

# Wave climate variability observed from space: some recent developments

**Ben Timmermans<sup>1</sup>, Christine Gommenginger<sup>1</sup> & Chris Banks<sup>1</sup>  
Andrew Shaw<sup>2</sup>**

1 National Oceanography Centre, UK

2 Skymat Ltd, Southampton UK

# Outline

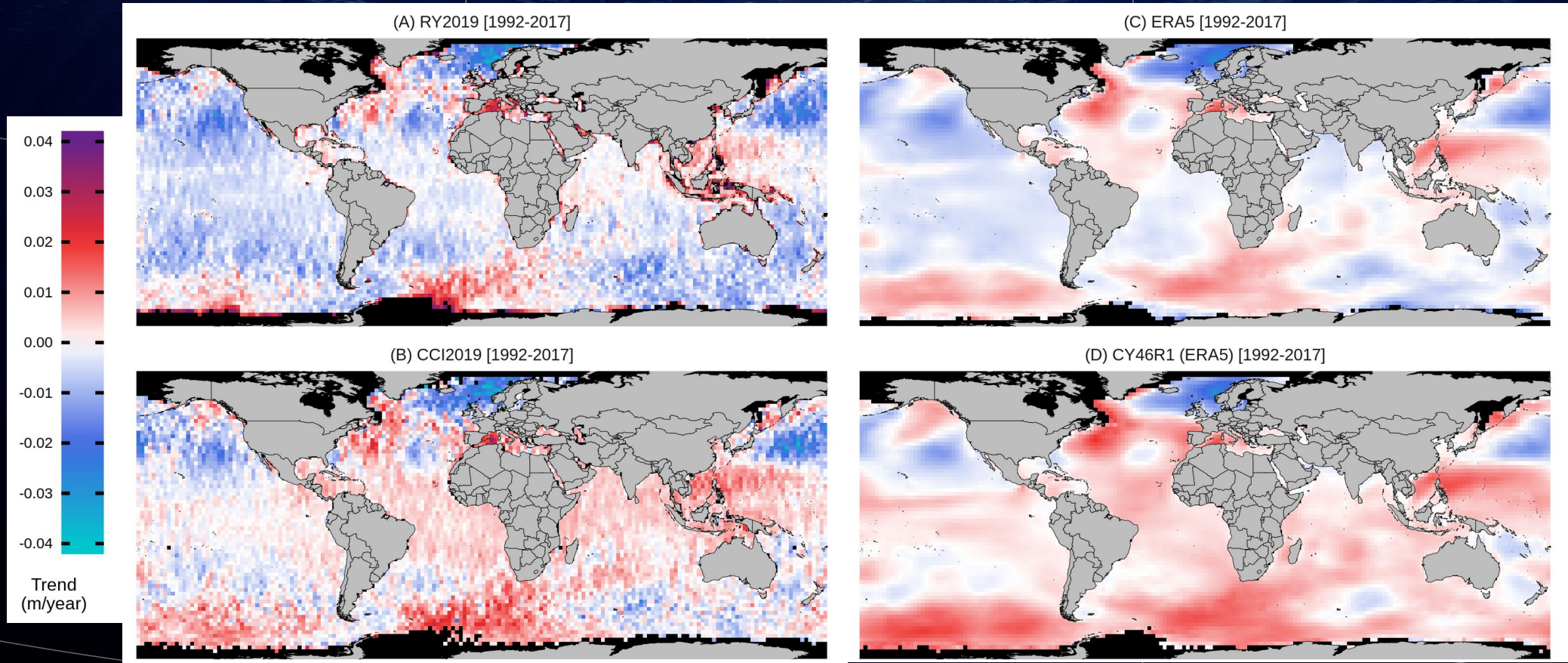
## Sea state from satellites: *a growing record*

- Global long term variability (briefly)
- **ESA Sea State CCI:**
  - Project summary
  - Altimetry record (significant wave height)
  - Sentinel-1 A/B SAR Wave Mode (significant wave height, wave period, swell wave height)

## Looking Ahead

- Product development (Sea State CCI phase 2)
- Accounting for sea state dependence using global observations (Sentinel-6 / Jason-3 Tandem)

# Long term Hs (JFM) linear trend intercomparisons



- General consistency in spatial structure but variability in magnitude across products.
- Differences vary with time period of interest (not shown).
- *Timmermans et al. 2020*

# Sea State CCI: Phase 1 complete

## Version 1.1 data, released mid-2020 (drawing from GlobWave)

- Time series spans: 1992 – 2018
- L2, L3, L4 altimetry products
- *Dodet et al., 2020; Timmermans et al. 2020*

## Version 3 data, released early 2022

- Result of rigorous processing methodology including updates to altimetry re-tracking (coastal), QC, and inter-mission calibration.
- Time series spans: 2002 – 2020
- Jason-1, Envisat, Jason-2, Cryosat-2, Saral-Altika, Jason-3, Sentinel-3A
- L2, L3, L4 products
- **Addition of data from imaging-SAR wave mode**
  - Envisat (2002 – 2012)
  - Sentinel-1 A/B (2015 – 2020)
  - **Hs (total), Hs (swell 1 & 2, windsea), period (Tm0, Tm1, Tm2)**

<https://climate.esa.int/en/projects/sea-state/data/>



sea state  
cci

## Product Validation and Intercomparison Report (PVIR)

version 0.1, October 2019



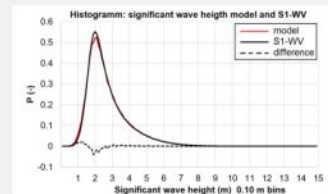
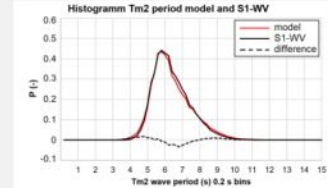
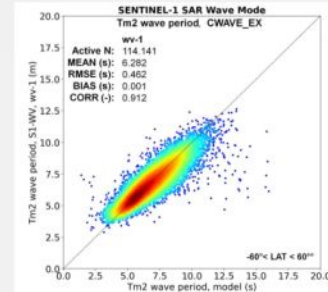
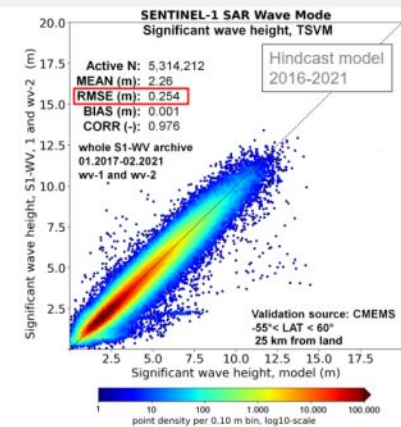
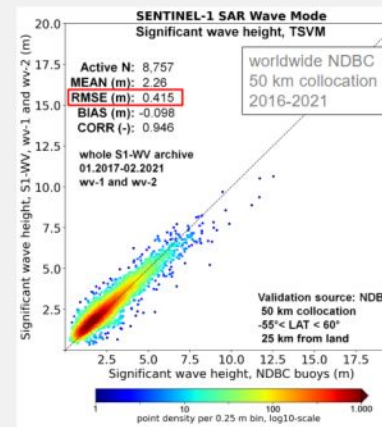
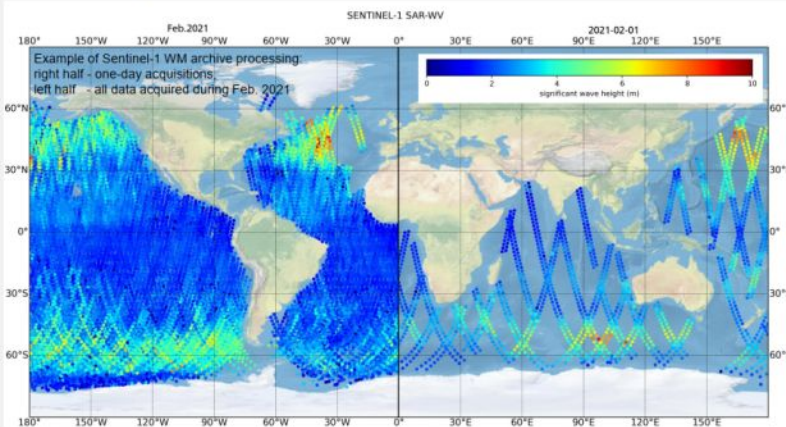
## Multiparametric sea state fields from synthetic aperture radar for maritime situational awareness

Andrey Pleskachevsky\*, Björn Tings, Stefan Wiehle, James Imber, Sven Jacobsen

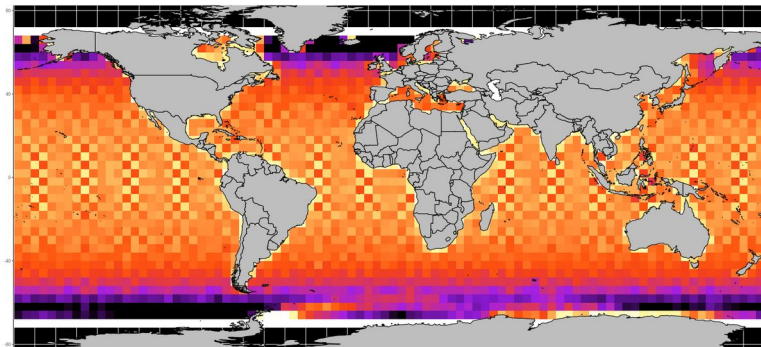
DLR, Maritime Safety and Security Lab Bremen, Am Fallturm 9, 28359 Bremen, Germany

## 5. Sentinel-1 Wave Mode Archive Processing in Scope of ESA Climate Change Initiative

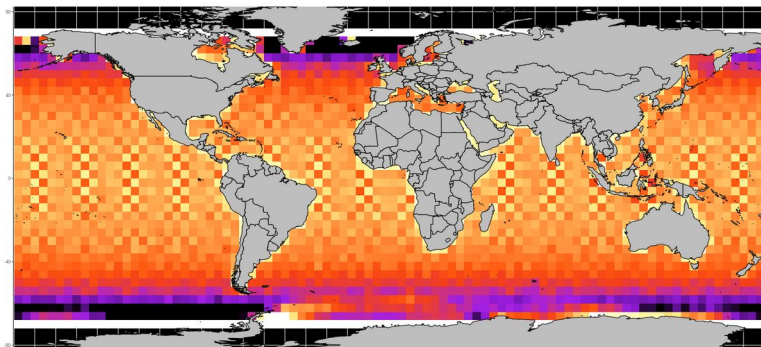
- Sentinel-1 Wave-Mode whole archive 2014-2021 processed (~15 Mio imagettes), validated, delivered to ESA:  
8 sea state parameters: wave height (swell's, wind-sea), periods (mean, cross-zero, wind-sea). Format: ID.nc for each ID-product
- Accuracy of 24 cm reached (significant wave height) – comparable to accuracy of altimeter and ground truth noise combination of classical approaches with machine learning
- Method adopted for Sentinel-1 modes IW, EW, WV and also for TS-X SM



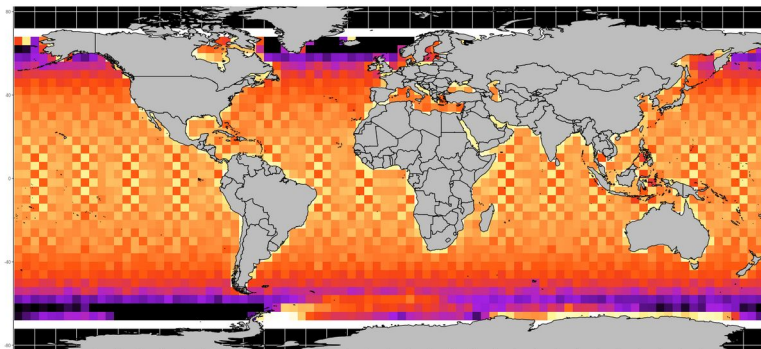
(C) 2018 [annual] jason-3: Cell track median counts



(D) 2019 [annual] jason-3: Cell track median counts

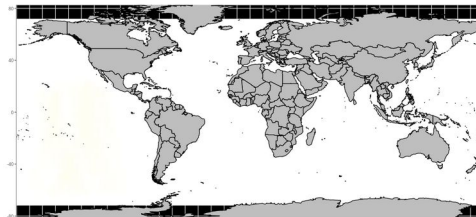


(E) 2020 [annual] jason-3: Cell track median counts

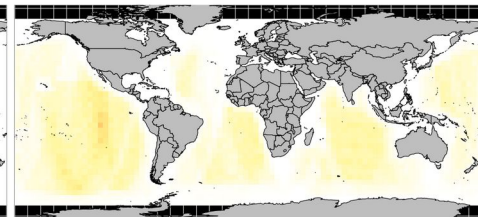


1500  
1250  
1000  
750  
500  
250  
0  
Counts

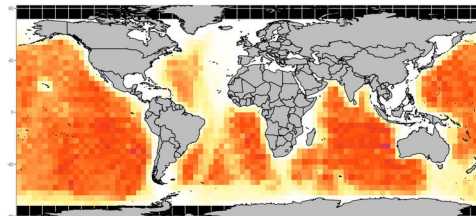
(A) 2014 [annual] Sentinel-1A/B (DLR): Counts



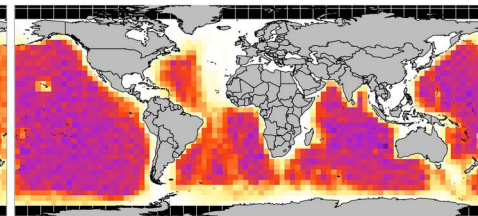
(B) 2015 [annual] Sentinel-1A/B (DLR): Counts



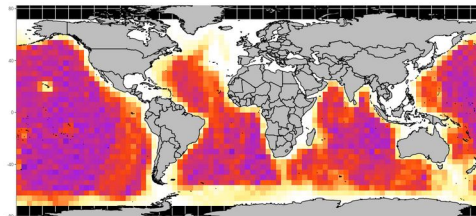
(C) 2016 [annual] Sentinel-1A/B (DLR): Counts



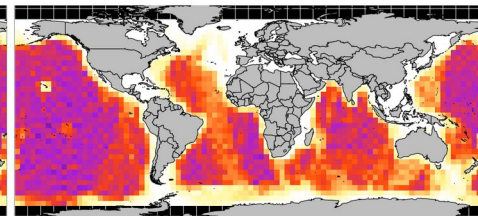
(D) 2017 [annual] Sentinel-1A/B (DLR): Counts



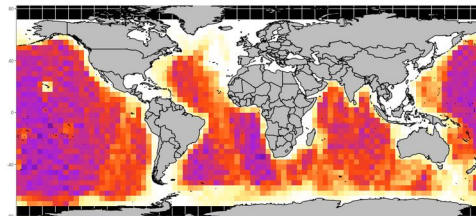
(E) 2018 [annual] Sentinel-1A/B (DLR): Counts



(F) 2019 [annual] Sentinel-1A/B (DLR): Counts



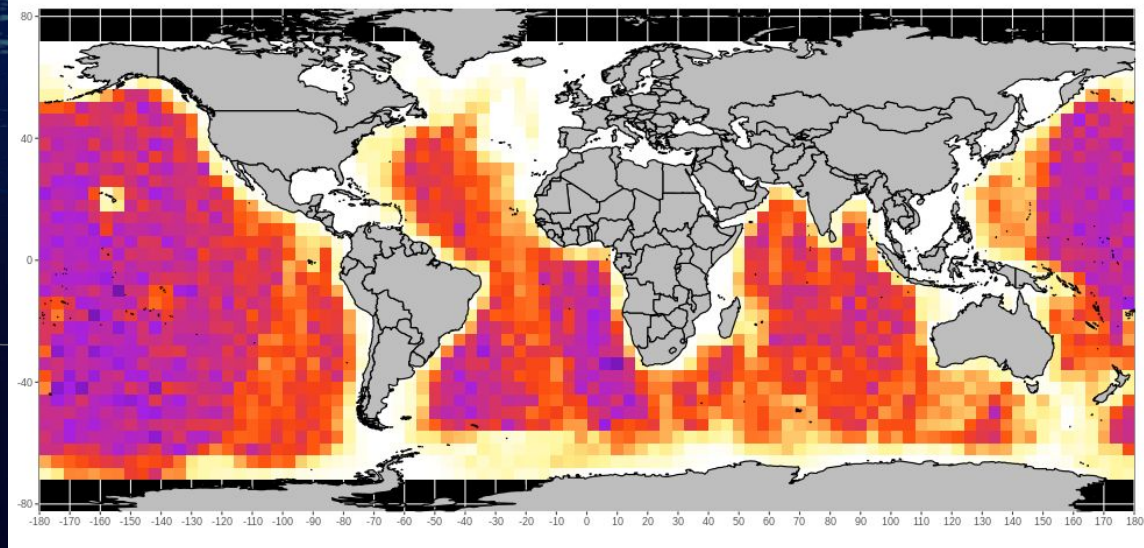
(G) 2020 [annual] Sentinel-1A/B (DLR): Counts



1500  
1250  
1000  
750  
500  
250  
0  
Counts

- Sentinel-1 wave mode **does not co-locate** well with many long term in situ wave buoys!

(G) 2020 [annual] Sentinel-1A/B (DLR): Counts



- Moored wave buoy locations from the CMEMS in situ TAC (May, 2022)



# Global wave period characteristics (Sea State CCI, S-1 A/B)

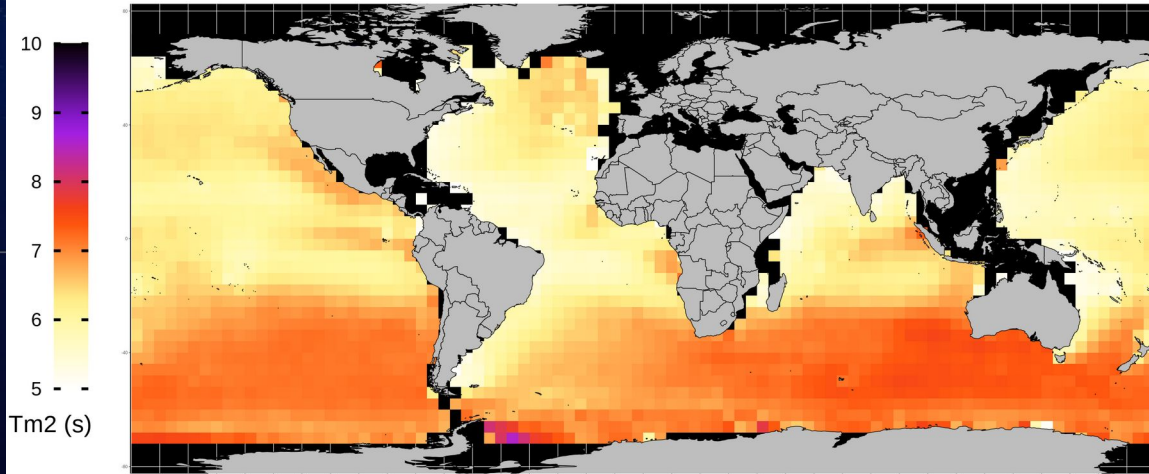
- A global record of wave period.
- $T_{m2}$  climatology (2014-2019) from Sentinel-1 A/B SAR wave mode.
- Permits observational comparison / validation against e.g. ERA5 reanalysis ...

**Regional differences attributable to:**

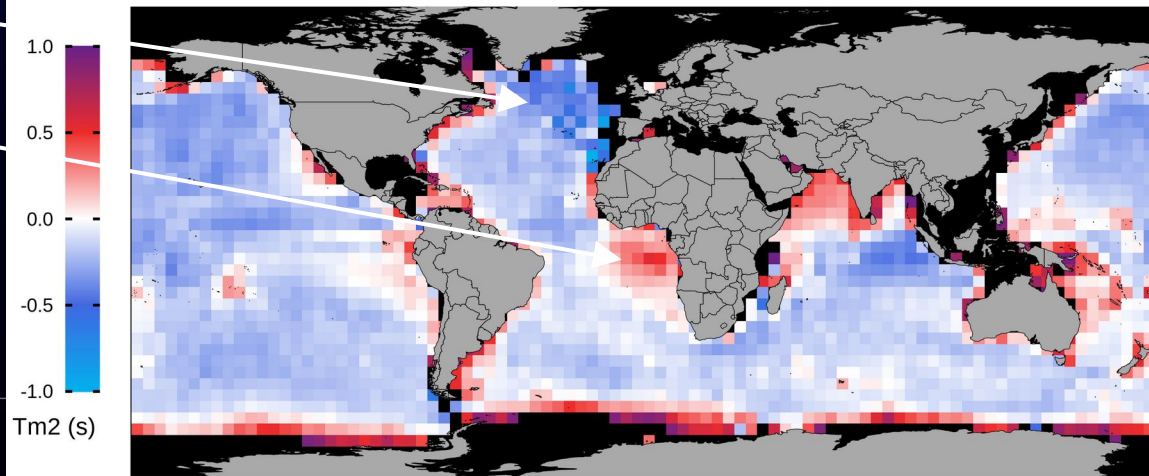
**1) Low sampling**

**2) ???**

(A) 2014-2019[annual] sentinel1\_SAR : Climatological  $T_{m2}$  mean

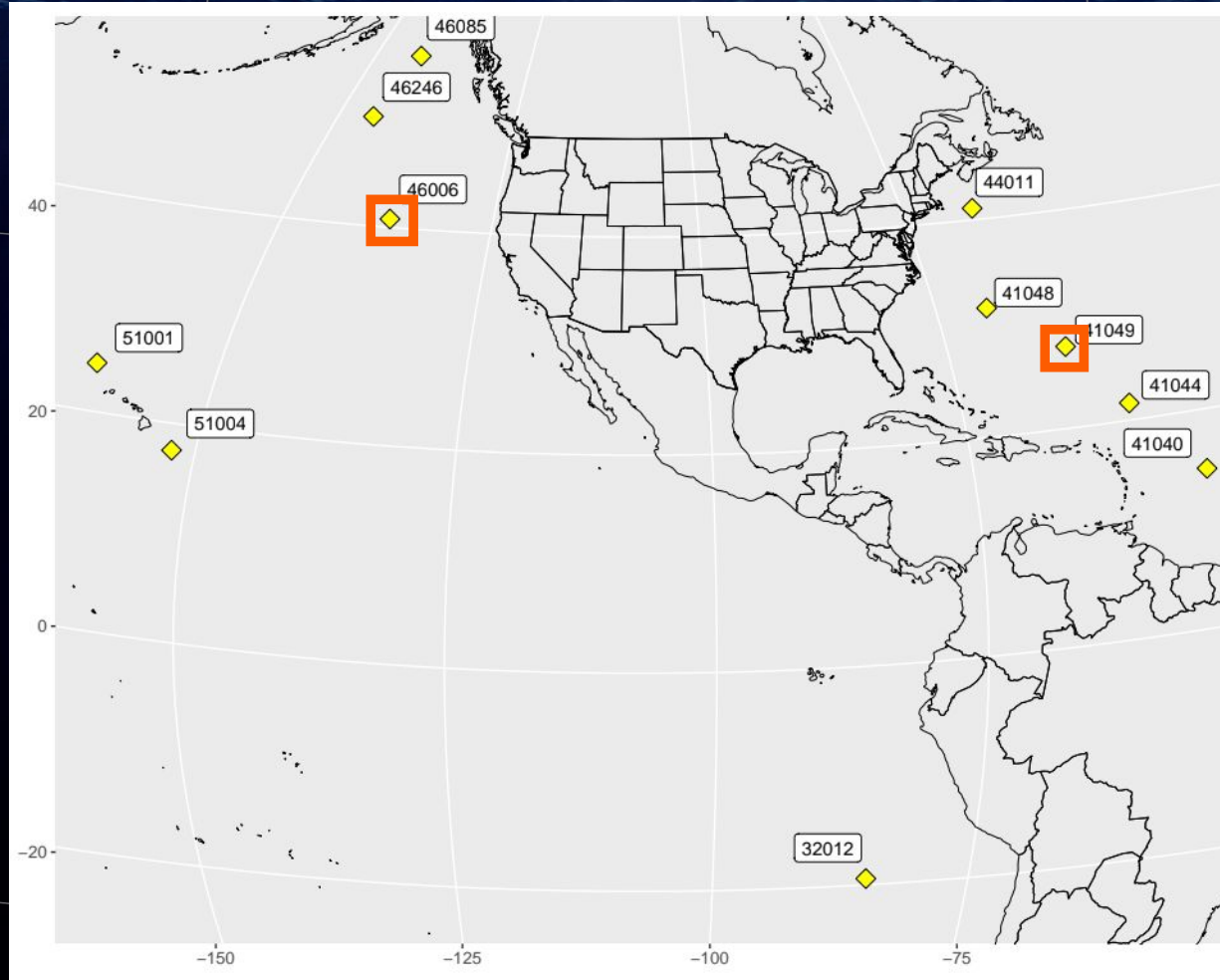


(B) 2014-2019[annual] (sentinel1\_SAR - ERA5): Diff. in climatological mean

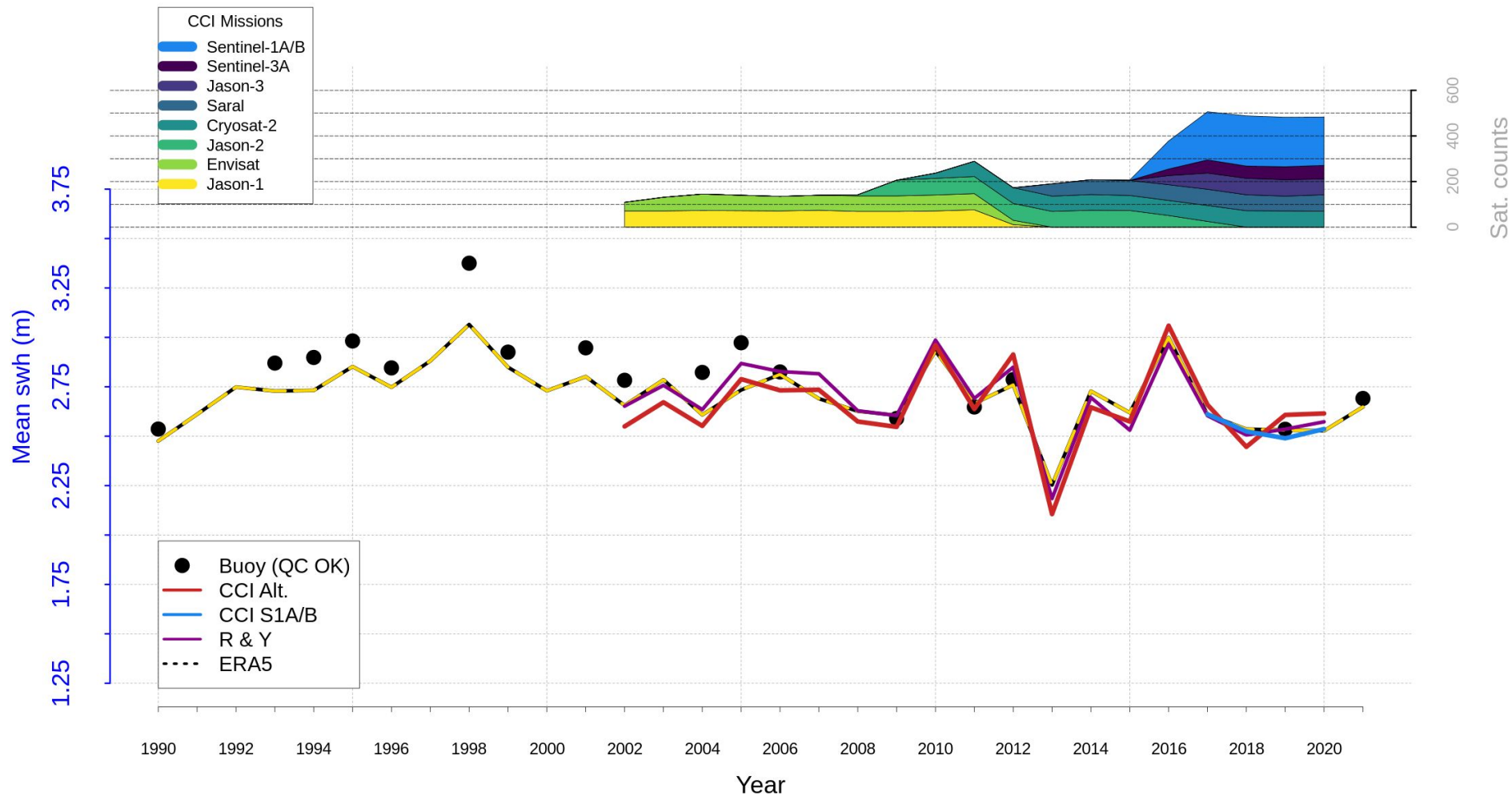




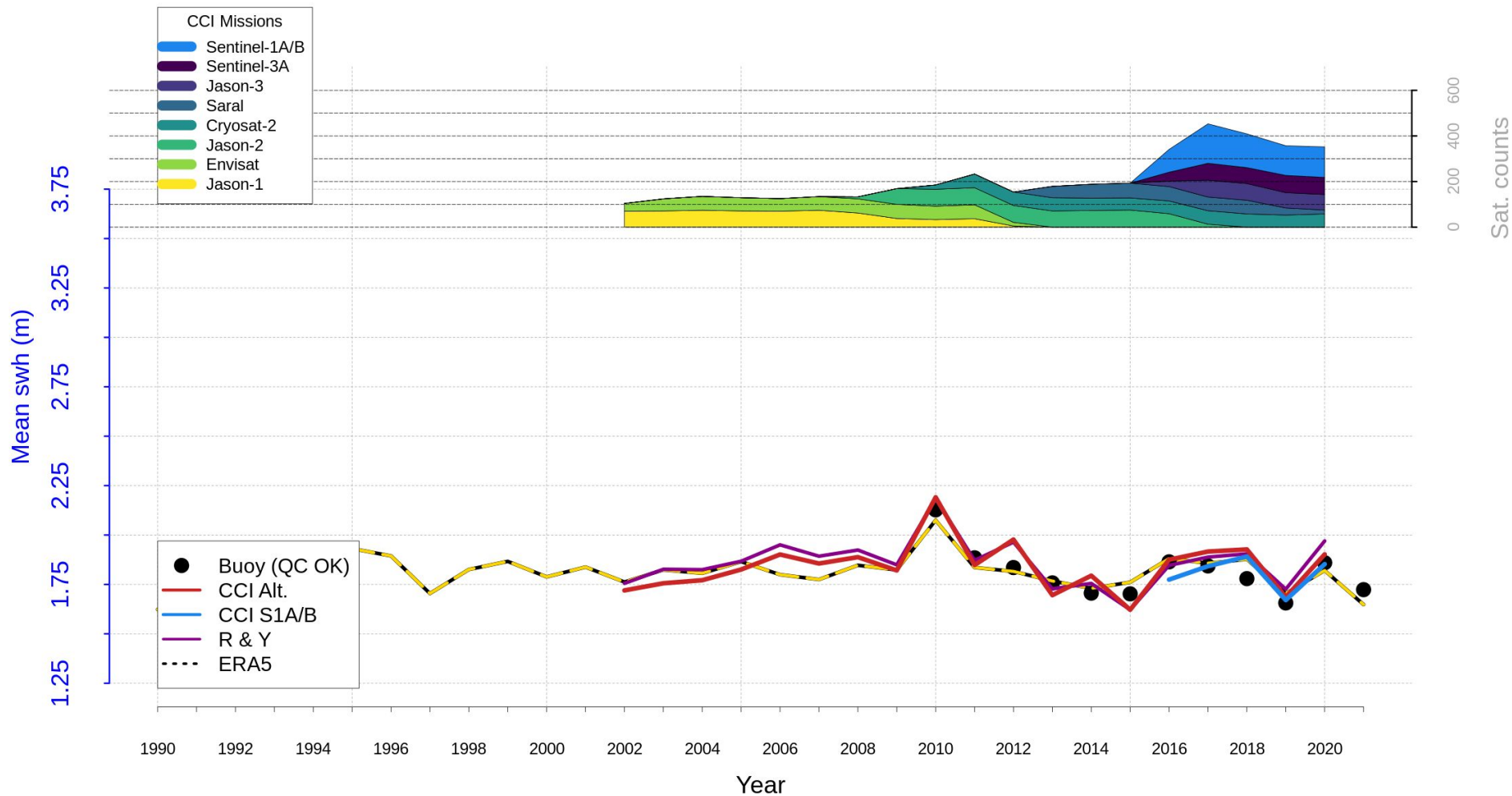
# Long term variability at buoy locations



# 46006 [Hs hourly annual] CCI Missions #: 1234569



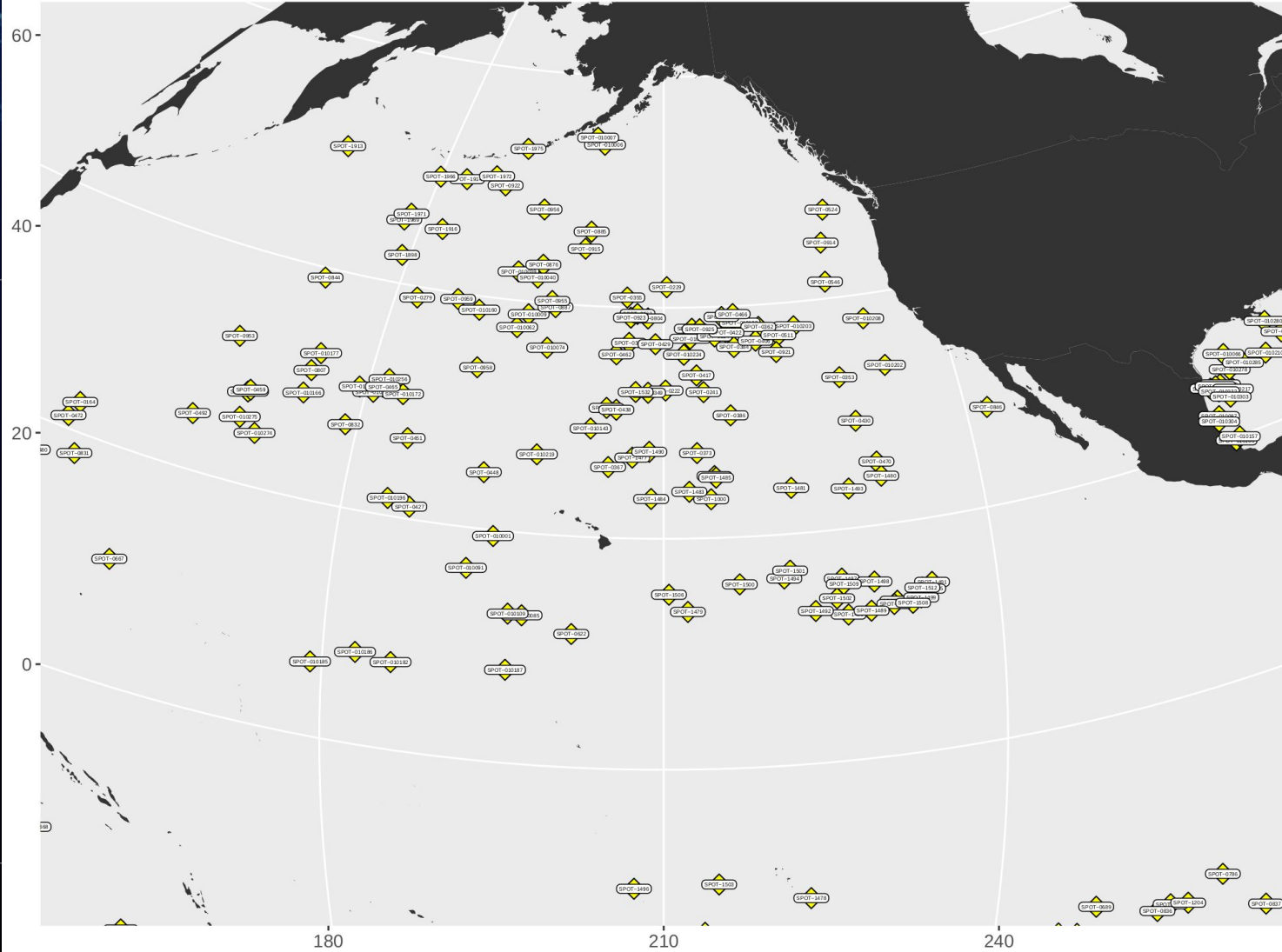
# 41049 [Hs hourly annual] CCI Missions #: 1234569



# Looking ahead ...

- ESA Sea State CCI Phase 2
  - Scope for consistent (multivariate) calibration across SAR wave mode products.
  - *Inclusion of new SAR wave mode missions / products...?*
  - *CFOSat ...*
- Sentinel-6 Tandem Phase triple co-location / validation
  - Interest in the sea state dependence of recent S-6 LRM and SAR observations.
  - ***Can we use Sentinel-1 multivariate observations to cross-validate against, e.g. ERA5, when looking at possible windsea / swell dominated seas?***

Sofar Ocean Drifting Buoys (location snapshot, N.Pacific): 2022-03-01



# Summary

- ESA Sea State CCI data released!

*Download data from:*

*<https://climate.esa.int/en/projects/sea-state/data/>*

- Sentinel-1 A/B and Envisat SAR wave mode multivariate data available
  - Good performance vs *in situ* observations
  - Good sampling rate but with coverage limitations

*Look out for:*

*Pleskachevsky, A., Tings, B. et al. 2022. Multiparametric Sea State Fields from Synthetic Aperture Radar for Maritime Situational Awareness. Remote Sensing of Environment*

*Timmermans et al. 2022, Global multivariate observations of ocean surface wave climate from remote sensing, Remote Sensing (in prep.)*

**Thanks!**

# References

Dodet et al. 2020, The Sea State CCI dataset v1: towards a sea state climate data record based on satellite observations, *Earth Syst. Sci. Data*, 12, 1929–1951, <https://doi.org/10.5194/essd-12-1929-2020>

Timmermans et al. 2020, Global Wave Height Trends and Variability from New Multimission Satellite Altimeter Products, Reanalyses, and Wave Buoys, *GRL*, 47, <https://doi.org/10.1029/2019GL086880>

Meucci et al. 2020, Comparison of Wind Speed and Wave Height Trends from Twentieth-Century Models and Satellite Altimeters, *Journal of Climate* <https://doi.org/10.1175/JCLI-D-19-0540.1>

Gemmrich et al. 2011, Observational changes and trends in northeast Pacific wave records, *GRL*, 38, <https://doi.org/10.1029/2011GL049518>



National  
Oceanography  
Centre

[noc.ac.uk](http://noc.ac.uk)

Challenger Waves SIG, London  
05 Sep 2022



# Intercomparison with in situ and other products

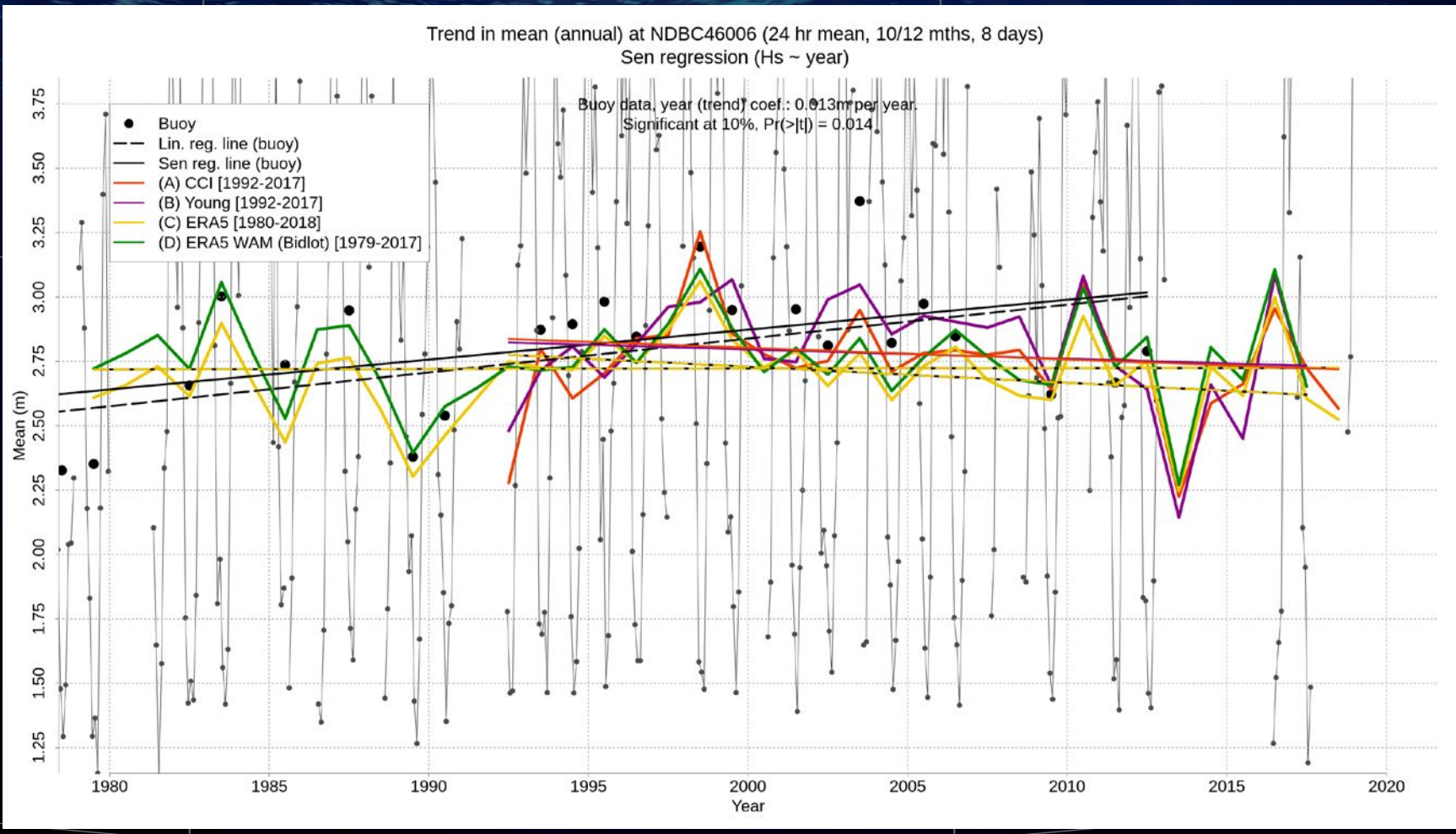
Better agreement between products towards the end of the altimeter era.

Trends are broadly consistent between satellite and model products.

Large variability in buoy data over interannual / decadal timescales.

Concerns over effect of introduction of data assimilation (Meucci et al., 2020)

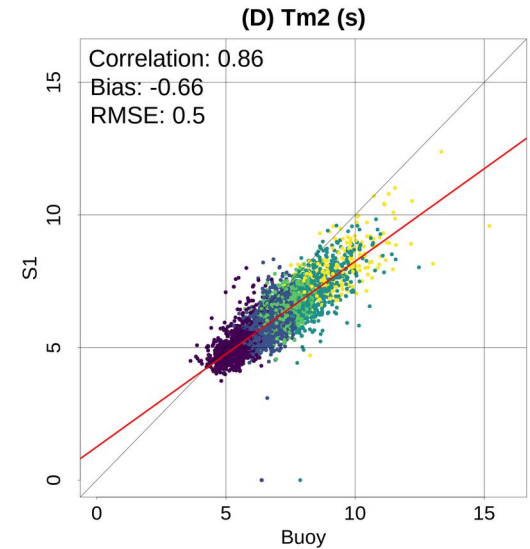
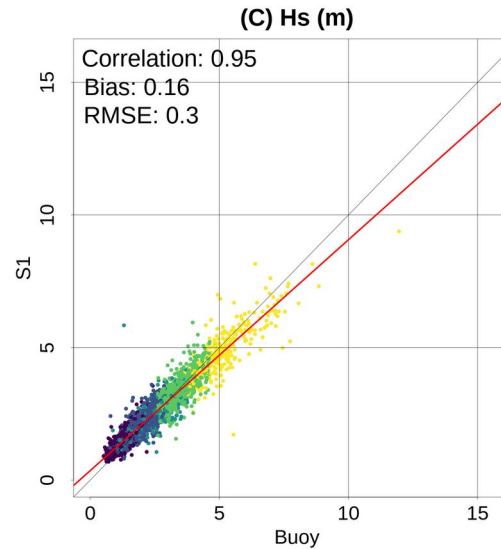
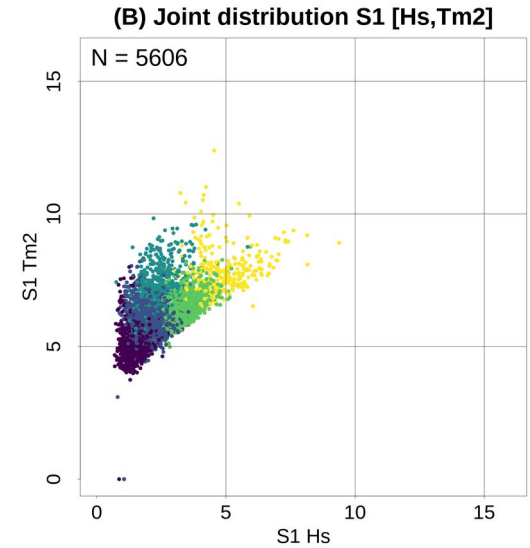
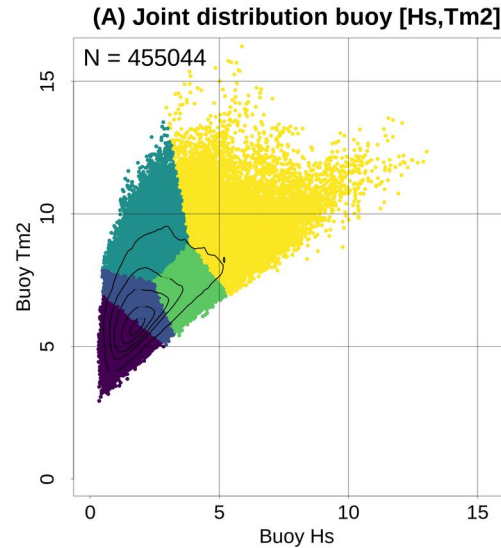
Concerns over the long-term stability of buoy data at this site, and others.



Impact of changes in buoy platform / sensor (Gemrich et al., 2011)

# S-1 A/B performance

- We compare the multivariate in situ (Pacific / Atlantic) sea state via the joint distribution of  $H_s$ ,  $Tm_2$
- NDBC buoys: 46246, 46085, 51004, 51001, 32012, 44011, 41040, 41044, 41048, 41049, 46006
- Sea state dependence indicated by colouring scheme.
- Some differences in bias for  $H_s$  and  $Tm_2$  with Envisat (wave mode).



# Summary: S6-JTEX planned activities

## Focus on triple collocation:

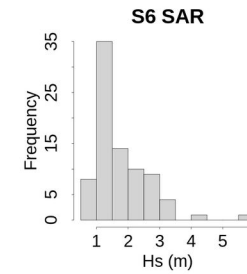
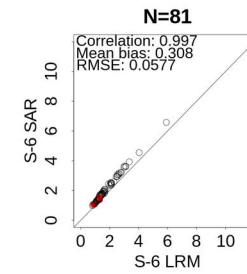
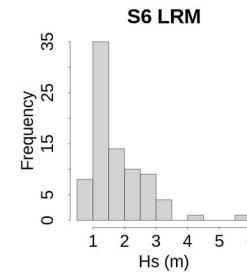
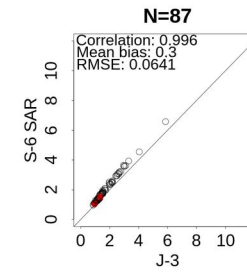
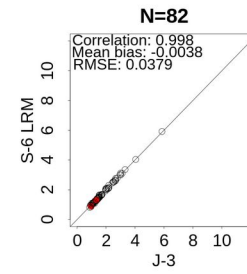
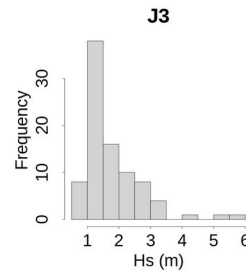
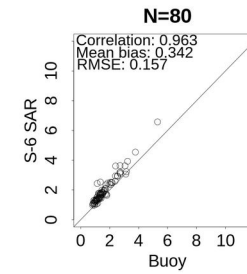
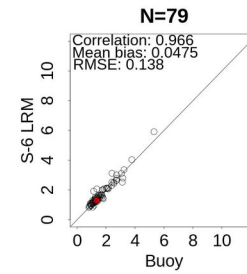
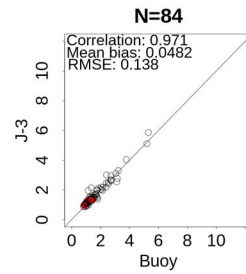
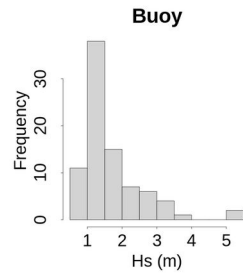
- Estimate errors in different types of sea state data without a priori assumption about reference.
- Sensitivity to sample size, statistical independence between modes, and representativity errors.

## Experiments with Tandem phase data include:

- S6-MF LRM, Jason 3 (LRM) and wave buoy to evaluate the consistency of S6-MF LRM data against Jason-3 and the same fiducial observations, in relation to long-term climate records for sea state.
- S6-MF SAR, Jason 3 (LRM) and wave buoys to examine the uncertainties of S6-MF interleaved SAR measurements against the common reference from Jason-3 and buoys.
- S6-MF SAR, S6-MF LRM and Jason 3 (LRM) in different oceanic regions to provide a broader view of performance across the globe, including conditions that are poorly represented by in situ data (e.g. Southern Ocean, Central Pacific).

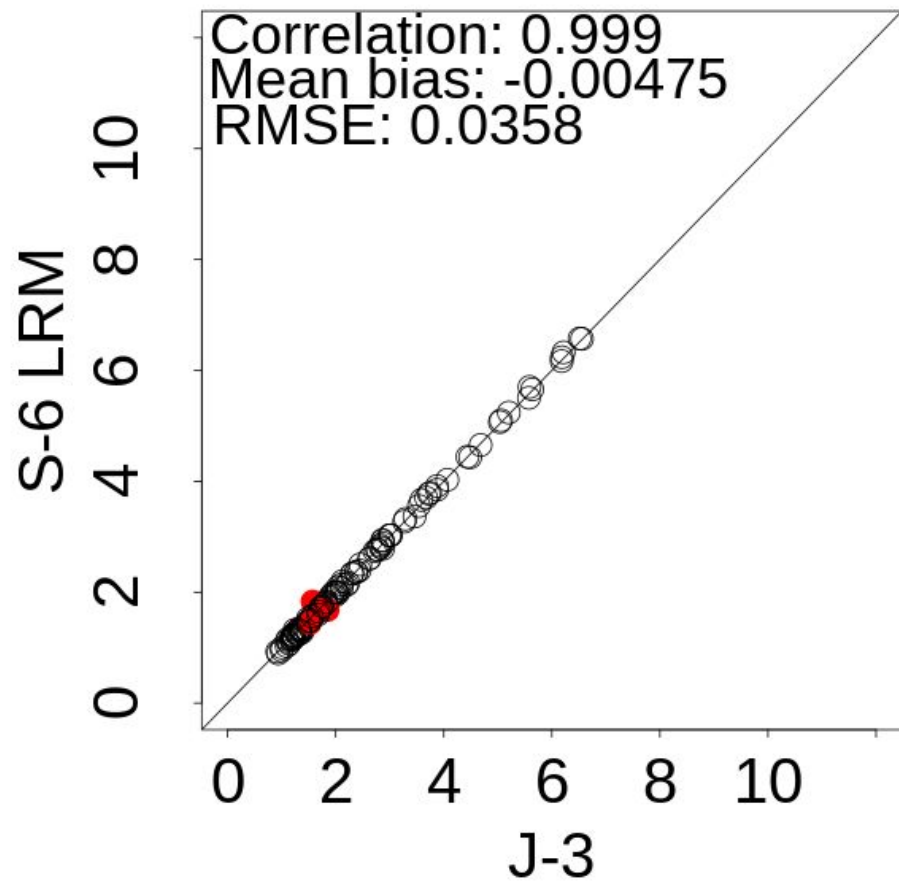
# Product intercomparisons at 46006

2020/12 - 2021/10 Buoy: 41049

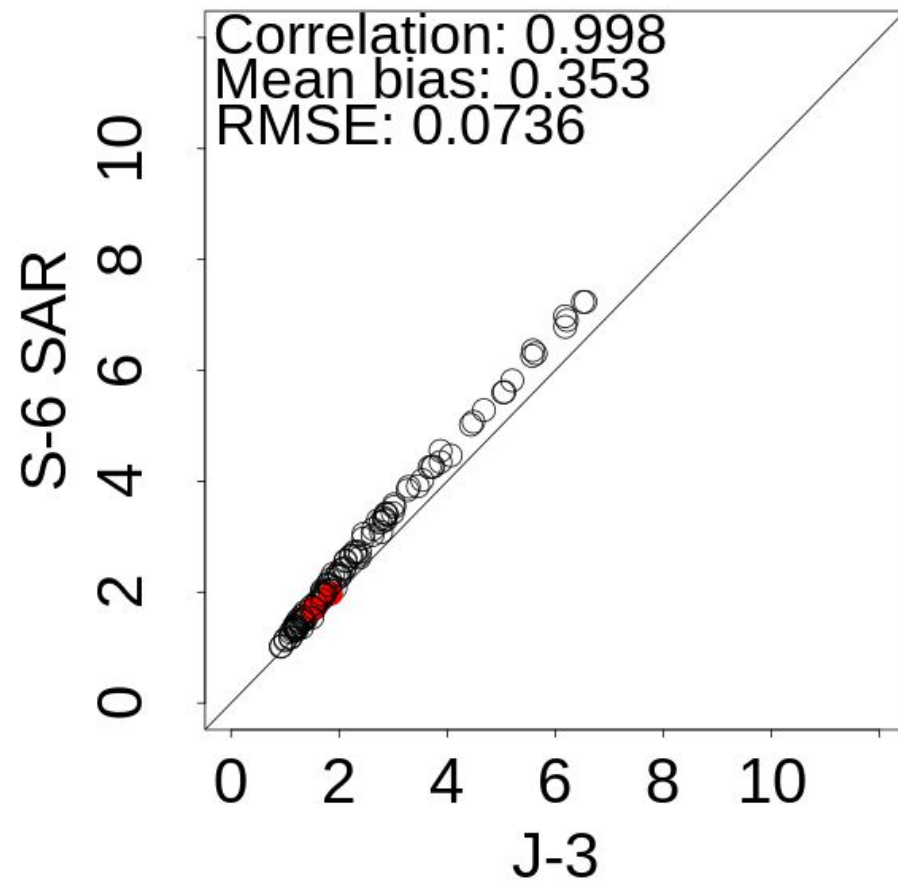


Product intercomparisons  
at 46006

**N=113**



**N=116**



# Product intercomparisons at 46006

