“Evaluation of Remote Sensing Altimeter and ASAR Wave Data in the East North Atlantic”

4AS JORNADAS DE ENGENHARIA HIDROGRÁFICA

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Lotfi Aouf, Météo-France

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OUTLINE

- **INTRODUCTION**

  - Wave Spectra; Significant wave height; Altimetry and *SAR*

- **RESEARCH DESCRIPTION**

  - Data; Methodology

- **RESULTS AND DISCUSSION**
- **CONCLUSIONS**
- **WORK PLAN (NEAR FUTURE)**

INTRODUCTION

Wave Climate

Measuring Ocean surface waves

***In situ* ~ Buoys** →

- disproportional distributed
- near the coasts of industrialized countries
- located in the north hemisphere
- Time series inhomogeneity

Remote Sensing ***(microwave sensors)***

- ***Radar Altimeters (RA)***
- **Synthetic Aperture Radar (SAR)**

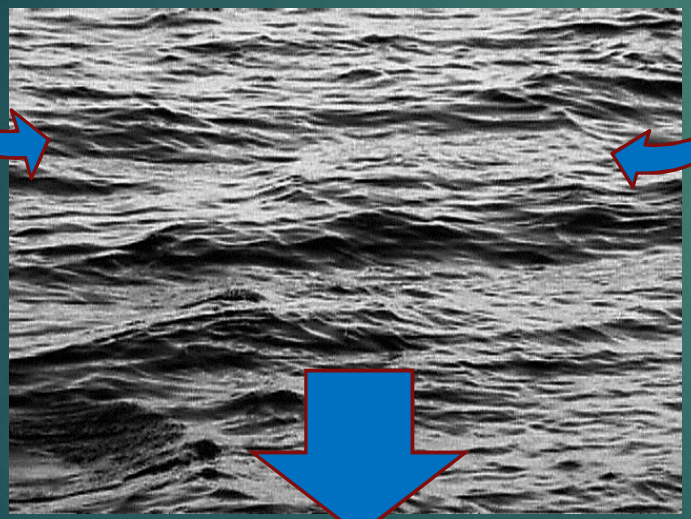
Wave reanalyses and hindcasts

Wave spectra ~ ocean surface 2 D ~ $F(f,\theta)$- buoy observations or SAR measurements

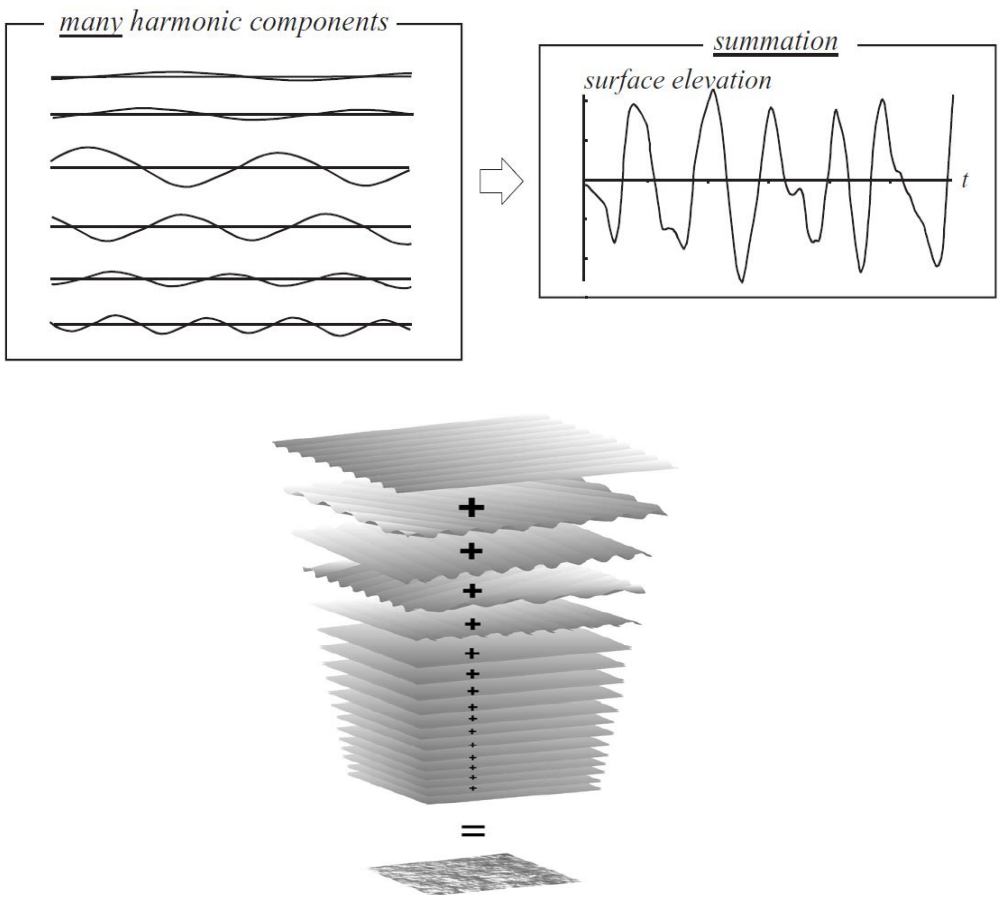
INTRODUCTION

The ocean wave field is the **SUM of many WAVES**

WIND SEA + **SWELL**



OCEAN WAVE SPECTRUM



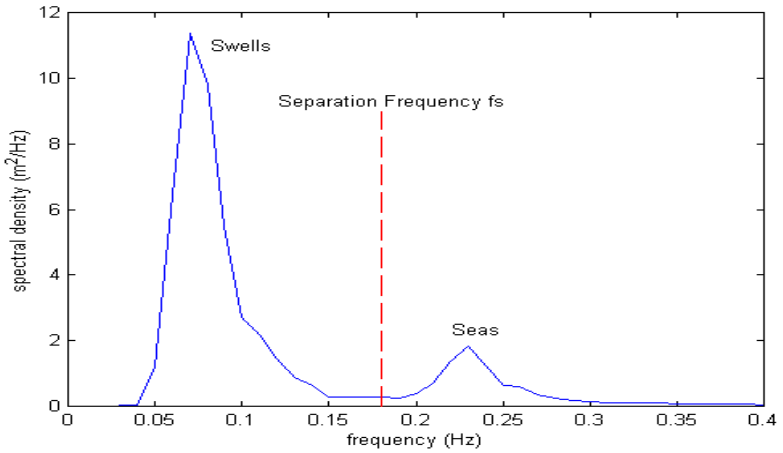
INTRODUCTION

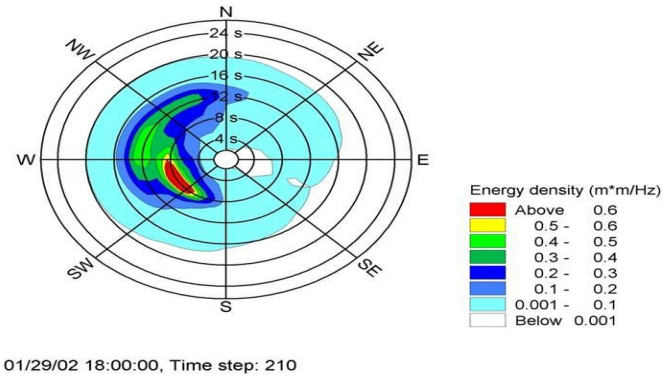
$F\ (f,\theta)$ (Energy spectrum - frequency (f) and propagation direction(θ).

$$m_0 = \iint f^0\, F(f,\theta)\, df\, d\theta$$

(significant wave height) $- \boldsymbol{H_{1/3}} = \mathbf{SWH} = \boldsymbol{H_s}$

$$SWH = 4.04\sqrt{m_0} \sim SWH = 4.04\sqrt{\int F\ (f,\theta)\, df\, d\theta}$$





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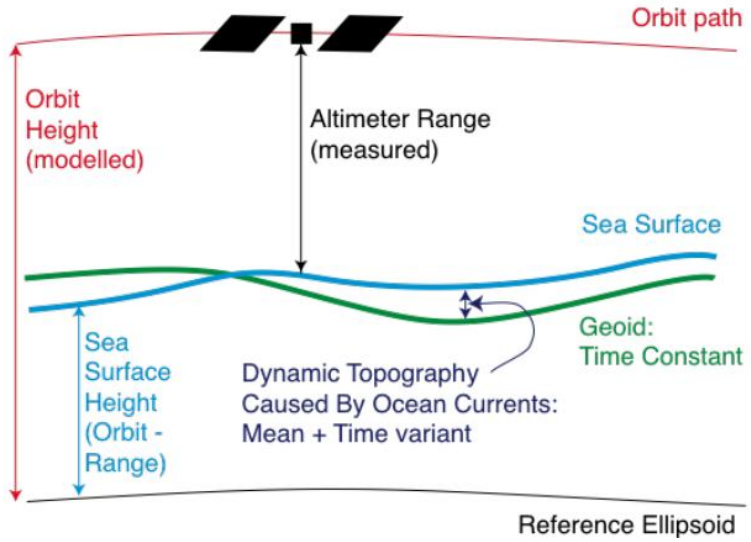
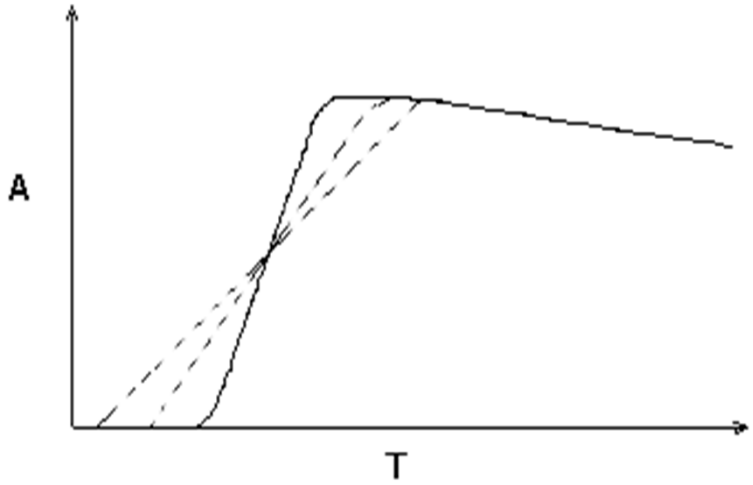
INTRODUCTION

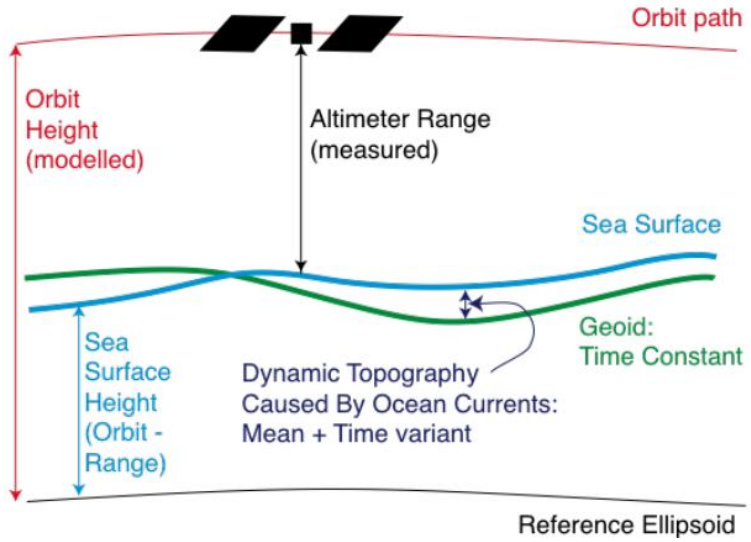
- SWH from altimeters



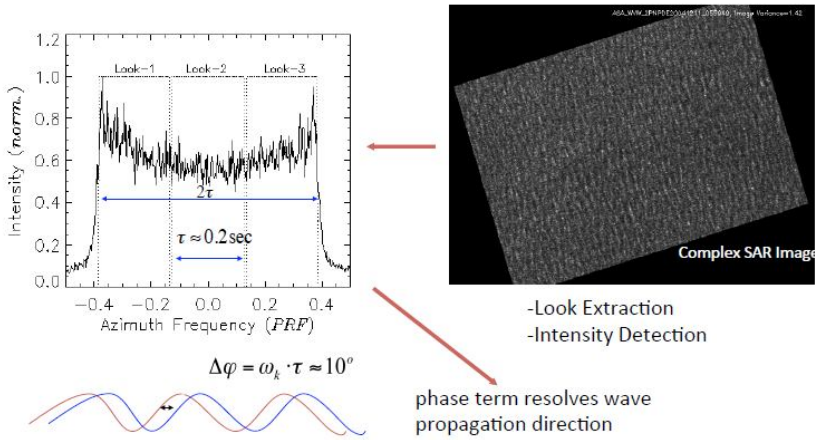


INTRODUCTION

- SWH from altimeters



- SWH from SAR



RESEARCH DESCRIPTION

STUDY

- Significant wave height (SWH) comparisons between remote sensing altimetry and Synthetic Aperture Radar (SAR)measurements and several wave buoy observations, are confronted with the ECMWF* ERA-Interim reanalysis, through a triple-collocation method.
- Different time and space resolutions for the different datasets.
- The buoy positions are the key element for the positioning of all measurements.
- The hour of the satellite overpass are the time key element the time of all observations.

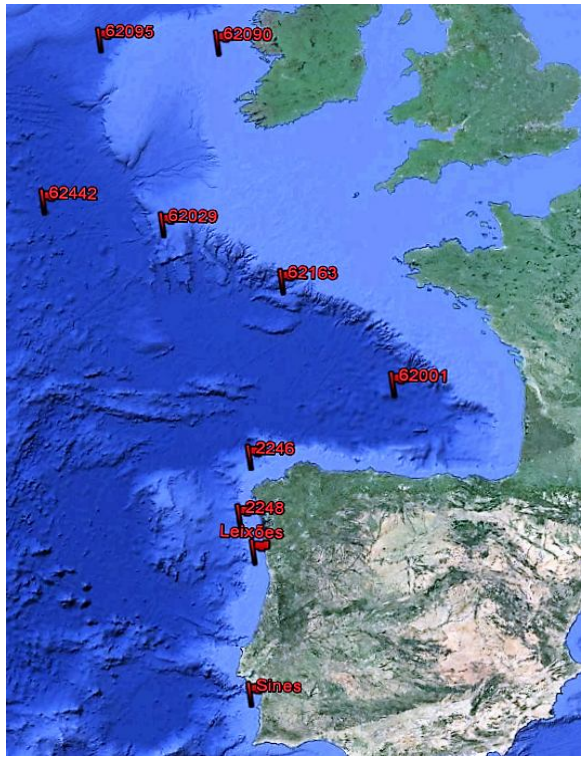
*European Center Medium-Range Weather Forecast

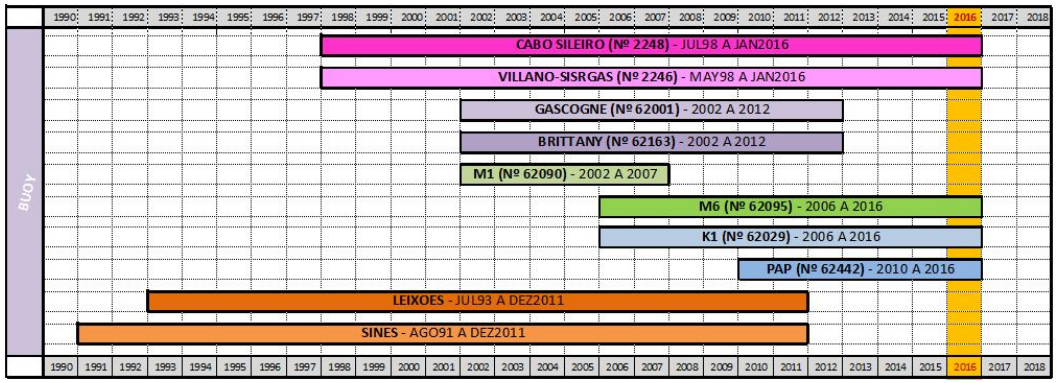
RESEARCH DESCRIPTION

DATA

Buoys observations

- *Puertos del Estado* (buoys 2246 and 2248);
- *UK Met Office* (buoys 62442 and 62029);
- *Météo-France* (buoys 62001 and 62163),
- *Marine Institute-Met Éireann* (buoys 62090 and 62095)
- *Instituto Hidrográfico* (Leixões e Sines buoys).





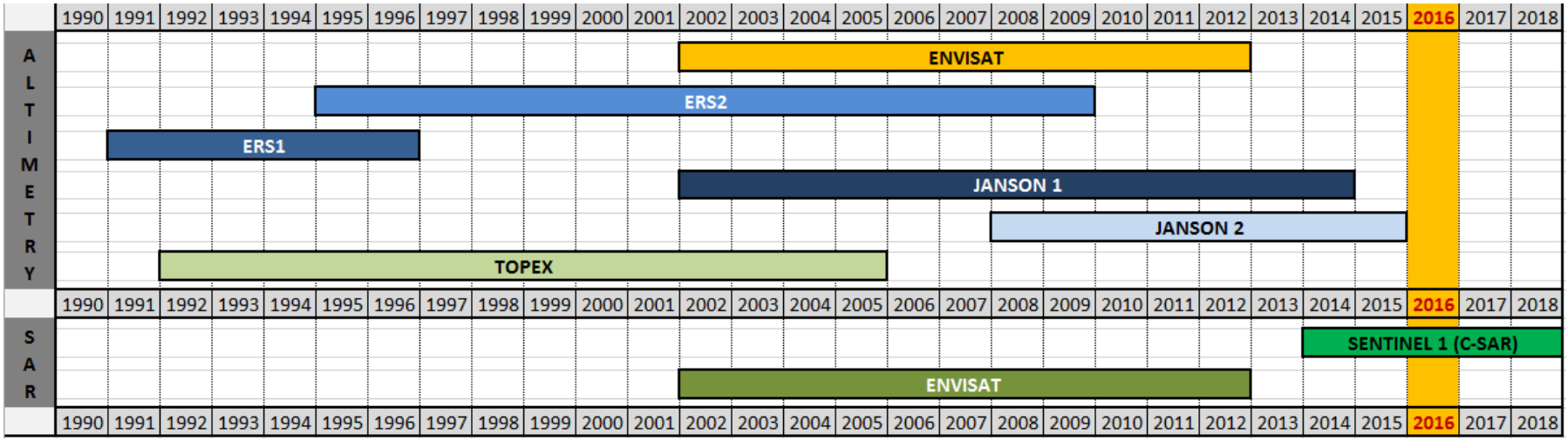
RESEARCH DESCRIPTION

DATA

Satellite measurements*

- **RA** (radar altimeter) – sample spacing ~ 8 Km (every second)
- **SAR** – sample spacing ~ 100 Km *(wave mode*, small images covering 6km x 5km to 10km x 5km and 20km x 20km)

***** Data made available from IFREMER (*GlobWave project)*



RESEARCH DESCRIPTION

DATA

ERA-Interim reanalysis*

- resolution 1º x 1º;
- 6H output;
- 2D wave energy spectrum F(f, θ);
- Altimetry wave data assimilation;
- No wave buoy data assimilated.

* Produced by European Center for Medium-Range Weather Forecasts (ECMWF).

Satellite	Data (period)
ERS-1	01 Aug 1991 to 03 Jun 1996
ERS-2	03 May 1995 to 21 Jul 2003
ENVISAT	21 Jul 2003 to 2012
Jason-1	20 Oct 2003 to 2014
Jason-2	01 Feb 2010 to 2015

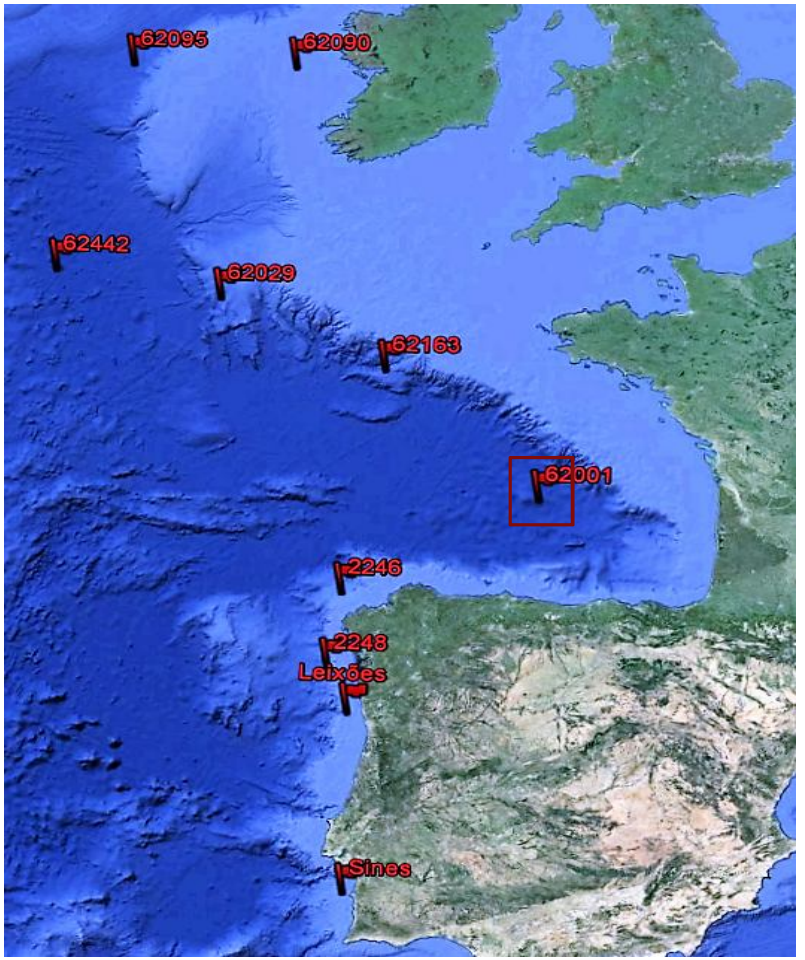
Assimilation of altimeter data in the ERA-Interim wave analysis.

RESEARCH DESCRIPTION

DATA COLOCATION METHOD

- Positioning – buoy position as key element
- Time – satellite overpass hour as key element

- BOX 1º (LAT) x 1º (LON)

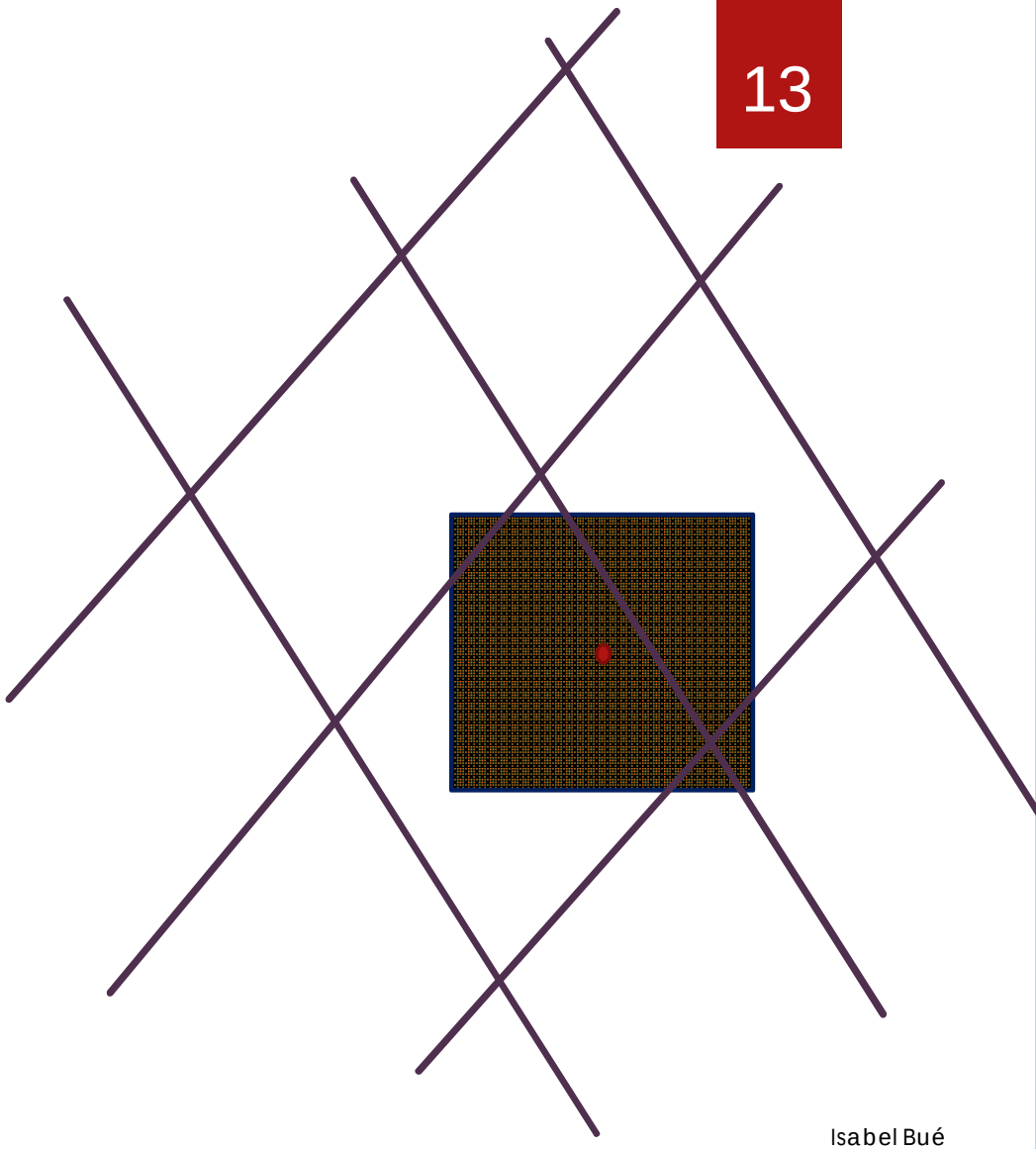


RESEARCH DESCRIPTION

DATA COLOCATION METHOD

- BOX 1º (LAT) x 1º (LON)
- RA – sample spacing ~ 8 Km (every second)
- SAR – sample spacing ~ 100 Km

(wave mode, small images covering 6km x 5km to 10km x 5km)



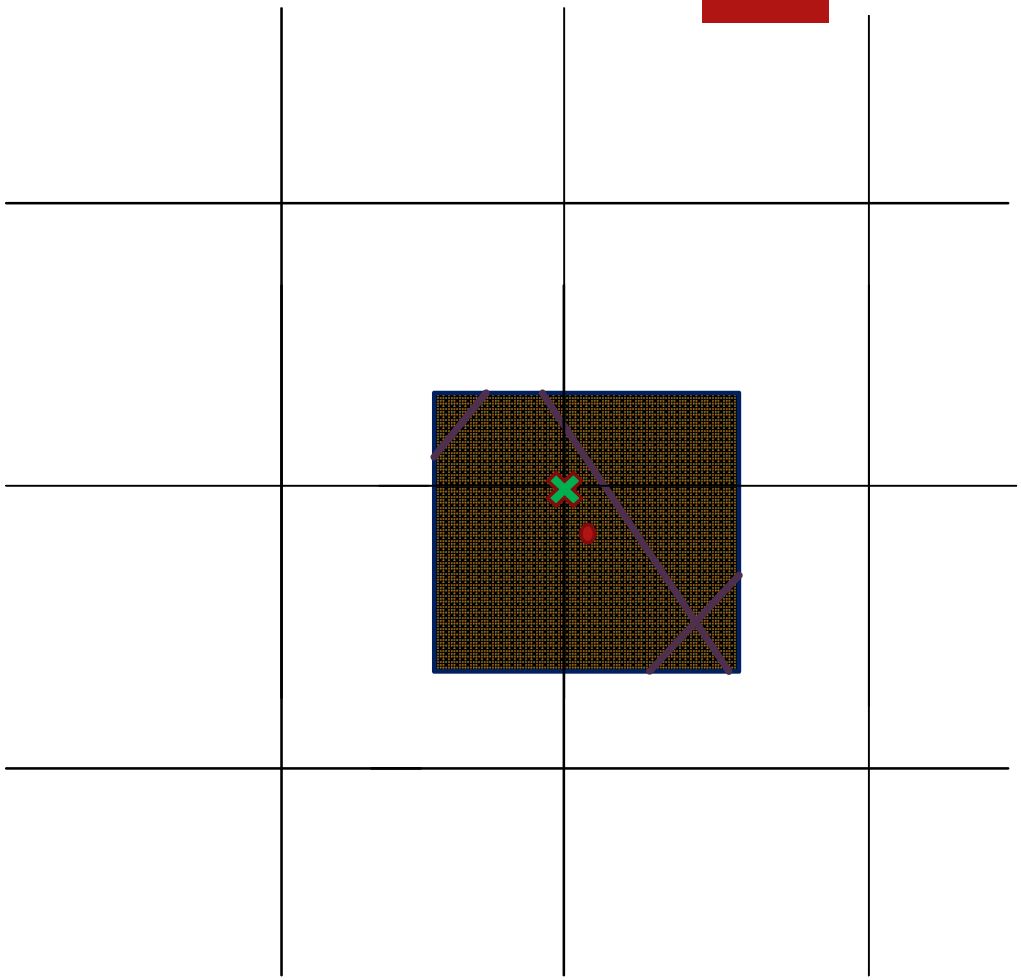
RESEARCH DESCRIPTION

DATA COLOCATION METHOD

- Positioning – buoy position as key element
- Time – satellite overpass hour as key element

- Time lagging
  - Buoy *versus* sensor measurements ~ 30 minutes
  - ERA-Interim *versus* satellite overpass > 30 minutes (but < 3 H)

* ERA-Interim reanalysis output at synoptic hours



RESEARCH DESCRIPTION

STATISTICS

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

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

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

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

*Standard error metric statistics: BIAS; root mean square error (RMSE); linear correlation coefficient (R) and scatter index (SI).
N - number data pairs; ***b*** – buoy observation ; ***s*** – satellite measurements (or model); overbar – mean value.

RESULTS AND DISCUSSION

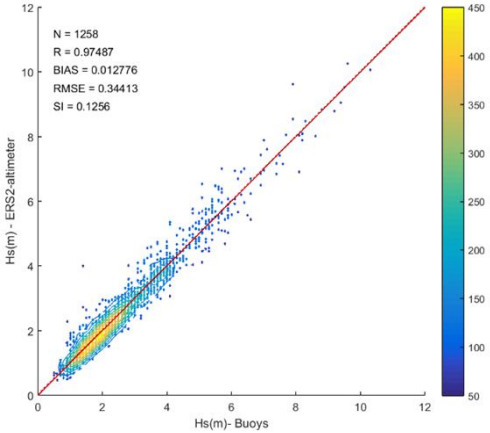
Altimeter versus buoy SWH (Leixões and Sines buoys not included).

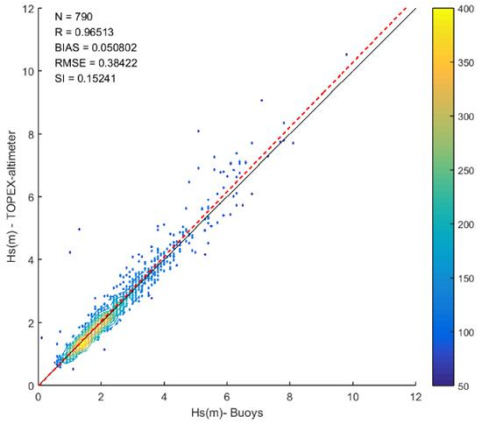
Satellite (altimeter)	N	R	Bias (m)	RMSE (m)	SI
ERS2 (1995-2009)	1258	0.9749	0.0128	0.3441	0.1256
TOPEX (1992-2005)	790	0.9651	0.0508	0.3842	0.1524
ENVISAT (2002-2012)	1607	0.9597	0.0254	0.4203	0.1536
JANSON1 (2002-2014)	2097	0.9763	0.1027	0.3509	0.1208
JANSON2 (2008-2015)	1519	0.9774	0.0457	0.3197	0.1126

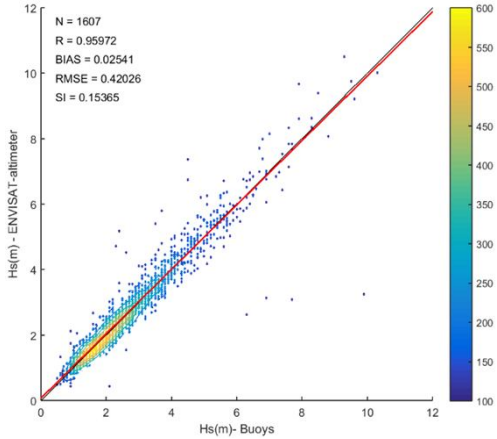
Statistics results – all buoy data (exception made for Leixões and Sines buoys) compared with each Altimeter sensor.

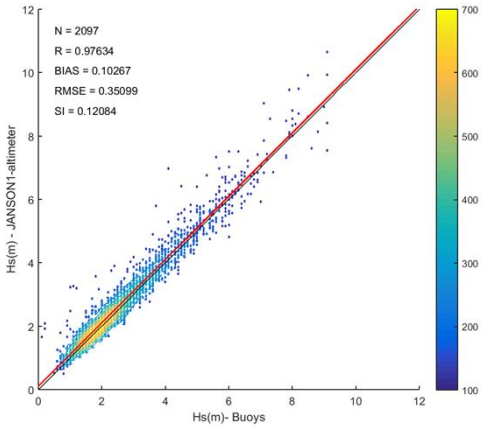
RESULTS AND DISCUSSION

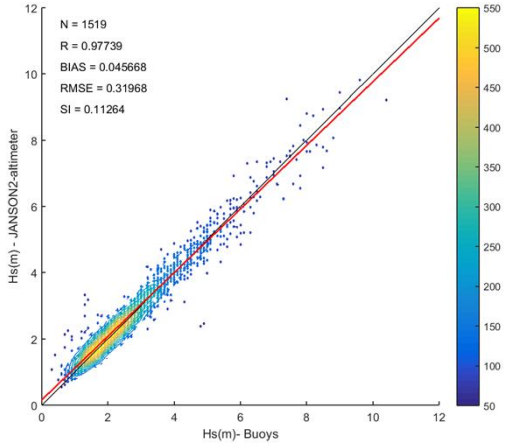
- Altimeter *vs.* buoy SWH* (Leixões and Sines buoys not included).









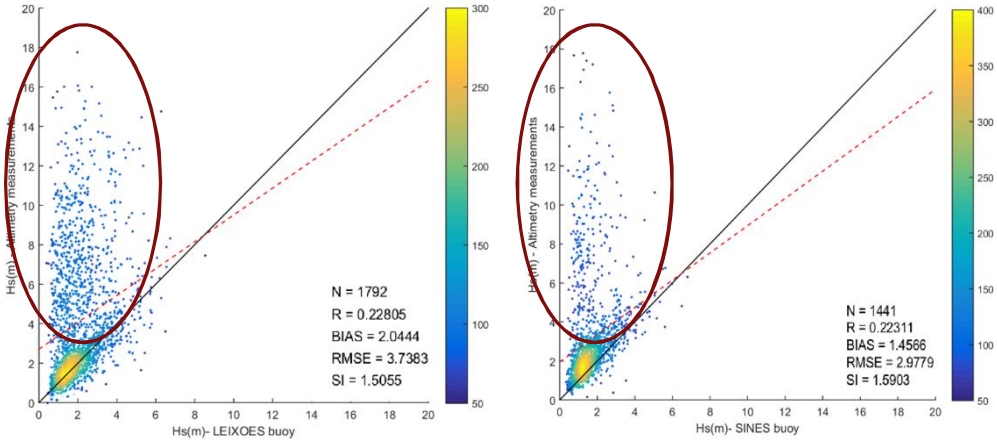


* All buoys data compared with each Altimeter sensor

RESULTS AND DISCUSSION

Altimeter *versus* Leixões and Sines buoy SWH measurements.

* All altimeter sensors compared with Leixões and Sines buoy SWH



Scatter plots – Altimeter vs. Leixões and Sines buoy SWH.

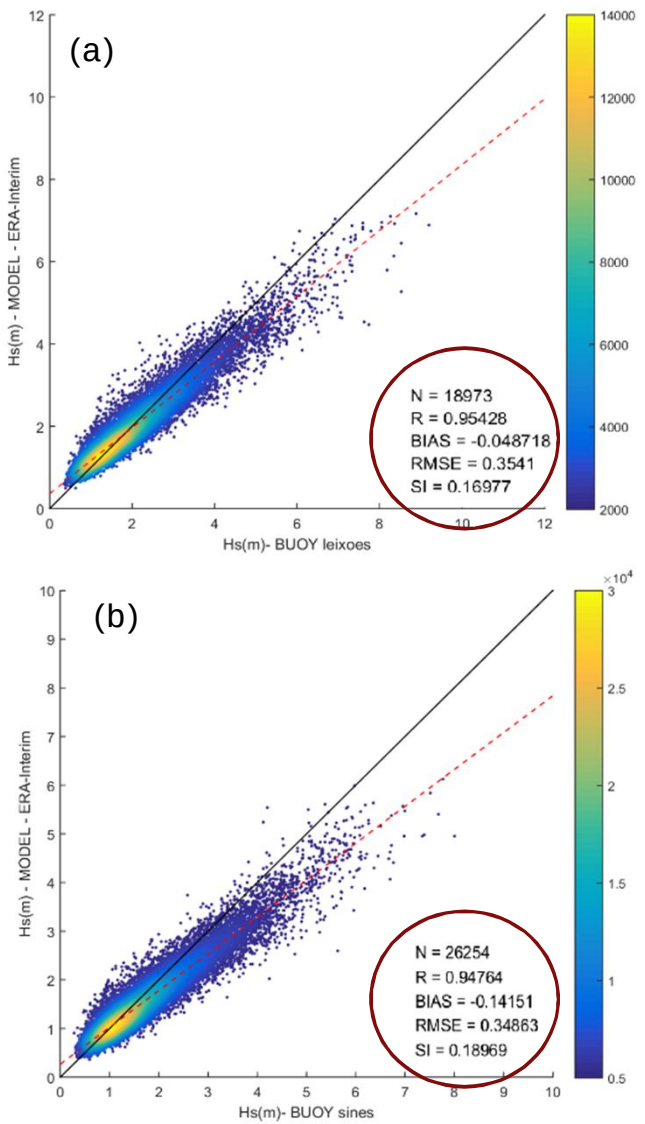
Satellite (altimeter)	N		R		Bias (m)		RMSE (m)		SI	
	Leixões	Sines	Leixões	Sines	Leixões	Sines	Leixões	Sines	Leixões	Sines
ERS1 (1991-1996)	45	54	0.755	0.298	-0.082	1.283	0.974	2.847	0.345	1.515
ERS2 (1995-2009)	269	293	0.489	0.164	0.529	2.088	1.379	4.573	0.645	2.525
TOPEX (1992-2005)	445	384	0.255	0.744	2.690	0.699	3.654	1.015	1.224	0.437
ENVISAT (2002-2012)	324	315			2.546	3.425	4.822	4.766	2.068	2.154
JANSON1 (2002-2014)	457	309	0.289	0.575	0.859	0.702	2.654	1.083	1.161	0.497
JANSON2 (2008-2015)	234	110	0.197	0.772	4.678	1.102	5.724	1.309	1.545	0.426

Statistics – Altimeter vs. Leixões and Sines buoy SWH.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

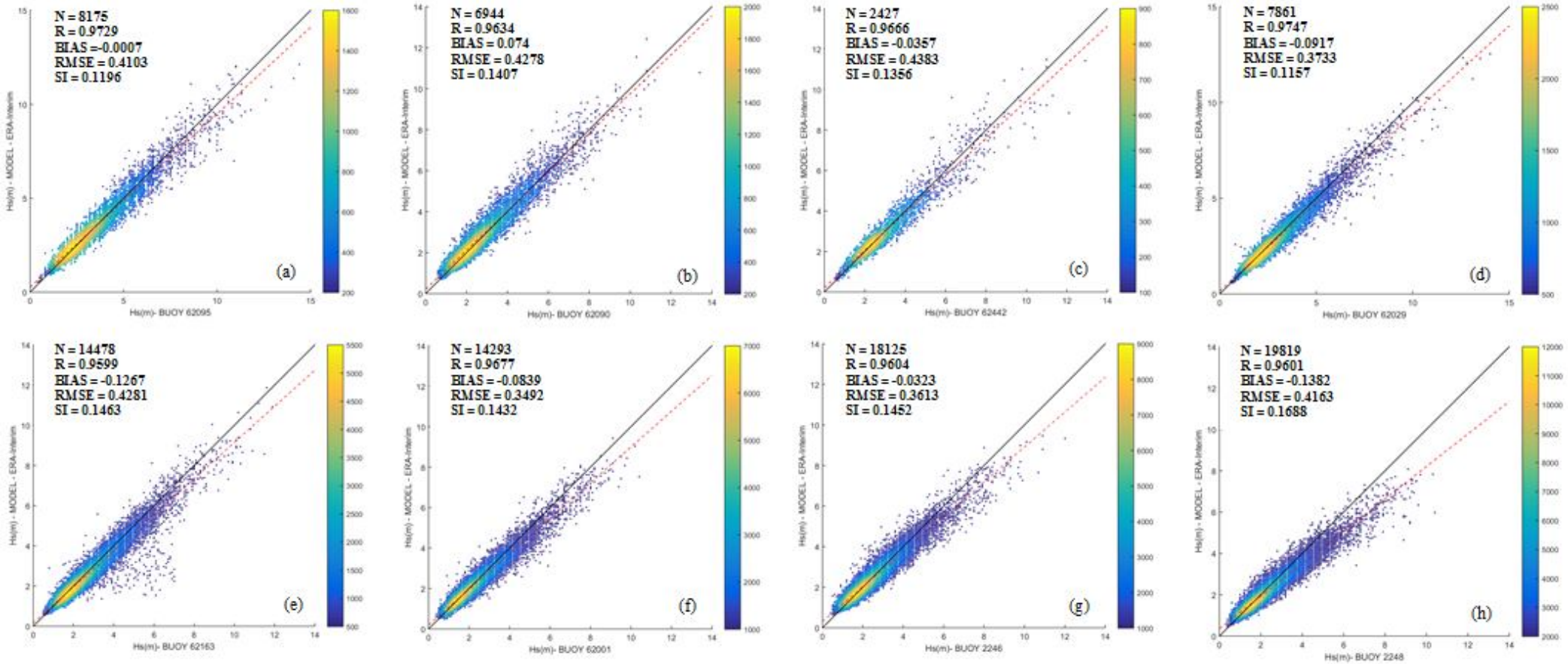
- ERA-Interim *versus* Leixões and Sines buoy SWH.



Scatter plots: (a) Leixões buoy and (b) Sines buoy.

RESULTS AND DISCUSSION

- ERA-Interim *vs.* buoy SWH* (Leixões and Sines buoys not included)



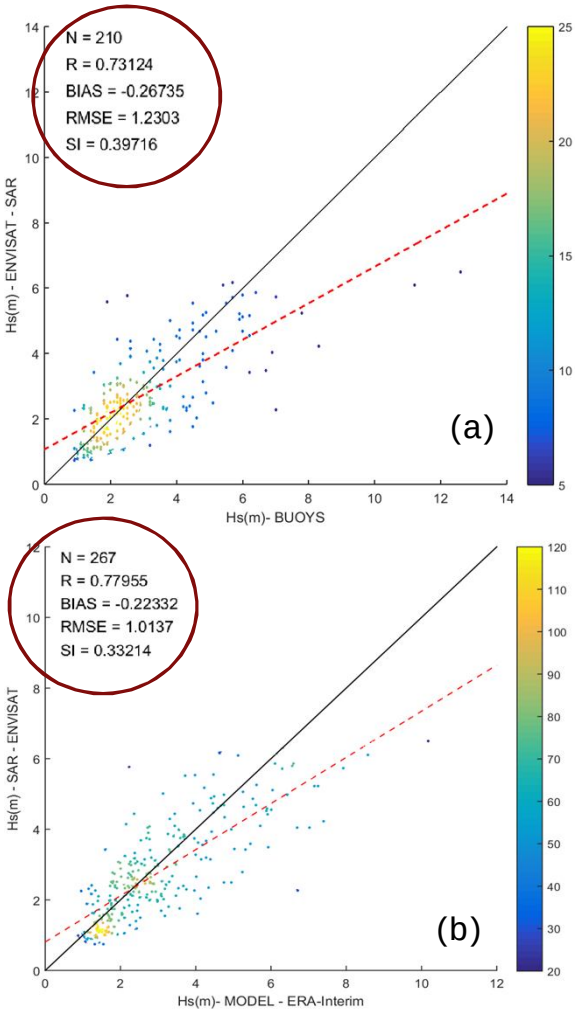
* Scatter plots: : (a) 62095 buoy, (b) 62090 buoy, (c) 62442 buoy, (d) 62029 buoy, (e) 62163 buoy, (f) 62001 buoy, (g) 2246 buoy and (h) 2248 buoy

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

- SAR *versus* buoys SWH; and
- SAR *versus* ERA-Interim.

* SAR data only from ENVISAT mission
** All buoy observations *vs.* SAR



Scatter plots: (a) SAR versus buoys and (b) SAR versus ERA-Interim.

CONCLUSIONS

- Altimeter and SAR wave observations (SWH) were compared with buoy observations and reanalysis data. The buoy positions were the center of the 1ºx1º sampling boxes.
- The comparison between the altimeter SWH and the in situ measurements showed very good agreement, exception made for Leixões and Sines buoys
  - **Altimetry low performance in coastal areas.**
- Despite the fact that SAR SWH neglects the high frequency waves, these wave estimations showed some agreement with buoy observations that would most probably be better if only the swell SWH had been compared
  - **Complex wave spectra extraction algorithms**.

FUTURE WORK

- Compare the Sentinel-1 C-SAR SWH measurements with buoy observations, and assess the goodness of incorporating SAR spectra into modeled wave spectra.

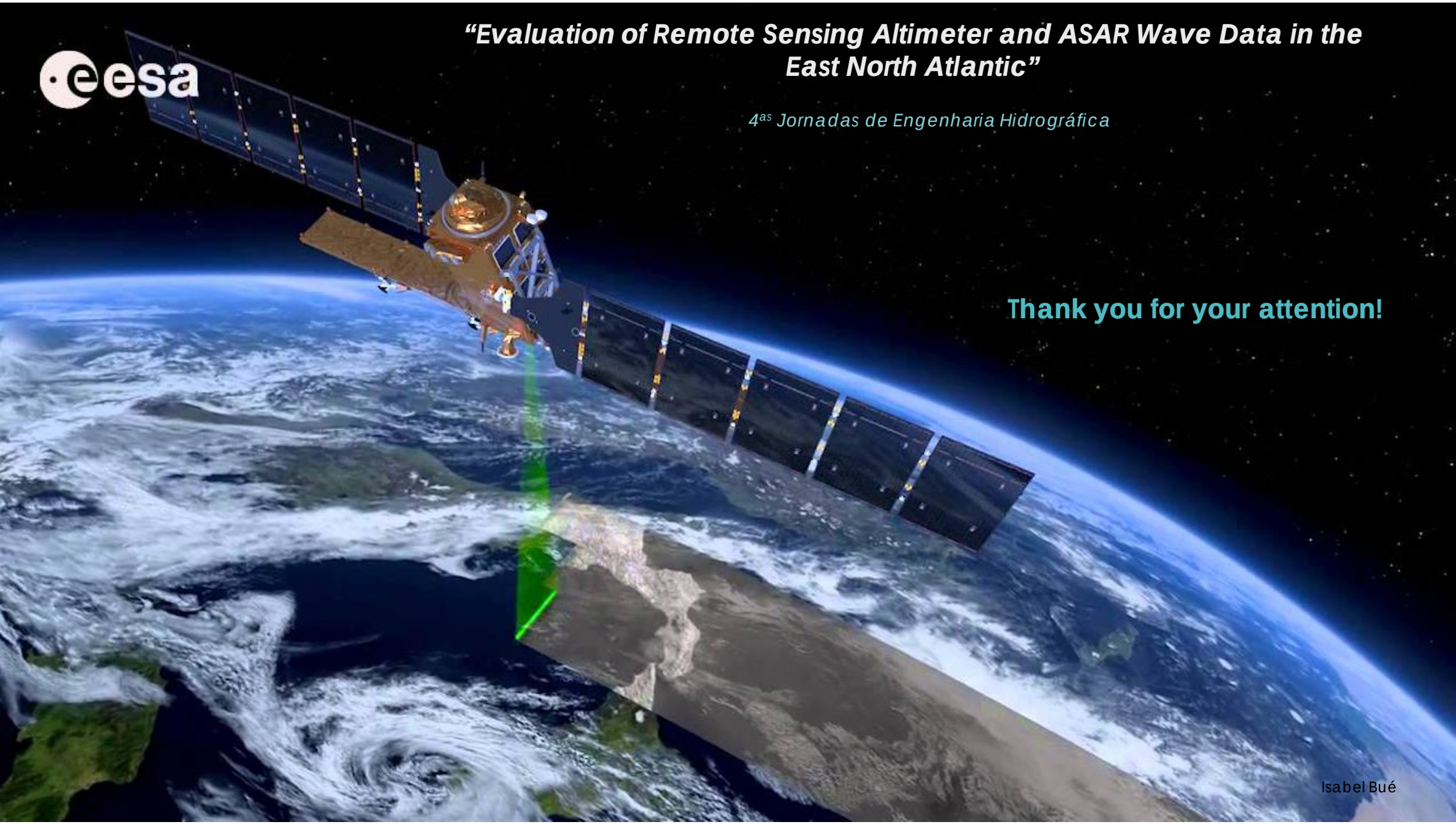
  - Altimeter, SAR, and reanalysis wave data will be collocated into buoy positions (triple-collocation method)

- **Investigation - main goals**

  - SWH altimeter *versus* buoys;
  - SWH swell SAR *versus* buoys;
  - SWH ERA-Interim *versus* buoys and SAR;
  - SAR spectra *incorporated* in ERA-Interim
    - ERA-Interim spectrum "corrected";
    - SWH (re)calculated from ERA-Interim;
    - "new" SWH compared again with buoys.

FUTURE WORK (short term)

- Apply the triple-collocation method to estimate the absolute errors of the different datasets.
- Optimal interpolation of 2D SAR wave spectra with ERA-Interim spectra (the re-assimilation post-processing process).
- The SWH computed from the corrected spectra will further be collocated and compared with buoy observations and altimeter SWH measurements, as well as with the original ERA-Interim SWH, to assess the goodness of the spectral correction model.
- Follow this method for existing SAR observations (used in this study) but also with data soon to be available from the C-SAR *Sentinel-1* and *Sentinel-3 Radar Altimeter*.



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Thank you for your attention!