ESA/ESOC - Precise Orbit Determination for Sentinel 6 Michael Freilich based on Galileo and GPS observations

Francesco Gini, Tim Springer, Michiel Otten, Florian Dilssner, Volker Mayer, Erik Schönemann, Rene' Zandbergen and Werner Enderle – Navigation Support Office

ESA/ESOC

OSTST 2022, Venice, Italy - 01/11/2022

Overview of Presentation

- Overview - Operational Precise Orbit Determination for the Sentinel Satellites at ESA/ESOC
- Sentinel 6 Precise Orbit Determination at ESA/ESOC
    - Overview of processing and models
    - Internal & external solutions validation for the ~500 days* processed
- Sentinel 6: a big step for the GNSS Interoperability in-space
- Conclusions & Future Work

*from 26th November 2020 (BOL) to 30th April 2022

Sentinel - Operational POD Processing at ESA/ESOC

For all Sentinels*

GNSS

Generation of **accurate Galileo and GPS products** (orbits, clocks, Bias and UPDs)

RINEX

GNSS Data Conversion of Sentinels Telemetry (L0) into observations (RINEX) nominal & redundant receiver

POD

Precise Orbit Determination parallel processing chains:

- Sentinel-1,-2,-3 A&B: GPS-based POD
- Sentinel-6A: Galileo, GPS, and Combined POD

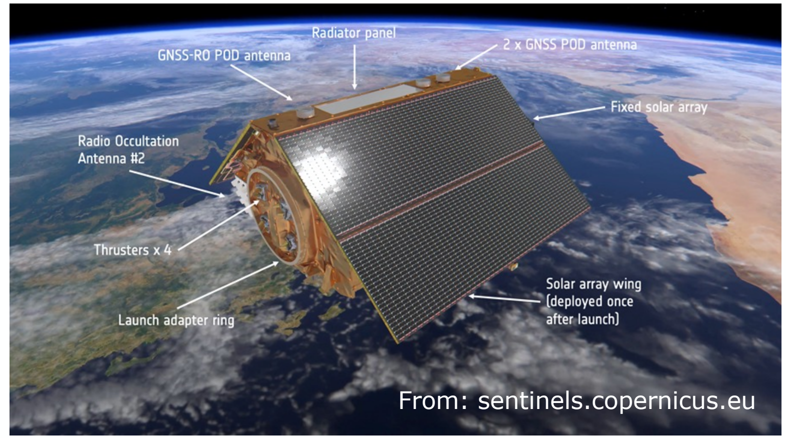
- Operational chain with GNSS-based POD Rapid (24h) and final (7days)

*Sentinel-5P does not downlink GNSS raw observations

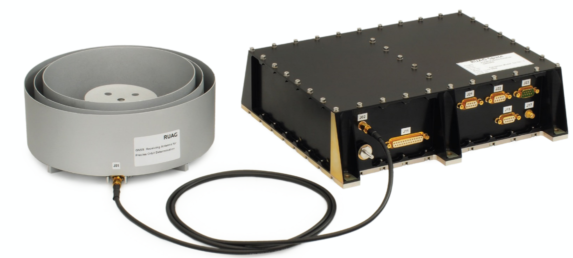
Sentinel 6 POD - Number of GNSS observations

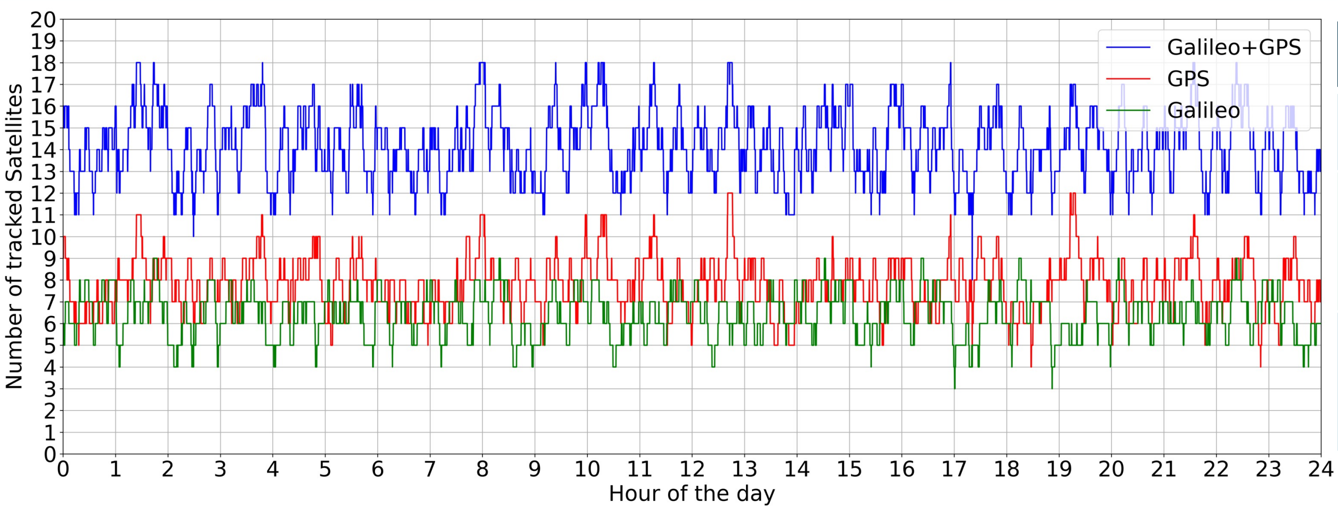
Two redundant GNSS receivers (RUAG PODRIX) on-board Sentinel-6, which provide:

- Galileo signals: E1-C, E5a-Q
- GPS signals:
    - L1 P(Y), L2 P(Y) – Block IIR
    - L1 C/A, L2C-L – Blocks IIR-M, IIF, III
    - L5 signals could be tracked



From: sentinels.copernicus.eu


RUAG PODRIX receiver, from: ruag.com



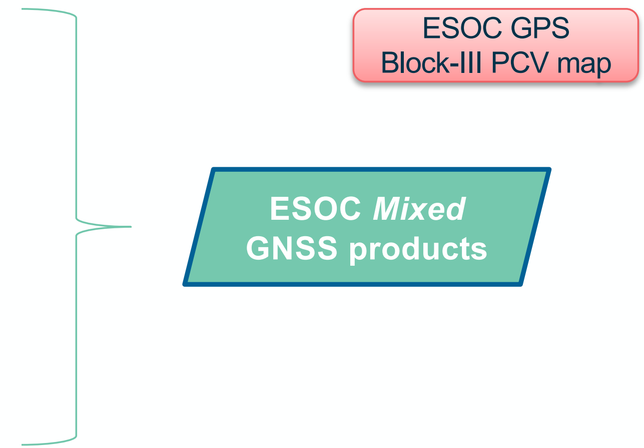
Observations	Galileo	GPS		Galileo + GPS
Frequency & Signal	E1-C E5a-Q	L1 C/A L2C-L	L1 P(Y) L2 P(Y)	all
Total 24h #obs.	55k	53k	14k	122k
		67k		
Average #obs. per epoch	6.4	6.1	1.7	14.2
		7.8		

1 obs. = dual-freq code+phase obs.

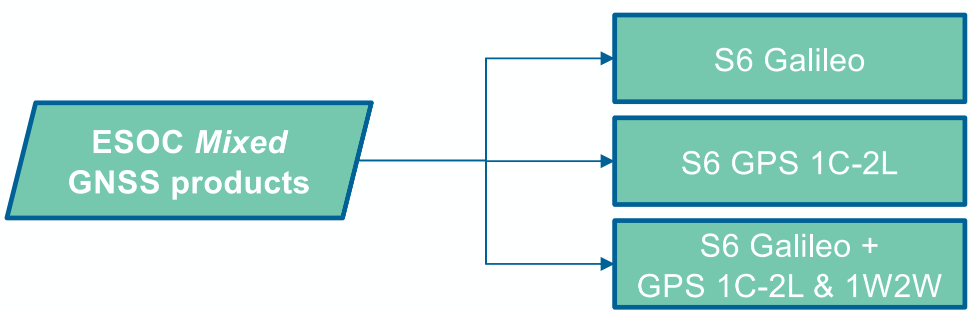
GNSS products generation and Sentinel-6 processing

GNSS products: ESOC internal GNSS mixed products consistent with the Sentinel-6 tracking scheme

	Galileo	GPS Block IIR	GPS all others
GNSS signals processed	E1-C E5a-Q (rinex: 1C-5Q)	L1 P(Y) L2 P(Y) (rinex: 1W-2W)	L1 C/A L2C-L (rinex: 1C-2L)
Mel-Wüb. Float Ambiguities Kurtosis	~2.4	~1.7	~1.6
Narrow-Lane Float Ambiguities Kurtosis	~5.3	~4.4	~4.0



Sentinel-6 processing:



For the combined Galileo + GPS processing:

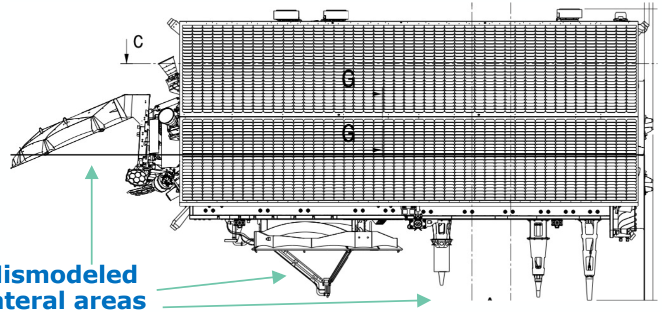
- Galileo is taken as a reference
- Epoch-wise ISB estimated for GPS 1C-2L
- Epoch-wise ISB estimated for GPS 1W-2W

No need of GNSS transmitter or receiver biases

Ambiguity-fixing is performed per signal

SLR observations are used only for validation purposes

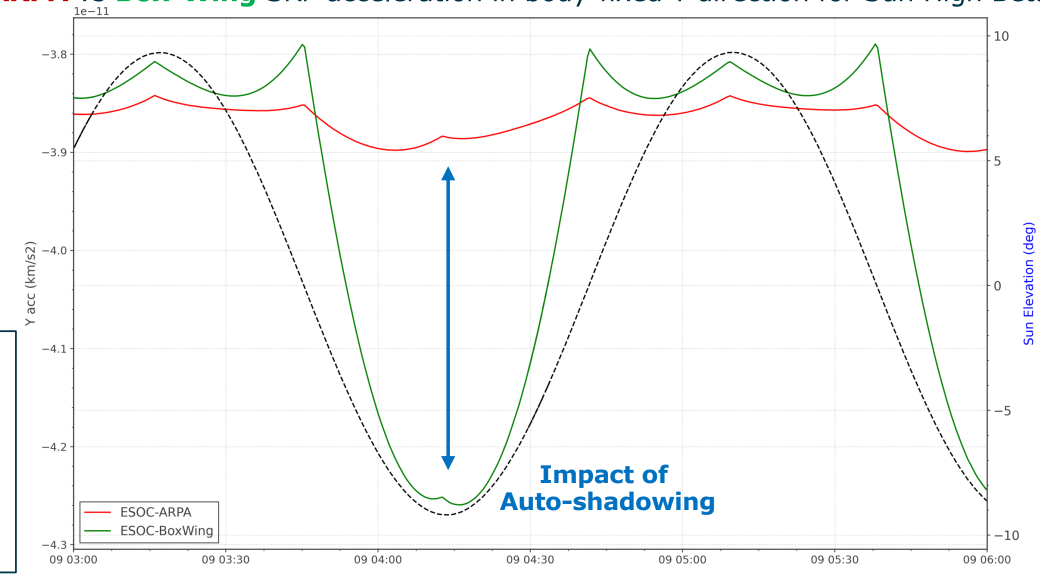
Sentinel 6 POD - Solar/Earth Radiation Pressure Raytracing Model (ARPA)



Mismodeled lateral areas in Box-wing model

From ESA Sentinel-6 POD context

ARPA vs **Box-Wing** SRP acceleration in body-fixed Y direction for Sun High Beta

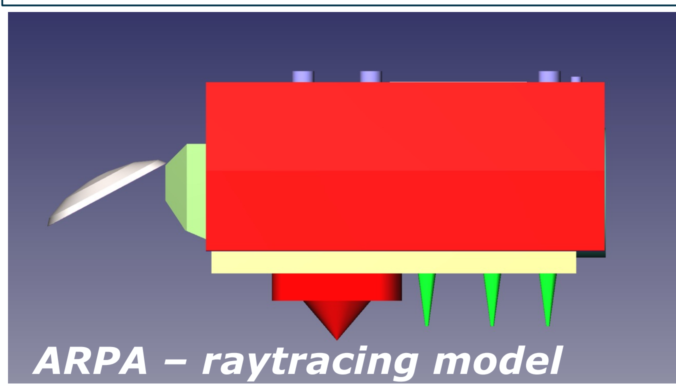


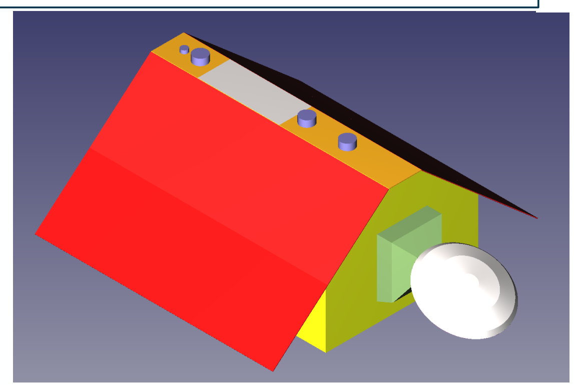
Box-Wing: The typical box-wing model underperforms for high-beta angles

- Strong shadowing effects
- Antennas lateral areas not accurately modeled for higher beta angles

ARPA: ESOC Raytracing model

- Ray-tracing for SRP/ERP based on ESA/ESOC ARPA (Aerodynamics and Radiation Pressure Analysis) tool
- Better performance, particularly in terms of Solar Radiation Pressure scaling coefficient: CR





Daily Radiation Pressure Scaling Coefficient (CR) Statistics

Model	CR std	CR mean
ESA-BW	0.25	1.01
ESA-ARPA	**0.13**	**0.99**

F.Gini 2014 PhD @ University of Padova, https://www.research.unipd.it/handle/11577/3423563

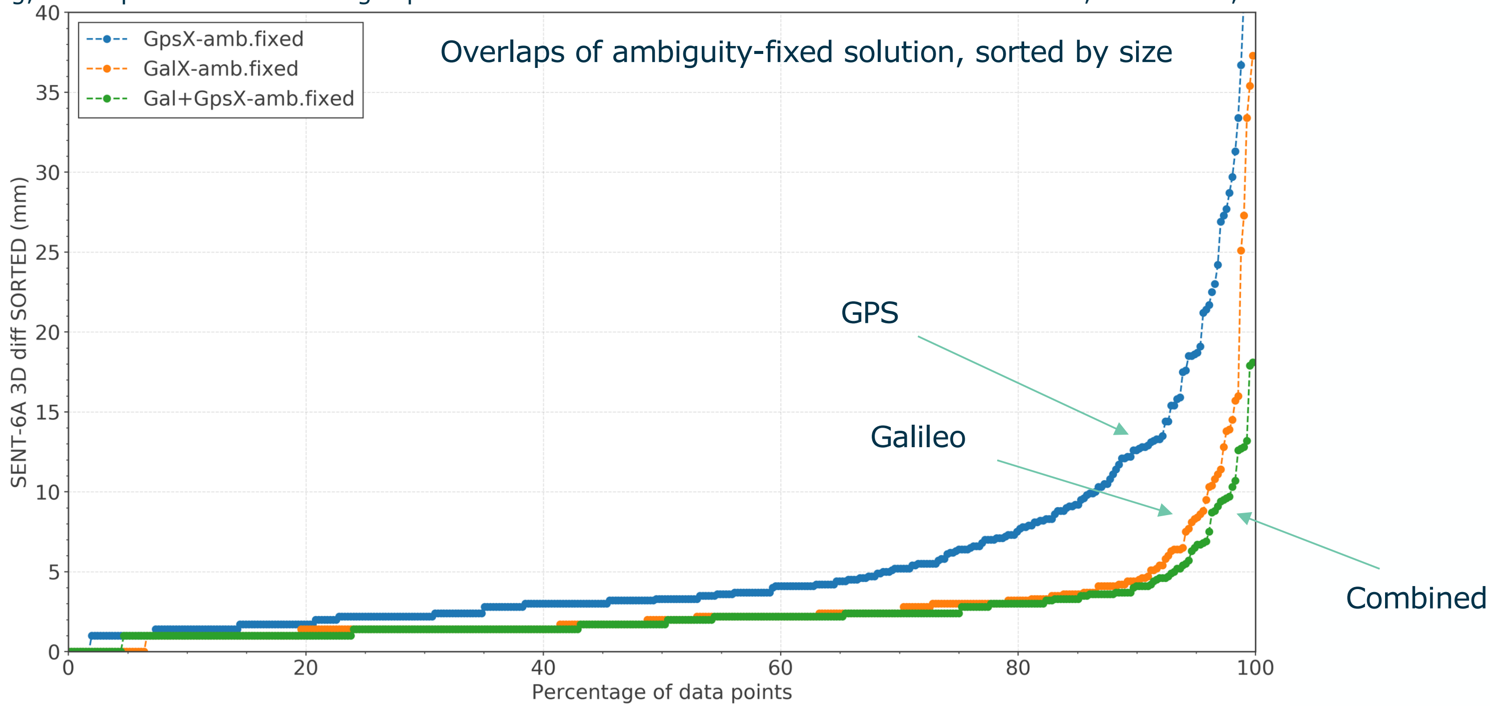
S6 POD - Internal consistency – Day-Boundary Orbital Overlaps

Day-boundary Overlaps* statistics at 80% & 95%

	Galileo		GPS		Galileo + GPS	
	80%	**95%**	**80%**	**95%**	**80%**	**95%**
Ambiguity-Fixed sol.**	**< 3 mm**	**< 8 mm**	< 8 mm	**< 25 mm**	**< 3 mm**	**< 7 mm**

*Daily arcs are 30h long, overlaps are at the midnight point

**amb.fix success rate: GAL~100%, GPS~86%, Gal+GPS~98%



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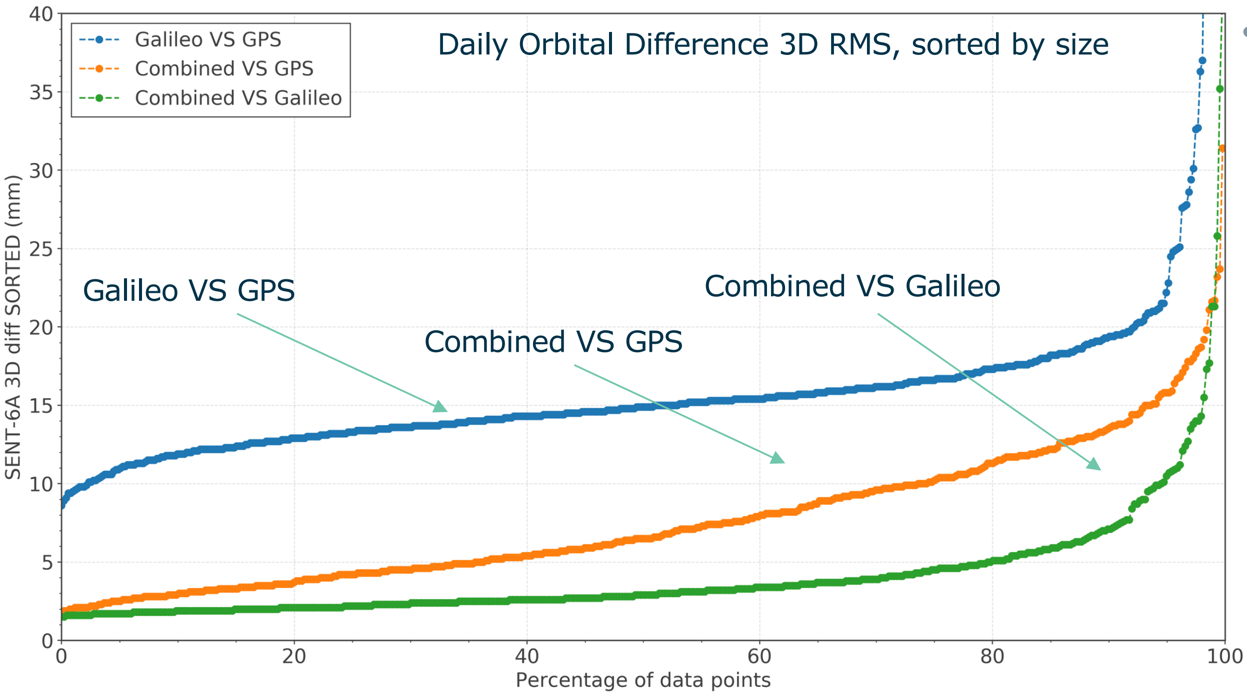
Sentinel 6 POD - Internal consistency – Orbital Comparisons

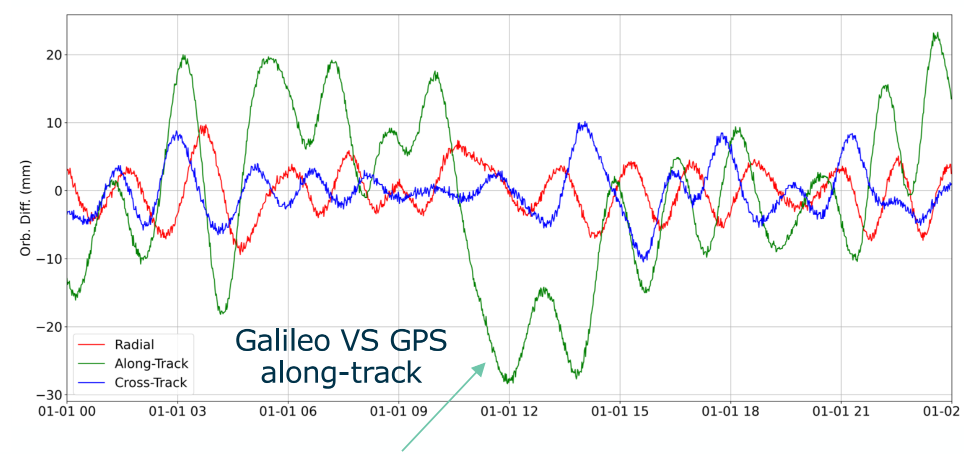
24h Orbital differences between ambiguity-fixed:

- Galileo-only solution
- GPS (1C2L)-only solution
- Galileo + GPS (all) solution



- Combined VS Galileo: 95%<1cm, AVG~ 3mm
- Combined VS GPS: 95%<2cm, AVG~10mm
- Galileo VS GPS: 95%<3cm, AVG~18mm

- **Galileo VS GPS**: predominant difference in the along-track component, which could be linked to the performance of the GPS-only solution (see also Overlaps and SLR residuals)



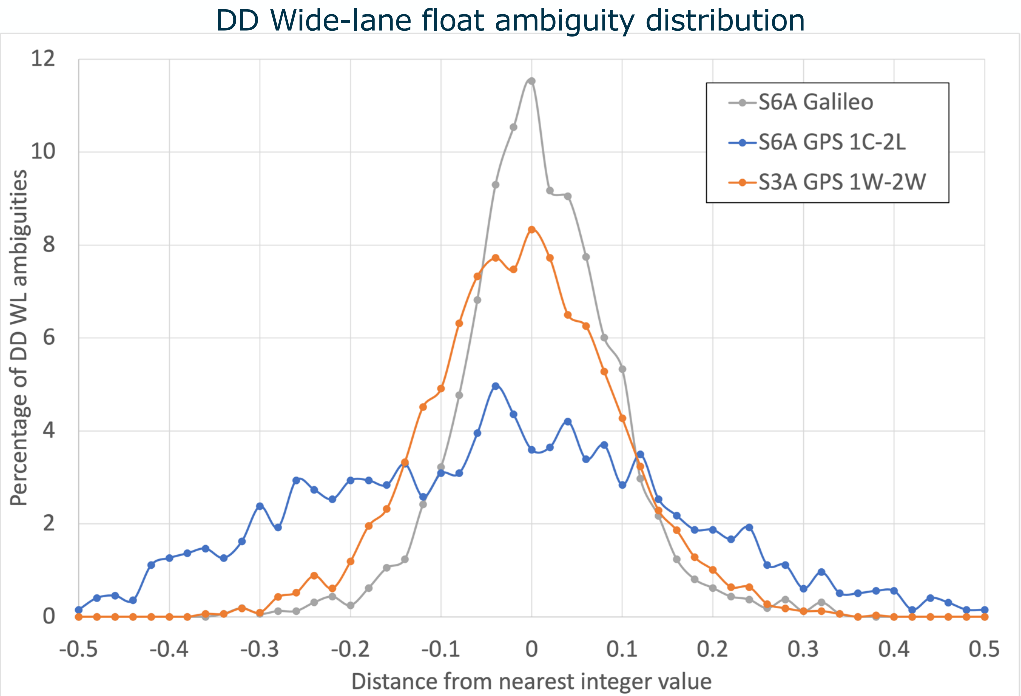
Sentinel 6 POD - Internal consistency – Float ambiguities distribution

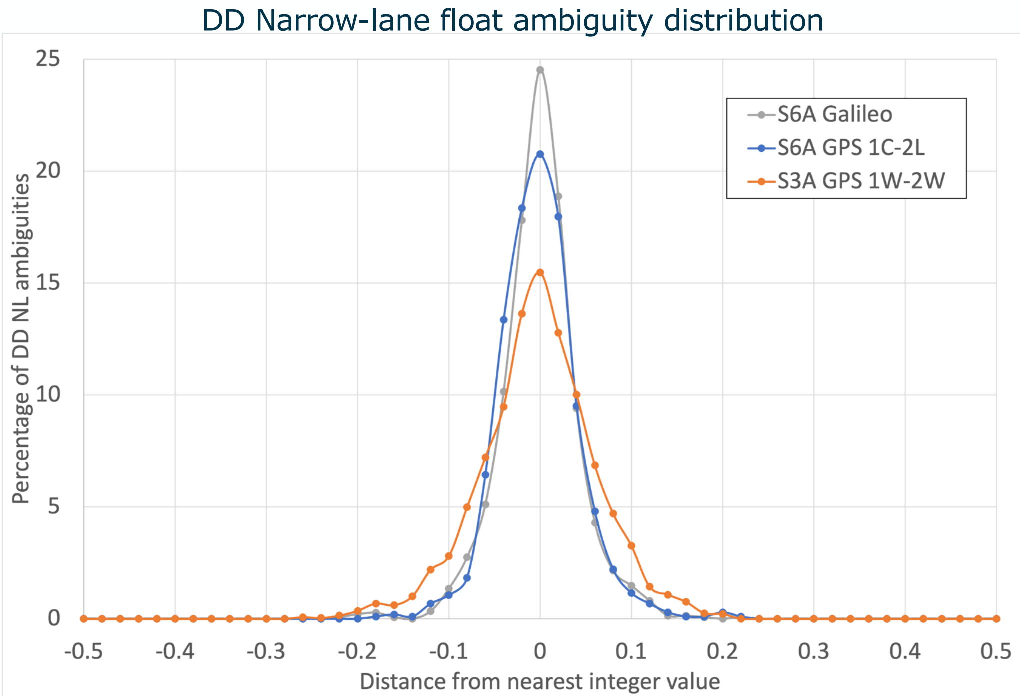
The distribution of the float ambiguities before the fixing process is a good indication of:

- The quality and consistency of the observations (wide-lane distribution)
- The quality of the ambiguities-float processing (narrow-lane distribution)

Excellent performance of Galileo

Poor WL distribution for GPS 1C-2L (while NL looks great). Possible explanation: code biases not stable at daily level (?)

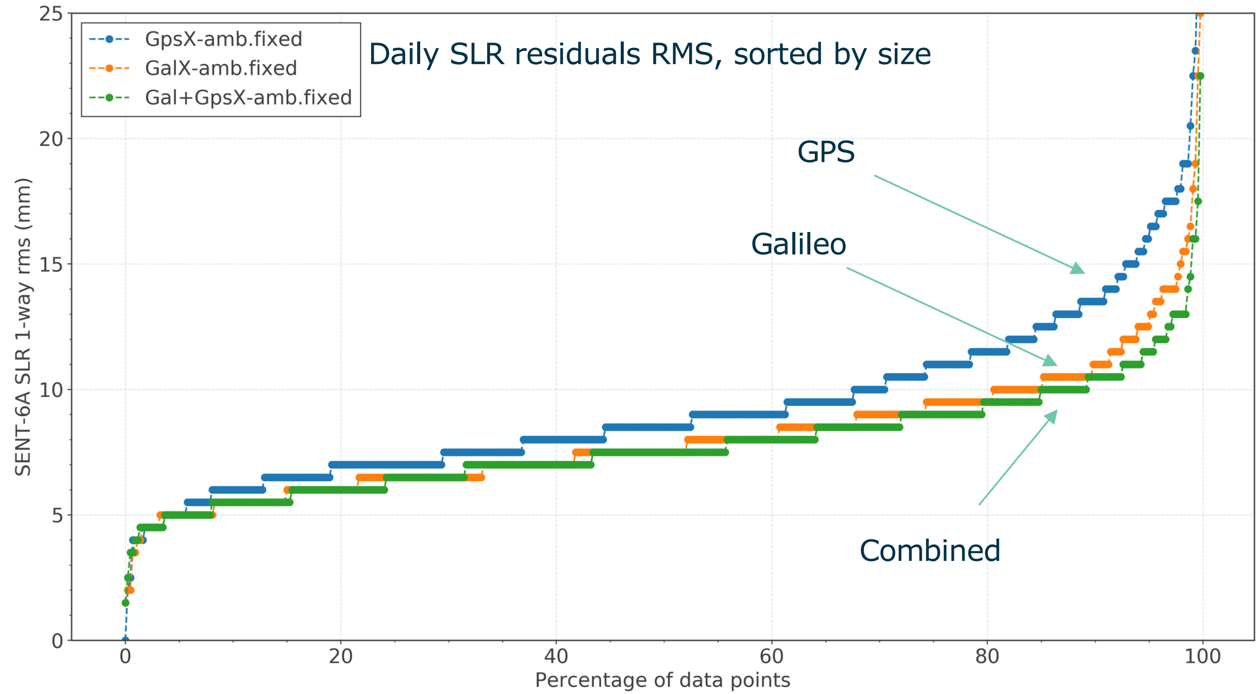




Sentinel 6 POD - External validation – Laser Ranging residuals

- High performance of all 3 solutions with the SLR independent validation
- In terms of residuals mean all solutions show a bias of ~1.4mm
- In terms of residuals RMS, the combined solution performes the best, followed by Galileo (within a sub-millimeter difference)
- The combined solution shows ~99% of the data points with RMS < 1.5cm
- The GPS-only solution shows again higher residuals than the other two solutions

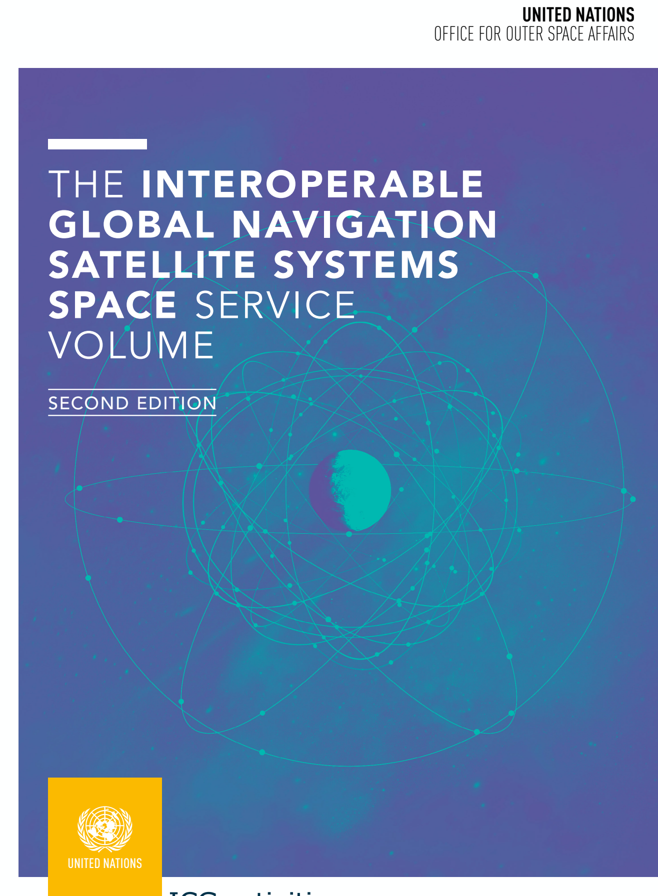
	Galileo	GPS	Galileo + GPS
SLR res. Mean (mm)	1.4	1.4	1.5
SLR res. RMS (mm)	8.1	9.3	7.8



GNSS Interoperability

In the context of GNSS Interoperability, the Sentinel 6 Michael Freilich mission is an important milestone for the multi-GNSS-based navigation in space

- **Thanks to its dual constellation PODRIX receiver, Sentinel-6 demonstrates:**
  - The excellent performance of the combined solutions based on the Galileo and GPS signals
  - The combined processing even leads to overcome the limitations of a single constellation
- **Still under investigation:**
  - Larger-than-expected orbital differences between the solutions based on the Galileo-only and GPS-only processing



ICG activities, source: www.unoosa.org

Conclusions & Future activities

Conclusions

- Excellent quality of the PODRIX Galileo observations
- Excellent performance of the Galileo & Combined processing
- Highly accurate surface modelling by means of raytracing superior and necessary to cope with the S6 geometry
- Excellent agreement between ESOC Galileo and CPOD combined solutions (RMS: radial<3mm, 3D<1cm)*
- Room for further improvements related to GNSS interoperability observations processing
- All GNSS products are produced in-house at ESOC showed:
    - Flexibility to generate ad-hoc GNSS products for specific tracking schemes
    - Good performance of *GNSS-mix* solution adopted for Sentinel 6, with no GNSS biases needed

Future activities

- Include in the POD processing the GNSS observations from the TriG receiver (NASA/JPL)
- Operationally set up and process Sentinel-6, all other Sentinels and other LEOs in a GNSS Network approach
- Investigate higher-than-expected orbit errors (e.g., overlaps, SLR) based on the GPS-only observations

* CPOD, COPERNICUS POD REGULAR SERVICE REVIEW JUL - SEP 2022

Thanks for your attention

For any question or request, please contact:

- Francesco Gini Francesco.Gini@esa.int
- Werner Enderle Werner.Enderle@esa.int

From: sentinels.copernicus.eu

Backup Slides

Sentinel 6 POD - Quality of the observations

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Observations quality

	Galileo	GPS
Melbourne-Wübbena (cm)	**8**	18
Iono Free Code-Carrier (cm)	**28**	56

- High quality of ALL observations
- High-accurate Galileo observations in space
- Galileo shows half the noise of GPS particularly thanks to the excellent code observations