Near coast Bathymetry based on wave characteristics - Inverse method

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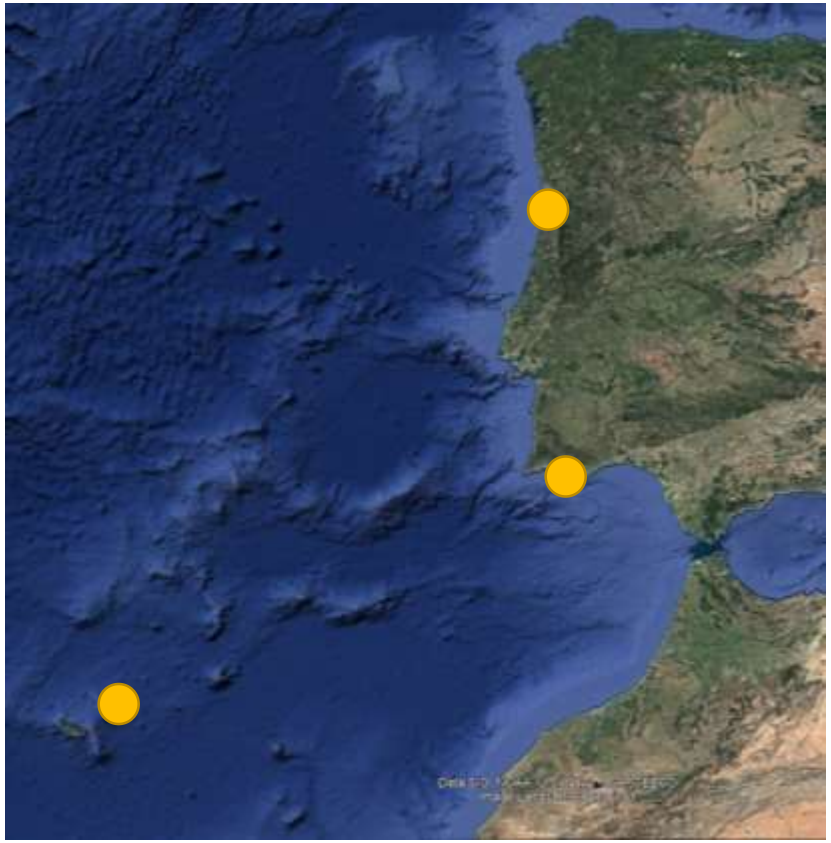
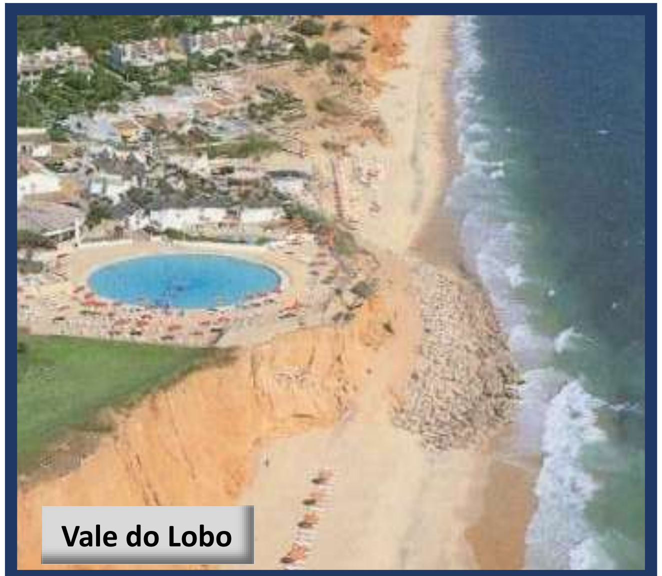
Context

- The occurrence of erosion episodes on sandy shores are a phenomena that occur globally.

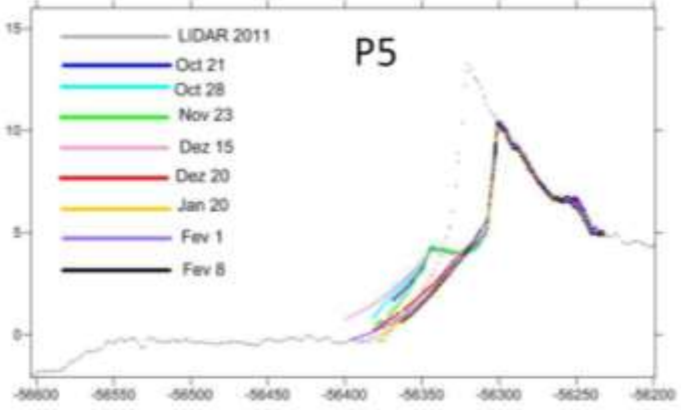



Scarped dunes , Mira, 2014

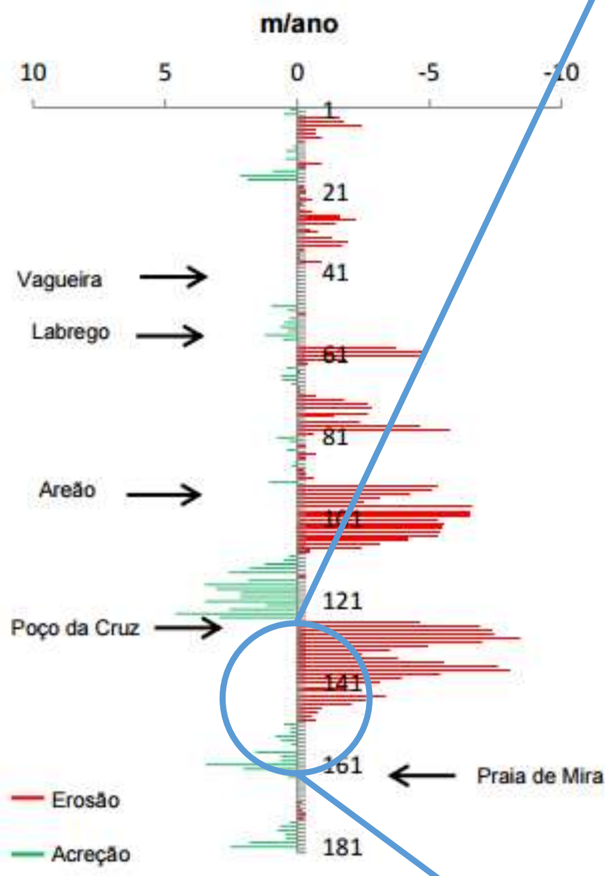

Vale do Lobo


Porto Santo, 2017

- Coastlines exposed to high energetic wave conditions, (NW Portugal)
  LST : 1×10^6 m^3/yr
  progressive sedimentary starvation,
  severely suffer these impacts.



Bouzas et al (2017)



2002-2010

Maia (2012)

Remote sensing techniques
Estimation of nearshore bathymetry

- Coastal bathymetry is an essential data for any study of submersion hazard or risk, or simply to characterize the morphology of the sea-bed. Estimation of bathymetry is possible from optical space-borne data and considerably reduces the costs and delays of this type of study.
- Among the existing bathymetry estimation studies, multispectral satellite imagery makes it possible to measure bathymetry using the optical properties of shallow waters. Nevertheless, this technique applies mainly in the immediate vicinity of the coast, for shallow water depths, as it requires sufficient water transparency.
- Other satellite techniques use the measurable wave characteristics to produce bathymetry.

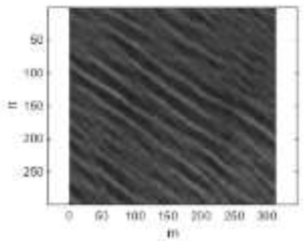
Sensor and data extraction

- Sentinel-1A (launched in 2014, with C-band (5.405 GHz)) SAR images;
- *Interferometric Wide swath* (IW) with level 1 High Resolution (HR) and Ground Range Detected (GRD) product [resolution=20×22m (range×azimuth), pixel spacing= 10×10m (range×azimuth), and 5×1 (number of looks)] is suited;
- The GRD consist of focused SAR data that have been detected, multi-looked and projected to ground range using an Earth ellipsoid model such as WGS84 (SENTINEL-1 Team, 2013);
- The Sentinel data are freely accessible (https://scihub.copernicus.eu/)
- They are downloaded through SNAP, which is a free available platform of tools provided by the European Space Agency. SNAP allows the image ortho-rectification through ground control points (GCP) and the images overlap.

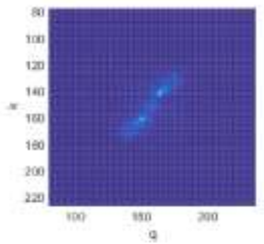
Coastal Bathymetry Mapping using Synthetic Aperture Radar (SAR) images (SENTINEL)

Steps of the methodology

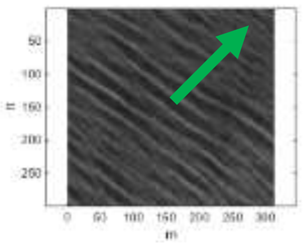
1) Detection of the wave front



2) Directional spectrum FFT

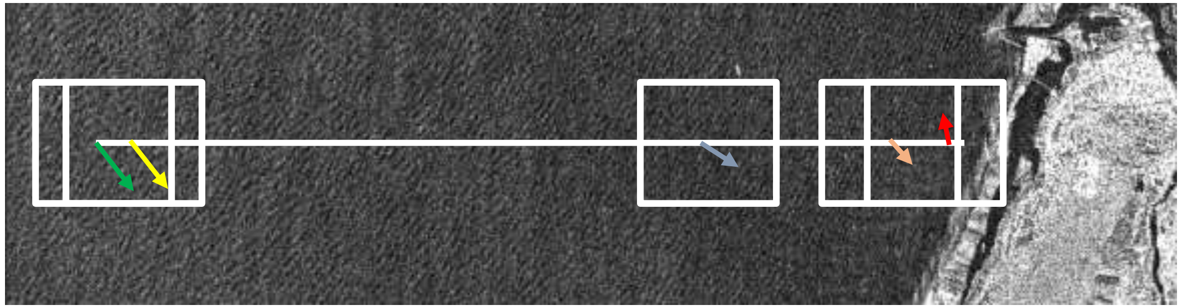


3) wavelength and wave direction (IQ)



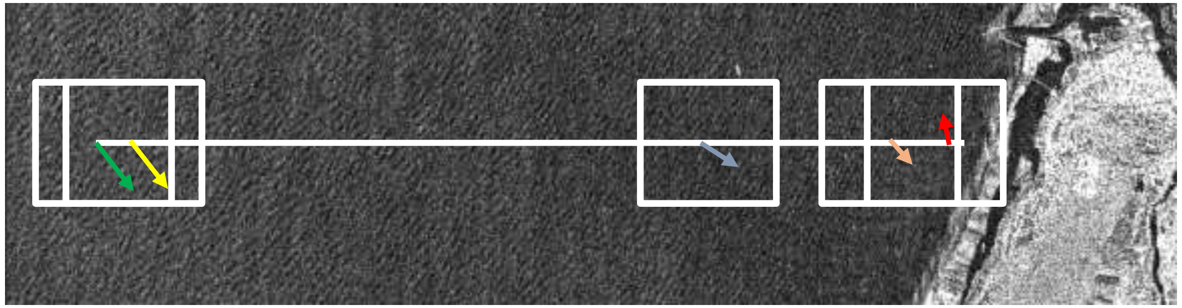
4) linear dispersion relation to estimate water depth

$$h = \frac{\lambda}{2\pi} atanh(\lambda/\lambda_0)$$



1. Detection of the wave front

- One satellite image of the sea surface covers a wide area, where the surface waves present distinct characteristics along such area;
- Image divided in a grid of small regions with centre points;
- a squared region (image cell) centred in each point of the grid;
- the cell dimensions should accommodate several wavelengths (typically on the order of 4 to 10) where the wave characteristics are reasonably constant.

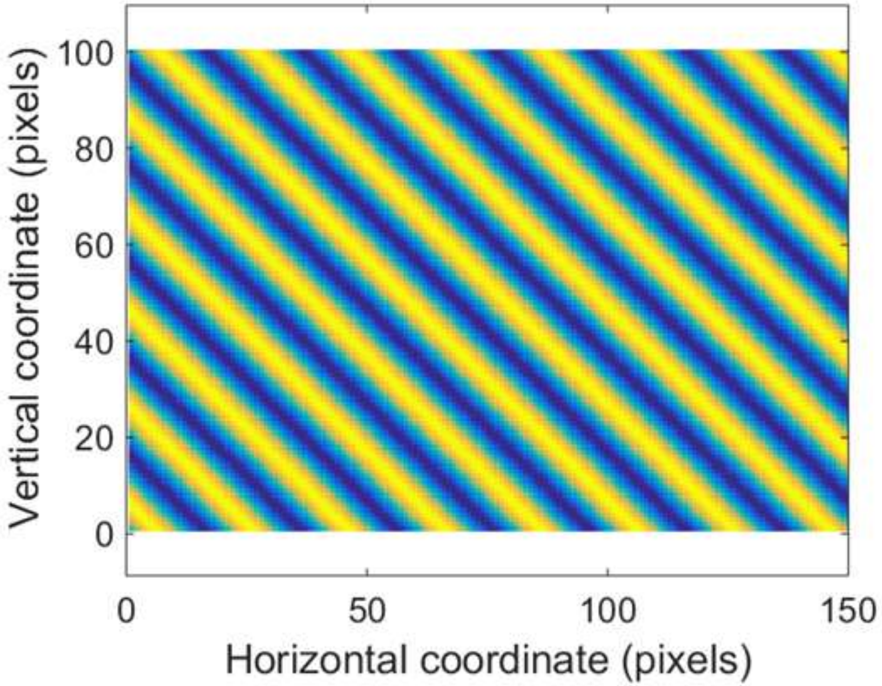


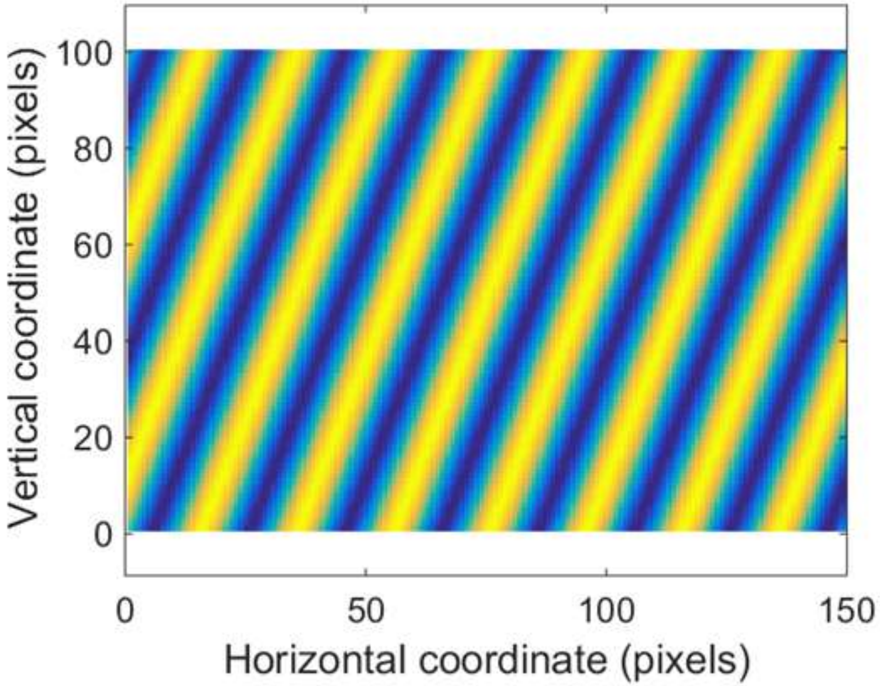
2. Directional spectrum FFT

- Two dimentional Fast Fourier transform (FFT) computed for each squared cell;
- The FFT represents the energy that a signal presents distributed with respect to the frequency of each of its components, when considering a decomposition of such signal in sinusoidal components. If a signal presents a sinusoidal-like dominant component, then its Fourier representation will reveal a high peak of energy at the frequency of such component. Therefore, as peaks are easily identifiable features, the FFT is a suitable tool for estimating the characteristics of the dominant sea waves in a specific region

2. Directional spectrum FFT

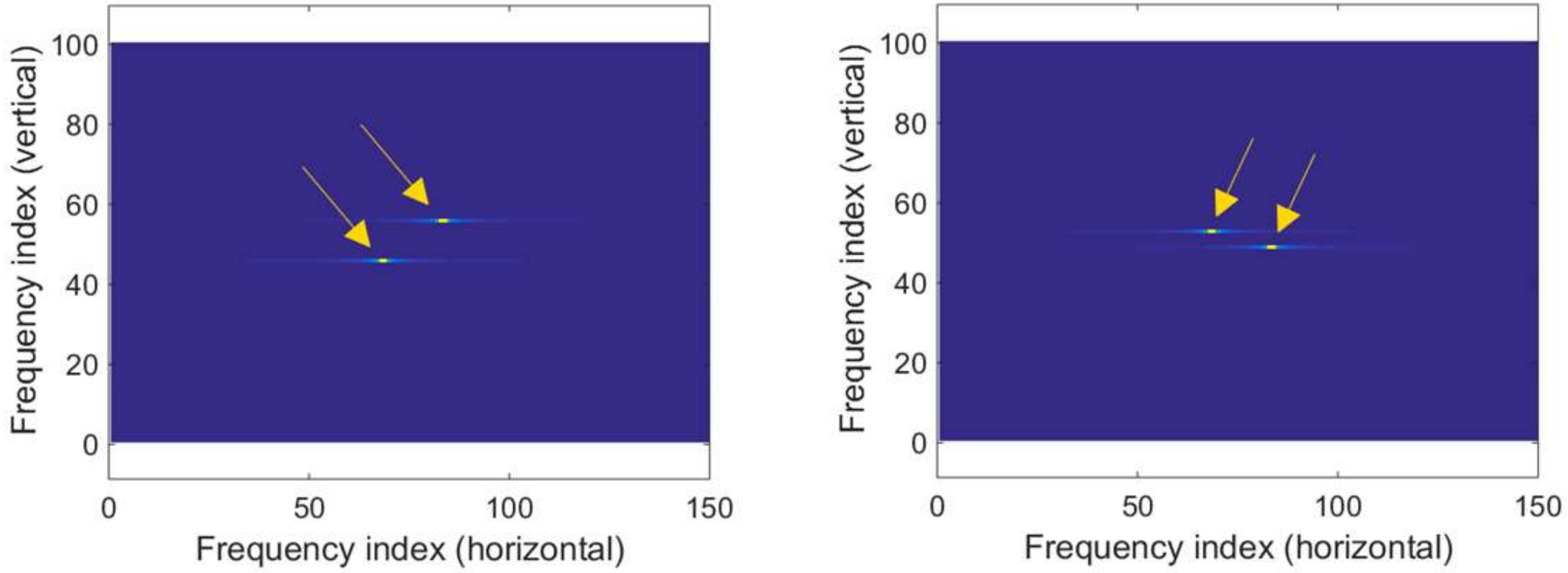
- Example: two-dimensional sinusoidal wave with linear wave-front, assuming a distinct propagation direction in each image, and distinct wavelength





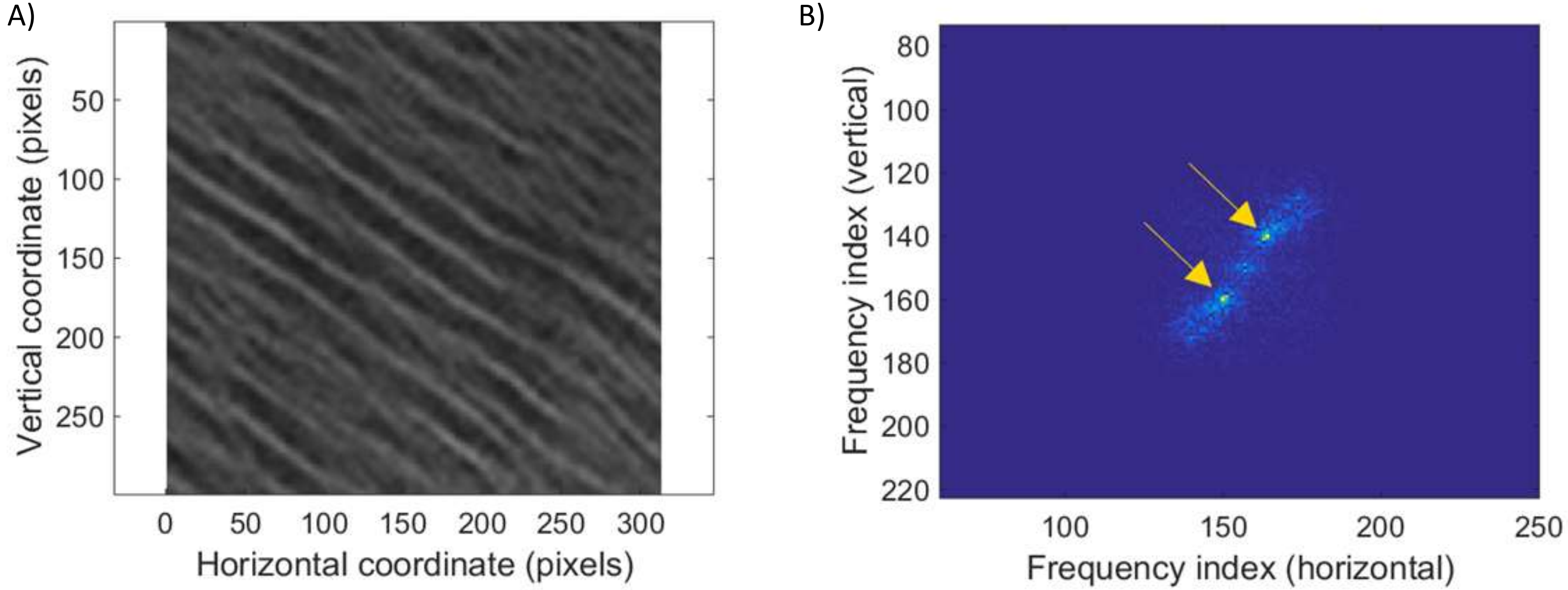
2. Directional spectrum FFT

- The application of the two-dimensional FFT to the two images in Figure 2 results in the frequency-domain representations;
- two sharp peaks appear near the centre of the transformed images



2. Directional spectrum FFT

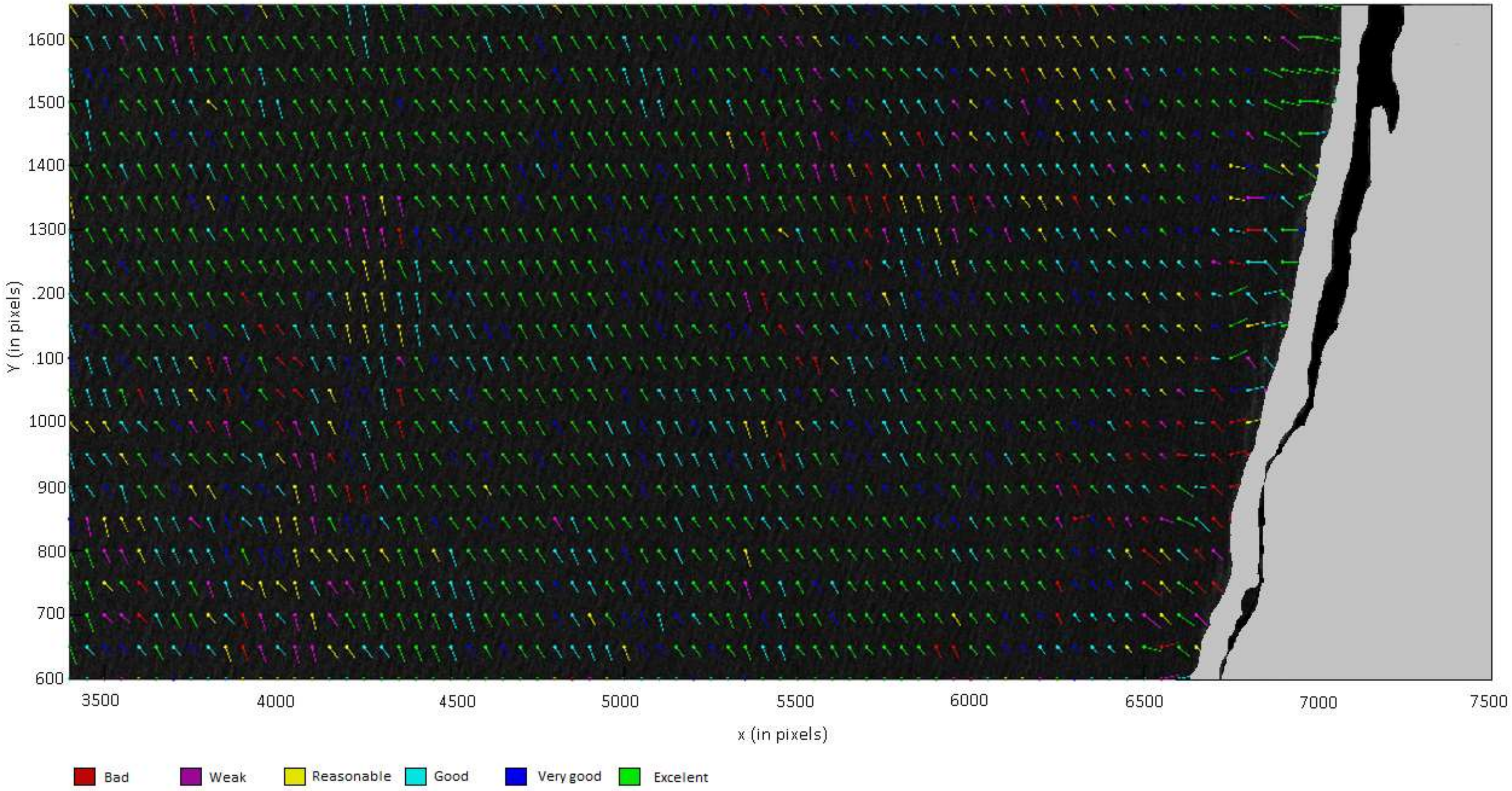
- a region of a satellite image of the sea near the Aveiro coast and its respective transformed representation, where the identification of the dominant peaks (dominant waves) is still quite clear



3. Wavelength and wave direction (IQ)

- As the cell image is discretized in (NxM) pixels (where N is the number of rows of pixels, and M the number of columns), its frequency-domain representation is also discretized in the two-dimensional frequency space (also in (NxM) points).
- Let dx be the number of columns between the two identified sharp peaks in the frequency-domain representation of the cell image, and dy the respective difference in number of rows.
- The wavelength (in number of pixels) of the dominant surface wave of that cell can be estimated through $\lambda = 1/\sqrt{(dx/2M)^2 + (dy/2N)^2}$.
- The value of the wavelength in meters is then obtained from the former by considering the image spatial resolution. The wave direction is the orientation of the segment connecting the two identified sharp peaks.

3. Wavelength and wave direction (IQ)



4. Bathymetric estimation from the linear theory

- The linear wave theory (Airy theory) describe the velocity field and pressure along the water column and establishes a relation between the wave celerity, the frequency and the water depth (linear dispersion relation).
- Airy's equations have asymptotic limits from deep to shallow water as the dynamics of the waves change and become non-dispersive in shallow waters (Phillips, 1997).
- The approach considered for determining the sea-bottom depth (h) satisfies the set of values of the wavelength (λ) and the wavelength at deep water (λ_0) given in the linear dispersion relation:
- $\lambda = \lambda_0 \tanh(kh)$ (1)
- where $\lambda_0 = gT^2/2\pi$, T is the wave period, g is the gravity acceleration, k is the wave number and h is the sea-bottom depth.

4. Bathymetric estimation from the linear theory

- The bathymetry is computed from:

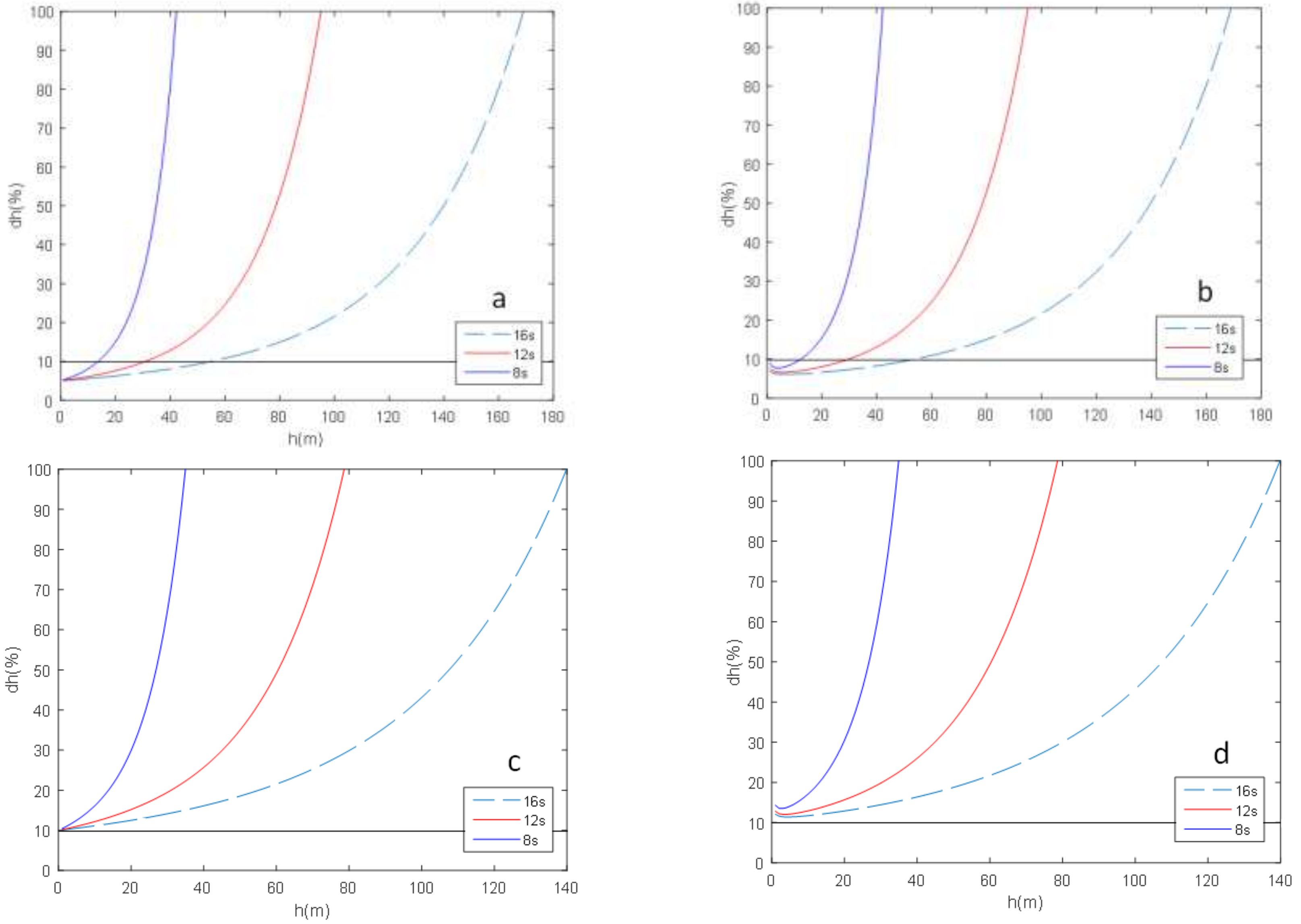
- $\mathrm{h} = \frac{\lambda}{2\pi}\mathrm{atanh}(\lambda/\lambda_0)$ (2)

- he value of λ_0 is determined for each image considering water depths higher than 200 m in order to ensure the deep water approximation (water depth larger than half the wavelength)
- After this procedure the estimated λ_0 and the values of λ computed for each cell of the image are replaced in the equation (2) retrieving the local cell depth.

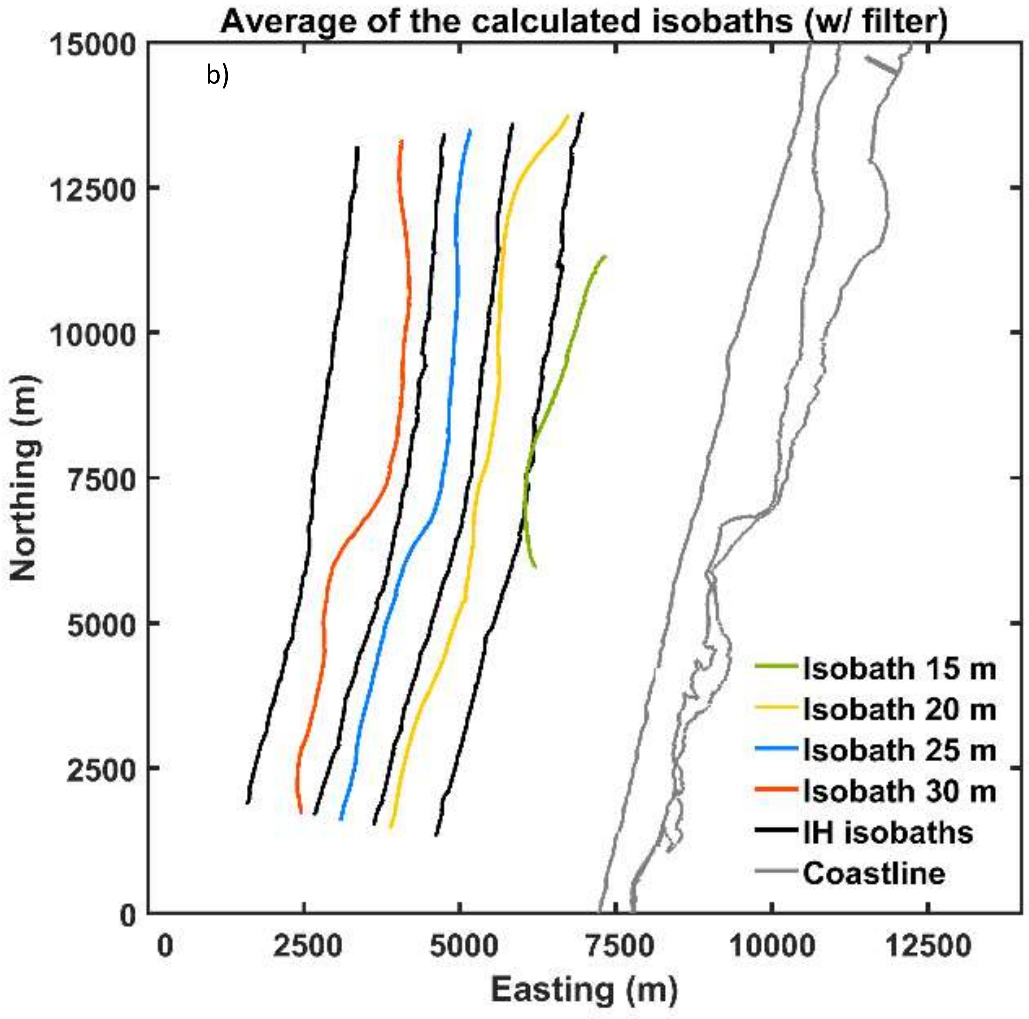
4. Bathymetric estimation from the linear theory

- Relative error of h (Δh) at different depths for offshore wave period of 8, 12 and 16s

- A) Δλ0=5%,
- B) Δλ=5%,
- C) Δλ0=10%
- D) Δλ=10%

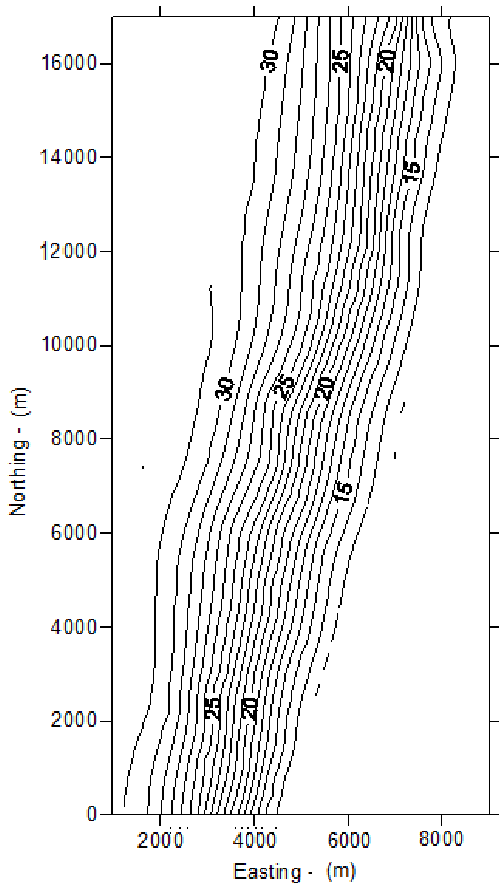


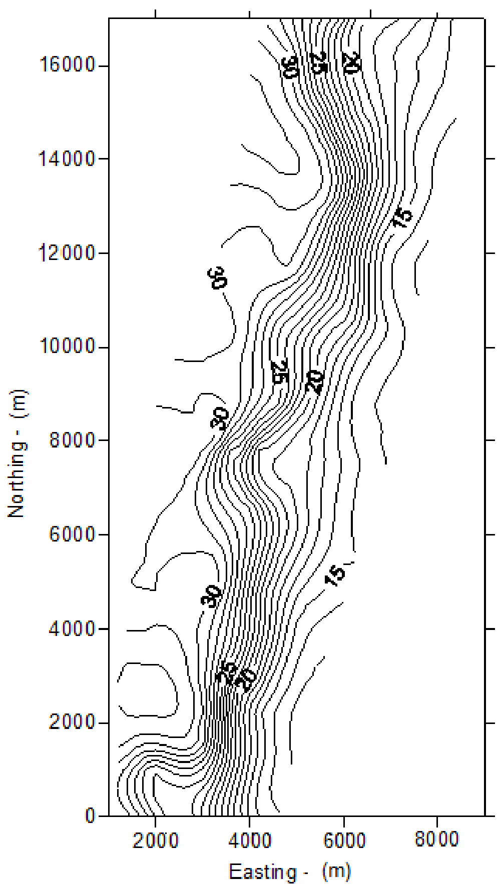
Study site: Bathymetric estimation versus in-situ bathymetry

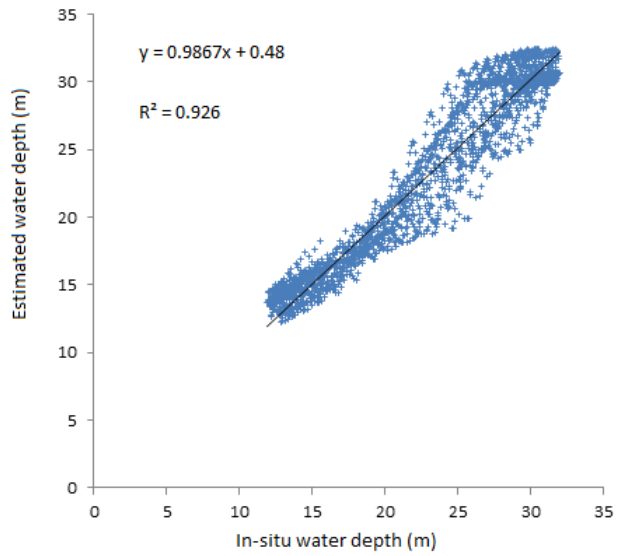


Average of the isobaths of 15, 20, 25 and 30 m from the four satellite images, over the IH bathymetry.

Study site: Bathymetric estimation versus in-situ bathymetry







Conclusions:

Coasts exposed to high energetic waves provide excellent opportunities to explore swell wave properties to infer bathymetry.

The high temporal resolution of the Sentinel-1A and the recurrent swell wave regime allow to investigate the repeatability of the FFT methodology in retrieving the nearshore bathymetry.

The errors of estimating the local bathymetry from these quantities was accessed which allowed to quantify the water depth limits of application of this methodology.

The computed bathymetry was quantitatively compared with the measurements made in 2013 and available at RAIA Observatory. The relative error of the water depth ranges between 6% and 10%, but increases for the higher depths and depends on the accuracy of the computed wavelength at deep-waters.

THANK YOU VERY MUCH

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