Scientific Activities: Coastal Assessment

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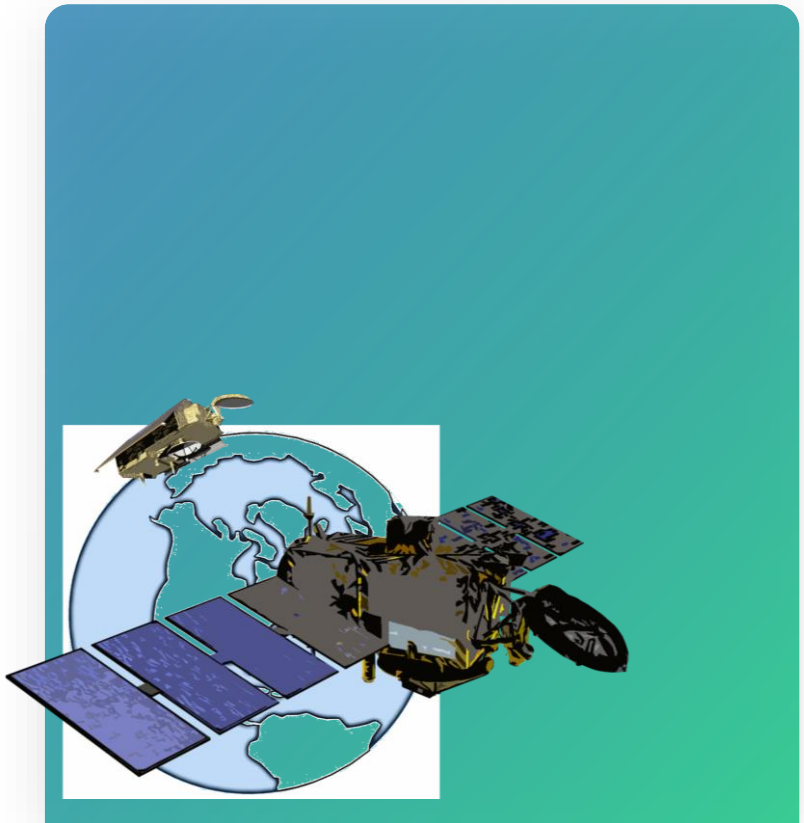


S6-JTEX Final Meeting
24th April 2024

Assessment of Coastal Performances

Tasks

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and a retracked Jason-3 product
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Planned Steps

1. Retrack the J3 and S6-MF LRM waveforms with specific retrackers: ALES and WHALES; Retrack S6-MF SAR waveforms with the CORAL retracker
2. Performance assessment analysis in terms of L2 noise and outlier analysis in the coastal zone
3. Intercomparison of S6 and J3 based on L2 products in the coastal zone will be performed focusing on bias, drift and their geographical patterns
4. Added “for free”: Comparison against tide gauges

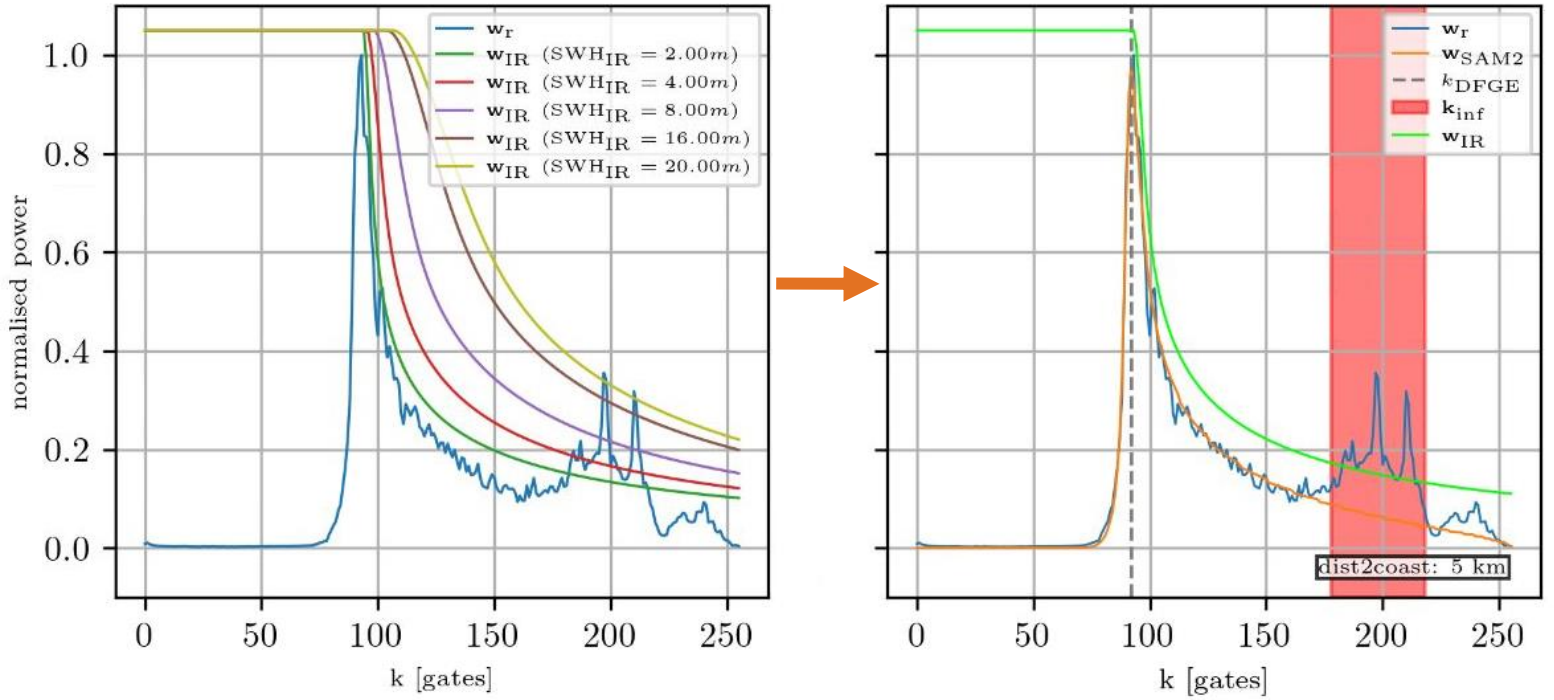
The CORALv1 Retracker

Schlembach F., Passaro M., Dettmering D., Bidlot J., Seitz F.: **Interference-sensitive coastal SAR altimetry retracking strategy for measuring significant wave height**. Remote Sensing of Environment, 274, 112968, 10.1016/j.rse.2022.112968, 2022

Adaptive Interference Masking (AIM)

→ senses and masks interference within the trailing edge

Generation of a single-look SAMOSA model $\mathbf{w}_{\mathrm{SAM2}}$ to produce the interference reference waveform $\mathbf{w}_{\mathrm{IR}}(\mathrm{SWH}_{\mathrm{IR}})$



detected interference gates

$$\mathbf{k}_{\mathrm{inf}} = \mathrm{True}(\mathbf{w}_{\mathrm{r}} > \mathbf{w}_{\mathrm{IR}})$$

Methods: CORALv2 Coastal Retracker

Schlembach F., Passaro M., Dettmering D., Bidlot J., Seitz F.:

Adaptive Interference Maskin

→ senses and masks inter

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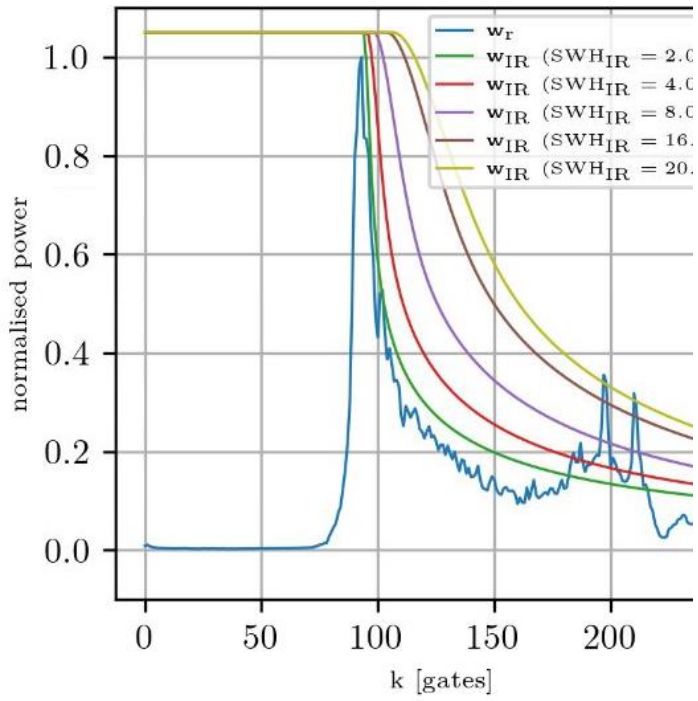
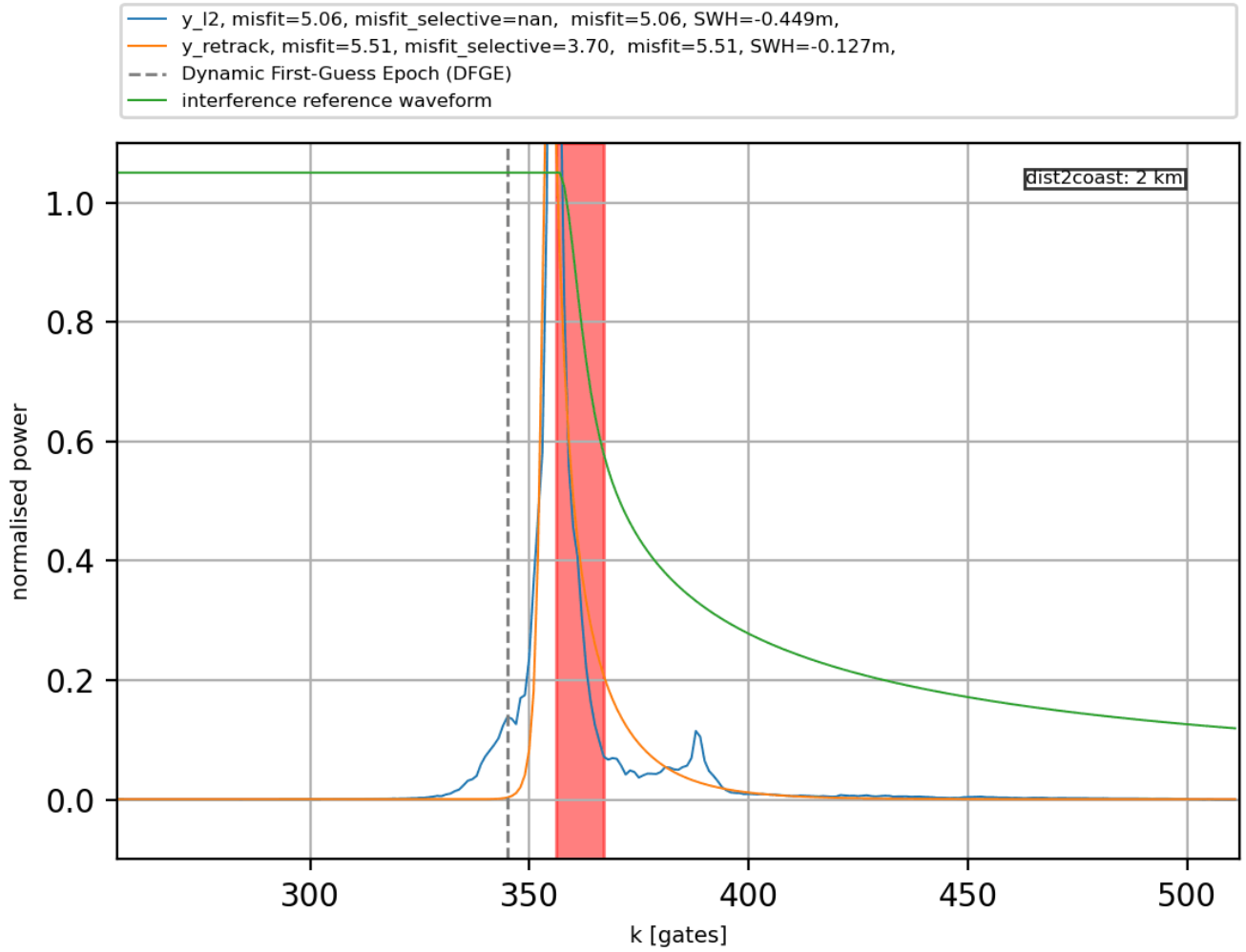
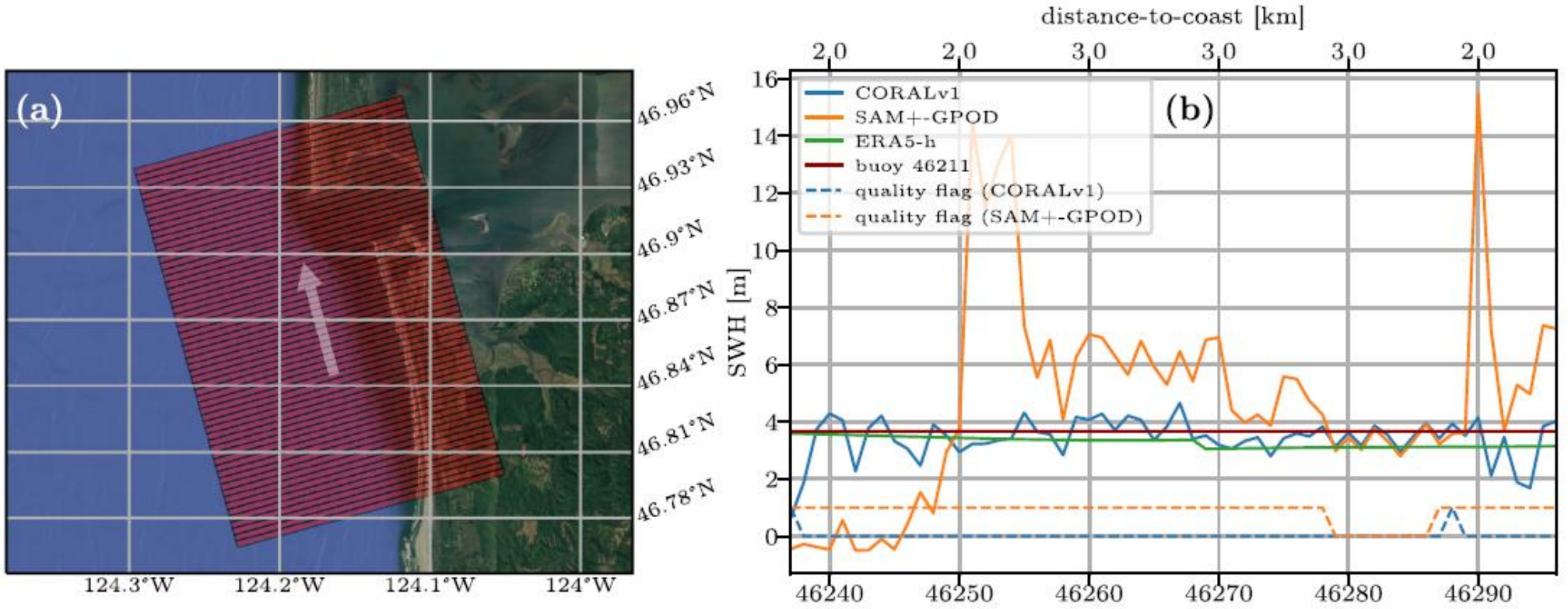


S3A_SR_1_SRA_BS_20180414T050110_20180414T055139_20180509T202346_3029_030_090_____MAR_O_NT_003.nc, samplus-coral (gpod), record#: 46403



The CORALv1 Retracker

Retracking waveforms with strong coastal interference by CORALv1 in comparison with SAMOSA+



Performance Assessment Analysis: Noise and Outliers

Assessed as a function of sea state and distance-to-coast (open ocean, coast: < 5/10/20 km).

For S6 LRM (LR), S6 SAR (HR) and retracked J3

L2 noise

Defined as the standard deviation of twenty 20-Hz records.

Outlier analysis

Three types of outliers are defined

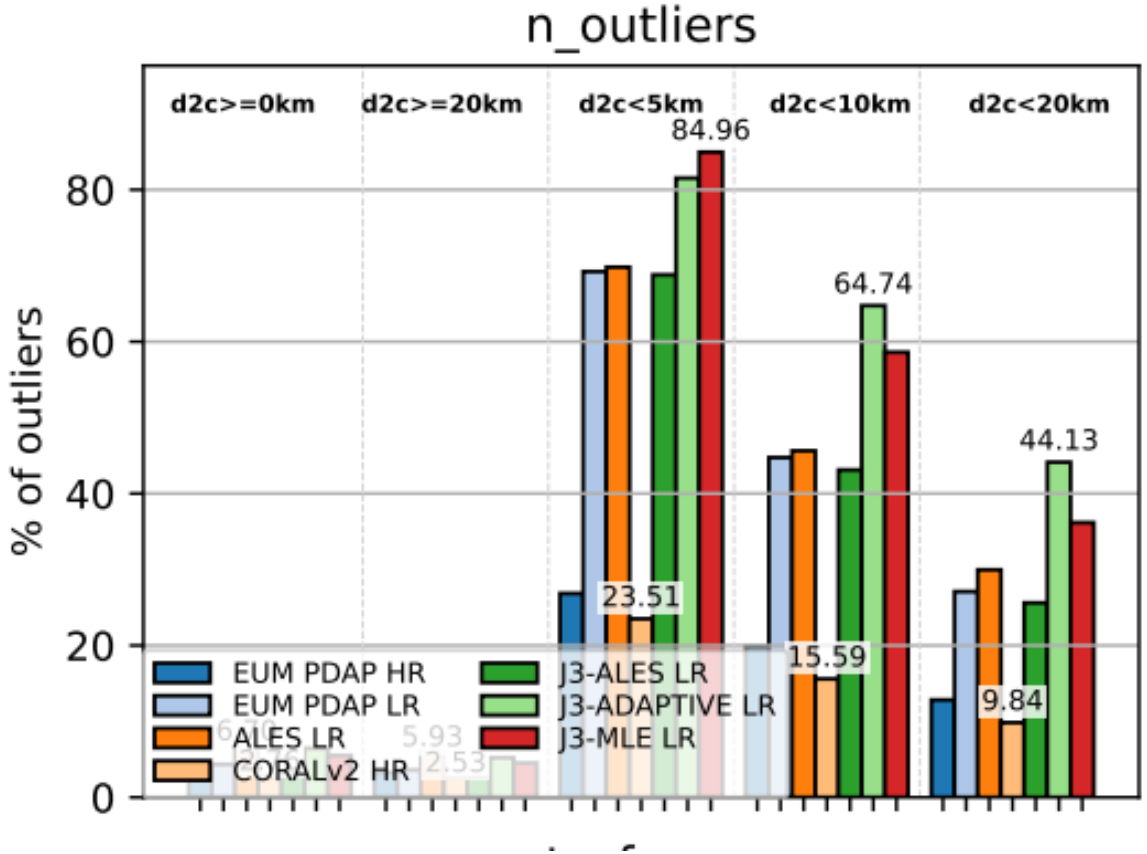
- **invalid** Data missing (already set to NaN) or quality flag set to 'bad'
- **out_of_range** If a value is out of the expected range of SWH = [−0.25,25] m , SLA = [−2,2] m

- **mad_factor** This criterion compares the value with its 20 closest neighbours
  - Data are discarded if they exceed median plus 3 * 1.4826 * MAD (median absolute deviation, i.e. a robust standard deviation)

Schlembach et al. 'Round Robin Assessment of Radar Altimeter Low Resolution Mode and Delay-Doppler Retracking Algorithms for Significant Wave Height'. *Remote Sensing* 12, no. 8 (January 2020): 1254. https://doi.org/10.3390/rs12081254.

Performance Assessment Analysis: Noise and Outliers

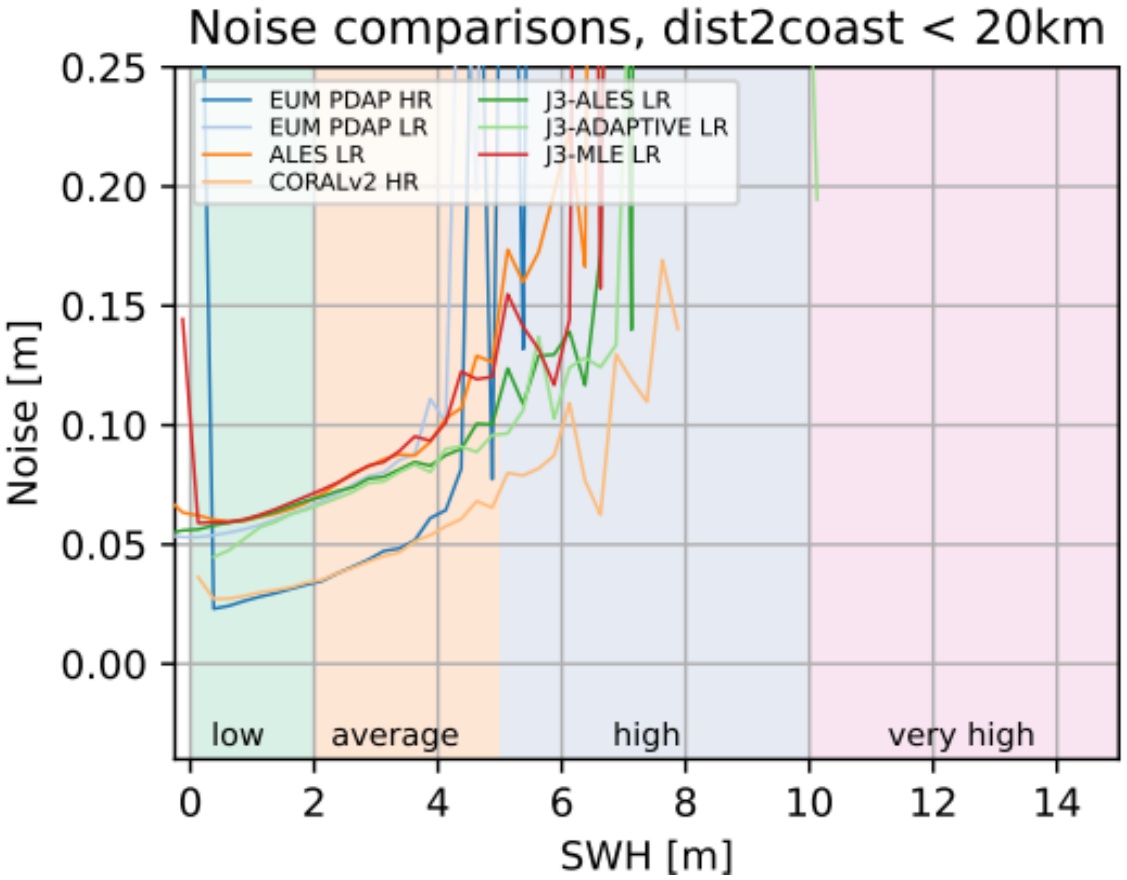
- **SLA:** outliers



- Largest improvements from SAR in the last 5 km, significantly better than LRM
- LRM S6 coastal valid data amount can be largely improved by ALES reprocessing
- Largest number of outliers close to the coast found in J3-MLE LR and J3-ADAPTIVE, lowest number found in standard EUM PDAP HR and CORALv1 (from 85% to 23%!!!)

Performance Assessment Analysis: Noise and Outliers

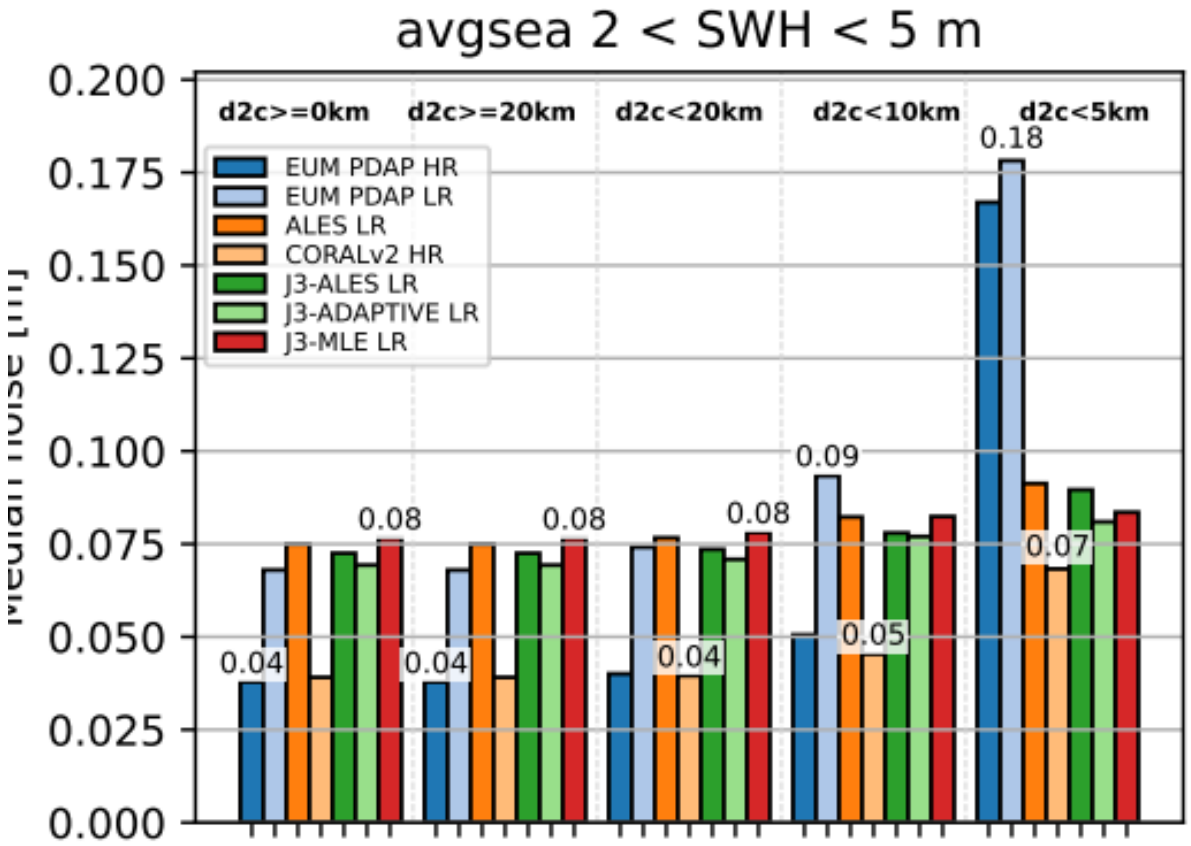
- **SLA:** noise



- Coastal noise statistics only representative til roughtly SWH = 4m
- Best performances for LRM reached by J3-Adaptive, J3-ALES LR and EUM PDAP LR
- Large improvement in precision seen with SAR data, CORALv1 strongly improve the noise at very low SWH

Performance Assessment Analysis: Noise and Outliers

- **SLA:** noise



- Coastal noise statistics only representative til roughtly SWH = 4m

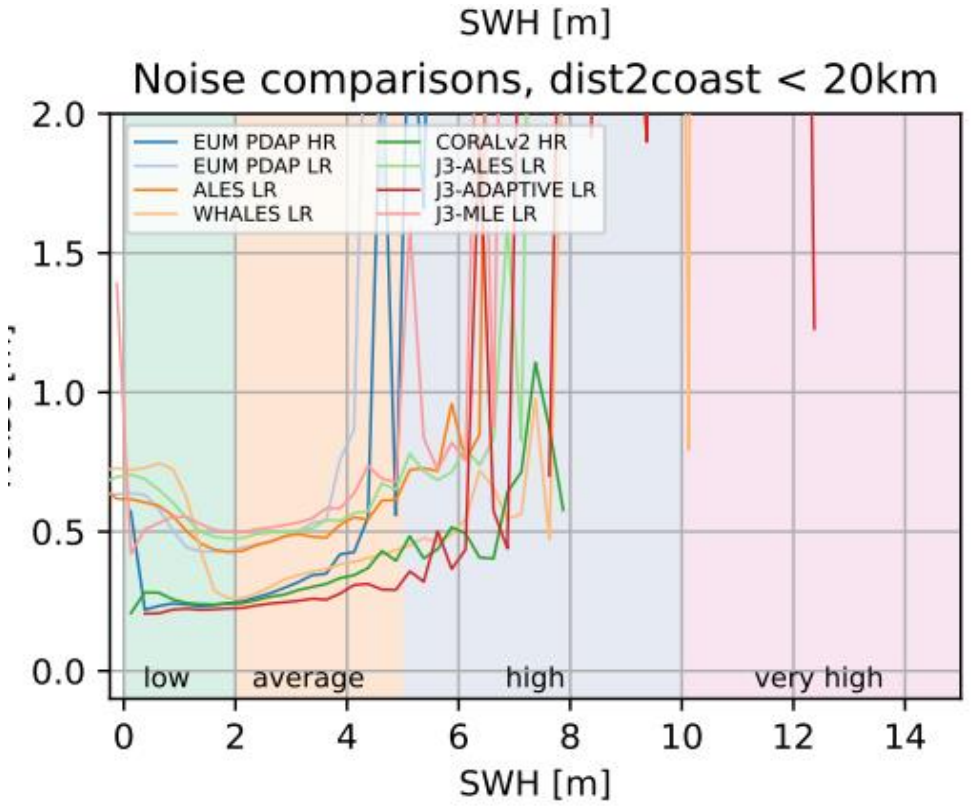
- Coral shows the best noise performances close to the coast, while keeping the largest amount of data (quantity and quality possible by retracking SAR data!)

- "Good" performances of J3-MLE LR simply due to huge data flagging (only 15% of data kept in the last 5 km)

Performance Assessment Analysis: Noise and Outliers

Preliminary results

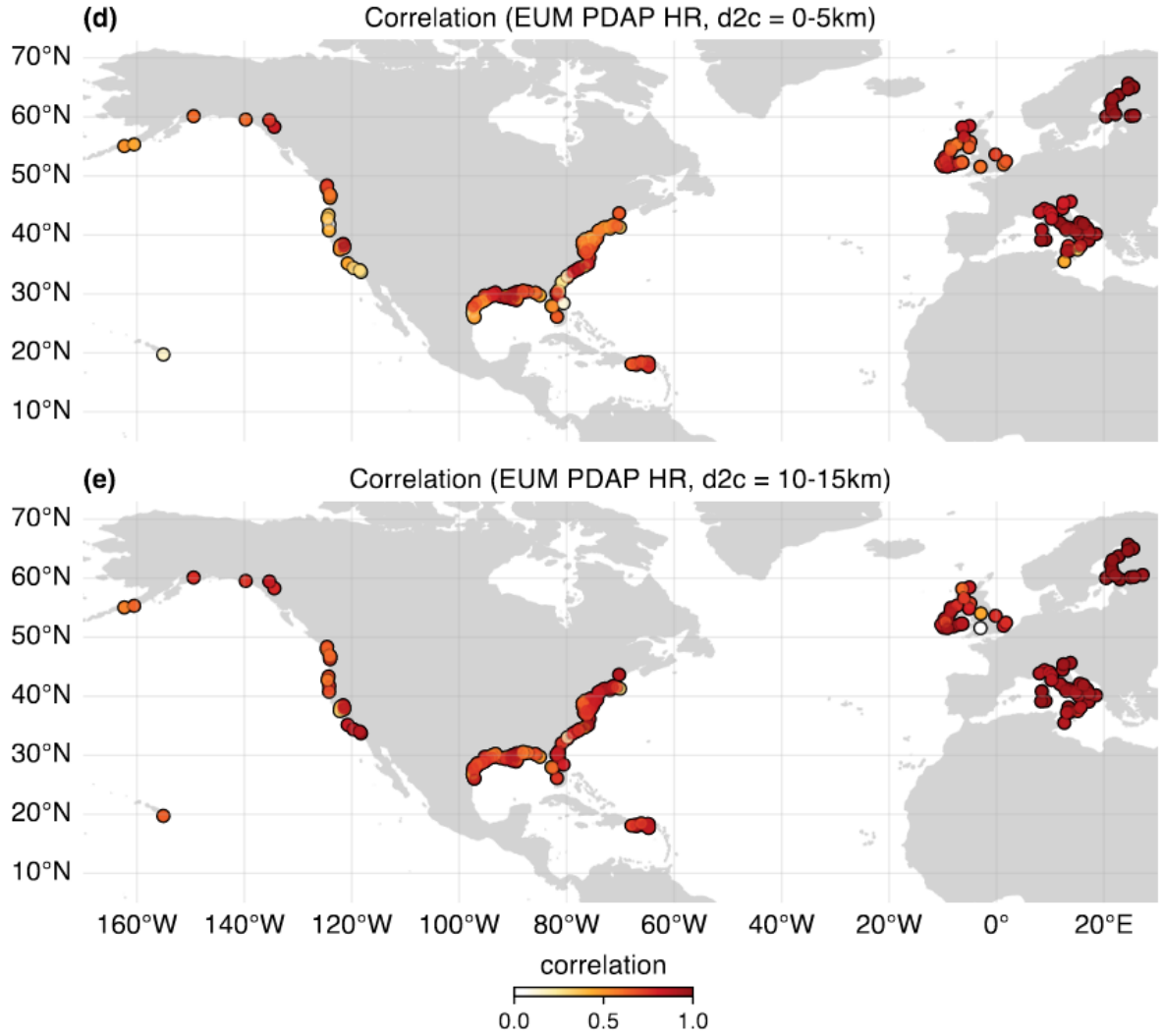
- **SWH:** noise



- S6 WHALES LRM reprocessing reaches the same level of noise as SAR data for average sea states (also in the open ocean, not shown)
- SAR data have better noise performances for low SWH
- Best overall performances reached by J3-ADAPTIVE LR

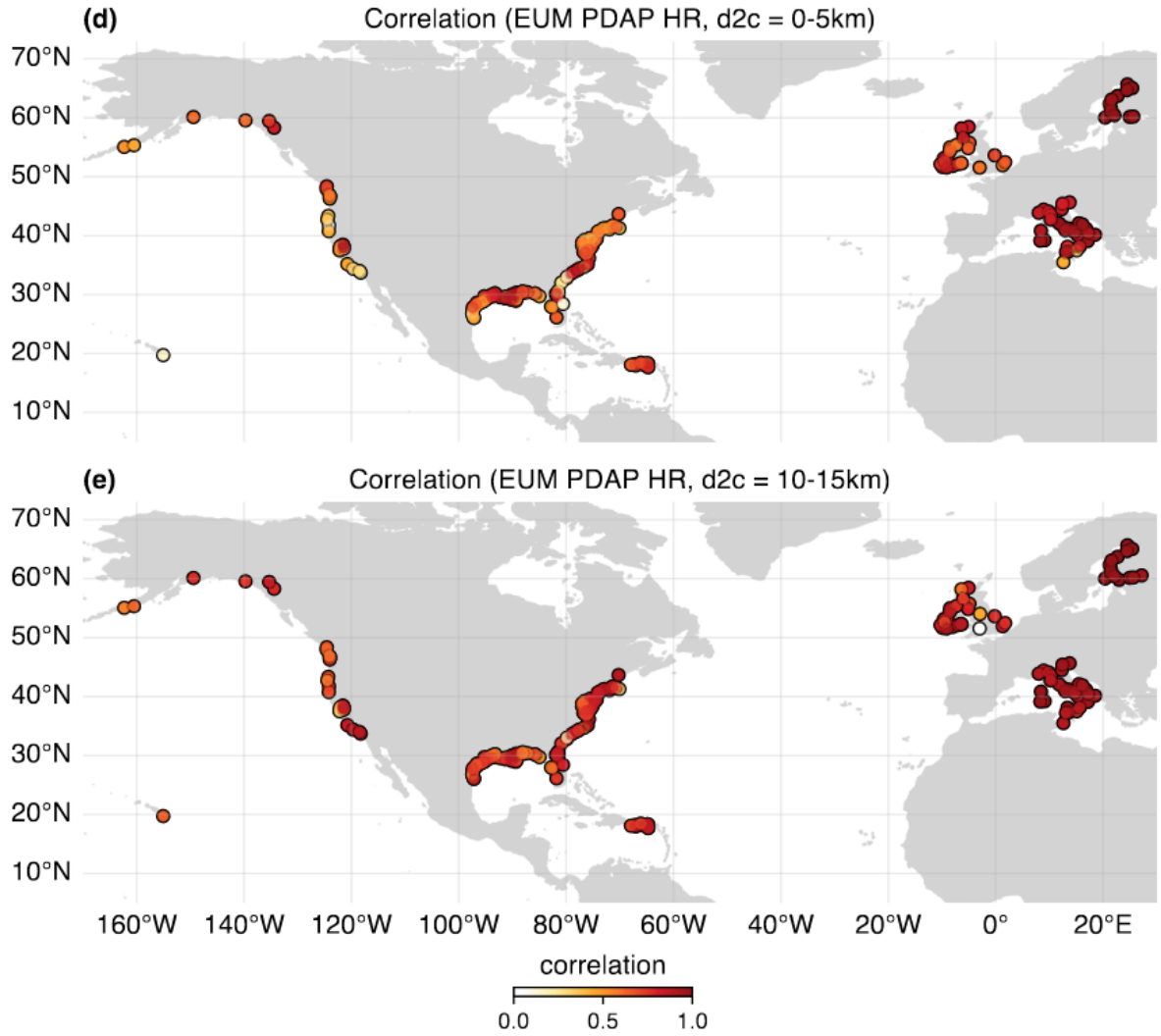
Comparison against tide gauges

- **SLA evaluated against hourly TGs from GESLA (all with records during S6 cycles 13-22)**
- **TG detided using a 40-h Loess Filter, DAC removed**
- **Altimetry data interpolated on nominal tracks**
- **SLAs larger than +- 1.5 m are removed (outlier check to have meaningful correlation). Number of remaining samples saved to check for data quantity**
- **Altimetry data selected with a radius of 250 km from TG and binned according to distance to coast**
- **Maximum time gap: 5 hours.**



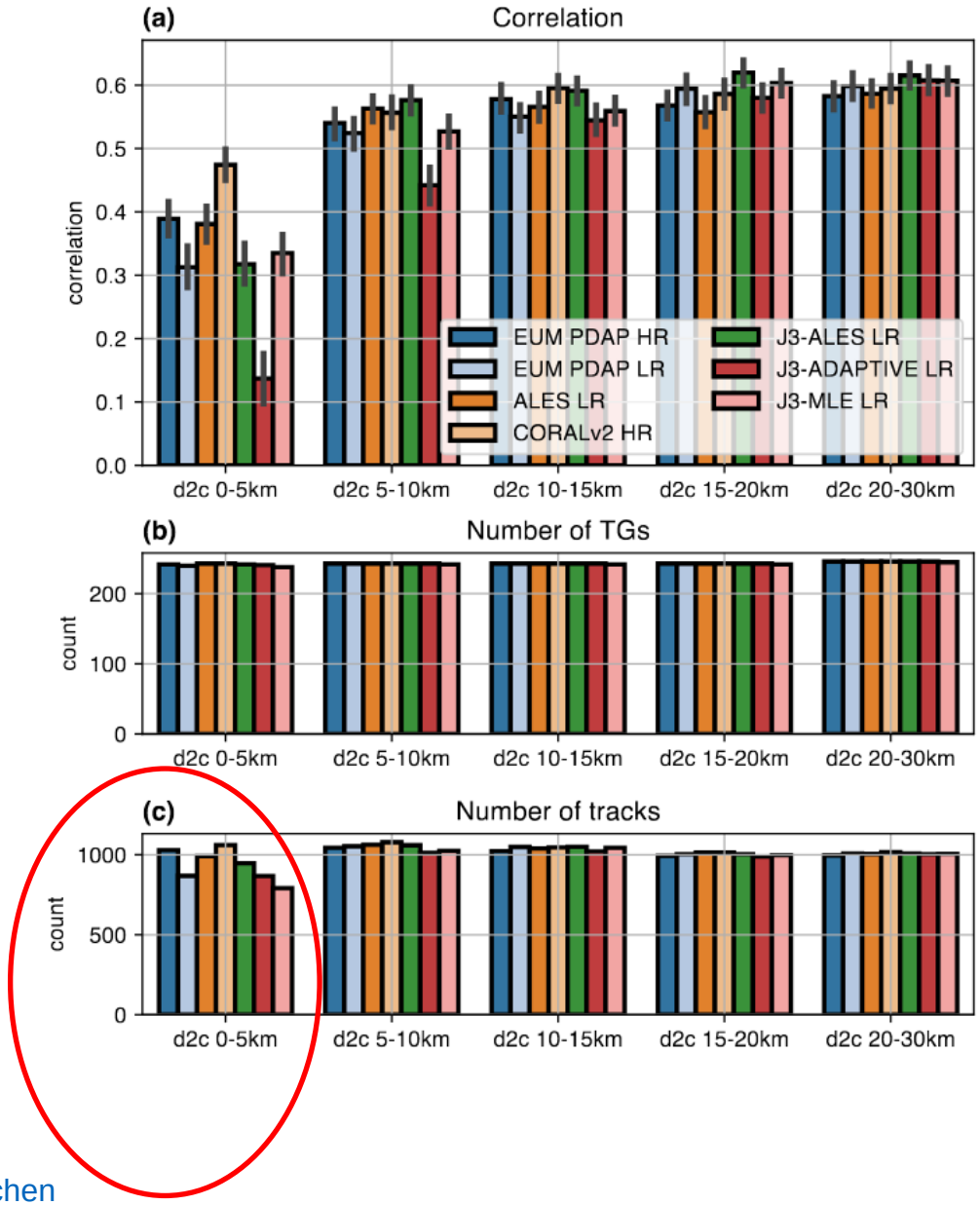
Comparison against tide gauges

- Note the high number of TGs (>200) which helps given the shortness of the time series
- Firstly, we show correlation for bins 0-5 km and 10-15 km, considering official S6 product
- Regional clusters are present, as known (example: very high correlation in the Baltic Sea)



Comparison against tide gauges

- Significant differences among dataset in the last 10 km, more pronounced in the last 5 km
- In the last 5 km, S6 products outperform J3 products
- The best performing dataset is the coastal-dedicated retracking of SAR altimetry (CORALv2 HR), with 0.47 correlation and highest amount of valid data



Comparison against tide gauges

- **Significant differences among dataset in the last 10 km, more pronounced in the last 5 km**
- **In the last 5 km, S6 products outperform J3 products**
- **The best performing dataset is the coastal-dedicated retracking of SAR altimetry (CORALv2 HR), with 0.47 correlation and highest amount of valid data**
- **While EUM PDAP HR performs better than its LR counterpart EUM PDAP LR, the coastal dedicated reprocessing (ALES LR) of S6 LR waveforms increase the performance of the latter in both data quality and quantity.**
- **The worst performing dataset in terms of correlation is the J3 ADAPTIVE LR in both 0-5 km and 5-10 km. We are told this is due to a software error that has been corrected, but could not verified as this was after our analysis**

Table 1. Mean correlation between the different altimetry datasets and tide gauges per distance-to-coast class.

Altimetry Dataset	0–5 km	5–10 km	10–15 km	15–20 km	20–30 km
EUM PDAP HR	0.39	0.54	0.58	0.57	0.58
EUM PDAP LR	0.31	0.52	0.55	0.59	0.60
ALES LR	0.38	0.56	0.57	0.56	0.59
CORALv2 HR	0.47	0.56	0.60	0.59	0.59
J3-ALES LR	0.32	0.58	0.59	0.62	0.62
J3-ADAPTIVE LR	0.14	0.44	0.54	0.58	0.61
J3-MLR LR	0.33	0.53	0.56	0.60	0.61

Bias Analysis

Method

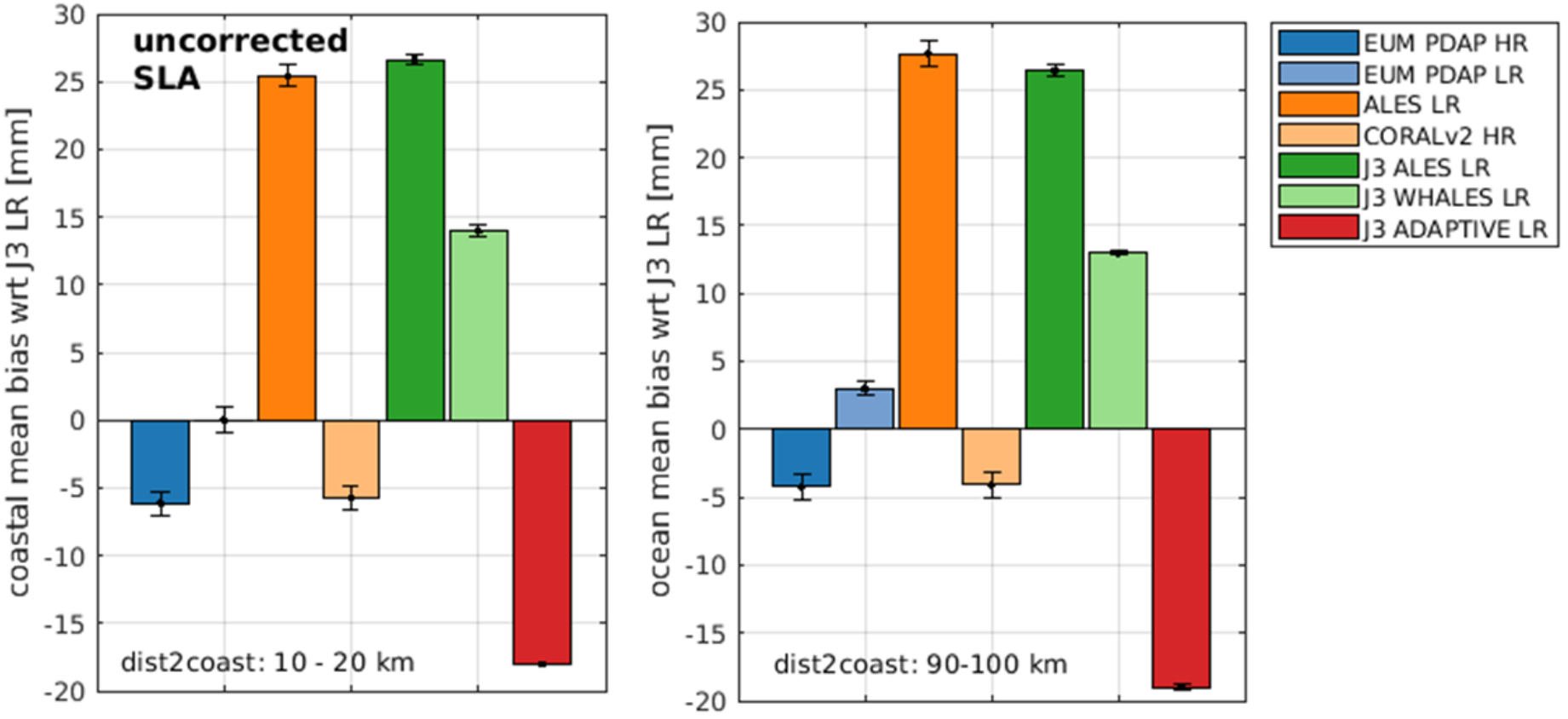
Tandem phase of Sentinel-6A with Jason-3: three datasets available that should show the same signal: S6 HR, S6 LR, J3 LR (plus additional retracking)

➢ Analyse along-track data (hf) instead of crossover differences

Processing steps

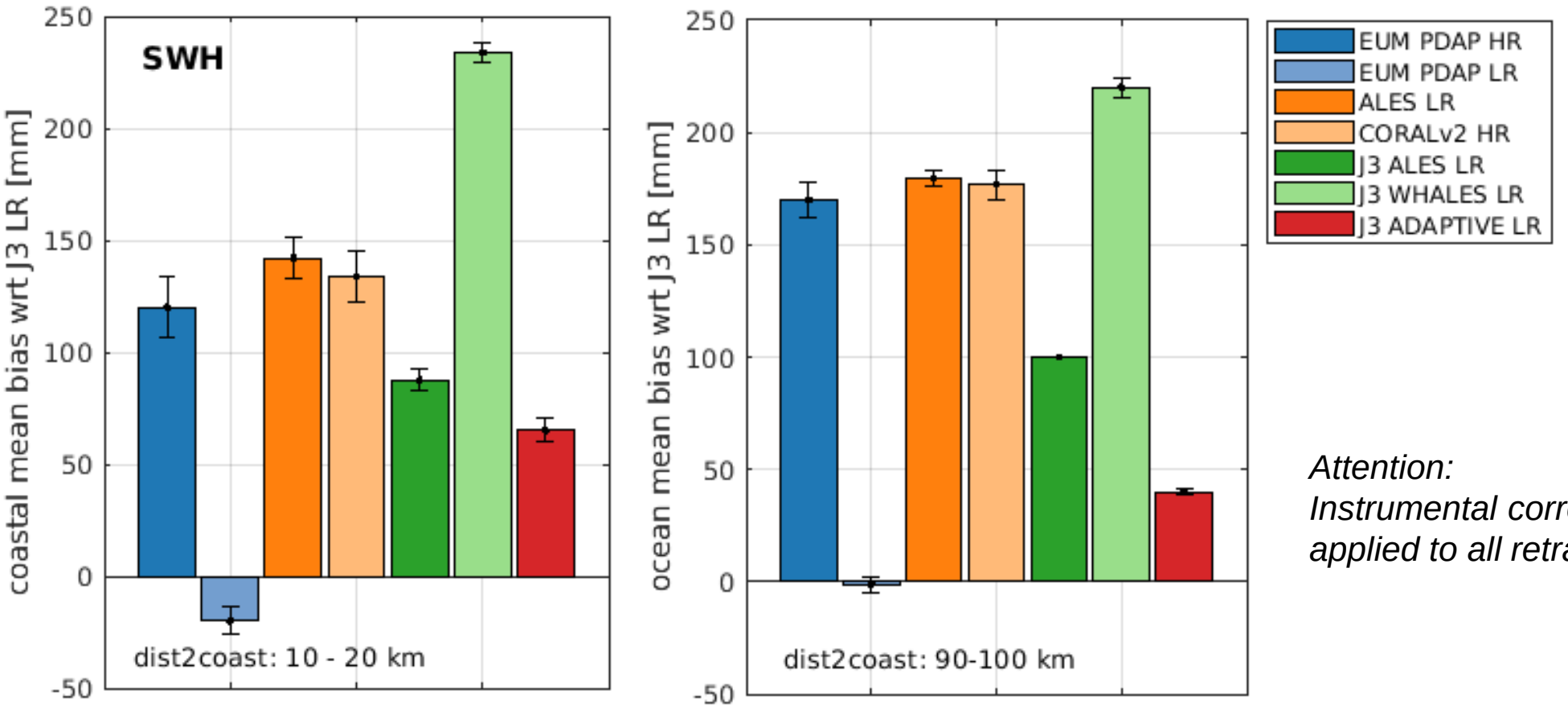
- Extract global data with max distance to coast of 100 km
- Interpolate S6 data to J3 data points (nearest neighbor)
- Build differences with respect to J3 LR Ocean Product; exclude outliers outside a 95% quantile
- Biases are computed as median over all passes and over all cycles; their uncertainties are derived as standard deviations from the spread over the different cycles
- Potential differences between coastal areas and “open” ocean are analysed
- Products: SLA (uncorrected, only SSB), SWH, tropw, ionos

Bias Analysis: SLA



- No significant differences (95% confident level) between coast and ocean

Bias Analysis: SWH



Attention:
Instrumental correction not applied to all retrackers!

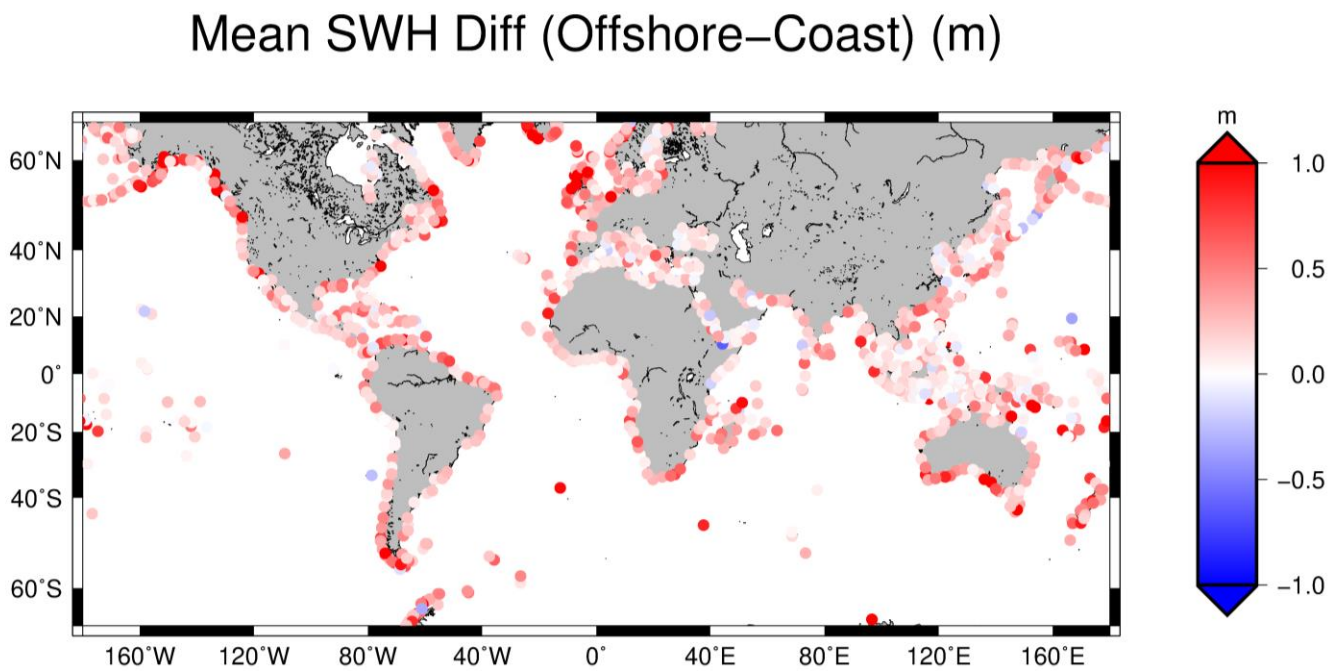
- Significant differences between coast and ocean for: S6 PDAP HR, S6 CORAL HR, S6 ALES LR, J3 Adaptive
- Probably related to different sea states in both areas? => bias depends on SWH;

Conclusions

- The improvement in the coastal zone from LR to HR (SAR) altimetry was evident throughout all the work, except for the "known" issues concerning SWH differences between SAR and LRM
- Dedicated coastal retracking of SAR altimetry substantially improve the performances
- Dedicated coastal retracking of LR altimetry is able to perform at least as good as non-coastal retracked SAR altimetry

Future work proposed: Capability of S6 to observe SWH gradient in the coastal zone

- It has been demonstrated that nadir altimetry has the capability to assess the SWH attenuation typical of the transition from offshore to coastal zone due to several issues such as land sheltering and interaction with bathymetry (Nature Communications, Passaro et al., 2021).
- Global mean attenuation of SWH towards the coastline from **>3 km** from offshore at 30 km amounts to 22%, with strong regional variations



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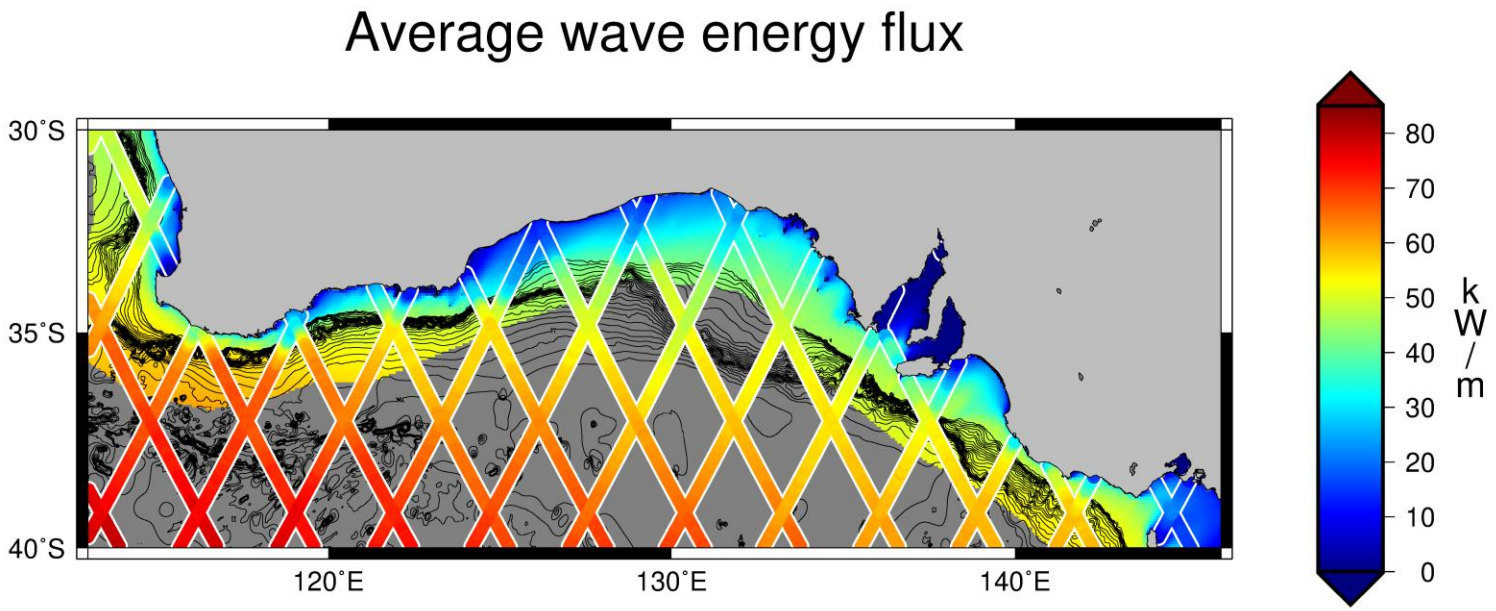
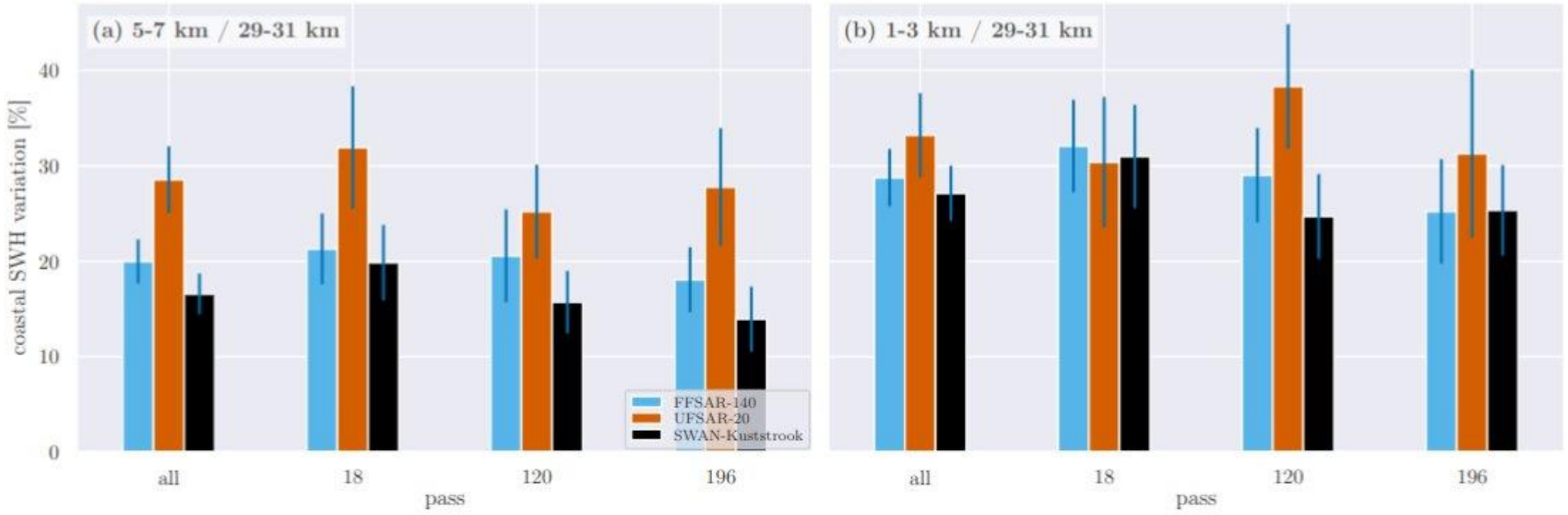


Future work proposed: Capability of S6 to observe SWH gradient in the coastal zone

- Thanks to its improved performances, S6 may be able to quantify this decay at least up to 1 km from the coast, as first results show (Remote Sensing of the Environment, Schlembach et al., 2023).

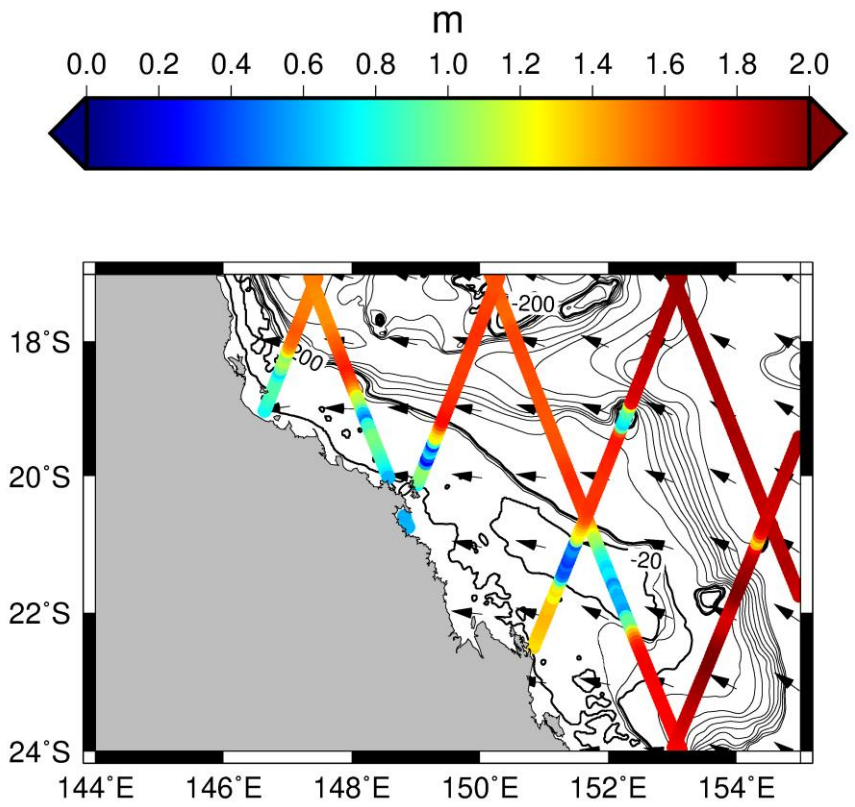


- we estimate coastal SWH variations of up to 1 km from the coast

$$\Delta_{\text{2-30/6-30}} = (1 - \frac{\text{median}(\text{SWH}_{\text{1-3/5-7}})}{\text{median}(\text{SWH}_{\text{29-31}})}) \cdot 100$$

Future work proposed: Capability of S6 to observe SWH gradient in the coastal zone

- We also plan to conduct case studies in areas of particular interest, such as coral reefs to study their role as wave barriers.



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- Passaro M., Hemer M., Quartly G.D., Schwatke C., Dettmering D., Seitz F.: Global coastal attenuation of wind-waves observed with radar altimetry. Nature Communications, 12, 3812, 10.1038/s41467-021-23982-4, 2021
- Schlembach F., Ehlers F., Kleinherenbrink M., Passaro M., Dettmering D., Seitz F., Slobbe C.: Benefits of fully focused SAR altimetry to coastal wave height estimates: A case study in the North Sea. Remote Sensing of Environment, 289, 113517, 10.1016/j.rse.2023.113517, 2023

Thanks for your attention!

Scientific Activities: Coastal Assessment

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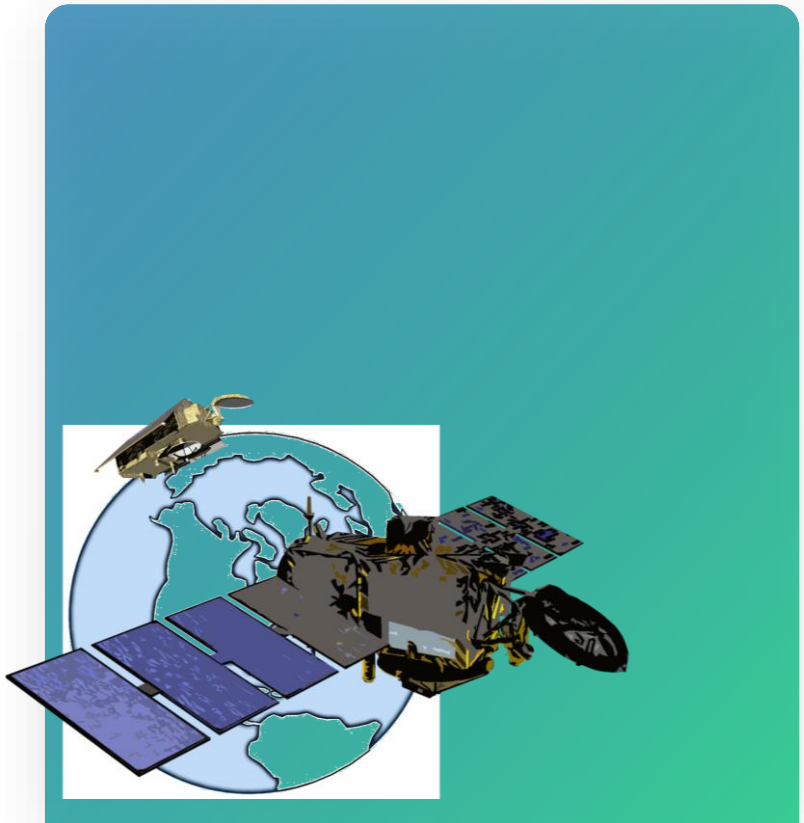

S6-JTEX PM5
Online, 31st January 2023

Assessment of Coastal Performances

Tasks

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Planned Steps

1. Retrack the J3 and S6-MF LRM waveforms with specific retrackers: ALES and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
2. Performance assessment analysis in terms of L2 noise and outlier analysis in the coastal zone, for S6 LRM, SAR-RAW and SAR-RMC & retracked J3
3. Intercomparison of S6 and J3 based on L2 products in the coastal zone will be performed focusing on bias, drift and their geographical patterns

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Tandem phase of Sentinel-6A with Jason-3: three datasets available that should show the same signal: S6 HR, S6 LR, J3 LR (plus additional retracking)

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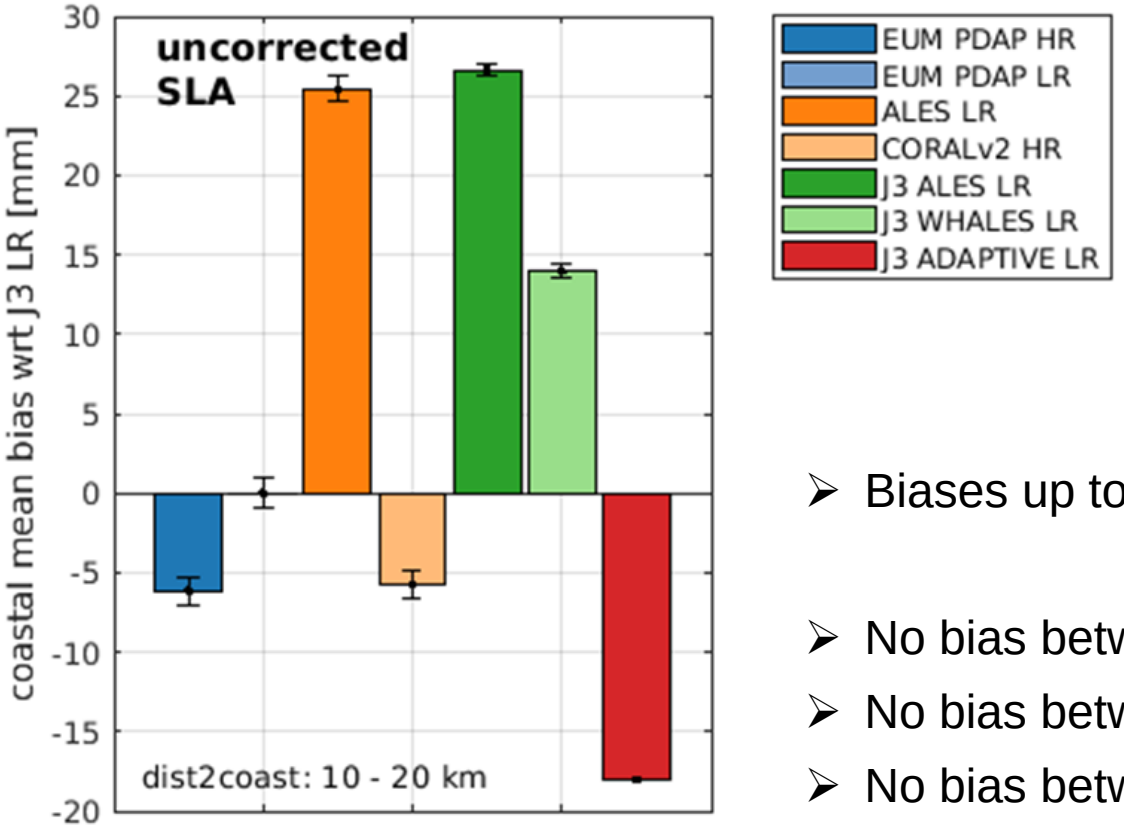
- Potential differences between coastal areas and “open” ocean are analysed
- Products: SLA (uncorrected, only SSB), SWH, tropw, ionos

Bias Analysis: SLA – mean values



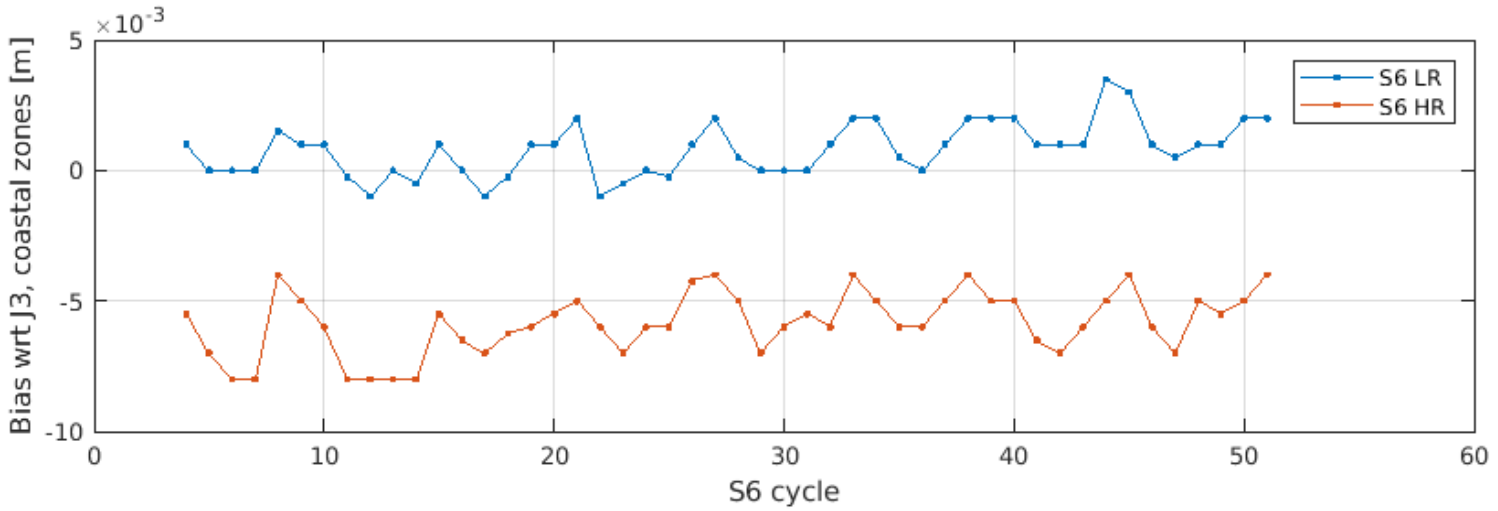
SLA = Hsat – Range – SSB - MSS

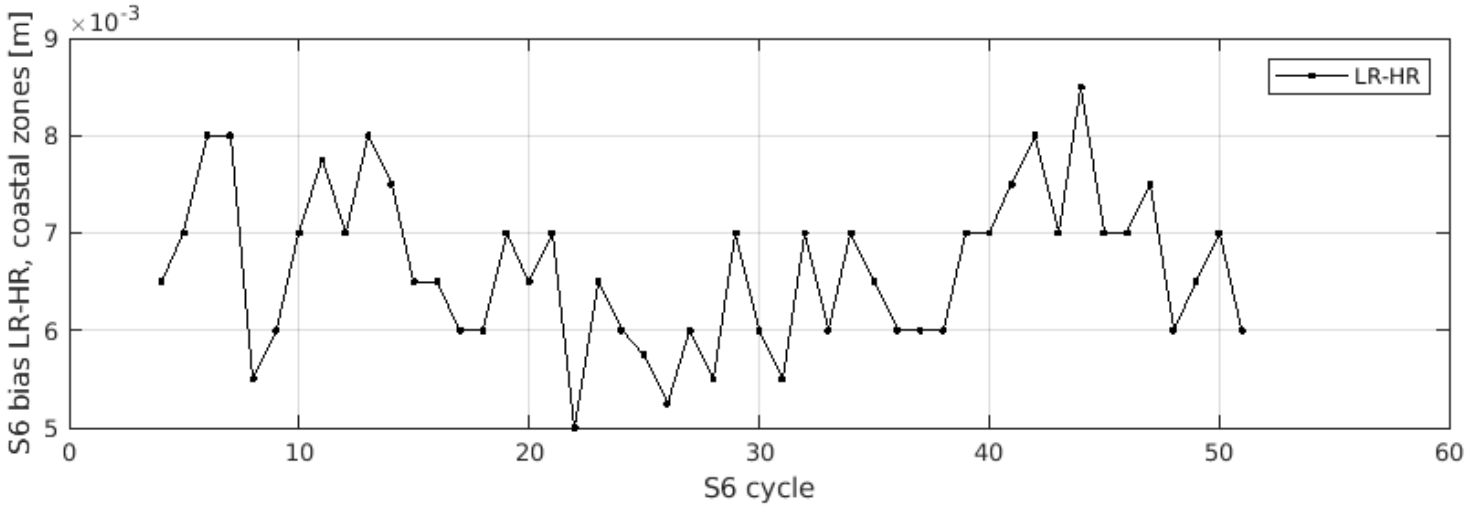
- Biases up to 2.6 cm wrt Jason-3 LR

- No bias between S6 LR and J3 LR (official L2 products)
- No bias between S6 HR PDAP and CORAL
- No bias between S6 LR ALES and J3 LR ALES

Cycles: 13-22

Bias Analysis: SLA – time dependency



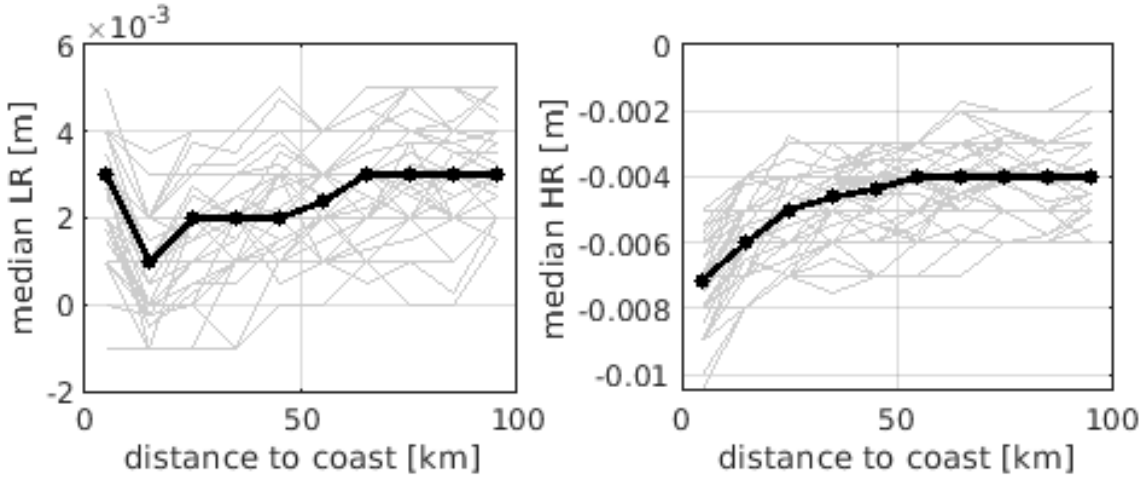


- Small drifts visible in S6 HR and LR (with respect to J3); but not significant

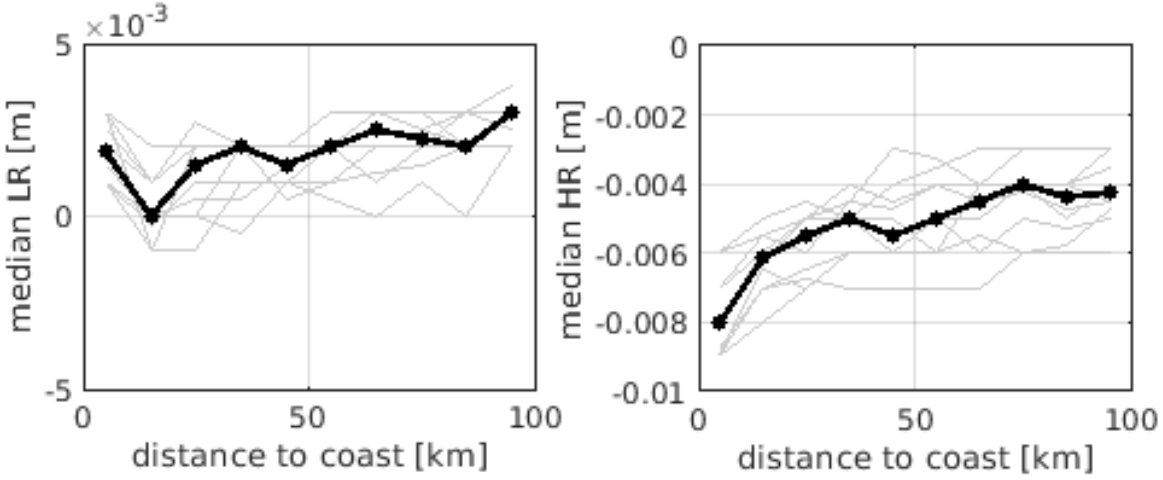
Info:
Long time series not available for all retrackers

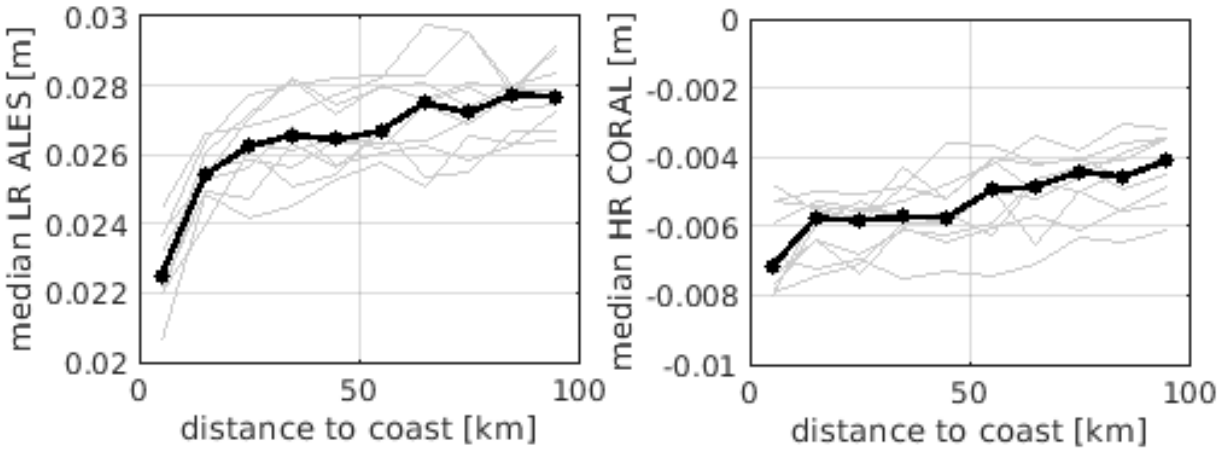
Bias Analysis: SLA – distance to coast dependency

Cycles 4-51



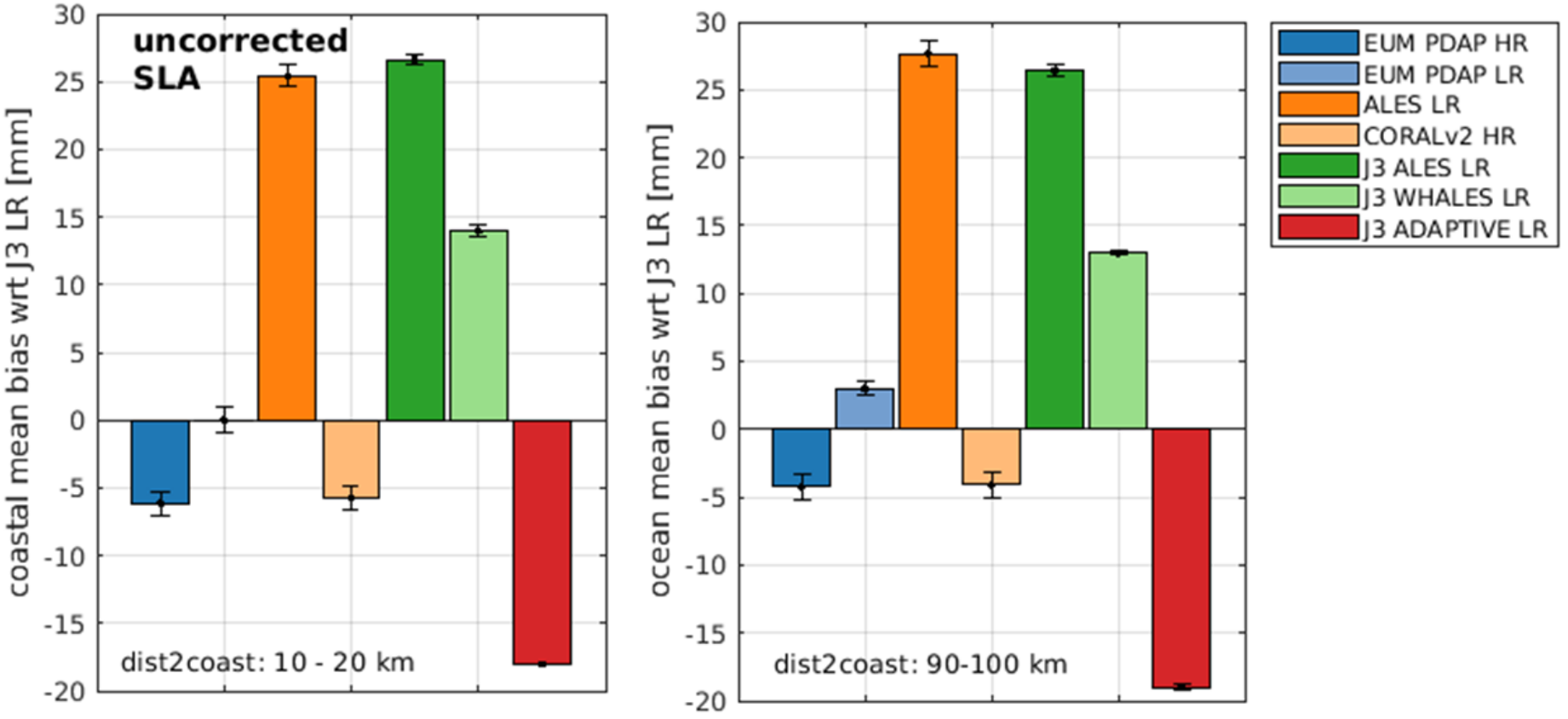
Cycles 13-22





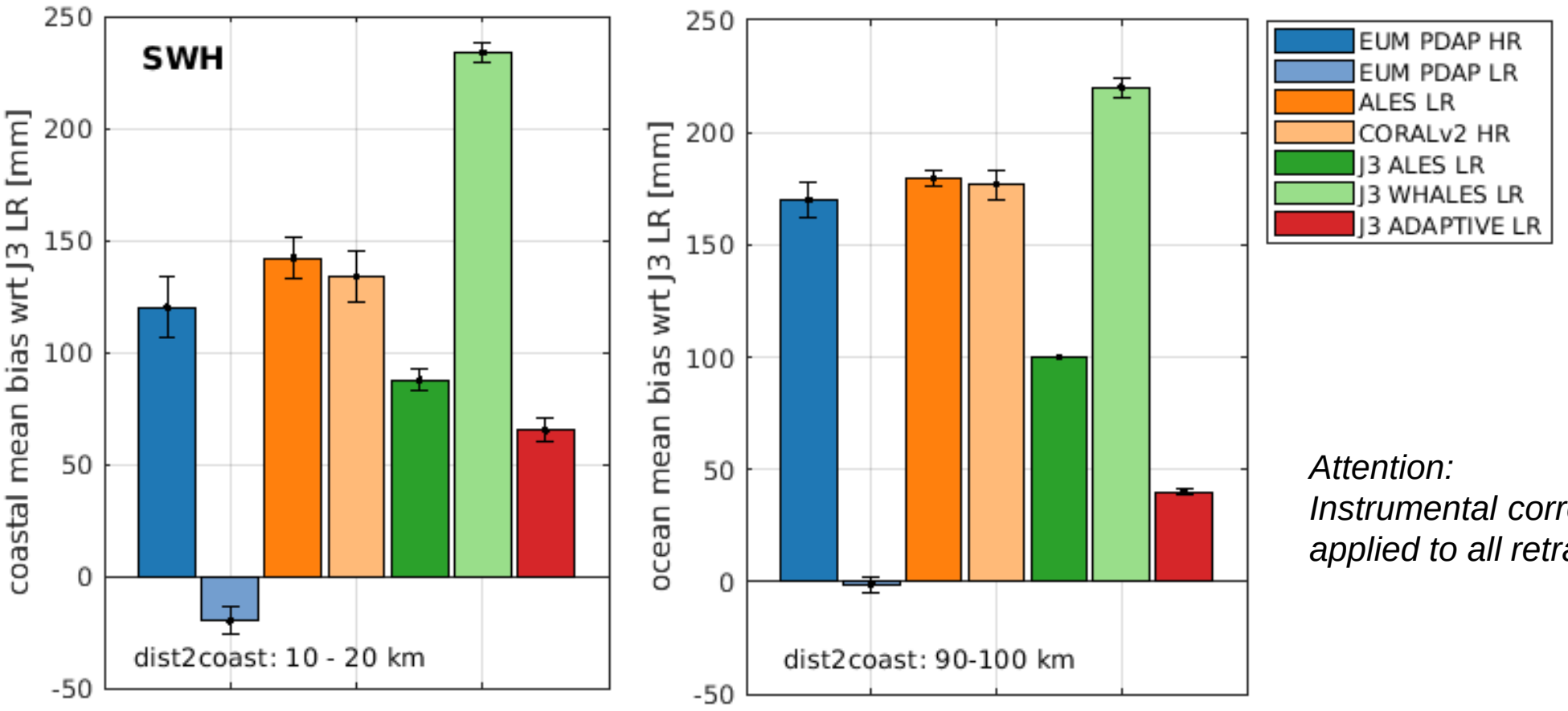
- Correlation with distance-to-coast visible, especially for HR
- Few data points and high measurement noise in class 0-10 km => not to be used
- cycle-to-cycle variations used as uncertainty measure for a significance test

Bias Analysis: SLA



- No significant differences (95% confident level) between coast and ocean, except of Jason-3 Adaptive

Bias Analysis: SWH



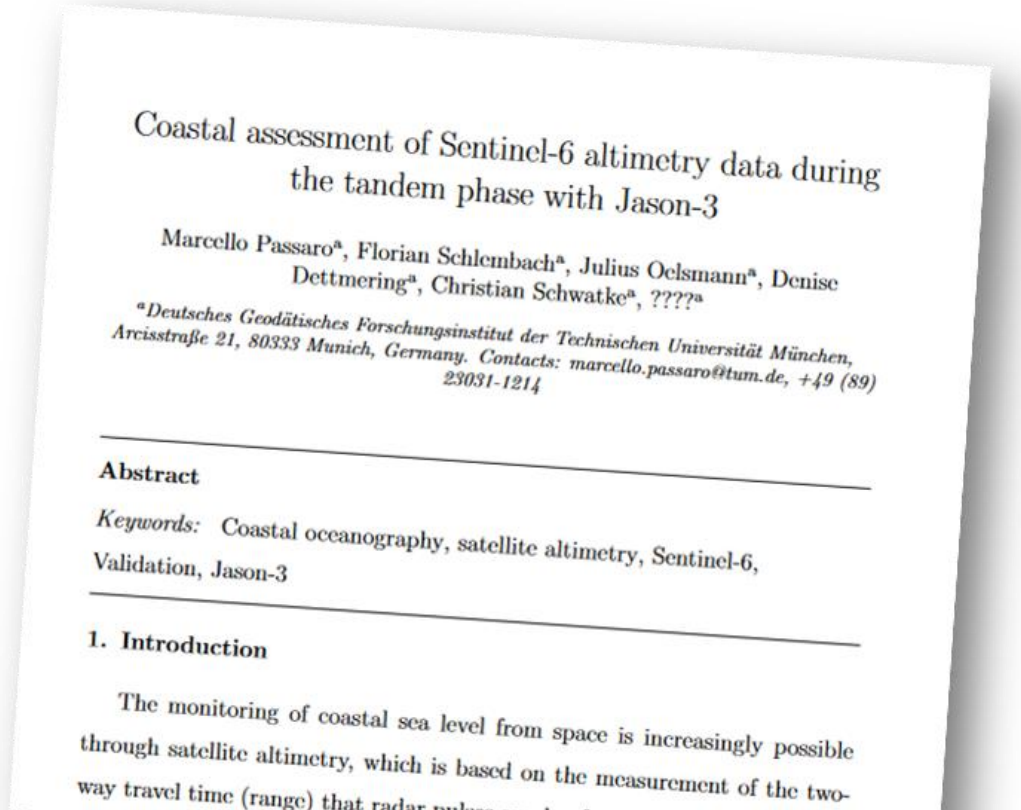
Attention:
Instrumental correction not applied to all retrackers!

- Significant differences between coast and ocean for: S6 PDAP HR, S6 CORAL HR, S6 ALES LR, J3 Adaptive
- Probably related to different sea states in both areas? => bias depends on SWH; further analyses necessary…

Paper Status

Coastal assessment of Sentinel-6 altimetry data during the tandem phase with Jason-3

- Outlier analysis ✓
- Along-track noise analysis ✓
- Bias analysis ✓
- Validation of sea level anomalies against tide gauges !



Coastal assessment of Sentinel-6 altimetry data during the tandem phase with Jason-3

Marcello Passaro[a], Florian Schlembach[a], Julius Oelsmann[a], Denise Dettmering[a], Christian Schwatke[a], ????[a]

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Abstract

Keywords: Coastal oceanography, satellite altimetry, Sentinel-6, Validation, Jason-3

1. Introduction

The monitoring of coastal sea level from space is increasingly possible through satellite altimetry, which is based on the measurement of the two-way travel time (range) that radar

Scientific Activities: Coastal Assessment

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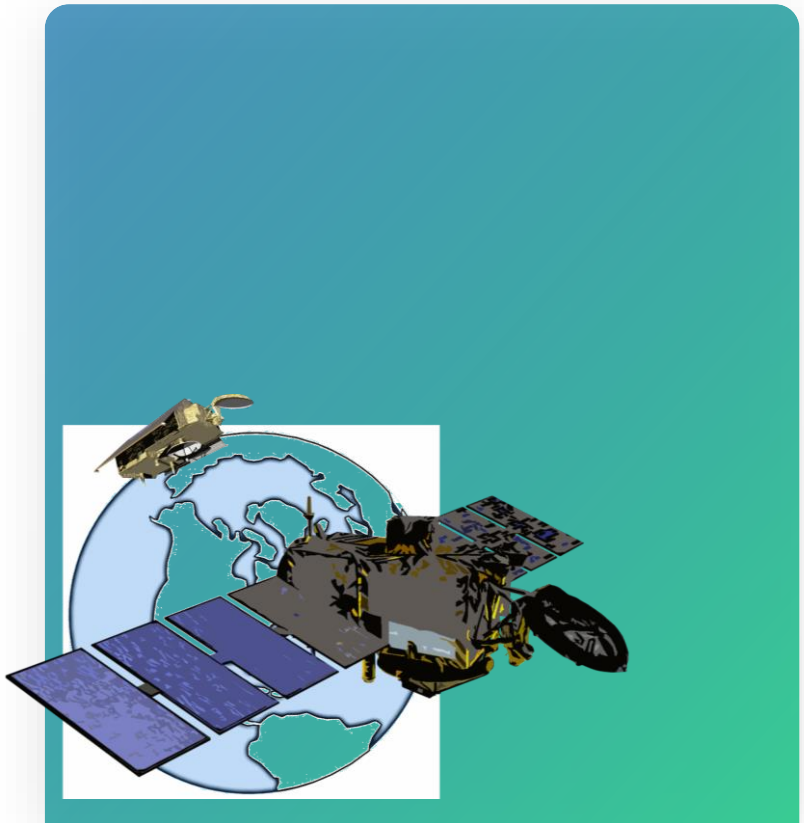


S6-JTEX PM4
Online, 11th October 2022

Assessment of Coastal Performances

Tasks

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and a retracked Jason-3 product
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Planned Steps

1. Retrack the J3 and S6-MF LRM waveforms with specific retrackers: ALES and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
2. Performance assessment analysis in terms of L2 noise and outlier analysis in the coastal zone, for S6 LRM, SAR-RAW and SAR-RMC & retracked J3
3. Intercomparison of S6 and J3 based on L2 products in the coastal zone will be performed focusing on bias, drift and their geographical patterns

Assessment of Coastal Performances

Updates

1. **An analysis comparing coastal performances between RAW and RMC modes on Sentinel-6 in terms of outliers and L2 noise was performed**
2. **The structure of the article was defined and writing has begun (introduction, data, part of the methods). The on-going draft was submitted to CLS**
3. Our data archive was updated to the F06 baseline, on which our final analysis will be based. We chose 10 cycles to analyse for the final results (13 to 22 in S6 and corresponding in J3), which have been retracked with our in-house coastal retrackers (ALES, WHALES), CORAL retracking is ongoing

RAW-vs-RMC Comparison

Used S6-MF Data

- Dedicated RAW2RMC converted S6MF data provided by EUMETSAT Helpdesk
- Cycles 25-27
- Baseline F03

Investigated Statistical Metrics

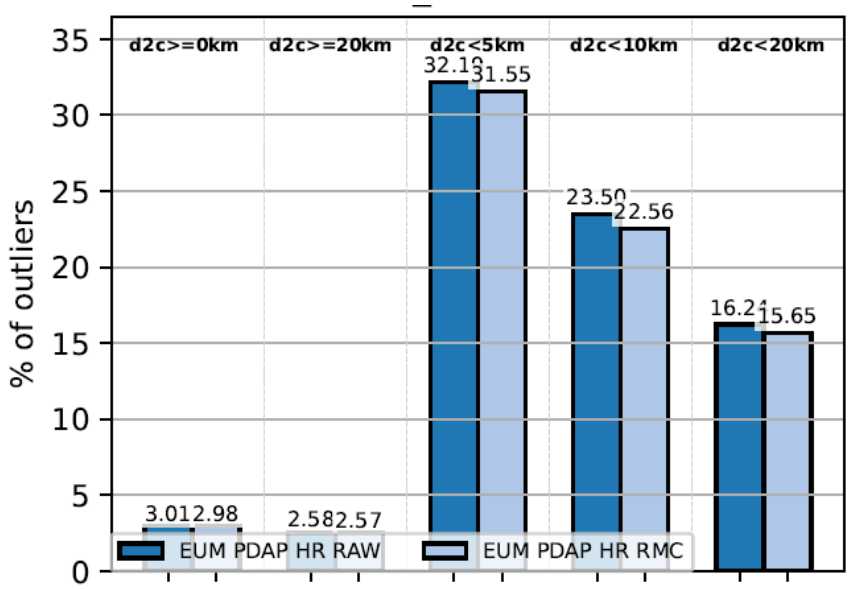
- Outliers (total, invalid, out_of_range, mad_factor)
  - invalid = quality flag
  - out_of_range → SWH = [−0.25,25] m , SLA = [−2,2] m
  - mad_factor → absolute deviation from median of 20 adjacent samples exceeds 3 * 1.4826 * MAD (median absolute deviation, i.e. a robust standard deviation)
- L2 noise: standard deviation of 20-Hz estimates within 1-Hz along-track distance

On
- SWH
- SLA

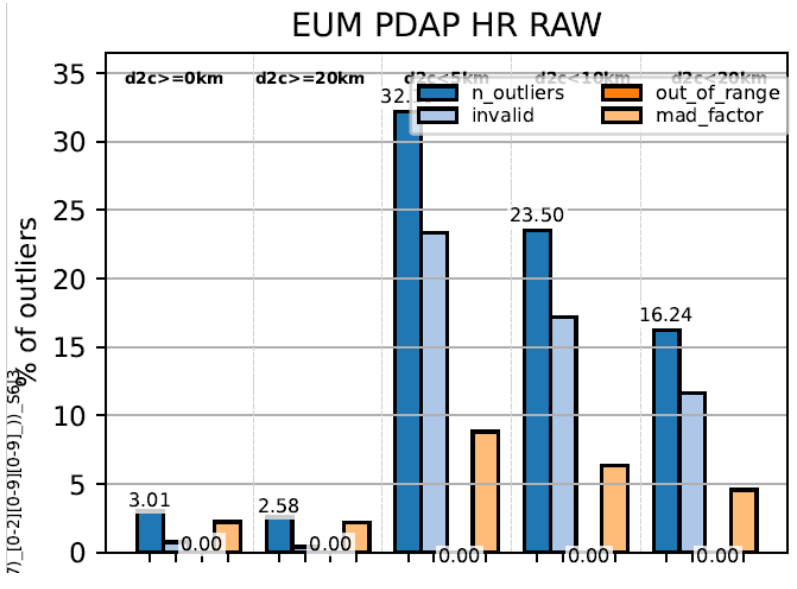
RAW-vs-RMC Comparison: SWH

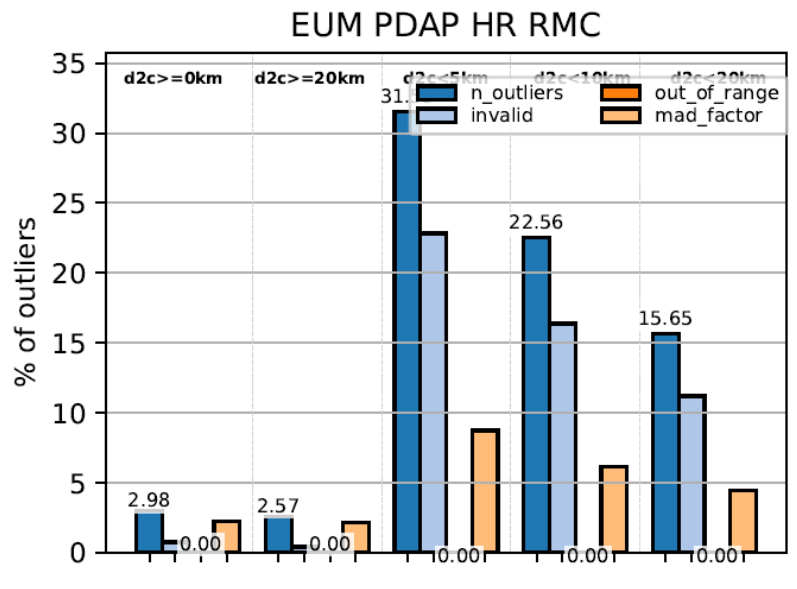
Outliers

Total number of outliers



PDAP HR and LR: outlier types

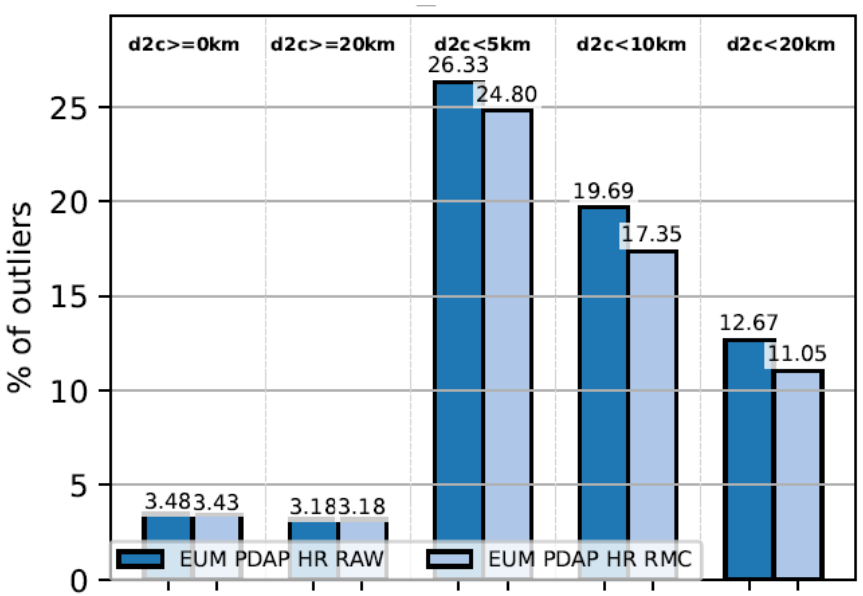




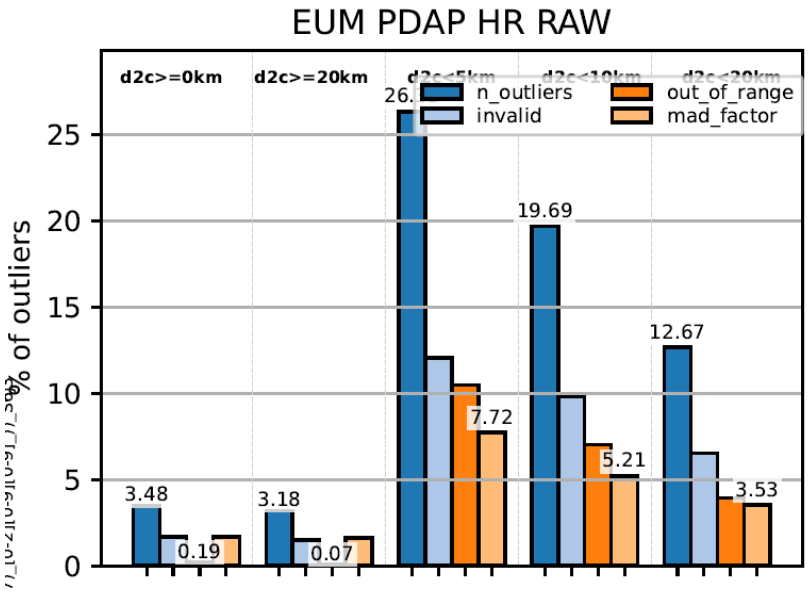
RAW-vs-RMC Comparison: SLA

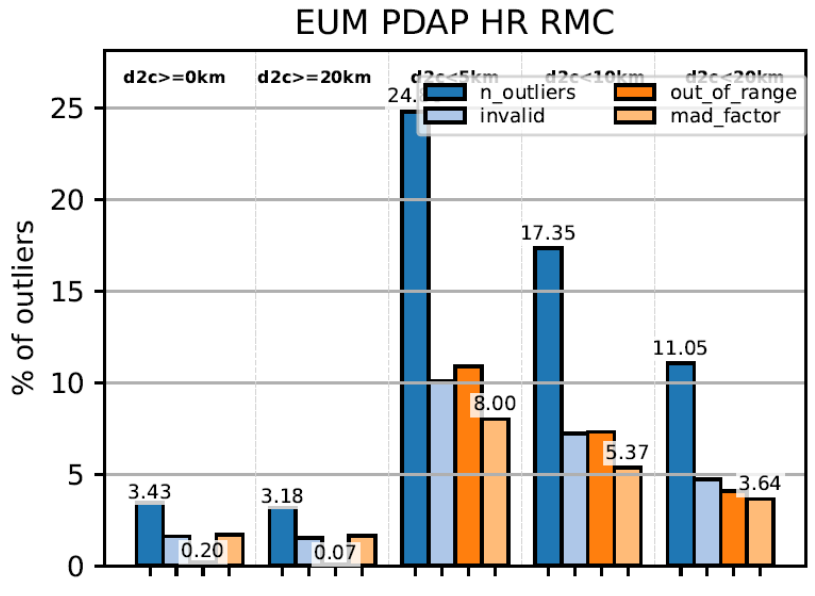
Outliers

Total number of outliers



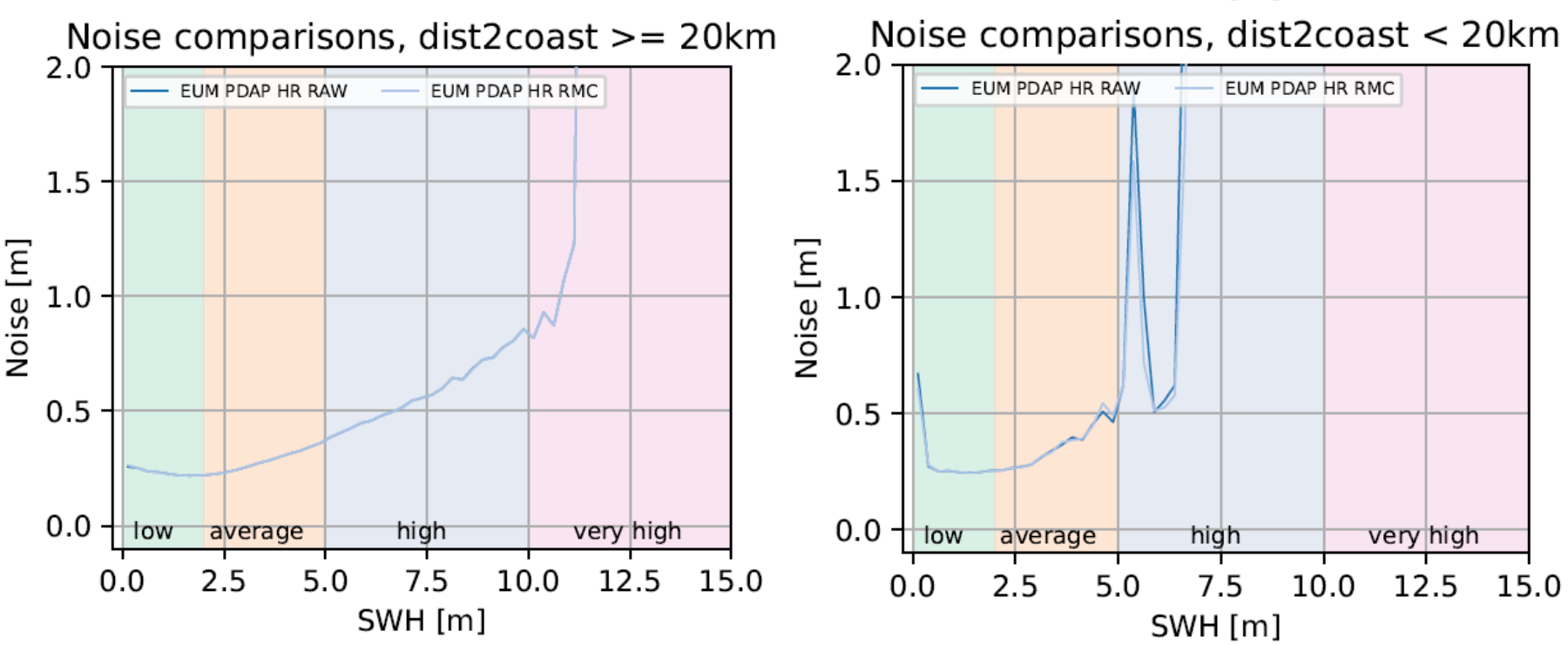
PDAP HR, RAW vs. RMC: outlier types





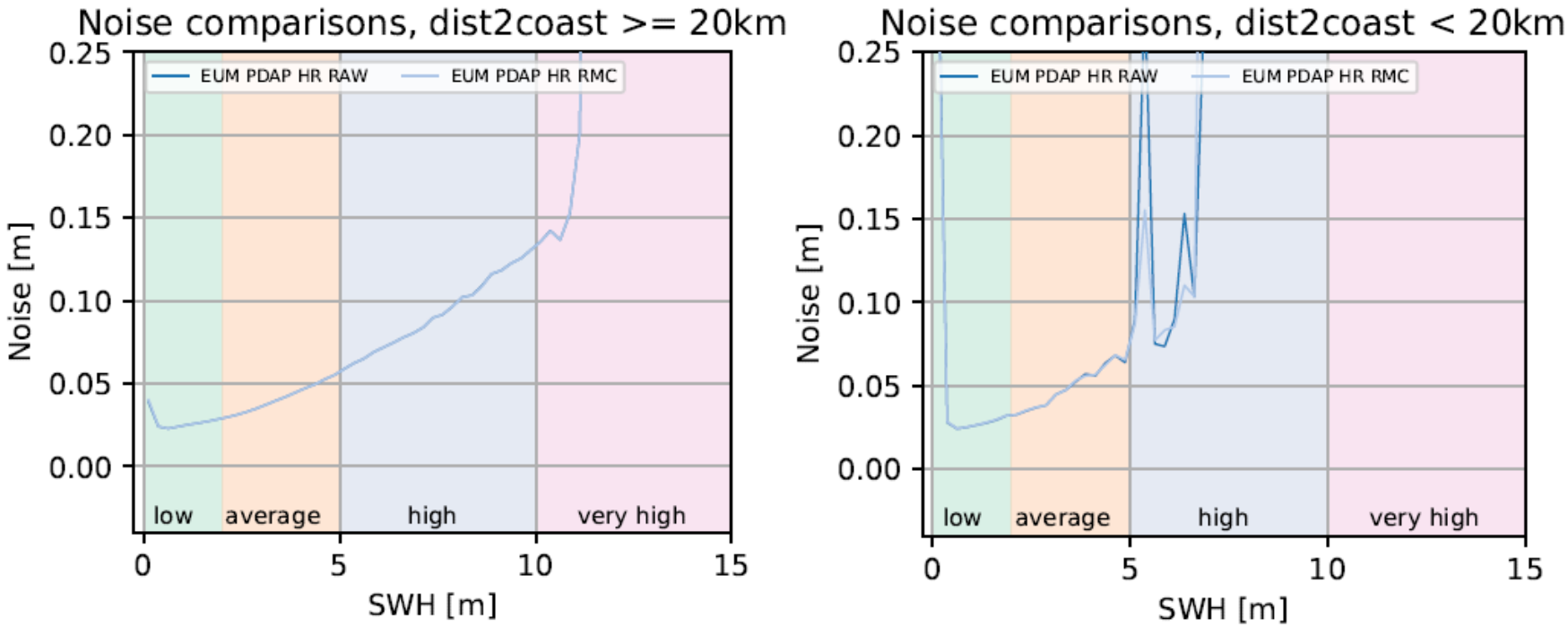
RAW-vs-RMC Comparison: SWH

L2 Noise



RAW-vs-RMC Comparison: SLA

L2 Noise



RAW-vs-RMC Comparison

Conclusion

- RMC has slight advantages in terms of outliers due to its subwaveform-nature

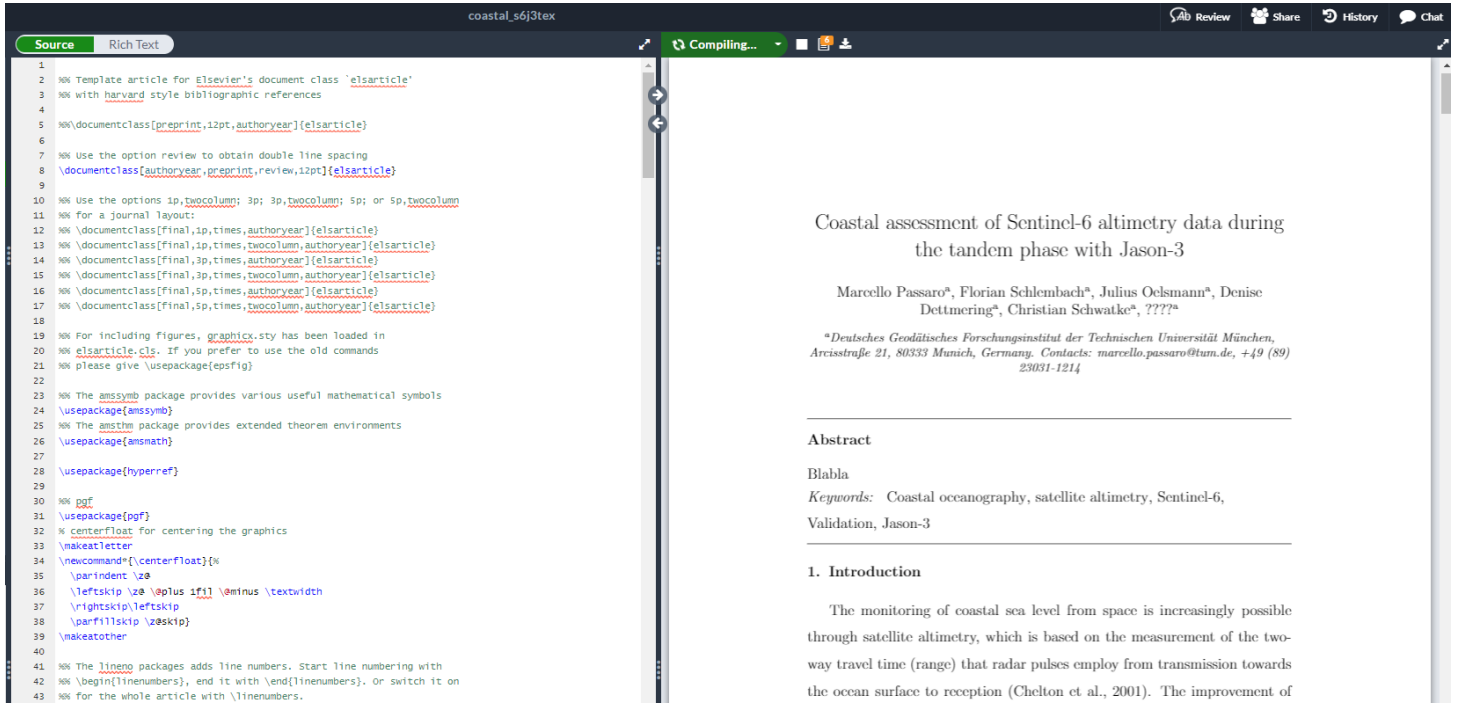
  → discarding of potential spurious interference in the trailing edge of the multilooked waveform

- Identical L2 noise for both RAW and RMC

→ No significant differences are observed for RAW- and RMC-processed PDAP HR data in terms of **outliers** and **L2 noise**

Paper Publication Status

Paper is in preparation and an early draft was submitted to CLS (currently 15 drafted PDF pages)



Question: *Which journal shall be chosen for publication? What is the general preference for the project?*

TUM currently has no additional funds for publishing open access.

Hence, the option is to publish subscription-based/non-open access.

Actions planned for the next 3 months

- Processing of CORAL retracking of the 10 cycles of S6 MF dataset (baseline F06) is ongoing
- Performance of statistical analysis of outliers and L2 noise on the targeted 10 cycles (>2100 tracks)
- First steps in tide-gauge analysis
- Continue writing of manuscript

Summary

Coastal Assessment

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and J3
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Data

- Sentinel-6A/POS-4 L1B LR NTC + L2 HR/LR NTC (coastal areas), from PODAAC
- Jason-3/POS-3B L1B/L2 GDR-F standard (coastal areas), from AVISO

Tools

- ALES retrackers and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
- Round Robin Assessment framework adopted from SeaState_cci project

Deliverables

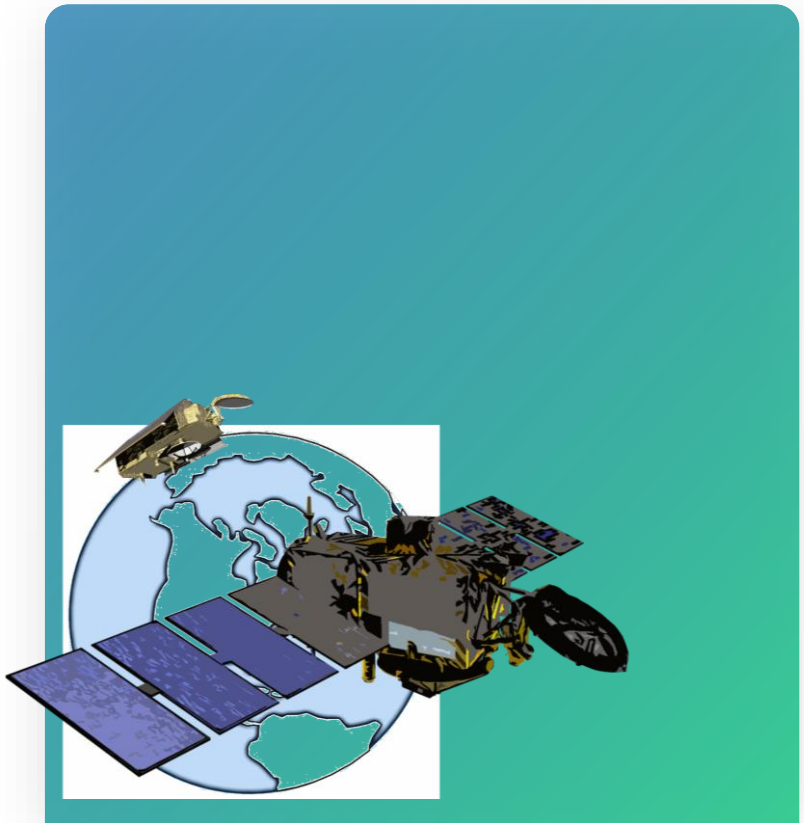
- Manuscript to be submitted for peer review
- Regular updates at meetings

Scientific Activities: Coastal Assessment

Marcello Passaro, Florian Schlembach, Julius Oelsmann, Denise Dettmering

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)

Technical University of Munich



S6-JTEX PM4
Online, 1st June 2022

Assessment of Coastal Performances

Tasks

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Assessment of Coastal Performances

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- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and a retracked Jason-3 product
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Status at PM3:

1. Adaptation of the software to process J3 LRM waveforms with ALES and WHALES retrackers
2. Adaptation of the software to process S6 SAR waveforms with the Coral retracker
3. Statistics produced for cycle 35 (baseline 04)
4. Process Jason-3 GDR-F and consider results from the “Adaptive retracker”
5. L2 product comparison started: global bias statistics for cycles 20-39

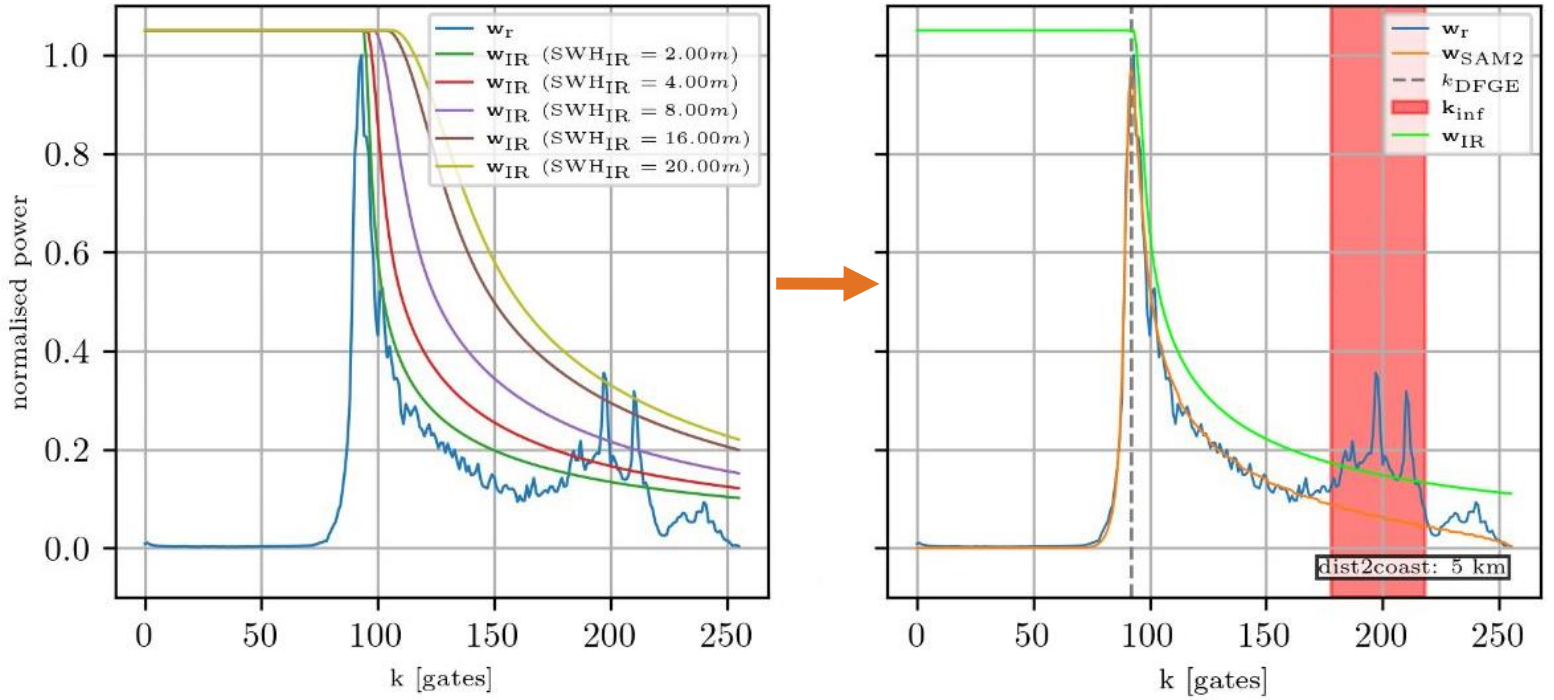
The CORALv1 Retracker

Schlembach F., Passaro M., Dettmering D., Bidlot J., Seitz F.: **Interference-sensitive coastal SAR altimetry retracking strategy for measuring significant wave height**. Remote Sensing of Environment, 274, 112968, 10.1016/j.rse.2022.112968, 2022

Adaptive Interference Masking (AIM)

→ senses and masks interference within the trailing edge

Generation of a single-look SAMOSA model $\mathbf{w}_{\mathrm{SAM2}}$ to produce the interference reference waveform $\mathbf{w}_{\mathrm{IR}}(\mathrm{SWH}_{\mathrm{IR}})$



detected interference gates

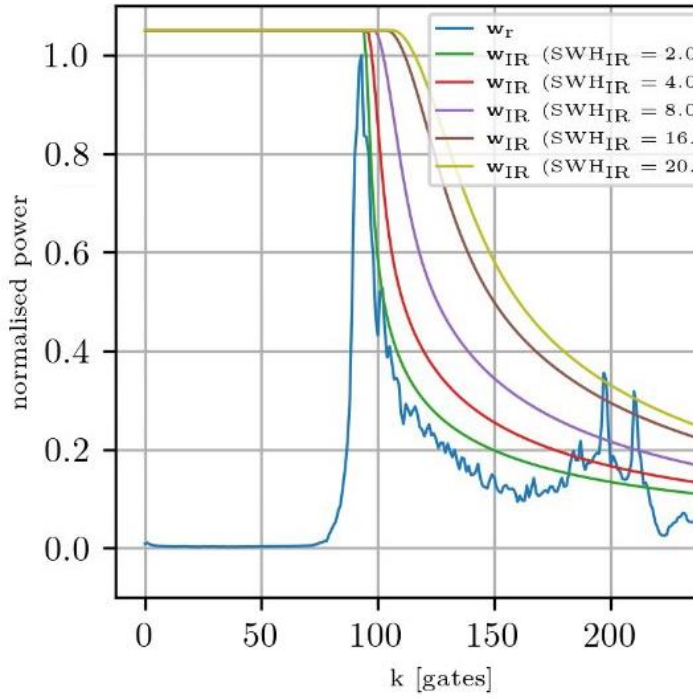
$$\mathbf{k}_{\mathrm{inf}} = \mathrm{True}(\mathbf{w}_{\mathrm{r}} > \mathbf{w}_{\mathrm{IR}})$$

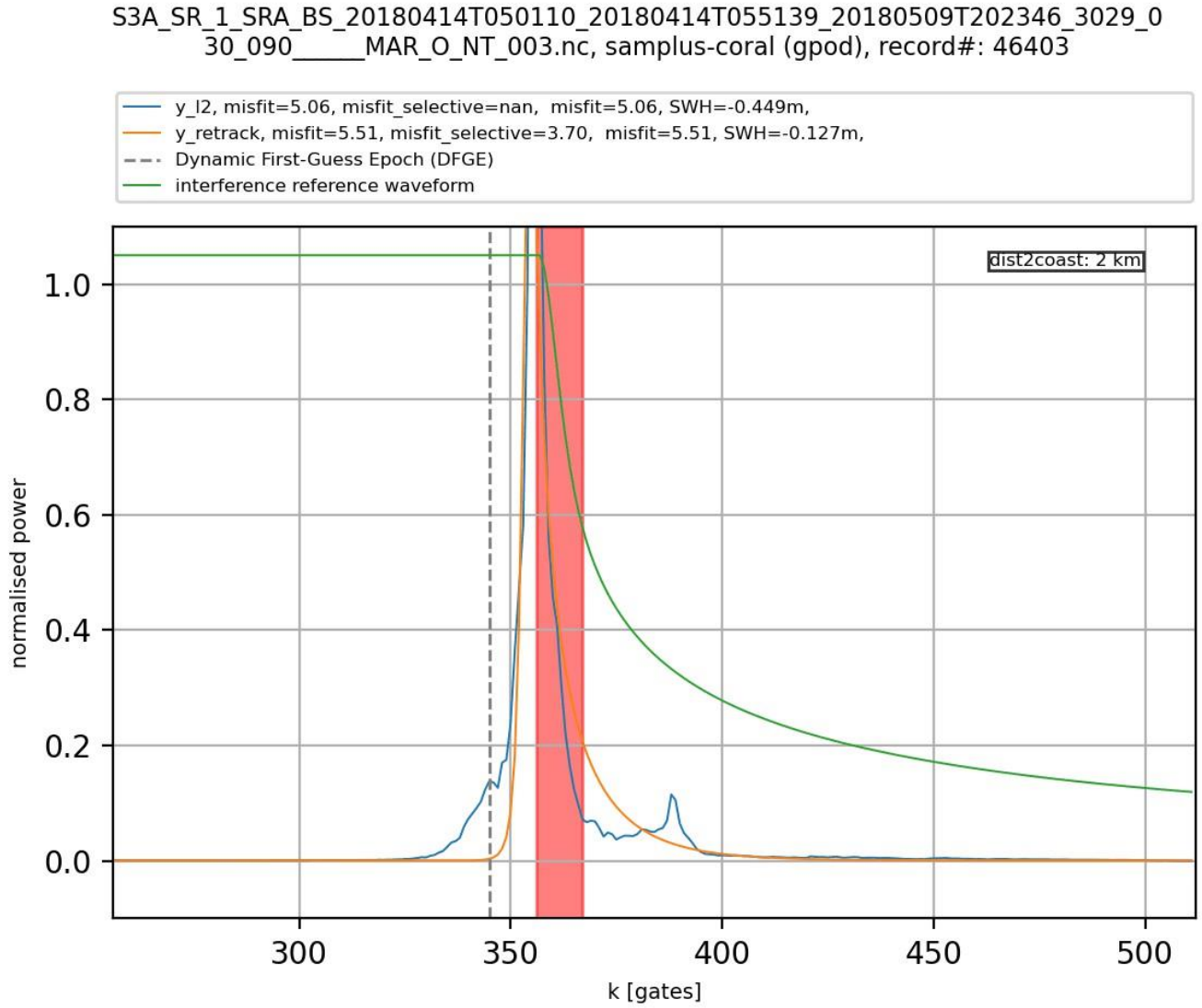
The CORALv1 Retracker

Adaptive Interference Masking (AIM)

→ senses and masks interference within the $\mathbf{w}_S$

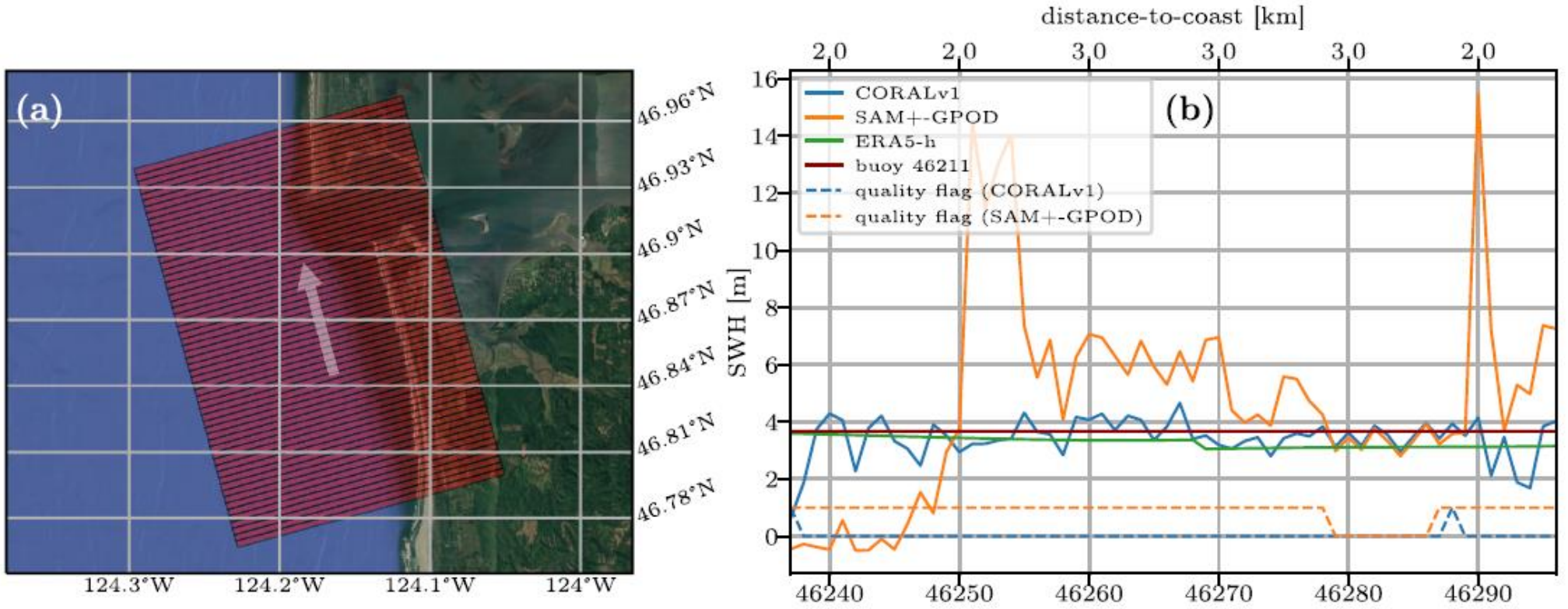
Generation of a single-look SAMOSA model





The CORALv1 Retracker

Retracking waveforms with strong coastal interference by CORALv1 in comparison with SAMOSA+



Performance Assessment Analysis: Noise and Outliers

Assessed as a function of sea state and distance-to-coast (open ocean, coast: < 5/10/20 km).

For S6 LRM (LR), S6 SAR (HR) and retracked J3

L2 noise

Defined as the standard deviation of twenty 20-Hz records.

Outlier analysis

Three types of outliers are defined

- **invalid** Data missing (already set to NaN) or quality flag set to ’bad’

- **out_of_range** If a value is out of the expected range of SWH = [−0.25,25] m , SLA = [−2,2] m

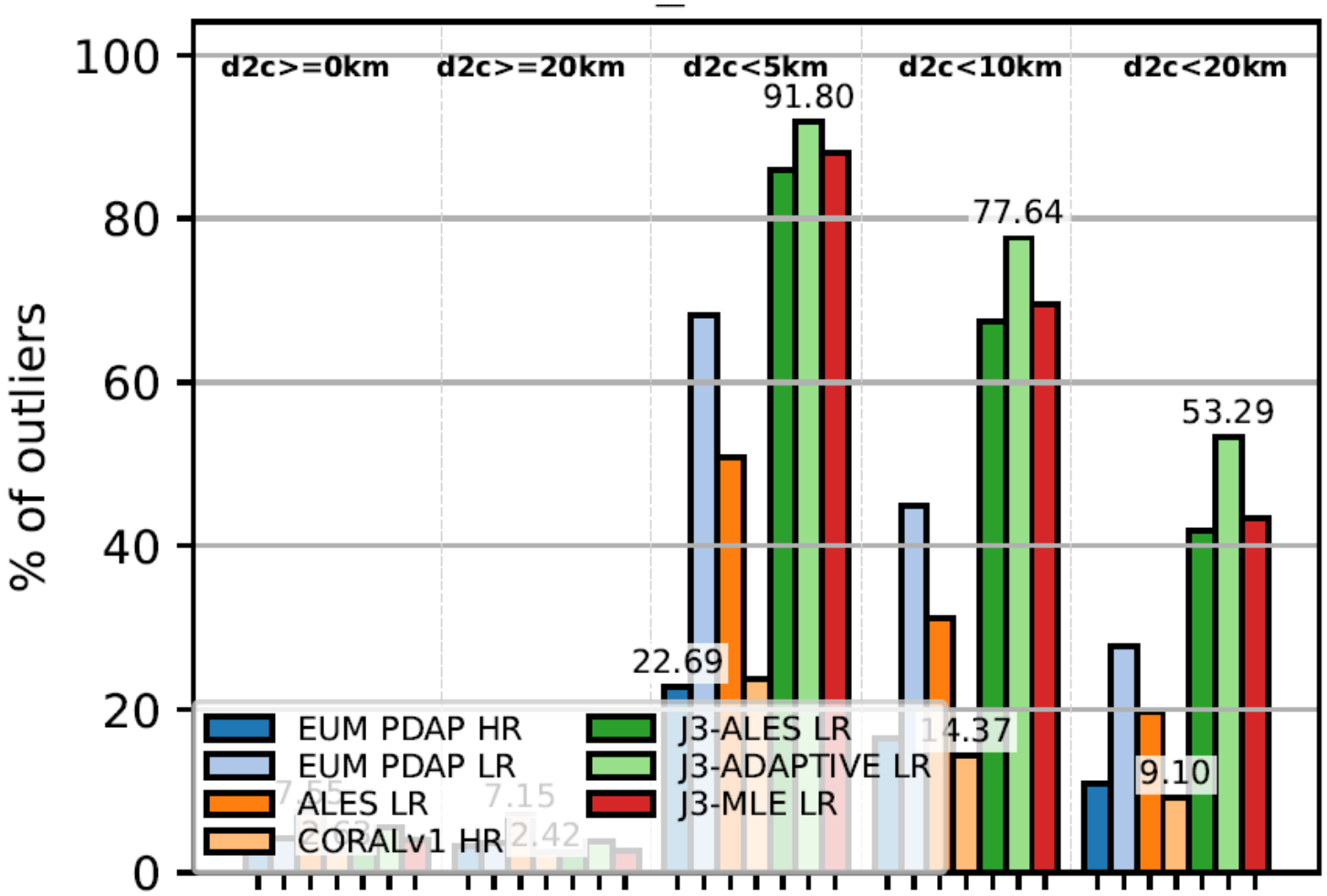
- **mad_factor** This criterion compares the value with its 20 closest neighbo
  - Data are discarded if they exceed median plus 3 * 1.4826 * MAD (median absolute deviation, i.e. a robust standard deviation)

Schlembach et al. ‘Round Robin Assessment of Radar Altimeter Low Resolution Mode and Delay-Doppler Retracking Algorithms for Significant Wave Height’. *Remote Sensing* 12, no. 8 (January 2020): 1254. https://doi.org/10.3390/rs12081254.

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SLA:** outliers

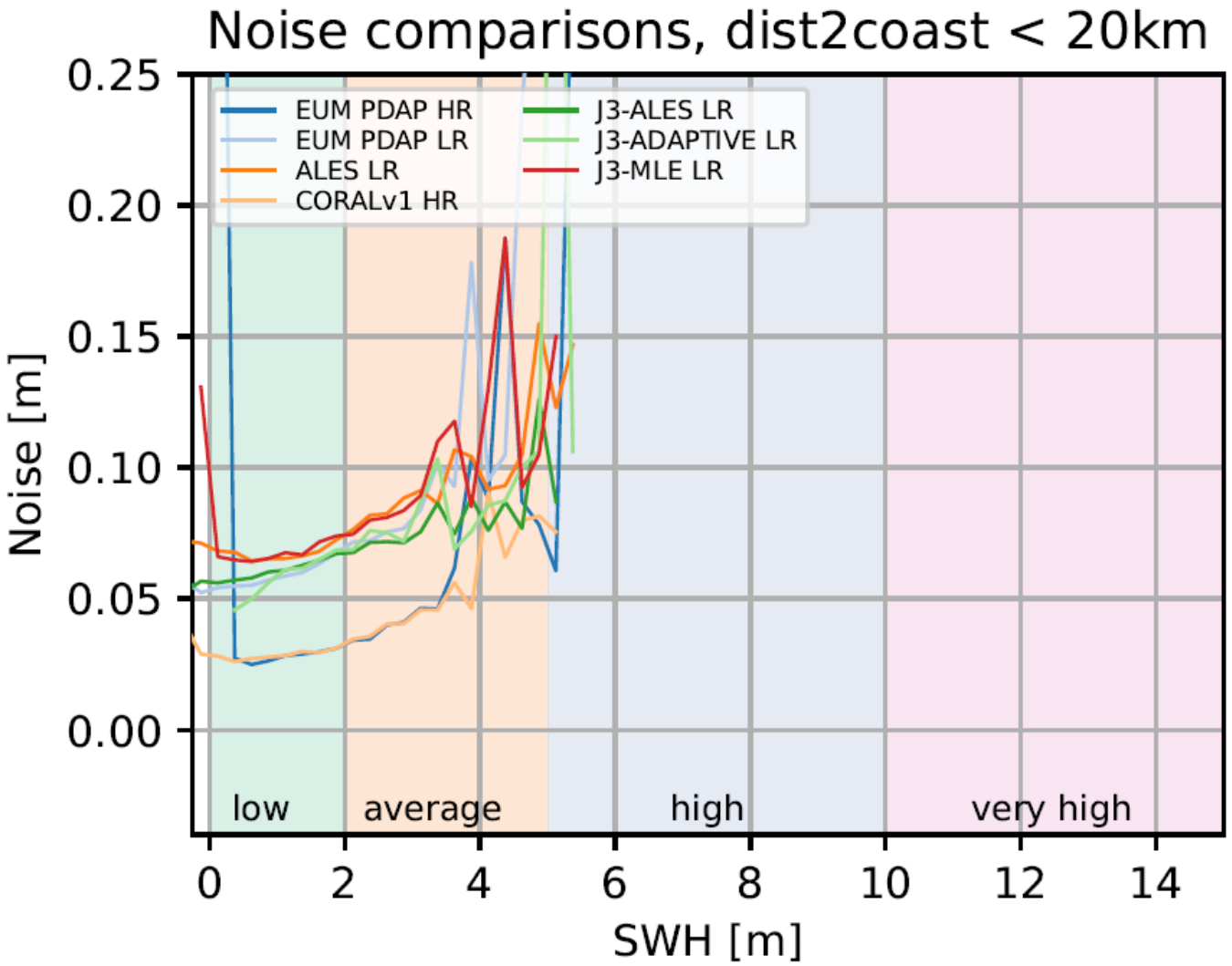


- Largest improvements from SAR in the last 5 km, significantly better than LRM
- LRM S6 coastal valid data amount can be largely improved by ALES reprocessing
- Largest number of outliers close to the coast found in J3-ADAPTIVE, lowest number found in standard EUM PDAP HR and CORALv1 (from 91% to 22%!!!)

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SLA:** noise

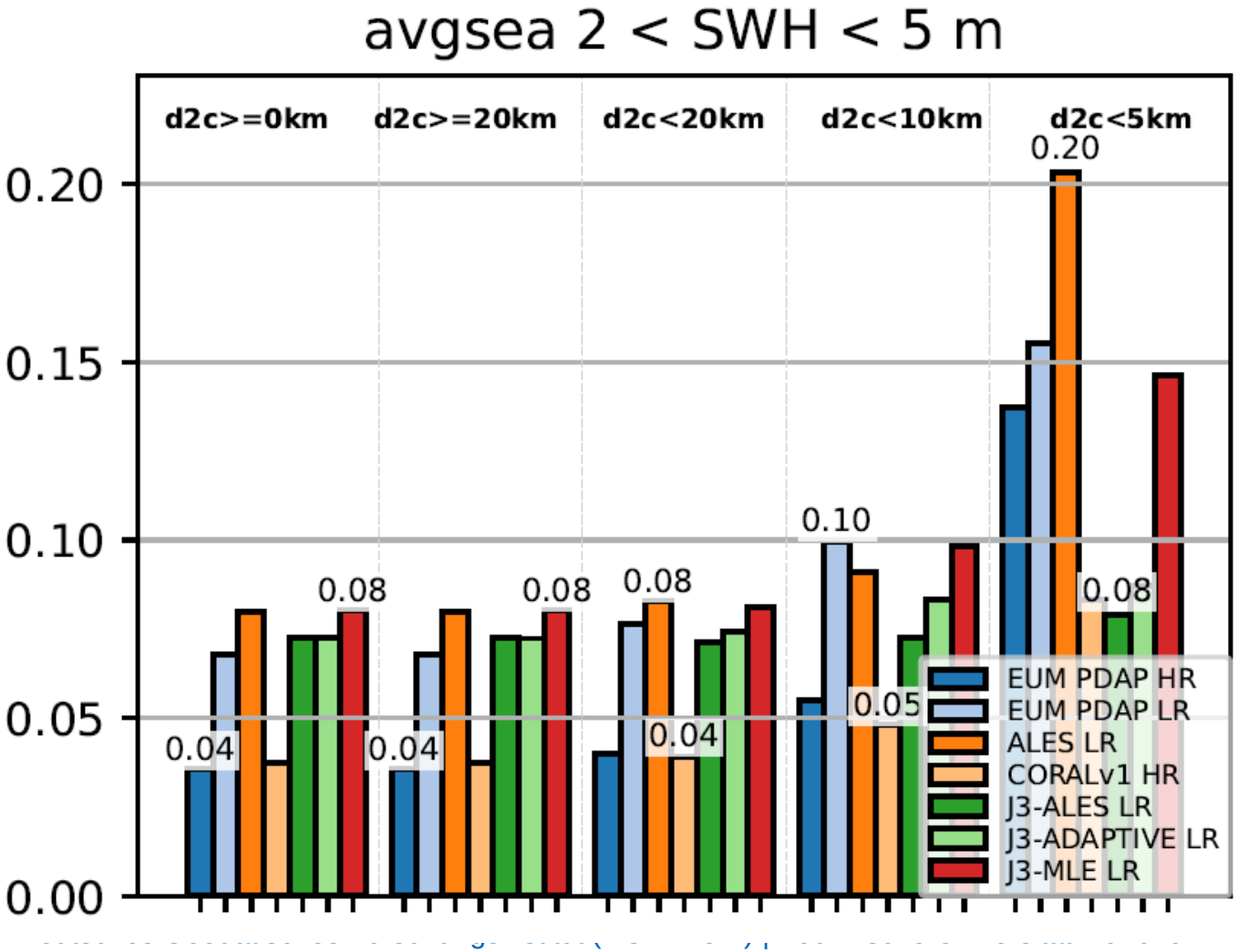


- Coastal noise statistics only representative til roughtly SWH = 4m
- Best performances for LRM reached by J3-Adaptive, J3-ALES LR and EUM PDAP LR
- Large improvement in precision seen with SAR data, CORALv1 strongly improve the noise at very low SWH

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SLA:** noise

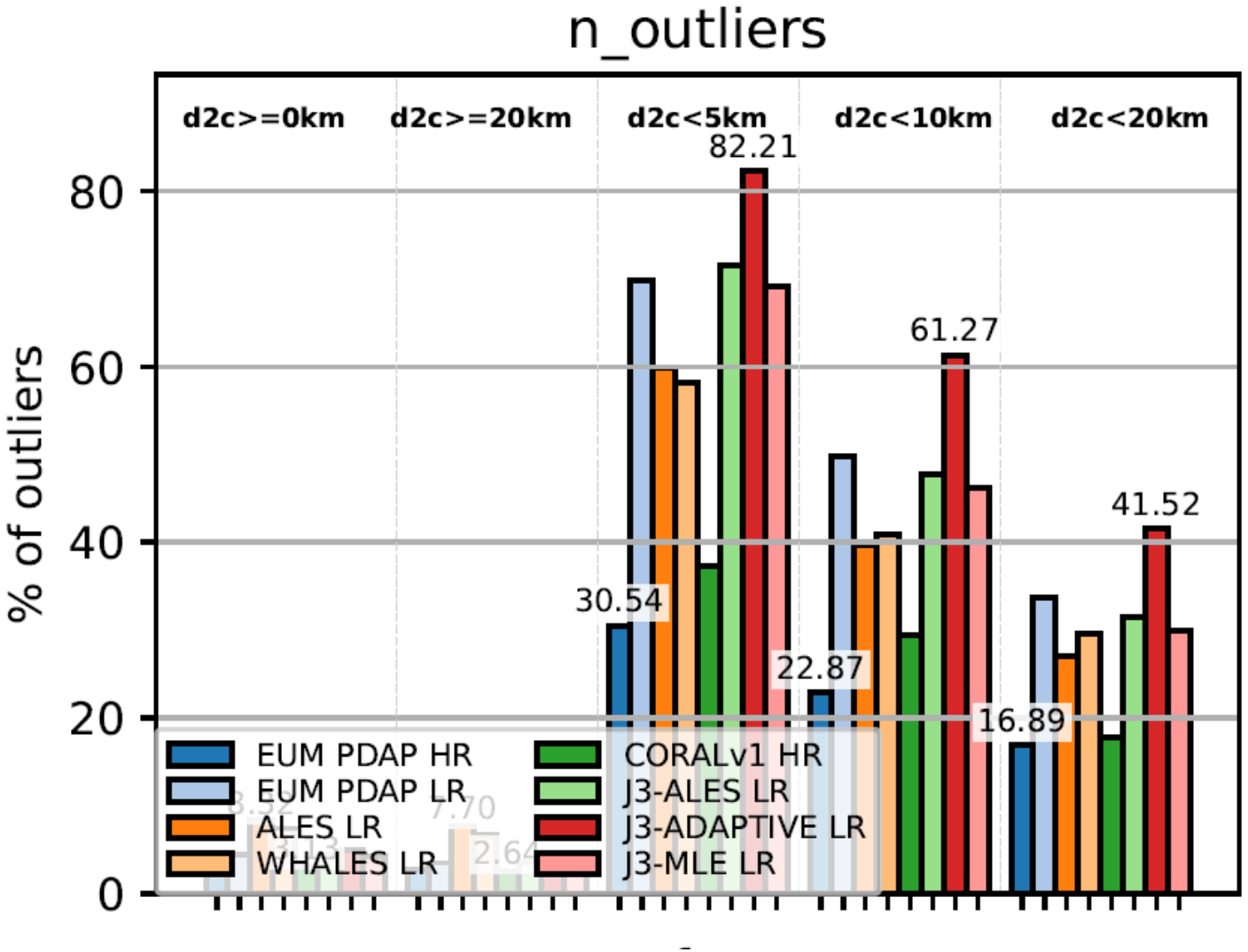


- Coastal noise statistics only representative til roughtly SWH = 4m
- Best coastal performances reached by J3-ALES LR, J3-Adaptive LR and S6 CORALv1 Hr
- In terms of noise very close to coast, ALES (LR) works much better for J3 than for S6 (from the best to the worst performances)...still undetected problem in the implementation (maybe due to larger window considered in S6?)

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** outliers

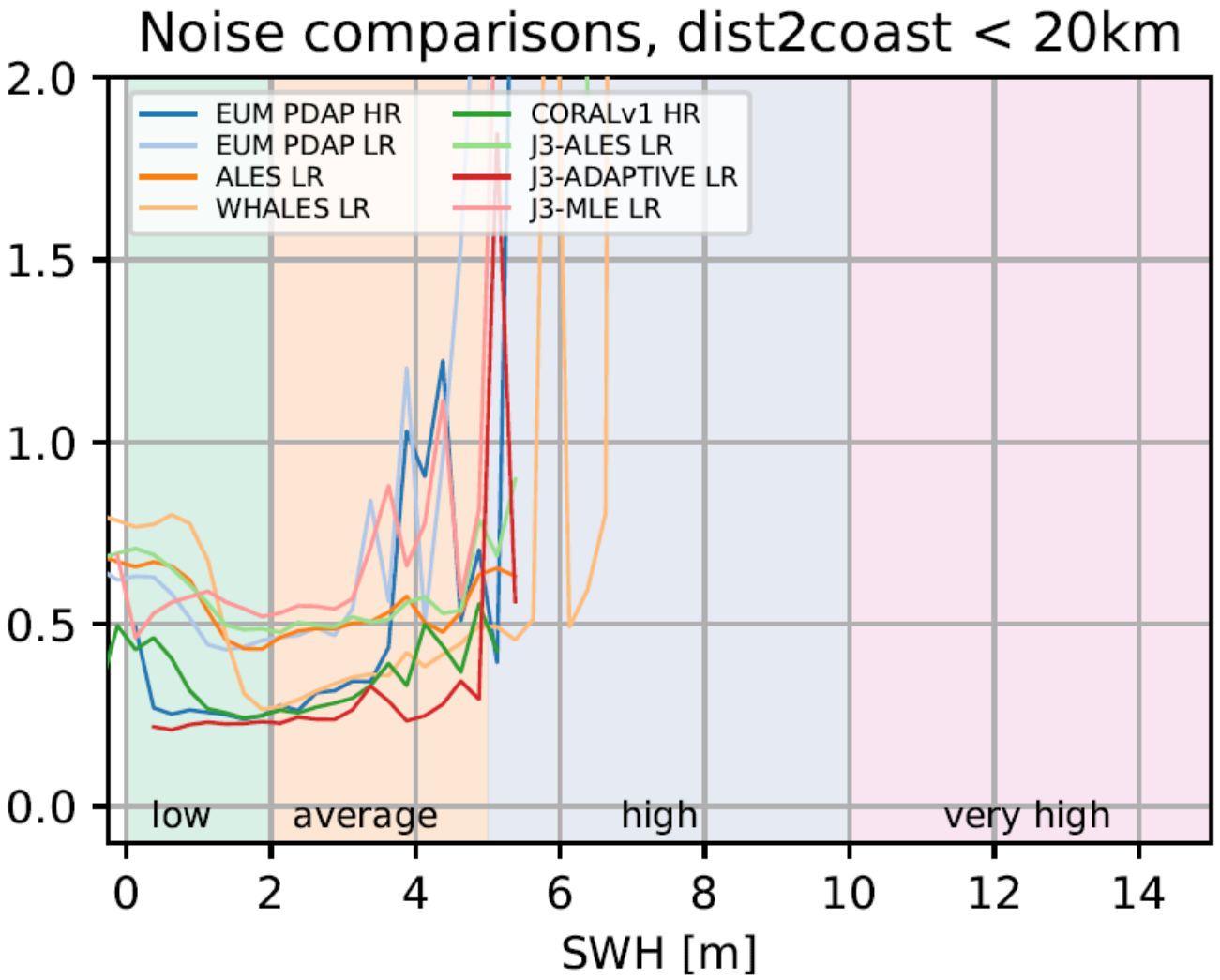


- Largest improvements from SAR in the last 5 km, significantly better than any LRM reprocessing analysed
- Largest number of outliers close to the coast found in J3-ADAPTIVE, lowest number found in standard EUM PDAP HR (from 82% to 31%!!!)

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** noise



- S6 WHALES LRM reprocessing reaches the same level of noise as SAR data for average sea states (also in the open ocean, not shown)

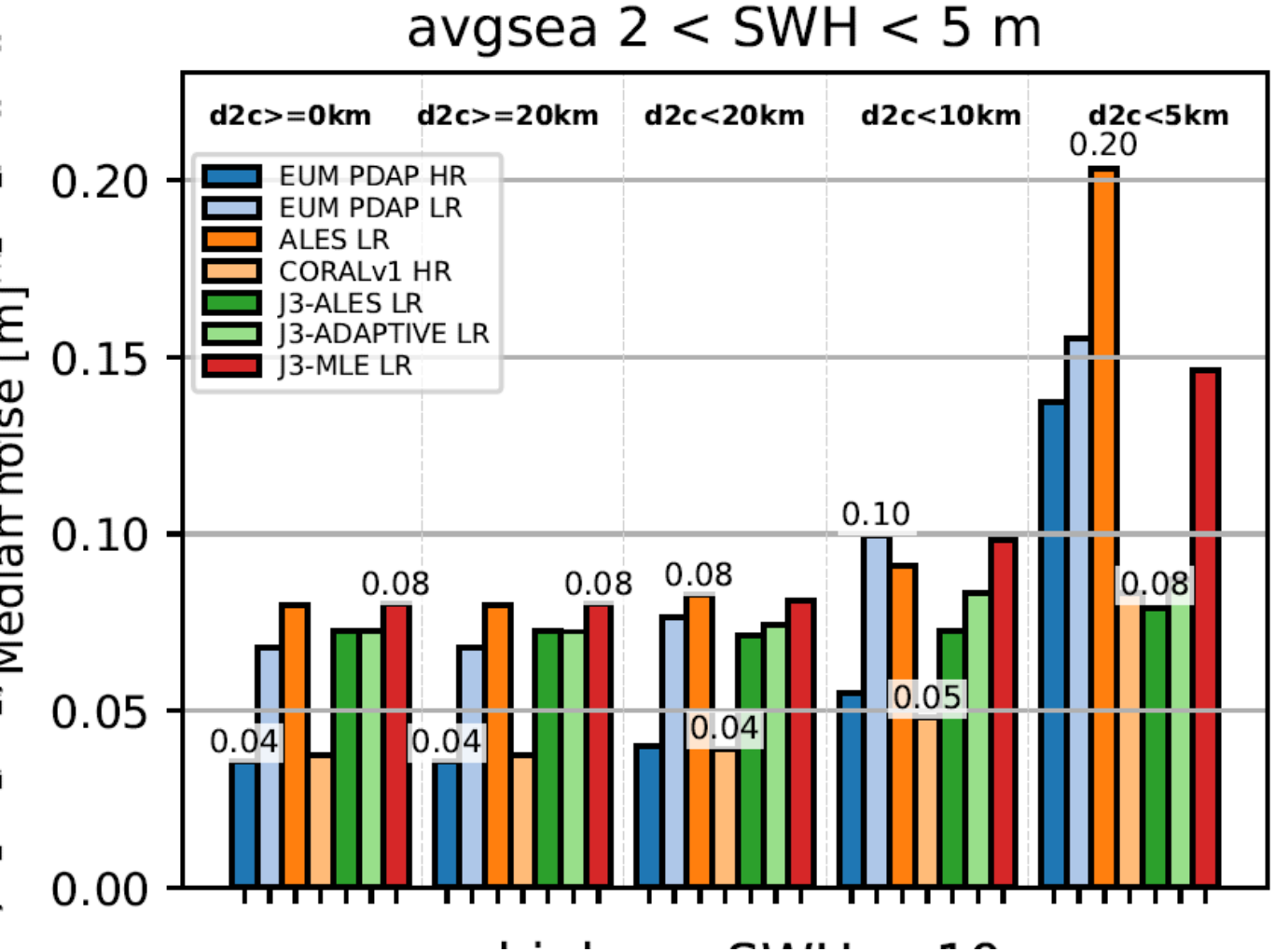
- SAR data have better noise performances for low SWH

- Best overall performances reached by J3-ADAPTIVE LR

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** noise



- J3-ADAPTIVE and J3-ALES (for LRM altimetry) succeed in maintaining similar noise to open ocean also when „reaching the coast“.
- CORALv1 (for SAR altimetry) gets close to this, but remember SAR keeps many more data than LRM in the last 5 km)

Global offsets between L2 products (S6 wrt J3)

Analysis of differences in L2 products on a global scale (0 – 100 km offshore)

S6 cycles 20-39, LR and HR, 20-Hz

L2 products: Uncorrected SLA (hsat-range-mssh), SWH, wet tropo corr (radiometer), iono corr (smoothed dual frequency)

BIAS => Median => median of differences per distance class, median over all passes and cycles

STD => Standard deviation => scatter of differences per distance class, median over all passes

- Only passes with LR, HR and J3 data
- Differences larger 1 m are excluded from analysis
- Distance classes: 10 km from 0 to 100 km

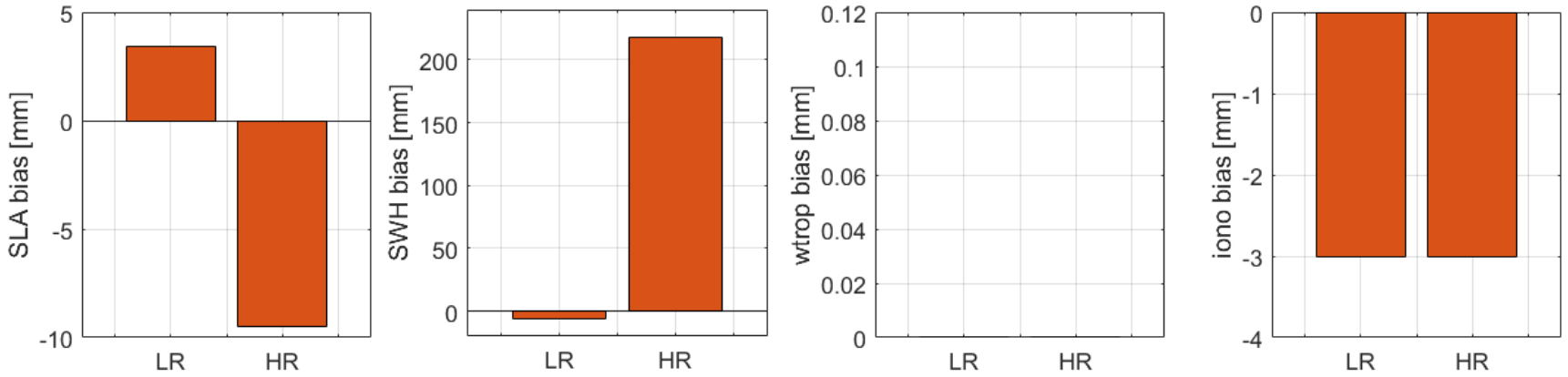
Global offsets between L2 products (S6 wrt J3)

Preliminary results

Analysis of differences in L2 products on a global scale (0 – 100 km offshore)

S6 cycles 20-39, LR and HR, 20 Hz

[illegible] ual frequency)



coastal zones
0 – 10 km

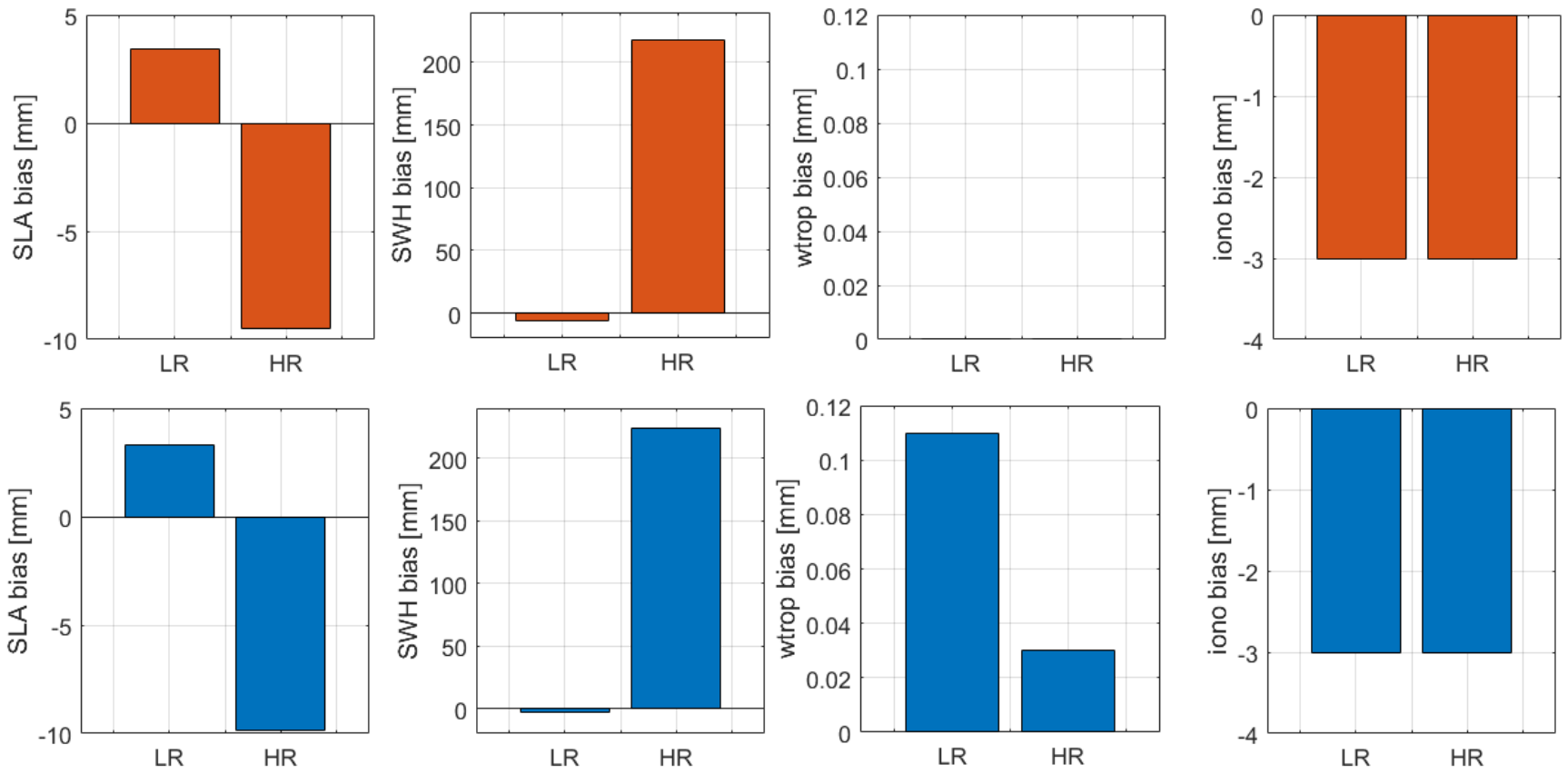
Global offsets between L2 products (S6 wrt J3)

Preliminary results

Analysis of differences in L2 products on a global scale (0 – 100 km offshore)

S6 cycles 20-39, LR and HR, 20 Hz

[illegible] ual frequency)



coastal zones
0 – 10 km

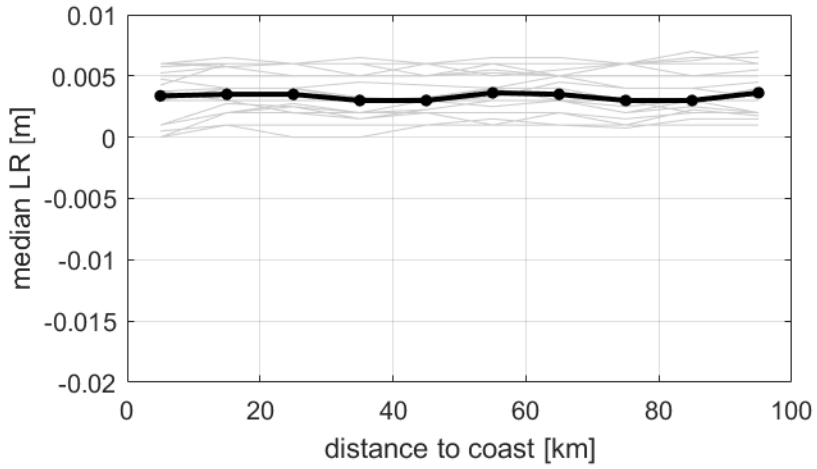
Open ocean
10 – 100 km

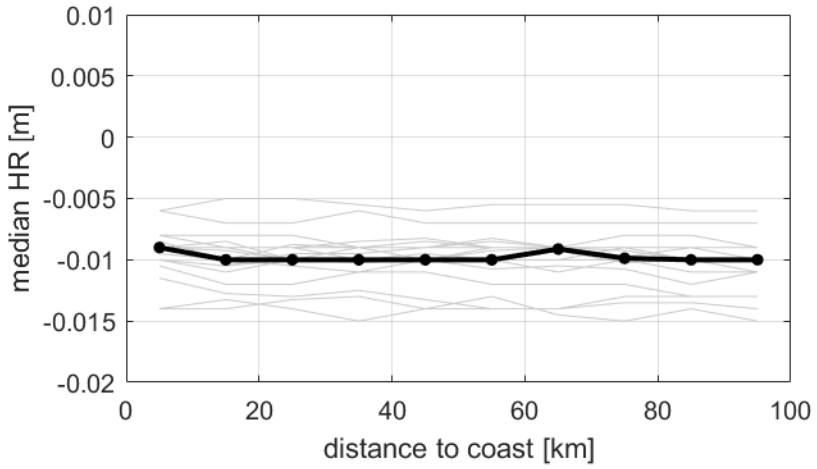
Global offsets between L2 products (S6 wrt J3)

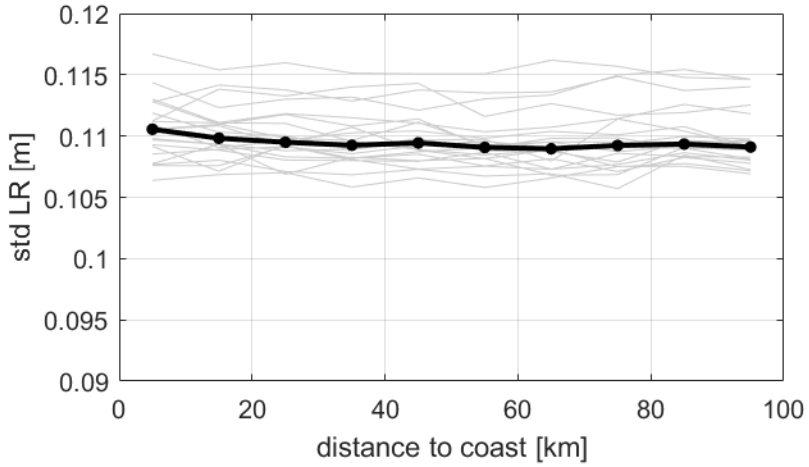
Preliminary results

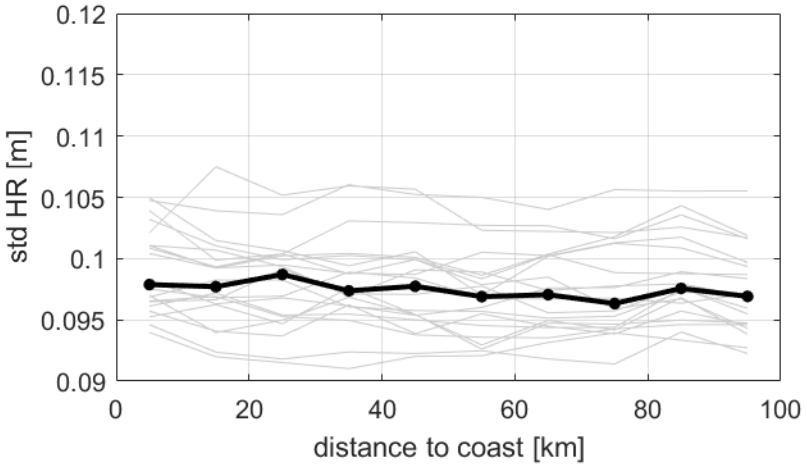
Uncorrected SLA

(grey lines: values per cycle; bold line: median of cycles 20-39)







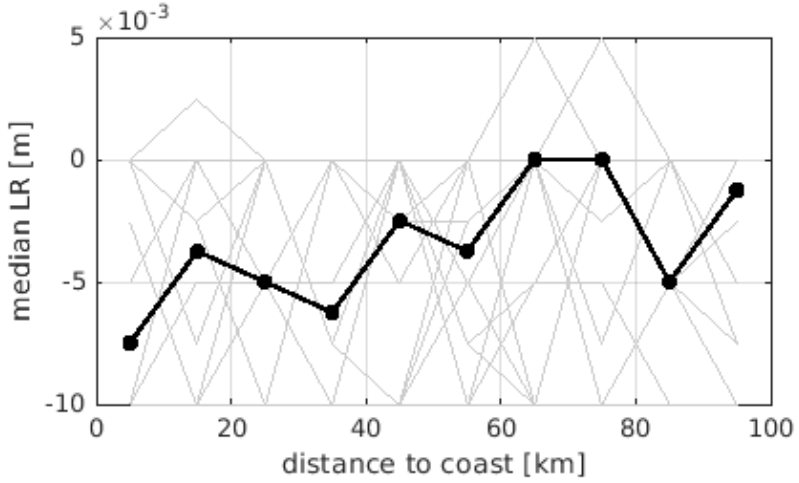


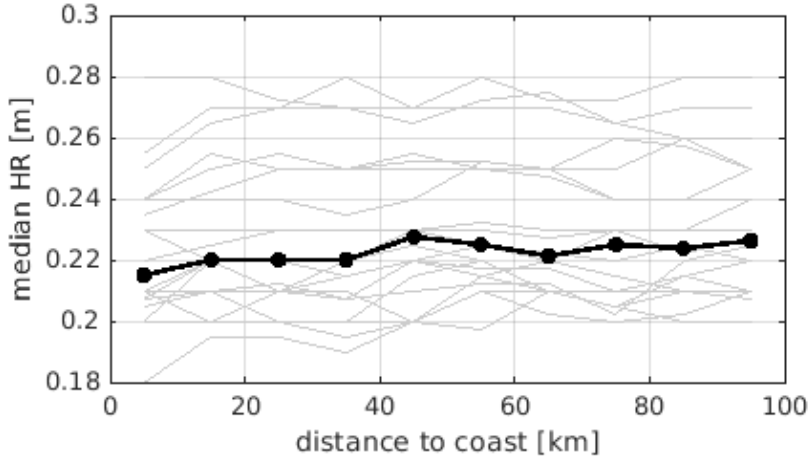
Global offsets between L2 products (S6 wrt J3)

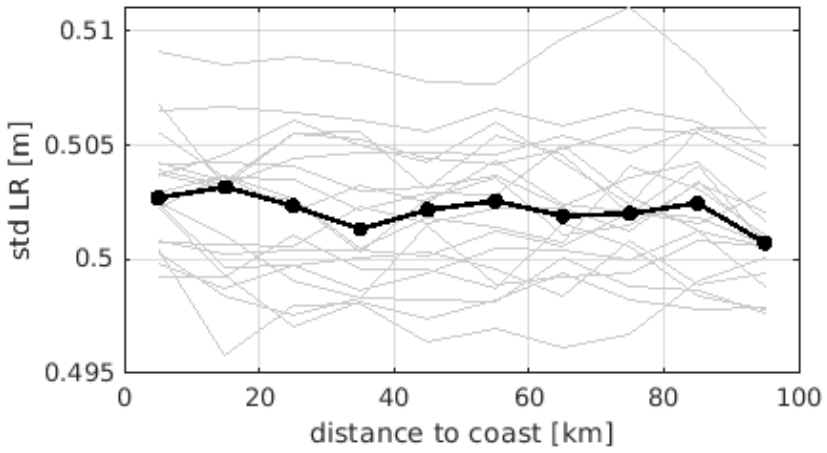
Preliminary results

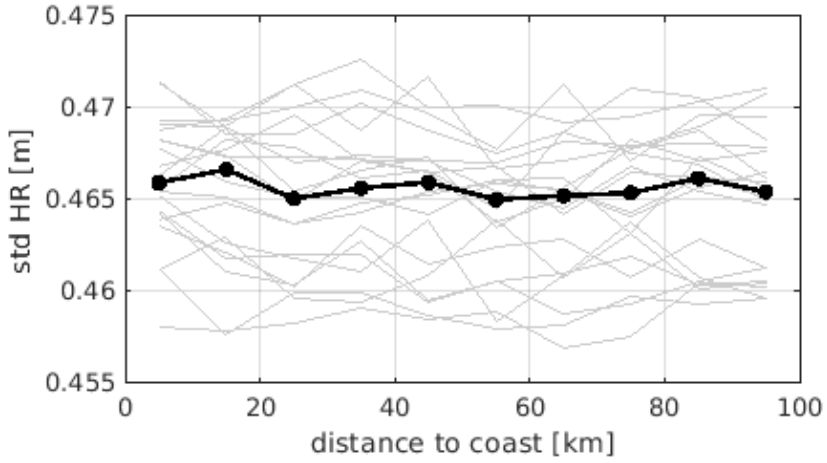
SWH

(grey lines: values per cycle; bold line: median of cycles 20-39)







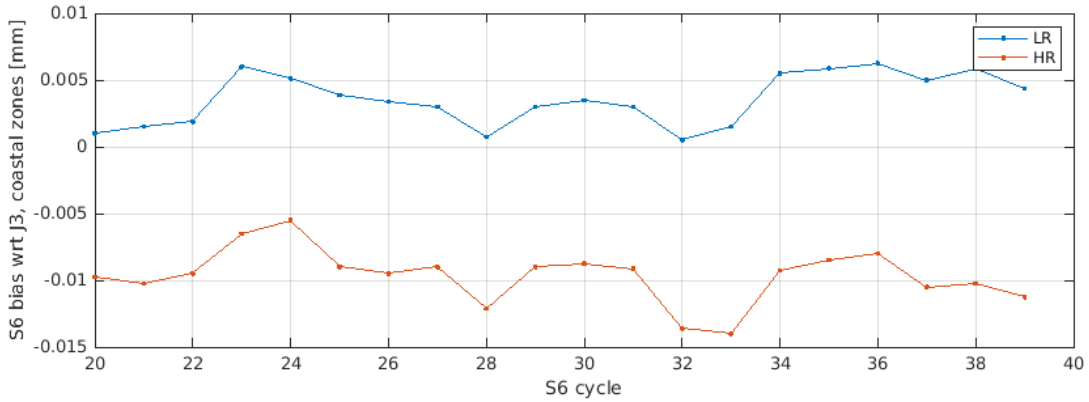


Global offsets between L2 products (S6 wrt J3)

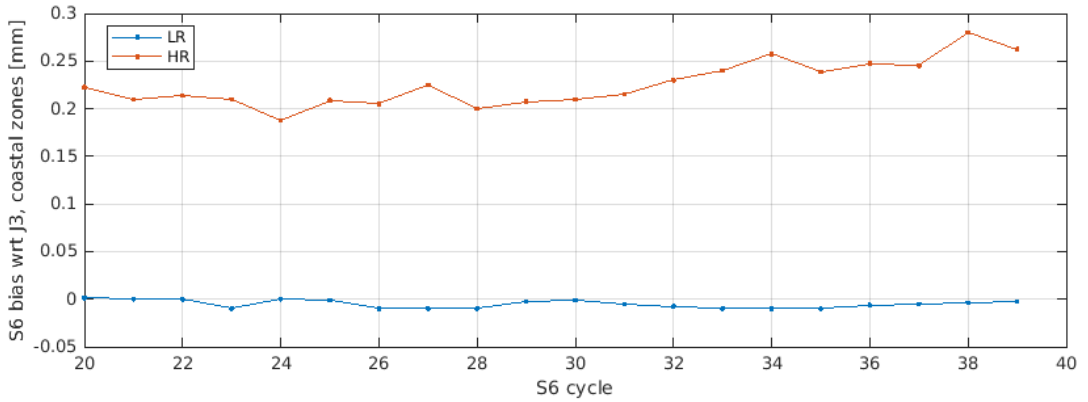
Preliminary results

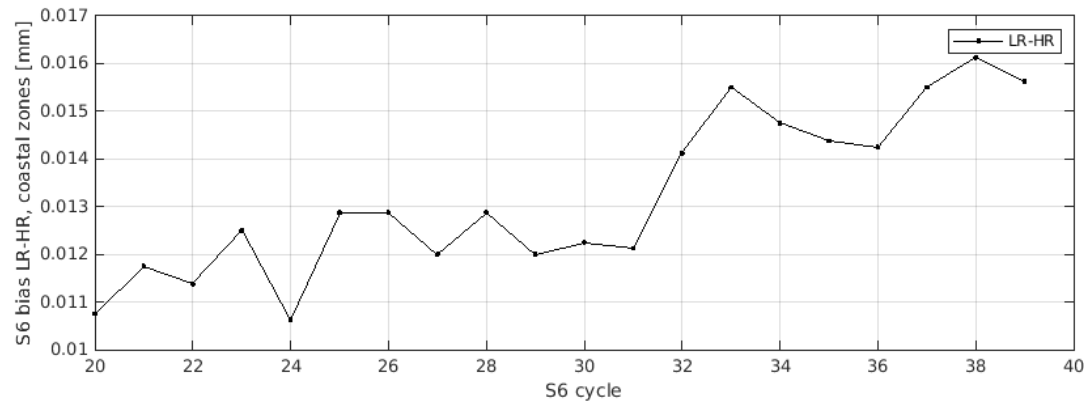
Temporal variations, coastal areas (<20km)

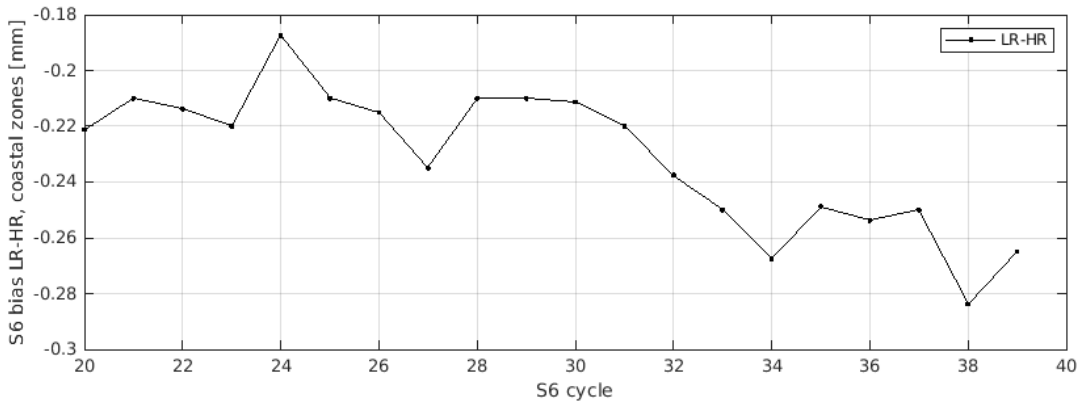
Uncorrected SLA



SWH







NTC PODAAC, baseline mixture

Actions planned for the next 3 months

- Study potential systematics in S6-J3 offsets (geographical or temporal; update to reprocessed data)
- Prelimary results of the comparison SAR-RMC vs SAR-HR in the coastal zone
- Structure of manuscript

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Tools

- ALES retrackers and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
- Round Robin Assessment framework adopted from SeaState_cci project

Deliverables

SPARE SLIDES

2. CORALv1: AIM (cont‘d)

CORALv1 improves the quality flag by using the **selective misfit**

→ excluding of interference gates $\mathbf{k}_{\mathrm{inf}}$ from the misfit calculation

$$\mathrm{misfit}_{\mathrm{selective}} = 100 * \sqrt{\frac{1}{N}\sum_{i}^{N}(w_{r,i} - w_{\mathrm{SAM2},i})^2}$$

$$i \notin \mathbf{k}_{\mathrm{inf}} = \mathrm{True}(\mathbf{w}_{\mathrm{r}} > \mathbf{w}_{\mathrm{IR}})$$

$$q_{\mathrm{CORALv1}} = \mathrm{misfit}_{\mathrm{selective}} > 4$$

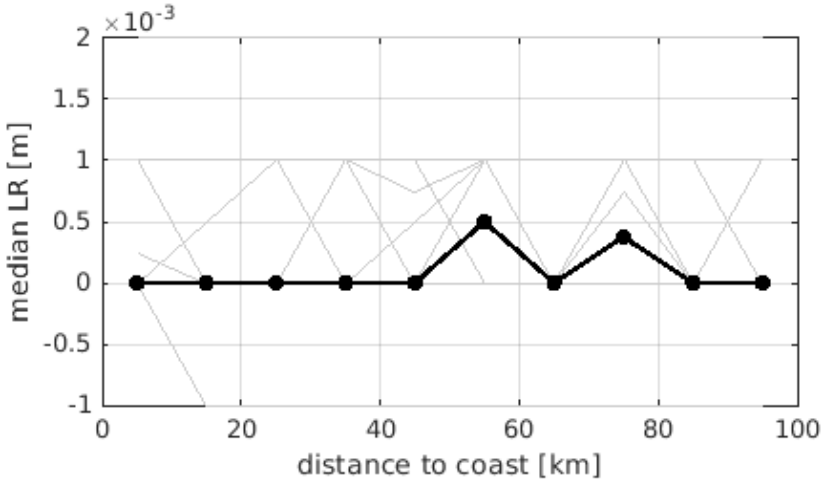
→ AIM better determines the goodness of the fit and recovers strongly interfered waveforms → **quantity** of records

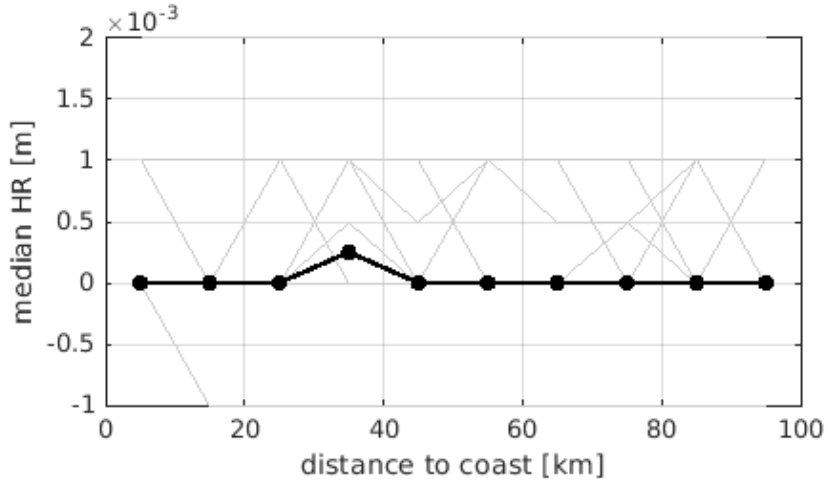
Global offsets between L2 products (S6 wrt J3)

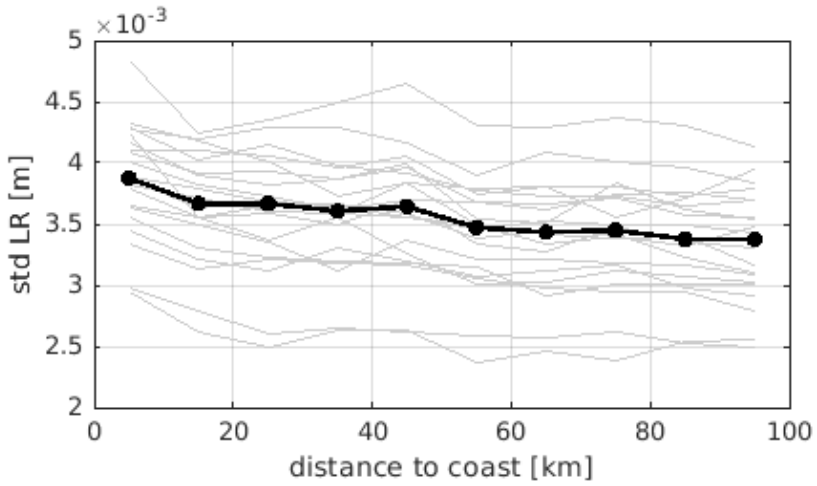
Preliminary results

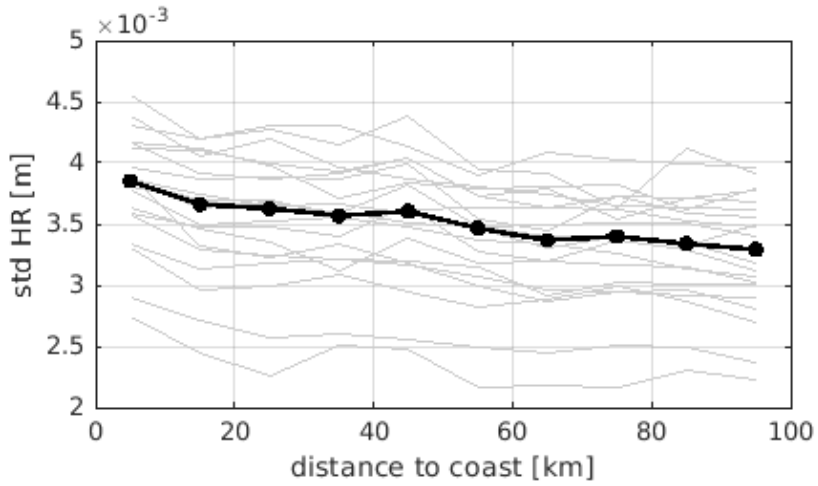
Wet troposphere corrections (radiometer)

(grey lines: values per cycle; bold line: median of cycles 20-39)







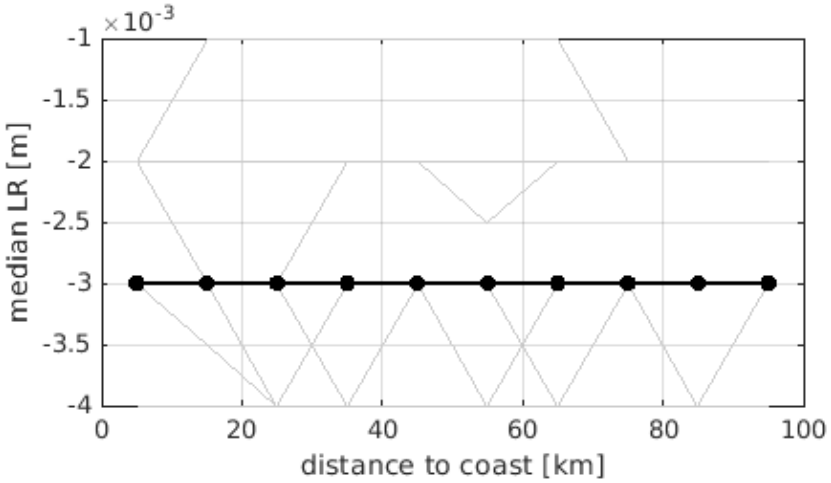


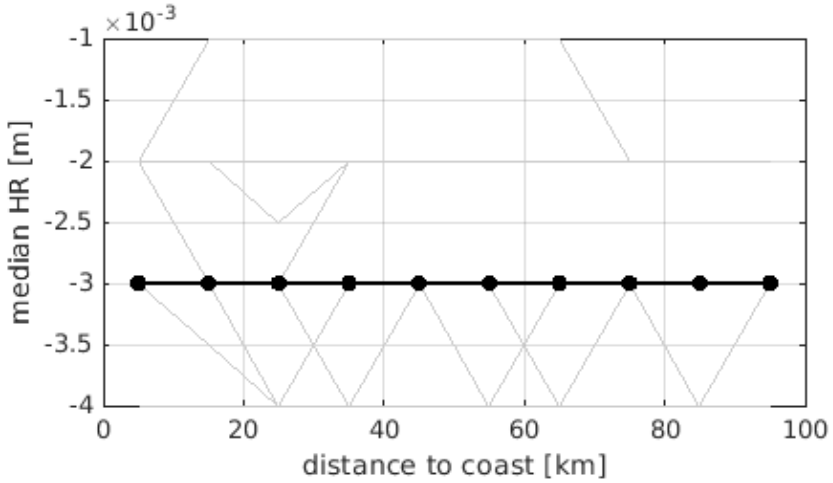
Global offsets between L2 products (S6 wrt J3)

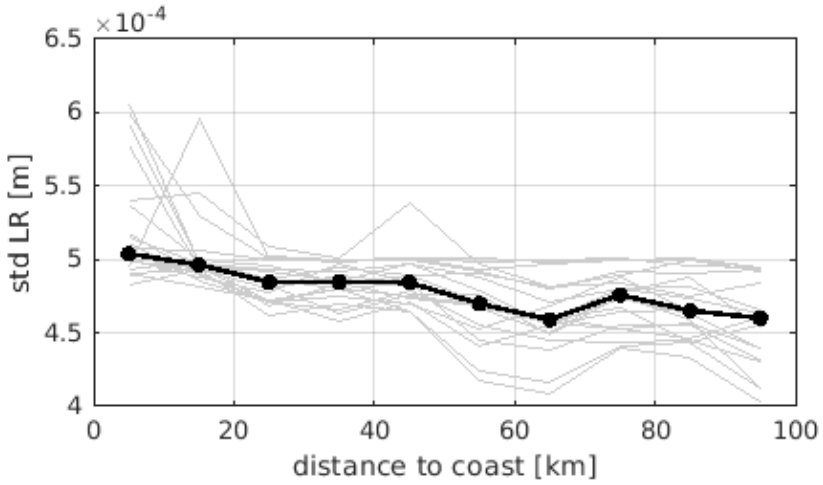
Preliminary results

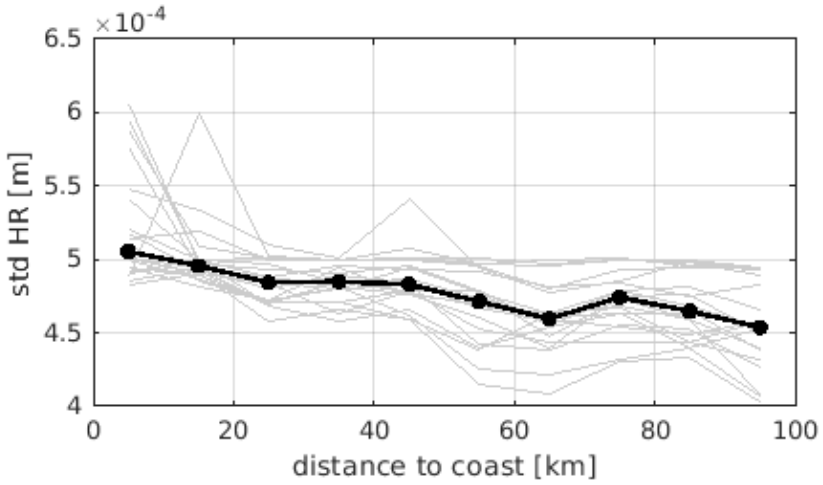
Ionospheric correction (dual frequency)

(grey lines: values per cycle; bold line: median of cycles 20-39)









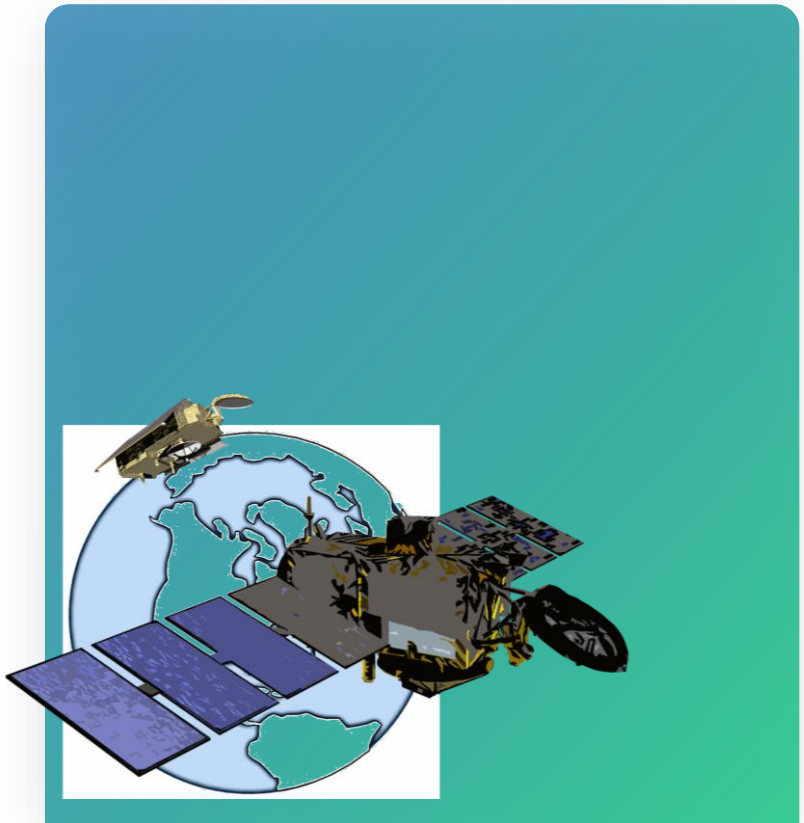
SLIDES FROM PREVIOUS MEETINGS

Scientific Activities: Coastal Assessment

Marcello Passaro, Florian Schlembach, Julius Oelsmann, Denise Dettmering

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)

Technical University of Munich



S6-JTEX PM2 MEETING
Online, 18th of March 2022

Assessment of Coastal Performances

Tasks

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and a retracked Jason-3 product
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Planned Steps

1. Retrack the J3 and S6-MF LRM waveforms with specific retrackers: ALES and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
2. Performance assessment analysis in terms of L2 noise and outlier analysis in the coastal zone, for S6 LRM, SAR-RAW and SAR-RMC & retracked J3
3. Intercomparison of S6 and J3 based on L2 products in the coastal zone will be performed focusing on bias, drift and their geographical patterns

Assessment of Coastal Performances

Tasks

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and a retracked Jason-3 product
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Status at PM2:

1. Adaptation of the software to process S6-MF LRM waveforms with ALES and WHALES retrackers (ongoing)
2. Statistics produced for cycle 35 (baseline 04)

REMINDER

- What is ALES? ALES is an adaptive subwaveform retracker widely used in LRM altimetry especially in the coastal zone (e.g. used in Sea Level CCI coastal product)

- What is WHALES? WHALES is an ALES-like LRM retracker tuned for SWH estimation, including a weighted fitting to improve noise performances (e.g. used in Sea State CCI)

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

Assessed as a function of sea state and distance-to-coast (open ocean, coast: < 5/10/20 km).

For S6 LRM (LR), S6 SAR (HR) and retracked J3 (not yet done)

L2 noise

Defined as the standard deviation of twenty 20-Hz records.

Outlier analysis

Three types of outliers are defined

- **invalid** Data missing (already set to NaN) or quality flag set to ’bad’

- **out_of_range** If a value is out of the expected range of SWH = [−0.25,25] m , SLA = [−2,2] m

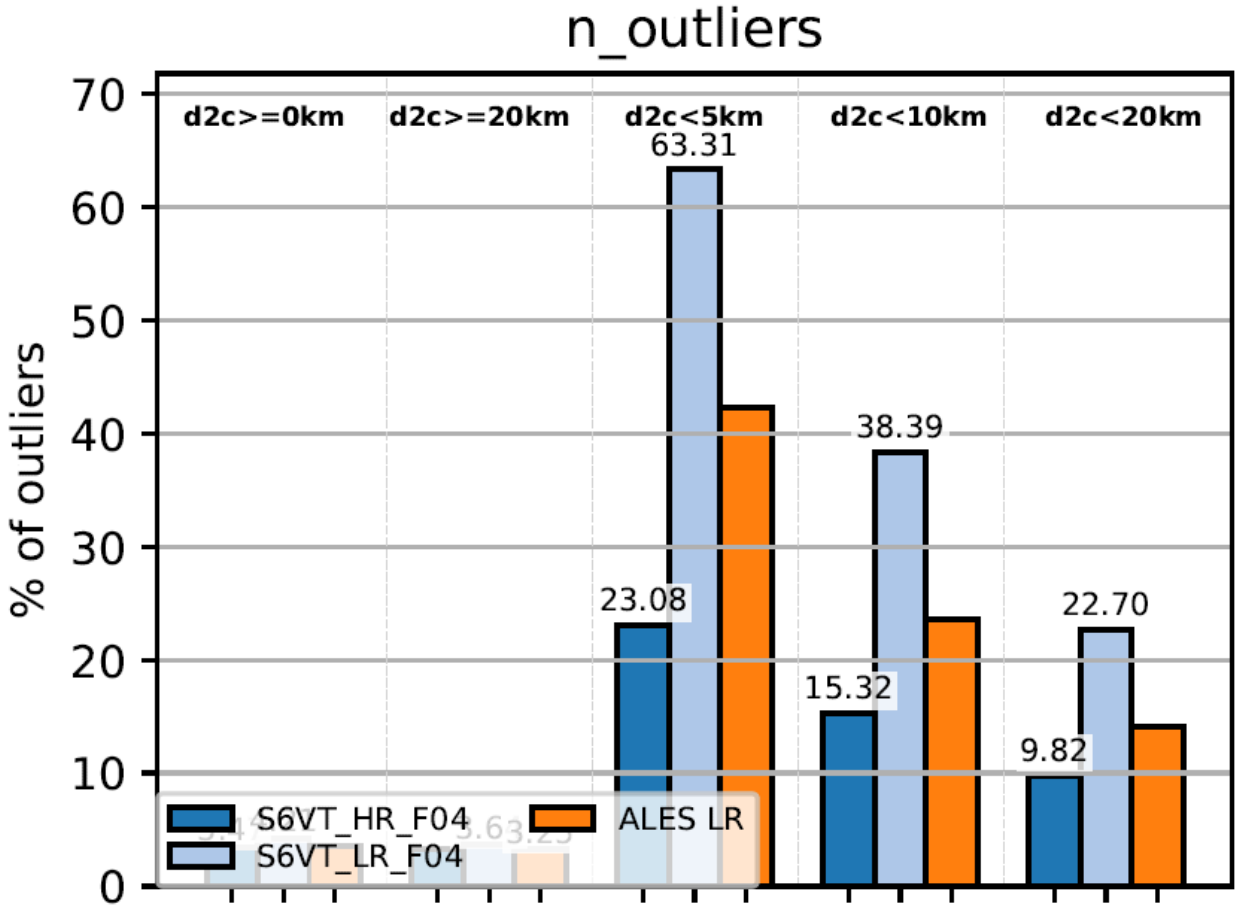
- **mad_factor** This criterion compares the value with its 20 closest neighbo
  - Data are discarded if they exceed median plus 3 * 1.4826 * MAD (median absolute deviation, i.e. a robust standard deviation)

Schlembach et al. ‘Round Robin Assessment of Radar Altimeter Low Resolution Mode and Delay-Doppler Retracking Algorithms for Significant Wave Height’. *Remote Sensing* 12, no. 8 (January 2020): 1254. https://doi.org/10.3390/rs12081254.

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SLA:** outliers

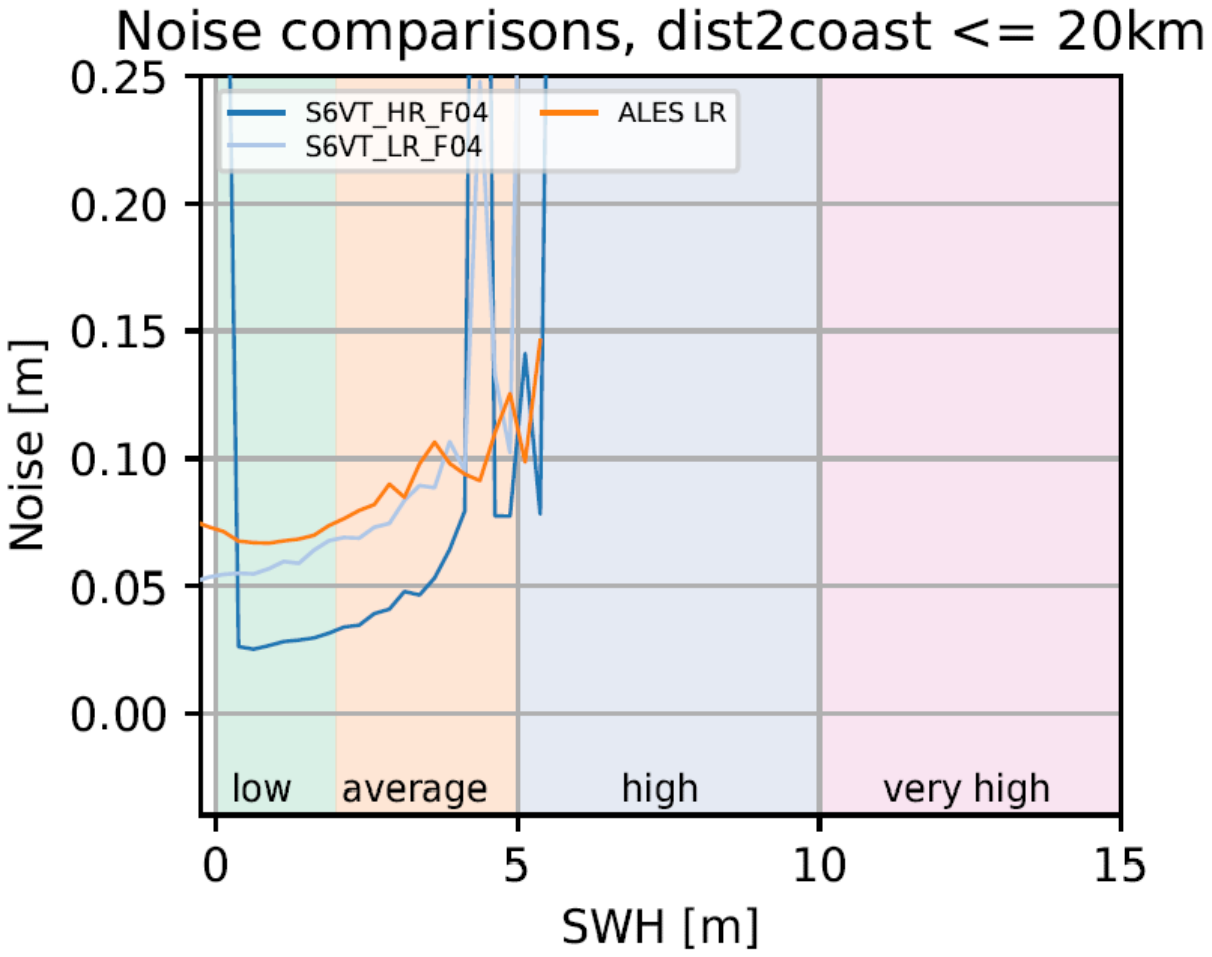


- Largest improvements from SAR in the last 5 km, significantly better than LRM
- LRM S6 coastal valid data amount can be largely improved by ALES reprocessing

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SLA:** noise

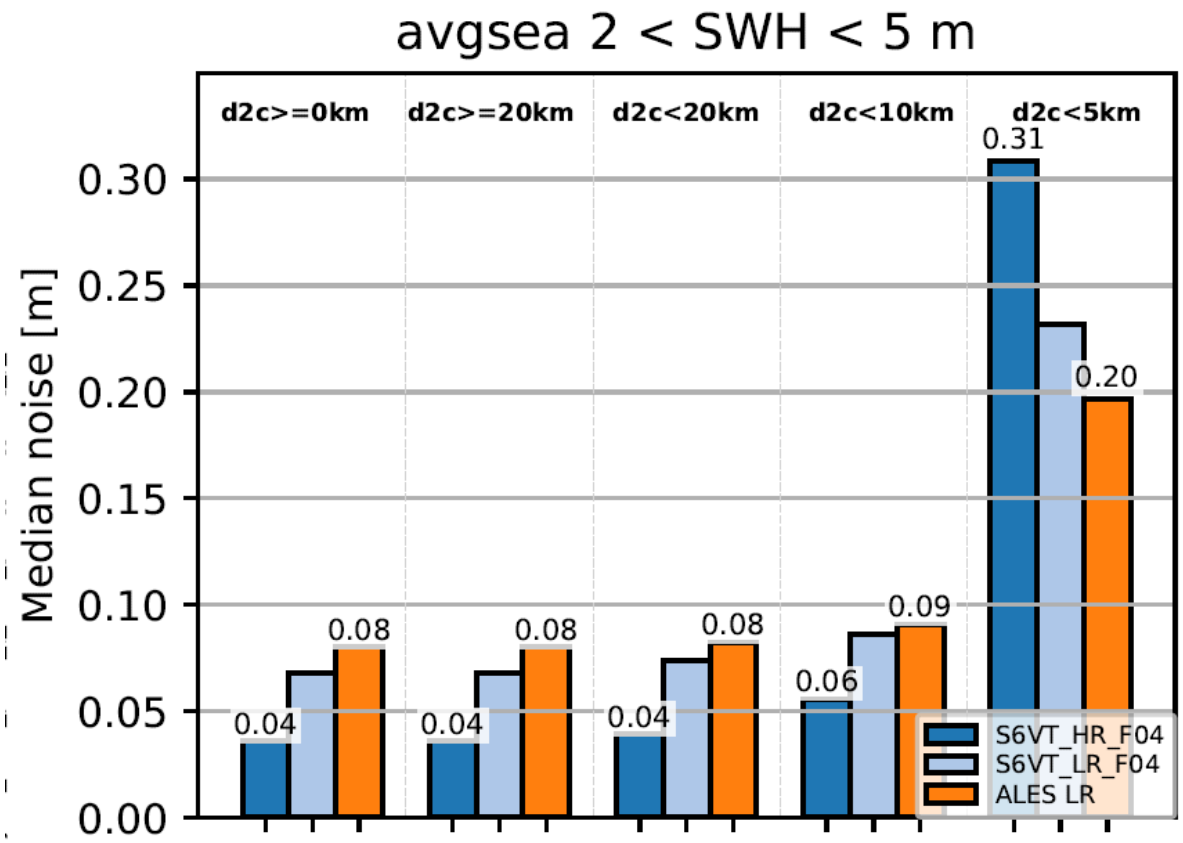


- Coastal noise statistics only representative til roughtly SWH = 4m
- ALES implementation still incomplete (settings still inherited from Jason in terms of SSB and subwaveform choice), therefore still noisier
- Large improvement in precision seen with SAR data

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SLA:** noise



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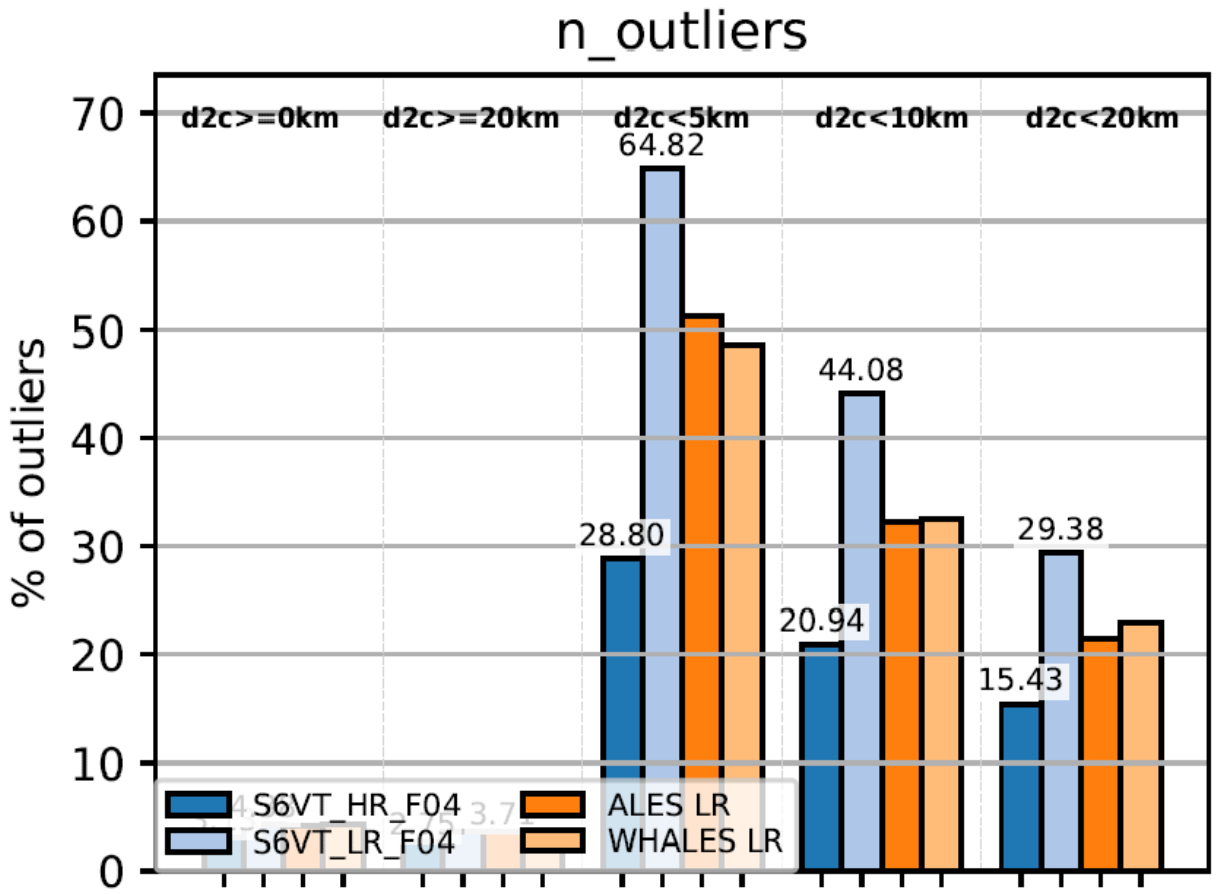
Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** outliers



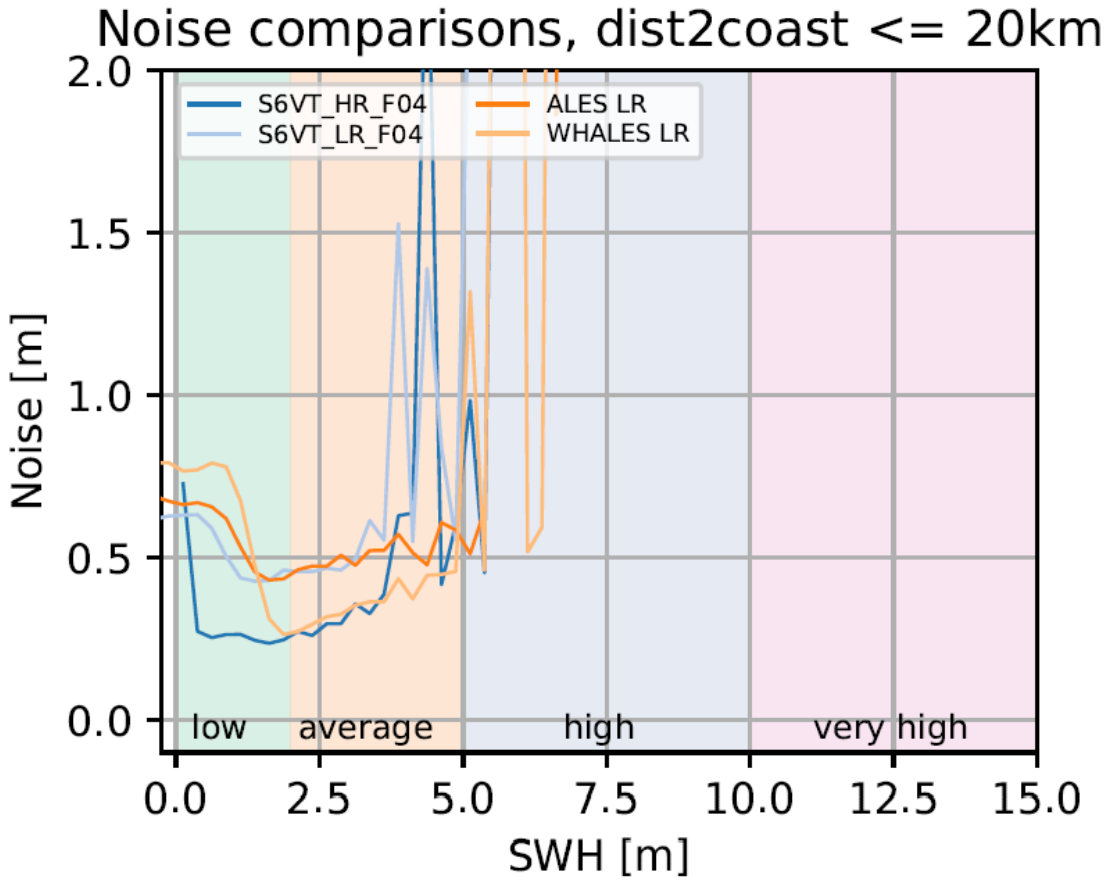
- Largest improvements from SAR in the last 5 km, significantly better than any LRM reprocessing analysed

- LRM S6 coastal valid data amount can be largely improved by ALES and WHALES reprocessing

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** noise



- S6 WHALES LRM reprocessing reaches the same level of noise as SAR data for average sea states (also in the open ocean, not shown)

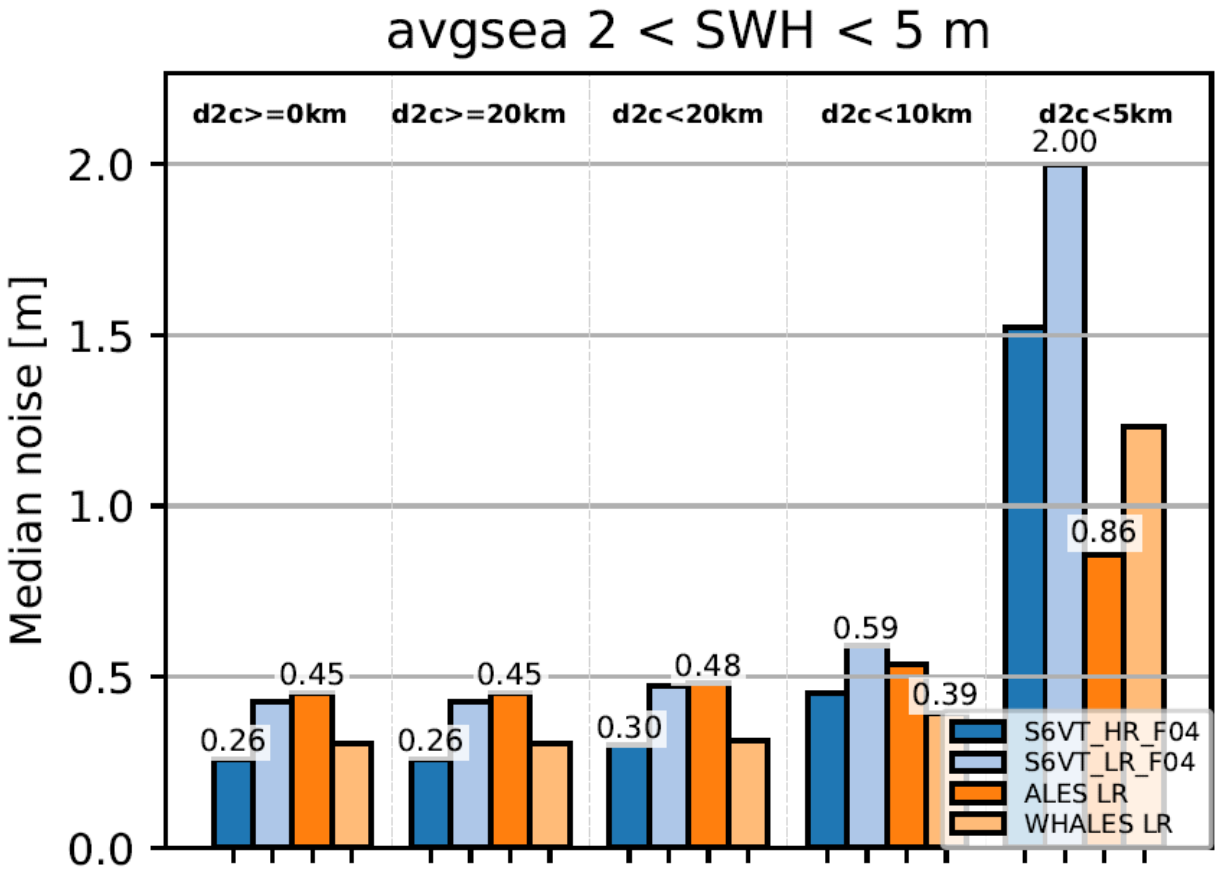
- SAR data have much better noise performances for low SWH

- All of this to be checked again when WHALES adaptation is complete and when the adaptive retracker from J3 is considered

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** noise



- S6 WHALES LRM reprocessing reaches the same level of noise as SAR data for average sea states (also in the open ocean, not shown)
- SAR data have much better noise performances for low SWH
- All of this to be checked again when WHALES adaptation is complete and when the adaptive retracker from J3 is considered

Actions planned for the next 3 months

- Recompute Montecarlo simulation for ALES S6 and Sea State Bias
- Prelimary results of the comparison SAR-RMC vs SAR-HR in the coastal zone
- Process Jason-3 GDR-F and consider results from the “Adaptive retracker”
- Prepare data formats for ALES and WHALES for Jason-3 and show preliminary results

Questions:

- Data retracking and reprocessing takes time and we cannot wait each time new releases and adapt for them. On which S6 baseline should we base our results for the publication? F04?

Summary

Coastal Assessment

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and J3
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Data

- Sentinel-6A/POS-4 L1B LR NTC + L2 HR/LR NTC (reprocessd 03/22) (coastal areas), from EUMETSAT
- Jason-3/POS-3B L1B/L2 GDR-F standard (coastal areas), from CNES

Tools

- ALES retrackers and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
- Round Robin Assessment framework adopted from SeaState_cci project

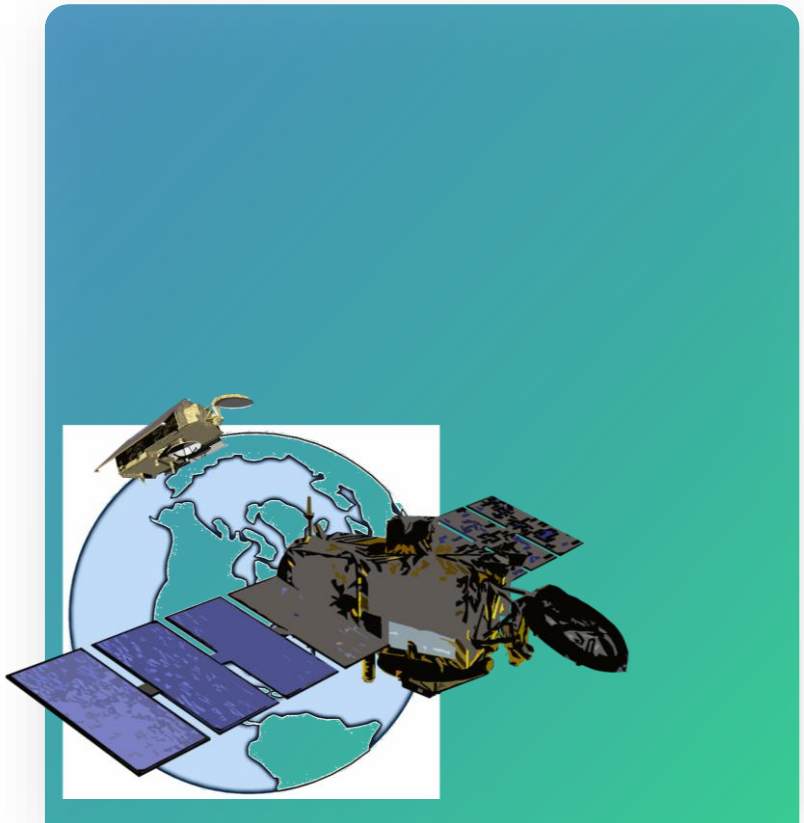
Deliverables

Scientific Activities: Coastal Assessment

Marcello Passaro, Florian Schlembach, Julius Oelsmann, Denise Dettmering

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)

Technical University of Munich



S6-JTEX PM1 MEETING
Online, 10th of December 2021

Assessment of Coastal Performances

Tasks

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and a retracked Jason-3 product
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Planned Steps

1. Retrack the J3 and S6-MF LRM waveforms with specific retrackers: ALES and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
2. **Performance assessment analysis in terms of L2 noise and outlier analysis in the coastal zone, for S6 LRM, SAR-RAW and SAR-RMC & retracked J3**
3. Intercomparison of S6 and J3 based on L2 products in the coastal zone will be performed focusing on bias, drift and their geographical patterns

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

Assessed as a function of sea state and distance-to-coast (open ocean, coast: < 5/10/20 km).

For S6 LRM (LR), S6 SAR (HR) and retracked J3

L2 noise

Defined as the standard deviation of twenty 20-Hz records.

Outlier analysis

Three types of outliers are defined

- **invalid** Data missing (already set to NaN) or quality flag set to ’bad’

- **out_of_range** If a value is out of the expected range of SWH = [−0.25,25] m , SLA = [−2,2] m

- **mad_factor** This criterion compares the value with its 20 closest neighbo
  - Data are discarded if they exceed median plus 3 * 1.4826 * MAD (median absolute deviation, i.e. a robust standard deviation)

Schlembach et al. ‘Round Robin Assessment of Radar Altimeter Low Resolution Mode and Delay-Doppler Retracking Algorithms for Significant Wave Height’. *Remote Sensing* 12, no. 8 (January 2020): 1254. https://doi.org/10.3390/rs12081254.

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

- **SWH** from S6 L2 HR/LR NTC
  - swh_ocean
  - swh_ocean_qual (quality flag)

- **SLA** from S6 L2 HR/LR NTC
  - range_ocean
  - range_ocean_qual (quality flag)

SLA = altitude – range_ocean

- (iono_cor_gim + model_dry_tropo_cor_zero_altitude + model_wet_tropo_cor_zero_altitude + sea_state_bias +

solid_earth_tide + ocean_tide_sol2 + ocean_tide_non_eq + internal_tide + pole_tide + dac)

- mean_sea_surface_sol1

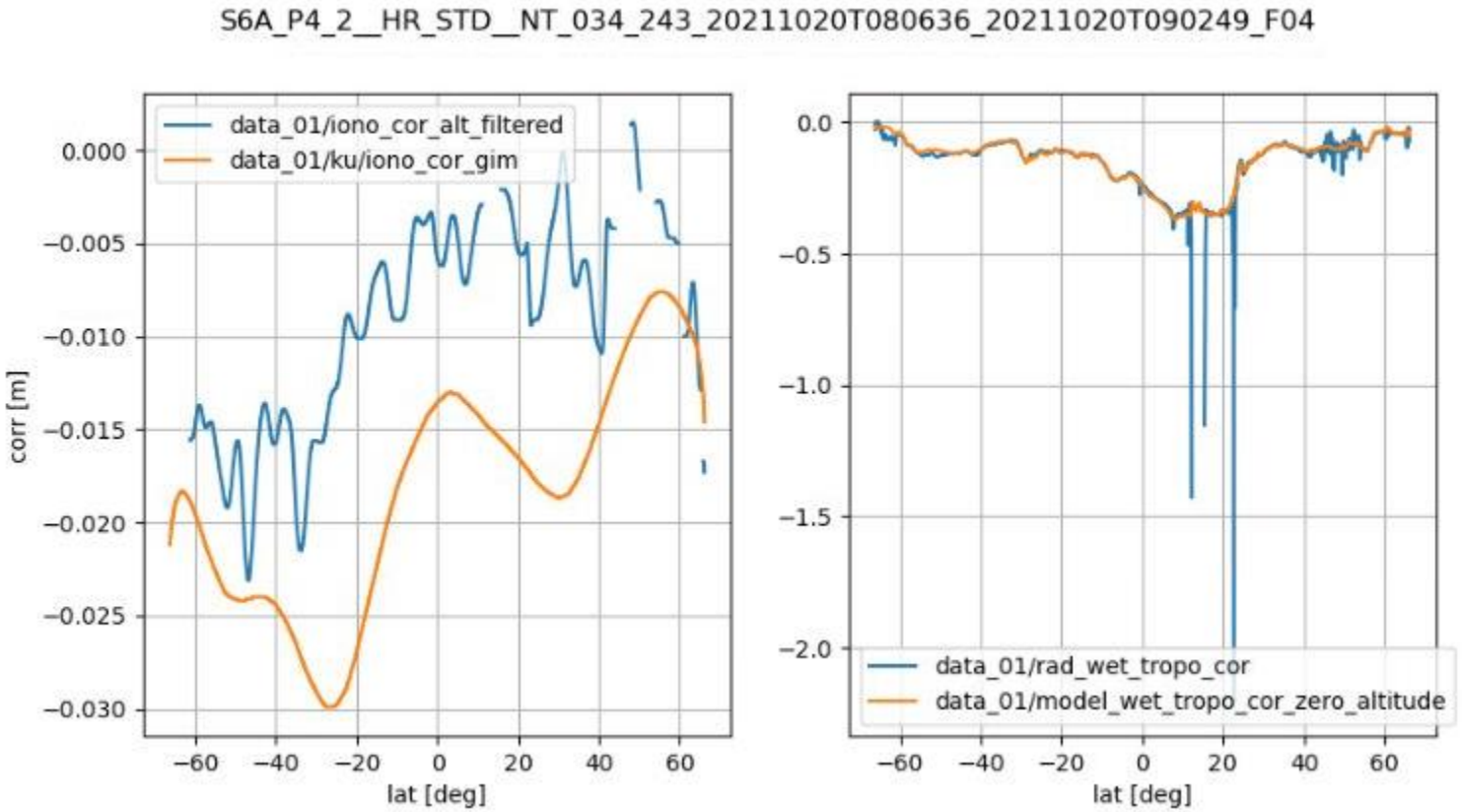
→ Apart from the modelled ionospheric (iono_cor_gim) and wet tropospheric (model_wet_tropo_cor_zero_altitude)

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

- **Measured vs. modelled corrections: ionosphere and wet troposphere**

iono_cor_alt_filtered vs. iono_cor_model

rad_wet_tropo_cor vs. model_wet_tropo_cor_zero_altitude



Planned Step 2: Performance Assessment Analysis: Noise and Outliers

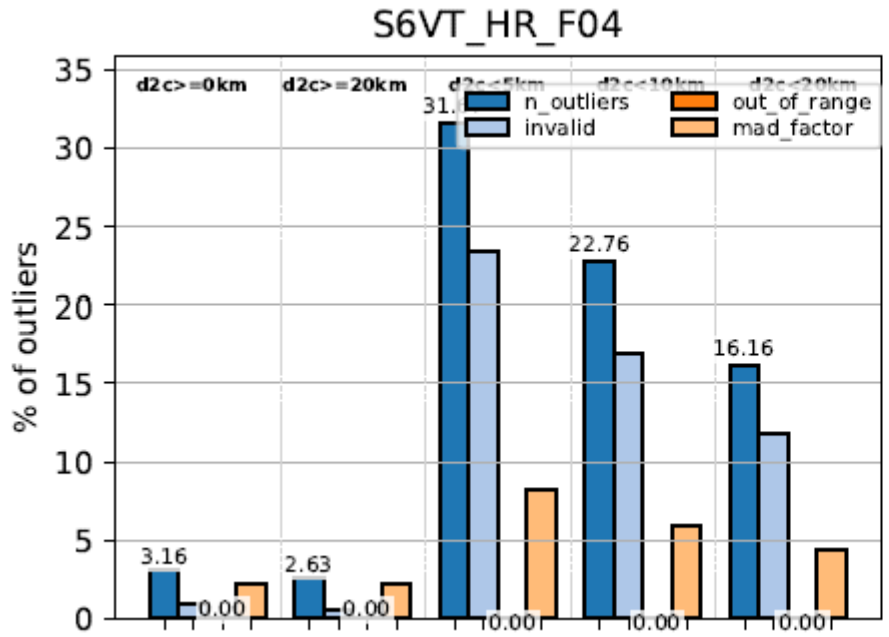
- **Preliminary results for S6A HR and LR**
  - baseline F04 only
  - 3 cycles: 34-36, all 254 relative Orbits
  - period of time (dd/mm/yy): 10/10/2021 – 09/11/2021

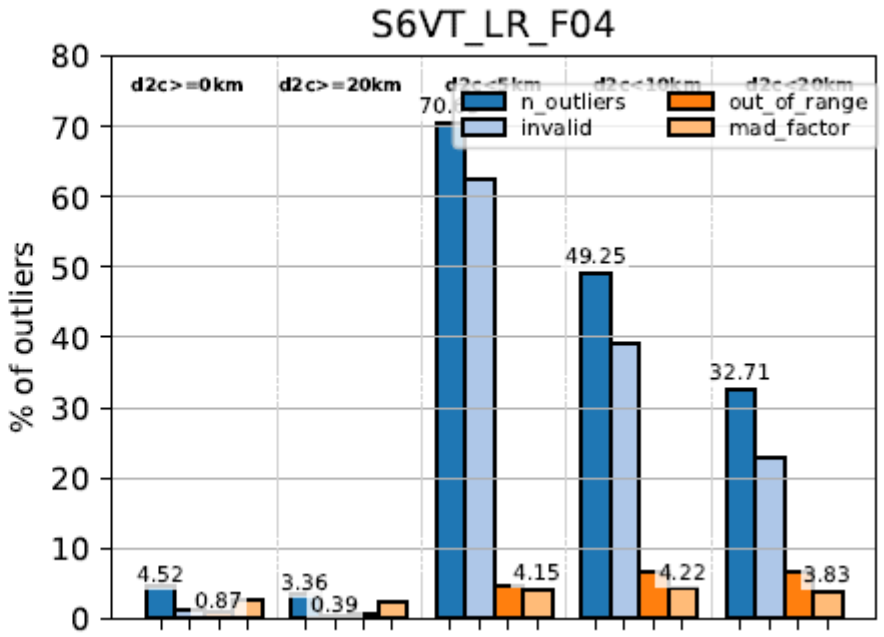
  - L2 file pattern: S6A_P4_2__**{HR|LR}**_____*_*_*_*_03[4-6]_*_*_EUM__VAL_NT_F04
  - 3* 254 netCDF files, as being uploaded on EUMETSAT FTP
  - SAR-RMC mode active for HR processing chain

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** outliers





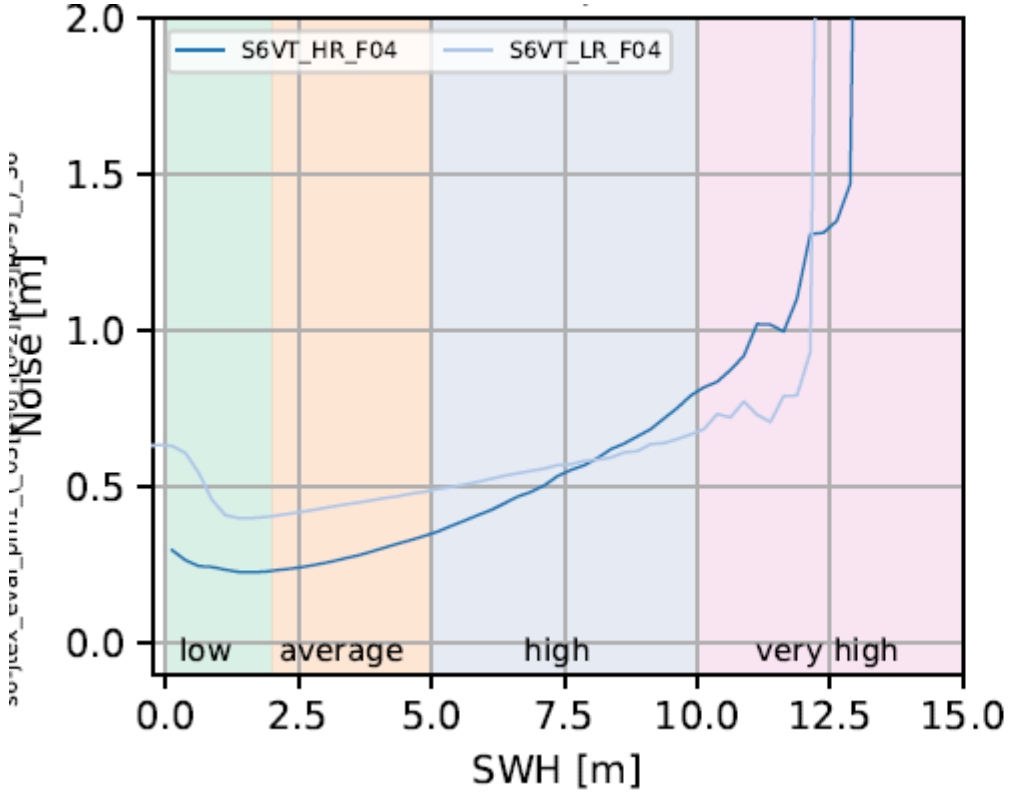
Number of total outliers is dominated by invalid type (quality flag), HR has less values flagged bad

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

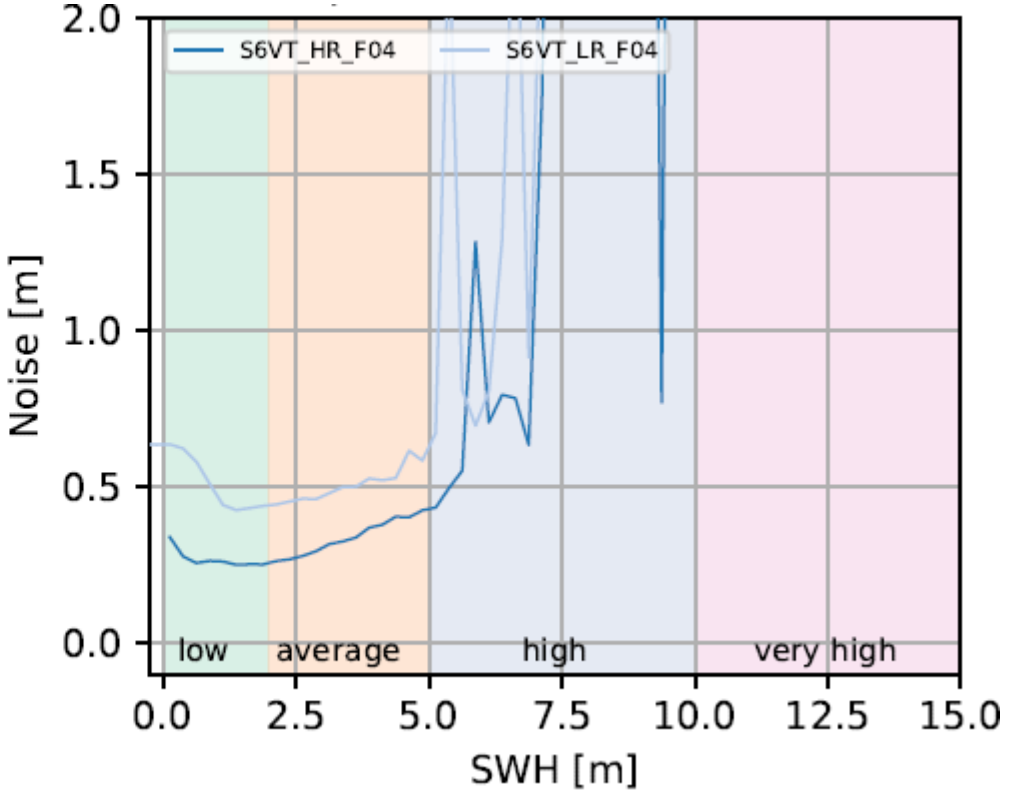
Preliminary results

- **SWH:** L2 noise (invalid outliers excluded)

open ocean



distance-to-coast < 20 km

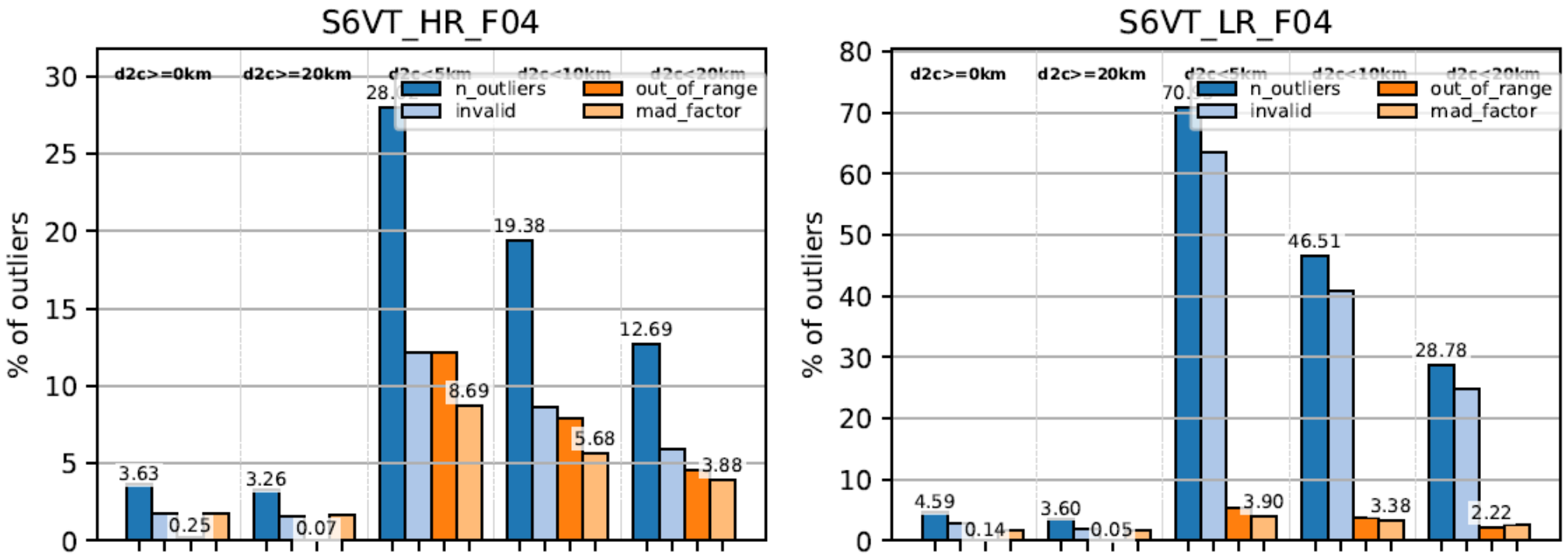


Lower L2 noise for HR for low and average sea states for open ocean and coast

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SLA:** outliers



Number of total outliers is dominated by invalid type (quality flag), HR has less values flagged bad

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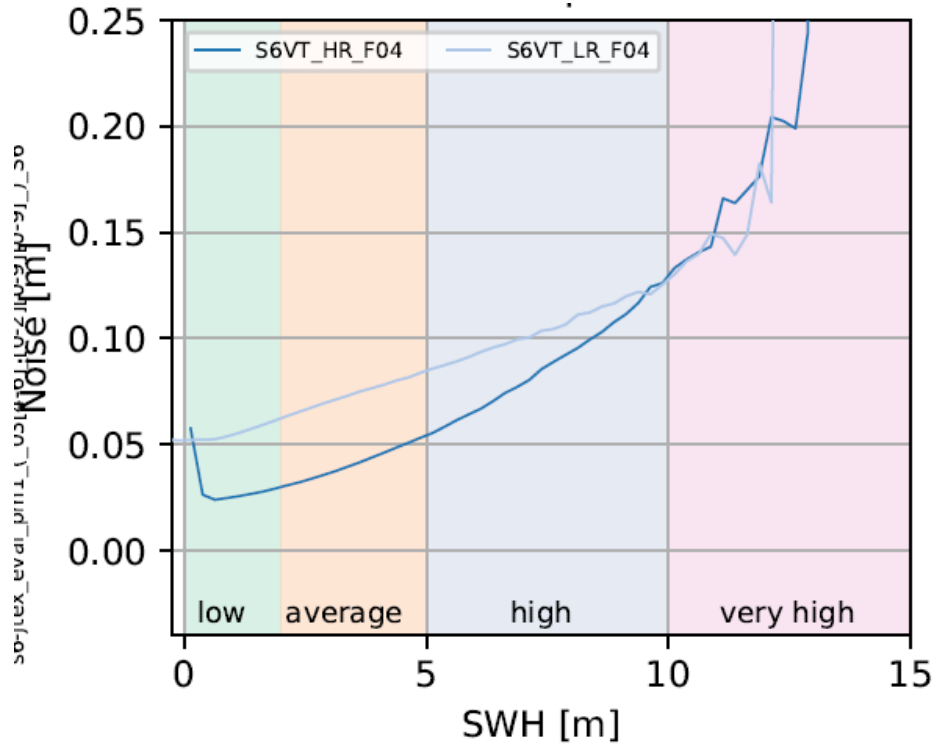
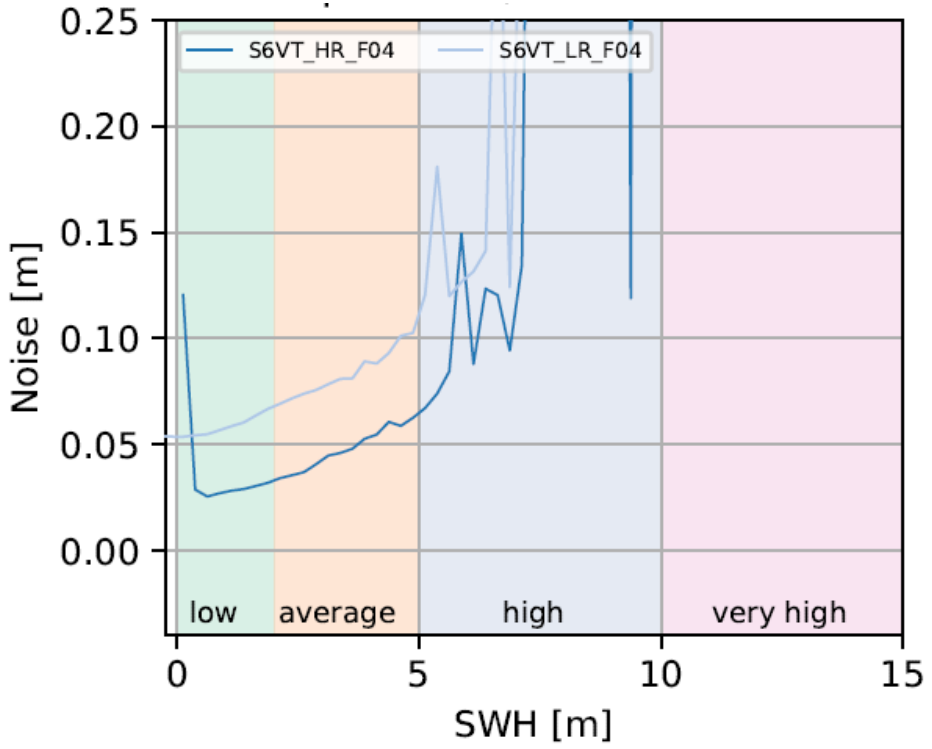
Preliminary results

- **SLA:** L2 noise (invalid outliers excluded)

open ocean



distance-to-coast < 20 km



Lower L2 noise for HR for low and average sea states for open ocean and coast

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

Preliminary results

- SWH
  - HR shows more “valid” values than LR, which are not flagged bad
  - L2 noise level of HR is better than for LR
- SLA
  - HR shows more “valid” values than LR, which are not flagged bad
  - HR exhibits more out_of_range and mad_factor outliers
  - L2 noise level of HR is better than for LR

General question regarding coastal assessment

- The coastal assessment science activity defines the assessment of **SAR-RMC**, SAR-RAW, and retracked J3
- How to assess SAR-RMC in the coastal zone if this mode is supposed for the open ocean?

Science Activity Summary: Coastal Assessment

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and J3
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
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Tools

- ALES retrackers and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
- Round Robin Assessment framework adopted from SeaState_cci project

Deliverables

- Manuscript to be submitted for peer review

Scientific Activities: Coastal Assessment

Marcello Passaro, Florian Schlembach, Julius Oelsmann, Denise Dettmering

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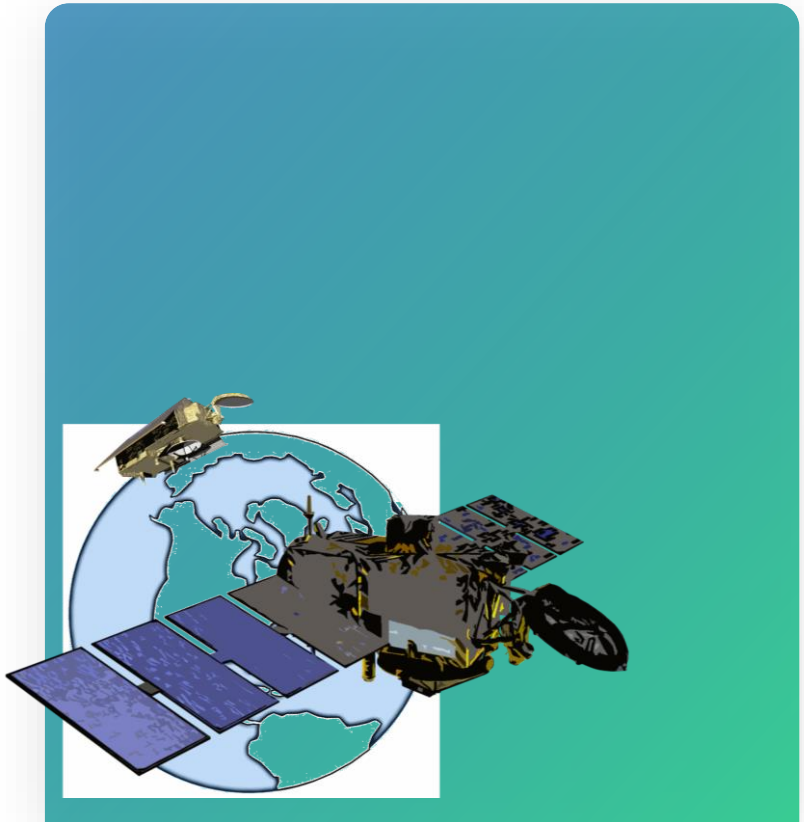

S6-JTEX KO MEETING
Online, 3rd of September 2021

Assessment of coastal performances

Tasks

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and J3
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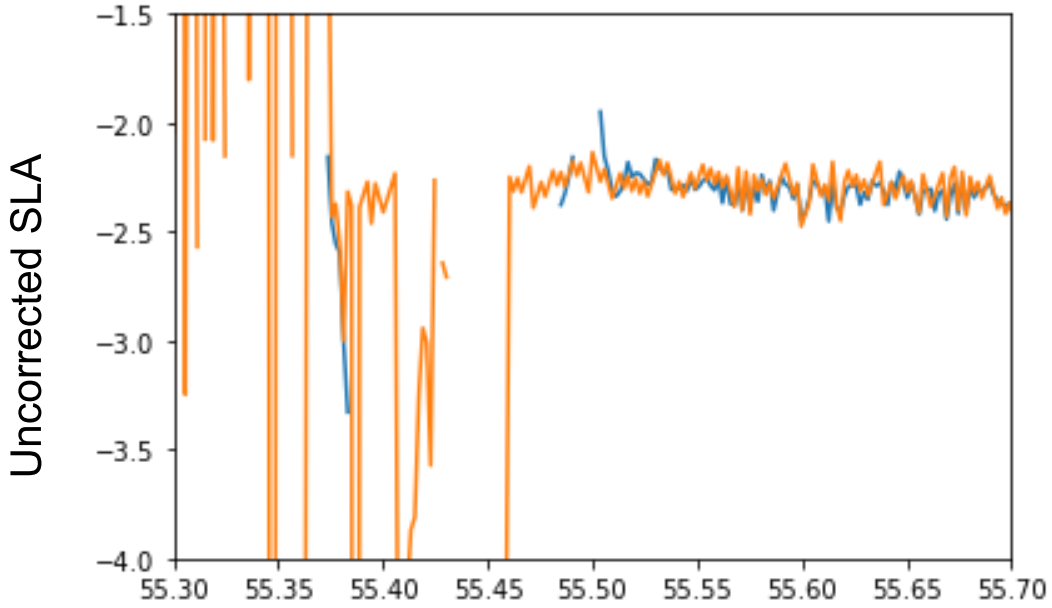
2. Performance assessment analysis in terms of L2 noise and outlier analysis in the coastal zone, for S6 LRM, SAR-RAW and SAR-RMC & retracked J3
3. Intercomparison of S6 and J3 based on L2 products in the coastal zone will be performed focusing on bias, drift and their geographical patters

Planned Step 1: Retrack J3 and S6-MF LRM waveforms

Example 1: an example of land-to-ocean transition with/without ALES for S6-MF LRM (presented at the S6VT)

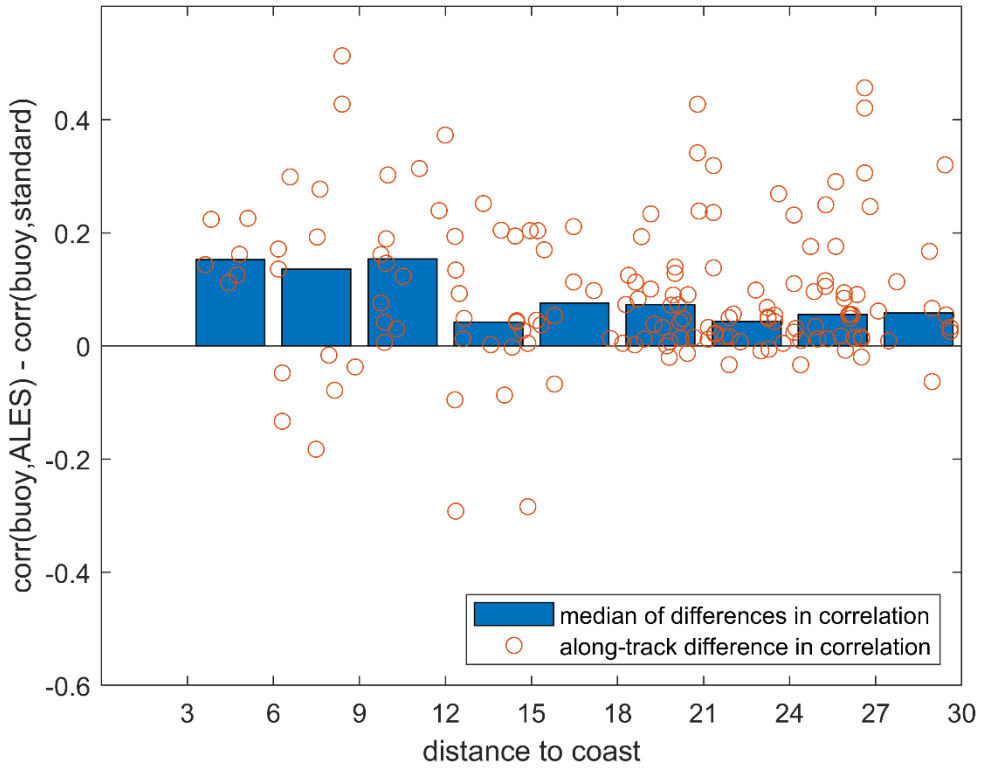


ALES

LRM Ocean Product

Planned Step 1: Retrack J3 and S6-MF LRM waveforms

Example 2: global increase in correlation against buoys using SWH from ALES



From: *Passaro M., Hemer M., Quartly G.D., Schwatke C., Dettmering D., Seitz F.*: **Global coastal attenuation of wind-waves observed with radar altimetry**. Nature Communications, 12, 3812,, 2021

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

Assessed as a function of sea state and distance-to-coast (open-ocean, coast: < 5/10/20 km).

L2 noise

- Defined as the standard deviation of twenty 20-Hz records.

Outlier analysis

- for S6 LRM, SAR-RAW and SAR-RMC & retracked J3

Three types of outliers are defined

- **invalid** Data missing (already set to NaN) or quality flag set to ’bad’

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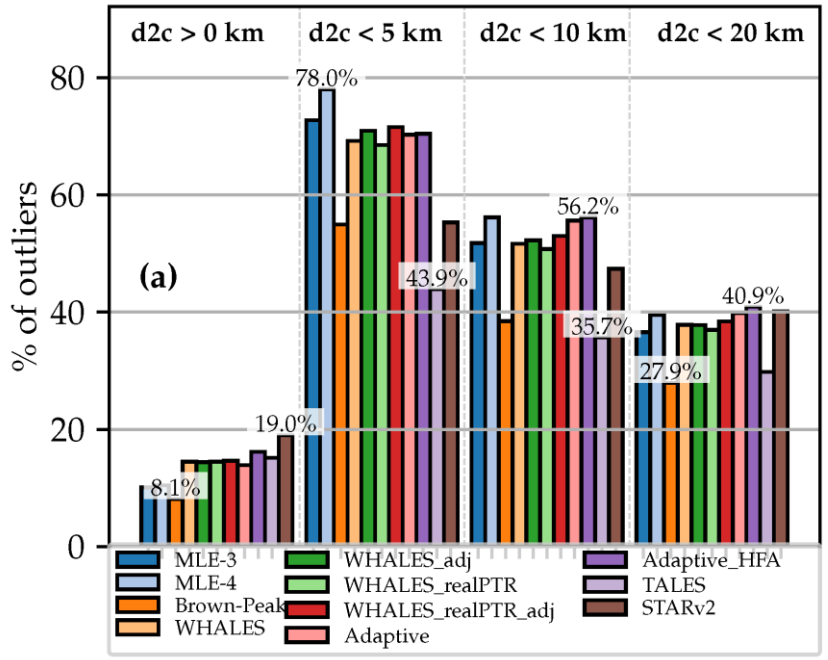
- **mad_factor** This criterion compares the value with its 20 closest neighbours
  - Data are discarded if they exceed median plus 3 * 1.4826 * MAD (median absolute deviation, i.e. a robust standard

Planned Step 2: Performance Assessment Analysis: Noise and Outliers

Example: outliers statistics in the Round Robin of SWH retrievals (Sea State CCI)

e.g. total number of outliers for different retracking methods applied to Jason-3



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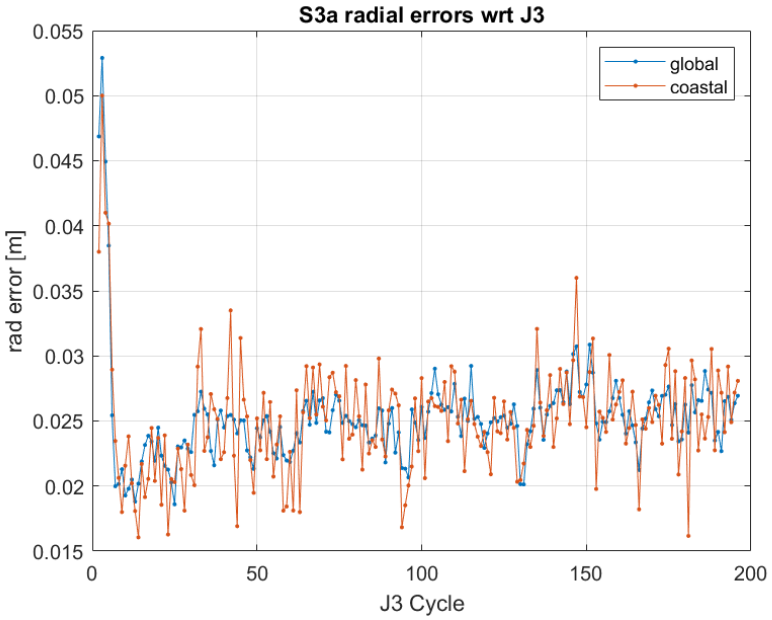
Planned Step 3: Intercomparison of S6 and J3 based on L2 products

Example: results of multi-mission crossover analysis => special behavior in coastal areas detectable?

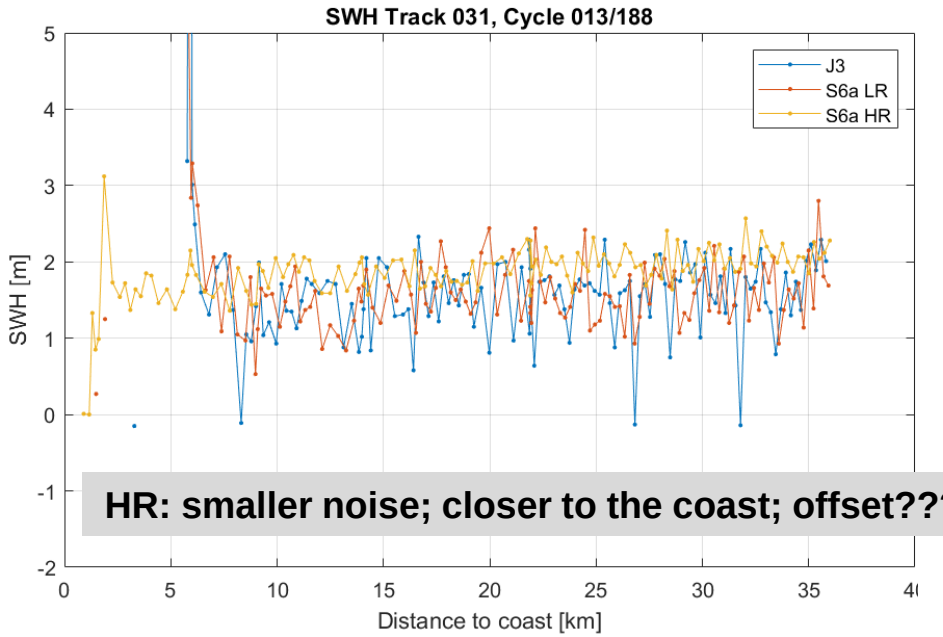


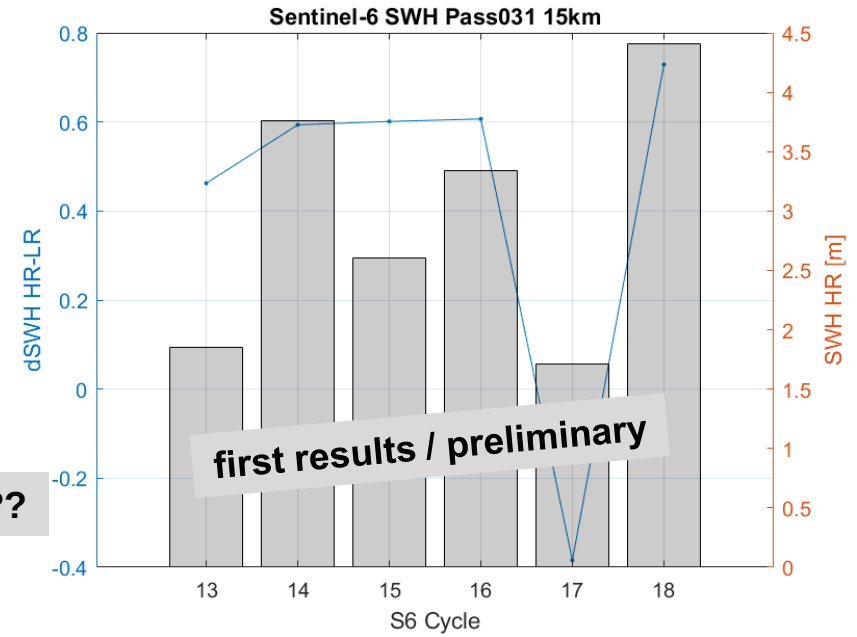
Sentinel-3A:

- Larger noise due to less crossover points
- No systematic differences between coastal/global

Planned Step 3: Intercomparison of S6 and J3 based on L2 products

Example: systematic effect in SWH?





Summary

Coastal Assessment

- Comparison of the coastal performances of S6-MF in its different modes of operation (LRM, SAR-RAW and SAR-RMC) and J3
- In terms of: range, significant wave height, consistency of the relevant geophysical corrections
- Statistics will be referred to the 20-km limit from the global coastline

Data

- Sentinel-6A/POS-4 L1B LR NTC + L2 HR/LR NTC (reprocessd 03/22) (coastal areas), from EUMETSAT
- Jason-3/POS-3B L1B/L2 GDR-F standard (coastal areas), from CNES

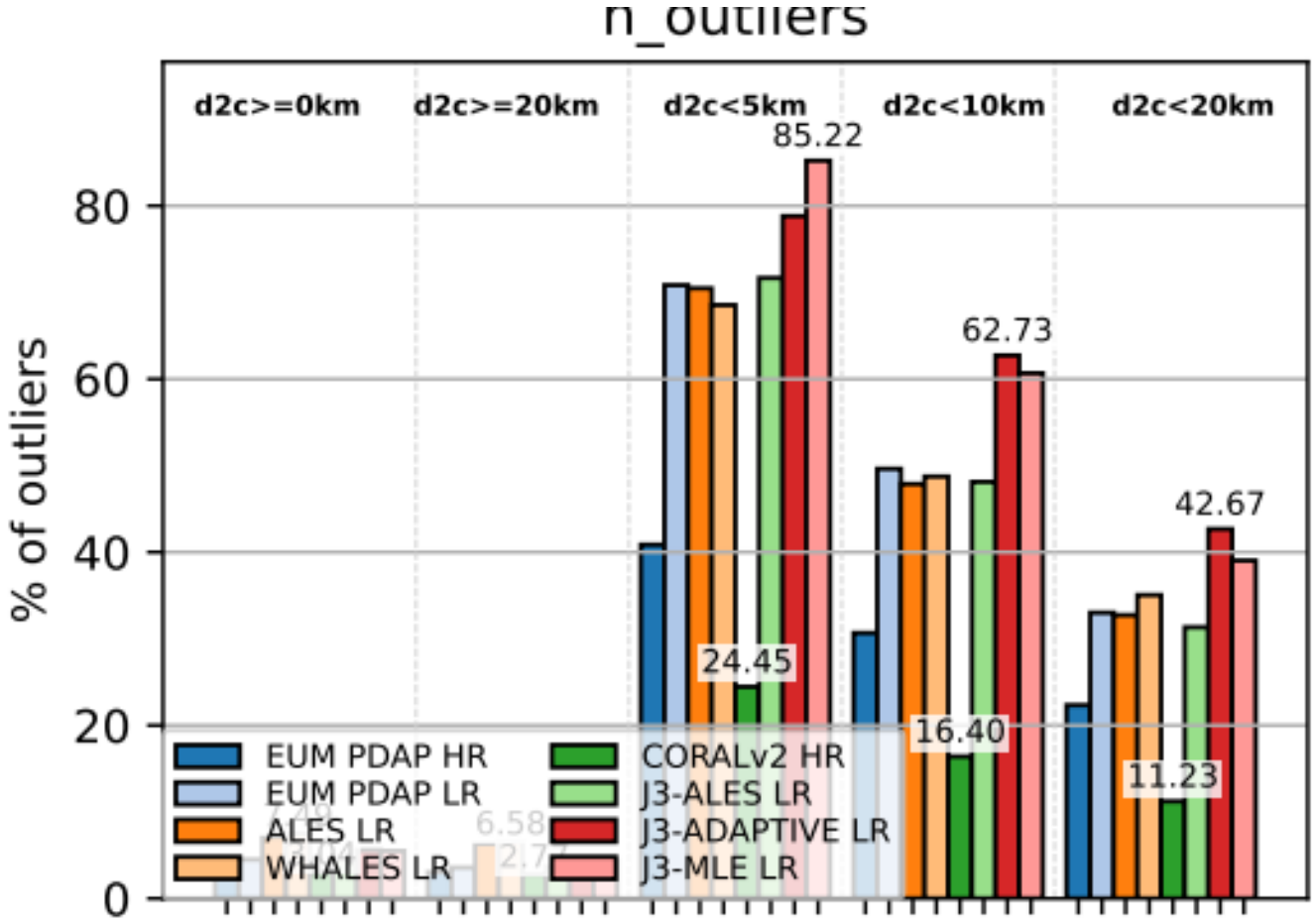
Tools

- ALES retrackers and heritage from other ongoing projects (for example, WHALES from Sea State CCI)
- Round Robin Assessment framework adopted from SeaState_cci project

Deliverables

Performance Assessment Analysis: Noise and Outliers

- **SWH:** outliers



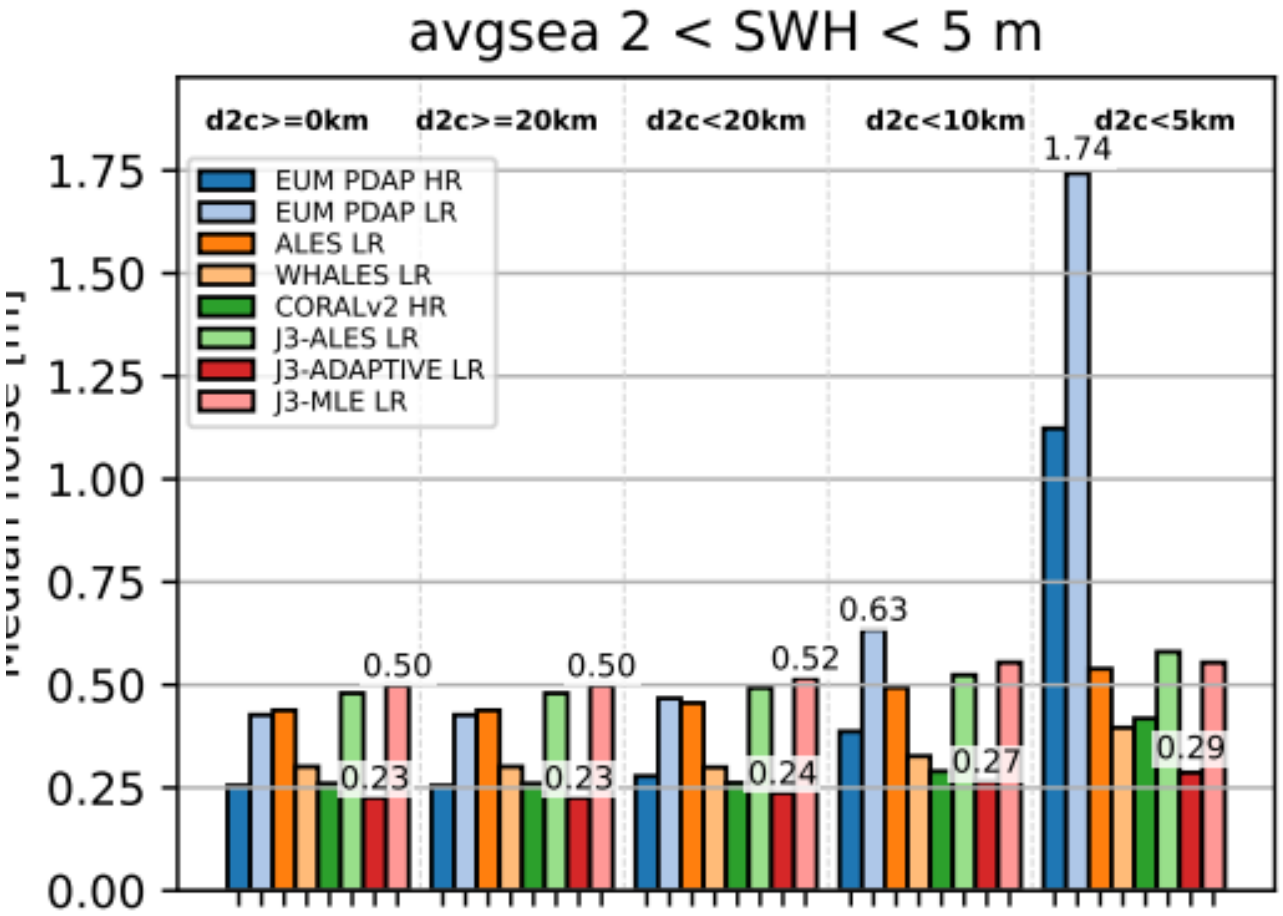
- Largest improvements from SAR in the last 5 km, significantly better than any LRM reprocessing analysed

- Largest number of outliers close to the coast found in J3-ADAPTIVE, lowest number found in standard EUM PDAP HR (from 82% to 31%!!!)

Performance Assessment Analysis: Noise and Outliers

Preliminary results

- **SWH:** noise



- J3-ADAPTIVE and J3-ALES (for LRM altimetry) succeed in maintaining similar noise to open ocean also when „reaching the coast“.
- CORALv1 (for SAR altimetry) gets close to this, but remember SAR keeps many more data than LRM in the last 5 km)