satellite ocean color observations, including satellite-derived ocean remote-sensing reflectance, $R_{rs}(\lambda)$, as well as satellite-derived IOPs such as $b_{bp}(\lambda)$ and the total absorption coefficient of seawater, $a(\lambda)$, have been developed for application at the global oceanic scale (Wang et al., 2022). Although the study of Wang et al. (2022) suggests that PON can be estimated from satellite ocean color products, the PON vs. IOP relationships have not yet been investigated using field measurements collected over a broad range of oceanic and coastal marine environments.

The main objective of the present study is to examine the relationships between the PON and particulate IOPs, including $b_{bp}(\lambda)$, $a_p(\lambda)$, $a_{ph}(\lambda)$, and $a_d(\lambda)$, from in situ near-surface measurements collected over a broad range of marine bio-optical environments. For this purpose, we assembled datasets of concurrent PON and IOP measurements from the open-ocean pelagic environments, Arctic seas, and coastal waters around Europe. The relationships between PON and spectral IOPs are presented and discussed in terms of variability and its sources, as observed in the relationships examined across the different marine environments. This analysis provides insights into the potential applicability of different particulate IOPs to serve as proxies for PON.

2 Materials and methods

2.1 Geographic locations of in situ measurements

A dataset of in situ biogeochemical and optical measurements was assembled from multiple field experiments performed in various open-ocean and coastal regions covering a broad range of PON, POC, and particulate IOPs collected at depths between the sea surface and 10 m (Fig. 1; Table 1). The whole dataset (referred to as WD) consists of three subsets of data collected in different regions that generally represent different marine bio-optical environments.

The first subset of data (referred to as OOD for the open-ocean dataset) includes measurements made during three cruises conducted in open-ocean waters in the Pacific and Atlantic oceans. The BIOSOPE (Biogeochemistry and Optics South Pacific Experiment) cruise took place from October to December 2004 in the eastern South Pacific Ocean along an east-to-west transect from the Marquesas Islands to the coast of Chile (Claustre et al., 2008; Stramski et al., 2008). The KM12-10 cruise was carried out in June 2012 in tropical waters off the Hawaiian Islands (Johnsen et al., 2014; Reynolds and Stramski, 2021). The ANTXXVI/4 cruise was conducted in April and May 2010 along a south-to-north transect in the Atlantic Ocean between Chile and Germany (Uitz et al., 2015).

The second subset of data (referred to as AOD for the Arctic Ocean dataset) includes measurements collected in the western Arctic seas, specifically in the Chukchi Sea and western Beaufort Sea, during three cruises, HLY1001 in June–July 2010, HLY1101 in June–July 2011, and MR17-05C in August–September 2017 (Arrigo, 2015; Reynolds and Stramski, 2019; Shiozaki et al., 2019). The data collected in these high-latitude environments are characterized by the presence of specific phytoplankton communities and a relatively high contribution of dissolved organic matter (CDOM) and non-algal particulate matter to the IOPs of seawater (Reynolds and Stramski, 2019).

The third subset of data (referred to as CWD for the coastal-water dataset) consists of data collected as part of the COASTlOOC (Coastal Surveillance Through Observation of Ocean Color) research project, which involved numerous experiments in various coastal waters around Europe in 1997 and 1998 (Massicotte et al., 2023a). This dataset represents the bio-optical variability encountered across diverse coastal waters, including shelf and relatively shallow environments in the Baltic Sea, North Sea, Wadden Sea, English Channel, and Adriatic Sea, as well as waters affected by many river plumes around Europe (Babin et al., 2003a, b). A small fraction of CWD (< 3 % of COASTlOOC data) includes measurements collected in open-ocean waters in the Atlantic Ocean between the Bay of Biscay and the Canary Islands and off the shelf in the Mediterranean Sea, where the bio-optical variability is expected to be driven primarily by phytoplankton and associated material.

The total number of concurrent POC and PON measurements, N_{POM}, in the whole dataset, WD, is 432 (Table 1). The contributions of OOD, AOD, and CWD to this total number are 18.8 %, 25.2 %, and 57.4 %, respectively. These measurements of PON and POC are used to discuss the variability in the POC / PON ratio in Sect. 3.1. The number of concurrent measurements of PON and IOPs that are used to examine the relationships between these variables is smaller than N_{POM}. Specifically, the relationship between PON and the backscattering coefficient b_{bp} presented here is based on 284 measurements in the whole dataset, WD (Sect. 3.2.1), and the relationships between PON and the absorption coefficients, a_p, a_{ph}, and a_d, are based on 392 measurements (Sect. 3.2.2).

2.2 Measurement methods

The measurement and data processing protocols are described in detail in the references cited in Sect. 2.1. Here we provide a brief summary. Samples for POC and PON determination were collected by filtration of seawater through pre-combusted 25 mm Whatman GF/F filters. After filtration, the samples were transferred into glass vials, dried at 55 °C, and stored until post-cruise analysis. The mass of particulate organic carbon and nitrogen on the sample filters was determined by high-temperature combustion via standard CHN CE3 analysis following the JGOFS (Joint Global Ocean Flux Study) protocols (Knap et al., 1996). The samples were acid-treated prior to the CHN analysis to remove inorganic carbon. The mass concentration of suspended particulate matter (SPM) was determined gravimetrically by measuring the dry