

Listen to the ocean

Evaluating Sentinel-3A SRAL performance near the coast of southwest England

Francesco Nencioli¹ and Graham Quartly¹

¹Plymouth Marine Laboratory, UK



*Mission
Performance
Centre*



The work performed in the frame of this contract is carried out with funding by the European Union. The views expressed herein can in no way be taken to reflect the official opinion of either the European Union or the European Space Agency.

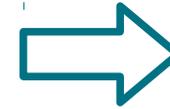


Advantages of Sentinel-3A SRAL



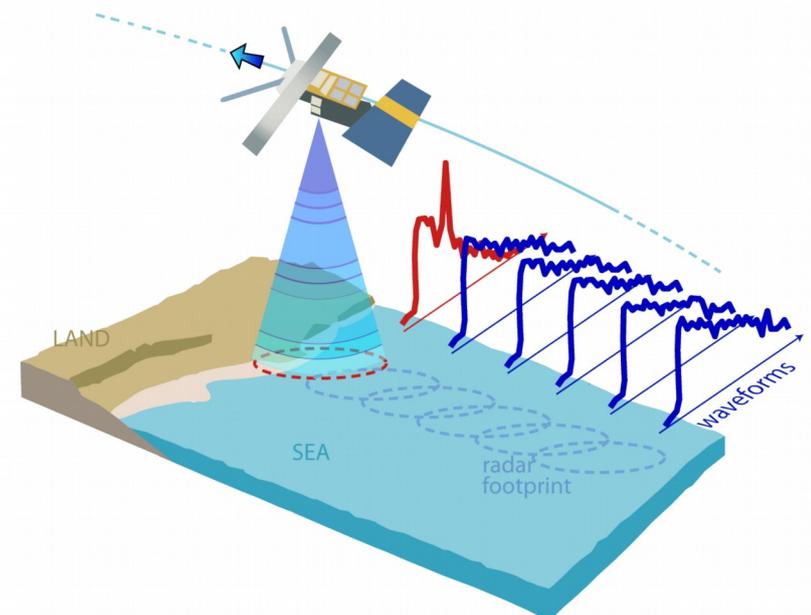
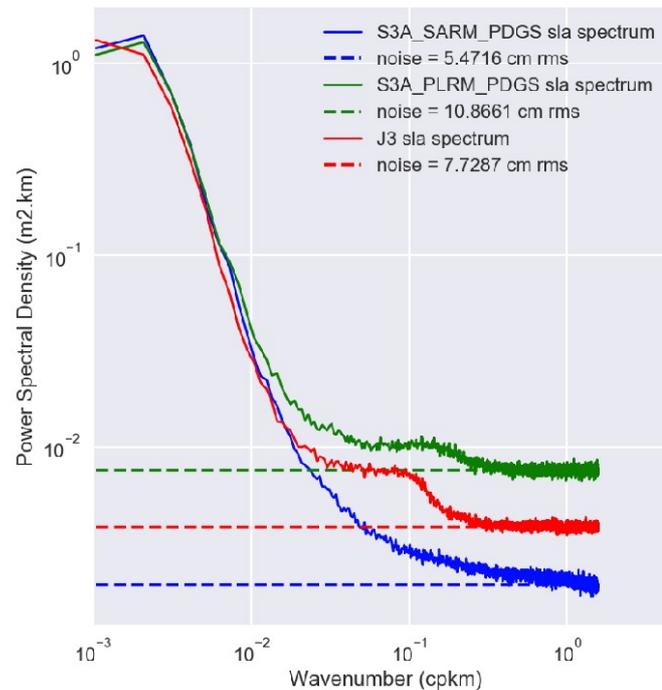
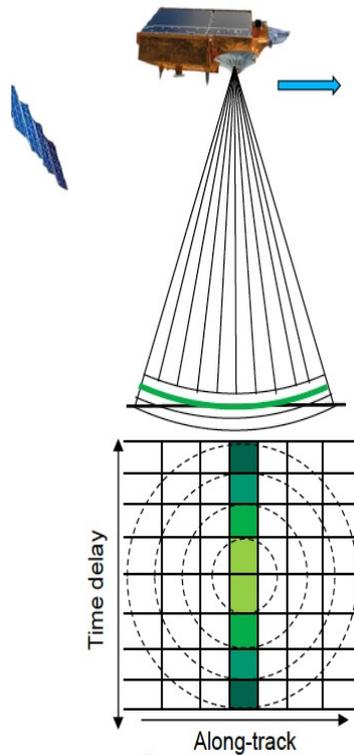
SAR instrument (dual-frequency delay-Doppler)

- Smaller footprint
- Lower noise levels



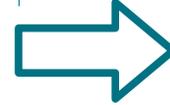
Higher spatial resolution

- (1) Improved accuracy near the coast**
- (2) Resolution of smaller scale dynamics (below large mesoscale $\sim O(100 \text{ km})$)**



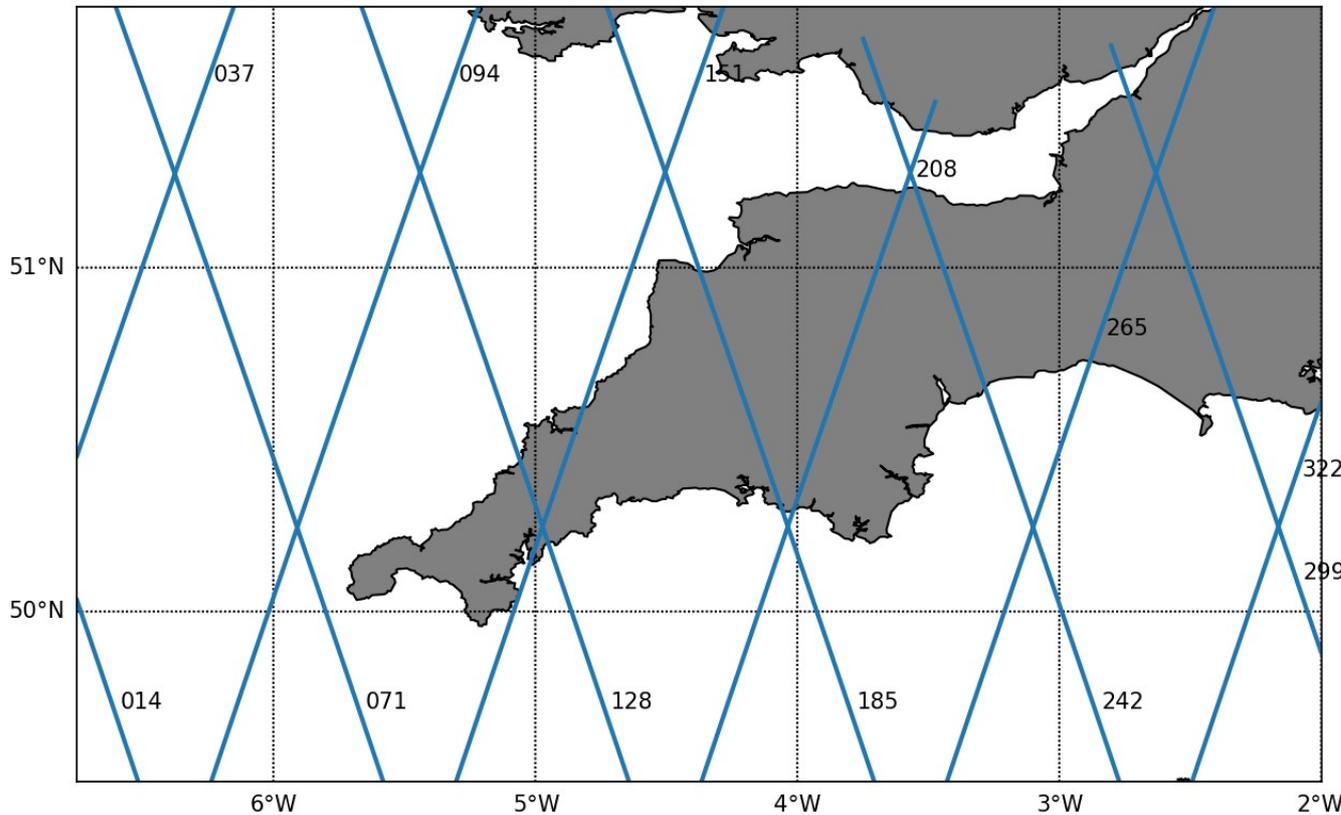
(source: <https://Sentinel.esa.int/web/Sentinel/user-guides/>)

- (1) Improved accuracy near the coast
- (2) Resolution of smaller scale dynamics (below large mesoscale $\sim O(100 \text{ km})$)



Assess both aspects in the coastal region of southwest England

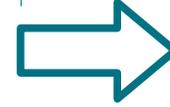
SW England and Sentinel3 tracks



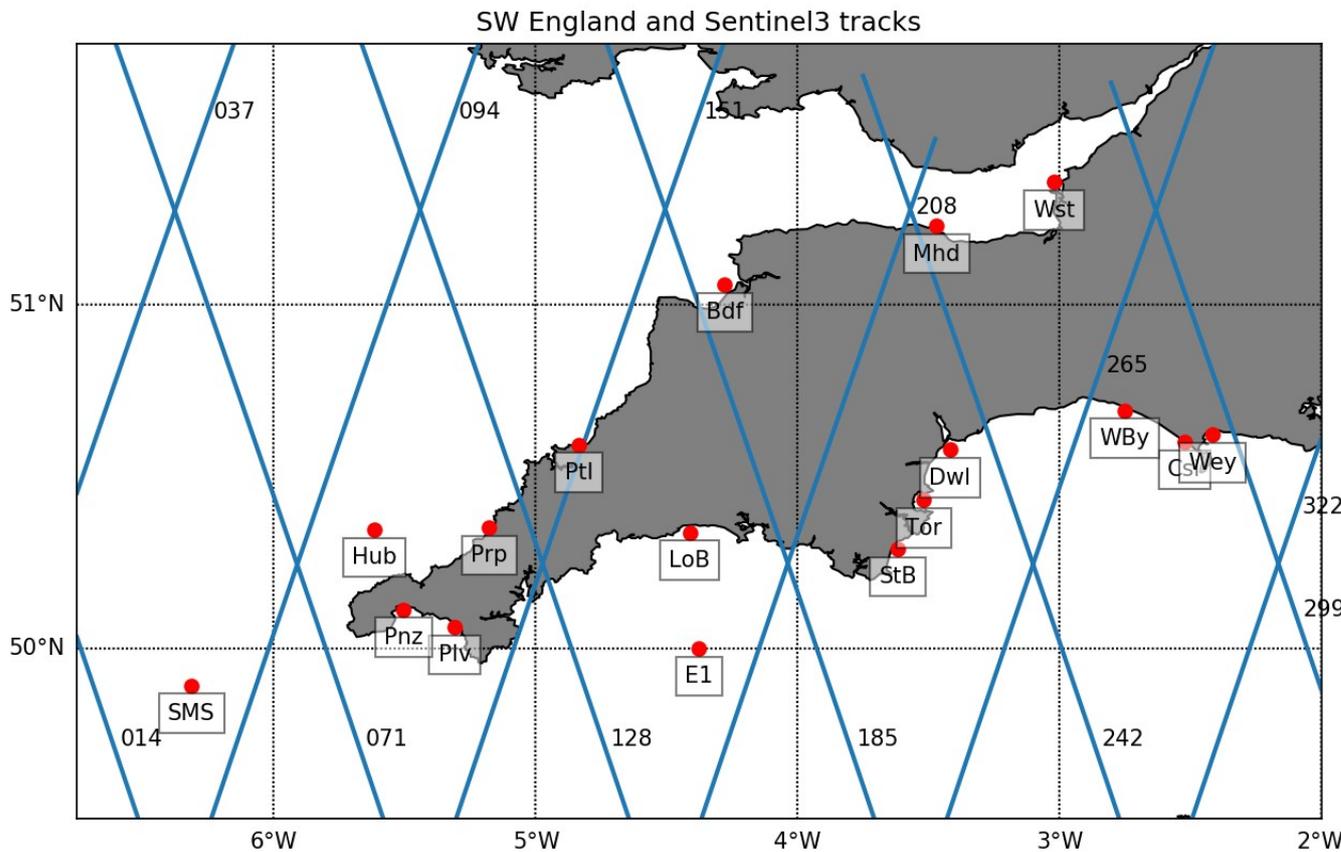
Sentinel-3A data

- 12 tracks
- Complex coastal morphology (different incidence angles)

- (1) Improved accuracy near the coast
- (2) Resolution of smaller scale dynamics (below large mesoscale $\sim O(100 \text{ km})$)



Assess both aspects in the coastal region of southwest England



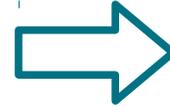
Sentinel-3A data

- 12 tracks
- Complex coastal morphology (different incidence angles)

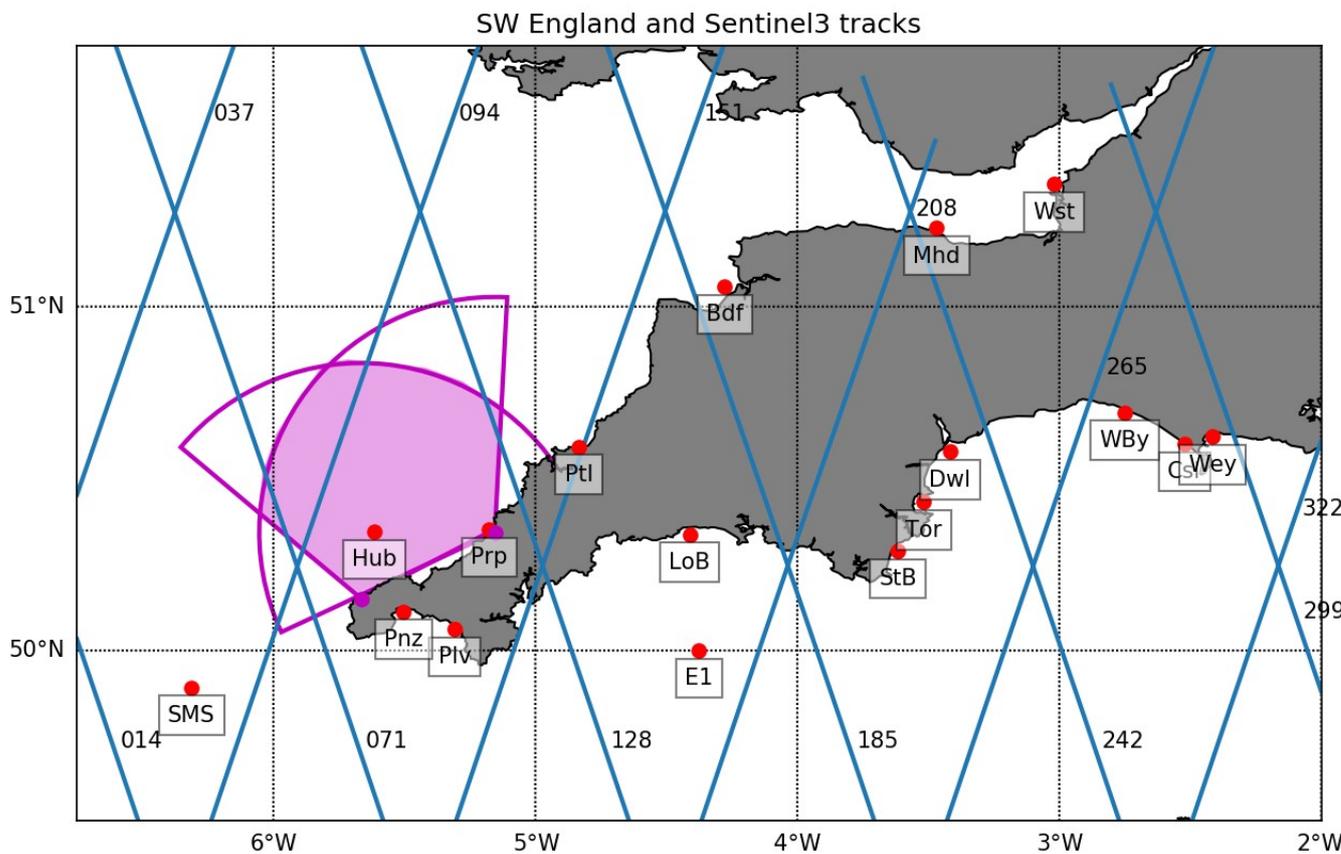
In-situ wave data

- Time-series from 17 buoys
- Good coverage of various coastal conditions (offshore to inshore)

- (1) Improved accuracy near the coast
- (2) Resolution of smaller scale dynamics (below large mesoscale $\sim O(100 \text{ km})$)



Assess both aspects in the coastal region of southwest England



Sentinel-3A data

- 12 tracks
- Complex coastal morphology (different incidence angles)

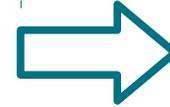
In-situ wave data

- Time-series from 17 buoys
- Good coverage of various coastal conditions (offshore to inshore)

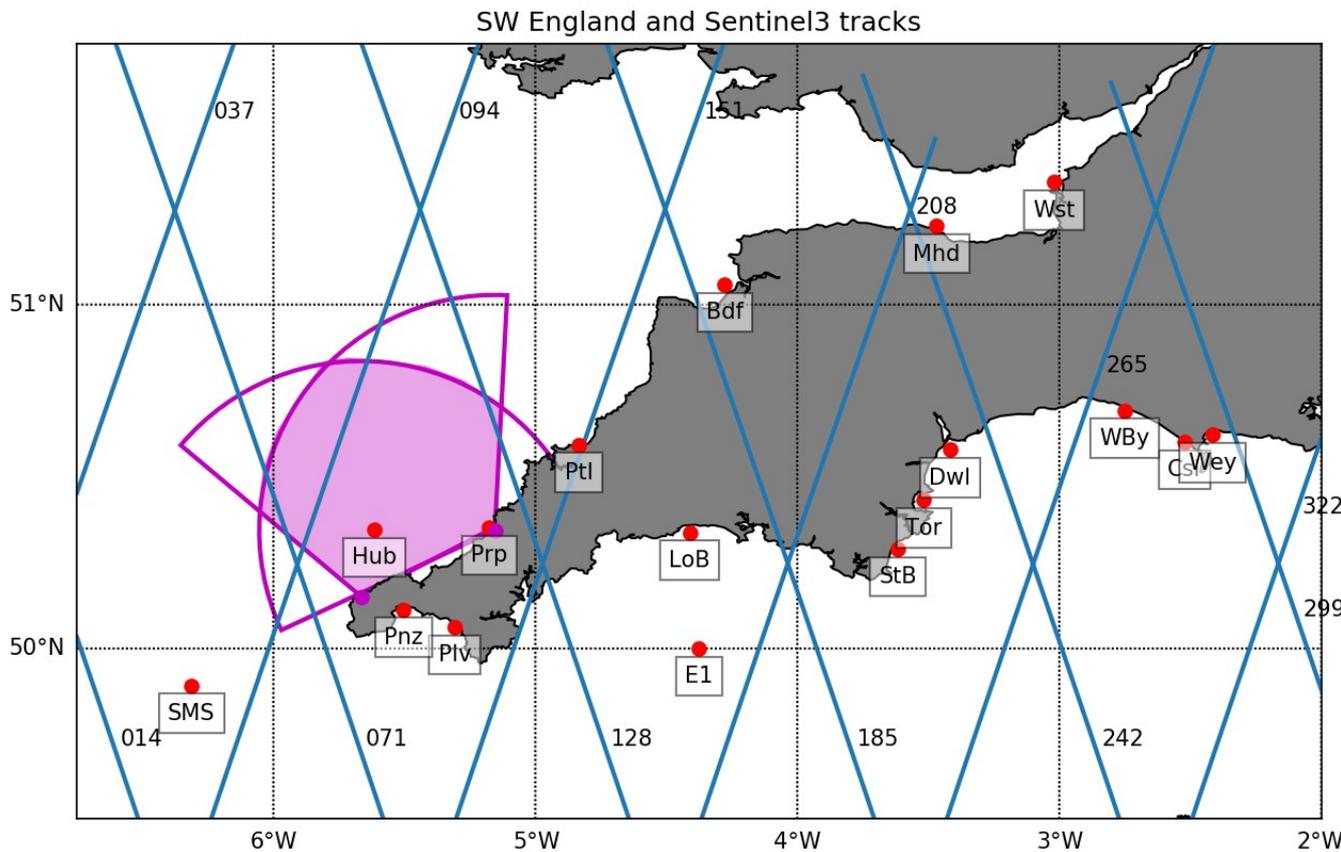
HF Radar data

- Time-series of 2-dimensional velocity and wave fields

- (1) Improved accuracy near the coast
- (2) Resolution of smaller scale dynamics (below large mesoscale $\sim O(100 \text{ km})$)



Assess both aspects in the coastal region of southwest England



Sentinel-3A data

- 12 tracks
- Complex coastal morphology (different incidence angles)

In-situ wave data

- Time-series from 17 buoys
- Good coverage of various coastal conditions (offshore to inshore)

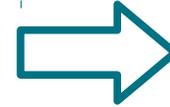
HF Radar data

- Time-series of 2-dimensional velocity and wave fields

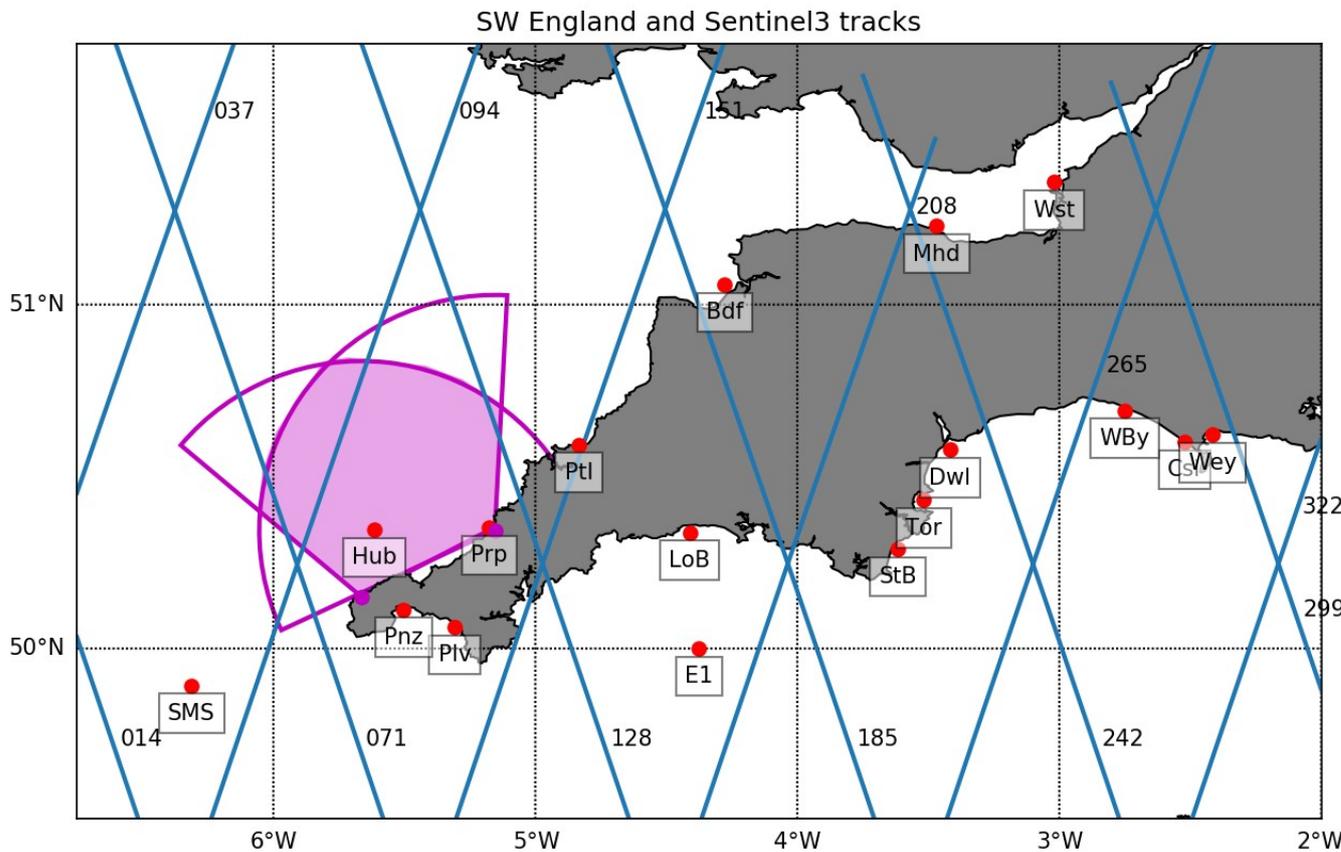


In-situ data to evaluate performances (with respect to PLRM mode) of SAR significant wave height and velocity obs.

- (1) Improved accuracy near the coast
- (2) Resolution of smaller scale dynamics (below large mesoscale $\sim O(100 \text{ km})$)



Assess both aspects in the coastal region of southwest England



Sentinel-3A data

- 12 tracks
- Complex coastal morphology (different incidence angles)

In-situ wave data

- Time-series from 17 buoys
- Good coverage of various coastal conditions (offshore to inshore)

HF Radar data

- Time-series of 2-dimensional velocity and wave fields



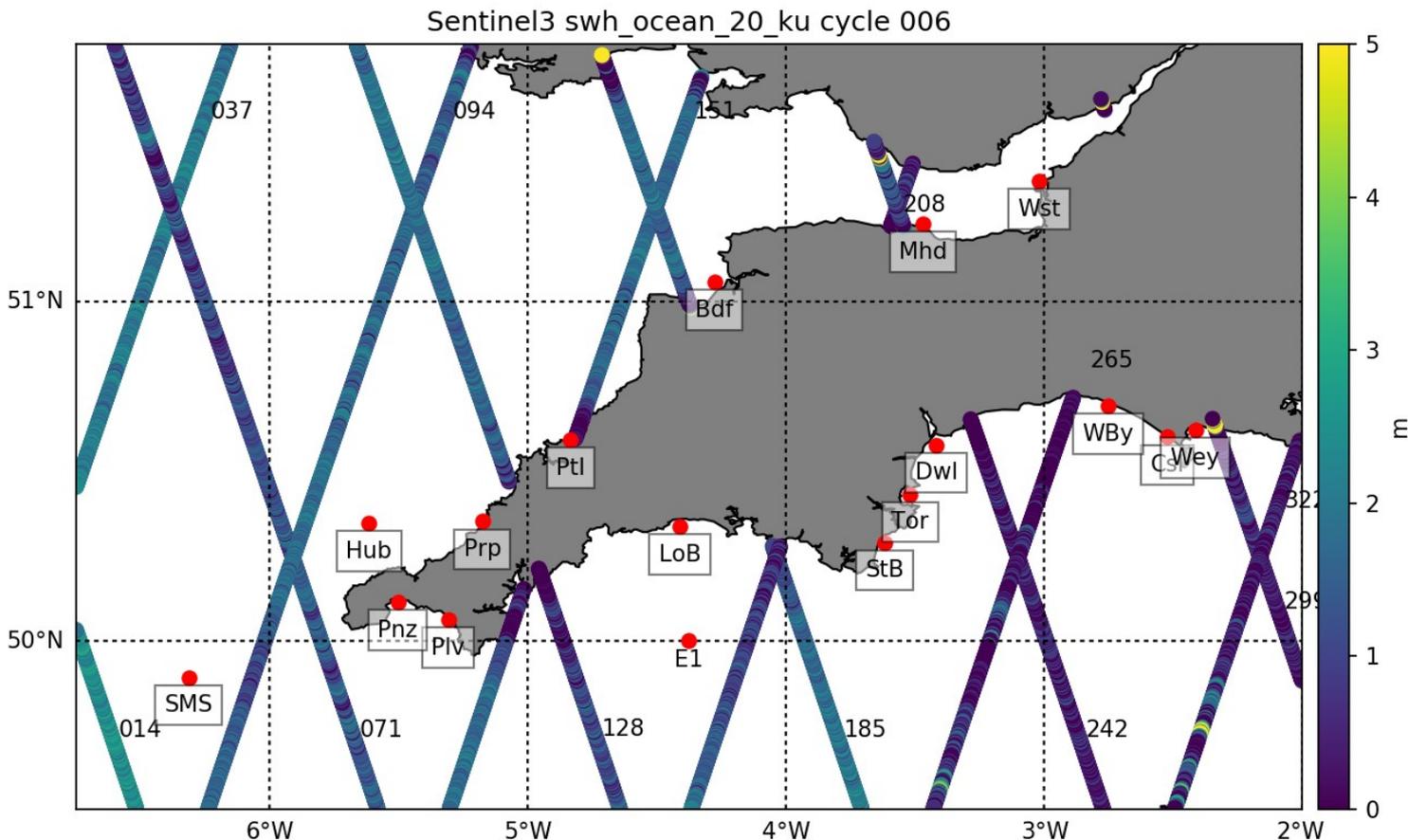
In-situ data to evaluate performances (with respect to PLRM mode) of SAR **significant wave height** and ~~velocity obs.~~

Sentinel-3A data specifications:

- Analysis based on **PB 2.27 reprocessed** dataset (released Feb 2018)
- **Cycles 002 to 031** (from Mar-2016 to May-2018)
(cycles 001 incomplete for SAR; PLRM incomplete also in cycles 002 and 003)
- 20 Hz Ku-band observations (variables **swh_ocean_20_ku** and **swh_ocean_20_plrm_ku**)
- Alongtrack spatial resolution of ~**340 m**

Sentinel-3A data specifications:

- Analysis based on **PB 2.27 reprocessed** dataset (released Feb 2018)
- **Cycles 002 to 031** (from Mar-2016 to May-2018)
(cycles 001 incomplete for SAR; PLRM incomplete also in cycles 002 and 003)
- 20 Hz Ku-band observations (variables **swh_ocean_20_ku** and **swh_ocean_20_plrm_ku**)
- Alongtrack spatial resolution of **~340 m**



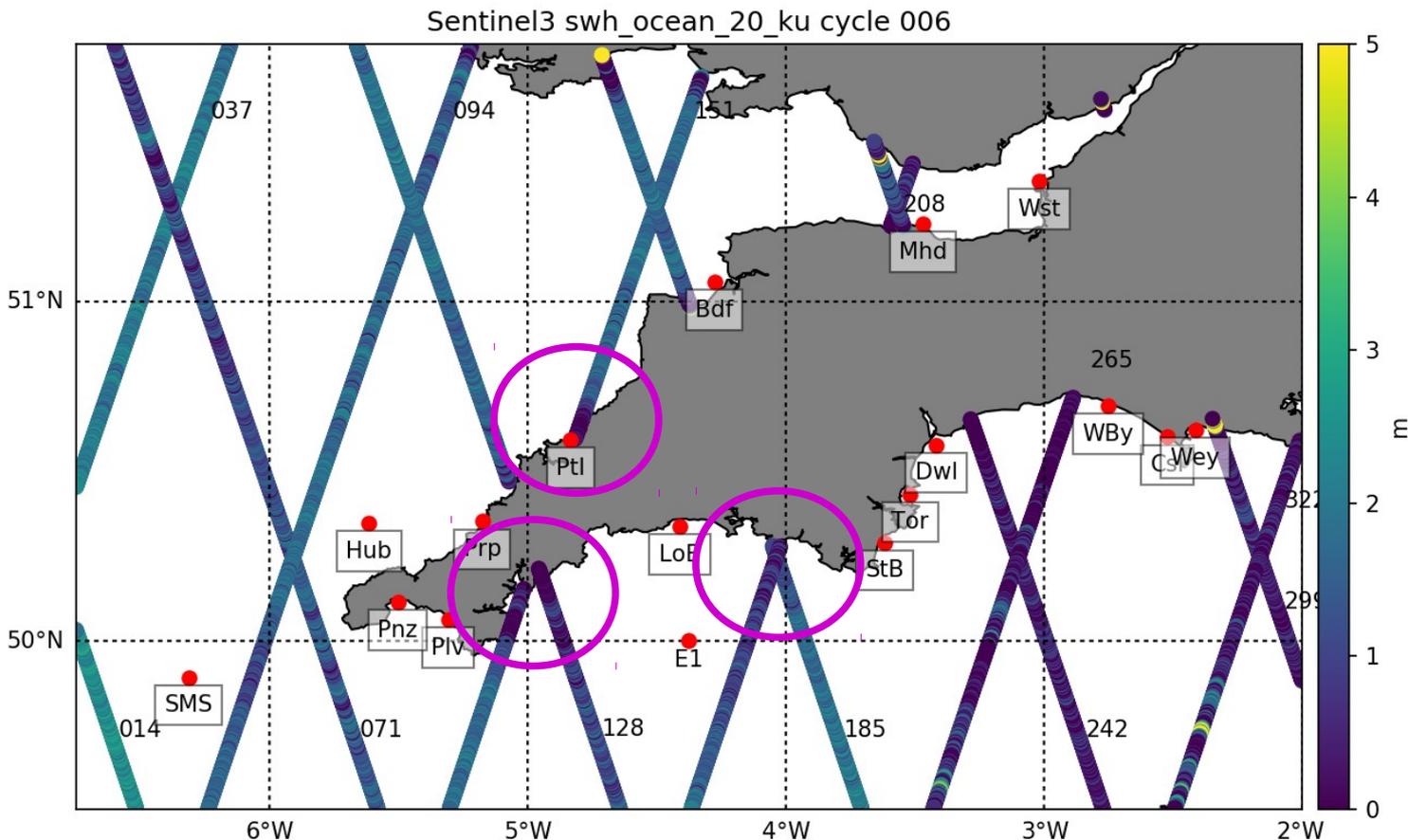
General characteristics

- 1) Noisy alongtrack observations

Only data with QF==0 and distance from the coast > 0 were used

Sentinel-3A data specifications:

- Analysis based on **PB 2.27 reprocessed** dataset (released Feb 2018)
- **Cycles 002 to 031** (from Mar-2016 to May-2018)
(cycles 001 incomplete for SAR; PLRM incomplete also in cycles 002 and 003)
- 20 Hz Ku-band observations (variables **swh_ocean_20_ku** and **swh_ocean_20_plrm_ku**)
- Alongtrack spatial resolution of **~340 m**



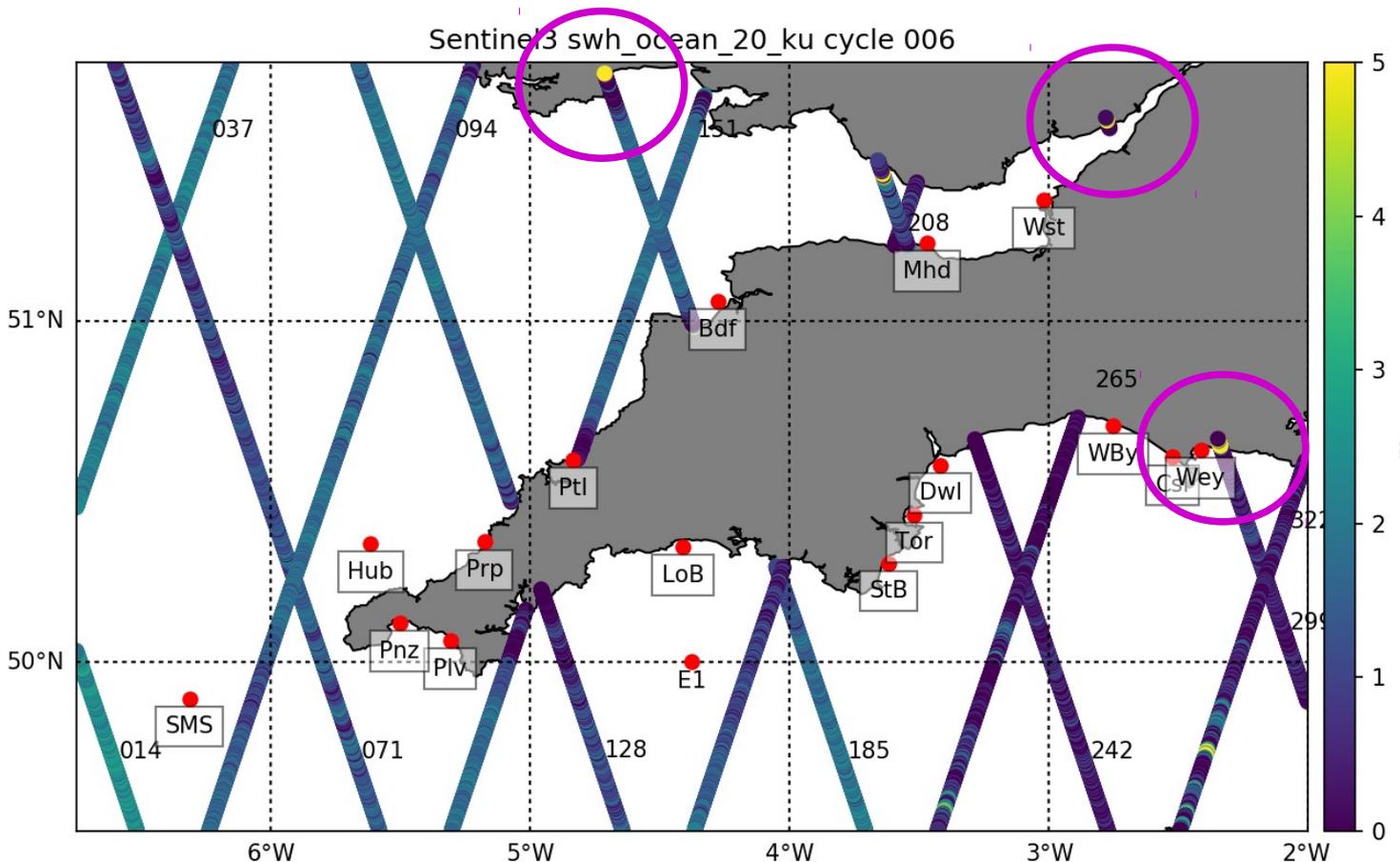
General characteristics

- 1) Noisy alongtrack observations
- 2) Variations with respect to distance from the coast

Only data with $QF==0$ and distance from the coast > 0 were used

Sentinel-3A data specifications:

- Analysis based on **PB 2.27 reprocessed** dataset (released Feb 2018)
- **Cycles 002 to 031** (from Mar-2016 to May-2018)
(cycles 001 incomplete for SAR; PLRM incomplete also in cycles 002 and 003)
- 20 Hz Ku-band observations (variables **swh_ocean_20_ku** and **swh_ocean_20_plrm_ku**)
- Alongtrack spatial resolution of **~340 m**



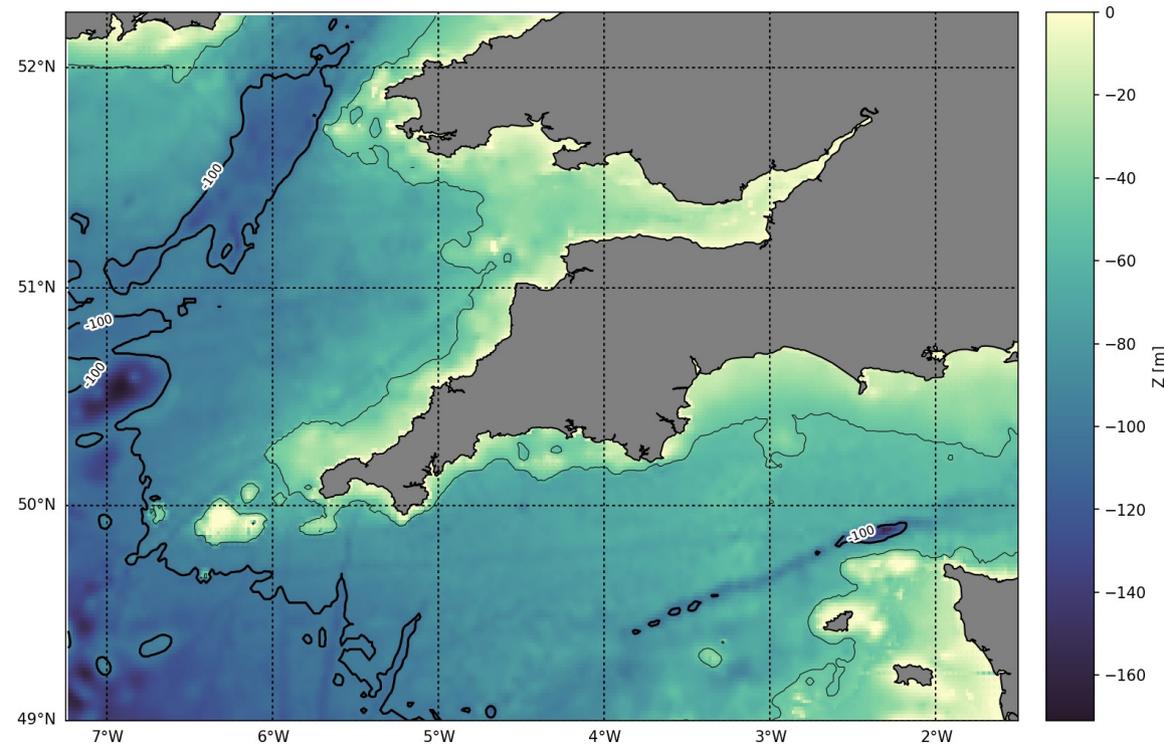
General characteristics

- 1) Noisy alongtrack observations
- 2) Variations with respect to distance from the coast
- 3) Issues with land flagging

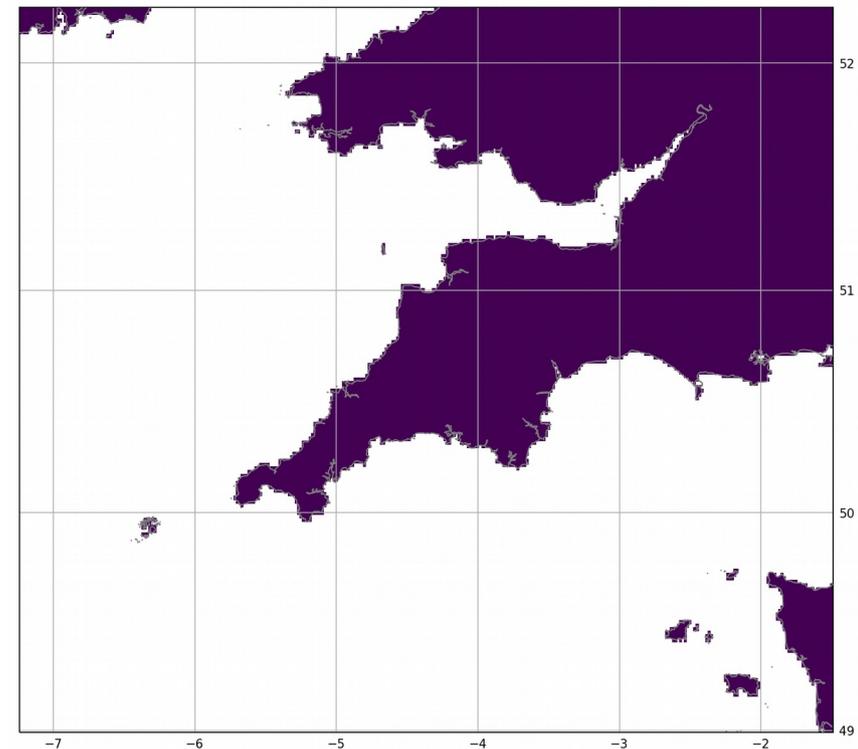
Only data with QF==0 and distance from the coast > 0 were used

Sentinel-3A data processing: Custom distance from land

- Land mask based on ETOPO 01 (<https://ngdc.noaa.gov/mgg/global/global.html>)
- 1 arc-minute resolution (1.852 km)

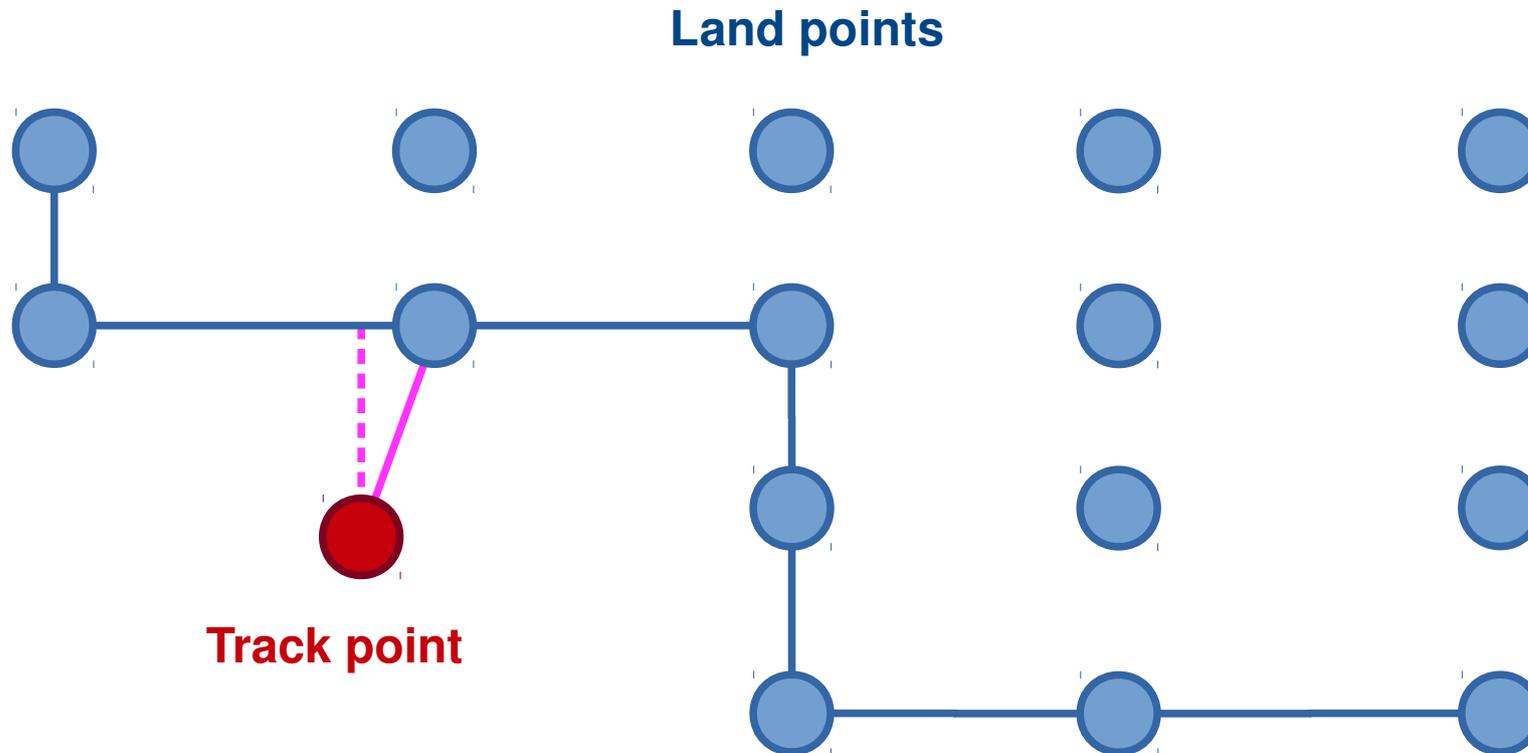


Points with elevation > 0 m



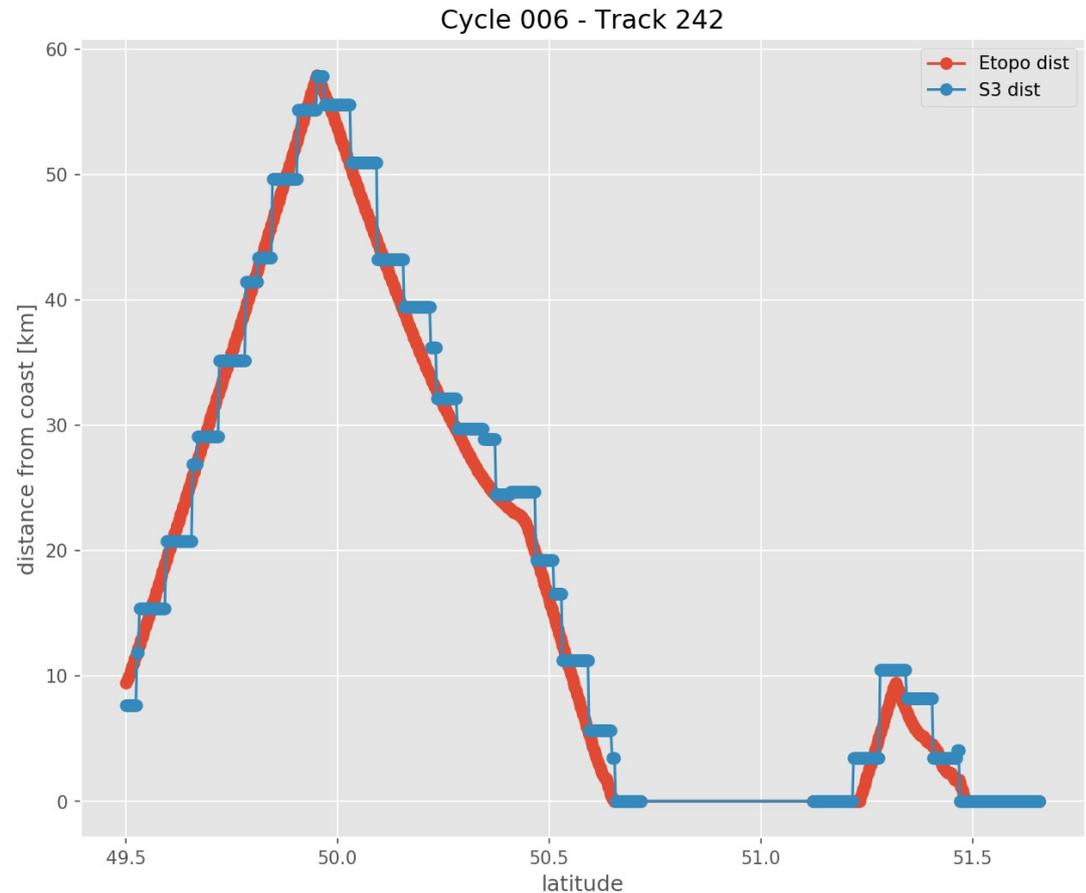
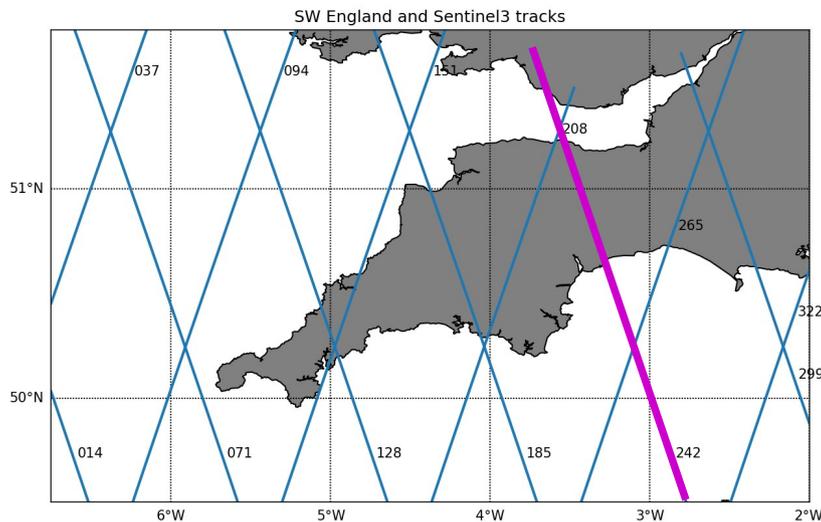
Sentinel-3A data processing: Custom distance from land

- Land mask based on ETOPO 01 (<https://ngdc.noaa.gov/mgg/global/global.html>)
- 1 arc-minute resolution (1.852 km)
- New distance is from track point to closest land point (still room for improvement)



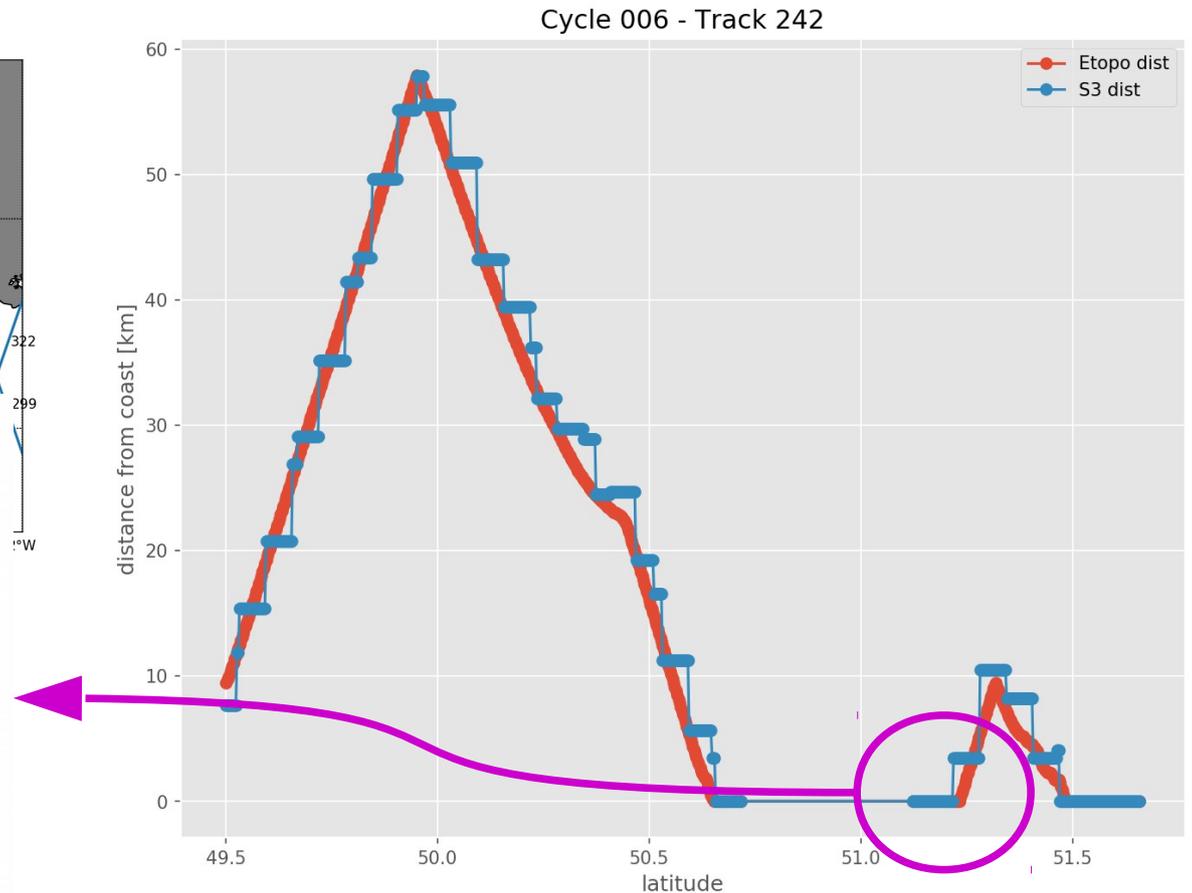
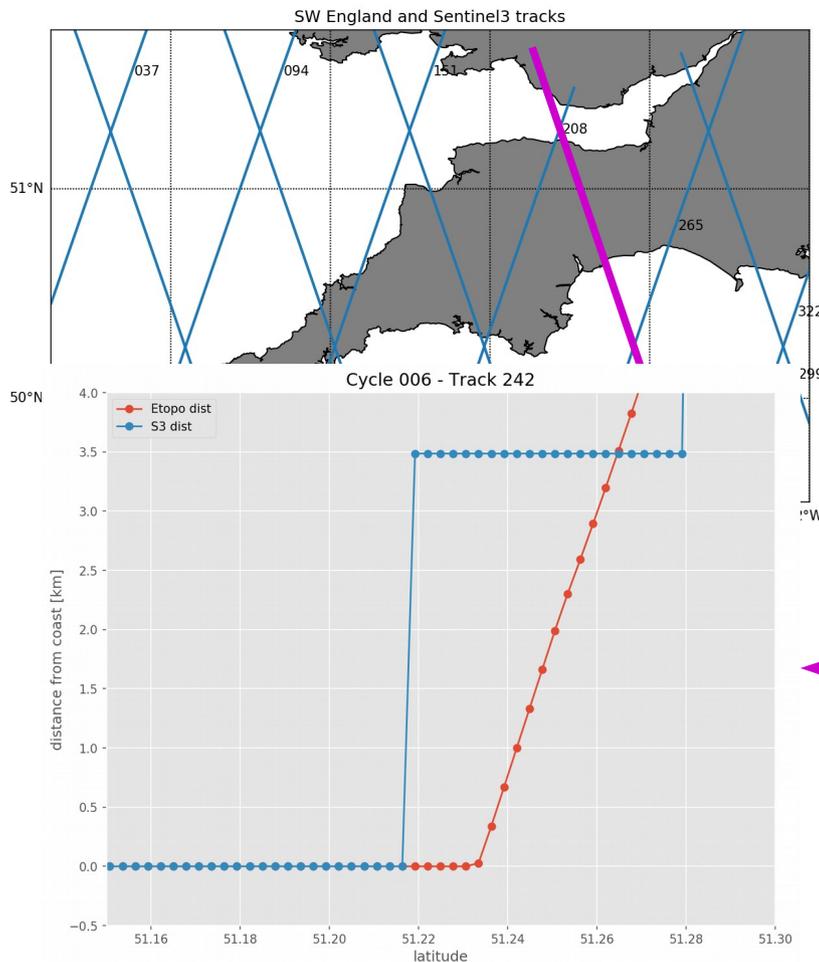
Sentinel-3A data processing: Custom distance from land

- Land mask based on ETOPO 01 (<https://ngdc.noaa.gov/mgg/global/global.html>)
- 1 arc-minute resolution (1.852 km)
- New distance is from track point to closest land point (still room for improvement)
- **Example track 242**



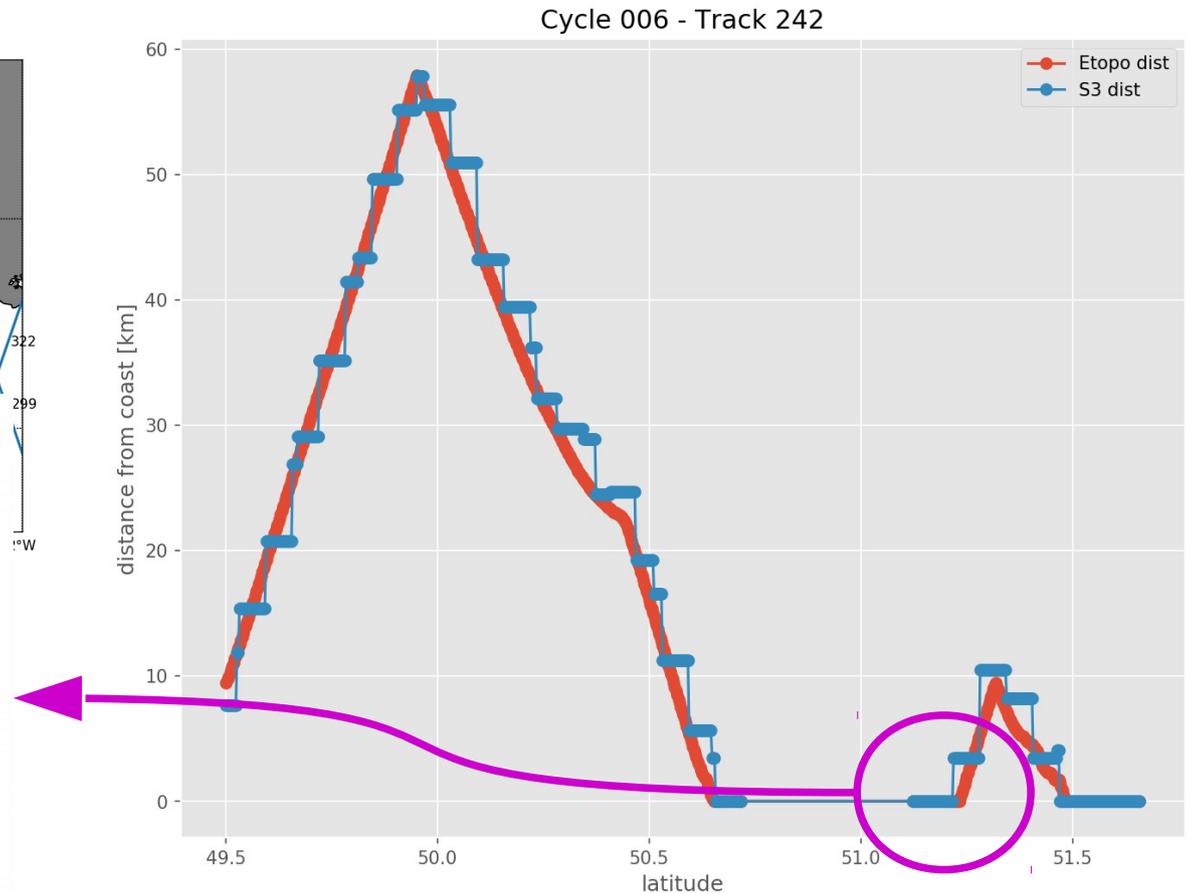
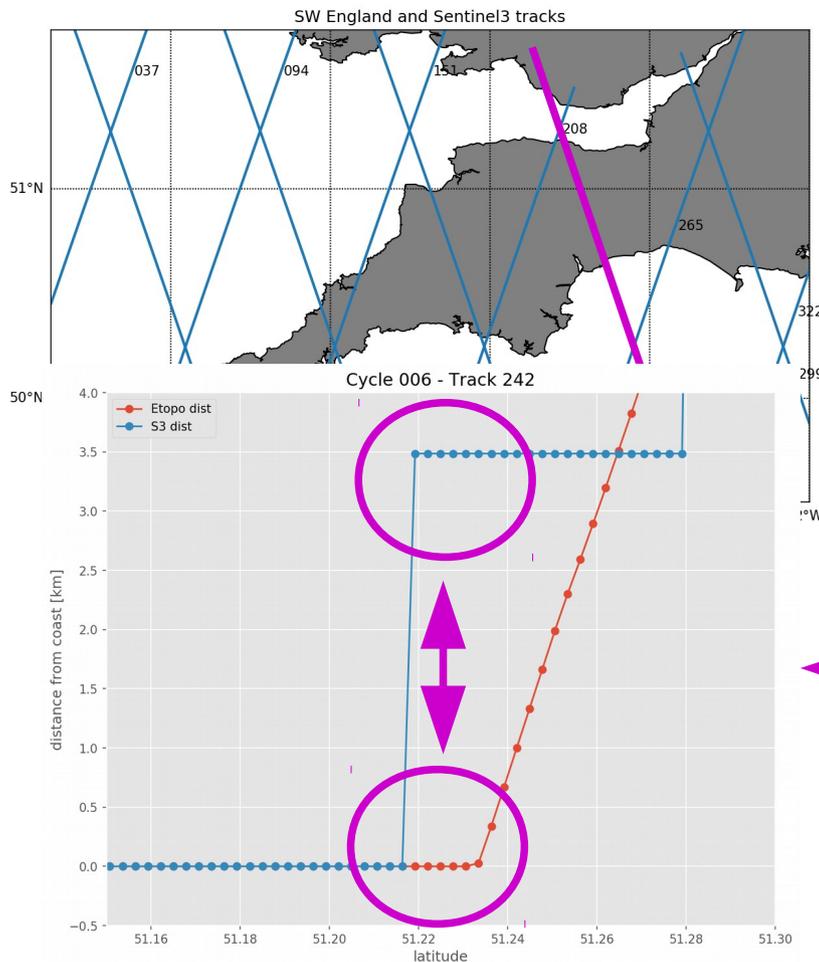
Sentinel-3A data processing: Custom distance from land

- Land mask based on ETOPO 01 (<https://ngdc.noaa.gov/mgg/global/global.html>)
- 1 arc-minute resolution (1.852 km)
- New distance is from track point to closest land point (still room for improvement)
- **Example track 242**



Sentinel-3A data processing: Custom distance from land

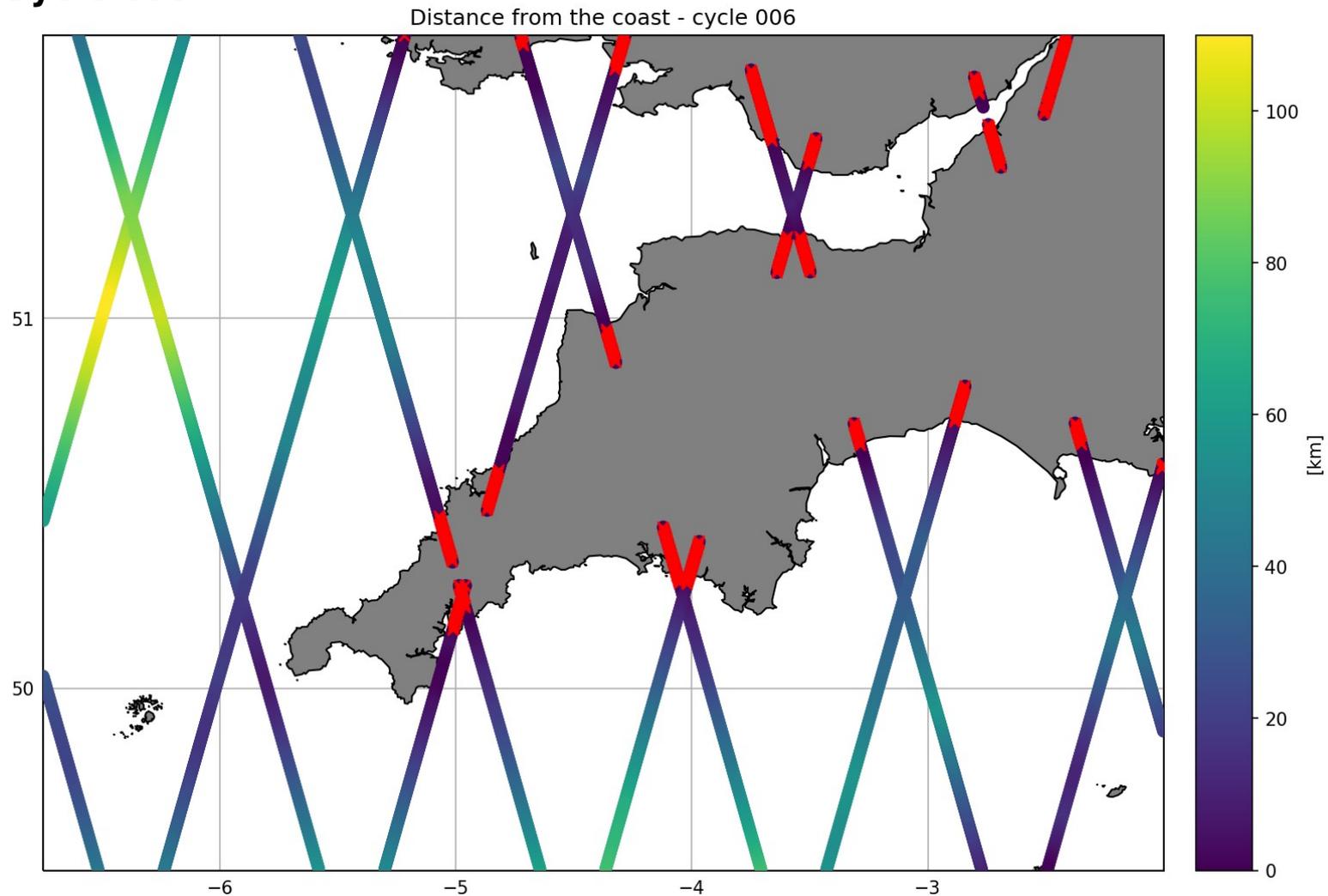
- Land mask based on ETOPO 01 (<https://ngdc.noaa.gov/mgg/global/global.html>)
- 1 arc-minute resolution (1.852 km)
- New distance is from track point to closest land point (still room for improvement)
- **Example track 242**



→ Land points as sea points !!!

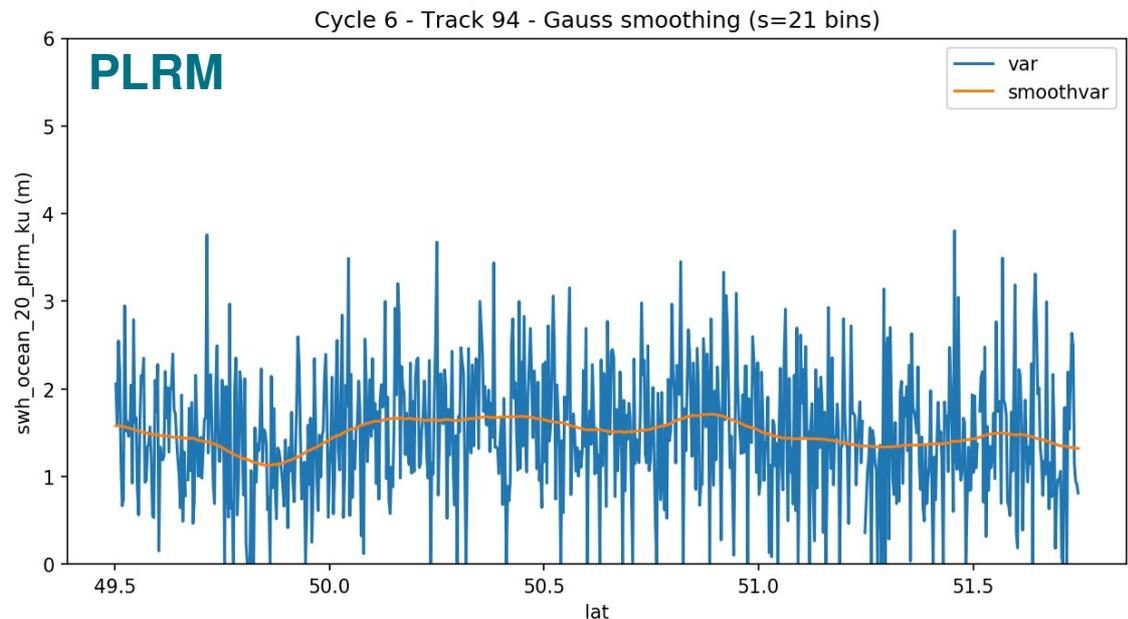
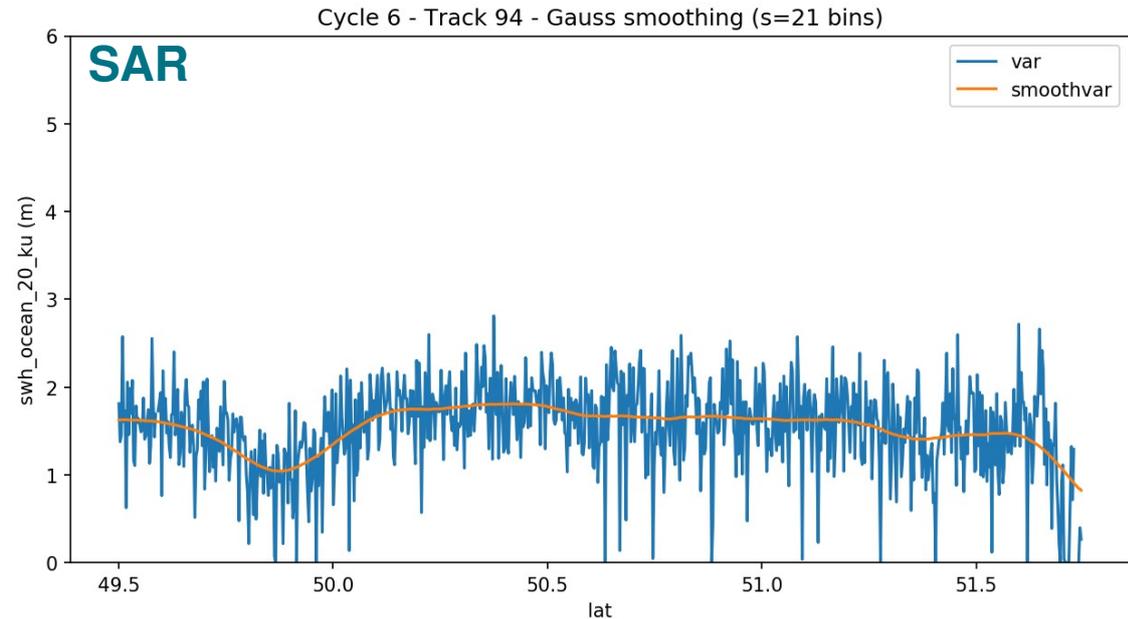
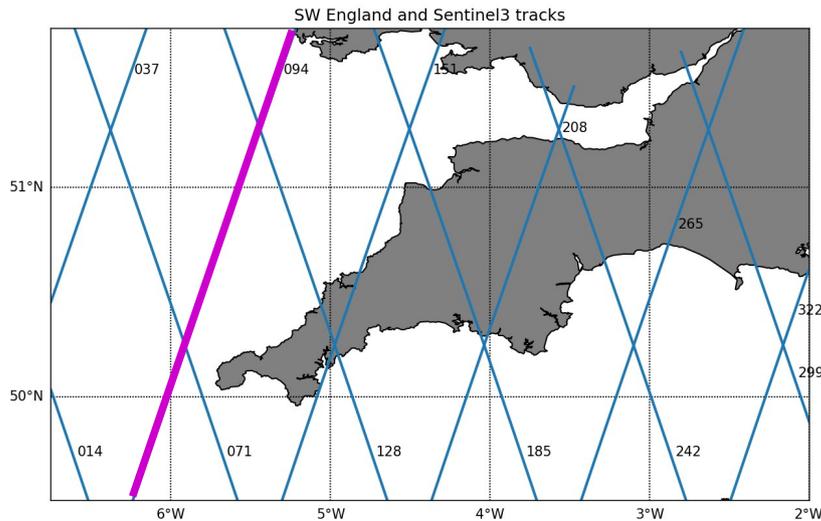
Sentinel-3A data processing: Custom distance from land

- Land mask based on ETOPO 01 (<https://ngdc.noaa.gov/mgg/global/global.html>)
- 1 arc-minute resolution (1.852 km)
- New distance is from track point to closest land point (still room for improvement)
- **Example Cycle 006**



Sentinel-3A data processing

Example of open sea track (Track 94 – cycle 006)



Raw signal

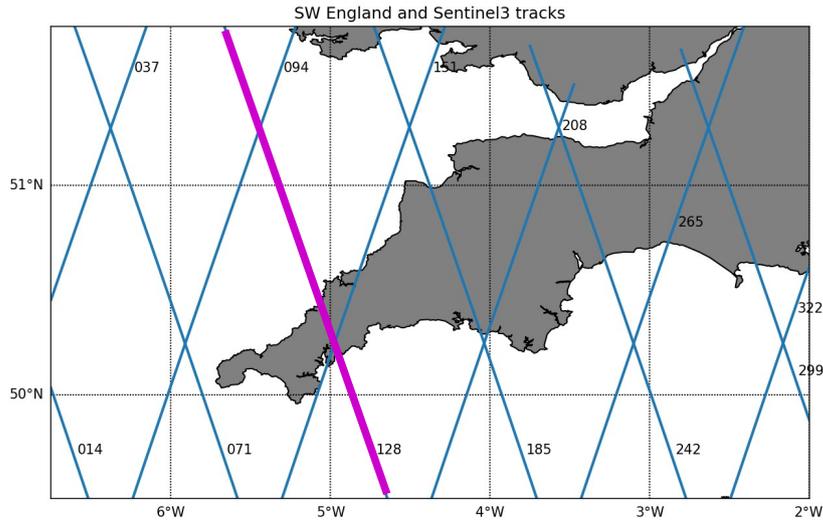
- Alongtrack noise in both SAR and PLRM
- PLRM characterized by larger noise
- Noise reduced applying **moving average filter**: Gaussian window with 50-bin FWHM (~17 km)

Smoothed signal

- Often (but not always) slight **offset** between SAR and PLRM

Sentinel-3A data processing

Example of coastal track (Track 128 – cycle 006)

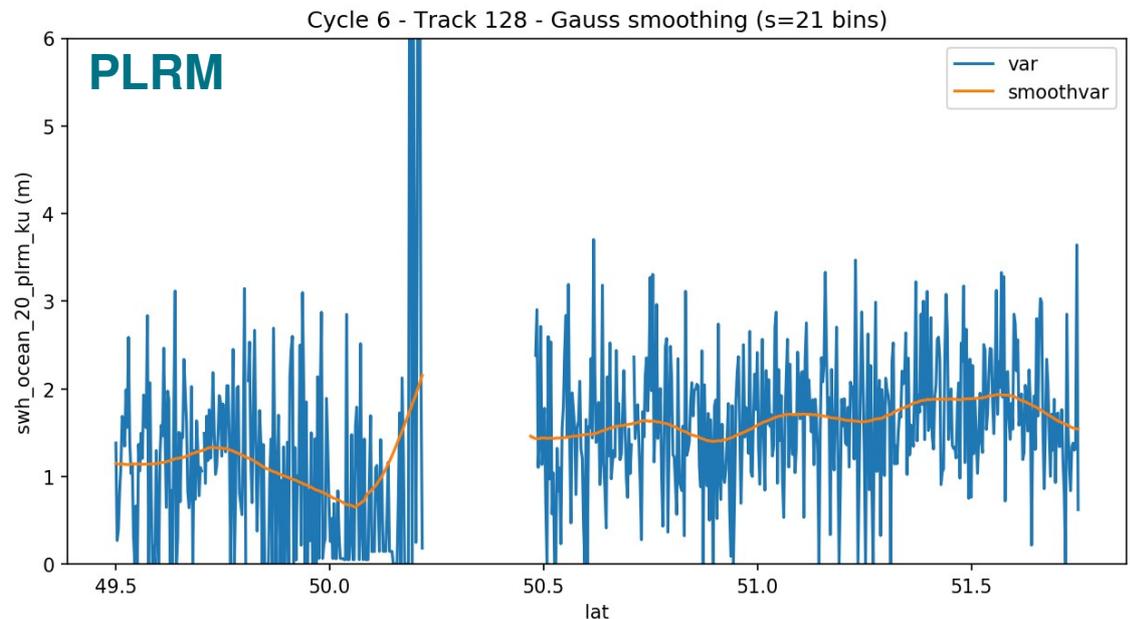
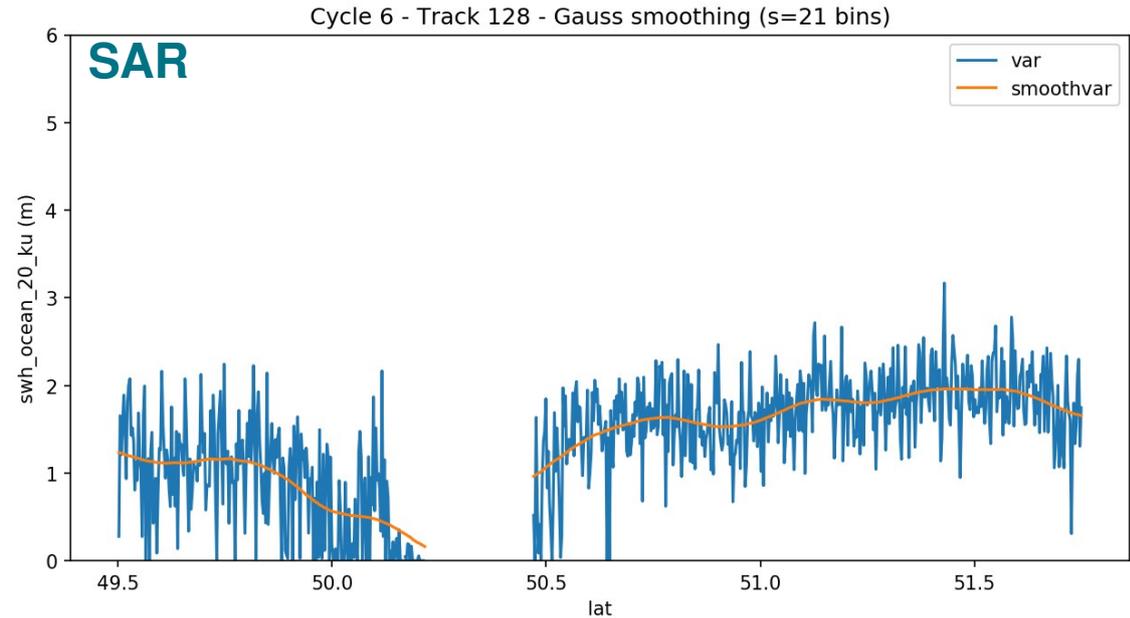


Raw signal

- Alongtrack noise in both SAR and PLRM
- PLRM characterized by larger noise
- Noise reduced applying **moving average filter**: Gaussian window with 50-bin FWHM (~17 km)

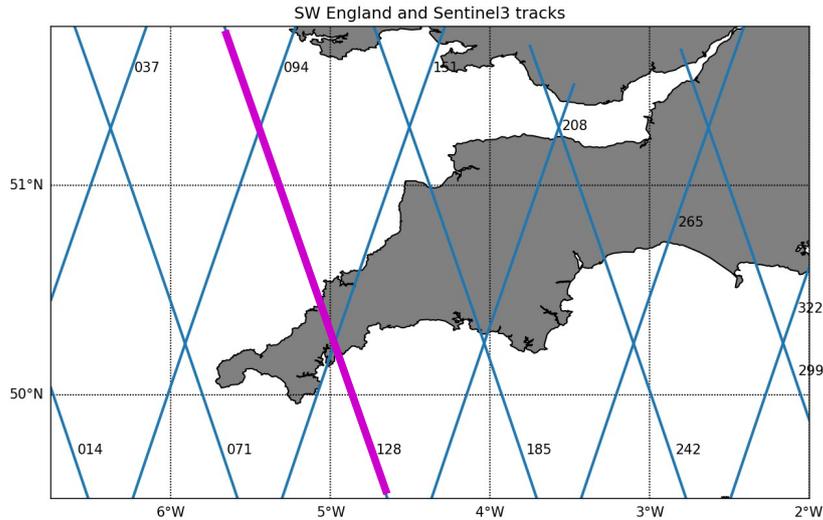
Smoothed signal

- Often (but not always) slight **offset** between SAR and PLRM



Sentinel-3A data processing

Example of coastal track (Track 128 – cycle 006)

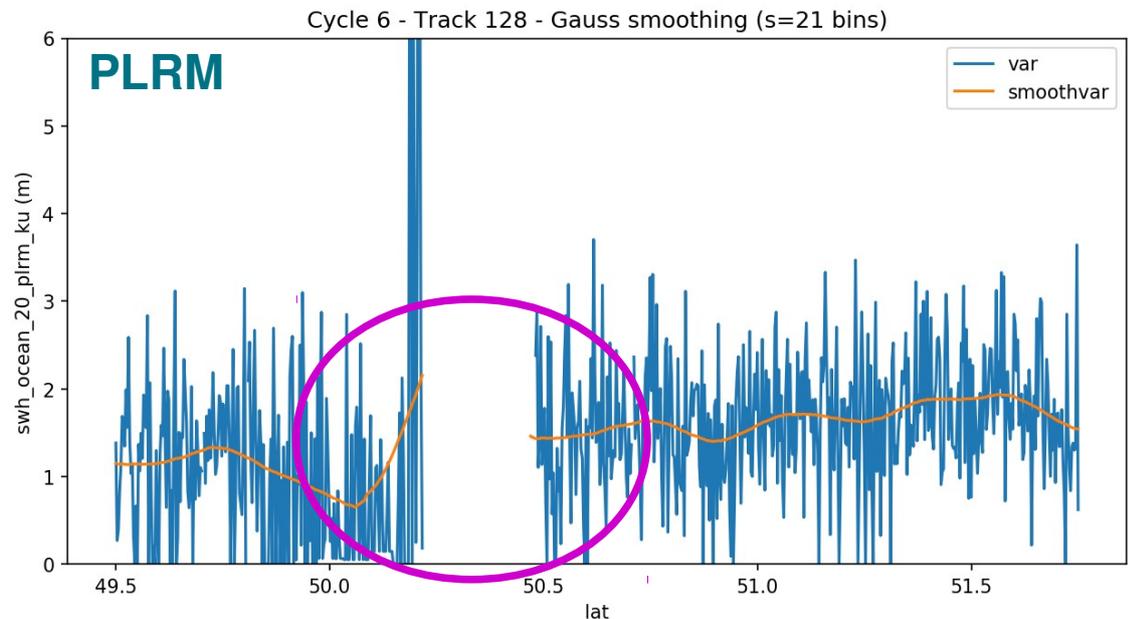
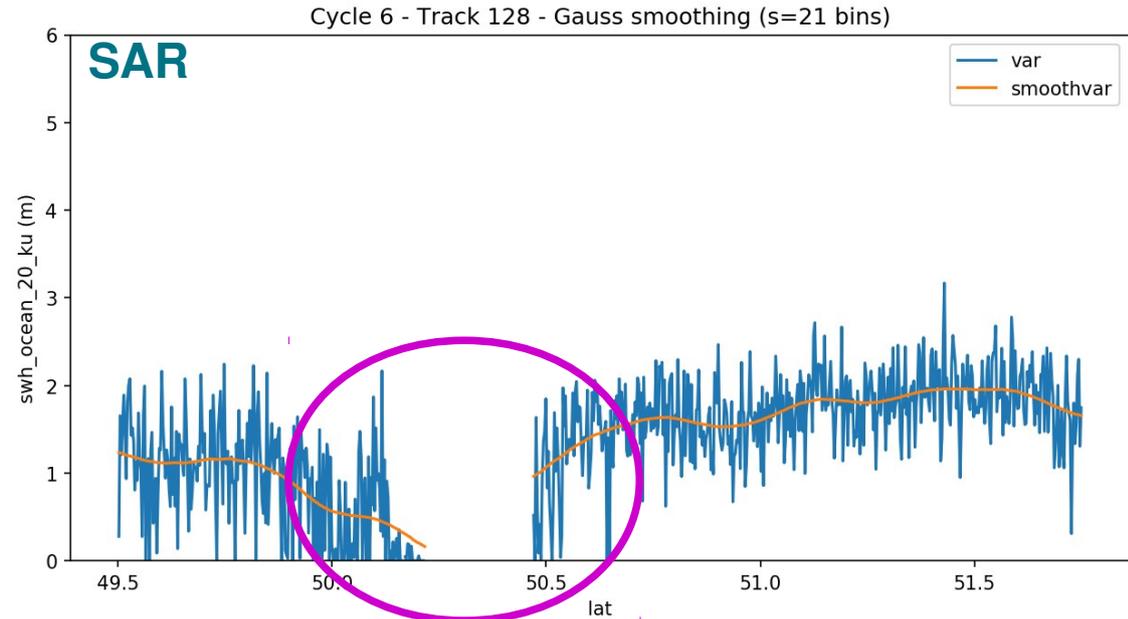


Raw signal

- Alongtrack noise in both SAR and PLRM
- PLRM characterized by larger noise
- Noise reduced applying **moving average filter**: Gaussian window with 50-bin FWHM (~17 km)

Smoothed signal

- Often (but not always) slight **offset** between SAR and PLRM
- **Marked differences near the coast**

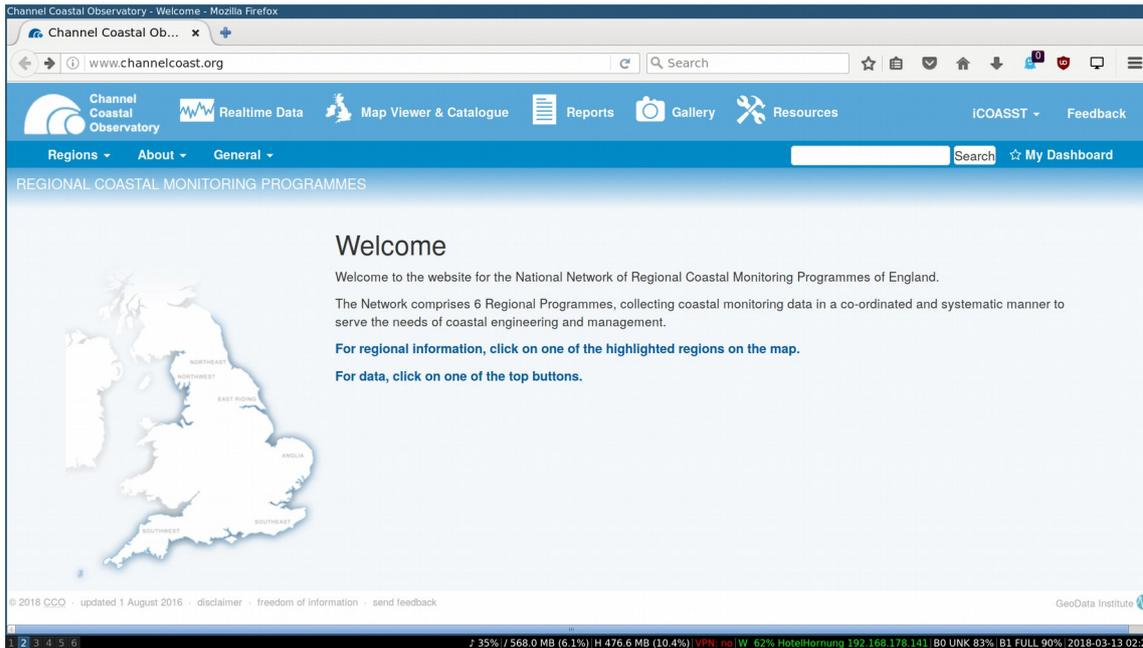


Wave data from two monitoring programs:

1. Coastal Channel Observatory

- 16 wave buoys in SW England
- Part of National Network of Regional Coastal Monitoring
- Time-series of **swH**, **direction** and **period**
- **30-min averages** from **Jan-2016 to Apr 2018**

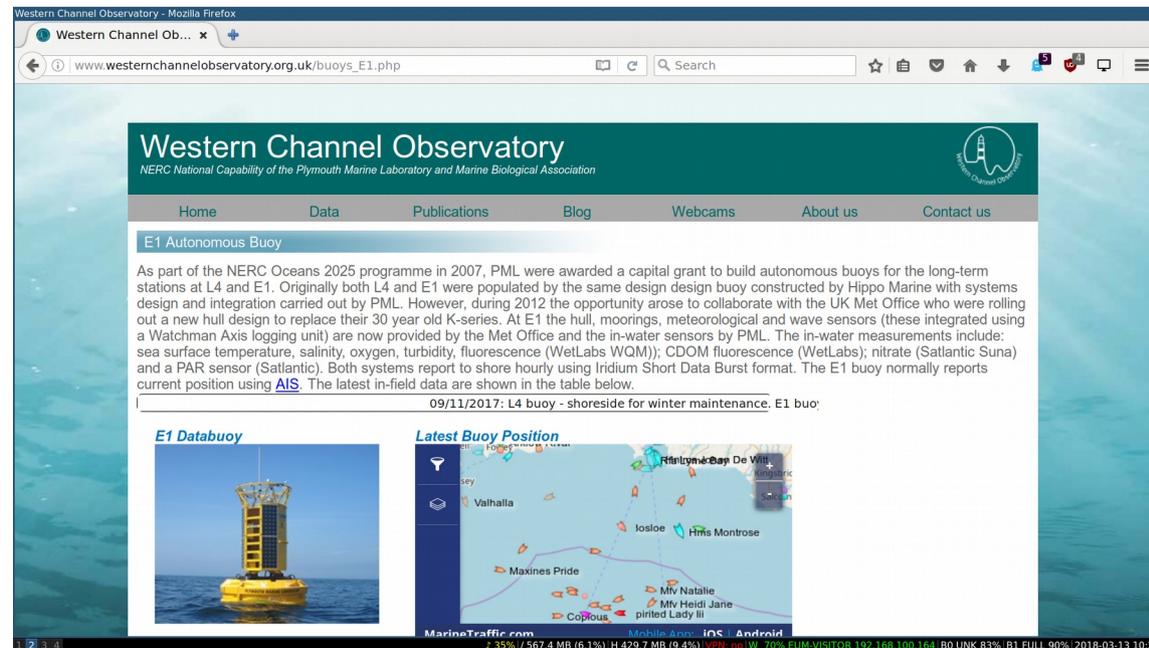
Further info at:
<http://www.channelcoast.org>



2. Western Channel Observatory

- E1 buoy in front of Plymouth sound
- Mooring financed by NERC and managed by PML
- Time-series of **swH** and **direction**
- **1-hour averages** from **Jan-2016 to present**

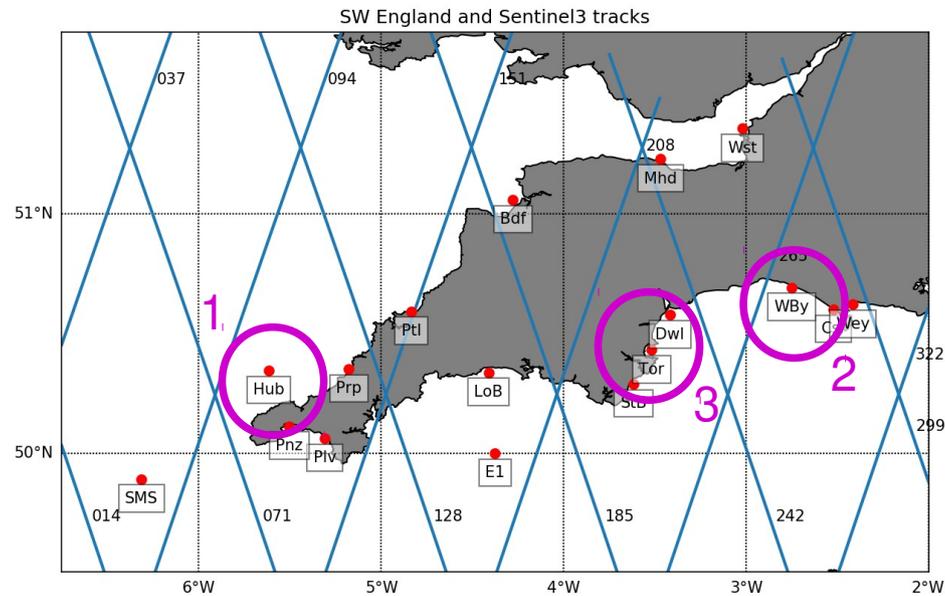
Further info at:
<http://www.westernchannelobservatory.org.uk/>



Wave buoy timeseries (total)

→ Example from 3 buoys representative of different morphological conditions:

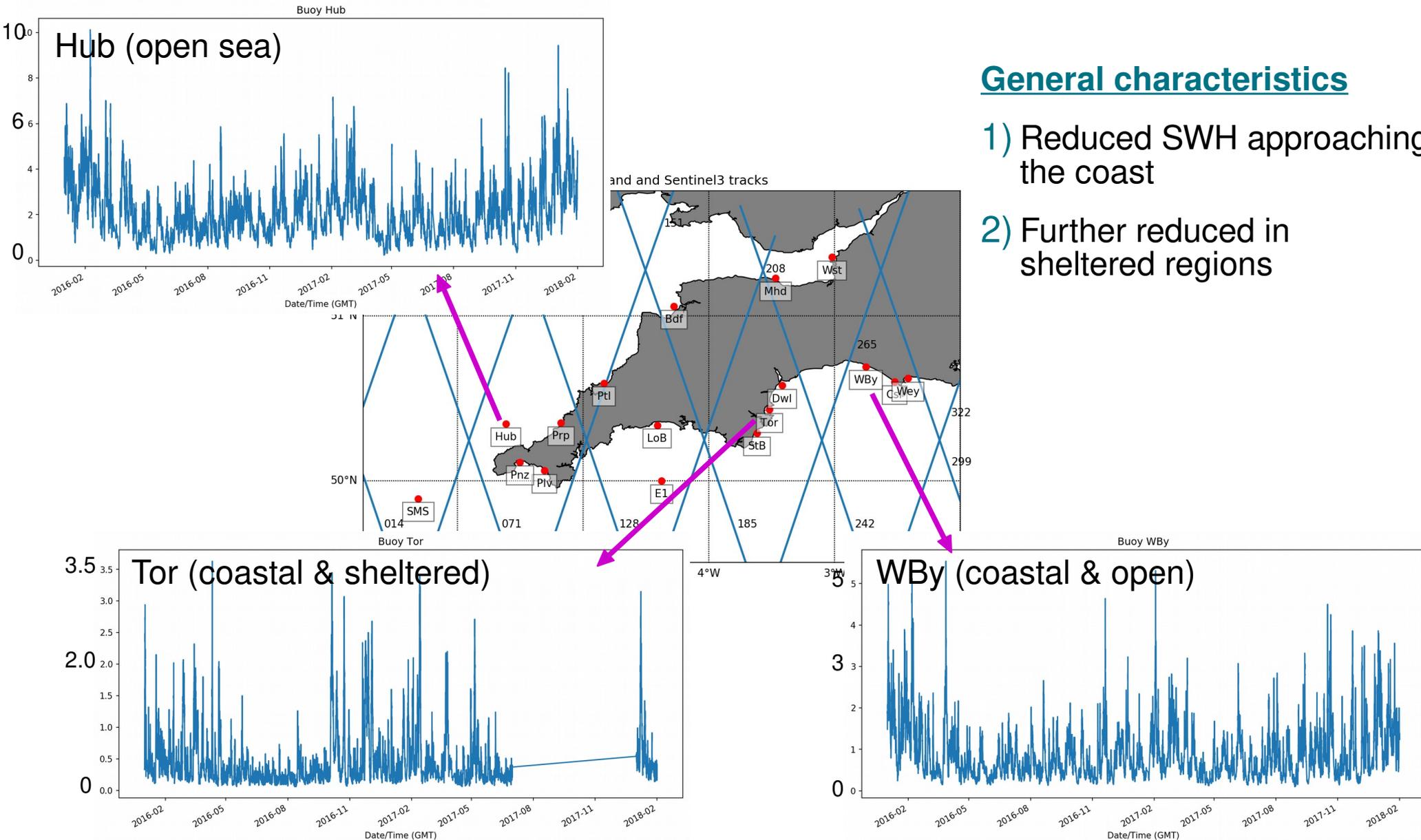
- 1) Open sea
- 2) Coastal & open
- 3) Coastal & sheltered



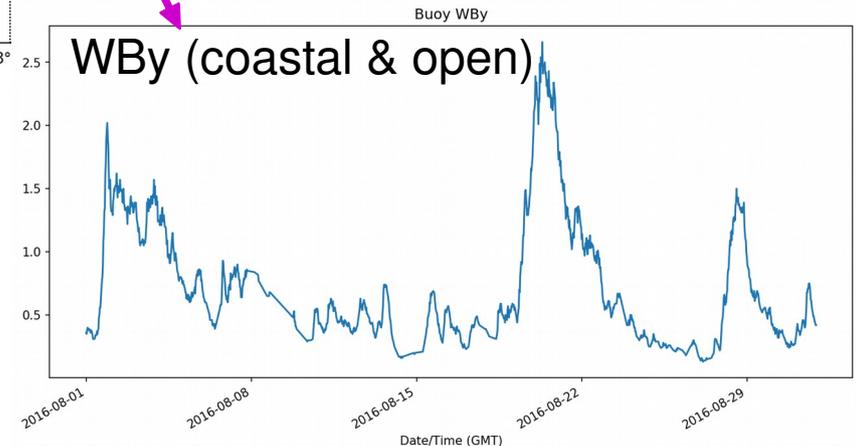
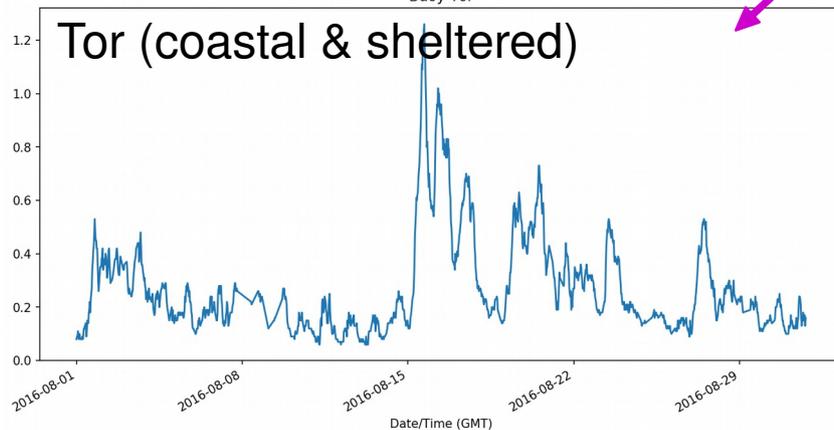
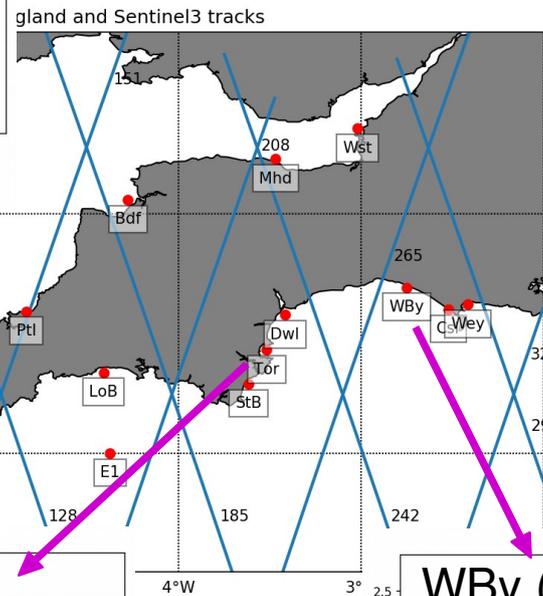
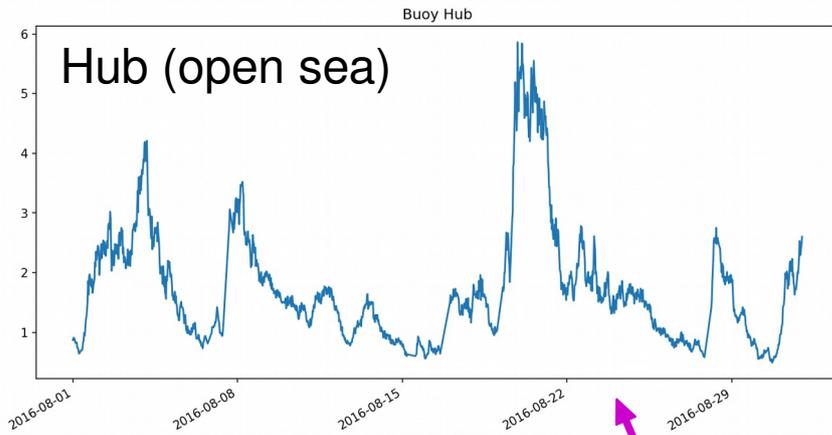
Wave buoy timeseries (total)

General characteristics

- 1) Reduced SWH approaching the coast
- 2) Further reduced in sheltered regions



Wave buoy timeseries (Aug 2016)

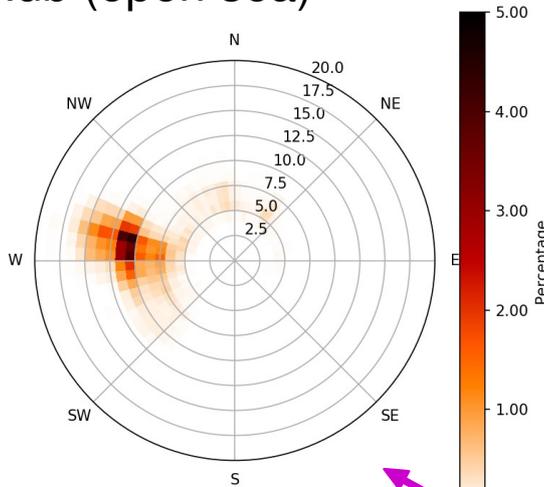


General characteristics

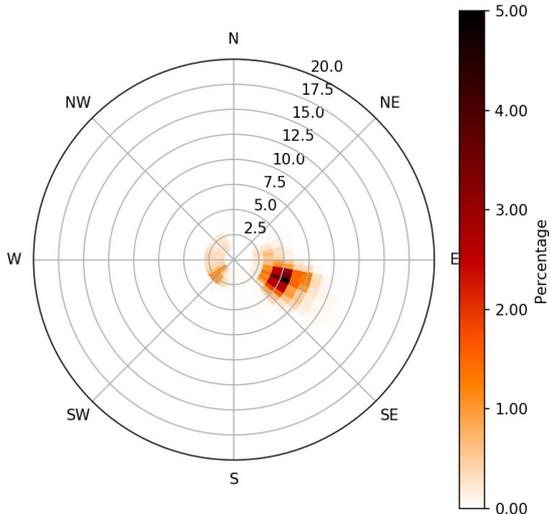
- 1) Reduced SWH approaching the coast
- 2) Further reduced in sheltered regions
- 3) Presence of tidal oscillations (not removed for the analysis!!!)

Wave buoy spectra (total)

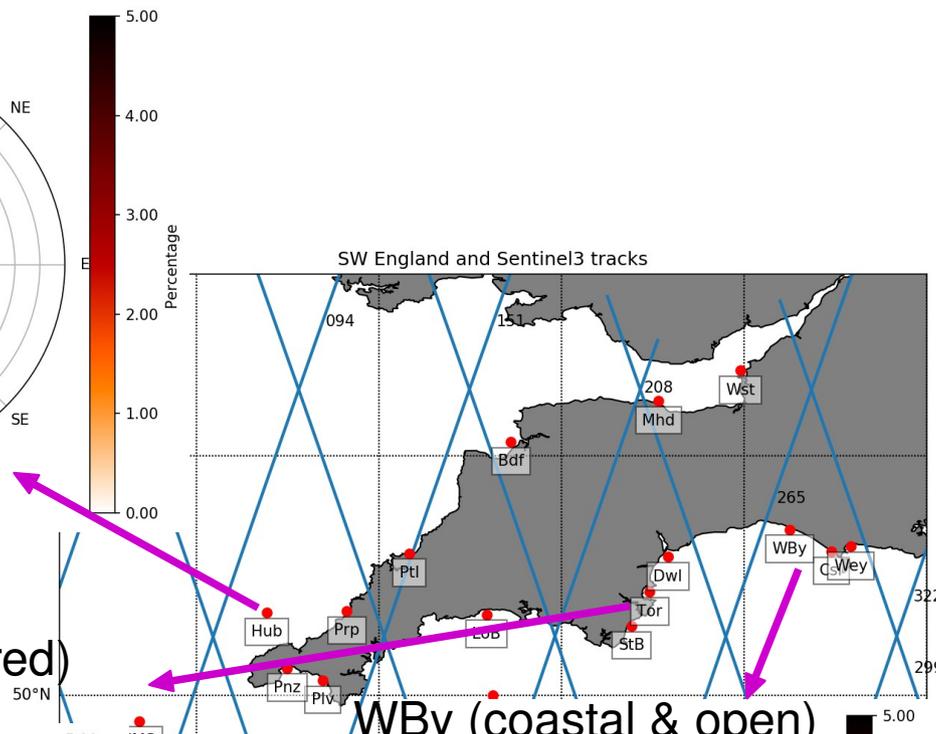
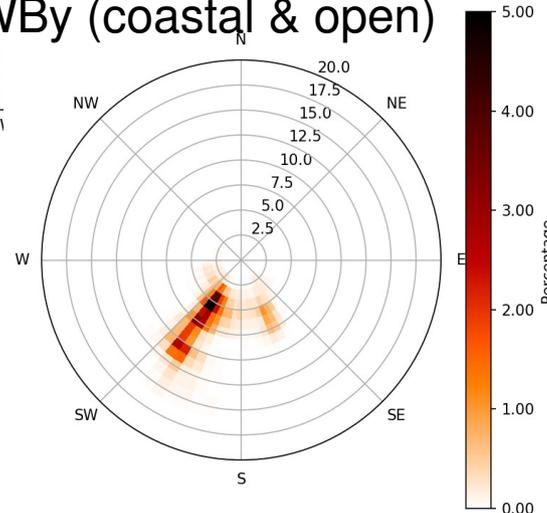
Hub (open sea)



Tor (coastal & sheltered)



WBy (coastal & open)

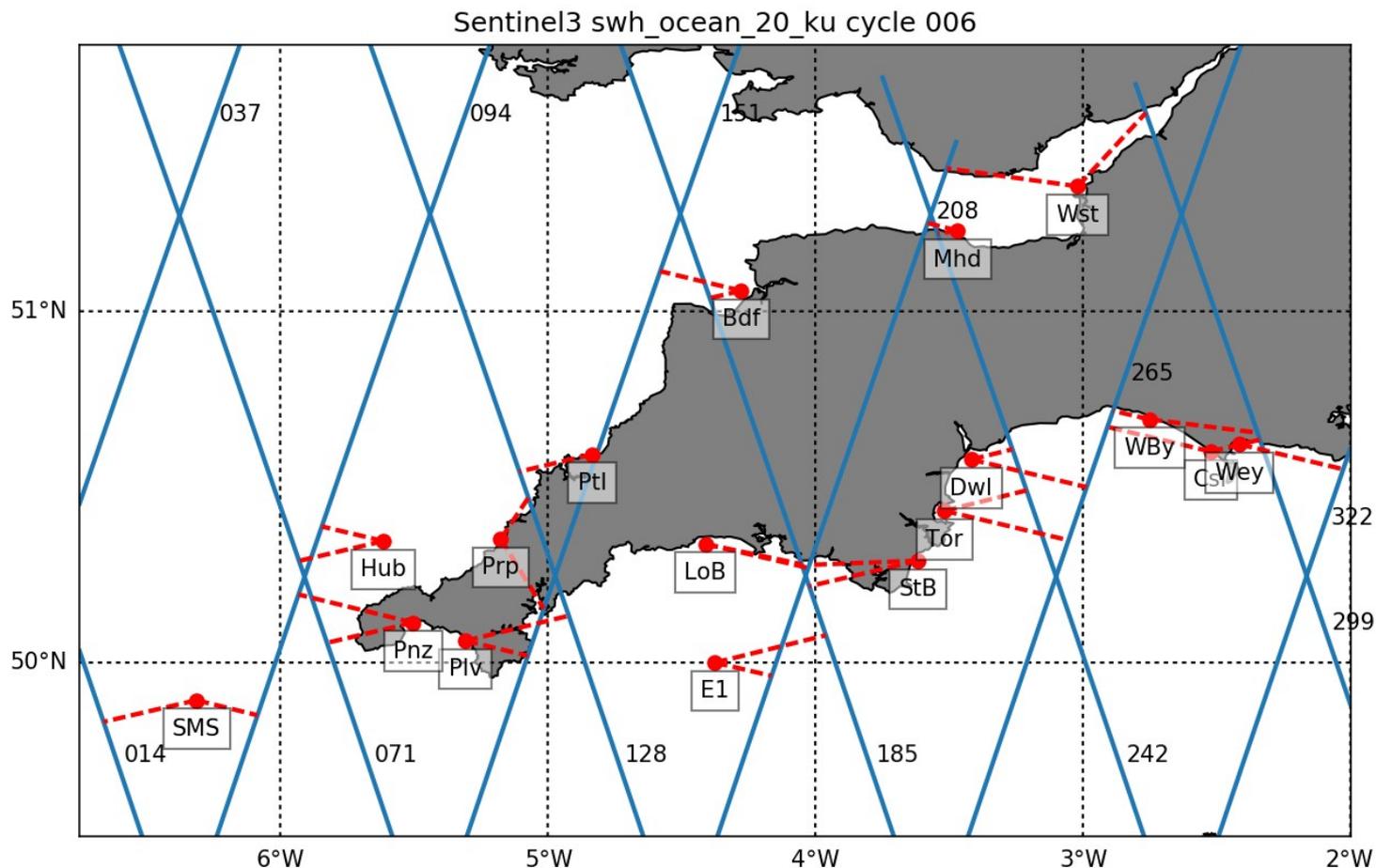


General characteristics

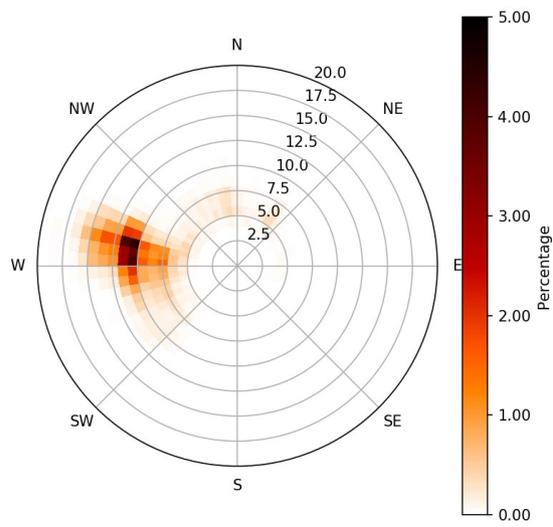
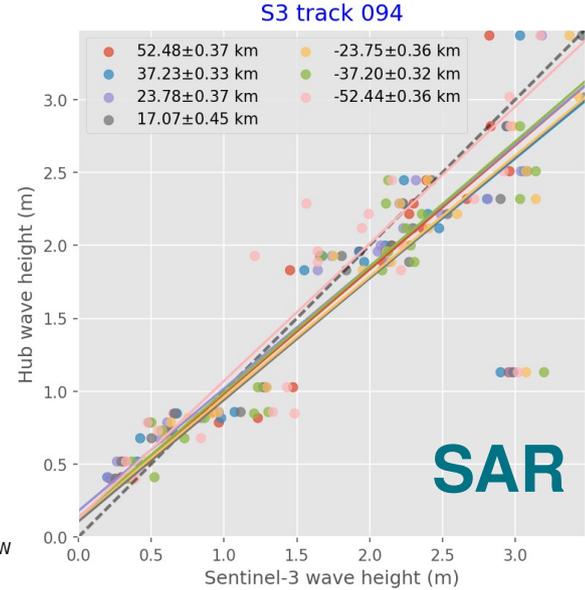
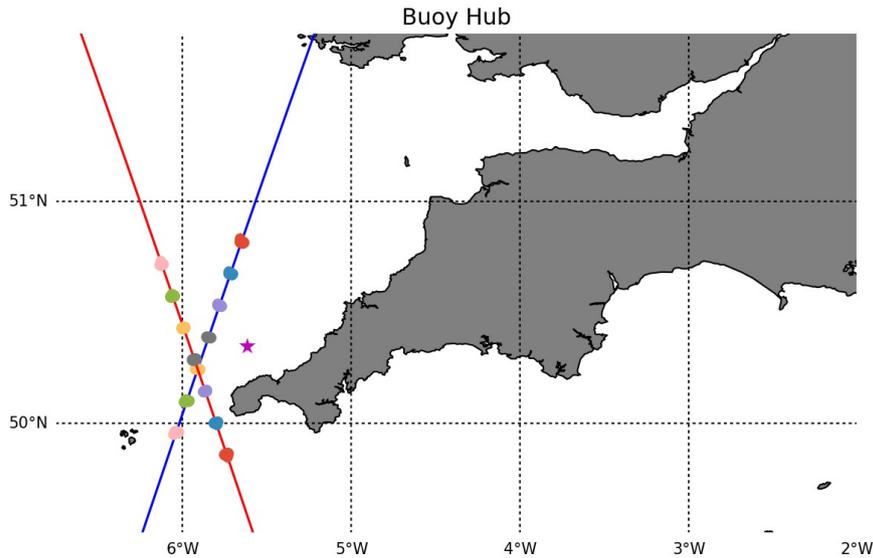
- 1) Reduced SWH approaching the coast
- 2) Further reduced in sheltered regions
- 3) Presence of tidal oscillations (not removed for the analysis!!!)
- 4) Main swells in open sea between NW and SW
- 5) Swell direction changes due to interaction with the coast (refraction)

Completely automated analysis

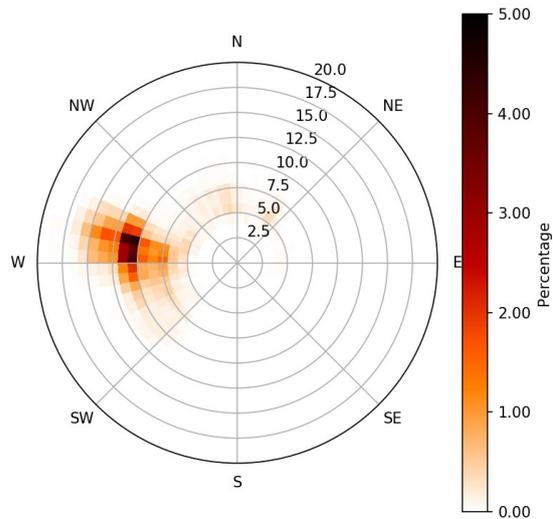
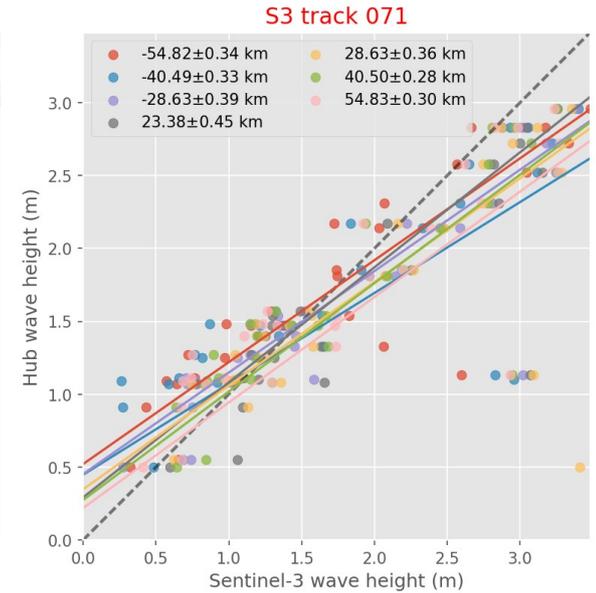
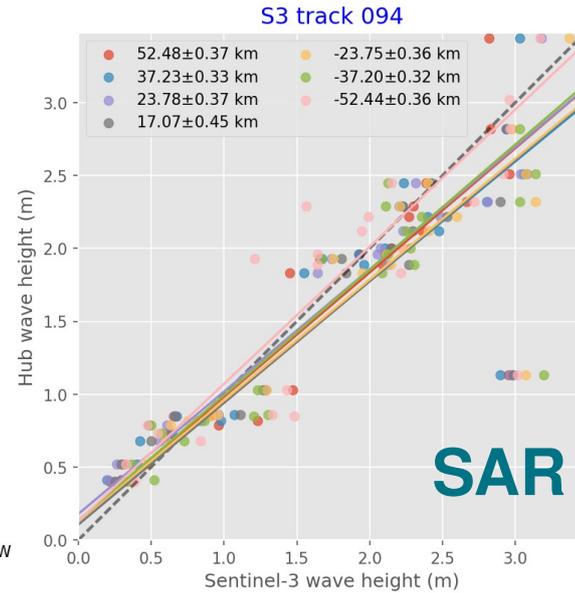
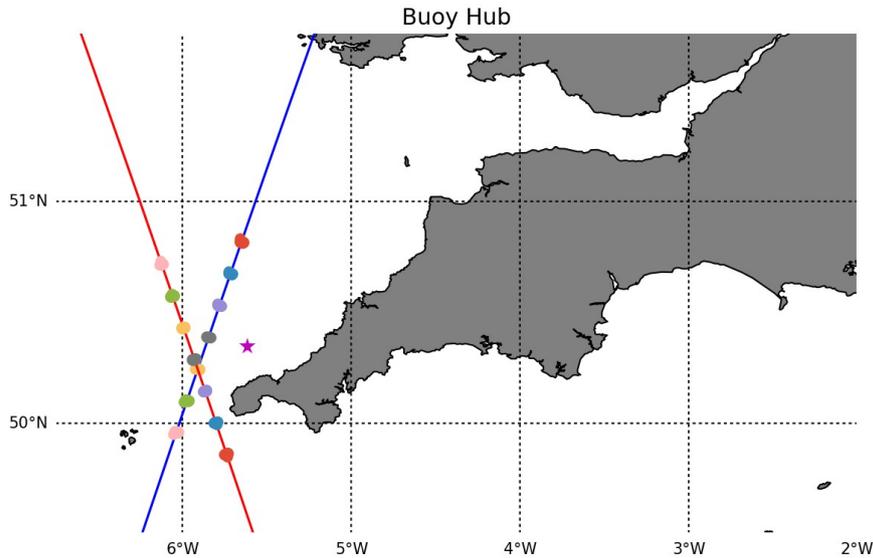
- For each buoy found the **two closest tracks**
- For each S-3A passage identified **closest buoy observation** in the timeseries
- **Scatter plots** between buoy observations and S-3A SWH every 50 bins from the closest point (~17 km spacing, matching scale of smoothing filter)
- Can be **extended** to a broader region, but is **sensitive to dataset outliers/bad flagging**



Correlation plot: (1) Open conditions (Hub)

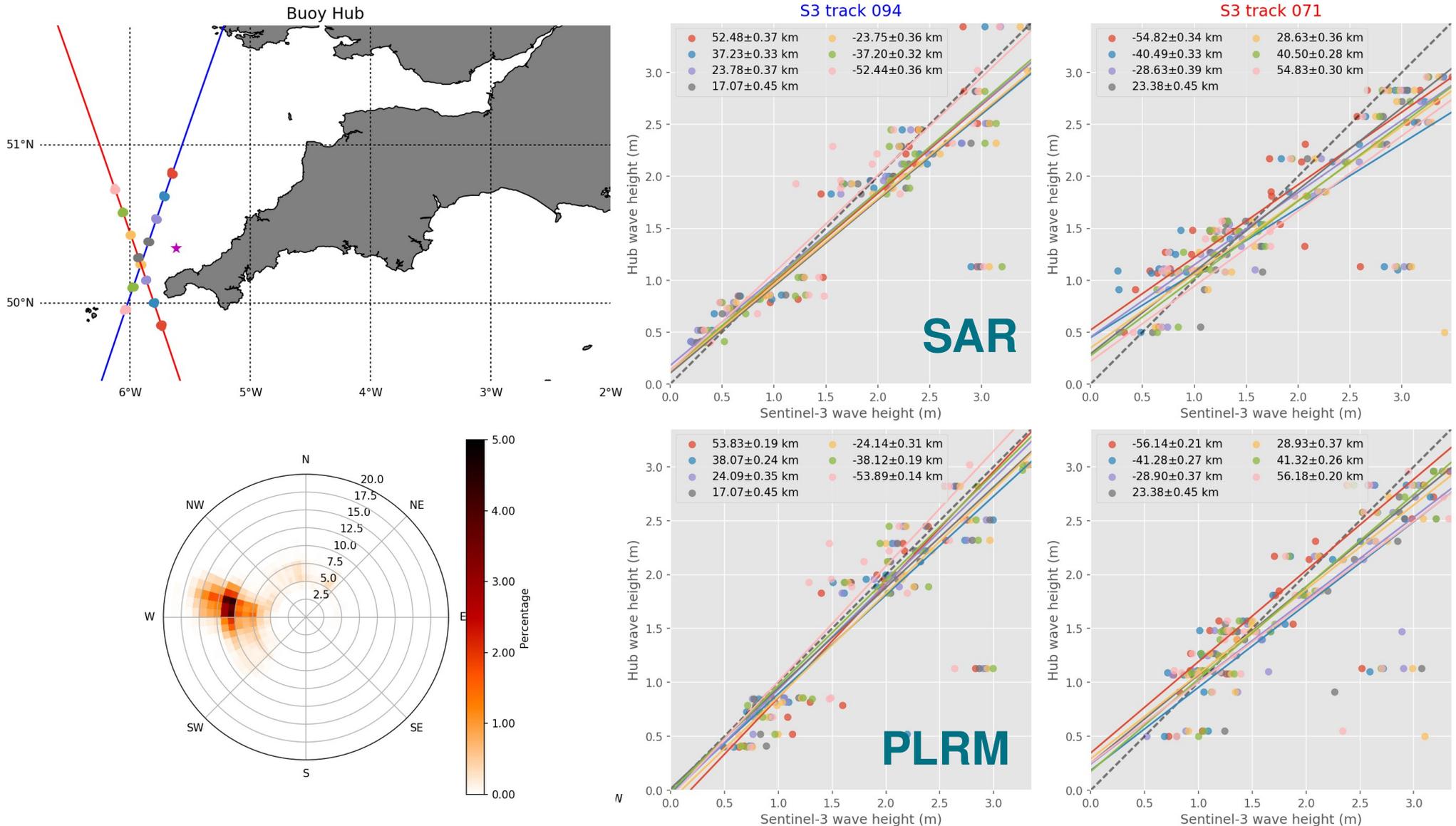


Correlation plot: (1) Open conditions (Hub)



→ Good correlation between buoy and S-3A SAR at all distances

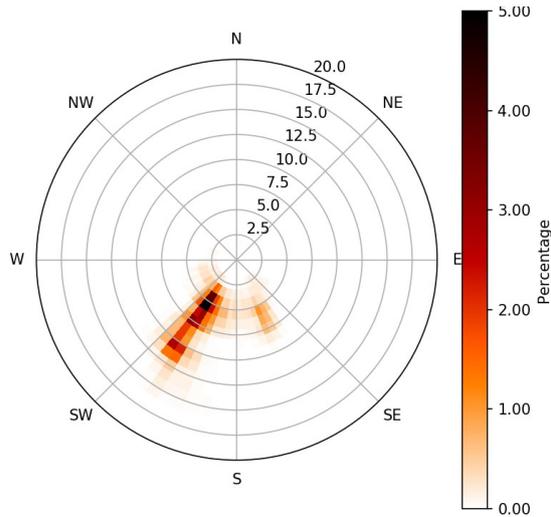
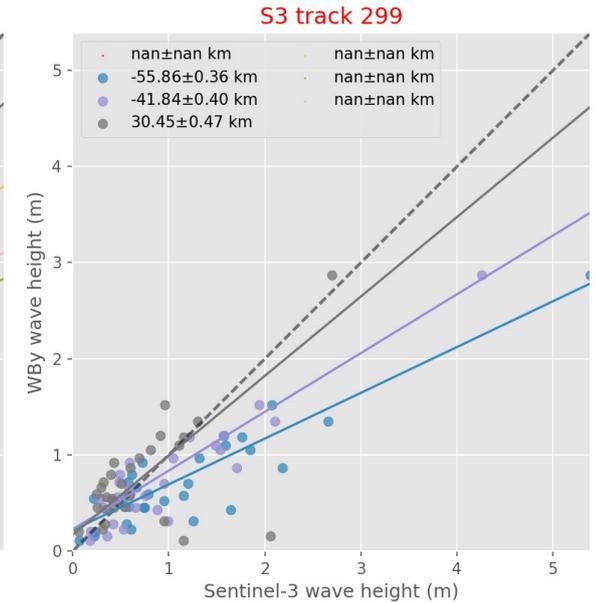
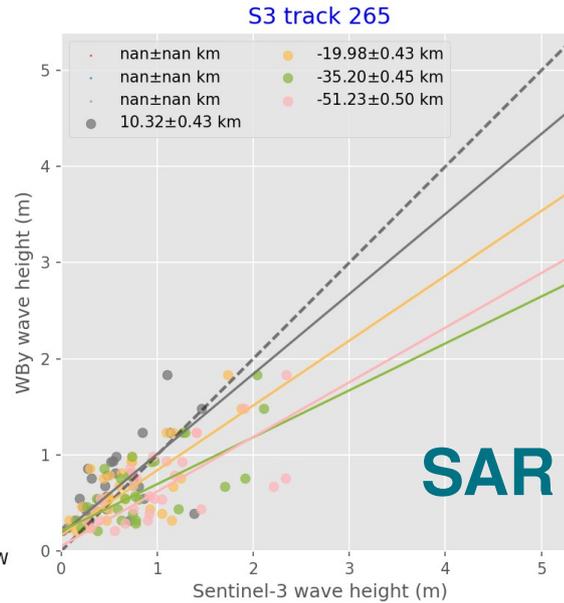
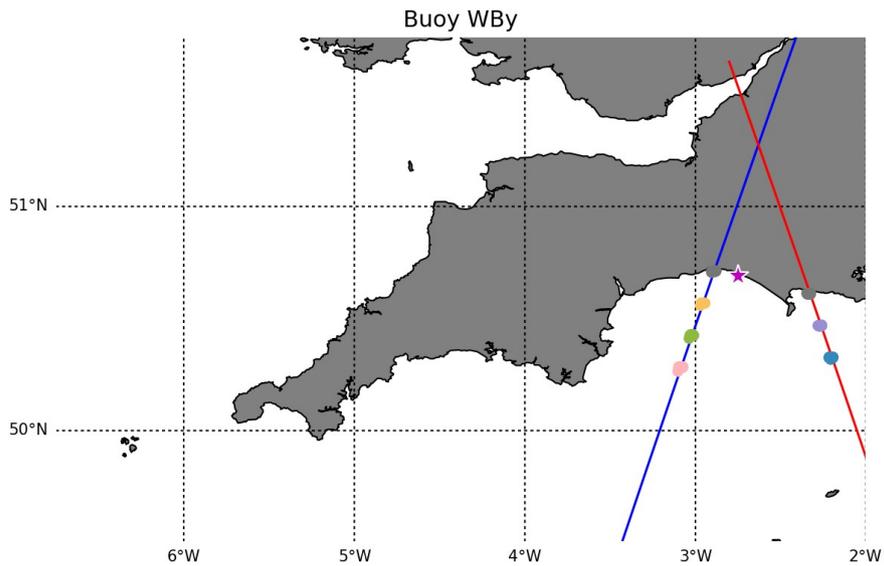
Correlation plot: (1) Open conditions (Hub)



➔ **Good correlation** between buoy and S-3A SAR at **all distances**

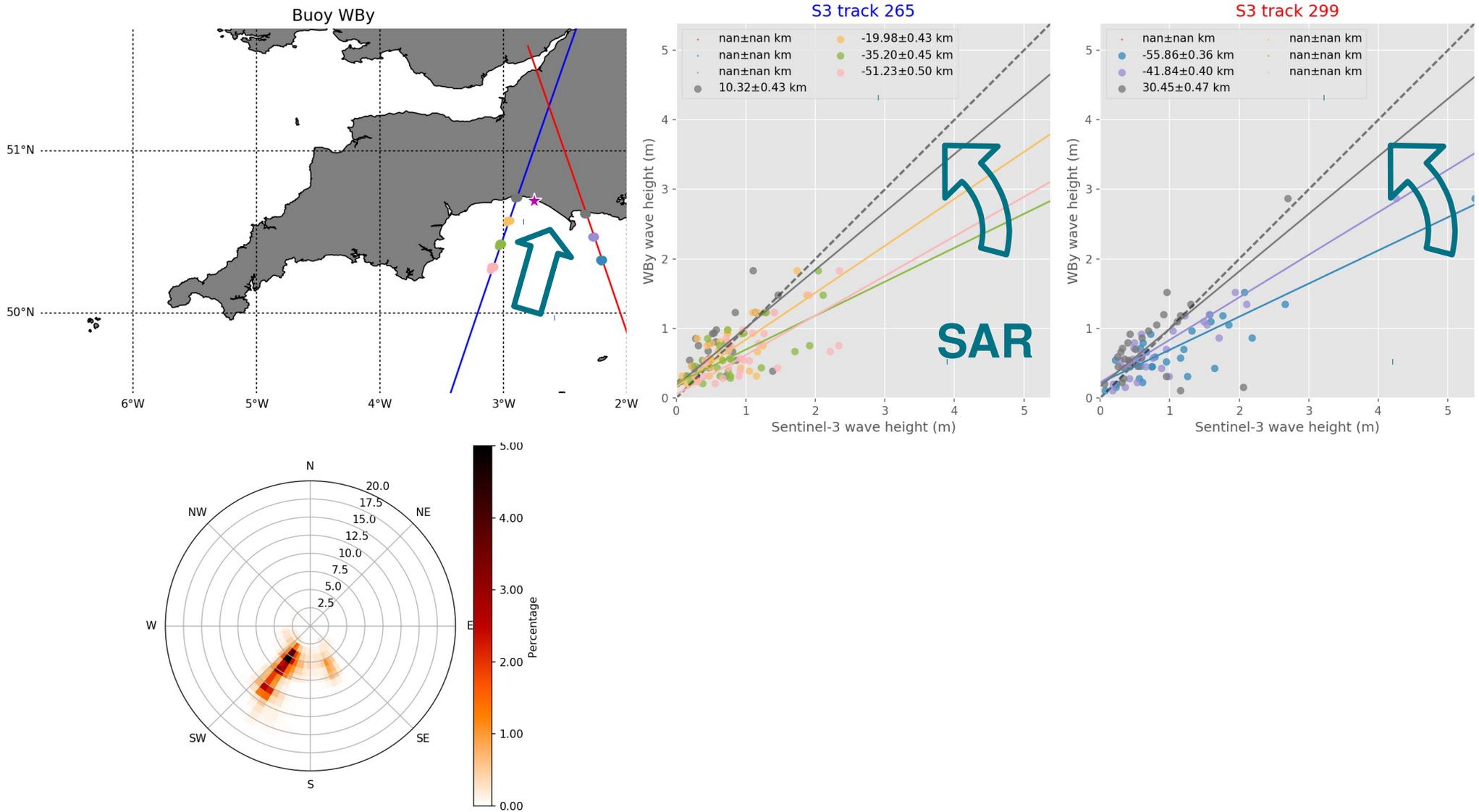
➔ **Similar good correlation** for S-3A PLRM

Correlation plot: (2) Coastal and open conditions (WBy)



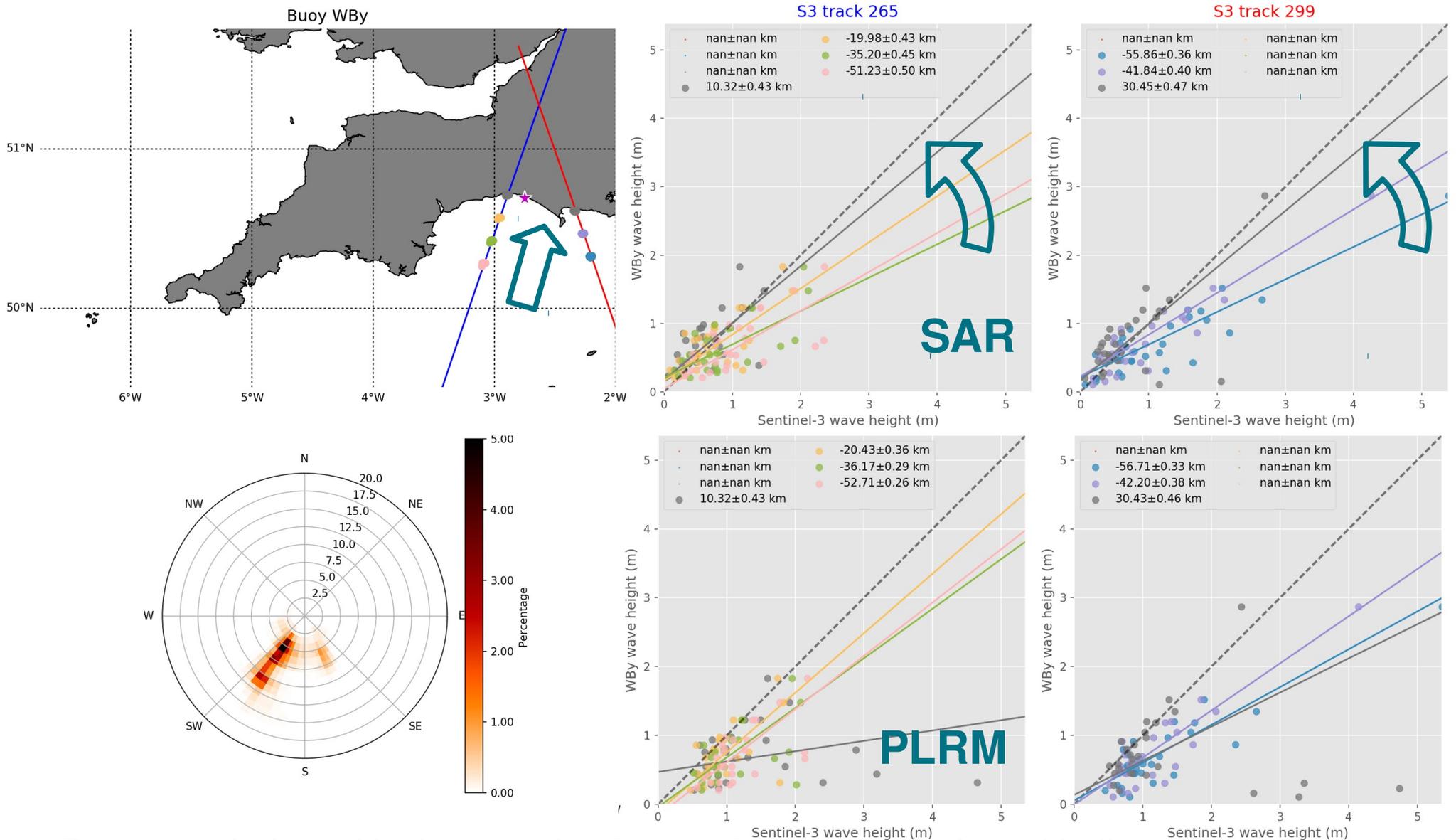
→ Best correlation with closest point

Correlation plot: (2) Coastal and open conditions (WBy)



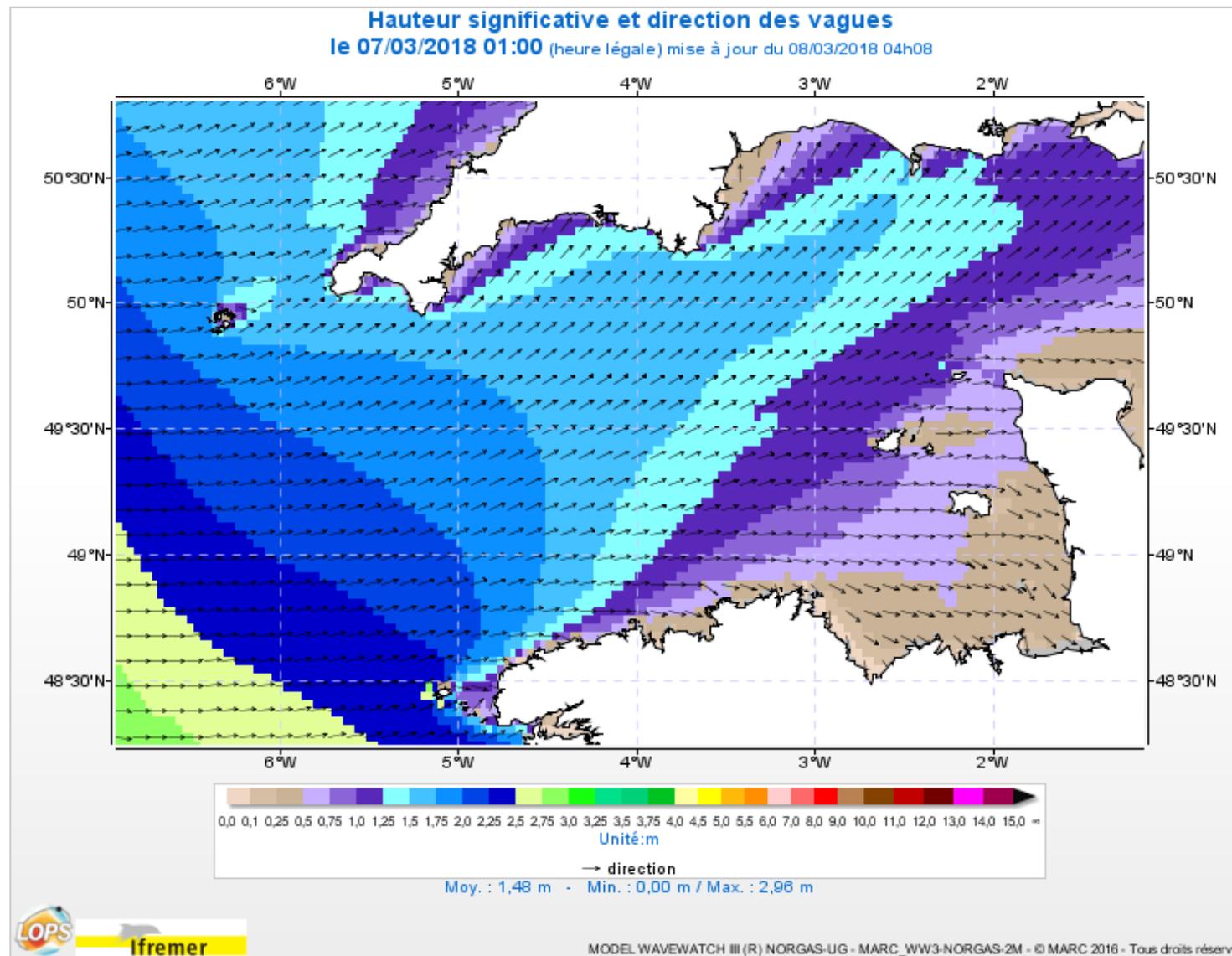
→ **Best correlation** with closest point (**Increasing wave heights** with distance from the coast)

Correlation plot: (2) Coastal and open conditions (WBy)



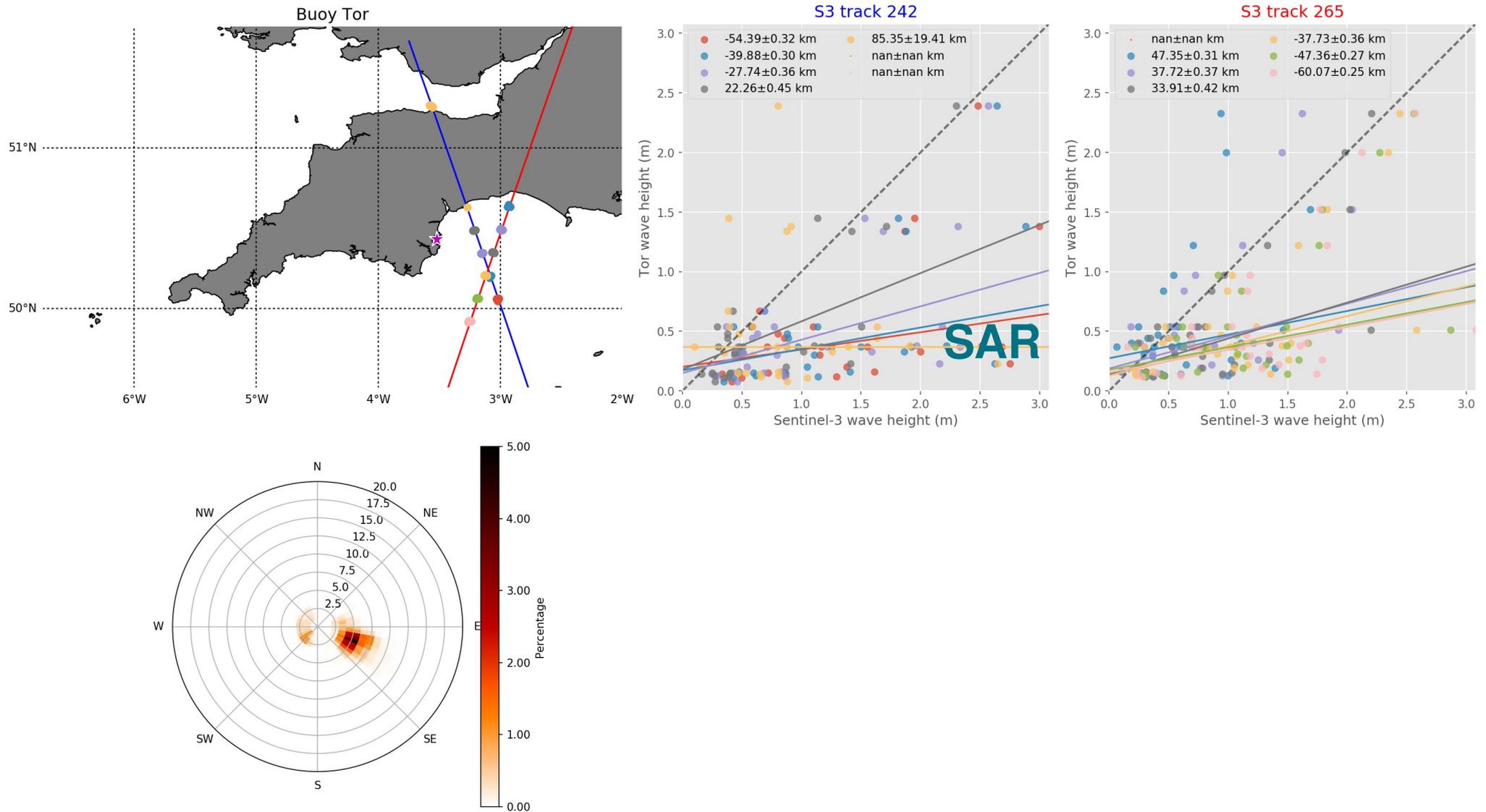
- ➔ **Best correlation** with closest point (**Increasing wave heights** with distance from the coast)
- ➔ **Correlation** close to the coast **not as good** for PLRM (coastal contamination)

S-3A SWH observations consistent with operational model results



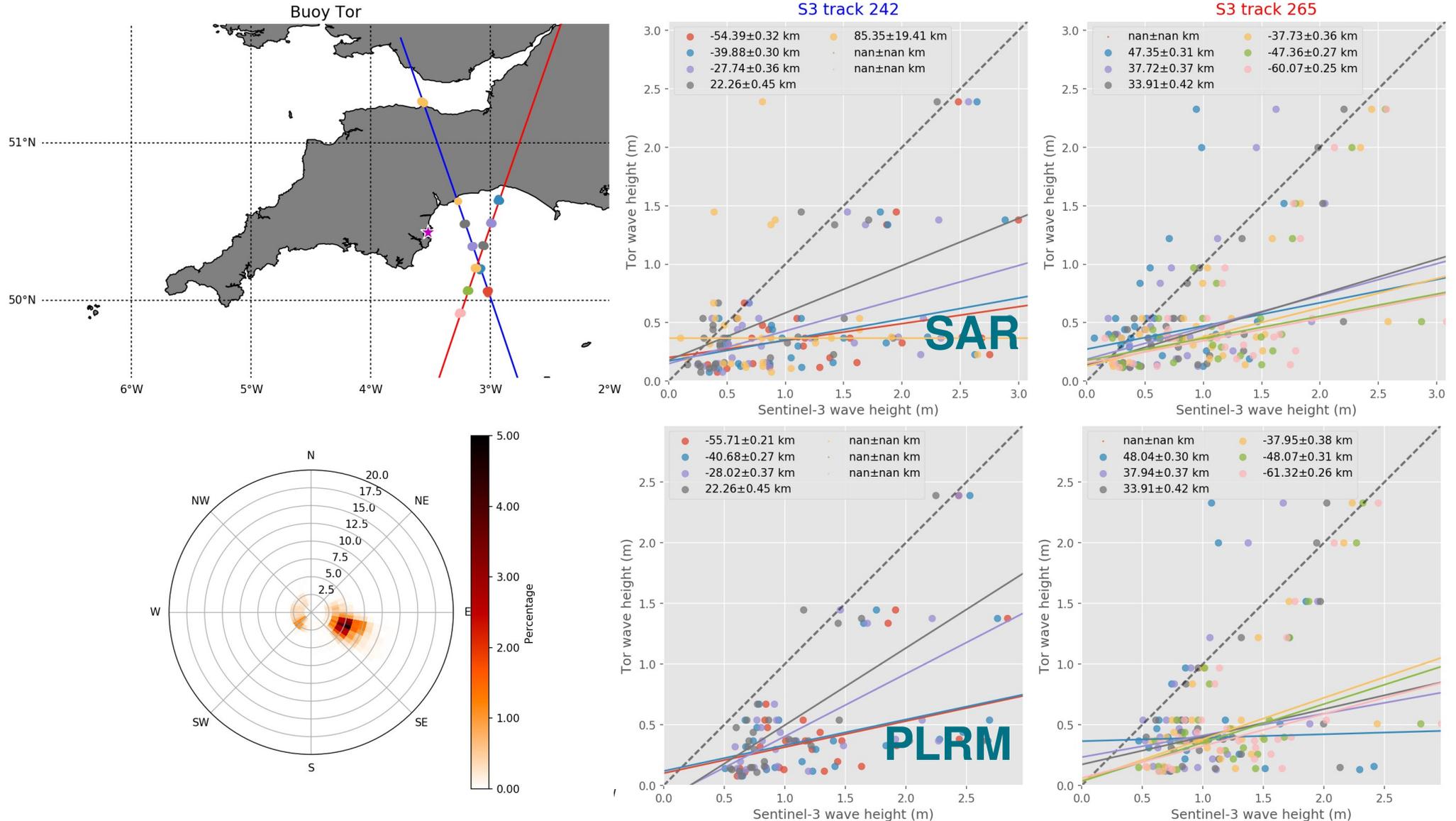
- Decrease in SWH towards the coast **significant**
- Due to **sheltering effect** of coast morphology on dominant W to SW swells

Correlation plot: (3) Coastal and sheltered conditions (Tor)



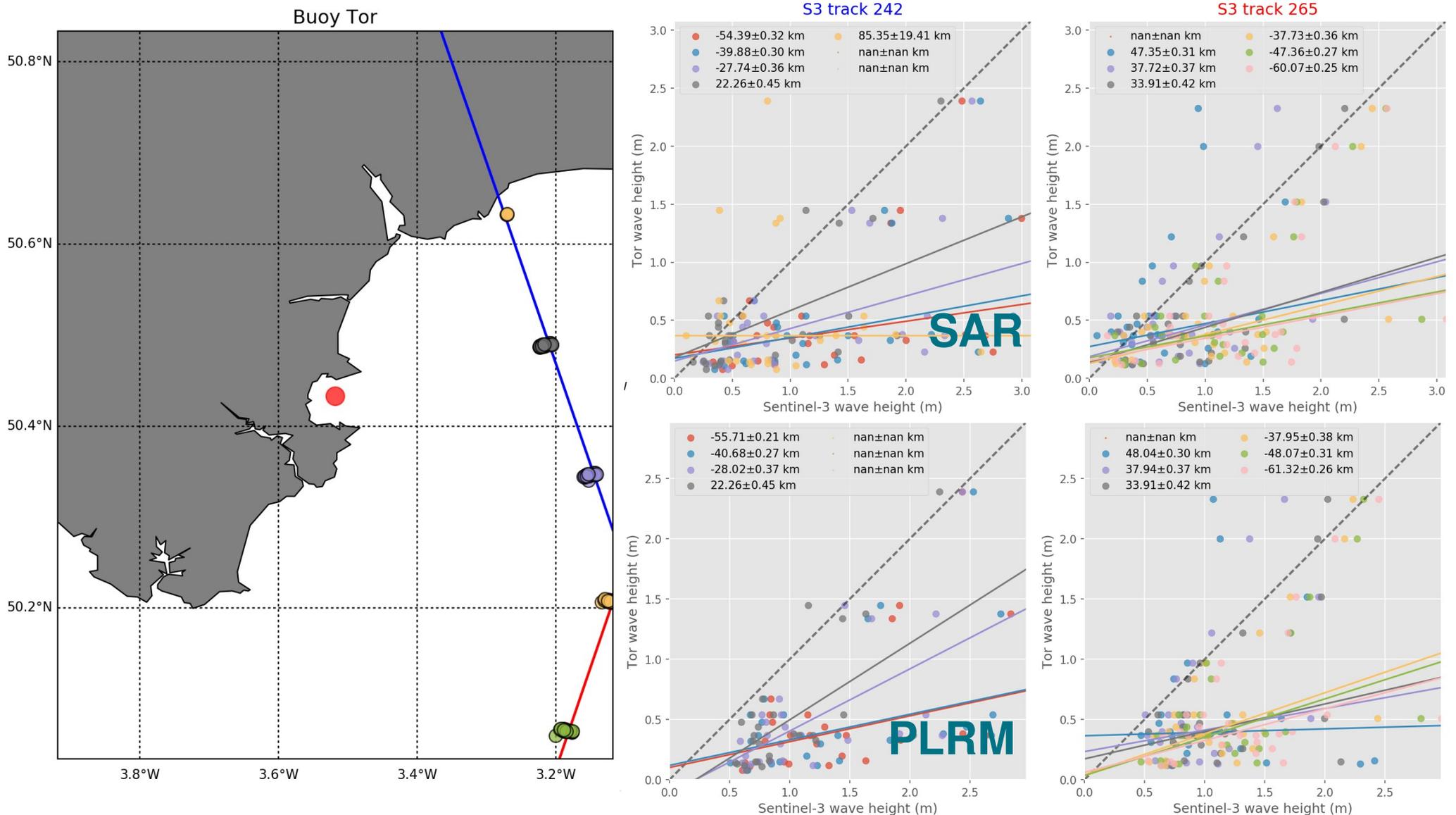
→ Similar trend but **correlation not as good** as open case (even though same bay)

Correlation plot: (3) Coastal and sheltered conditions (Tor)



- ➔ Similar trend but **correlation not as good** as open case (even though same bay)
- ➔ Analogous performance for PLRM

Correlation plot: (3) Coastal and sheltered conditions (Tor)



- ➔ Similar trend but **correlation not as good** as open case (even though same bay)
- ➔ Analogous performance for PLRM

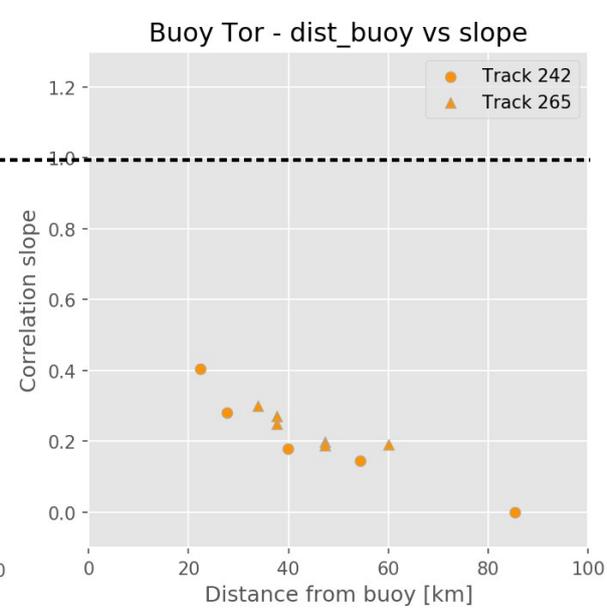
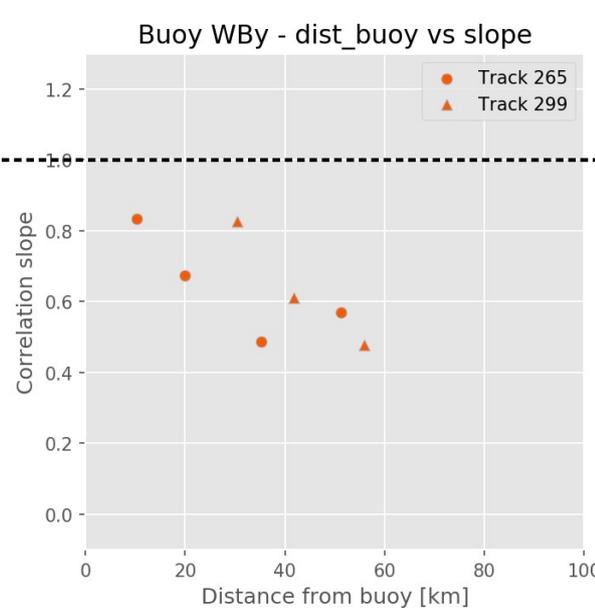
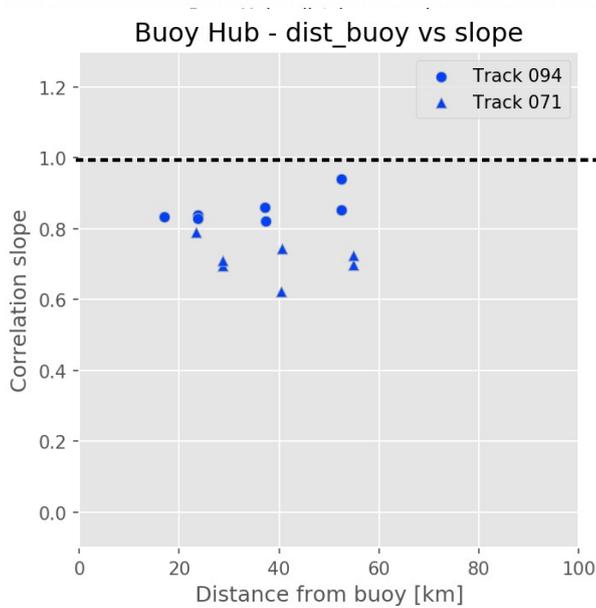
Individual correlation-slope scatter plots

(1) Open

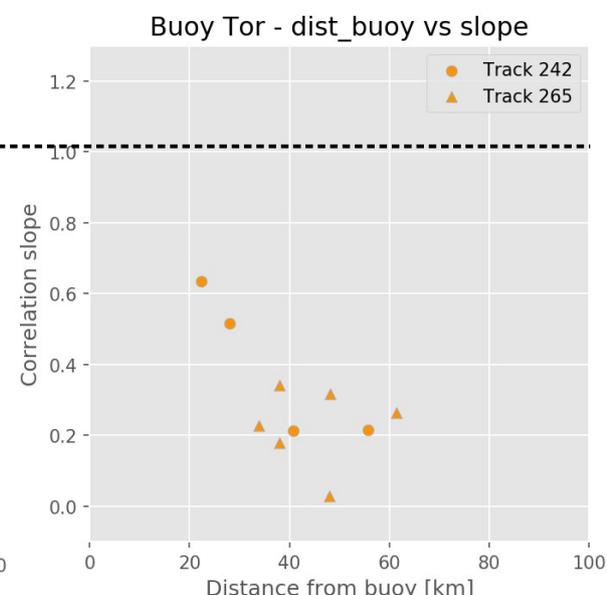
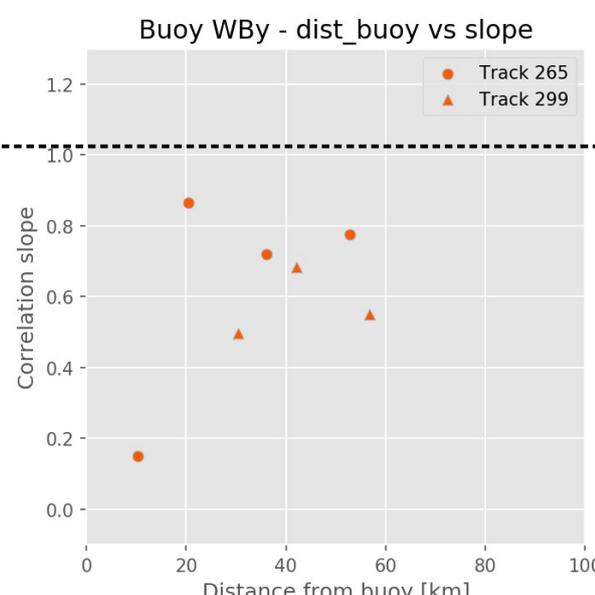
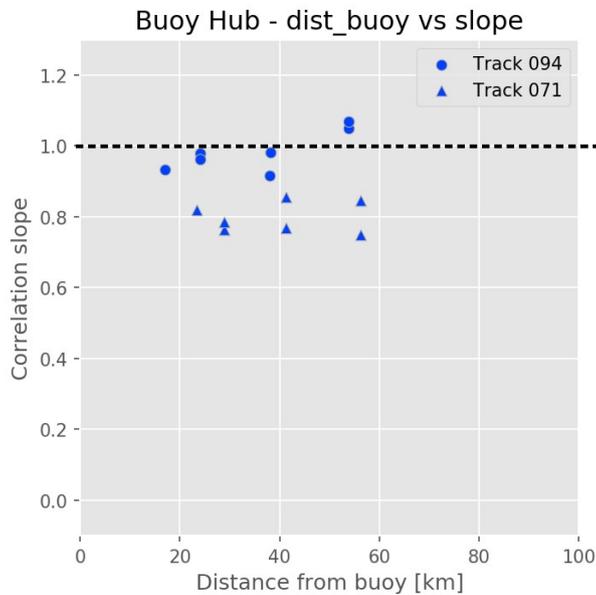
(2) Coastal

(3) Sheltered

SAR



PLRM



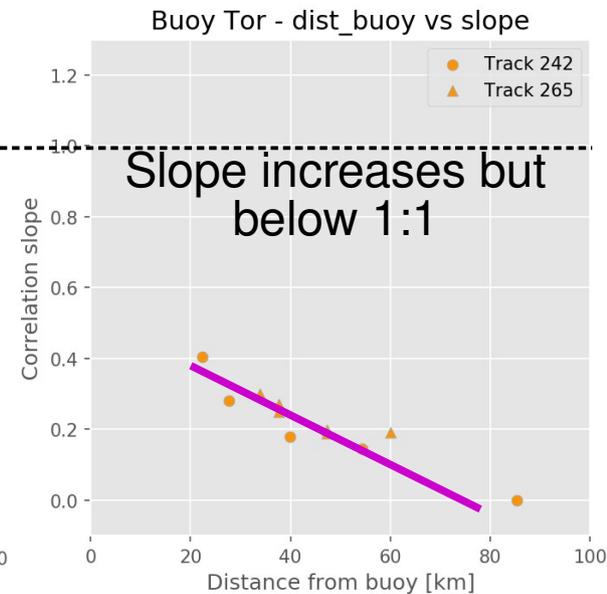
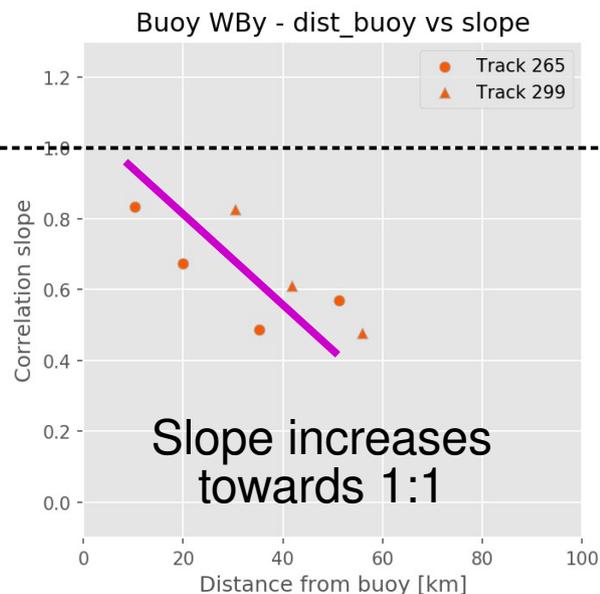
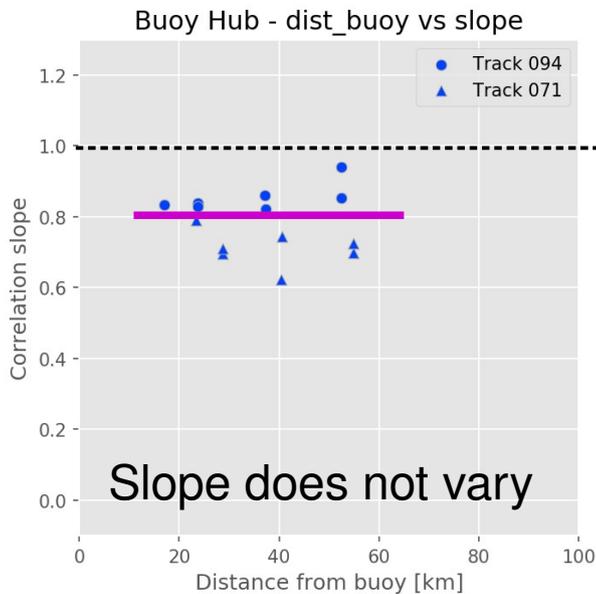
Individual correlation-slope scatter plots

(1) Open

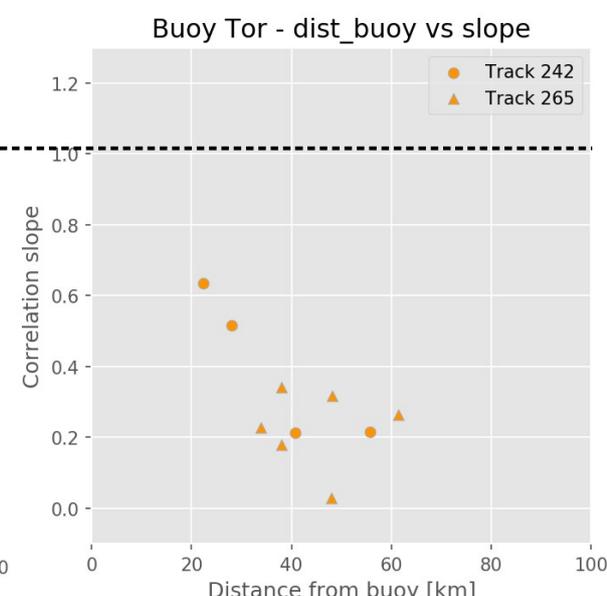
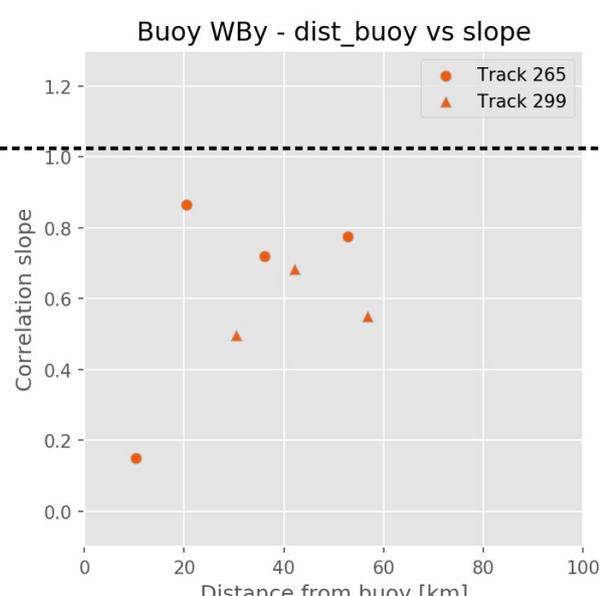
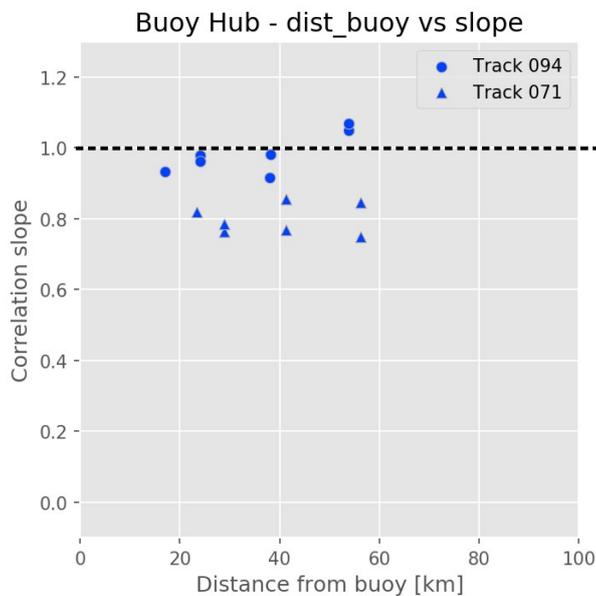
(2) Coastal

(3) Sheltered

SAR



PLRM



Total correlation-slope scatter plots

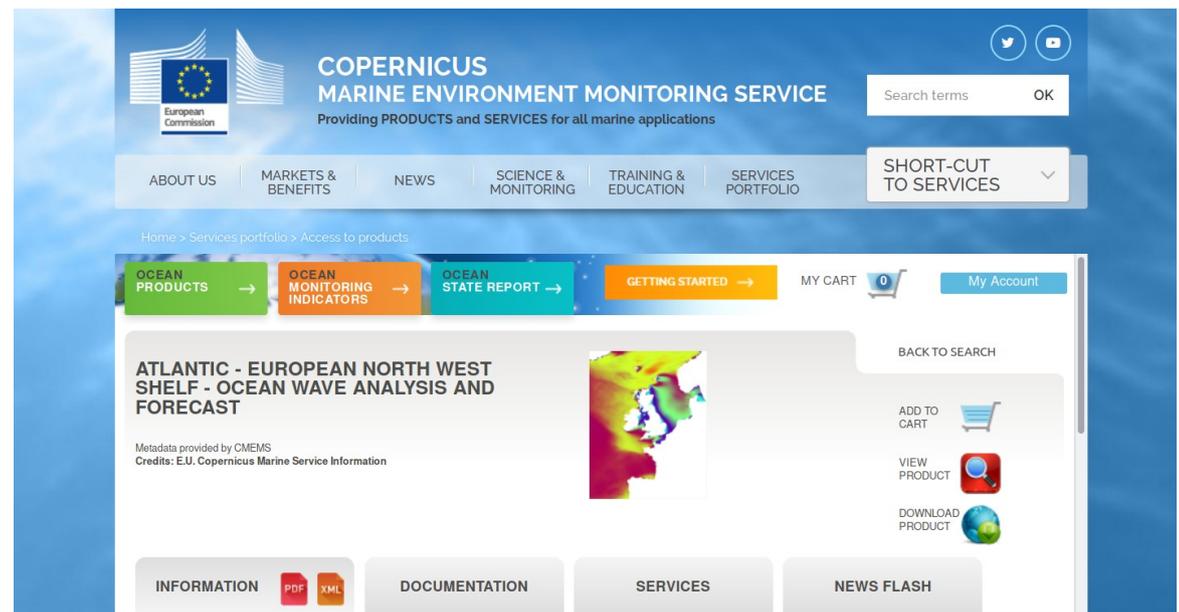
Identify the combination of coastal buoy + S3 track to use:

Question: For which area buoy measurements are representative?

Solution: Wave model to identify the spatial correlation around buoy measurements

MetOffice WWIII-AMM7

- Wave watch III model
- 7 km spatial resolution
- Hourly temporal resolution
- From Apr 2014 to present
- Available at CMEMS

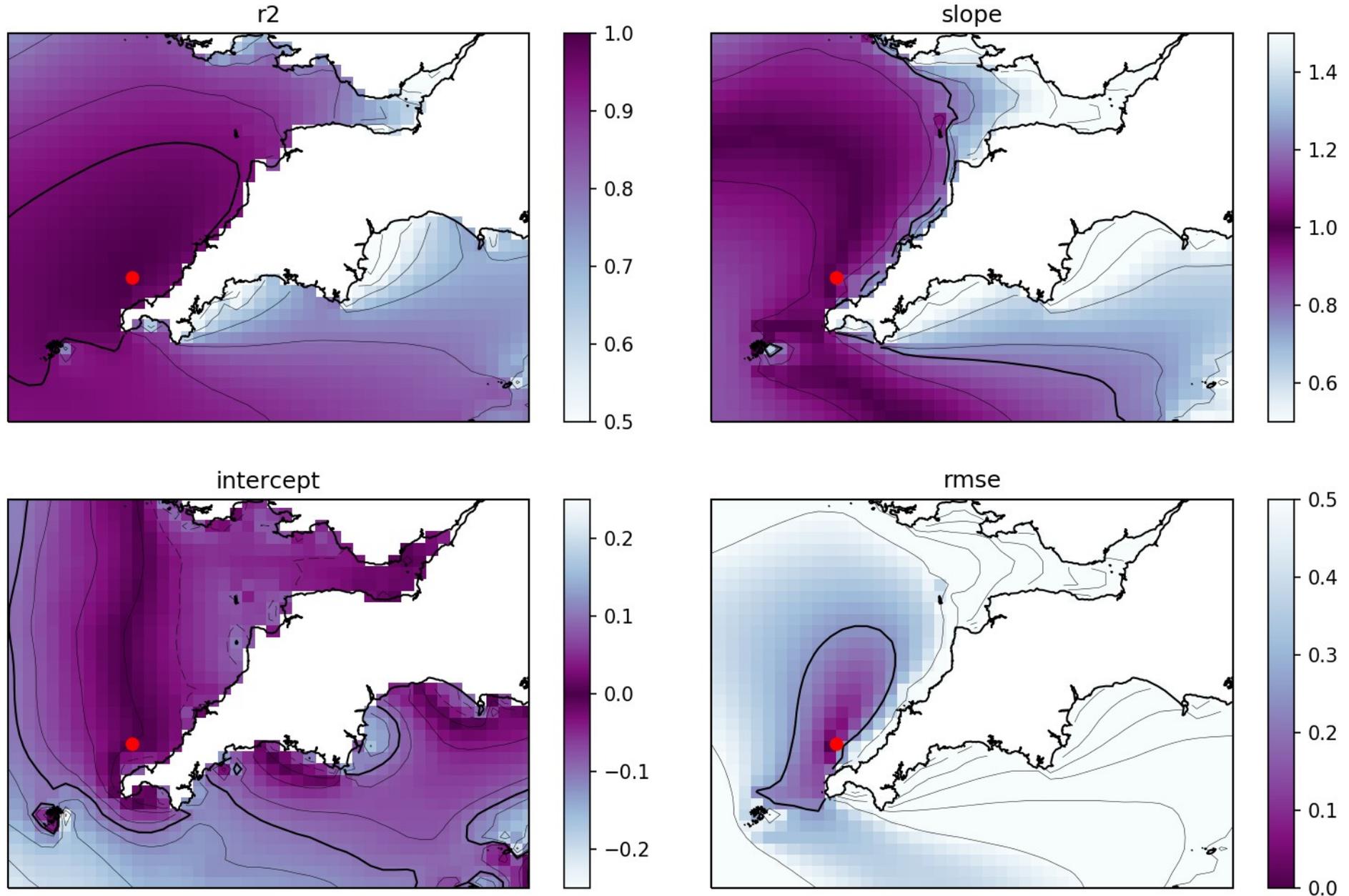


Computed correlations between closest point to the buoy and rest of model points

4 parameters derived:

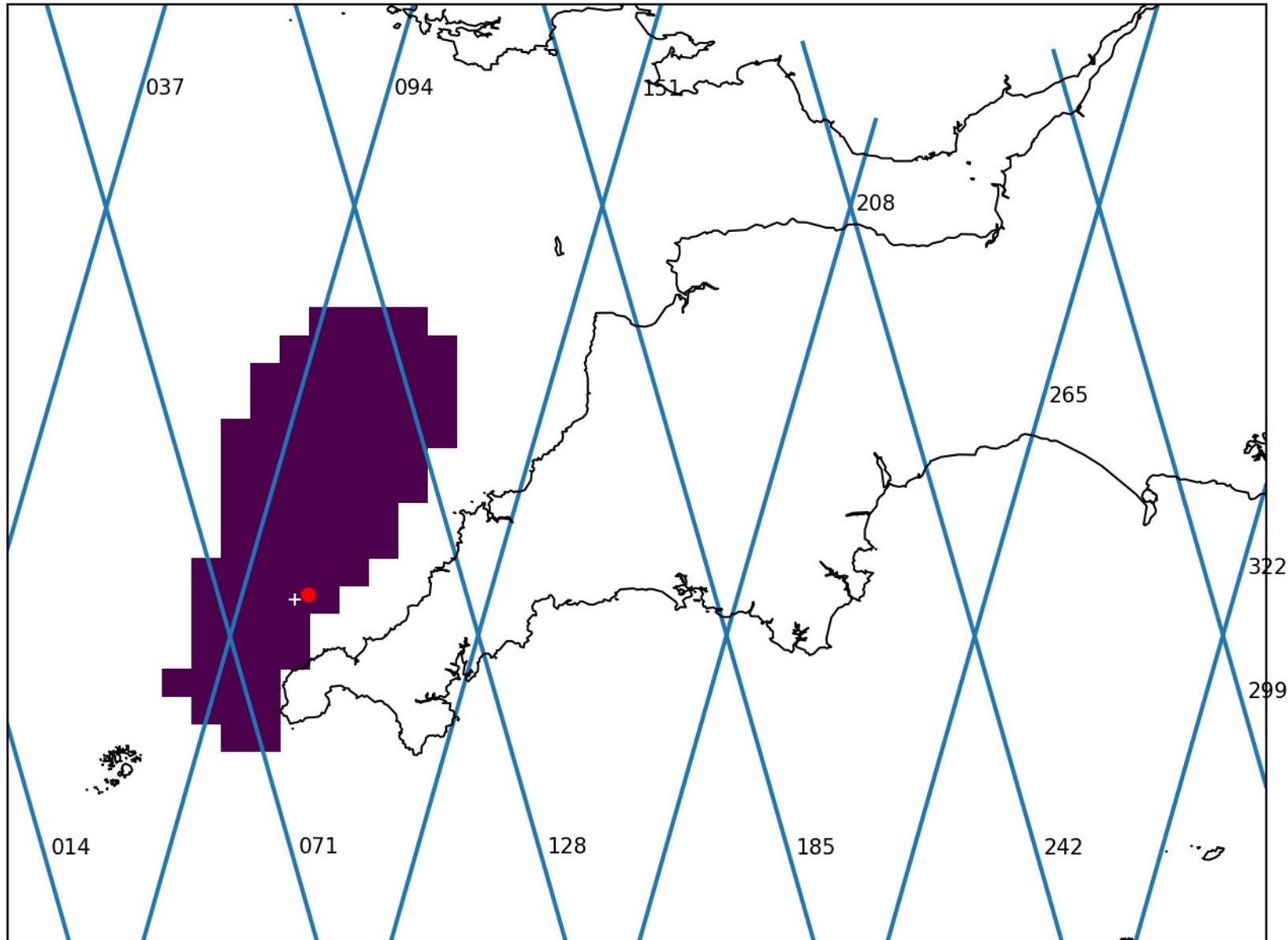
- 1) Correlation coefficient (**r²**)
- 2) Root mean square error (**RMS**)
- 3) Regression **slope**
- 4) Regression **intercept**

Total correlation-slope scatter plots (HuB: Open Sea)

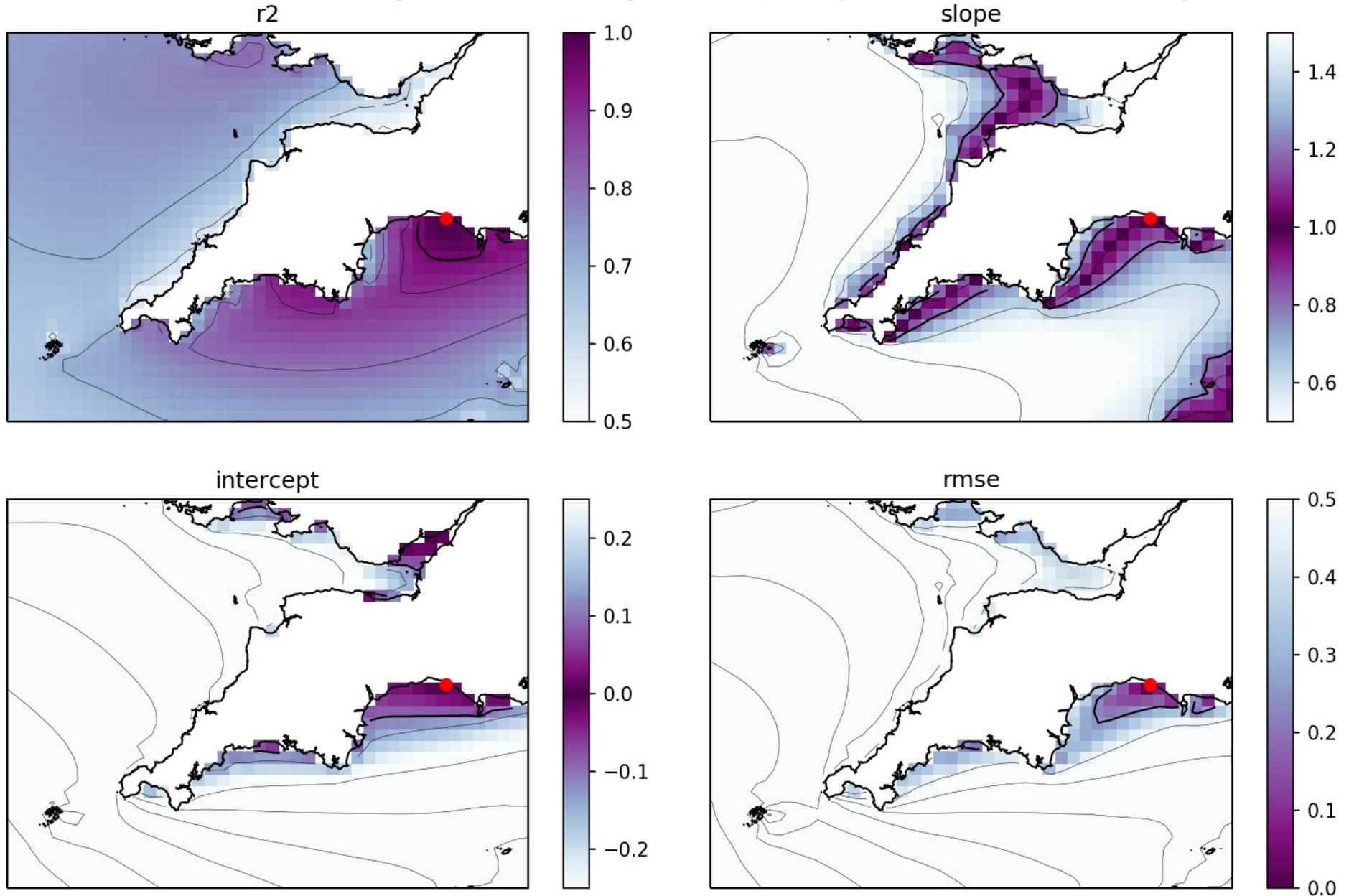


Total correlation-slope scatter plots (HuB: Open Sea)

Buoy Hub ($r_2 \geq 0.95$; $0.80 \geq \text{slope} \leq 1.20$; $-0.10 \geq \text{intercept} \leq 0.10$; $\text{rmse} \leq 0.25$;)

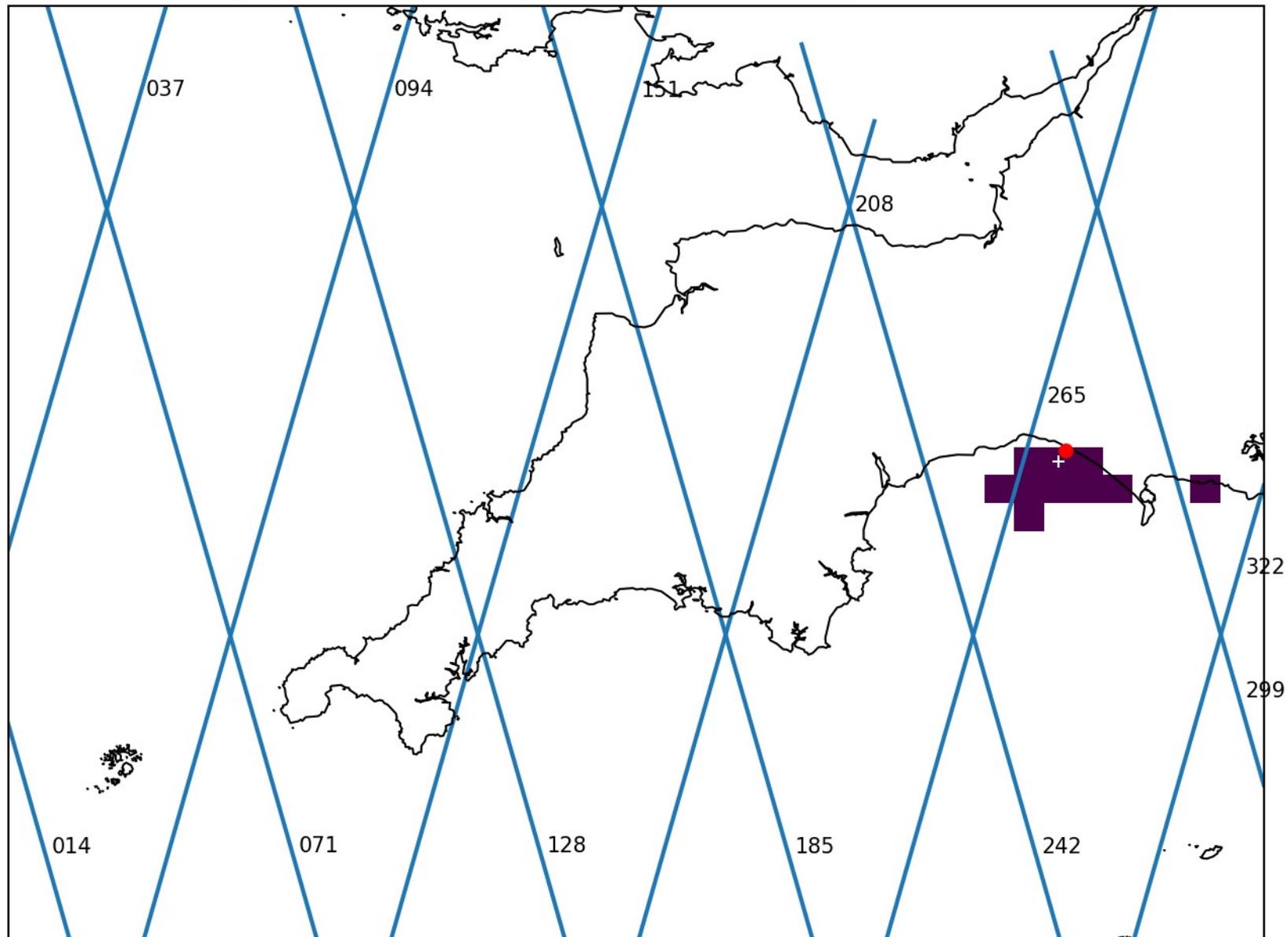


Total correlation-slope scatter plots (WBy: Coastal and Open)



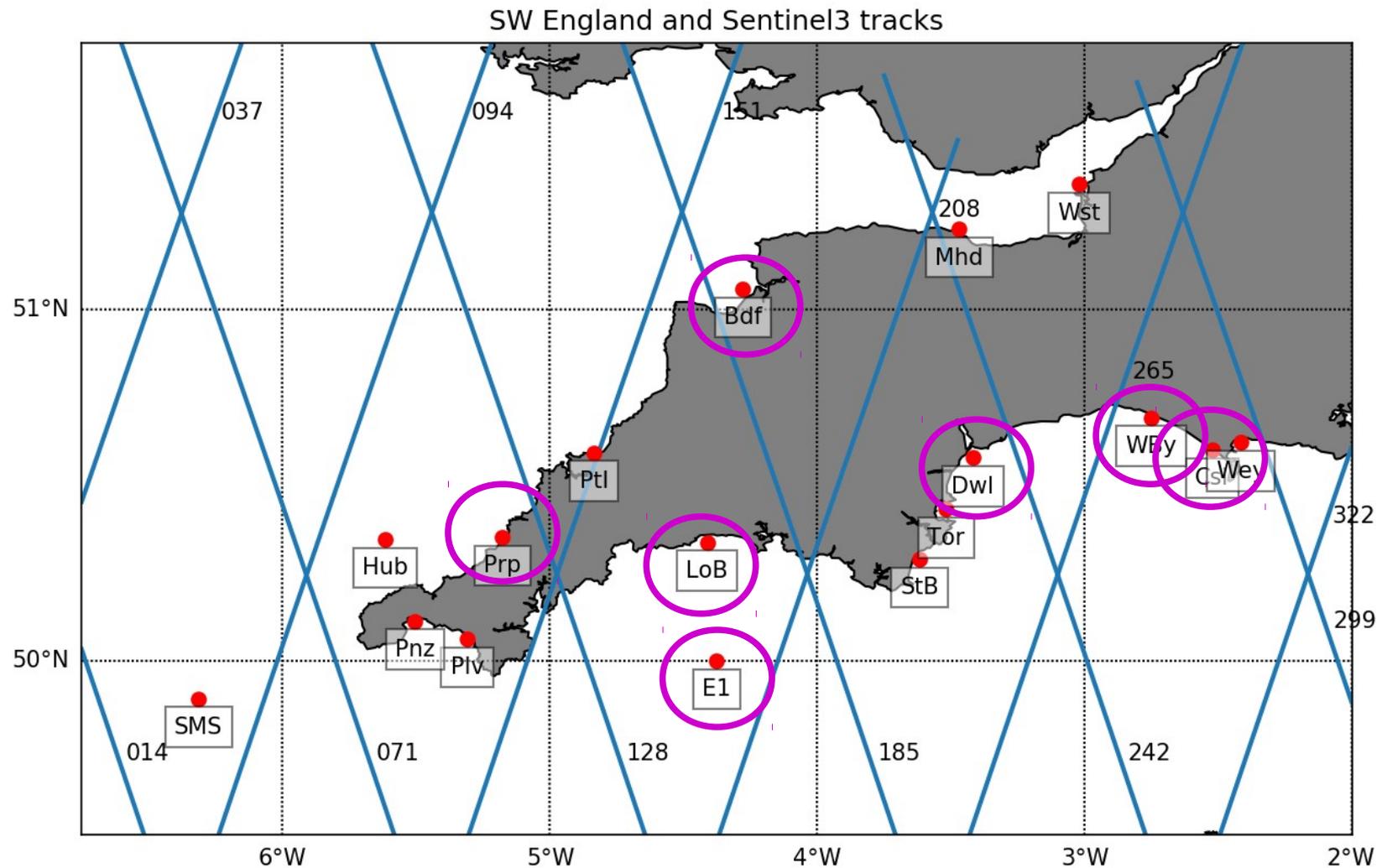
Total correlation-slope scatter plots (WBy: Coastal and Open)

Buoy WBy ($r^2 \geq 0.95$; $0.80 \geq \text{slope} \leq 1.20$; $-0.10 \geq \text{intercept} \leq 0.10$; $\text{rmse} \leq 0.25$;)

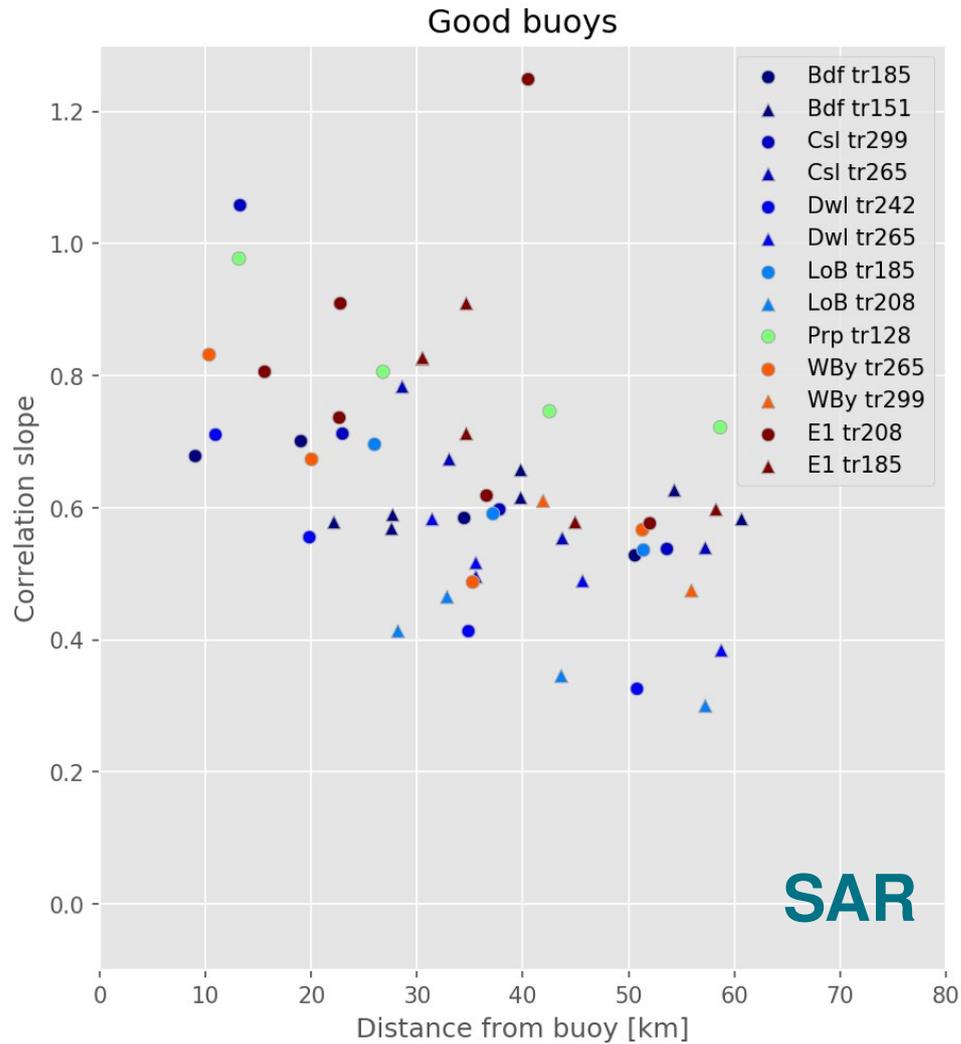


Total correlation-slope scatter plots

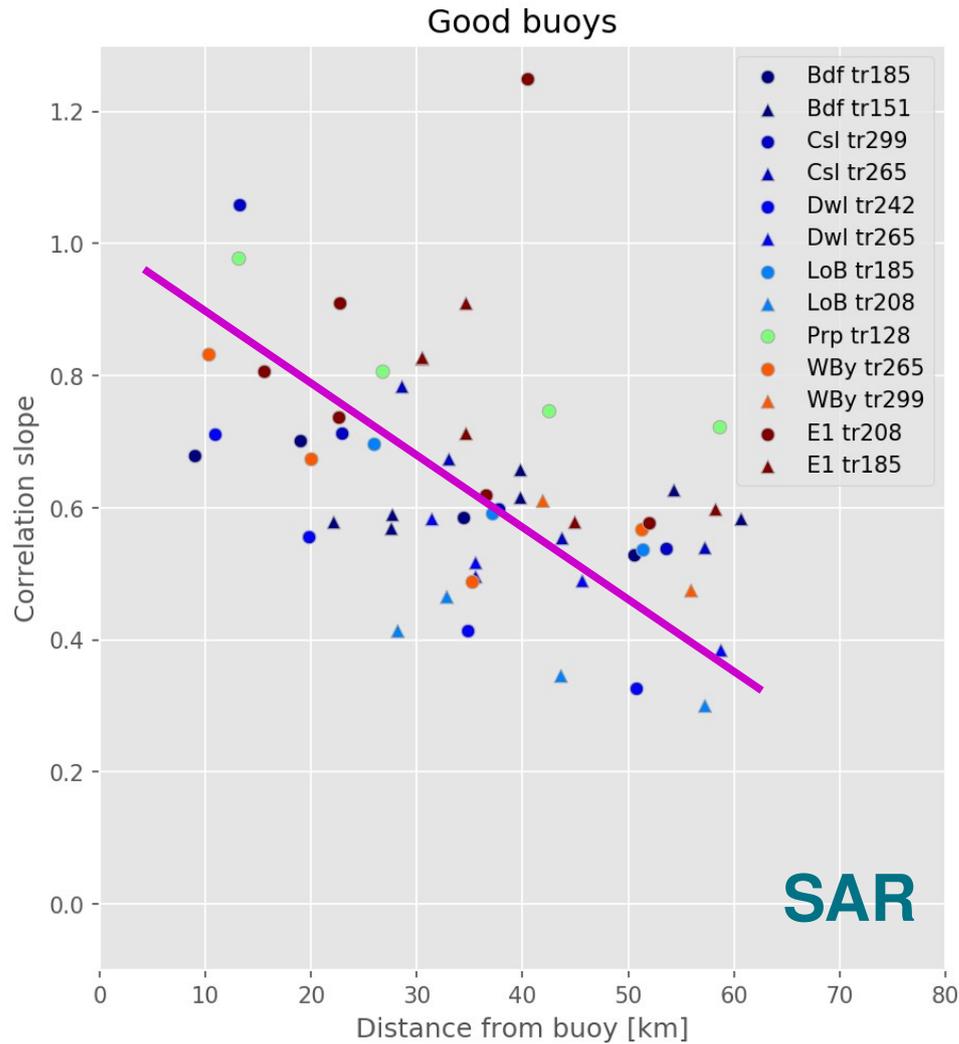
→ Identified 7 coastal open buoys



Total correlation-slope scatter plots

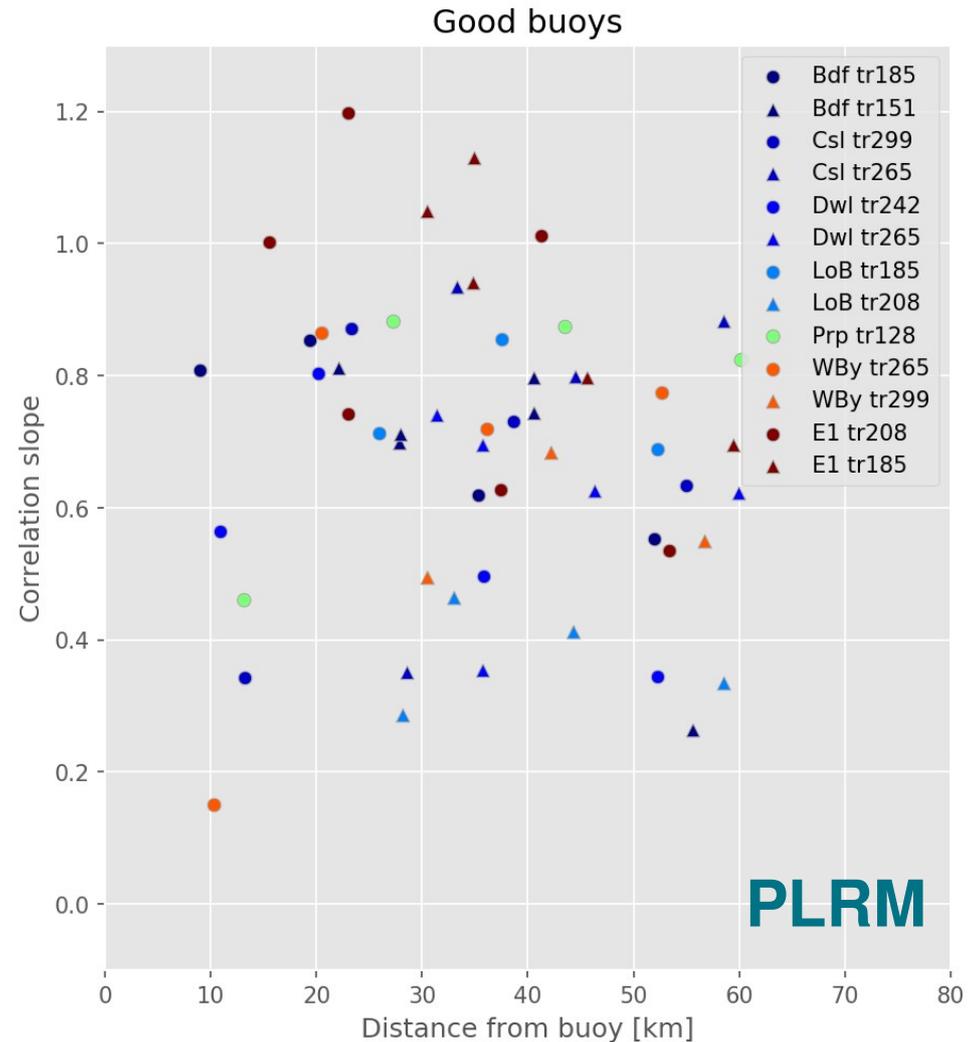
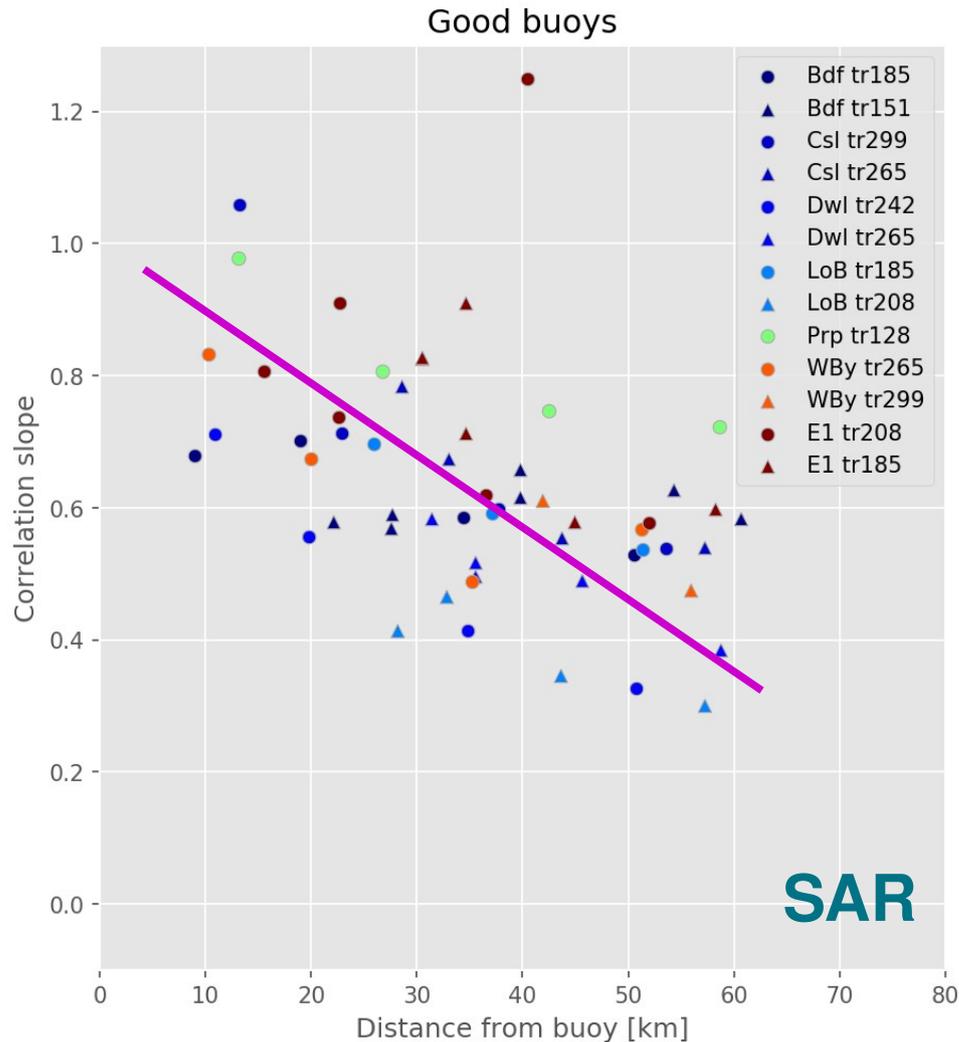


Total correlation-slope scatter plots



SAR: Correlation towards 1:1 ratio with decreasing distance from buoy (and coast)

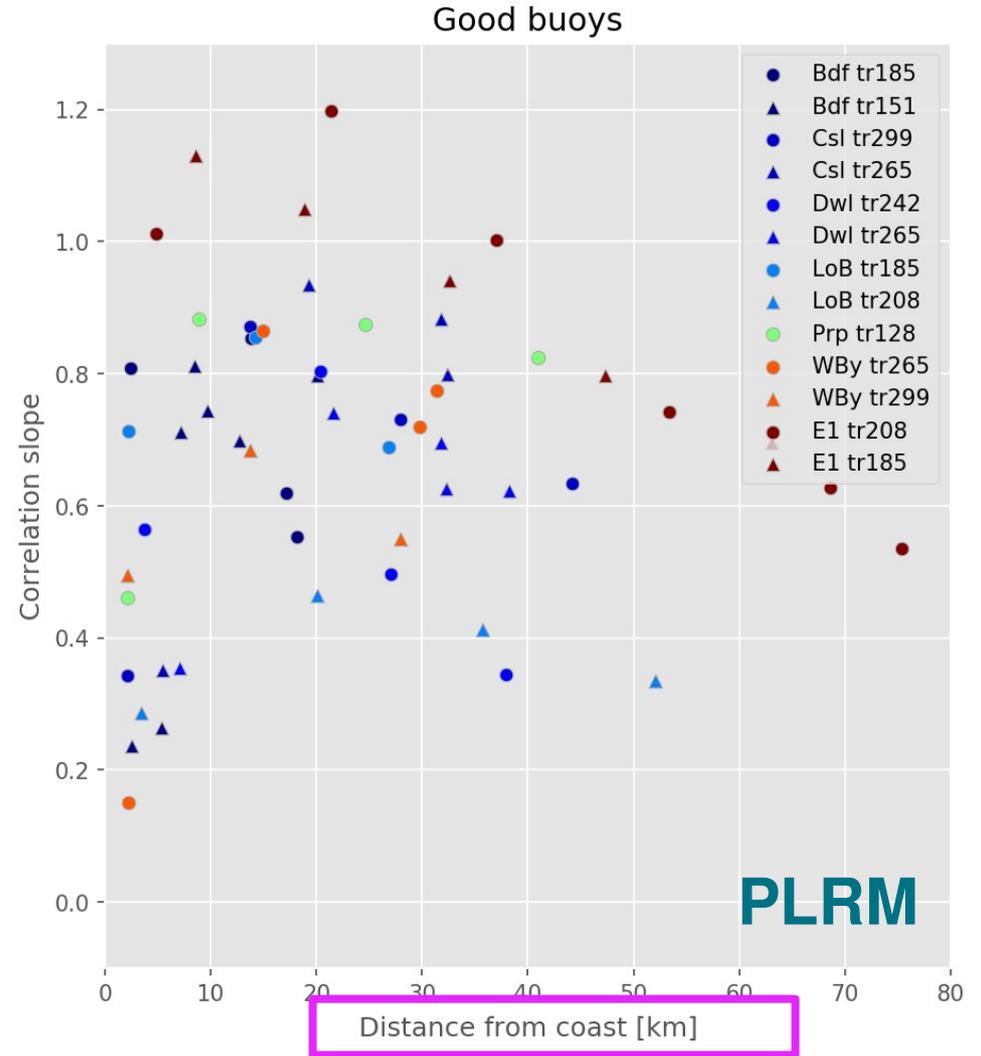
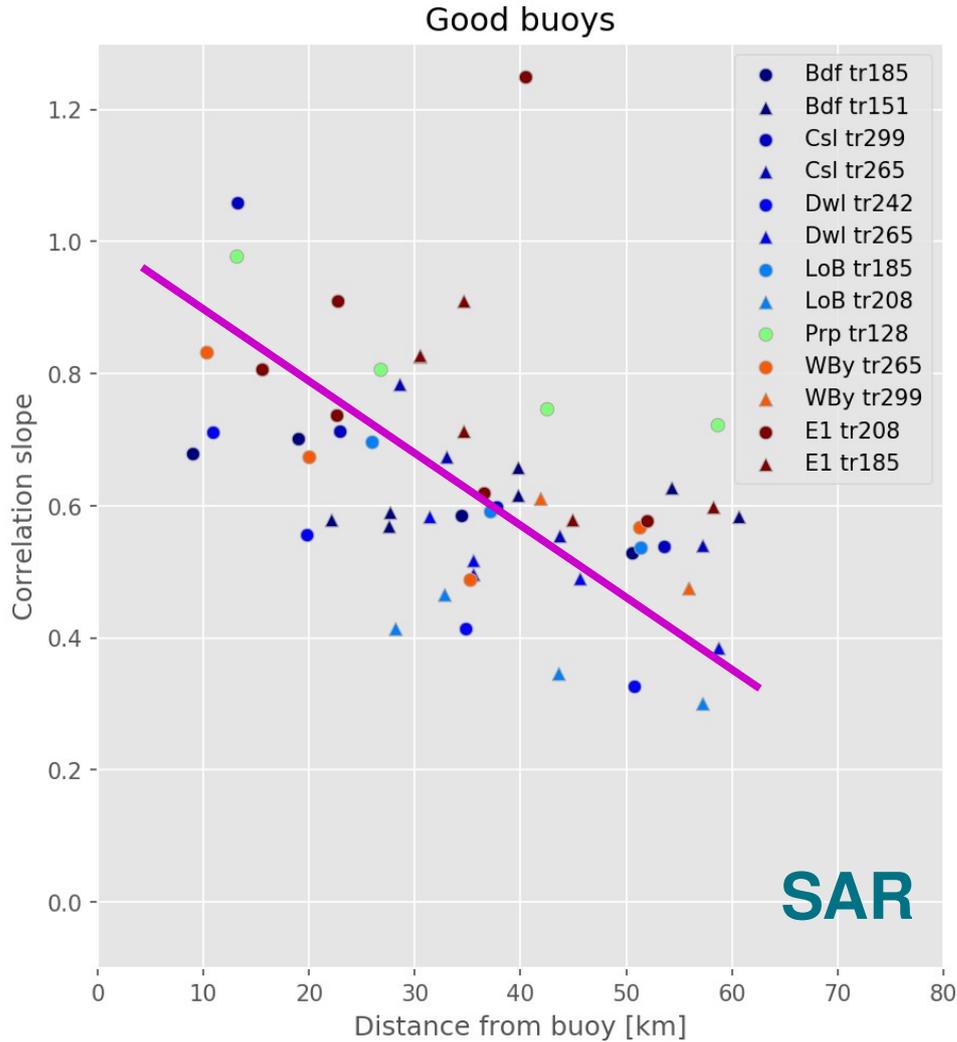
Total correlation-slope scatter plots



SAR: Correlation towards 1:1 ratio with decreasing distance from buoy (and coast)

PLRM: No clear correlation with decreasing distance from buoy

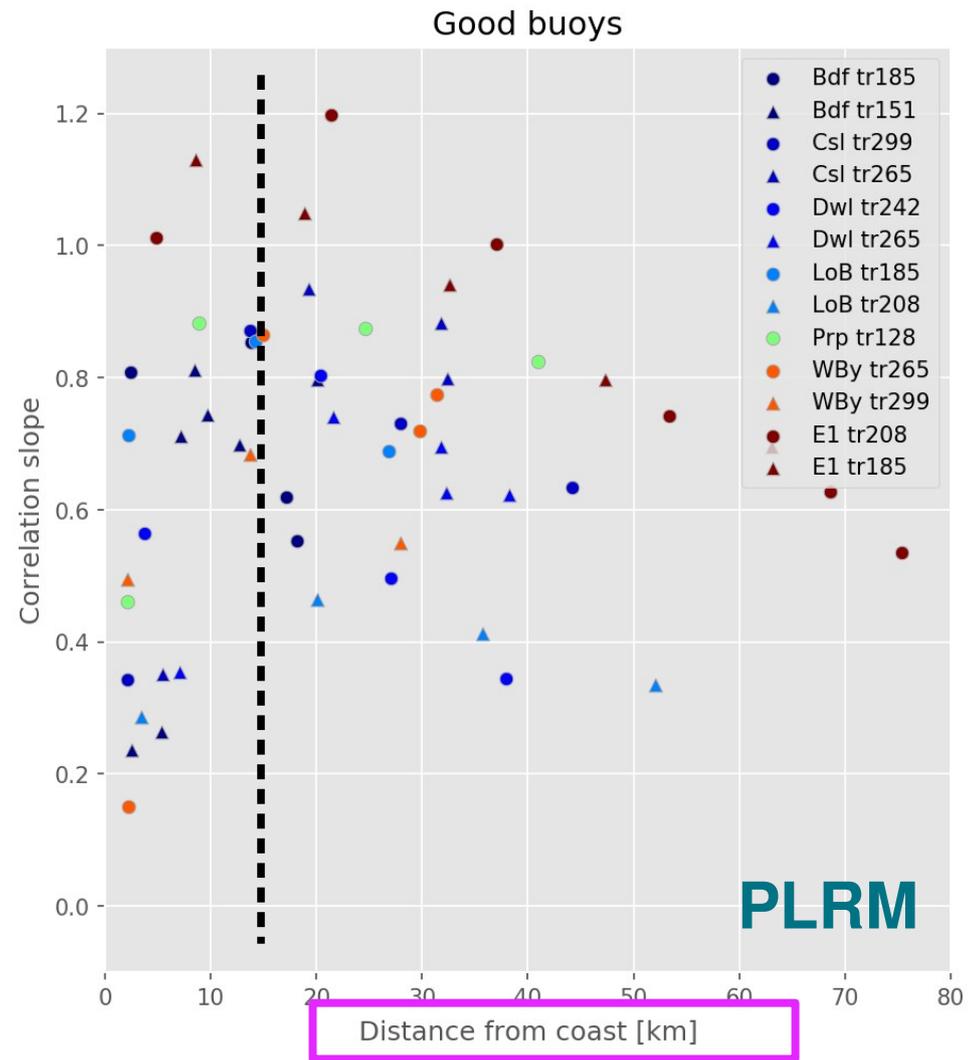
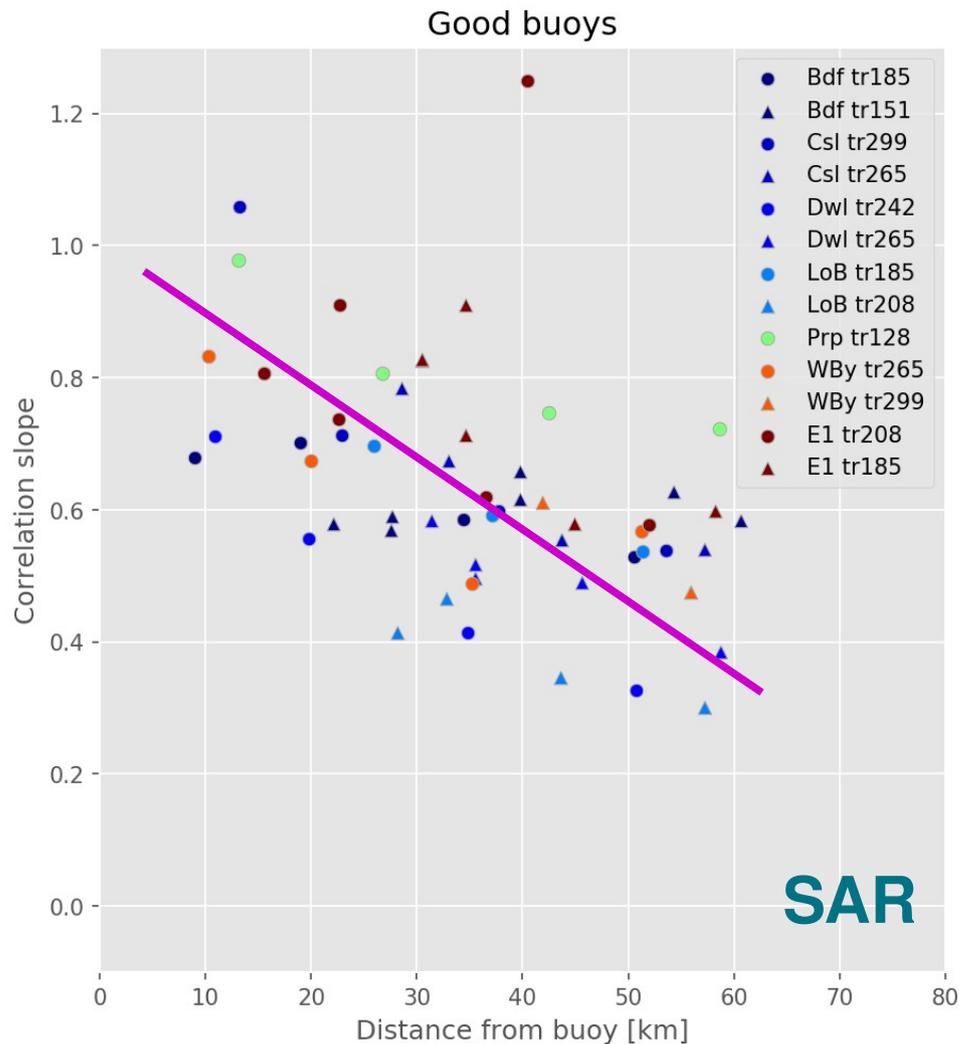
Total correlation-slope scatter plots



SAR: Correlation towards 1:1 ratio with decreasing distance from buoy (and coast)

PLRM: No clear correlation with decreasing distance from buoy

Total correlation-slope scatter plots



SAR: Correlation towards 1:1 ratio with decreasing distance from buoy (and coast)

PLRM: No clear correlation with decreasing distance from buoy

Correlation degrades sharply from 1:1 ratio approaching the coast (20 to 10 km from the coast)

Sentinel-3A SAR observations of SWH:

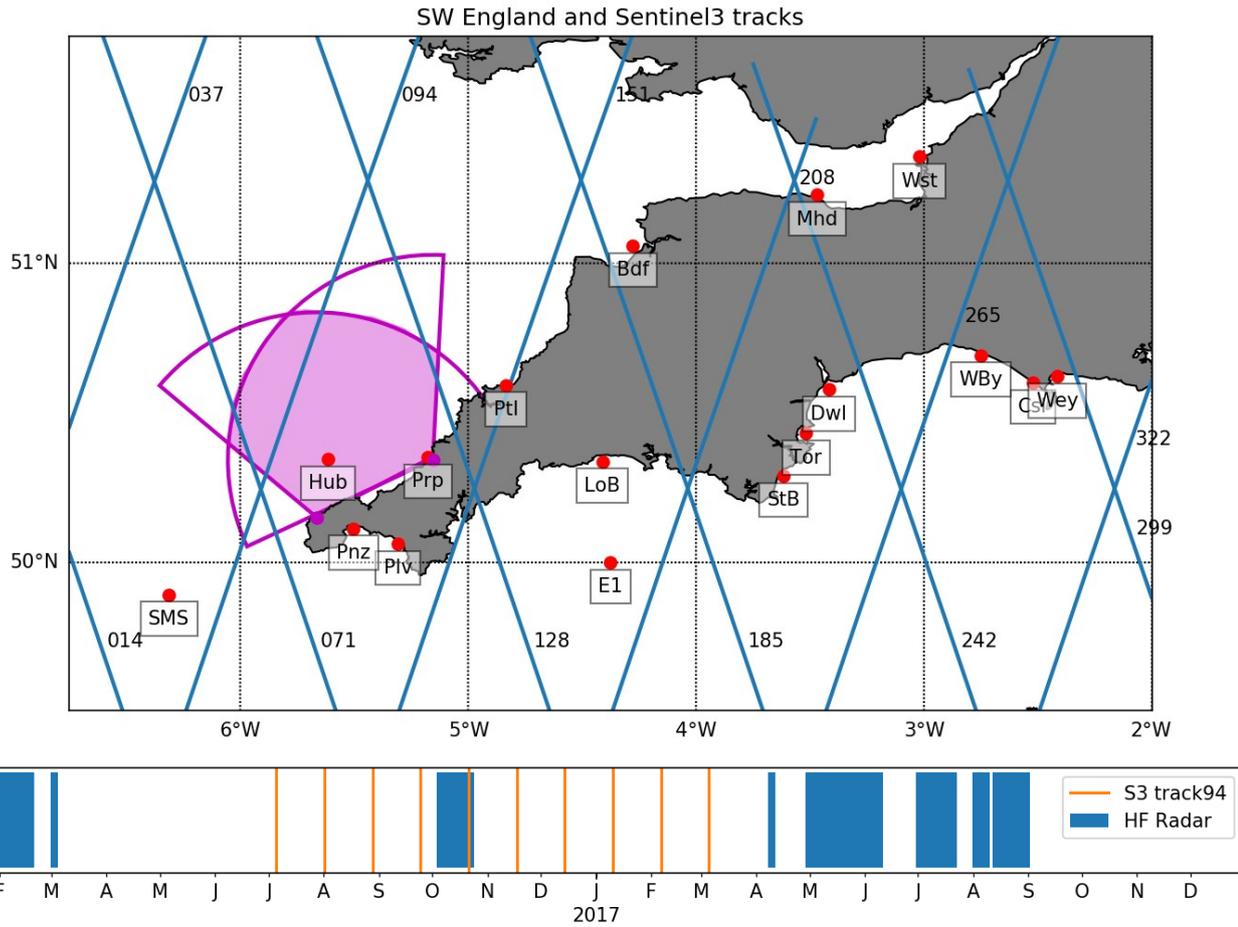
- **Accurate values** close to shore (<20 km)
- **Accurate trends** towards the coast
- **Better performance** compared PLRM

However not everywhere, not every time....

Future Work

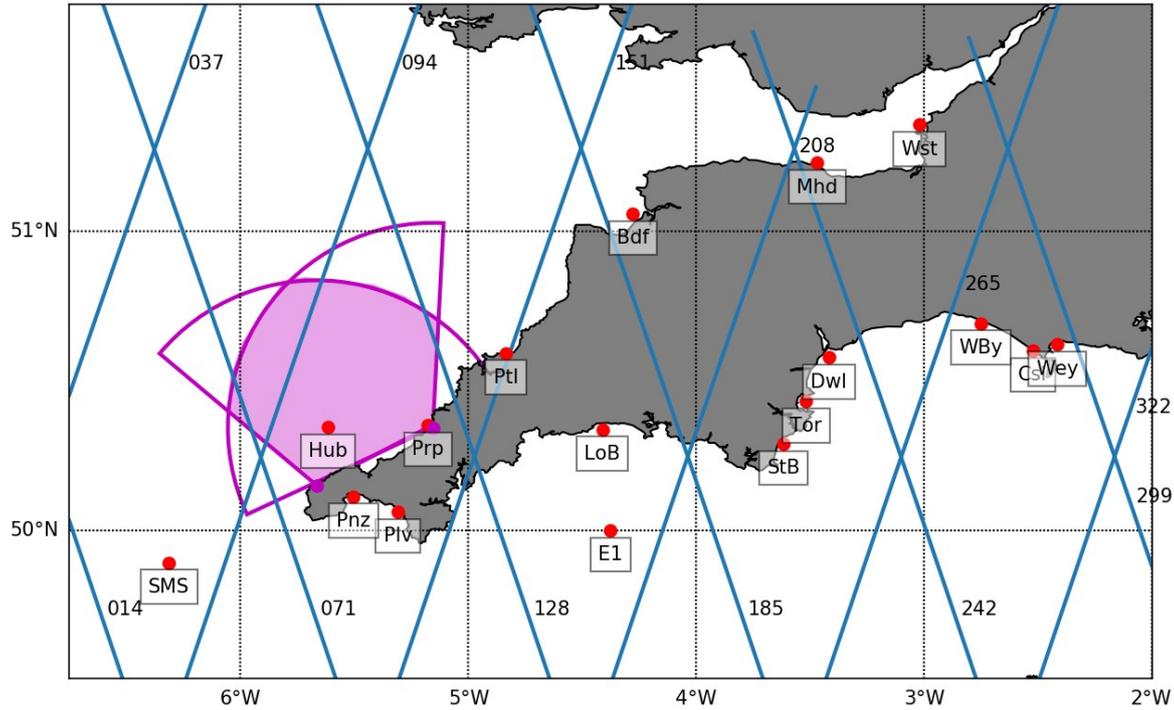
- Investigate performance based on conditions/locations (e.g. swell direction; wave period; wave height)
- Complement the analysis with HF Radar observations (waves and currents)
- Extend the analysis:
 - Broader region
 - Sentinel-3B observations

HF measurements still under processing (University of Plymouth)

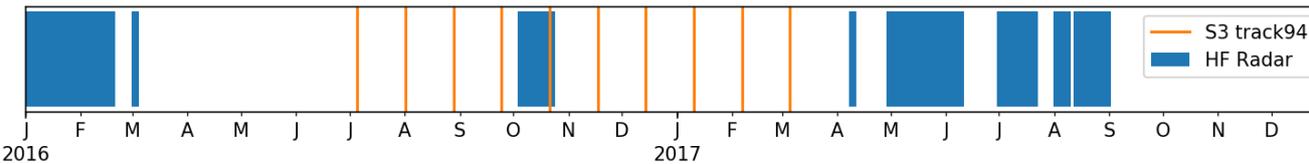
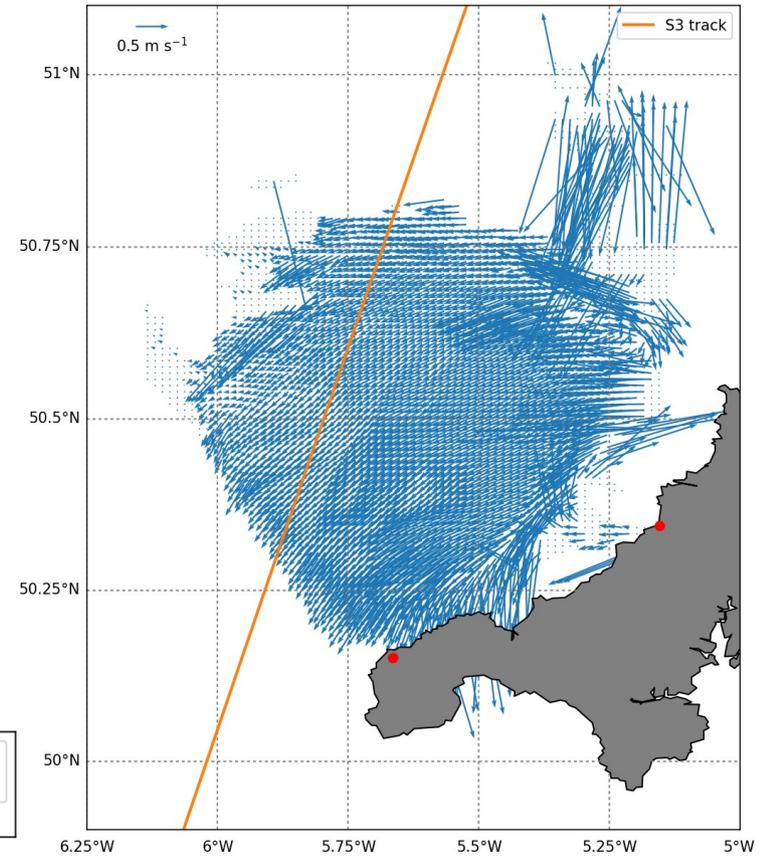


HF measurements still under processing (University of Plymouth)

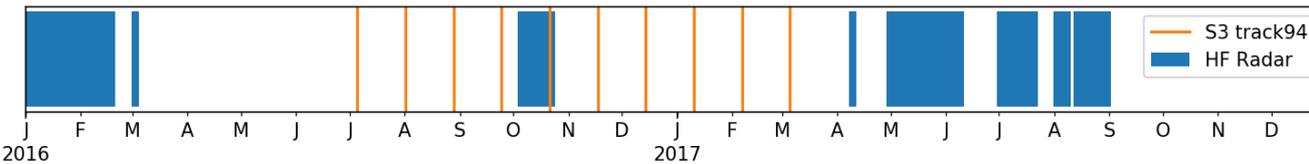
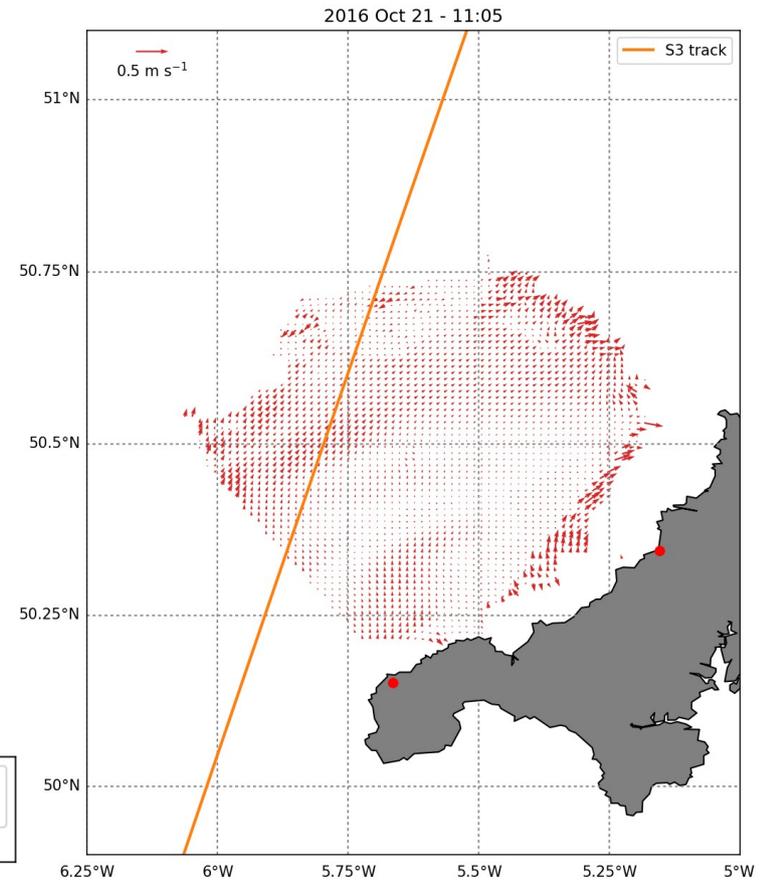
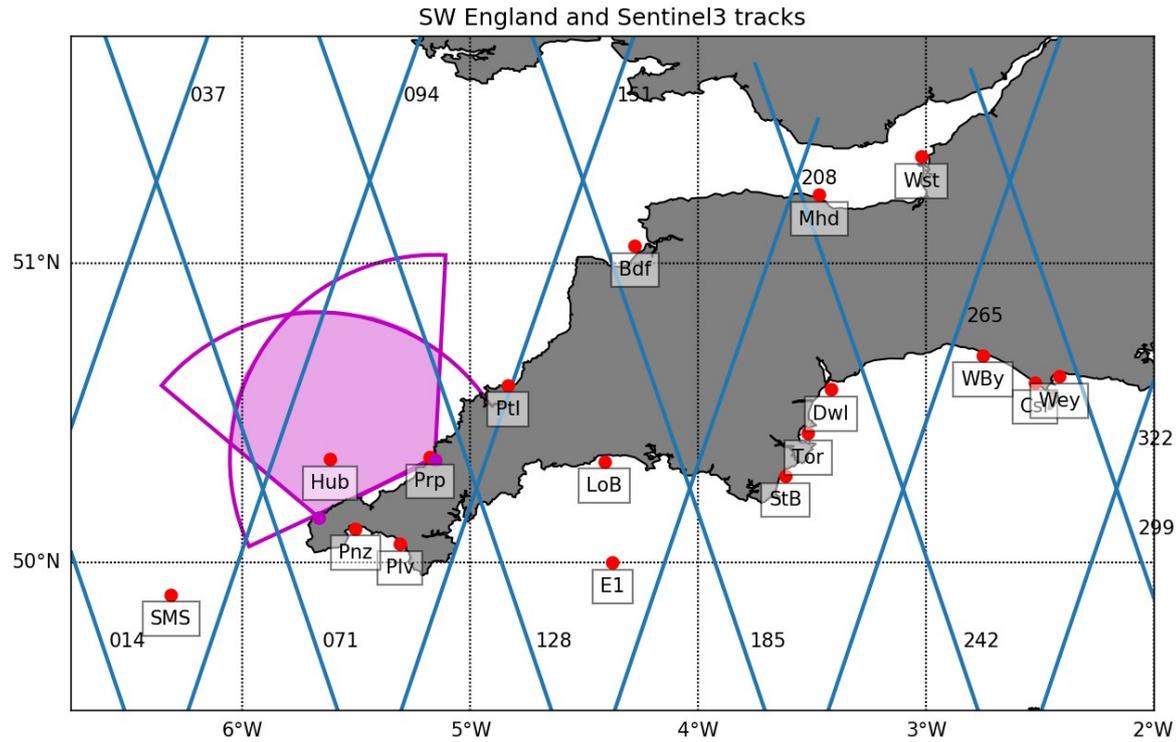
SW England and Sentinel3 tracks



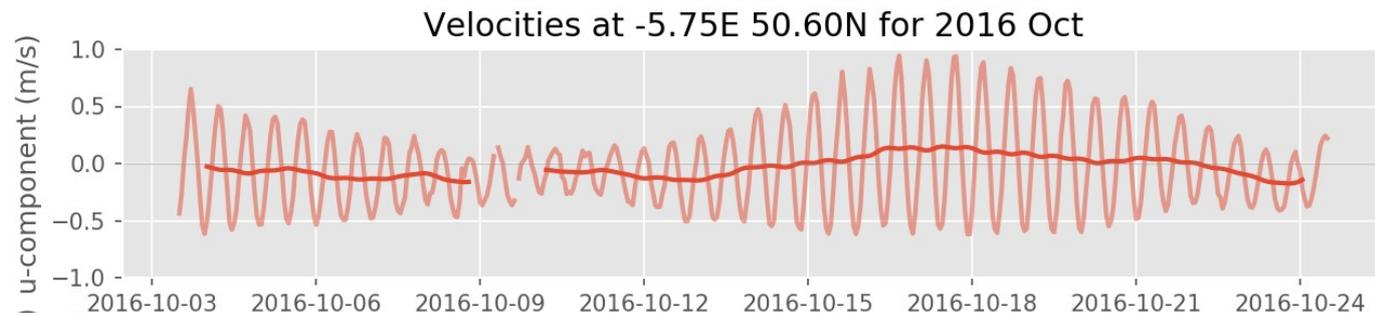
2016 Oct 21 - 11:05



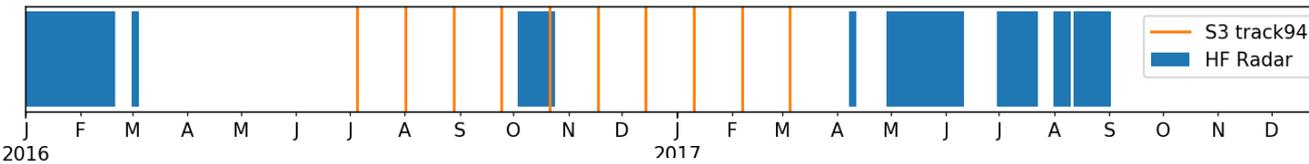
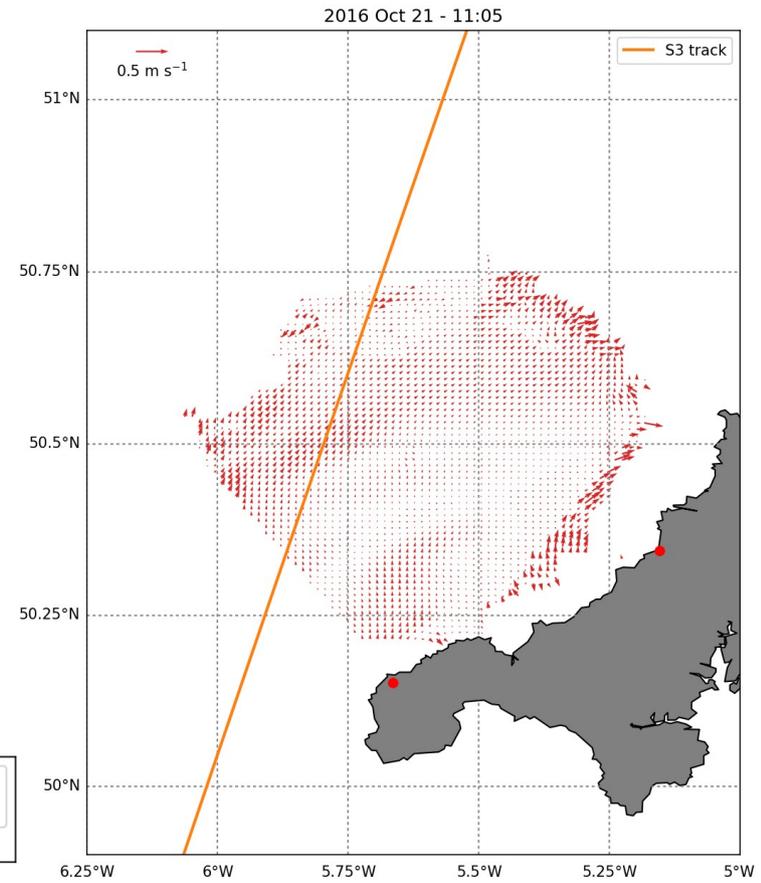
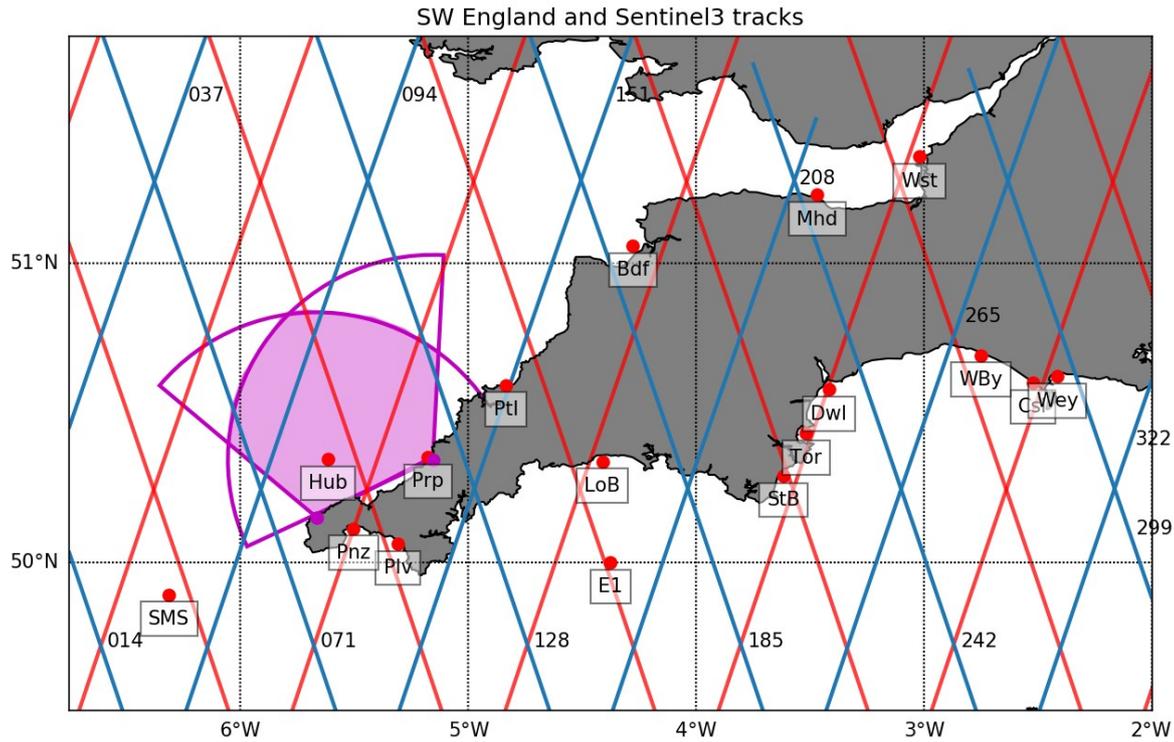
HF measurements still under processing (University of Plymouth)



- No strong current structures after tide removed
- Useful observations for **wave coastal variations**



HF measurements still under processing (University of Plymouth)



- ➔ No strong current structures after tide removed
- ➔ Useful observations for **wave coastal variations**
- ➔ Good site for **Sentinel-3B**

