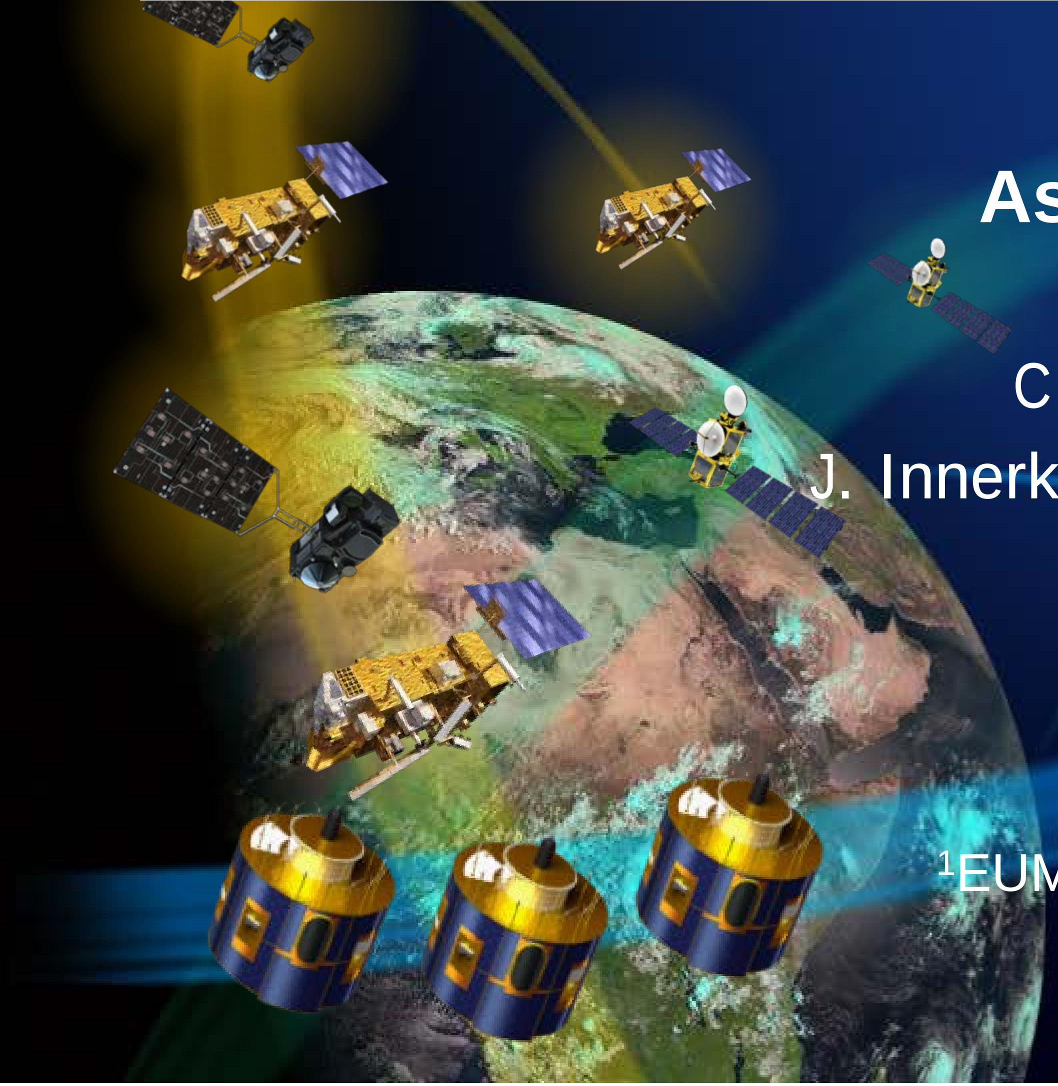

# Assessment of Spire Commercial RO Data


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# Outline

- Study background
- Numbers (of occultations, constellations,…)
- Statistics (of bending angles)
- POD
- Conclusions

# ESA Study

- *"This project will establish a first independent quality baseline of the quality of commercial GNSS-RO data from an operational small satellite constellation […]. Spire Global will provide a minimum of 30,000 GNSS-RO profiles for Wegener Center and EUMETSAT to assess its quality […]"*
- Funded by ESA via its "Express Procurement Procedure".
- This presentation gives an overview of the statistical validation of bending angle data as provided by Spire, and some initial results on lower level processing (POD).

# Study history

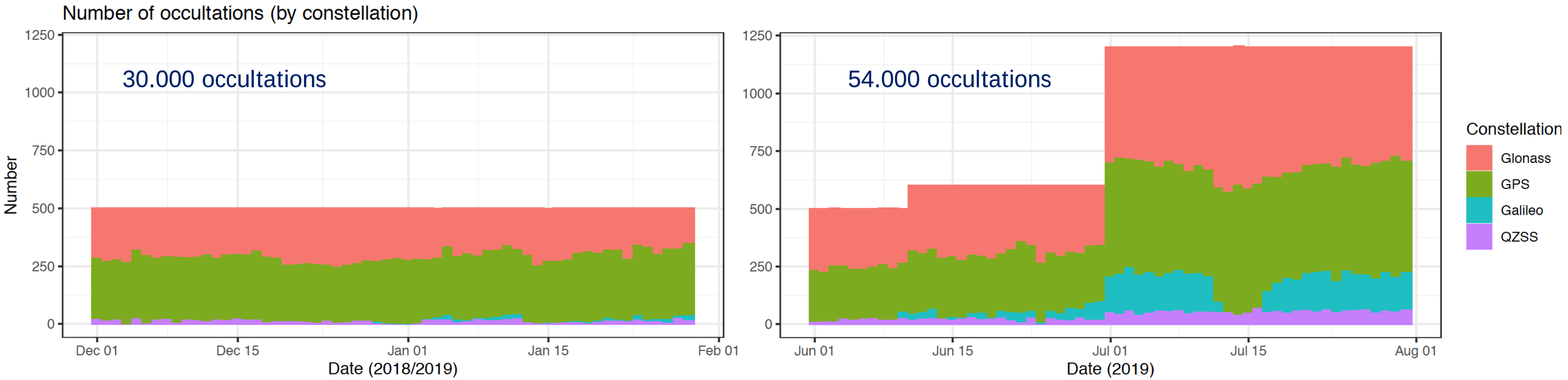
- 30.000 occultations (500/day) during December 2018 and January 2019

- Initial bending angle data provided by Spire was statistically optimised.
  - Spire re-delivered raw bending angle data.

- Spire further offered additional data to the study consortium due to improved receiver performance (June and July 2019 – another 54.000+ occultations) and did so recently.

- Spire provided a very good technical support, fixing several issues (e.g. data formats) and answering many technical question in details. Thank you!

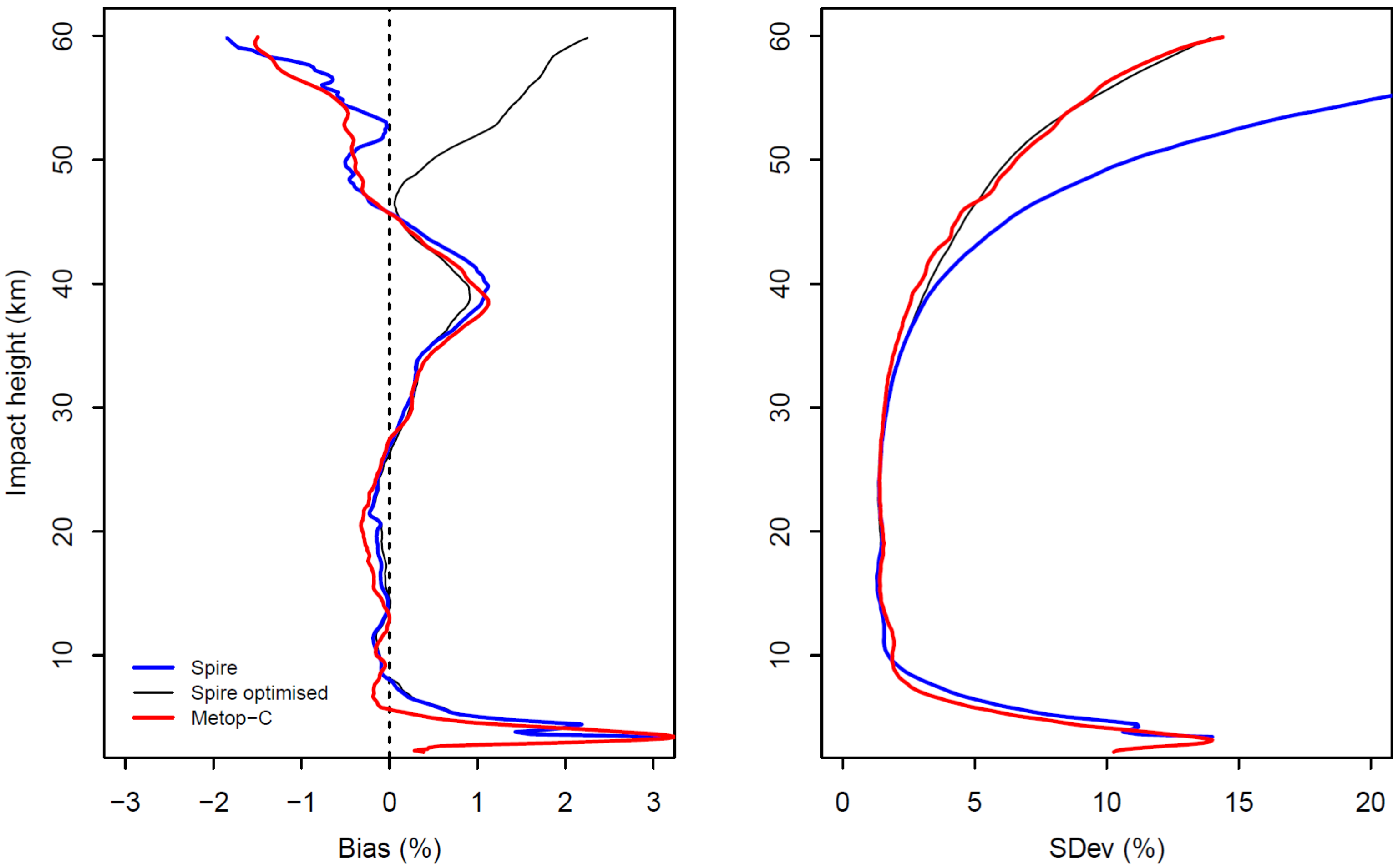
# Daily occultation numbers




- Number of daily occultations in Dec/Jan 2018/19 (left) and Jun/Jul 2019 (right).
- 4 GNSS constellations
- 18 different satellites, some different instrument/firmware versions; mostly sun-synchronous orbits around 500 km orbit height;
- Data is quality controlled (based on retrieval diagnostics, but not auxiliary/NWP data)

# Global covariance statistics (Dec 2018/Jan 2019)

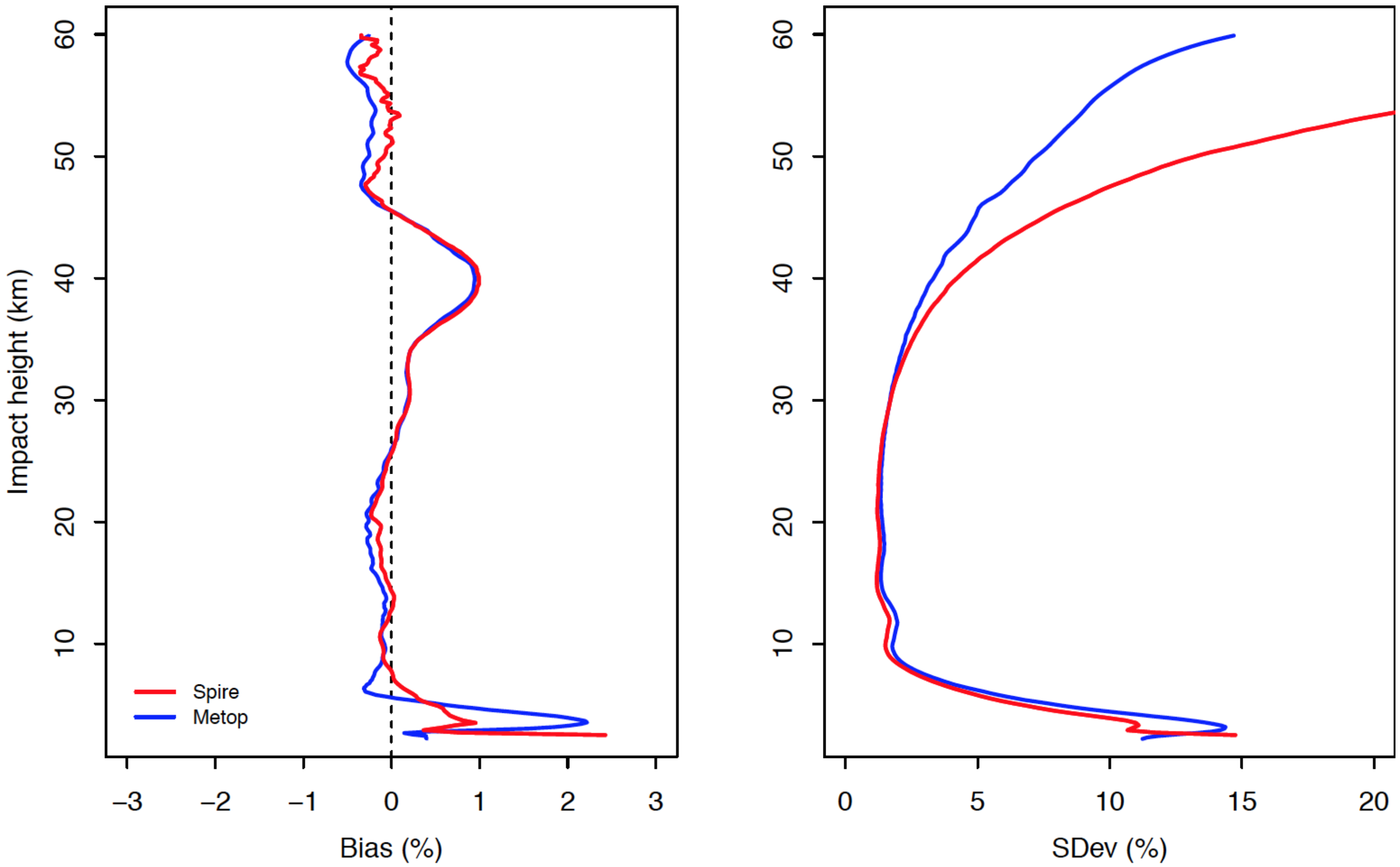
- Above 40 km: optimised data looks as good as GRAS, but raw bending angles are not;
- Note: Bias around 40 km is a known ECMWF issue.
- Core region: Excellent agreement (as expected) – but note discontinuity around 20 km (WO/GO transition in Spire retrievals?)
- Troposphere: similar to GRAS for both Bias and SDevs which surprised us – we think our current retrieval needs improvement.



# Global covariance statistics (Jun/July 2019)

- High up: as before;
- Core region: again excellent agreement, same structure between 12 and 20 km;
- Troposphere improved; Bias lower than for GRAS, Sdevs also (slightly) improved.

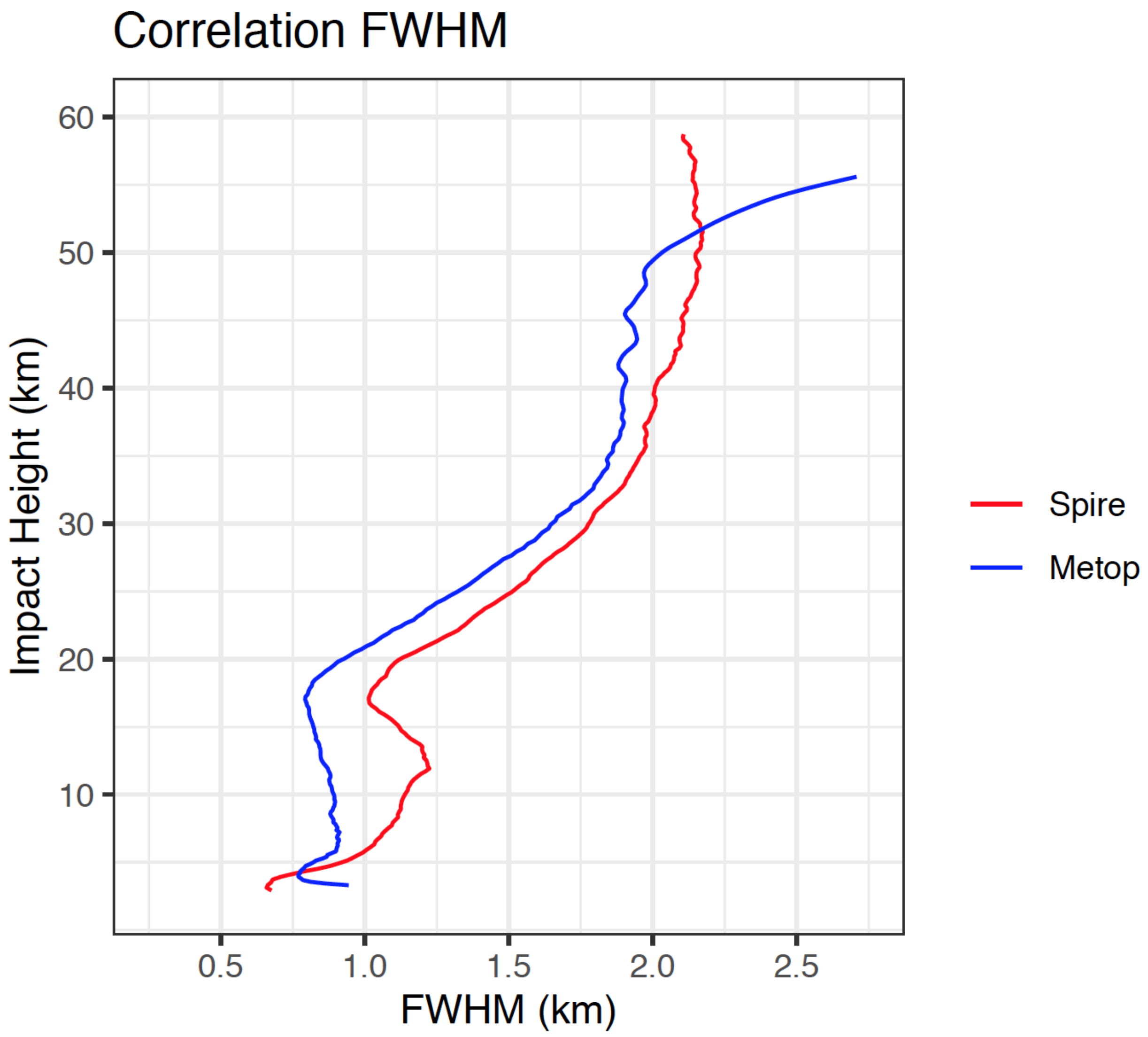
- Note: colours changed…
- …and statistics is calculated against operational ECMWF short range forecasts and GRAS products.



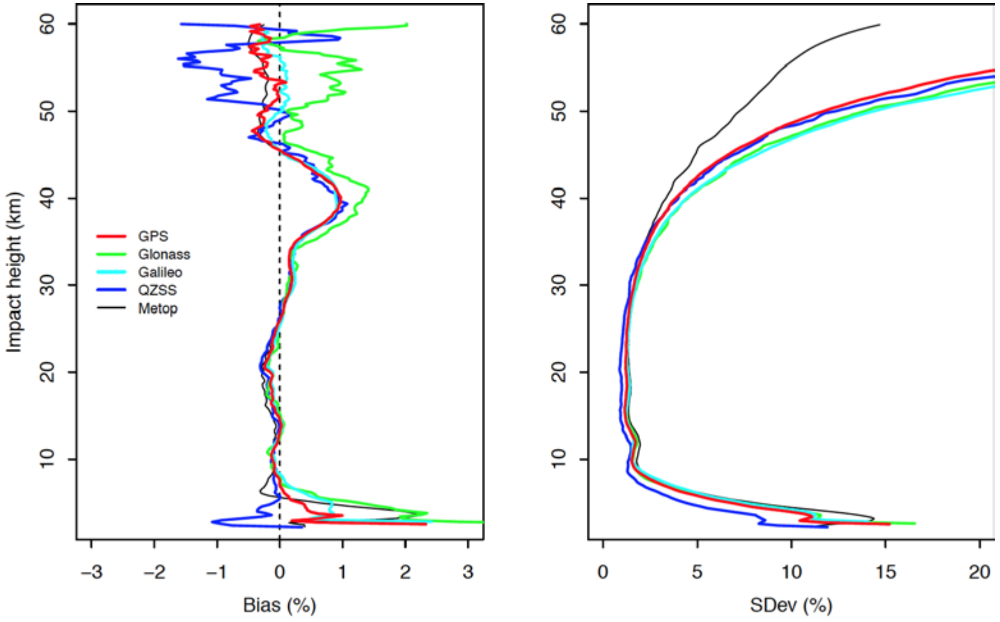
# Vertical correlation length

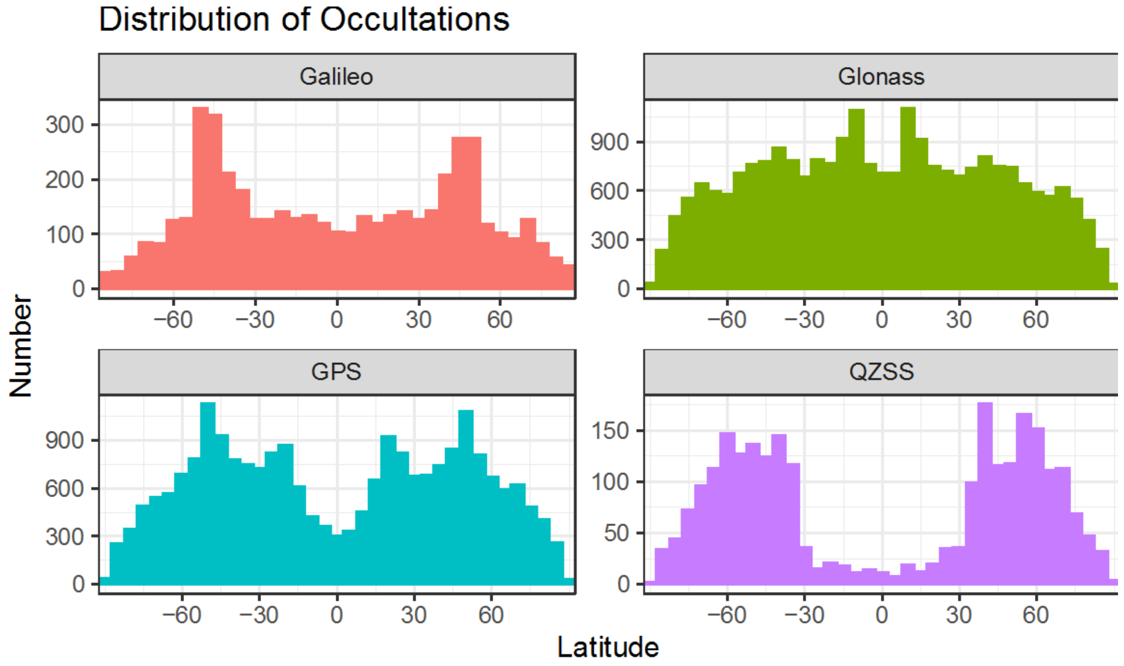
- Full Width at Half-Maximum (FWHM) of vertical correlation peaks (June/July 2019)

- Driven by vertical smoothing…
- …suggesting that Spire data is more smoothed/filtered than GRAS, likely explaining lower SDevs in Spire data below the tropopause.



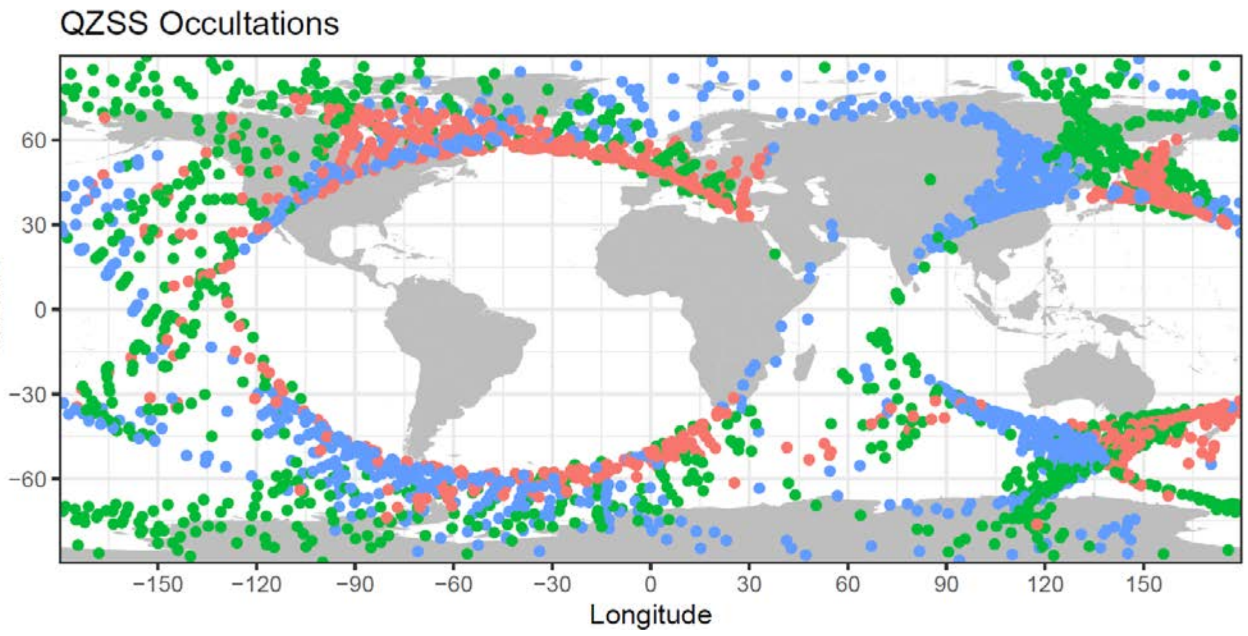
# Statistics by GNSS constellation

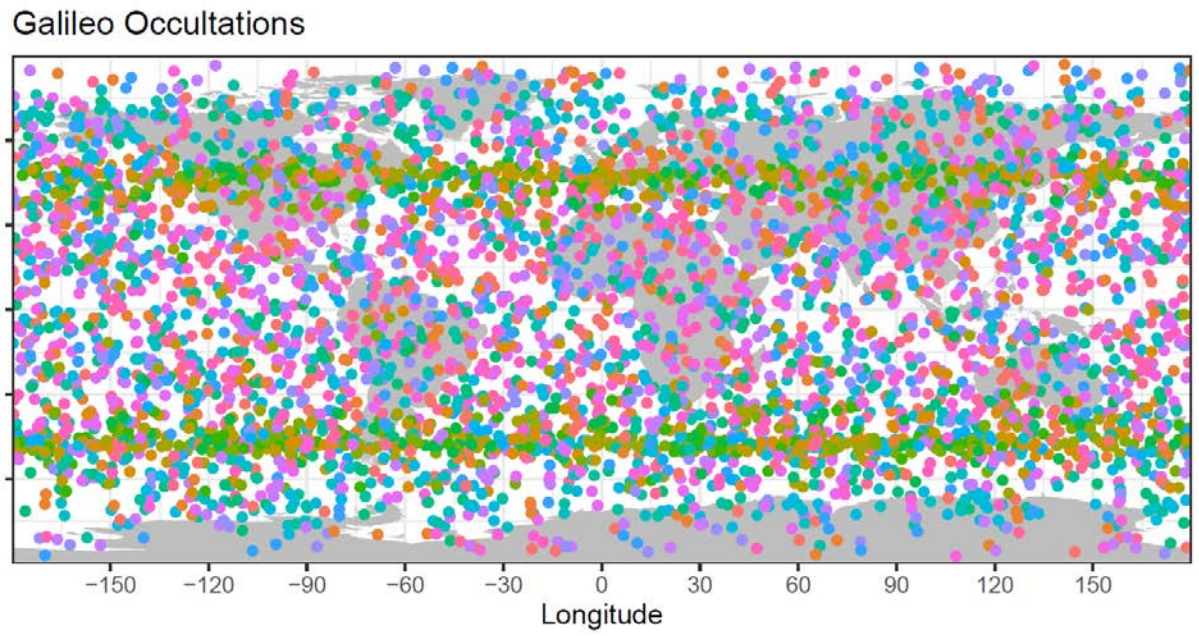



- Latitudinal distribution between constellations seems to be quite different – is that due to sampling effects?
- Statistics from July 2019.

# Distribution of occultations

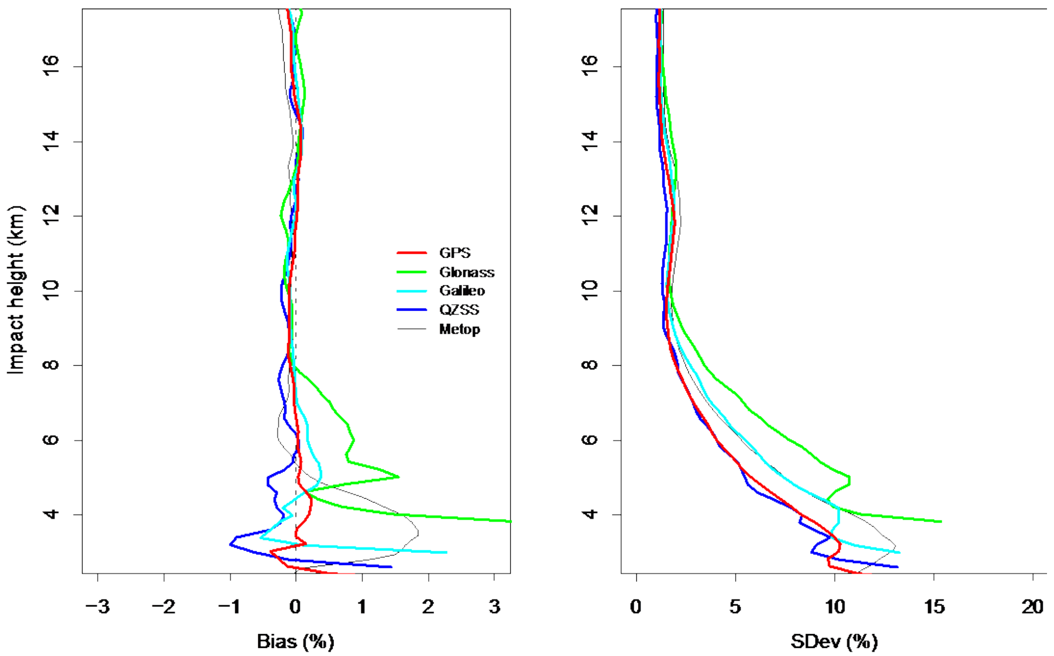


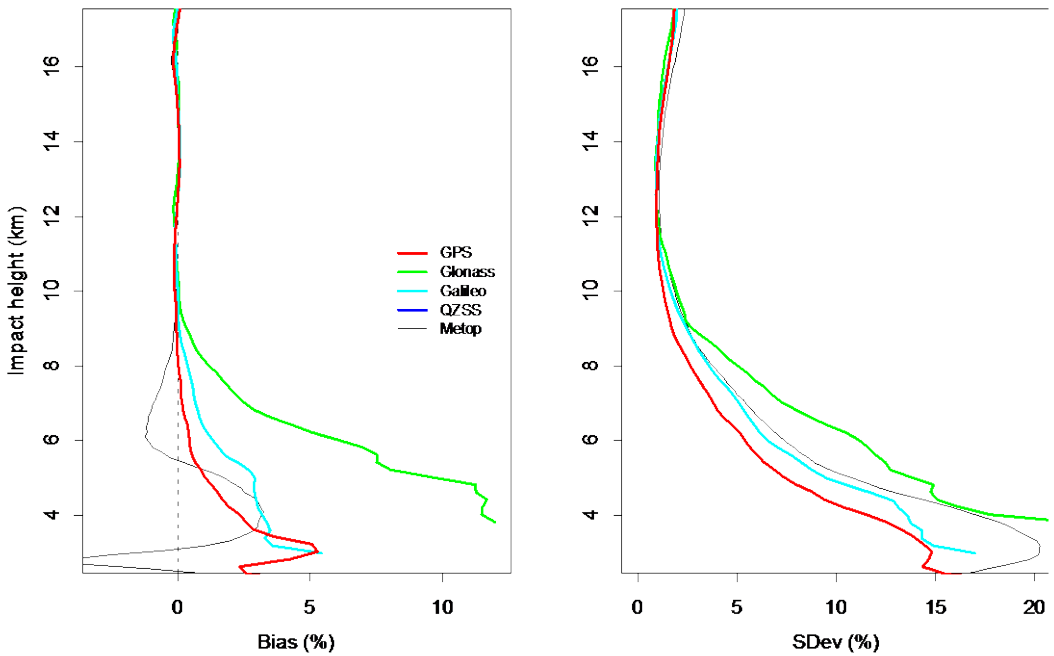

- Due to different orbit geometries, different GNSS constellations exhibit different distributions of occultations.
- Data from July 2019.

# Statistics by GNSS constellation

Mid-latitudes

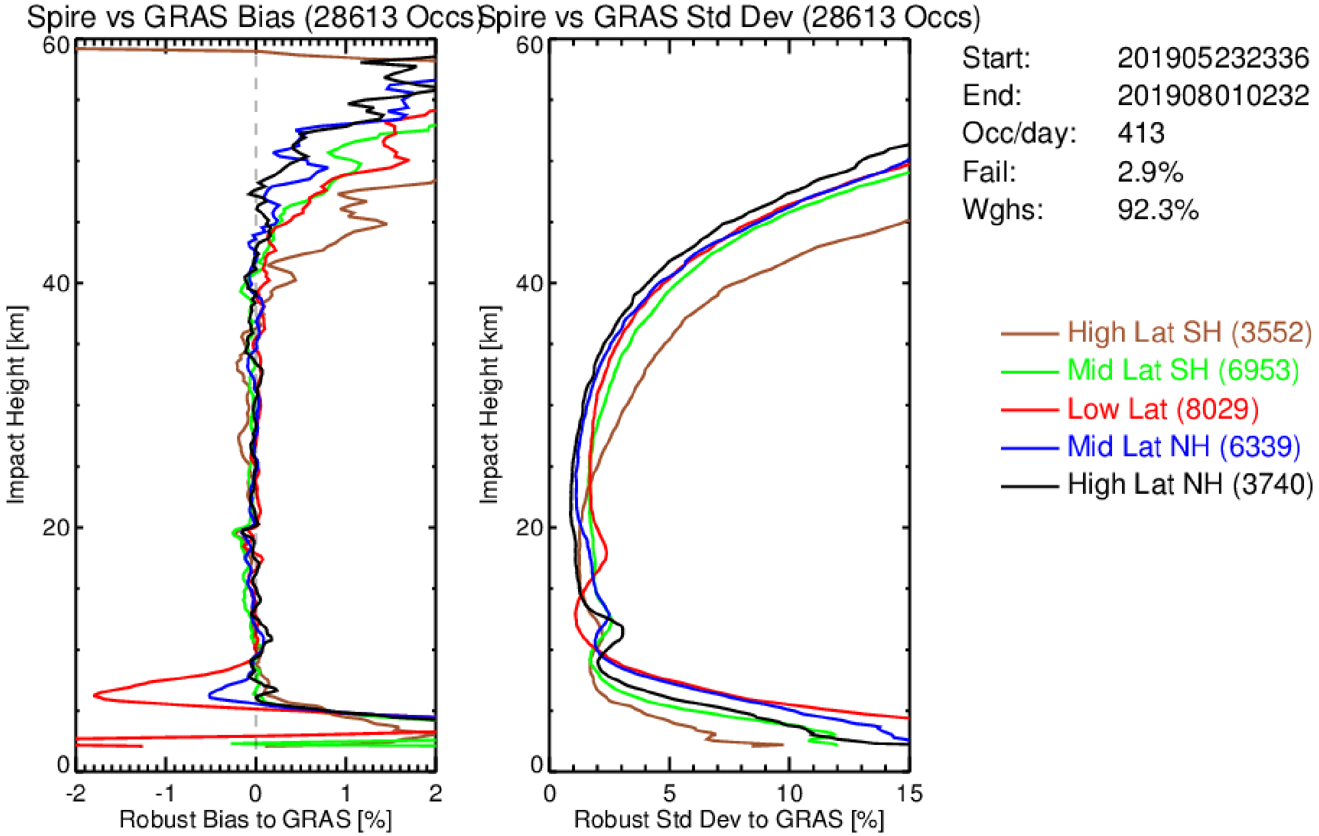



Tropics




- GLONASS stands out; poorer performance in the troposphere is only partially due to sampling (note the scale of the bias axis). Will be addressed in the future.
- Statistics from July 2019.

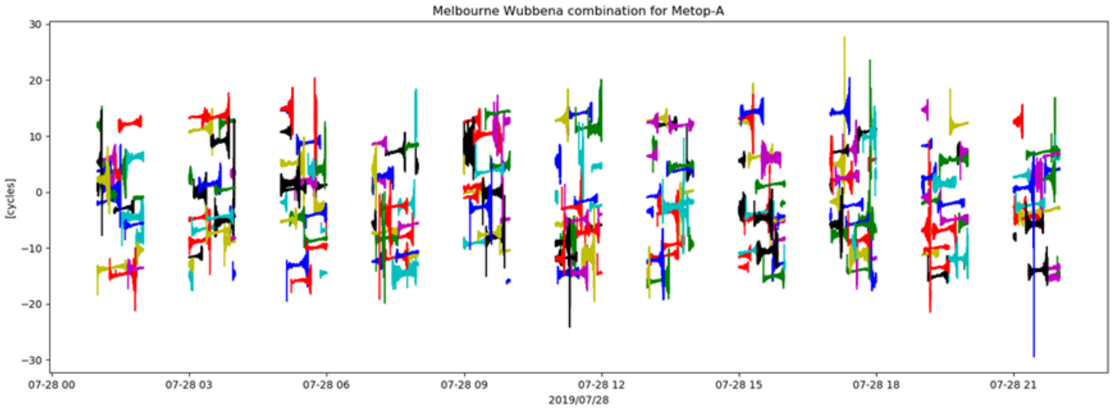
# Co-located Spire and GRAS occultations



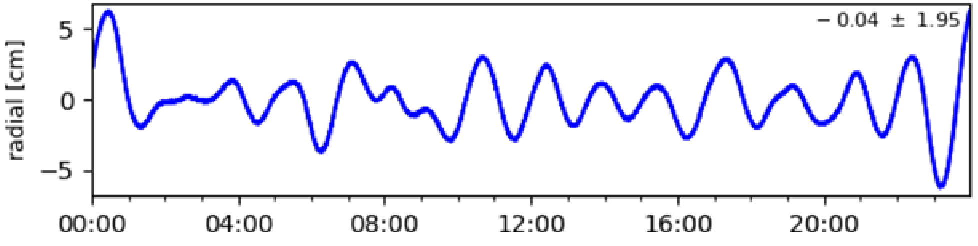

- Colocations within 3 hrs / 300 km
- Excellent agreement in the core region (up to 40 km),
- Increased deviations above and below
- Increased standard deviation around tropopause probably due to different smoothing
- Known GRAS issues showing up in the troposphere
- SH high latitudes not fully understood

# POD degradation due to lower (~hourly) duty cycle?

- Using GRAS/Metop-A data and POD, but introducing hourly data gaps
  - Orbit agreement ~5 cm (3d RMS), and 0.04 mm/s (3d RMS);
  - Satisfies EPS-SG requirements



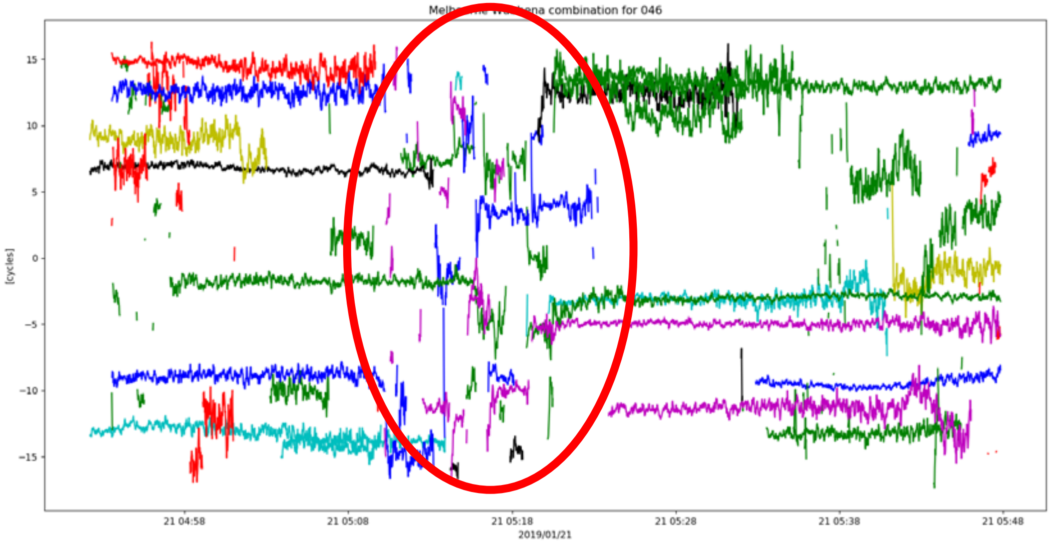

➢ hourly duty cycles won’t provide problems if zenith antenna data (and POD) is ok.

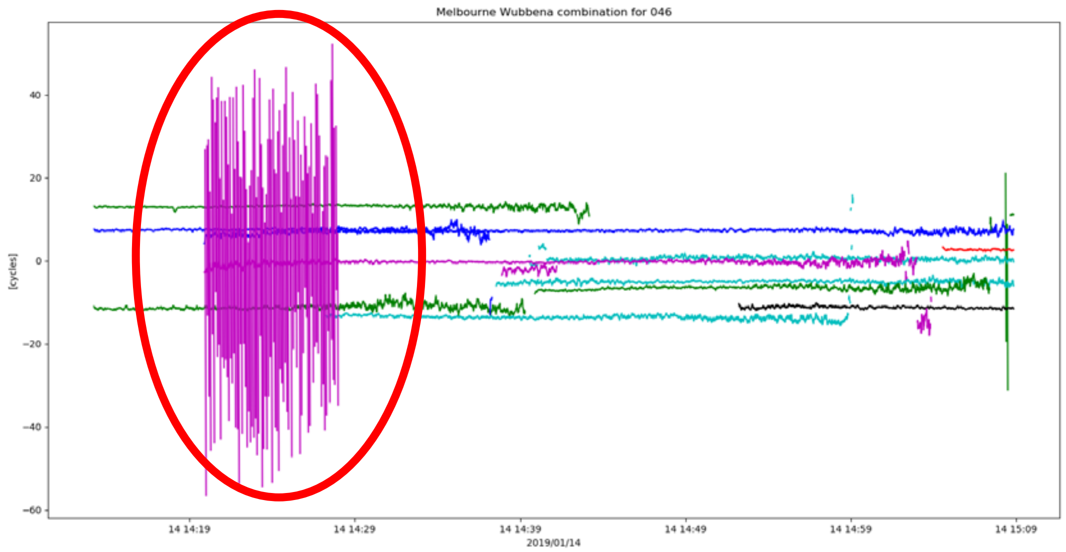


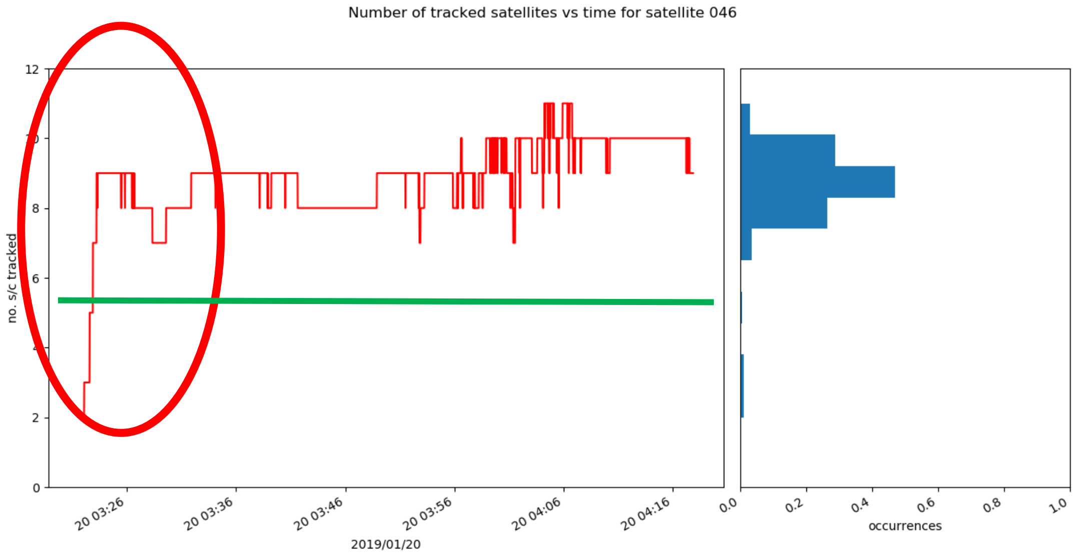

# Comparison Start: 2019-07-28 00:00:00.00 #
# Comparison End: 2019-07-28 23:59:00.00 #

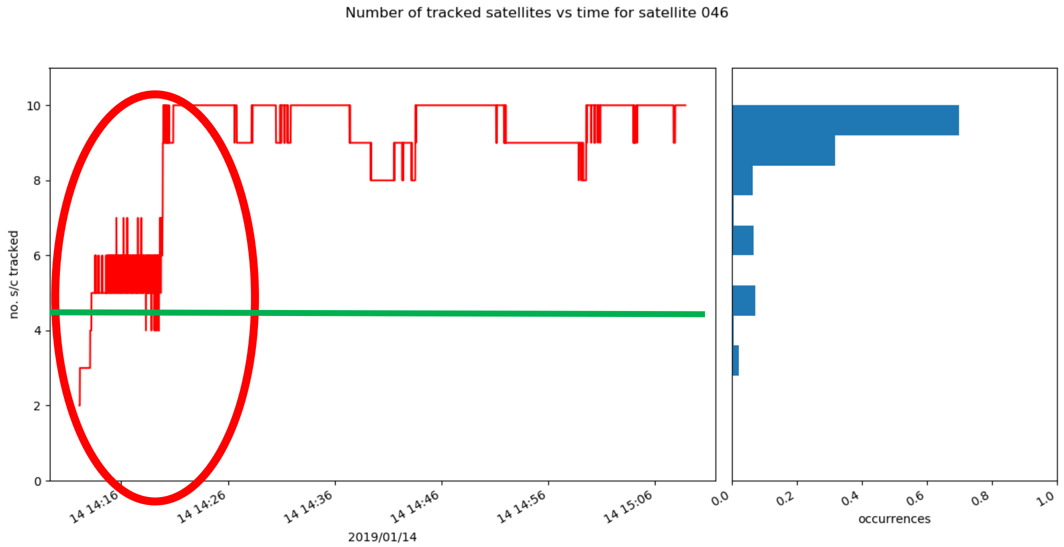
| Satellite : L14 | | MEAN | STD | RMS | MAX |
|---|---|---|---|---|---|
| Radial position | cm: | -0.04 | 1.95 | 1.95 | 6.24 |
| Cross position | cm: | -0.36 | 1.50 | 1.54 | 7.35 |
| Transverse position | cm: | -1.27 | 4.56 | 4.73 | 24.43 |
| Clock bias | cm: | nan | nan | nan | nan |
| 3D position | cm: | 4.06 | 3.47 | 5.34 | 24.57 |
| Radial velocity | mm/s: | -0.01 | 0.04 | 0.04 | 0.21 |
| Cross velocity | mm/s: | 0.00 | 0.02 | 0.02 | 0.06 |
| Transverse velocity | mm/s: | 0.00 | 0.01 | 0.01 | 0.05 |
| Clock drift | mm/s: | nan | nan | nan | nan |
| 3D velocity | mm/s: | 0.03 | 0.03 | 0.04 | 0.22 |

# Melbourne-Wübbena combination – Spire FM046

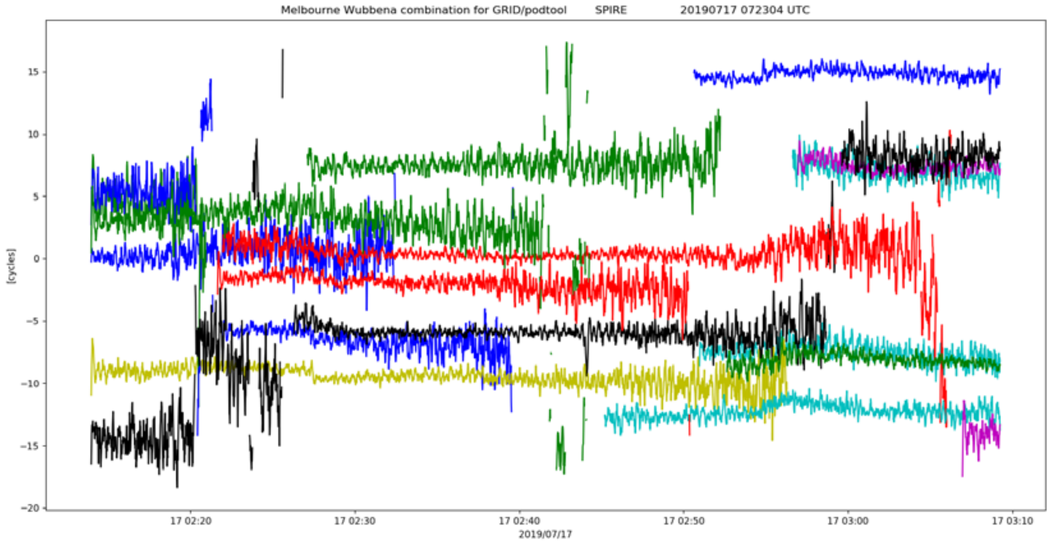


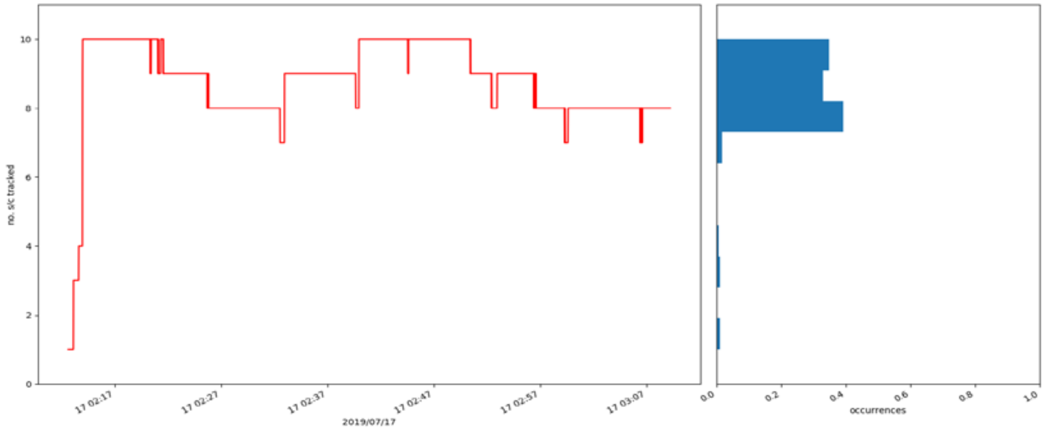



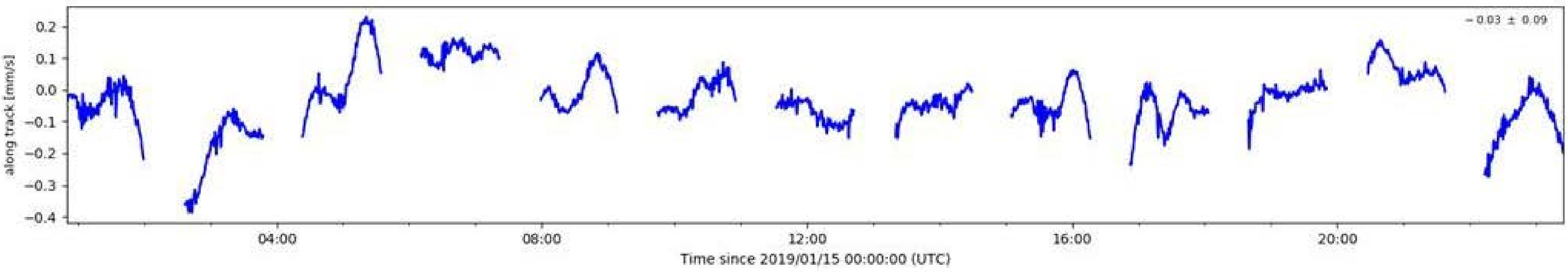
# Newer satellites behave better – Spire FM101




- More recent Spire receivers perform better.
- POD processing proved difficult initially as Spire zenith data exhibits several challenges:
  - Often only single frequency measurements only
  - Tracking failures, specially in early satellites
  - Tracking down to -20°elevation
  - Initial orbit agreement only ~ 40 cm 3d RMS
- For perspective:
  - EUMETSAT vs UCAR ~15-20 cm 3d RMS for COSMIC-I;
  - EUMETSAT vs DLR/CNES/Delft ~5 cm 3d RMS for Metops and Sentinel-3s
  - Early days of GRAS: ~30 cm 3d RMS

# After some learning on both sides…




| Satellite : FM086 | | MEAN | STD | RMS | MAX |
|---|---|---|---|---|---|
| Radial position | cm: | 4.09 | 13.57 | 14.18 | 36.57 |
| Cross position | cm: | -10.77 | 7.21 | 12.96 | 30.55 |
| Transverse position | cm: | 2.59 | 13.07 | 13.33 | 39.15 |
| Clock bias | cm: | nan | nan | nan | nan |
| 3D position | cm: | 22.26 | 7.15 | 23.38 | 47.44 |
| Radial velocity | mm/s: | 0.01 | 0.12 | 0.12 | 0.93 |
| Cross velocity | mm/s: | -0.02 | 0.06 | 0.06 | 0.30 |
| Transverse velocity | mm/s: | -0.03 | 0.09 | 0.10 | 0.39 |
| Clock drift | mm/s: | nan | nan | nan | nan |
| 3D velocity | mm/s: | 0.14 | 0.09 | 0.17 | 0.97 |

- Along-track velocity differences for Spire FM086
- 3D-RMS in the order of 20-25 cm, 1d 10-15 cm, small bias left
- Satisfies GRAS POD velocity requirement.

# Conclusions

**General:**

- Spire provided ~ 84.000 occultations to the study consortium.
- For the first time, data from four different constellations became available.
- The Spire instruments and processing are evolving quickly.

**Data Quality:**

- In the core region (upper troposphere to mid-stratosphere), Spire data is highly consistent with GRAS (and very likely other RO missions), though probably exhibits more vertical smoothing.
- Above 40 km, random errors exceed noise levels known from GRAS.
- In the troposphere, measurements penetrate close to the ground, with systematic and random uncertainties being in a similar order of magnitude as for operational GRAS data (which has weaknesses in its wave optics);
- Differences between RO products from different GNSS constellations, especially in the troposphere, need to be better understood (and might benefit other future missions as well)

# Conclusions (cont'd)

**POD:**

- Lower duty cycles of Spire satellites are not problematic from a POD point of view
- POD solutions agree in the order of 20-25 cm (3d-RMS); along-track velocity ~ 0.1 mm/s (within Metop requirement)

**Next steps for this project:**

- Processing and analysis of lower level data has started at both Uni Graz and EUMETSAT
- Further evolution of POD and product comparison

- Spire provided excellent technical support to the study consortium.