



# Starting with the coastal bathymetry :

3D mapping, changes in seabed elevation and sediment budgets

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# An exhaustive review of end-users' requests

## WHO

**FINAL END USERS**

**Portugal:** apa (agência portuguesa do ambiente), Mira (Câmara Municipal), figueira da foz. para todos, ALCOBAÇA (De lugar ao Amor), município de Vagos, MARINHA GRANDE (A NOSSA IDENTIDADE).

**France:** REGION SUD (PROVENCE ALPES CÔTE D'AZUR), République Française (Préfecture du Var, Ministère de la Transition Écologique et Solidaire), Littoral Aquitain (Groupe d'Intérêt Public), Conservatoire du littoral.

**Greece:** HELLENIC REPUBLIC (REGION OF EAST MACEDONIA & THRACE), Φορέας διαχείρισης ΔΕΛΤΑ ΝΕΣΤΟΥ ΒΙΣΤΩΝΙΔΑΣ-ΙΣΜΑΡΙΔΑΣ ΚΑΙ ΚΑΛΟΤΟΥ (Delta Nestos Lakes Vistonida-Ismarida Management: Body), Περιφέρεια Πελοποννήσου (ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ).

**Romania:** COSMOMAR, ROMANIA (INSTITUTUL NAȚIONAL DE MONITORIZARE ȘI PROTECȚIE A APĂRII), APELE ROMÂNE (Administrația Bazinală de Apă Dobrogea-Litoral), SFÂNTU GHEORGHE (MARINE AND FLUVIAL RESEARCH STATION).

## HOW

	Revisit	Horizontal accuracy	Vertical accuracy
Portugal	1/year; seasonally (end summer/winter); post-storms	10 m	n/a
France	2 – 3/year	5 – 10 m	0.2 – 1 m
Greece	n/a	10 m	n/a
Romania	Monthly to every 2 years	10 m	n/a

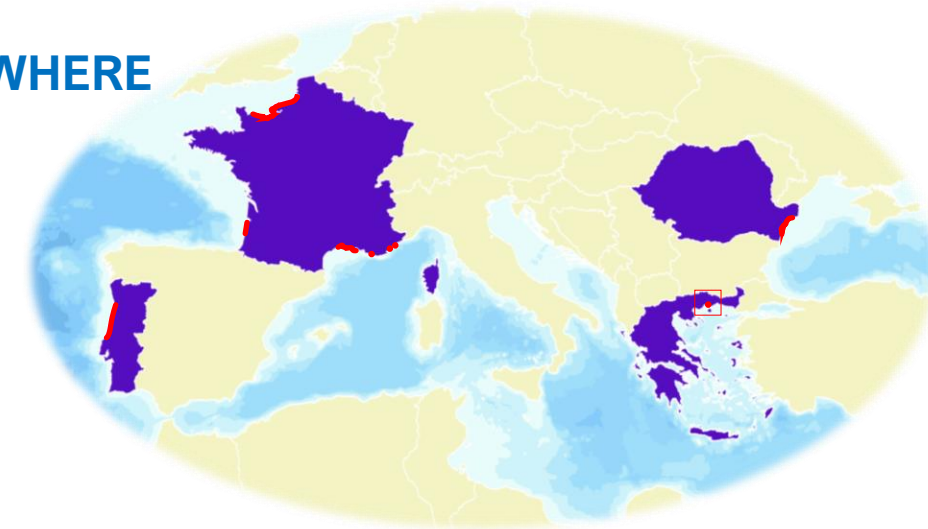
## WHY

Monitor the bathymetry as the main indicator of variations in the near-shore geomorphology due to wave climate and/or antropogenic activities (e.g., dredging operations).

High-frequency monitoring of major storm events.

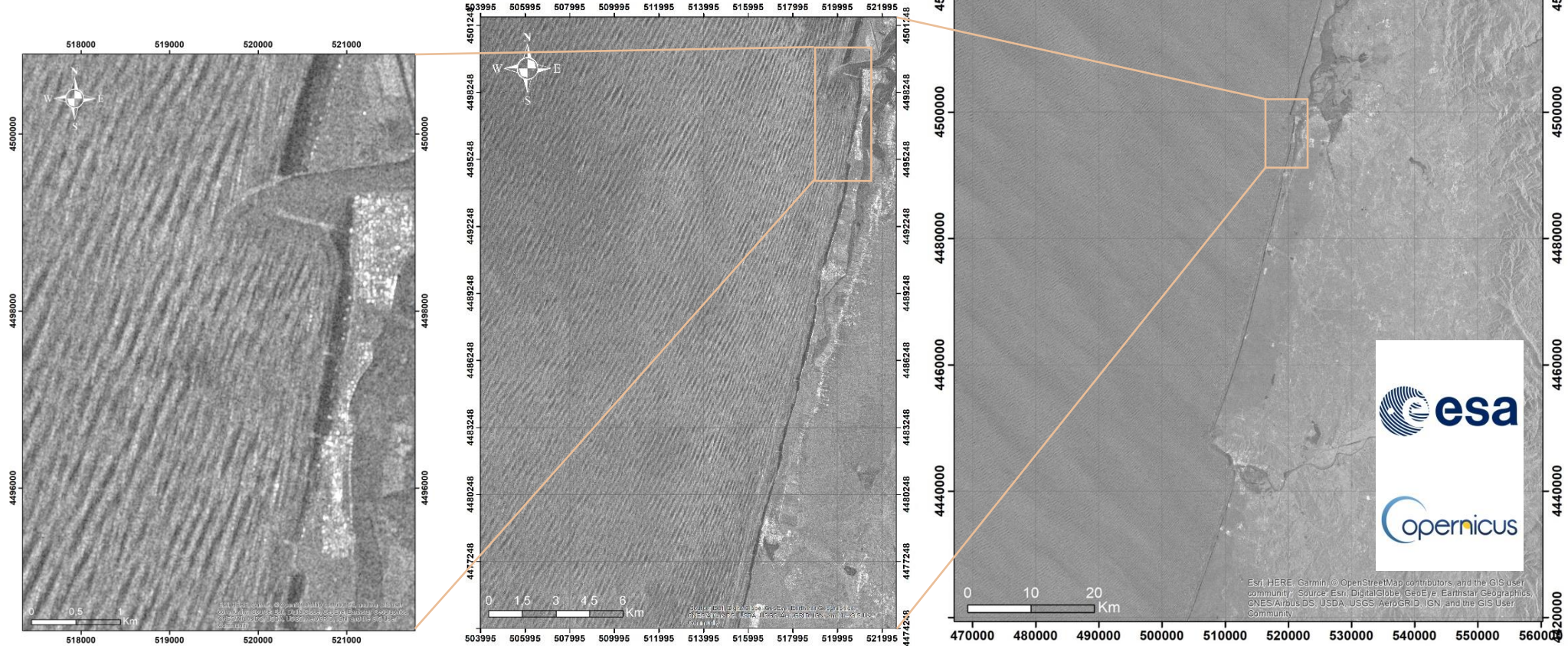
Need a post-storm emergency mapping of the bathymetry to management applications as harbour security.

## WHERE





Open-source spatial data:  
example of a Sentinel-1  
image with visible **swell** in  
the coastal stretch Aveiro –  
Figueira Foz (Portugal) –  
30/01/2015



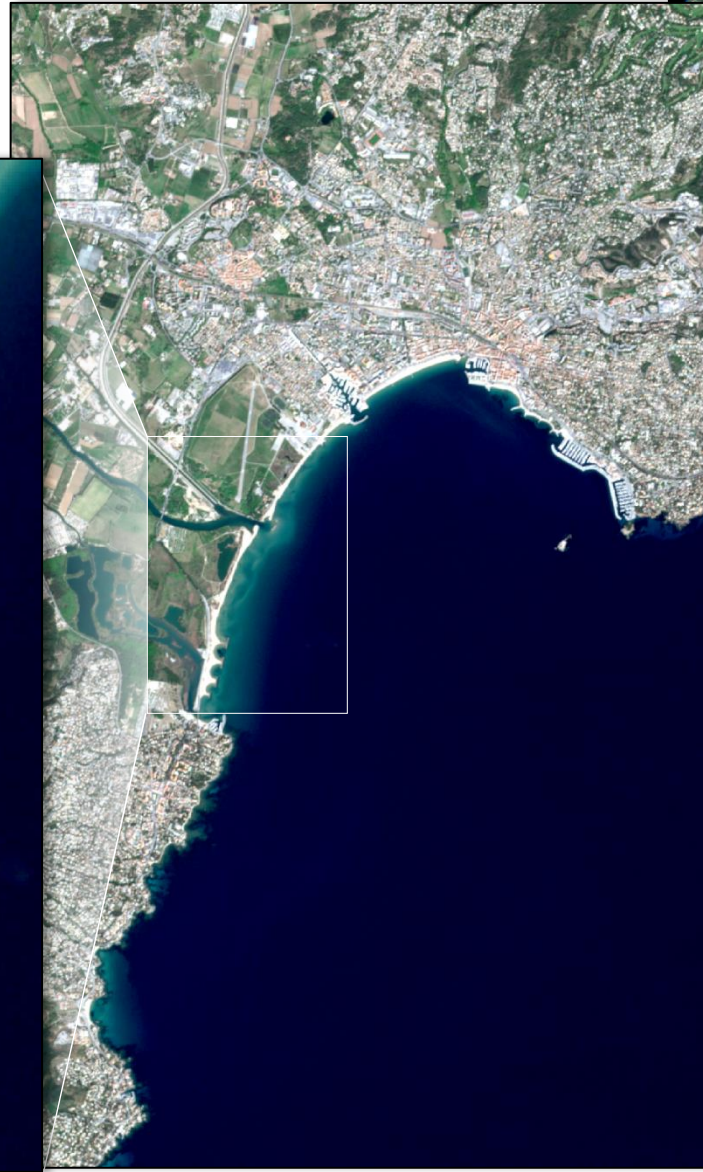
Visually not so obvious to derive  
**bathymetry** ...



Open-source spatial data:  
example of a Sentinel-2  
image with visible **sand**  
**morphologies** in the PACA  
region (France) – 11/04/2020



21/01/2021



Space for Shore - Final Meeting



# Method for extracting from radar satellite imagery

## Spectral analysis:

- Fourier Fast Transform – FFT (Pereira et al., 2019)
- Wavelet Transform – WT (Santos et al., 2020)



Wavelength and  
wave direction

## Linear Wave Theory (Airy's Theory)



Water depth  
(tidal correction)

Pereira, P.; Baptista, P.; Cunha, T.; Silva, P.A.; Romão, S.; Lafon, V. Estimation of the Nearshore Bathymetry from High Temporal Resolution Sentinel-1A C-Band SAR Data—A Case Study. *Remote Sens. Environ.* **2019**, *223*, 166–178.

Santos, D., Abreu, T., Silva, P.A., Baptista, P. Estimation of Coastal Bathymetry Using Wavelets. *J. Mar. Sci. Eng.* **2020**, *8*(10), 772.



# Method for extracting from optical satellite imagery

## Bathymetry extraction

--> Quasi-analytical model based on existing technics

Lee, Z., Carder, K. L., Mobley, C. D., Steward, R. G., & Patch, J. S. (1998). Hyperspectral remote sensing for shallow waters. I. A semianalytical model. *Applied optics*, 37(27), 6329-6338.

### TOSCA MORITO



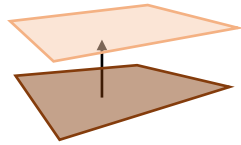
Capo, S., Lubac, B., Marieu, V., Robinet, A., Bru, D., & Bonneton, P. (2014). Assessment of the decadal morphodynamic evolution of a mixed energy inlet using ocean color remote sensing. *Ocean Dynamics*, 64(10), 1517-1530.



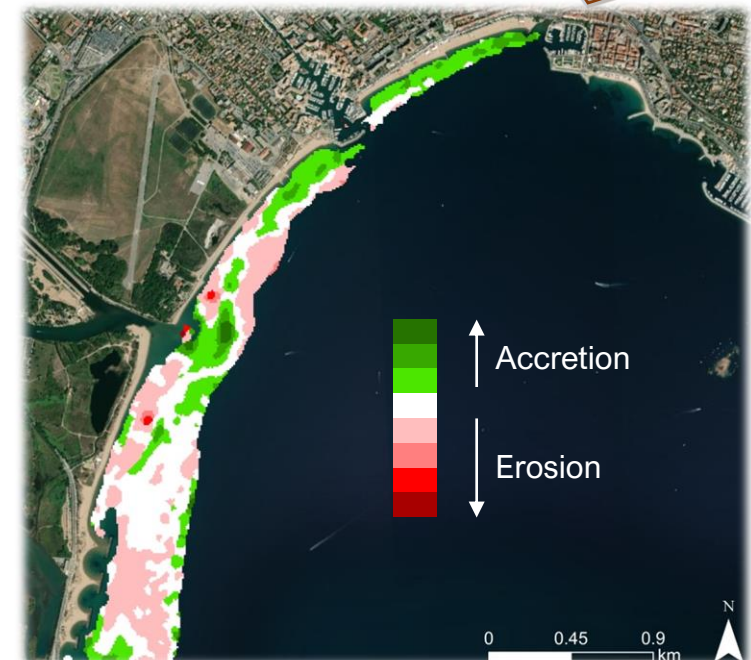
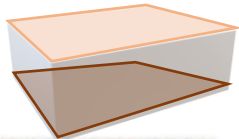
## Change analysis

Differences between 2 dates :

- Vertical change measurement in [m]

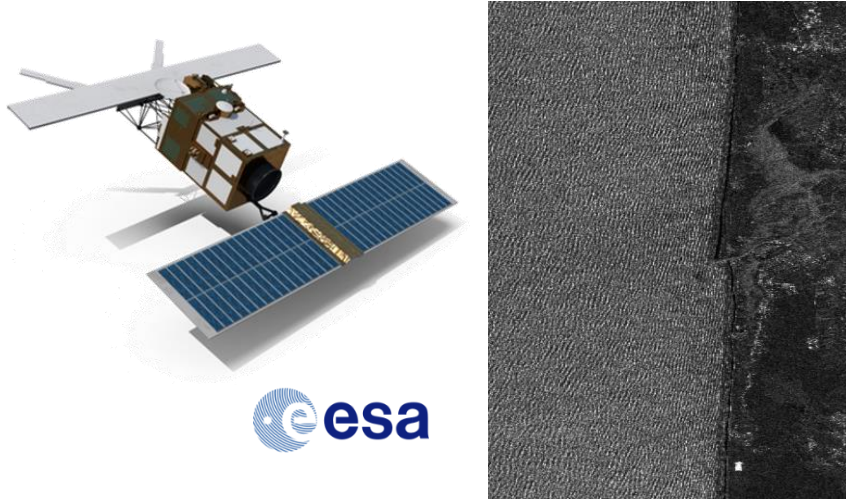


- Volume change estimation in [m<sup>3</sup>]

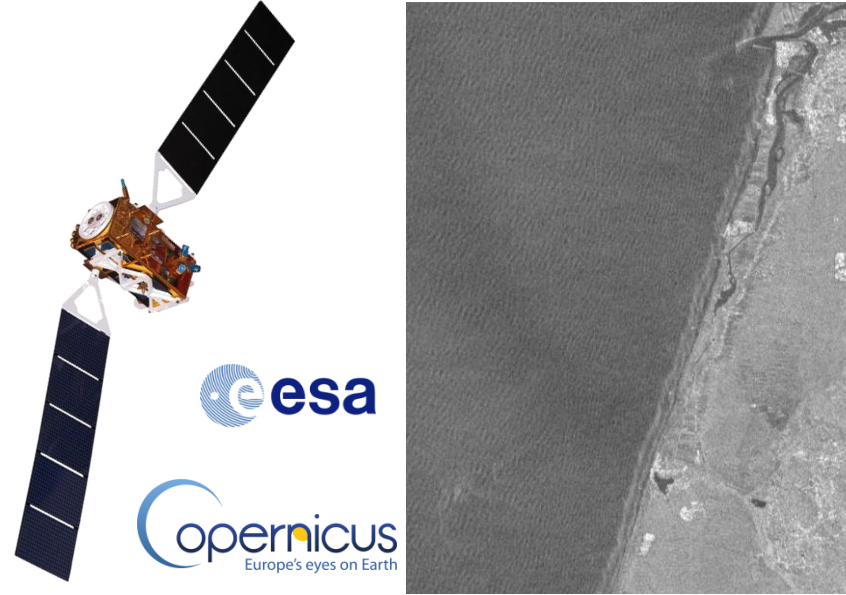


# Databases exploited

ERS-1 (resolution 12.5 m)



Sentinel-1 (resolution 10 m)



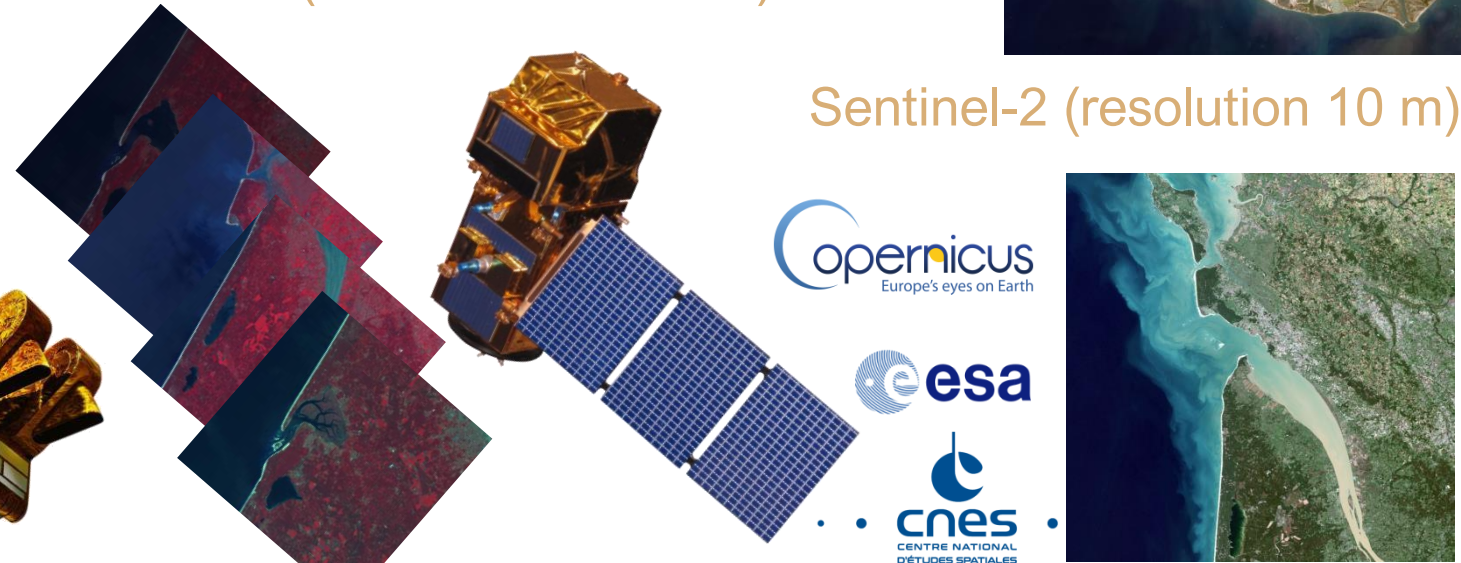
Landsat 8 (resolution 30 m)



SPOT-1/2/3/4/5 (resolution 10-20 m)



Sentinel-2 (resolution 10 m)



21/01/2021

AIRBUS  
DEFENCE & SPACE

Space for Shore - Final Meeting



# Demonstration areas and periods



## PORTUGAL

### Aveiro Region

~ 647 km<sup>2</sup>

2011 & 2015-2020

1/yr (Winter)

13 products

### Mondego Region

~20 km<sup>2</sup>

2015-2020

1/yr (Winter)

12 products

### Figueira Foz Region

~ 259 km<sup>2</sup>

2015-2020

1/yr (Winter)

12 products

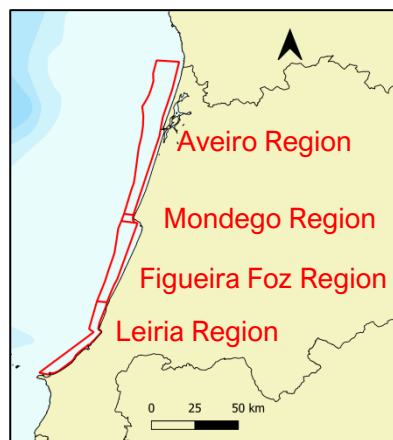
### Leiria Region

~ 113 km<sup>2</sup>

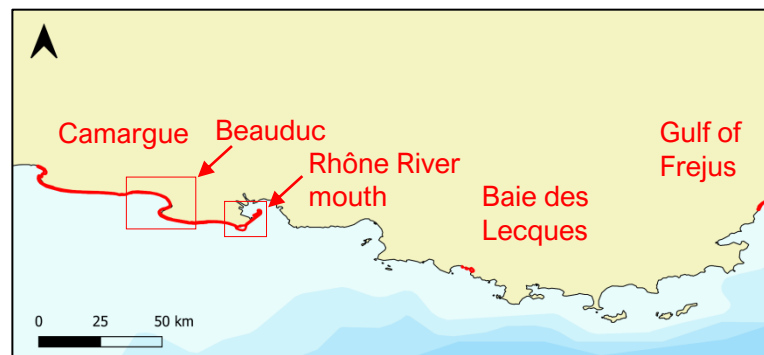
2015-2020

1/yr (Winter)

12 products



## FRANCE



### PACA Region

#### Camargue

~ 41 km<sup>2</sup>

2013-2020

1/yr (Summer)

17 products

#### Beauduc

~11 km<sup>2</sup>

2013-2020

2/yr (seasonal)

25 products

#### Rhône River mouth

~15 km<sup>2</sup>

1993-2020

1/yr (Summer)

23 products

#### Baie des Lecques

~ 2 km<sup>2</sup>

2015-2020

2/yr (seasonal)

10 products

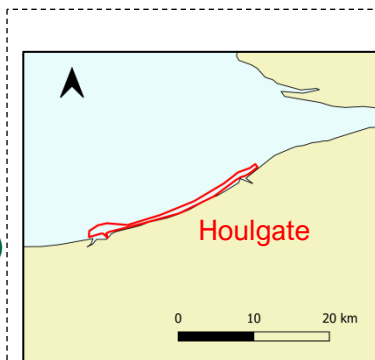
#### Gulf of Frejus

~ 2 km<sup>2</sup>

2015-2020

2/yr (seasonal)

28 products



## New Aquitaine Region

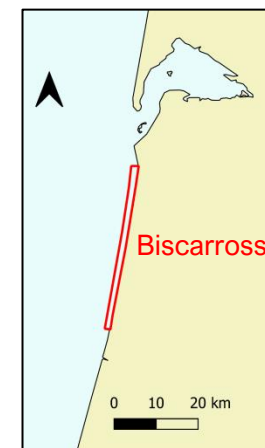
### Biscarrosse

~ 41 km<sup>2</sup>

2017-2018

1/yr (Summer)

4 products



## Normandy Region

### Houlgate

~ 10 km<sup>2</sup>

2015-2020

1/yr (Summer)

11 products



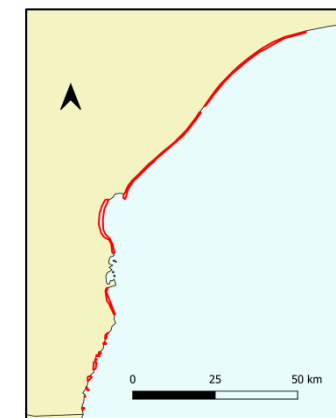
## ROMANIA

~ 47 km<sup>2</sup>

2015-2020

1/yr (Summer)

9 products



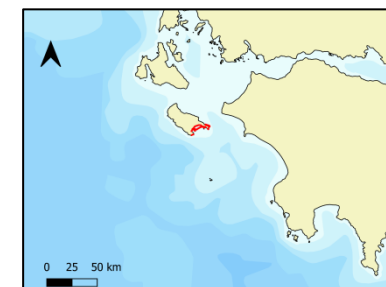
## GREECE

~ 25 km<sup>2</sup>

2020

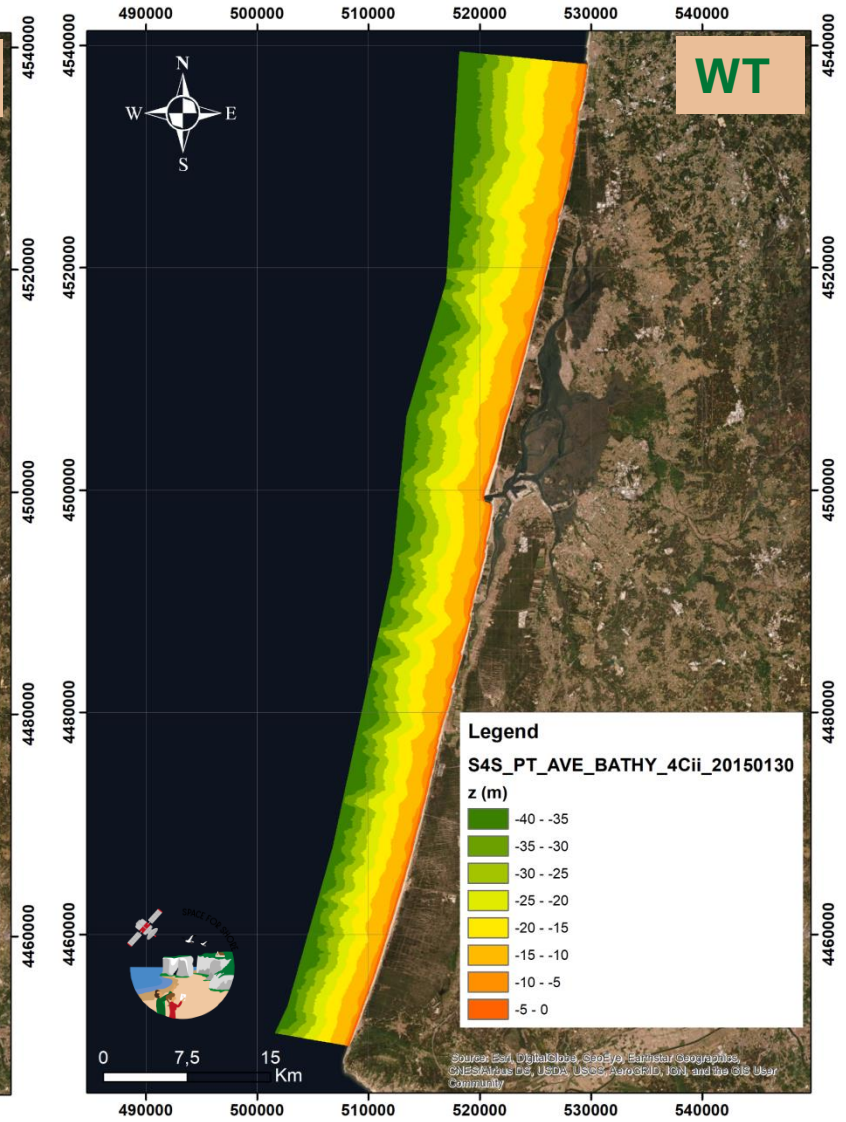
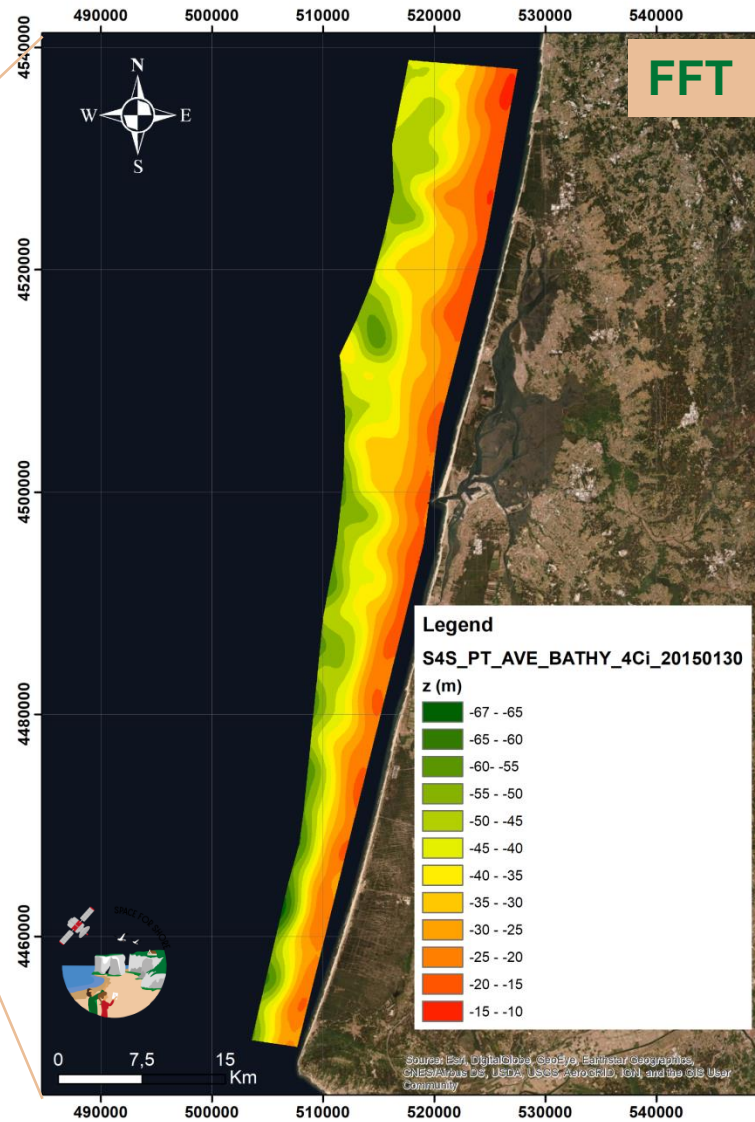
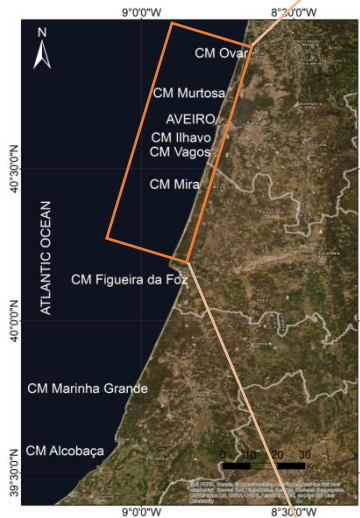
1/yr

1 product



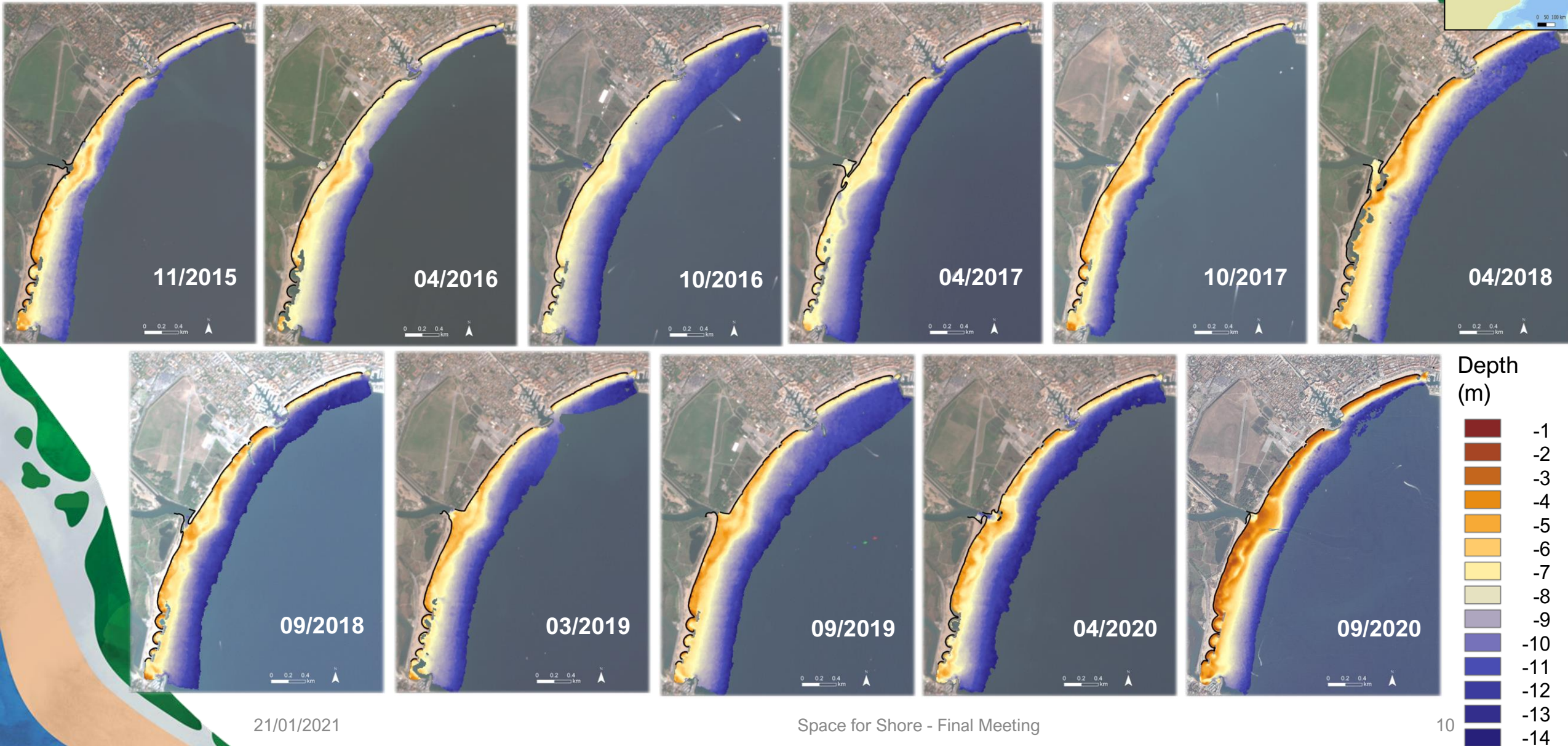


# Product display from radar data and spectral analysis





# Product display from optical data and semi-analytical model

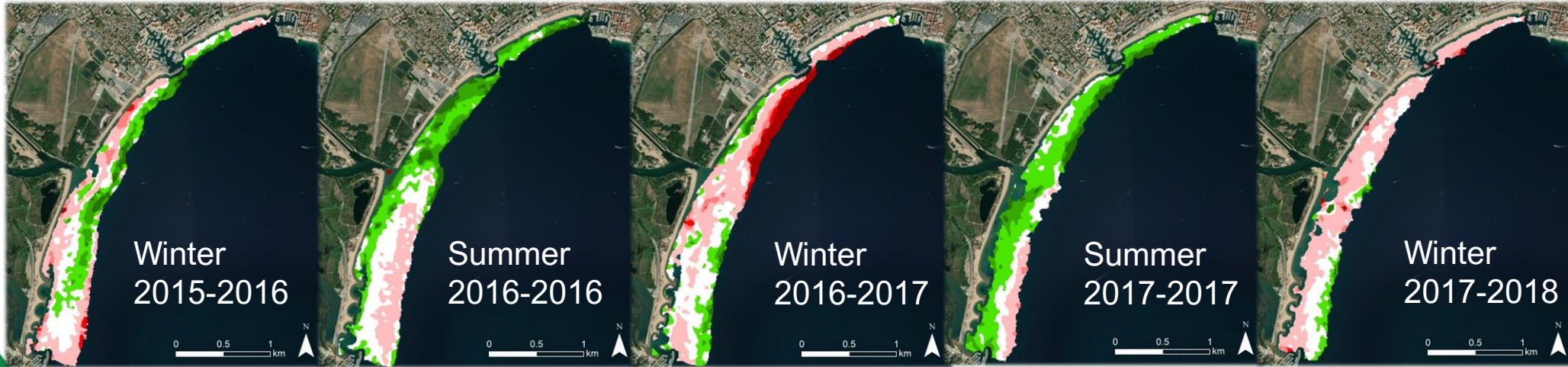




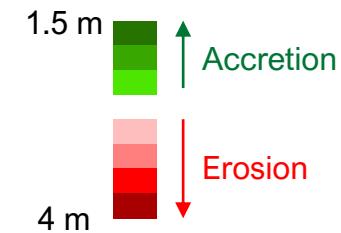
# Product display from optical data and semi-analytical model

## Short-term evolution

Significant alternation of sedimentary accretion (summers) and erosion (winters)



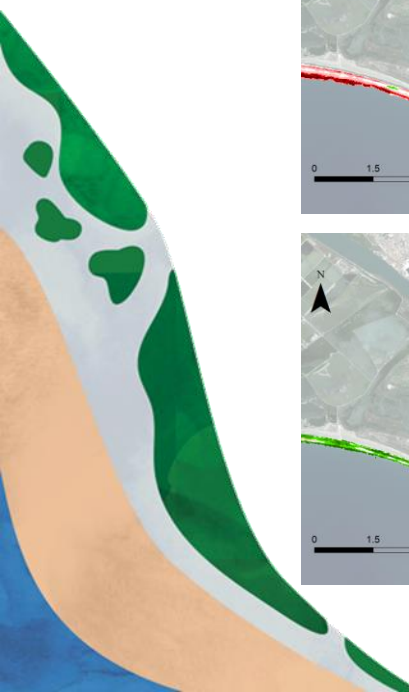
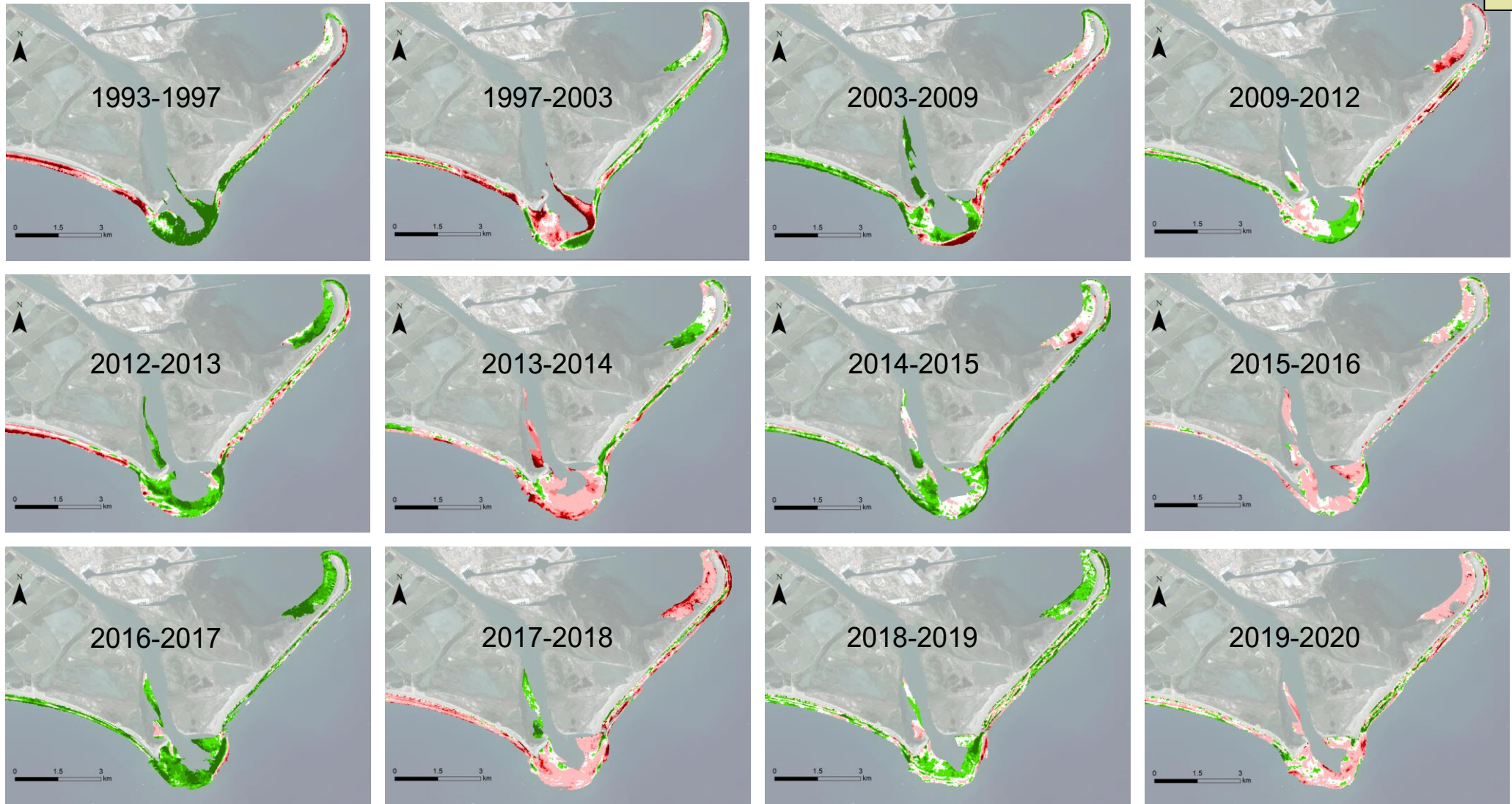
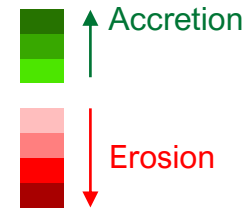
Balanced equilibrium over the entire period which contrasts with a strong seasonal dynamic





# Product display from optical data and semi-analytical model

## Long-term evolution



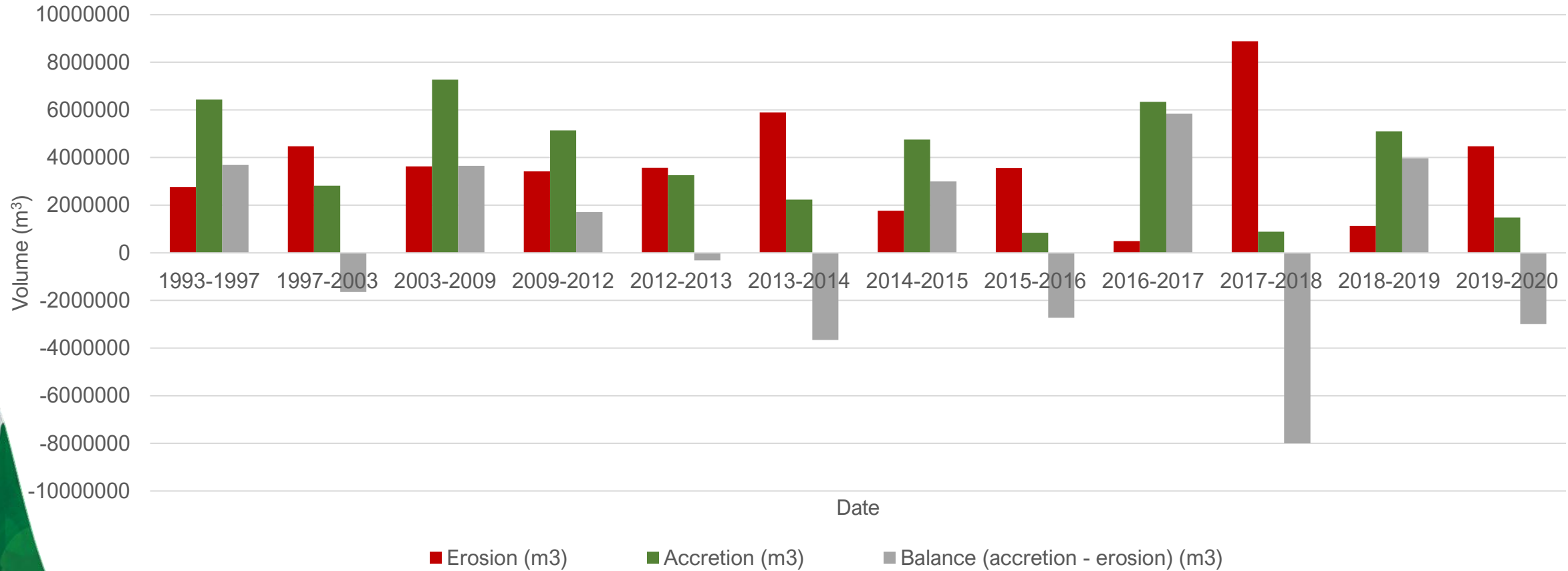


# Product display from optical data and semi-analytical model

## Long-term evolution



### Sediment budget

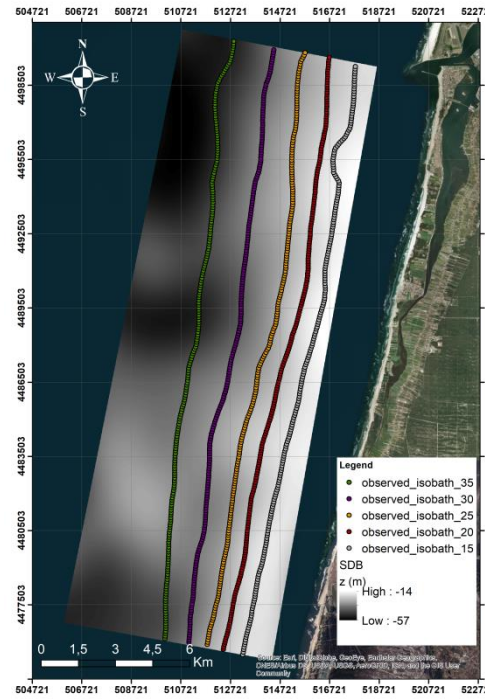


# Validation experiment – SAR bathymetry

## HOW

- Extraction of depth at the position of observed isobaths from satellite derived bathymetry
- Differences of depth observed bathymetry (OB) and satellite derived bathymetry (SDB):

$$\Delta Z = Z_{OB} - Z_{SDB}$$



## WITH

Bathymetric surveys with single (SB) or multibeam (MB) echosounder from:

**Institutions**

- Porto da Figueira da Foz
- APA (Agência Portuguesa do Ambiente)
- Porto de Aveiro
- Municipalidade da Figueira da Foz
- CESAM (centre for environmental and marine studies)
- universidade de aveiro

**Project**

- Interreg España - Portugal (Fundo Europeu de Desenvolvimento Regional)
- MARRISK



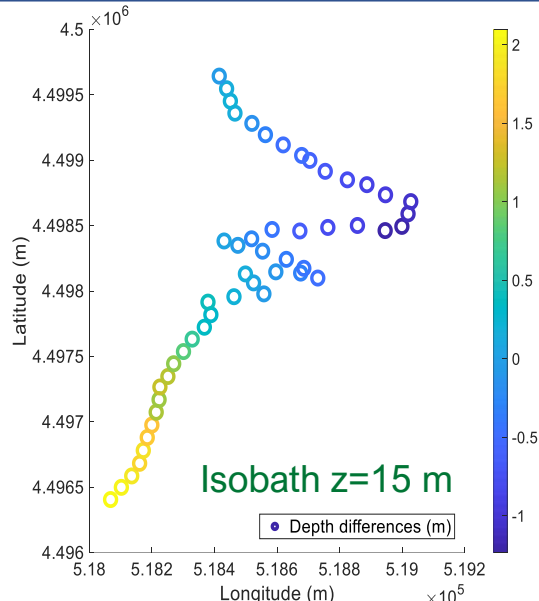
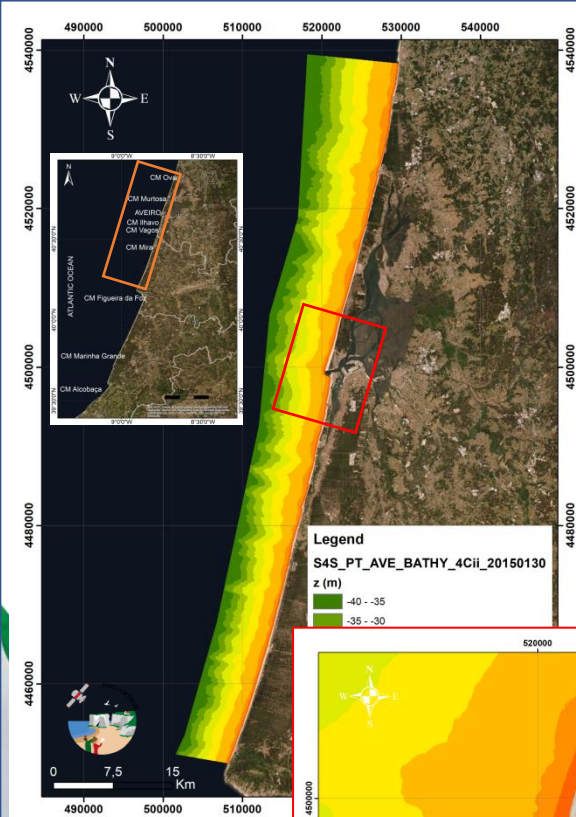
## FOR

Region	Sentinel-1 Date	Validation Dataset		
		Type	Source	Date
Aveiro	30/01/15	SB	Administração do Porto de Aveiro - APA S.A.	02/2015
			Universidade de Aveiro - UA	2015
	31/01/16	SB	Administração do Porto de Aveiro - APA S.A.	10/2016
	31/01/17	MB	Programa COSMO, Agência Portuguesa do Ambiente-APA	09/2017
	02/01/18			07/2018
	02/01/18			08/2018
	02/02/19			06/2019
28/01/20	SB	Universidade de Aveiro - UA	23/01/2020	
Mondego	02/01/18	MB	Programa COSMO, Agência Portuguesa do Ambiente-APA	08/2018
	02/02/19			09/2019
Figueira Foz	30/01/15	SB	Universidade de Aveiro - UA	09/02/2015
	31/01/16			18/10/2016
	31/01/17			27/06/2017
	02/01/18	MB	Programa COSMO, Agência Portuguesa do Ambiente-APA	08/2018
	02/02/19			08/2019



# Validation results – SAR bathymetry

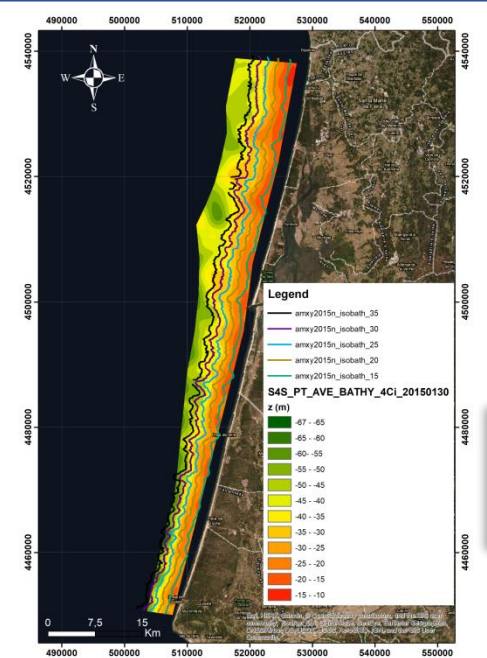
Sentinel-1 – derived bathymetry results (01/30/15) VS field survey (02/11/15)



**WT method**

**Mean RMSE = 2.57 m**

Isobath (m)	Mean RMSE (m)
20	2.74
15	2.38
12	2.05
10	1.82
8	2.89
6	3.60
4	3.10
2	1.68



**FFT method**

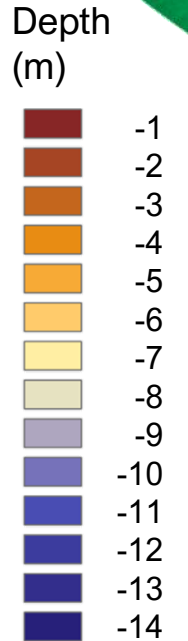
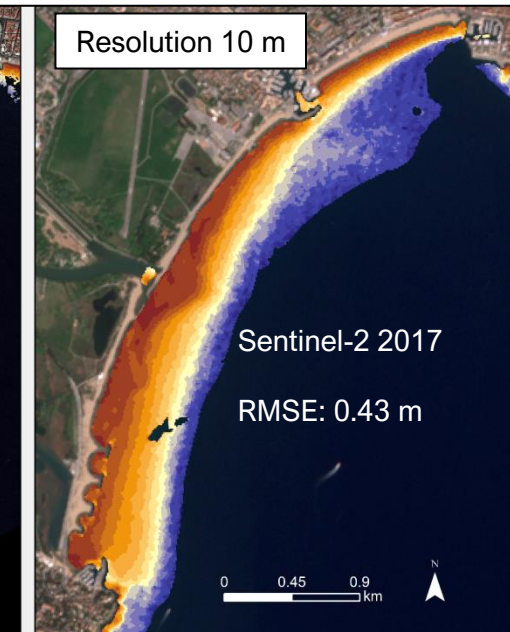
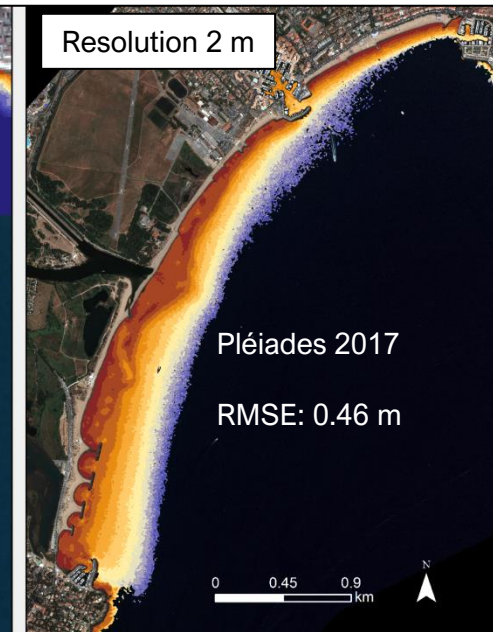
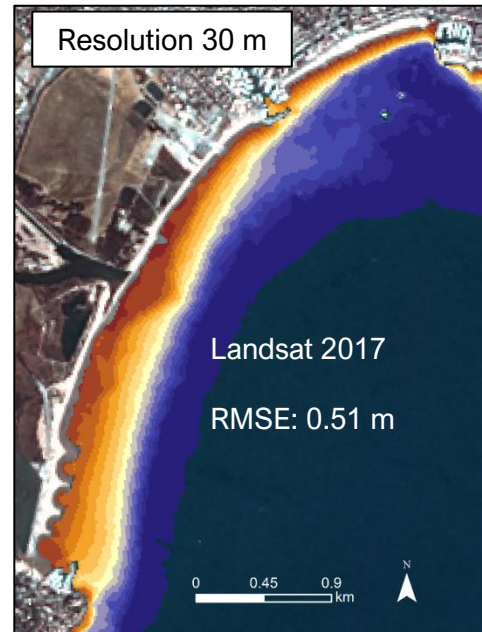
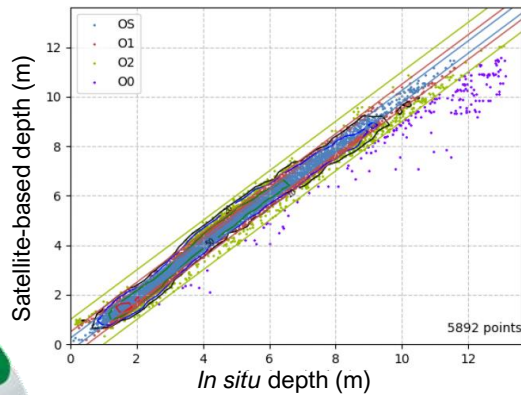
**Mean RMSE = 7.46 m**

Isobath (m)	Mean RMSE (m)
35	8.17
30	8.16
25	6.83
20	5.49
15	9.87

# Validation results – Optical bathymetry



Example of validation for Sentinel-2 derived bathymetry (2017)



Data source	Date	Site	Validation data		Results			
			Source	Date	RMSE	BIAS	Median	Mean absolute error
Landsat 8	09/04/2017	Saint-Raphaël (France)	Aix-Marseille Univ - CEREGE	07/2017	0.51	0.06	0.31	0.39
Sentinel 2A	07/06/2017				0.43	-0.07	0.2	0.28
Pléiades 1A	07/06/2017				0.46	-0.06	0.24	0.32
Sentinel 2B	07/29/2018	Camargue (France)	SYMADREM	07/01/2018	0.79	-0.1	0.33	0.49



# Approval from scientists

## SAR-BASED EXTRACTION



«This work has considered the wavelet spectral analysis to obtain bathymetric data. This new imaging methodology has been explored from Aveiro to Leiria Regions. **When compared to the FFT results, there are considerable improvements for the entire spatial domain**, significantly reducing the errors of the retrieved depths. In addition, the wavelet analysis allows expanding the analysis for shallower depths. **The wavelet image processing methodology shows very promising results over variable bathymetries**»



## OPTICAL-BASED EXTRACTION

« The dense dot plot obtained allows to rebuild topography more accurate than the one achieved with field survey based on transects widely spaced ... **interesting for future monitoring actions**»

« .... **Useful to perform long term sediment budgets...** »

« **Impressed by recent upgrades** ... error margin still important, **almost equivalent to accuracy levels achieved by Lidar techniques**, ... satellite-derived data interesting and exploitables ... »



UNIVERSITÉ  
CAEN  
NORMANDIE



# Users' requirement achievement level

	Vertical accuracy		Revisit		Production area	
	Requested	Achieved	Early request	Produced after POC	Requested	Achieved after POC
<b>Portugal</b>	n/a	2.6 m (Sentinel-1)	1/year; seasonally (winter/summer)	Yearly from 2015 to 2020 (winter).	From Ovar to Peniche	From Ovar to Peniche

*Sentinel-1 constellation (S-1A and S-1B) produces SAR acquisitions over Portuguese coast in Interferometric Wide (IW) swath mode around 06h40 and 18h40 UTC time and with an average revisit time less than 5 days*

↳ *Enhance to obtain suitable images to derive bathymetry (winter)*

	Vertical accuracy		Revisit		Production area	
	Requested	Achieved	Early request	Produced after POC	Requested	Achieved after POC
<b>France</b>	0.2 – 1 m	0.5	2-3/year	2/year; yearly	Calvados, Seine-Maritime, 5 PACA sites, Biscarrosse	Calvados, 5 PACA sites, Biscarrosse
<b>Romania</b>	n/a	n/a	1/month to 1/2 years	Yearly	Sulina-Sfântu Gheorghe, Mai-Vama Veche	Sulina-Sfântu Gheorghe, Mai-Vama Veche
<b>Greece</b>	n/a	n/a	n/a	1 date	Vistonis-Maroneia	Laganas



# End-users' testimonies



C. Pinto (Portuguese Environmental Agency): “The product bathymetry, for detecting submerged sandbars and their evolution, **may eventually be integrated in the APA's assessments** regarding the vulnerability of some coastal sections, **in an essentially qualitative perspective**. The current resolution of the bathymetry does not serve for a quantitative assessment in terms of, for example, local assessment of the sedimentary balance.”

J. São-Marcos (Figueira da Foz Harbour Administration): “My main concern is to understand the migration of the submerged sandbar at Figueira da Foz tidal inlet to guarantee safe navigation. Therefore, **any bathymetric information**, even if it is not completely validated, **will be useful for our critical analysis**.”



C. De Paris (SYMADREM): “Frequent data obtained at large scale are **very useful to understand site dynamics and better protect** the protection infrastructures ...”

K. Bergeron (CAVEM): “... **essential tool for communicating** future land planning and strategy ...”



# ESA's expectation achievement level

- ✓ First application of an innovative method (*i.e.* WT) to obtain nearshore bathymetry from SAR satellite images.
- ✓ Dual approach efficient for coastal areas exposed at low and high wave energy.
- ✓ Bathymetry change over a long time period (1993 – 2020).
- ✓ Changes in nearshore sedimentary volumes estimated from optical imagery in clear waters.
- ✗ Based on SAR data, and in turbid waters, current accuracy achieved only allows to qualitative assessment of morphodynamic changes.



Researching for:

- improving the accuracy
- applying to other coastal areas



# Publications & conference presentations

## □ Workshop and conference presentations:

- **Baptista, P.** Near coast Bathymetry based on wave characteristics – Inverse methods. *Interdisciplinary Earth Observation (EO): Land, Ocean, and Atmosphere Workshop*. INESTEC-University of Porto (Portugal). 12/11/2019 (Invited speaker).
- **Fernández-Fernández, S.** Near coast Bathymetry based on wave characteristics – Inverse methods: Case study. *Interdisciplinary Earth Observation (EO): Land, Ocean, and Atmosphere Workshop*. INESTEC- University of Porto (Portugal). 12/11/2019 (Invited speaker).
- **Lafon, V., Dehouck, A., Robinet, A., Kalousi, G., Stelzer, K., Baptista, P., Costa, S., Echave, I., Gade, M., Tatui, F., Parcharidis, I., Sabatier, F., Serban, I.** 2019. New trends in coastal erosion monitoring at the European scale: The Space for Shore comprehensive solution. ESA EO Φ-WEEK 2019.
- Santos, D., Abreu, T., Silva, P.A., **Baptista, P.** Levantamentos batimétricos a partir de imagens de SAR. *6<sup>as</sup> Jornadas de Engenharia Hidrográfica – 1<sup>as</sup> Jornadas Luso - Espanholas de Hidrografia*. Instituto Hidrográfico – Lisboa (Portugal). 03-05/11/2020.



# Sandbars