Nearshore sea state variability from diverse long-term satellite observations produced by the ESA Sea State CCI consortium

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ESA CCI & S6-JTEX

Waves SIG 25
(NOC Liverpool) 30 June 2025

Outline

NEW DATA AVAILABLE from Sea State CCI!

— Updates to existing missions (current missions to 2023/2024)
— “Re-tracked” data for earlier missions (ERS-1/2, Topex)
— FIRST processing of Sentinel-1 SAR “Wide Swath” (IW) coastal data

Altimetry and swath data for coastal wave analysis

— How can we use altimetry data close to the coast?
> Issues with temporal sampling and sea state gradients.
— Use of swath data (the future...?)

Sea State CCI User Consultation and Science meeting

— Wide range of speakers and attendees: ECMWF; MeteoFrance; “COWCLIP”; industry (EDF, ...), ESA and the Sea State CCI Team...
> Abstract submission **closing TODAY**!
> Registration **remains OPEN**!

National Oceanography Centre

ESA Sea State CCI

— https://climate.esa.int/en/projects/sea-state/

— *Phase 1 complete (early 2022); Phase 2 underway*

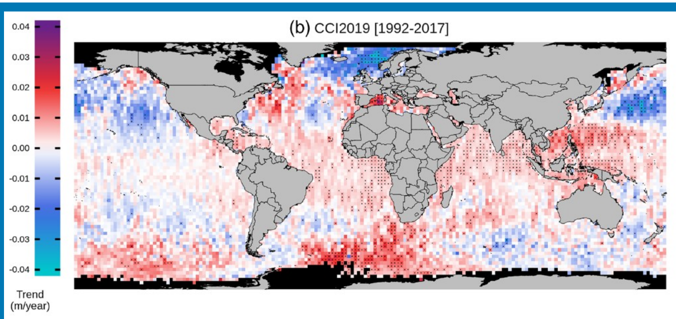
— Version 4 (AVAILABLE for testing): altimetry missions from ERS-1 (1992) onwards;

> Re-tracked (WHALES), up to 2023/24

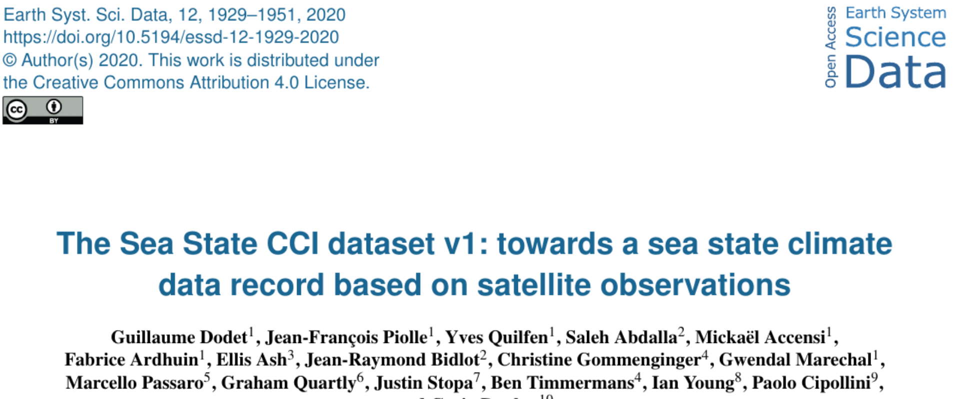
> Intercalibrated (Dodet et al., 2020)

> “Denoised data” generated via the approach of Quilfen & Chapron (2019)

> (New) uncertainty estimates provided



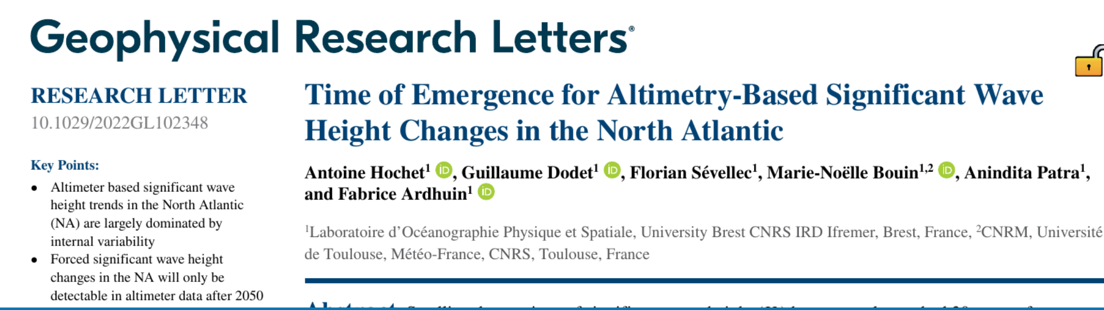
Timmermans et al. (2020):
Long term wave height trends


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],


Geophysical Research Letters

RESEARCH LETTER
10.1029/2022GL102348

Key Points:

- Altimeter based significant wave height trends in the North Atlantic (NA) are largely dominated by internal variability
- Forced significant wave height changes in the NA will only be detectable in altimeter data after 2050

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 de Toulouse, Météo-France, CNRS, Toulouse, France

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

Altimetry and swath data for coastal wave analysis

Coastal applications

— **Many reasons to learn about nearshore wave climate!**

— **However, complicated by coastal morphology...**

— **Satellite data can be useful but also complicated by:**

> **> low sampling frequency**

> **> spatial heterogeneity**

— **"Naive" spatial aggregation is inappropriate...**

Timmermans et al. (2020): Reliability of Extreme Significant Wave Height Estimation from Satellite Altimetry and In Situ Measurements in the Coastal Zone

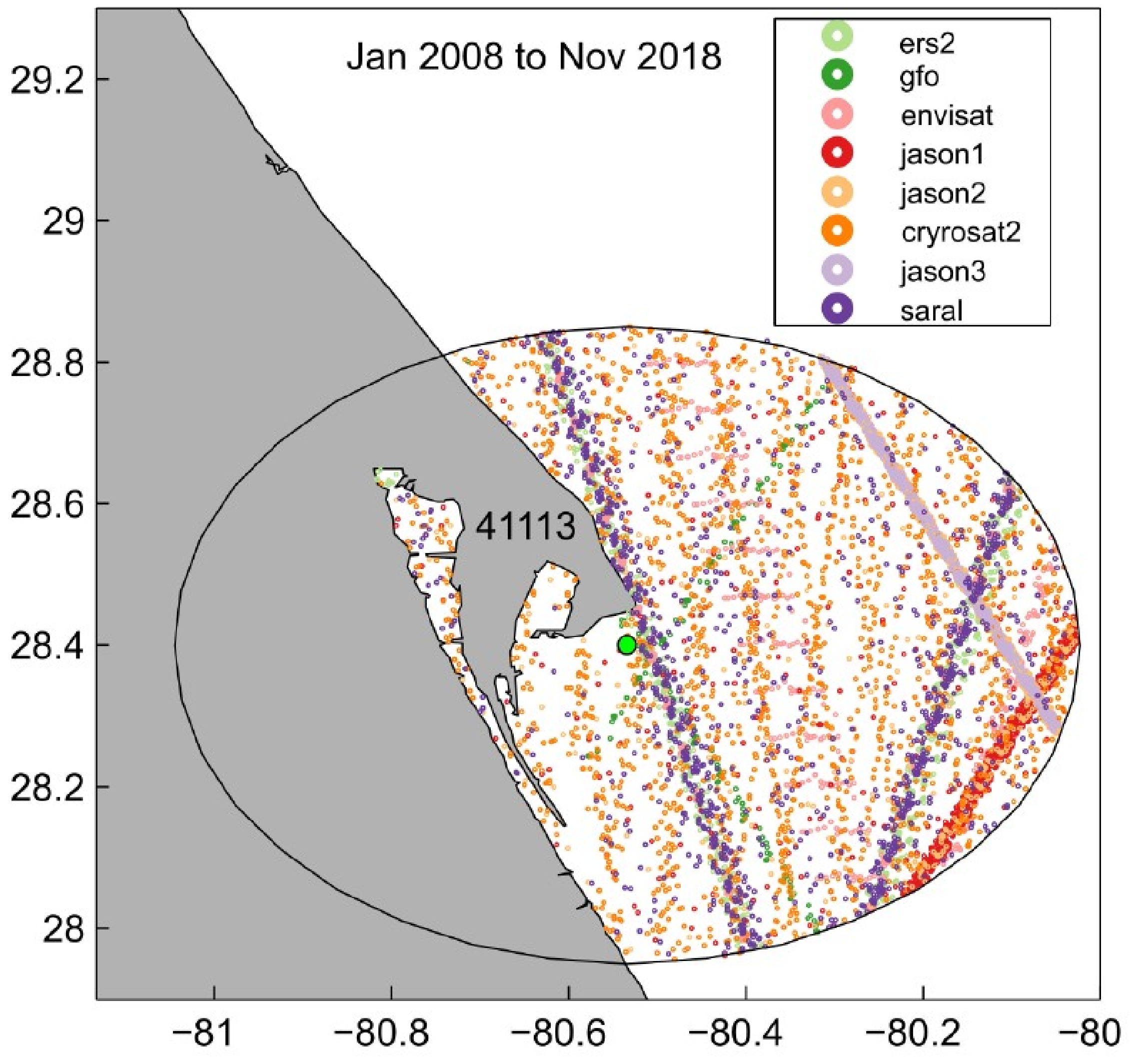
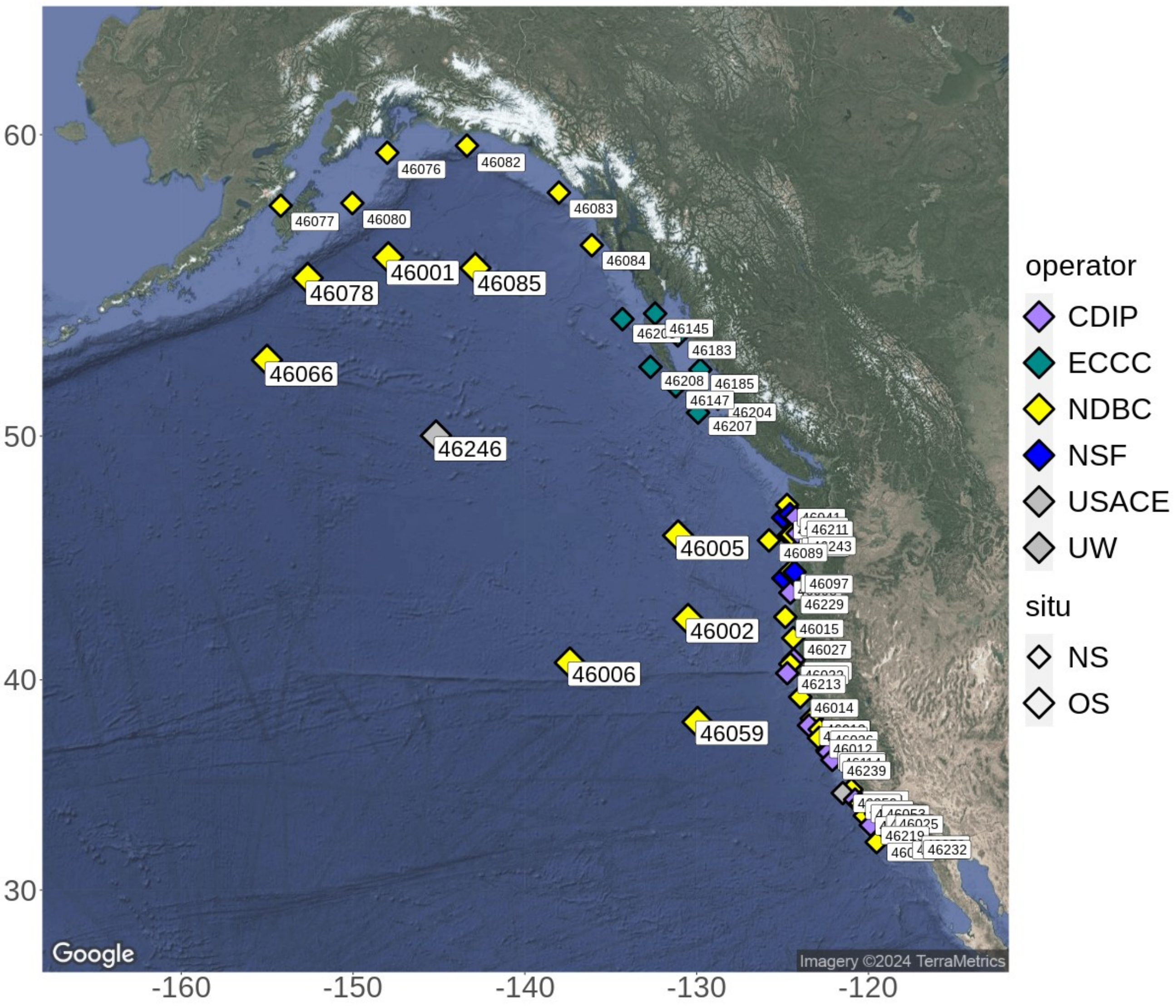


Figure 4. Spatial distribution of satellite tracks contributing to Hs measurements within a 50 km radius of buoy 41113 (region #3).

In situ

— Comparison of coverage and platform variability for Northeast Pacific *in situ* data

— Note many more buoys located nearshore than offshore in deep water



Buoy-Sat along-track gradients

— Buoy 46027, Oregon coast

— Buoy provides ~hourly measurements of Hs (~20 minutes time integration)

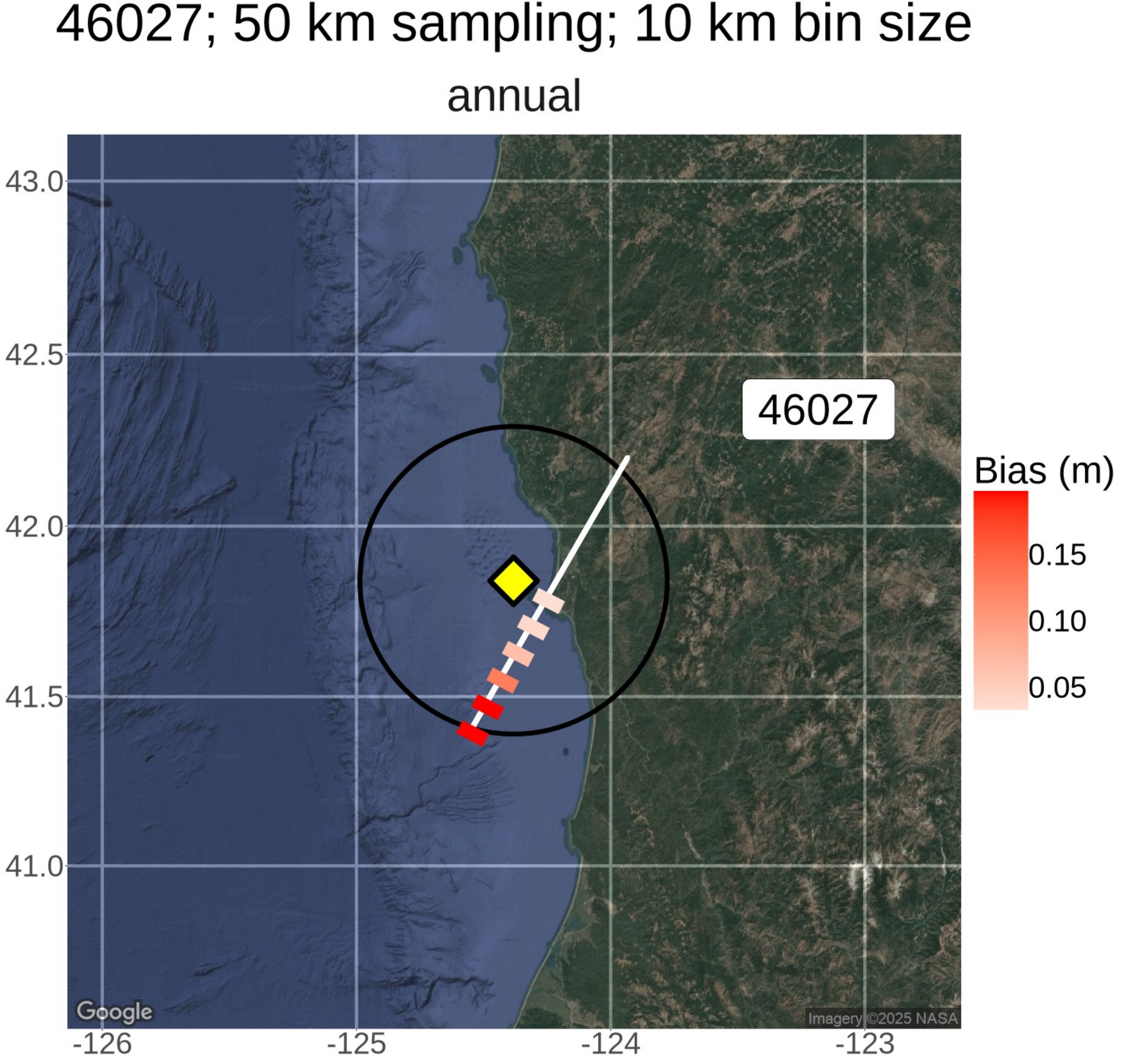
— Jason 3 (CCI v3) 2017-2020 (~10 day repeat)

— Paired time series (< 30 minutes)

— Hs mean bias, from time series

— 1 Hz along-track data, 10 km bin size

— Compute along-track gradient

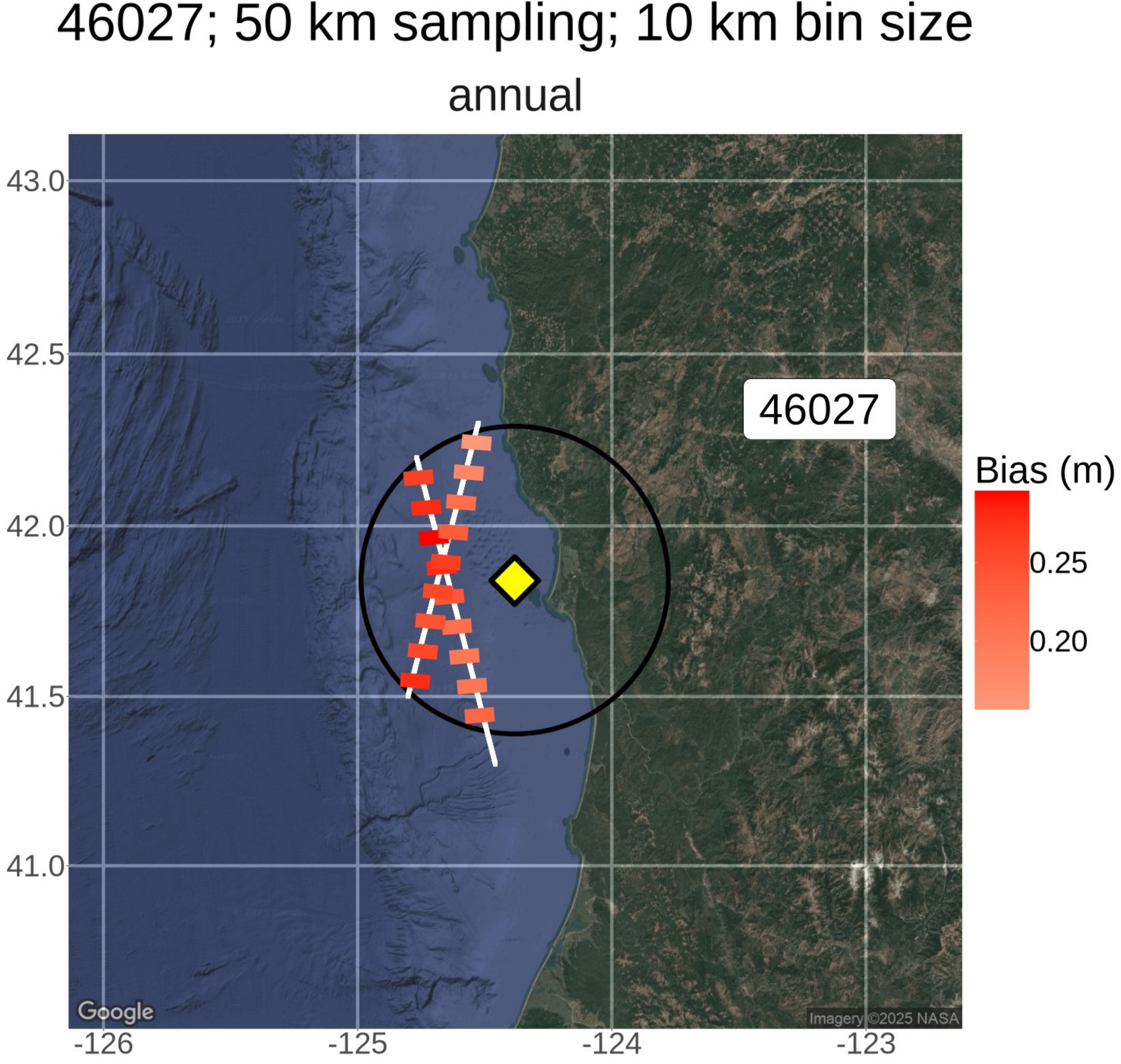


Buoy-Sat along-track gradients

— Sentinel-3B (CCI v4) 2018-2023

— Hs mean bias

— 1 Hz data, 10 km bin size



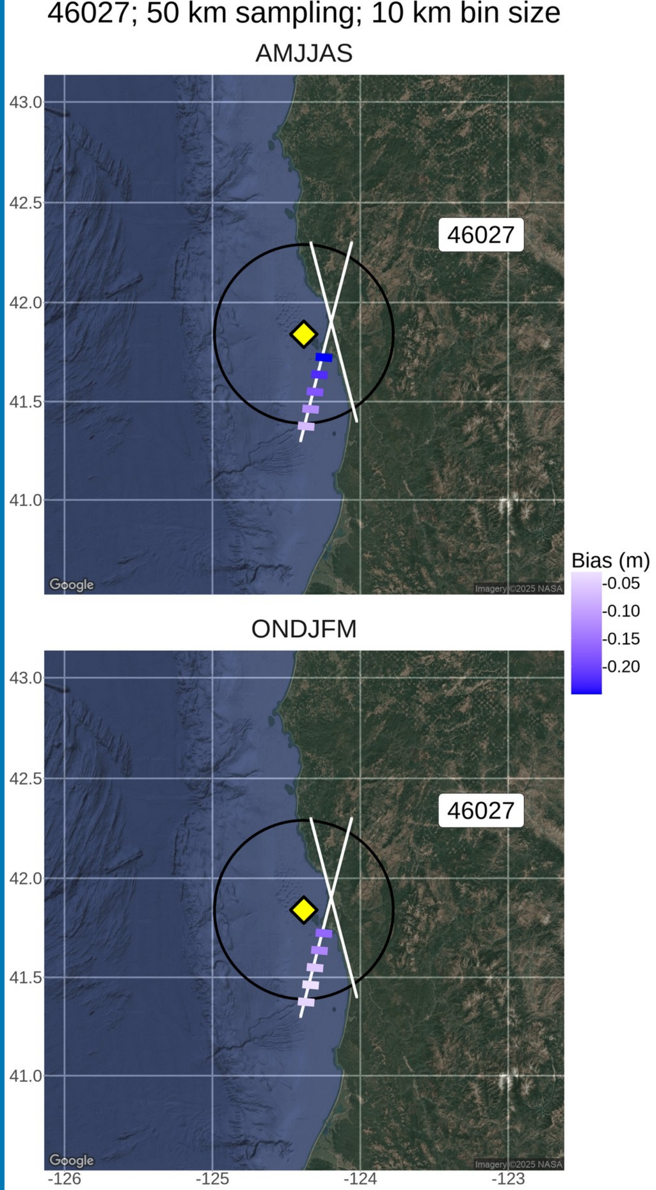
Buoy-Altimeter along-track gradients

— **Sentinel-3A (CCI v4) 2016-2023**

— **Hs mean bias**

— **1 Hz data, 10 km bin size**

— **Gradient reversal: closer to the coast and affected by local morphology?**



Assessment of data conflict...

… if the collocation is reasonable!

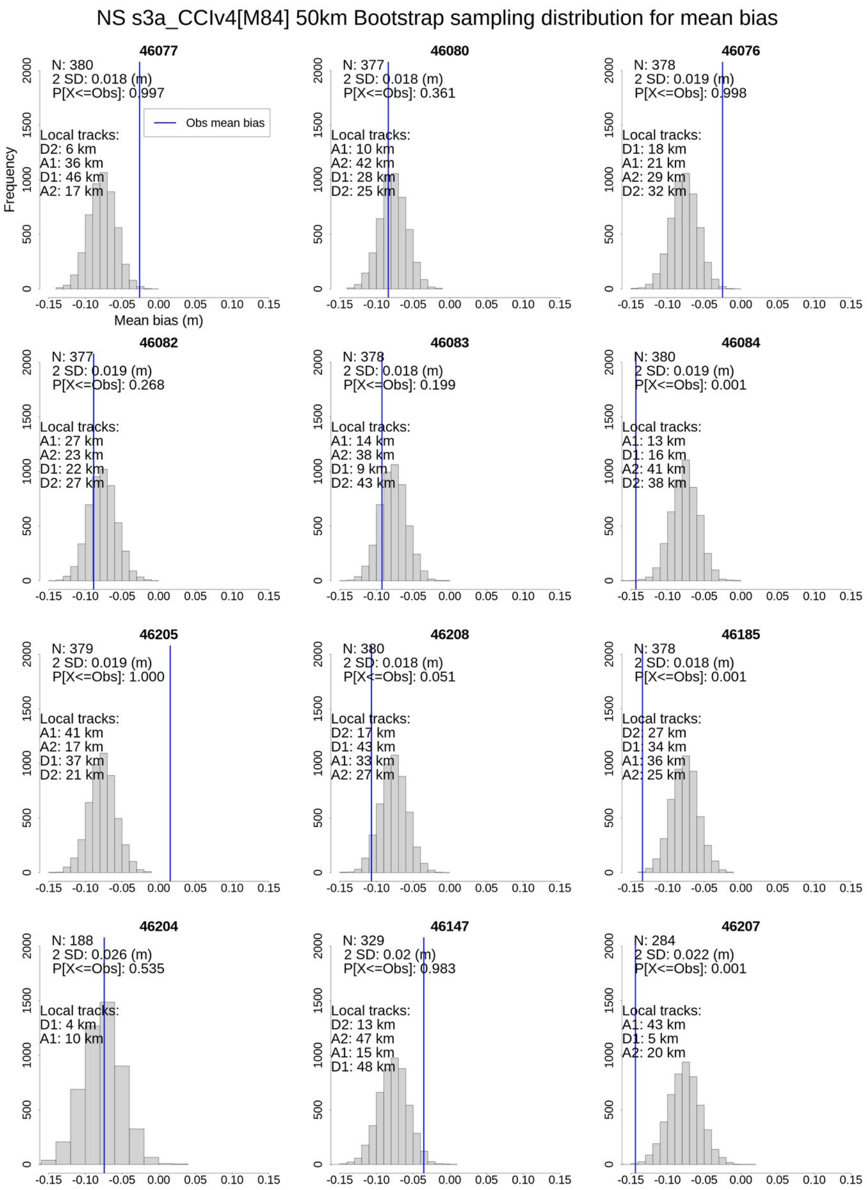
— Evaluate the "likelihood" of Hs mean bias from the "population" of biases from all buoys.

— Bootstrap probability distribution should be centred on zero (it's not!).

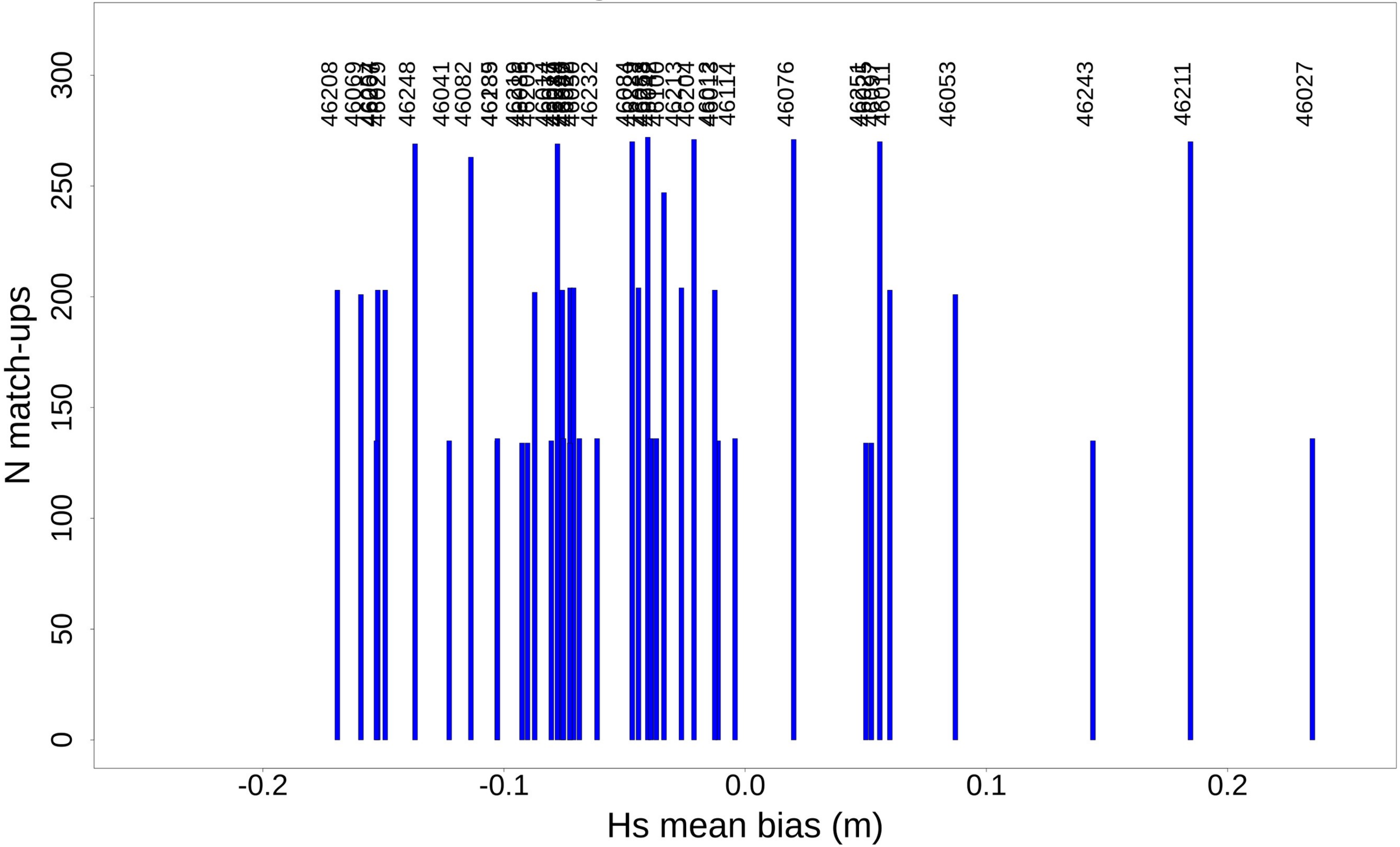
— Outliers (blue line) indicate conflict (for some reason).

— Can be applied to other comparison statistics, such as correlation, RMSE, scatter index, ...

— Can an error model can be developed to explain disagreement?



46 "Nearshore" buoys: s3b_CCIv4 Hs mean bias dist.



Conclusions:

— We can...

> Develop a detailed multimission-based representation of local sea state gradients from paired time series.

> Use this to examine the effects of nearshore collocation “errors”

— In principle we can...

> Develop an observation-based error model conditional on relevant covariates (bathymetry, distance to coast, ...)

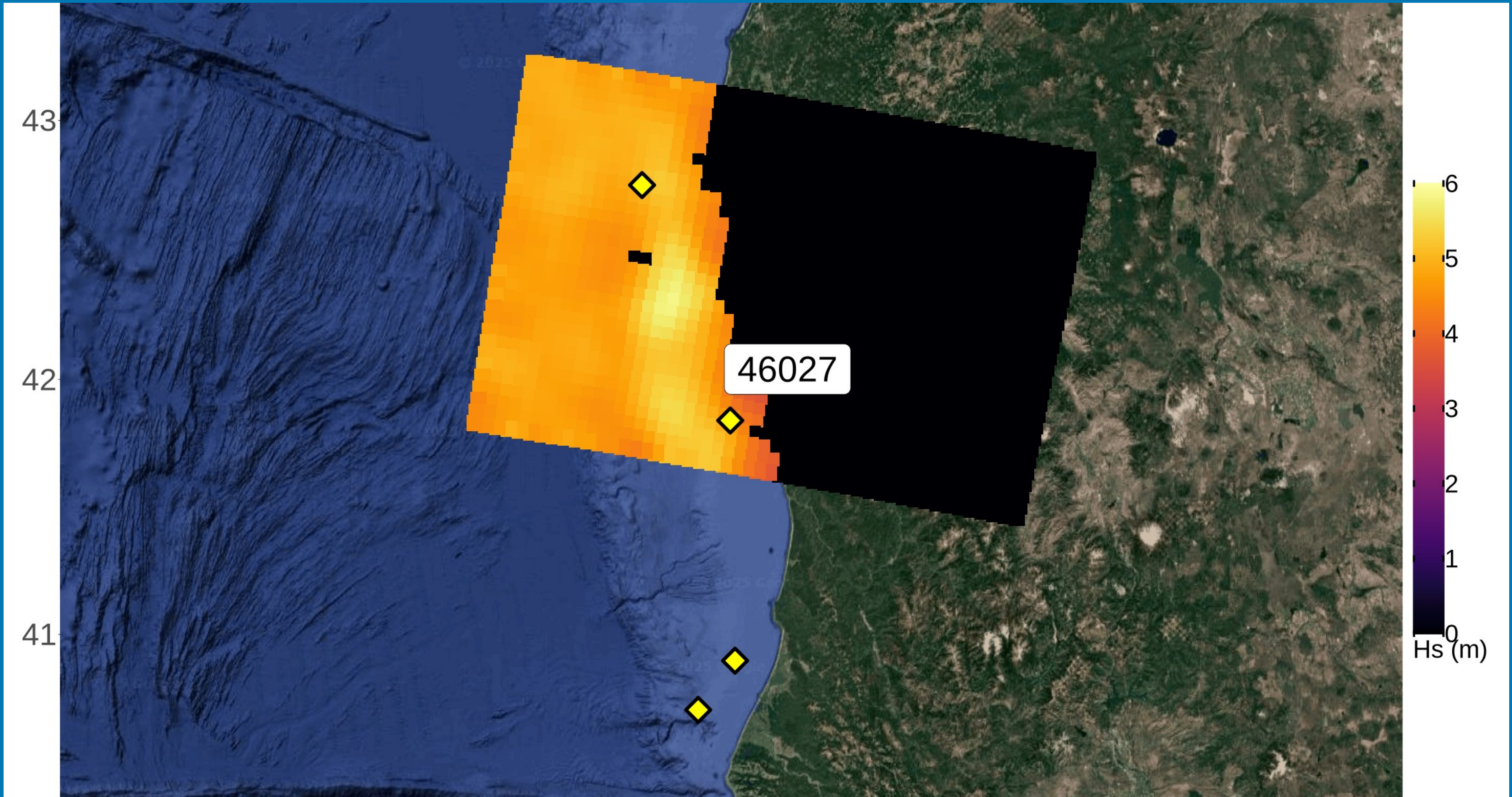
> Use this approach to filter collocations and detect “outliers” (maybe due to buoy mal-operation, local effects not accounted for …)

> Use this approach to interpolate to arbitrary nearshore locations, and provide climate change assessment, analysis, and so on.

Sentinel-1(A) IW mode

Local Hs gradients directly from Sentinel-1 swath measurements...

— Sentinel-1A (CCI v4) Synthetic Aperture Radar single “imagette”



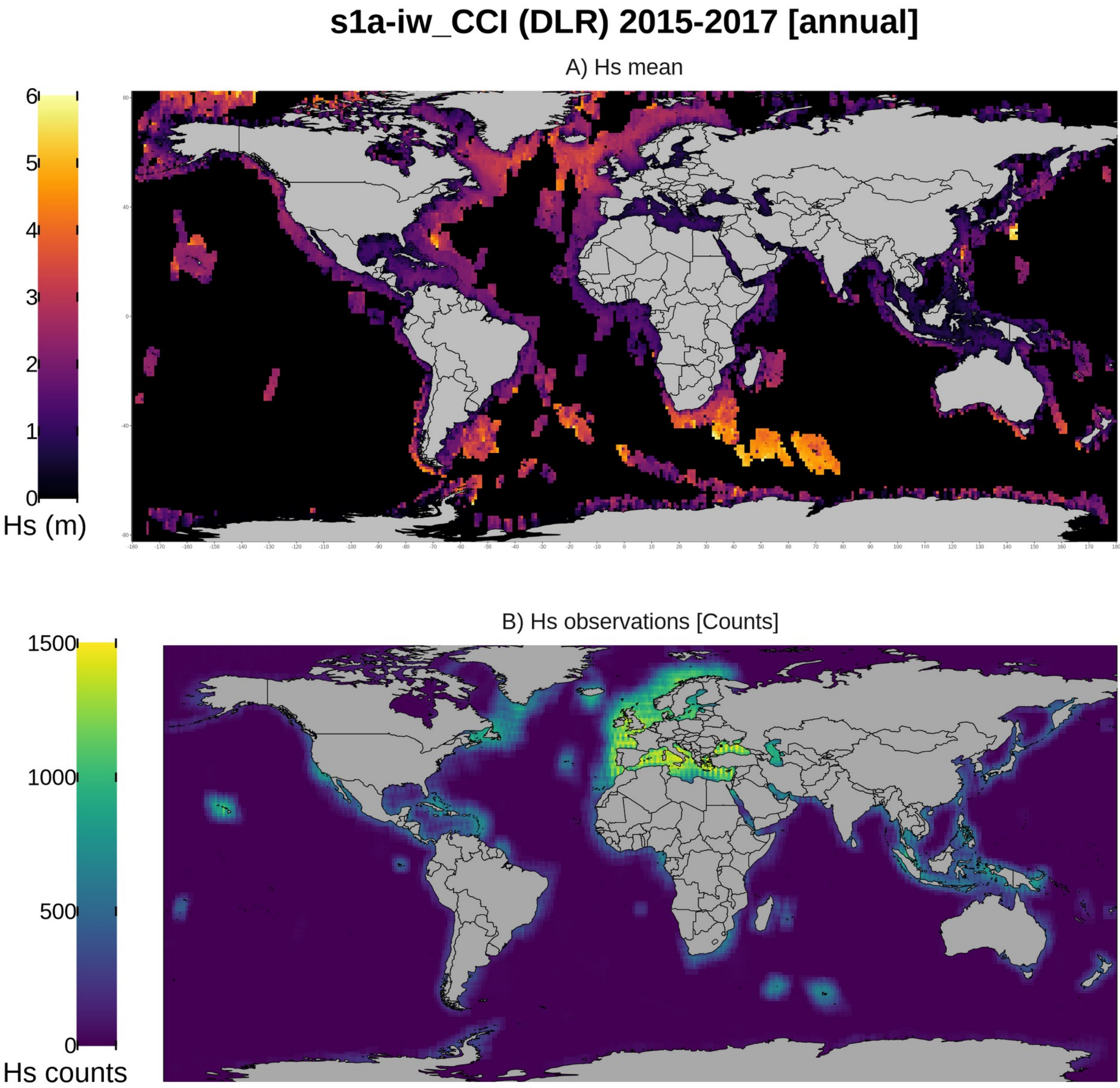
S1-A IW mode:
Available parameters

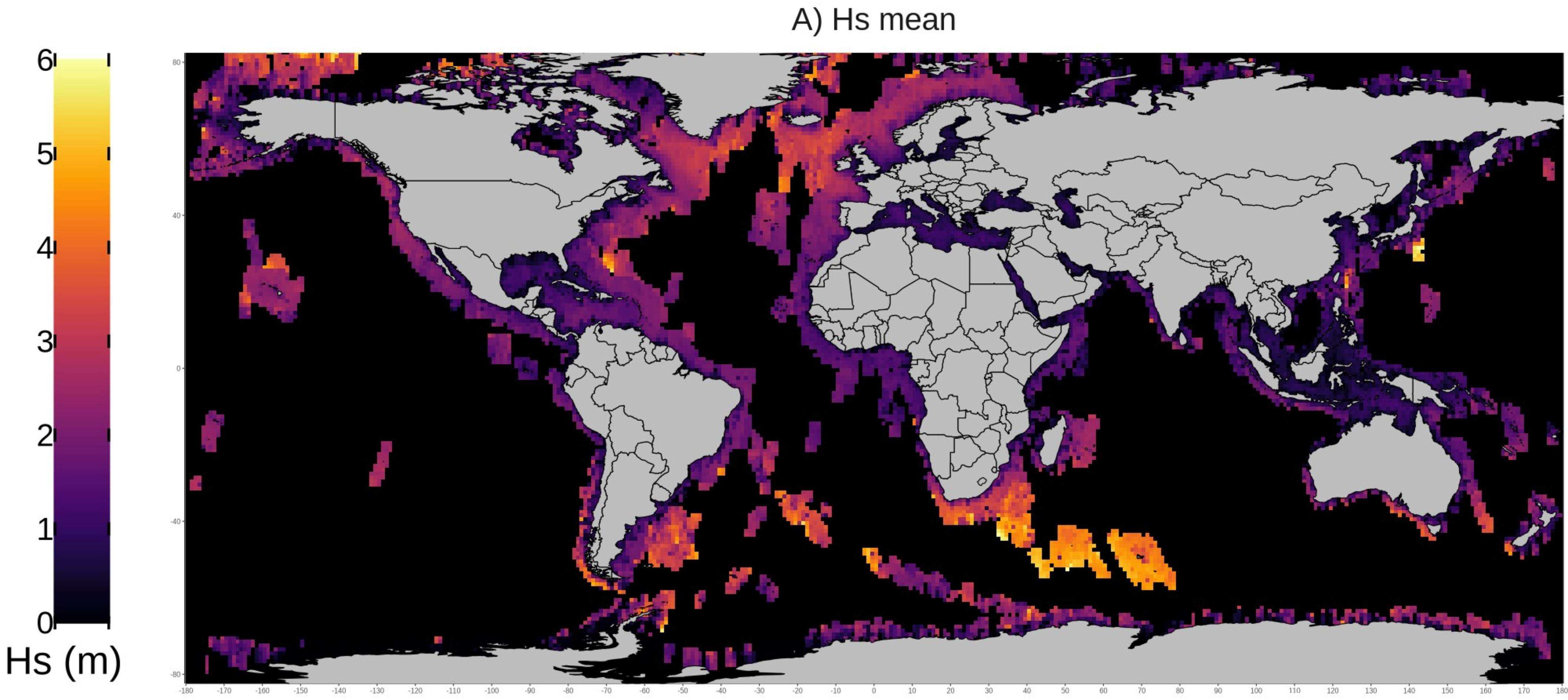
```
netcdf S1A_IW_GRDH_1SDH_20200101T035722_20200101T0
dimensions:
        time = 1 ;
        row = 38 ;
        col = 49 ;
variables:
        double swh ;
        double swh_uncertainty ;
        ubyte swh_quality ;
        short swh_rejection_flags ;
        double Tm0 ;
        double Tm0_uncertainty ;
        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 ;
```

S1-A IW mode: Global coverage and Hs climatology (2015-2017)

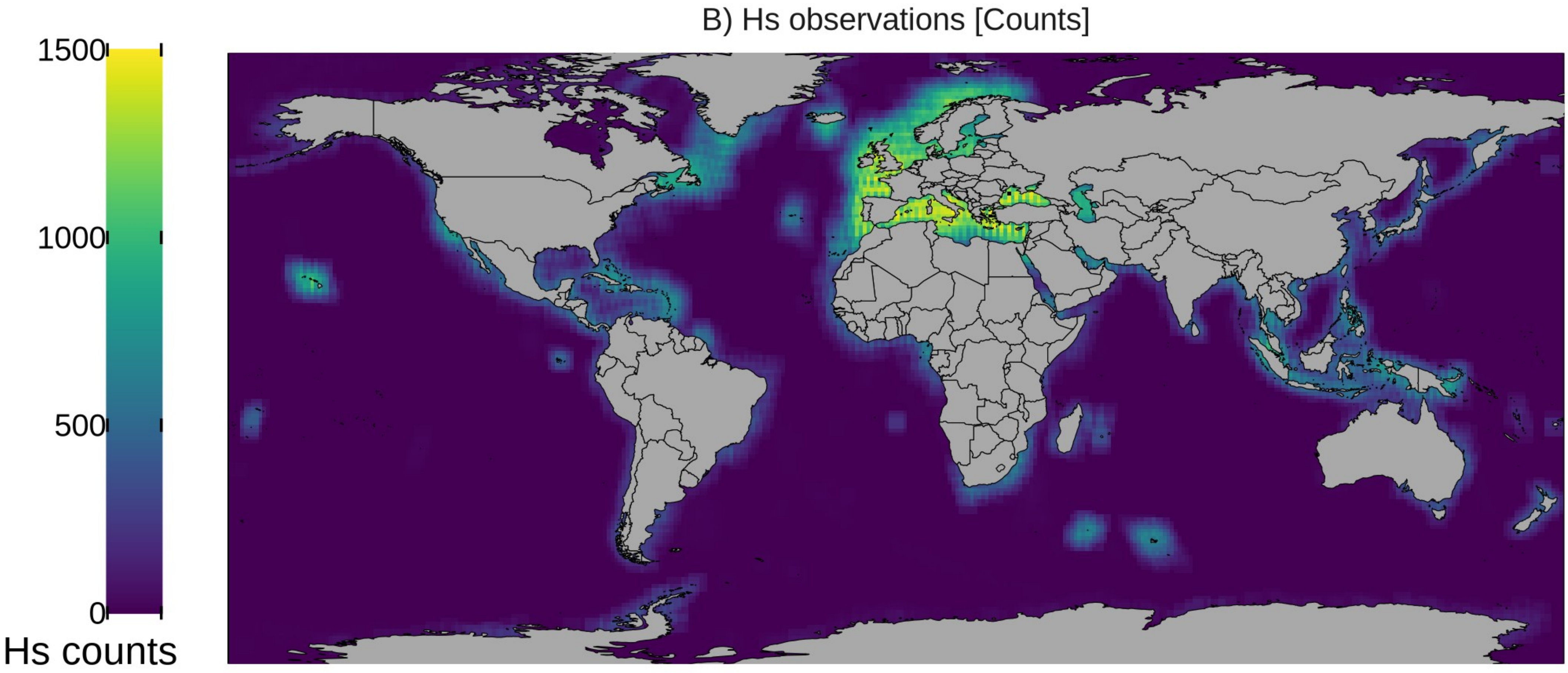
— **Global coastal coverage ;**

— **Imagette coverage / sampling suggests regional analyse ;**





A) Hs mean
6
5
4
3
2
1
0
Hs (m)
80
40
0
-40
-80
-180
-170
-160
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180


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

Sea State CCI User Consultation and Science meeting

— Wide range of speakers and attendees: ECMWF; MeteoFrance; “COWCLIP”; industry (EDF, ...), ESA and the Sea State CCI Team...

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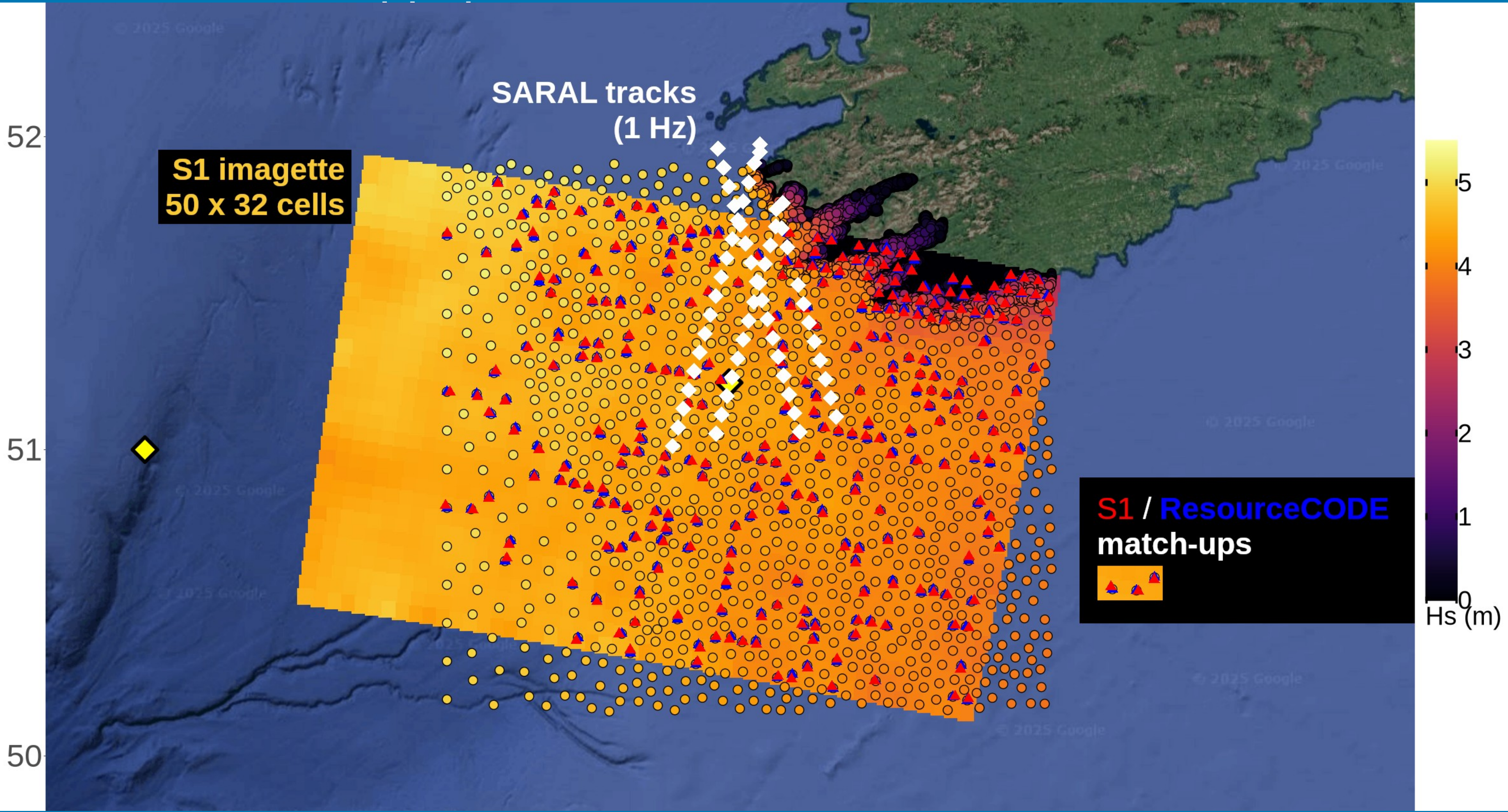
Additional Slides

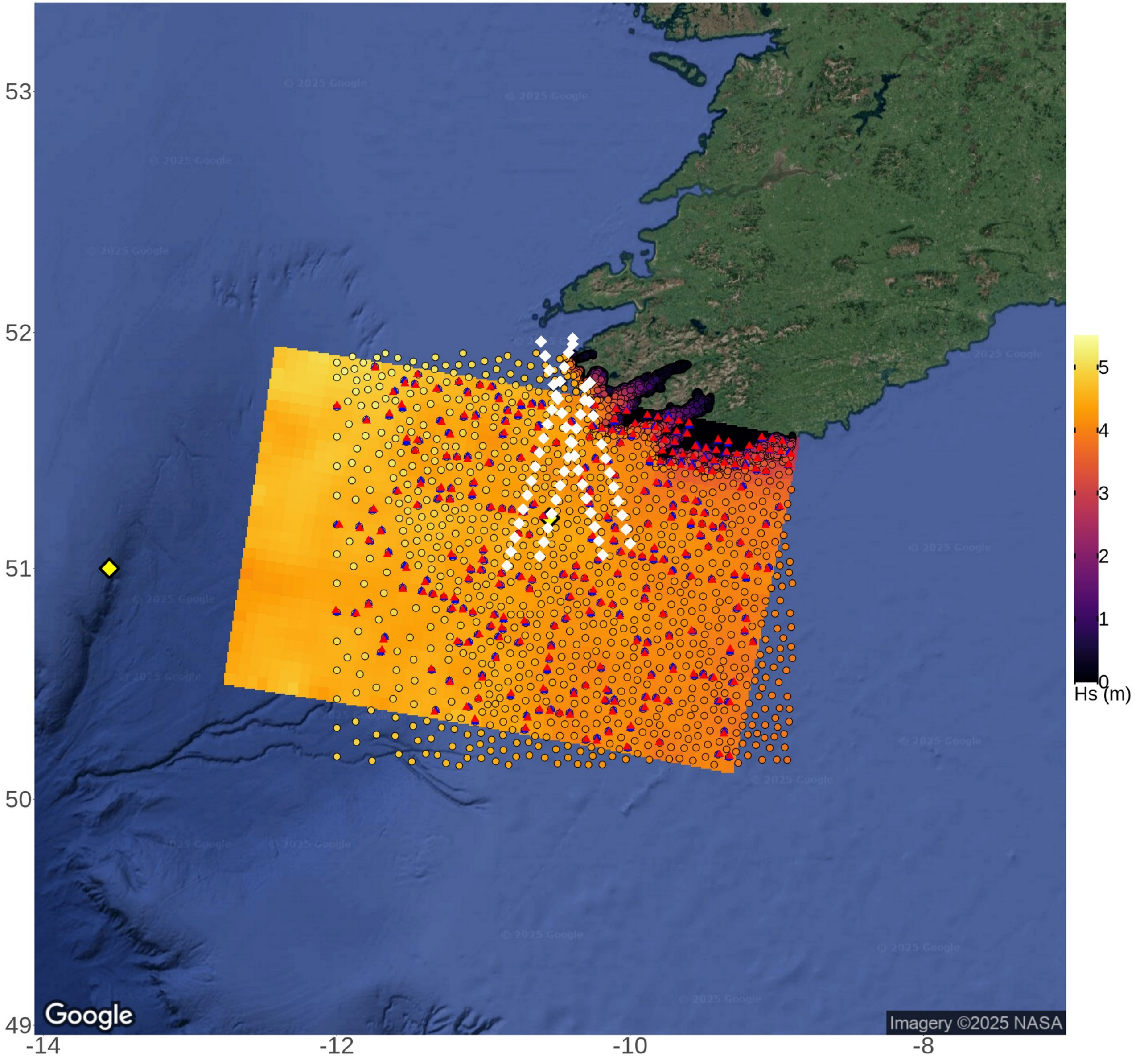

SARAL tracks
(1 Hz)
S1 imagette
50 x 32 cells
S1 / ResourceCODE
match-ups
52
51
50
5
4
3
2
1
0
Hs (m)

S1-IW collocation

— **S1 fields can be collocated with ResourceCODE grid to ~1 km ;**

— **Choices of collocation approach ;**

— **Altimetry can be introduced (SARAL tracks shown) ;**



ResourceCODE hindcast

- Accensi *et al.* (2021) ;
- Wave / current hindcast for European shelf (1993-2024) ;
- Unstructured grid to high resolution < 1 km ;
- Fields of parameters (wave period, partition parameters , ...) ;

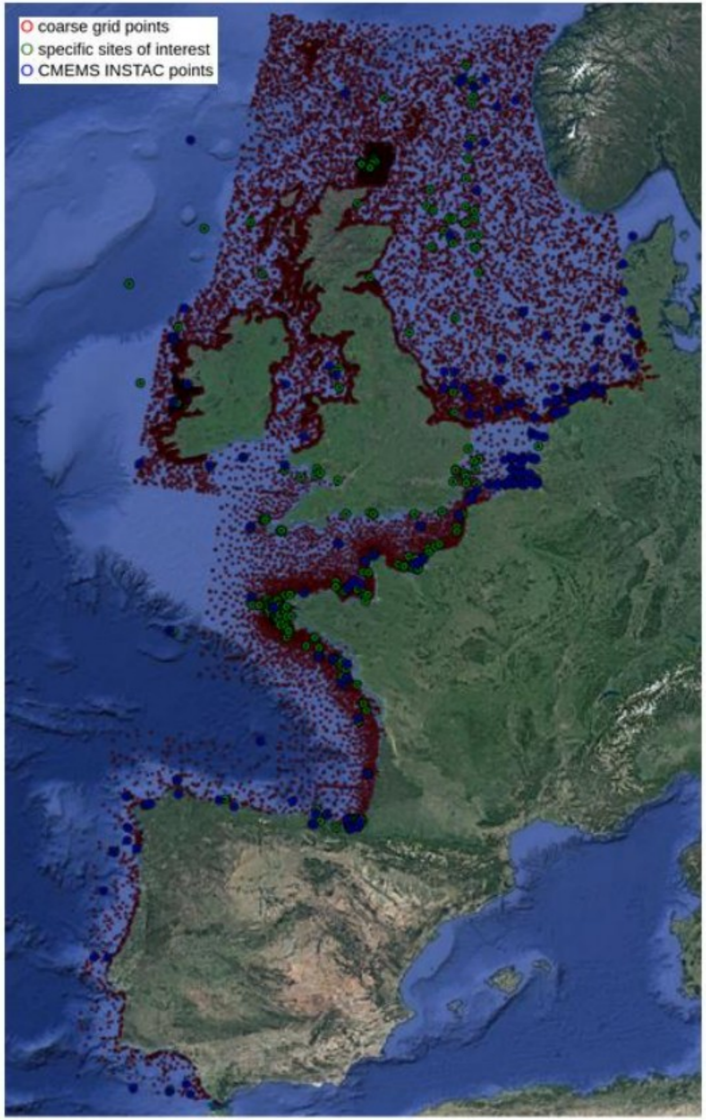
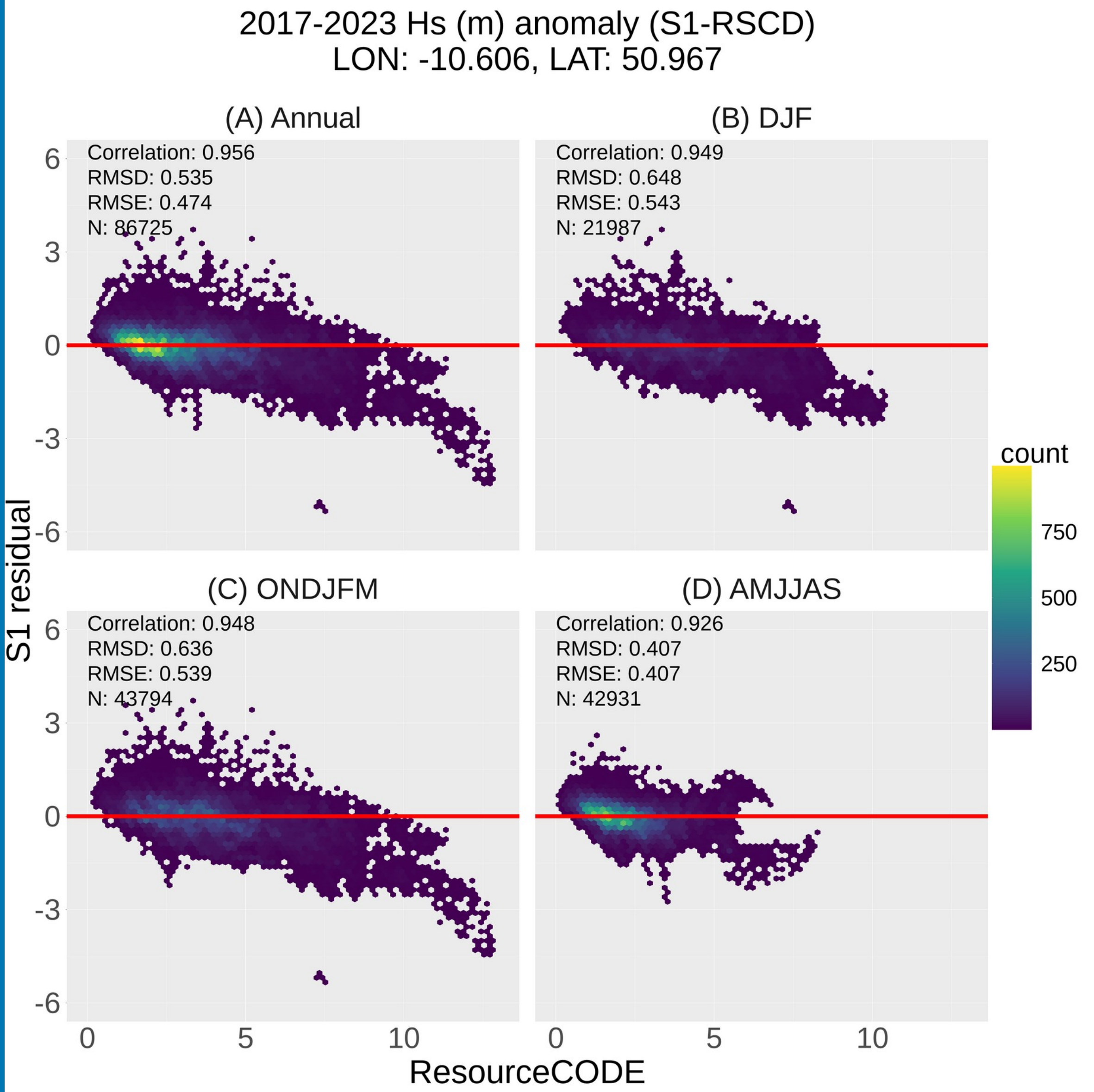


Fig. 3. Directional spectra output locations

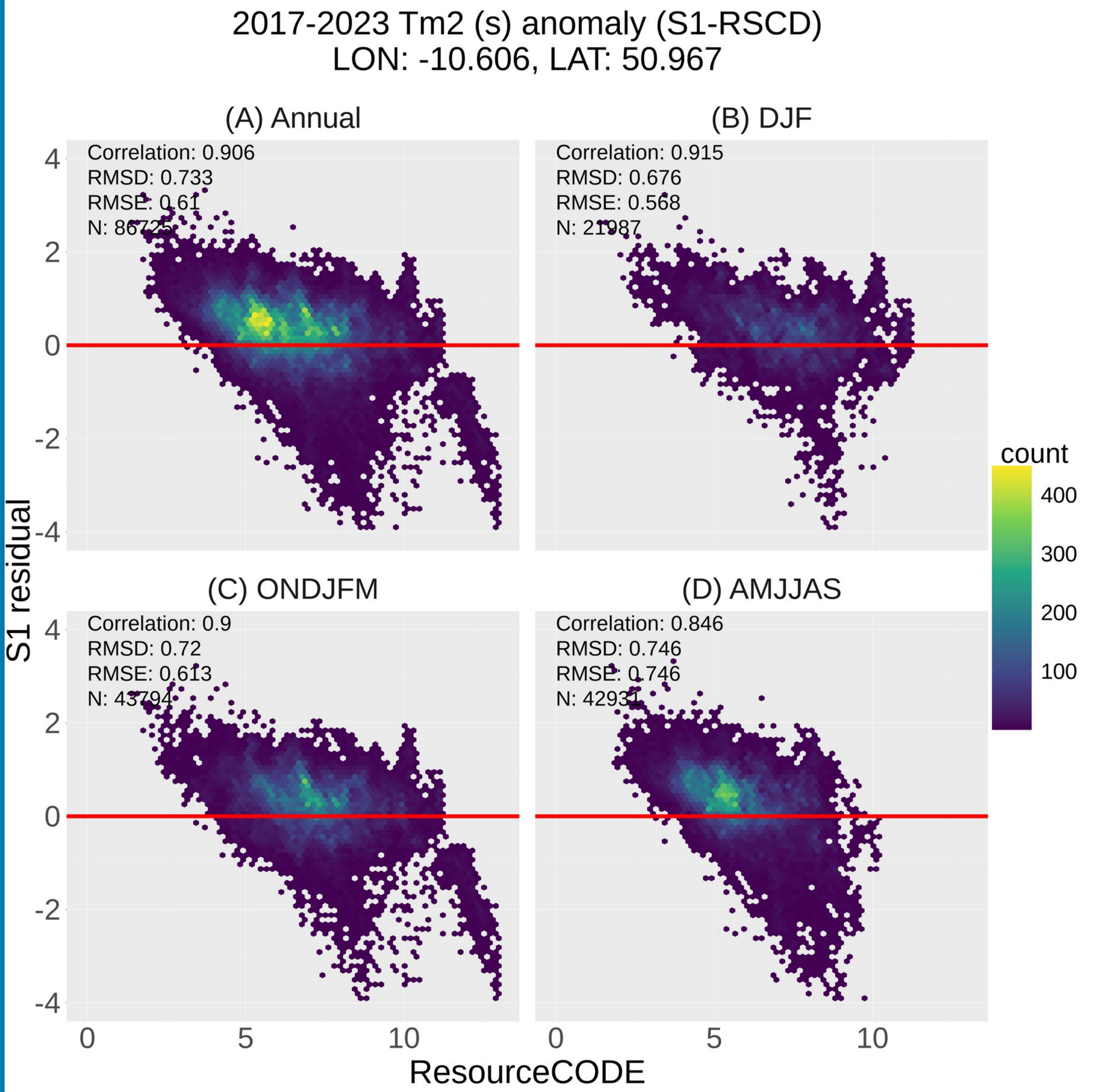
S1A / ResourceCODE comparisons (Hs)

- **Large collocation set (86725) ;**
- **“GOOD” data flag applied ;**
- **Low Hs mean bias ;**
- **Best performance for NH summer ;**
- **Sea state dependent bias at high Hs ;**



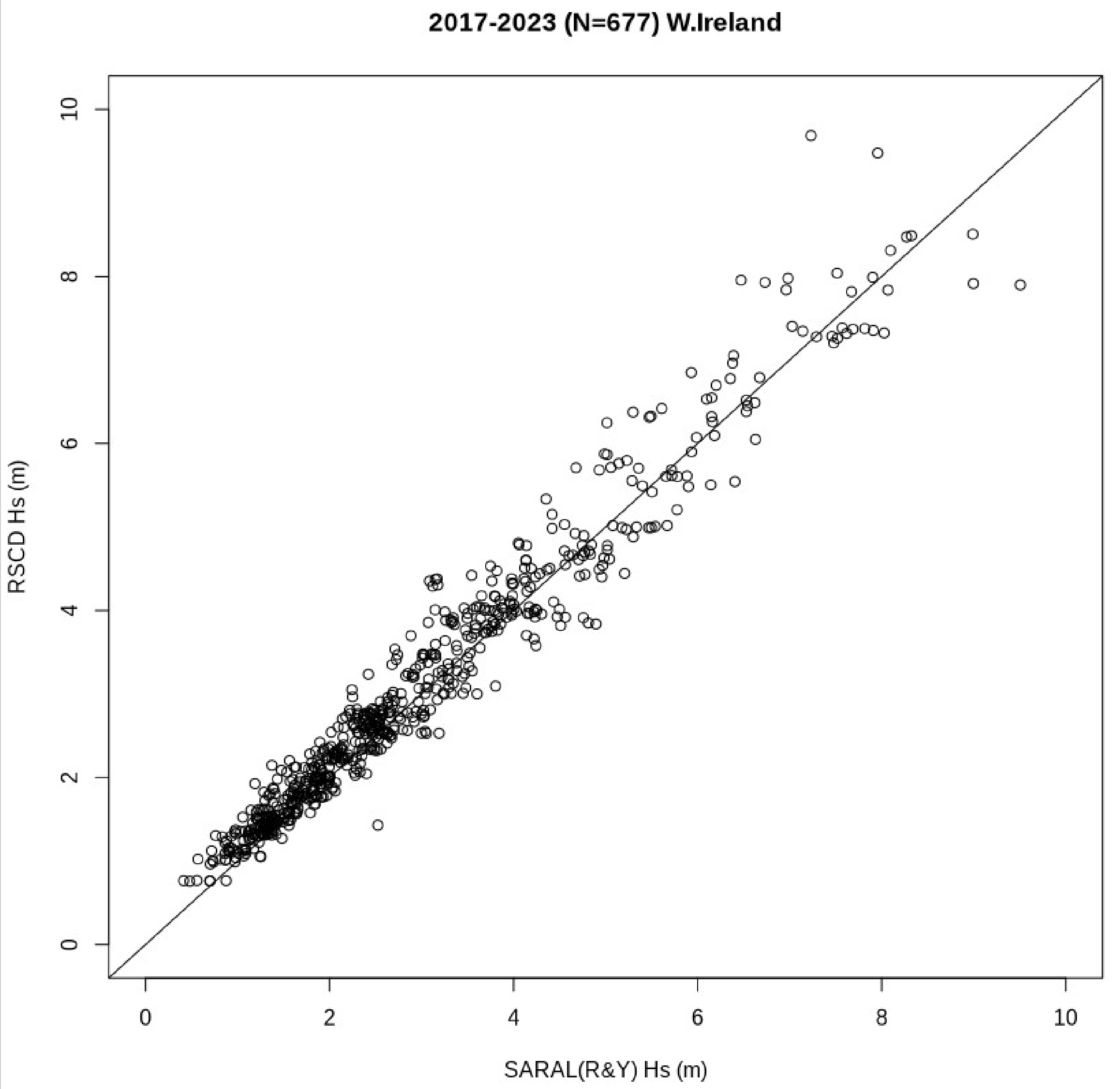
S1A / ResourceCODE comparisons (Tm2)

- **Reasonable performance ;**
- **Slight bias ;**



SARAL / ResourceCODE comparisons (Hs)

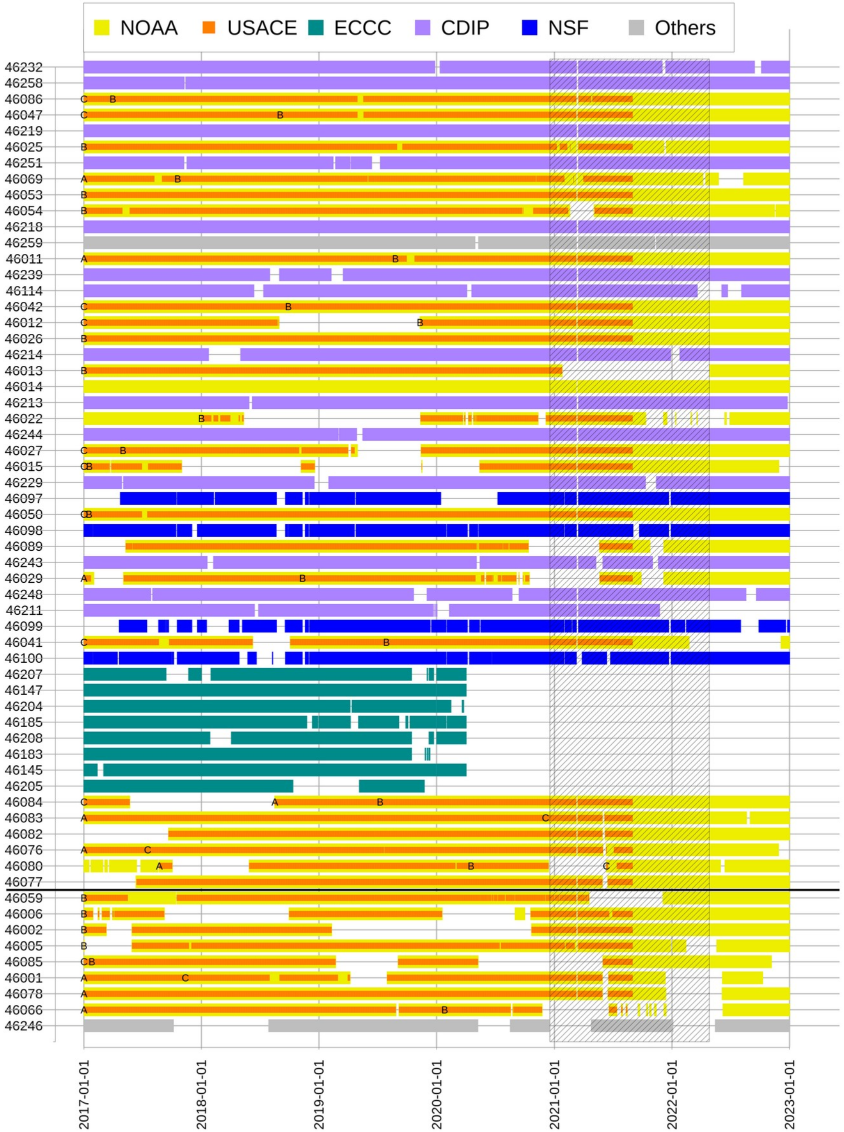
— RSCD good agreement with altimeter Hs



Variability across platforms

— Comparison of coverage and platform variability for Northeast Pacific *in situ* data

— Note, payload denoted by (small!) black letters

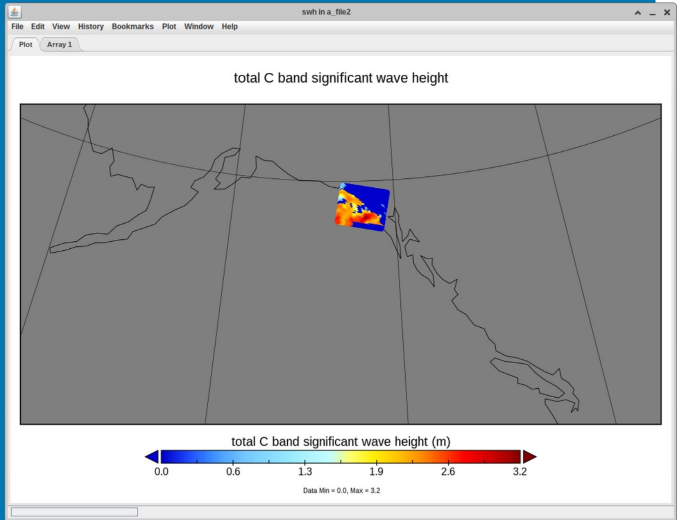


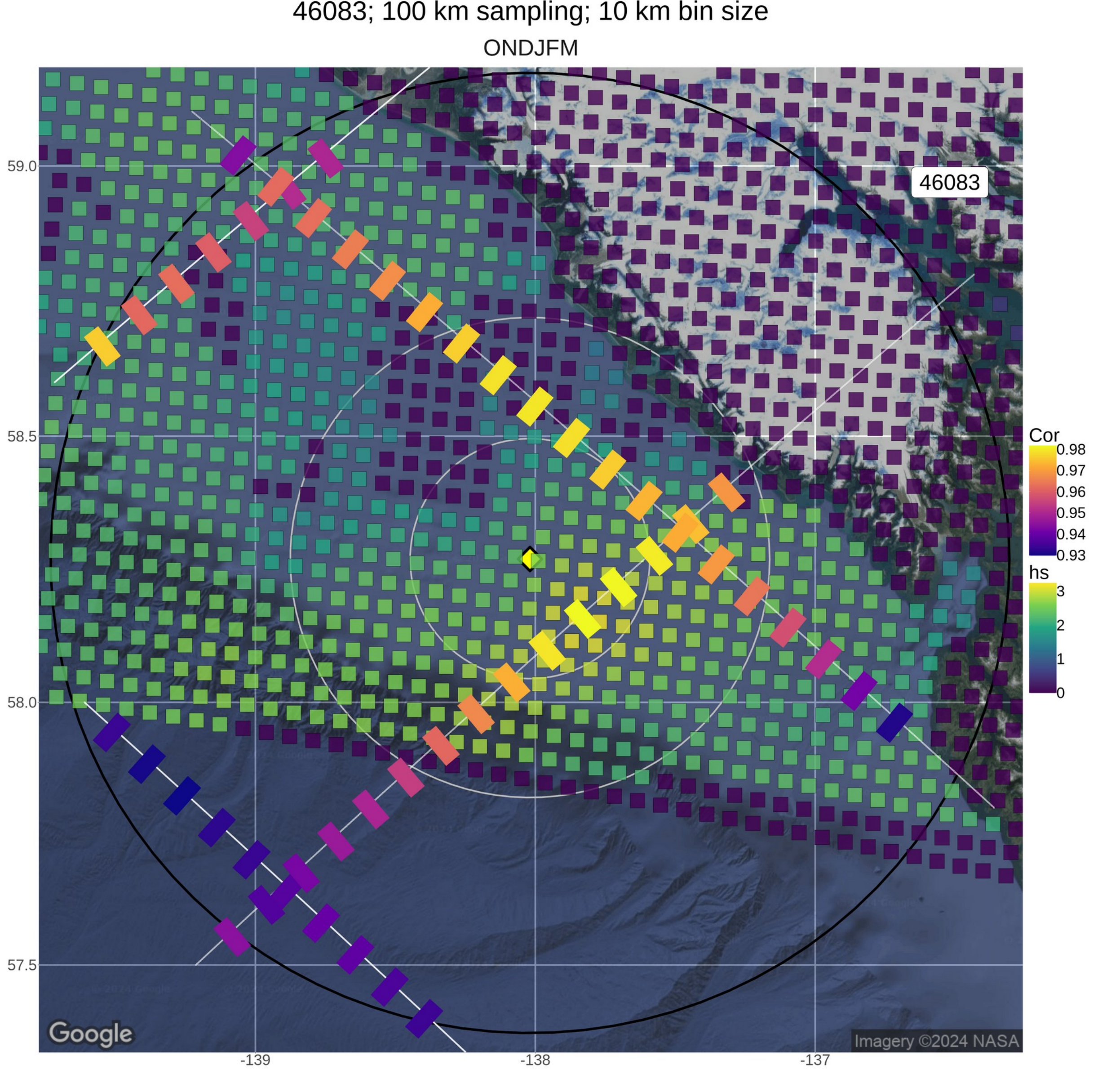
S1-A IW mode:
Local coverage from single imagette

— **Coastal coverage ;**

— **Spatial resolution improvements over 1 Hz altimetry ;**

— **Opportunities to evaluate and intercompare spatial climatology from different sources ;**





Coastal models for energy resource assessment:

— **U.S. coast (Yang et al., 2023) ;**

— **ResourceCode framework for European shelf (Accensi et al., 2021) ;**

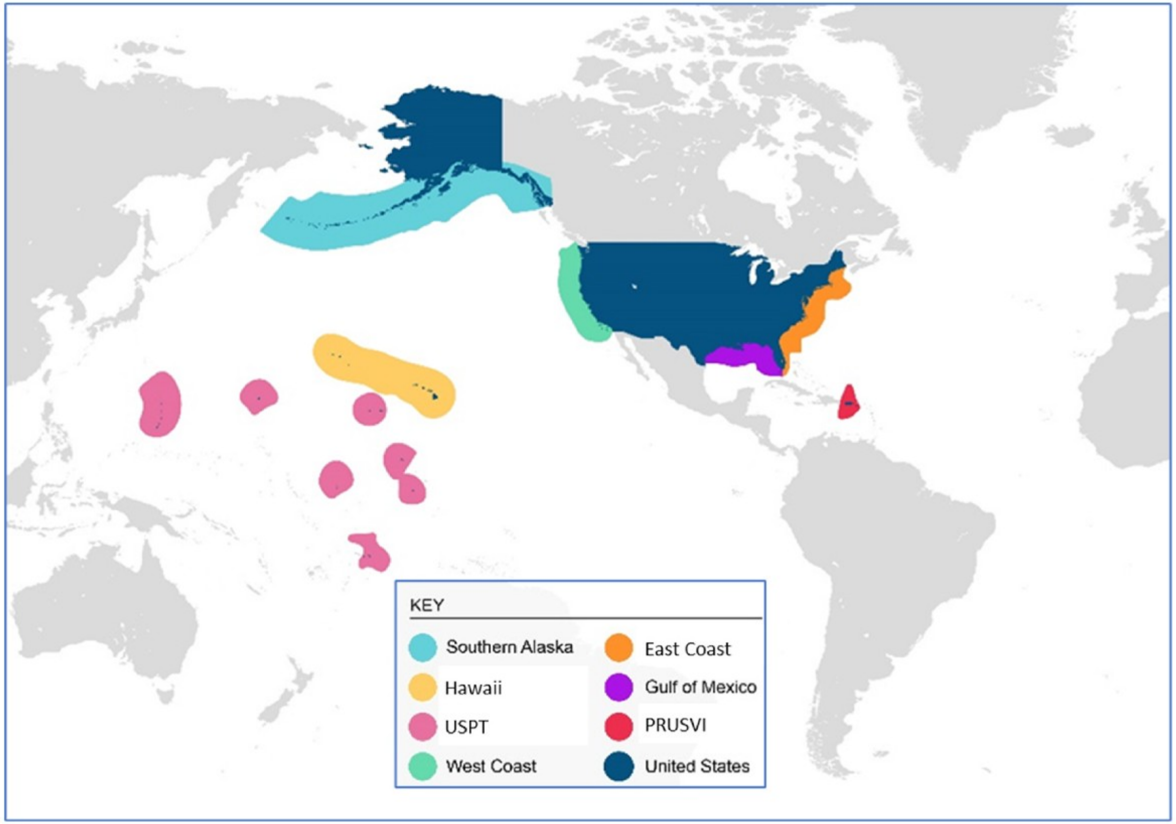


Fig. 1. U.S. EEZ regions corresponding to Table 1 for wave resource assessment.

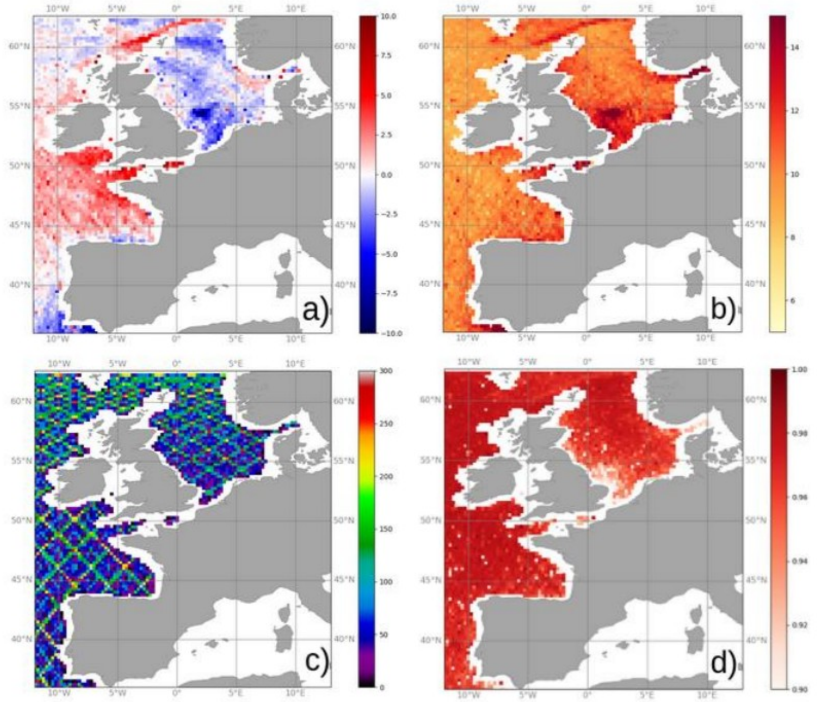


Fig. 5. yearly estimates averaged over 1993-2018.
a) NB; b) NRMSE; c) matches-up; d) R

Uncertainty validation (L2)

- **De-noised data not examined in Phase 1 ;**
  - > Contains information on uncertainty
- **Impact of de-noised data on estimation of spatial gradients (collocation process).**

Jason-3 GDR | Jason-3 CCI denoised