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)

30,000 occultations

54,000 occultations
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.
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

- 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.
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…

<table>
<thead>
<tr>
<th>Satellite</th>
<th>MEAN</th>
<th>STD</th>
<th>RMS</th>
<th>MAX</th>
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<tr>
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<td>13.57</td>
<td>14.18</td>
<td>36.57</td>
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<tr>
<td>Cross position</td>
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<tr>
<td>Transverse position</td>
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<td>13.33</td>
<td>39.15</td>
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<tr>
<td>Clock bias</td>
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<td>nan</td>
<td>nan</td>
<td>nan</td>
</tr>
<tr>
<td>3D position</td>
<td>22.26</td>
<td>7.15</td>
<td>23.38</td>
<td>47.44</td>
</tr>
</tbody>
</table>

- 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.