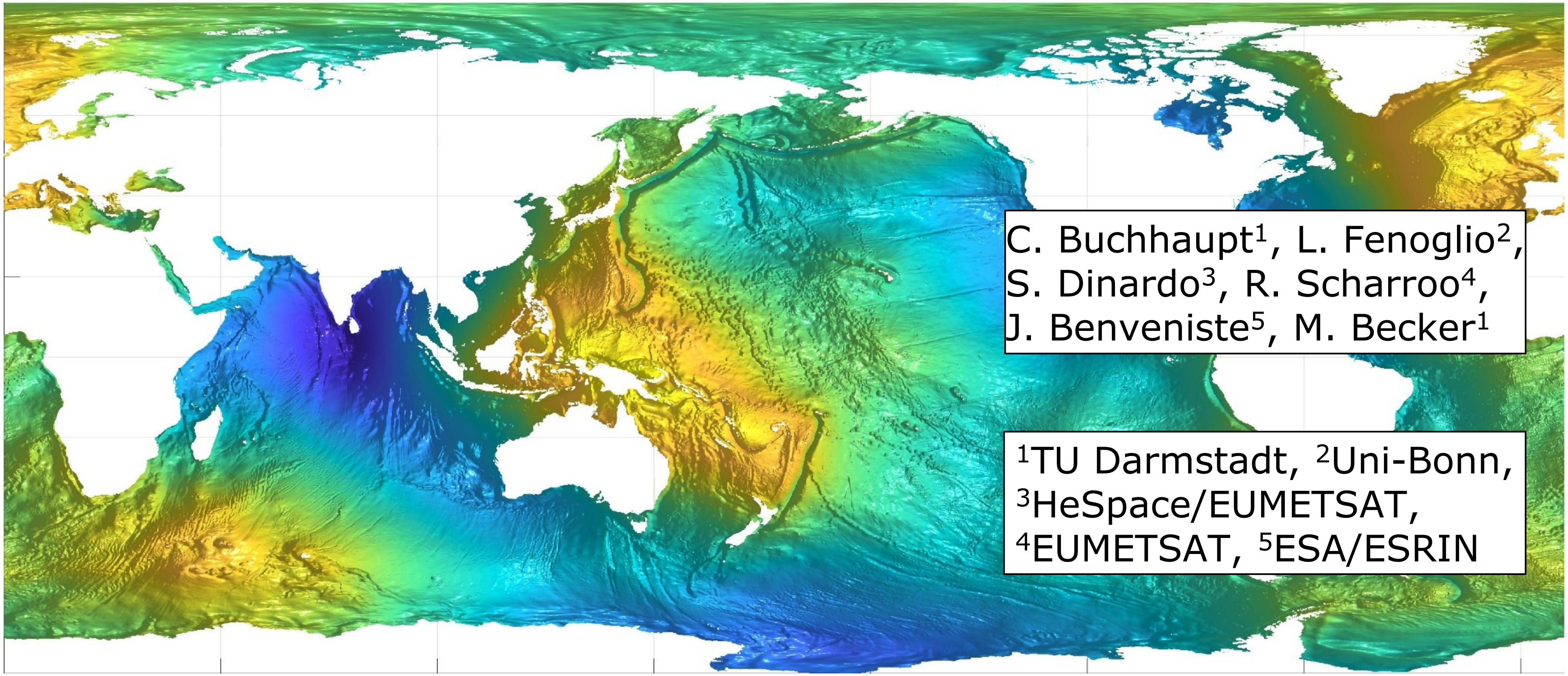
Impact of Geoid Curvatures and Slopes on LRMC, RDSAR and SAR Mode Waveforms



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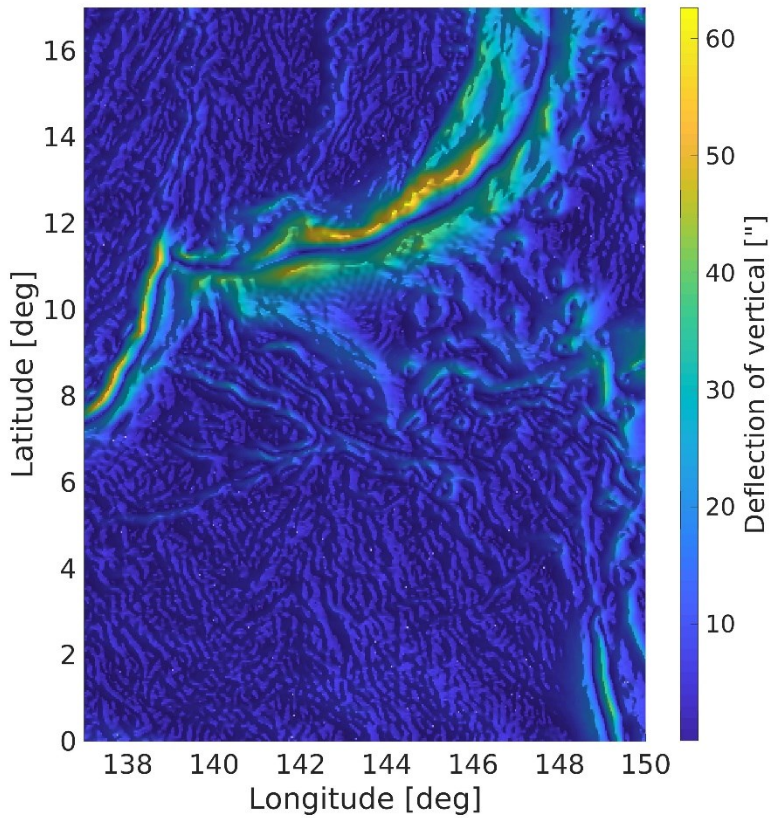
Motivation

Geoid Slopes



Deflection of vertical in the Mariana Trench

Approximating the earth by a sphere is a widely used method in radar altimetry

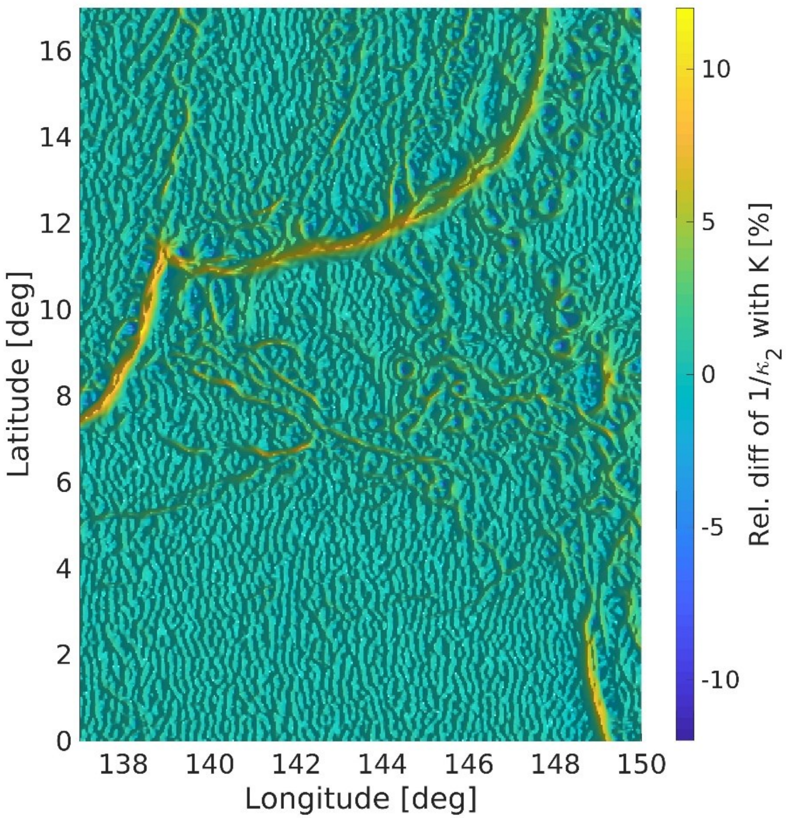
Sandwell and Smith (2014*) stated that slopes have a significant effect on the retracked sea surface heights of conventional altimetry signals

How big is the impact on unfocused SAR or the upcoming LRMC mode?

** Sandwell, DT, Smith WHF. 2014: "Slope correction for ocean radar altimetry", Journal of Geodesy. Volume 88, p. 765-771.*

Motivation

Geoid Curvatures



Relative difference between principal radius of curvature and square root of Gaussian curvature of the reference ellipsoid in the Marianna Trench

Another measure are changes in the local radii of curvatures

Curvatures quantify how much the surface bends

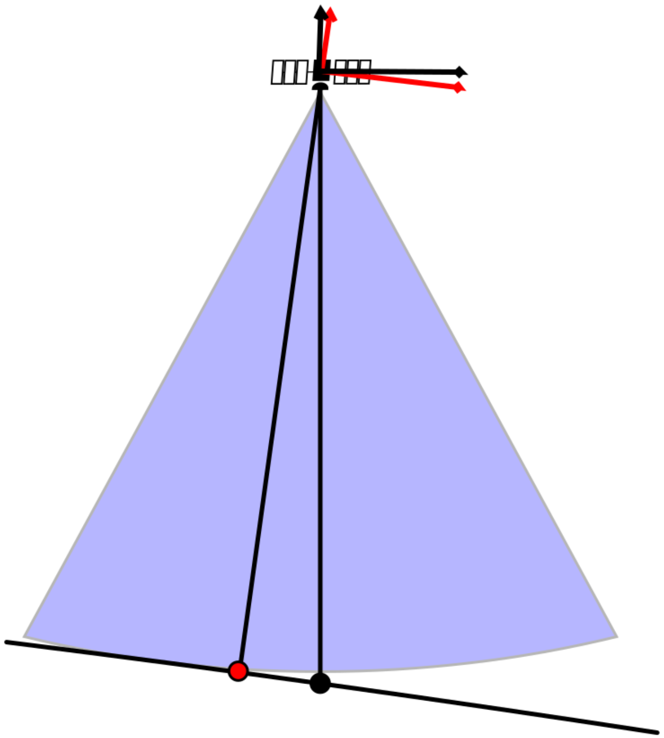
Curvatures are directional with maxima and minima κ_1 and κ_2 called principal curvatures

Directions of κ_1 and κ_2 form a rectangular coordinate system

Radii's are computed by $R_i = 1/\kappa_i$

How big is the influence of κ on unfocused SAR or LRMC mode?

Geometry of Conventional Altimetry



Geometry of CA: Black arrows show vertical and horizontally velocity components with respect to the reference ellipsoid and the black dot the nadir. The red vectors and circle belong to the local torus coordinate system.

L1B-Processing:

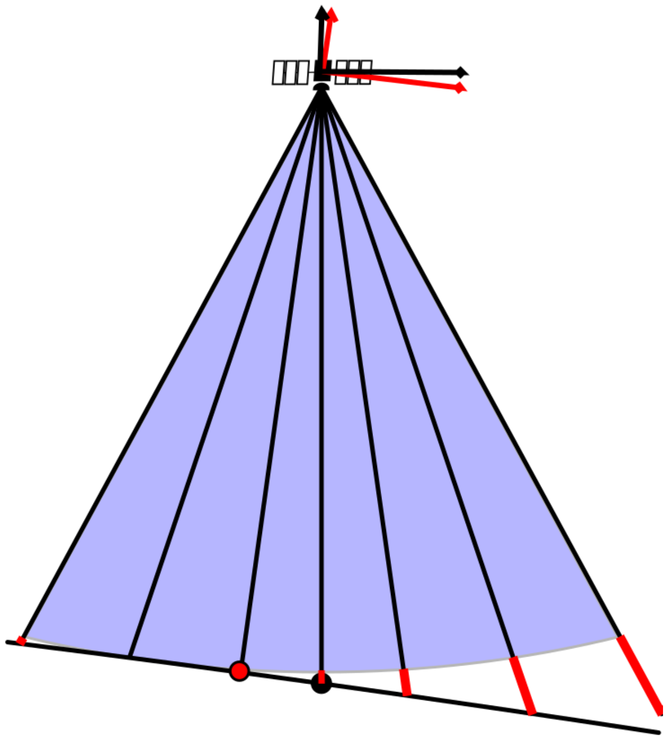
- No knowledge on the local surface curvature necessary
- Processing focused on nadir location
- Velocity vectors (vertical and horizontal) changes
- This slightly impacts the inner burst's horizontal alignment

L2-Processing:

- Local surface approximation should be included in the retracking model

Motivation

Geometry of LRMC



Geometry of LRMC: Black arrows show vertical and horizontally velocity components with respect to the reference ellipsoid and the black dot the nadir. The red vectors and circle belong to the local torus coordinate system.

L1B-Processing:

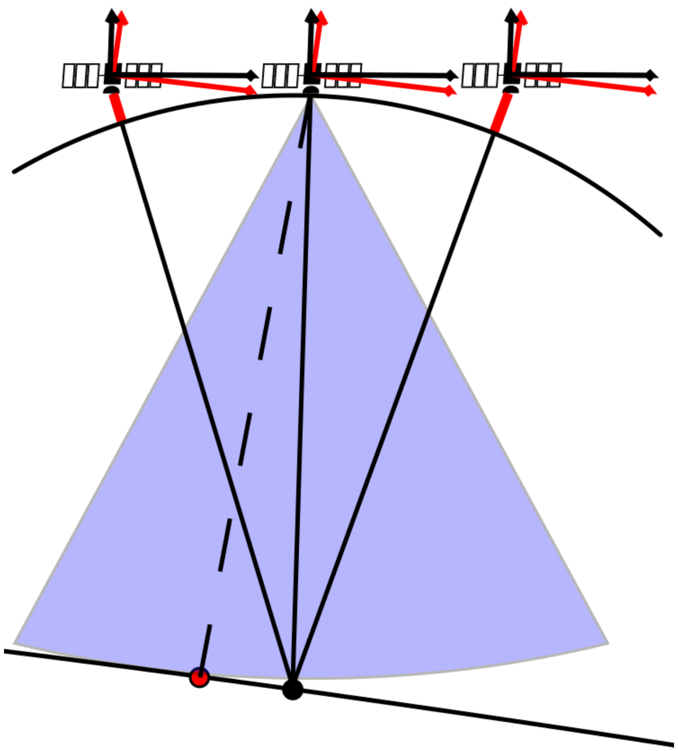
- Beams come from one burst
- Knowledge on the local surface crucial to calculate slant range correction properly
- Vertical velocity changes
- Significant impact on the Doppler centroid location within the stack

L2-Processing:

- Local surface approximation and its impact on the L1B-Processing need to be included in the retracking model

Motivation

Geometry of Unfocused SAR



Geometry of SAR: Black arrows show vertical and horizontally velocity components with respect to the reference ellipsoid and the black dot the nadir. The red vectors and circle belong to the local torus coordinate system.

L1B-Processing:

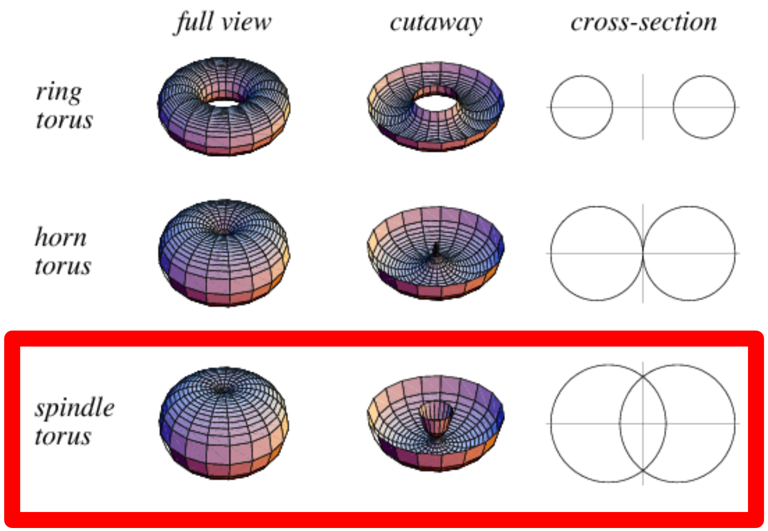
- Beams come from different bursts
- As each beam is focused to one dedicated surface location knowledge of neighbored area not necessary
- Change in vertical velocity shifts the Doppler centroid which needs to be accounted for

L2-Processing:

- Local surface approximation and its impact on the L1B-Processing need to be included in the retracking model

Methodology

Local Surface Representation



Different kind of tori.
Source: http://mathworld.wolfram.com/Torus.html

With elementary differential geometry* each neighborhood around a point on a curved surface is approximable by a best fitting torus

For the geoid a spindle torus is the best manifold parametrized as

$$\vec{X}(h,p,q) = \begin{bmatrix} (R_2 - R_1 + (R_1 + h)\cos p)\cos q \\ (R_2 - R_1 + (R_1 + h)\cos p)\sin q \\ (R_1 + h)\sin p \end{bmatrix}$$

With R_1 and R_2 the principal radii of curvature

In this study an own torus coordinate system with origin at nadir $\vec{X}(\vec{0})$ and burst location $\vec{X}(h_s, p_s, q_s)$ is assigned to each 20 Hz surface location

**Visit: http://web.mit.edu/hyperbook/Patrikalakis-Maekawa-Cho/mathe.html for a nice introduction*

Methodology

Local Surface Parameter

- h_s: Height in torus coordinates
- x_s: Along track coordinate of satellite
- y_s: Across track coordinate of satellite
- Standard: $x_s = y_s = 0$

- v_h: Vertical rate in torus coordinates
- v_x: Nadir velocity in along track direction
- v_y: Nadir velocity in across track direction

- $\alpha_x = 1 + h_s[\kappa_1 \cos^2 \Omega + \kappa_2 \sin^2 \Omega]$: Along track curvature coefficient
- $\alpha_y = 1 + h_s[\kappa_2 \cos^2 \Omega + \kappa_1 \sin^2 \Omega]$: Across track curvature coefficient
- $\alpha_{xy} = h_s \sin\Omega \cos\Omega\, (\kappa_1 - \kappa_2)$: Mixed curvature coefficient, Ω being the angle between the torus coordinate system and the horizontal platform velocity
- Standard: $\alpha_x = \alpha_y = \alpha = 1 + h/R_e$: R_e the local earth radius and $\alpha_{xy} = 0$

Methodology – RDSAR

Changes in the L1B/L2-Processing

❖L1B-Processing

- Velocities in torus coordinates are used

❖L2-Processing

- SINC2*- retracker was updated to include torus coordinates of scattering elements

- RDSAR is a good reference as its L1B processing does not change significantly

* Buchhaupt et, al. 2018: “A Fast Convolution Based Waveform Modell for Conventional and Unfocused SAR Altimetry”, Advances in Space Research, Volume 62, Issue 6, p. 1445-1463

Changes in the L1B/L2-Processing

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❖L1B-Processing

- Velocities in torus coordinates are used if calculated
- Range Cell Migration correction changes to

$$\Delta r_{sl} = \sqrt{h_s^2 + \alpha_x x_D^2} - h_s$$

With x_D the along track coordinate of the Doppler beams

❖L2-Processing

- SINCS*-Retracker was updated to include torus coordinates of scattering elements

* Buchhaupt et, al. 2018: "A Fast Convolution Based Waveform Modell for Conventional and Unfocused SAR Altimetry", Advances in Space Research, Volume 62, Issue 6, p. 1445-1463

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Changes in the L1B/L2-Processing

❖L1B-Processing

- Velocities in torus coordinates are used
- Additional range-shift necessary to compensate that the Doppler centroid is not necessarily the nadir location

$$\Delta r_{sl} \mathrel{+}= \frac{\alpha_x x_s^2}{2h_s}$$

❖L2-Processing

- SINCS*-Retracker was updated to include torus coordinates of scattering elements

* Buchhaupt et, al. 2018: “A Fast Convolution Based Waveform Modell for Conventional and Unfocused SAR Altimetry”, Advances in Space Research, Volume 62, Issue 6, p. 1445-1463

Products Compared

- In total 3 Products for each processing mode (RDSAR, LRMC and SAR) were processed

❖ Sphere (state of the art)

- Local surface is approximated by a sphere
- $x_s = y_s = 0$
- $\alpha_x = \alpha_y = 1 + h/R_e$

❖ Slopes

- x_s and y_s computed by using EIGEN-6C4 Spherical Harmonics
- $\alpha_x = \alpha_y = 1 + h/R_e$

❖ Geoid

- All parameters are computed by using EIGEN-6C4 coefficients up to degree and order 2190

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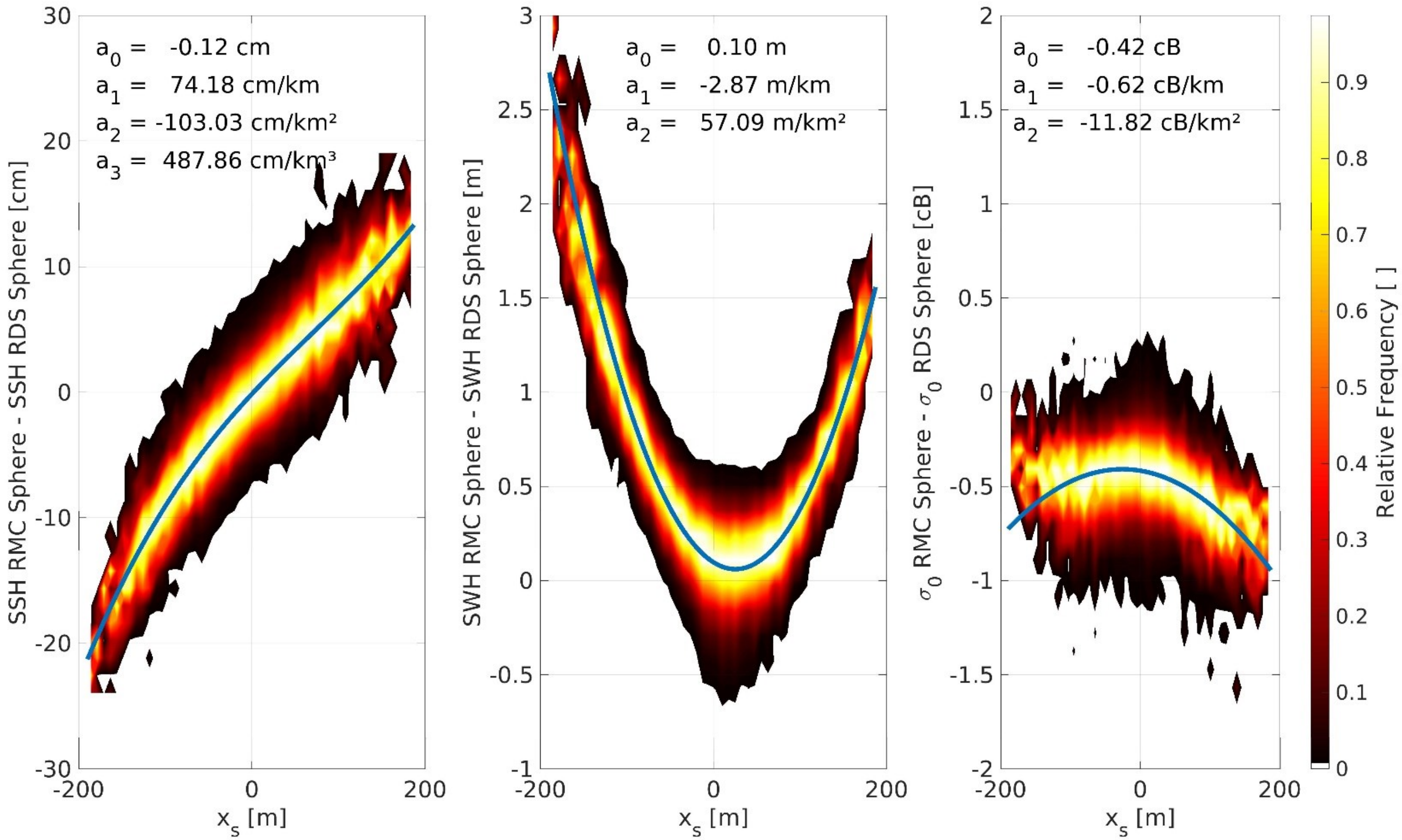
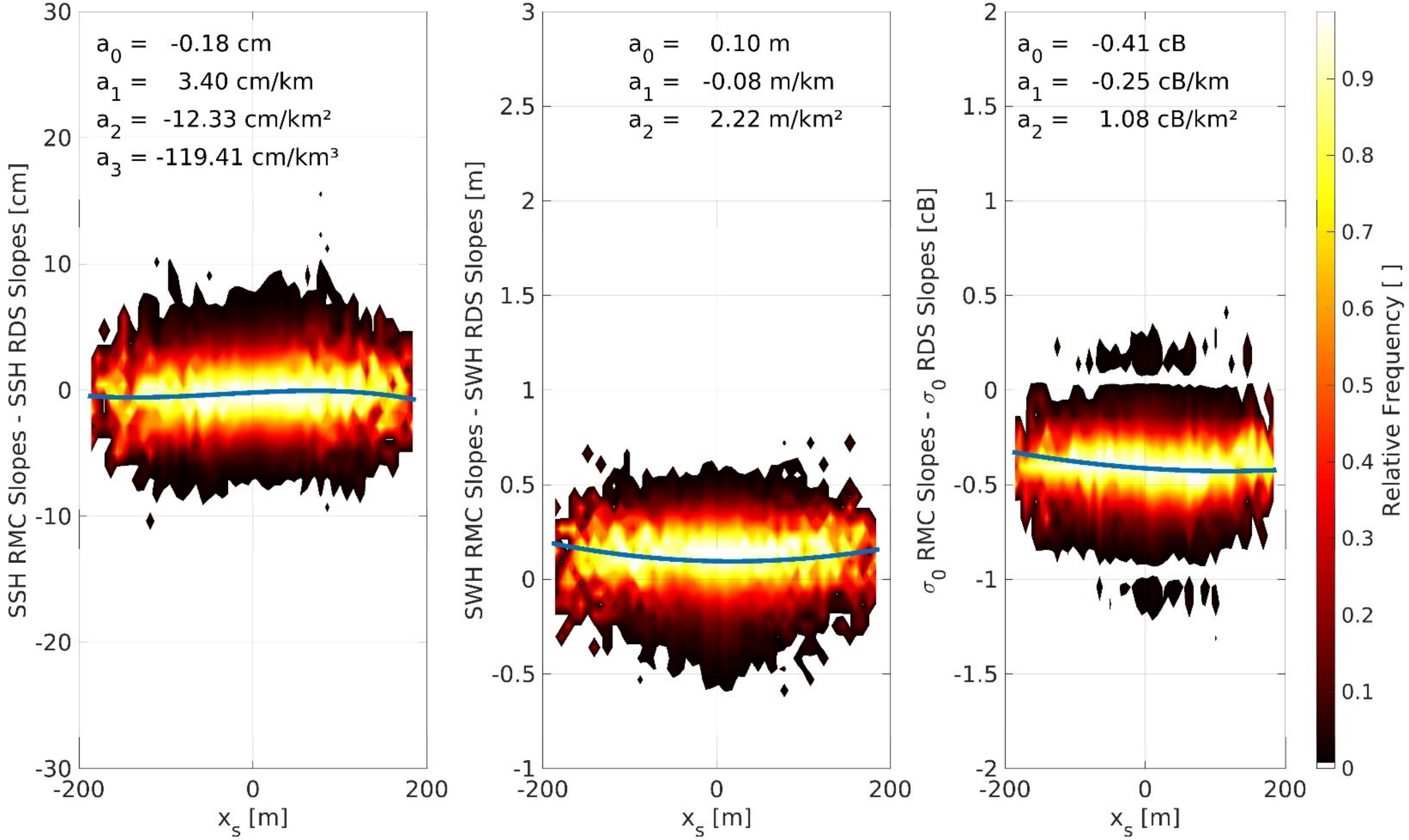
Results - LRMC

Standard Processing



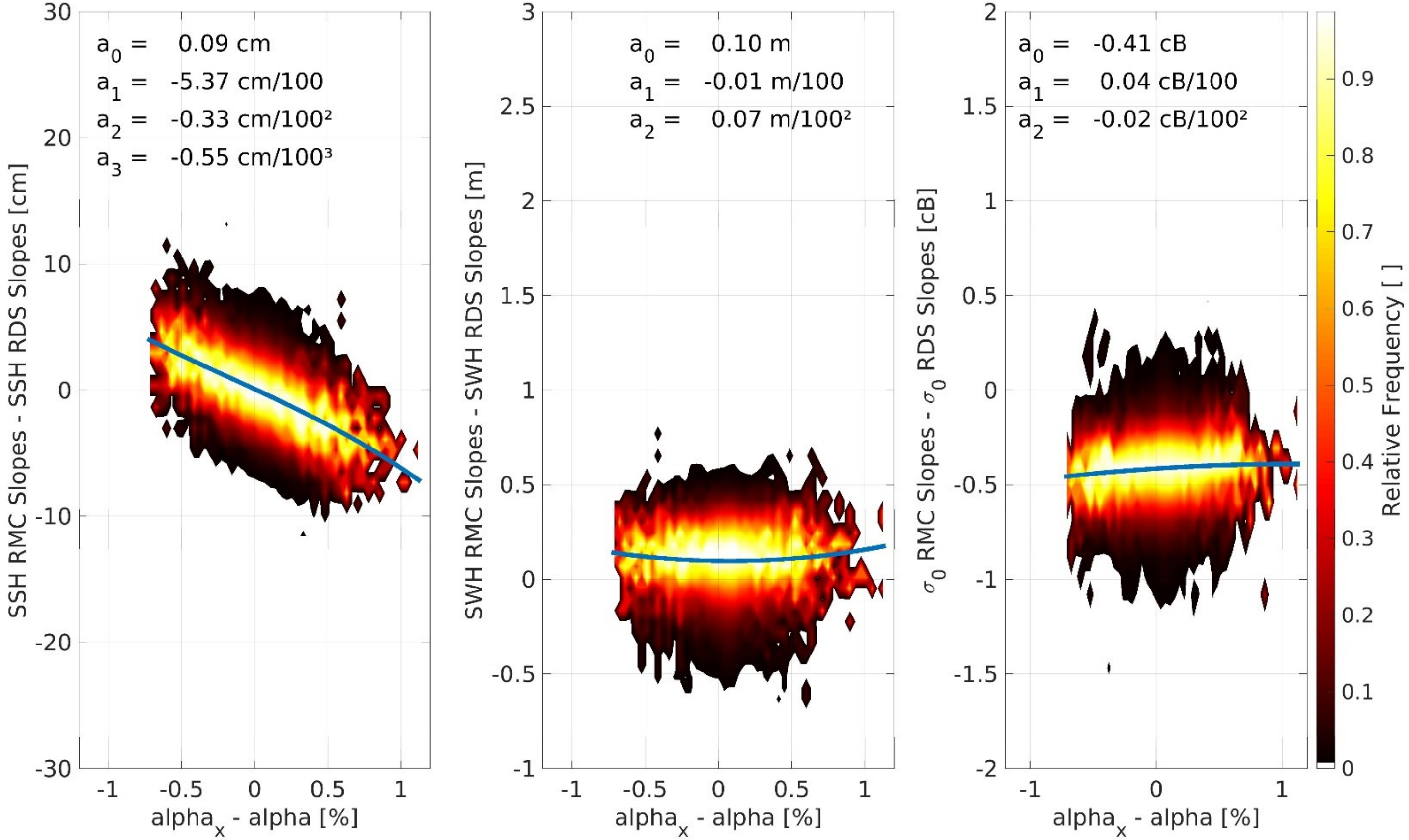
Results - LRMC

Implementation of Geoid Slopes - I



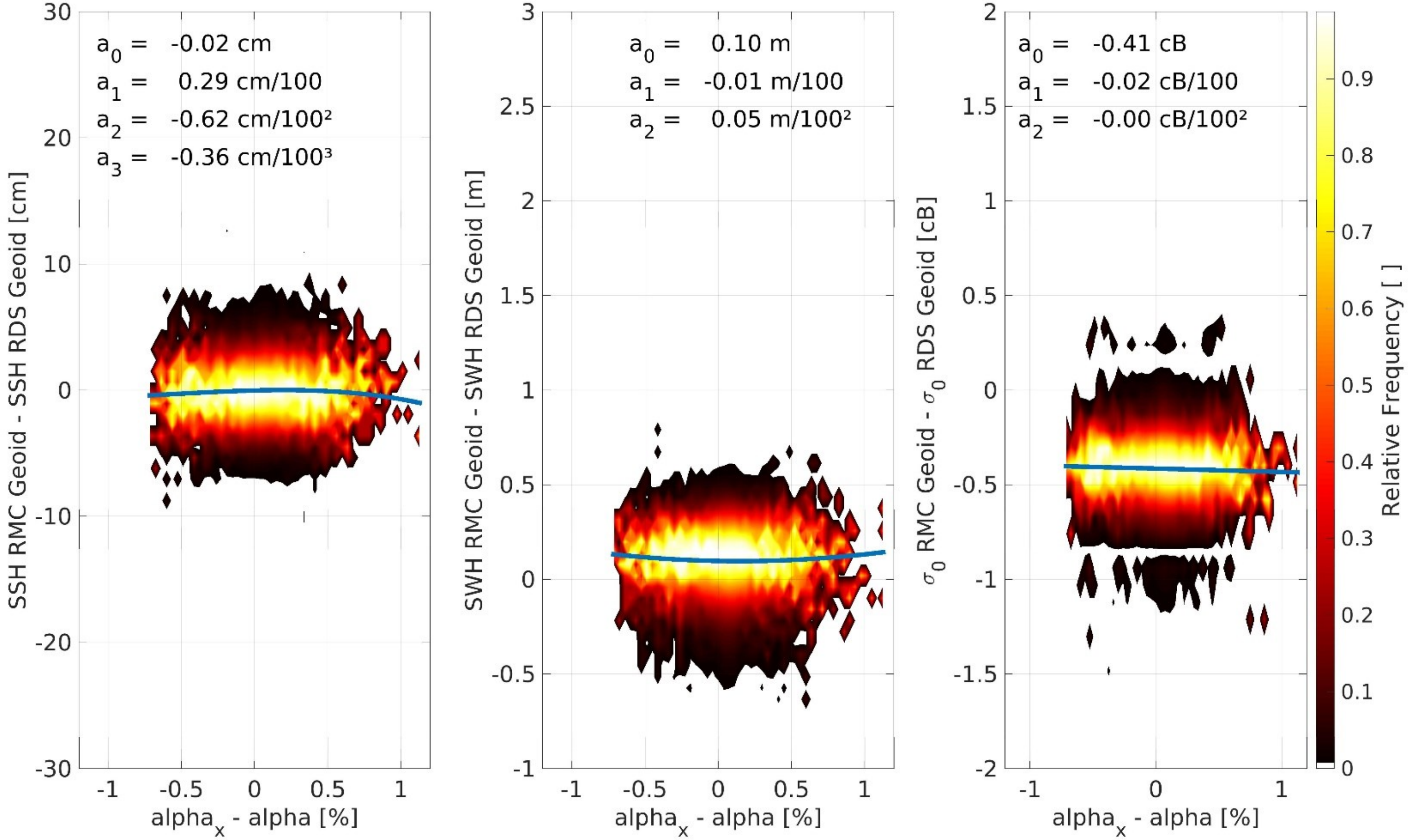
Results - LRMC

Implementation of Geoid Slopes - II



Results - LRMC

Implementation of Full Geoid



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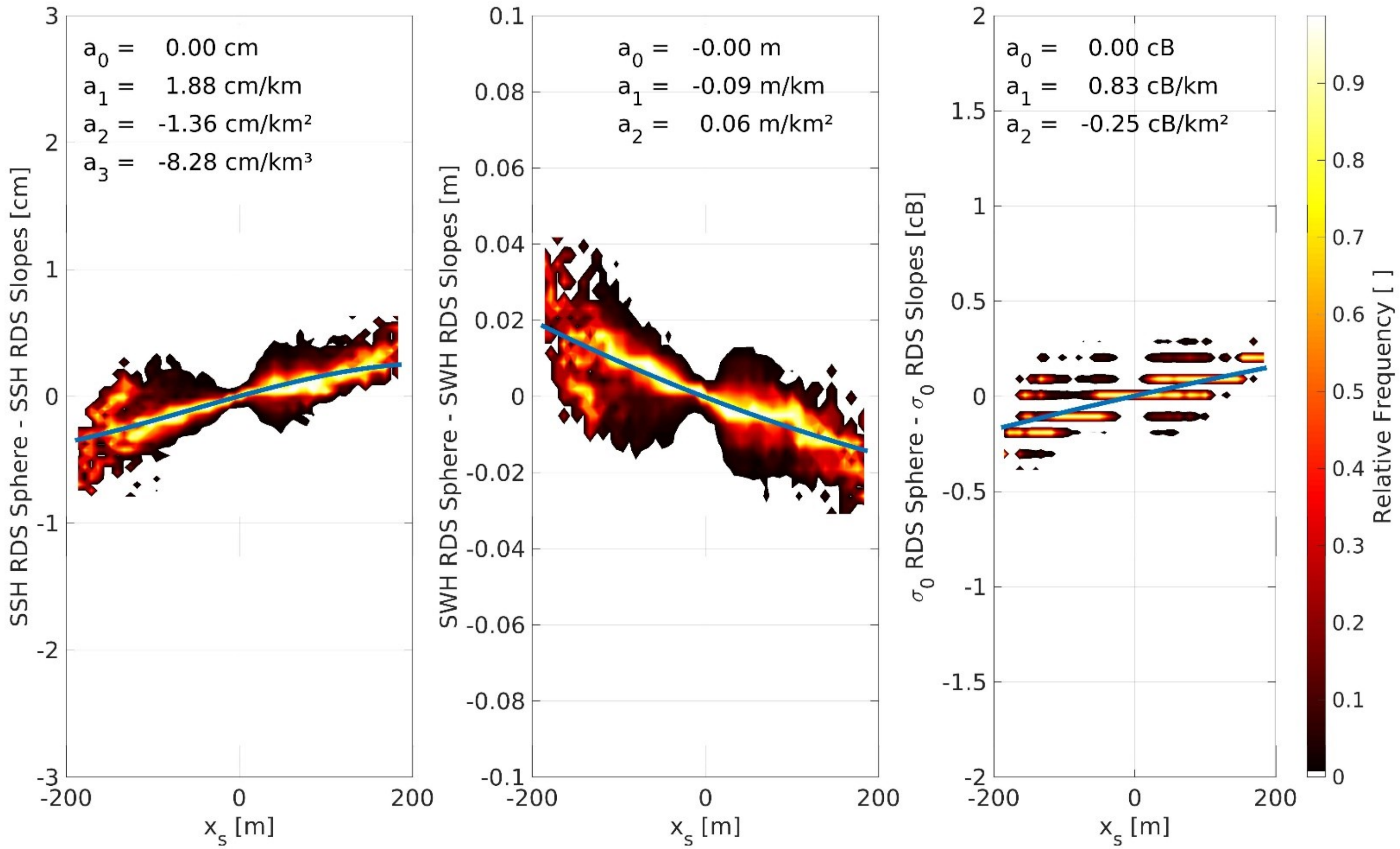
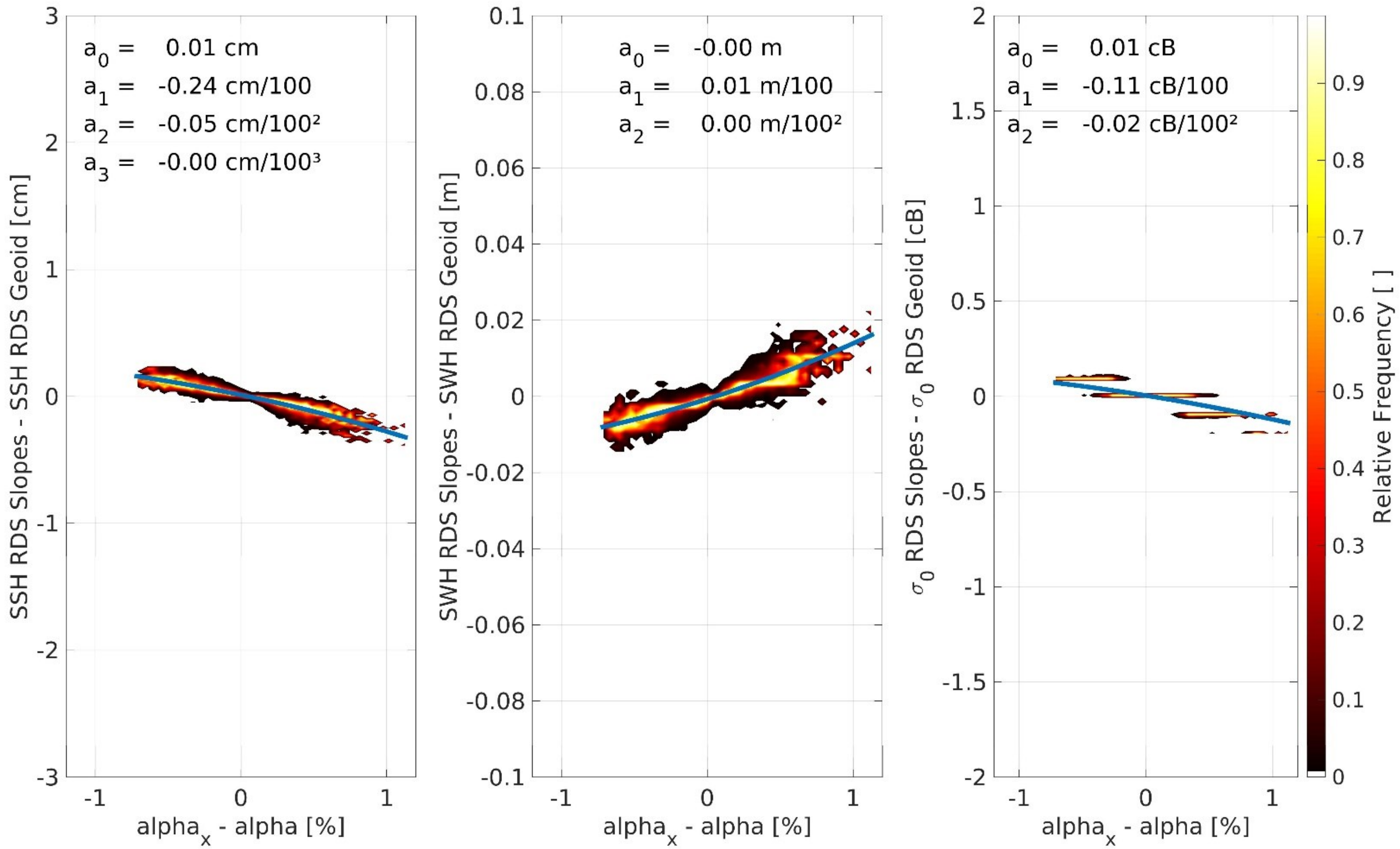
Results - RDSAR

Standard Processing vs Geoid Slopes



Results - RDSAR

Geoid Slopes vs Full Geoid



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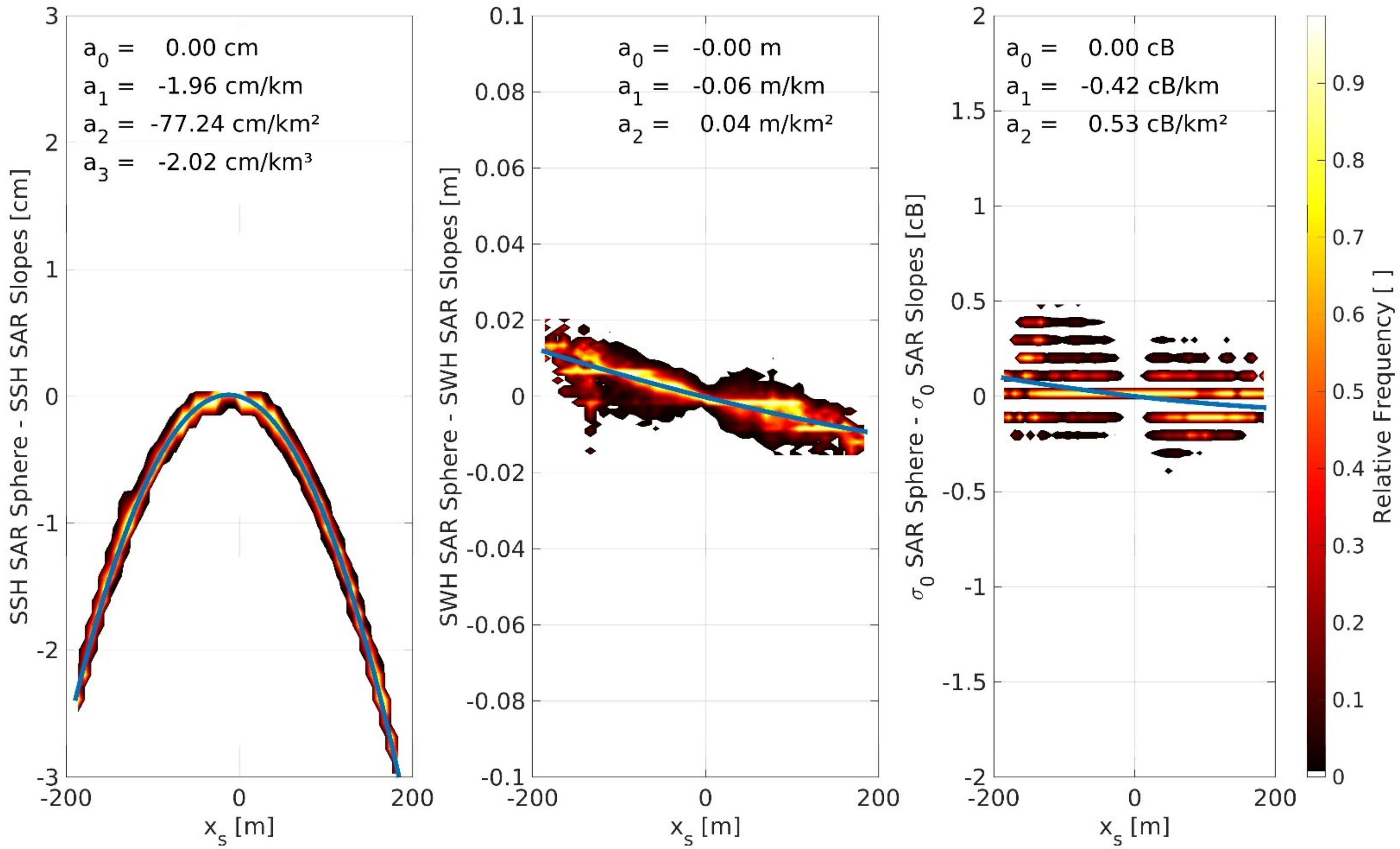
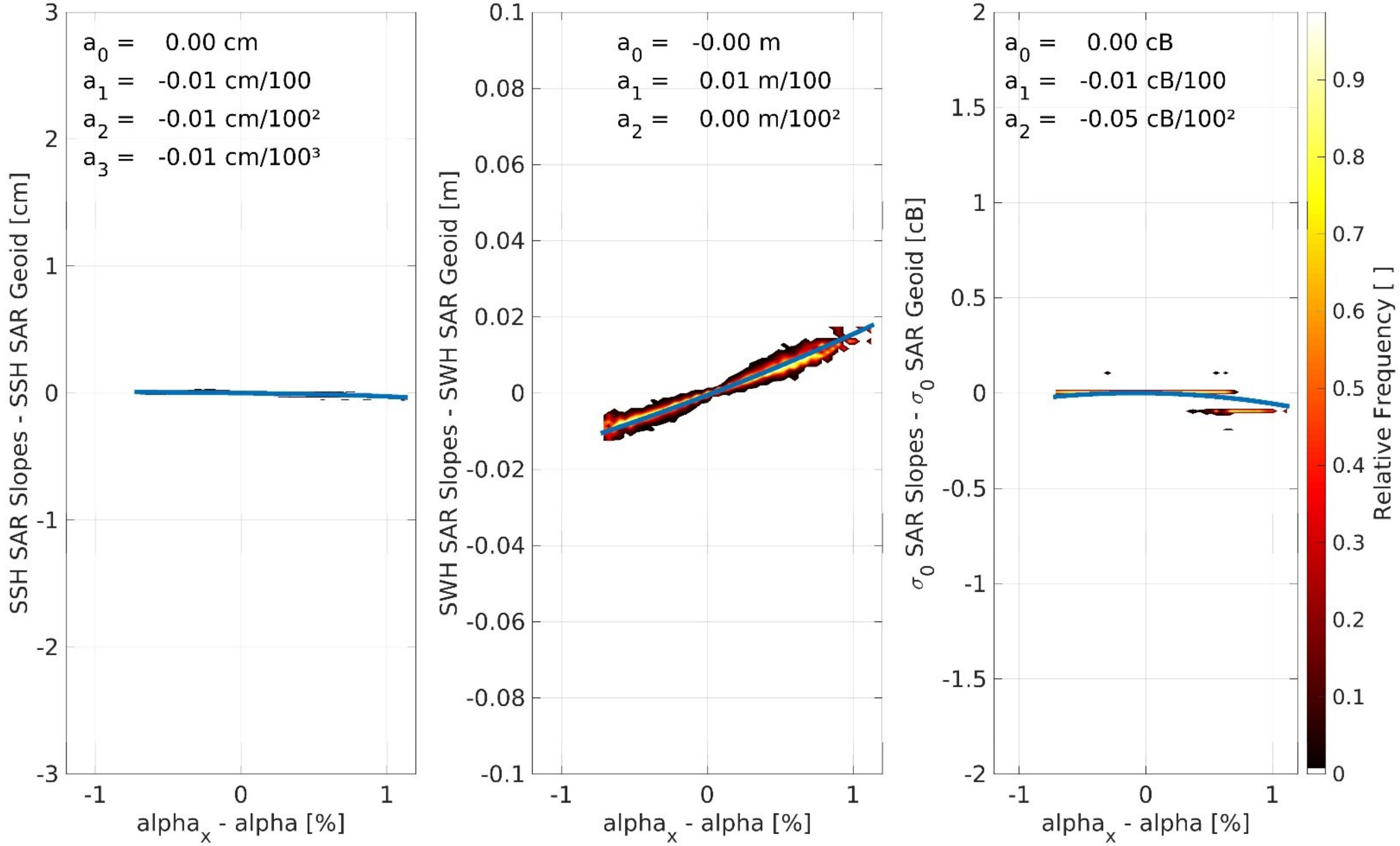
Results - SAR

Standard Processing vs Geoid Slopes



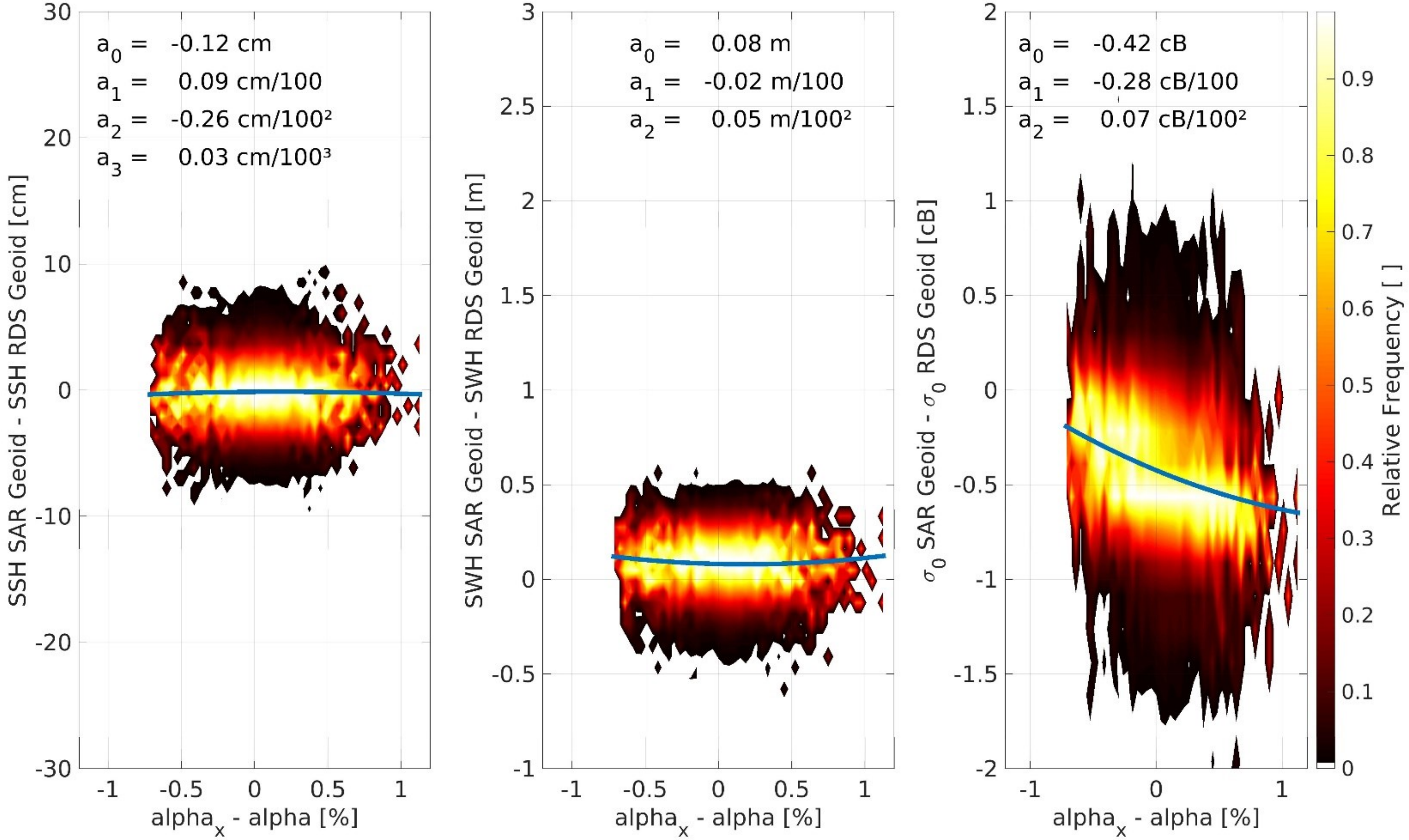
Results - SAR

Geoid Slopes vs Full Geoid



Results - SAR

Implementation of Full Geoid



Conclusion

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- LRMC is highly affected by both geoid slopes and curvatures
  - Ignoring slopes results in huge sea level and SWH offsets
  - Omitting the curvatures results in sea level errors of $-10\ to\ 10\ cm$
  - SWH is not affected significantly by geoid curvatures
  - Implementing these quantities in LRMC processing of Jason-CS is highly recommended

- SAR is impacted by geoid slopes
  - Omitting slopes results mainly in a sea level error of $\frac{\alpha_x x_s^2}{2h}$ where SWH is just slightly affected
  - No significant effects of Geoid curvature

- RDSAR is affected by both slope and curvature but slope impact is about 10 times bigger than those from curvatures

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