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Long-term high frequency phytoplankton dynamics, recorded from a coastal water autonomous measurement system in the eastern English Channel

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ABSTRACT

In this paper, high frequency fluorescence fluctuations, recorded from 2004 to 2011 using an autonomous underwater monitoring system in the eastern English Channel, at 20-min time resolutions, are analyzed. Annual blooms are superposed to multiscale fluctuations. The probability density function (pdf) of the fluorescence time series obeys a power law with slope −2. The pdf for annual portions also obeys power laws, with slopes related to the annual average. Empirical mode decomposition (EMD) is used to study the dynamics and display the power spectrum, which is different from the temperature power spectrum. EMD is also used to extract a trend and isolate the blooms from the high frequency dynamics.

1. Introduction

In the geosciences, fields and processes possess highly variable stochastic fluctuations on a large range of spatial and temporal scales. These are often superposed to more regular, deterministic variations associated with astronomical forcing, such as the annual, daily, or tidal cycles. This paper focuses on the important role played in aquatic ecosystems by phytoplankton abundance, and its stochastic fluctuations, as well as the deterministic aspects linked with its seasonal variations. In fact, phytoplankton growth is influenced by nutrients, temperature and light (both fields having a strong annual cycle). In the eastern English Channel, the main species contributing to the phytoplankton bloom is *Phaeocystis* (Monchy et al., 2012; Schapira et al., 2008). It has been shown to impact on the local coastal ecosystem (Dauvin, 2008; Grattepanche et al., 2010; Seuront and Vincent, 2008; Spilmont et al., 2009). Several methods have been used to monitor the *Phaeocystis* abundance in this region, including: in situ sampling (Grattepanche et al., 2010; Houliez et al., 2013; Lefebvre et al., 2011); ocean color inversion (Lubac et al., 2008); and automatic high frequency sampling (Zongo et al., 2011).

Fluorescence is commonly used as a proxy for phytoplankton biomass in oceanology (Neal et al., 2006). In situ measurements of this proxy made by the MAREL Carnot are recorded in FFU (Fluresceine Fluorescene Unit). Areas strongly oligotrophic or conversely, strongly eutrophic, and the concentrations of some phytoplankton species may introduce a bias in the use of fluorescence as a proxy the phytoplankton biomass (Cloern et al., 1995; Eppley et al., 1977). This range of extreme variations is not present in our areas; therefore fluorescence is a good proxy to study the phytoplankton biomass in the framework of this study (Aminot and Kérouel, 2004).

In the last 15 years, European Union legislation has been implemented to protect the marine environment: first to obtain better quality freshwaters and coastal waters, and to better control the input of nutrients (Water Framework Directive), and more recently to protect the marine environment using a set of indicators or descriptors (Marine Strategy Framework Directive). Several descriptors are related with phytoplankton biomass. In such framework, monitoring programs are needed, especially high frequency monitoring to better understand the multi-scale dynamics of phytoplankton in coastal waters. Such high frequency

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automated systems are more and more installed in coastal waters around the globe (Frieder et al., 2012; Lovato et al., 2013; Nam et al., 2005).

Here a system belonging to the MAREL devices is considered. This study analyzes a time series recorded at a fixed coastal location every 20 min, taken over several years in the Eastern English Channel. Fluorometers can record at much higher frequency (Seuront et al., 1996a,1996b), but in the framework of long-term sampling, since a sampling rate of 20 min is 1000 times more frequent than a sampling rate of 15 days, such sampling rate is often called “high frequency”. The fixed buoy station used is capable of recording various biogeochemical parameters simultaneously. The analyses focused here on fluorescence data, proxy of phytoplankton abundance, and on other quantities that can be linked to its determinism e.g. water temperature, nutrients concentration, and light. Our objective was to have a better understanding of fluorescence bloom dynamics, i.e. its probability distribution, its time–frequency distribution, and its statistics in relation with other variables.

The next section presents the material and methods: first, the databases are presented, and then analyses methods; the following section shows the results; and the last one the discussion and conclusion.

2. Material and methods

2.1. Databases

The time series data analyzed was taken from the MAREL network (Automatic monitoring network for littoral environment, IFREMER, France), which is based on a deployment of moored buoys equipped with physico-chemical measuring devices, and works in continuous and autonomous conditions (Berthome, 1994; Blain et al., 2004; Woerther, 1998; Zongo et al., 2011). These stations use automatic systems for seawater analysis and real time data transmission, and record several parameters such as temperature, salinity, nutrients, dissolved oxygen, pH, and turbidity, with a fixed time resolution.

Other time series from the MAREL network have been previously studied. These include: Dur et al. (2007), Schmitt et al. (2008a), and Zongo and Schmitt (2011), who considered data recorded in the Seine estuary; and Maneux et al. (2010), Sottolichio et al. (2011), Etcheber et al. (2011), and Lanoux et al. (2013), who studied time series in the Gironde estuary in relation to water quality monitoring and hypoxia studies.

The MAREL Carnot measuring station is situated in the eastern English Channel, in the coastal waters of Boulogne-sur-mer (northern France) at position 50°44′25N, 1°34′3E (Fig. 1). It records data with a 20-min resolution, except nutrients, which are recorded with a periodicity of 12 h (Zongo et al. 2011). Water depth at this position varies between 5 and 11 m; the measurements are carried out using a floating system inserted in a tube, 1.5 m below the surface. Two studies have been published using this dataset: Zongo and Schmitt (2011) considered the scaling properties of pH fluctuations, and Huang and Schmitt (2014) studied the cross-correlation between temperature and oxygen data. Since 2004, this station has registered more than fifteen physico-chemical parameters. Table 1 presents the parameters used in this study, as well as their range and uncertainly.

This study focuses mainly on temperature and fluorescence data. Unfortunately, due to maintenance problems and failure of the automatic devices, several data are missing from in the series (Dur et al., 2007). The percentage for fluorescence was close to 80%, which represents 168,948 data acquired; and for temperature, it was close to 88%, which represents 138,574 data acquired

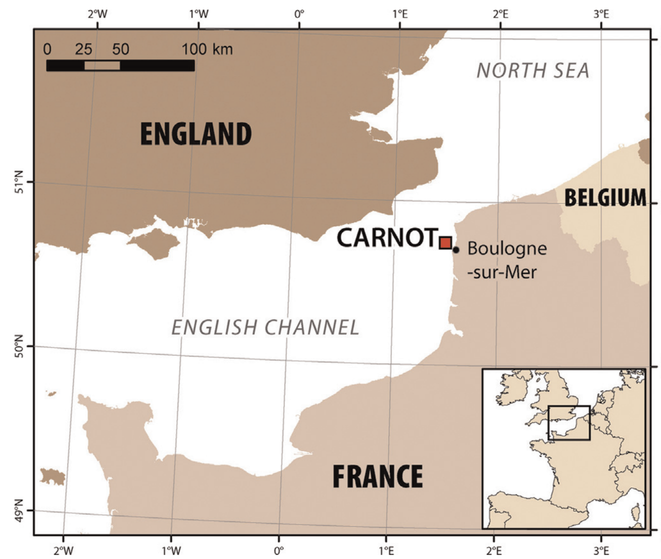

Fig. 1. A map showing the measurement location in Boulogne-sur-mer's coastal waters (France) at position 50°44′25 N, 1°34′3E, in the eastern English Channel.

(see Table 1). Since analyses were performed on an annual basis, data from years 2004 to 2011, inclusive, were selected.

Established in 1997, the SOMLIT program is a certified observation service. Its main function is to follow the temporal evolution in the long-term of a set of biogeochemical parameters along the French coast. This network gathers data from nine marine stations, which share the same protocol for sample analysis. The different parameters measured by this network are common to all stations, and have been chosen for their relevance as indicators of the ecosystem's health. Currently there are 16 biogeochemical parameters, and the sampling frequency varies between one week and one month, depending on the stations.

The SOMLIT station samples at Wimereux, southwest of Boulogne-sur-Mer, which were recorded every two weeks, will be considered here. These samples were taken on board the R/V SEPIA at two locations: the coastal point (50°40′75 N; 1°31′17′ E) and the offshore point (50°40′75N; 1°24′60E). Here, only the temperature profiles from the coastal point, which is the closest to MAREL Carnot, are used. These profiles were collected in situ using a CTD (Conductivity, Temperature, Depth) sensor. As part of this study, the SOMLIT data between the beginnings of the year 2007 until the end of the year 2011 were considered. Table 2 shows the temperature deltas between the surface and the bottom during the summer period. This table shows also the depth of their thermoclines. During the winter period the average of bottom/up delta from SOMLIT is around −0.15 °C. It can thus be assumed that the winter stratification is negligible in our study area unlike the summer period.

2.2. Methods

If the bloom mechanism is partly understood—it needs nutrients, spring increasing temperatures, and a good turbulence level (Steele and Gifford, 2010)—the precise mechanism is still not understood, and the reason for high or low blooms years is still unknown. The objectives of the methods used are to try to find out more about this determinism.

Many environmental studies in the aquatic areas use principal component analysis (PCA) method. The PCA is both a geometrical and statistical approach which allows to identify the correlations (and decorrelations) held among a multivariate data set. In this type of analysis, there is no test of the null hypothesis. In the framework of the present study the toolbox “princomp” from