellites were not yet in final tandem phase)

# Improvements for S-3A - antenna offset calibration

- Independent investigations of different groups (DLR, CNES) revealed a
  - **+1 cm shift in y-direction** („cross-track“) of **all antenna positions (GPS, DORIS, SLR)**

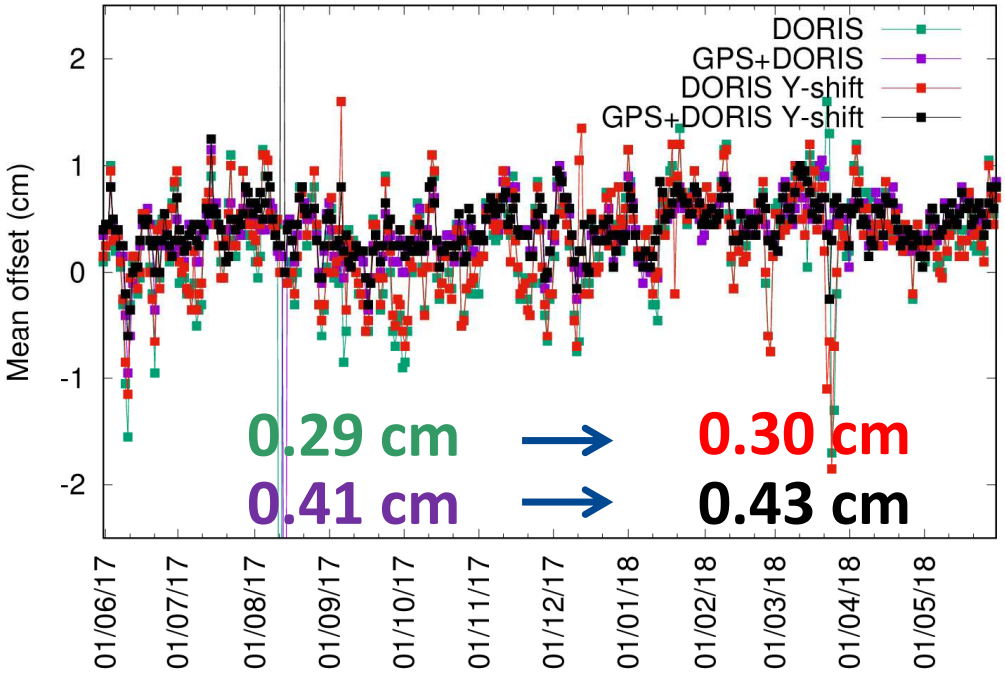
  **=>** CNES GDR-F for Sentinel-3 satellites

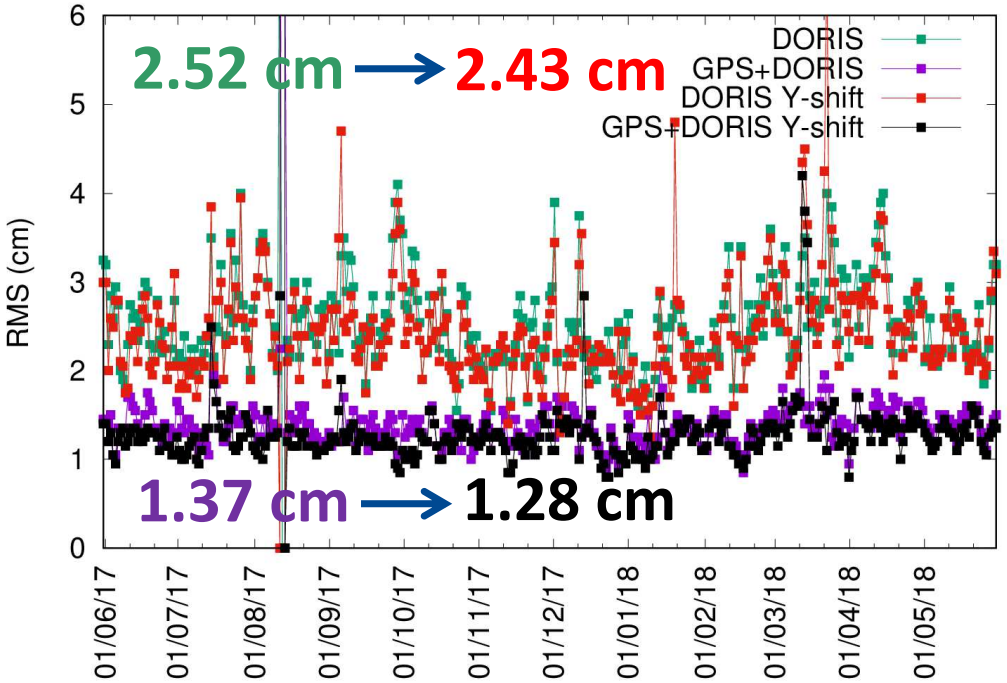
  **or**
  - **-1 cm shift in y-direction** of the **CoG coordinates**

  **=>** Montenbruck et al. (2018) Precise orbit determination of the Sentinel-3A altimetry satellite using ambiguity-fixed GPS carrier phase observations, Journal of Geodesy, 92: 711, DOI 10.1007/s00190-017-1090-2

⇒ **Investigation of these new setups by doing a reprocessing of the DORIS and GPS+DORIS solutions based on this new configuration**

# Daily mean offsets (cm) and RMS (cm) of SLR validation




- Nine SLR stations used, station elevation cut-off angle at 10°
- Mean offsets are equivalent (within sub-mm)
- RMS values decrease by 0.9 mm for both orbit solutions

# Summary and future plans

- Quality and performance assessment for **S-3A & S-3B DORIS orbits** from the **CPOD Service** are shown.
- The performance of the S-3A & S-3B CPOD DORIS orbits is good and promising.
- The **DORIS orbits** are, however, not yet on the same level as other DORIS or GPS(+DORIS) orbits. In particular the SLR validation reveals larger (~doubled) RMS values than for other S-3A/S-3B orbit products.
- The **combined DORIS+GPS** orbits show a very good performance, probably mainly due to the strength of the GPS observations.
- Proposed new antenna offsets/CoG coordinates give slightly better results

⇒ Further investigations to improve the DORIS orbits are still needed

- find the best elevation cut-off angle and the best elevation-dependent weighting scheme
- check again the conversion of the DORIS phase observables to range-rate
- find the optimal a priori sigma for the DORIS observations
- find the optimal relative weighting scheme between the different observation techniques for a combined orbit solution

# Thank you for your attention!

Acknowledgements:
The Copernicus POD Service is financed under ESA contract no. 4000108273/13/1-NB, which is gratefully acknowledged.
The work performed in the frame of this contract is carried out with funding by the European Union. The views expressed herein can in no way be taken to reflect the official opinion of either the European Union or the European Space Agency.