Retracking Sentinel-3 SAR altimeter waveforms with the ACDC algorithm

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INTRODUCTION

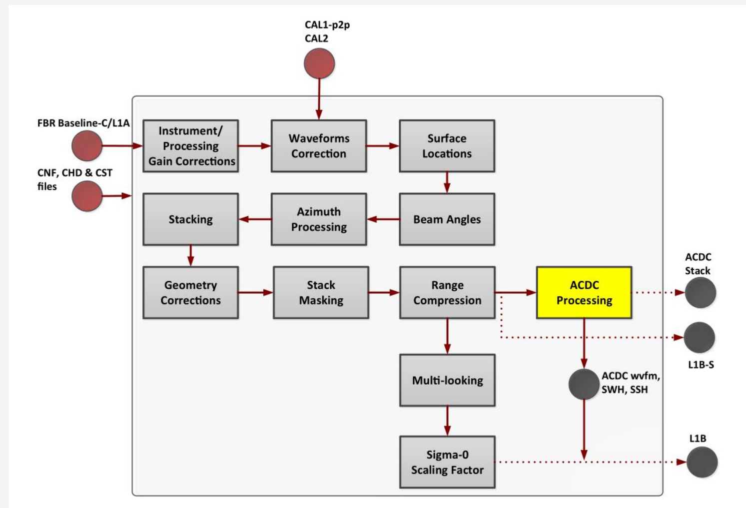
The ACDC algorithm

In this work, a Delay-Doppler Processor for satellite altimetric data has been ajusted to include the Amplitude Compensation and Delay Compensation (ACDC) algorithm (Ray *et al.*, 2015b) with the aim to improve the precision of geophysical parameter estimates retrieved from Sentinel-3 altimetric echoes over open ocean. This retracking algorithm, previously evaluated with synthetic aperture radar (SAR) mode oceanic CryoSat-2 data set (Makhoul *et al.*, 2018), is based on a lower order approximation of the analytical model of the open ocean SAR altimeter backscattered power waveform developed in (Ray *et al.*, 2015a).

Two processing steps are applied to the Delay-Doppler map after a number of corrections, which correspond to the compensation of the variation in the maximum power of each beam (Amplitude Compensation) and the range-dilation of power in each Doppler beam with respect to the zero Doppler one (Dilation Compensation). A multilook echo is then obtained by averaging all power waveform samples in the resulting ACDC Delay-Doppler map, from which oceanic geophysical parameters can be inferred in a fitting procedure.

Algorithm status

- The ACDC algorithm has been implemented at stack level in the DDP chain.
- Tests have been performed on a few S3A tracks starting from L1A products.



METHODOLOGY

The ACDC algorithm takes as starting point a lower order approximation of the theoretical model for SAR altimeter open ocean backscattered echo developed by (Ray et al., 2015)

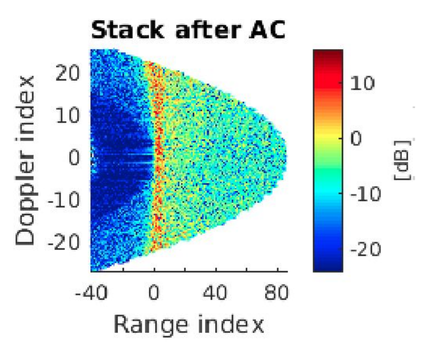
$$P_{k,l} = P_u \cdot B_{k,l} \cdot \sqrt{g_l} \cdot f_0\left(g_l \cdot (k - epoch)\right)$$

The fundamental observation on which the ACDC algorithm is built is that the waveforms in the different Doppler beams l are dilated versions of the same waveform and that the scale of the dilation is set by the parameter g_l.

1 Amplitude Compensation

$$P^{AC}_{k,l} = \frac{P_{k,l}}{B_{k,l}\sqrt{g_l}} = P_u f_0\left(g_l \cdot (k - epoch)\right)$$

We can compensate the variation in the maximum power of each beam by the amplitude factor $B_{k,l}$ times the dilation term g_l, obtaining the amplitude compensated (AC) stack. Note that the AC power has the same peak amplitude for all values of the Doppler index.

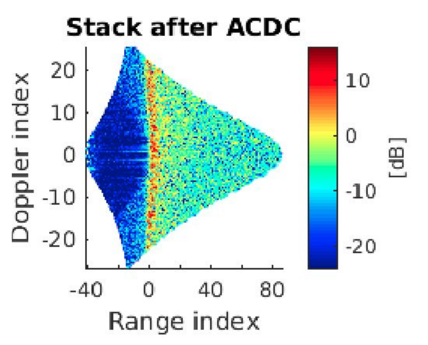


2 Dilation Compensation

$$P^{ACDC}_{k,l} = P_u f_0\left(g_0 \frac{g_l}{g_0} \cdot (k - epoch)\right) = P_u f_0\left(g_0 \kappa_{k,l}\right),$$

with $g_l \equiv g_l(H_s)$ and $B_{k,l} \equiv B_{k,l}(epoch)$

The power in each Doppler beam is a range-dilated version of the Doppler zero beam. Via a known dilation tem g_0 it is possible to compensate for this variation, and write the AC power in terms of the DC range $\kappa_{k,l}$. The power now depends on range and not on Doppler.

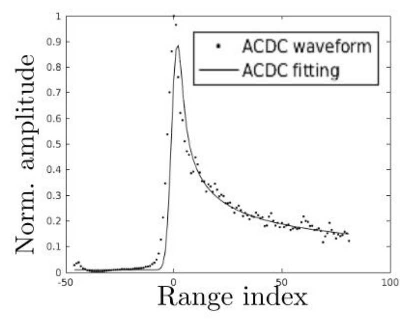


The AC and DC steps depend implicitly on H_s and epoch

3 Multilooking

$$\Psi_n = \frac{\sum_{k,l} w(\kappa_{k,l} - n\delta) P^{ACDC}_{k,l}}{\sum_{k,l} w(\kappa_{k,l} - n\delta)}$$

Because the ACDC power map is independent to the along-track direction we can construct an ACDC multilook waveform by averaging all power waveform samples in the map that have the same DC range with some weighting functions.



4 Retracking

$$\underset{\beta=(P_u, g_0, \epsilon)}{\text{minimise}} \frac{1}{2}\sum_n \left(\Psi_n - \Psi^{model}_n(P_u, g_0, \epsilon)\right)^2,$$

with $\Psi^{model}_n(P_u, g_0, \epsilon) = P_u \cdot f_0\left(g_0 \cdot (\kappa_n - \epsilon)\right)$

The resulting multilook waveform can be fitted by a model function via the solution of a least-squares problem. The retrieved parameters $\{P_u, g_0, \epsilon\}$ correspond to the maximum power, the dilation term (dependent on H_s), and the "error" in estimating k_0 (epoch), respectively.

The ACDC algorithm allows to implement a simpler and faster retracker, which is included in the DDP chain itself as specific initial estimates of epoch and H_s are required for its operation.

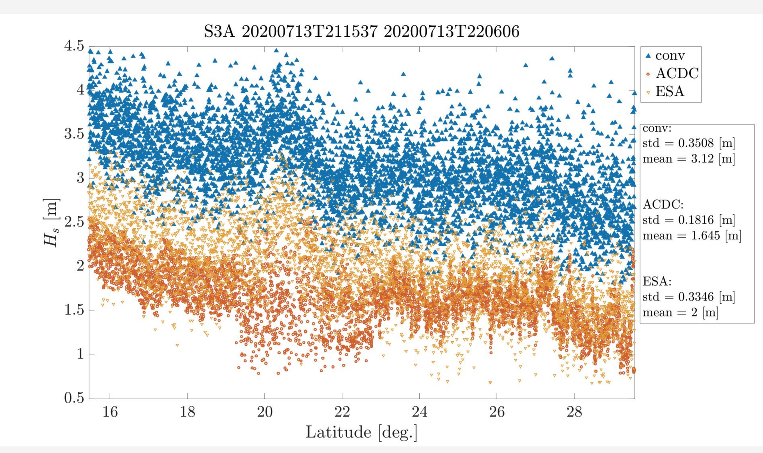
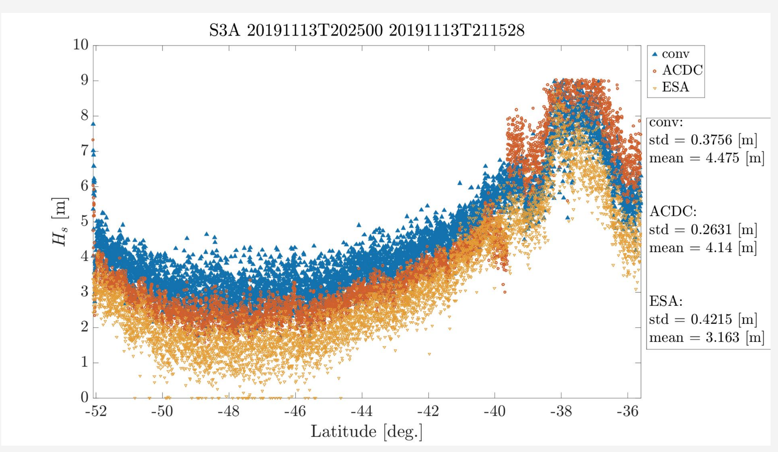
Processing blocks that have been reviewed to improve performance:

1. **Decrease sensitivity of parameters to initial estimates:** select initial estimates as a weighted cumulative moving average as they go far from the current surface.
2. **Dynamic thermal noise estimation:** for each surface, find n_N such $\frac{\partial \Psi_n}{\partial n}\Big|_{n=n_N} \leq \beta$ and estimate noise with $n \in [n_0, n_N]$

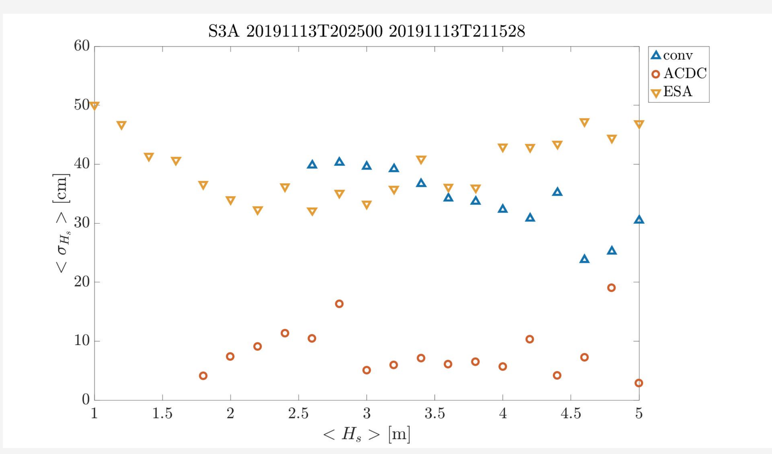
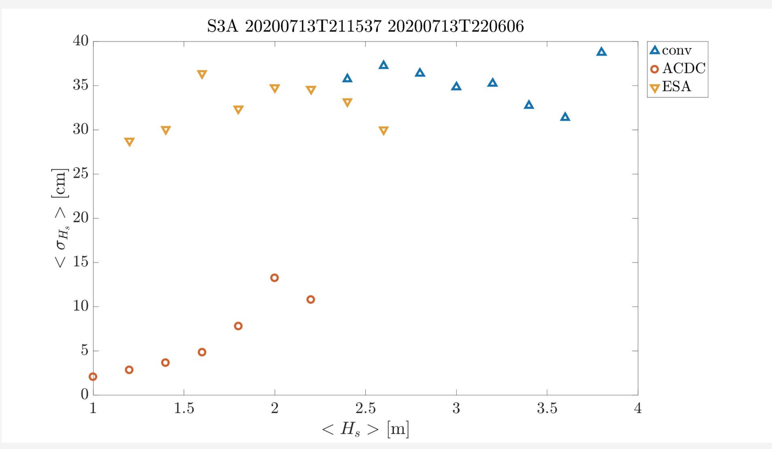
RESULTS

- **Validation dataset**:
  - The analysis is performed with S3A SAR ocean altimetry data over two regions in the central Pacific Ocean (orbit 257) on 2020-07-13 and the Agulhas box (orbit 256) on 2019-11-13.
  - Standard L2 products of the EUMETSAT CODA and retracked dataset with an in-house DD L2 processor, named DeDop-Waver/"conventional" (Makhoul *et al.*, 2018), are used in the comparative analysis.
- **Evaluation Criteria** of the comparative performance analysis:
  - H_s estimates are retrieved in the fitting procedure, and plotted against latitude.
  - Precision is measured by computing the mean, $<H_s>$, and standard deviation, σ_{Hs} of H_s estimates of 20 successive echoes after detrending ("STD at 20 Hz"). By sorting $<H_s>$ in 0.2 m bins, the mean of the corresponding standard deviation, $<\sigma_{Hs}>$, is computed.

H_s *vs* latitude

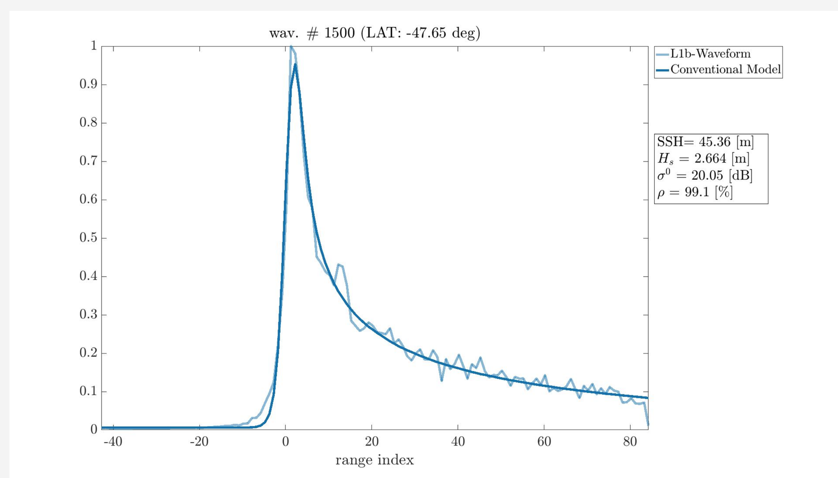



Precision *vs* H_s

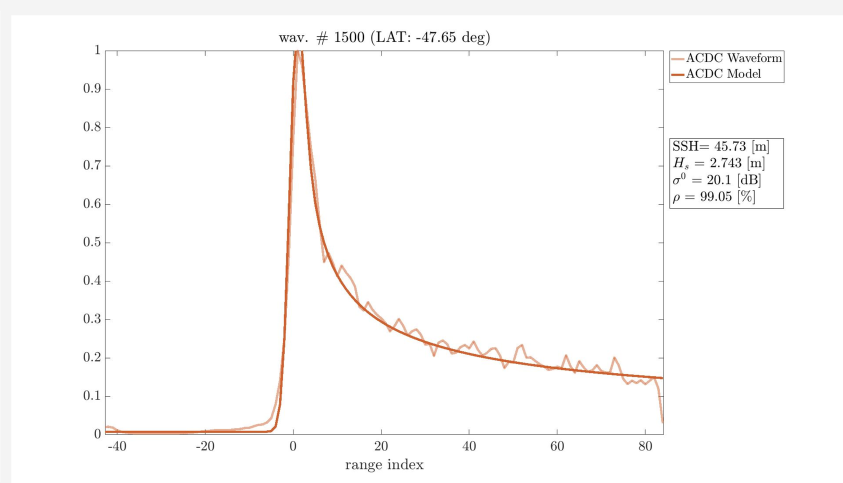



Fitted SAR alimeter open ocean backscatter echoes (Agulhas)

"Conventional" SAR ocean retracking



ACDC retracking



Sea surface heigh (SSH), Significant wave height (H_s), backscattering coefficient (σ_0) and Pearson correlation coefficient (ρ)

CONCLUSIONS

The performance of the ACDC processing algorithm is evaluated in terms of its precision against an in-house "conventional" SAR altimeter retracker with S3A data, showing a noticeable reduction of noise levels (improved precision) in the retrieval of significant wave height.

- The ACDC technique implemented at stack level improves the noise performance of H_s by 15-20 cm.
- Although the technique is promising, further improvements in the algorithm are required to assure stability of the estimates.

Future work:

- Reduce further the sensitivity to initial estimates of H_s by reformulating the minimisation problem (MLE/Bayes).
- Process new regions of the CCI-sea state dataset.

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Makhoul, E., Roca, M., Ray, C., Escolà, R., and Garcia-Mondéjar, A. (2018). Evaluation of the precision of different Delay-Doppler Processor (DDP) algorithms using CryoSat-2 data over open ocean. Advances in Space Research, 62(6):1464–1478.
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