

# Replica removal of FFSAR data

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Sentinel-6 radargram of Garonna river, France

Sentinel-6 radargram of sea-ice, Antarctica



Due to missing pulses in the chronogram (only 2 on S6A) we have replicas (parabolas) with FFSAR processing



Sentinel-6 radargram of Garonna river, France

Sentinel-6 radargram of sea-ice, Antarctica



Retracker (here square sinc) could be trapped by replicas resulting in wrong surface elevation estimate



Sentinel-6 radargram of Garonna river, France

Sentinel-6 radargram of sea-ice, Antarctica



Retracker (here OCOG) could be trapped by replicas resulting in wrong surface elevation estimate





Sentinel-6 radargram of sea-ice, Antarctica



Replicas can create an error of **15m** in range epoch (for both sinc and ocog retrackers) with FFSAR which is very problematic.



# What is the replica problem and its impact ?: the interference



Simulation of Sentinel-3 interference phenomenon

Replica is not just extra signal out of the water surface, they also interfere in complex each-other, leading with Sentinel-3 to destruction of signal inside water surface !

✤ For river bellow 1st FFSAR replica (<90m for S3):</p>

no interference, extra signal only outside of the surface

For river between 1st FFSAR replica and 2<sup>nd</sup> peak of UFSAR PTR (>90m and <450m for S3):</p>

constructive/destructive interference inside the surface

For river after 2<sup>nd</sup> peak UFSAR PTR (>450m for S3):

stabilization around a « gaussian » shape



## What is the replica problem and its impact?: the smearing

- Due to along-track error in the range cell migration of the FFSAR stack [see Buchhaupt 2020, Ehlers current work], we observe a blurring effect on the FFSAR impulse response proportional to the integration time (data-block size processing).
- In case of mean-square slope, only pulses around the specular surface receive backcattering signal, leading to a convexe parabola shape w.r.t. azimuth
- \* In case of doppler frequency windowing only near-zero doppler are kept, leading to a concave parabola shape w.r.t. azimuth



## Replica removal solution #1: Deconvolution

Let  $S_{ob}$  the open-burst signal we want to retrieve from  $S_{cb}$  the closed-burst signal. The problem can be formulated as a convolution problem :

 $S_{cb}(f_d, x) = S_{ob}(f_d, x) \star K(f_d, x) + \epsilon(f_d, x)$ 

Where  $\epsilon$  is the noise and K the kernel, here the 2D impulse-response with replica <u>only</u>.

To find  $S_{ob}$  different methods can be used :

 $\begin{array}{l} & \underline{\text{naive method}} : S_{ob} = \mathcal{F}^{-1} \left( \frac{\mathcal{F}(S_{cb})}{\mathcal{F}(K)} \right) \\ & \underline{\text{wiener filter method}} : S_{ob} = \mathcal{F}^{-1} \left( G \frac{\mathcal{F}(S_{cb}))}{\mathcal{F}(K)} \right), G^{-1} = 1 + \frac{1}{|\mathcal{F}(K)|^2 SNR} \\ & \underline{\text{richardon-lucy method (iterative)}} : S_{ob}^{k+1} = S_{ob}^k \left( \frac{S_{cb}}{S_{ob}^k \star K} \star K \right) \\ & \underline{\text{optimization method}} : S_{ob} = \mathcal{F}^{-1}(X), \text{ with } X = argmin \left( \frac{1}{2} |\mathcal{F}(K)X - \mathcal{F}(S_{cb})| + \Gamma(X) \right) \\ & \underline{\text{min}} \end{array}$ 





## Replica removal solution #1: Deconvolution

• Prior deconvolution processing, we estimate the mean-square slope (MSS) by optimization because of its effect on PTR replica distribution.



## Replica removal solution #1: Deconvolution



Sentinel-6



Wiener deconvolution

#### Conclusion for this solution:

- Very powerful (noise robust) and not time consuming method
- Requires implementation effort and a perfect knowledge of the mean-square slope value for every point of the radargram a



# Replica removal solution #2 : Removing pulses (only for S6A)

\* By using one pulse every three pulses on Sentinel-6A we re-create a perfect inter-leaved chronogram

#### Original Sentinel-6 chronogram (with 2 missing pulses)



#### Modified Sentinel-6 chronogram (we use one pulse every three pulses)



#### Difference between modified Sentinel-6 radargram and original Sentinel-6 radargram







# Replica removal solution #2 : Removing pulses (only for S6A)



Conclusion for this solution:

We have guarantee that replica are completly absent

Aliasing on rough surfaces, due to PRF/3 that cannot contain all the doppler frequencies...



## Replica removal solution #3 : Doppler windowing

Due to opposite parabola effect, it is possible over specular data to apply a doppler windowing in order to remove the furthest replicas. Note that replica problem concerns mainly specular targets !



## Replica removal solution #3 : Doppler windowing

FFSAR 500hz with Doppler windowing





#### Conclusion for this solution:

FFSAR 500hz

No implementation effort, no aliasing, both works for Sentinel-6 and Sentinel-3 Remove a lot of signal on rough surfaces



### Recommendation for future mission :

#### Is there a possibility to play on the chronogram to put the replica level as low as possible ?



Let Tb be the duration of one burst, BRI the gap between two bursts and  $|FM| = \frac{2fcv^2}{ch}$  the doppler rate. Then :

- The n-th root of un-focused SAR PTR is at :  $\frac{n}{Tb*|FM|}$
- The n-th replica of fully-focused SAR PTR is at :  $\frac{n}{BRI*|FM|}$

The level of the first replica in dB is at :

 $10 \log \left( \left| \operatorname{sinc} \left( \frac{\operatorname{Tb}}{\operatorname{BRI}} \right) \right|^2 \right)$ 

\* Altitude and velocity has no impact on the replicas level in dB





Number of missing pulses and the number of pulses per burst are the only ones that can reduce the replicas level in dB





## Recommendation for future mission :

- The level of the replica can be reduced as much as possible (replicas should be ideally under -50dB from the main peak). The level of -50dB can be achieve with POS4 configuration by having 632 number of pulses per burst instead of 64...
- The best solution is a perfect interleaved chronogram. With few missing pulses (Sentinel-6 case) we can, by removing pulses, create a sub-sample interleaved chronogram. Note that UFSAR can still use the full PRF and is not impacted by this solution.



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Thanks for your attention !



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