Global sea state variability from new multivariate multi-mission satellite altimeter products, reanalyses and wave buoys

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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)

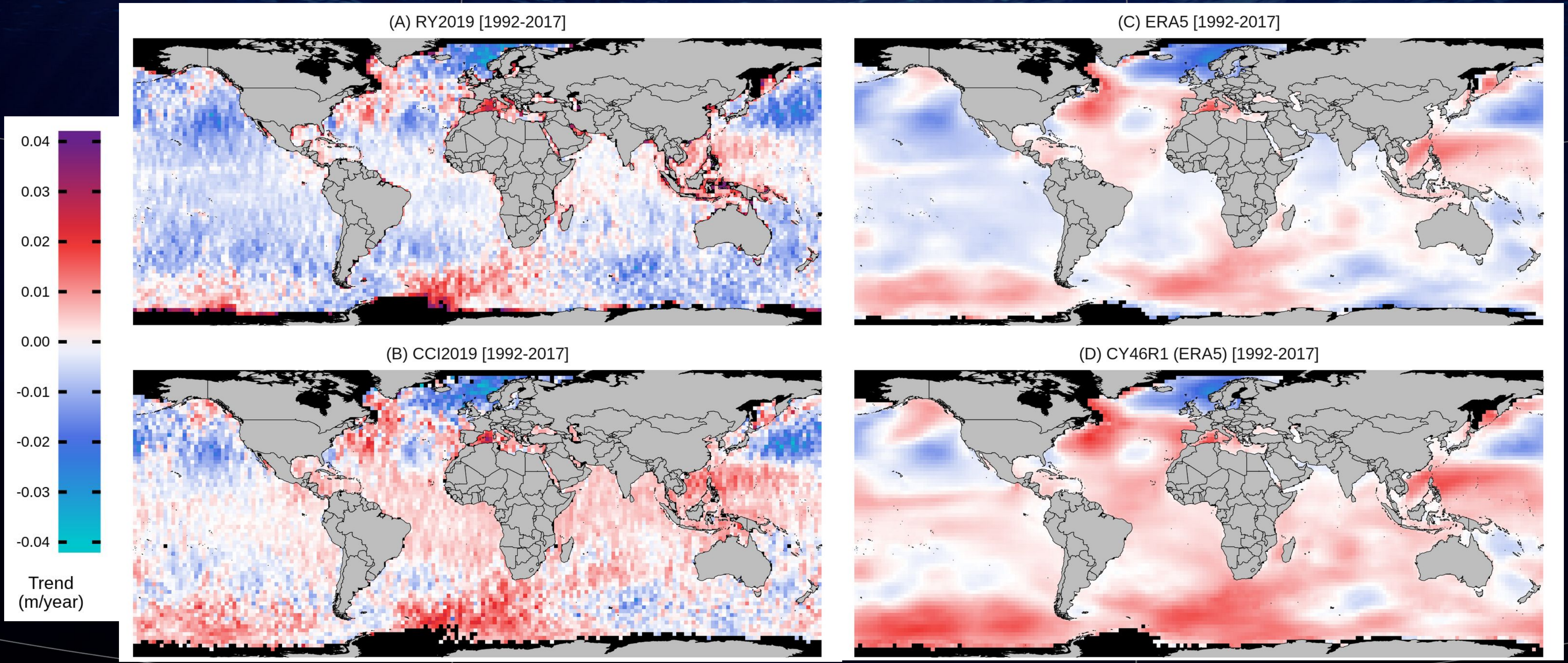
Opportunities from remote multivariate observations of the sea state

- Sentinel-1 A/B performance and contribution

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*

Intercomparison with in situ and other products

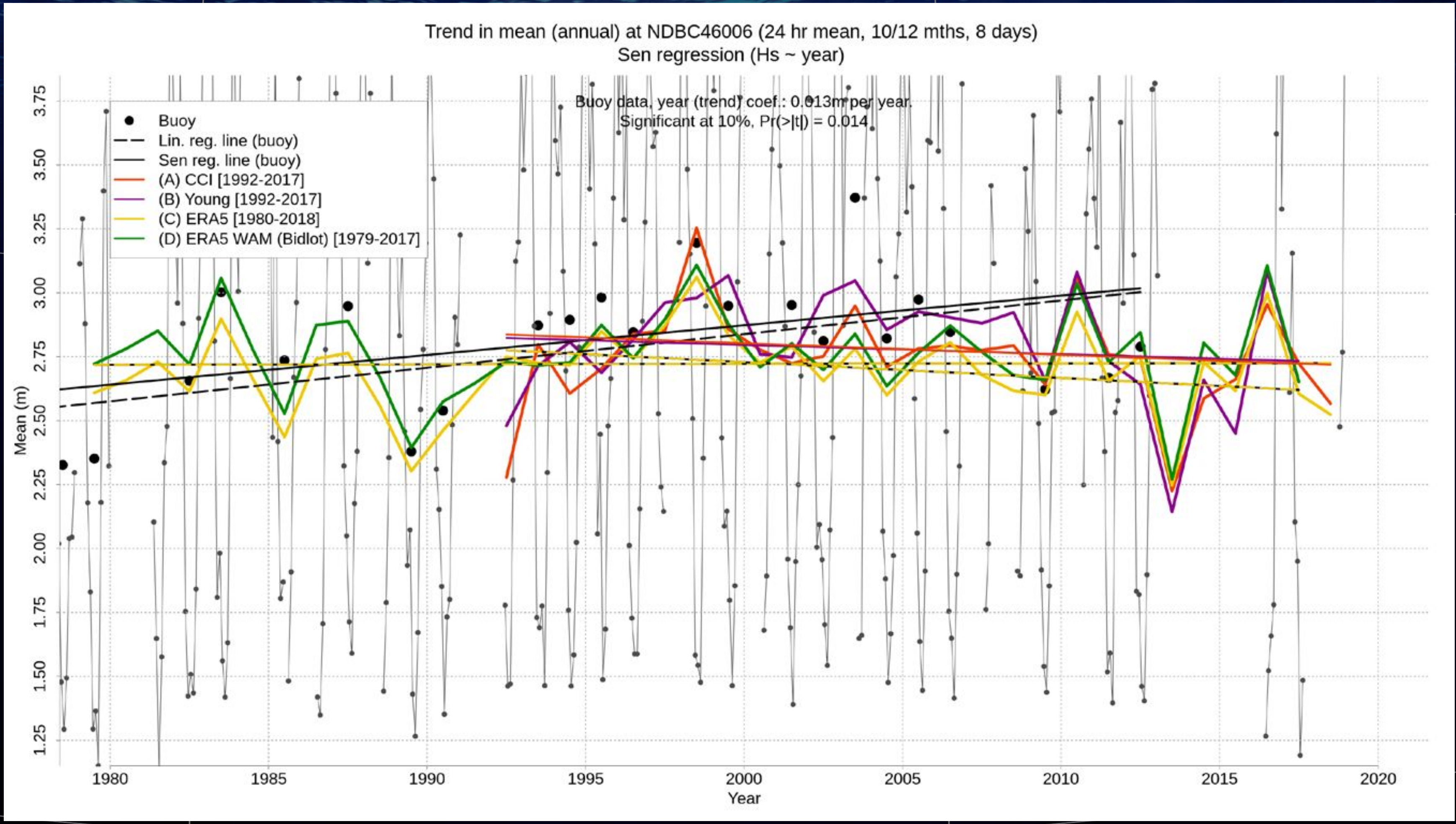
Better agreement between products towards the end of the altimeter era.

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 (Gemmrich et al., 2011)

Sea State CCI: Phase 1 complete

Version 1.1 data, released mid-2000

- Time series spans: 1992 – 2018
- L2, L3, L4 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/

Opportunities from recently acquired data

- Updated retracking for improved data quality in the coastal zone
- **Multivariate observations of sea state from SAR wave mode (Envisat, Sentinel-1 A/B)**
- **Increased data sampling of Hs (total) due to the addition of SAR wave mode**

Please see poster TODAY for details of the Sentinel-1 Wave Mode production...

Multiparametric Sea State from spaceborne Synthetic Aperture Radar and Sentinel-1 Wave Mode Archive Processing in Scope of ESA Climate Change Initiative CCI

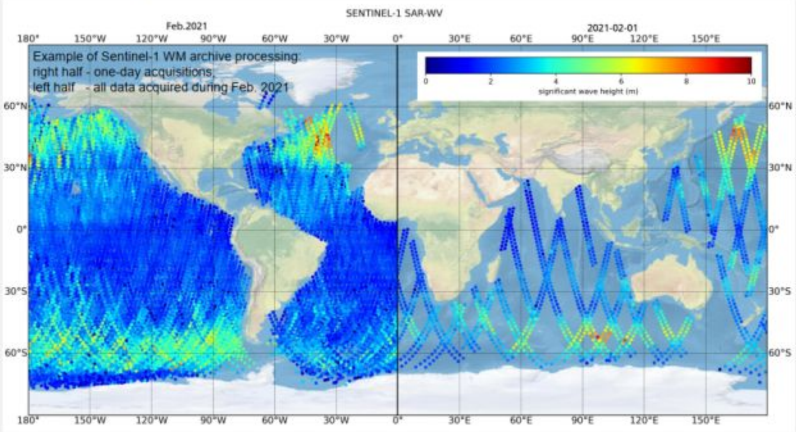
Andrey Pleskachevsky, Björn Tings, Sven Jacobsen *– DLR, Earth Observation Center, Maritime Safety and Security Lab Bremen*
Egbert Schwarz, Detmar Krause, Sergey Voinov *– DLR, Earth Observation Center, Maritime Safety and Security Lab Neustrelitz*

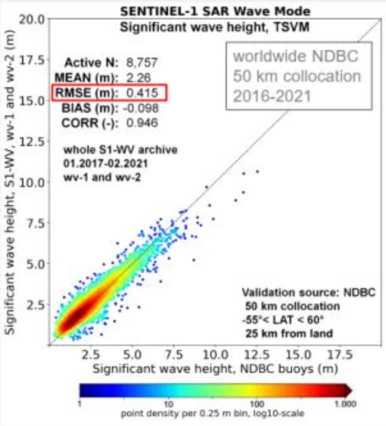
5. Sentinel-1 Wave Mode Archive Processing in Scope of ESA Climate Change Initiative

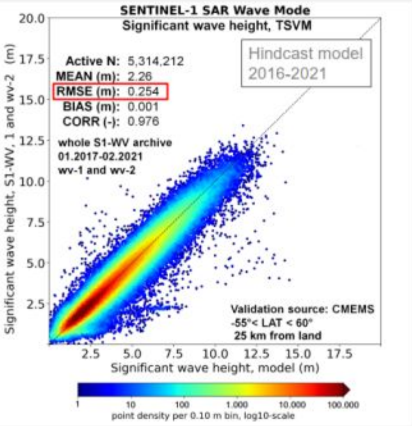
— **Sentinel-1 Wave-Mode whole archive 2014-2021 processed (~15 Mio imagettes), validated, delivered to ESA:**
8 sea state parameters: wave height (swell's, wind-sea), periods (mean, cross-zero, wind-sea). Format: ID.nc for each ID-product

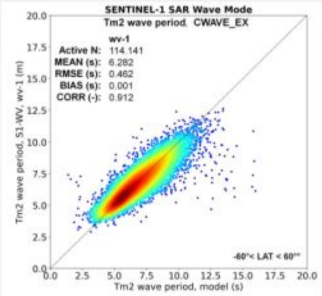
— **Accuracy of 24 cm reached (significant wave height) –** comparable to accuracy of altimeter and ground truth noise
combination of classical approaches with machine learning

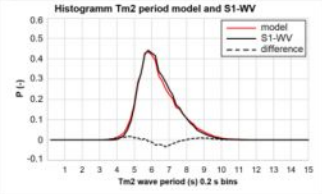
— **Method adopted for Sentinel-1 modes IW, EW, WV and also for TS-X SM**

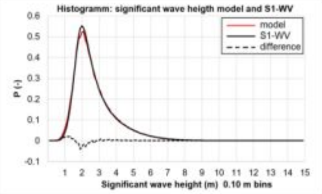




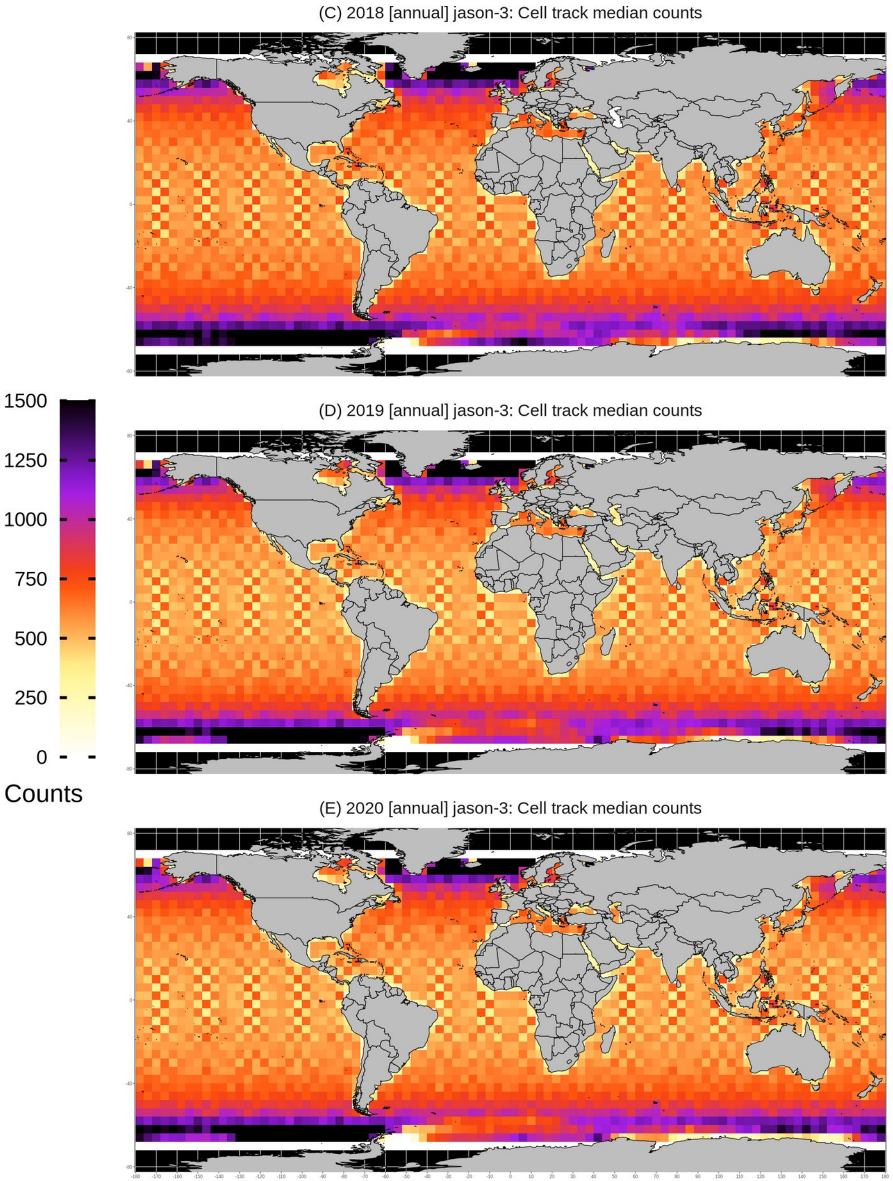


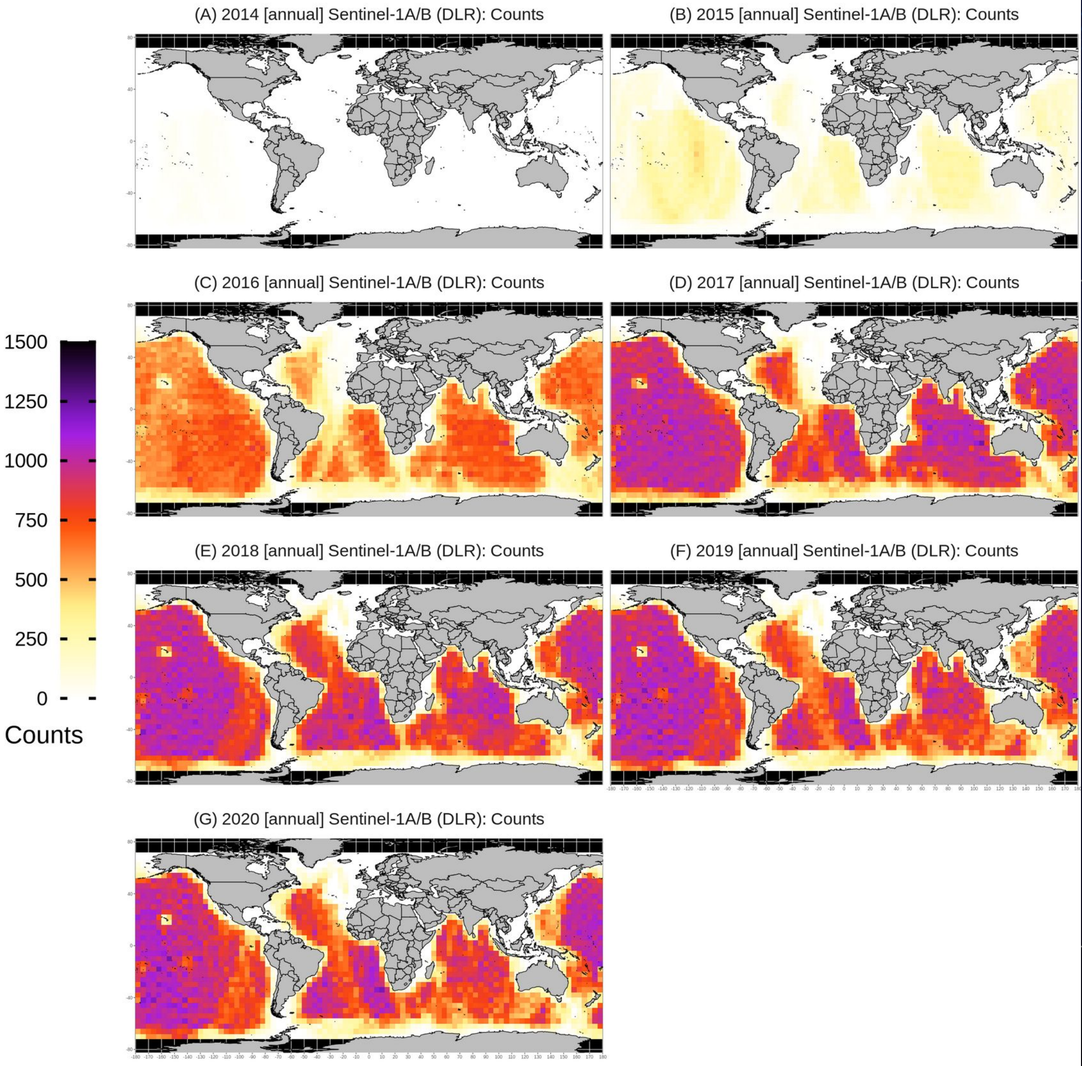




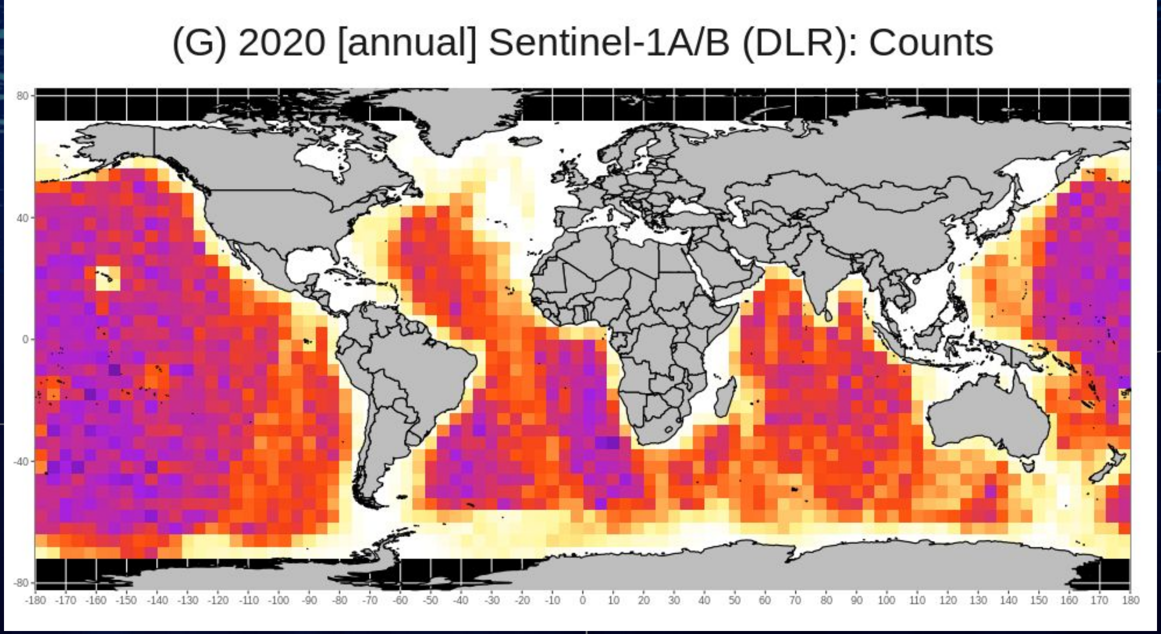


Pleskachevsky, A., Tings, B., Jacobsen., S., 2022. Multiparametric Sea State Fields from Synthetic Aperture Radar for Maritime Situational Awareness. Remote Sensing of Environment (in review)


(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

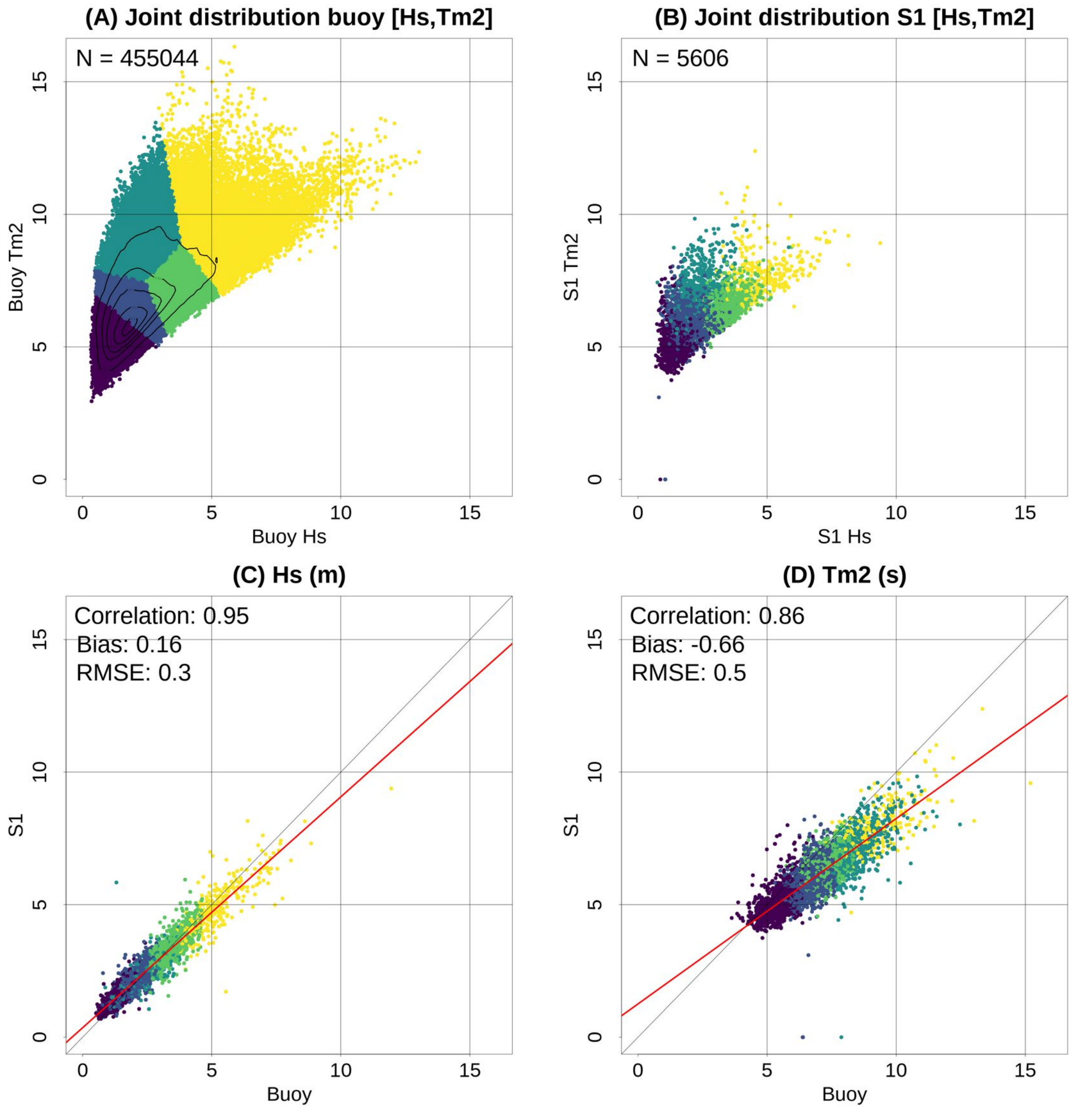
- Sentinel-1 wave mode **does not co-locate** well with many long term in situ wave buoys!



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

S-1 A/B performance

- We compare the multivariate in situ (Pacific / Atlantic) sea state via the joint distribution of *Hs*, *Tm2*
- 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 *Hs* and *Tm2* with Envisat (wave mode).



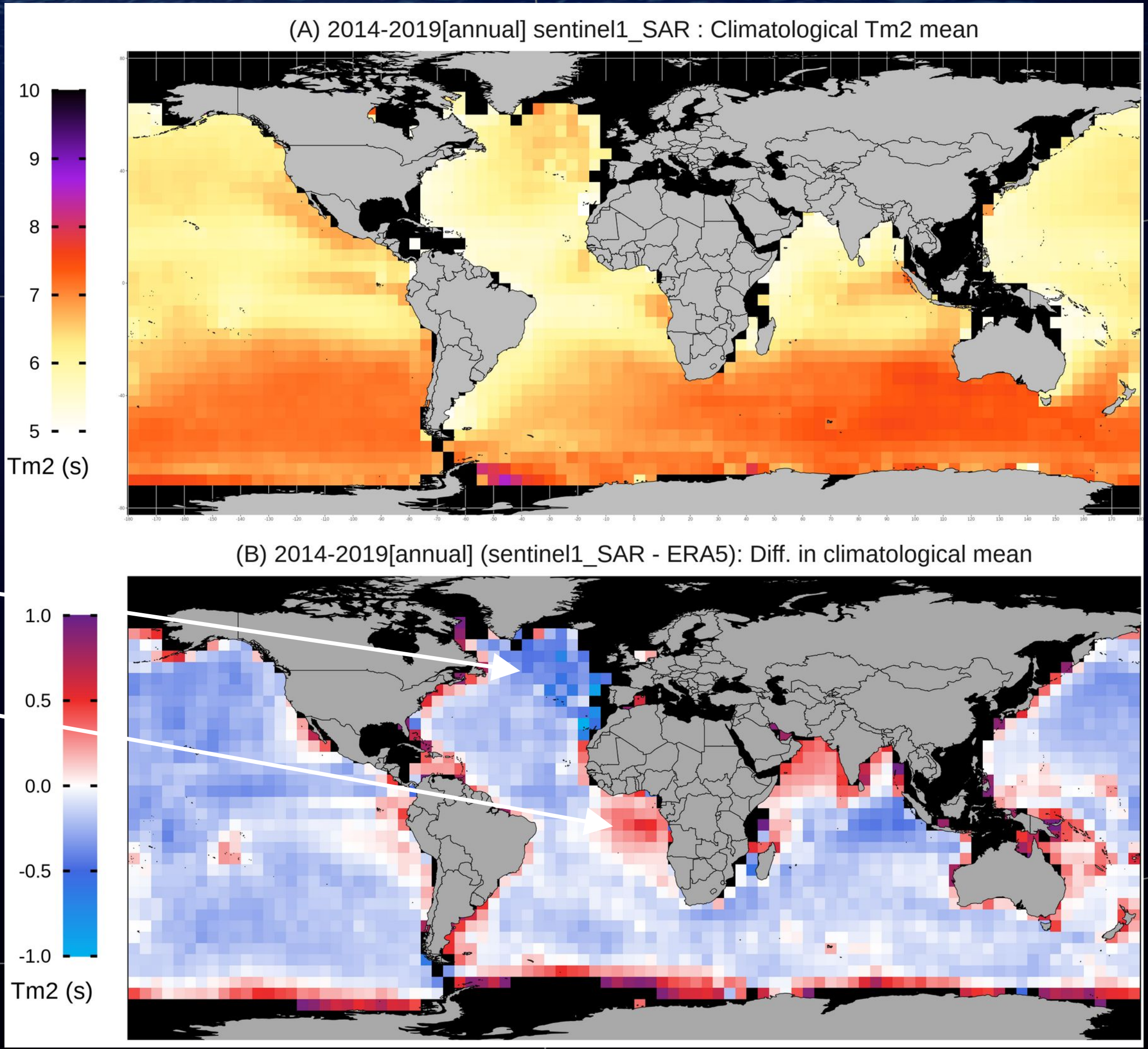
Global wave period characteristics (Sea State CCI, S-1 A/B)

- *A global record of wave period.*
- *Tm2* climatology (2014-2019) from Sentinel-1 A/B SAR wave mode.
- Permits observational comparison / validation against e.g. ERA5 reanalysis ...

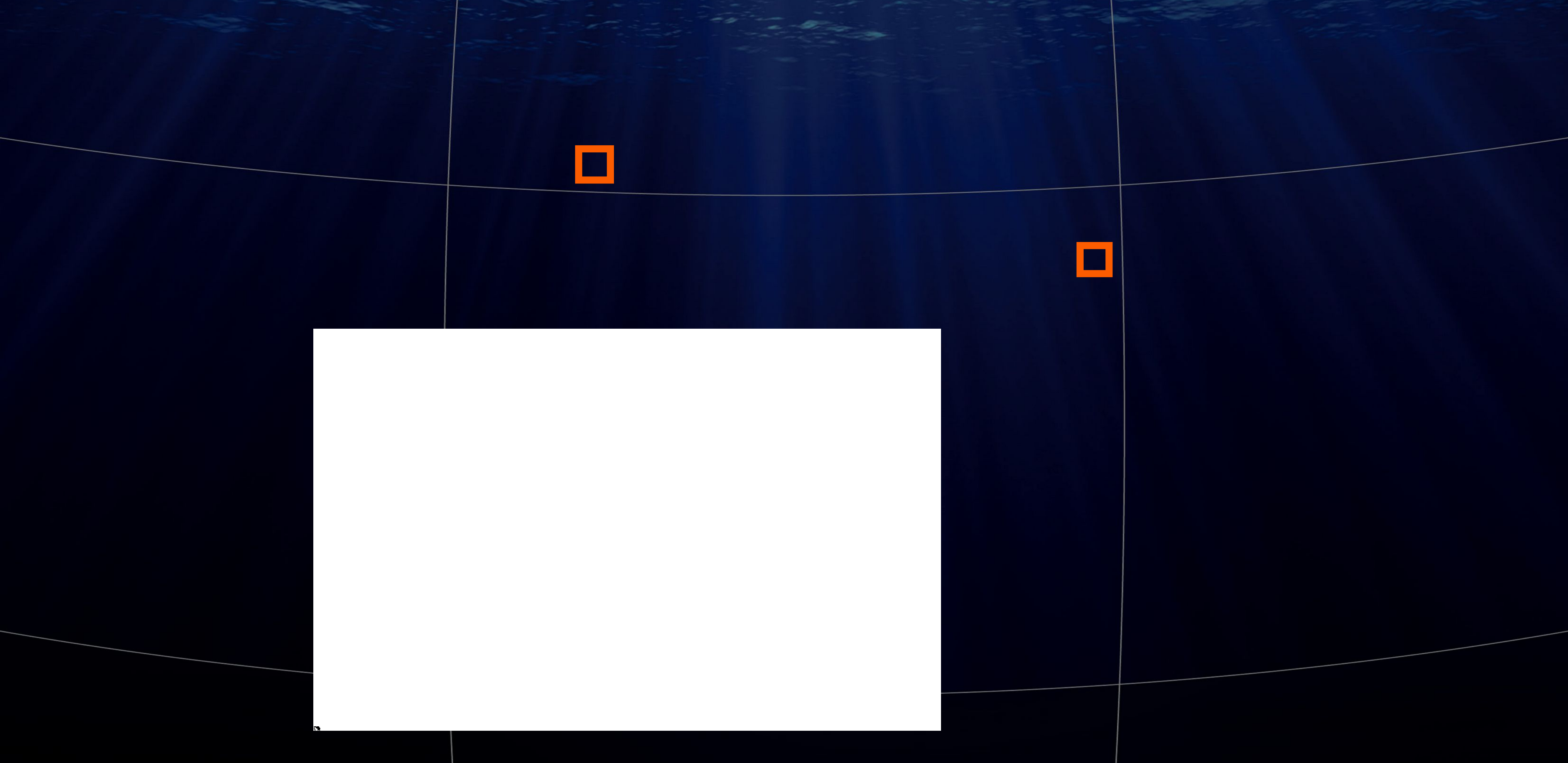
Regional differences attributable to:

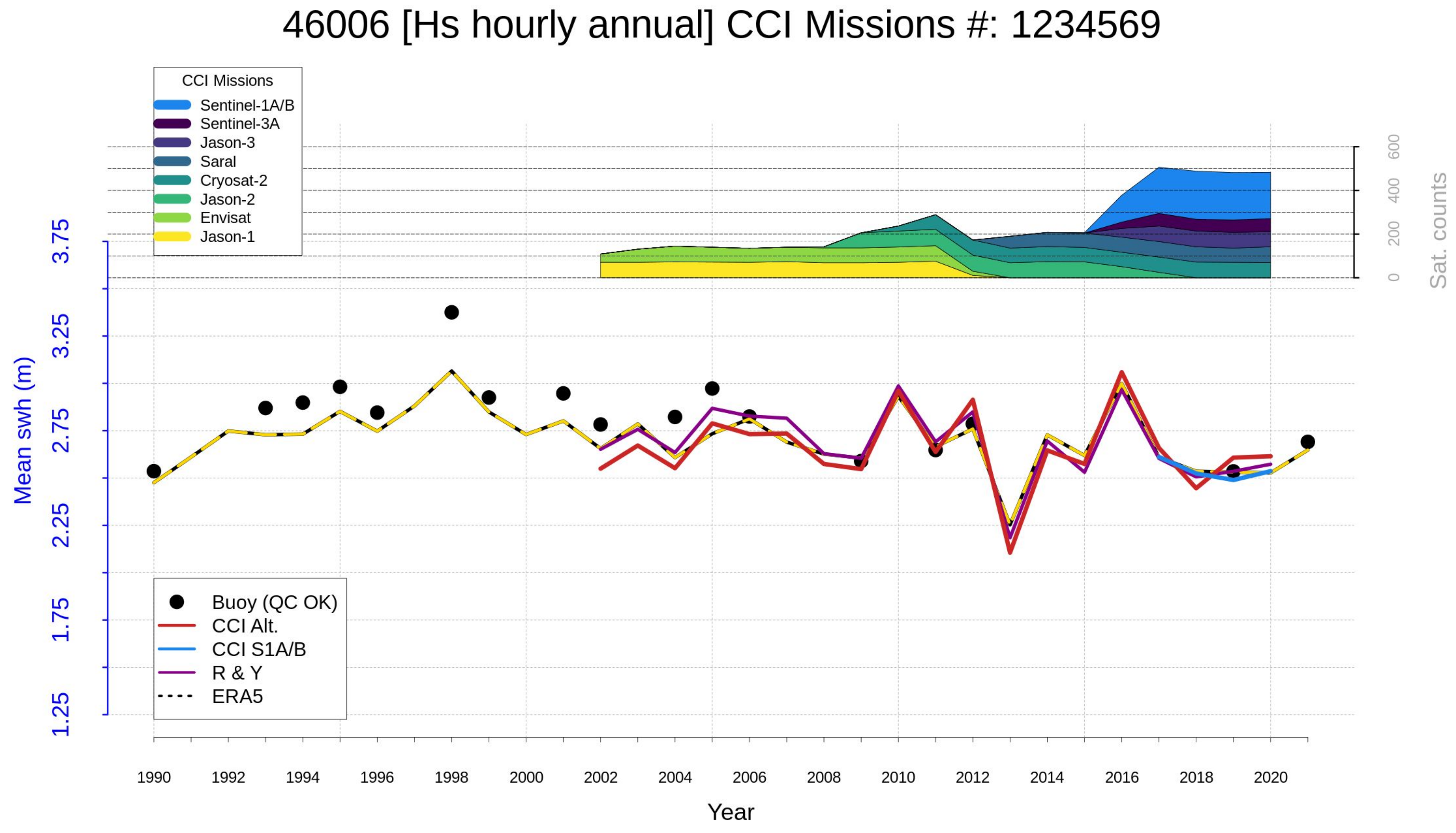
1) Low samping

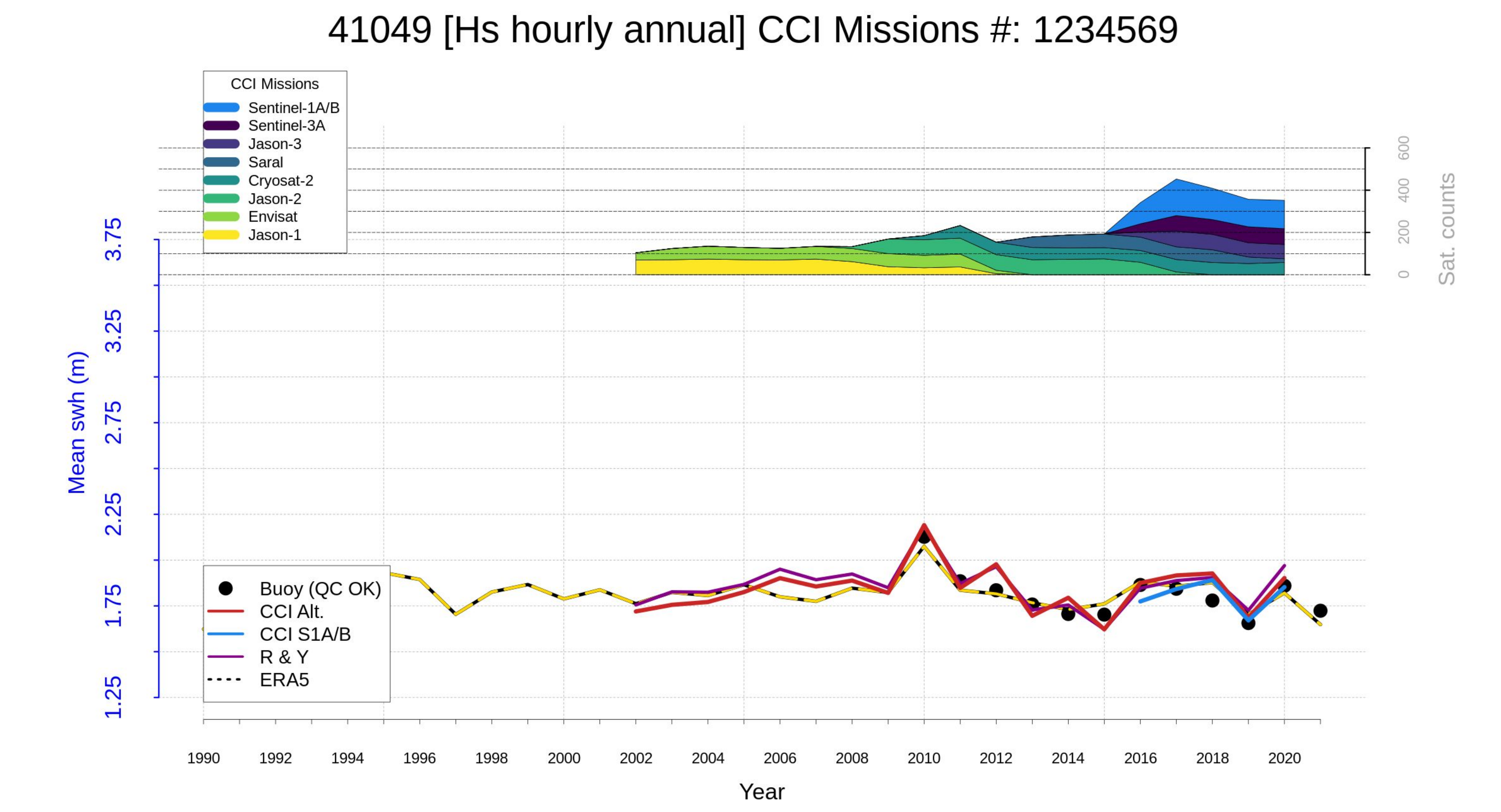
2) ???



Long term variability at buoy locations




46006 [Hs hourly annual] CCI Missions #: 1234569
CCI Missions
Sentinel-1A/B
Sentinel-3A
Jason-3
Saral
Cryosat-2
Jason-2
Envisat
Jason-1
Buoy (QC OK)
CCI Alt.
CCI S1A/B
R & Y
ERA5
Mean swh (m)
Sat. counts
Year
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
1.25
1.75
2.25
2.75
3.25
3.75
0
200
400
600


41049 [Hs hourly annual] CCI Missions #: 1234569
CCI Missions
Sentinel-1A/B
Sentinel-3A
Jason-3
Saral
Cryosat-2
Jason-2
Envisat
Jason-1
Buoy (QC OK)
CCI Alt.
CCI S1A/B
R & Y
ERA5
Mean swh (m)
1.25
1.75
2.25
2.75
3.25
3.75
Sat. counts
0
200
400
600
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year

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...?*

- 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?***

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., Jacobsen., S., 2022. Multiparametric Sea State Fields from Synthetic Aperture Radar for Maritime Situational Awareness. Remote Sensing of Environment (in review)

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

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

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Summary: S6-JTEX planned activities

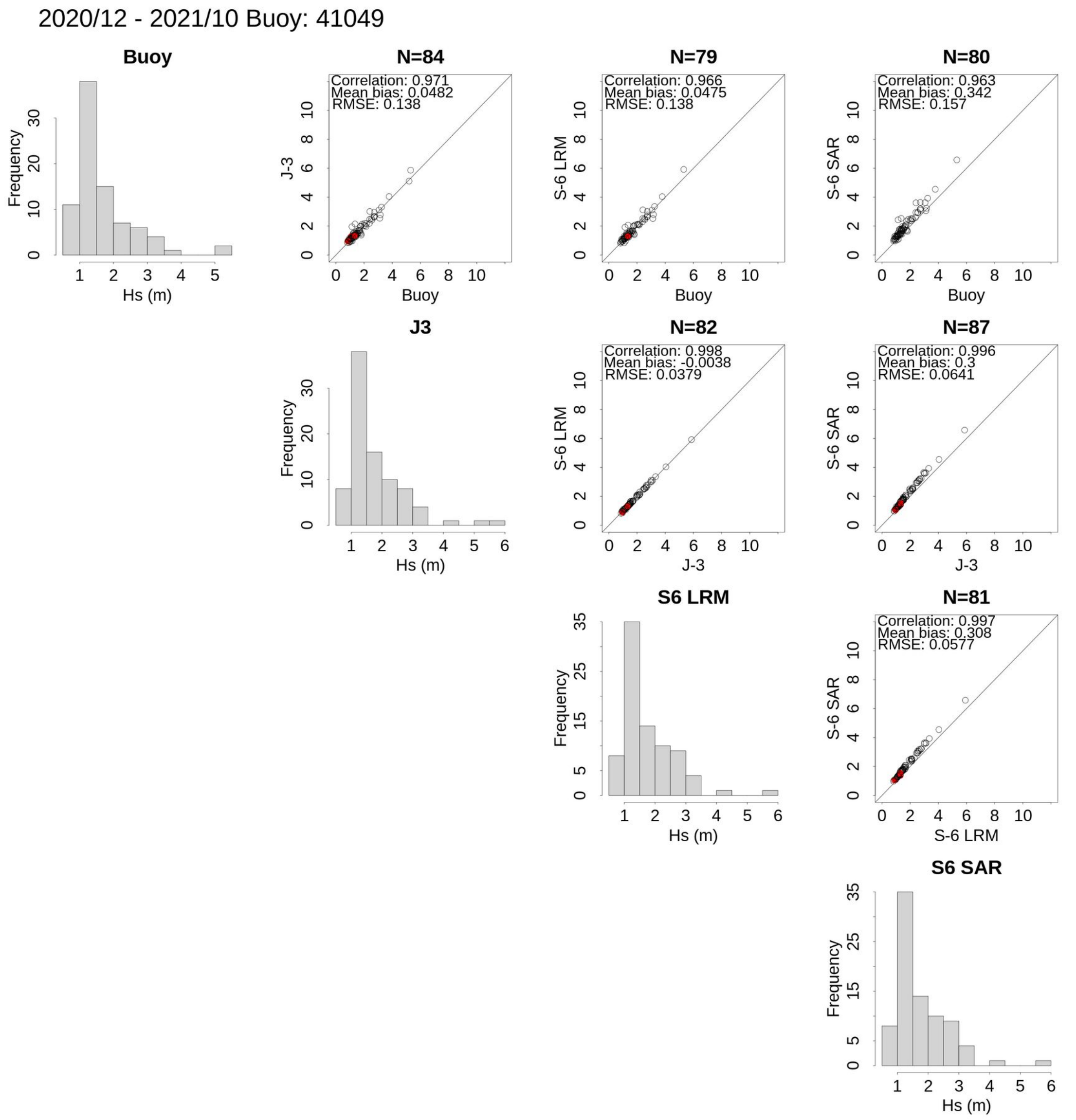
Focus on triple collocation:

- 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.

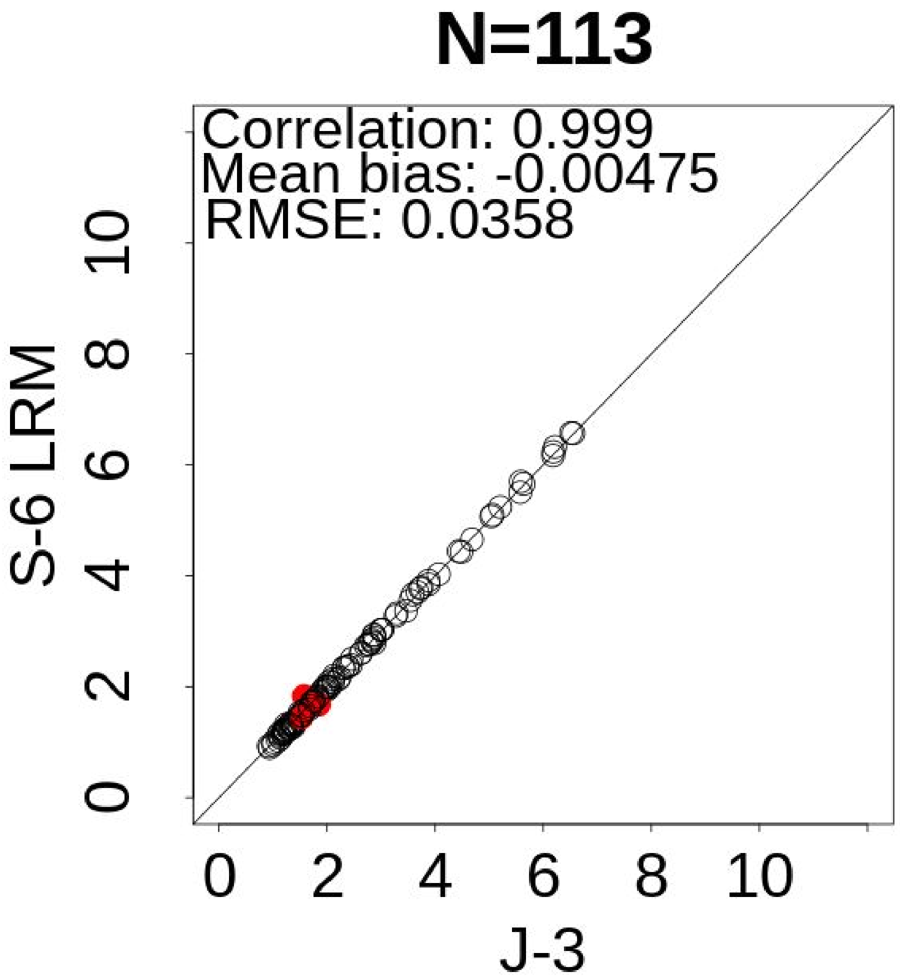
Experiments with Tandem phase data include:

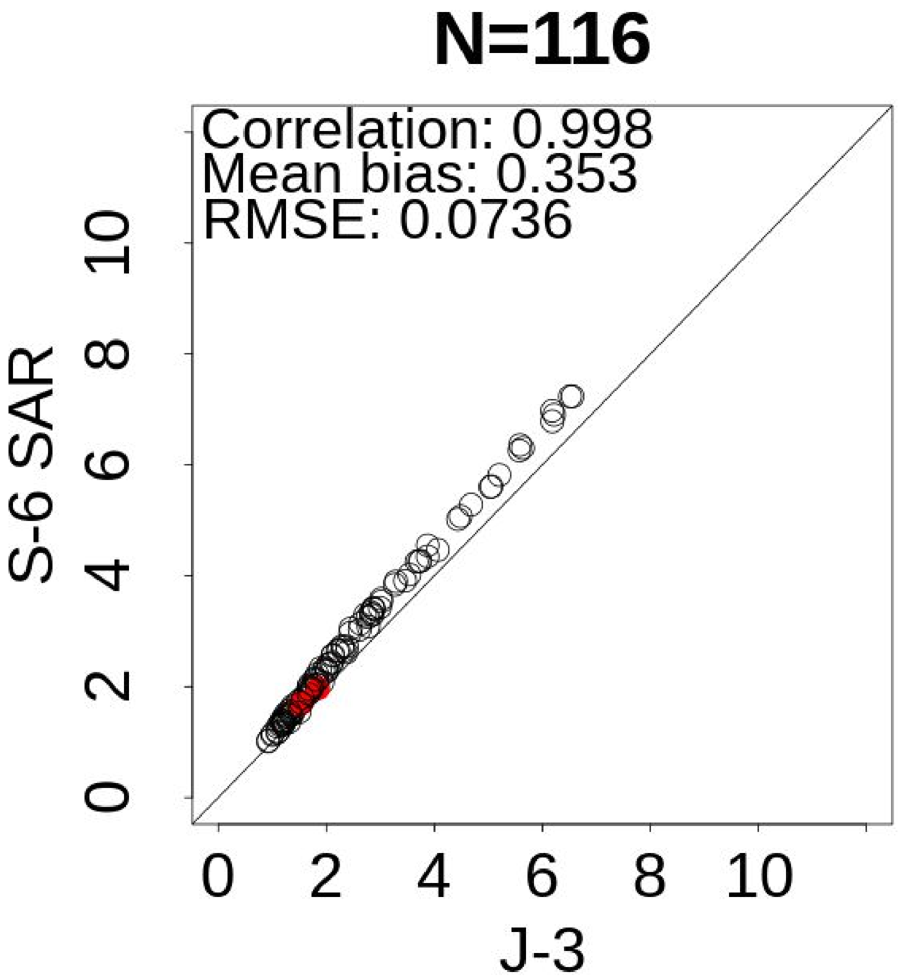
- S6-MF LRM, Jason 3 (LRM) and wave buoy to evaluate the consistency of S6-MF LRM data against Jason-3 and the same fiducial observations, in relation to long-term climate records for sea state.
- S6-MF SAR, Jason 3 (LRM) and wave buoys to examine the uncertainties of S6-MF interleaved SAR measurements 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



Product intercomparisons at 46006





Product intercomparisons at 46006