

climate change initiative

→ SEA STATE

Sea State CCI: beyond the significant wave height



sea state
cci



TUM
Technische Universität München



PML
Plymouth Marine Laboratory



National
Oceanography Centre
NATIONAL ENVIRONMENT RESEARCH COUNCIL



SatOC



UNIVERSIDAD
DE CANTABRIA



ECMWF



CLS
Centre National d'Etudes Spatiales

Fabrice Ardhuin & Guillaume Dodet,

With contributions from NOC, PML, SatOC, CLS, TUM,

ECMWF, DLR, OceaDataLab, U. Galati, IH

Cantabria, IsardSat , Ifremer, NERSC, LOPS

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→ THE EUROPEAN SPACE AGENCY

Sea State in IPCC AR6 Chapter 1: coastal & sea ice

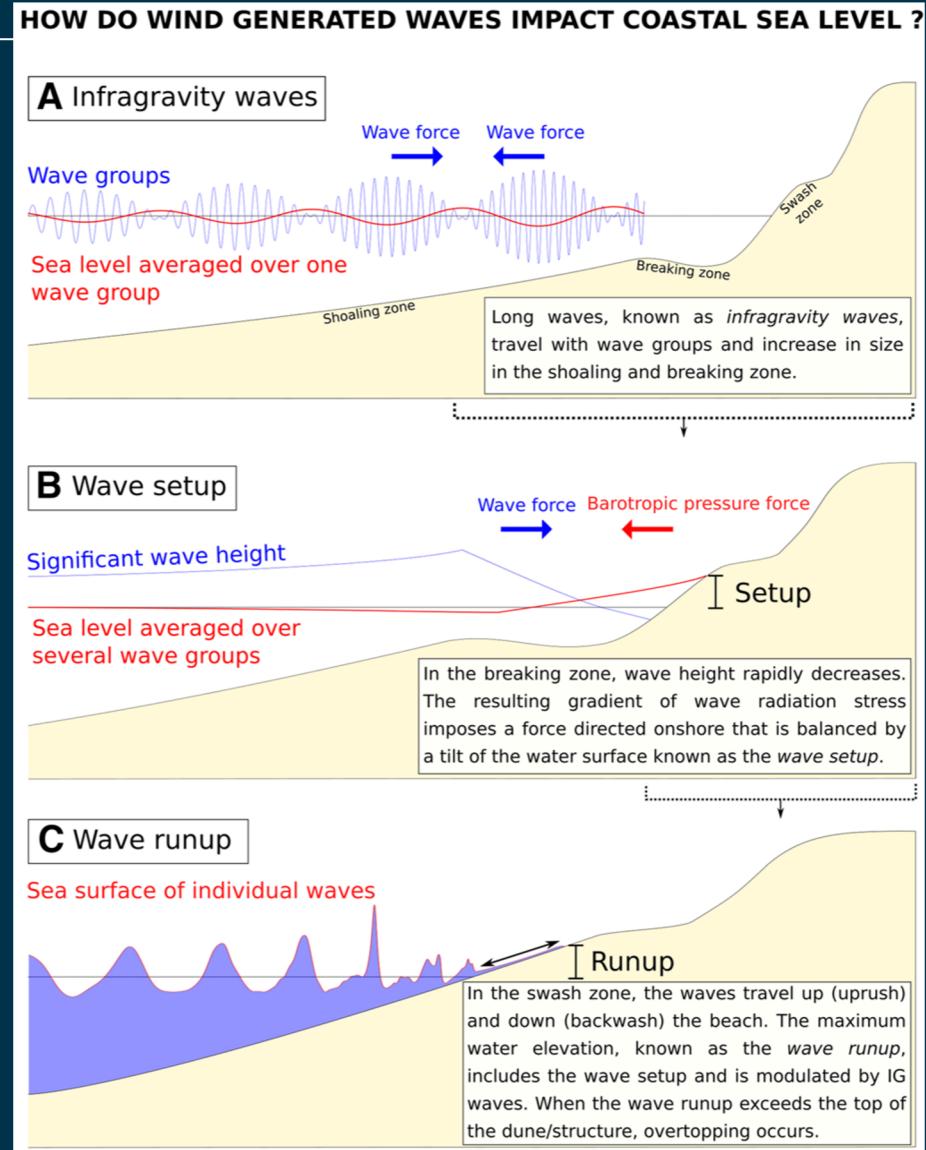
“Waves [a.k.a. Sea State] contribute to ESL via wave setup, infra-gravity waves and swash processes (Dodet et al., 2019) [...] The SROCC (Oppenheimer et al., 2019) reported the dependency of these processes on **nearshore geomorphology** and **deep-water wave climate**, and thus sensitivity to internal climate variability and climate change. [...] Trends in wave contributions to ESL are typically derived from trends in wave conditions observed offshore.”

Before the Sea State CCI :

“On the basis of satellite altimeter observations, the SROCC reported increasing extreme wave heights in the Southern and North Atlantic Oceans of around 1.0 cm yr^{-1} and 0.8 cm yr^{-1} over the period 1985-2018 (**medium confidence**). The SROCC (Collins et al., 2019) also identified sea-ice loss in the Arctic as leading to increased wave heights over the period 1992 to 2014 (**medium confidence**). ”

Thanks to the ongoing Sea State CCI work :

“Since the SROCC, the satellite wave record has been shown to be sensitive to alternate processing techniques, leading to important differences in reported trends (Timmermans et al., 2020).” [blabla on issues with reanalyses and hindcasts, citing Stopa et al. 2019] To summarise, satellite era trends in wave heights of order 0.5 cm yr^{-1} have been reported, most pronounced in the Southern Ocean. However, sensitivity of processing techniques, inadequate spatial distribution of observations, and homogeneity issues in available records limit confidence in reported trends (**medium confidence**). ”



(Dodet et al., 2019)²

Sea State in IPCC AR6 Chapter 1: coastal & sea ice



3 papers produced by the CCI and cited in AR6 Chapter 1:

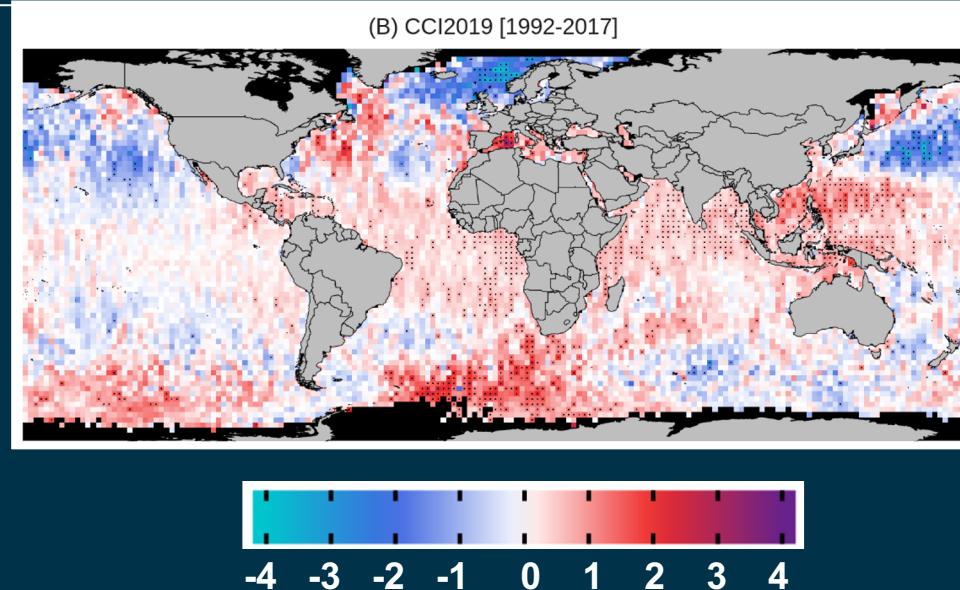
Dodet, G., Melet, A., Arduin, F., Bertin, X., Idier, D., & Almar, R. (2019). The Contribution of Wind-Generated Waves to Coastal Sea-Level Changes. *Surveys in Geophysics*. doi:10.1007/s10712-019-09557-5

Stopa, J.E., F. Arduin, E. Stutzmann, and T. Lecocq, 2019: Sea State Trends and Variability: Consistency Between Models, Altimeters, Buoys, and Seismic Data (1979–2016). *Journal of Geophysical Research: Oceans*, 124(6), 3923–3940, doi:10.1029/2018jc014607.

Timmermans, B.W., C.P. Gommenginger, G. Dodet, and J.-R. Bidlot, 2020: Global Wave Height Trends and Variability from New Multimission Satellite Altimeter Products, Reanalyses, and Wave Buoys. *Geophysical Research Letters*, 47(9), doi:10.1029/2019gl086880.

Timmermans, B., D. Stone, M. Wehner, and H. Krishnan, 2017: Impact of tropical cyclones on modeled extreme wind-wave climate. *Geophysical Research Letters*, doi:10.1002/2016gl071681.

Stopa, J.E., F. Arduin, and F. Girard-Arduin, 2016: Wave climate in the Arctic 1992–2014: seasonality and trends. *The Cryosphere*, 10(4), 1605–1629, doi:10.5194/tc-10-1605-2016.



(trend in wave height, cm/year,
Timmermans et al., 2019)

Sea State CCI: data production and validation



After production of “**Version 1**” of the dataset (2019),
selection of processing algorithms for altimeters (LRM & SARM) and SAR-wave-mode data (Sentinel 1 & Envisat)

The year **2021** was marked by the production of “**Version 2**” dataset:

- Retracked waveforms: less noisy and more coastal data compared to Version 1:
 - Envisat, Jason-1, Jason-2, Jason-3, Cryosat-2, SARAL (Sentinel 3A to be added in **Version 3**)

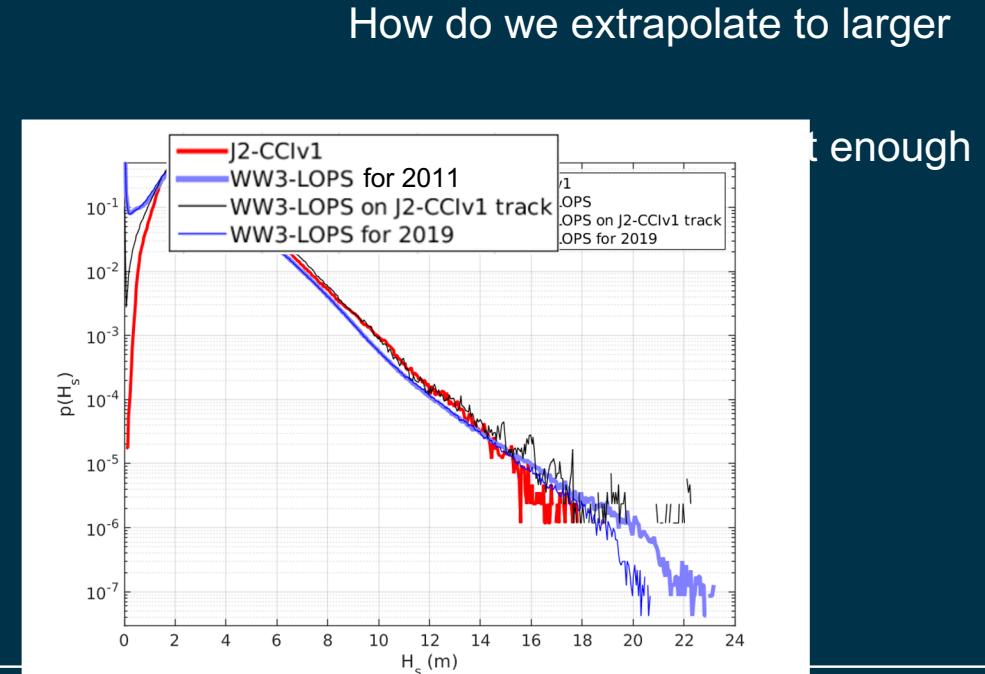
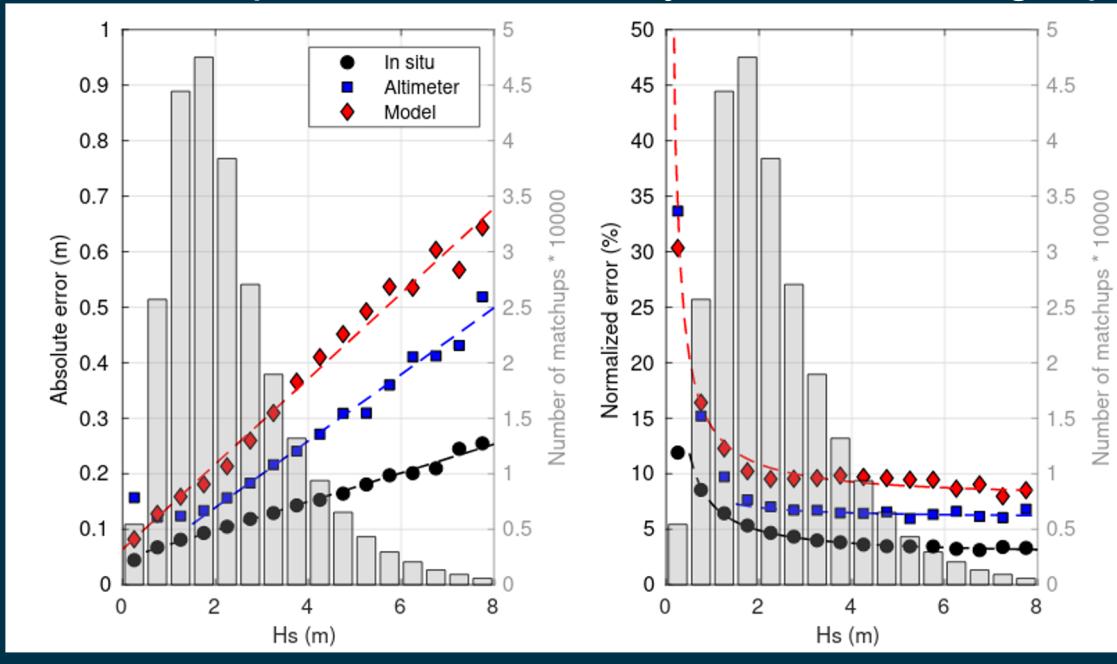
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 - Update on uncertainty estimates using triple-collocation method:



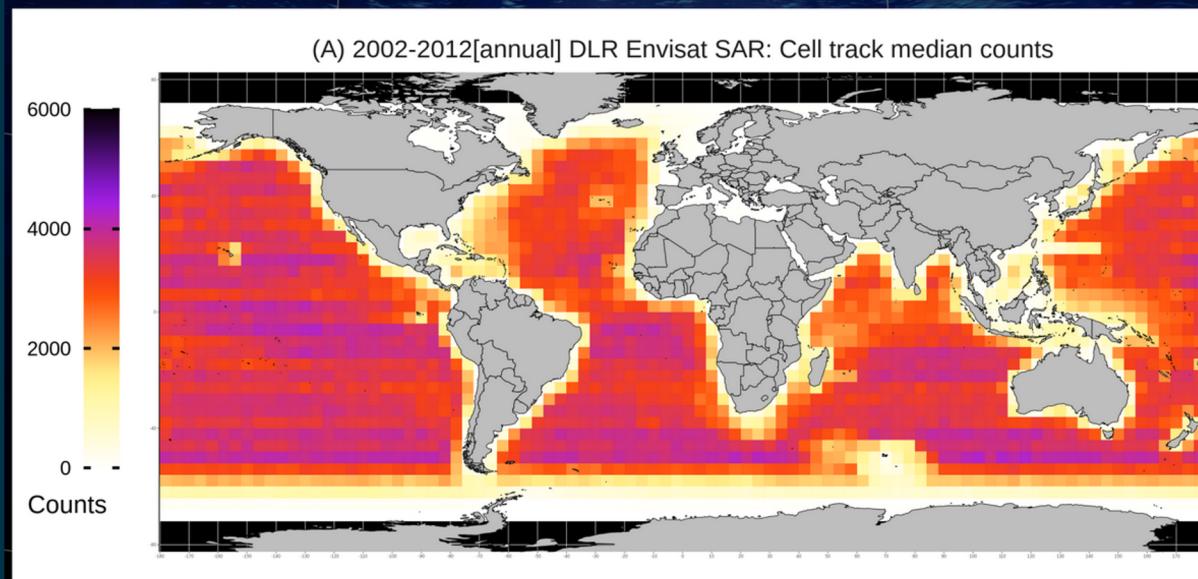
Sea State CCI: data production and validation

Sea State CCI “Version 2” is the first global data set to include both altimeters and SAR imagery

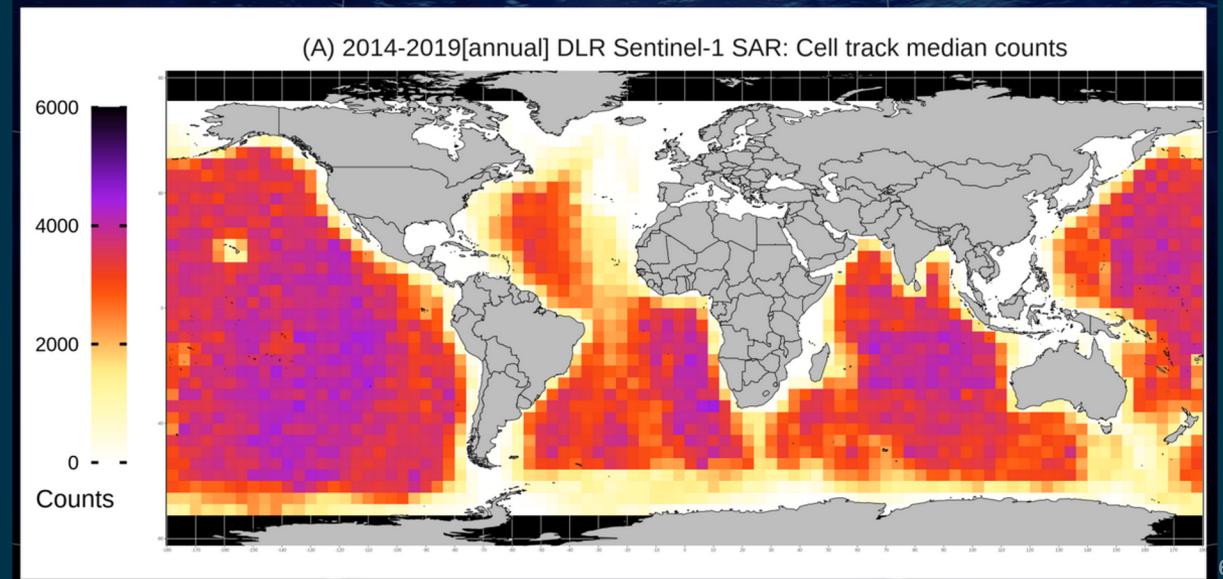
- Additional parameters: wave period and direction parameters from Sentinel 1 and Envisat ASAR.
- And extended coverage for wave heights (except north-east Atlantic: only wave mode has been processed.)

A first validation effort has been completed. More is coming.

Envisat SAR coverage (12/2002 - 03/2012)



Sentinel-1 SAR coverage (12/2014 - 03/2019)

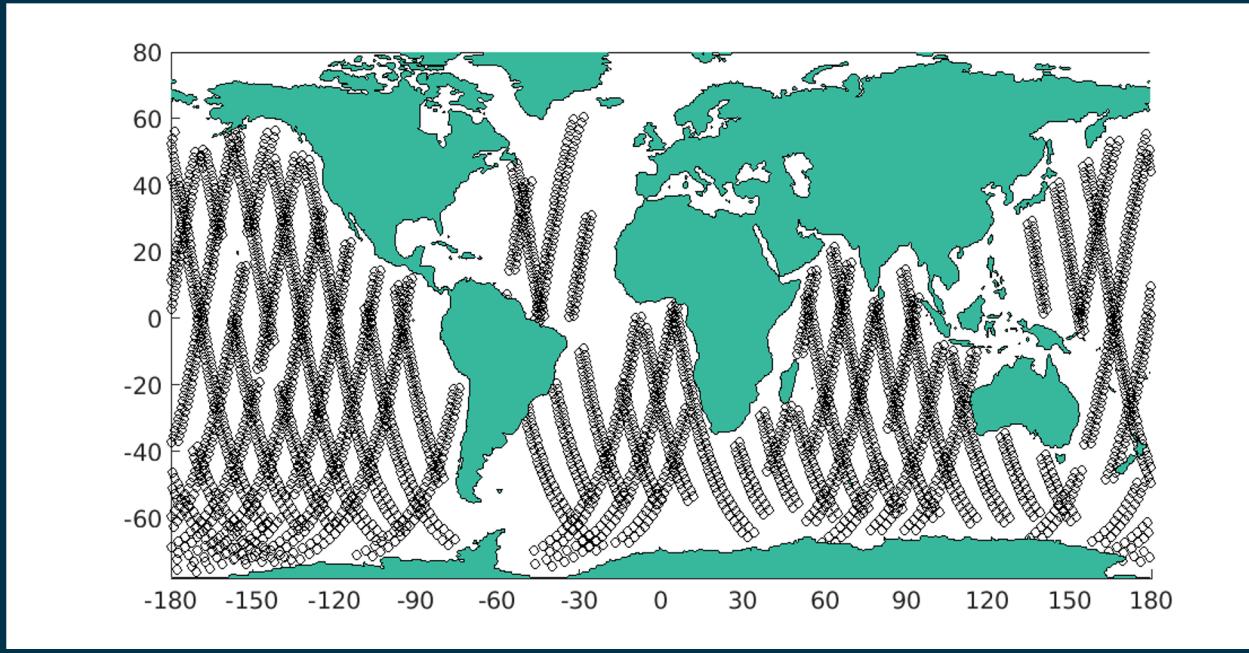


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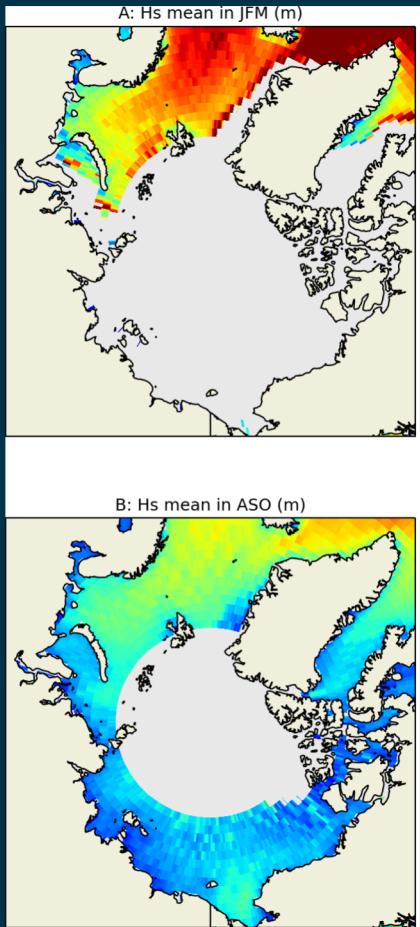
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Example of 1-day coverage from S1A + S1B in wave mode (01/01/2019)

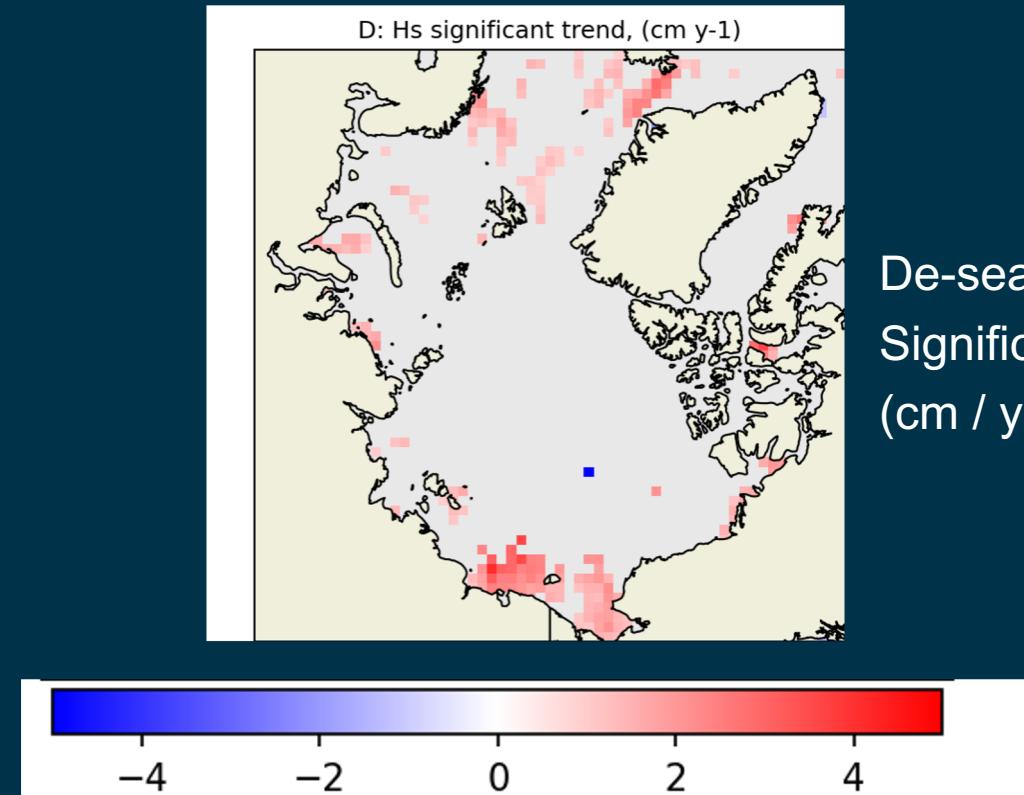


Sea State CCI: case studies

Among the different case studies considered (coastal, extremes ...) the Sea State CCI v2 dataset is also used to look at the Arctic, confirming strong trends in wave height (Stopa et al. 2016, Casas-Prat and Wang, 2020) and linking sea surface, wave impact and changes in the Marginal Ice Zone



Seasonal mean
wave height (m)



De-seasonalized
Significant trends
(cm / year)

Sea State CCI: beyond the wave heights

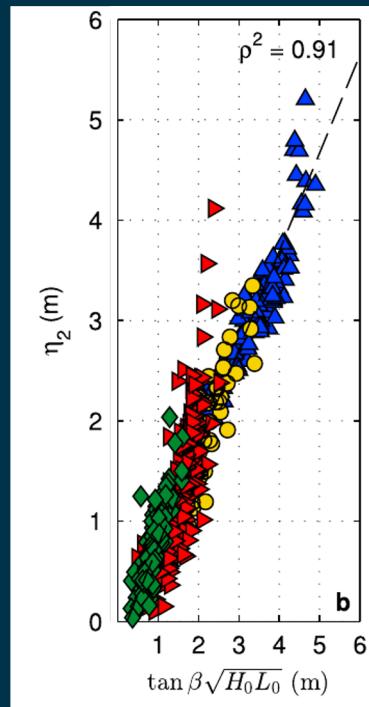
Why do wave periods and directions matter ?

"Waves contribute to Extreme Sea Level (ESL) via wave setup, infra-gravity waves and swash processes ..."

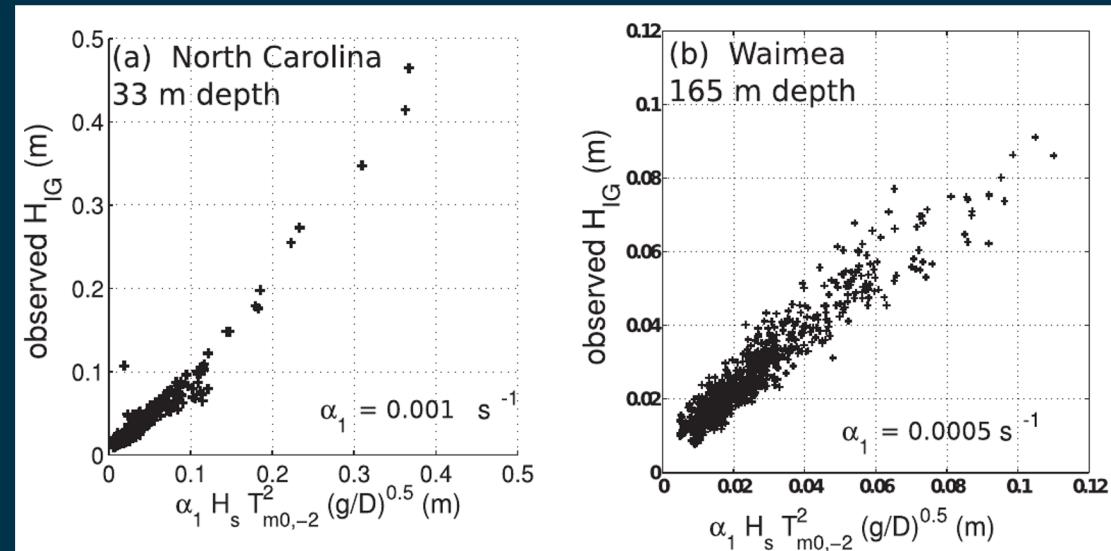
ESL is roughly proportional to offshore **wave height H_0 , squared period $T_0^2 = 2 \pi L/g$,**

and bottom topography plays a big role

Run-up:
(yes, these
are meters,
Taken from
Dodet et al.
JGR 2018)



Infragravity wave heights: scales with 1/sqrt(depth)
Ardhuin et al. 2014)



Wave period is also a key parameter for the wave energy flux
(see L. Rusu & Rusu, Energy 2021, on marine renewable energies)

Sea State CCI: perspectives for phase 2



- Extending coverage in time (critical for identifying climate patterns in interannual variability)
- More dense coverage with more missions (necessary to better sample extremes)
- Beyond the significant wave height:
 - Periods are important for coastal application
 - Mean square slope and wind is important for air-sea fluxes: requires calibrated NRCS from altimeters