



# An Investigation of the Impact of Vertical Water Particle Motions on Fully-Focused SAR Altimetry

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- . Motivation
- . Methodology
- · Results
- · Conclusion





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#### This study is based on PhD Buchhaupt 2019

#### Model Improvement for SAR Altimetry

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# Motivation





Differences between LRM and SAR altimetry with respect to the illuminated area.

Compared to LRM in SAR processing Doppler beams are formed.

### Usual wording:

"Doppler beams are steered to dedicated along-track locations."

### Better wording:

"Doppler beams are steered to dedicated relative velocities, which can - under a frozen sea assumption - be related to alongtrack coordinates."

Question adressed in PhD Buchhaupt 2019: "Is the frozen sea assumption applicable for SAR processing?"

#### Answer:

"No, it leads to sea state dependent SWH biases."



# Motivation



## Scattering surface elements are in motion!



Wave particle motion of ocean waves in deep water and during approaching the coast. Source : WAVES (https://www.thegeographeronline.net/uploads/2/6/6/2/26629356/1398548\_orig.jpg) by Steven Heath, licenced under CC BY-NC-SA 4.0.





- Current state of the art: Sea surface is frozen
  - Correct for Conventional Altimetry as illumination time is short

$$P_C(\tau) = FSSR(\tau) * PTR(\tau) * PDF(\tau)$$

- This work: Sea surface has a dynamic vertical component
  - In waveform model:  $\eta \rightarrow \eta + \eta_t t_s + \frac{1}{2}\eta_{tt} t_s^2$
  - PDF in SAR stack model becomes a two dimensional function

 $P_D(\tau, x_D) = FSSR(\tau, x_D) ** PTR(\tau, x_D) ** PDF(\tau, x_D)$ 

- New parameters:
  - 1. Standard deviation of vertical wave velocity  $\sigma_w$
  - 2. Standard deviation of vertical wave acceleration  $\sigma_a$  (not estimated)
- This is integrated in the SAR stack retracker called SINCS-OV



# Methodology

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The figure below shows the impact of small vertical velocities with 10 cm/s standard deviation on the along-track PTR with different number of processed bursts.

The blue curve coresponds to unfocused SAR, the red PTR to LRMC-F and the orange one to fully focused SAR.



Left: Along track response of a point target for a frozen sea. Right: Response for a non frozen sea with small vertical velocities.



## **Region of Interest and Datasets**





The region of interest is the NEA CryoSat-2 SAR box as it contains a high variety of SWH values up to ten metres. The whole year 2013 is considered. Used datasets: 1. TUDaBo RDSAR SINC2 SINC2 ZSK 2. TUDaBo SAR SINCS SINCS-OV ZSK

3. TUDaBo LRMC-F SINCS-OV ZSK

LRMC-F is focused LRMC with an integration time of 0.05 seconds.

ZSK means that the distribution of each sample is transformed from exponential to zero skewed Weibull being close to a normal distribution.

Parameter	Exponential	ZSK
SNR	1	3.24
Skewness	2	0
Kurtosis	9	2.7

Stochastical parameters with and without ZSK transformation.

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### State-of-the-Art SAR and RDSAR processing.



2D histogramm of 1 Hz SWH differences between SINC2 RDSAR and SINCS SAR.



### Results

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#### Zero skewness SAR and RDSAR processing as in PhD Buchhaupt 2019.



2D histogramm of 1 Hz SWH differences between SINC2 ZSK RDSAR and SINCS-OV ZSK SAR.



### Results

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### Zero skewness LRMC-F and RDSAR processing.



2D histogramm of 1 Hz SWH differences between SINC2 ZSK RDSAR and SINCS-OV ZSK LRMC-F.





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The  $\sigma_{\!\scriptscriptstyle v}$  retracking ouput can be compared with ECMWF model

parameters with the relation  $\sigma_v = \frac{\pi}{2} \frac{H_s}{T_{02}}$ 

With  $H_s$  the significant wave height and  $T_{02}$  the mean zero up-crossing period.





## Results

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the mean wave steepness with  $\mu_m \approx 0.1586 \frac{{\sigma_v}^2}{H_s}$ 



Histogramm of 1 Hz values for SAR, LRMC-F and ECMWF Left: Standard deviation of vertical velocities  $\sigma_v$  Right: Wave steepness  $\mu_m$ 

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- With LRMC-F the SWH consistency with respect to RDSAR improves.
- The estimates standard deviations of vertical wave particle velocities have a good consistency with ECMWF.
- The estimated wave steepnesses have a reasonable range.
- However, it is still necessary to thoroughly validate all geophysical parameters with in-situ data.
- An additional examination of fully focused SAR shall be considered in future works.