Evaluation of High Frequency Radars skills for wave height observation at the west coast of the Iberian Peninsula

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Outline

- INTRODUCTION
- DATASETS
  - *In situ* observations
  - High Frequency Radars
  - Satellite altimetry
- METODOLOGY
- RESULTS AND DISCUSSION
- CONCLUSIONS
- REFERENCES

Alfanzina (ALFA) HFR (https://www.hidrografico.pt/radar.map)

Introduction

Western Iberian Peninsula

- Strongly influenced by low-presure systems from the North Atlantic Ocean;

- Storms and severe sea states (winter);

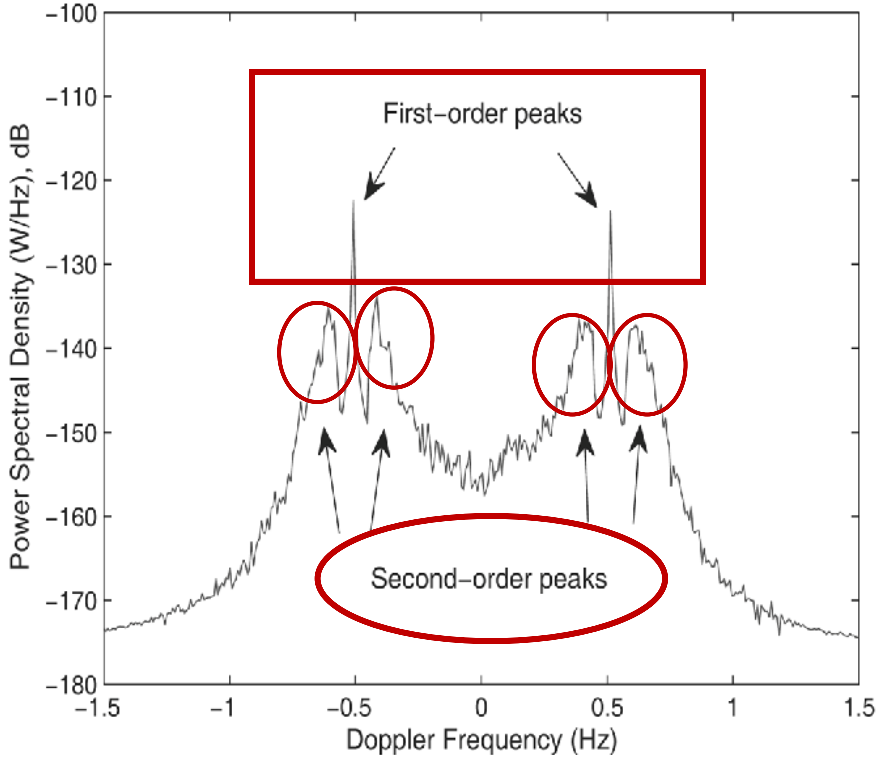
- *In situ* observations allow continuous monitoring of coastal areas:
  - Disproportionally distributed;
  - Most of them in the northern hemisphere and
  - Near to developed countries.

- Satellite Altimeter (AS) is a good alternative:
  - Global coverage;
  - Day and night operating capability;
  - Less accurate near the coastline (land contamination).

- High Frequency Radars (HFR) could be an option for monitoring coastal areas and the sea-state.

Introduction

- **High Frequency Radars (HFR)**
- <u>**Currents**</u> (1st order peaks – radar echo spectrum)
  - **> 100 km (coastline)**
- <u>**Wave parameters**</u> (SWH, T, MWD) – 2nd order spectrum (lower energy, closer noise floor, easly contaminated)
  - **< 30 km (coastline)**
  - **lower amplitude peaks**
  - wave parameters through a least-squares fitting technique between 2nd order radar spectrum and a Pierson-Moskowitz model with a cardioid directional distribution function



Backscatter Doppler spectrum – 1st and 2nd order peaks (Zhang *et al.*, 2012)

Introduction

- **MOTIVATION**

- HFR wave observations are a cost-effective complement to *in situ* sensors, by increasing spatial coverage with lower maintenance costs.

- *In situ* observations can benefit from the improved temporal sampling and higher resolution provided by HFRs.

- Different remote sensing techniques, such as High Frequency Radar (HFR) or satellite altimetry, can act as complementary systems for wave height observations, filling out the information gaps of *in situ* sensors.

MAIN GOALS

- Evaluate the skills for measuring wave height of the *SeaSonde* CODAR HFR systems in the western Iberian Peninsula through comparisons between HFR, buoys and Satellite altimeter measurements.
- The ability of the HFR system to detect wave height extreme events is also evaluated.

Datasets

- ***In situ* observations**

  - 12 wave buoys

- **High Frequency Radars**

  - 9 CODAR SeaSonde HFR

- **Satellite Altimetry**

  - Sentinel-3 (A&B) SRAL

- **Time window**

  - January 2017 – December 2019 (36 months)

Datasets

➢ ***In situ* observations**

Buoy	Distance from shore (km)	Availability wave data (%)
Peñas (SP)	19	87.68
Baves (SP)	37.5	91.38
Villano-Sisargas (SP)	30.5	95.74
Silleiro (SP)	44.16	99.93
Leixões (coastal) (PT)	19.2	69.79
Leixões (oceanic) (PT)	72.95	69.41
Nazaré (coastal) (PT)	7.42	55.91
Nazaré (oceanic) (PT)	14.15	79.47
Sines (PT)	5	83.14
Faro (coastal) (PT)	6.63	96.42
Faro (oceanic) (PT)	64.7	57.41
Cádiz (SP)	53.7	99.96

- "ground thruth"
- 7 PT (Instituto Hidrográfico);
- 5 SP (*Puertos del Estado*);
- hourly observations.

Datasets

➢ High Frequency Radars

HFR site	Frequency (MHz)	RC resolution (km)	Maximum distance SWH data (km)
PRIO	4.86	5.1	25.5
VILA	4.86	5.1	25.5
SILL	4.86	5.1	25.5
FIST	4.86	Data not available	
SJUL	12.43	1.85	18.5
ESPL	12.92	2.15	34.4
SAGR	13.5	1.85	29.6
ALFA	13.5	1.85	29.6
VRSA	12.47	1.51	22.65
MAZA	13.5	1.67	20.04

- CODAR *SeaSonde* HFR systems;
- Operating frequency:
  - 4.86 MHz (wave height– 20 m);
  - 12-13.5 MHz (wave height – 1 to 8 m);
- 5 HFR PT (Instituto Hidrográfico) + 1 HFR;
- 5 SP (*Puertos del Estado*);

Datasets

High Frequency Radars

HFR site	Frequency (MHz)	RC resolution (km)	Maximum distance SWH data (km)
PRIO	4.86	5.1	25.5
VILA	4.86	5.1	25.5
SILL	4.86	5.1	25.5
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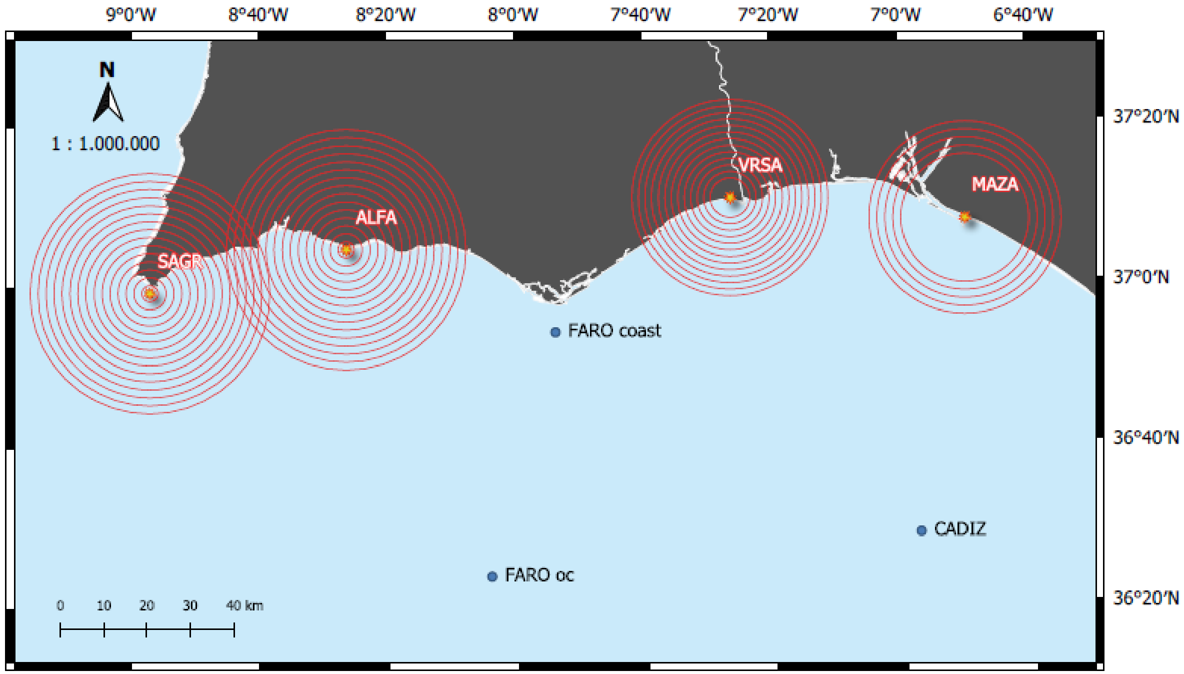
ALFA	13.5	1.85	29.6
VRSA	12.47	1.51	22.65
MAZA	13.5	1.67	20.04

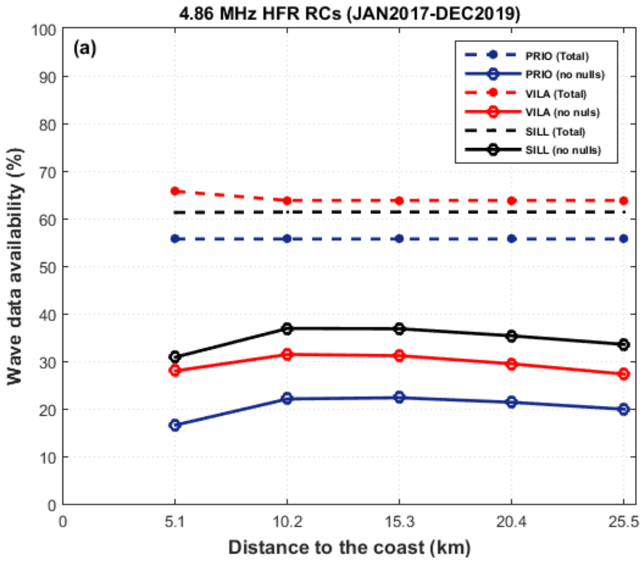
- RC (range cells);
- Ocean spectrum homogeneity through each HFR RC (CODAR *SeaSonde* system);
- Different availability among HFR RC.

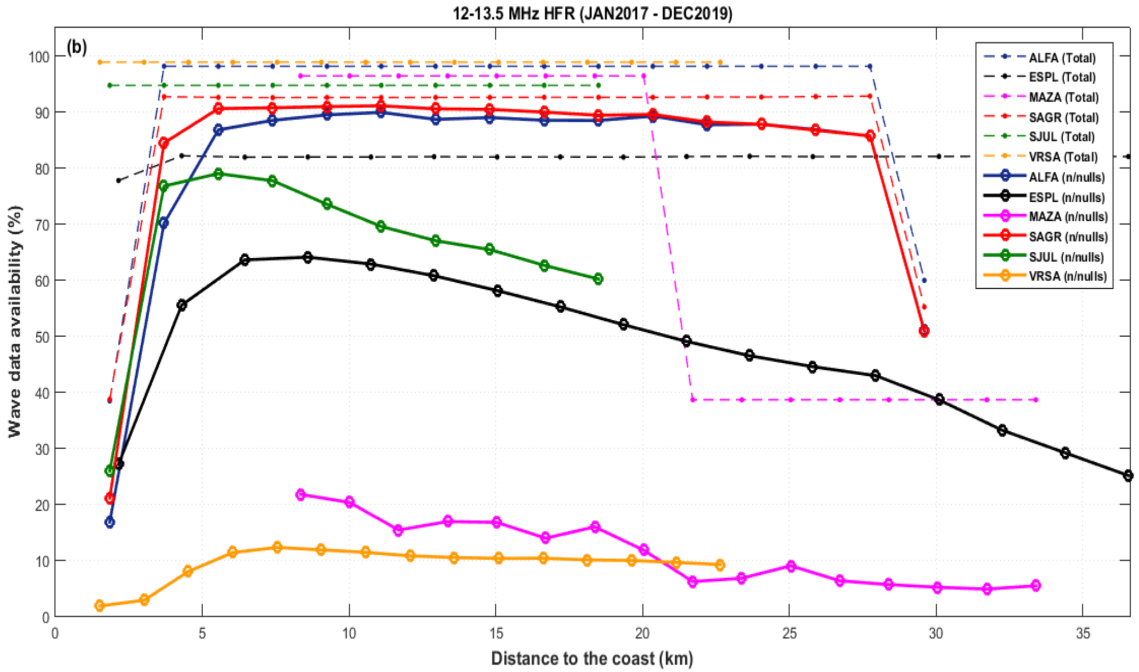


HFR in Algarve region (SAGR, ALFA, VRSA and MAZA).

Datasets

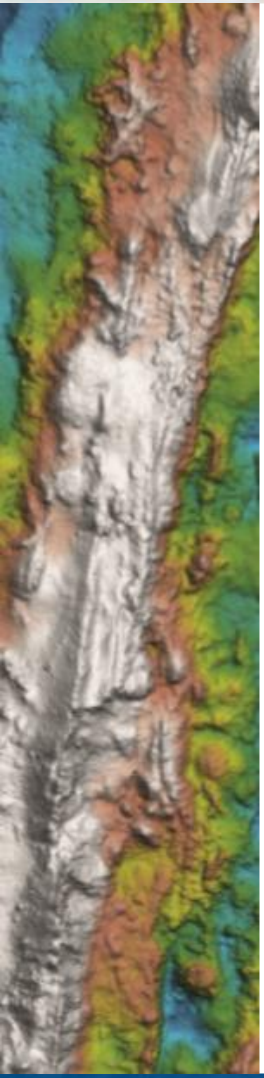
- **HFR wave data availability vs. distance to coast**





- low availability too close/far from the coast,
- wave data availability < 25/30 km shoreline;
- Galician HFR availability – 20% - 40% (maintenance periods);
- ALFA & SAGR > 83 %;
- VRSA & MAZA < 20 % (sheltered area + low sea-states).

Datasets

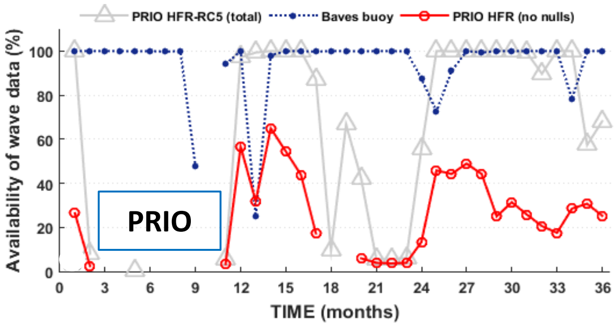


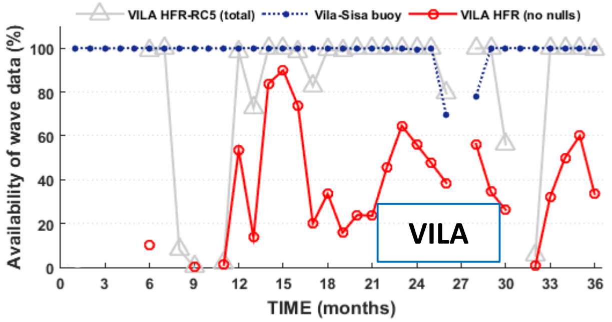
➢ HFR wave data availability vs. Buoy

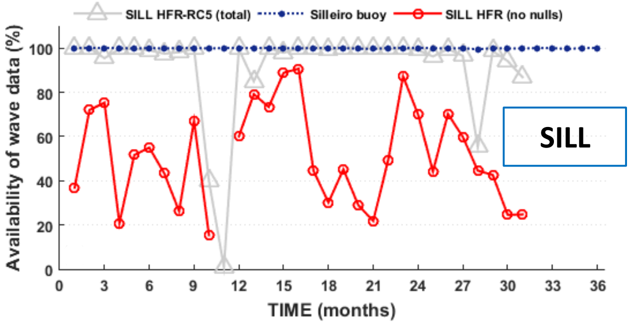
- In the presence of low-sea states (**<u>wave height < 2 m</u>**), the strength of the 2nd order spectra can be very weak, and **<u>spurious contributions</u>** to the spectrum would have a significant impact.

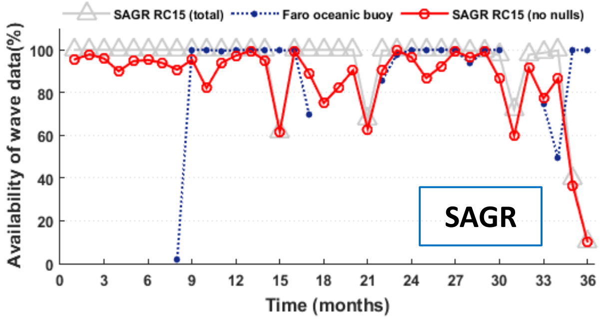
- As a first step to the HFR wave parameters evaluation, radar nulls and other spurious values detected during data screening are excluded.

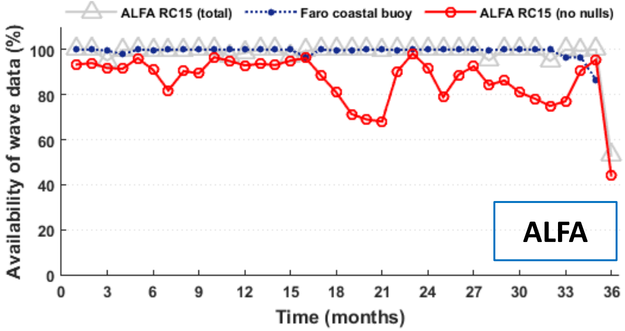
- **<u>INOP:</u>**
  - **PRIO** (FEB-NOV2017 / JUN-AUG2018);
  - **VILA** (JAN-JUN & SEP-NOV2017/ MAR&JUL2019);
  - **SILL** (NOV2017 / AUG-DEC2019).

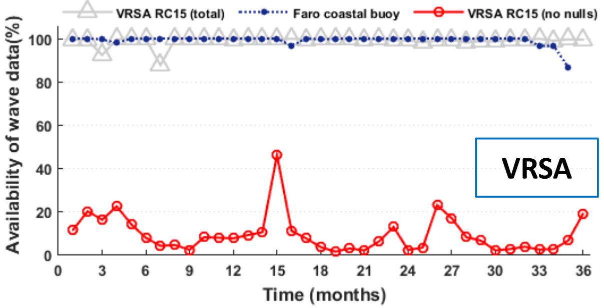


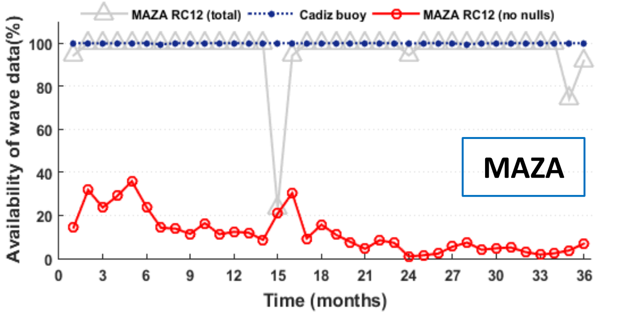






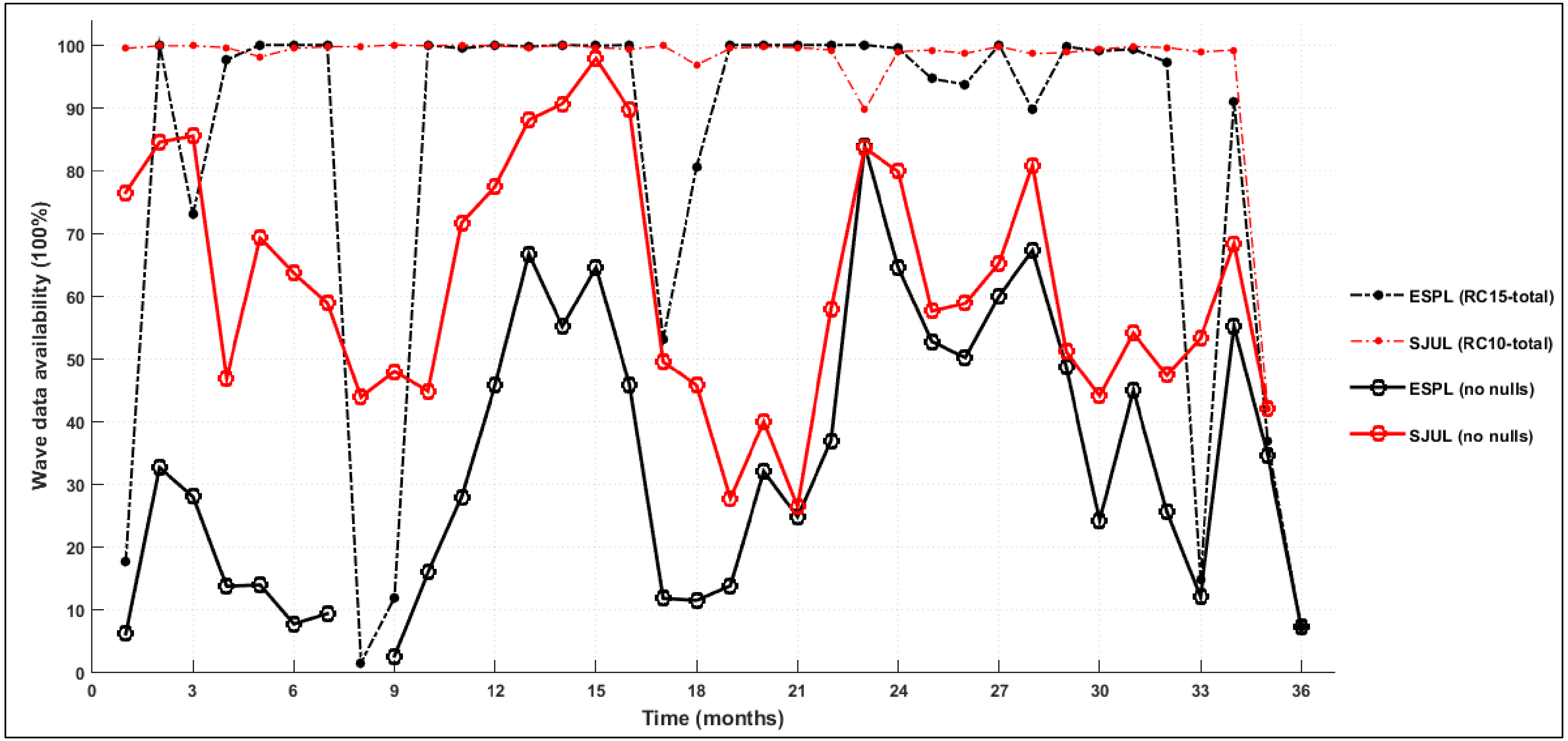






Data sets

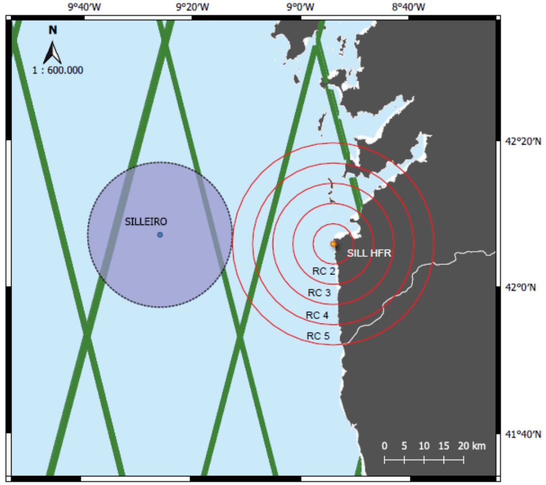
➢ HFR wave data availability (SJUL & ESPL)

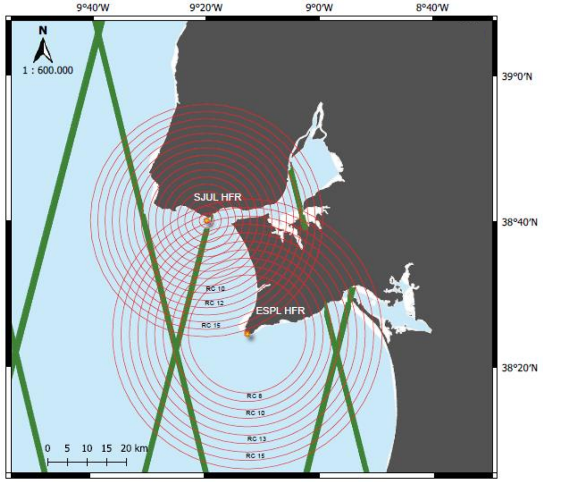


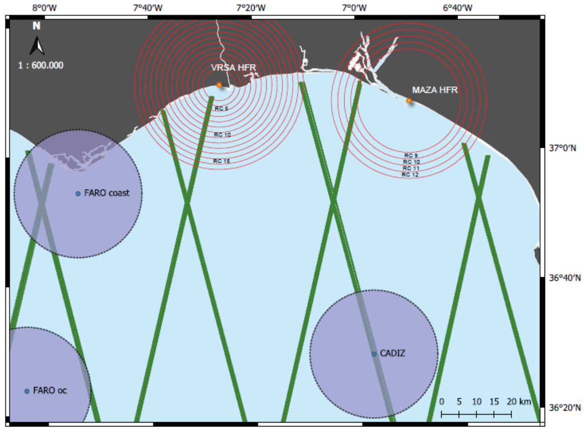
Data sets

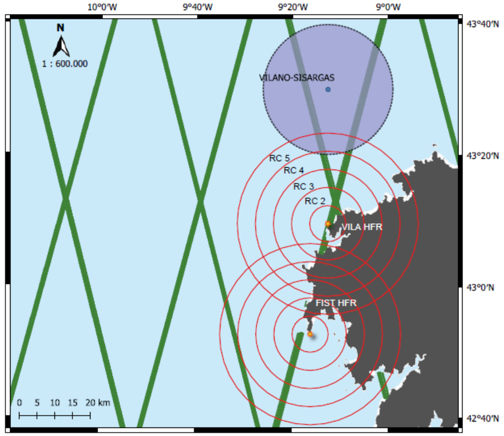
➢ **Satellite Altimetry**

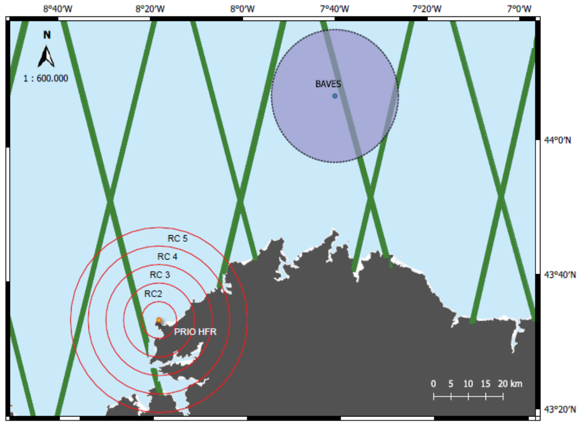
- Sentinel-3 SRAL;
- Copernicus Online Data Access (CODA) (https://coda.eumetsat.int/);
- 1 Hz (7 km) & 20 Hz (≈ 340 m);
- 20 Hz sampling SWH measurements (S3A & S3B);

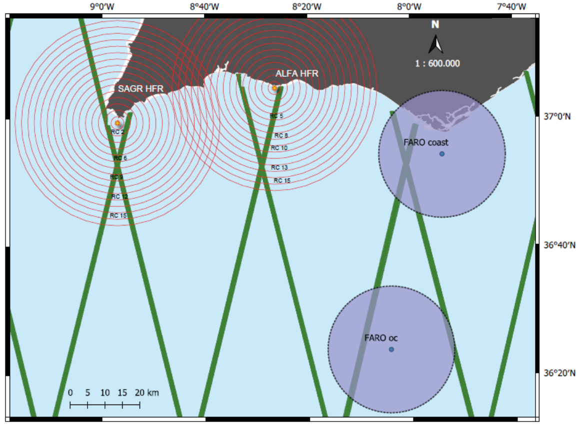












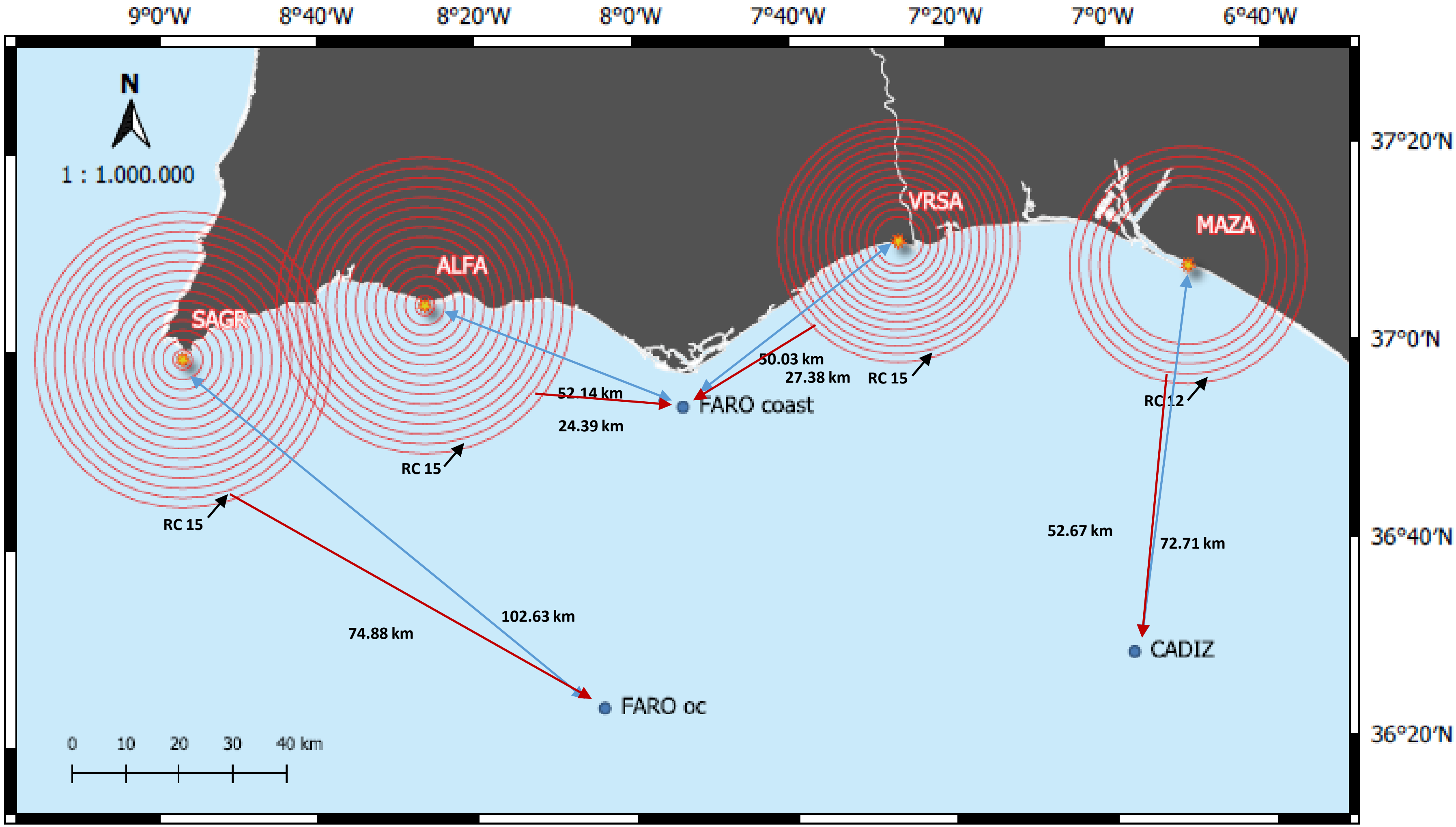
Metodology

➢ HFR analysis

Data comparisons:

1. HFR vs. Buoy

- Selection of the outermost RC, closest to the buoy position.



Metodology

➢ HFR analysis

Data comparisons:

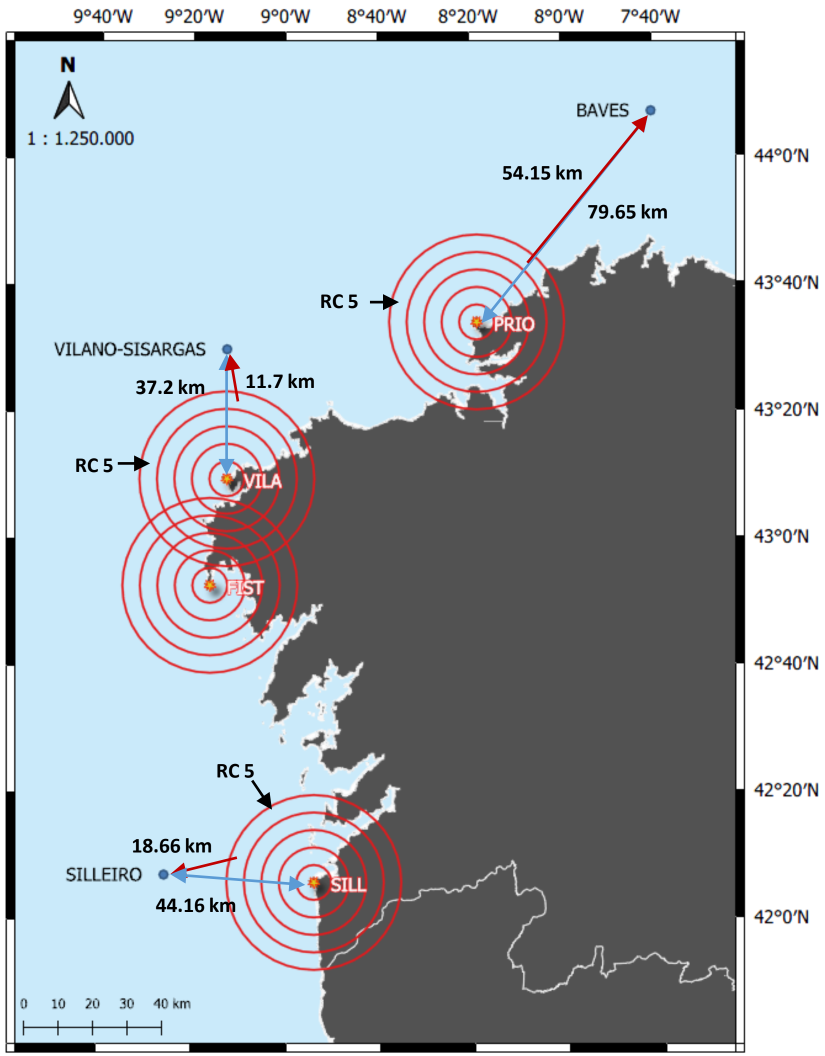
1. HFR vs. Buoy

- Selection of the outermost RC, closest to the buoy position;

- In line-of-sight with the HFR antenna transmission azimuth;

- Enough data to be compared.

HFR (RC)	Buoy	Distance RC-buoy (km)
PRIO (5)	Baves	54.15
VILA (5)	Villano-Sisargas	11.7
SILL (5)	Silleiro	18.66
ALFA (15)	Faro coastal	24.39



Metodology

➢ HFR analysis

Data comparisons:

<u>- No overlap between HFR RC and buoys</u>

<u>- S3 tracks overlap all the HFR RC</u>

2. HFR vs. SA (S3)

- Buoy observations to validate S3 SWH;

- S3 data as reference for HFR/S3 analysis;

- HFR performance vs. distance to the coast

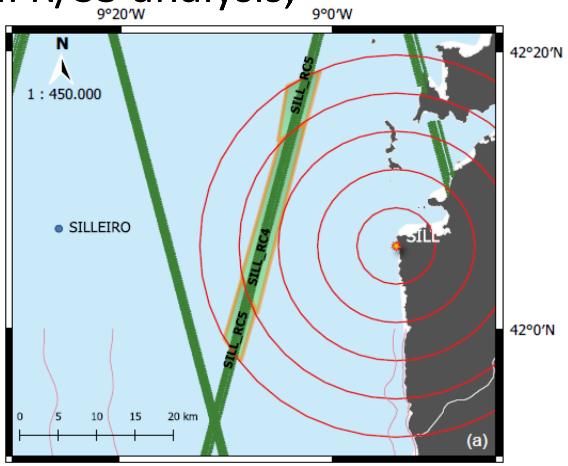
Buoy	N	R	Bias (m)	RMSE (m)	SI	slope
Peñas (SP)	46	0.94	0.10	0.42	0.20	0.95
Baves (SP)	63	0.99	-0.03	0.21	0.08	0.99
Villano-Sisargas (SP)	26	0.99	0.05	0.25	0.09	1.09
Silleiro (SP)	54	0.99	-0.07	0.24	0.09	1.05
Leixões (coast.) (PT)	34	0.98	0.04	0.27	0.12	1.01
Leixões (oc.) (PT)	41	0.98	0.03	0.26	0.11	1.05
Nazaré (coast.) (PT)	23	0.98	0.19	0.33	0.10	1.02
Nazaré (oc.) (PT)	21	0.99	-0.03	0.17	0.06	0.94
Sines (PT)	42	0.91	-0.45	0.65	0.25	0.94
Faro (coast.) (PT)	51	0.95	-0.05	0.19	0.20	0.92
Faro (oc.) (PT)	34	0.98	-0.03	0.17	0.10	1.08
Cádiz (SP)	65	0.89	-0.16	0.28	0.20	1.01

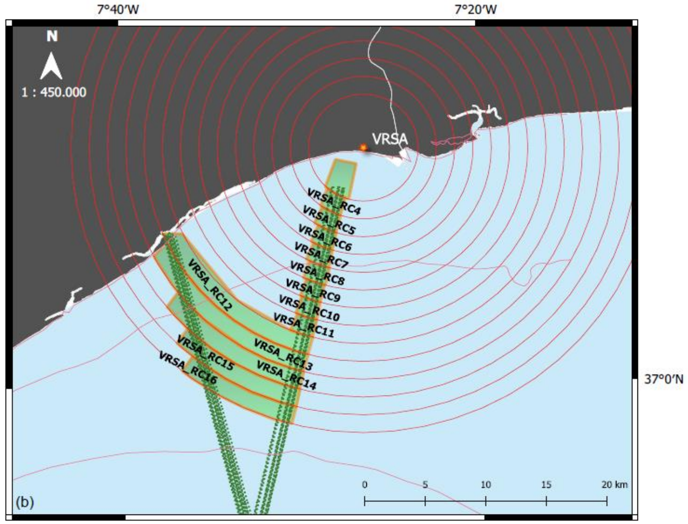
$$R = \frac{\sum_{i=1}^{N}(s_i - \bar{s})(b_i - \bar{b})}{\sqrt{\sum_{i=1}^{N}(s_i - \bar{s})^2 \sqrt{\sum_{i=1}^{N}(b_i - \bar{b})^2}}}$$

$$Bias = \left(\frac{1}{N}\sum_{i=1}^{N}(b_i - s_i)\right)$$

$$RMSE = \left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}(b_i - s_i)^2}\right)$$

$$SI = \left(\frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}[(s_i - \bar{s}) - (b_i - \bar{b})]^2}}{\bar{b}}\right)$$

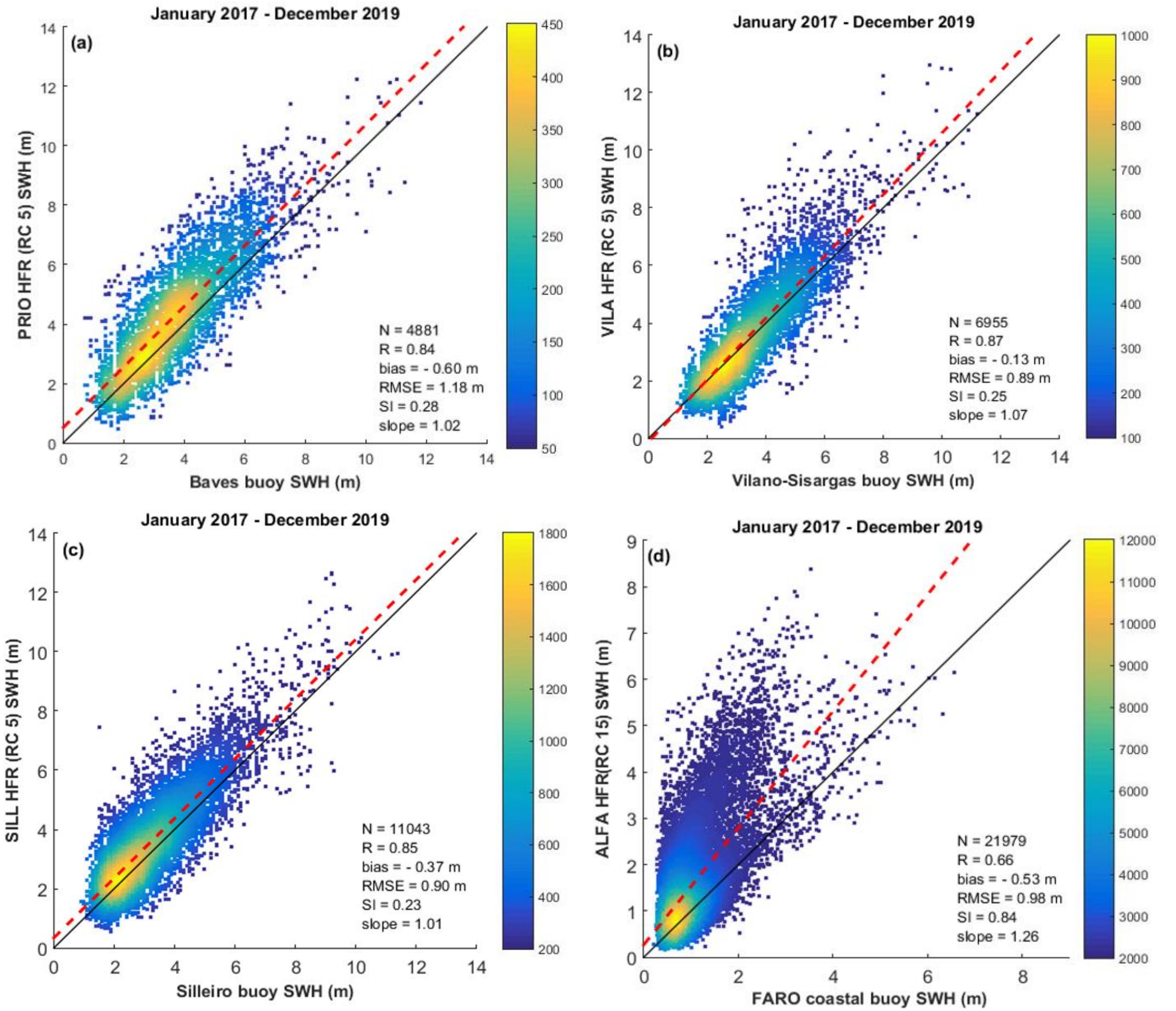




<u>Statistics:</u>
R – correlation coefficient;
RMSE – root-mean-squared error;
SI – scatter index

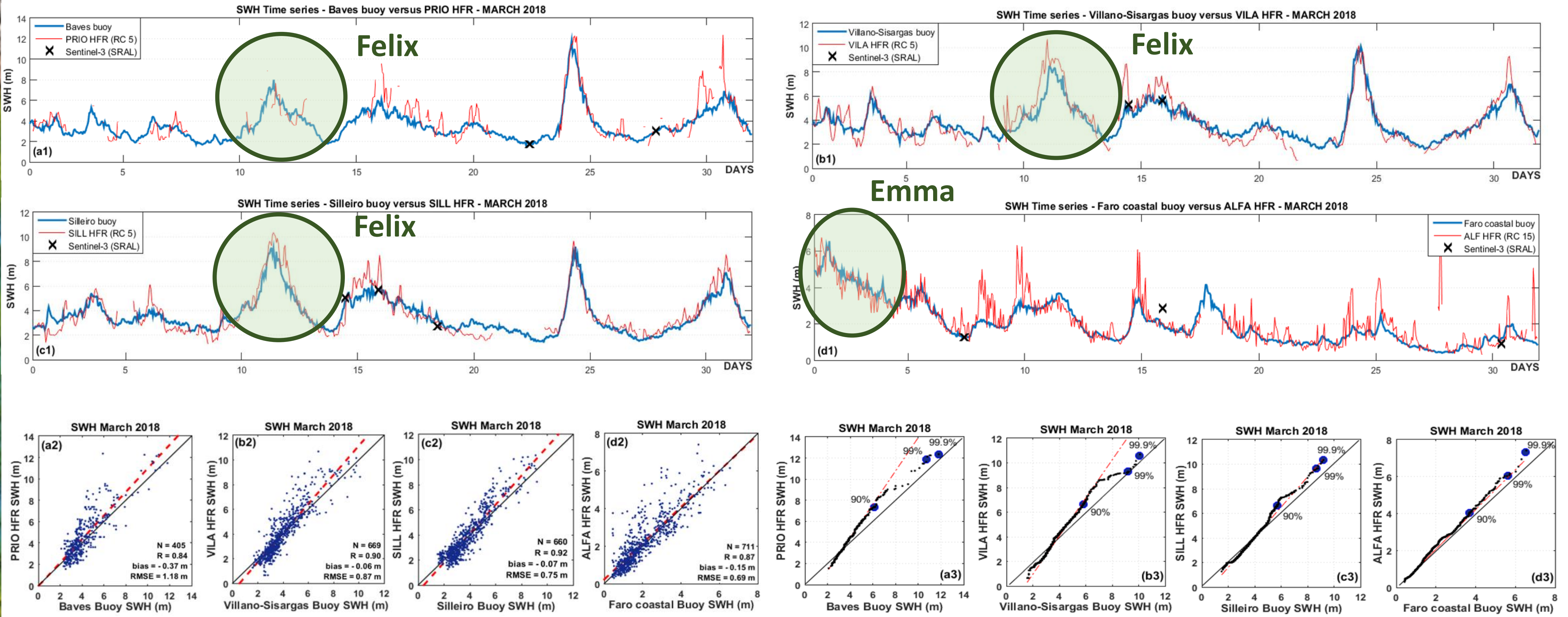
Results and Discussion

- **HFR vs. buoy**
  - 36 months time window;
  - R > 0.84 (ALFA – R=0.66)
  - RMSE – 0.89 - 1.18 m
  - Negative Bias = HFR overestimation
  - ALFA HFR
    - Sheltered area;
    - SWH < 2 m (low sea-states).



Results and Discussion

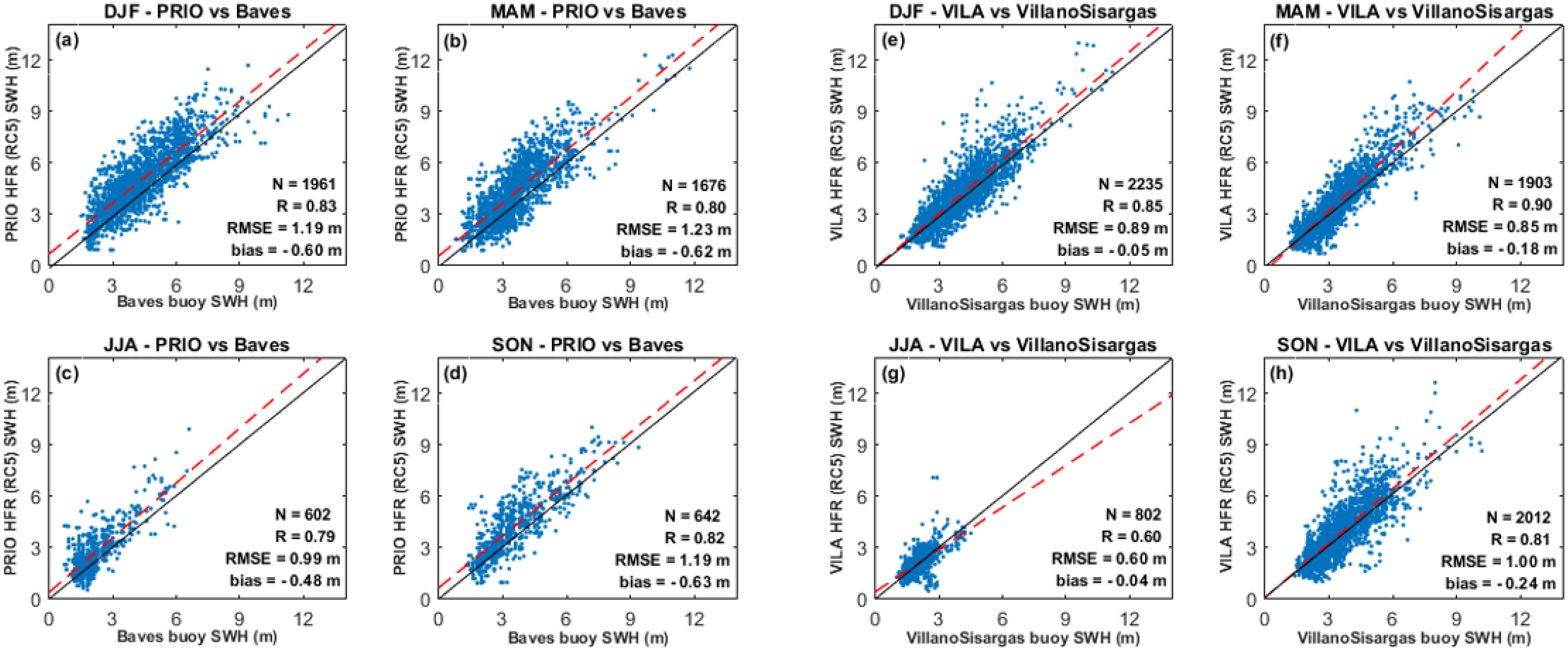
➤ Extreme wave event analysis



*** <u>P 90% < EXTREME EVENT < P 99%</u>** (Atan et al., 2015) ≈ **6m/4m (Galician/Algarve)**

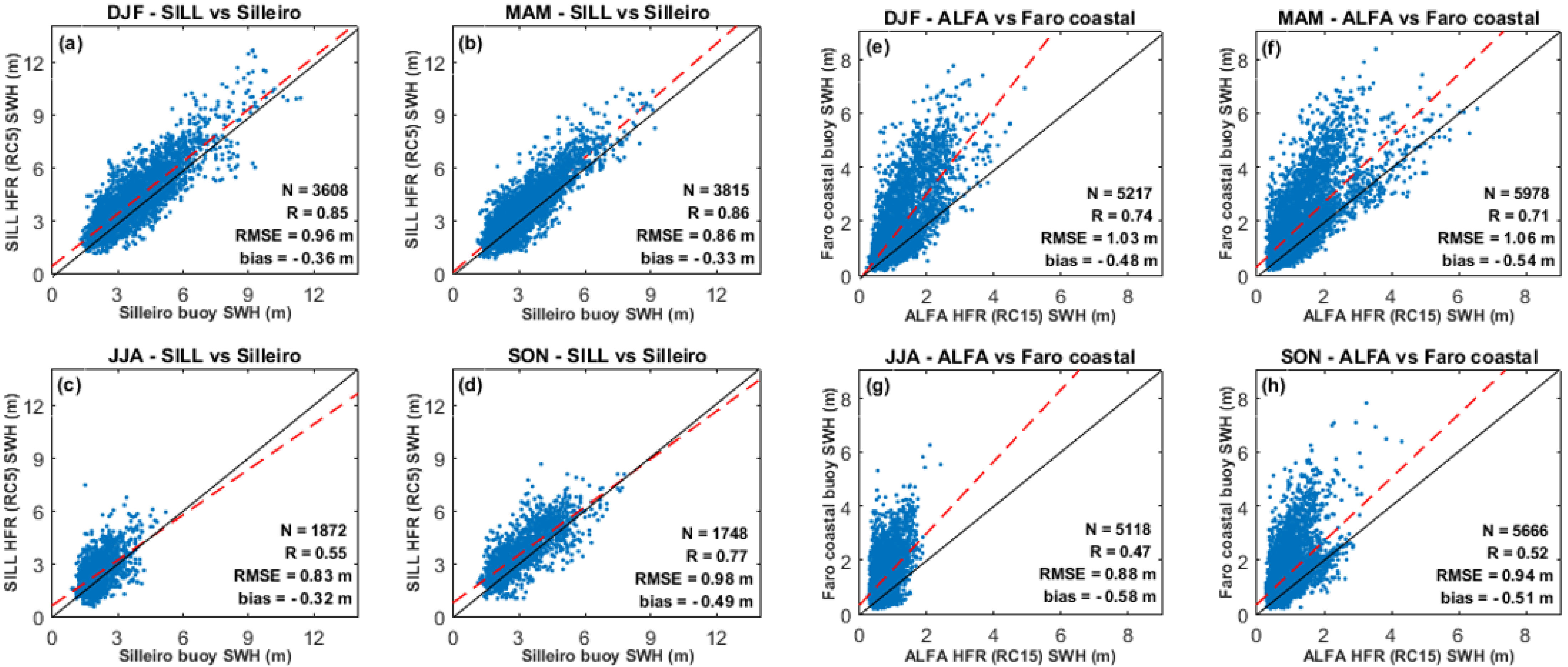
Results and Discussion

➢ **Seasonal analysis**



Results and Discussion

➢ Seasonal analysis



Results and Discussion

➢ Galician HFR vs. Sentinel-3

	PRIO HFR			VILA HFR			SILL HFR		
RC	R	Bias (m)	RMSE (m)	R	Bias (m)	RMSE (m)	R	Bias (m)	RMSE (m)
1	-	-	-	0.88	−1.07	1.32	-	-	-
2	0.94	−1.01	1.48	0.88	−0.29	0.82	-	-	-
3	0.96	−0.50	0.78	0.93	−0.15	0.61	-	-	-
4	0.99	−0.37	0.57	0.94	−0.002	0.53	0.95	−0.63	0.81
5	0.86	−0.65	1.23	0.94	−0.12	0.53	0.94	−0.70	0.93

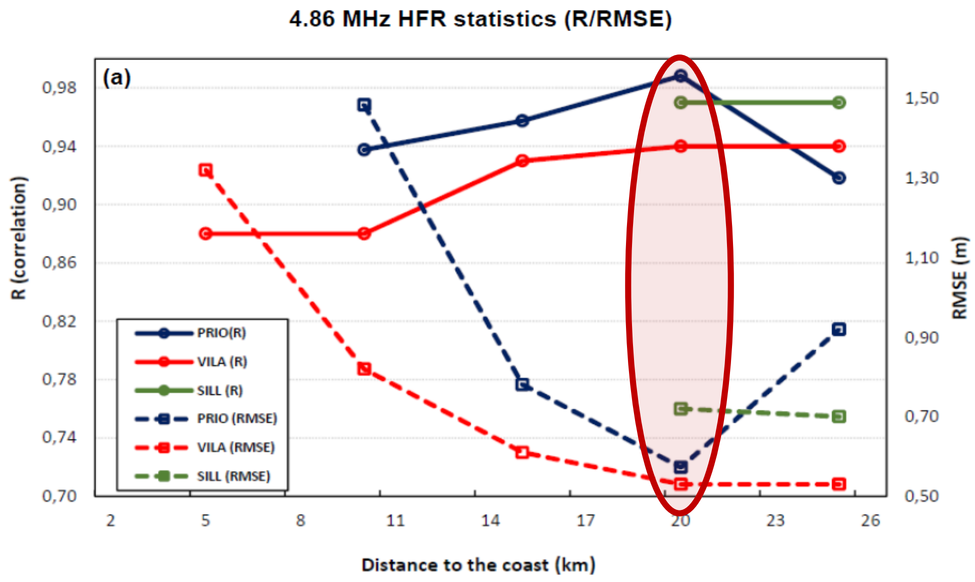
- Negative Bias (HFR overestimation);

- RMSE values vary in the inverse proportion with the R;

- R – 0.86 to 0.99;

- RMSE – 0.53-0.81 m;

RC 4 ≈ 20 km

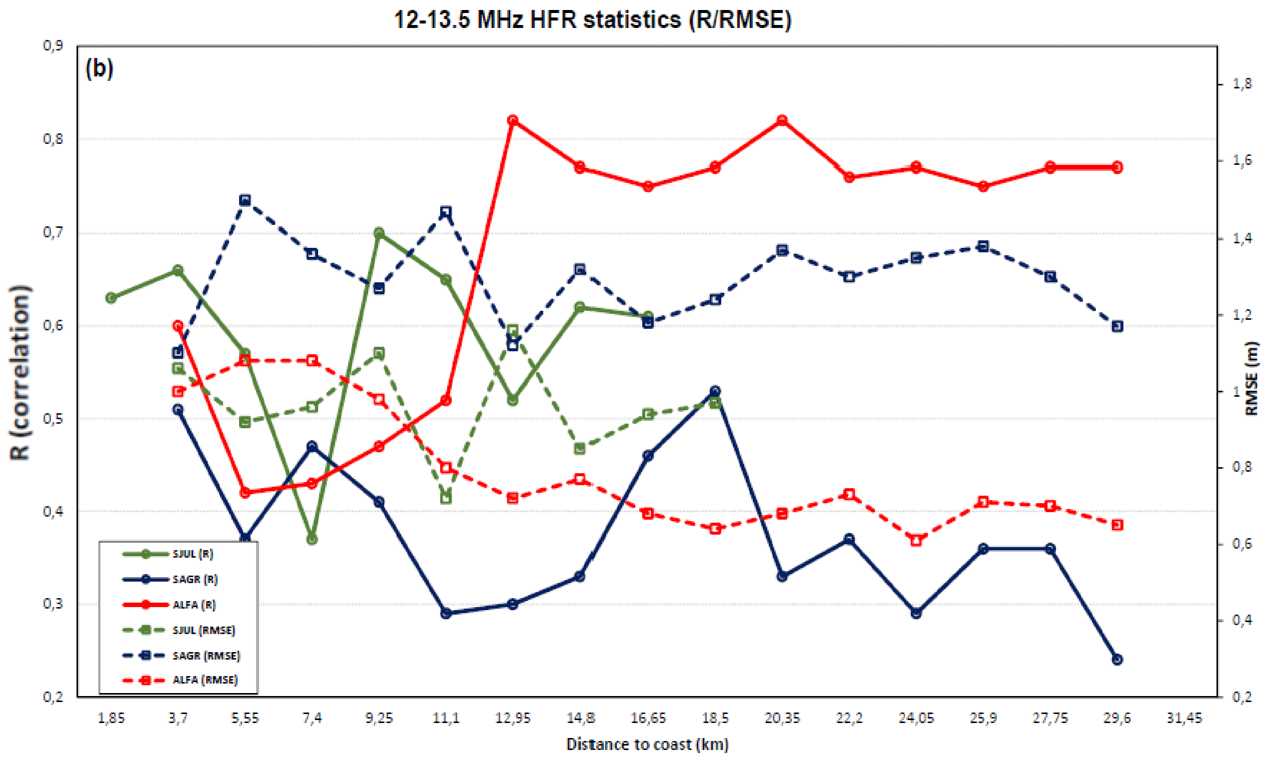


Results and Discussion

➢ 12-13.5 MHz HFR sites vs. Sentinel-3

	SJUL HFR			SAGR HFR			ALFA HFR		
RC	R	Bias (m)	RMSE (m)	R	Bias (m)	RMSE (m)	R	Bias (m)	RMSE (m)
1	-	-	-	-	-	-	-	-	-
2	0.63	−0.40	1.06	0.51	−0.47	1.10	0.60	−0.46	1.00
3	0.66	−0.36	0.92	0.37	−0.77	1.50	0.42	0.01	1.08
4	0.57	−0.45	0.96	0.47	−0.74	1.36	0.43	−0.10	1.08
5	0.37	−0.48	1.10	0.41	−0.59	1.27	0.47	−0.13	0.98
6	0.70	−0.23	0.72	0.29	−0.62	1.47	0.52	−0.16	0.79
7	0.65	−0.35	1.16	0.30	−0.29	1.12	0.82	−0.40	0.72
8	0.52	−0.11	0.85	0.33	−0.36	1.32	0.77	−0.32	0.77
9	0.62	0.10	0.94	0.46	−0.40	1.18	0.75	−0.25	0.68
10	0.61	0.12	0.97	0.53	−0.38	1.24	0.77	−0.24	0.64
11	-	-	-	0.33	−0.32	1.37	0.82	−0.32	0.68
12	-	-	-	0.37	−0.20	1.30	0.76	−0.25	0.73
13	-	-	-	0.29	−0.23	1.35	0.77	−0.25	0.61
14	-	-	-	0.36	−0.35	1.38	0.75	−0.27	0.71
15	-	-	-	0.36	−0.36	1.30	0.77	−0.14	0.70
16	-	-	-	0.24	−0.34	1.17	0.77	−0.15	0.65

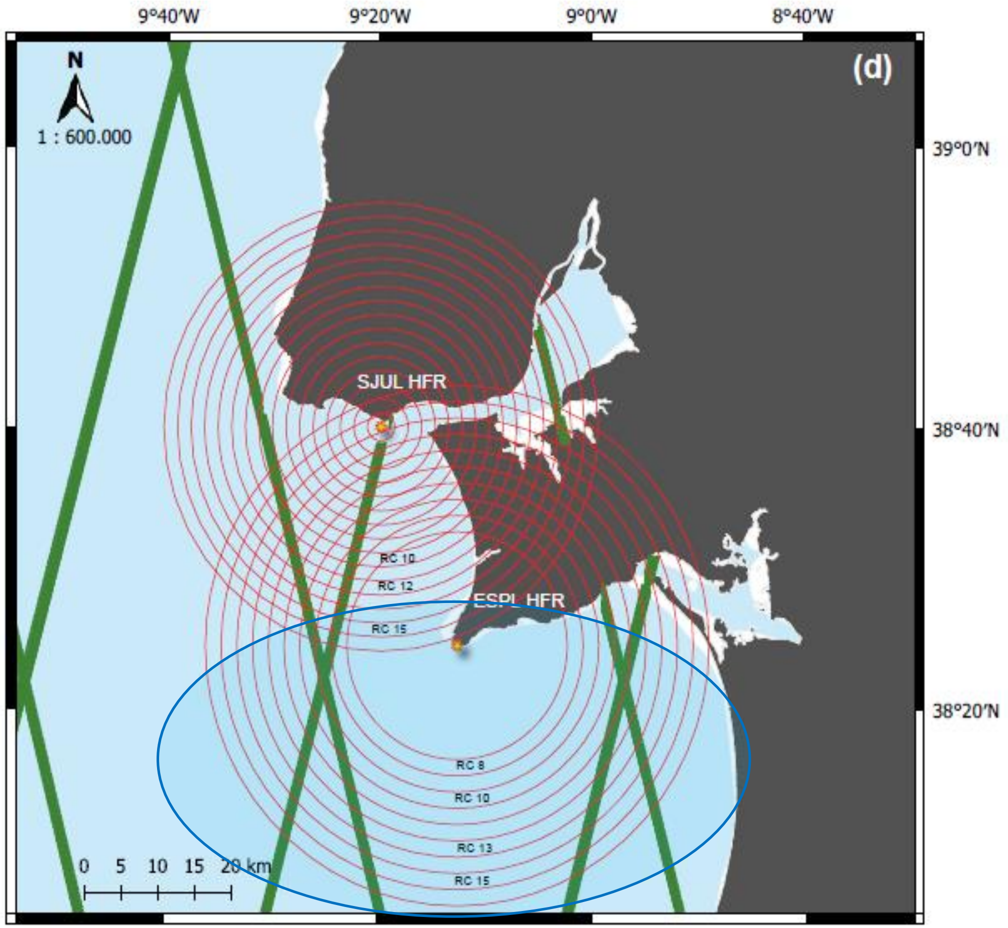
- ALFA HFR:
  - R – 0.75 to 0.82;
  - RMSE – 0.61-0.77 m;
  - RC 7 – RC 15.



Results and Discussion

➢ 12-13.5 MHz HFR sites vs. Sentinel-3

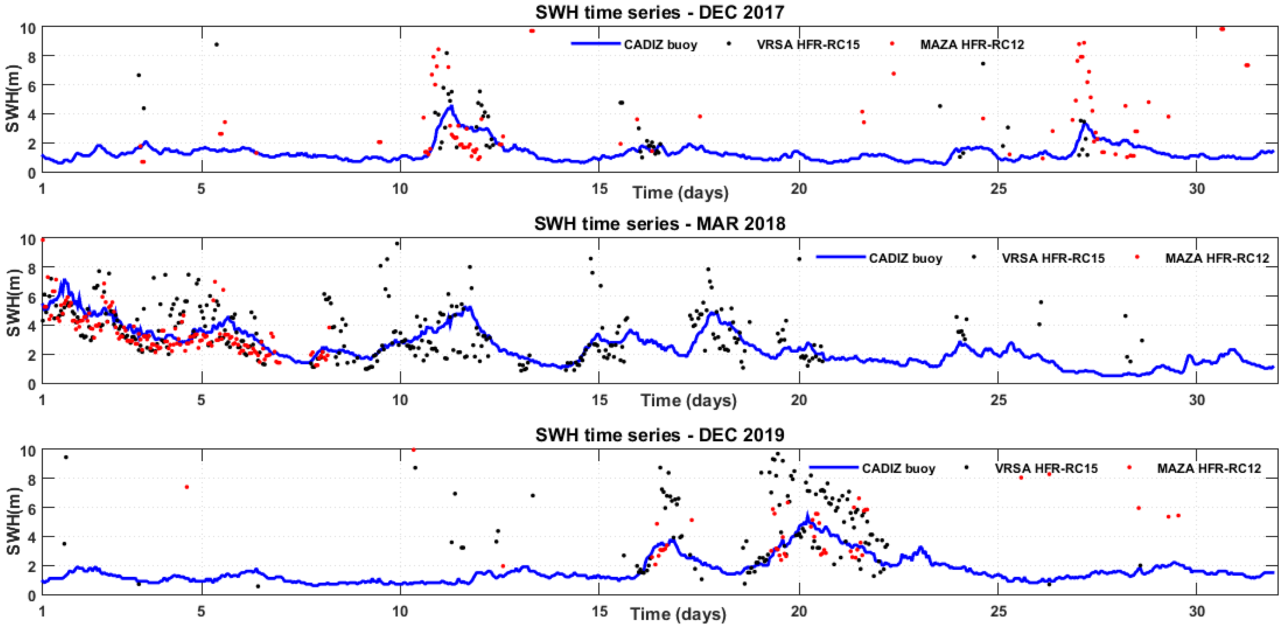
	ESPL HFR			VRSA HFR			MAZA HFR		
RC	R	bias (m)	RMSE (m)	R	bias (m)	RMSE (m)	R	bias (m)	RMSE (m)
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	-	2 observation pairs (N = 2)			-	-	-
5	-	-	-	1 observation pair (N = 1)			-	-	-
6	-	-	-	1 observation pair (N = 1)			-	-	-
7	-	-	-	1 observation pair (N = 1)			-	-	-
8	0.33	−0.05	1.31	1 observation pair (N = 1)			-	-	-
9	0.19	−0.30	1.70	-	-	-	0.14	−0.86	1.28
10	0.84	−0.44	0.74	-	-	-	0.36	−0.44	0.57
11	0.83	−0.70	0.94	-	-	-	0.10	−1.27	2.14
12	0.63	−0.69	1.27	4 observation pair (N = 4)			0.46	−0.92	1.26
13	0.75	−0.67	1.12	3 observation pair (N = 3)			-	-	-
14	0.17	−1.63	2.35	-	-	-	-	-	-
15	0.28	−2.44	3.41	-	-	-	-	-	-
16	0.30	−1.27	2.26	-	-	-	-	-	-

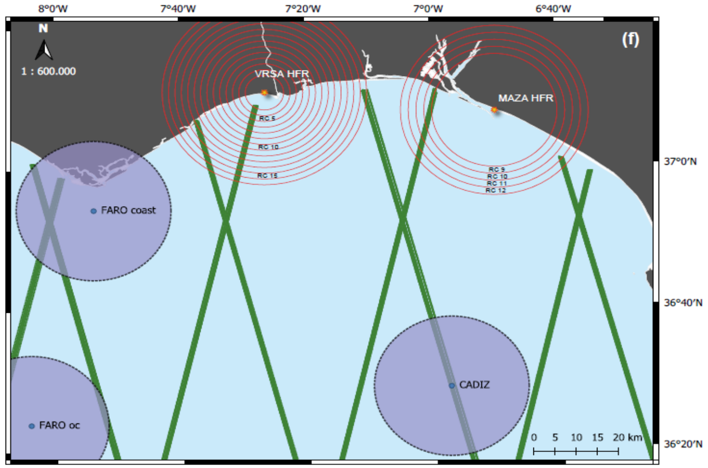


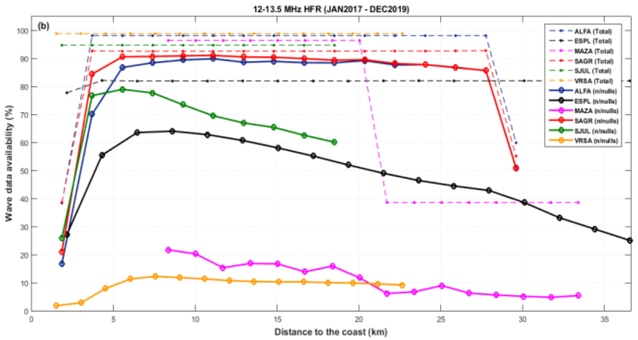
Results and Discussion

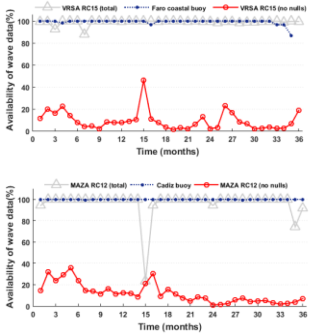
➢ 12-13.5 MHz HFR sites vs. Sentinel-3

	ESPL HFR			VRSA HFR			MAZA HFR		
RC	R	bias (m)	RMSE (m)	R	bias (m)	RMSE (m)	R	bias (m)	RMSE (m)
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	-	2 observation pairs (N = 2)			-	-	-
5	-	-	-	1 observation pair (N = 1)			-	-	-
6	-	-	-	1 observation pair (N = 1)			-	-	-
7	-	-	-	1 observation pair (N = 1)			-	-	-
8	0.33	−0.05	1.31	1 observation pair (N = 1)			-	-	-
9	0.19	−0.30	1.70	-	-	-	0.14	−0.86	1.28
10	0.84	−0.44	0.74	-	-	-	0.36	−0.44	0.57
11	0.83	−0.70	0.94	-	-	-	0.10	−1.27	2.14
12	0.63	−0.69	1.27	4 observation pair (N = 4)			0.46	−0.92	1.26
13	0.75	−0.67	1.12	3 observation pair (N = 3)			-	-	-
14	0.17	−1.63	2.35	-	-	-	-	-	-
15	0.28	−2.44	3.41	-	-	-	-	-	-
16	0.30	−1.27	2.26	-	-	-	-	-	-









Conclusions

- HFR have potential for wave data retrieving in coastal areas, especially in higher sea-states;
- HFR ability in detecting wave height extreme events (Emma & Felix storms – March 2018);
- HFR SWH measurements overestimation;
- Seasonality is present in HFR measurements;
- Lower sea-states (< 2 m) can cause spurious contributions in the directional spectra and contaminate wave measurements;
- Low availability of wave data in HFR sites has contributed to its lower performance;
- Proximity to the HFR sites, as well as their lower maintenance costs, ensures continuous data return (apart from wave data availability);
- HFR presents better temporal/spatial resolutions, rather than buoys;
- HFR covers larger and closest to shoreline areas;
- With appropriate improvements, the gap of wave data along coastal areas can eventually be overcome by HFR wave measurements.

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Article

Evaluation of HF Radar Wave Measurements in Iberian Peninsula by Comparison with Satellite Altimetry and In Situ Wave Buoy Observations

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Thank you for your attention

"True Knowledge exists in knowing that you know nothing."
Sócrates (469-399 b.c.)

QUESTIONS?

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