Water Level monitoring over continental areas from Fully-Focused SAR altimeter processing

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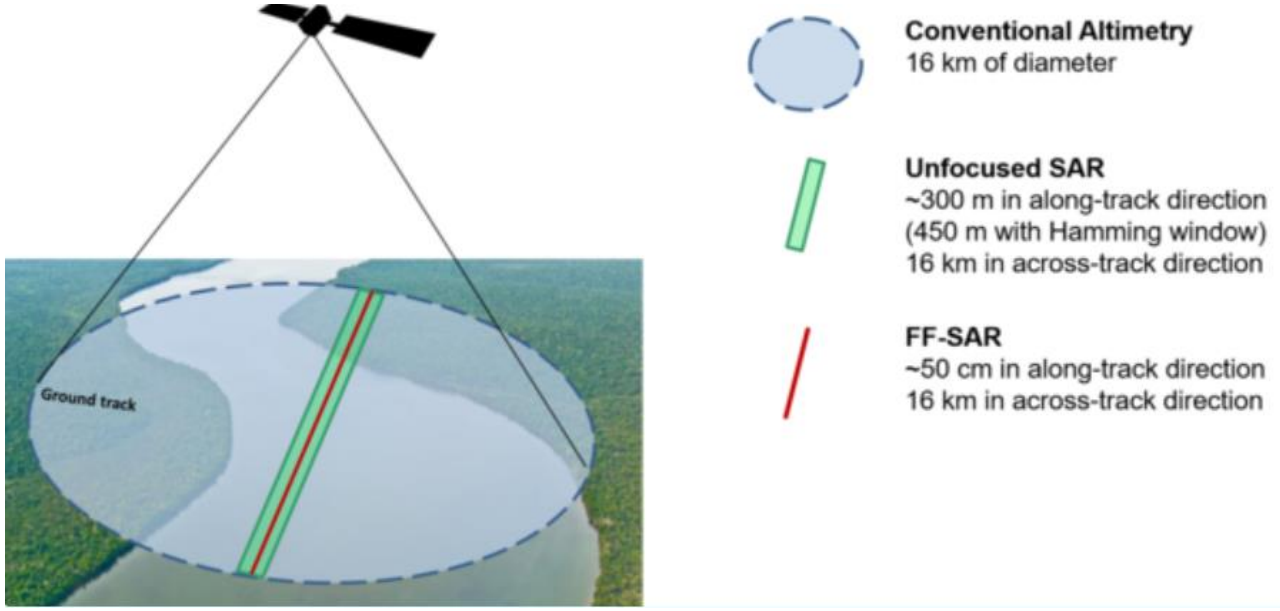
Context of the study

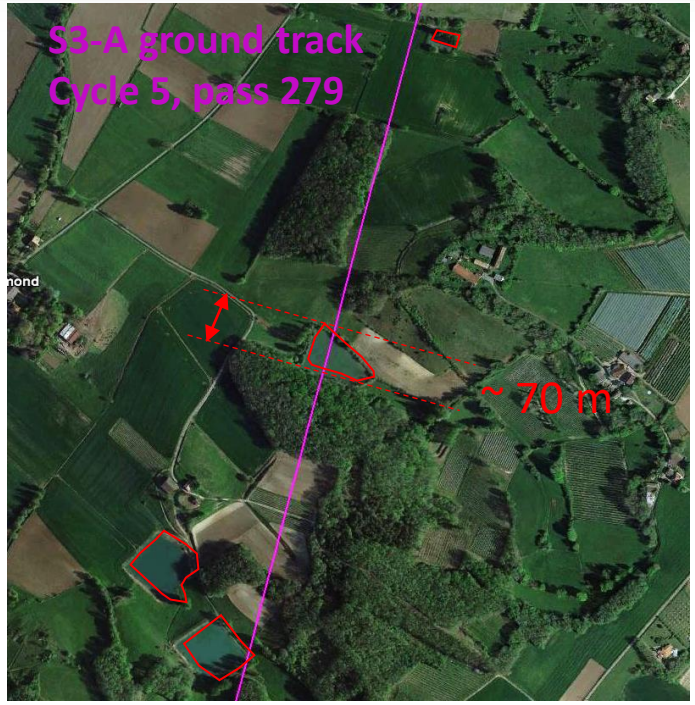
- Fully-Focused SAR[1]: innovative processing to reduce the altimeter along-track resolution to the theoretical limit (~50cm)
- Preliminary validation results over inland waters (several water bodies)
- ESA and CNES project: SMAP open source software (FFSAR Standalone Multi-mission Altimetry Processor)
- FFSAR performance assessment: 1 year of Sentinel-3A measurements over ~700 virtual stations (VS) acquired in Open-Loop mode (OLTC v5) over continental areas
- Prepare the analysis of the future Jason-CS / Sentinel-6 measurements



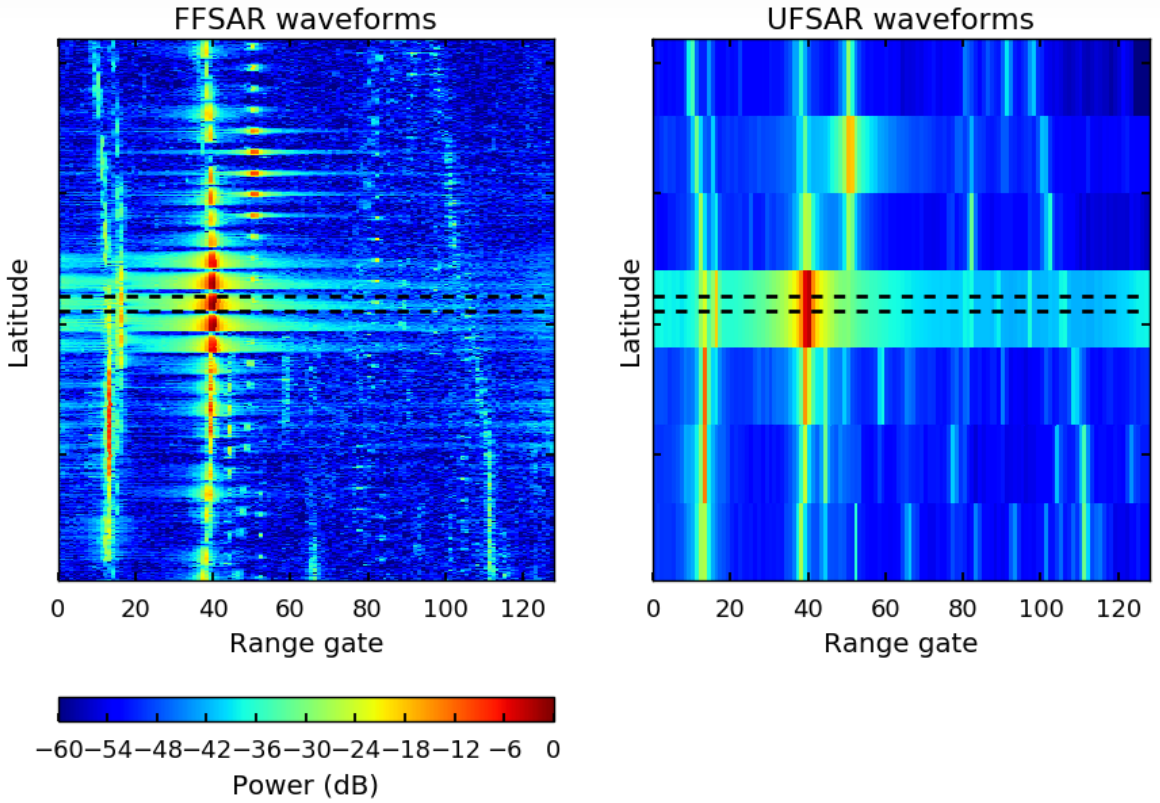
Footprints of the different modes over a watercourse

1. Egido and Smith, ”Fully Focused SAR Altimetry: Theory and Applications” 2017

Previous validation over inland waters



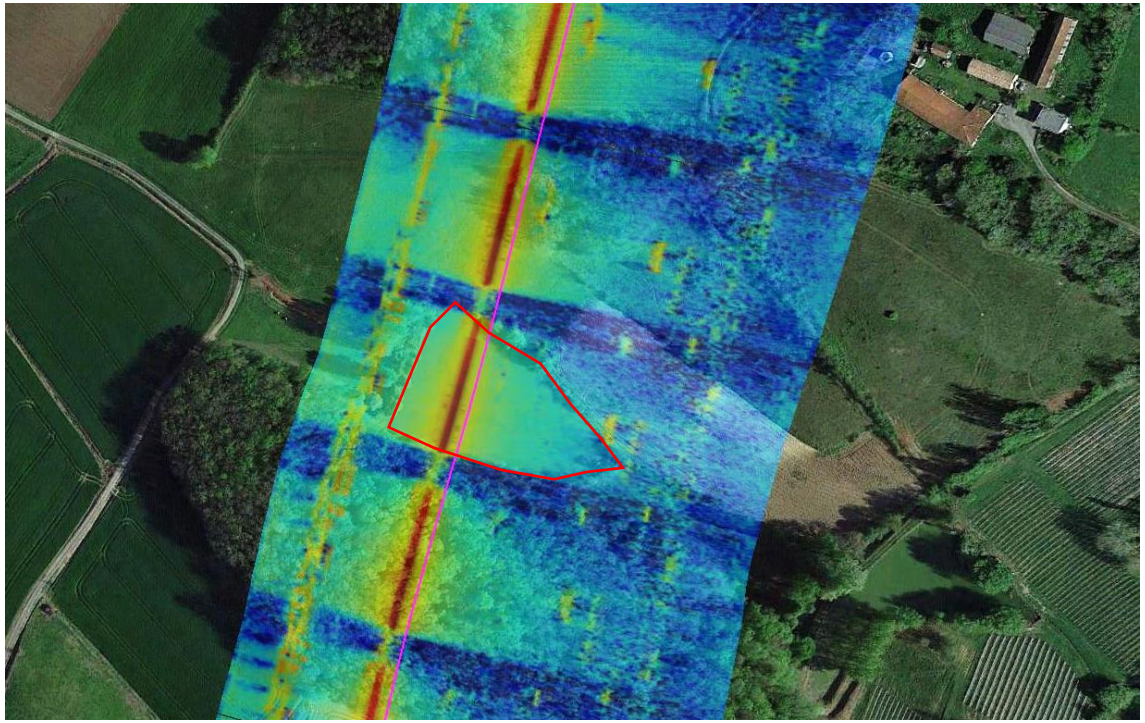
Small lake on the S3A ground track with many other water bodies nearby (P.Rieu et al, OSTST 2018)



→ 104 FF-SAR measurements on the pond: 4.5 mm std
→ Small scales well resolved by FF-SAR, but 'replicas' of the pond are observed due to the closed-burst mode of Sentinel-3A (will not be present on Sentinel-6 open burst)

Previous validation over inland waters

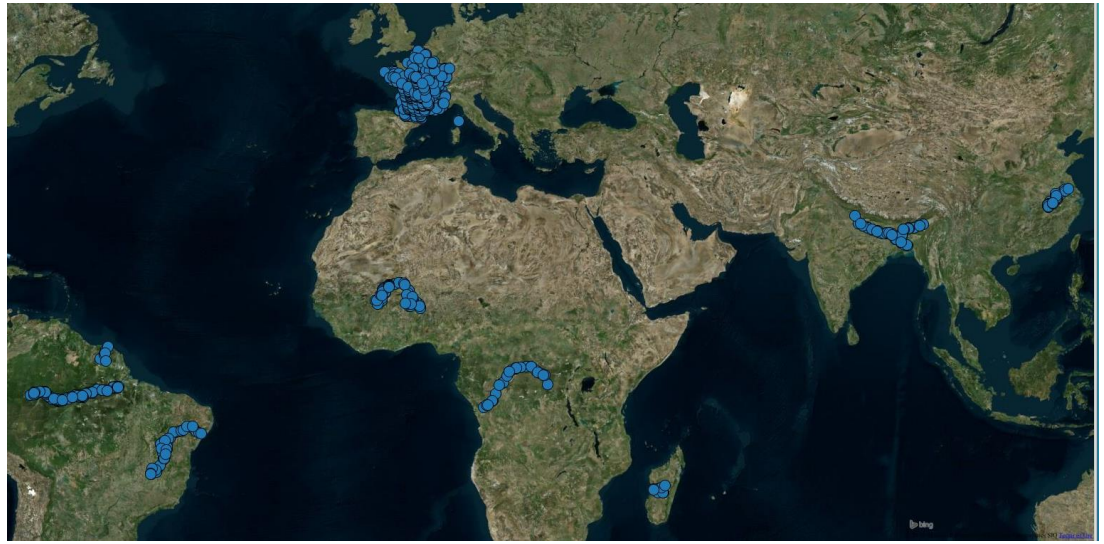
- Sentinel-3A: the altimeter emits 256 times and switch to receive mode (close burst)
- The sidelobes of the FF-SAR impulse response create ‘replicas’ of the pond every ~ 100m
- Here, the pond is small enough so that replicas don’t interfere with the main signal



Small lake on the S3A ground track with many other water bodies nearby (P.Rieu et al, OSTST 2018)

FF-SAR: processing configurations

Data locations



FFSAR processing: 720 Sentinel-3A VS over different hydrological basins (French rivers, The Amazon, The Congo, the Niger, the Yangtze …)

Processing

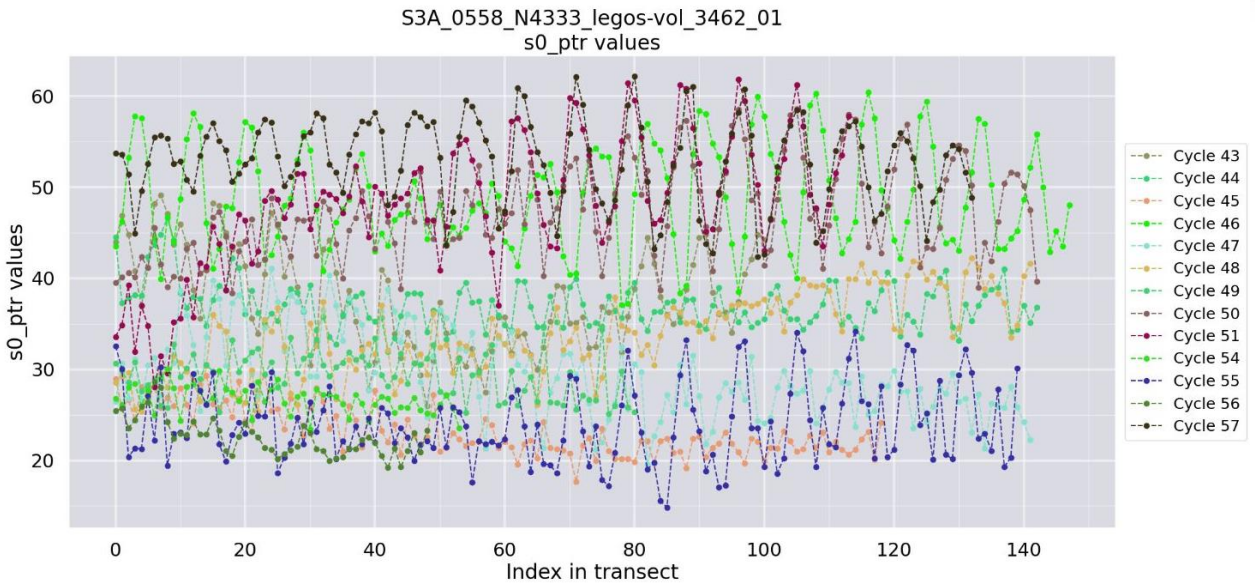
- 1-year of Sentinel-3A measurements: April 2019 – April 2020 (OLTC v5)
- 720 Sentinel-3A Virtual Stations
- Hamming: Azimuth + Range
- Illumination time: 180 bursts
- Along-track resolution: 10 m (trade-off between speckle noise and resolution)
- Retracking: OCOG (with and without zeropadding), PTR ($sinc^2$ retracking), MultiPTR (3 firsts peaks estimation from a given echo)
- SMAP : open-source software (ESA/CNES)

Additional data computation

- Type of targets (lakes, reservoirs, rivers)
- Targets' size from static water mask (PEKEL)
- VSs colocation from centerlines
- Addition of geophysical corrections, geoid (EGM08) and water mask information

FF-SAR: Along-track sigma0 values

Along-track measurements over quite a large target in France (~5000 m *700m) (lat/lon: 43.33 °, 0,676°)



Sigma0 (rtk sinc²) along track profile as a function of the cycle number when applying a water mask filtering (PEKEL occurrence > 1)

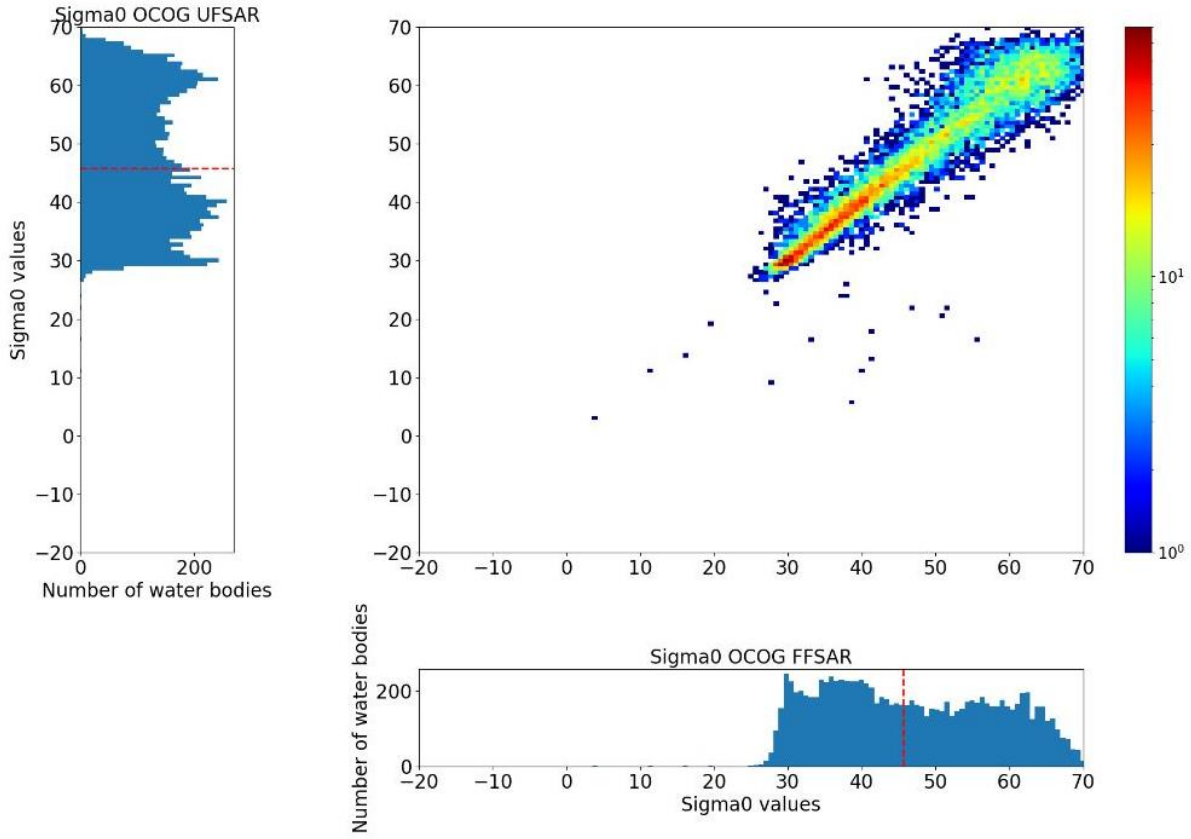
- Large range of sigma0 values according to the cycle number
- Large along track variations (sigma0 rebounds) => FFSAR replicas. Known issue of Sentinel-3

FF-SAR/UF-SAR

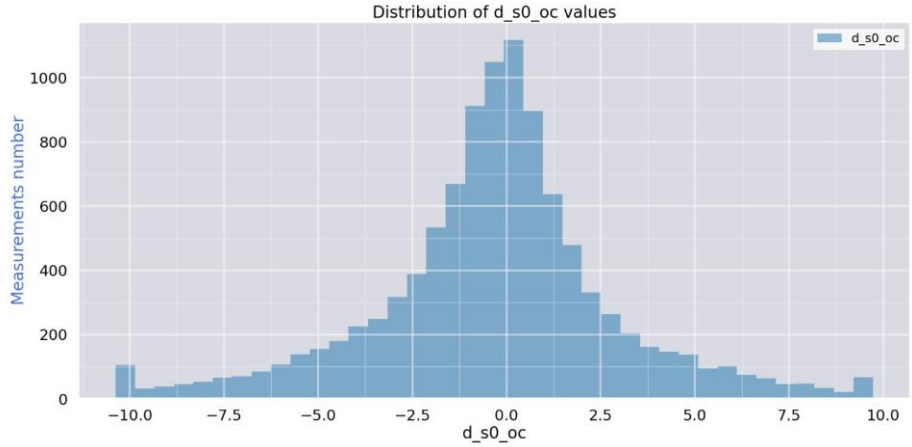
- Comparisons of Fully-Focused SAR (FFSAR) and unfocused SAR (UFSAR from Sentinel-3A PDGS products):
  - Sigma0 and range OCOG estimates are compared from HR measurements
  - Precision is assessed from the editing of the transect (1 point by transect)
- FFSAR main benefit : the along-track resolution (small water bodies can be seen with a significant number of estimates)
- FFSAR limitations:
  - “Replicas“ created by the sidelobes of the Azimuth Impulse Response every ~ 100 m
  - Spatial averaging necessary (10 m in this processing) to reduce speckle noise

Transect example over a target in France (lat/lon: 46,0 °/1,67°). FFSAR data are represented by blue points and UFSAR data by red points. Pekel occurrence values are displayed as a blue gradient (from 1 white to 100 deep blue)

FF-SAR/UF-SAR: sigma0 OCOG



Distribution of FFSAR or UFSAR sigma0 OCOG when applying a water mask filtering (PEKEL occurrence > 80)



Distribution of the difference between sigma0 OCOG FFSAR and UFSAR when applying a water mask filtering (PEKEL occurrence > 80)

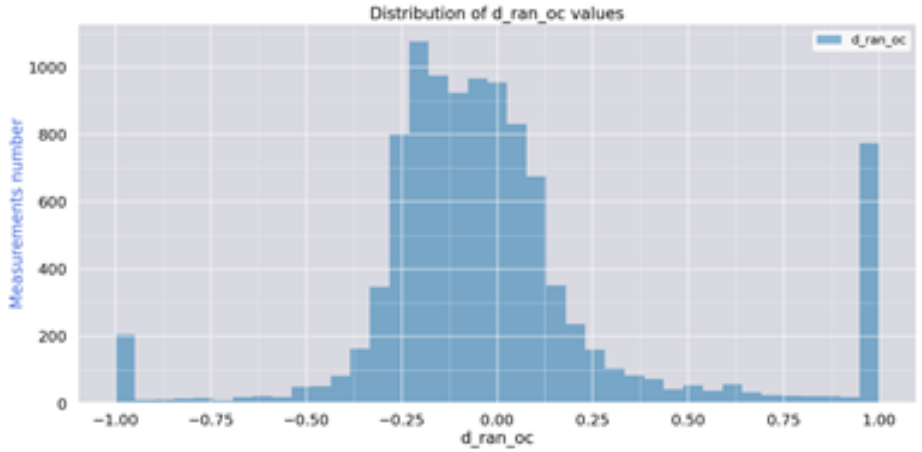
- Consistent sigma0 distribution between UFSAR and FFSAR (OCOG retracking)
- The higher the sigma0 values, the greater the dispersion between UFSAR and FFSAR.
- The dispersion is created by the replicas that occurs mainly with high sigma0 values

FF-SAR/UF-SAR: range OCOG

Distribution of the range difference between FFSAR (OCOG) and UFSAR when applying a water mask filtering (PEKEL occurrence > 80)

Median value: - 6 cm

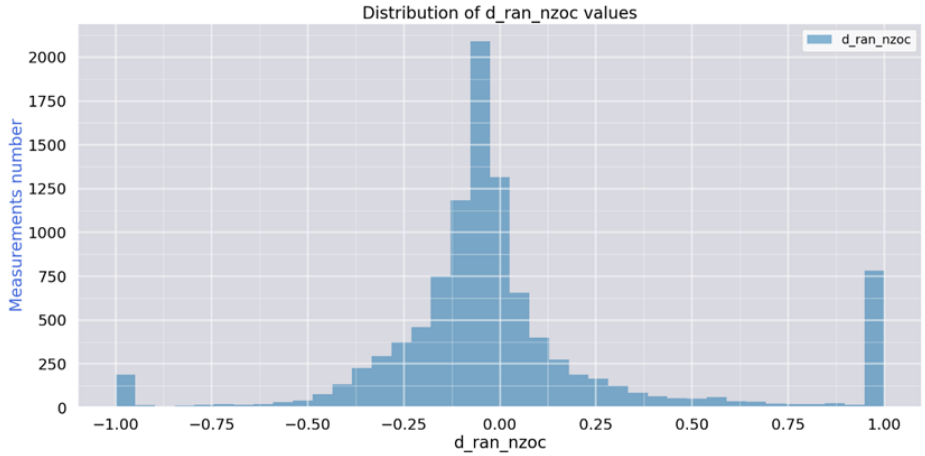
MAD value (median deviation from the median) : 14 cm



Distribution of the range difference between FFSAR (OCOG without zeropadding) and UFSAR when applying a water mask filtering (PEKEL occurrence > 80)

Median value: - 4 cm

MAD value (median deviation from the median) : 10 cm



- UFSAR/FFSAR range differences : not significant diagnosis without editing
- Closer results using FFSAR without zeropadding (closer to the PDGS processing baseline)
- MAD values (median deviation from the median) similar than the precision of the UFSAR range estimate

FFSAR/UFSAR: Transects editing

For each transect:

- HR selection w.r.t the shape of the water body
- Sigma0 thresholds (reference value + dynamic)
- Water Surface Height (WSH) thresholds
- WSH standard deviation threshold
- Calculation of the WSH median and standard deviation values

From a user's point of view, the use of the FFSAR processing allows different selections of HR points for small water bodies

- Possible use of a small buffer (hundred of meters) around rivers centerlines thanks to the along-track resolution
- Increases the ability to track small water bodies
- Improves the precision of the range estimation

FFSAR measurement over a VS in the Garonne river (bleu dots). Green polygon represents a buffer around a given centerlines

FF-SAR/UF-SAR: WSH precision

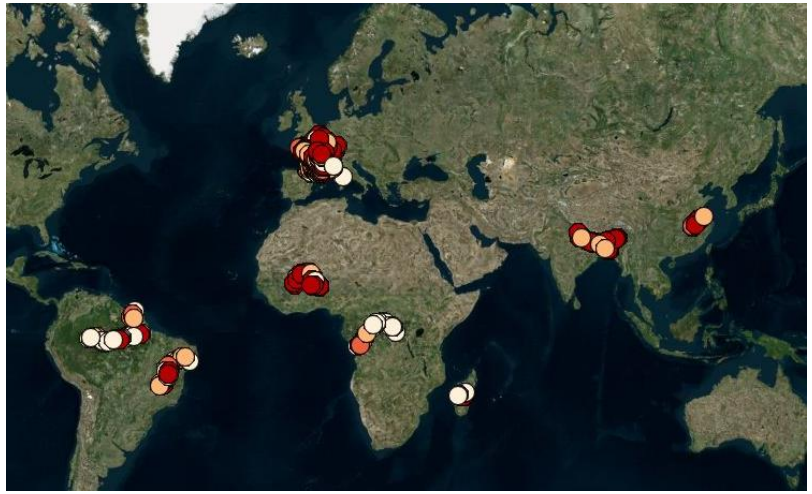
FFSAR processing (sinc²)
Mapping of the standard deviation values of WSH after editing

- 0.00 - 0.10 [6281]
- 0.10 - 0.20 [803]
- 0.20 - 0.30 [443]
- 0.30 - 2.00 [1508]

~ 9000 transects remaining after editing

Data loss: 14 %

WSH STD median value: ~4 cm



UFSAR processing
Mapping of the standard deviation values of WSH after editing

- 0 - 0.1 [2323]
- 0.1 - 0.2 [2551]
- 0.2- 0.3 [618]
- 0.3 - 2 [2905]

~ 8400 transects remaining after editing

Data loss: 20 %

WSH STD median value : ~15 cm

- Similar precision for OCOG (zeropadding) and sinc² retracking (median value : ~4 cm)
- Twice as precise using zeroppading
- Significant improvement of the precision using FFSAR processing :
  - Influence of the along-track resolution
  - Number of views of a same water body
  - Especially on small watercourse
- UFSAR precision could be better in some cases
  - Sentinel-3A “replicas” (sidelobes of the PTR)

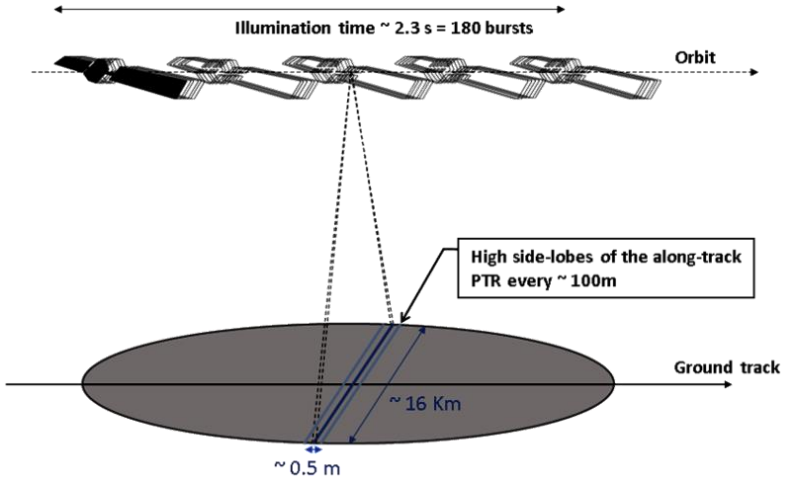
FF-SAR/UF-SAR: WSH precision

Example of a greater UFSAR precision

The Lake Chao (~760 km², lat/lon : 31.53°/117.58°)

FFSAR precision: ~16 cm (rtk OCOG)

UFSAR precision: ~3 cm



Sentinel-3A FFSAR processing : the altimeter emits 256 times and switch to receive mode. The interleaved mode of Jason-CS/Sentinel-6 (much more continuous) should reduce the high PTR sidelobes

- FF-SAR processing could be affected by “replicas” => error on the range estimation
- UF-SAR precision could be higher depending on the water body size and the environmental conditions
- FF-SAR precision should be more consistent with Jason-CS/Sentinel-6 (interleaved mode)

Conclusion and perspectives

FF-SAR shows high potential with a better along-track resolution and precision than UF-SAR processing (* ~4 w.r.t UFSAR).

The precision improvement is related to the use of 0pad (OCOG) or $sinc^2$ retracking (twice as precise than OCOG without 0pad) and the along-track resolution (sampling + number of view of a given water body).

From a user point of view the use of FF-SAR data allows a better selection of the measurements (narrow rivers). A greater sampling of UF-SAR data (80 Hz for instance) would allow similar approaches.

The precision improvement must be tempered regarding Sentinel-3A « replicas ». It limits its use for tracking small water bodies, potentially affecting the precision over large targets (depending on the environmental conditions). Over large water bodies UF-SAR could be more precise.

There will be no replicas issues thanks to the interleaved mode of Jason-CS/Sentinel-6 (open burst). It will allow better use of FF-SAR capacities over water bodies of different size.

SMAP: open source software (FF-SAR Standalone Multi-mission Altimetry Processor) will be available (GitHub) by the end of the year (portable to any OS Windows, macOS and Unix/Linux platforms) and will be announced by CNES/ESA