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# High frequency variability of particle size distribution and its dependency on turbulence over the sea bottom during re-suspension processes

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ABSTRACT

The impact of tidal current, waves and turbulence on particles re-suspension over the sea bottom is studied through Eulerian high frequency measurements of velocity and particle size distribution (*PSD*) during 5 tidal cycles (65 h) in a coastal environment of the eastern English Channel. High frequency variability of *PSD* is observed along with the velocity fluctuations. Power spectral analysis shows that turbulent velocity and *PSD* parameters have similarities in their spectral behaviour over the whole range of examined temporal scales. The low frequency variability of particles is controlled by turbulence ($\beta \simeq -5/3$) and the high frequency is partly driven by dynamical processes impacted by the sea bottom interactions with turbulence (wall turbulence). Stokes number (*St*), rarely measured in situ, exhibits very low values, emphasizing that these particles can be considered as passive tracers. The effect of tide and waves on turbidity and *PSD* is highlighted. During slack tide, when the current reaches its minimum value, we observe a higher proportion of small particles compared to larger ones. To a lower extent, high significant wave heights are also associated with a greater concentration of suspended sediments and the presence of larger particles (larger Sauter's diameter $D_A$, and lower *PSD* slope $\xi$).



## 1. Introduction

Marine particles cover a broad range in diameters from nanometers, mainly as colloids, to few millimeters and even centimeters in the presence of big *Phaeocystis* colonies, diatoms chains, or cyanobacteria filaments. Intermediate size particles include viruses, heterotrophic bacteria, pico-, nano-, and micro-, phytoplankton, micro-, meso-, and macro-zooplankton, non-living particles, and mineral particles (Stramski et al., 2004). These particles do not solely appear as individual entities in the water column, but are mainly present as marine algal flocs and aggregates (Eisma, 1986; Fowler and Knauer, 1986; Hill, 1998; Boss et al., 2009). The variability of the marine particle size distribution (*PSD*) impacts the different biological processes occurring in oceanic waters and vice versa. For instance, trophic interactions are tightly linked to the size distribution of the different living and non-living particles involved all over the trophic system (McCave, 1984). In the other way, blooms of specific phytoplankton species modify the general *PSD* shape by affecting one given size class. Phytoplankton degradation processes as well as zooplankton grazing also affect the *PSD* shape by promoting the small particles size classes compared to larger ones. Physical processes occurring in the water column are also related to the *PSD*. For example, the settling velocity of the suspended matters is strongly controlled by the particles size. In contrast, the size distribution of floc or aggregate depends on the balance between aggregation and breakage, two processes driven by diffusive turbulent transport and differential settling (McCave, 1984). McCave suggested that particles in the Brownian range ($<1.0$ μm) are pumped rapidly into larger size classes by aggregation. The instantaneous turbulent kinetic energy modifies the proportion between particles/floccule, fine, coarse, microflocs and macroflocs (Lefebvre et al., 2012). The re-suspension of marine sediments is also strongly size dependent (Wells and Goldberg, 1992; Mikkelsen and Pejrup, 2001; Fettweis et al., 2006).

Turbulence is one of the most important physical phenomena which determines the re-suspension and the settling of the suspended particles in the coastal as well as oceanic waters (Eisma, 1986; Van Leussen, 1988; Umlauf and Burchard, 2005; Fettweis et al., 2006; Burchard et al., 2008; Van der Lee et al., 2009). For instance, observations on floc in the field show that smaller flocs occur in high energy environments (Kranck and Milligan, 1992; Berhane et al., 1997). At a critical magnitude of turbulence, shear overcomes the binding strength of flocs and tends to destroy aggregates (Eisma, 1986). For primary (disaggregated) particles significantly larger than 1.0 μm, and for the process of smaller flocs (microflocs) growing into larger flocs (macroflocs), turbulent shear is thought to be the dominant

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collision mechanism, except during periods of slack current velocities when differential settling of suspended particles onto one another may be responsible for most of the flocs formation and rapid clearing of the water (Van Leussen, 1988).

Studies done by Wolanski and Gibbs (1995) in Fly River Estuary show that the mean floc size was affected by the turbulence of tidal currents. The largest floc sizes were observed in the low tidal currents ($<0.5$ m/s) and comparatively smaller floc sizes were observed in the high tidal currents ($>0.5$ m/s).

In the present study, we analyse the dynamics of *PSD* and its relation with turbulence from in situ measurements. We conducted simultaneous measurements of velocity and *PSD* from instruments fixed on a frame positioned on the sea floor in the coastal waters of eastern English Channel. This study area, characterized by low depth, exhibits a large range of variability of bio-optical properties related to the occurrence of different phytoplankton blooms, bottom sediments re-suspension confined in the coastal areas, and numerous river inputs (Velegrakis et al., 1999; Loisel et al., 2007; Vantrepotte et al., 2007). The study carried out by Velegrakis et al. (1999) showed that re-suspension of fine-grained particles takes place during the spring tides and correlates well with the distribution of the bottom lithological type. In this paper, we will assess whether the re-suspended particles are passive tracers, or have an inertia that influences their transport by turbulence. For this, we estimate from in situ measurements their Stokes number *St*, which is a dimensionless number explaining the effect of inertia on the particles in a fluid motion. The impact of hydro-dynamical forcing on the particles behaviour is examined for different size classes of particles (silt/clay, fine, micro/coarse and macro flocs).

In the first section we present the study area as well as the different measurements and methods used to assess the coupling between turbulence and the particles behaviour over the sea bottom. The meteorological and hydrodynamic contexts occurring during the field measurements are then provided in the next section. The velocity field and the particle size distribution variability are described and their relationships are analysed. The Stokes numbers of these different particles, rarely measured in situ, are also estimated.

## 2. Data and methods

### 2.1. Study area

The measurements were conducted in the coastal waters of the eastern English Channel at a fixed station (50°45.676 N, 01°35.117 E) from 25 to 28 June 2012 (Fig. 1A). The different instruments (explained in the data section) are fixed on a structure which was positioned on the seafloor. The English Channel is a mega tidal sea having a tidal range that varies from 3 to 9 m, and experiencing a tidal current of amplitude close to 1.0 m/s (Desprez, 2000; Seuront and Schmitt, 2005; Korotenko et al., 2012). The biogeochemical environment during the particular sampling period is defined from in situ data collected few days before the experiment (21 June) in the frame of the SOMLIT program in two different areas and in high tide period (Fig. 1B). Significant stratification can be noticed from the surface to the bottom at the coastal station for Chlorophyll-a (Chl-a), particulate organic carbon (POC) and suspended particulate matter (SPM) (Table 1). The SPM and Chl-a values are relatively low for a coastal environment, in good agreement with the summer low fresh water discharge, and the absence of phytoplankton bloom. The POC concentration is however relatively high. Besides, the relatively high POC/Chl-a ratio values, a proxy of the carbon mass of living and non-living organisms with respect to the autotrophic organisms (Loisel et al., 2007), indicate that the particulate organic

**Table 1**
Biogeochemical data collected from SOMLIT few days before the time series measurements (21 June 2012) from the stations C and L (shown in Fig. 1B).

| Site | Depth | Temperature (°C) | Salinity (psu) | POC (μg/l) | SPM (mg/l) | Chl-a (μg/l) |
|---|---|---|---|---|---|---|
| C | Surface | 15.83 | 34.43 | 341.9 | NA | 0.5 |
| C | Bottom | 14.82 | 34.76 | 239.67 | 1.54 | 0.5 |
| L | Surface | 14.88 | 34.93 | 220.9 | 0.48 | 1.21 |
| L | Bottom | 13.92 | 35.06 | 85.804 | 1.63 | 0.18 |

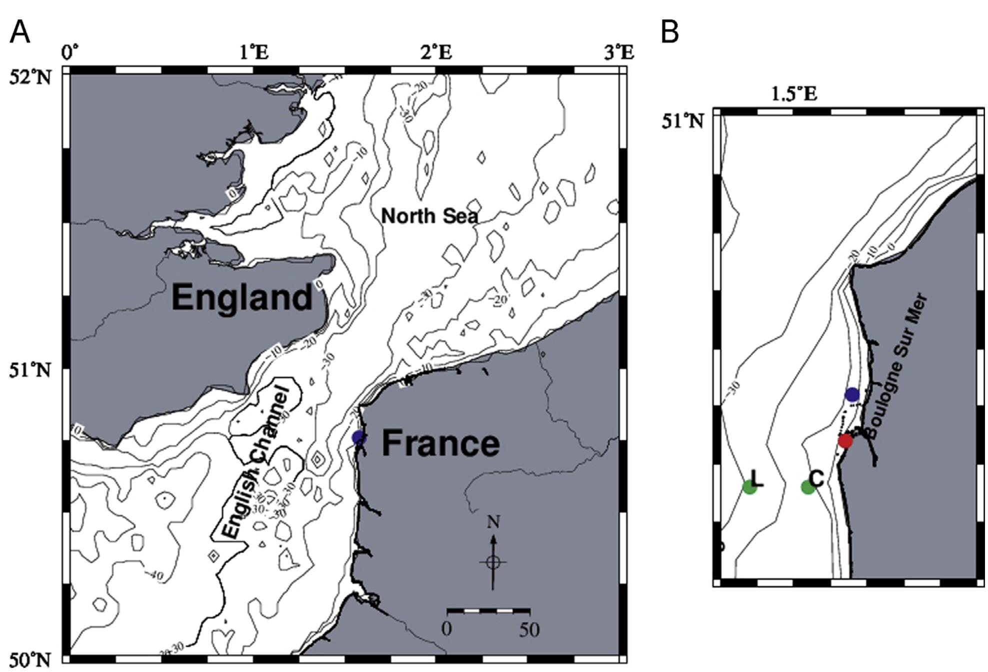


**Fig. 1.** Location (blue dot) of the sampling area in the eastern English Channel together with the isobaths (A). Zoom on the sampling area (blue dot), the meteorological station (red dot) and SOMLIT stations (green dot) in (B). (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this paper.)