Performance comparison of Sentinel-3 and CryoSat-2 Delay-Doppler (SAR) processing baselines over Open Ocean and Coastal zones

E. Makhoul[1], A. Garcia-Mondéjar[1], R. Escolà[1], G. Moyano[1], M. Roca[1], D. Cotton[2], M. Restano[3], A. Ambrózio[3], J. Benveniste[3]

[1]isardSAT, [2]SatOC, [3]ESA-ESRIN

Outline

- Introduction
- Methodological framework
- Delay-Doppler processor (L1B)
- Analytical retracker (L2)
- Results: Performance comparison
- Conclusions

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Introduction

- Study carried out within **SCOOP** (*SAR Altimetry Coast & Open Ocean Performance*), ESA-SEOM Programme funding:
  - **Characterize** expected **performance S-3** costal zone & open-ocean
  - Develop & **evaluate ameliorations** to processing baseline (L1B+L2)
  - **isardSAT** to develop, implement & test ***Delay-Doppler Processor*** (DDP) → ***original + improved S-3*** processing ***baselines***

- **Preliminary comparative assessment of the S-3 processing baseline against CS-2** for **geophysical retrievals** [validation exercise]

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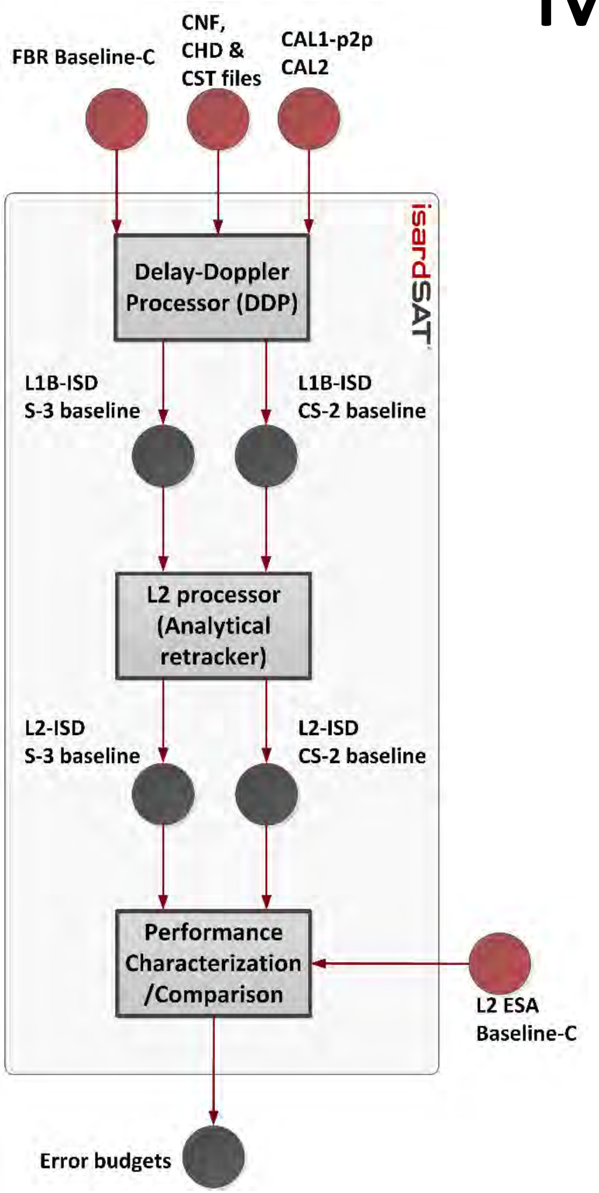
Methodology



- **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***)
- Performance **Geophysical retrievals**:
  - ***ISR L2*** a la Sentinel-3 and CryoSat-2: ***SAR ocean analytical retracker*** [Chris Ray et al. 2015]
  - ***ESA L2*** a la CryoSat-2: ***Laxon/Ridout sea-ice***

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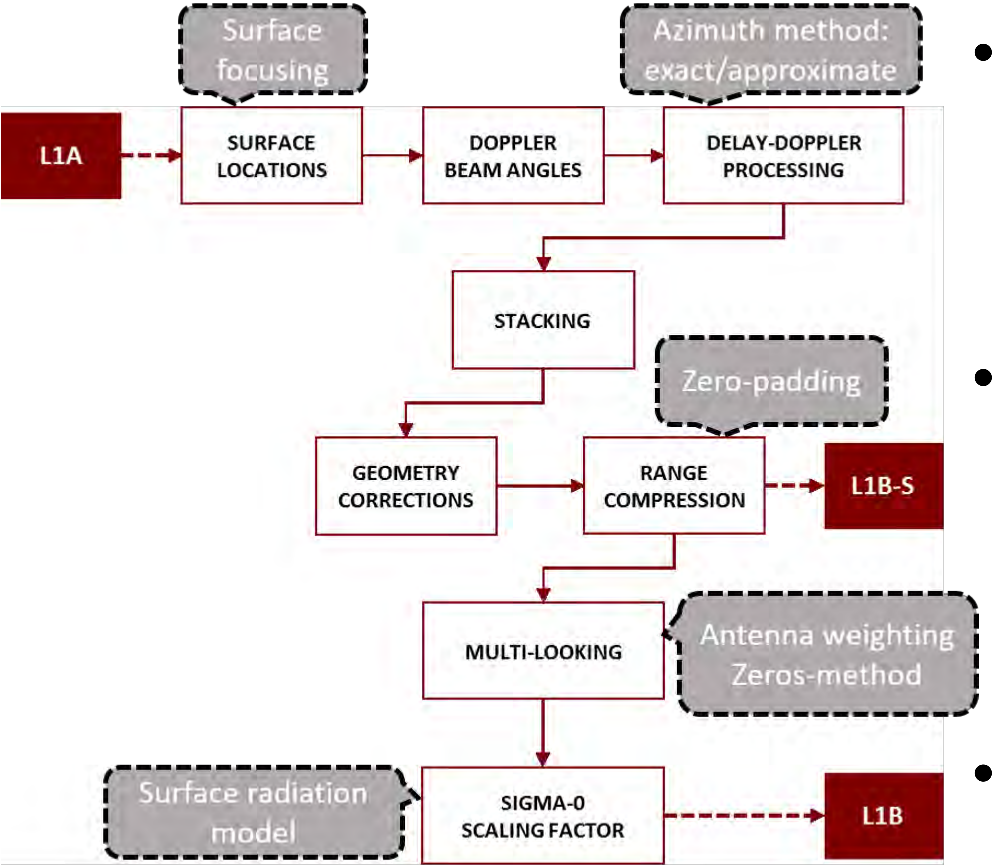
Delay-Doppler Processor (DDP)



- **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
- **Flexibility & Re-configurability**

(*) isardSAT DDP is included as open source in the DeDop platform, further details on presentation: Mònica Roca et al. “DeDop: The tool to process altimetry data yourself” at SAR altimetry workshop 2016

Processing baselines CS-2 & S-3

CS-2

- **Zero-padding** in range of **2**
- **Along-track Hamming** windowing (inter-burst)
- Stack masking of **edge beams:**
  - Beams with **look angle above** a given threshold are discarded

$$b \mid \; -0.6 \geq \theta_{look}\,(b) \geq 0.6$$

S-3

- **No zero-padding**
- **No Hamming** windowing
- Stack masking of **noisy beams**:
  - Beams with **noise floor** above a threshold are discarded

$$b \mid \mu_n(b) > \mu_{n,stack} + 3 \cdot \sigma_{n,stack}$$

Zero-samples included in the **multi-looking**

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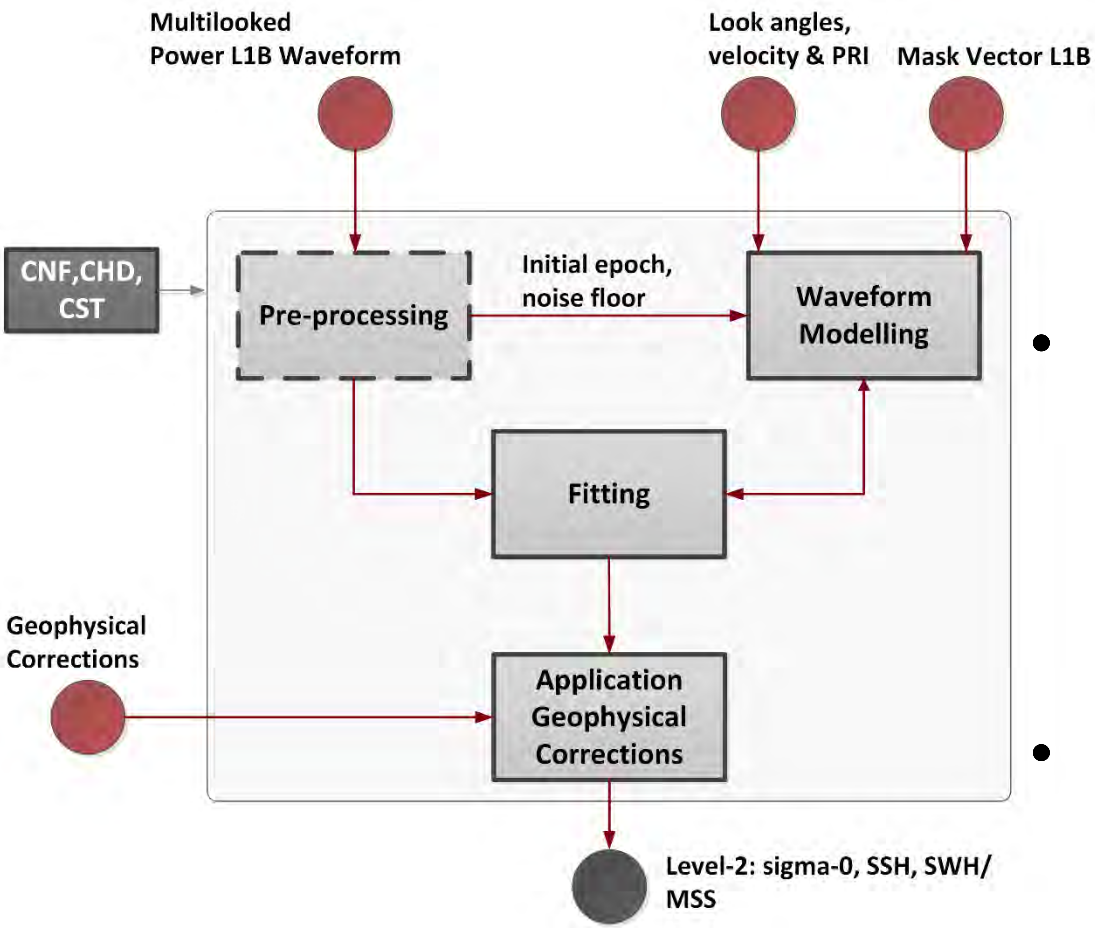
Analytical Retracker (L2)



- **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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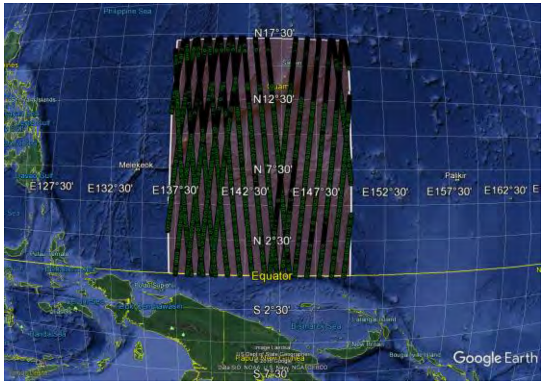
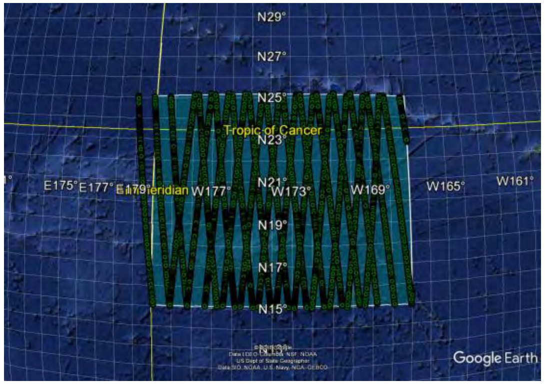
Areas of Interest (AOI)

AOI-1: West Pacific



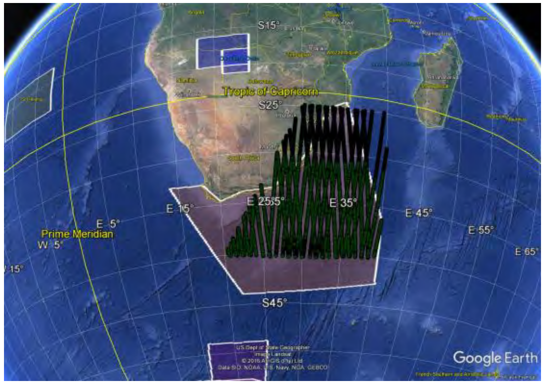
- Period 2013
- # tracks 375

AOI-2: Central Pacific



- Period 2013
- # tracks 360

AOI-3: Agulhas



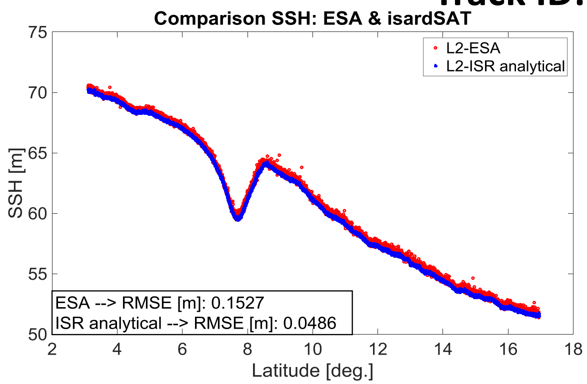
- Period 2013
- # tracks 517

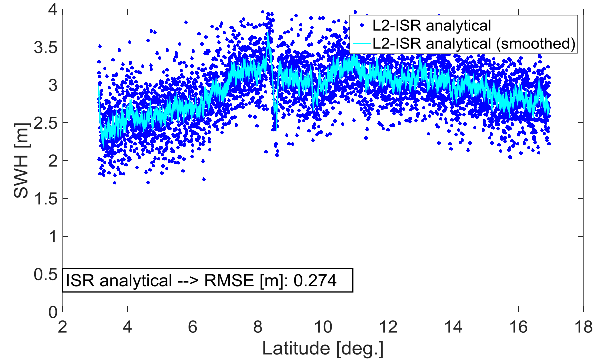
(*) Single CAL1-p2p & CAL2 applied to all regions and tracks, obtained as a temporal average of all CAL1 & CAL2 products from 01/03/2011 to 30/04/2016

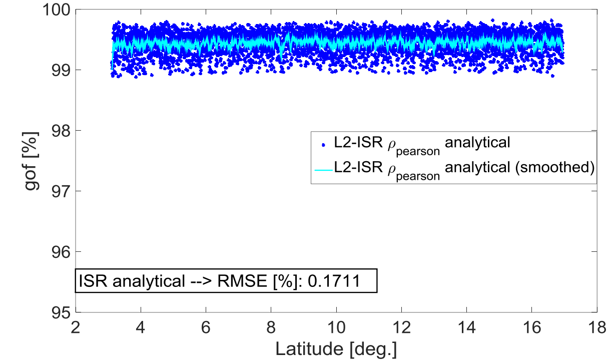
AOI-1: individual results

Track ID: 20130110T065127_20130110T065515

S-3

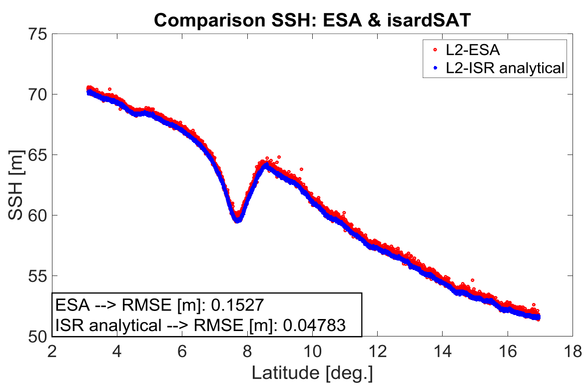


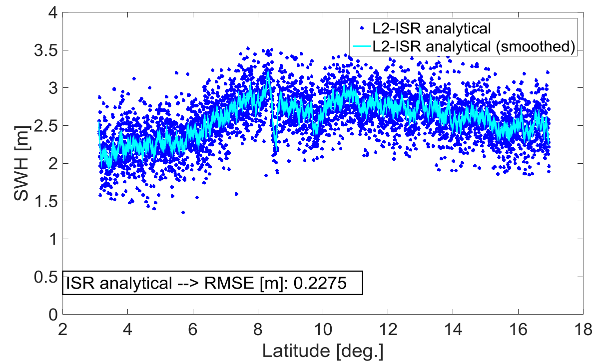


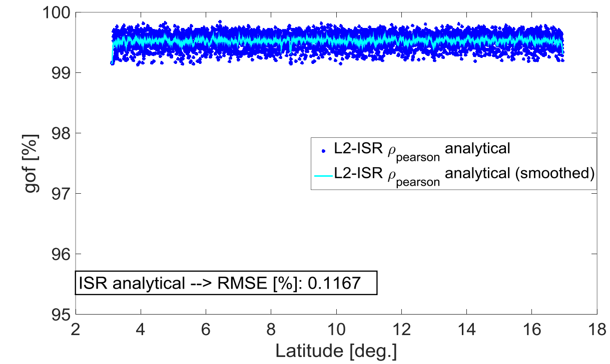


SSH **SWH** **gof (good. fit.)**

CS-2

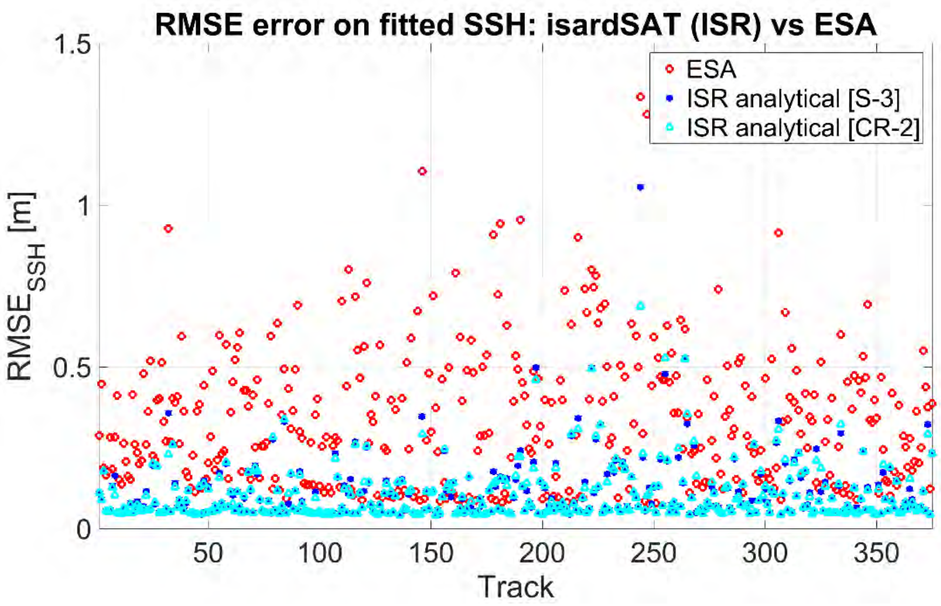


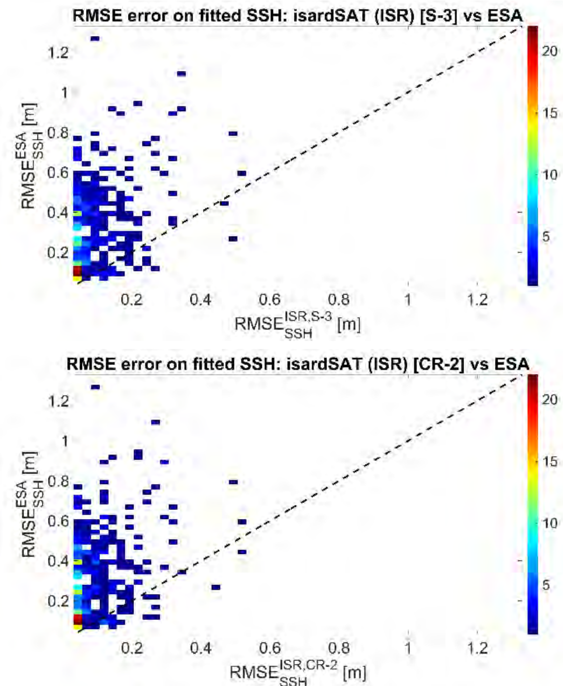




(*) **RMSE (root mean square error)** computed **w.r.t smoothed version** of the geophysical retrievals **over track** using a **sliding window** with a size of **20 samples (surfaces)** → equivalent to **1-Hz averaging**

AOI-1: SSH noise-performance





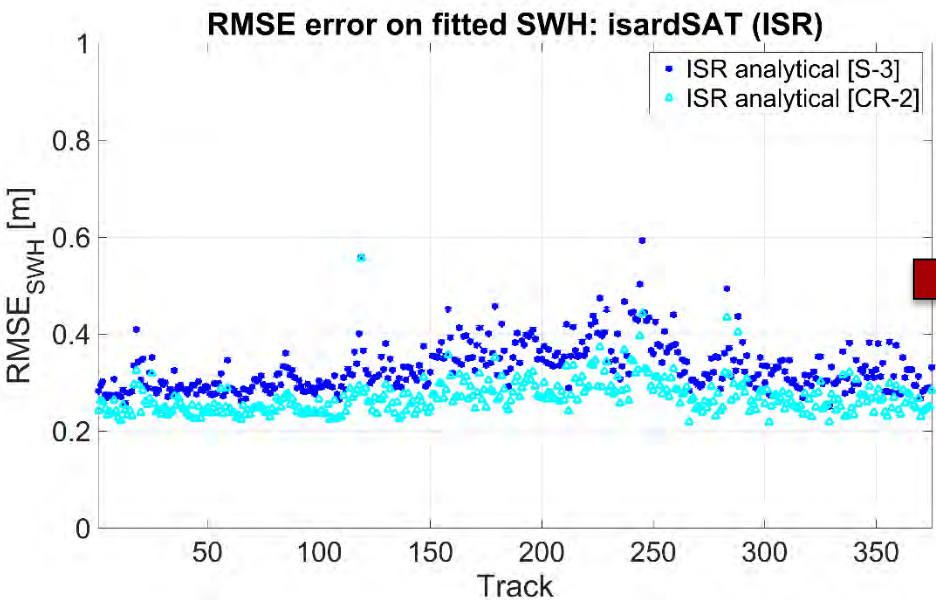
RMSE 2-D histogram (ISR [S-3/CS-2] vs ESA)

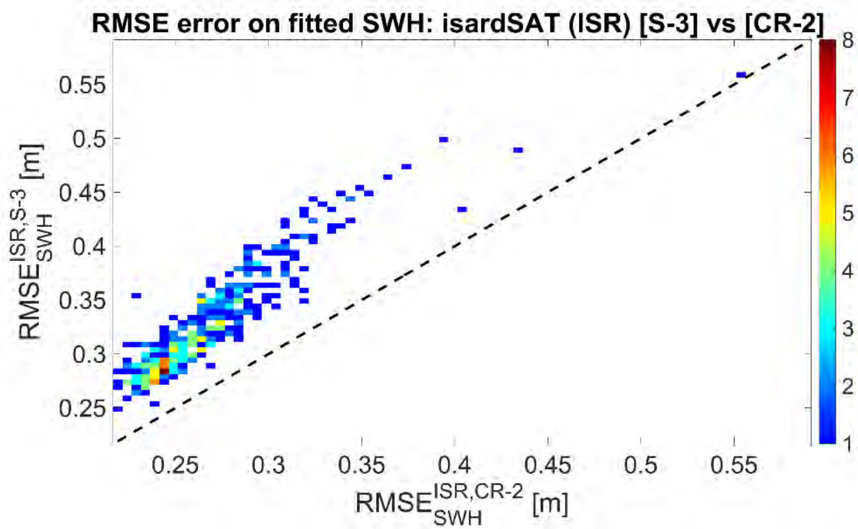
Source	μ_{RMSE} [m]	σ_{RMSE} [m]
ESA	**0.3404**	**0.2101**
ISR a la S-3	0.1093	0.0918
ISR a la CS-2	**0.1078**	**0.0826**

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

- **ISR retracker** (**analytical SAR ocean**) provides **improved** performance compared to **sea-ice ESA retracker**
- **CS-2 baseline** has **similar** performance (**slightly better**) compared **to S-3** one

AOI-1: SWH noise-performance





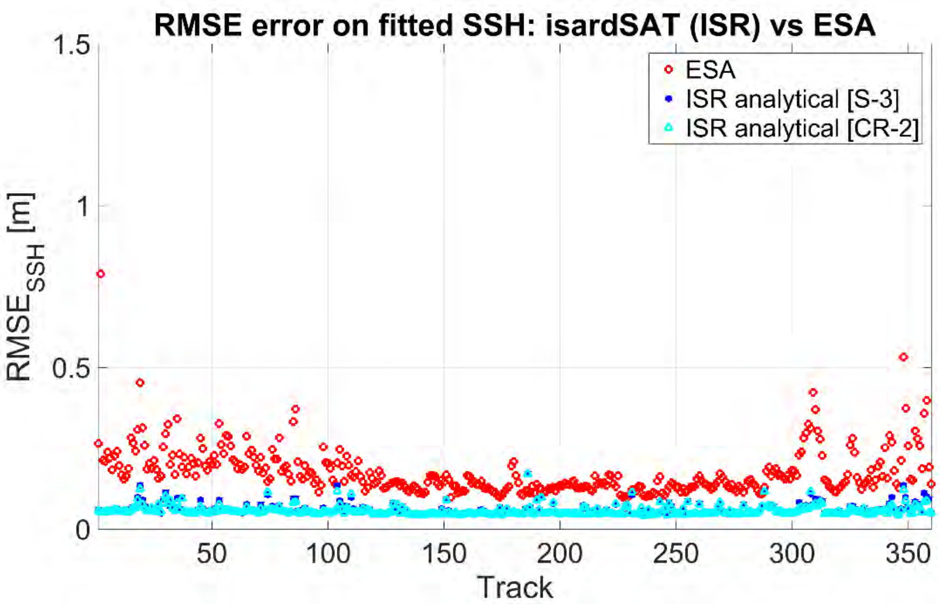
RMSE 2-D histogram (CR-2 vs S-3)

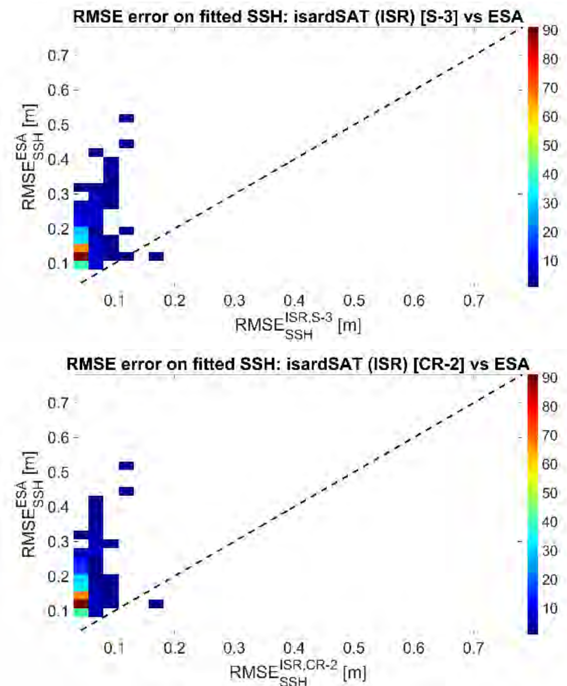
Source	μ_{RMSE} [m]	σ_{RMSE} [m]
ISR a la S-3	0.3315	0.0493
ISR a la CS-2	**0.2706**	**0.0362**

- **CS-2 baseline** improved performance (**around 6 cm less noisy**) compared **to S-3** one
- **CS-2 baseline better** performance in terms of **accuracy (mean RMSE)** and **stability (std of RMSE)**

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

AOI-2: SSH noise-performance





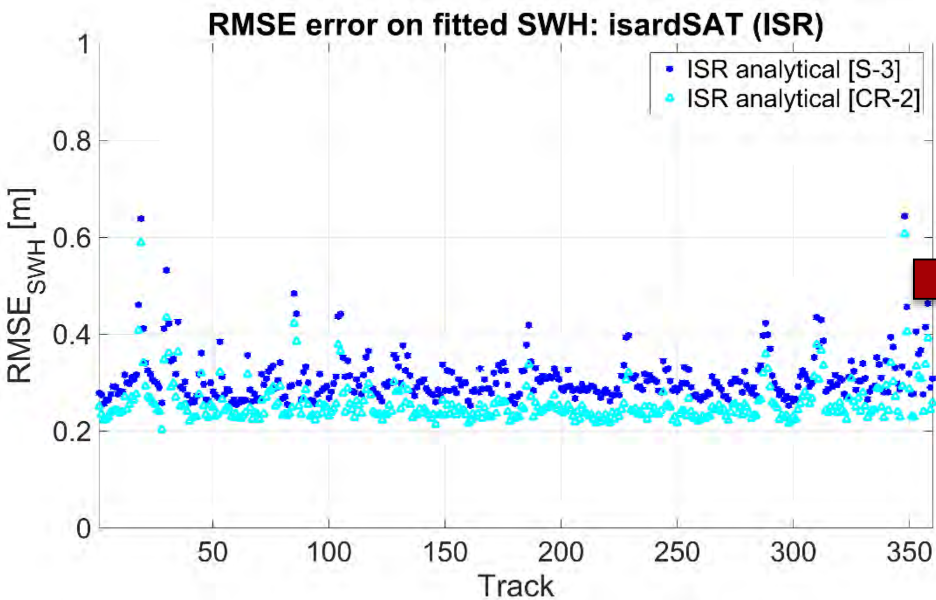
RMSE 2-D histogram (ISR [S-3/CS-2] vs ESA)

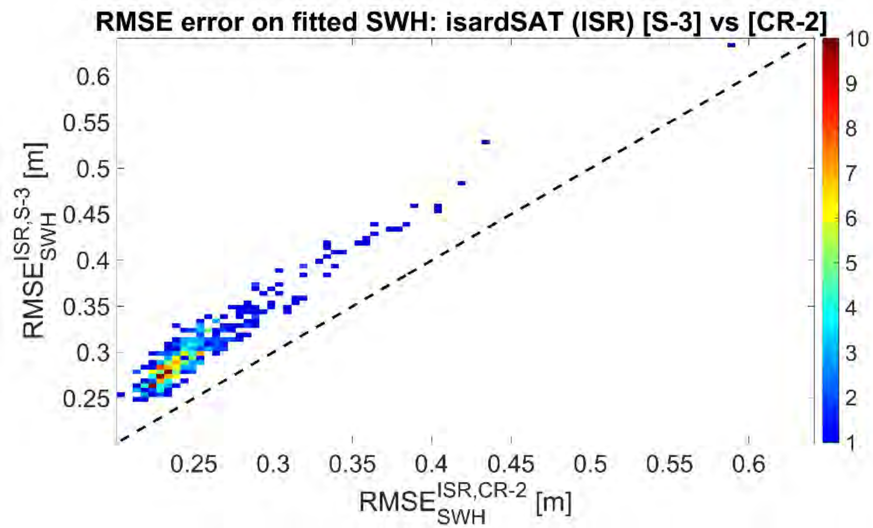
Source	μ_{RMSE} [m]	σ_{RMSE} [m]
ESA	0.1760	0.0714
ISR a la S-3	0.0619	0.0168
ISR a la CS-2	0.0594	0.0153

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

- **ISR retracker (analytical SAR ocean)** provides **improved** performance compared to **sea-ice ESA retracker**
- **CS-2 baseline** has **similar** performance (**slightly better**) compared **to S-3** one

AOI-2: SWH noise-performance





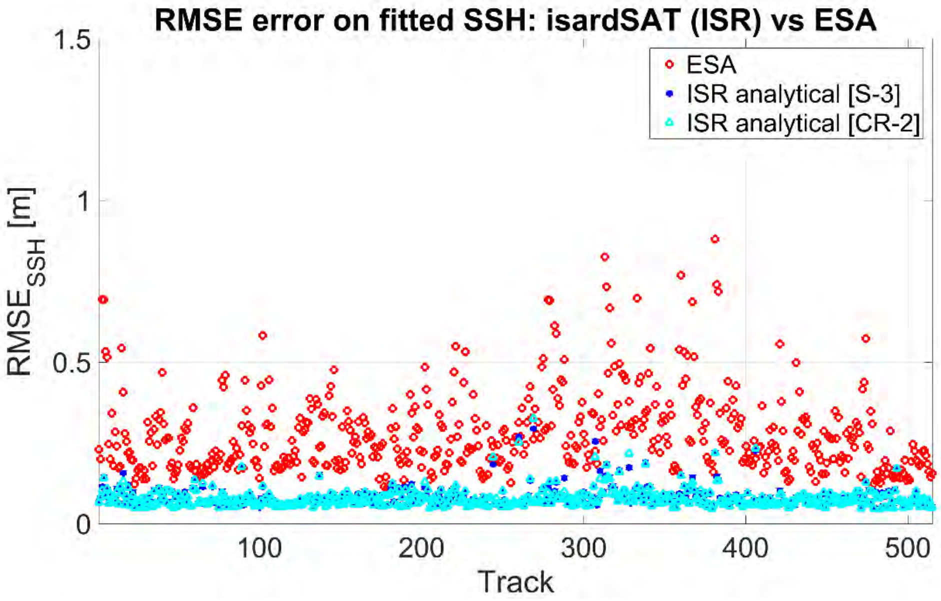
RMSE 2-D histogram (CR-2 vs S-3)

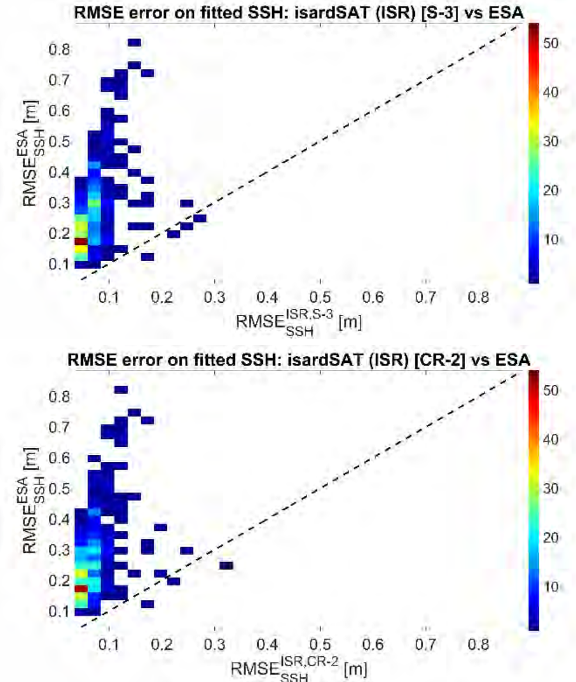
Source	μ_{RMSE} [m]	σ_{RMSE} [m]
ISR a la S-3	0.3086	0.0492
ISR a la CS-2	**0.2572**	**0.0441**

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

- **CS-2 baseline** improved performance (**around 5 cm less noisy**) compared **to S-3** one
- **CS-2 baseline better** performance in terms of **accuracy (mean RMSE)** and very small improvement in **stability (std of RMSE)**

AOI-3: SSH noise-performance





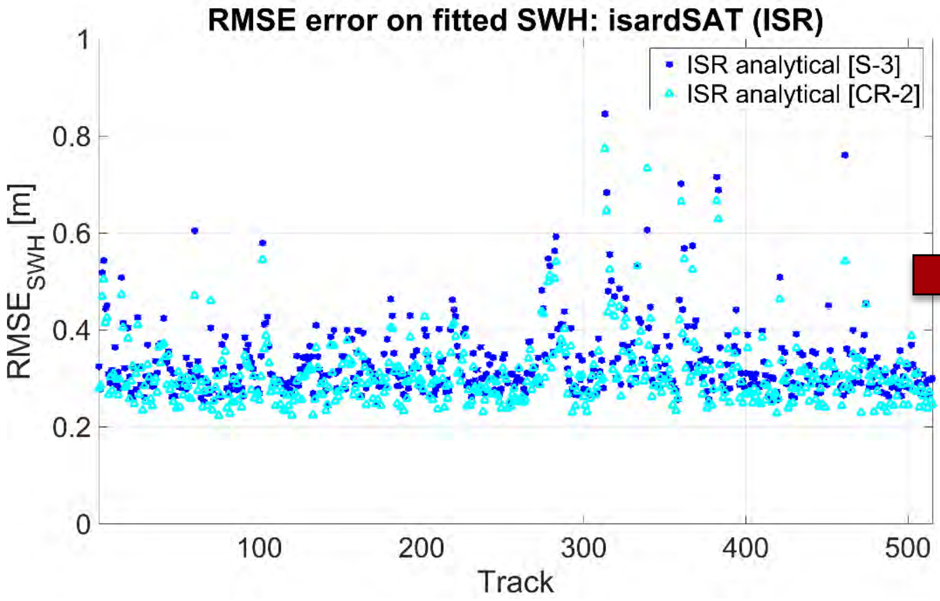
RMSE 2-D histogram (ISR [S-3/CS-2] vs ESA)

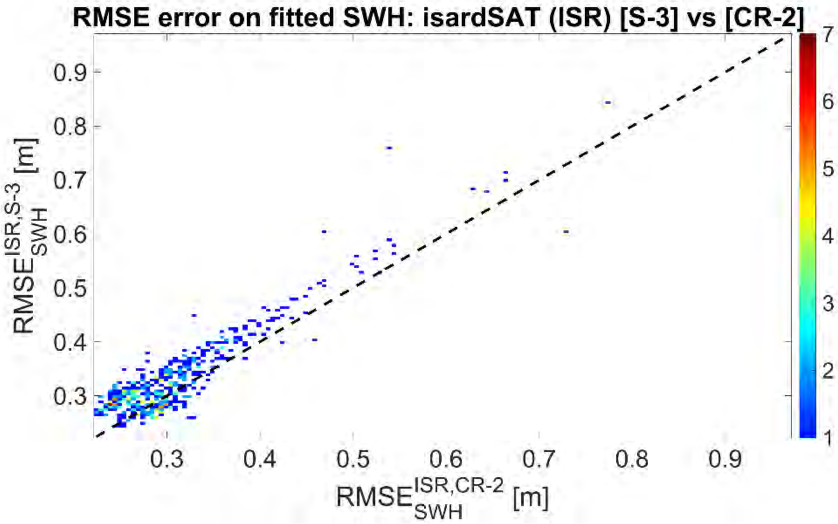
Source	μ_{RMSE} [m]	σ_{RMSE} [m]
ESA	0.2785	0.1237
ISR a la S-3	0.0814	0.0291
ISR a la CS-2	0.0805	0.0290

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

- **ISR retracker (analytical SAR ocean)** provides **improved** performance compared to **sea-ice ESA retracker**
- **CS-2 baseline** has very **similar** performance compared **to S-3** one

AOI-3: SWH noise-performance





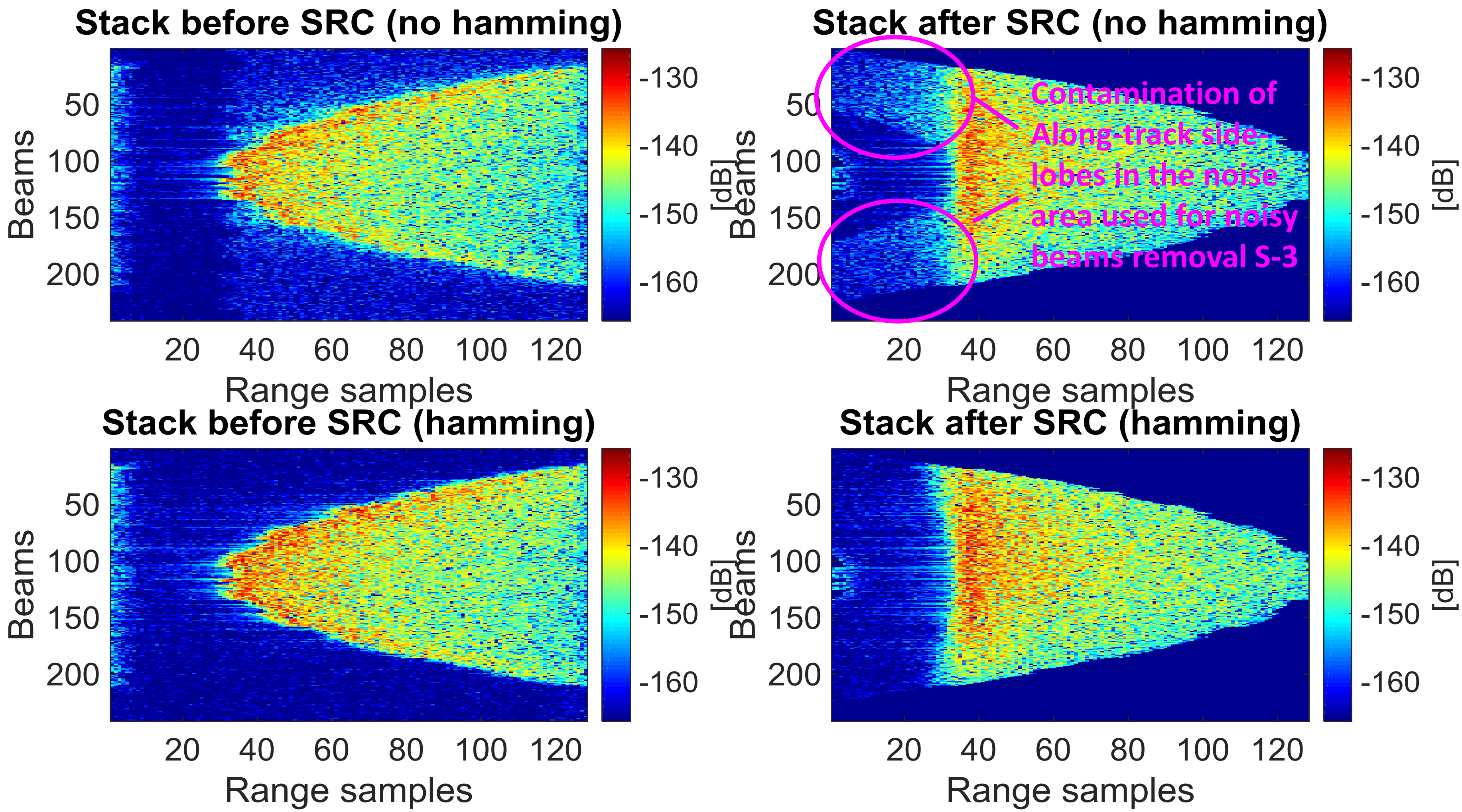
RMSE 2-D histogram (CR-2 vs S-3)

Source	μ_{RMSE} [m]	σ_{RMSE} [m]
ISR a la S-3	0.3348	0.0812
ISR a la CS-2	**0.3105**	**0.0760**

- **CS-2 baseline improved very little** performance **(2 cm less noisy)** compared **to S-3** one
- **CS-2 baseline better** performance in terms of **accuracy (mean RMSE)** and very small improvement in **stability (std of RMSE)**

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

Impact of Windowing



- Impact on the **geophysical retrieval performance (SWH)** & **impairment** on the **noise floor estimation** at stack level **for noisy beams removal a la S-3**

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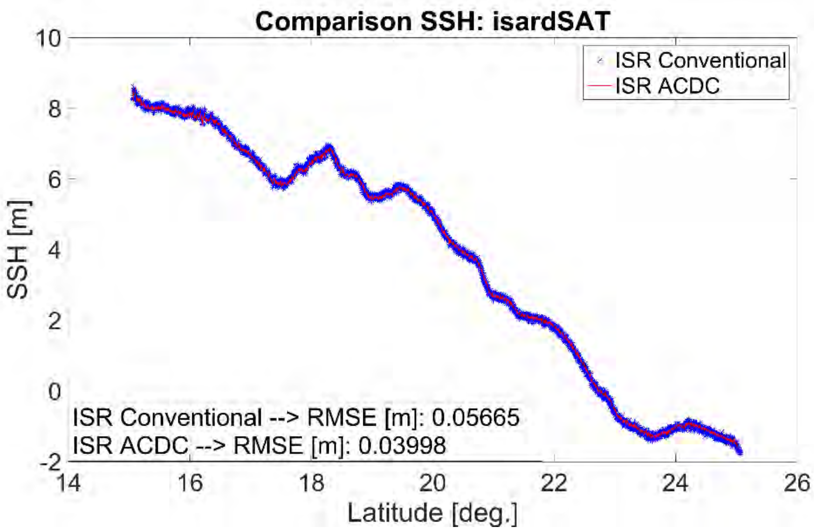
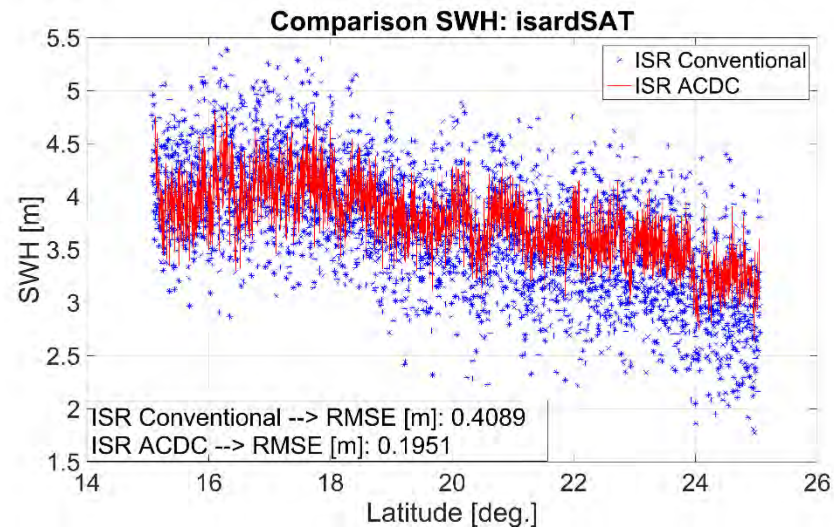
Conclusions

- **Preliminary comparative evaluation** of **CS-2** and **S-3** processing **baselines** (preparation **Phase-2 SCOOP**)
- **L1B + L2 complete processing chain** adapted at **isardSAT** (refined **analytical SAR ocean retracker**)
- **CS-2** provides an **improved estimation noise** for **SWH** retrieval (3 ROIs)
- **CS-2** provides **slightly better performance** in estimation noise for **SSH**
- **No windowing** results into **side-lobe contamination (noisy beams removal) → performance degradation**

Future Studies

- Explore **methodologies** for noisy **beams removal** → SNR-based (Peak-to-noise ratio)
- Inclusion of **ACDC processing** at L1B (improved estimation noise performance)





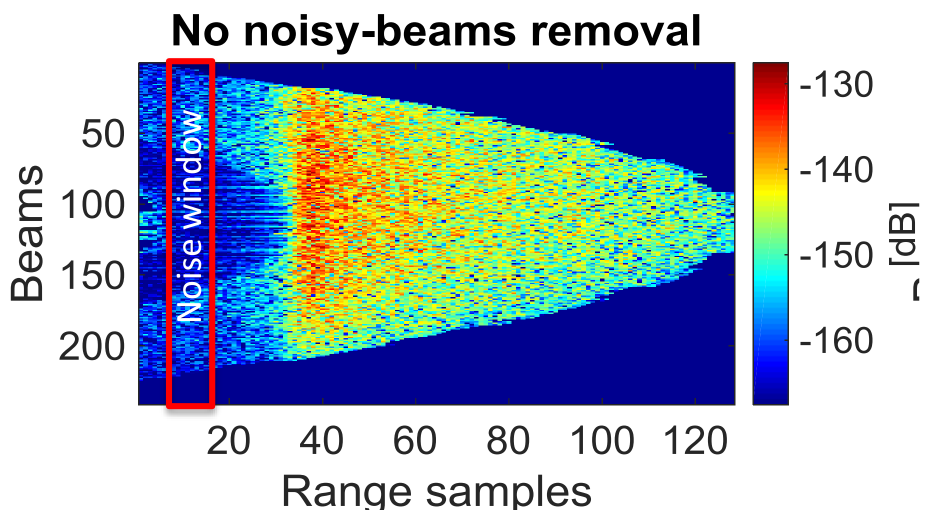
(*) E. Makhoul, C. Ray, M. Roca, A. Garcia and R. Escolà, "Application and Evaluation of ACDC Delay-Doppler processing over CryoSat-2 for Open-Ocean zones" at SAR altimetry workshop 2016

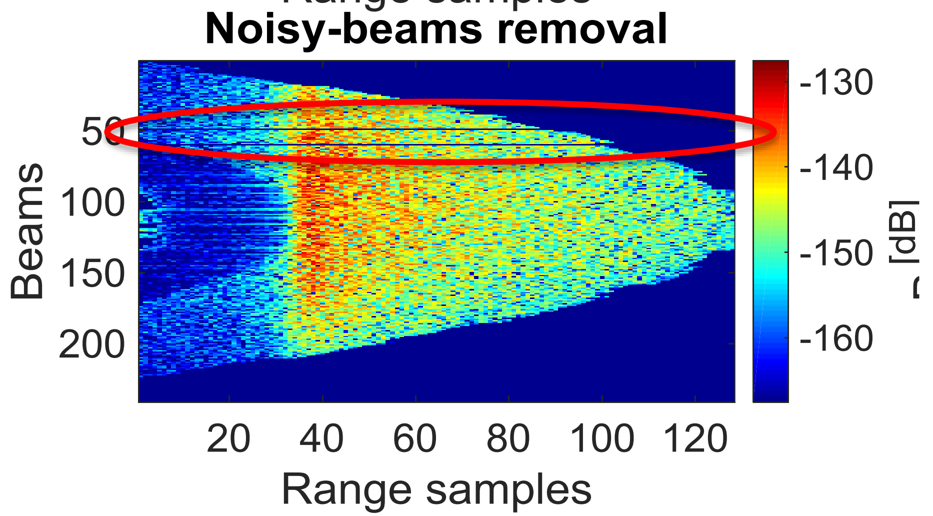
Thank you !!

eduard.makhoul@isardsat.co.uk

Noisy Beams Removal (I)

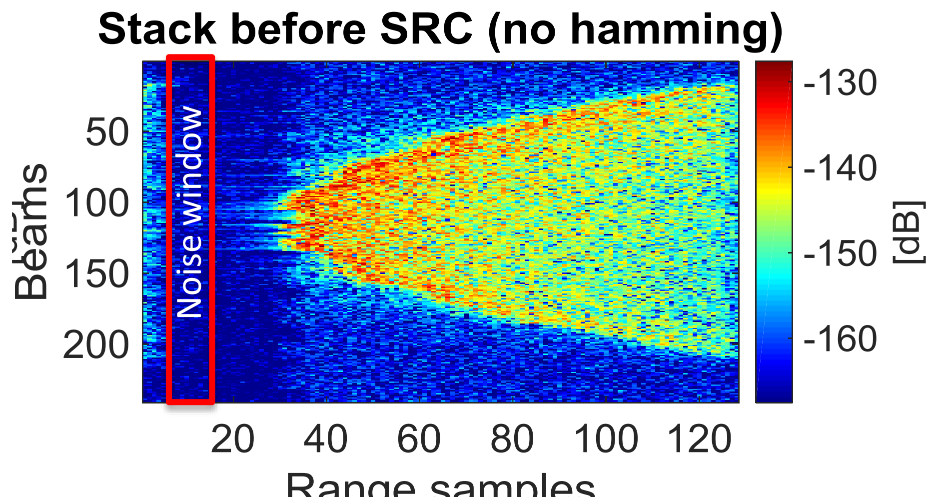
- **S-3** removes **noisy beams as** $b \mid \mu_n(b) > \mu_{n,stack} + 3 \cdot \sigma_{n,stack}$ (statistics of noise in the estimation window)
- **Side-lobes contaminate** estimation of **noise statistics**
- Removal of **few "noisy" beams** (even those **not at edges & with sufficient SNR**)

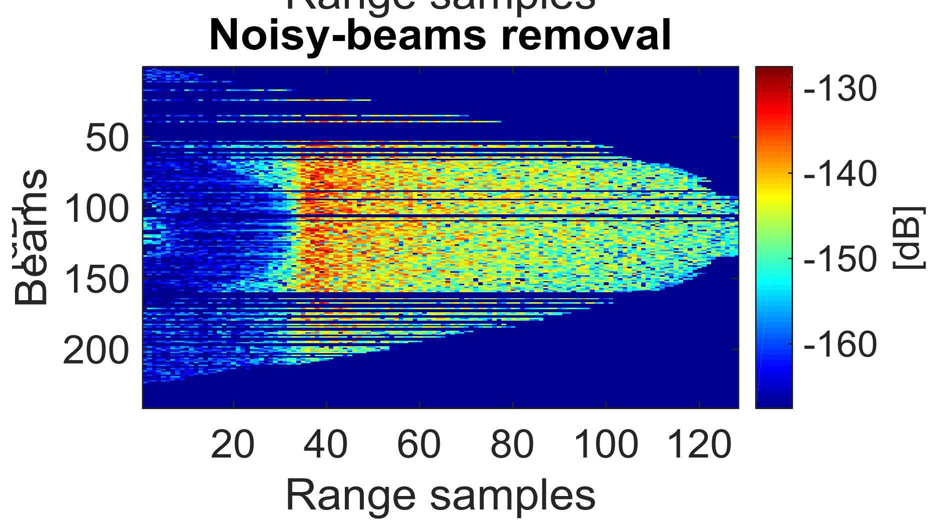




Noisy Beams Removal (II)

- **Alternative**: **estimate noise statistics before SRC** (minimize impact of side-lobes)
- **Higher number beams filtered out** → even those **with sufficient SNR**
- Alternative is to **use windowing (along-track)** + **strategy based on the SNR** (or **peak-to-noise ratio/PNR**)

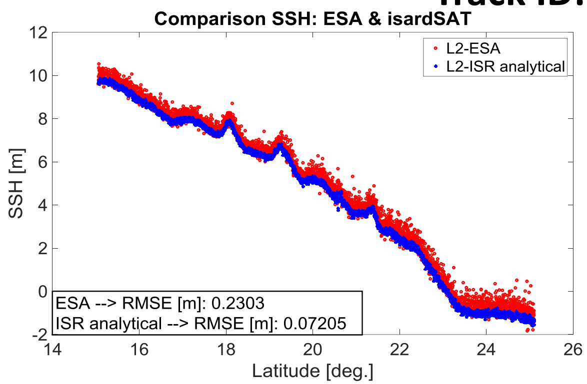


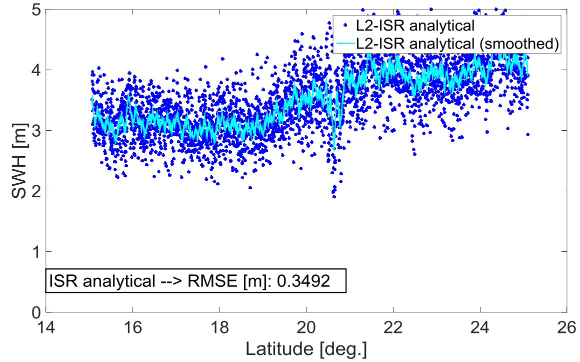


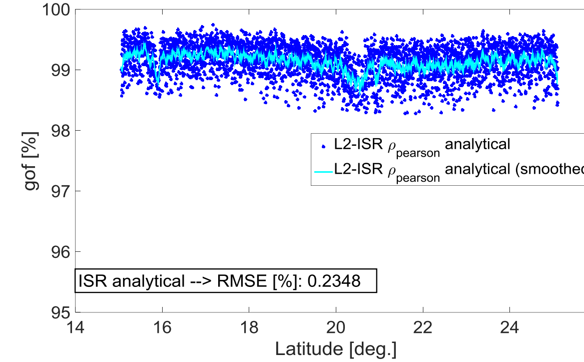
AOI-2: individual results

Track ID: 20130130T030619_20130130T030904

S-3

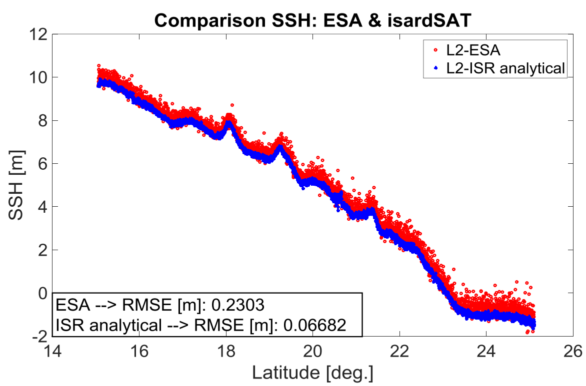


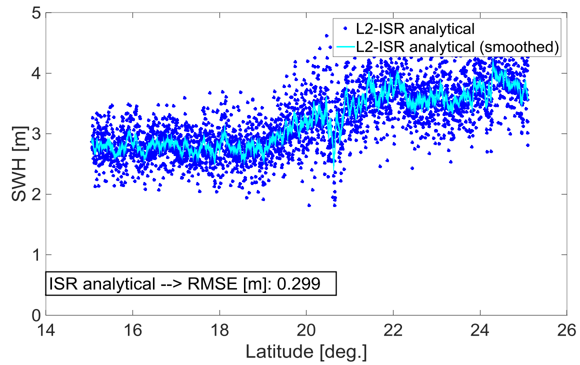


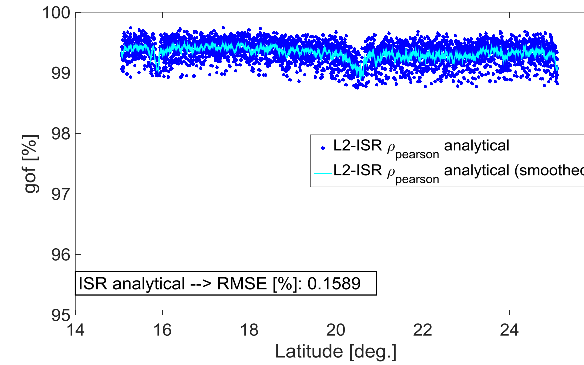


SSH **SWH** **gof (good. fit.)**

CS-2





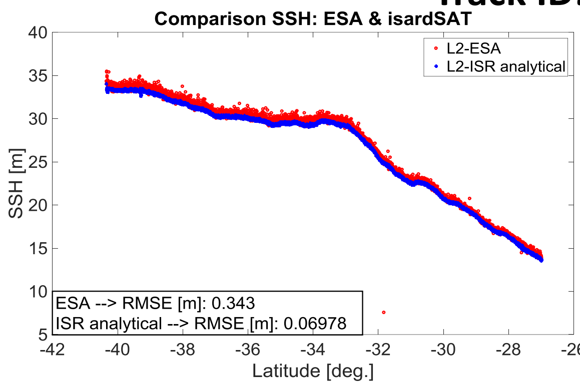


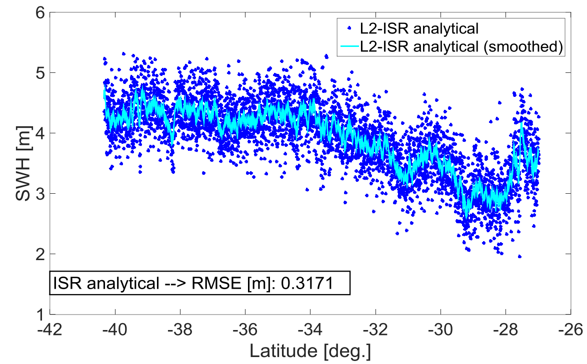
(*) **RMSE (root mean square error)** computed **w.r.t smoothed version** of the geophysical retrievals **over track** using a **sliding window** with a size of **20 samples (surfaces)** → equivalent to **1-Hz averaging**

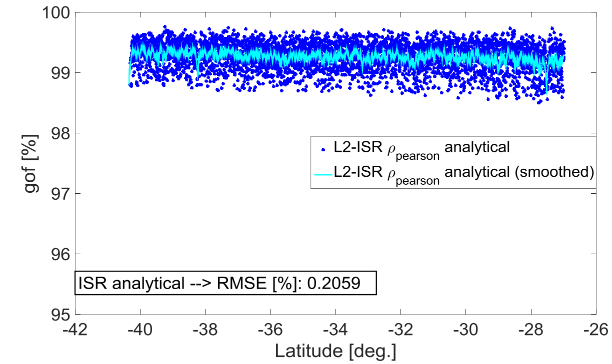
AOI-3: individual results

Track ID: 20130106T134449_20130106T134901

S-3

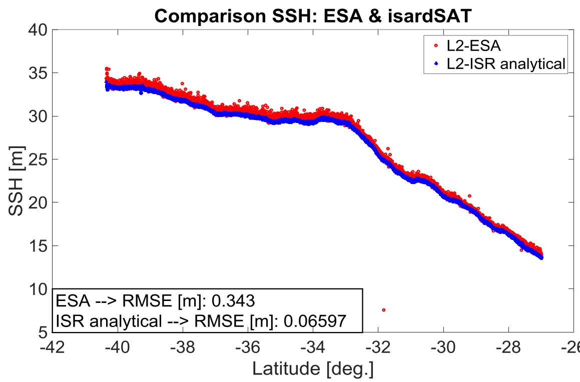


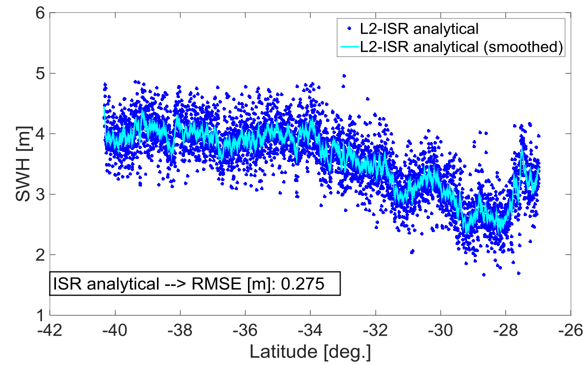


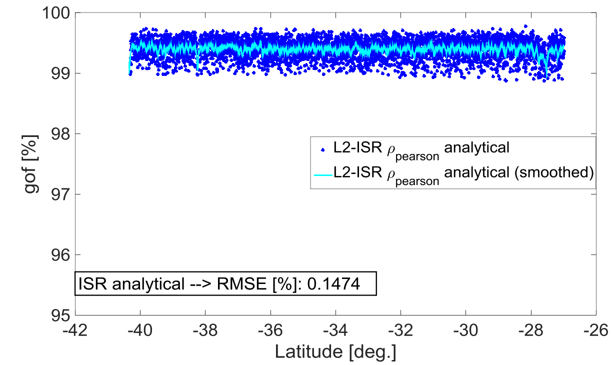


SSH **SWH** **gof (good. fit.)**

CS-2





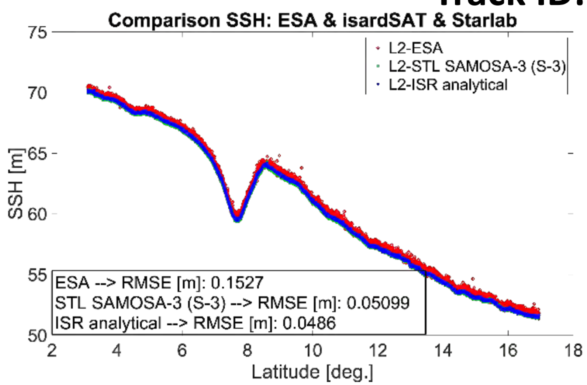


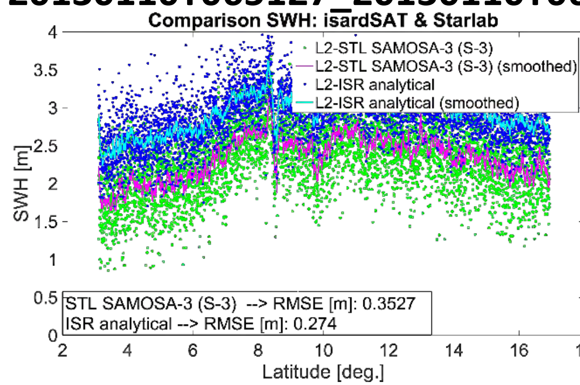
(*) **RMSE (root mean square error)** computed **w.r.t smoothed version** of the geophysical retrievals **over track** using a **sliding window** with a size of **20 samples (surfaces)** → equivalent to **1-Hz averaging**

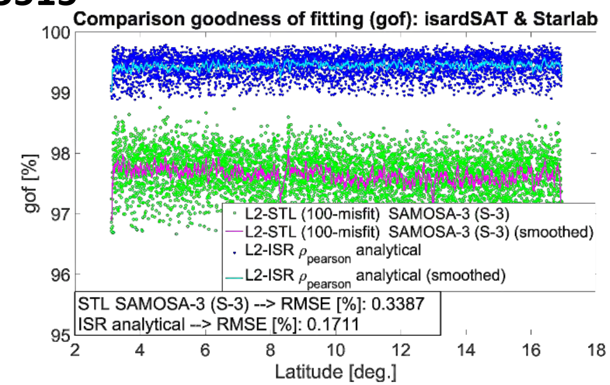
AOI-1: Comparison ESA & Starlab

Track ID: 20130110T065127_20130110T065515

S-3

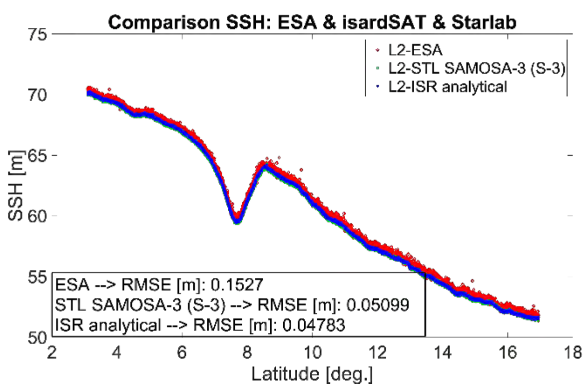


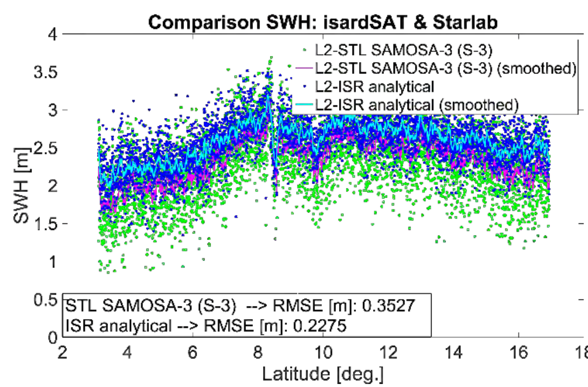


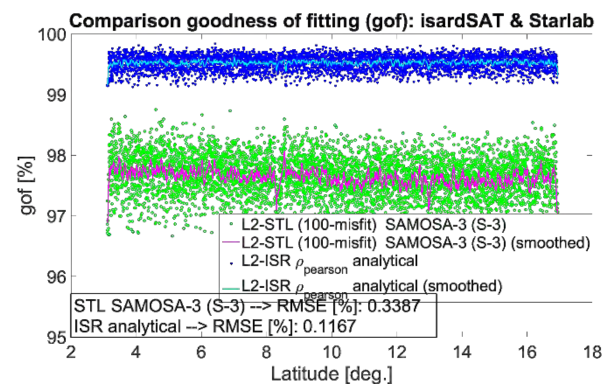


SSH **SWH** **gof (good. fit.)**

CS-2





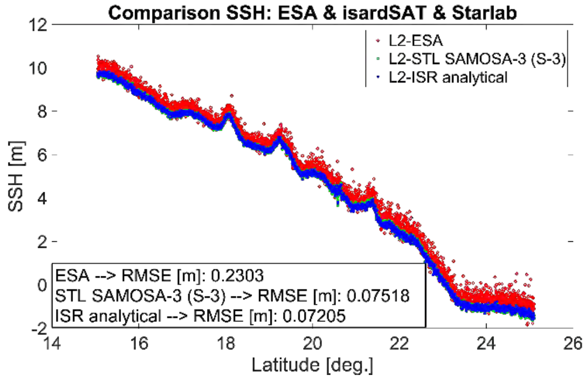


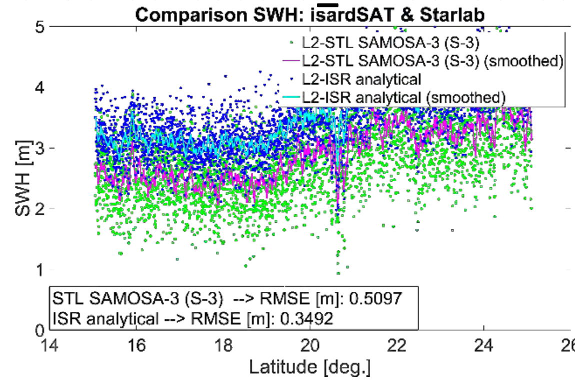
(*) RMSE (root mean square error) computed w.r.t smoothed version of the geophysical retrievals over track using a sliding window with a size of 20 samples (surfaces) → equivalent to 1-Hz averaging

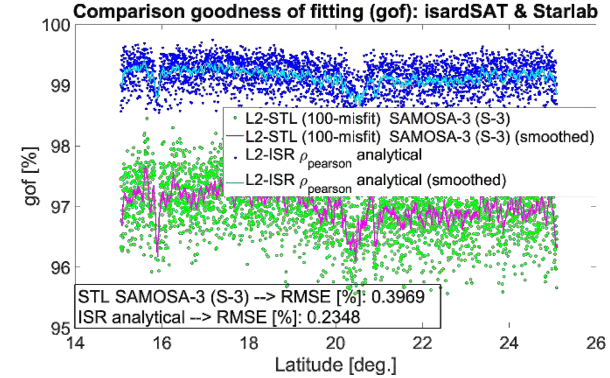
AOI-2: Comparison ESA & Starlab

Track ID: 20130130T030619_20130130T030904

S-3

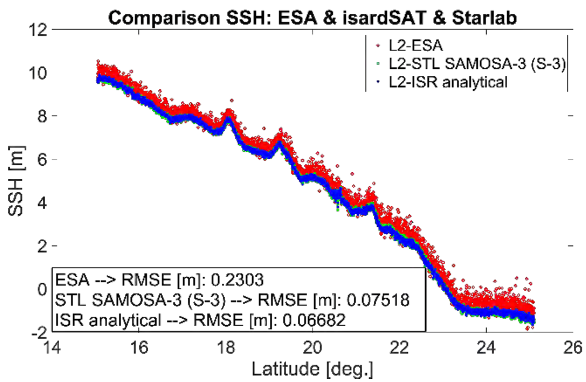


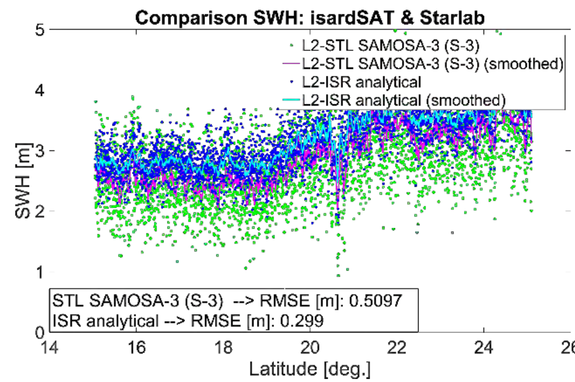


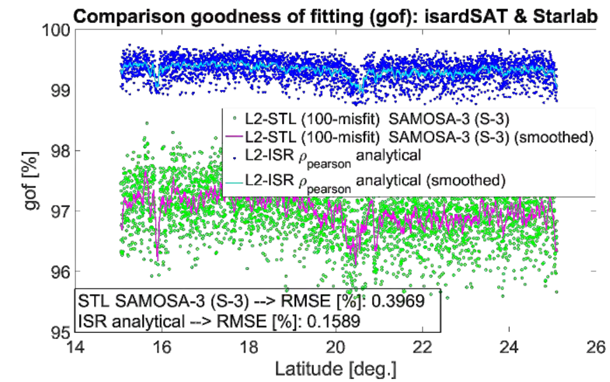


SSH **SWH** **gof (good. fit.)**

CS-2





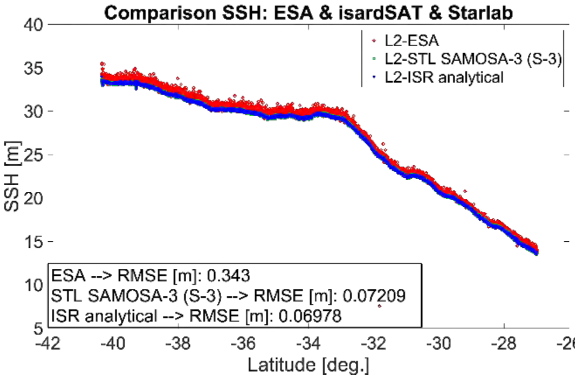


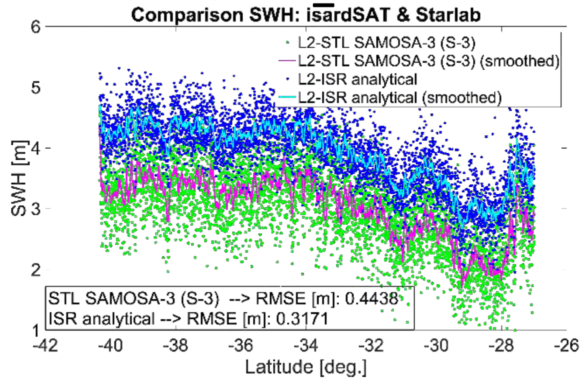
(*) RMSE (root mean square error) computed w.r.t smoothed version of the geophysical retrievals over track using a sliding window with a size of 20 samples (surfaces) → equivalent to 1-Hz averaging

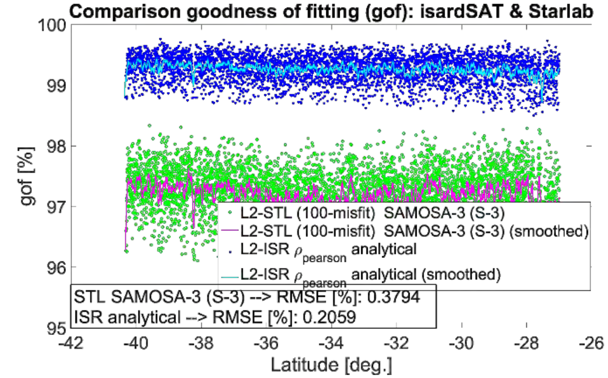
AOI-3: Comparison ESA & Starlab

Track ID: 20130106T134449_20130106T134901

S-3

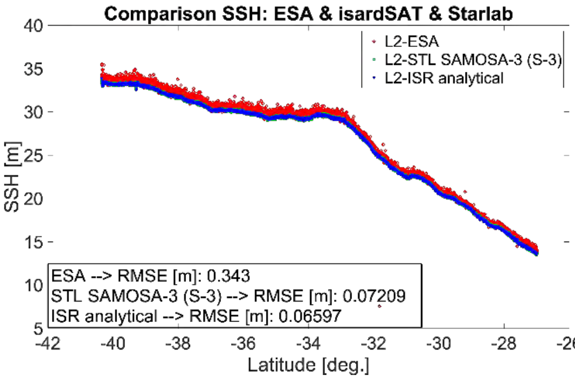


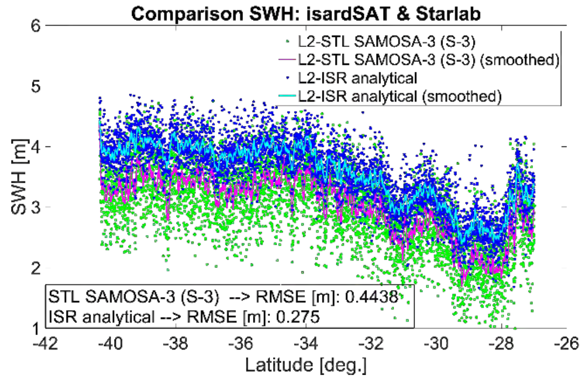


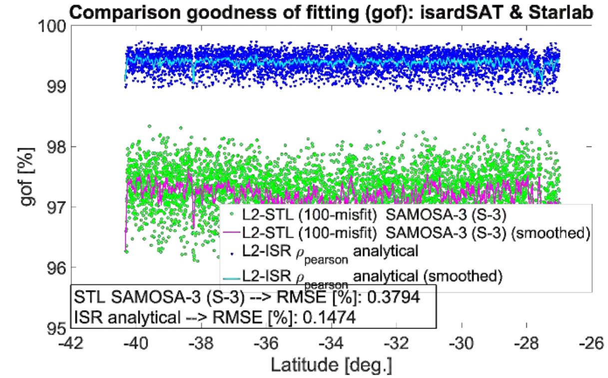


SSH **SWH** **gof (good. fit.)**

CS-2



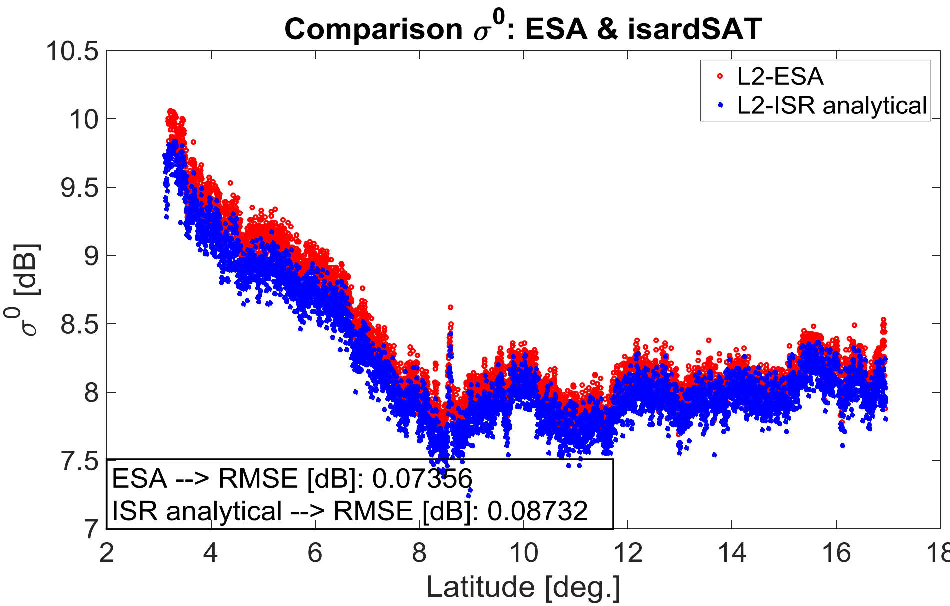




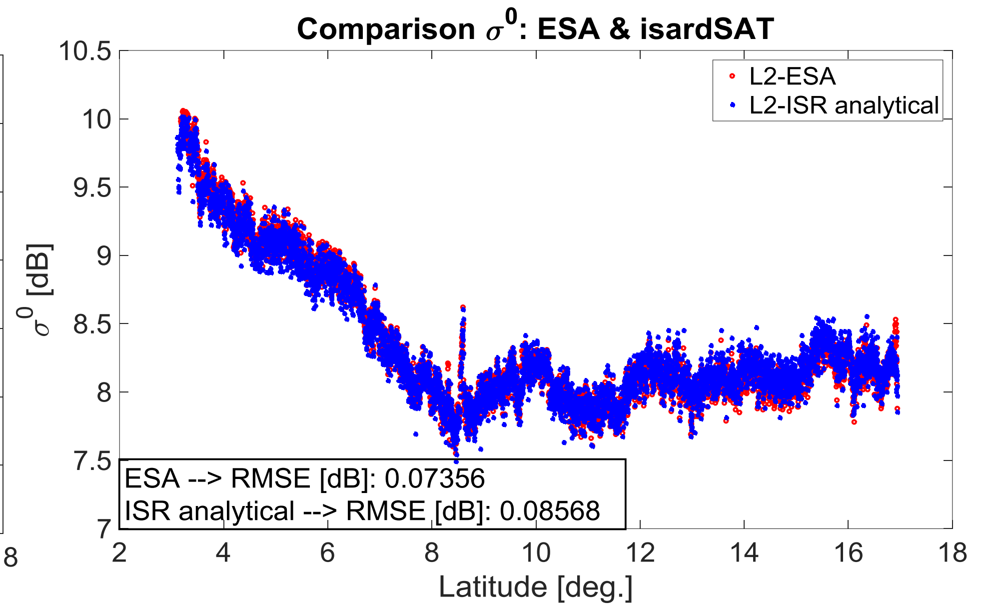
(*) RMSE (root mean square error) computed w.r.t smoothed version of the geophysical retrievals over track using a sliding window with a size of 20 samples (surfaces) → equivalent to 1-Hz averaging

AOI-1: individual results- sigma0

S-3

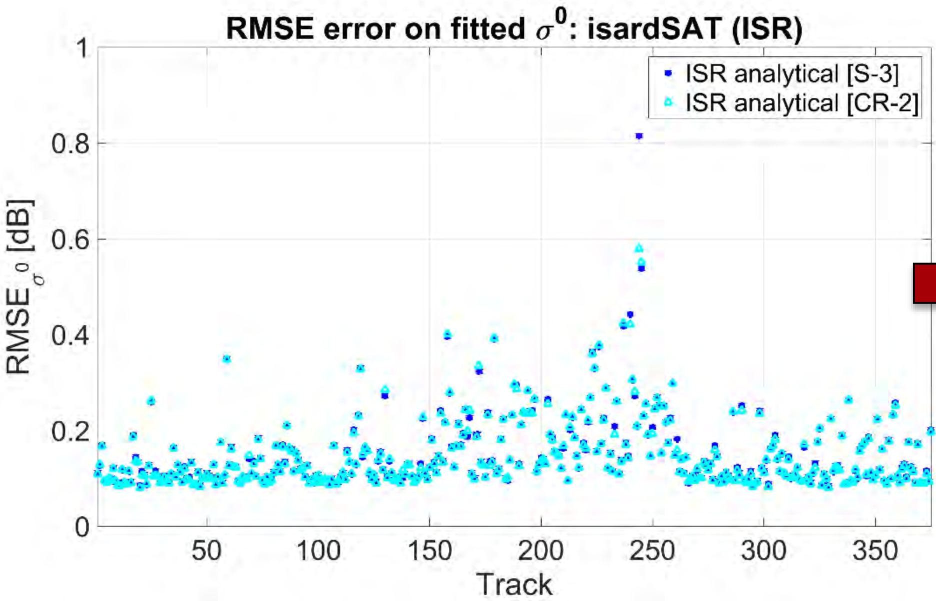


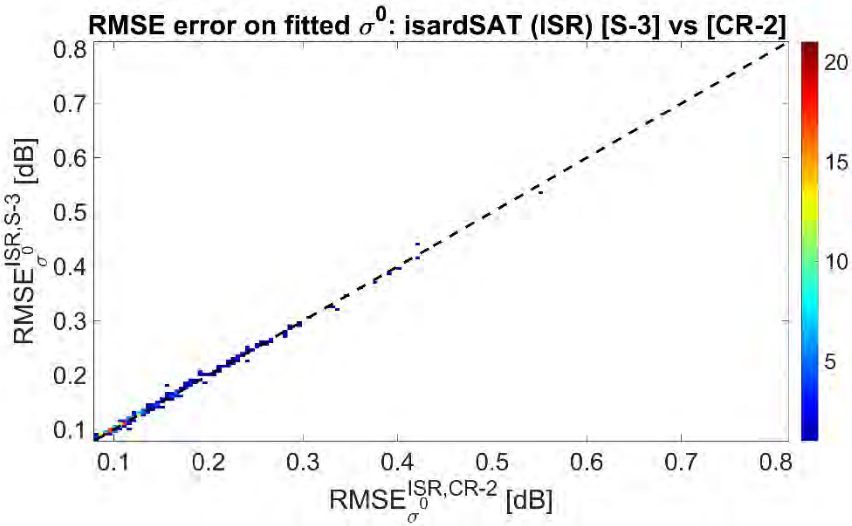
CS-2



(*) RMSE (root mean square error) computed w.r.t smoothed version of the geophysical retrievals over track using a sliding window with a size of 20 samples (surfaces) → equivalent to 1-Hz averaging

AOI-1: Sigma0 performance





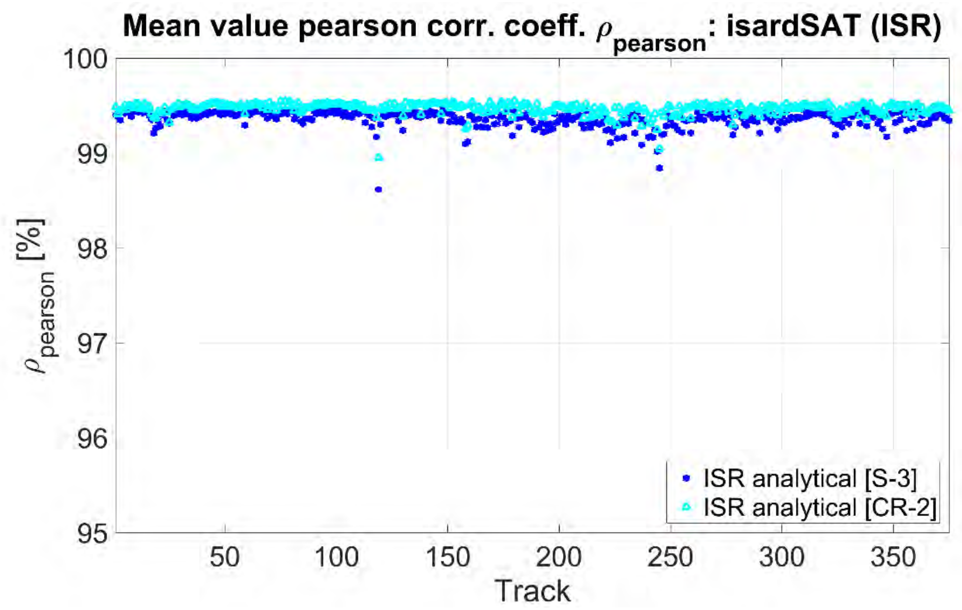
RMSE 2-D histogram (CR-2 vs S-3)

Source	μ_{RMSE} [dB]	σ_{RMSE} [dB]
ISR a la S-3	**0.1507**	**0.0753**
ISR a la CS-2	0.1488	0.0710

Analytical retracker CS-2 baseline provides slightly **improved performance compared to S-3**

(*) σ_{RMSE} is an indicator of the stability along time/space of the geophysical parameter noise estimation

AOI-1: gof mean values

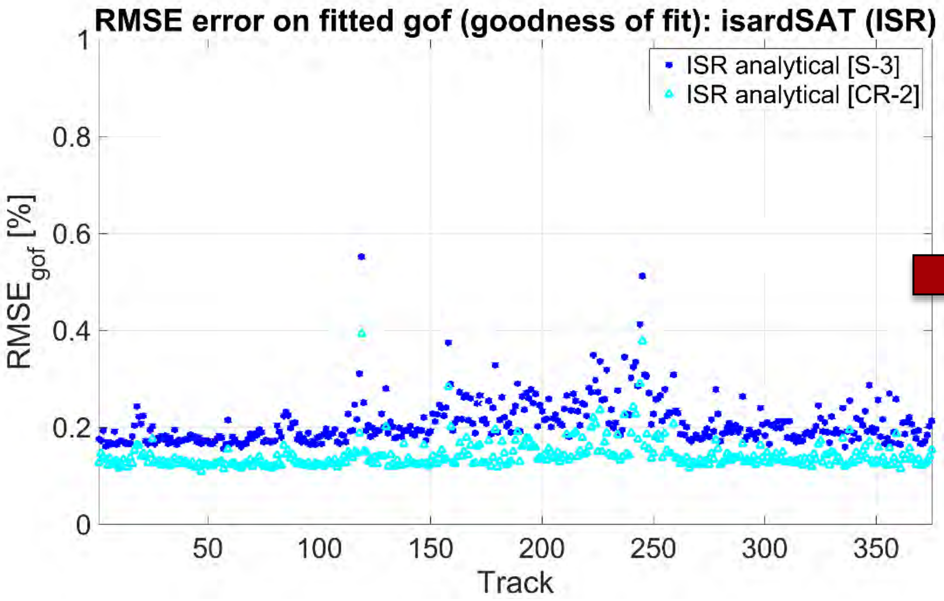


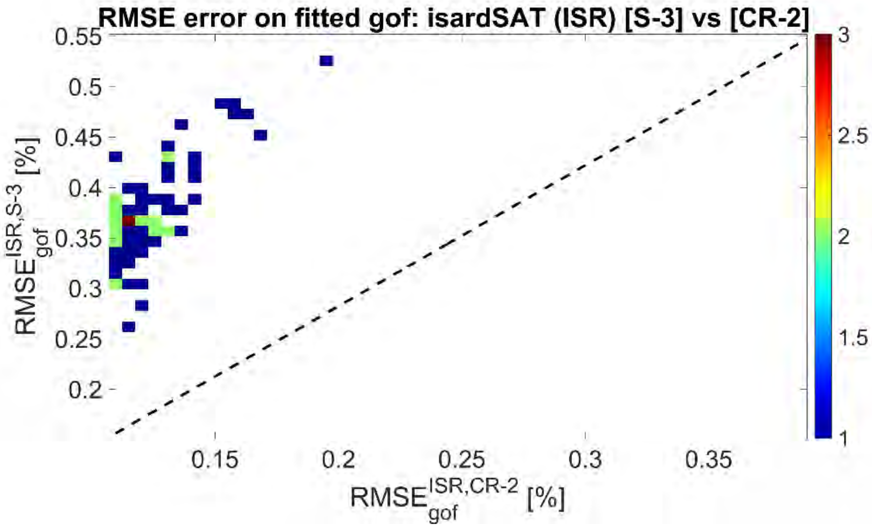
Source	$\mu_{\rho_{pearson}}$ [%]	$\sigma_{\rho_{pearson}}$ [%]
ISR a la S-3	99.36	0.0885
ISR a la CS-2	99.47	0.0619

- **CS-2 baseline** provides a slightly **more accurate and more stable fitting** of the data compared **to S-3**

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

AOI-1: gof noise-performance



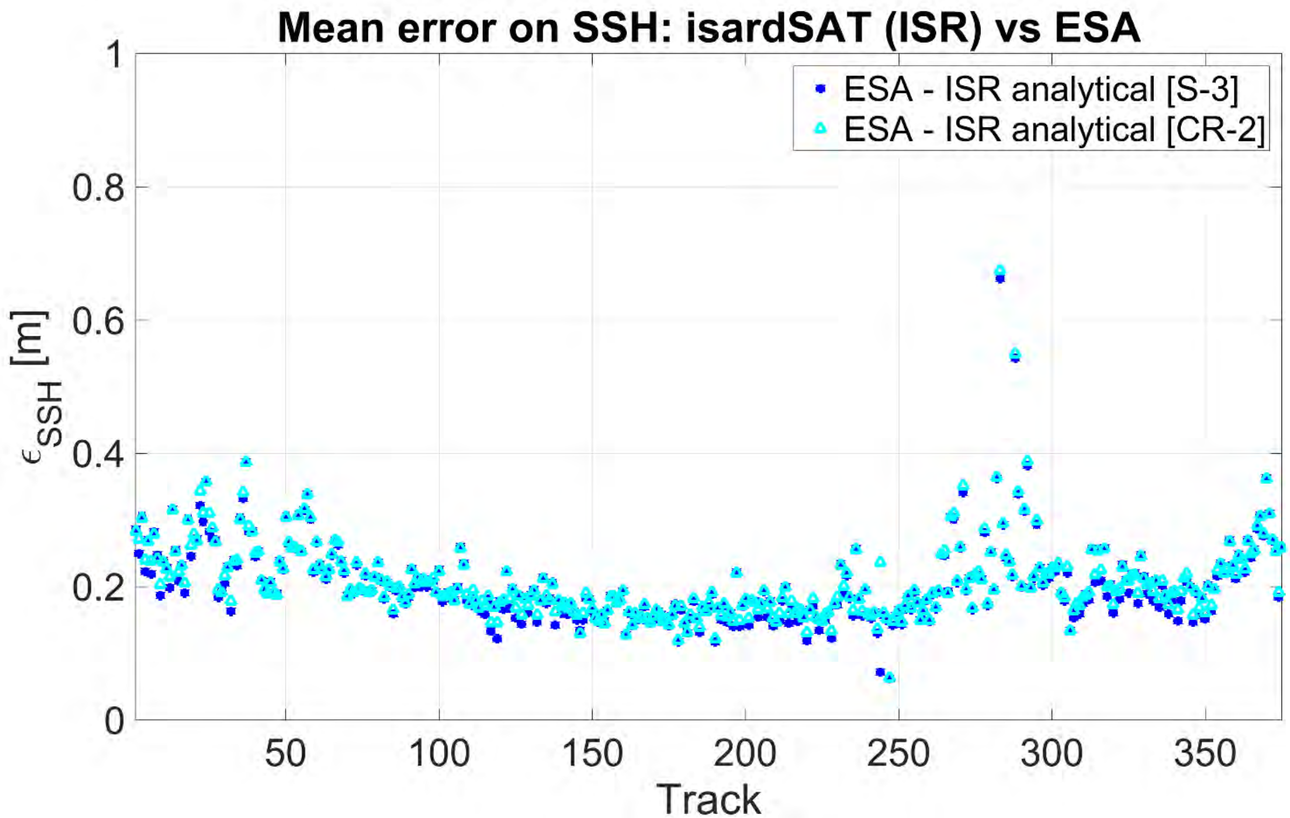


Source	μ_{RMSE} [%]	σ_{RMSE} [%]
ISR a la S-3	0.2095	0.0464
ISR a la CS-2	0.1430	0.0299

- **CS-2 baseline** provides a **more stable fitting** of the data compared **to S-3**

(*) σ_{RMSE} is an indicator of the stability along time/space of the accuracy on the geophysical parameter estimation

AOI-1: SSH mean error



Source	μ_ϵ [m]	σ_ϵ [m]
ISR a la S-3	0.2036	0.0589
ISR a la CS-2	0.2079	0.0580

- **Different** retracked **epoch** as **ESA** is a **sea-ice** and **ISR** is an **SAR ocean model**