Validation of the latest long term satellite observations from the ESA Sea State Climate Change Initiative (CCI) project

Ben Timmermans[1], Dougal Lichtman[2] & Guillaume Dodet[3]

1 National Oceanography Centre, Southampton, UK
2 National Oceanography Centre, Liverpool, UK
3 Laboratoire d'Océanographie Physique et Spatiale, Brest, France
ben.timmermans@gmail.com

Waves SIG 2026
(IC London) 23 June 2026

ESA Sea State CCI

— *Phase 2 completion (end 2026)*

— **Version 5 (AVAILABLE for testing): altimetry missions from ERS-1 (1992) onwards;**

> Re-tracked altimetry from source (WHALES)

> Intercalibrated (Dodet et al., 2020) and "Denoised data" (Quilfen & Chapron, 2019)

> Multivariate sea state parameters (Tm0, Tm1, Tm2, Swell Hs / partition parameters) from Synthetic Aperture Radars (also CFOSat).

> Uncertainty estimates provided (Level-4 gridded, Level-2 along-track)

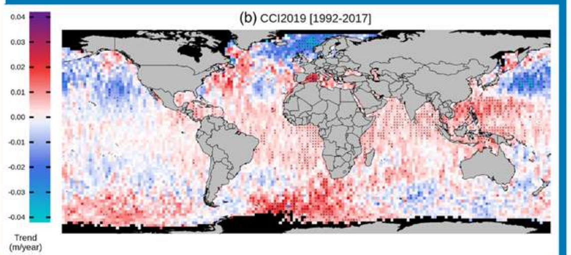
Earth Syst. Sci. Data, 12, 1929–1951, 2020
https://doi.org/10.5194/essd-12-1929-2020

Open Access Earth System Science Data

The Sea State CCI dataset v1: towards a sea state climate data record based on satellite observations

Guillaume Dodet[1], Jean-François Piolle[1], Yves Quilfen[1], Saleh Abdalla[2], Mickaël Accensi[1], Fabrice Ardhuin[1], Ellis Ash[3], Jean-Raymond Bidlot[2], Christine Gommenginger[4], Gwendal Marechal[1], Marcello Passaro[5], Graham Quartly[6], Justin Stopa[7], Ben Timmermans[4], Ian Young[8], Paolo Cipollini[9], and Craig Donlon[10]

Timmermans et al. (2020): Long term wave height trends



CCI Sea State Product User Guide

This document presents the Product User Guide (PUG) for CCI Sea State datasets versio... different datasets produced within the **ESA CCI Sea State** project, built upon state-of-the-... retrieval of sea state parameters, tracing also their evolutions and changes.

Currently, the version up to date is the fourth, (version version 4) that have been made av... this release improves and extends the version 1 and 3 altimeter time series for the period... adds new products from the Synthetic Aperture Radar (SAR) instrument IW/EW image mo...

Search

https://umr-lops.github.io/cci-seastate-pum/v4.0/intro.html

Geophysical Research Letters
RESEARCH LETTER
10.1029/2022GL102348

Time of Emergence for Altimetry-Based Significant Wave Height Changes in the North Atlantic

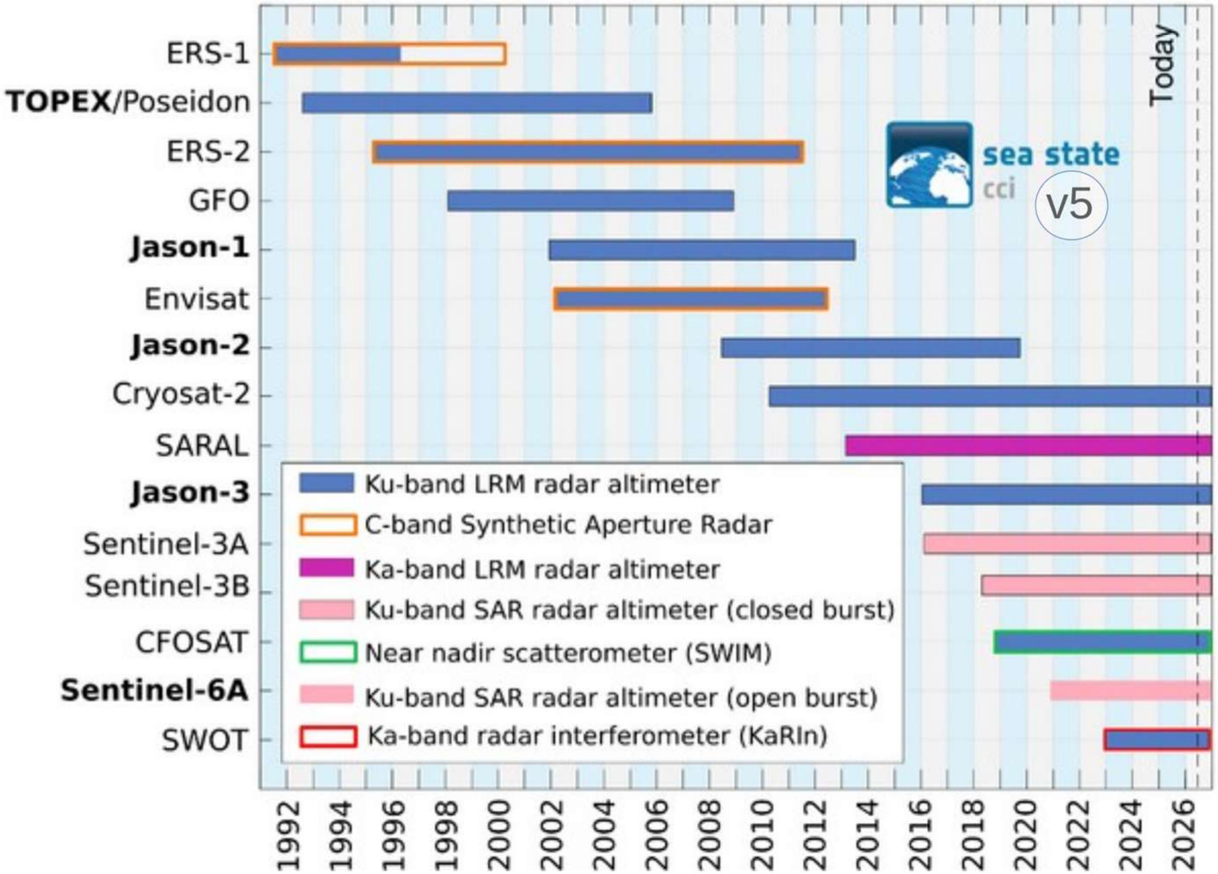
Antoine Hochet[1], Guillaume Dodet[1], Florian Sévellec[1], Marie-Noëlle Bouin[1,2], Anindita Patra[1], and Fabrice Ardhuin[1]

[1]Laboratoire d'Océanographie Physique et Spatiale, University Brest CNRS IRD Ifremer, Brest, France, [2]CNRM, Université

Key Points:
- Altimeter based significant wave height trends in the North Atlantic (NA) are largely dominated by internal variability

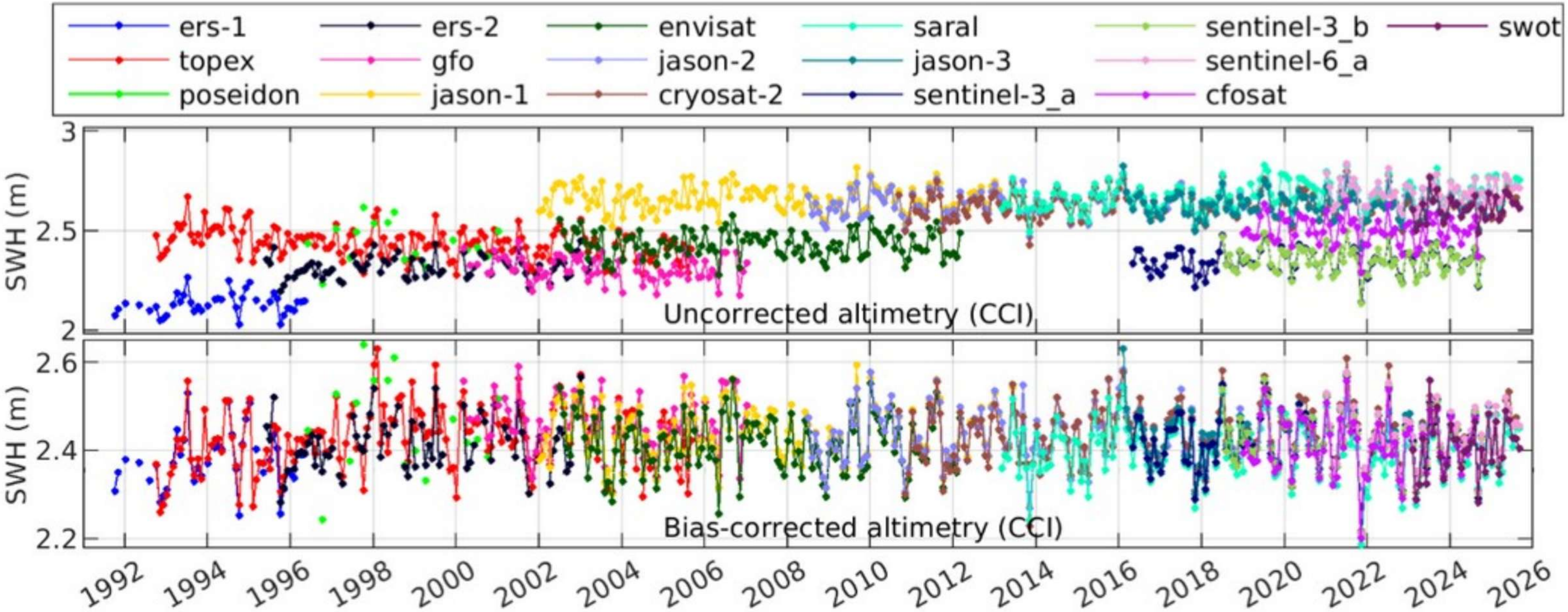
Hochet et al. (2023): Time of emergence of long term trends in North Atlantic

Radar altimetry missions in Sea State CCI dataset version 5



Dodet, G., Timmermans, B.W., Piolle, J.F., Passaro, M., Ardhuin, F., 2026. Refined altimeter calibration reveals stronger trends in wave climate. Presented at the OSTST2026, Wiesbaden

Long-term consistency in altimeter data



Dodet, G., Timmermans, B.W., Piolle, J.F., Passaro, M., Ardhuin, F., 2026. Refined altimeter calibration reveals stronger trends in wave climate. Presented at the OSTST2026, Wiesbaden

Sources of validation data

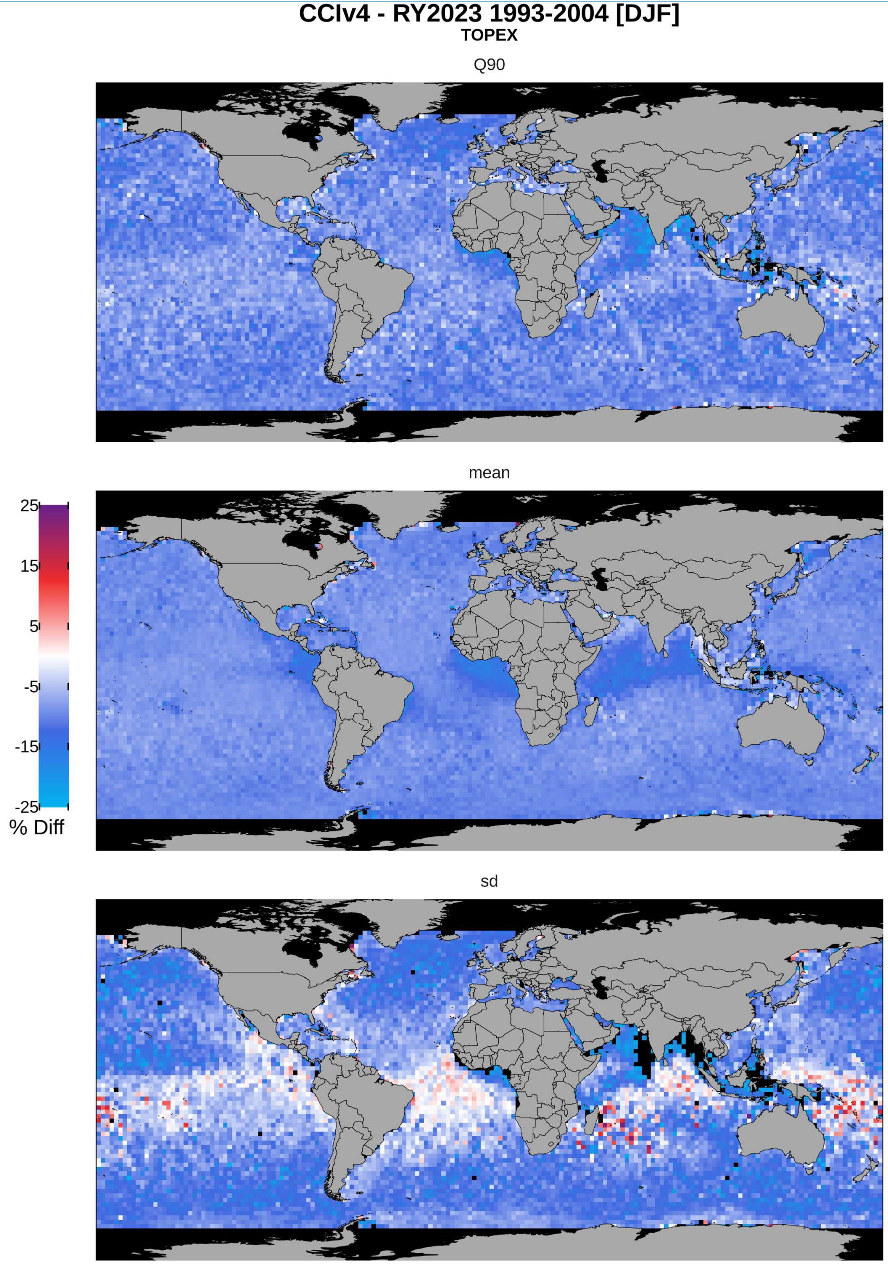
— Ribal & Young (2019) intercalibrated altimetry dataset

— In situ measurements from moored buoys ...

> How reliable is this?
> What can we do to gain a better understanding?

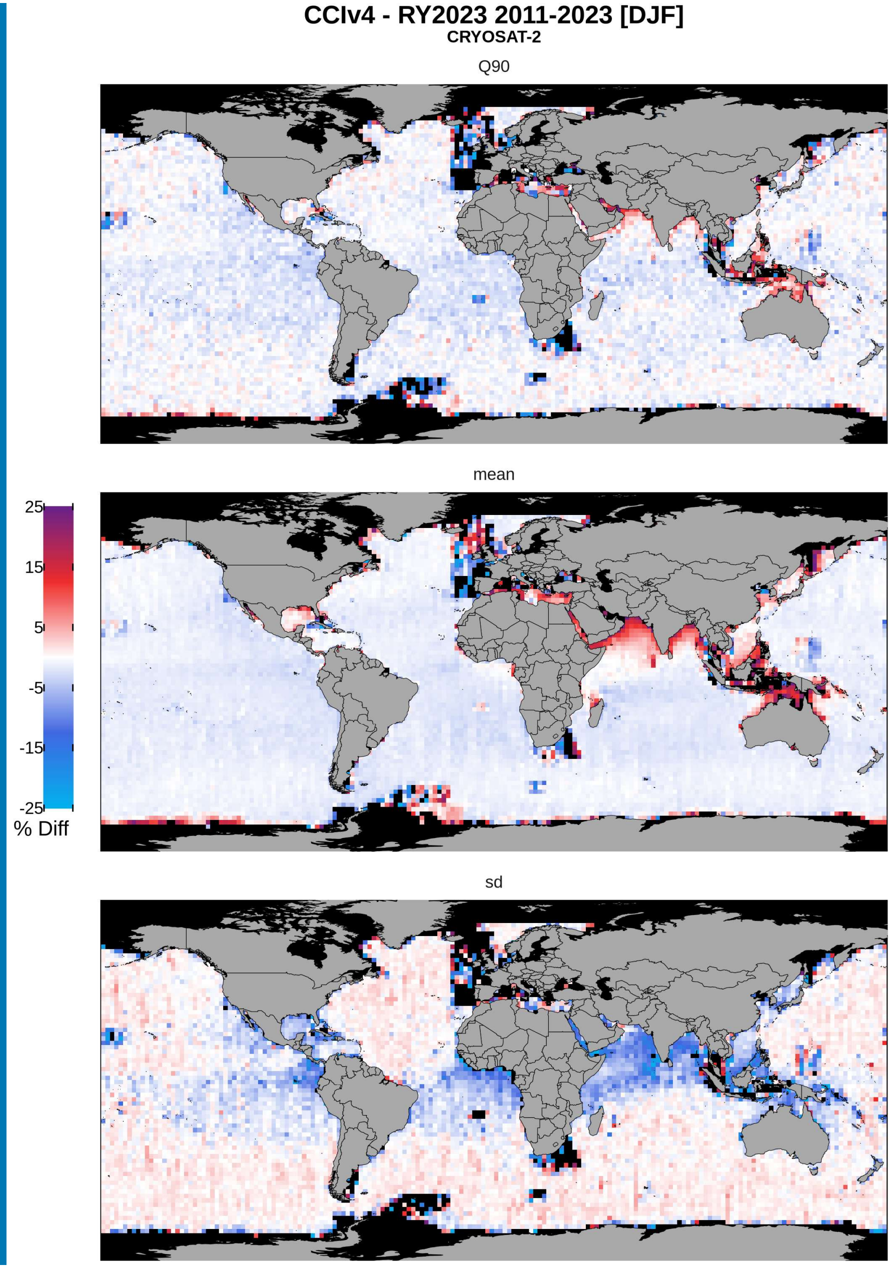
— Drifting "Sofar" Spotter data

> Does this data compare with altimeters?



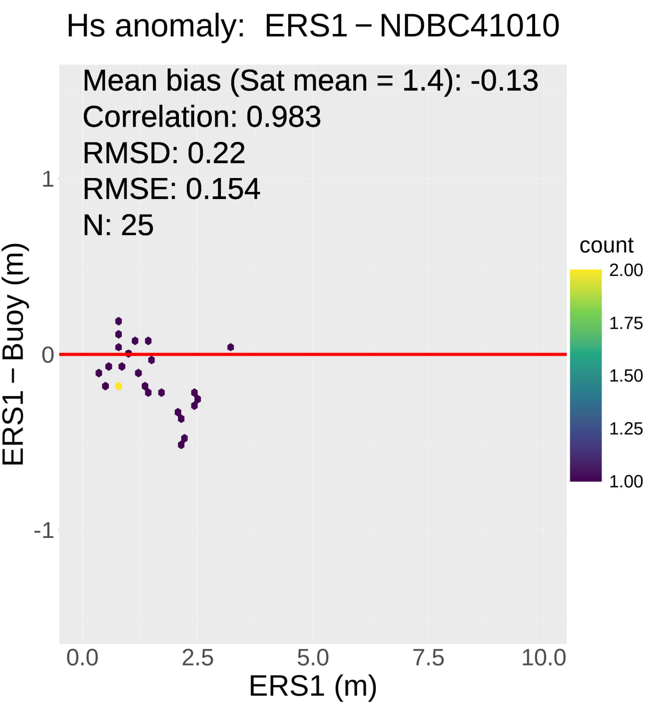
CCI L4v4 compared with Ribal & Young ...

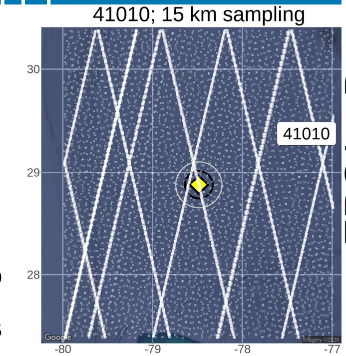
— Hs mean

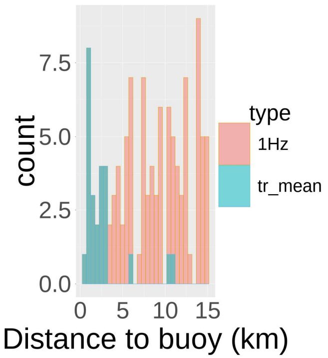


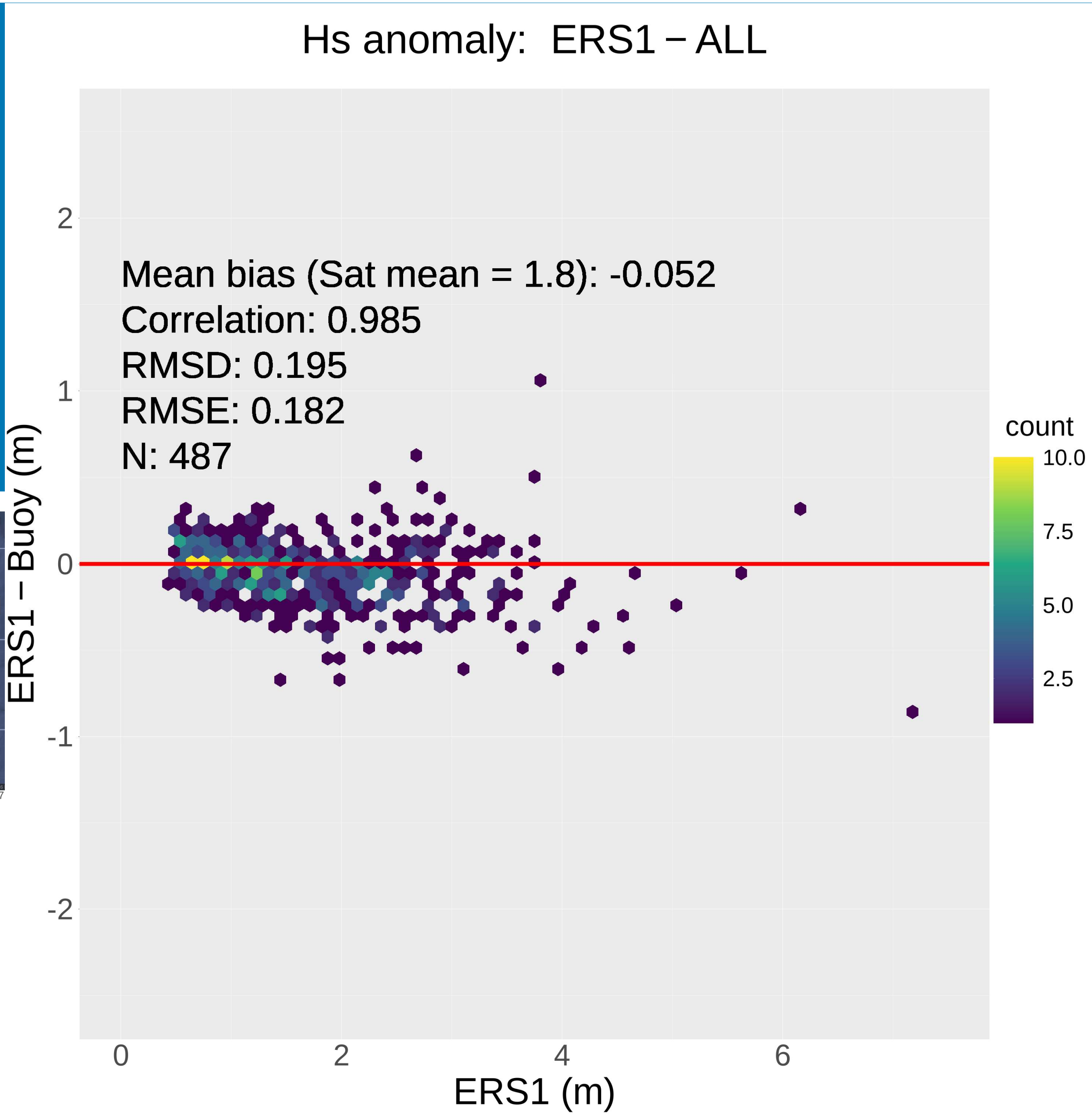
ERS-1 V5 data

- **Active NDBC buoys (25) > 50 km offshore**
  32302 41001 41006 41008 41009 41010 41017
  42001 42002 42003 42019 42020 44004 44008
  44009 44011 44014 46001 46002 46005 51001
  51002 51003 51004 51026
- Collocation at 15 km radius (30 minutes)
- Complete years: 1992 to 1995 (incl.)









Stability of in situ record

— Gemmrich et al. 2011 identified “step changes” in all the NDBC buoys they considered, when looking at the historic record

— Detailed meta data available

— Widely cited, but followed up…?

GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L22601, doi:10.1029/2011GL049518, 2011

Observational changes and trends in northeast Pacific wave records

Johannes Gemmrich,[1] Bridget Thomas,[2] and Richard Bouchard[3]

Received 1 September 2011; revised 14 October 2011; accepted 18 October 2011; published 18 November 2011.

Table 1. Buoy history of payloads and hull types, and step changes Γ that occurred at the start of the new configuration[a]

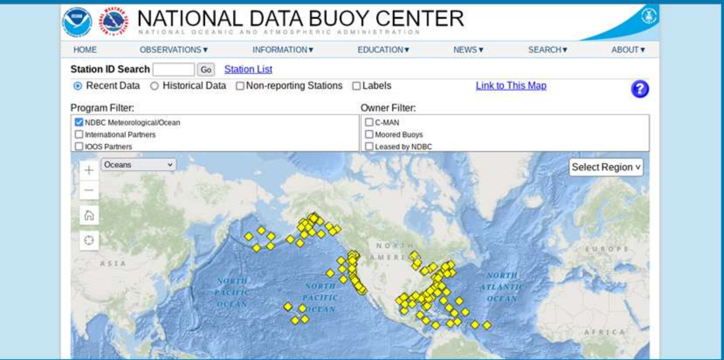
Service Date	Hull	Payload	Processor	Γ [m]
		46001 (H_{av} = 2.73m)		
12/74–04/76	12D	EEP	EEP	
07/76–09/79	10D	PEB	WSA	−0.24
10/79–07/80	10D	UDACS(A)	WDA	0.22
08/80–06/82	10D	GSBP	WDA	0
07/82–03/90	6N	GSBP	WDA	0.19
07/90–05/06	6N	DACT	WA	0
06/06–current	6N	ARES4.4	WPM	−0.08
		C46184 (H_{av} = 2.78m)		
09/87–04/00	6N	Zeno	Zeno	
04/00–current	6N	WM	WM	
06/95–06/98	6N	Zeno	Zeno	0.16
05/99–04/00	6N01	Zeno861	Zeno861	−0.20
05/02–08/02	6N03	WM064	WM064	−0.29
09/02–05/03	6N03	WM064	WM064	−0.27
05/03–12/09	6N	WM	WM	0.41
		46004/C46004 (H_{av} = 2.87m)		
10/76–10/77	10D	PEB	WSA	
09/78–05/80	12D	PEB UDACS	WSA	0
02/81–06/83	12D	UDACS(A)	WDA	0.32
06/83–06/88	6N	GSBP	WDA	0.12
06/88–05/99	6N	Zeno	Zeno	0
05/99–02/00	6N05	WM036	WM036	−0.20
05/01–04/02	6N03	WM064	WM064	−0.66
05/02–12/10	6N	WM	WM	0.59
		46036/C46036 (H_{av} = 2.87m)		
08/86–09/87	6N	GSBP	WDA	
09/87–07/98	6N	Zeno	Zeno	
07/98–current	6N	WM	WM	
07/89–06/94	6N	Zeno	Zeno	0.17
09/94–07/96	6N02	Zeno862	Zeno862	−0.28
04/00–05/01	6N03	WM064	WM064	−0.09
05/06–11/07	6N02	WM092	WM092	0.13
11/07–05/09	6N03	WM039	WM039	−0.20
05/09–05/10	6N01	WM156	WM156	0.22
		46005 (H_{av} = 2.77m)		
10/76–08/78	10D	PEB	WSA	
08/78–06/80	12D	PEB	WSA	0
06/80–11/81	6N	MXVII(MOD)	WDA	0.27
11/81–10/85	12D	UDACS(A)	WDA	0
02/86–08/90	6N	GSBP	WDA	0.21
01/91–09/04	6N	DACT	WA	0
09/04–06/10	6N	ARES	WPM	−0.14
06/10–current	3D	AMPS	WPM	0

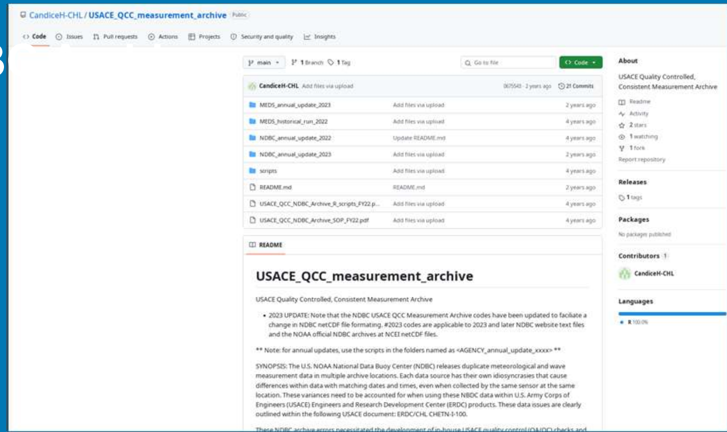
In situ data sources...

NOAA National Data Buoy Centre Quality Controlled

CMEMS In Situ TAC

USACE





— Convenient
— No meta data!
— Quality control?

— Comprehensive source
— *PARTIAL* NDBC meta data...

— Comprehensive historic meta data.
— Open standard
— Missing data in recent release!

https://www.ndbc.noaa.gov/

Atlantic NDBC buoys covering 1991 to 1996 (and onwards)

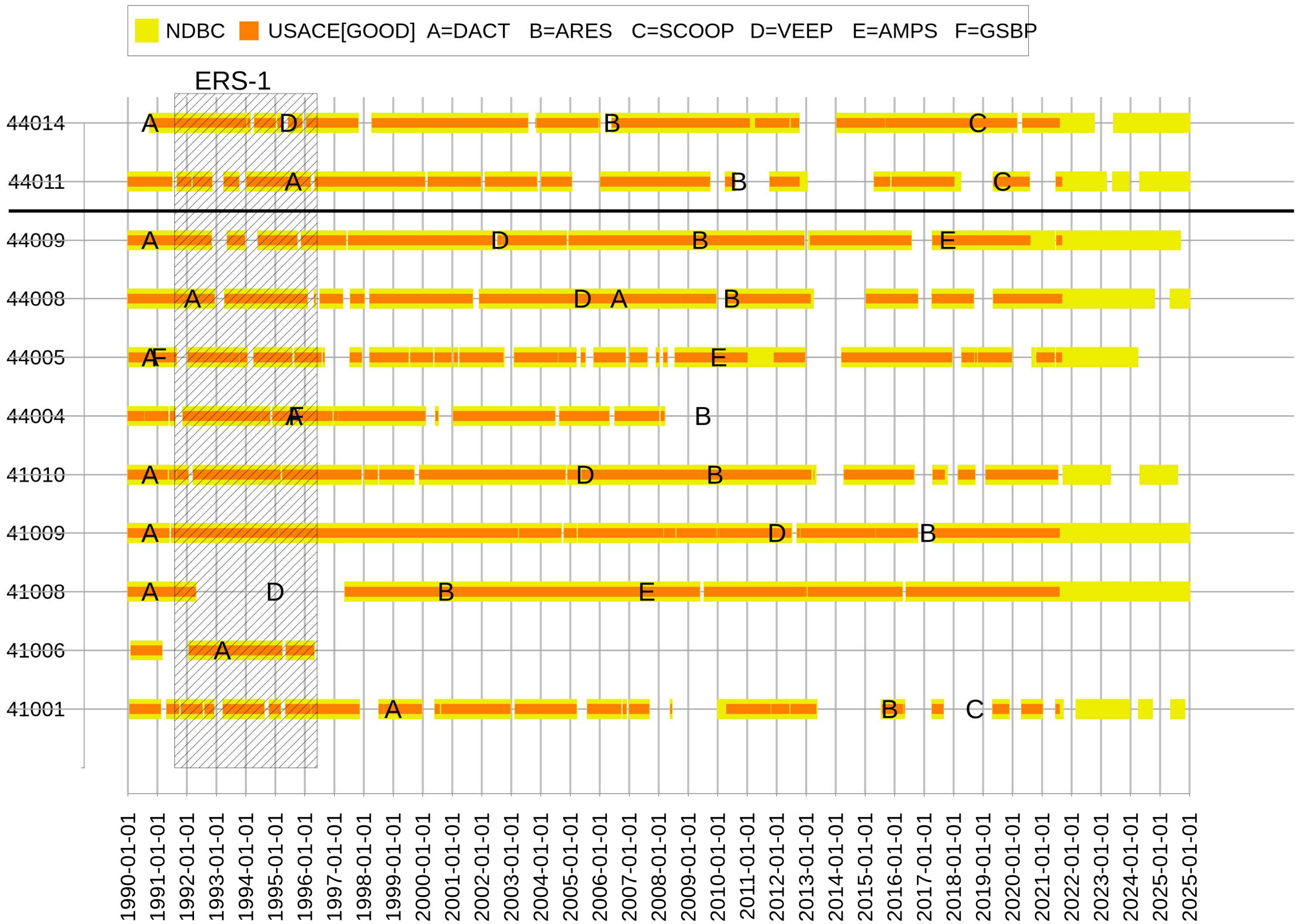
— Operational coverage with Hs measurements

— [YELLOW] Data from NDBC

— [ORANGE] "Good" flagged data from USACE

— Payloads noted by **LETTERS** see legend]

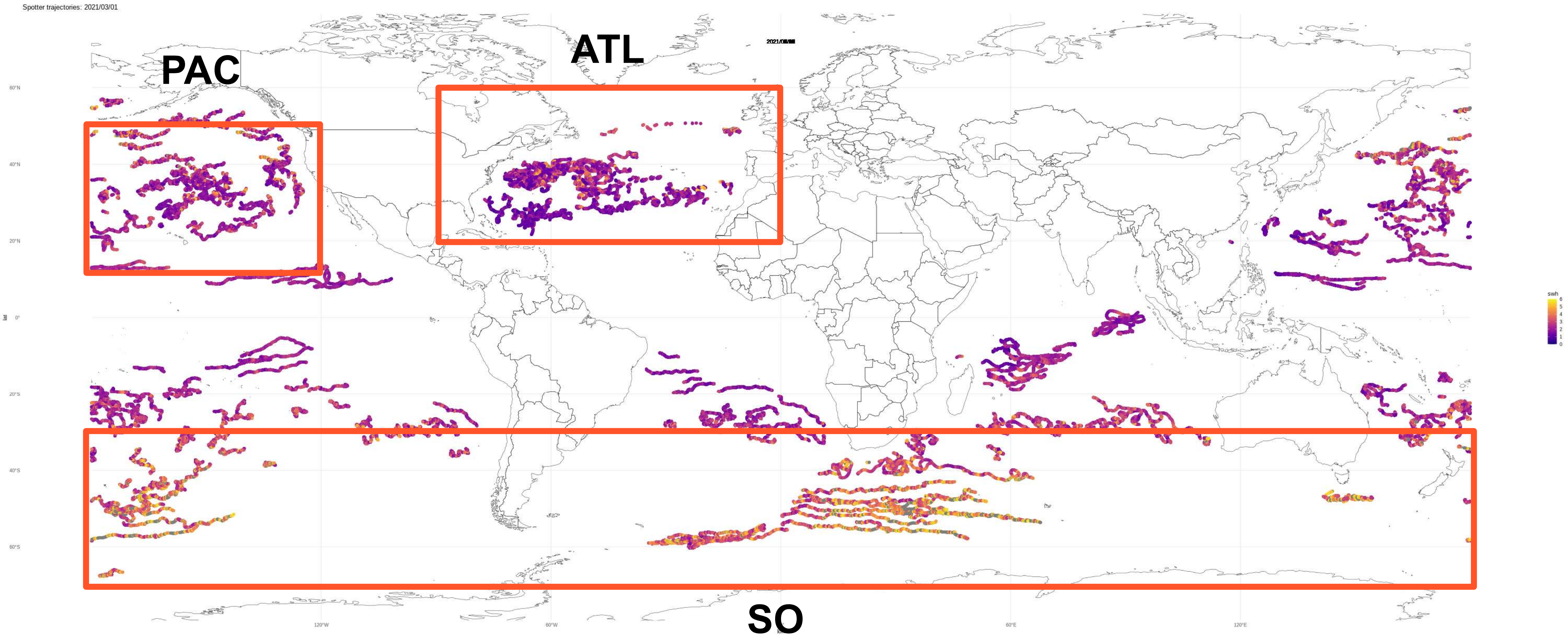
— ERS-1 operation shown by hatching



Validation against Sofar “Spotter” drifting buoys

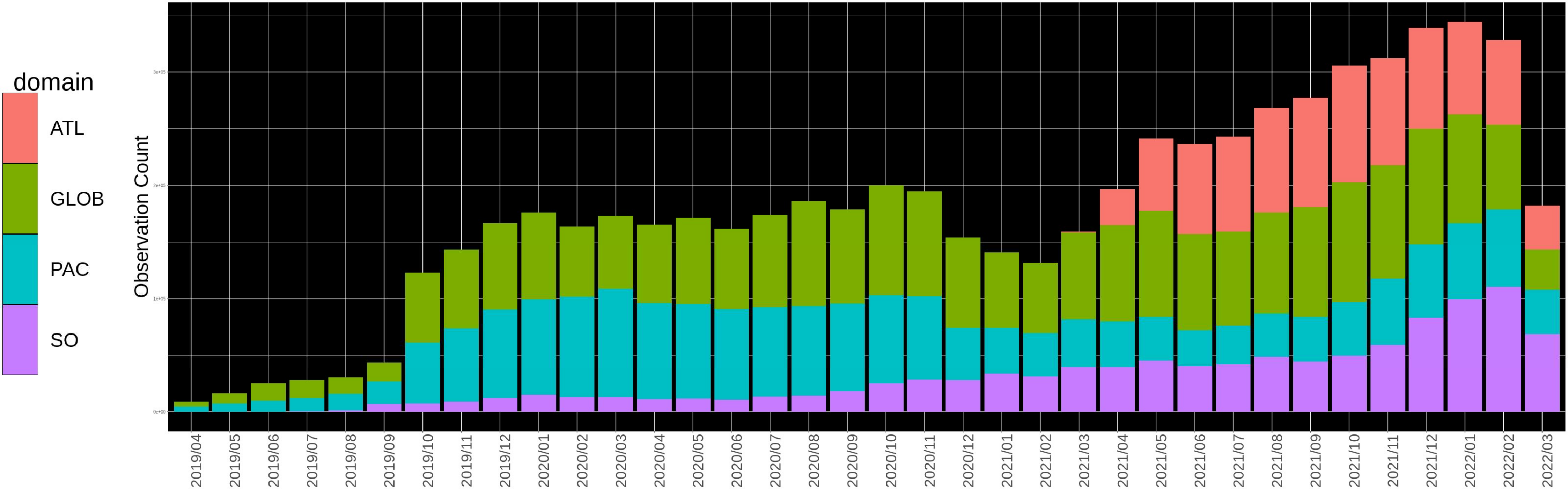
Spotter global coverage

— Spotter distribution and trajectories starting 2021/04/01
— Initial analysis covering Atlantic [ATL]...

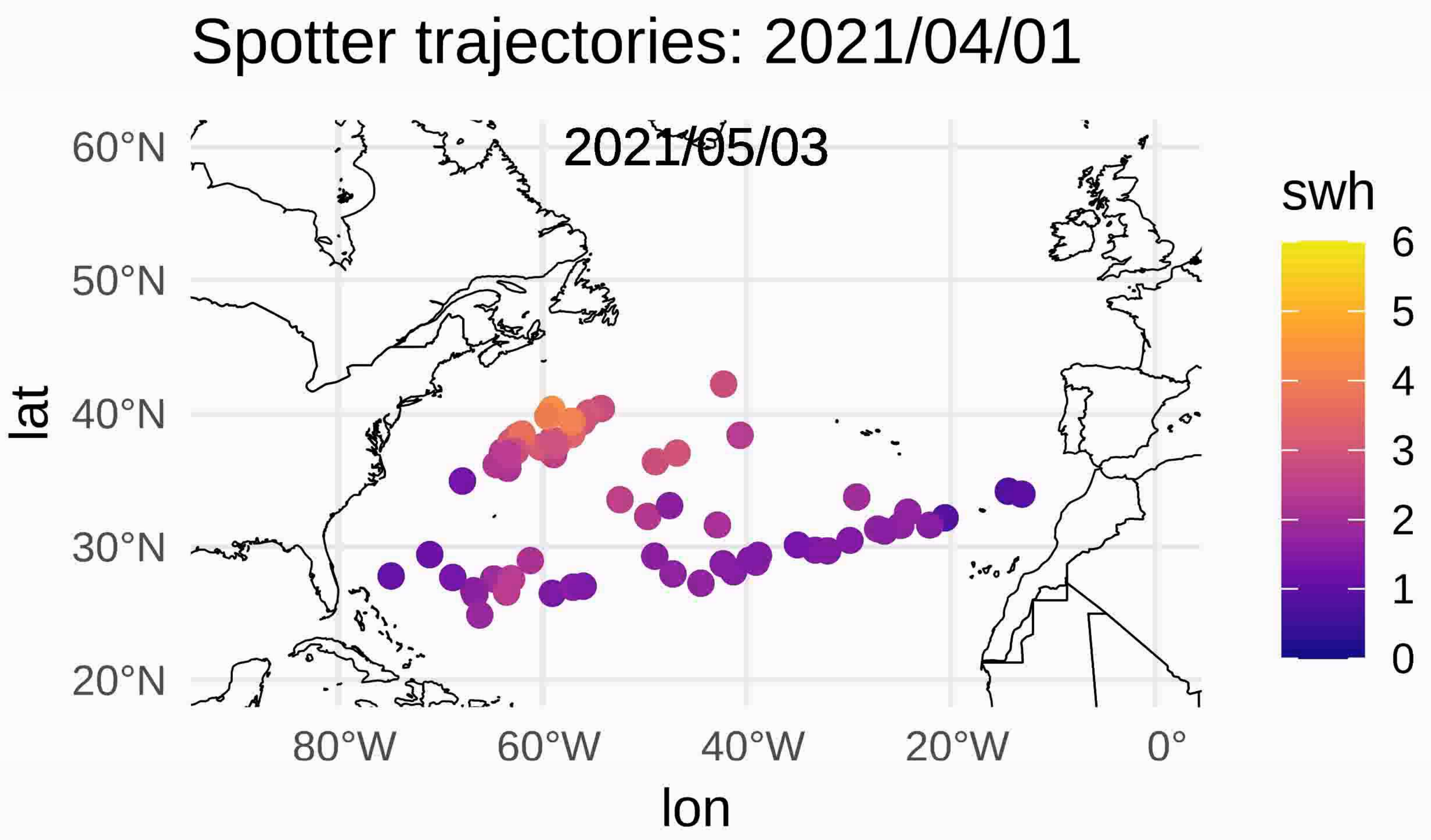


Spotter temporal coverage

— Spotter distribution and trajectories starting 2021/04/01
— Initial analysis covering Atlantic ...

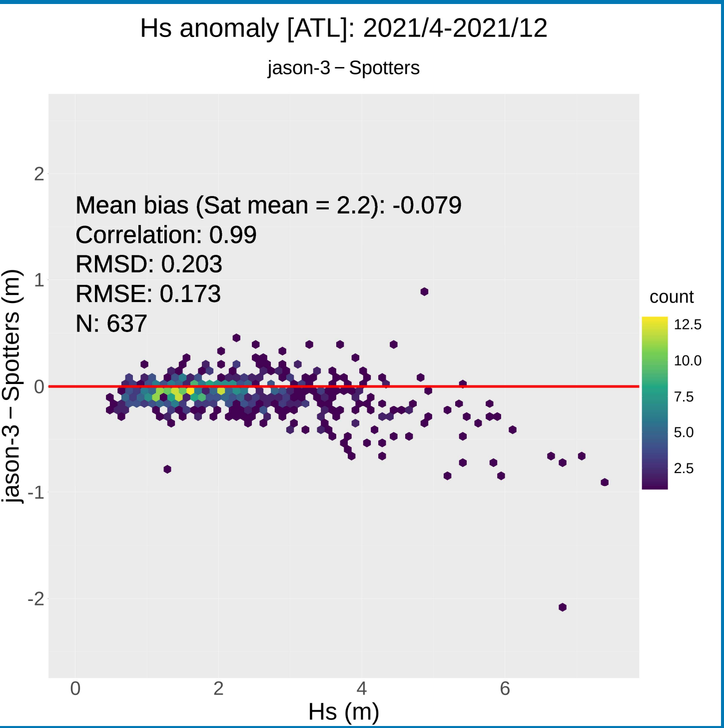


Topex

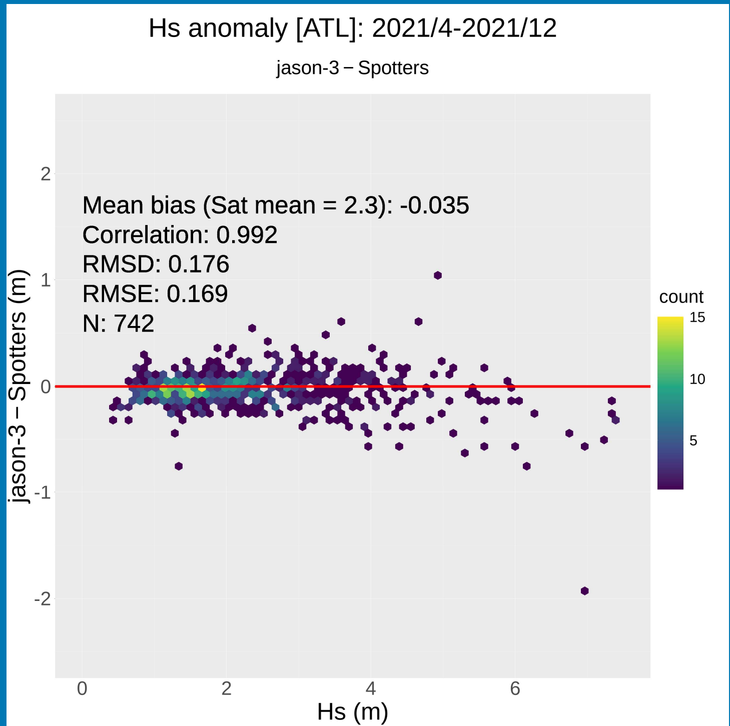

Spotter trajectories: 2021/04/01
2021/05/03
swh
6
5
4
3
2
1
0
60°N
50°N
40°N
30°N
20°N
lat
80°W
60°W
40°W
20°W
0°
lon

Spotter Collocations

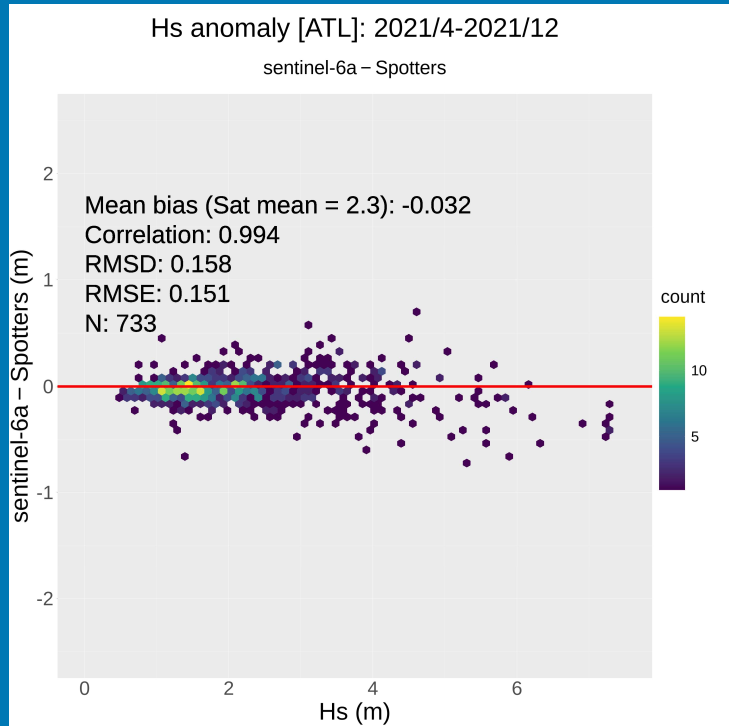
— CCI V4 vs V5
— Jason-3, Sentinel-6A



Jason-3 V4 (*swh_denoised*)



Jason-3 V5 (*swh_denoised*)



Sentinel-6A (*swh_denoised*)

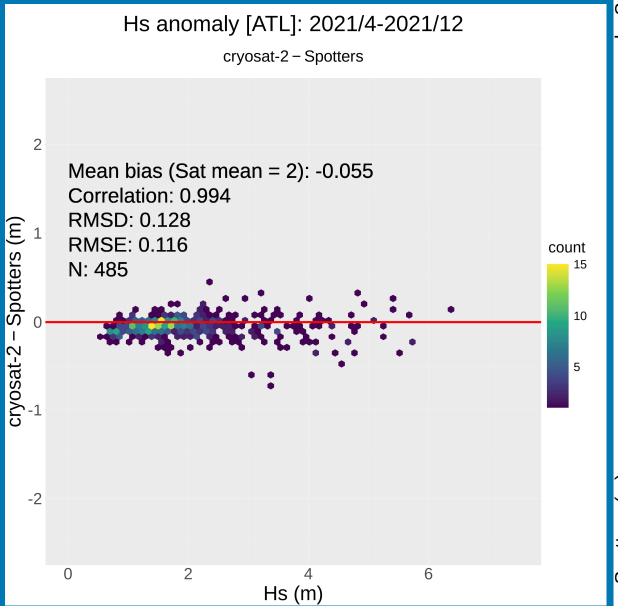
Spotter Collocations

— **CCI V4**

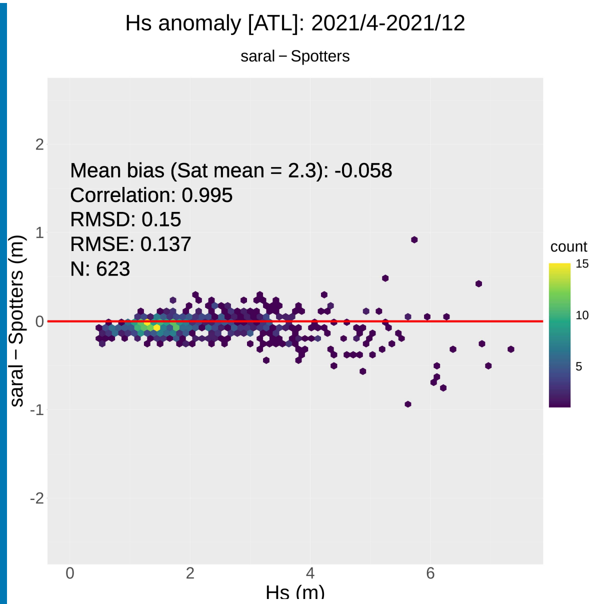
— **2021/04 to 2021/12 (incl.)**

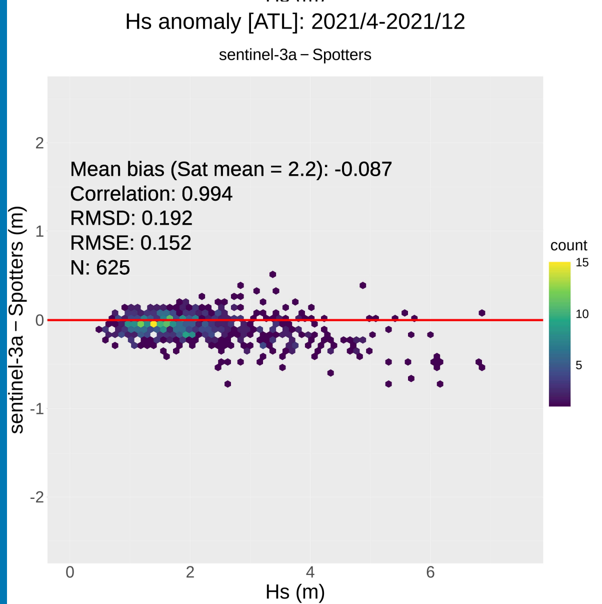
— **~25 km max radius**

— **~15 minutes max difference**

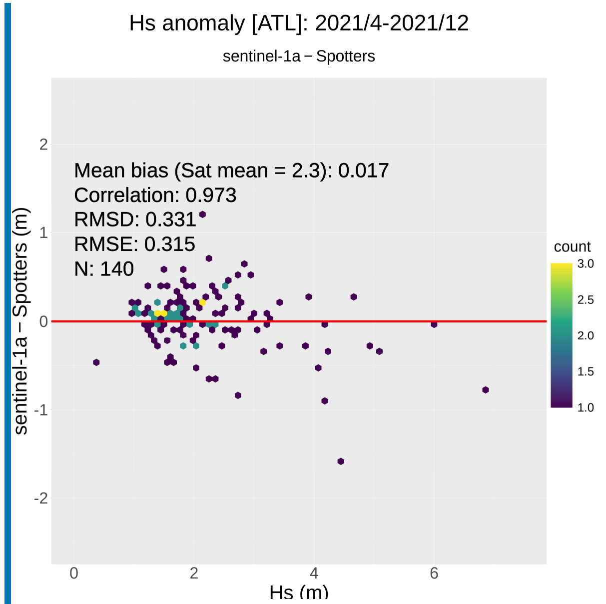


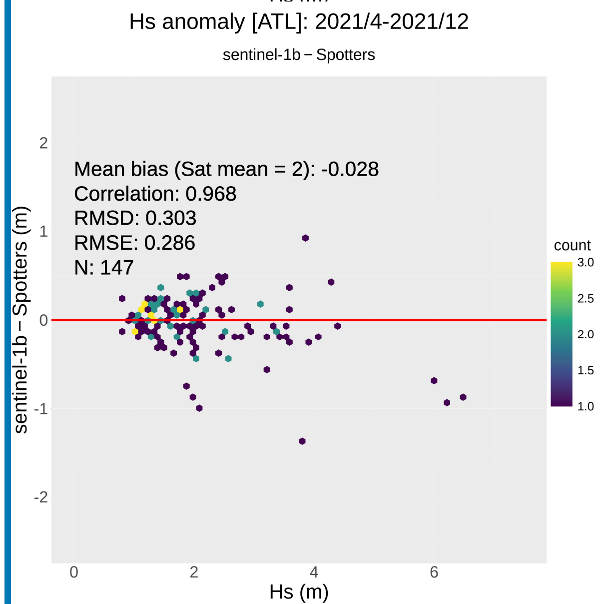
Cryosat-2





SARAL (top) & Sentinel-3A (bottom)





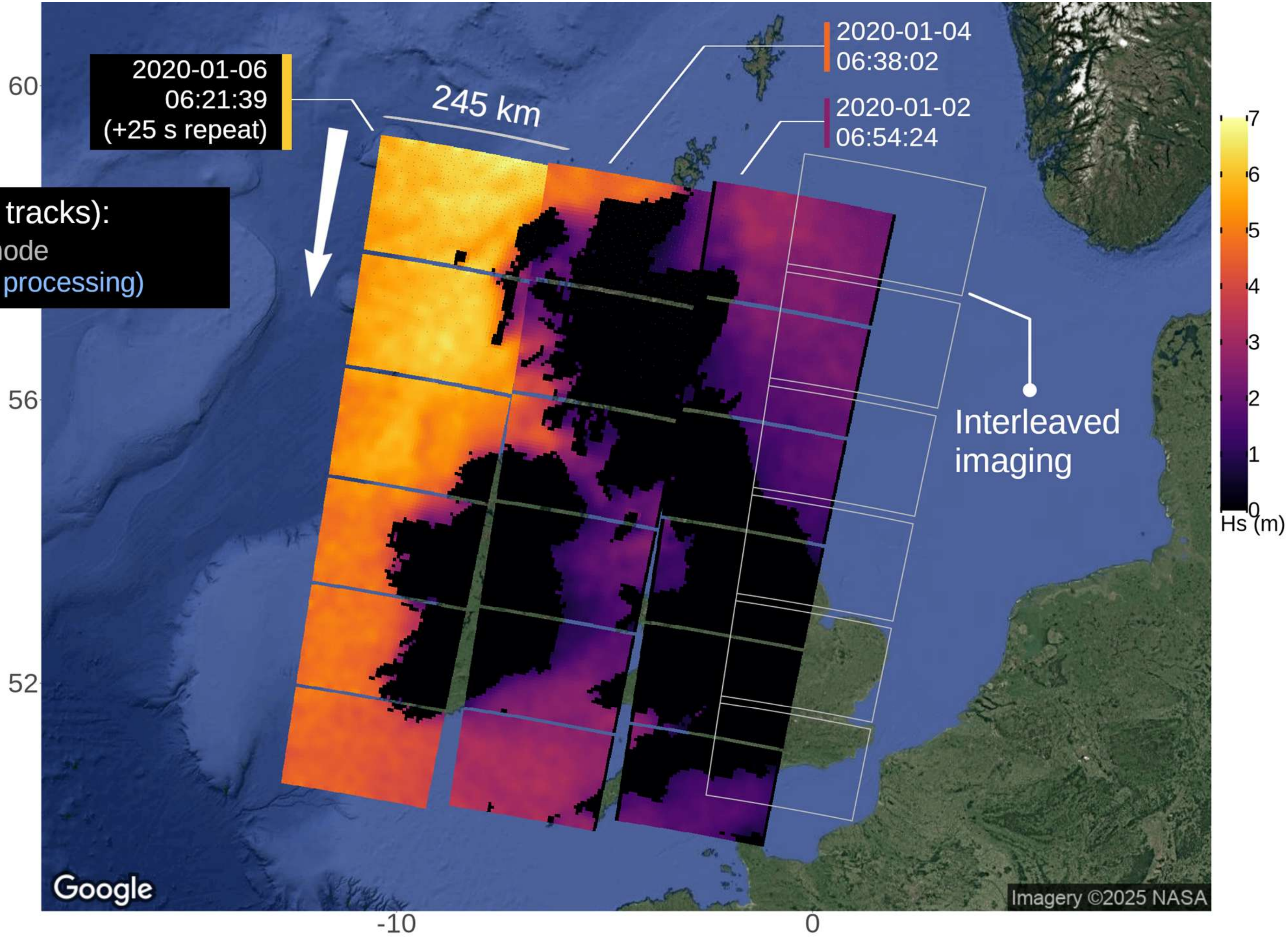
Sentinel-1A (top), 1B (bottom)

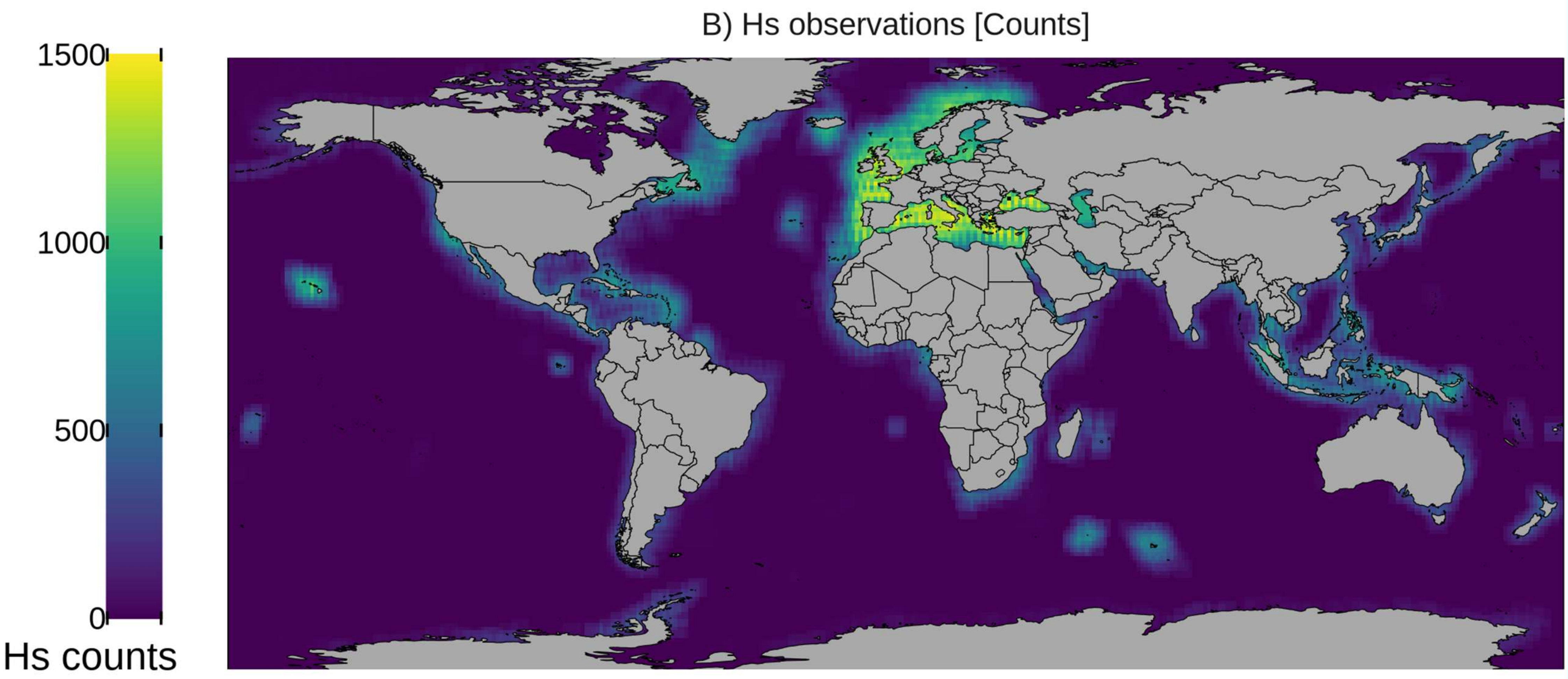
Sentinel-1(A) IW mode

Sentinel-1A (Descending tracks):
Interferometric Wide-swath mode
Hs field snapshots (CCI DLR processing)

— Sentinel-1A from 2014
— Sentinel-1B from 2016 to 2021
— Imagettes processed to provide multi-parameter sea state

— Ascending tracks not shown ;
— S-1B not shown ;
— 25 s repeat imagettes

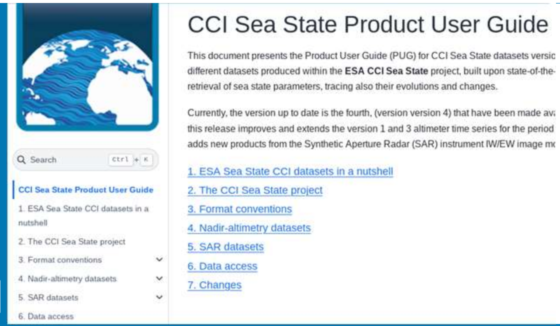



B) Hs observations [Counts]
1500
1000
500
0
Hs counts

S1-A IW mode: Available parameters

```
netcdf S1A_IW_GRDH_1SDH_20200101T035722_20200101T0
dimensions:
        time = 1 ;
        row = 38 ;
        col = 49 ;
variables:
        double swh ;
        double swh_uncertainty ;
        ubyte swh_quality ;
        short swh_rejection_flags ;
        double Tm0 ;
        double Tm0_uncertainty ;
        double Tm1 ;
        double Tm1_uncertainty ;
        double Tm2 ;
        double Tm2_uncertainty ;
        double swell_swh_primary ;
        double swell_swh_primary_uncertainty ;
        double swell_swh_secondary ;
        double swell_swh_secondary_uncertainty ;
        double windwave_swh ;
        double windwave_swh_uncertainty ;
        double windwave_period ;
        double windwave_period_uncertainty ;
```

Conclusions



Sea State CCI Version 5 data is available for testing …!

> Newly re-tracked long term altimetry record from 1991/1

> Sea state parameters beyond SWH from SARs, with uncertainties

> Sentinel-1 “IW” mode coastal data available for the first time

> Most rigorous formal & quality controlled global dataset of sea state observations!

— Findings and issues:

> Calibration differences between other datasets (e.g. Ribal & Young, 2019) prompt questions

> *In situ* measurements show minor discrepancies in some case; motivates closer look at *in situ*

> Good agreement with Sofar “Spotter” drifters for recent missions

Presentations from the Sea State CCI User Consultation and Science Meeting (October 2025) are online...

References

— Passaro, M. *et al.* Global coastal attenuation of wind-waves observed with radar altimetry, *NATURE COMMUNICATIONS (2021) 12:3812 https://doi.org/10.1038/s41467-021-23982-4*

— Timmermans, B; Gommenginger, C. G.; Donlon, C.; Uncertainty in Sea State Observations from Satellite Altimeters and Buoys during the Jason-3/Sentinel-6 MF Tandem Experiment *Remote Sensing, 2024, 16, 2395 https://doi.org/10.3390/rs16132395*

— Pleskachevsky, A.; Tings, B.; Wiehle, S.; Imber, J.; Jacobsen, S.; Multiparametric sea state fields from synthetic aperture radar for maritime situational awareness, *Remote Sensing of Environment 280 (2022) https://doi.org/10.1016/j.rse.2022.113200*

— Accensi, M. *et al.* Resourcecode framework: A high-resolution wave parameter dataset for the European shelf and analysis toolbox *Proceedings of the European Wave and Tidal Energy Conference: 14th EWTEC 5-9th September 2021 Plymouth, UK. EWTEC, pp. 2182-1-2182-9*