Assessment of renewable wave energy resources in the French façade coastal zone

Sonia Ponce de León[1,3], Marco Restano[2], Jérôme Benveniste[3]

[1] Centre for Marine Technology and Ocean Engineering (CENTEC), IST, Universidade de Lisboa, Portugal

[2] SERCO/ESRIN, Frascati, Italy

[3] European Space Agency (ESA-ESRIN), Frascati, Italy

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Motivation

The wave energy conversion technology is another sustainable energy source to supply energy offshore far from the grids and support the development of the **Blue Economy**.

The impact of the listed studies is twofold:

- They confirm that the wave energy resource is significant.
- That specific areas in the world have better wave resource than others.

Fusco et al (2010)
Fusco and Ringwood (2011)
Arinaga and Cheung (2012)
Ringwood and Brandle (2015)
Roberstson et al (2016)
Friedrich and Lavidas (2017)
Reguero et al (2019)
Lavidas (2020)
Guillou et al (2020)
Said and Ringwood (2021)
Among many other authors

Objectives

- Investigate the feasibility of satellite altimetry-based assessments of wave renewable energy potential.

- Use the homogenized multi-mission altimeter (Ku-band) data “Sea State Climate Change Initiative” of the European Space Agency to estimate a map of the wave power density.

- Estimate the wave power density along the coast, taking advantage of the high-resolution satellite altimetry data products likethe Sentinel-3 mission, and using the improved geophysical retrieval algorithm SAMOSA+ (Dinardo et al., 2018, Dinardo 2020).

- Compare the wave power at coastal locations estimated from S3 SAMOSA2 with S3 SAMOSA+.

Data and Methods

- We use "CCI SEA STATE" data base (version 1.1), (1991-2018), [Dodet et al. (2020); Abdalla et al. (2021)] and Sentinel 3 & SAMOSA+ (Dinardo et al., 2018, Dinardo 2020) high resolution coastal products.

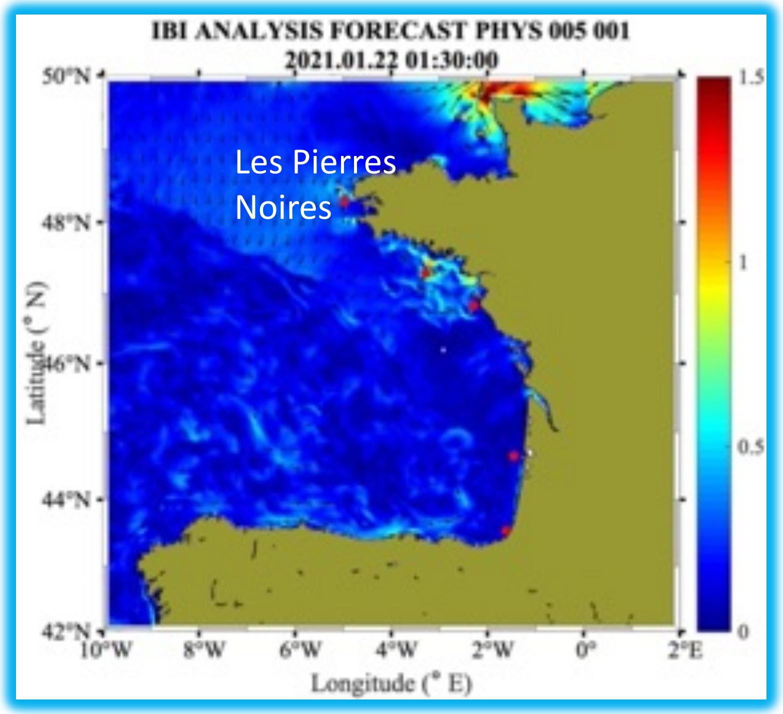
- The empirical model of Gommenginger et al. (2003) was employed to estimate the wave period, required for the estimation of the wave power density from the Ku-band radar altimeter significant wave height and the radar backscatter coefficient.

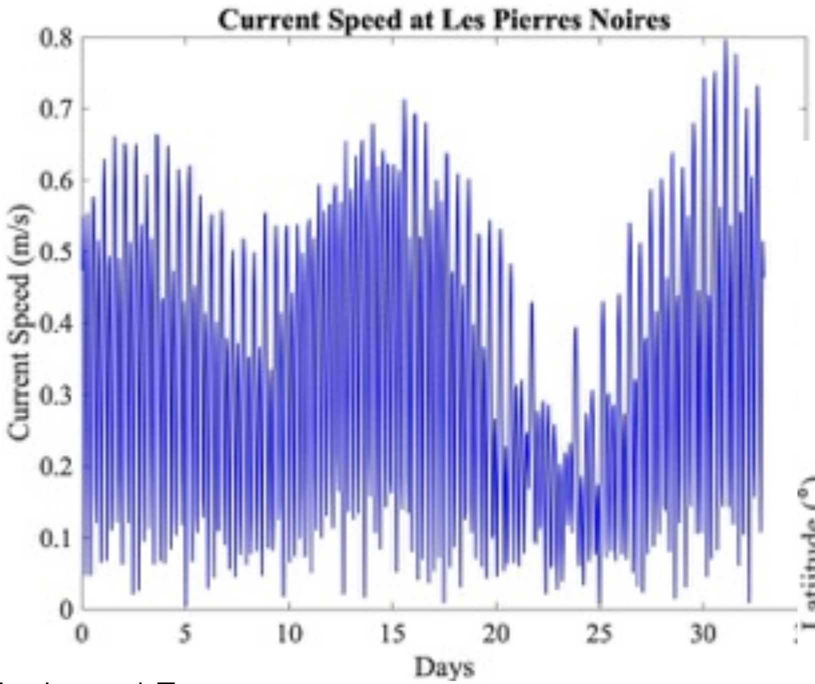
- The method has been validated with different wave buoys along the French and Iberian Pensinsula.

10 missions are considered in the CCI Sea State data base:

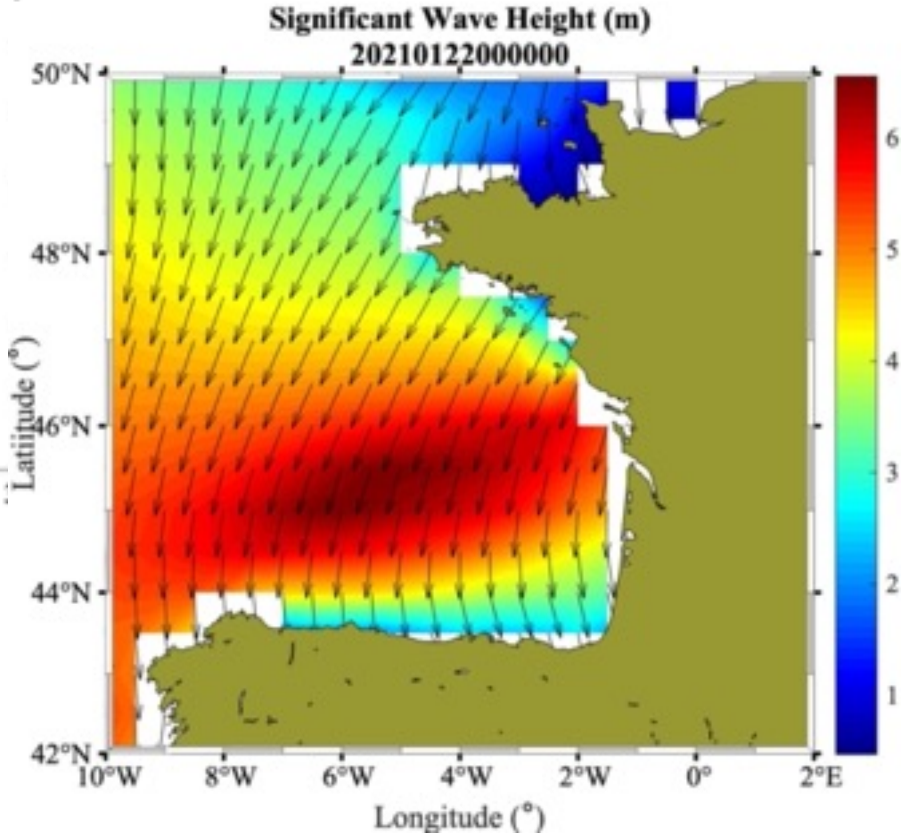
TOPEX, ENVISAT, ERS-1, ERS-2, GFO, SARAL, JASON-1, JASON-2, JASON-3, CRYOSAT

Study region





ERA-5



Ocean current from MERCATOR Ocean (IBIS):
Atlantic-Iberian Biscay Irish- Ocean Physics Analysis and Forecast
IBI_ANALYSISFORECAST_PHY_005_001

spatial resolution : 0.028 degrees
since: 2019-05-04 to present
Temporal resolution: hourly mean, daily mean, monthly mean,15-minutes mean

The wave power

For real seas, the wave power density P_{wave} can be computed by means of the expression:

$$P_{wave} = \frac{\rho g^2 H_s^2 T_e}{64\pi} \quad (W/m) \qquad (1)$$

In (1), $\boldsymbol{\rho}$ is sea water density (1025 kg/m^3), $\boldsymbol{g}$ is the acceleration of gravity (9.81 m/s^2),

H_s is the significant wave height (m) (the mean of the 1/3 highest waves) and

T_e is energy period, defined by m(-1)/m(0).

T_e can be derived from the zero-crossing period T_z , as

$$T_e = 1.18 * T_z.$$

The method

We have the Hs directly from the altimeter, but we need to estimate the wave period using satellite altimeter data.

Gommenginger et al (2003), proposed a simple linear relationship between the variable $X=(\sigma_0\ Hs^2)^{0.25}$ and T_z:

$$T_z = a * X + b \qquad (a \text{ and } b \text{ to be computed})$$

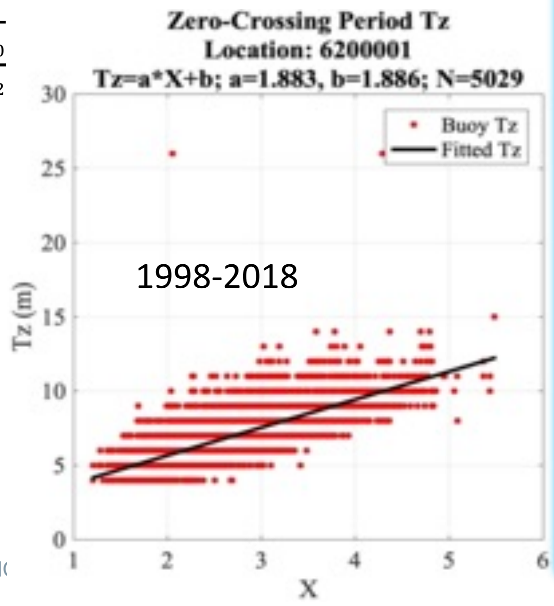
σ_0-radar backscatter coefficient

The coefficients ***a*** and ***b***, are computed from values of X derived from the altimeter measurements and T_z values from wave buoys. **A collocation of the altimeter and buoy measurements must be performed to get X, T_z pairs**.

Mean (T_m) period and zero-crossing period (T_z) are computed from the moments of the 1d ocean wave spectra following Tucker (1991).

$$T_m = \frac{m_0}{m_1}$$

$$T_z = \sqrt{\frac{m_0}{m_2}}$$



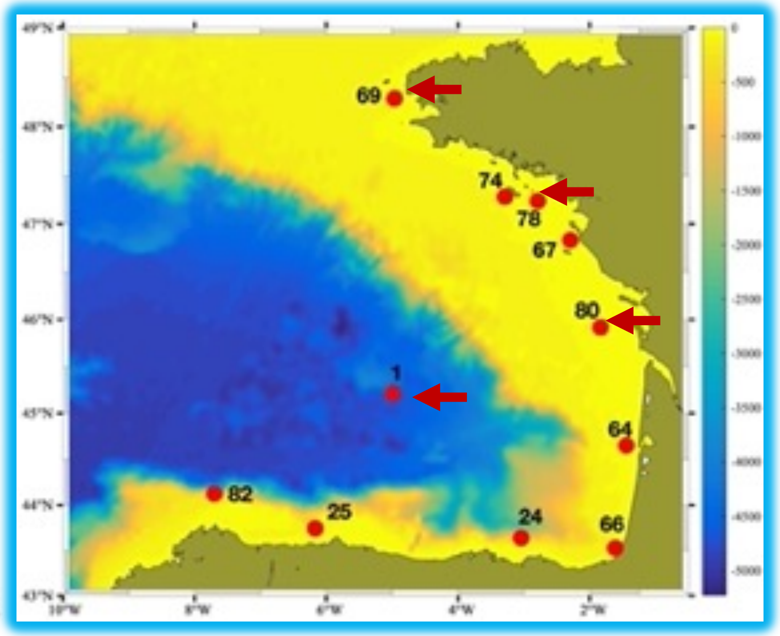
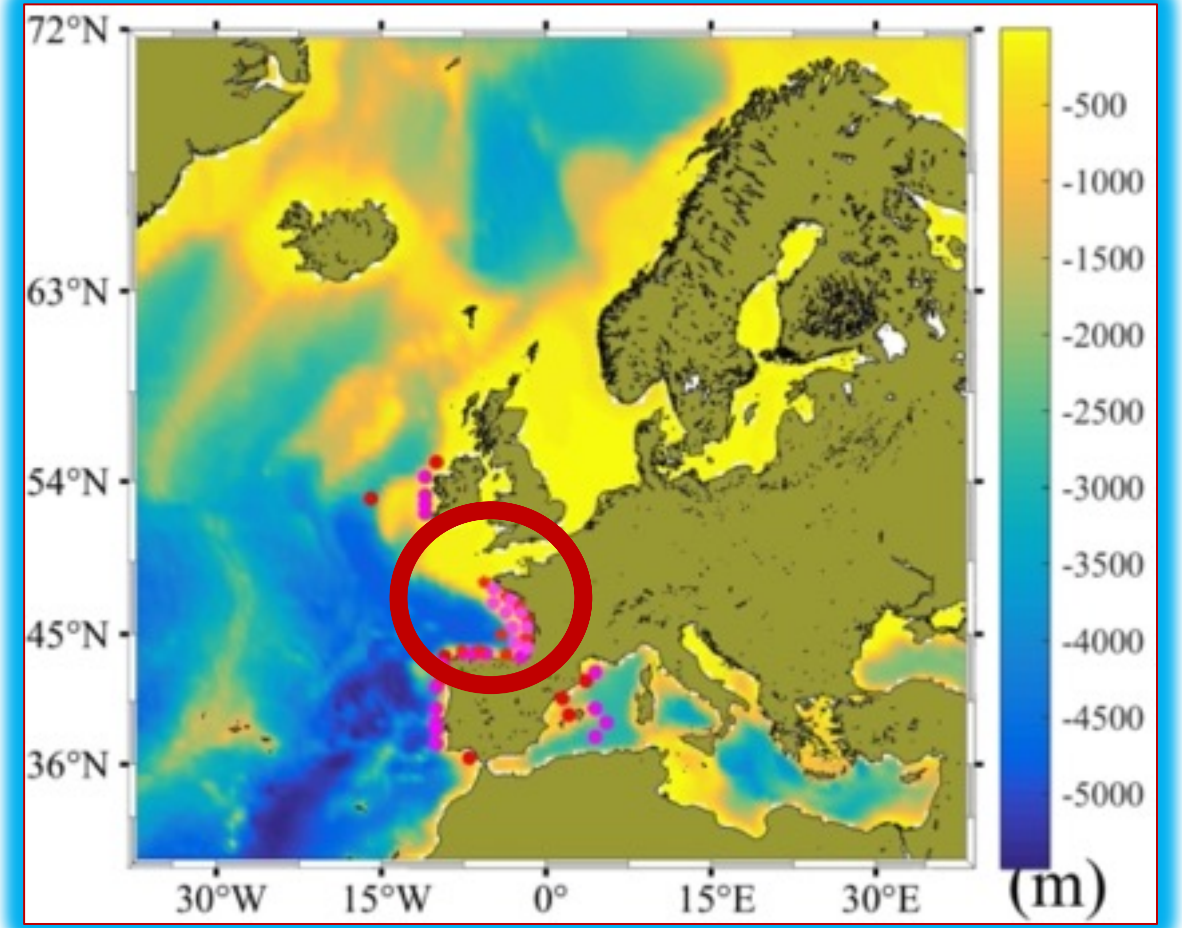


Table 1. Zero-lag correlation coefficients (a & b) for the Hs estimated from the satellite altimetry data and buoys. Legend: CC-correlation coef. Wave buoys networks: CANDHIS & SHOM (France), PAS-Ports of Authorities of Spain.

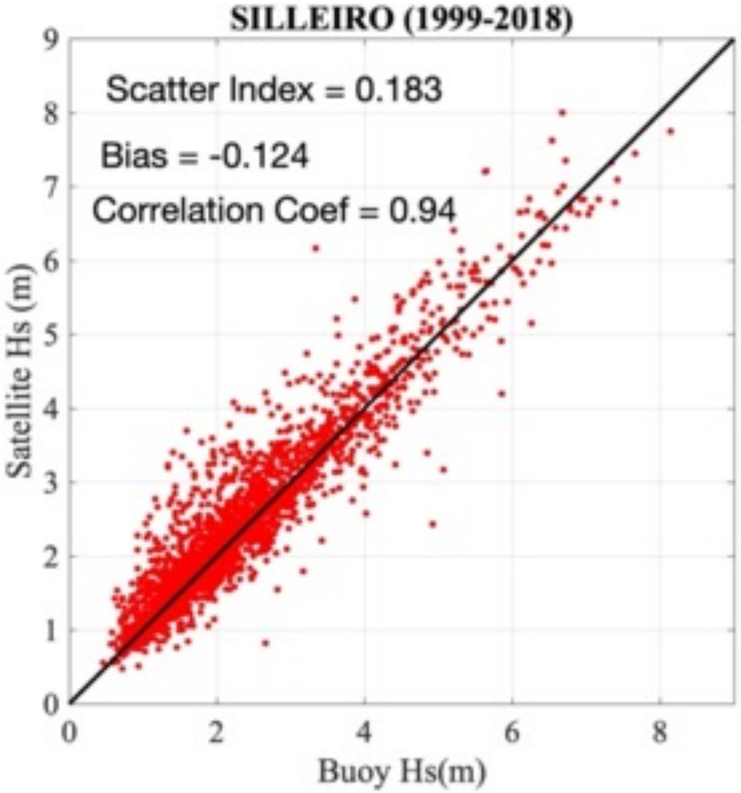
Buoys	Buoy/satellite fit	Regression coefficients
69 (2008-2018)	Bias=-0.44;Slope=1.20 Si=0.19;CC=0.96	a=1.5917 b=2.0901
74 (2011-2018)	Bias=-0.28;Slope=1.11 Si=0.20;CC=0.97	a=1.6616 b=1.7943
78 (2010-2018)	Bias=0.82;Slope=1.59 Si=0.51;CC=0.92	a=1.4302 b=1.6812
67 (2005-2018)	Bias=--0.79;Slope=1.67 Si=-0.43;CC=0.90	a=1.1129 b=2.6728
80 (2014-2018)	Bias=-0.14;slope=1.0562 Si=0.16;CC=0.97	a=2.216 b=0.571
64 (2004-2018)	Bias=-0.26;Slope=1.11 Si=0.21;CC=0.96	a=1.713 b=2.025
66 (2004-2018)	Bias=-0.29 slope=1.11 Si=1.24;CC=0.94	a=2.21 b=1.3477
1 (1998-2018)	Bias=0.038;Slope=0.98; Si=0.17,CC=0.96	a=1.8834 b=1.8863
24 (1990-2018)	Bias=-0.05;; slope=0.98 SI=0.28;CC=0.91	a=1.9861 b=1.1065
25	Bias=-0.14;slope=0.98; SI=0.37;CC=0.82	a=1.734 b=1.649
82	Bias=-0.14 ;Slope=1.023 SI=0.25;CC=0.91	a=1.679 b=1.517

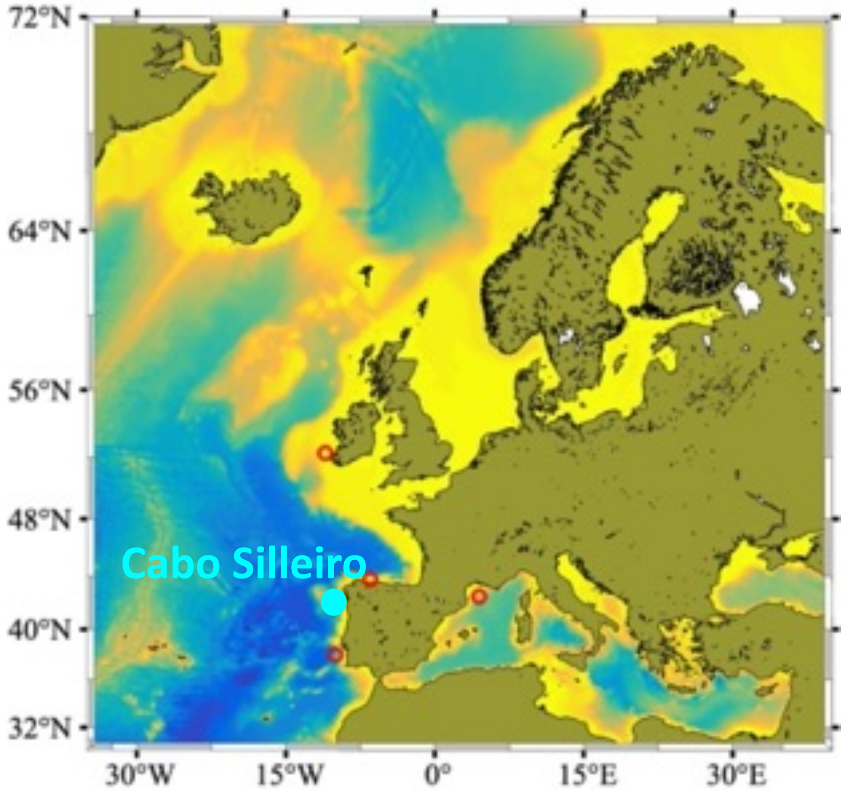
Validation of the method

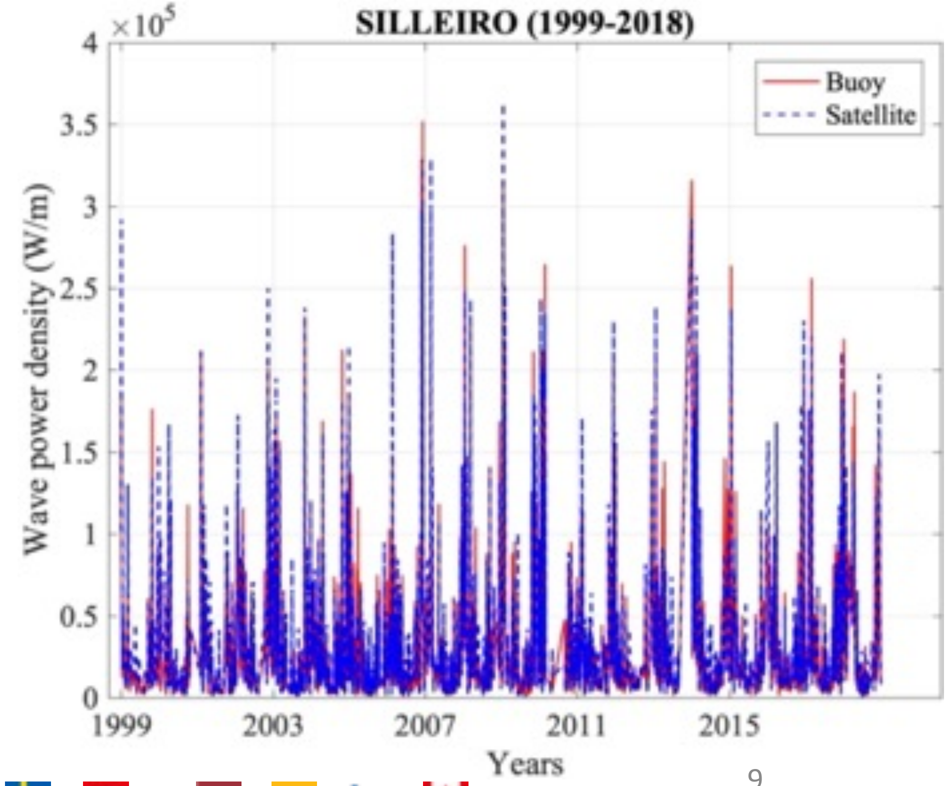


Validation of the employed method at wave buoy's locations (red circles) & locations of the assessment of the wave power from satellite altimeters of ESA CCI Sea State data (magenta circles) (1991 - 2018)

Wave power density estimated from satellite altimetry data and wave buoys

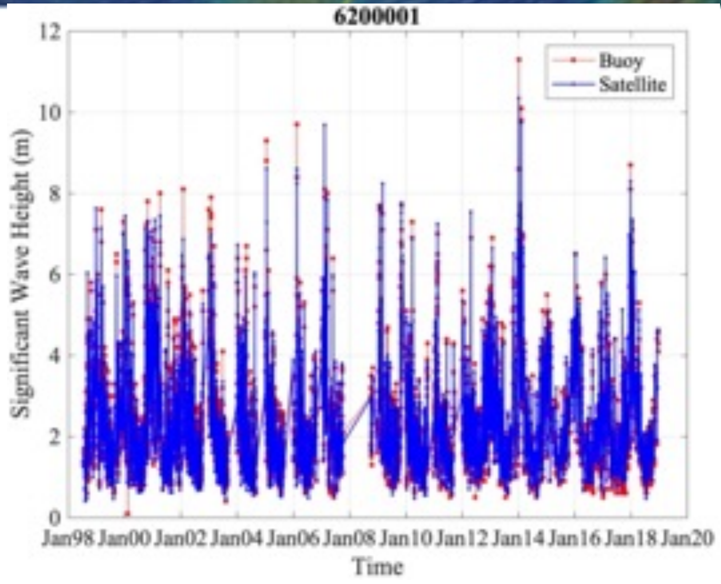


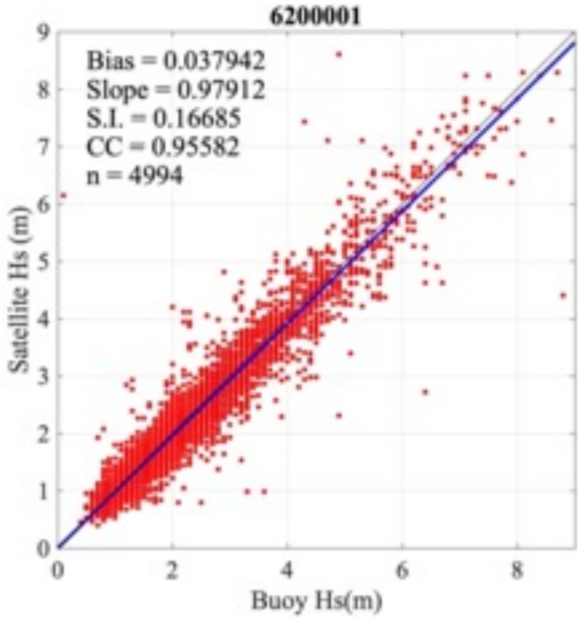


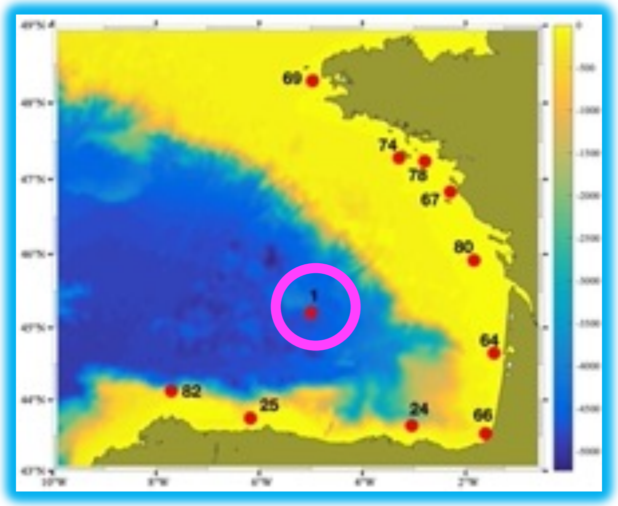


Deep water buoy 6200001

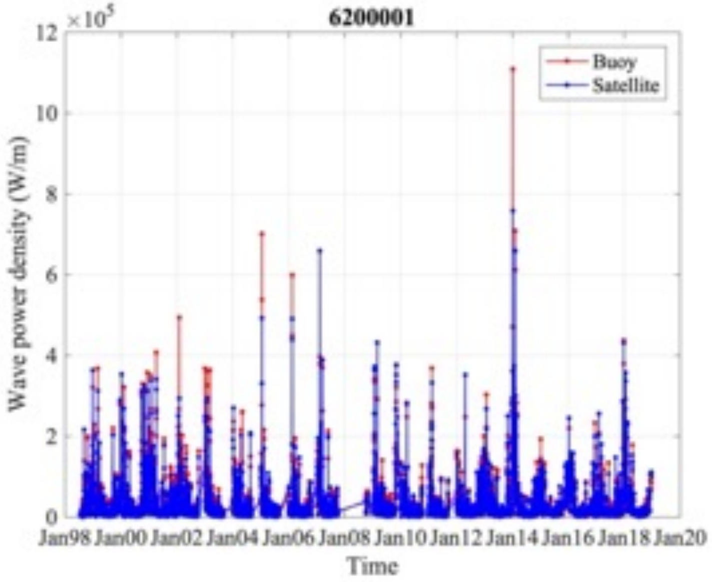
Buoy/Satellite Fit

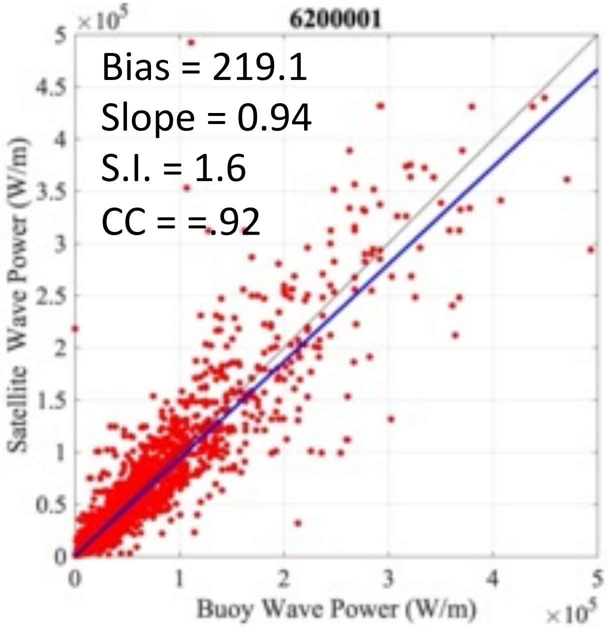






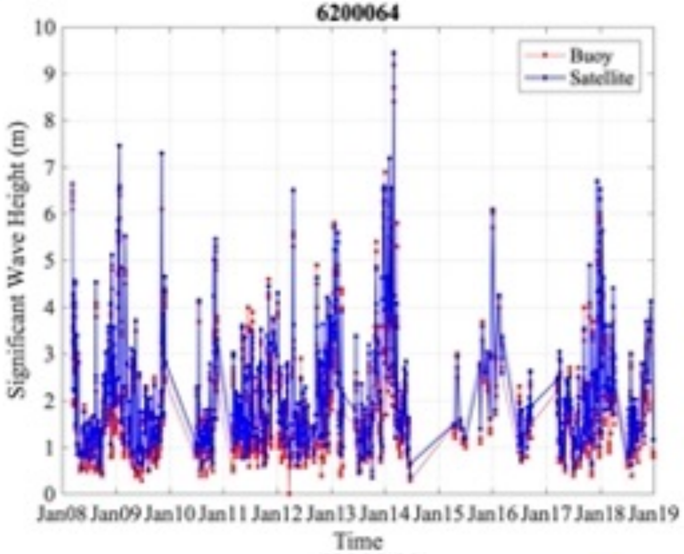
Wave Power Density Buoy/Satellite Fit

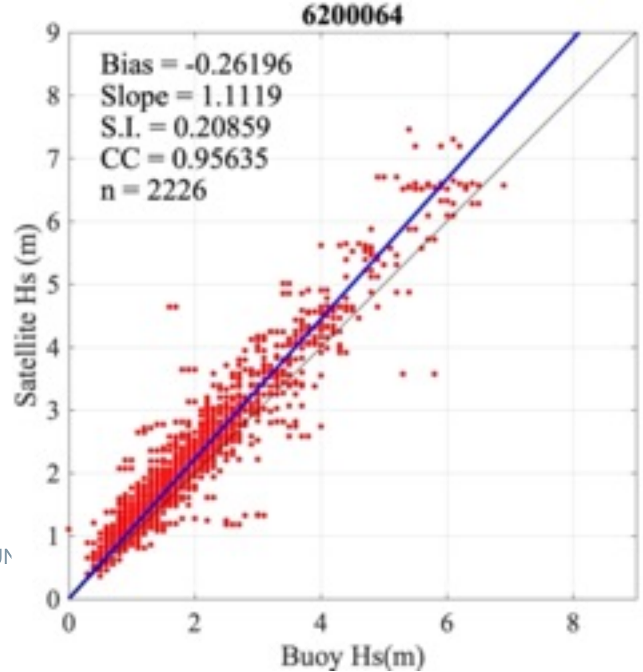


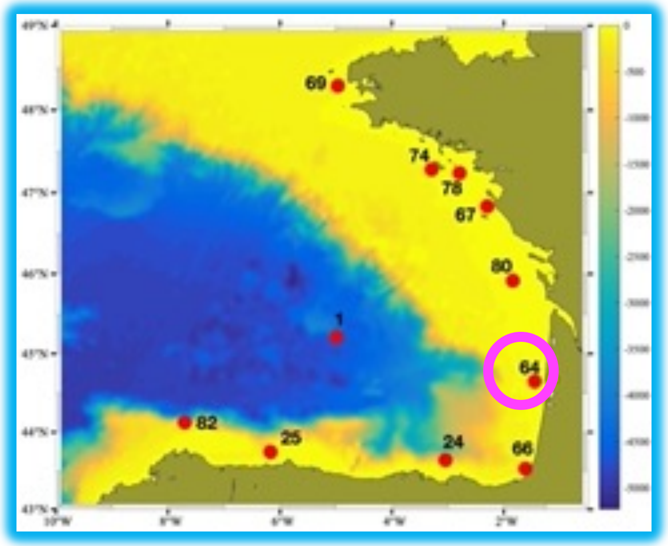


Coastal buoy 6200064 (Depth = 52 m)

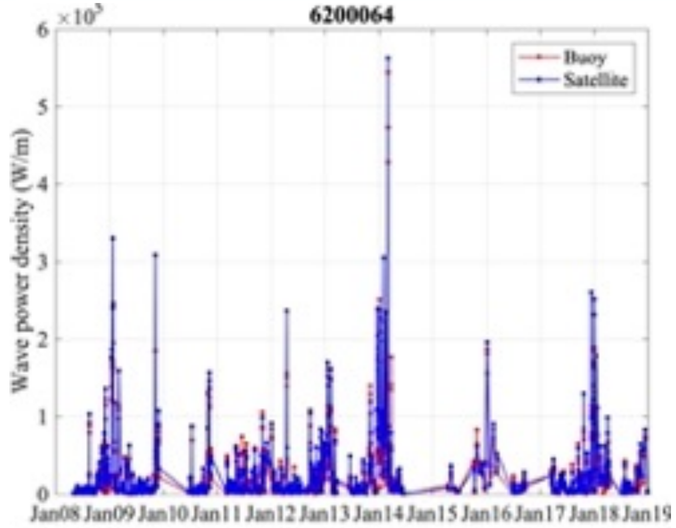
Buoy/Satellite Fit

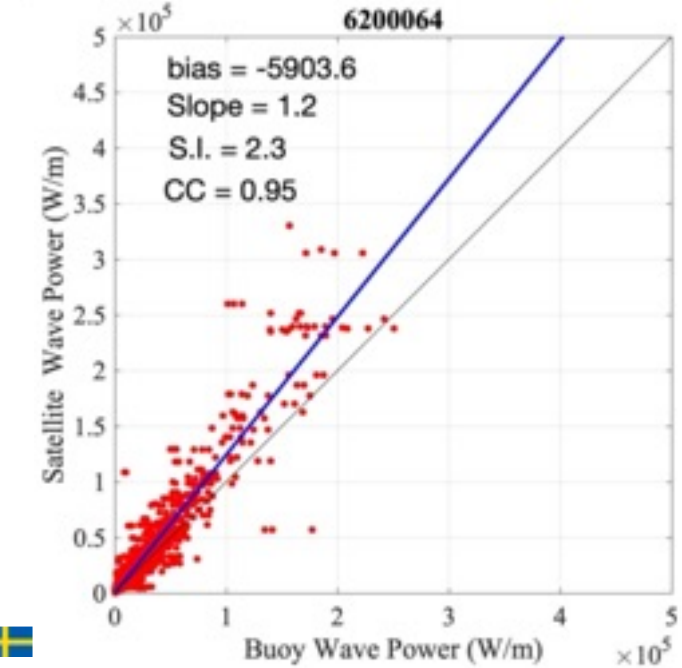






Wave Power Density Buoy/Satellite Fit





Yearly mean wave power density estimated from the wave BUOYS

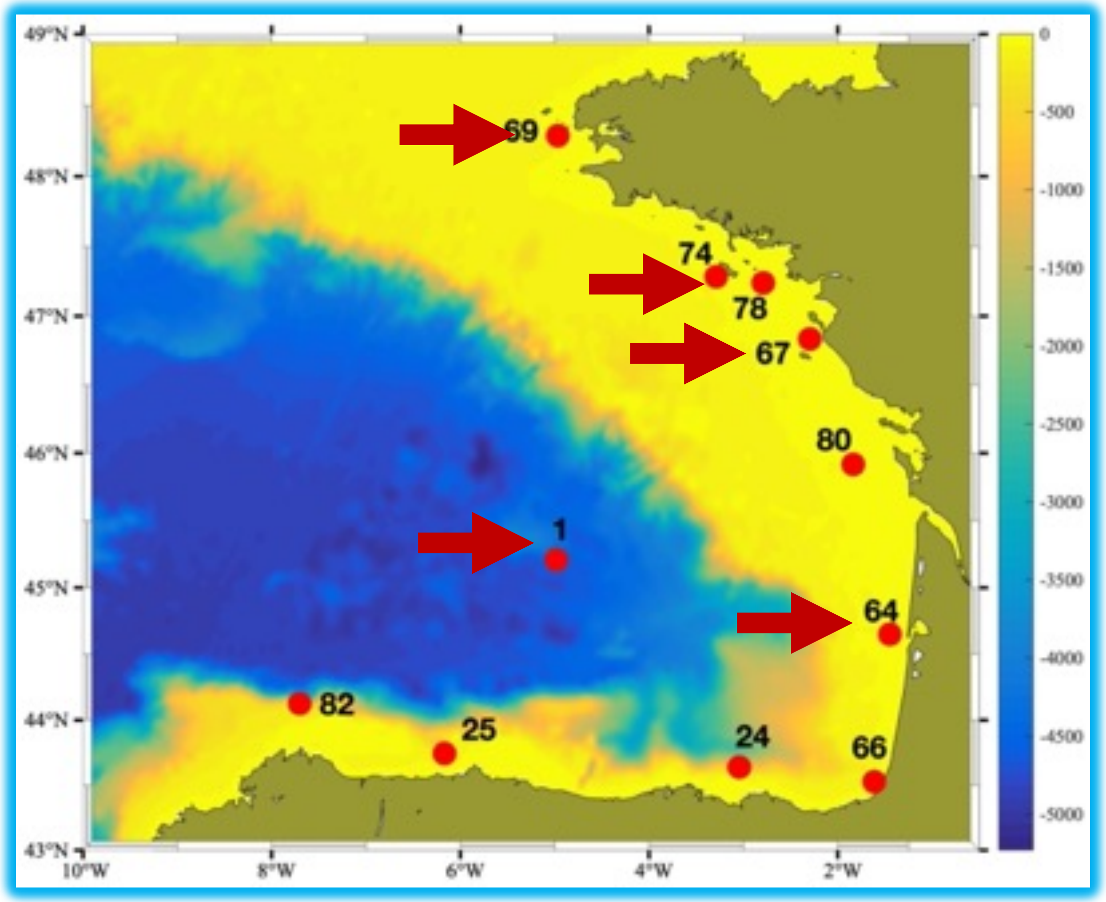
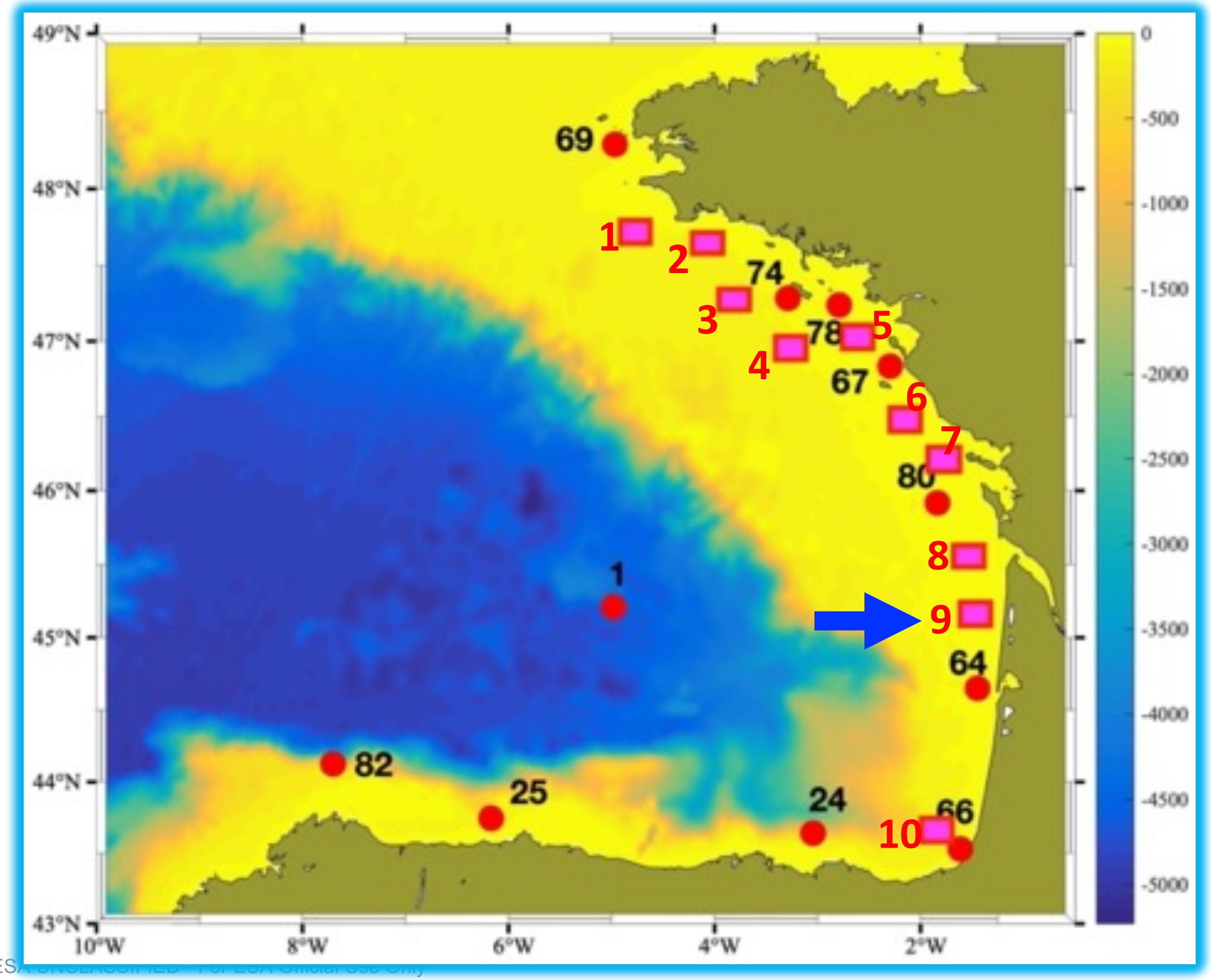


Table 2. Yearly mean WAVE Power density (W/m).

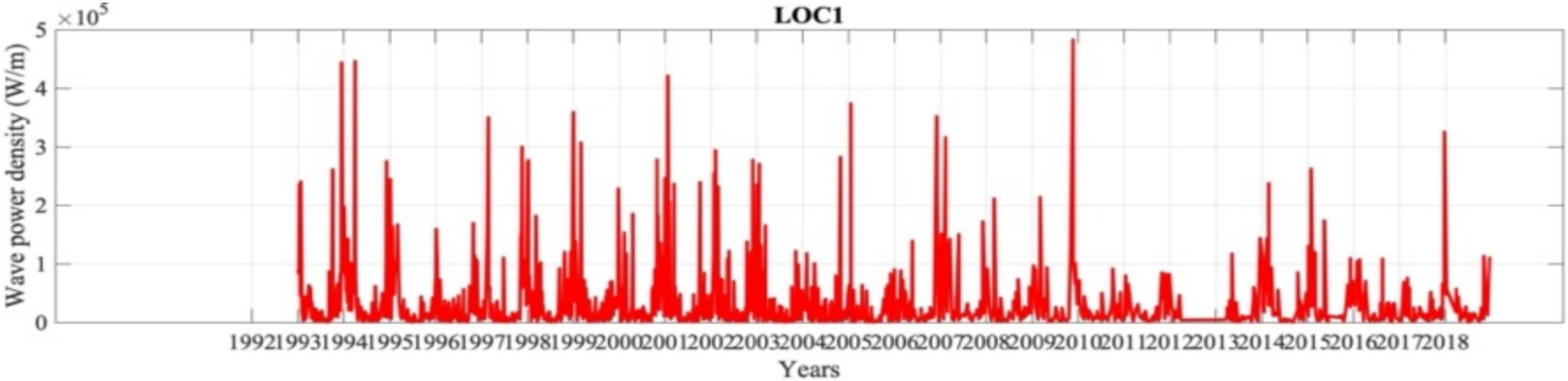
BUOY #	Length	Wave power density
69	2008-2018	21756
74	2011 2018	21989
78	2010-2018	7007.8
67	2005-2018	5965
80	2014-2018	15186
64	2008-2018	20017
66	2004-2018	18334
1	1998-2018	34008
24	1990-2018	23730
25	1997-2018	22151
82	1996-2022	29989

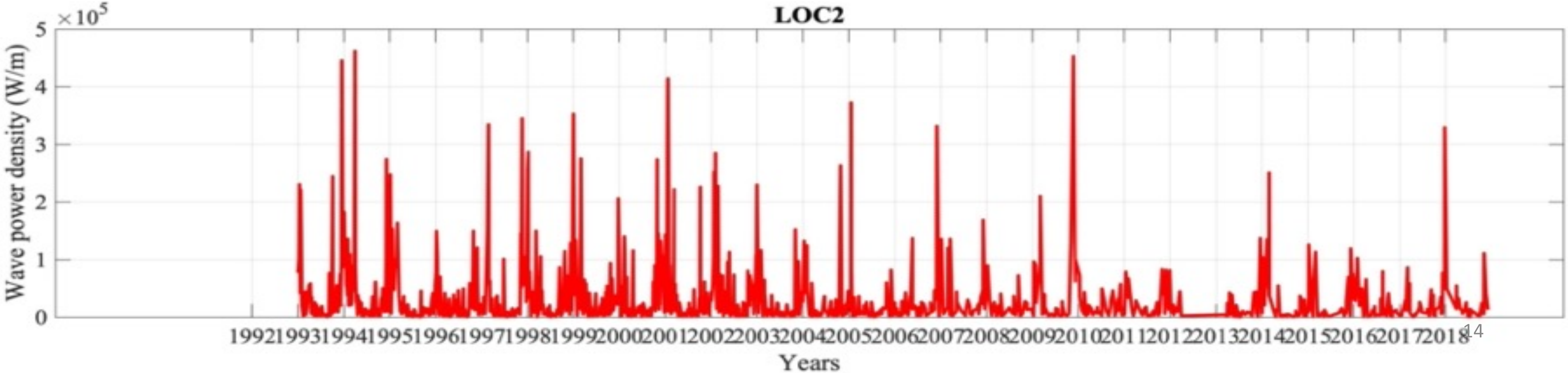
Yearly mean wave power density estimated in other locations using "only" satellite altimetry data



Location	Wave power (W/m)
1	32980
2	30133
3	27857
4	22738
5	19827
6	21180
7	21201
8	24184
9	25412
10	23719

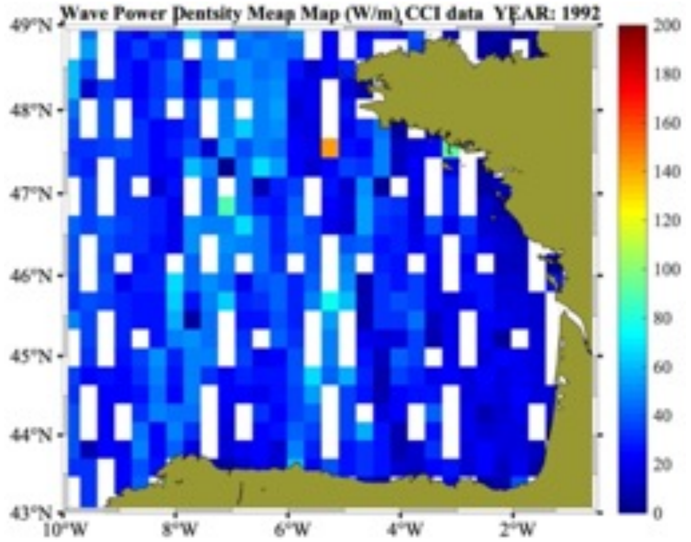
Local estimation of the wave power density using only the CCI Sea State data



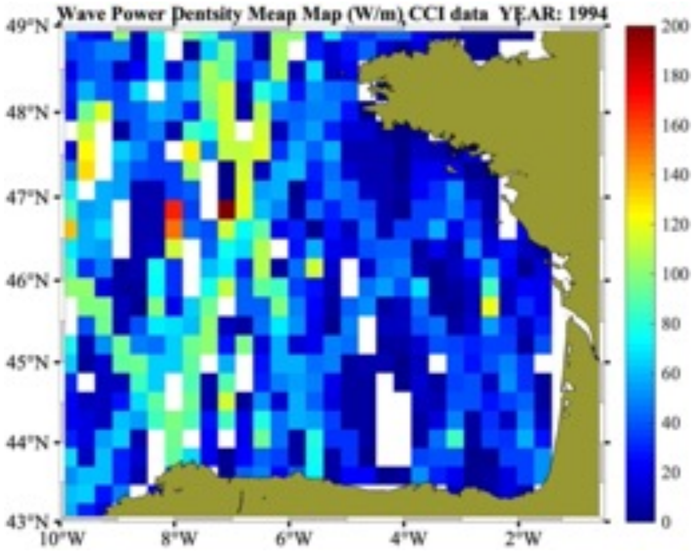


Yearly mean wave power density maps (CCI Sea State data)

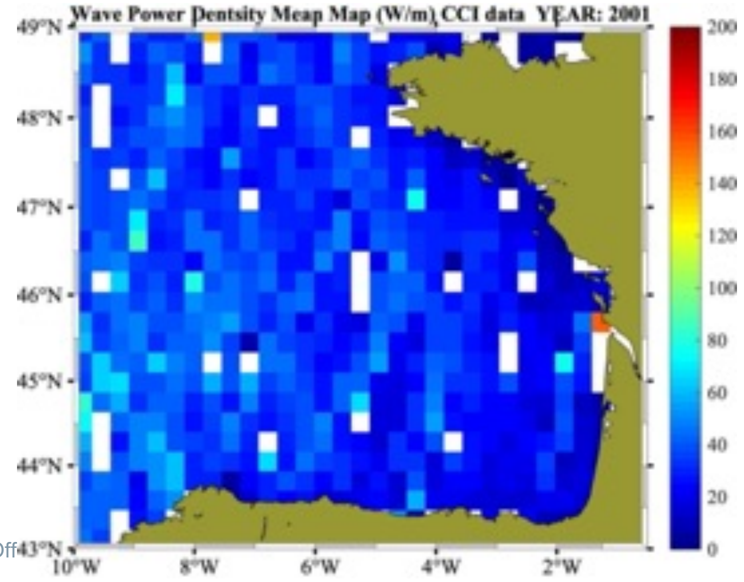
1992



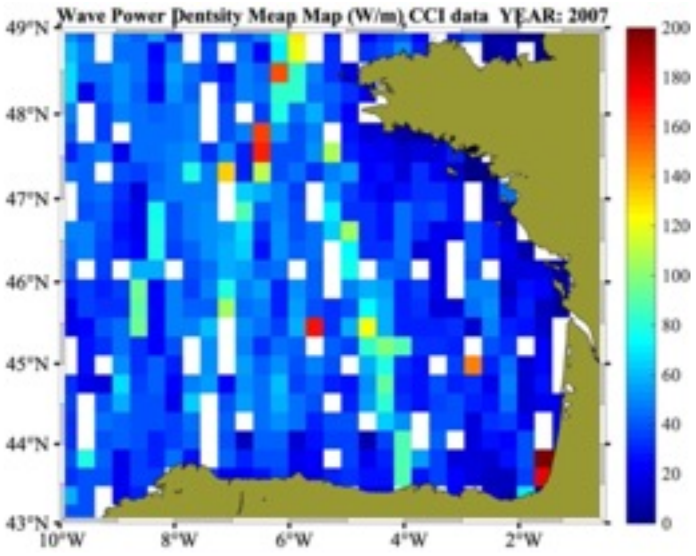
1994



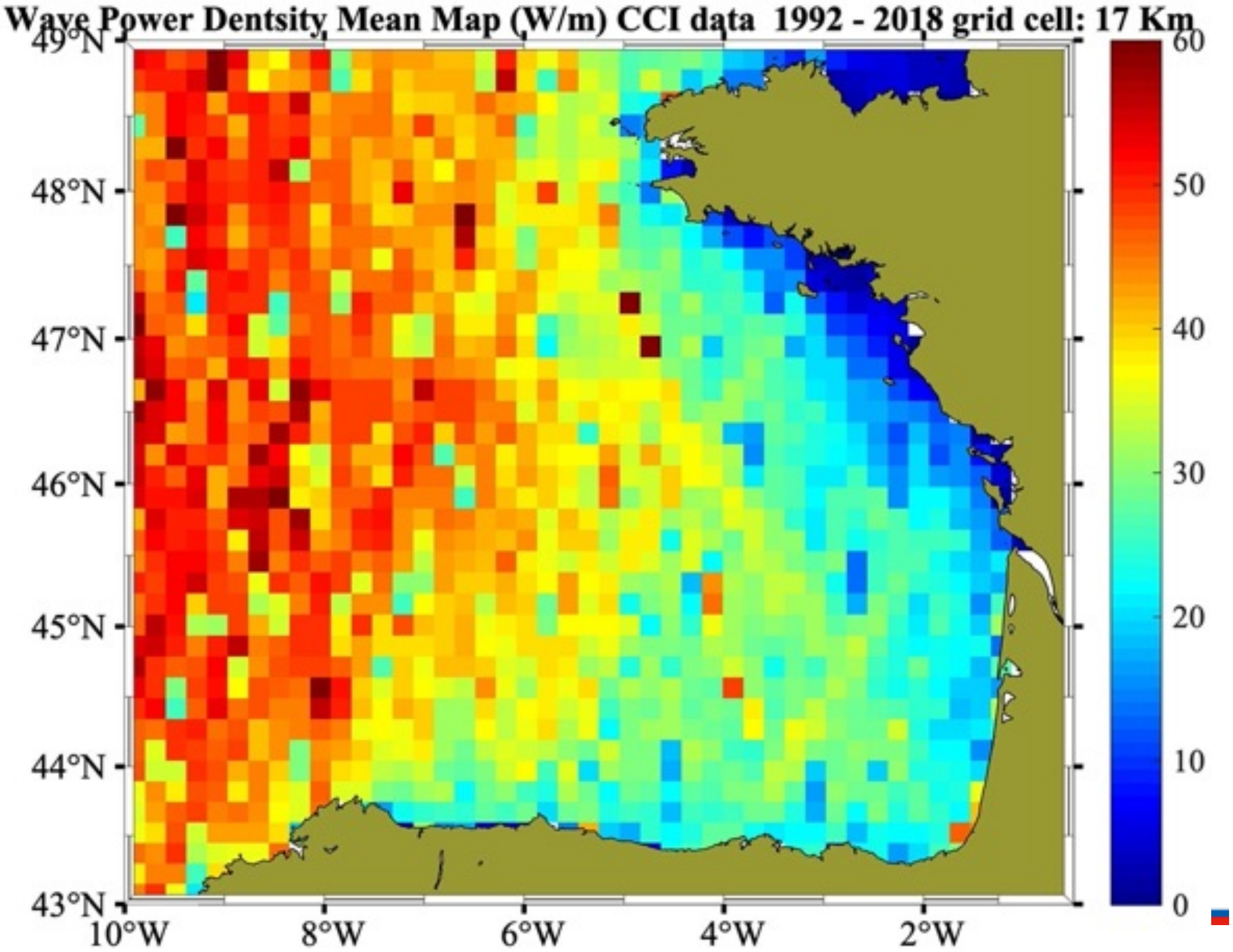
2001



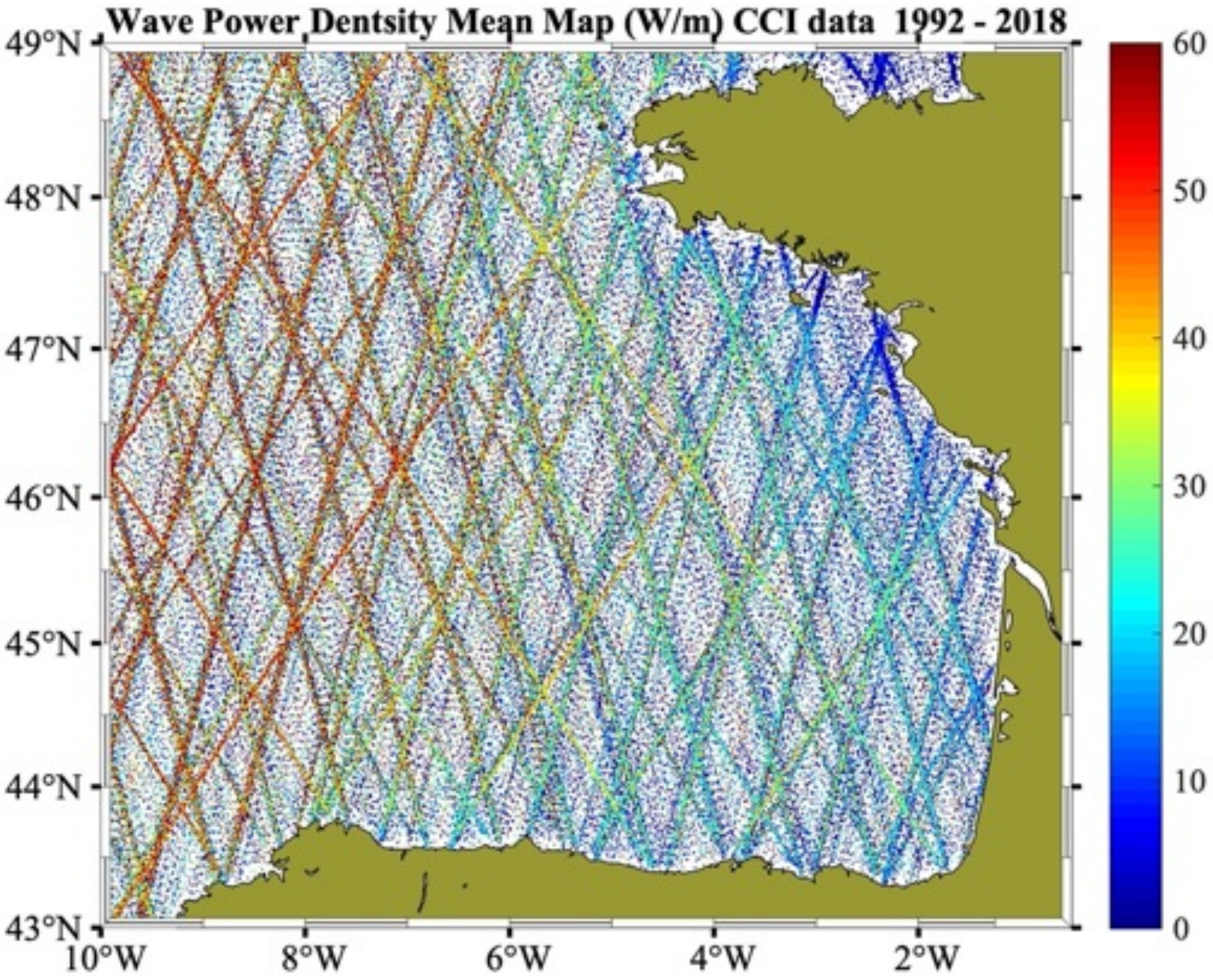
2007



26-year wave power density mean map (CCI Sea State data)



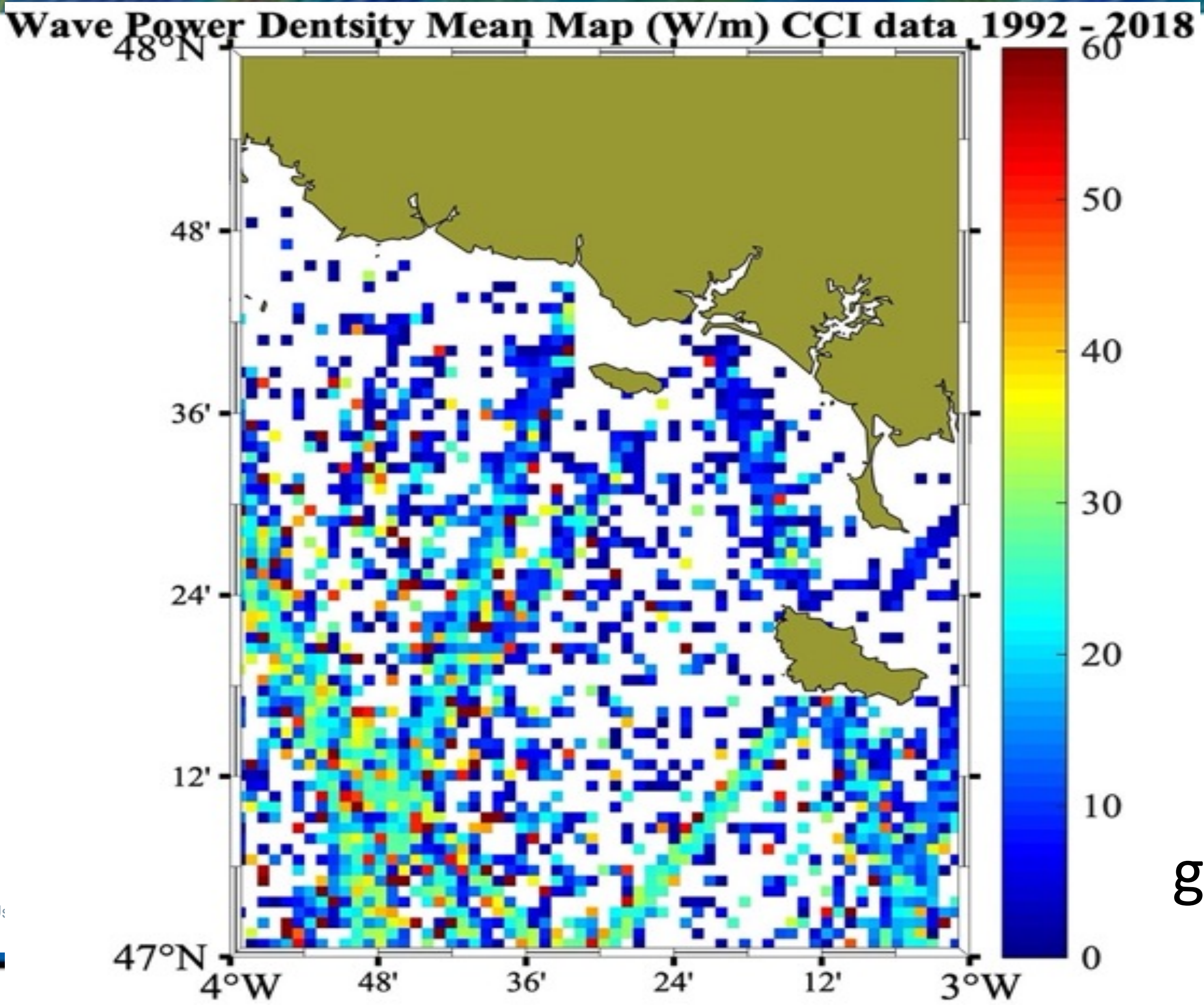
26-year wave power density mean map (1992-2018) CCI Sea State



TOPEX, ENVISAT, ERS-1, ERS-2, GFO, SARAL, JASON-1, JASON-2, JASON-3, CRYOSAT

grid cell: 1.3 km

26-year mean map wave power density near the coast (1992-2018) CCI Sea State



grid cell: 1.3 km

SAMOSA+: Improved Retracker estimates

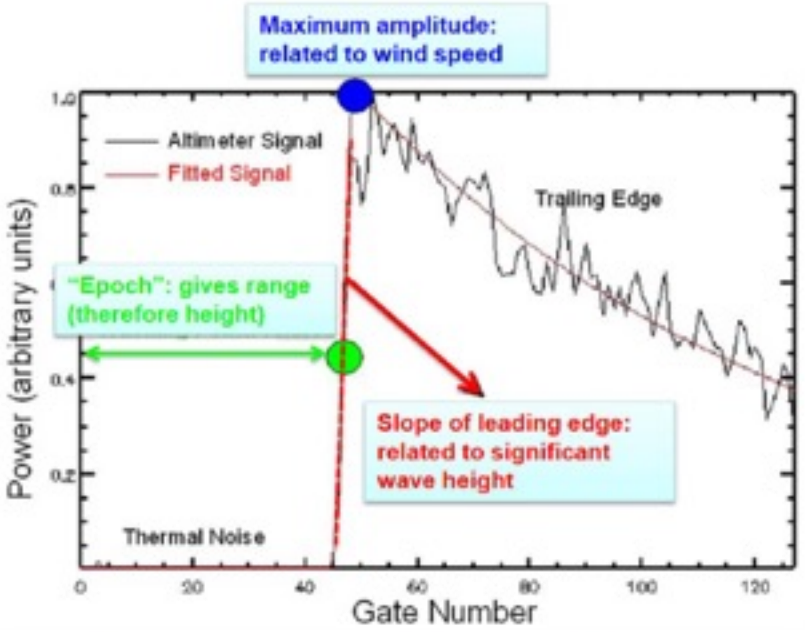
- **Analytical retrackers** try finding the **best fitting model** for each **L1b experimental waveform**.

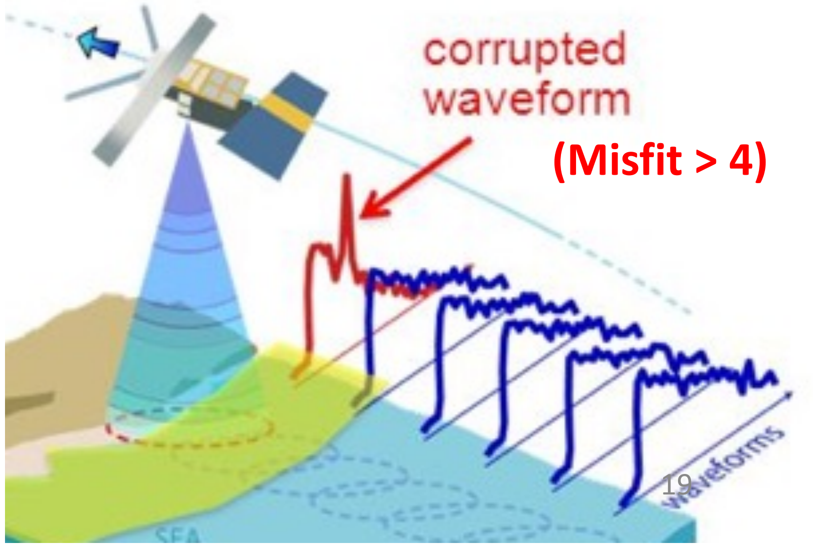
- If a **best fitting model is found**, the **associated parameters** are provided in **output products** (**epoch** → **SSH, SWH, Pu**) as **L2 estimates**.

- *The **misfit parameter** measures the **mean quadratic error** between **waveform** and **model** ('mqe' in official Sentinel-3 products) and gives an **indication** on the **quality of estimates**.*

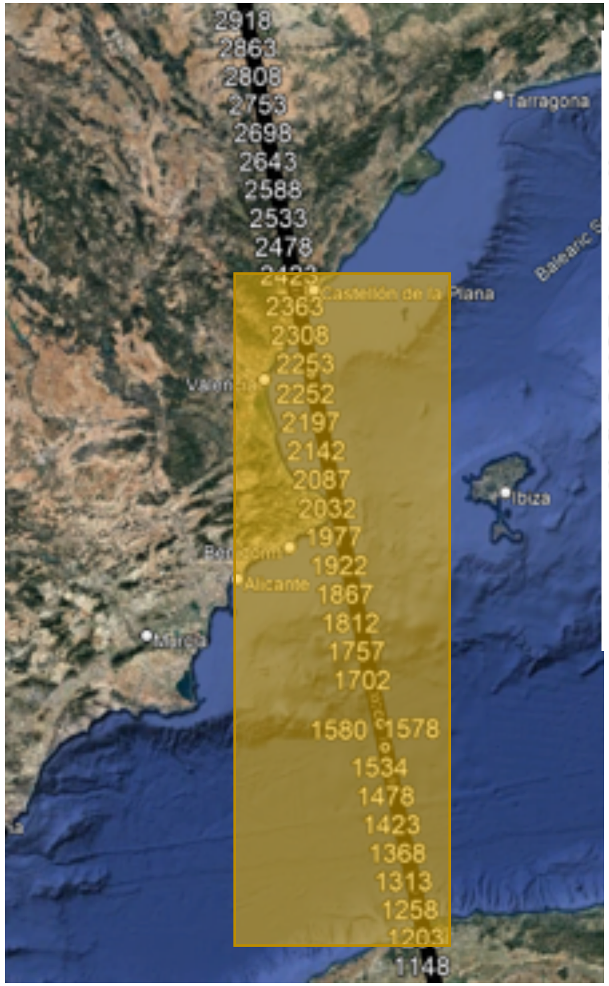
- *A **misfit < 4** indicates **reliable estimates** (EUMETSAT helpdesk, Dinardo et al., 2018).*

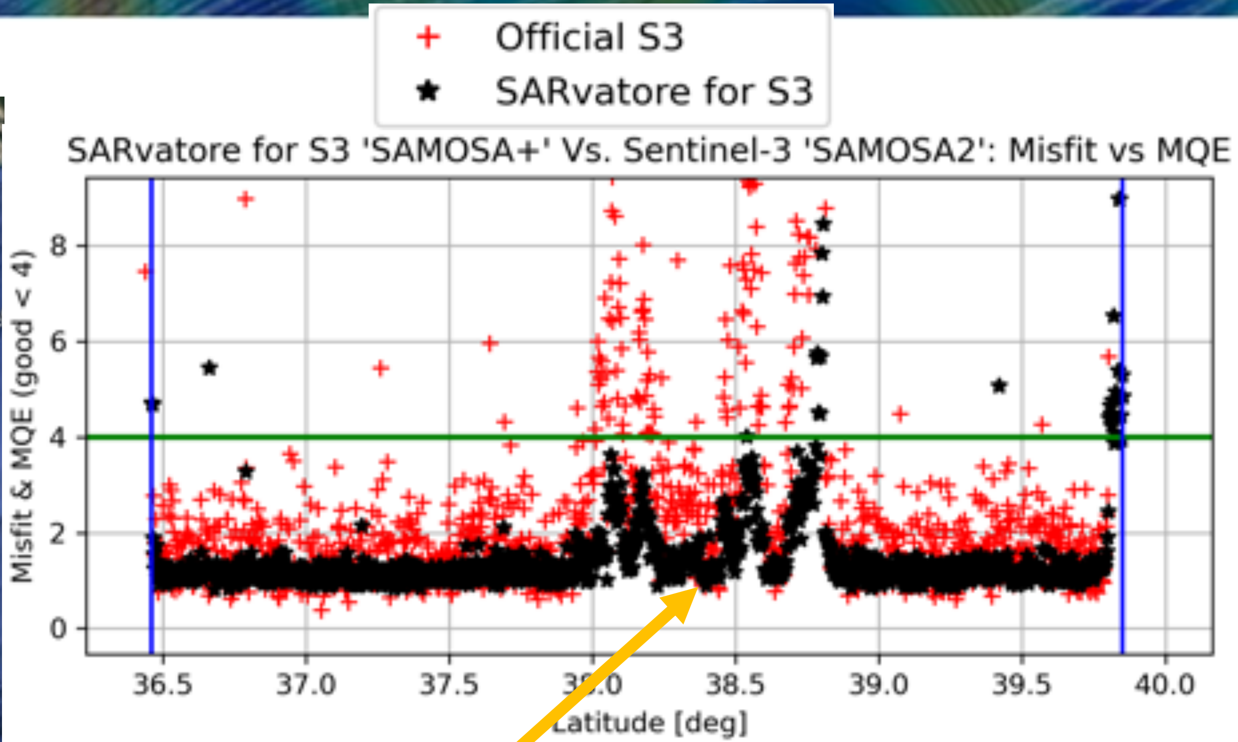
- The value is higher in **presence of islands** or in **approaching the coastal zone:** the received waveforms are corrupted and do not respect the retracking model.

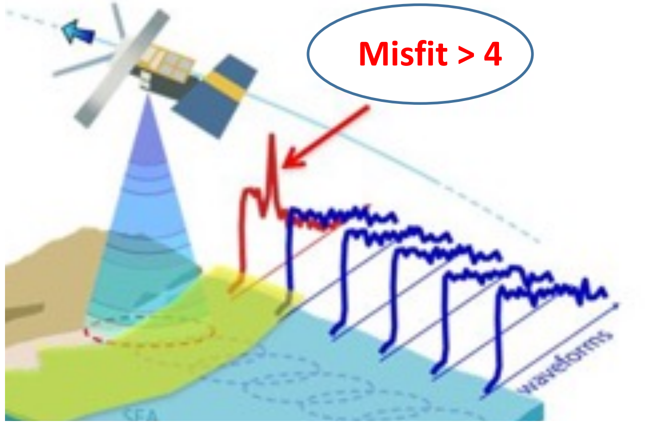


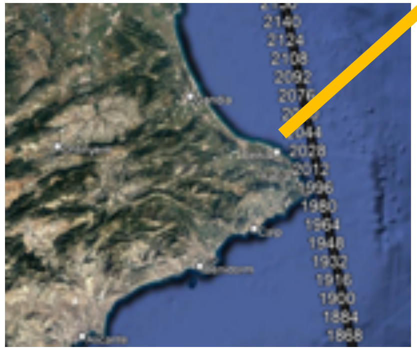


SENTINEL-3 SAMOSA+ & SENTINEL-3 SAMOSA2 in the coastal zone





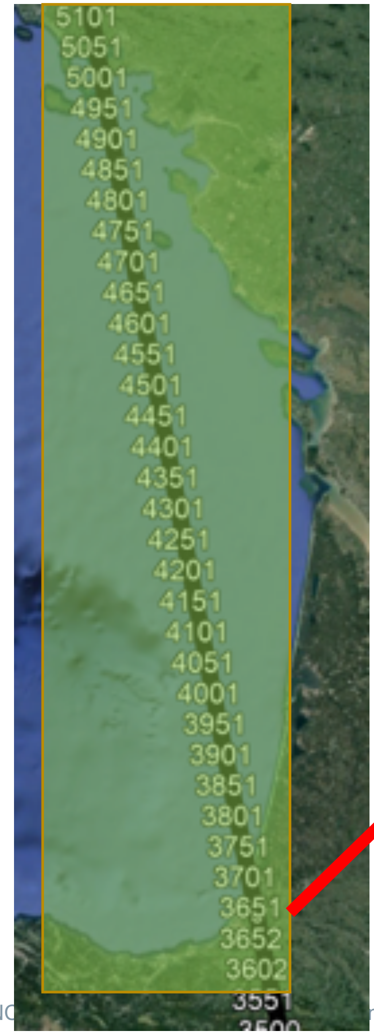


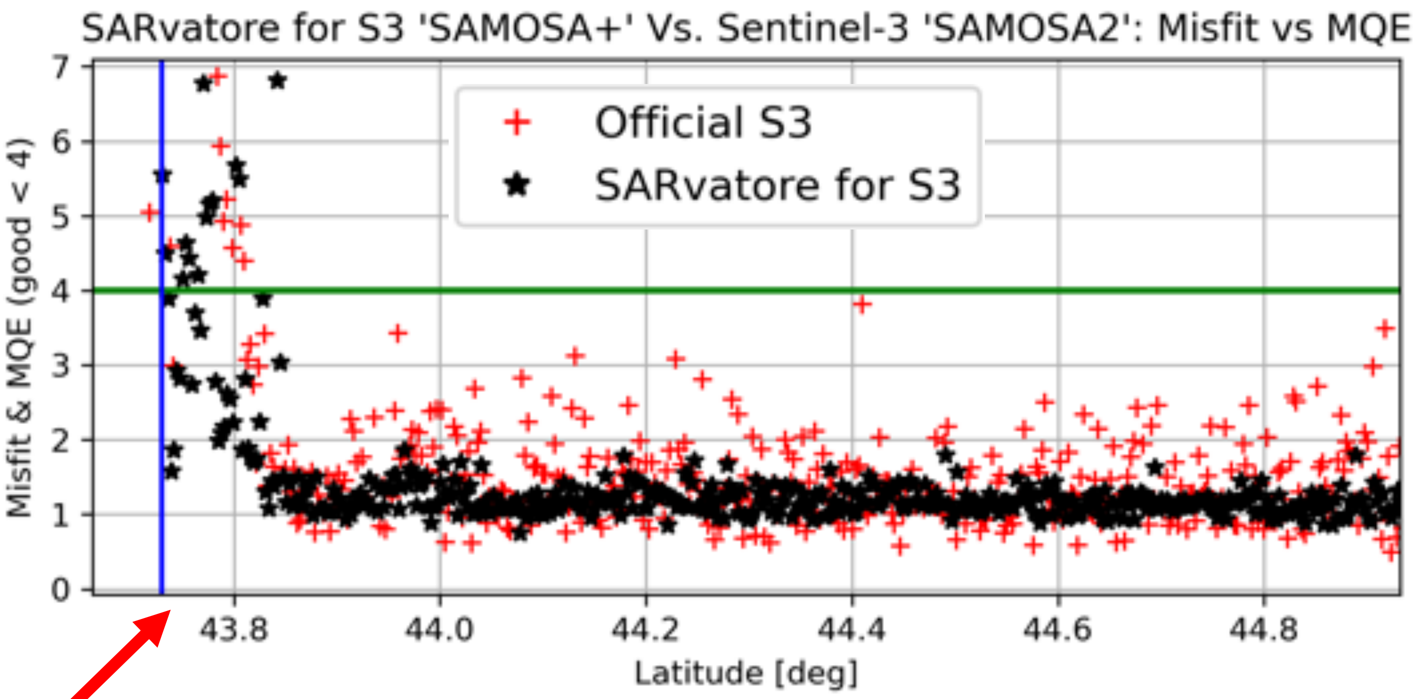


- Overall, **SAMOSA+** presents a **lower misfit** & provides **more valid estimates** in scenarios in which **contamination is present.**

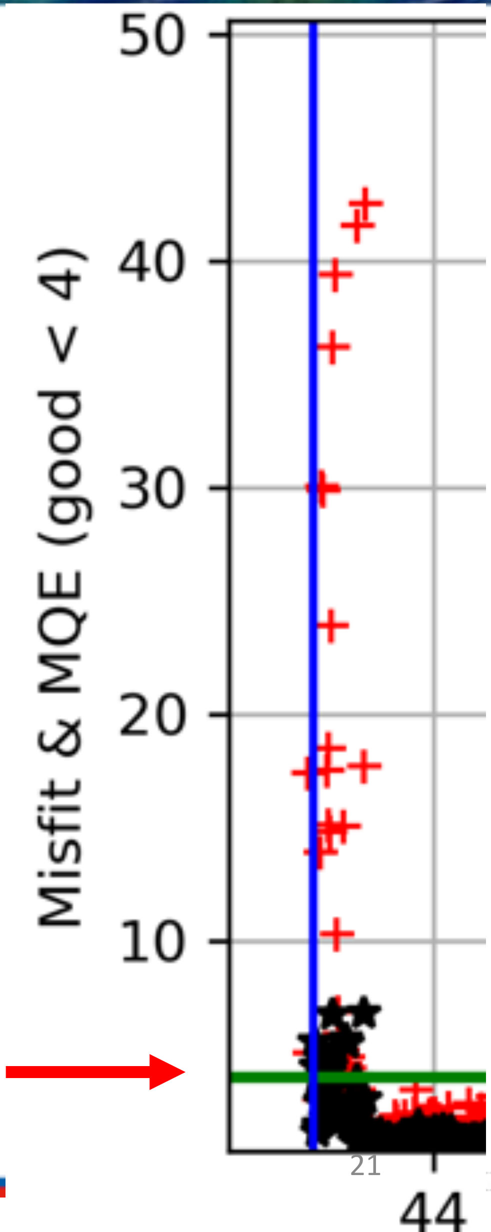
- Misfit is around 1-2 in the open ocean, increasing in the coastal zone (vertical blue lines) due to land contamination of the altimetry footprint.

SENTINEL-3 SAMOSA+ & SENTINEL-3 SAMOSA2 in the coastal zone





The number of valid SAMOSA+ estimates is typically higher close to the coast with respect to SAMOSA2.



Method shortcomings

- Relies on the existence of wave buoys in the region of interest.
- The altimeter tracks should pass close to the buoy in order to obtain reasonable estimates of ***a*** and ***b.***
- The effect of the length of the buoy time record in the calculation of ***a*** and ***b*** needs to be investigated.
- Proximity to the coast is a challenge for altimeter observations.
- Interpolation of ***a*** and ***b*** to the position of interest is challenging because it depends on the existence of enough buoys and their relative position.

Concluding remarks

- The different characteristics of chosen locations show some correspondence between variability and mean wave power which is important information in putting together a marine renewable energy strategy for any jurisdiction.

- These results obtained using CCI SEA STATE data do not give information very near the coast where the wave energy recuperation machines could be installed. The local energy available depends on bathymetry and wave-current interaction. *Data closer to the coast are required and will be supplied for recent years with Sentinel-3A/B altimeter data processed with SAMOSA+ in the ESA Altimetry Virtual Lab hosted in the EarthConsole®.*

- The method will be extended to other coastal locations worldwide. *The investigation is still under development* to compare Sentinel-3 high-resolution altimetry products obtained with different retracking strategies (official SAMOSA2 & AVL SAMOSA+).

Future work

- Investigate the improvement in the wave power estimates near the coast using new retrackers.
- Perform wave power assessments in other regions with this method.
- Investigate the effect of the distance between the altimeter track and buoy and of the length of the buoy record on the regression coefficients value (the altimeter data extraction is slow so shorter extraction intervals are better)
- Investigate the effect of the interpolation method on the regression coefficients in the wave power estimates.