2D SAR Altimetry Retracking – Lessons Learned

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Actually to Be More Precise:

Addressing LR-HR Inconsistencies on SAR Altimetry SSH and SWH Measurements

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Introduction

- LR signals sampled w.r.t. range (epoch) and pulse-to-pulse-time (slow-time)
  - Incoherent processing with integration time of pulse width
  - Signal stable w.r.t slow-time
  - Retracking only focuses on fitting power within range samples

- HR signals sampled w.r.t. range (epoch) and relative velocity between scatterer and platform (azimuth)
  - Coherent processing with integration time of burst length
  - State-of-the-art focuses on fitting power in range samples
  - Sensitive to velocities occurring on the sea surface -> inconsistencies

Introduction: Random Effects

- Vertical wave particle velocities (VWPV)

- Causes azimuth blurring effect proportional to:
  - Burst duration τ_B
  - Twice the reciprocal carrier wavelength $^2/_{\lambda_c}$
  - Attenuation factor due to slope correlations $a_v = \sqrt{\frac{Var[\eta_t|\vec{\nabla}\eta]}{Var[\eta_t]}}$

- Very small dependency on incidence angle
- Dominates horizontal velocity component
  - $\sqrt{\sigma_v^2 \cos \Theta_i^2 + \sigma_h^2 \sin \Theta_i^2} \approx \sigma_v^2$

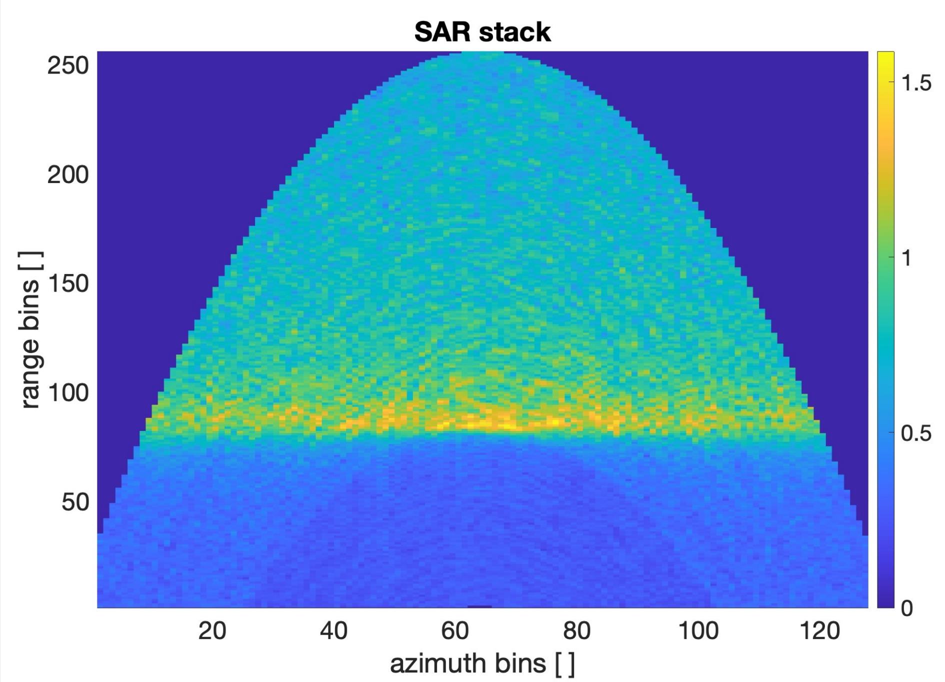
Introduction: Non-Random Effects

- Mean vertical wave particle velocities at given incidence
  - $E\left[\eta_t \middle| \vec{\nabla}\eta\right] \propto \sin\Theta_i$

- Horizontal velocities
  - Caused by currents, wind induced movement and swell
  - Leads to Doppler-shift $\Delta f_D = \frac{2}{\lambda_c} u_x \sin\Theta_{i,x}$
  - Acts like a Doppler frequency scaling $f_D \mapsto \left(1 + \frac{u_x}{v_x}\right) f_D$
    - u_x combines all horizontal and the mean vertical components
    - v_x describes the along-track velocity of the nadir

Introduction: 2D SAR Retracking

- Idea: Use of Doppler information given in stack
- Estimated parameters
  - Wind speed
  - SSH
  - SWH = $4\sigma_z$
  - VWPV variation σ_v
  - Along-track surface velocity u_x
- Aim: Minimization of LR-HR inconsistencies



Note: Stack retracking requires handing of exponential distributed sample noise.
Here we transform it towards a symmetric Weibull distributed. This is further called ZSK.

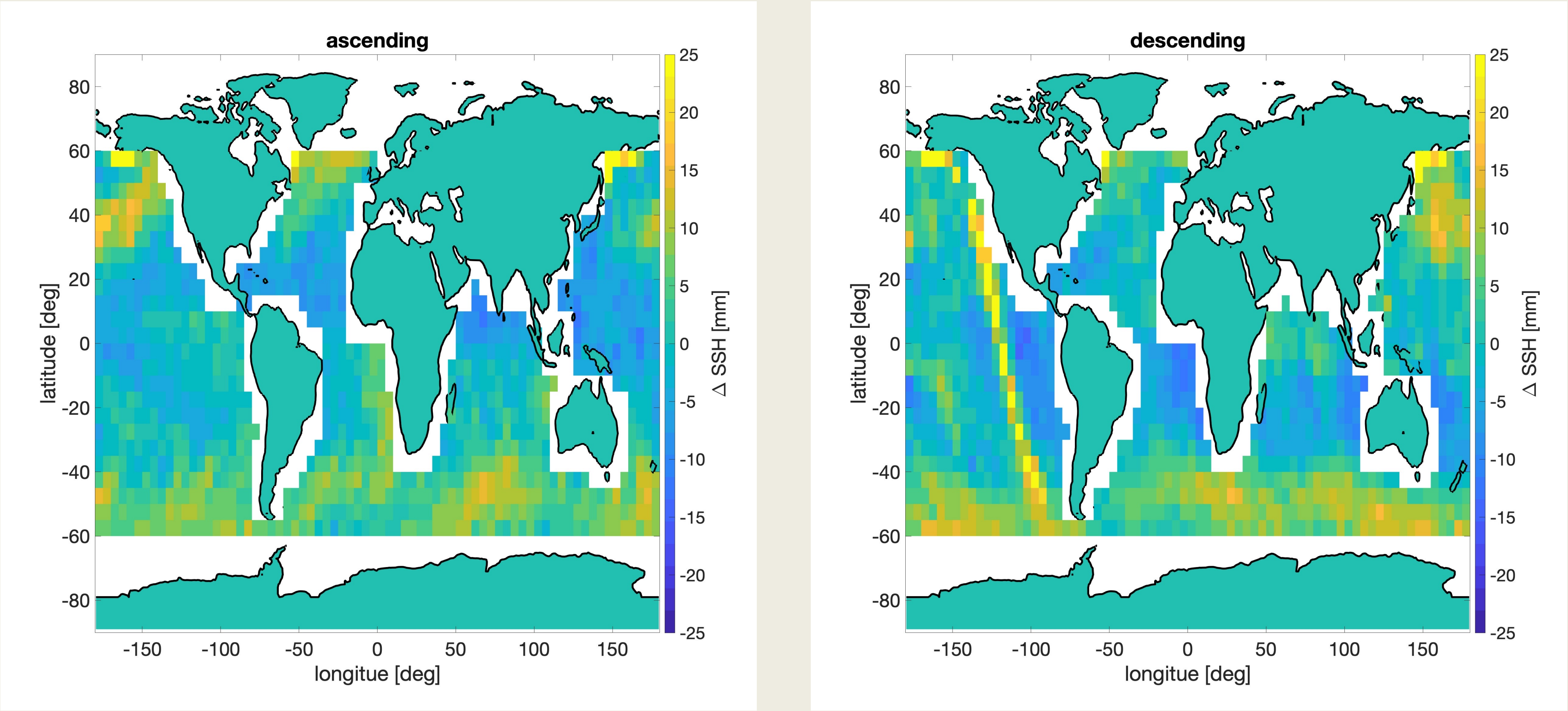
Sentinel-6A Cycle 44 Global Analyses

- Three different SAR (HR) retrackers used:
  - SINCS STD: Close to current state-of-the-art
  - SINCS-OV ZSK: VWPV stack retracker
  - SINCS-OV2 ZSK: VWPV plus u_x stack retracker

- Reduced SAR (LR) retrackers used:
  - SINC2 STD: Close to current state-of-the-art
  - SINC2 ZSK: Zero Skewness version of SINC2 STD

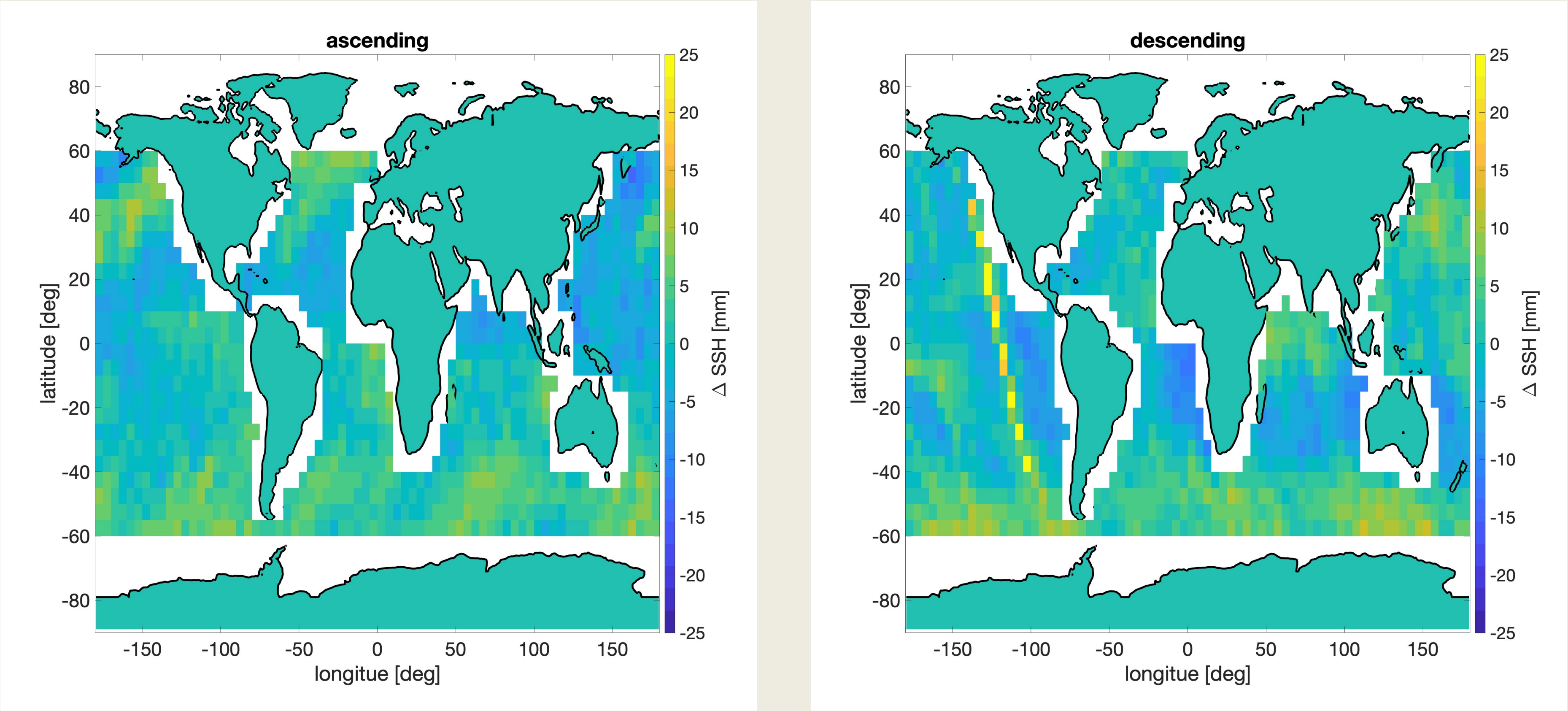
- SINCS STD is compared with SINC2 STD
- SINCS-OV ZSK and SINCS-OV2 ZSK with SINC2 ZSK

Sentinel-6A Cycle 44 SSH HR-LR Differences



HR – LR SSH estimates. LR retracker is SINC2 STD. HR retracker is SINCS STD.
Left: Ascending tracks. Right: Descending tracks.

Sentinel-6A Cycle 44 SSH HR-LR Differences



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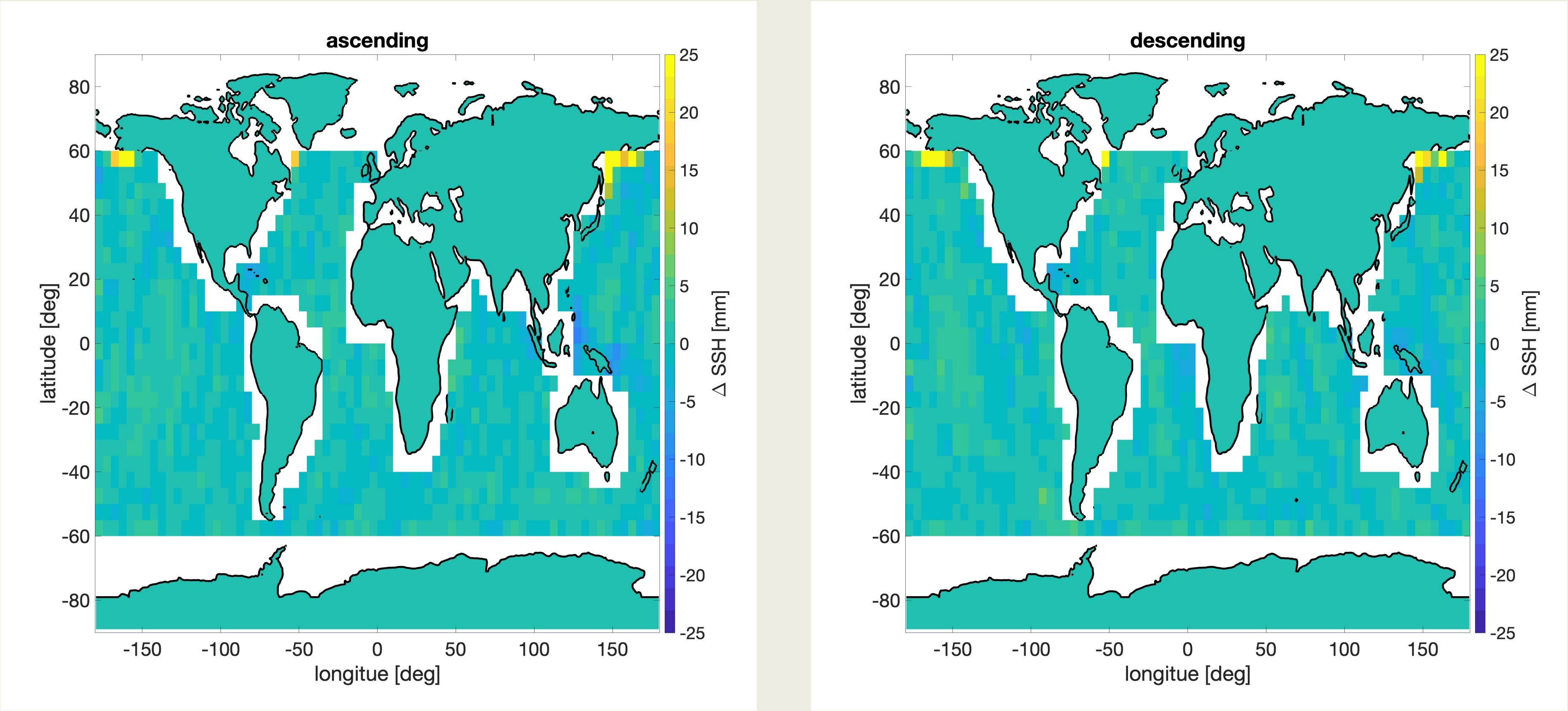

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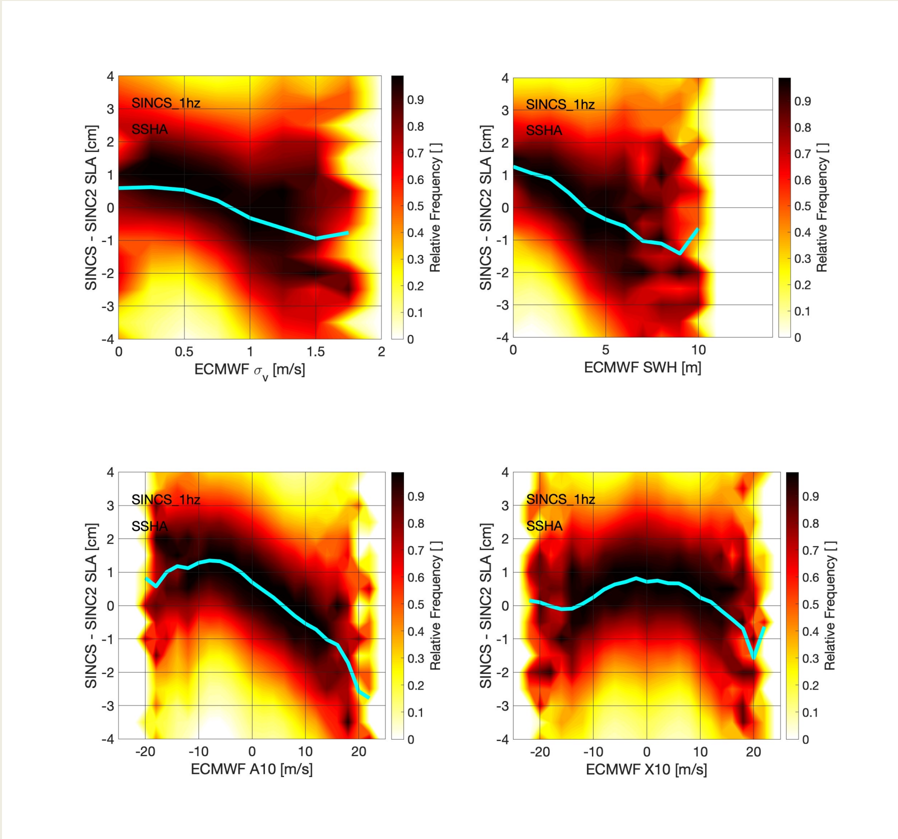

1-Hz HR-LR SLA differences w.r.t ECMWF parameters.
LR retracker is SINC2 STD.
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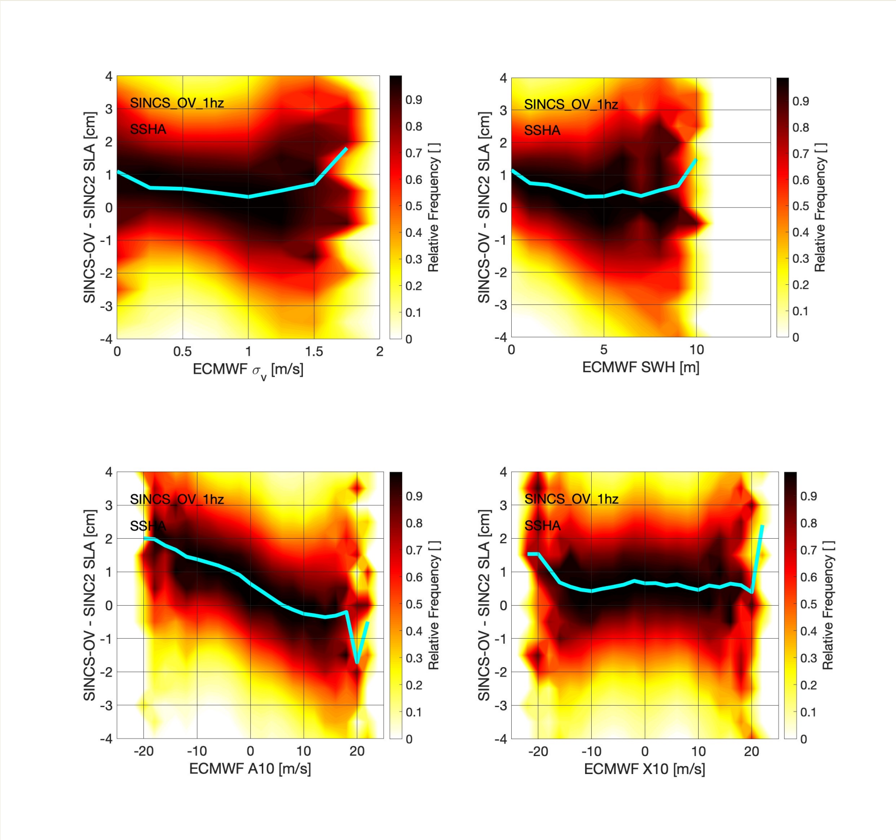
Sentinel-6A Cycle 44 SSH HR-LR Differences



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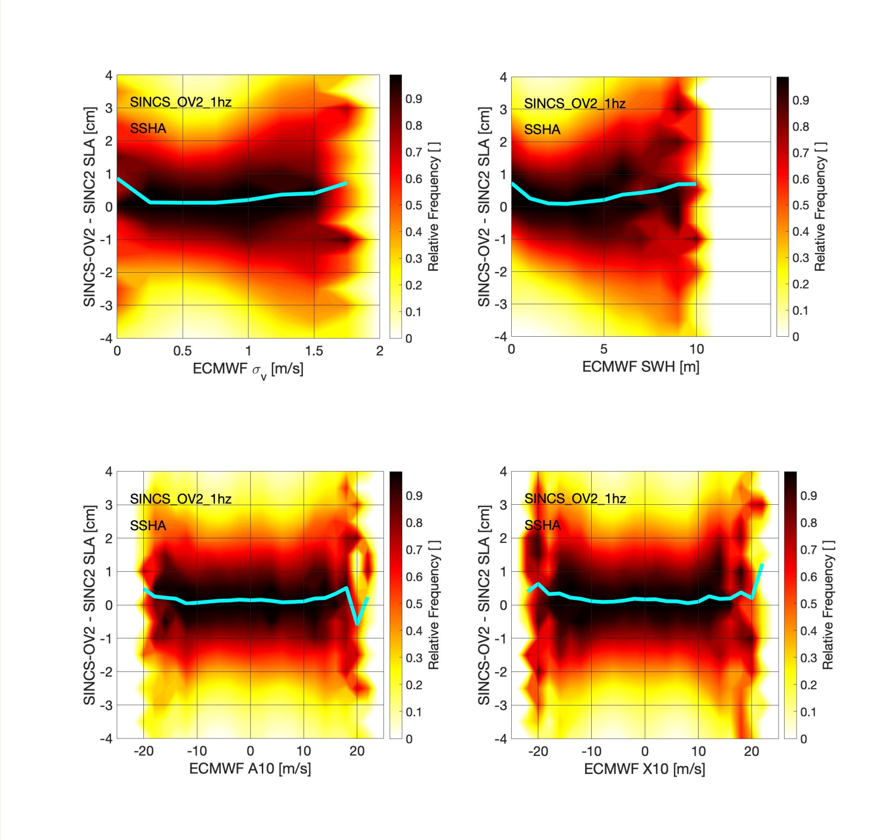

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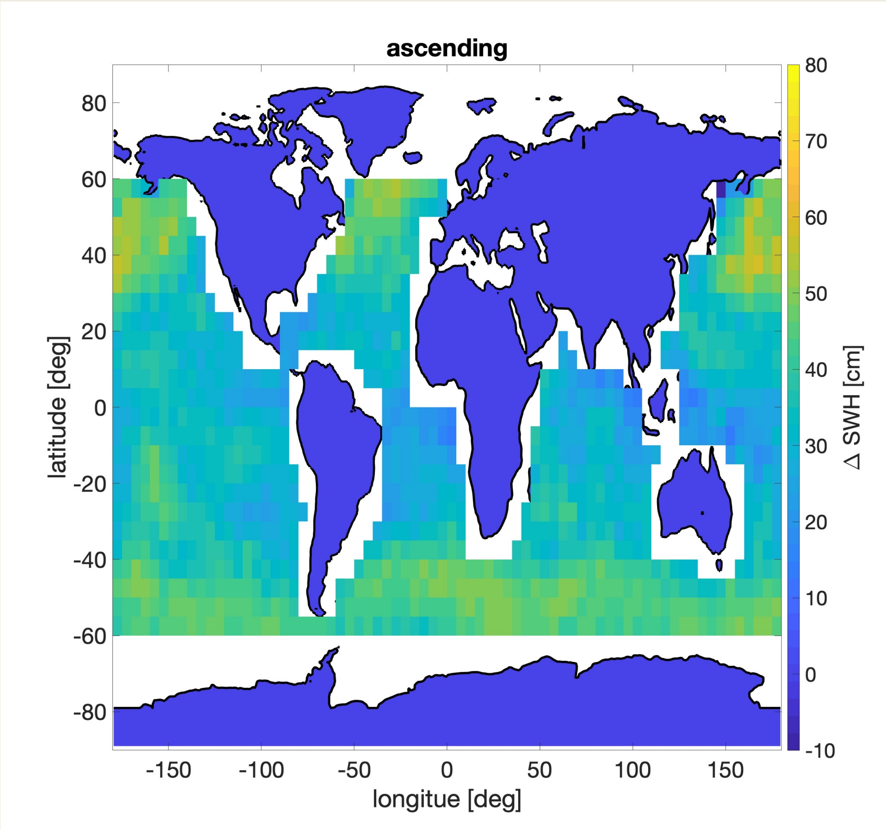
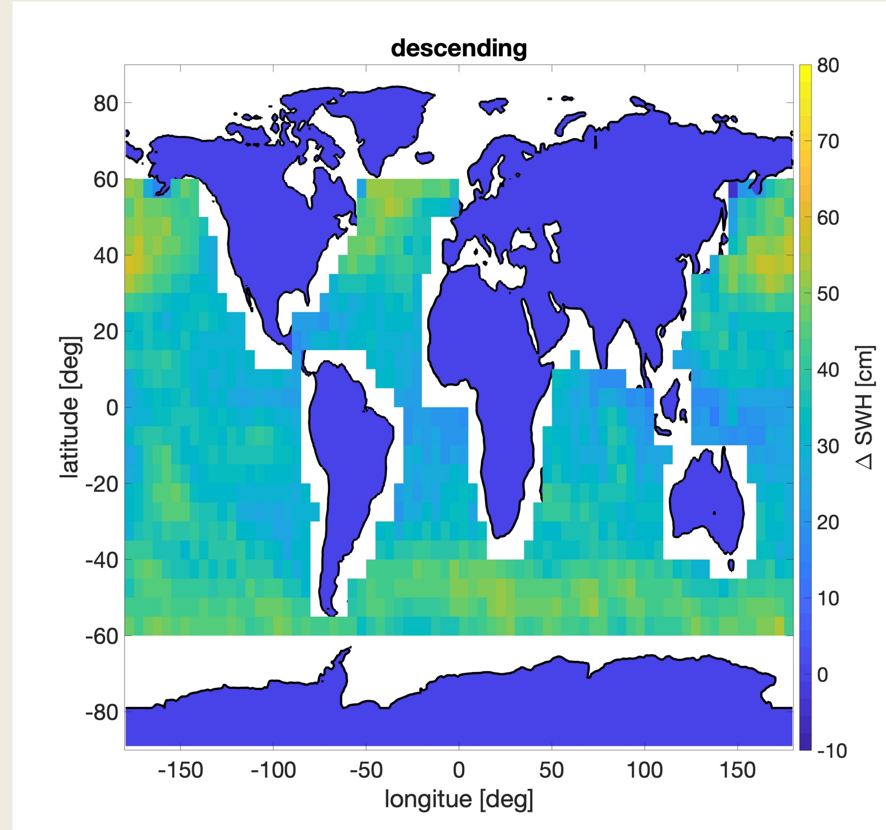
Sentinel-6A Cycle 44 SWH HR-LR Differences





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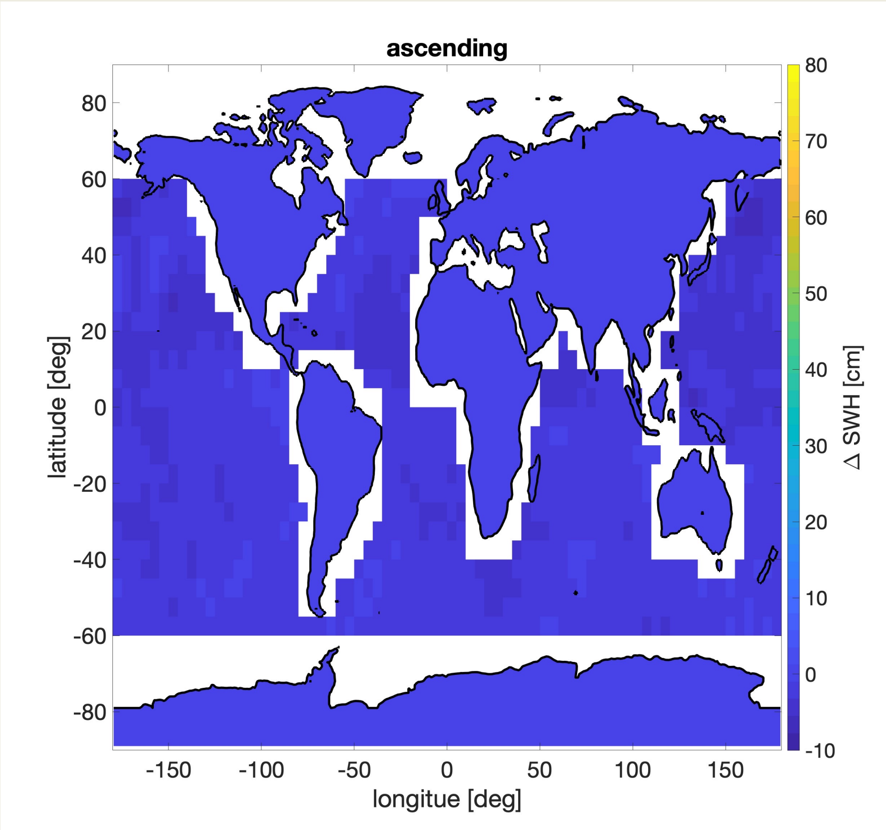

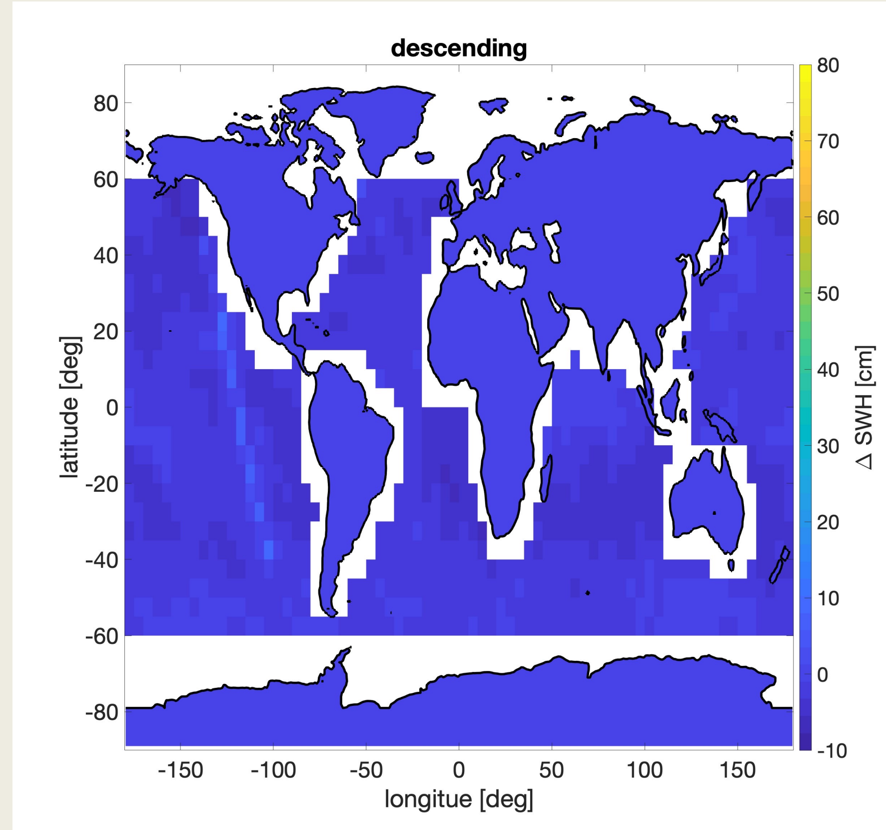

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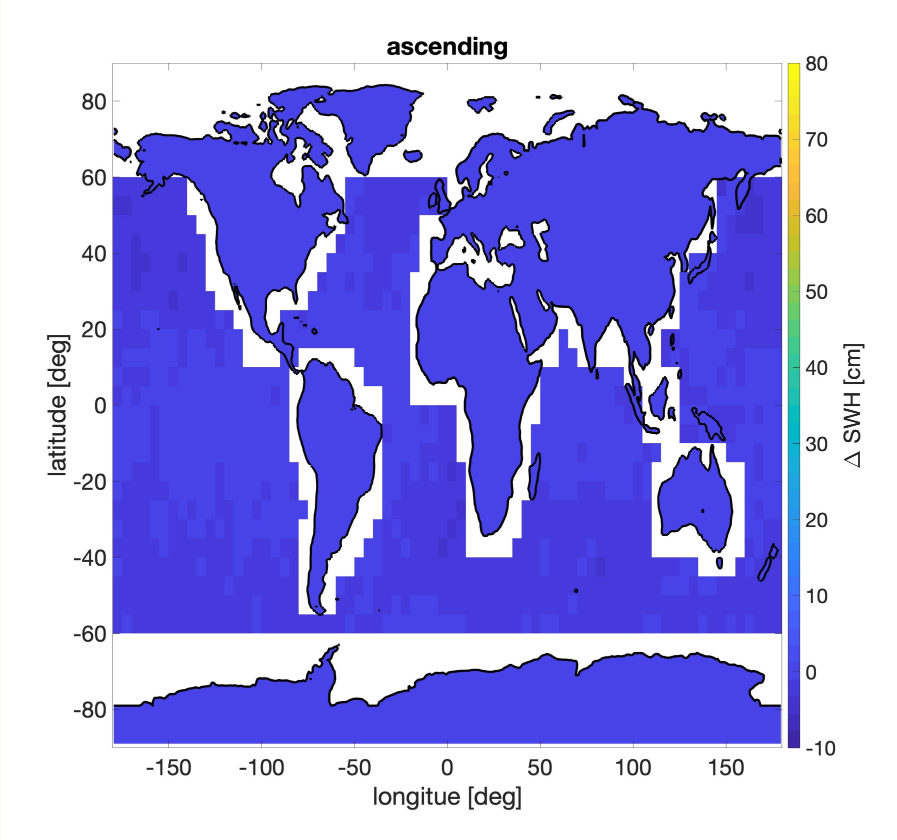

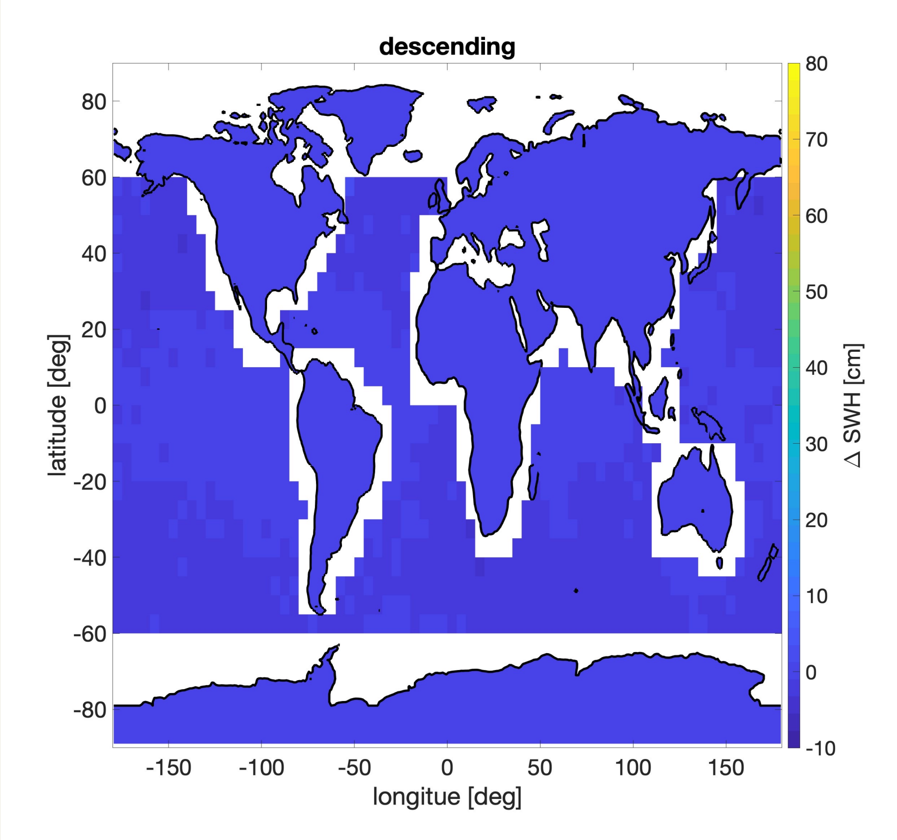

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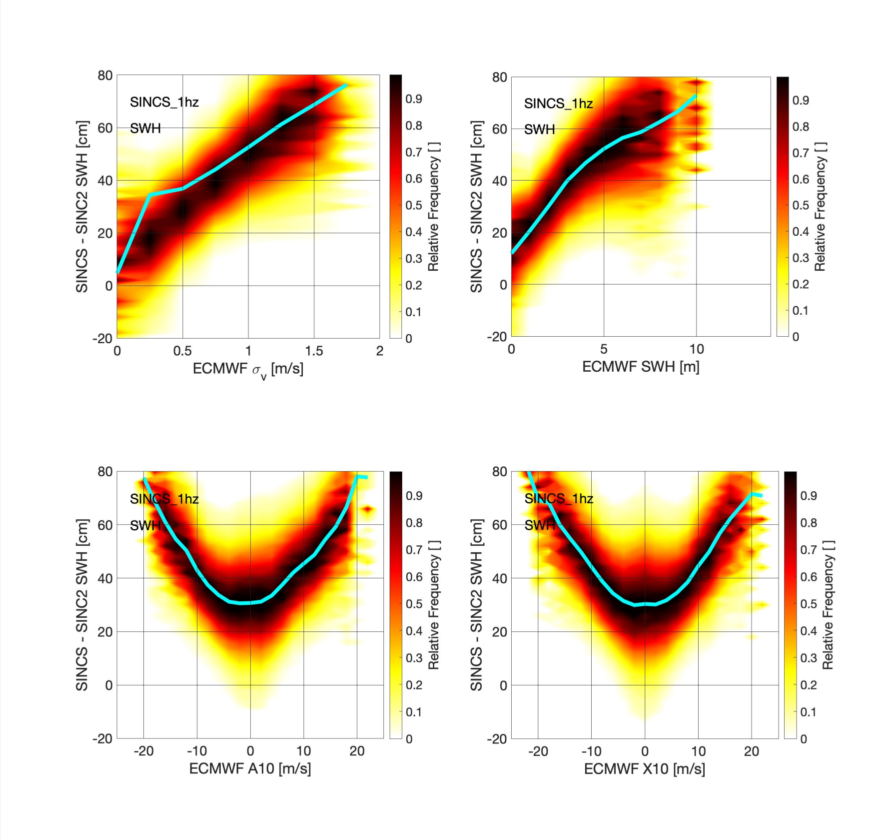

1-Hz HR-LR SWH differences w.r.t ECMWF parameters.
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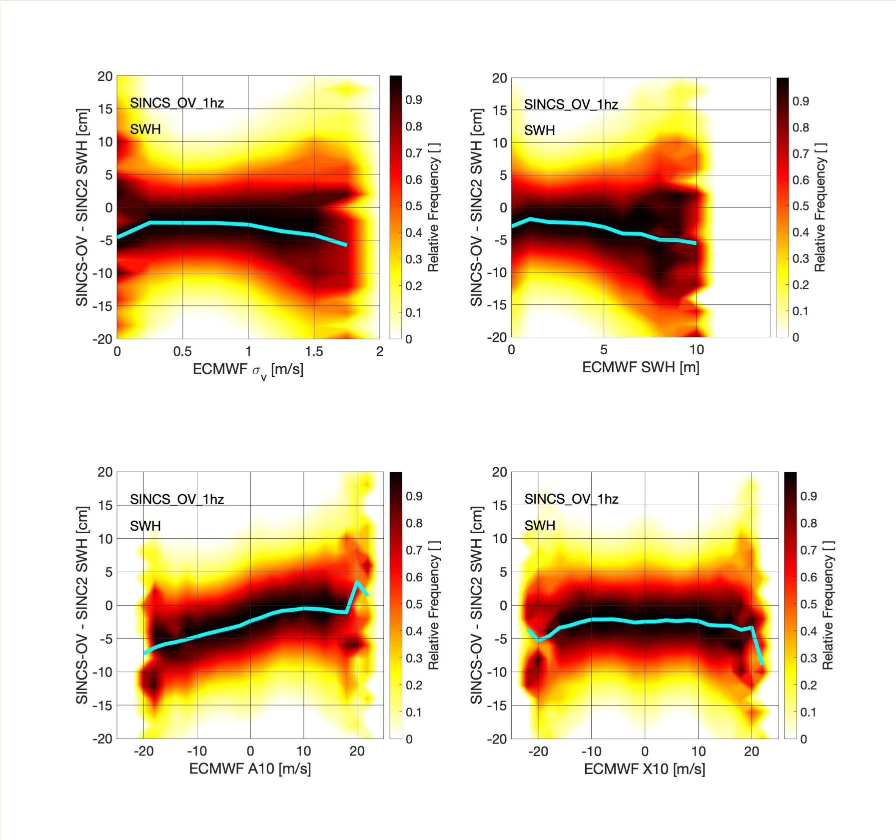

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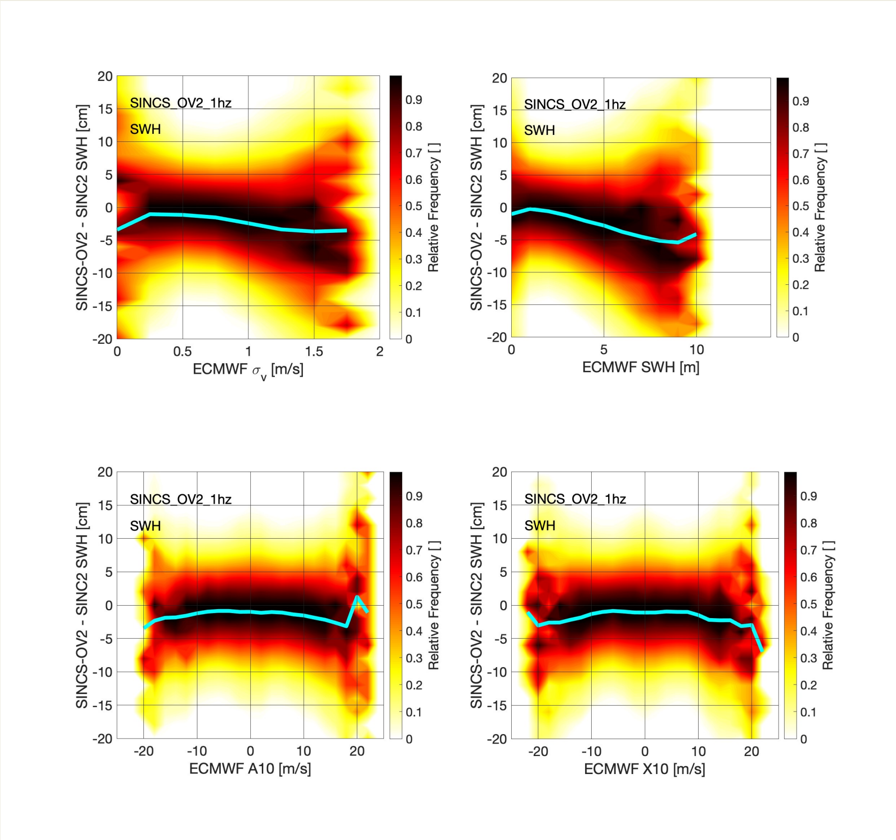

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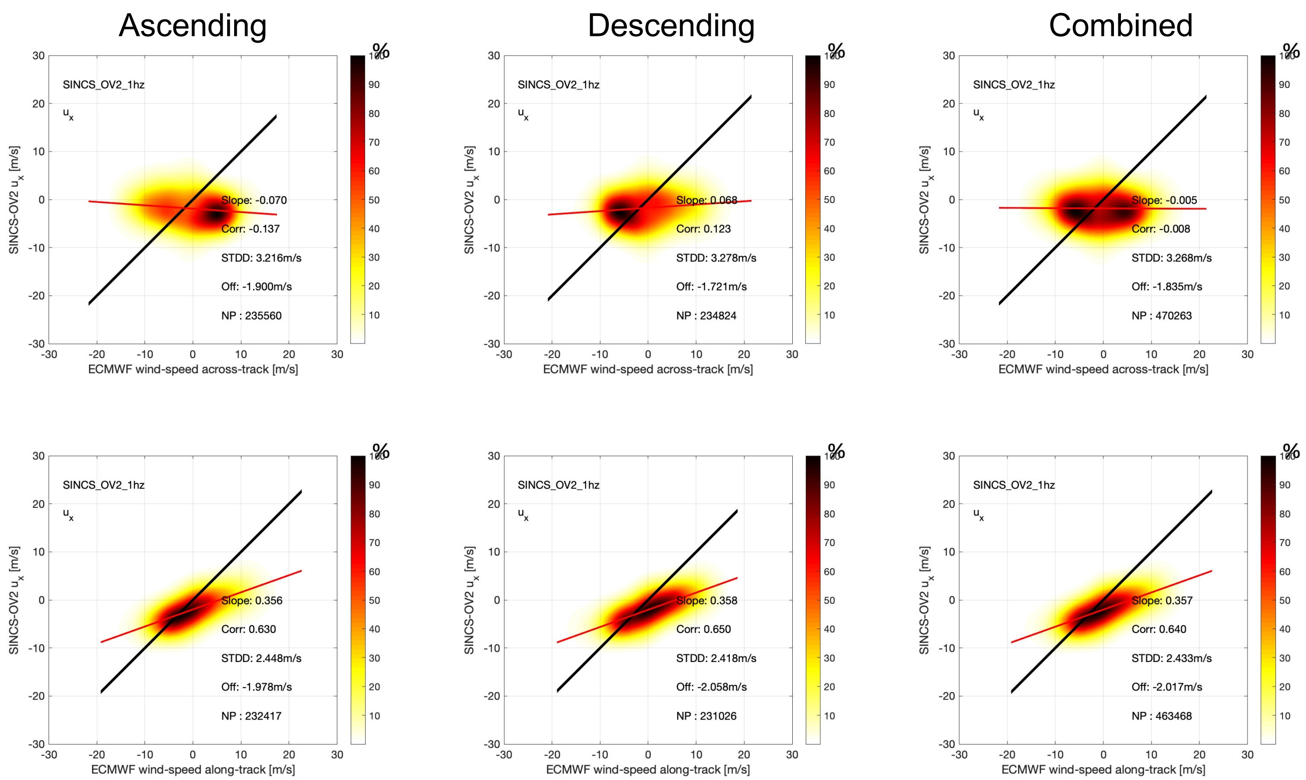
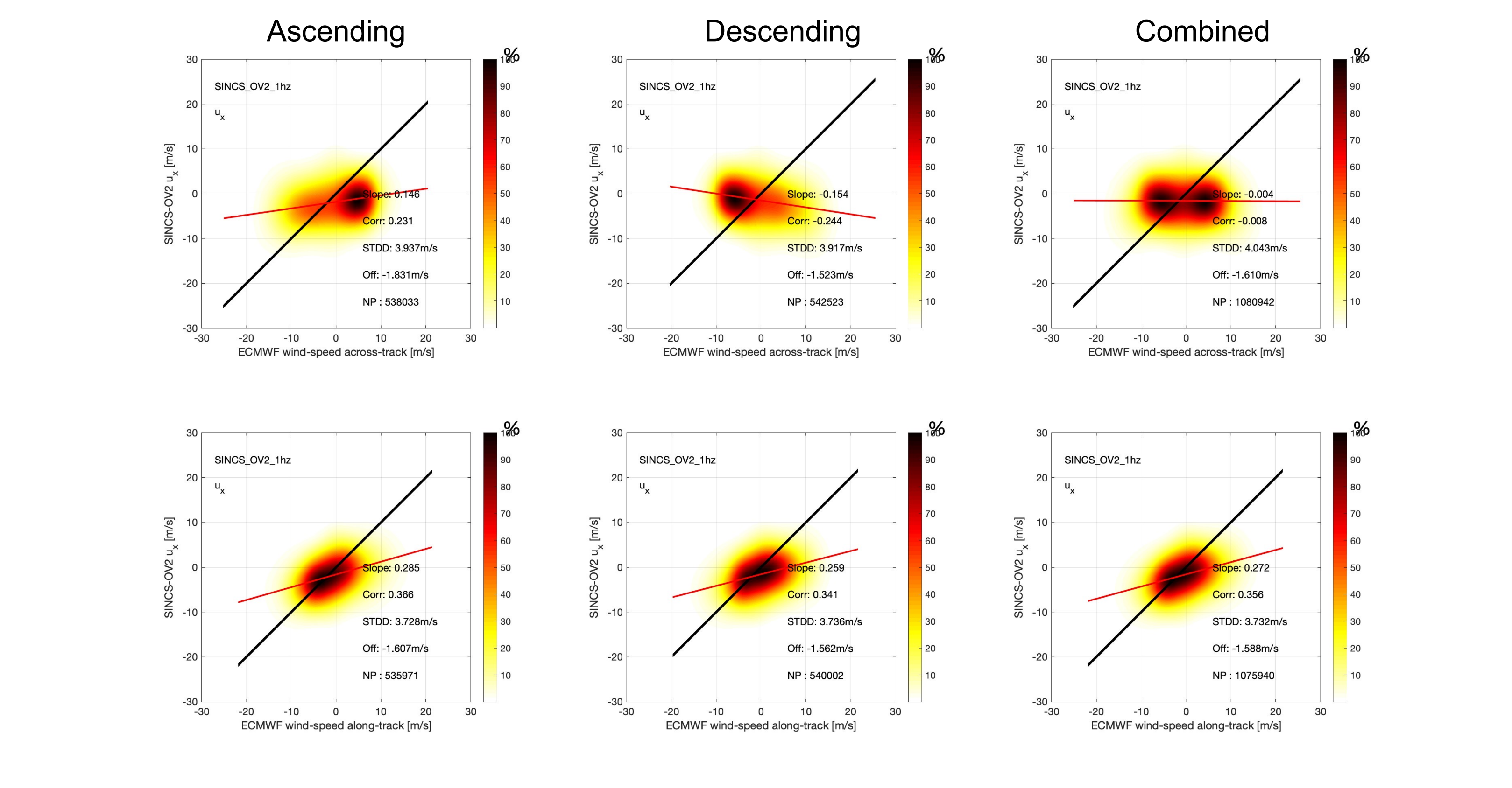
u_x w.r.t Wind Speed – Sentinel-6A



Scatterplot between 1-Hz SINCS-OV2 ZSK estimated along-track surface velocities and ECMWF wind speed values.

u_x w.r.t Wind Speed – Sentinel-3A



Scatterplot between 1-Hz SINCS-OV2 ZSK estimated along-track surface velocities and ECMWF wind speed values.

Conclusion

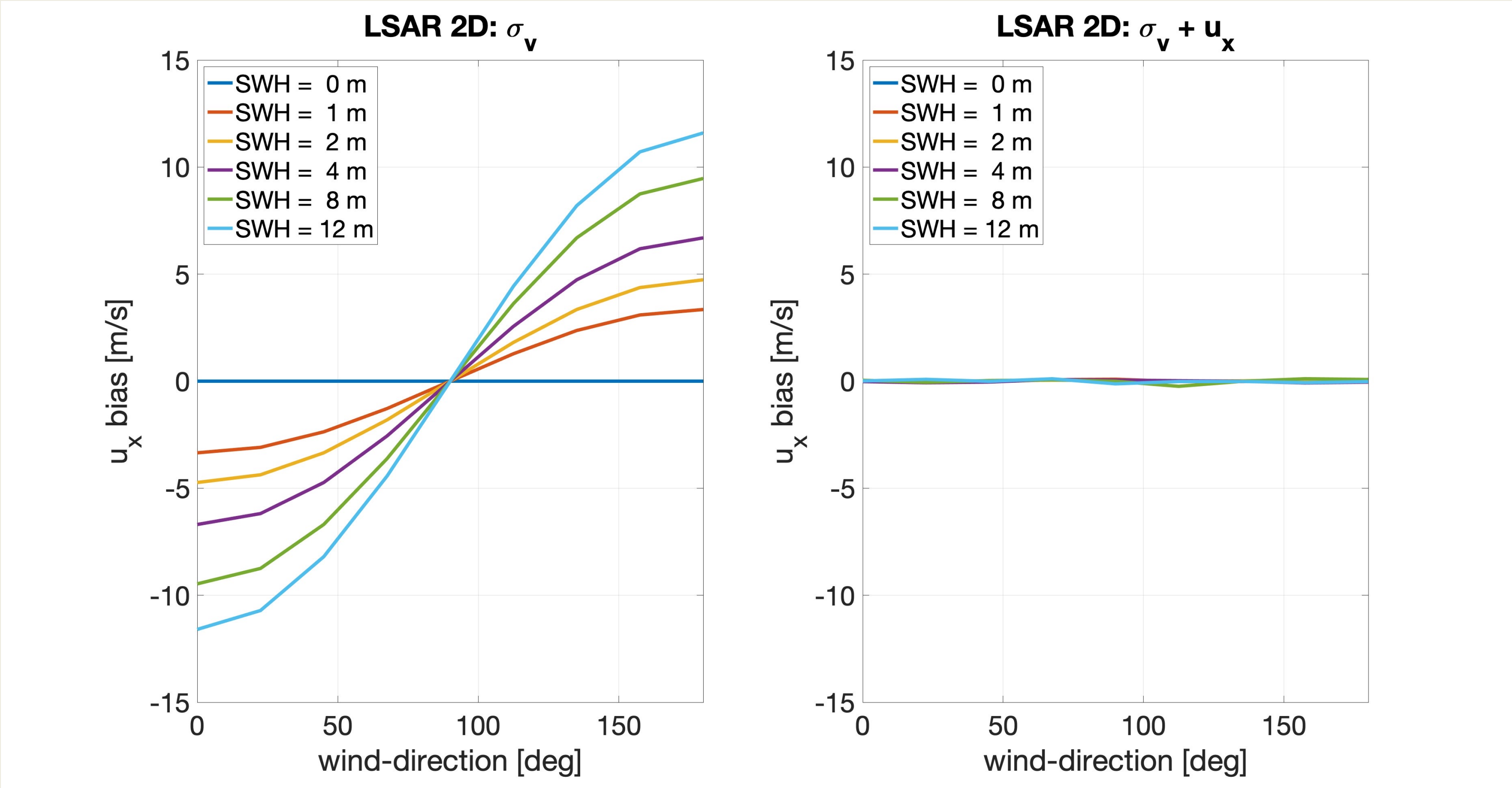
- 2D SAR retracking can retrieve two additional wind-wave parameters, the VWPV standard deviation σ_v and the along-track surface velocity u_x.
- Reduces the inconsistencies w.r.t. reduced SAR (LR).
  - Usually between $\pm$1cm (S3A) and $\pm$2cm (S6A) for SSH depending on along-track surface velocity.
  - Up to circa 40cm (S3A) and 60cm (S6A) for SWH depending on VWPV variation.
- Relationship between u_x and along-track windspeed
  - However, different behavior for S6A and S3A
  - How about swell and currents?
- Overall work in progress, but $\sigma_v + u_x$ needs to be considered in the future e.g. with 2D SAR retracking.

Simulation of Sentinel-6A Data

- Performing 10,000 Monte-Carlo-Runs for each SWH and wind direction θ_w combination:
  - $H_s = \{$ 0m, 1m, 2m, 4m, 8m, 12m $\}$
  - $\theta_w = \{\, 0°,\ 22.5°,\ 45°,\ 67.5°,\ 90°,\ 112.5°,\ 145°,\ 167.5°,\ 180° \,\}$
  - $\sigma_v = \sqrt{0.01365\, g\, H_s}$ (Eq. based on elevation skewness of 0.1)
  - $U_{10} = 2.1375\, \sqrt{g\, H_s}$ (Eq. base on Pierson-Moskowitz spectrum)
  - $u_x = \frac{U_{10}}{2}$ (Eq. based on conservative estimate)
  - $g = 9.81\, {}^{m}/_{s^2}$ is the gravity acceleration.

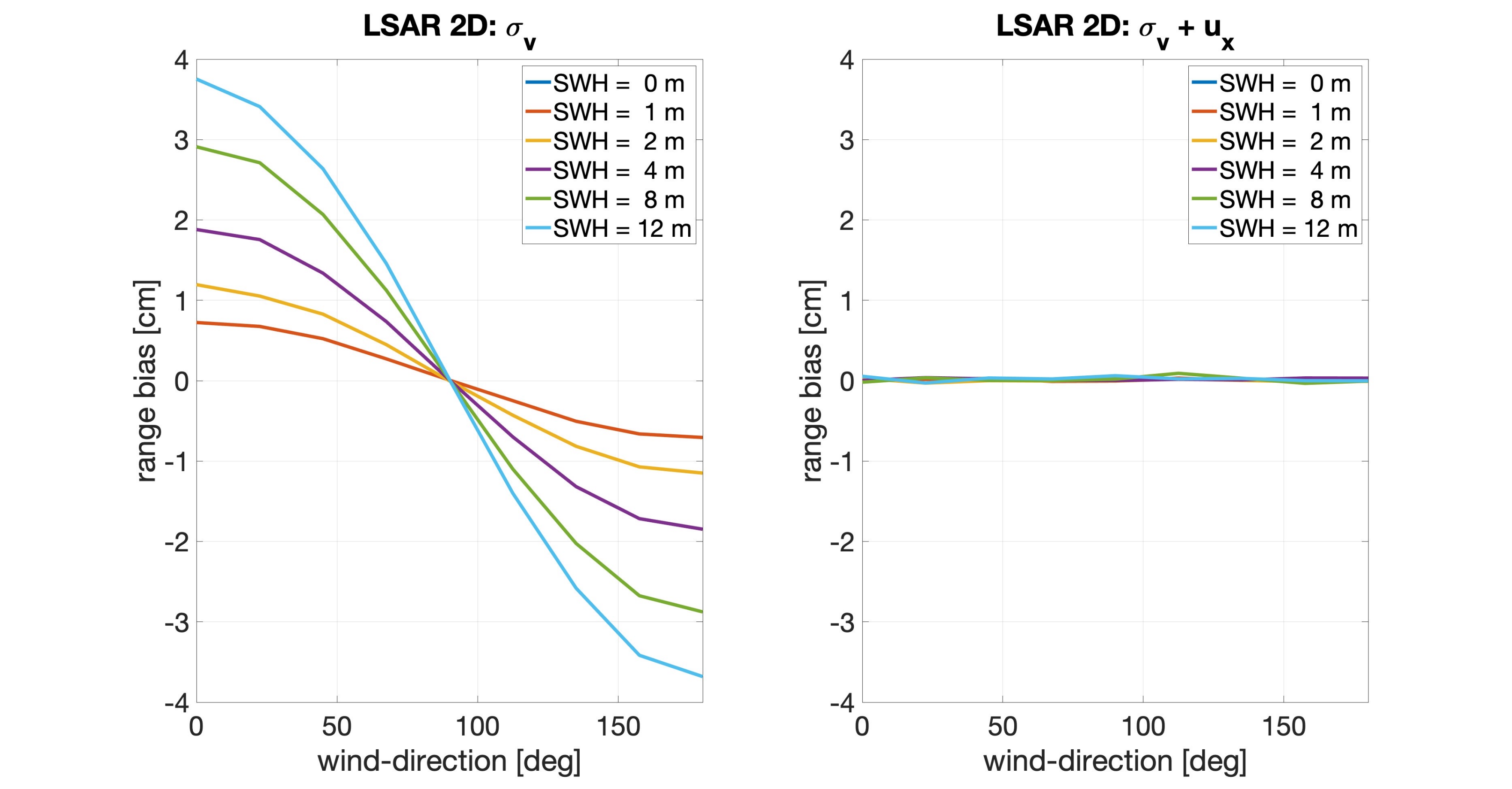
- Retracking done with Levenberg-Marquardt Algorithm and
  - SINCS-OV ZSK (LSAR 2D: σ_v)
  - SINCS-OV2 ZSK (LSAR 2D: $\sigma_v + u_x$)

Simulation of Sentinel-6A Data



Estimated minus modelled u_x values in meter per second as function of SWH and wind-direction w.r.t. altimeter track.
Left: SINCS-OV ZSK which does not estimate u_x. Right: SINCS-OV2 ZSK which does estimate u_x.

Simulation of Sentinel-6A Data



Estimated minus modelled range values in meter as function of SWH and wind-direction w.r.t. altimeter track.
Left: SINCS-OV ZSK which does not estimate u_x. Right: SINCS-OV2 ZSK which does estimate u_x.

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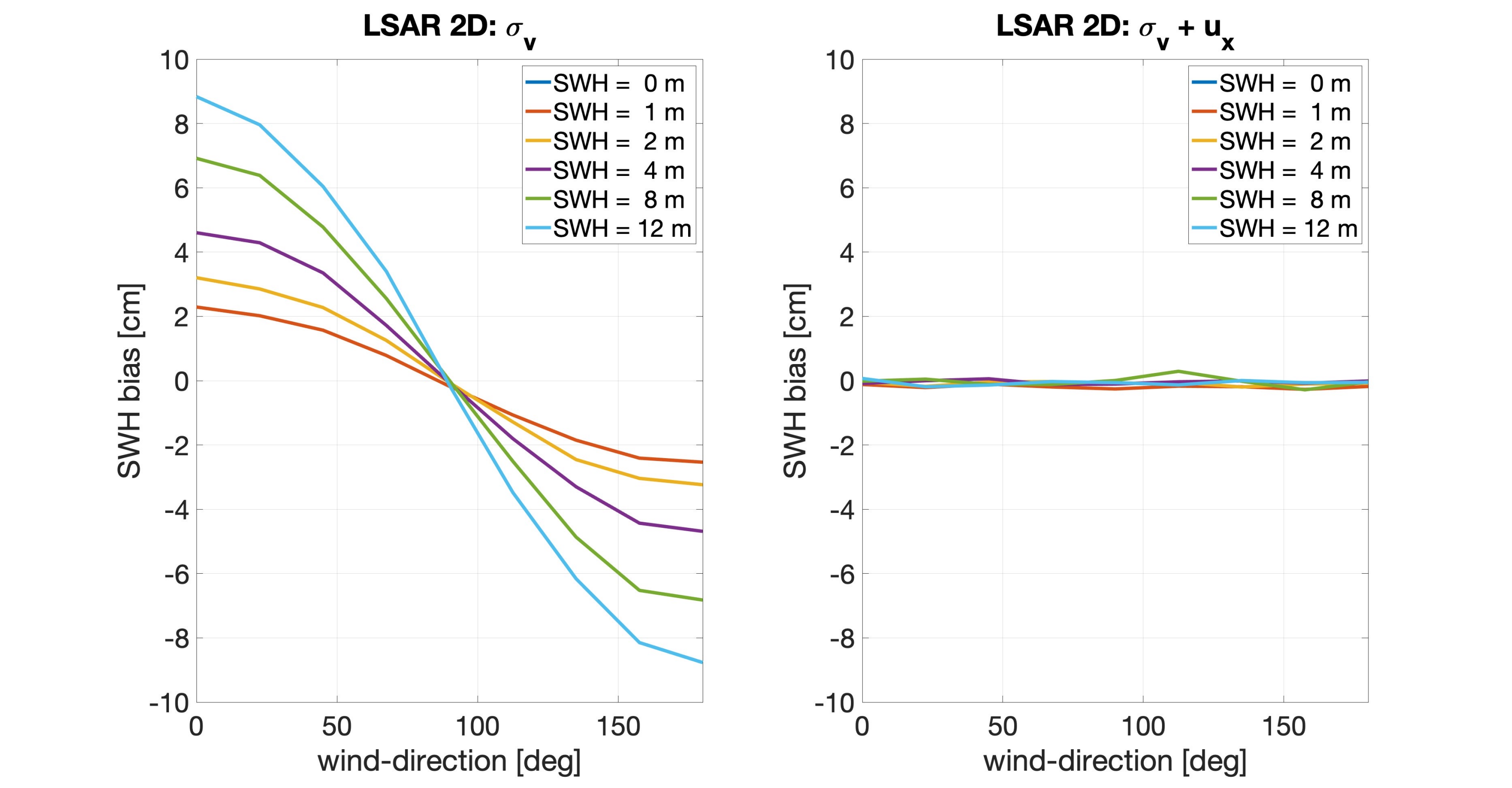

Estimated minus modelled SWH values in meter as function of SWH and wind-direction w.r.t. altimeter track.
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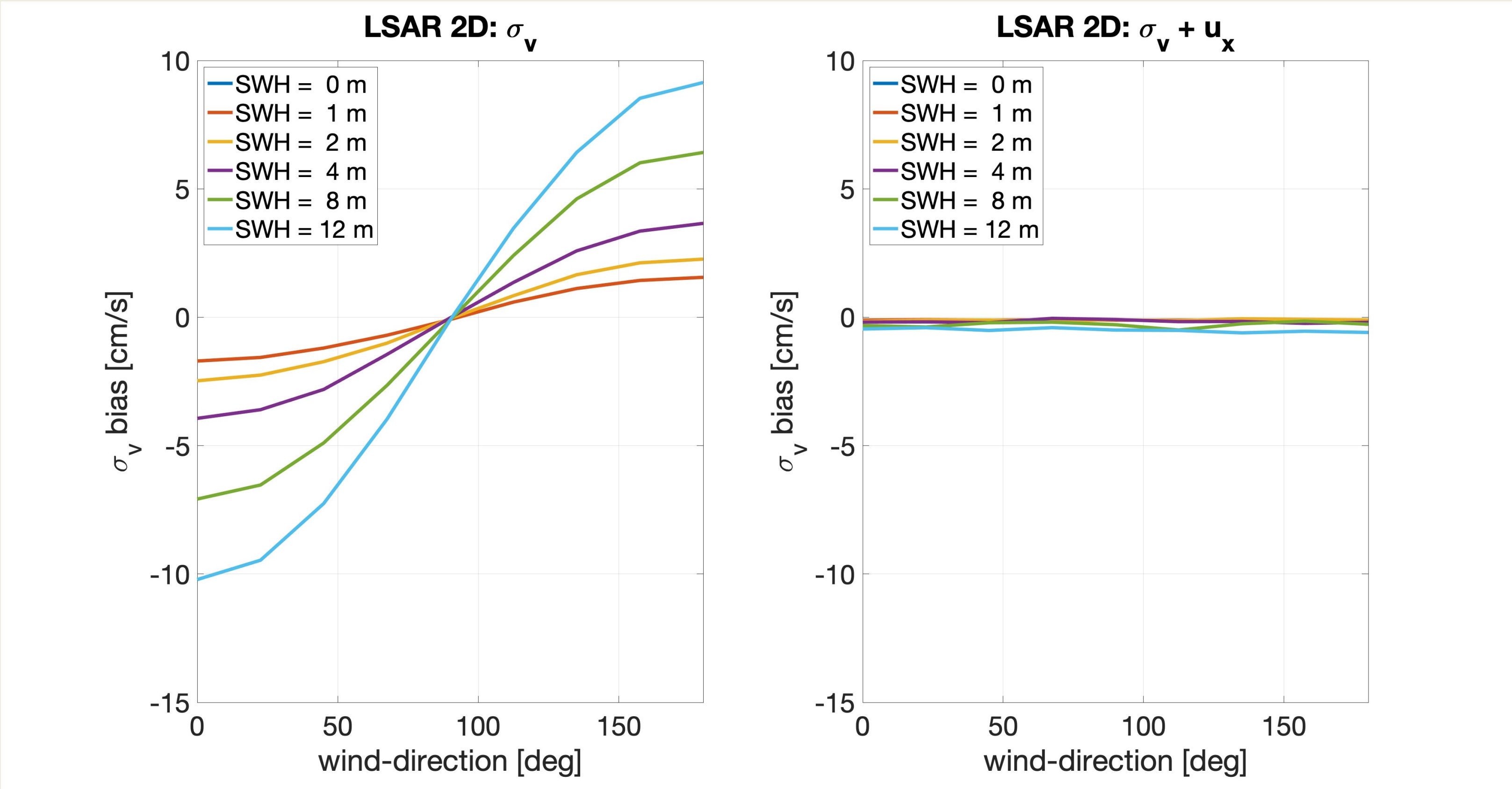

Estimated minus modelled σ_v values in meter per second as function of SWH and wind-direction w.r.t. altimeter track.
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