ON THE ASSESSMENT OF SEA LEVEL ACCURACY FROM SENTINEL-3A SRAL AND SURFACE WATER OCEAN TOPOGRAPHY KaRIn SATELLITE ALTIMETRY MISSIONS

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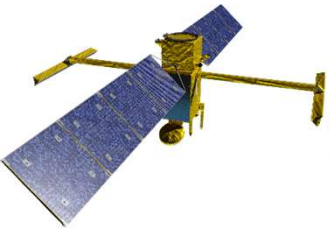
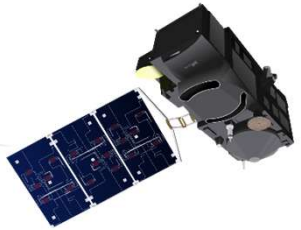
9th Sentinel-3 Validation Team Meeting (Frascati, ESA-ESRIN)





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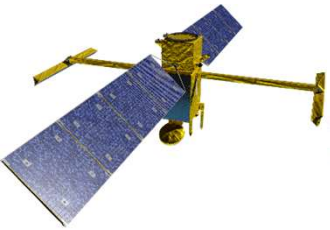

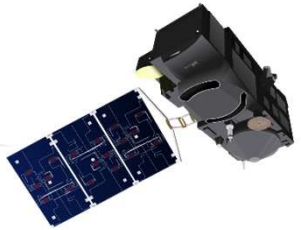

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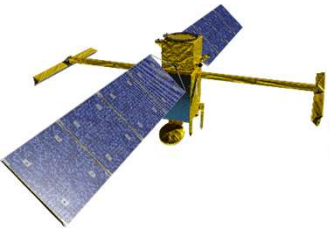

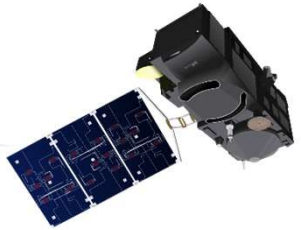

Validation of the Surface Water and Ocean Topography (SWOT) KaRIn Sea Level Data

J. Gómez-Enri, B. Arribas-Rodríguez, B. Tejedor, O. Álvarez, C. J. González, S. Vignudelli

Abstract— **The Ka-band interferometer altimeter (KaRIn) onboard the U.S-French SWOT satellite is the first swath altimeter in operation. Its main innovation is its two-dimensional view of the earth surface, widening the ocean and land applications of satellite altimetry. The main objective of our work was to validate the sea level derived from KaRIn with the water levels from three tide gauges located around the Spanish coasts at stations in: Huelva, Barcelona, and Bilbao. To do this, we estimated the standard deviation of the differences (SDD) between the altimeter and the ground-truth data. The accuracy of the Sentinel-3A (S3A) satellite was also computed for comparison. We analyzed two / one track at each location for SWOT / S3A, respectively. From the options available to compute the sea level anomaly from SWOT, we tested the wet tropospheric correction (WTC), the mean sea surface (MSS), and the tidal model. The comparisons with the tide gauges revealed that the ECMWF model for the WTC gave a higher number of valid data and the same level of accuracy as the correction derived from the Advanced Microwave Radiometer instrument. The same accuracy was observed regardless of the MSS used (CNES and DTU). Finally, the FES tidal model improved the accuracy with respect to the DTU model. The average SDD of SWOT oscillates between 7.4±0.8 cm (Bilbao) and 12.2±2.3 cm (Barcelona). A more in depth analysis of the SWOT data at the Barcelona station revealed a cycle with anomalous sea level anomalies not detected in the data screening. Removing that cycle, the average SDD dropped to 8.7±1.7 cm. Sentinel-3A showed 4% to 24% better accuracy than SWOT.**

Index Terms— **Swath altimetry, validation, sea level anomaly, tide gauge.**

I. INTRODUCTION

The Surface Water and Ocean Topography mission (SWOT hereinafter) [1] [2] was launched successfully on 16th December, 2022. It is a United States of America (National Aeronautics and Space Administration: NASA) and French (Centre National d'Etudes Spatiales: CNES) mission with contributions from the Canadian and United Kingdom Space Agencies. The carries a Ka-band Radar Interferometer (KaRIn) comprising two Synthetic Aperture Radar (SAR) antennas separated by a 10-m mast and a Jason-3 class dual frequency (Ku/C bands) conventional nadir-looking altimeter (Poseidon-3C). It also carries an Advanced Microwave Radiometer (AMR) to correct the range measurement delays due to the liquid water and water vapor content in the atmosphere. The KaRIn SAR interferometer is unique with respect to previous satellite altimeter missions as it provides range measurements across two sub-swaths of 50 km to both sides of the 10-km swath covered by the nadir altimeter. A complete description of the KaRIn instrument and its derived products is available in [3].

The main objective of the SWOT mission is to provide a two-dimensional view of the ocean sea level and terrestrial surface waters with high accuracy and precision [4]. This is a step forward in satellite altimetry as all the previous missions were designed to provide along-track nadir measurements. The post-processing of multi-mission along-track altimeter data allows the generation of two-dimensional sea level and derived products [5] [6] on a daily to monthly basis. These gridded datasets cannot achieve the wavelength resolution of KaRIn [4] [5]. Some authors [4] [7] have demonstrated that KaRIn measurements can unravel small scale ocean processes resolving wavelengths of up to 5 km, much lower than the 50 km resolution of previous altimeter missions, and even better than the expected resolution for SWOT (15 km). This is certainly a kind of revolution in satellite altimetry after more than three decades of nadir-looking observations, paving a new era in resolving many aspects of our oceans in the context of climate change and rises in sea levels. In this context, the accuracy of the ocean/terrestrial products from KaRIn has to be continuously assessed and quantified for comparison with past and present satellite altimeter missions. This is crucial for the continuity of swath altimetry and will feed the knowledge for the design of future swath missions, such as the European Union (EU) Copernicus Sentinel-3 Next Generation Topography mission [8], which is in its early stage of development. In addition, the two-dimensional spatial structure of KaRIn data allows the possibility of differentiate better between systematic / non-systematic errors and ocean signals. This can be done through spectral and spatial correlation analysis that cannot be possible when analyzing nadir altimetry

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(Corresponding author: J. Gómez-Enri). Authors contributed equally to this article.

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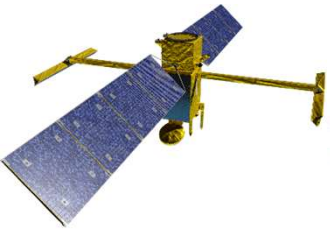

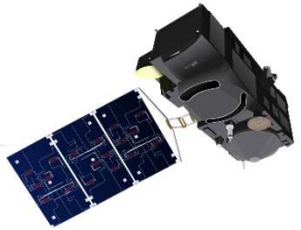

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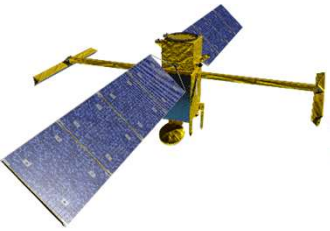
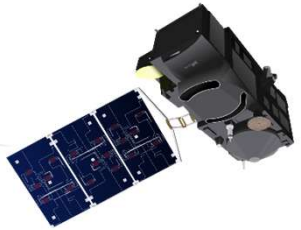
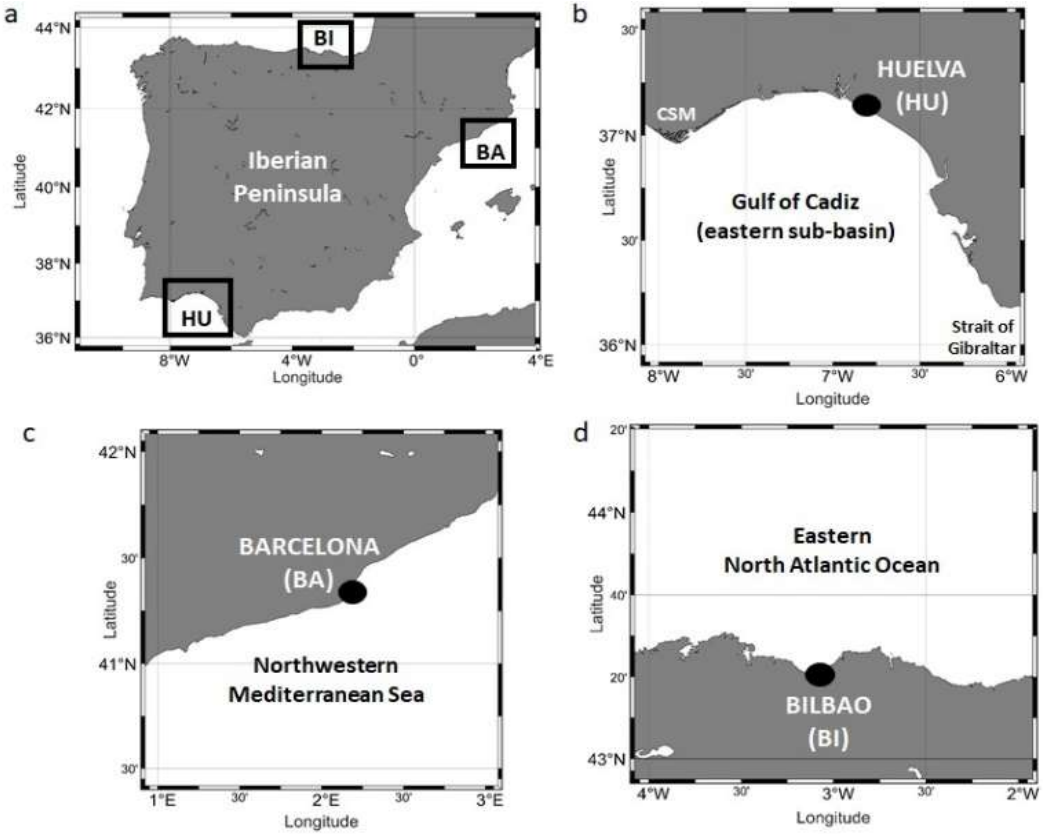






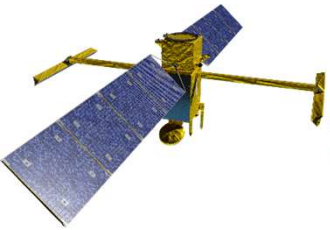
Previously used for validation of Envisat RA-2, CryoSat-2, Sentinel-3A/B.

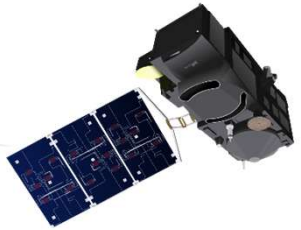
Atlantic Ocean and Mediterranean Sea.

Selected according to in-situ data and S3A/SWOT tracks availability.

Different hydrdynamic conditions for a better interpretation of SWOT/S3A data performances.

	Tide gauge location					
	E_GoC (HU)		NW_MS (BA)		E_NAO (BI)	
	Orbit number					
SWOT	#154 (D)	#447 (A)	#320 (D)	#363 (A)	#141 (A)	#376 (D)
S3A	#322 (D)		#356 (A)		#051 (D)	





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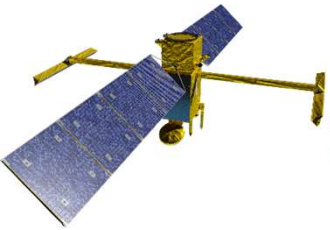
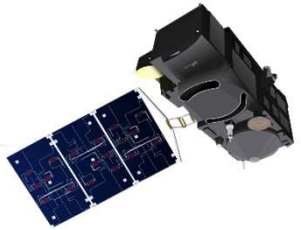




Time period: July 2023 - February 2025

SWOT	Data from the High-level Tool for Interactive Data Extraction (HiTIDE) available at: https://hitide.podaac.earthdatacloud.nasa.gov/ (doi: 10.5067/SWOT-SSH-2.0). 'Expert' data from Version C (science data product) of Level 2 KaRIn Low Rate (LR) Sea Surface Height Data Product. Twenty-eight 21-day cycles. Regular grid of 2 km x 2 km along the track.
S3A	Data from the marine product (SM__WAT.006.01.00) available in the EUMETSAT data store: https://data.eumetsat.int/product/EO:EUM:DAT:0415# Level 2 along-track Non Time Critical sea level data were obtained at 20 Hz of posting rate (instrument) operating in Synthetic Aperture Radar (SAR) mode. Baseline collection 06. Twenty-one 27-day cycles. Range obtained using the SAMOSA 2.5 retracking scheme.

In-situ

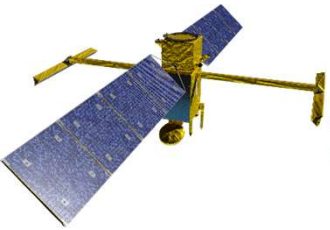
Three radar tide gauges with data freely available through the Spanish Puertos del Estado (https://www.puertos.es/servicios/oceanografia)

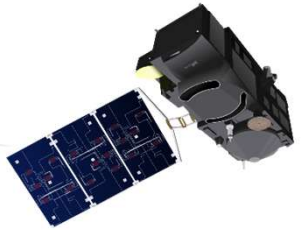
5-min sea level product to ensure the closest measurements in time to SWOT/S3A measurements.

Miros radar (1-mm accuracy) operating at a 2-Hz frequency and are part of the PSMSL and the GLOSS.

Data follow strict quality control and maintenance operations to ensure continuity and traceability.

Satellite data selected considering a 100-km radius to the TG stations.





ssha_Karin SLA_S3A

	SWOT (LR product)	S3A (marine product)
Wet Troposphere	AMR measurements Model: ECMWF	MWR measurements
Dry Troposphere	Model: ECMWF	
Ionosphere	Model: GIM (Iijima et al., 1999)	Radar measurements
Mean Sea Surface (MSS)	CNES CLS (version 2022) DTU18 (version 2018)	CNES CLS (version 2015)
Ocean Tide[vi]	FES2014b (Carrère et al., 2016) GOT4.10c (Ray, 2013)	FES2014b (Carrère et al., 2016)
Solid Earth Tide	Cartwright and Taylor (1971) and Cartwright and Edden (1973)	
Pole Tide	Wahr (1985) and Desai et al. (2015)	
Internal Tide	Zaron (2019)	
DAC	Model: AVISO (Carrère and Lyard, 2003)	
Sea State Bias	Model (empirical)	5% SWH (Aldarias et al., 2001)

SLA_SWOT = ssha_karin + height_cor_xover

SLA_TG = water_level – tide_prediction – DAC

Temporal mean removed from all the time series

$$\mathrm{SDD} = \sqrt{\sum_{i=1}^{N} \frac{((SLA\_Alt(i) - SL\ \_TG(i)) - mean(SLA\_Alt(i) - SLA\_TG(i)))^2}{(N-1)}}$$

i corresponds to each valid cycle used
N gives the number of valid cycles

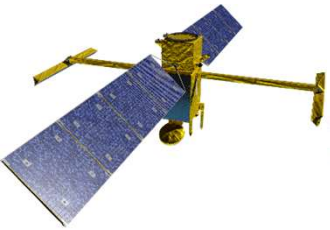
Data exclusion criteria (time series)

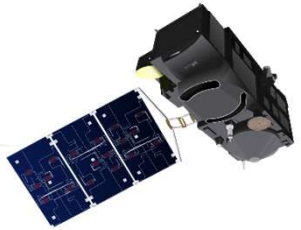
(i) values (SLA) up/down ±1 m;

(ii) those with a quality flag for SLA estimation different to zero

(iii) values outside the median ±3σ

(iv) SDD was estimated at each along-track (S3A) and grid (SWOT) position if the number of valid measurements in the time series (after screening) was higher than 80% of the number of measurements (before screening)





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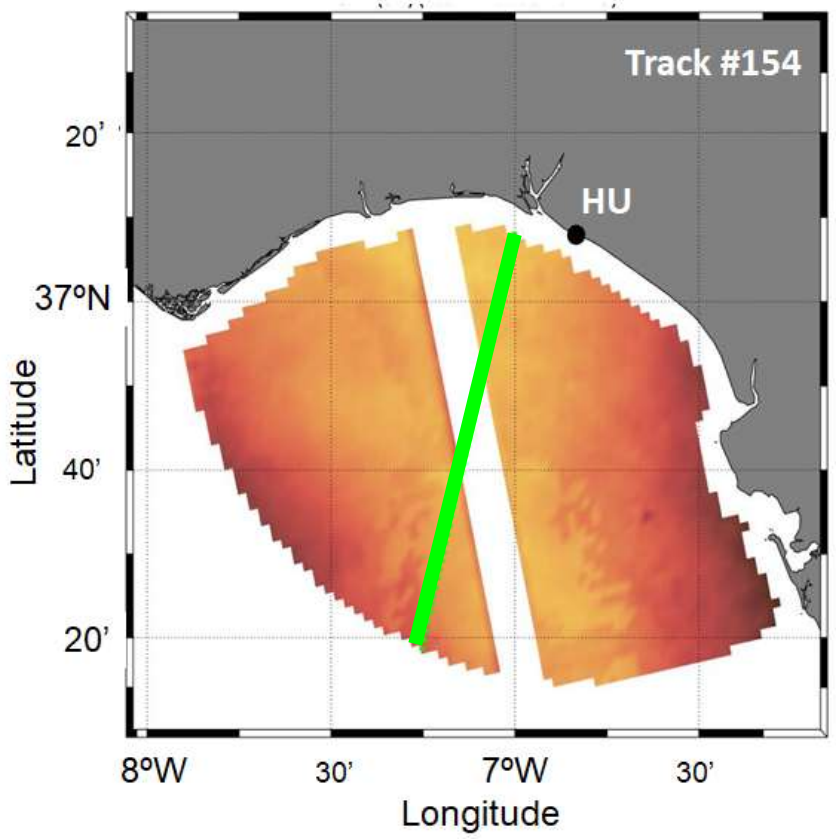
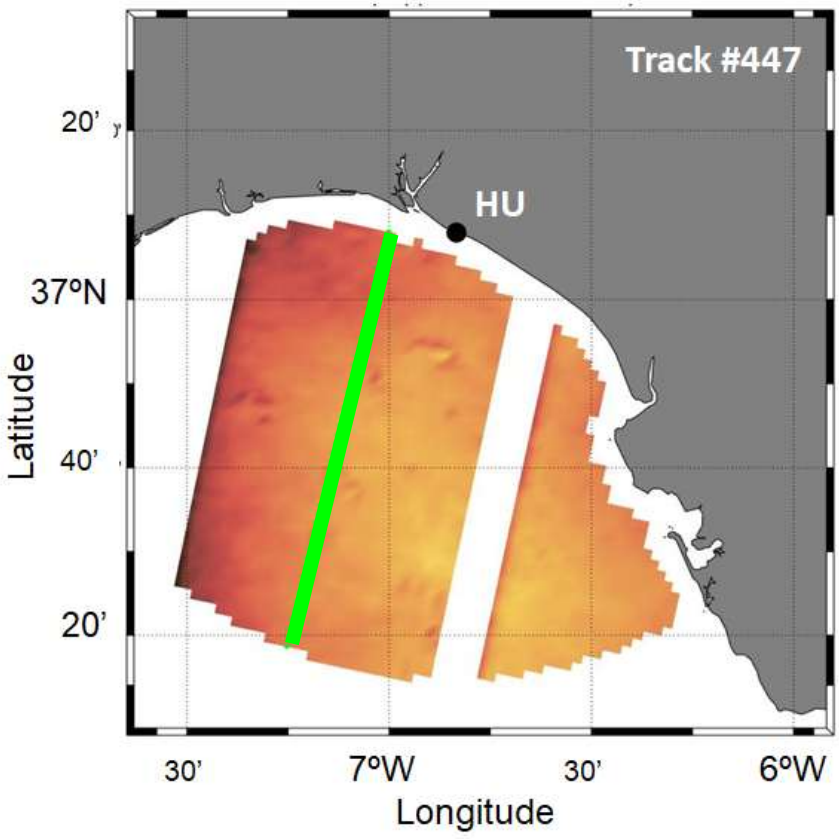
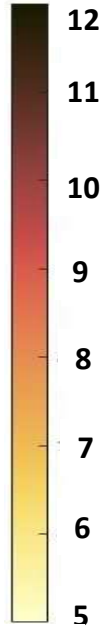
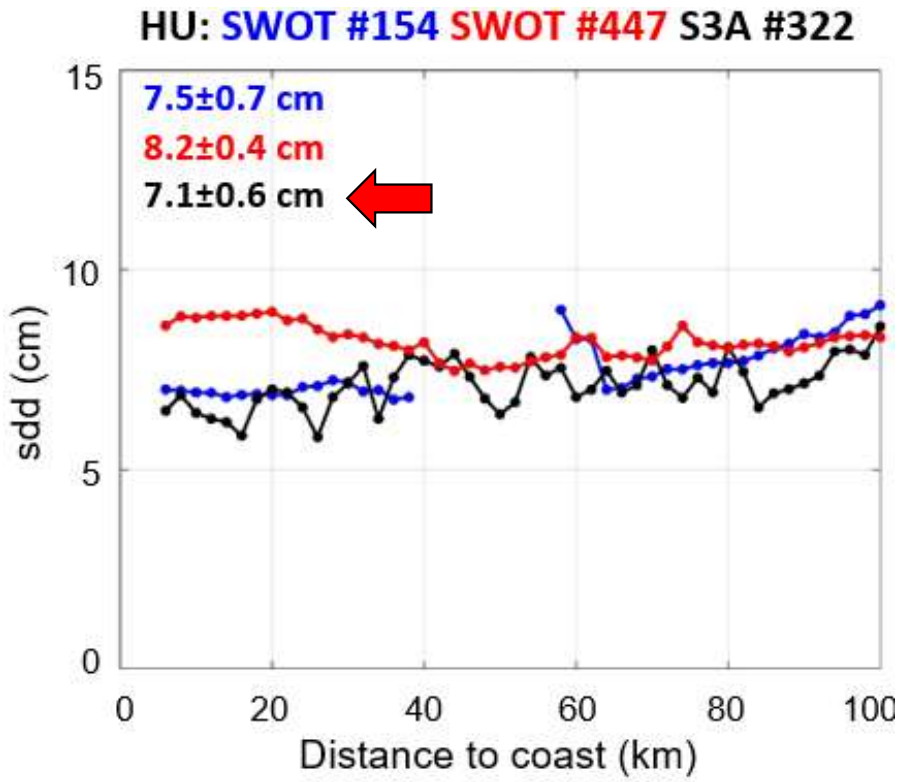

Track #154
HU
20'
37°N
40'
20'
Latitude
8°W
30'
7°W
30'
Longitude

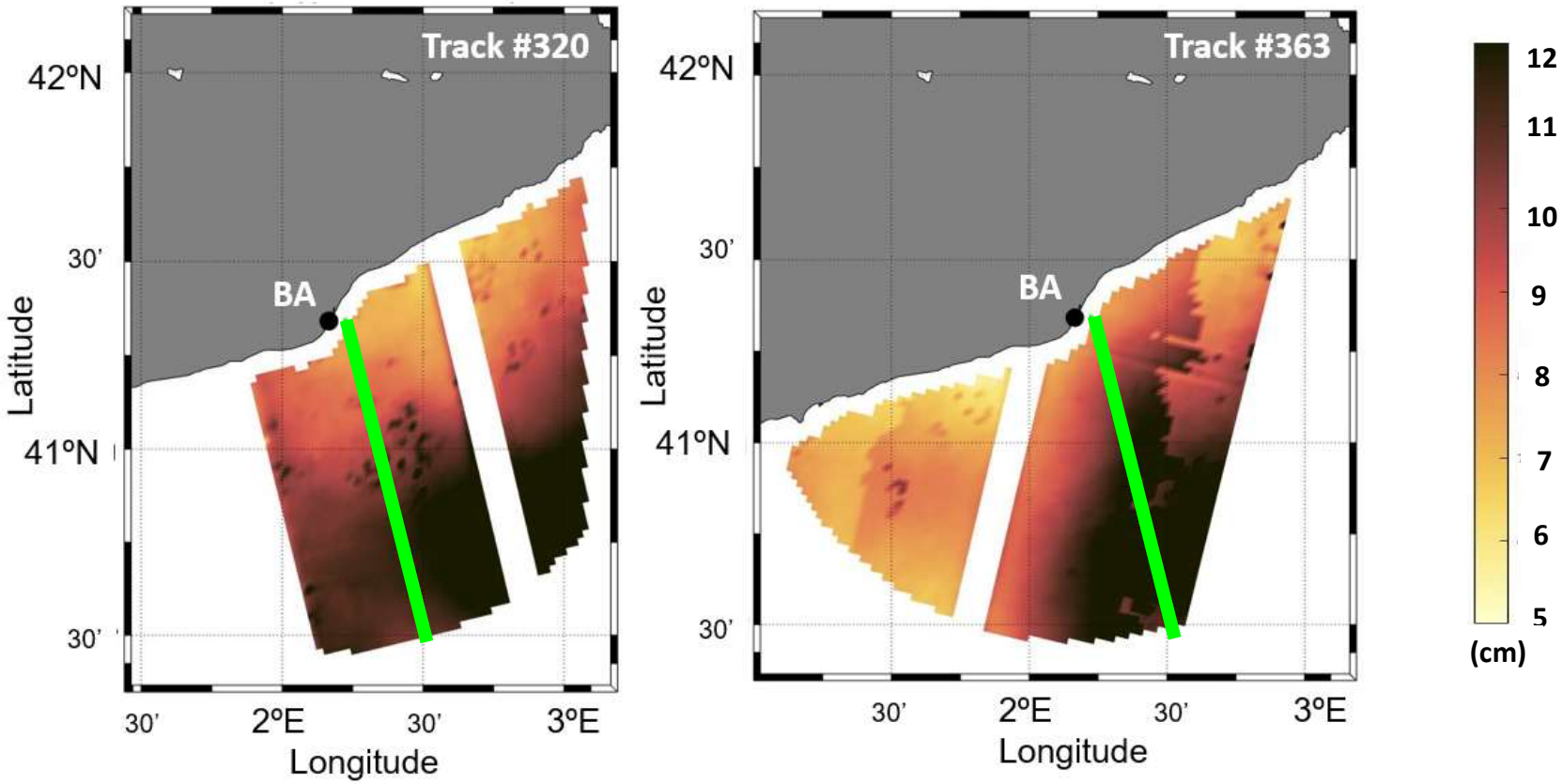

Track #447
HU
20'
37°N
40'
20'
Latitude
30'
7°W
30'
6°W
Longitude


12
11
10
9
8
7
6
5
(cm)

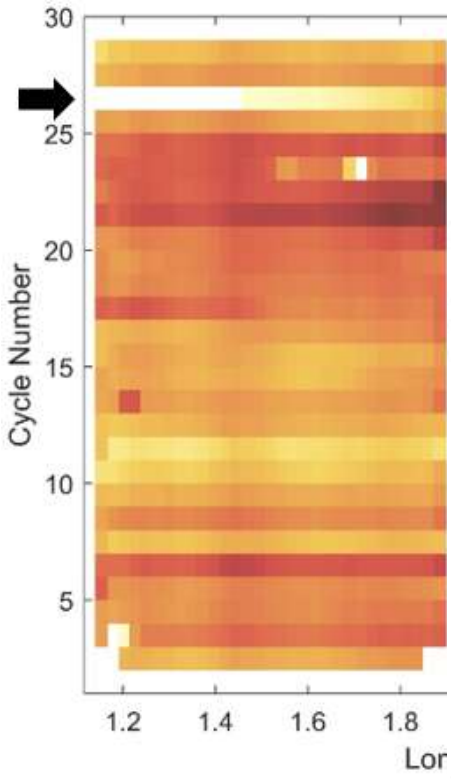
HUELVA

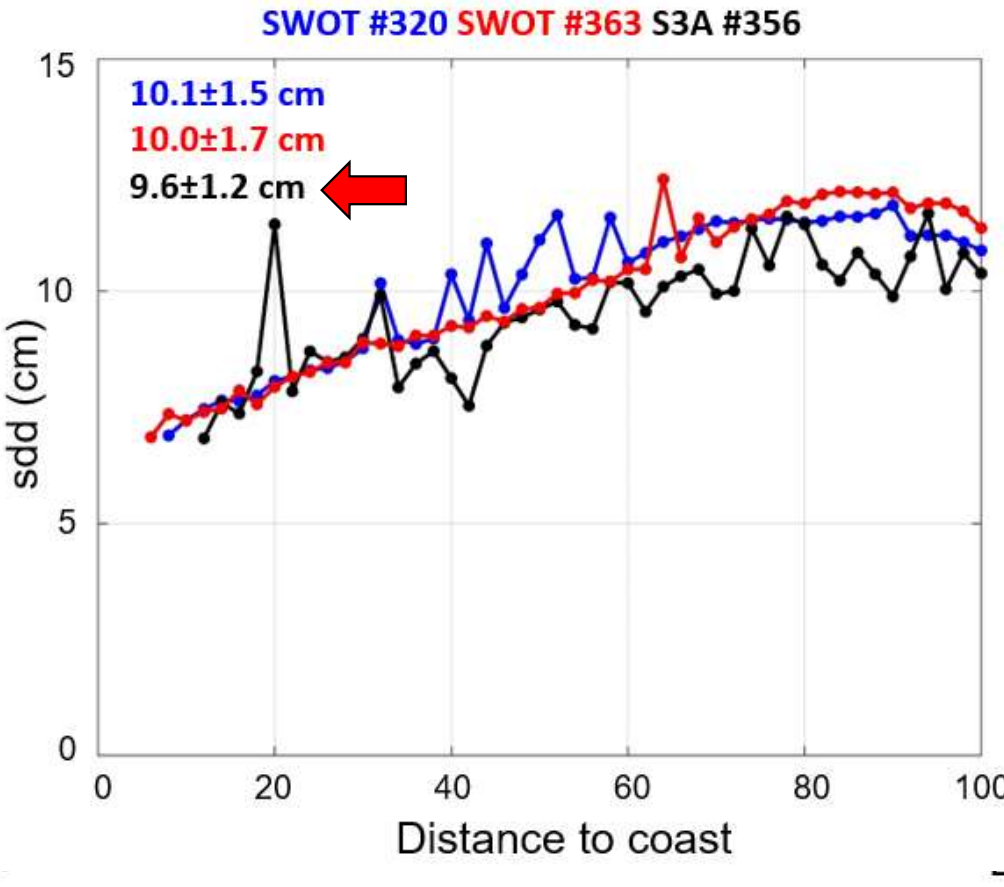

HU: SWOT #154 SWOT #447 S3A #322
7.5±0.7 cm
8.2±0.4 cm
7.1±0.6 cm
sdd (cm)
Distance to coast (km)
0
5
10
15
0
20
40
60
80
100

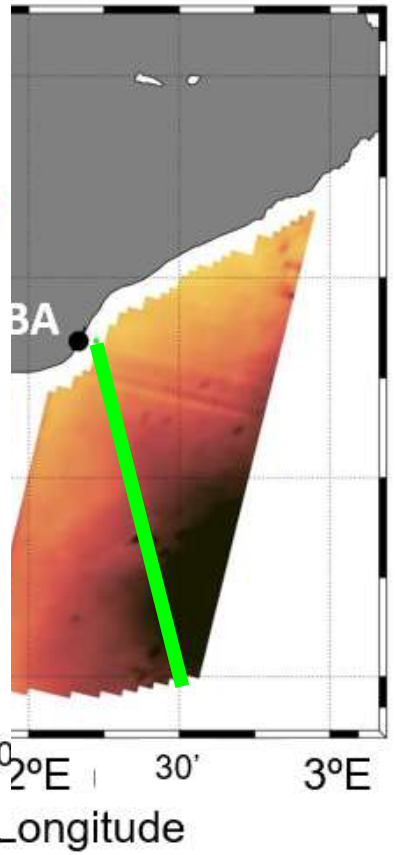
BARCELONA


Track #320
Track #363
BA
BA
42°N
41°N
30'
2°E
3°E
Latitude
Longitude
12
11
10
9
8
7
6
5
(cm)

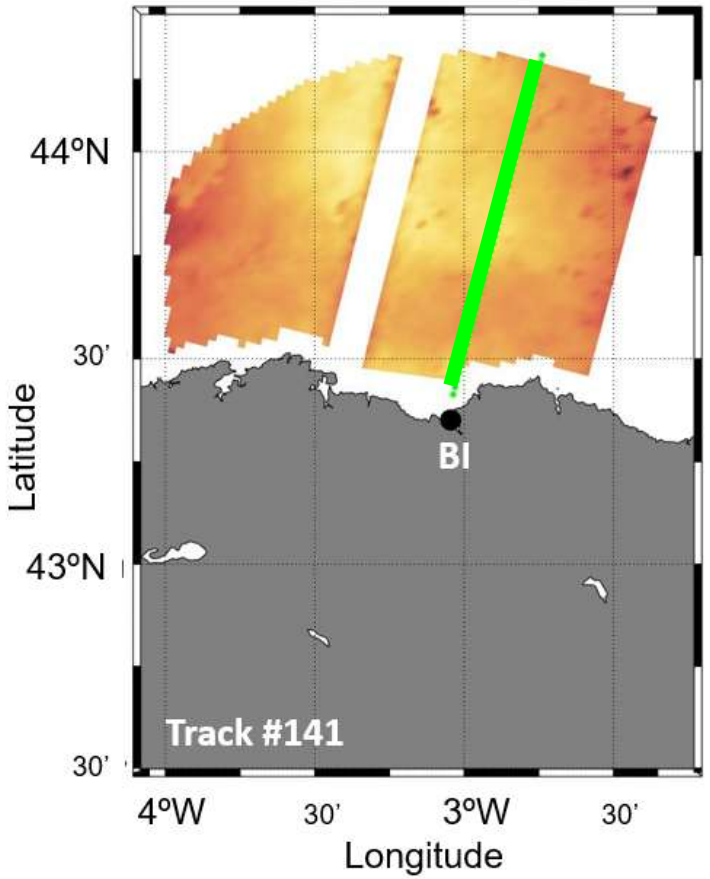
BARCELONA

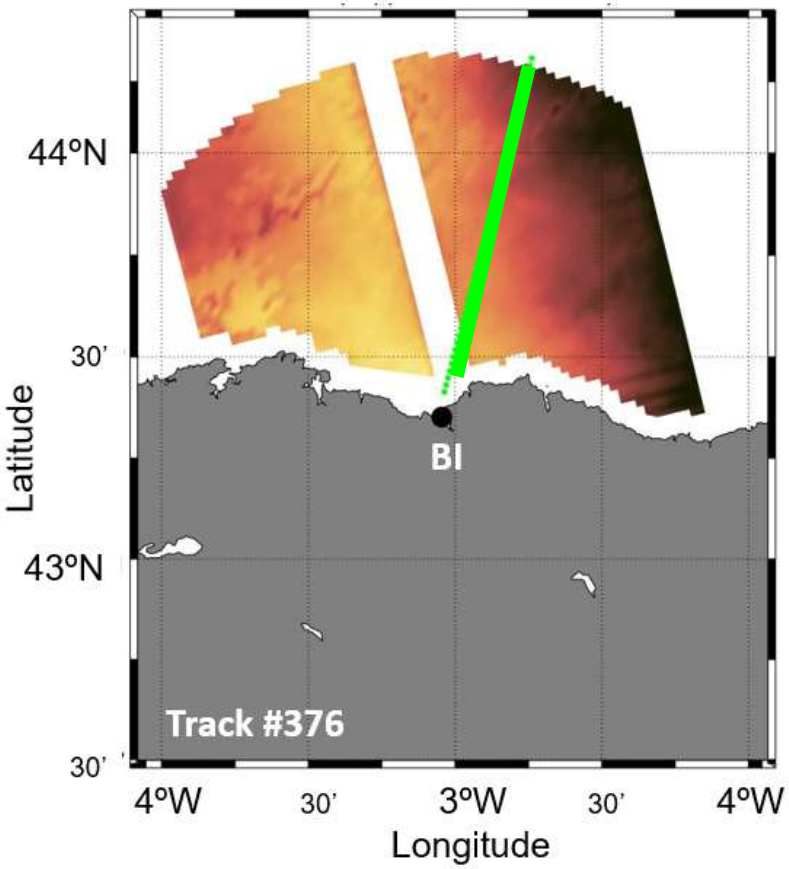

30
25
20
15
10
5
Cycle Number
1.2
1.4
1.6
1.8
Lor

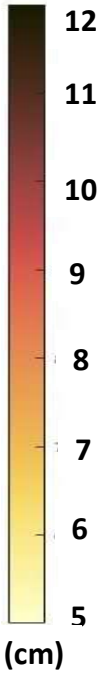

SWOT #320 SWOT #363 S3A #356
10.1±1.5 cm
10.0±1.7 cm
9.6±1.2 cm
15
10
5
0
sdd (cm)
0
20
40
60
80
100
Distance to coast


BA
2°E
30'
3°E
Longitude

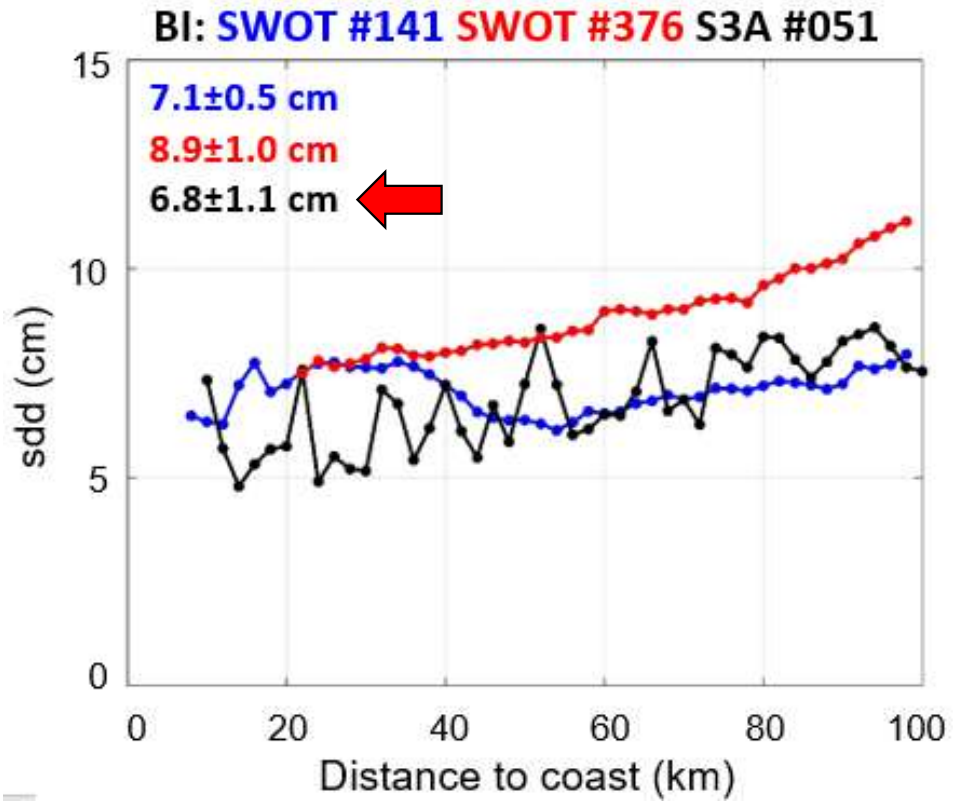
BILBAO

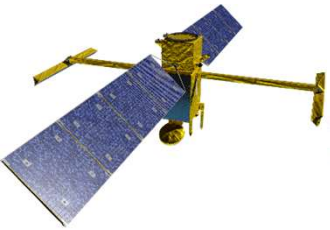

44°N
30'
43°N
30'
Latitude
BI
Track #141
4°W
30'
3°W
30'
Longitude

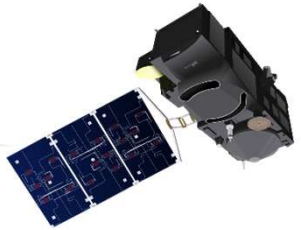

44°N
30'
43°N
30'
Latitude
BI
Track #376
4°W
30'
3°W
30'
4°W
Longitude


12
11
10
9
8
7
6
5
(cm)

BILBAO


BI: SWOT #141 SWOT #376 S3A #051
7.1±0.5 cm
8.9±1.0 cm
6.8±1.1 cm
sdd (cm)
Distance to coast (km)
0
5
10
15
0
20
40
60
80
100



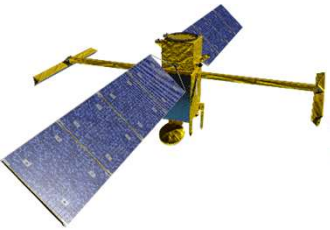


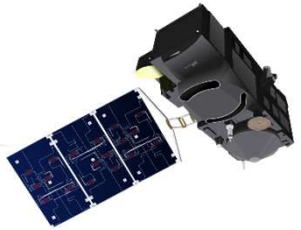
Bullets to discuss during the coffee break

- **Both missions are conceptually different, so the ways to retrieve the *Range* are different, and hence its accuracy.**

- **There are some discrepancies in the source of the range and geophysical corrections applied to both datasets.**

- **The different source of the sea state bias correction could explain some of the discrepancies in the accuracy between both missions.**





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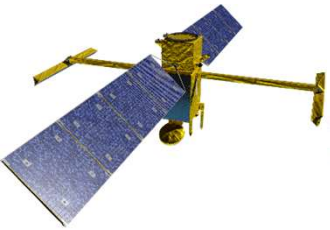
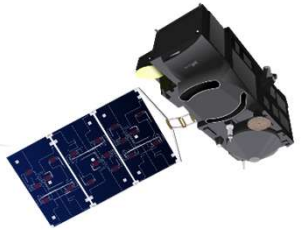
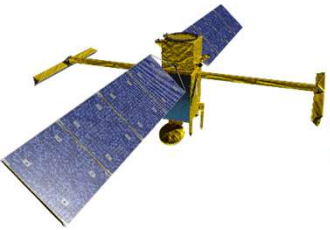


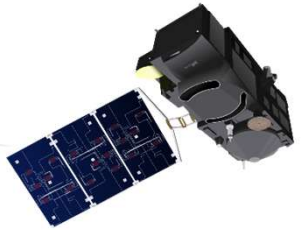


- **Overall, SWOT underperforms compared to S3A in sea level data quality. Sentinel-3A showed a better accuracy than SWOT in the three locations analyzed for a [5 –100] km track segment. However, it should be considered that SWOT is an experimental mission, with is steadily improving.**

- **In percentage, the sea level anomaly from S3A is between 4% and 24% better than the anomalies derived from SWOT.**

- **This implies that there is still space for improvement for the SWOT KaRIn data quality, in order to be in line with present satellite nadir altimeter mission… but also for S3A/B/C.**

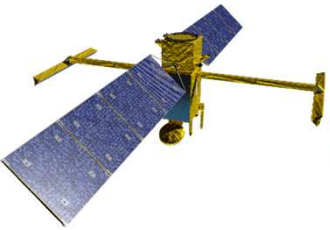


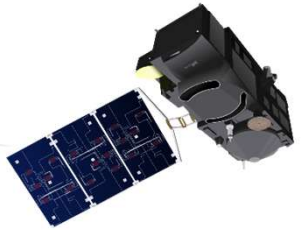


Recommendations

- **State institutions like the Spanish Puertos del Estado provides free access to real time and historical sea level/wind/waves data along the Spanish coasts.**

- **More efforts of coordination between institutions in order to increase the number of test sites for validation.**
- **A common set of range/geophysical corrections for all the satellite altimetry missions (this excludes the SSB correction).**
- **More validation exercises with SWOT to feed the knowledge for the design of future swath missions (Sentinel-3 Next Generation Topography mission).**





¡Muchas Gracias!