Delay-Doppler Processing of altimetric SAR data over open ocean: precision evaluation of different algorithms

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- Introduction
- Methodological framework
- Delay-Doppler processor (L1B)
- Re-tracking (L2)
- Experimental results: precision performance
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- **SAR altimerty** has entered into a **Golden age** (CryoSat-2, Sentinel-3 and future Sentinel-6, Sentinel-9)

- Understand how the SAR mode can be efficiently exploited to improve performance of altimetric products (processing)

- **Comparative** assessment in terms of **precision**:
  - Conventional **S-3/CS-2** processing baseline
  - Amplitude Compensation & Dilation Compensation (**ACDC**)

- Projects involved in the design and analysis:
  - **Sentinel-6 L1B GPP** (Ground Processor Prototype) ESA
  - **SCOOP** (*SAR Altimetry Coast & Open Ocean Performance*), ESA-SEOM

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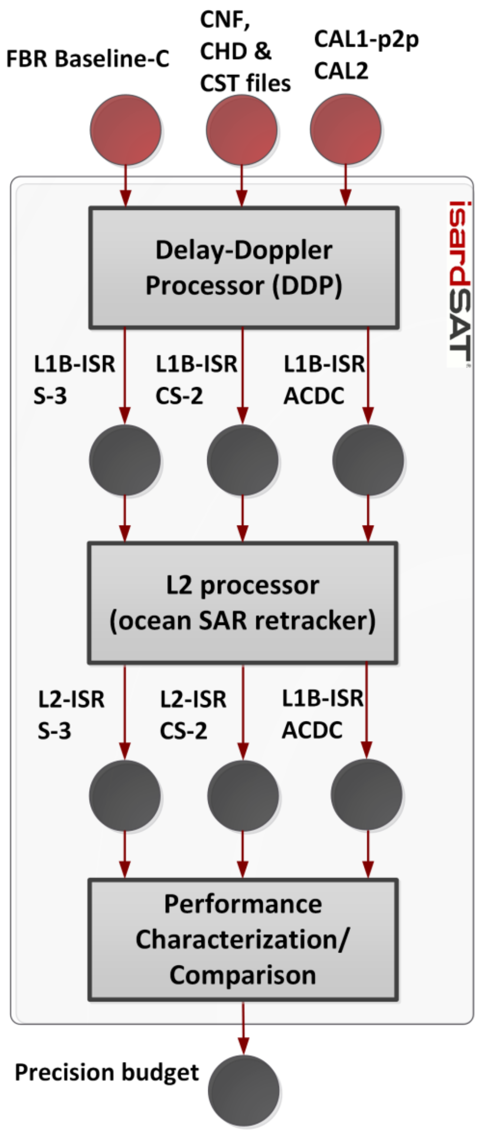
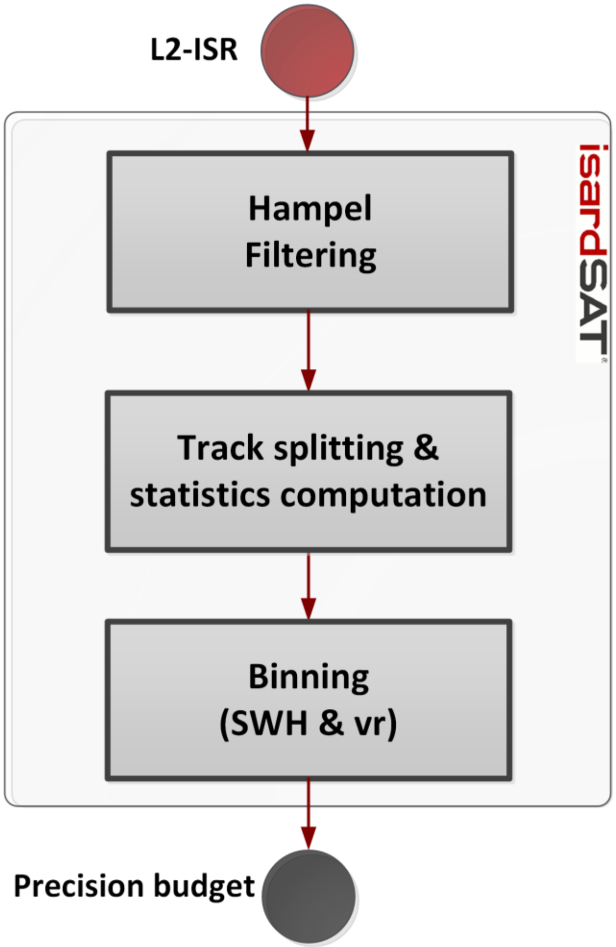
Methodology (I)



- **Inputs:**
  - Uncalibrated ***FBR CS-2 baseline-C***
  - ***CAL1-p2p & CAL2*** averaged over a 5-years cycle of CS-2
- **isardSAT (ISR) in-house L1B & L2** processors (tuned to ***CS-2 & S-3 baselines + ACDC***)
- Precision Performance **Geophysical retrievals**:
  - ***ISR L2*** fully adapted to L1B DDP: ***SAR ocean fully-analytical retracker*** [Chris Ray et al. 2015]

Methodology (I): Precision performance



- **Hampel filtering:**
  - Remove outliers
  - Median filter approach
- **Statistics computation**
  - Each track split into ***consecutive & non-overlaping segments of 20 samples***
  - ***Standard deviation*** of ***detrended block [SSH & SWH]:*** *for i-block*

$$\sigma^{i}_{SSH/SWH} = std\{detrend\{SSH/SWH^{i}\}\}$$

- **Binning**:
  - Average of $\sigma^{i}_{SSH/SWH}$ for all i that fall in each j-th bin of SWH

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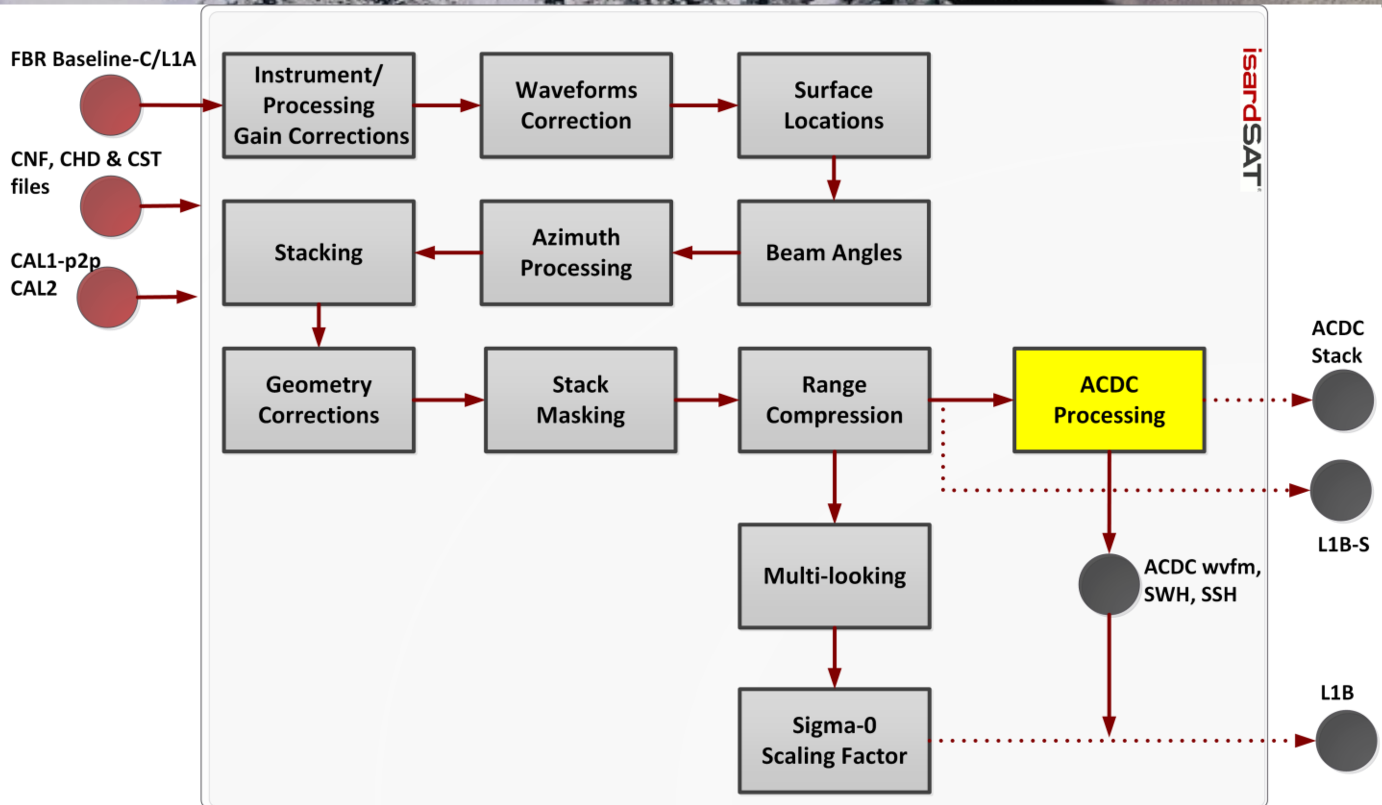
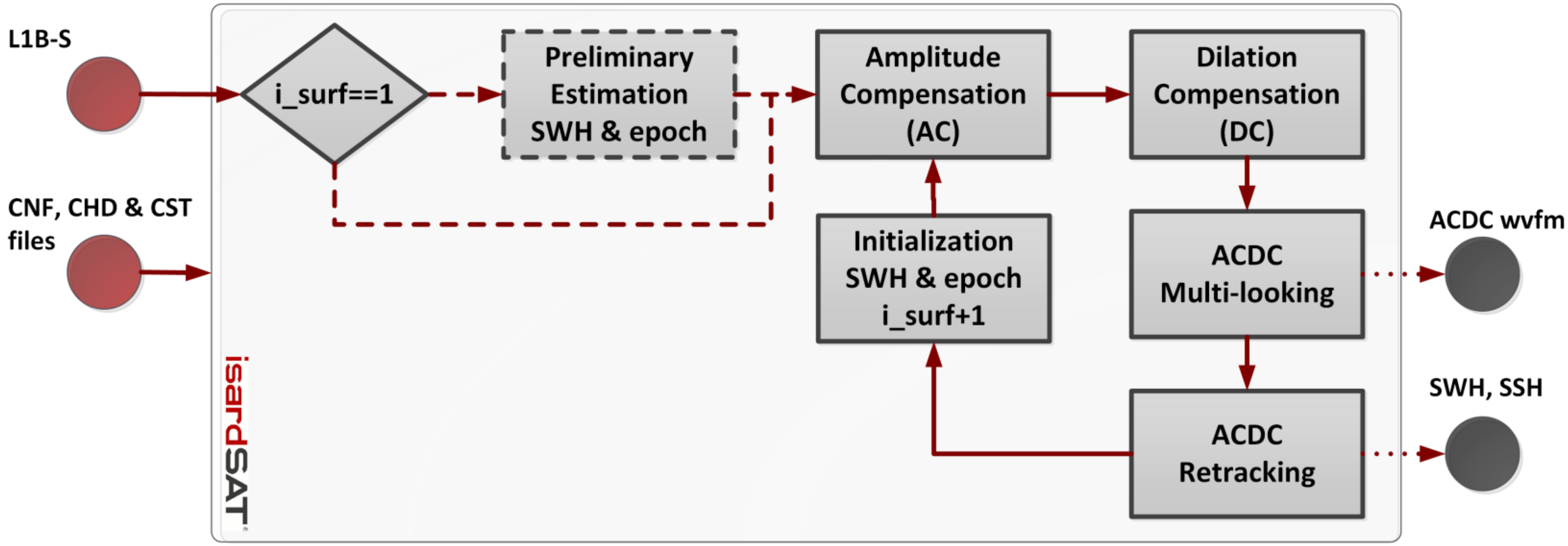
Delay-Doppler Processor (DDP)



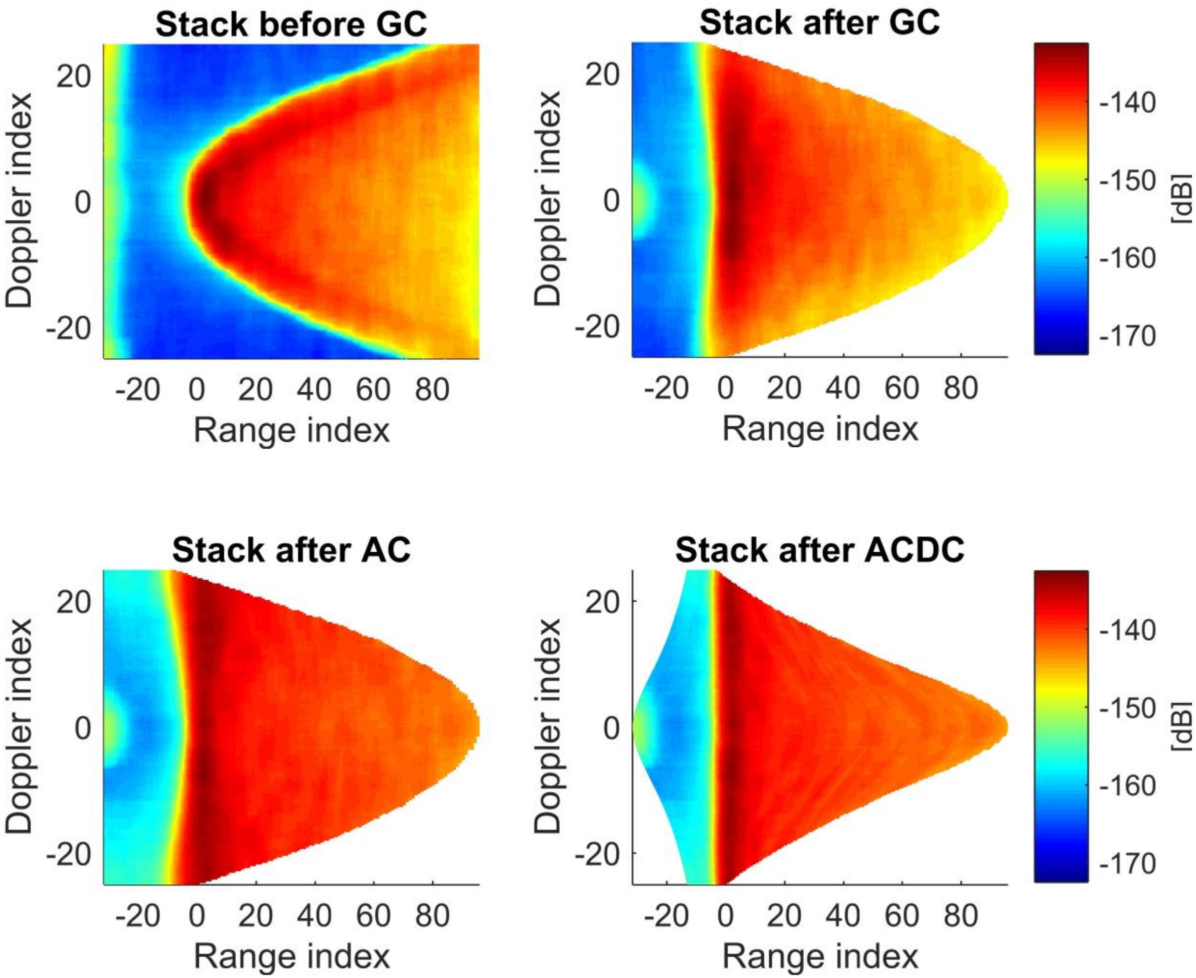
- **In-house experience** on **DDPs**:
  - Sentinel-6/Jason-CS GPP; Sentinel-3 L0/L1 GPP; CryoSat-2 DDP
- A la **Sentinel-6 architecture**:
  - Stacking + geom. Corr. + range compression → easing validation / integration improvements at stack level (ACDC processing)
- **Flexibility & Re-configurability**

Amplitude Compensation Dilation Compensation ACDC (I)



- In-house **implementation at stack** level (original *Ray et al.* at burst level)
  - Along- & across-track amplitude compensation (equalization in range and Doppler)
  - Across-track dilation compensation (waveform widening correction away from central beam)
- **Initial estimates (1st surface)** of **SWH & epoch** based on SAR **ocean fully-analytical retracker Ray et al.**
- **Parameter estimates** of the **previously processed waveforms** used for **initial estimates** for **ACDC processing of consecutive waveforms (statistical approach)**

Amplitude Compensation Dilation Compensation ACDC (II)



1) **Amplitude Compensation** per range-bin k & Doppler beam l

2) **Compensation** of a **Doppler-dependent range dilation** w.r.t **central Beam**

3) **ACDC Multilooking** (**averaging samples with similar DC range**)

4) **Simpler & Faster ACDC waveform retracker**

(*) GC stands for geometry corrections

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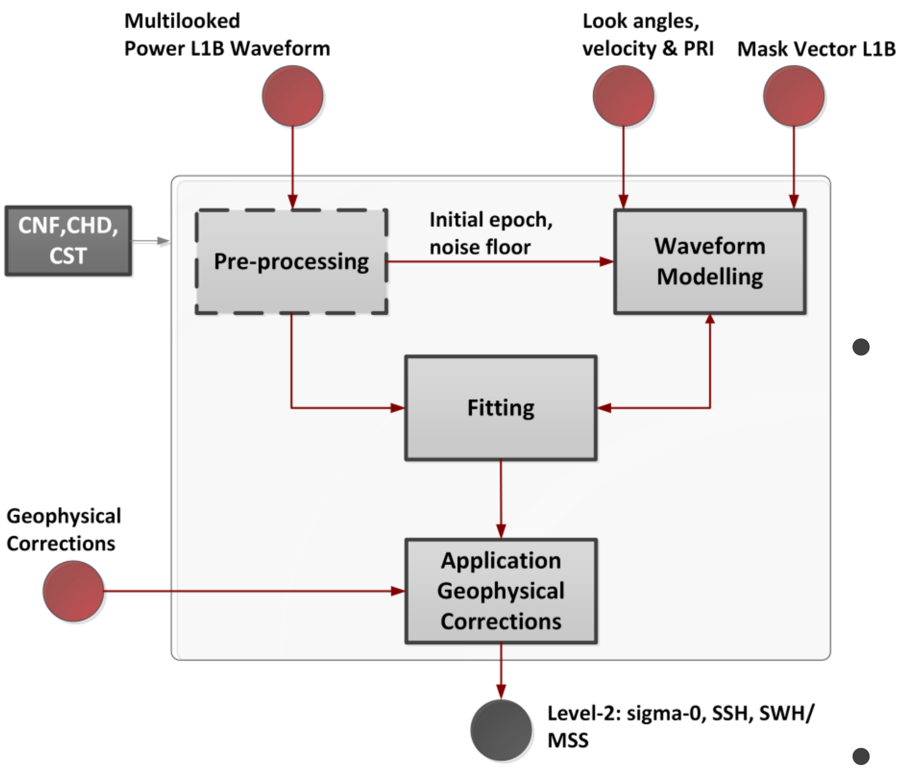

- **Fully analytical** SAR model (*Chris Ray et. al 2015*)
  - Complete model**:** ***1st*** and ***2nd*** order ***basis functions*** included + mapped through ***LUTs***
- **Synergy** with **L1B** processing
  - ZP, window type, stack masking, zeros-method…
  - ***Look angle*** exploitation → ***model stack***
- Pre-processing:
  - ***Adaptive noise estimation***
  - ***Initial epoch*** (threshold-retracker)

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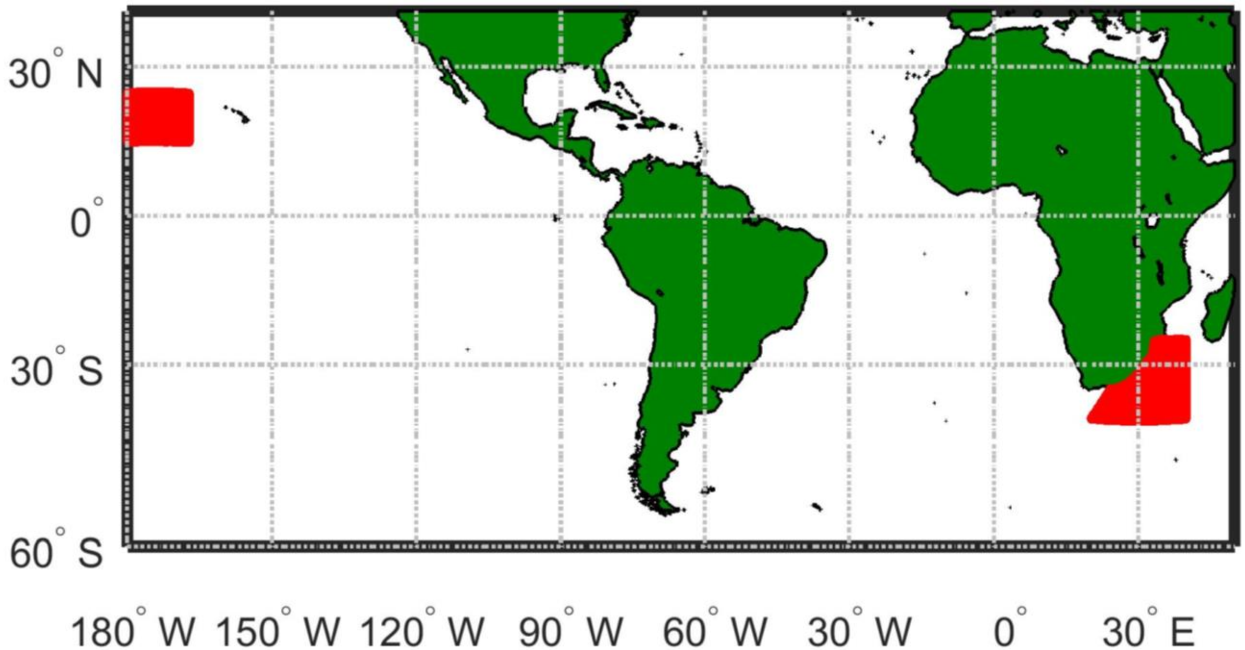
Areas of Interest (AOIs)



Central Pacific (whole 2013 year)
- Homogeneous region
- Low/medium radial velocity

Agulhas (whole 2013 year)
- High-dynamics region
- High radial velocities

(*) **results shown in this presentation have been included in a journal paper currently under review**: E. Makhoul, M. Roca, C. Ray, A. Garcia-Mondejar, R. Escolà, "Evaluation of the precisión of different Delay-Doppler Processor (DDP) algorithms using CryoSat-2 data over open ocean", submitted to *Advances in Space Research* (under review).

1. **CS-2**
   - ***Zero-padding*** of ***2*** in range
   - ***Intra-burst Hamming***
   - ***Stack masking*** of edge beams [beams with ***look angle*** above/below $\pm\mathbf{0,6\ deg}$ discarded]
   - ***Zeros*** accounted for in ***multi-looking***
2. **S-3**
   - ***No zero-padding***
   - ***No intra-burst Hamming***
   - ***Stack masking*** of noisy beams [beams with ***noise floor*** above a threshold are discarded]
   - ***Zeros*** accounted for in ***multi-looking***
3. **CS-2 no zeros**:
   - ***CS-2 baseline with no zeros in mutli-looking***
4. **ACDC (with CS-2 configuration)**

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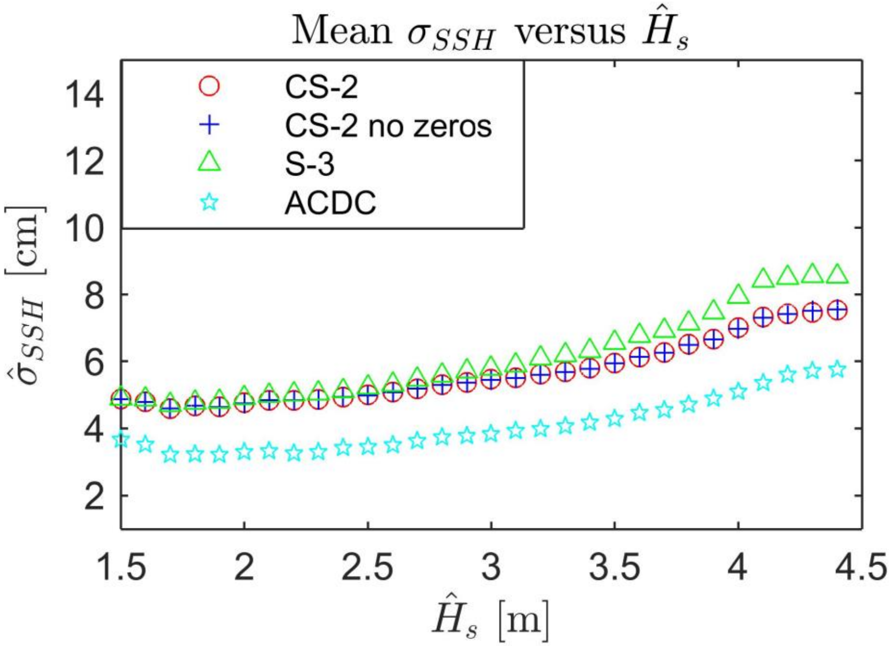
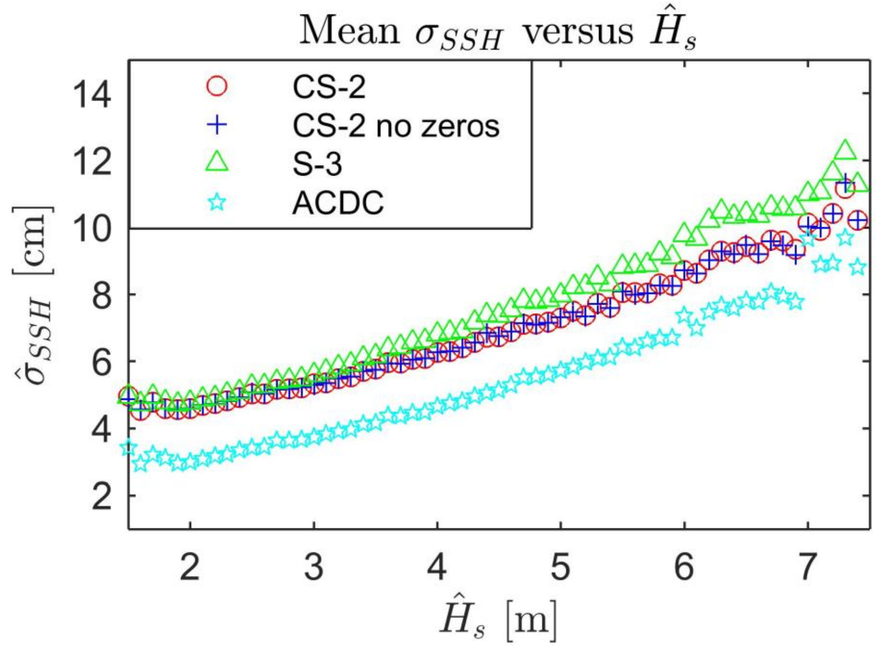
SSH precision

Central Pacific



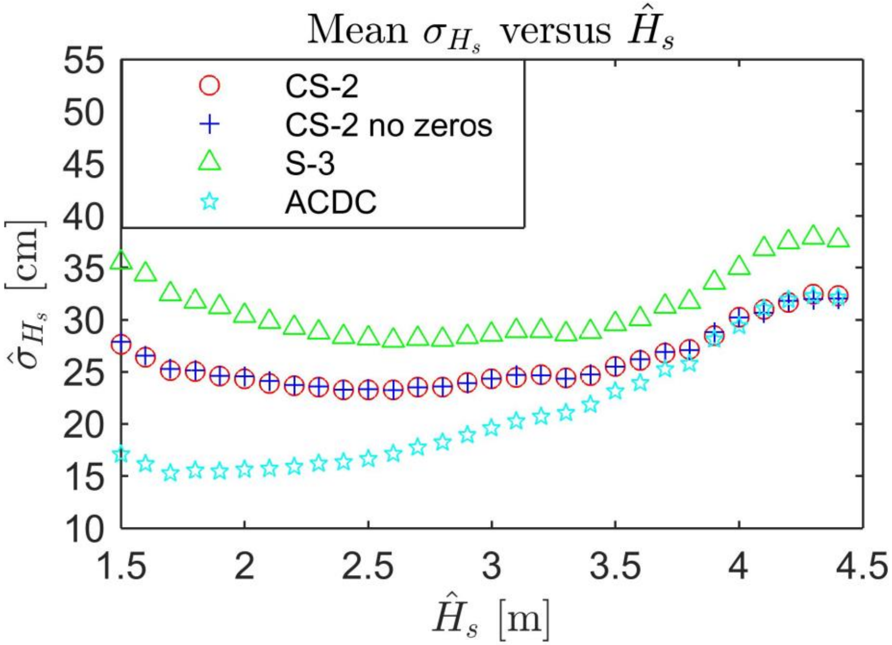
Agulhas



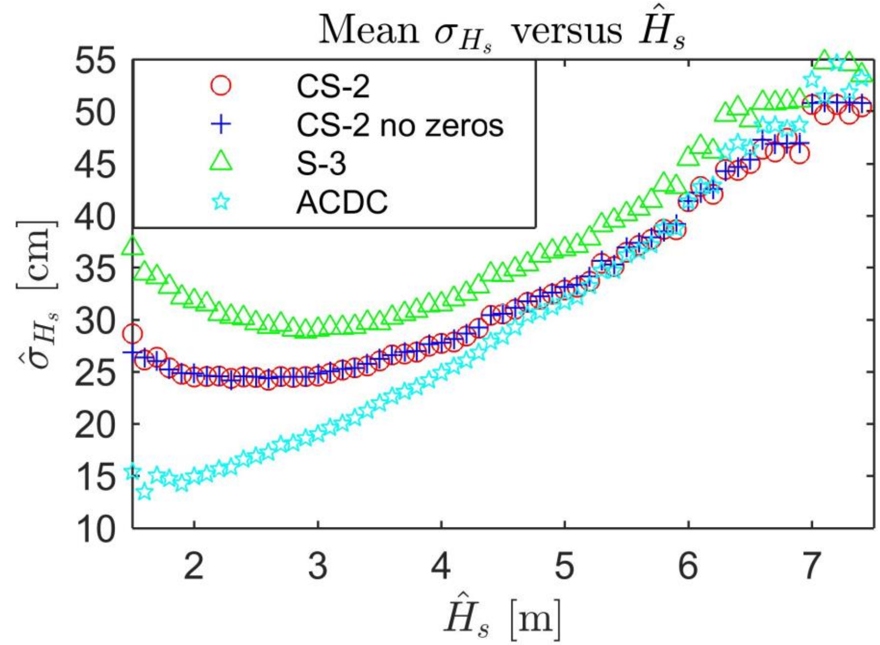
- Estimation noise increases as a function of SWH
- CS-2 with/without zeros very similar performance
- ACDC processing outperforms conventional processing (2 cm improvement)

SWH precision

Central Pacific



Agulhas



- Very good noise performance 25-35 cm for SWH 1.5-5 m
- CS-2 with/without zeros very similar performance
- CS-2 baselines improved performance w.r.t S-3 (5 cm)
- ACDC processing outperforms conventional CS-2 processing for LOW SWH < (10 cm improvement in precision for 1.5 m)

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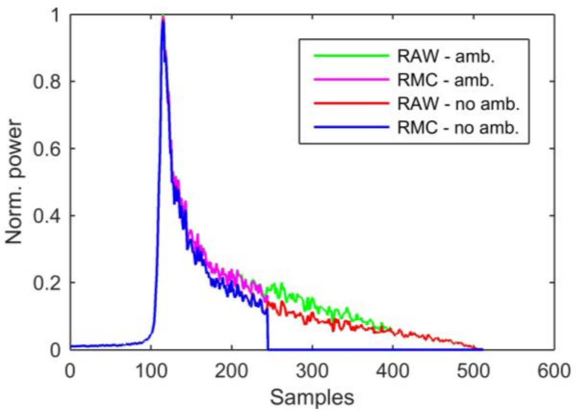
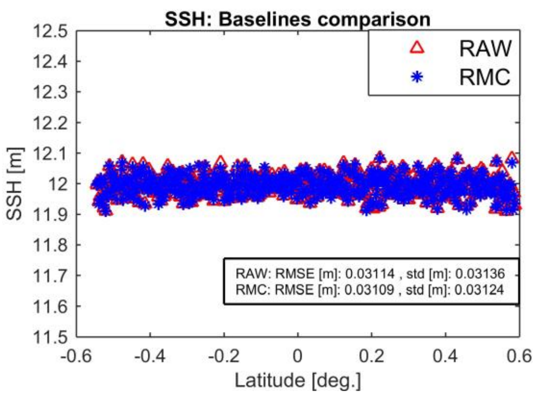
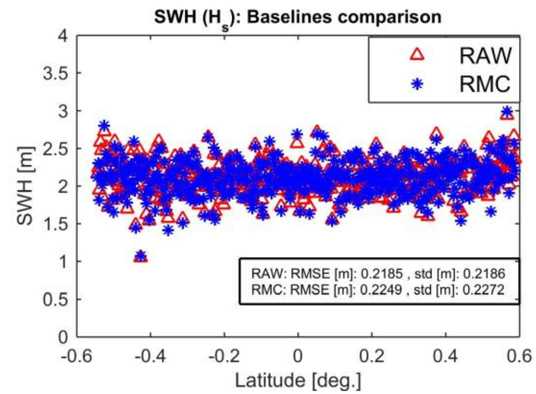
- Precision performance comparative study of different DDP :
  - Very good noise performance in SWH for conventional (25-35 cm for SWH 1.5-4 m)
  - CS-2 including and not the zeros in ML show similar results
  - S-3 degraded performance compared to CS-2 (1 cm degradation on SSH and 5 cm in SWH)
  - ACDC shows the best performance in SSH and SWH precision (improvement of 2 cm in SSH and 10-15 cm in SWH)
- Consistency on the results between two regions (homogeneous vs high-dynamics)
- Further studies to be performed in terms of accuracy with well-calibrated third-party data

- isardSAT developing the Ground Processor Prototype (GPP):
  - S-6 presents important technological improvements: interleaved near-continuous operation mode (HR or SAR and LR or LRM simultaneously) + digital architecture (matched filter operation instead of analog de-ramping) + on-board processing (RMC)







(*) **results presented in poster session, Instrument Processing (IPM_003)**: E. Makhoul, R. Escolà, A. Garcia-Mondéjar, G. Moyano, P. Garcia, M. Roca, M. Fornari, R. Cullen, "S6 P4 GPP: The Sentinel-6 Poseidon-4 Ground Processor Prototype: New simulation results".

THANK YOU !!

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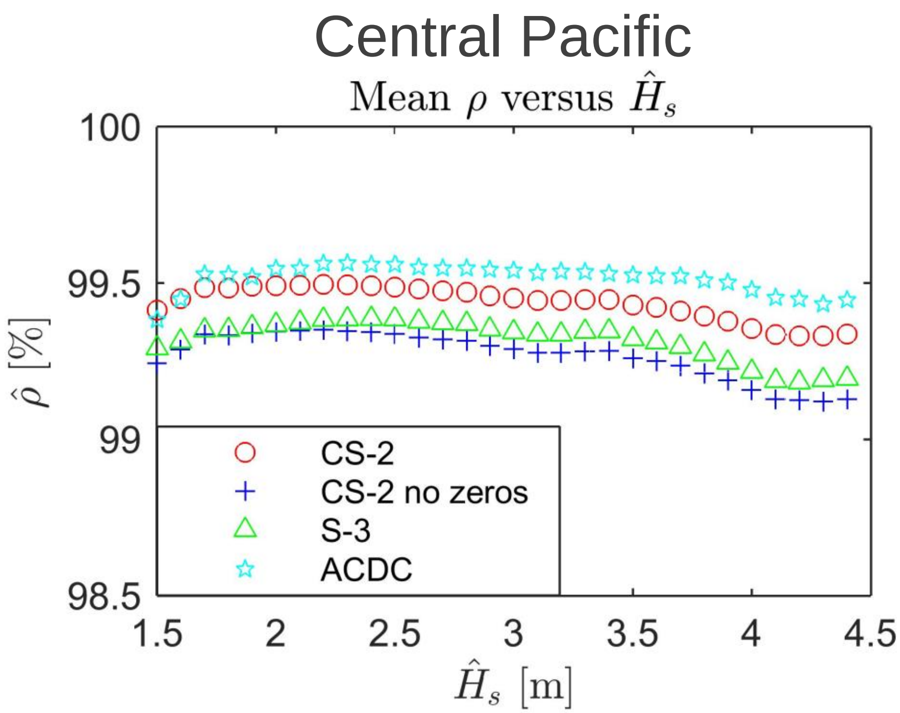
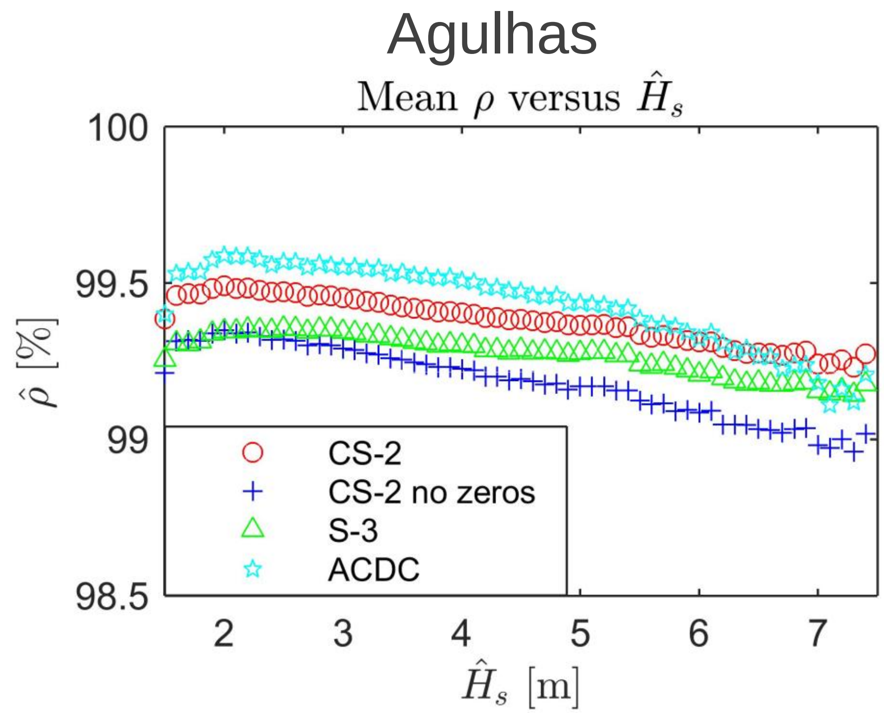
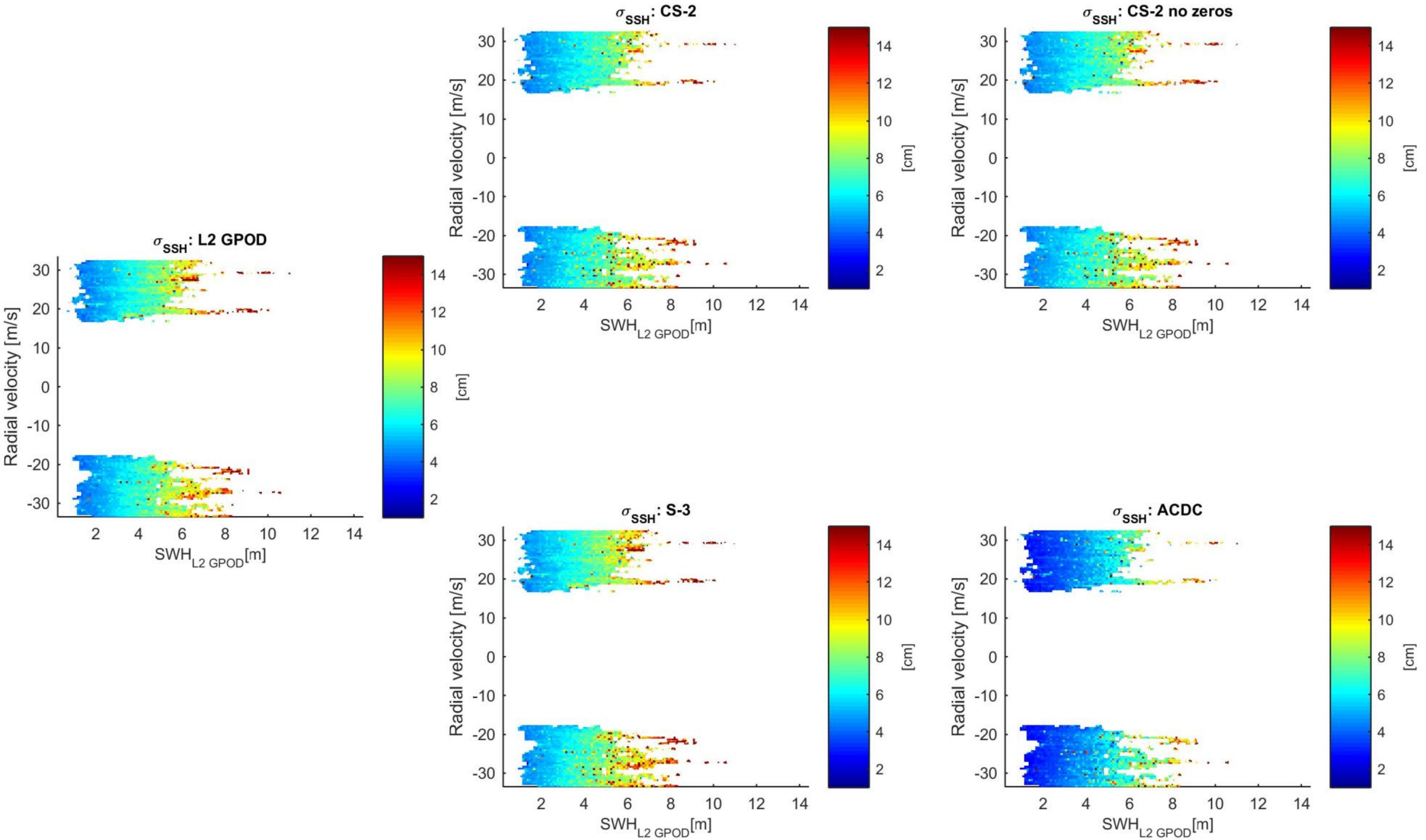
Correlation coefficient



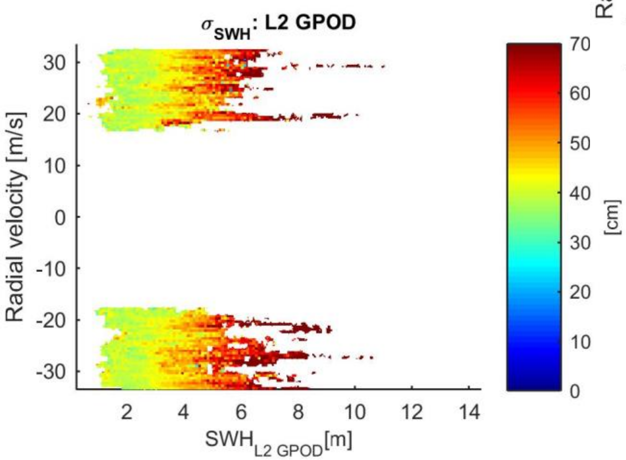


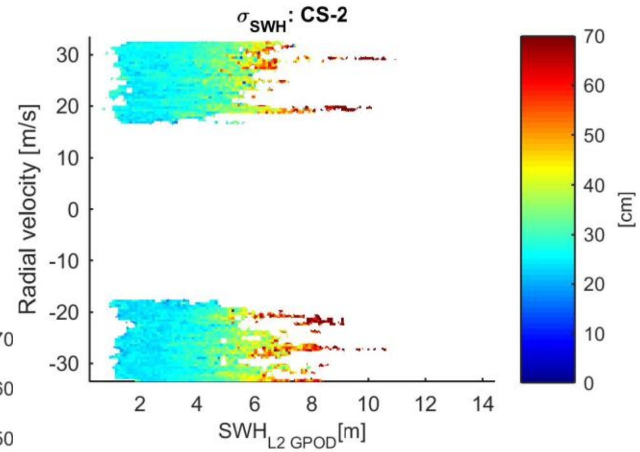
- Degradation on CS-2 no zeros w.r.t CS-2: Stack mask differences in L1B and L2 higher impact on CS-2 with no zeros in ML (discrepancies at end waveform)
- ACDC provides the best performance

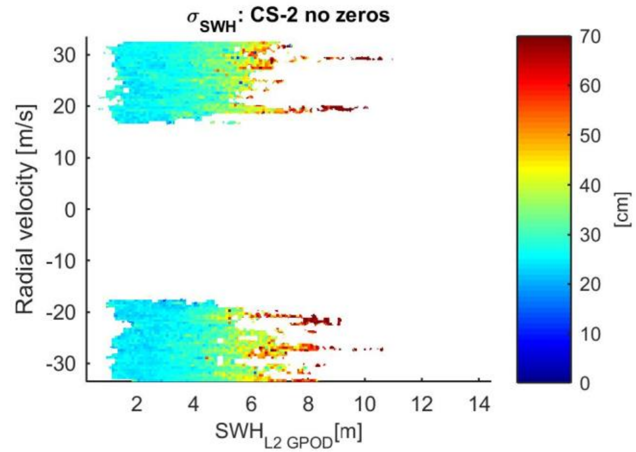
SSH precision maps: SWH and radial velocity dependency (Agulhas)

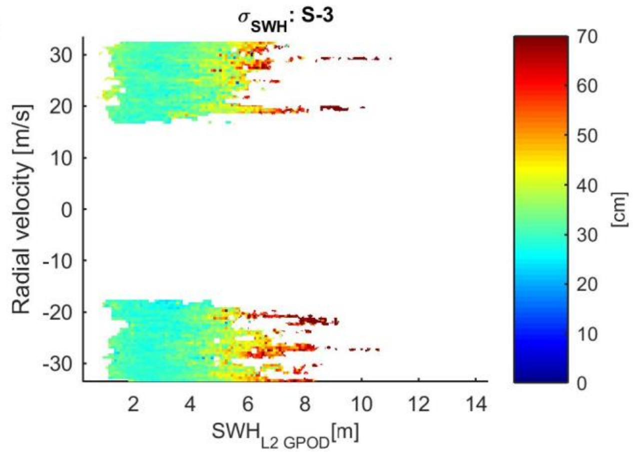


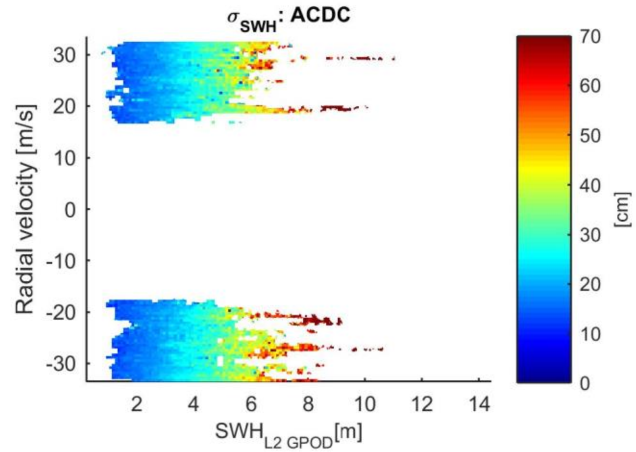
SWH precision maps: SWH and radial velocity dependency (Agulhas)











Impact of zeros in multi-looking