A WAVELET ANALYSIS ON HIGH FREQUENCY BIO-OPTICAL PROPERTIES IN THE NORTHWESTERN MEDITERRANEAN SEA (BOUSSOLE SITE)

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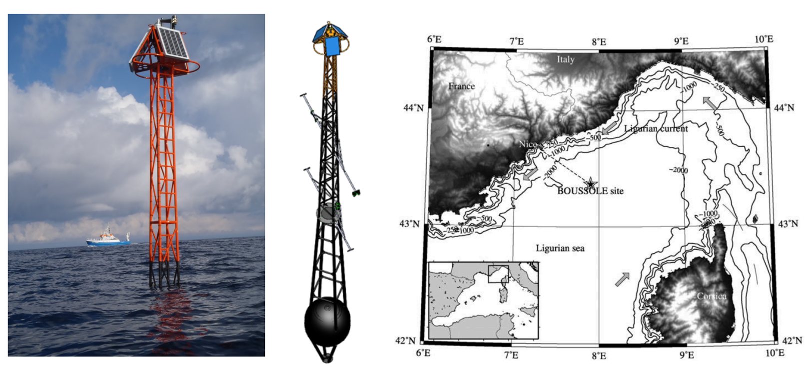
MAIN GOAL

A wavelet analysis has been applied to high frequency field observations of bio-optical properties at the BOUSSOLE site, in order to decompose, describe and estimate the spectral characteristics of optical signals as a function of time. The primary goal of the study is the identification of different period frequencies (from diel variability to annual cycle) and their temporal evolution

BOUSSOLE SITE



- The buoy is located in the northwestern Mediterranean Sea (open ocean waters)
- Since 2003, high frequency observations of **bio-optical parameter** every **15 minutes at 9 meters**
- **A long term** bio-optical **time-series**
- Hobilabs, HS-IV (442, 488, 555, 620 nm) for particulate backscattering (b_{bp}) at 550 nm and WET Labs C-star beam transmissometers for beam attenuation coefficient (c_p) at 660 nm

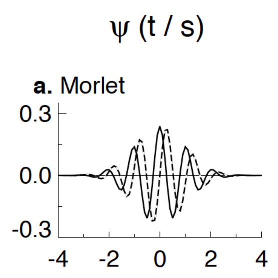
$$b_{bp} = 2\pi\chi_p(\beta(140) - \beta_w(140)) \qquad c_p(660) = -\frac{1}{0.25}\ln\left(\frac{Tr}{100}\right)$$

- Wetlabs ECOFLNTUs for Fluorescence (Fls)

METHODOLOGY

Step 1: Fill the gaps with the **Singular Spectrum Analysis** (**SSA**) statistical technique that is able to simulate the measurements with statistical robustness and coherence with original time-series

Step 2: Application of **Wavelet Analysis** that performs a time-scale **decomposition of** the **signal** by estimating its spectral characteristics as a function of time specifically for non-stationary time-series (Cazalles *et al.*, 2008; *Oecologia*):



Wavelet transform: $\psi(t) = \pi^{-1/4} e^{i\omega t} e^{-t^2/2}$

The **global wavelet power spectrum** is defined as the averaged variance contained in all wavelet coefficients of the same frequency f:

$$\overline{S}_x(f) = \frac{\sigma_x^2}{T}\int_0^T \|W_x(f,\tau)\|^2 d\tau$$

The **average wavelet power spectrum** is the average of the global wavelet power spectrum: $\langle \overline{S}_x(f) \rangle$

Step 3: **cross wavelet analysis** between couple of parameters (Fls vs. b_{bp} and Fls vs c_p and b_{bp} vs. c_p) is the quantification of statistical relationships between two non-stationary signals (Cazalles *et al.*, 2008) in terms of cross correlation power spectrum and coherency:

Wavelet cross spectrum: $W_{x,y}(f,\tau) = W_x(f,\tau)^* W_y(f,\tau)$

Wavelet coherency and its average: $R_{x,y}(f,\tau) = \frac{\|\langle W_{x,y}(f,\tau)\rangle\|}{\|\langle W_{x,x}(f,\tau)\rangle\|^{1/2}\|\langle W_{y,y}(f,\tau)\rangle\|^{1/2}}$

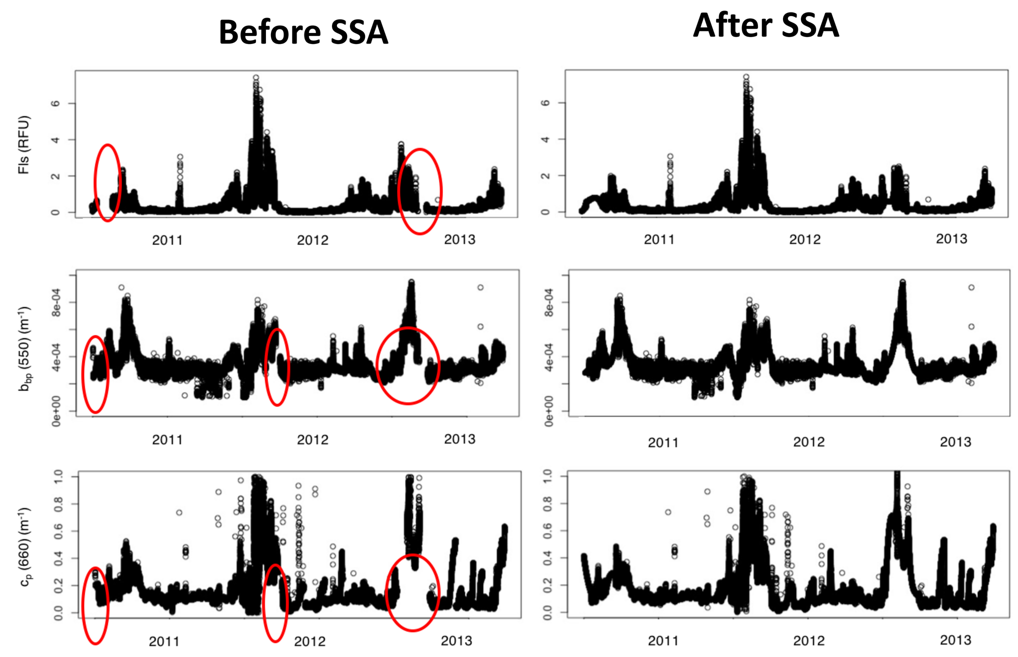


Figure 1: original and reconstructed time-series of Fls, b_{bp} and c_p in case of missing values (respectively 16, 17 and 12% of all observations) or when the values are considered outliers. The SSA method was applied in order to compute a reasonable simulations with measurements in continuity with the original time-series in the gaps.

RESULTS

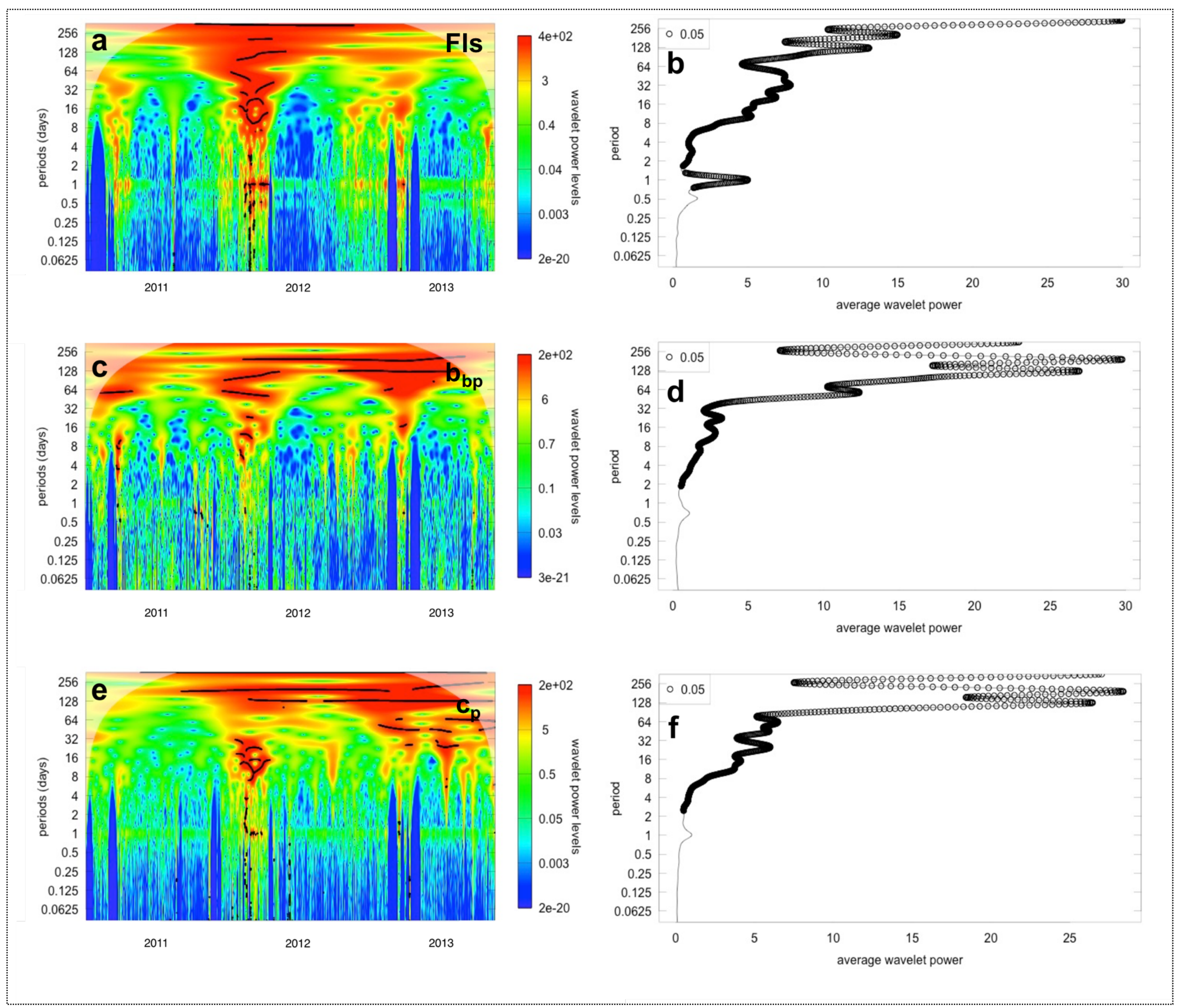


Figure 2: Wavelet analysis for the characterization of periodic frequencies of the high frequency observations of BOUSSOLE time series. Series of the Fls, b_{bp} (550) and c_p (660) (respectively **a**, **c**, **e**). Time-averaged wavelet spectrum of the series (**b**, **d**, **f**)

Figure 2 shows:

- high power levels (red color) from daily to annual scales in winter and spring and low levels (blue) during summer
- diel cycle ~ 5% of variance for Fls and ~ 2 % for b_{bp} and c_p
- from week to monthly cycles detected ~ 15% of total variance for all bio-optical parameters
- from 6-months to annual scales effect as > ~ 35% for Fls and > ~ 40% for b_{bp} and c_p

IOPs CYCLES HAVE CORRESPONDENT VARIANCES

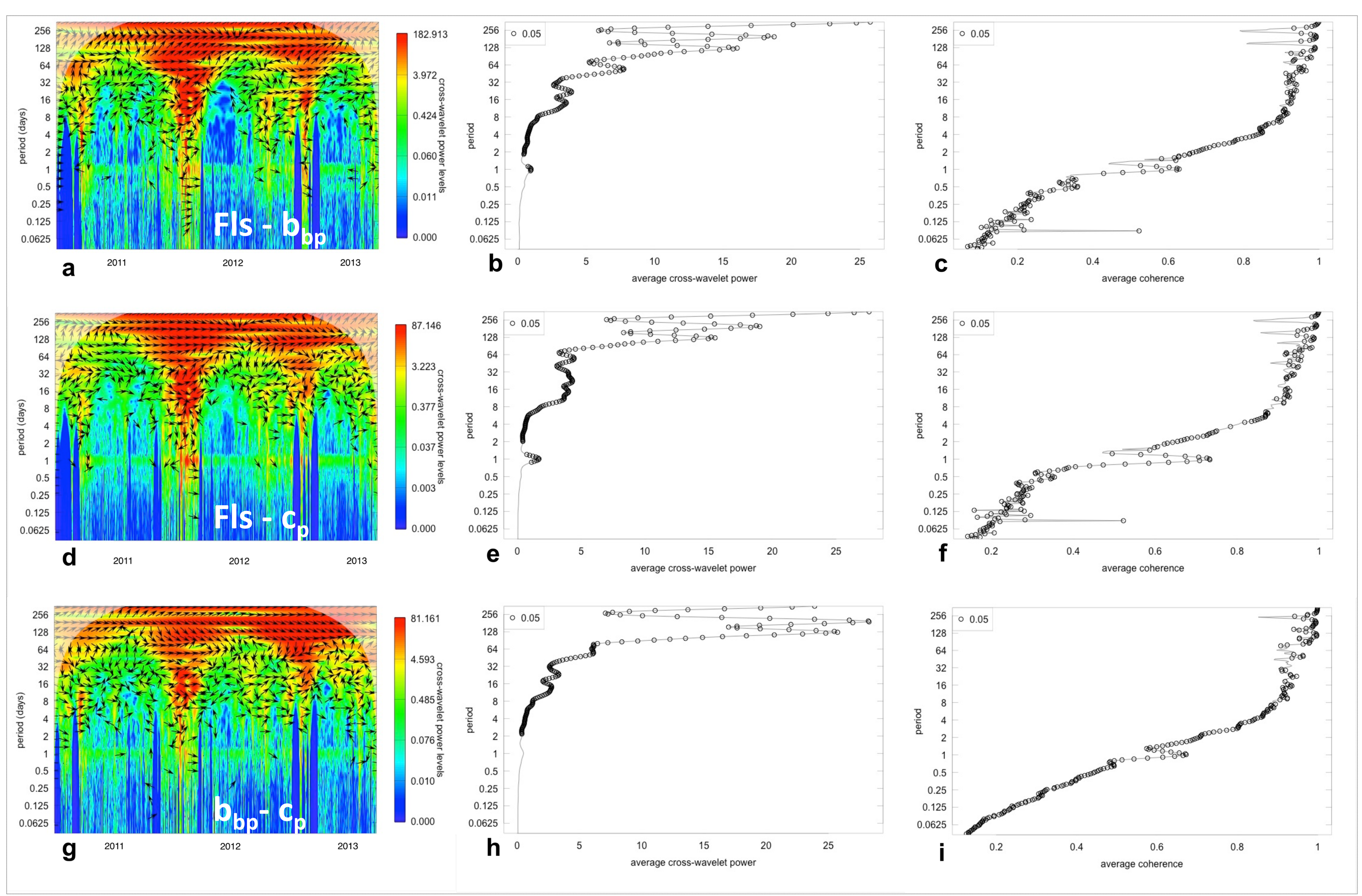


Figure 3: Cross wavelet analysis between bio-optical parameters at BOUSSOLE site (**a**, **d**, **g** respectively). The average of the cross power spectrum are respectively in **b**, **e**, **h**. The average coherency shows the correlation between the parameters at different periods (**c**, **f**, **i**).

Figure 3 shows:

- evidence of diel to annual phase between bio-optical properties
- period < 1 day → low correlation
  → *photoacclimation* effects?
- period > 1 day → high correlation
- strong convergence during productive seasons → *bloom* effects?

PHASE OR NOT PHASE AT THE DIFFERENT SCALES: WHY?

CONCLUSIONS:

- High power levels in correspondence of productive seasons and low power levels during unproductive periods for all the bio-optical properties
- Diel cycle evident of bio-optical properties during winter and spring seasons; and minor evidence in case of summer period
- Cycles from month to annual have a great impact on total variance in case of all the bio-optical parameters
- Coherences between bio-optical properties during productive periods and absence of phase during summer period from diel to annual scales
- Good correlation between Fls and optical parameters, especially with c_p (660)

FUTURE PERSPECTIVES:

- A wavelet analysis on different time-sampling (e.g. one obs. each day) and evaluate the impacts on cycles detection in relation to OCAPI geostationary mission
- A wavelet analysis on the different trophic regimes (mixing, bloom, decline and oligotrophy) of bio-optical BOUSSOLE long-term series
- Diurnal cycle detection using GOCI satellite data with the application of the same analysis: reconstruction and decomposition of time-series

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