A TRADE-OFF ANALYSIS OF FULLY FOCUSED SAR PROCESSING ALGORITHMS FOR HIGH PRF ALTIMETERS

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Abstract

The full focused processing in the frequency domain for high Pulse Repetition Frequency (PRF) radar altimeter science data is proposed. Considering a radar altimeter as a Synthetic Aperture Radar (SAR) instrument operating in near nadir-looking geometry, two SAR frequency-domain focusing algorithms, namely Range-Doppler and Omega-Key, are analyzed. Then a properly modified processor for radar altimeters is described and implemented. Simulation set-up using parameters from CryoSat and a preliminary result from in-orbit CryoSat data confirm the effectiveness of the full focused processing in the frequency domain. The proposed approaches, compared to the one formerly proposed in literature (that uses Back Projection), is less complex and more computationally efficient

Problem formulation

The high PRF (Pulse Repetition Frequency) altimeter instrument transmits pulses at high pulse repetition frequency guaranteeing coherence.

Coherent summation extended to the whole synthetic aperture is the new concept (**Full Focusing**), under the assumption that pulse coherence is maintained along the entire synthetic aperture.

Advantages:

- Along-track resolution up to its theoretical limit (half the along-track antenna length).
- Improvement of the ENL with respect to D/D

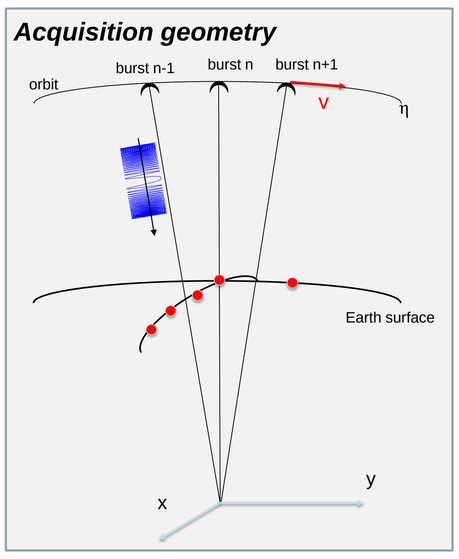
Drawback:

- Processing based on Back Projection is not computationally efficient

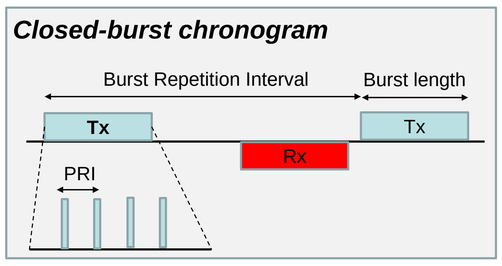
Due to similarity of the problem with Synthetic Aperture Radar in nadir acquisition, *we face the processing problem using the focusing algorithms already exploited in side-looking imaging SAR systems*.

***Purpose**: computational efficiency maintaining at the same time accuracy in results.*

Acquisition geometry



Closed-burst chronogram



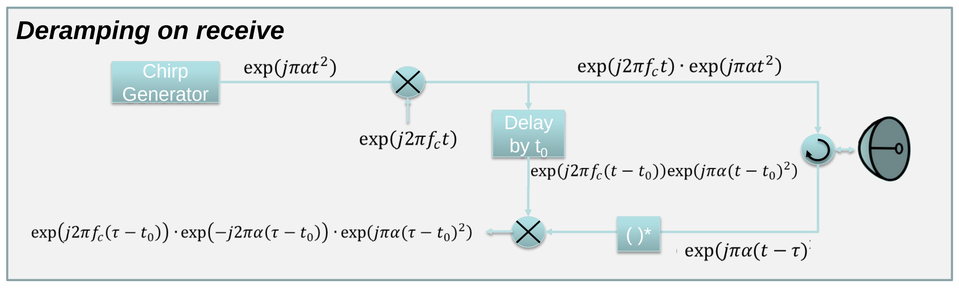
Unfocused IRF

$$h(\eta,t;R_{tkr}) \approx G(\vartheta,\beta)\cdot\exp\left\{j2\pi\left[f_c\tau' - (\alpha\tau' - f_D)t + \frac{\alpha}{2}\tau'^2\right]\right\}$$

$$\beta = \cos^{-1}\left(\frac{-\vec{R}_{yz}\cdot\vec{S}}{|\vec{R}_{yz}|\cdot|\vec{S}|}\right)$$

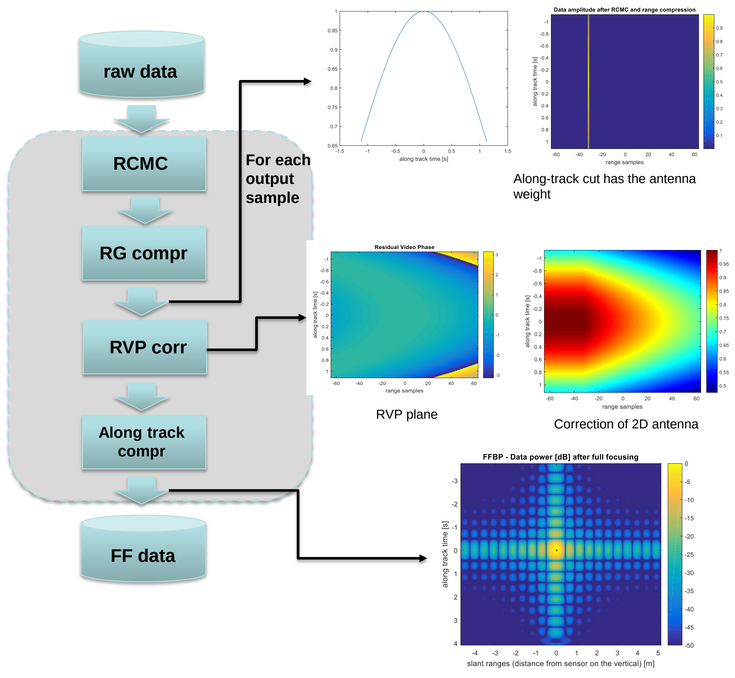
$$\vartheta = \cos^{-1}\left(\frac{-\vec{R}_{xz}\cdot\vec{S}}{|\vec{R}_{xz}|\cdot|\vec{S}|}\right)$$

Deramping on receive

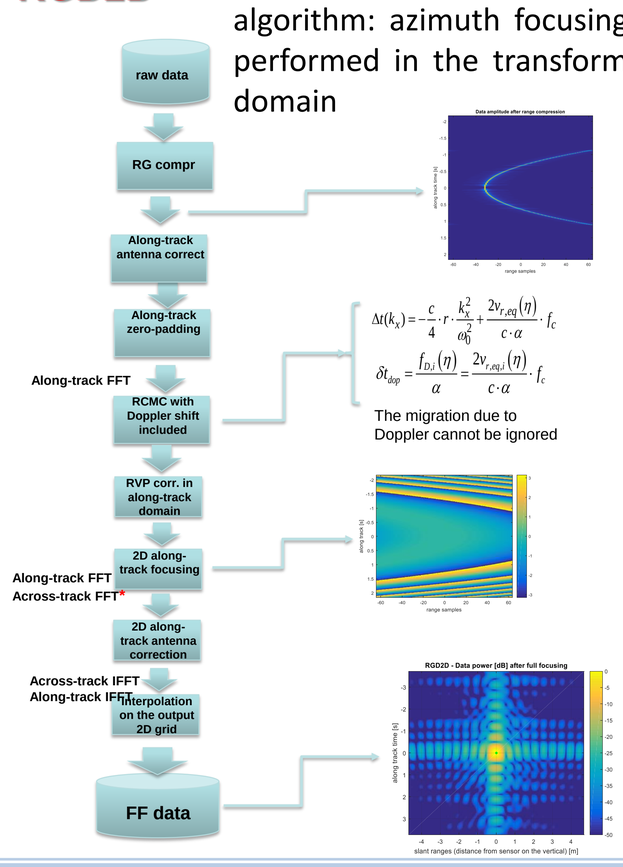


Algorithm comparison

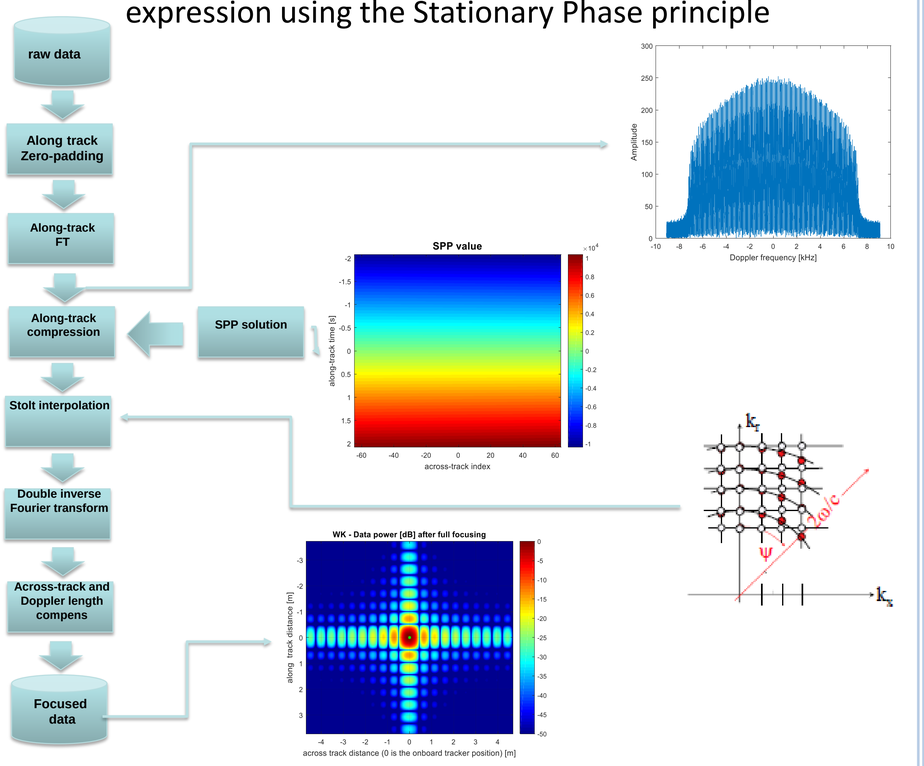
BP The Back Projection proposes to compensate every term of the unfocused IRF. It is applied for each output sample on ground surface.



RGD2D It is based on Range-Doppler algorithm: azimuth focusing is performed in the transformed domain



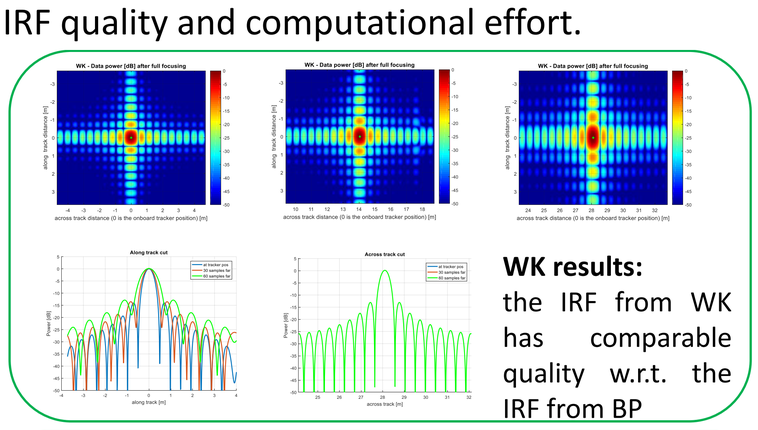
WK Omega-k (WK) algorithm is based on the idea that the exact transfer function can be written in a closed-form expression using the Stationary Phase principle



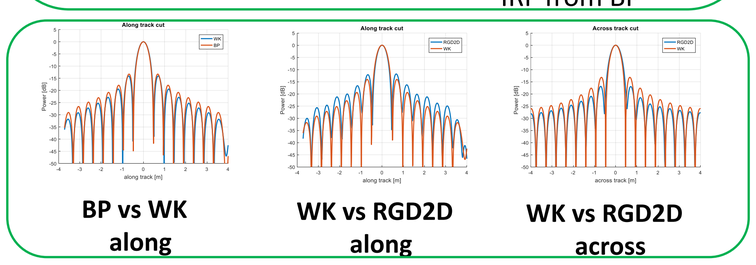
Simulation Results

Simulation results obtained using CryoSat parameters.

The WK algorithm is the best trade-off between IRF quality and computational effort.



WK results: the IRF from WK has comparable quality w.r.t. the IRF from BP



BP vs WK along | **WK vs RGD2D along** | **WK vs RGD2D across**

Comparison of the IRF quality parameters

Target (rg,az) [m, m]	Method	Along-track resolution	Across-track resolution	PSLR 2nd [dB] along/across	Misalingment along-track	Misalignment across-track
0, any	Theoret.	0.421m	0.415m	-13.26		
40, any	Theoret.	0.554m	0.415m			
0,0	WK	0.419m	0.410m	-14.05 -13.19	$<10^{-3}$m	$<10^{-3}$m
40,0	WK	0.559m	0.410m	-13.26 -13.12	$<10^{-3}$m	$<10^{-3}$m
0,1500	WK	0.419m	0.410m	-14.04 -13.19	$<10^{-3}$m	$<10^{-3}$m
0,0	BP	0.407m	0.410m	-13.27 -13.17	$<10^{-3}$m	$<10^{-3}$m
40,0	BP	0.536m	0.410m	-13.27 -13.18	$<10^{-3}$m	$<10^{-3}$m
0,1500	BP	0.407m	0.410m	-13.27 -13.17	$<10^{-3}$m	$<10^{-3}$m
0,0	RGD2D	0.419m	0.410m	-13.21 -16.94	$<10^{-3}$m	$<10^{-3}$m
40,0	RGD2D	0.512m	0.410m	-12.84 -16.57	$<10^{-3}$m	$<10^{-3}$m
0,1500	RGD2D	0.419m	0.410m	-11.37 -16.79	0.023m	$<10^{-3}$m

In Table below it can be noticed the reduction in computational effort given by focusing algorithms operating in frequency domain.

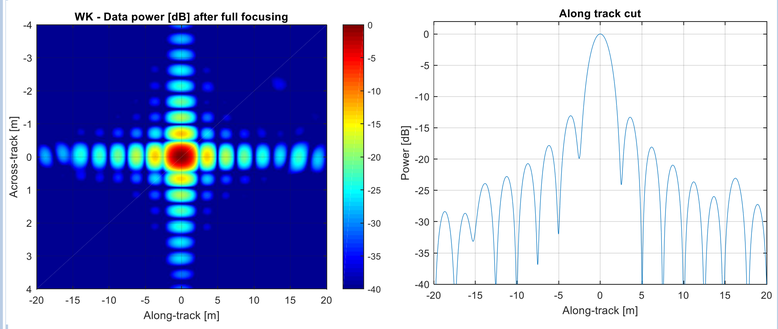
Evaluation of the computational effort

Method	Cost per sample [cplx mult]	Processing time [s]	Approximate value using Cryosat-2 parameters
BP	134564	8978	123200
WK	114	16.8	135
RGD2D	200	15.1	189

CryoSat acquisition

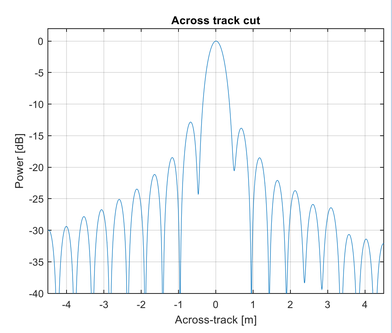
A demonstration of the WK algorithm is given by processing an in-orbit CryoSat acquisition in SAR mode over the Svalbard transponder, starting from a CryoSat FBR product.

The processed bandwidth was limited to 20% of the total Doppler bandwidth.



The transponder is correctly focused.

The along-track resolution equal to 2.24m, due to the Doppler bandwidth filtering.



References

- Scagliola, Guccione, Giudici, “FULLY FOCUSED SAR PROCESSING FOR RADAR ALTIMETER: A FREQUENCY DOMAIN APPROACH”, in proceedings of IGARSS 2018
- Guccione, Scagliola, Giudici, “2D Frequency Domain Full Focused SAR processing for High PRF Radar Altimeters”, submitted to MDPI Remote Sensing