An updated 25+ year (1991-2017) sea level record from the Arctic Ocean

Contribution to the ESA SL_CCI initiative

Stine Kildegaard Rose[1] Ole Baltazar Andersen[1] Marcello Passaro[2] Jérôme Benveniste[2]

[1]DTU Space - National Space Institute, Kgs. Lyngby, Denmark

[2]Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany

[3]European Space Research Institute, European Space Agency (ESA-ESRIN), Frascati, Italy

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Introduction

Why studying Arctic SL?

- Part of ESA's SL CCI: New improved SL record
- The Arctic SL challenging

Figure 1: *ESA Sea Level (SL) Climate Change Initiative (CCI)*

Improvements of CCI_SL DTU/TUM product

- Former (reprocessed but largely un-retracked) New (ALES+ retracked, REAPER and in house processed)
- No constrains to the MSS
- Dedicated Arctic processing
- Larger amount of data, especially in the sea-ice covered regions

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- Seasonal/permanent ice cover
- Regional coverage (satellites/tide gauges)
- Satellite instruments
- Insufficient geophysical models
- Residual orbit errors
- Retracking

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Data description

Making the 25+ years SL record based on satellite altimetry:

- ERS-1 (REAPER)
- ERS-2 (ALES+)
- Envisat (ALES+)
- CryoSat-2 (DTU inhouse LARS processing of SAR/SARIn, RADS (Scharroo et al., 2013) of LRM)

Table 1: *Geophysical corrections*

Corrections	Model	Comments
Wet troposphere	Prefer using model (ECMWF)	ERS1, not possible - as far as we know?
Ocean tides, etc	FES 2014	Not defined close to the coast
Inv. baro/ Atm. corr.	Inv. baro from GDR product	Inv. baro/ atm corr?? Best for arctic?
Mean sea surface	DTU15	

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ALES+ retracker

ALES+ (non-peaky waveforms)

1. Leading edge detection
2. First retracking (leading edge only)
3. Subwaveform extension
4. Second retracking of the extended subwaveform

ALES+ (peaky waveforms)

1. Leading edge detection
    1. External estimation of trailing edge slope*
2. First retracking (leading edge only)
3. Subwaveform extension
4. Second retracking of the extended subwaveform

* Brown-Hayne simplified model with trailing edge slope as 4th unknown (follows CLS solution proposed in CCI and adapts it to ALES)

$$V_m(t) = P_u \frac{|1 + \mathrm{erf}(u(c_\zeta, t, SWH))|}{2} e^{f(c_\zeta, t, SWH)}$$

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ALES+ performance in open waters

Difference of noise statistics

- Std. within 1-Hz block
- Mask: Maximum sea-ice extend (March 1992)
- Almost constant improvements
- Large improvements in coastal areas and in sea-ice proximity

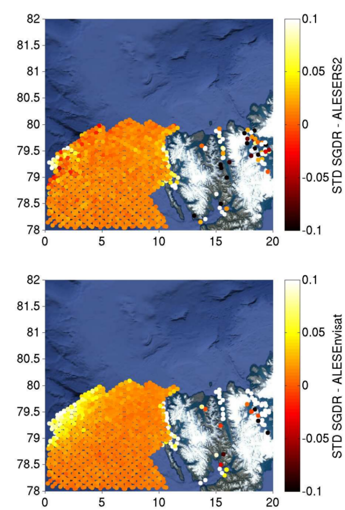

Figure 2: *Top: ERS-2, bottom: Envisat*

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ALES+ performance in open waters

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- Std. within 1-Hz block
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Difference of avg. noise (ERS-2)

- Noise reduction in the 72%
- Reduction of over 3 cm in 30%
- SGDR: Median Noise = 9.72 cm
- ALES: Median Noise = 8.49 cm

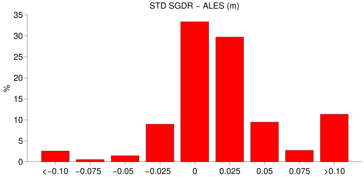

Figure 3: *ERS-2*

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ALES+ performance in open waters

Difference of noise statistics

- Std. within 1-Hz block
- Mask: Maximum sea-ice extend (March 1992)
- Almost constant improvements
- Large improvements in coastal areas and in sea-ice proximity

Difference of avg. noise (Envisat)

- Noise reduction in the 76%
- Reduction of over 3 cm in 27%
- SGDR: Median Noise = 6.74 cm
- ALES: Median Noise = 5.26 cm

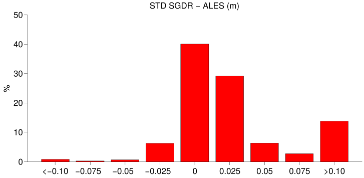

Figure 4: *Enisat*

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Validating ALES+

Comparing SLA to Ny Ålesund tide gauge (for ALES+)

- Pearson correlation coefficient ex. Ny Ålesund versus:
  - ALES: R=0.827 (2,723,430 points)
  - RADS: R=0.838 (315,037 points)

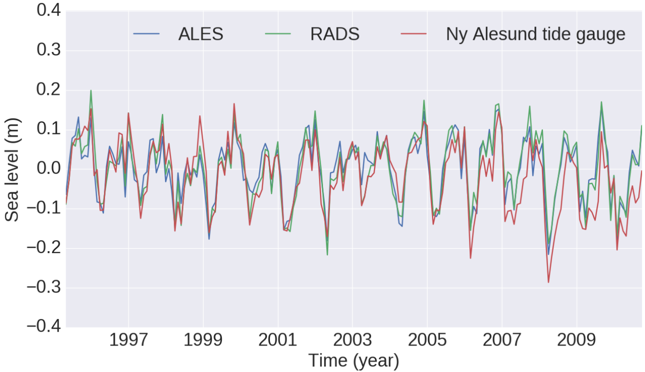

Figure 5: *Sea level anomaly*

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Validating ALES+

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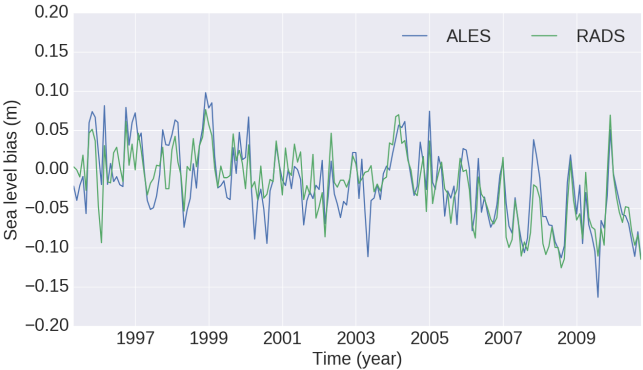

Figure 6: *Sea level bias*

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Ocean and lead discrimination

Data filtering

- Removing sea-ice/mixed surface measurements
- MAD outliers detected for every track

Table 2: *Ocean/lead discrimination thresholds*

Satellite	Ocean	Lead
ERS-1	PP < 1.5 σ^0 : 9 – 15	PP > 21 LEW < 3.0
ERS-2	PP < 1.5 σ^0 : 9 – 15	PP > 23 LEW < 3.0
Envisat	PP < 1.5 σ^0 : 9 – 15	PP > 21 LEW < 3.0
CryoSat-2	RADS	PP(SAR) > 35 PP(SARIn) > 15 LEW < 0.9 St. STD < 4.0

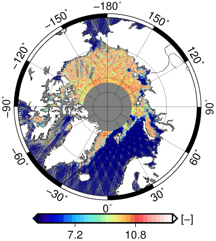

Figure 7: *Peakiness*

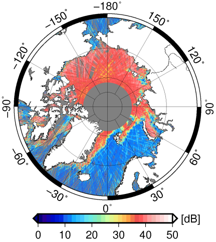

Figure 8: *Backscatter*

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Classification

- Using a unsupervised clustering: Kmeans
- 12 classes and 3 parameters: (PP, LEW, Sigma0)
- Classification is run by every month
- Slightly better correlation coefficient with Ny-Ålesund tide gauge for C2

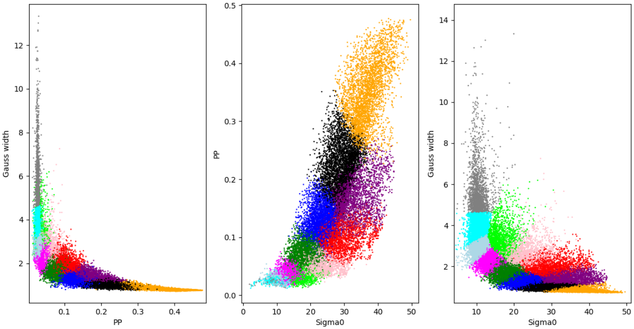

Figure 9: *Parameters plotted for all classes*

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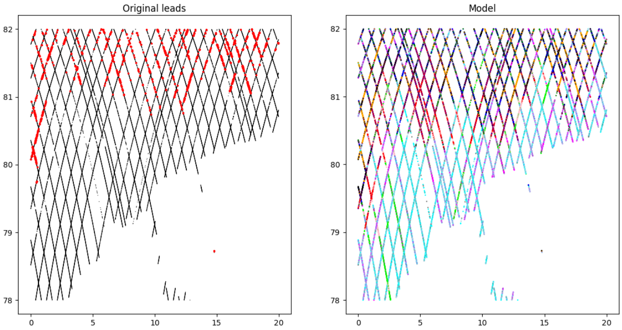

Figure 10: *Original detection versus kmeans model*

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The sea level record

Processing steps

- Weekly data are gridded using least squares collocation with second-order Markov covarinace function (Andersen, 1999)
- Grid size: 1° by 3°
- Inter-satellite bias determined

Issue

- Sparse Summer data (June-Aug.)
- Prandi et al. (2012) describes: correlation between the presence of sea ice and SLA data coverage. Using geoid data for missing data

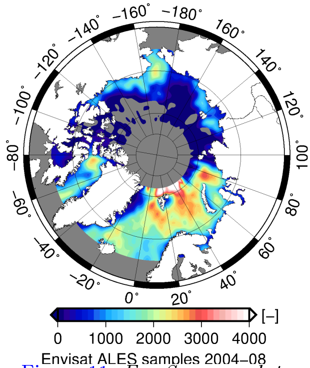

Figure 11: *Ex. Summer data*

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PRELIMINARY trends and seasonal variability

- Solving the harmonic function by ordinary least squares
- Seasonal maximum in late Autumn and minimum in late Spring
- Global trend 2.2 ± 0.2 mm/yr

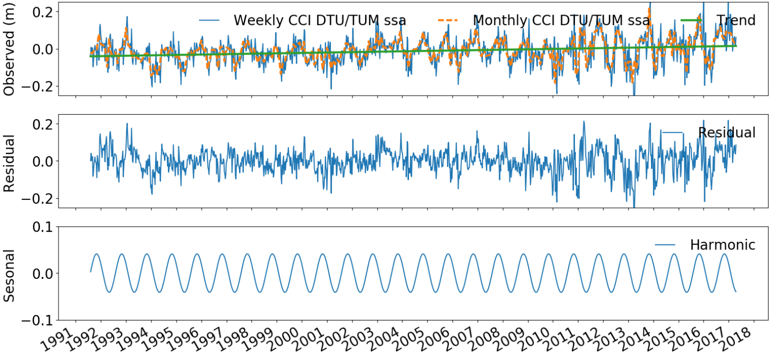

Figure 12: *Weekly SLA*

Validating against tide gauges

- Resampled to monthly median
- DTU/TUM ssa 250 km around tide gauge
- Ny Ålesund
  $R = 0.8630$

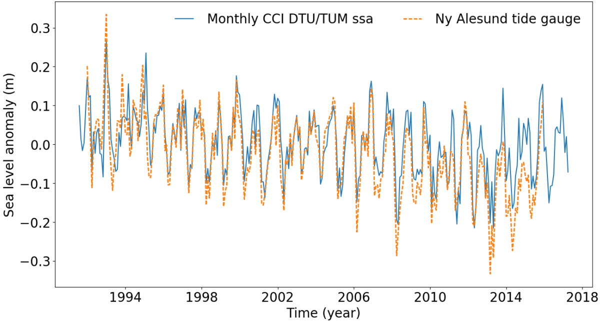

Figure 13: *Comparison against Ny-Ålesund*

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Summary

- 25+ years of radar altimetry data are processed
- ALES+ performs good in open ocean and in sea-ice cover
- Leads and open ocean are found. Avoiding introducing MSS errors
- DTU/TUM good fit to tide gauges
- Issue with Summer data especially around the Beaufort Gyre
- Preliminary sea level rise of 2.2 ± 0.2 mm/yr
- Data will in the near future be available through the CCI home page
- Antarctica version

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Future work

- Further improvement of lead/ocean descimination (classification, masks, . . .)
- Have a closer look at the sea level anomalies
- ALES+ retracking of ERS-1
- Improve/continue time series with SARAL/AltiKa and Sentinel 3a data
- Separating the tides, annual signal and sea level pressure better.
- We need to improve the MSS and apply a new MSS correction in the Arctic.

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Thank You for Listening!

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R. Scharroo, E. Leuliette, J. Lillibridge, D. Byrne, M. Naeije, and G. Mitchum. RADS : CONSISTENT MULTI-MISSION PRODUCTS. In *The Symposium on 20 Years of Progress in Radar Altimetry, Venice,*, number 2, pages 5–8. Eur. Space Agency Spec. Publ., ESA SP-710, 2013.

stine@space.dtu.dk