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ORIGINAL RESEARCH ARTICLE

The relationship between Suspended Particulate Matter and Turbidity at a mooring station in a coastal environment: consequences for satellite-derived products

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Summary From a data set of observations of Suspended Particulate Matter (SPM) concentration, Turbidity in Formazin Turbidity Unit (FTU) and fluorescence-derived chlorophyll-*a* at a mooring station in Liverpool Bay, in the Irish Sea, we investigate the seasonal variation of the SPM: Turbidity ratio. This ratio changes from a value of around 1 in winter (minimum in January—February) to 2 in summer (maximum in May—June). This seasonal change can be understood in terms of the cycle of turbulence and of the phytoplankton population that affects the nature, shape and size of the particles responsible for the Turbidity. The data suggest a direct effect of

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phytoplankton on the SPM:Turbidity ratio during the spring bloom occurring in April and May and a delayed effect, likely due to aggregation of particles, in July and August. Based on the hypothesis that only SPM concentration varies, but not the mass-specific backscattering coefficient of particles b_{bp}^*, semi-analytical algorithms aiming at retrieving SPM from satellite radiance ignore the seasonal variability of b_{bp}^* which is likely to be inversely correlated to the SPM:Turbidity ratio. A simple sinusoidal modulation of the relationship between Turbidity and SPM with time helps to correct this effect at the location of the mooring. Without applying a seasonal modulation to b_{bp}^*, there is an underestimation of SPM in summer by the Ifremer semi-analytical algorithm (Gohin et al., 2015) we tested. SPM derived from this algorithm, as expected from any semi-analytical algorithm, appears to be more related to in situ Turbidity than to in situ SPM throughout the year.

1. Introduction

Suspended Particulate Matter (SPM) is a major component of the coastal environment that is monitored for multiple purposes. We may name among them a better knowledge of sediment transport and the response of the suspended sediment load to resuspension, deposition, and river discharge. Through light absorption and scattering the SPM also contributes to water clarity and governs the amount of photons available for photosynthesis in the water column. Suspended matter is also a state variable of the sediment transport and biogeochemical models of coastal seas. The geographical distribution of SPM concentration is key for analyzing the deposition and erosion patterns in an estuary and evaluating the material fluxes from river to sea. Satellite remote-sensing, associated with instrumented moorings, provide useful data for investigating the spatial and temporal variation of SPM in estuarial and coastal zones. Some of these algorithms (Binding et al., 2003; Forget et al., 1999; Lahet et al., 2000; Li et al., 1998) are empirical and others (Eleveld et al., 2008; Gohin et al., 2005; Han et al., 2016; Nechad et al., 2010; Van der Woerd and Pasterkamp, 2008) are semi-analytical as they make use of the Inherent Optical Properties (IOPs) of the water constituents. Products of non-algal SPM derived from the Ifremer semi-analytical algorithm (Gohin et al., 2005; Gohin, 2011) have been provided for years to a large community and used, with or without in situ data, for validating hydro-sedimentary models (Edwards et al., 2012; Ford et al., 2017; Guillou et al., 2015, 2016; Ménésguen and Gohin, 2006; Sykes and Barciela, 2012; Van der Molen et al., 2016, 2017) or forcing the light component in biogeochemical modelling (Huret et al., 2007) over the northwest European continental shelf.

Autonomous observation platforms such as ferrybox or instrumented buoys typically do not provide SPM concentration directly but instead provide Turbidity measurements. Turbidity data are by far the most frequent data set related to SPM provided to the scientific community and managers of the coastal environment. For this reason and as Turbidity is tightly related to backscattering, Dogliotti et al. (2015) suggest making use of a semi-analytical relation to estimate Turbidity from marine reflectance and, in a second step, derive SPM from Turbidity. All semi-analytical methods aiming to retrieve directly SPM concentration assume the stability of the mass-specific backscattering, b_{bp}^*, which is considered as constant in space and throughout the seasons. This assumption remains to be verified in coastal waters where there is a seasonal variation in the nature of the SPM, from small mineral particles in winter to phytoplankton cells, aggregates and flocs in summer.

Martinez-Vicente et al. (2010) observed a seasonal effect on the scattering properties of particles at a coastal station of the Western English Channel (the L4 station located off Plymouth at 50.25N, 4.22W). These authors observed that the SPM:b_p(555) ratio (where b_p is the scattering coefficient of mineral and organic particles) varies between a winter mean of 2 and a summer mean of 1.1 g m^{-2}. The mean mass-specific particle backscattering coefficient, b_{bp}^* was 0.0027 m^2 g^{-1} for total SPM at 532 nm, and higher with respect to Suspended Particulate Inorganic Matter (SPIM). The measured mass-specific backscattering, b_{bp}^*, was 0.0075 in winter and 0.0023 m^2 g^{-1} in summer; which is at the lower end of values reported for coastal waters (Berthon et al., 2007; Snyder et al., 2008). Given the small amount of data available, however, the authors recognised that it was difficult to draw conclusions about the seasonality of this coefficient. At the L4 station, the SPM mean value was relatively low for a coastal site (1.00 ± 0.88 g m^{-3}) with peaks in winter (with a stronger contribution of SPIM). However, the highest winter peak of 9.94 g m^{-3} is lower than that observed in general in coastal waters (up to 100 g m^{-3} in winter). A particularly high content of mineral particles in winter and strong phytoplankton blooms in summer are likely to emphasise the variability of the inorganic:organic fraction for suspended particles in coastal waters with consequences for the backscattering properties.

In a study encompassing a large range of water types, Neukermans et al. (2012) observed that waters dominated by mineral particles backscatter up to 2.4 times more per unit mass, $b_{bp}^* = 0.0121$ m^2 g^{-1}, than waters dominated by organic particles, $b_{bp}^* = 0.0051$ m^2 g^{-1} at 650 nm. Similar conclusions were pointed out in Arctic seawaters by Reynolds et al. (2016) who observed that the average b_{bp}^* of mineral assemblages was almost twice that of organic assemblages. The positive dependency of the mass-specific backscattering coefficient on the SPIM:SPM ratio has also been shown by Bowers et al. (2014).

In the Irish Sea, McKee and Cunningham (2006) identified two water sub-types that are distinguished both optically and by the ratio of the concentrations of their constituents (Chl:SPIM). The Inherent Optical Properties (IOPs) at stations with a low ratio of chlorophyll-*a* to suspended particles, Group "Mineral", were highly correlated with the concentration of