The COASTℓOOC project dataset

Philippe Massicotte[1], Marcel Babin[4, 1], Frank Fell[2], Vincent Fournier-Sicre[3, 5], and David Doxaran[4]

[1]*Takuvik International Research Laboratory (IRL 3376) ULaval - CNRS, Biology department, Laval University, Quebec, Canada
[2]Informus GmbH, Berlin, Germany
[3]ACRI-ST 260 Route du Pin Montard, 06904 Sophia-Antipolis, France Phone: +33 4 92 96 75 00
[4]Laboratoire d'Océanographie de Villefranche, CNRS / Sorbonne Université , Villefranche-sur-mer, France
[5]*Data Processing Systems Procurement Manager European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) EUMETSAT-Allee 1, 64295 Darmstadt, Germany Office: +49 6151 807 7336 Mobile: +49 151 174 38520

Correspondence: Marcel Babin (marcel.babin@takuvik.ulaval.ca)

Abstract. Coastal Surveillance Through Observation of Ocean Color (COASTℓOOC) oceanographic expeditions were conducted in 1997 and 1998 to examine the relationship between the optical properties of seawater and related biological and chemical properties across the coastal-to-open ocean gradient along the European coasts. A total of 379 stations were visited along the coasts of the Gulf of Lion in the Mediterranean Sea ($n = 61$), Adriatic Sea ($n = 39$), Baltic Sea ($n = 57$), North Sea
5   ($n = 99$), English Channel ($n = 85$) and Atlantic Ocean ($n = 38$). A particular emphasis ~~has been~~ dedicated to the collection of a comprehensive set of apparent (AOPs) and inherent (IOPs) optical properties to support the development of ocean color remote sensing algorithms. The data were collected in situ using traditional ship-based sampling, but also from a helicopter, which is a very efficient means for that type of coastal sampling. The dataset collected during the COASTℓOOC campaigns is still today quite unique in that it is fully consistent in terms of operators, protocols, and instrumentation. This rich and historical
10   dataset is ~~still today~~ frequently requested and used by other researchers. Therefore, we present the result of an effort to compile and standardize a dataset which will facilitate their reuse in future development and evaluation of new bio-optical models adapted for optically-complex waters. The dataset is available at https://doi.org/10.17882/93570 (Massicotte et al., 2023).

1   Introduction

Since the launch of the Coastal Zone Color Scanner (CZCS) by NASA in 1978, ocean color remote sensing has been used to
15   monitor the state of, and the changes in global marine ecosystems both in time and space. In open oceans, the main component that affects the variations in the inherent (IOPs) and apparent (AOPs) optical properties of seawater is phytoplankton, which is usually represented by the concentration of chlorophyll *a* (Morel and Prieur, 1977). Such open ocean waters are traditionally termed Case 1 waters. Many simple empirical spectral band ratio algorithms have been developed to link changes in remotely-sensed ocean color (OC), measured as reflectance, to the variations in chlorophyll *a* concentration (see O'Reilly and Werdell
20   2019 for an extensive evaluation of OC band ratio algorithms). Because these algorithms perform surprisingly well, a plethora

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*Current address
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of studies have been conducted based on it, notably about phytoplankton phenology (e.g., Vargas et al. 2009) and phytoplankton primary production (see Carr et al. 2006 and references therein).

Space-borne monitoring of aquatic ecosystems is more challenging for optically complex Case 2 waters (Morel and Prieur, 1977) often found in coastal areas. In contrast to Case 1 waters, the optical properties of Case 2 waters are determined by several types of constituents occurring in highly variable concentrations. Inland rivers typically drain large catchment areas that deliver important quantities of optically significant substances such as chromophoric dissolved organic matter (CDOM) and suspended particulate matter (SPM) to the coastal waters (Hedges et al., 1997; Cole et al., 2007; Massicotte et al., 2017). In these areas, bottom reflectance and resuspension of sediments can also alter the signal of water-leaving reflectance (Lee et al., 1998). Because CDOM and SPM do not necessarily covary with chlorophyll a and can mask the signal from phytoplankton (Sat, 2000), bio-optical algorithms developed for Case 1 waters are generally not appropriate for optically-complex Case 2 waters (Gordon and Morel, 1983). Hence, in situ measurements of optically active components (CDOM, SPM, chlorophyll a), related radiometric quantities, AOPs and IOPs are, even to this day, critically needed to develop and improve bio-optical algorithms for coastal areas.

The objective of the Coastal Surveillance Through Observation of Ocean Color (COASTℓOOC) oceanographic expeditions was to acquire a comprehensive set of AOPs and IOPs along the European coasts. Concentrations of the optically significant components were also collected to help the development of new remote sensing algorithms in optically complex waters. Back in 1997 and 1998, the COASTℓOOC campaigns were among the very first concerted efforts to fill the knowledge gaps in coastal marine optics by establishing a large, homogenous, and complete optical dataset for coastal waters. A total of 379 stations were visited along the coasts of the Mediterranean, Adriatic, Baltic and North Sea, in the English Channel, and in the Atlantic Ocean, mostly in coastal, but also in open oceanic waters. While this unique set of data has been used or referenced over the years in numerous peer-reviewed publications (see list in Appendix A), a reference final dataset, with well-documented quality controls, has never been published. Even though the COASTℓOOC campaigns were carried out more than 20 years ago, the rich and historical dataset that has been collected still has great potential to contribute to the development and evaluation of new bio-optical models adapted for optically-complex waters. The goal of this paper is to formally present a quality-controlled and final reference version of the COASTℓOOC dataset, archived in a public repository where users can download it readily.

2 Study area and sampling overview

2.1 Study area and general sampling strategy

During the six COASTℓOOC campaigns, further referred to as C1 to C6, a total of 379 locations were visited (Fig. 1). The stations were located along the coasts of the Gulf of Lion in the Mediterranean Sea ($n = 61$), Adriatic Sea ($n = 39$), Baltic Sea ($n = 57$), North Sea ($n = 99$), English Channel ($n = 85$) and Atlantic Ocean ($n = 38$). Within each area, the stations were generally distributed along across-shore or along-shore transects to capture the land-to-sea gradients and document river plumes (Fig. 1B). COASTℓOOC campaigns were either ship-based (C1, C4, C5) or used a helicopter as a sampling platform (C2, C3, C6) between 1997-04-02 and 1998-09-25 (Fig. 2A). Compared to traditional ship-based sampling, the helicopter

platform allowed ~~to efficiently sample stations~~ close to the coast in areas difficult to access by boat (some samples were
55   collected in waters as shallow as 1 m, Babin 2003). Combining both ship and airborne sampling approaches allowed covering
the whole inshore to open-ocean aquatic continuum. The bathymetry (GEBCO Bathymetric Compilation Group 2020, 2020)
varied greatly across the stations, where it averaged 10 meters in the Adriatic Sea and 2600 meters in the Case 1 Mediterranean
Sea (Fig. 2B).

2.2   Data collection

60   At each site, between six and eight liters of water just below the surface were collected using either Niskin or polyethylene
bottles for laboratory analyses. Water samples collected onboard the ship were ~~immediately processed~~ or within two hours if
sampled using the helicopter (see Babin 2003 for further details).

2.3   Suspended particulate matter and pigments

On board the ship, water samples were analyzed and/or stored immediately after collection. When using a helicopter as a
65   sampling platform, water samples were kept in six lite~~rs~~ polyethylene containers no longer than two hours after sampling.
Filtration was conducted at low vacuum onto 25 mm glass fiber filters (Whatman, GF/F) to collect particles for subsequent
analyses, as described below. Three separate subsamples (up to two liters each) were filtered for each sample with the following
purposes. To determine the concentration of suspended particulate matter (SPM; g m^{-3}), the particles collected onto a pre-
weighed GF/F filter were dried and stored in a freezer at -80 °C until the dry weight was determined less than two months later
70   in the laboratory (Van Der Linde, 1998). For pigment analysis, the filter with collected particles was inserted into a cryotube
and kept in liquid nitrogen until analysis less than three months later. High-performance liquid chromatography (HPLC) was
used as described by Vidussi et al. 1996 to determine liposoluble pigment concentrations. Total chlorophyll *a* is here defined
as the sum of chlorophyll *a*, divinyl-chlorophyll *a*, chlorophyll *a* isomer and epimer, chlorophyllids a, and phaeopigments. The
concentrations of particulate organic carbon and nitrogen (POC and PON, respectively) were determined using a Carlo Erba
75   NCS 2500 elemental analyzer as described in Ferrari et al. 2003. These determinations were made on particles collected on~~to~~
a GF/F filter precombusted at 450 °C for 2 h and stored in the freezer at -80 °C until analysis less than two months later.
Further details concerning laboratory analyses can be found in Babin 2003; Ferrari 2000; Ferrari et al. 2003. To determine the
concentration of dissolved organic matter (DOC, M), seawater samples were filtered on a 0.22 mm Millipore membrane. The
final filtrate was transferred to a 100-mL amber-glass bottle, stored in the refrigerator and analyzed within 3 weeks. DOC was
80   determined by high temperature catalytic oxidation using a Carlo Erba 480 analyzer. The methodological details can be found
in Ferrari 2000.

2.4   Optical measurements

At each station, an optical package was deployed in the water column from the surface, down to a few meters above the
ocean bottom in shallow waters, and to maximum depths of ca. 100 m in deep waters. The deployed package included a CTD

85 (conductivity, temperature, and depth) as well as an array of optical instruments to simultaneously measure the coefficients of beam attenuation, absorption and scattering, and irradiance in the water column. The Modular Data and Power System (MODAPS) data-gathering system from Wetlabs Inc., USA was used to combine the time-stamped data from the different instruments to produce a data matrix with a common depth grid. For further information, please refer to the COASTℓOOC final report (Aiken et al., 2022).

90 A specific aspect of COASTℓOOC is the use of a helicopter as a sampling platform, which has enabled high-frequency visiting of sites in very shallow waters (see section 2.1). A drawback of this approach is the difficulty to operate a helicopter stationary at a constant height, especially at low or varying wind speeds. This can result in vertical movements of the instrument package in water on the order of 1-2 m s^{-1}. To ensure the availability of data of sufficient quality close to the surface, several consecutive up- and downcasts were performed at each "helicopter" site. Across all the measured vertical profiles, the most

95 suitable casts for depth merging and surface extrapolation (not necessarily the same) were selected.

2.4.1 Irradiance measurements

The SeaWiFS Profiling Multichannel Radiometer (SPMR, Satlantic Inc, Canada) was used to measure the downward (E_d, W m^{-2} μm^{-1}) and upward (E_u, W m^{-2} μm^{-1}) irradiances in the water column. E_d and E_u at a total of 13 wavelengths from the blue part of the spectrum (ca. 410 nm) to the near-infrared (ca. 865 nm) were measured at a rate of 6 Hz . The actual

100 wavelengths differ slightly between upward and downward observations. Also, the set of nominal wavelengths were partly modified after campaign no. 1 (i.e., for campaigns 2 to 6) to better match the MERIS satellite channels (see below). For the ship-based measurements, concomitant observations of the in-air downward spectral irradiance at the sea surface were performed to account for changes in the incoming solar radiation during the in situ profiling (e.g., due to clouds). This approach was not achievable for the helicopter-based measurements, since there was no suitable place to mount the radiometer. For these

105 campaigns, measurements of E_d taken by the profiler while in air (before and after the in-water measurements) were used to assess E_d on the sea surface. In order to minimize the time lag between the in-water measurements and the E_d values on the sea surface, our processing code automatically chose the air measurements closest in time.

2.4.2 Irradiance surface extrapolation

To calculate the water-leaving reflectance, accurate measurements of both E_d and E_u just below the water surface ($z = 0^-$) are

110 needed. In case no spectrally matching in-air E_d reference data are available (as is the case for the helicopter-based campaigns), this was done by extrapolating both $E_d(z)$ and $E_u(z)$ vertical profiles toward the sea surface by fitting an exponential model for the depth dependence of the measured spectral irradiance values (equation 1):

$$\Gamma(\lambda, z) = \Gamma(\lambda, 0^-) e^{-K_\Gamma(\lambda) z} \tag{1}$$

where $\Gamma(\lambda, z)$ is either E_d or E_u measured at wavelength λ and at depth z, $\Gamma(\lambda, 0^-)$ is E_d or E_u estimated at the air-
115   water interface, and K_Γ is either the estimated diffuse attenuation coefficient for downward (K_{Ed}, m^{-1}) or upward (K_{Eu}, m^{-1})
irradiance.

In case spectrally matching in-air $E_d\ (0^+)$ reference data are available (as is the case for most ship-based campaigns), $E_d\ (0^-)$
is calculated from $E_d\ (0^+)$ by applying channel-specific air-sea transmission factors. The such derived $E_u\ (0^-)$ and $E_d\ (0^-)$ values
are then used to calculate the water reflectance $R\ (0^+)$ just below the sea surface:

120   $$R(0^-) = \frac{E_u(0^-)}{E_d(0^-)} \tag{2}$$

Vertical irradiance profiles in the red and near-infrared channels above 600 nm were fitted using a sum of two exponential
functions to account for Raman scattering significantly contributing especially to the upward light field at these wavelengths
(e.g., Sugihara et al. 1984). Not doing so will lead to a substantial underestimation of the extrapolated subsurface values due
to significant Raman contribution from excitation wavelengths with significantly lower K values (see Appendix 1).

125   ### 2.4.3   Irradiance depth merging

Depth-merged profiles were derived for all sites by applying a standardized approach. The underlying strategy for depth merg-
ing was to provide users with the information they need to do their own analyses, while modifying the original data as little as
possible. Processing was therefore limited to procedures that could be applied equally to all COASTℓOOC campaigns, whether
helicopter- or ship-based. For example, variations of the incoming solar radiation were not considered in the depth merging
130   process, since such observations were not available for the helicopter-based campaigns. However, if measured while operating
from research vessels, such information is included in the depth-merged profile data to allow users to do their own subsequent
analyses.

Typically, several up- and downcast vertical profiles were performed, especially when using the helicopter as a sampling
platform, to increase the potential availability of high-quality observations. The actual merging process was executed as follows.
135   First, any observation not meeting both of the two following conditions was discarded: (1) SPMR instrument tilt smaller than
20° and (2) SPMR vertical speed between 0.1 and 2.0 m s^{-1}. To automatically identify the best-suited cast for profile generation,
the observations meeting the above two conditions were then distributed cast-wise over 0.2 m wide vertical bins, starting at
zero depth. Finally, the cast with the highest number of bins containing at least one valid observation was selected for depth
profile generation, if it fulfilled two further conditions: (3) at least 2 m vertical distance between the highest and the lowest bin
140   and (4) at least 50% of the bins contain at least one observation. No depth merged data is provided for stations where there is no
cast meeting all of the above four conditions. Combining several casts of a station has not proven successful due to potentially
large discontinuities at depth levels where the number of available casts changes, especially in case of unstable atmospheric
conditions with the corresponding short-term irradiance fluctuations.

Actual depth merging was done by taking the median of all observations of a particular irradiance parameter within each
145   depth bin. Spectral irradiance observations were only considered for values above 0.01 W m^{-2} µm^{-1} to reduce the impacts of

potentially inaccurate dark current correction and significantly increasing radiometric noise. Finally, an attempt was made to identify and mask out remaining outliers in the depth-merged irradiance profiles. This was done by applying Grubb's test at 5% significance level (Guthrie, 2012) to the residual of a second-order polynomial fit of the logarithmic-transformed spectral irradiance observations for a 2 m depth window, sliding down in steps of 1 m. While this procedure has successfully identified

150 individual spikes, some obvious outliers extending over several depth bins remain in the merged dataset, and users will need to make their own judgment on how to identify and remove those. Examples of depth-merged irradiance profiles are shown in Fig. 3 for one clear-water site in the NE Atlantic and one CDOM-rich site in the Baltic Sea.

Note that extrapolated surface values and depth-merged profiles for a specific site are not necessarily derived from the same observations. This is especially true for helicopter-based operations typically comprising several up- and downcast close to the

155 water surface to increase the likelihood of having sufficient observations for the surface extrapolation, while usually only one or two deep-water casts were made to obtain observations at larger depth. The best-suited observations for surface extrapolation do therefore not necessarily correspond to the cast used for depth merging.

2.4.4 Profiles of the diffuse attenuation coefficient

Downward (K_{Ed}, m^{-1}) and upward (K_{Eu}, m^{-1}) spectral diffuse attenuation coefficients have been derived from the depth-merged

160 irradiance data by fitting an exponential function through the irradiance observations within a 2 m depth window, sliding down in steps of 0.2 m. The calculation was only performed if at least five observations were available within each bin. The choice of the binning window width was based on a compromise between two conflicting requirements. On the one hand, the window width should be small enough to allow resolving relatively narrow vertical features, such as for example a deep chlorophyll a maximum. On the other hand, it should be wide enough to allow for an accurate estimation of K. This relatively narrow

165 window width favors vertical resolution over accuracy: while even relatively narrow vertical features remain visible in the derived K profiles, these are on the other hand affected by remaining outliers, instrument tilt variations, or instrumental noise. Obviously, users may use the depth-merged irradiance profiles to derive K profiles or depth-integrated K values to better meet their individual requirements.

2.4.5 Chromophoric dissolved organic matter (laboratory measurements)

170 Measurements of chromophoric dissolved organic matter (CDOM) absorption (a_{CDOM}, m^{-1}) were performed in the laboratory using a spectrophotometer (Perkin Elmer, Lambda 12) on water samples filtered on a 0.22 μm Millipore membrane pre-rinsed with 50 ml of Milli-Q water (Babin, 2003). a_{CDOM} spectra were measured between either 300-750 nm or 350-750 nm at 1-nm increment.

2.4.6 Particulate, non-algal and phytoplankton absorption (laboratory measurements)

175 Water samples were filtered onto 25 mm glass fiber filters (Whatman, GF/F) at a low vacuum before absorption measurement (Babin, 2003). Total particulate absorption (a_P, m^{-1}) was measured on particles retained on the filters between 380 and 750 nm

at 1-nm increment using a spectrophotometer equipped with a 60 mm integrating sphere (Perkin Elmer, Lambda 19), and following the transmittance-reflectance (TR) method (Tassan and Ferrari, 1995, 1998). Afterward, pigments were removed from the particles with sodium-hypochloride to measure non-algal (or non-pigmented) absorption (a_{NAP}, m^{-1}). Finally, phytoplankton absorption (a_ϕ, m^{-1}) was retrieved by subtracting a_{NAP} from a_P. a_{CDOM} and a_{NAP} absorption spectra were fitted according to the following equation (Jerlov, 1968; Bricaud et al., 1981):

$$a_\tau(\lambda) = a_\tau(\lambda_0)e^{-S_\tau(\lambda-\lambda_0)} + k \tag{3}$$

Where a_τ is the absorption coefficient, either a_{CDOM} or a_{NAP} (m^{-1}), λ is the wavelength (nm), λ_0 is a reference wavelength (443 nm), S_τ is the spectral slope (nm^{-1}) that describes the approximate exponential decrease in absorption with increasing wavelength and k a background constant (m^{-1}) accounting for scatter in the cuvette and drift of the instrument. a_{CDOM} spectra were fitted using observations below 700 nm, whereas a_{NAP} fits were performed between 380 and 730 nm, excluding spectral regions between 400-480 nm and 620-710 nm to avoid possible residual pigment absorption (Babin, 2003). a_{CDOM} and a_{NAP} were baseline corrected by subtracting the background parameter (k) derived from the following equation:

$$\hat{a}_\tau(\lambda) = a_\tau(\lambda) - k \tag{4}$$

Finally, the spectral background of a_P spectra (i.e., the average absorption measured between 746 and 750 nm) were added to a_{NAP}. The underlying rationale is that absorption by phytoplankton in the near-infrared (NIR) is null, and that absorption measured in the NIR for total particles using the TR method is real (Tassan and Ferrari, 2003) and belongs exclusively to non-algal particles. The absorption signal measured for total particles retained on untreated filters is assumed more reliable than that measurement on bleached filters.

2.4.7 Total absorption and scattering (in situ measurements)

In situ vertical profiles of absorption (a, m^{-1}) and beam attenuation (c, m^{-1}) were acquired at nine wavelengths (412, 440, 488, 510, 555, 630, 532 or 650 depending on instrument configuration, 676, and 715 nm) using a flow-through in situ absorbance-attenuance meter (AC9, Wetlabs). As the measurements are referenced to pure (Milli-Q) water, the obtained absorption and attenuation coefficients exclude the contribution of water. To correct absorption measurements for incomplete recovery of scattered light, $a(715)$ was subtracted from $a(\lambda \leq 715)$. Scattering coefficients (b, m^{-1}), were calculated by subtracting absorption from attenuation. As the contribution of molecular (water) scattering is excluded (see above), this coefficient essentially corresponds to particle scattering and is hereafter denoted b_P (m^{-1}).

3 Data quality control and data processing

Different general quality control procedures were adopted to ensure the integrity of the data. First, the raw data were visualized and screened to eliminate errors both originating from the measurement devices, including sensors (systematic or random),

and errors inherent to measurement procedures and methods. Statistical metrics such as average, standard deviation, and range were computed to detect and remove anomalous values in the data. Then, data were checked for duplicates and remaining outliers. The complete list of variables is presented in Table 1.

4 Data description (an overview)

4.1 Spatial variability along the coastal-ocean gradient

The COASTℓOOC sampling strategy was primarily designed to capture the bio-optical gradient across the sampled ecosystems and along transects from the coast towards the open ocean within each area (Fig. 1). The following sections present an overview of a few selected variables measured in the different areas. An extensive and detailed explanatory visualization analysis is presented in the final report of the COASTℓOOC project (Aiken et al., 2022).

4.1.1 chlorophyll *a* and particulate organic carbon

As observed in Fig. 4, both total chlorophyll *a* and particulate organic carbon (POC) concentrations varied markedly across the sampled areas, reflecting the natural gradient captured by the sampling strategy. Across all the stations, total chlorophyll *a* ranged between 0.05 and 29 mg m^{-3}. The median chlorophyll *a* ranged between 0.1 mg m^{-3} in the Atlantic Ocean and 5.9 mg m^{-3} in the Baltic Sea (Fig. 4A). Based on the definition proposed by Antoine et al. 1996, the sampled stations were representative of a wide range of trophic status: oligotrophic ($n = 17$, chlorophyll $a \leq 0.1$ mg m^{-3}), mesotrophic ($n = 106$, $0.1 \leq$ chlorophyll $a \leq 1$ mg m^{-3}) and eutrophic ($n = 245$, chlorophyll $a > 1$ mg m^{-3}). A similar shore-to-sea gradient pattern could be observed for POC, with median values varying between 0.1 g m^{-3} and 0.8 g m^{-3} in the Mediterranean Sea (case 2) and Baltic Sea, respectively (Fig. 4B, range between 0.02 and 2.5 g m^{-3}).

4.1.2 Inherent optical properties (IOPs)

Averaged absorption spectra by area for total particulate (a_P), non-algal particles (a_{NAP}), phytoplankton (a_ϕ), and chromophoric dissolved organic matter (a_{CDOM}) are presented in Fig. 5. Phytoplankton maximum absorption peaks, at around 440 nm and 675 nm, are easily distinguishable in Fig. 5C and were found to be highly correlated with the concentration of total chlorophyll *a* (Pearson's $r > 0.90$). Across all the areas, $a_{CDOM}(350)$, a proxy for watercolor and dissolved carbon concentration, varied between 0.03 and 3.66 m^{-1}. These values fall within the ranges of the mean values reported globally in the ocean (0.14 m^{-1}), coastal (1.82 m^{-1}), and estuaries (4.11 m^{-1}) ecosystems (Massicotte et al., 2017). Overall, the highest absorption by dissolved organic matter was observed in the Baltic Sea (Fig. 5D). Sampled stations in this area were located West of the Oder River plume, which drains important quantities of humic substance from its catchment area. In contrast, the lowest CDOM absorption was observed in the Atlantic Ocean, where stations were located away from land and thus less influenced by terrestrial inputs (Fig. 1). The spatial variability of CDOM is further strengthened in Fig. 5E, where $a_{CDOM}(350)$ decreased by a factor of four

235   between the two most distanced points (approximately 40 km) of the westernmost transect sampled in the North Sea (see Fig.
1B).

     Light scattering by suspended particles in the water column is a driver of reflectance variability and is often used by remote
sensing applications to discriminate between Case 1 and Case 2 waters (Sat, 2000; Morel and Bélanger, 2006). The particulate
scattering coefficient at 440 nm, $b_p(440)$ ranged between 0.05 m^{-1} and 35.8 m^{-1} (Fig. 6A). The median values varied by almost

240   two orders of magnitude between the Atlantic Ocean and the Adriatic Sea (Fig. 6A). Furthermore, $b_p(440)$ showed more or less
the same spatial pattern as the downward irradiance attenuation coefficient at 443 nm, $K_{Ed}(443)$, which median values varied
between 0.05 m^{-1} and 1.21 m^{-1} in the Atlantic Ocean and the North Sea respectively (Fig. 6B, Pearson's $r = 0.76$).

4.1.3 Apparent optical properties (AOPs)

Subsurface reflectance $R(0^-)$ for all COASTℓOOC sites is shown in Fig. 7, reflecting the fundamental differences in the bio-

245   optical properties of the different areas visited. For example, due to enhanced CDOM absorption, reflectance in the blue part of
the spectrum is generally low at the Baltic Sea sites, while it is higher in the Case-1 waters encountered in the Atlantic Ocean
or the Mediterranean Sea. In the red and NIR, very high reflectance values are observed in the sediment rich waters of the
North Sea or the English Channel.

     Sample profiles of the diffuse attenuation coefficient $K_{Ed}(490)$ at a vertical resolution between 2.0 and 5.0 m are shown in

250   Fig. 8 for two transition zones, each ranging from turbid waters close to the coast to clearer waters further offshore. Fig. 8A
shows $K_{Ed}(490)$ values along a transect taken in the Lion's Gulf on 30. Sept. 1997 from site C4014 located ca. 5 km to the west
of the mouth of the main Rhône branch (Grand Rhône) to site C4019 some 20 km further south in clear Mediterranean waters.
While $K_{Ed}(490)$ at the offshore sites C4017 to C4019 adopts low values between ca. 0.02 and 0.05 m^{-1} reflecting clear-water
conditions, sites C4014 and C4015 are strongly influenced by the Rhône river plume, resulting in $K_{Ed}(490)$ reaching values of

255   up to 0.8 m^{-1} in the surface layer. The turbid Rhône freshwater is floating on top of much denser and clearer Mediterranean
seawater, resulting in a strong stratification. Fig. 8B shows a similar transect taken in the North Sea on 12. Sept. 1998 extending
from site C6063 close to the western shore of the island of Texel to site C6069 located ca. 22 km further west in the open North
Sea. Again, there is a distance-to-coast-dependent decrease of $K_{Ed}(490)$ values likely related to turbidity, from ca. 0.8 to 1.0
m^{-1} close to the coast down to values of ca. 0.2 to 0.3 m^{-1} offshore. In contrast to the transect in the Lion's Gulf, there is no

260   obvious stratification. $K_{Ed}(490)$ values are rather homogeneous over the entire water column, pointing to effective mixing.

4.2 Co-variability across bio-optical measurements

Few research papers have previously shown how optically significant components and AOPs/IOPs measured during the COASTℓOOC
missions co-varied (Ferrari, 2000; Ferrari et al., 2003; Babin, 2003; Babin et al., 2003). In this section, a brief overview of se-
lected pairwise relationships is presented. Figure 4 shows that total chlorophyll a co-varied with POC, and Fig. 9A shows

265   that this relationship is highly variable across the areas. Whereas the global Pearson's correlation is 0.79 ($n = 299$), it ranged
between 0.36 in the North Sea ($n = 88$) to 0.78 in the Adriatic Sea ($n = 37$) showing that optically significant components do
not necessarily covary altogether. Likewise, the global Pearson's correlation between a_ϕ and total chlorophyll a (Fig. 9B) was

relatively high ($r = 0.9$, $n = 338$). The lowest and highest correlations were observed in the North Sea ($r = 0.69$, $n = 88$) and the Adriatic Sea ($r = 0.91$, $n = 38$), respectively. POC concentration is well known to be an important driver of both IOPs and

270 AOPs in aquatic ecosystems (Stramski et al., 2008; Cetinić et al., 2012). Unsurprisingly, positive correlations were observed between POC and $K_{Ed}(443)$ (Fig. 9C, $r = 0.81$, $n = 204$) and $b_p(440)$ (Fig. 9D, $r = 0.67$, $n = 165$).

Based on the size-reactivity continuum model proposed by Benner and Amon 2015, physicochemical and photochemical processes are shaping the size distribution of organic matter along the aquatic continuum, and determine the contrasted intrinsic nature of the particles for each type of ecosystem. This is likely one key reason explaining why the observed relationships are

275 quite variable across the different sampled ecosystems (Fig. 9). For example, in coastal areas (e.g., Baltic Sea, Fig. 1), the POC content is generally influenced by large humic organic particles drained by rivers from the surrounding watershed (Babin et al., 2003). Consequently, in these areas, POC concentration (Fig. 4B), absorption (Fig. 5), and downward attenuation coefficients (Fig. 9C) were higher than in other sampled areas. In contrast, the stations that were farther away from the coast (such as the Atlantic Sea, Fig. 1) had lower POC concentrations (Fig. 4B) and absorption (Fig. 5). This is suggesting that the particulate

280 pool was typically made up of smaller, less colorful molecules that were mostly made by primary production in situ.

5 Code and data availability

The COASTLOOC data is provided as a collection of comma-separated values (CSV) files that are regrouping measurements associated with a particular type of measure. To aid the user to merge these files, there is a lookup table file called stations.csv that can serve as a table to join the data together based on the station's unique identifier. Table 1 shows the complete list of

285 available measurements and their associated principal investigators. The processed and tidied version of the data is hosted at SEANOE (SEA scieNtific Open data Edition) under the CC-BY license (https://www.seanoe.org/data/00824/93570/, Massicotte et al. 2023). All statistical analyses were performed in R version 4.2.2 (R Core Team, 2022). The code used to produce the figures and the analysis presented in this paper is available under the GNU GPLv3 license (10.5281/zenodo.7708653, Massicotte 2023).

6 Conclusions

The consolidated, quality-controlled, data collected during the COASTℓOOC oceanographic expeditions offer, even if collected more than twenty years ago, many possibilities to better understand the bio-optical dynamics along the land-to-sea gradient where optically-complex water drained from watersheds mix with seawater. In this paper, only a subset of variables has been presented. The reader is referred to Table 1 for a complete list and description of variables collected during the

295 COASTℓOOC expeditions.
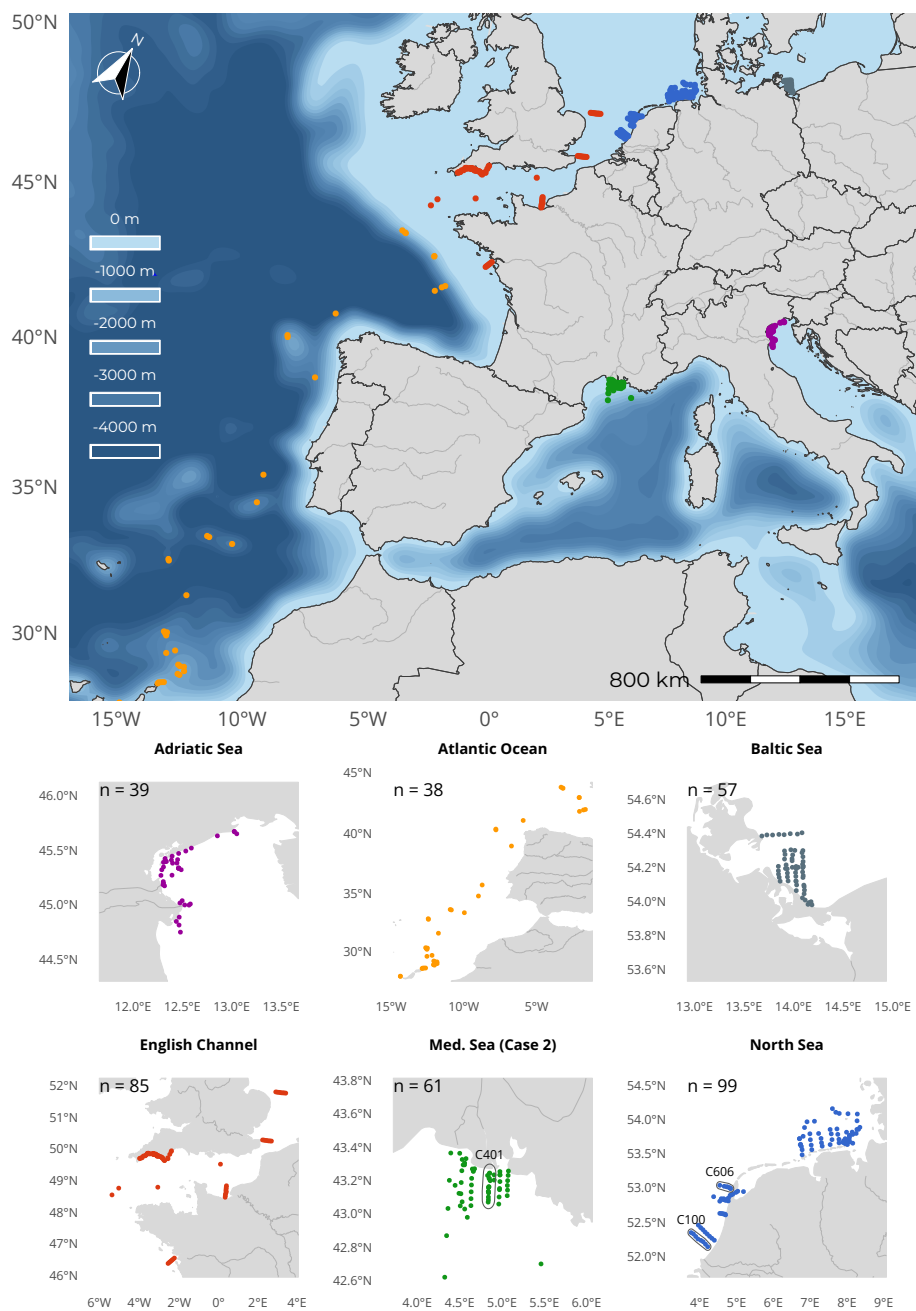
Figure 1. Map of the sampling stations. The three black outlines in the bottom panels (Mediterranean Sea and North Sea) identify the stations and the transects used in Fig. 5E (C100) as well as for the examples of vertical profiles of $K_{Ed}(490)$ in Fig. 8 (C401 and C606).
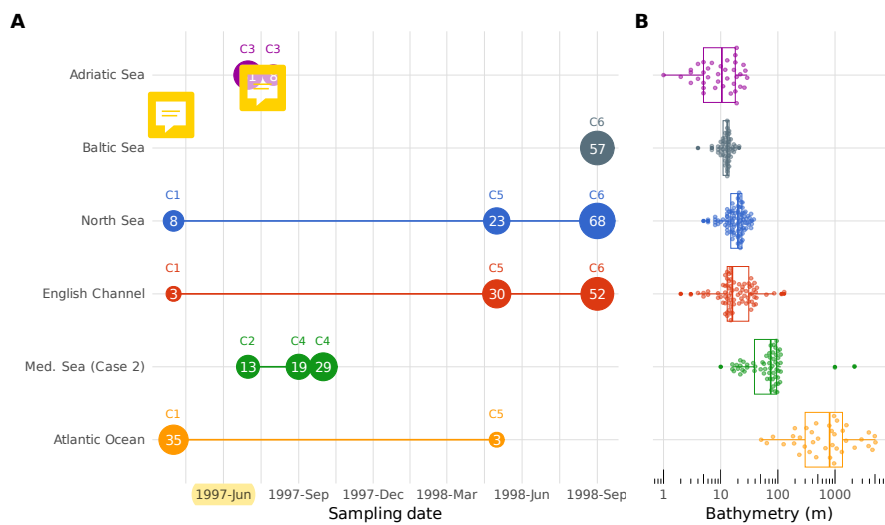
Figure 2. (**A**) Overview of the temporal sampling for the six areas. The numbers in the circles indicate the number of visited stations each month. (**B**) Boxplot showing the bathymetry at the sampling locations by area. The labels on top of each circle identify the COASTℓOOC campaigns (C1 to C6).
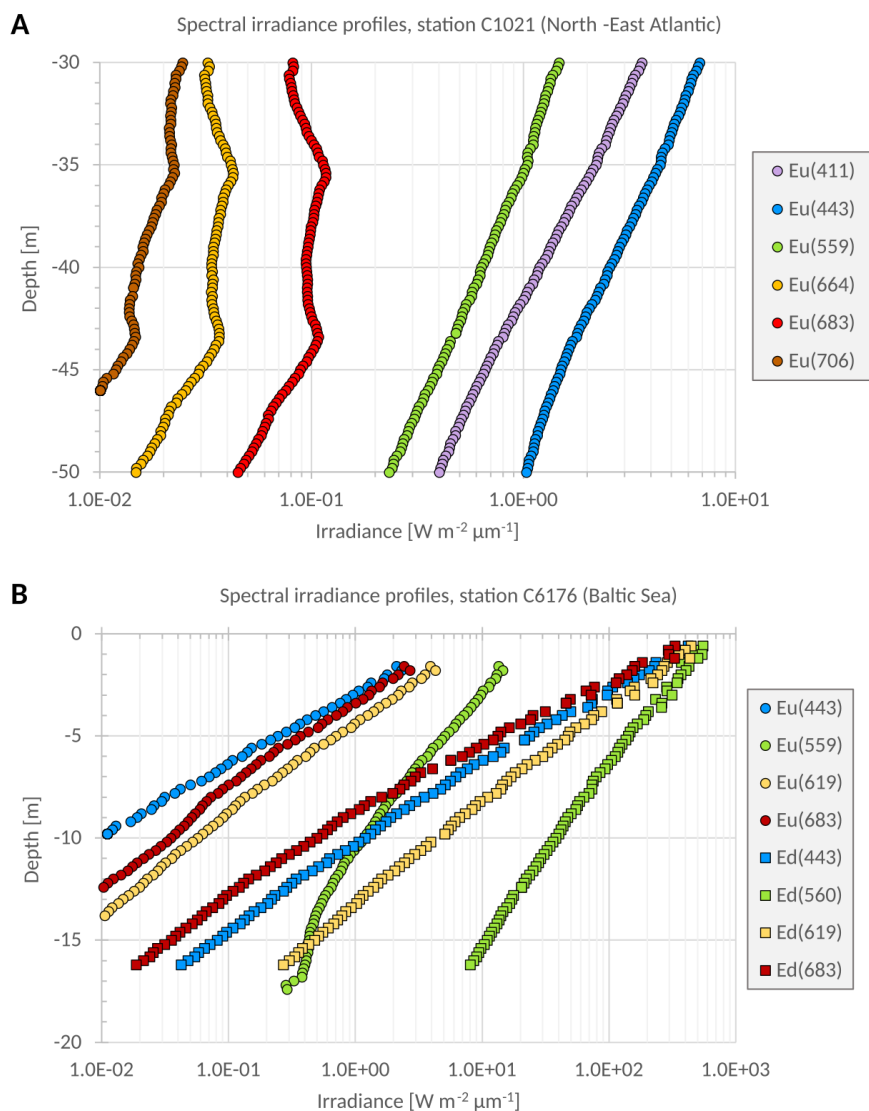
Figure 3. (A) Vertical profile of the upwelling irradiance taken on 11 April 1997 at station C1021 located in the North-East Atlantic offshore Northern Portugal. A double deep chlorophyll maximum with the corresponding irradiance increase due to chlorophyll fluorescence is observed at water depths of ca. 35 m and 45 m, most prominently at 683 nm, but also at 664 nm and even at 706 nm. Attenuation in the blue to green wavelengths is correspondingly enhanced as reflected by the change in slope at a depth of ca. 34 m. **(B)** Vertical profiles of the upwelling and downwelling irradiance taken on 25 September 1998 at station C6176 located in the Baltic Sea offshore Usedom Island in North-East Germany. Baltic Sea waters are rich in CDOM, resulting in strong absorption in the UV and blue. The reduced decrease of the upwelling irradiance at 559 nm towards larger depths is likely caused by reflection of downwelling irradiance from the ocean bottom. Chlorophyll fluorescence is likely the reason for the relatively enhanced upwelling irradiance at 683 nm for depths below ca. 7 m.
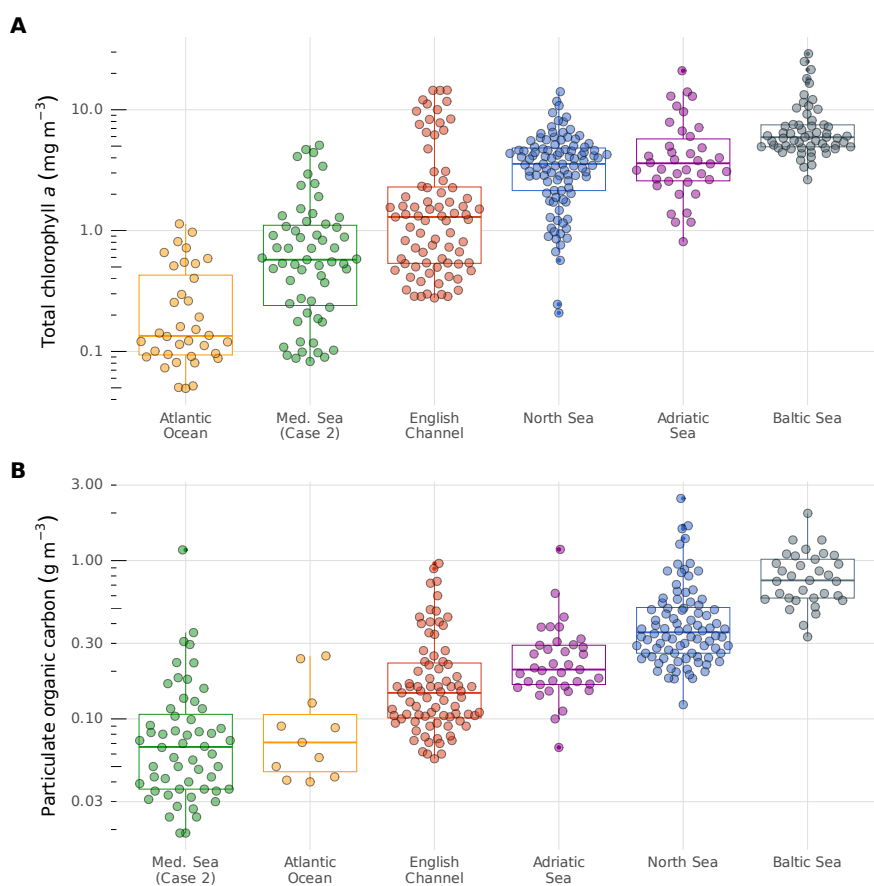
Figure 4. (**A**) Total chlorophyll *a* and (**B**) particulate organic carbon across the sampled areas.
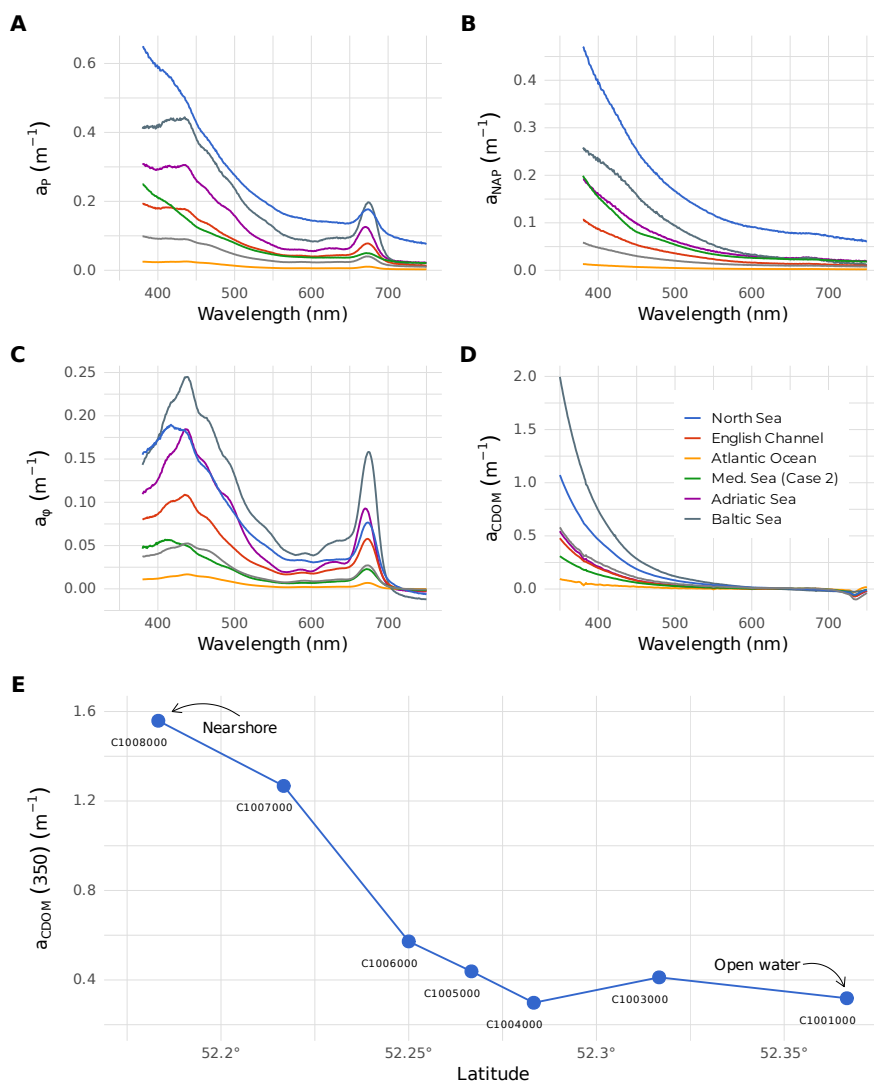
Figure 5. (**A**) Average total particulate (a_p), (**B**) non-algal (a_{NAP}), (**C**) phytoplankton (a_ϕ) and (**D**) chromophoric dissolved organic matter (a_{CDOM}) absorption spectra in each area. (**E**) $a_{CDOM}(350)$ along the westernmost transect in the North Sea (see Fig. 1B).
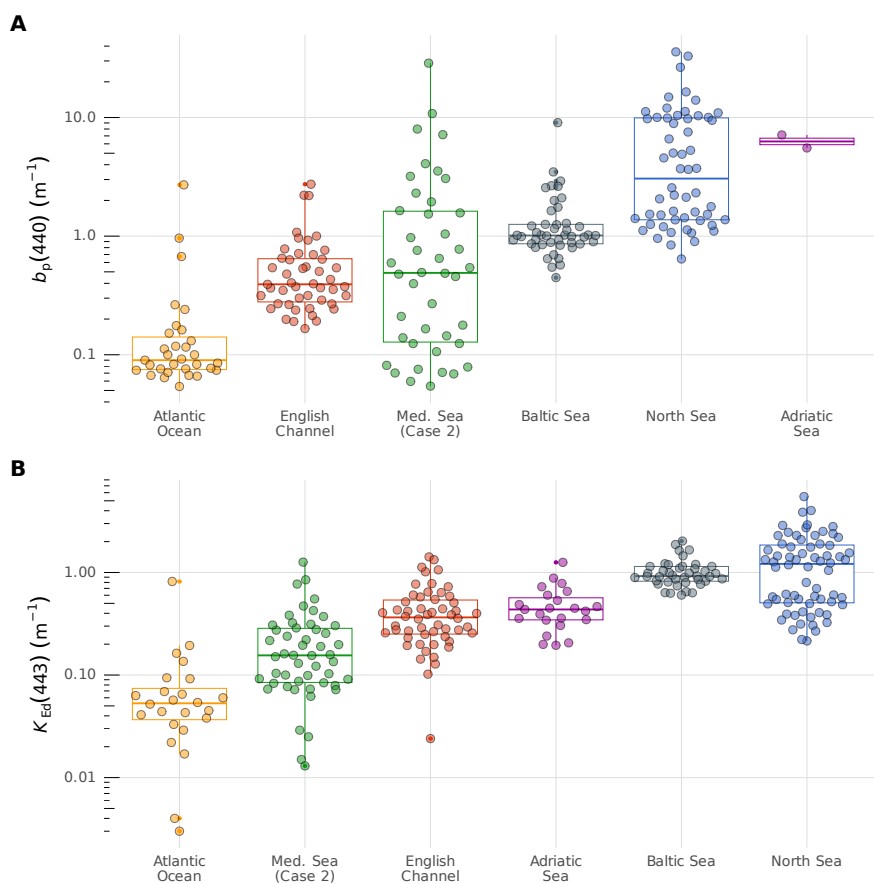
Figure 6. (**A**) Particulate scattering coefficient at 440 nm ($b_b(440)$) and (**B**) attenuation coefficient for downward irradiance at 443 nm ($K_{\mathrm{Ed}}(443)$) across the sampled areas.
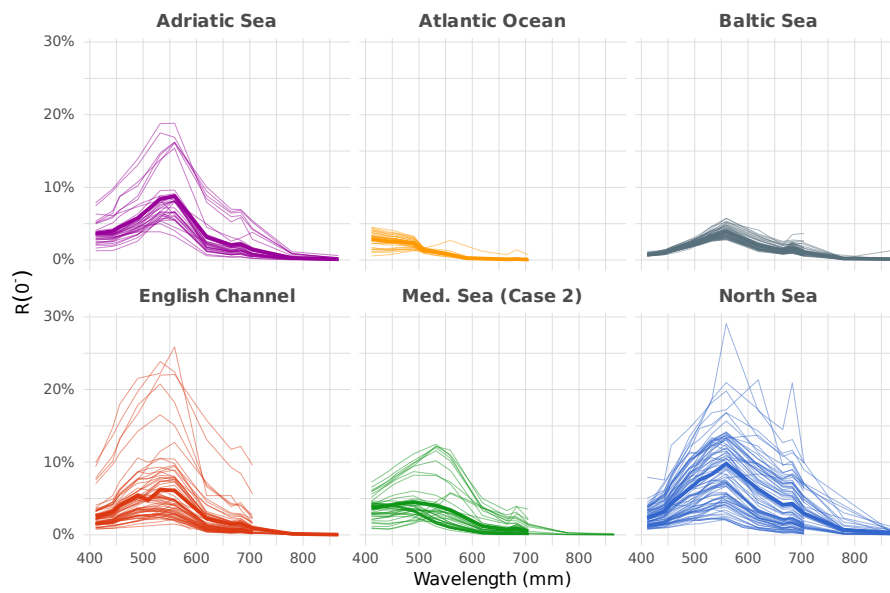
Figure 7. Subsurface reflectance $R\left(0^{-}\right)$ across the sampled areas. The thick lines represent the regional averages. Note that $R\left(0^{-}\right)$ at wavelengths above 705 nm could only be derived from helicopter-based measurements.
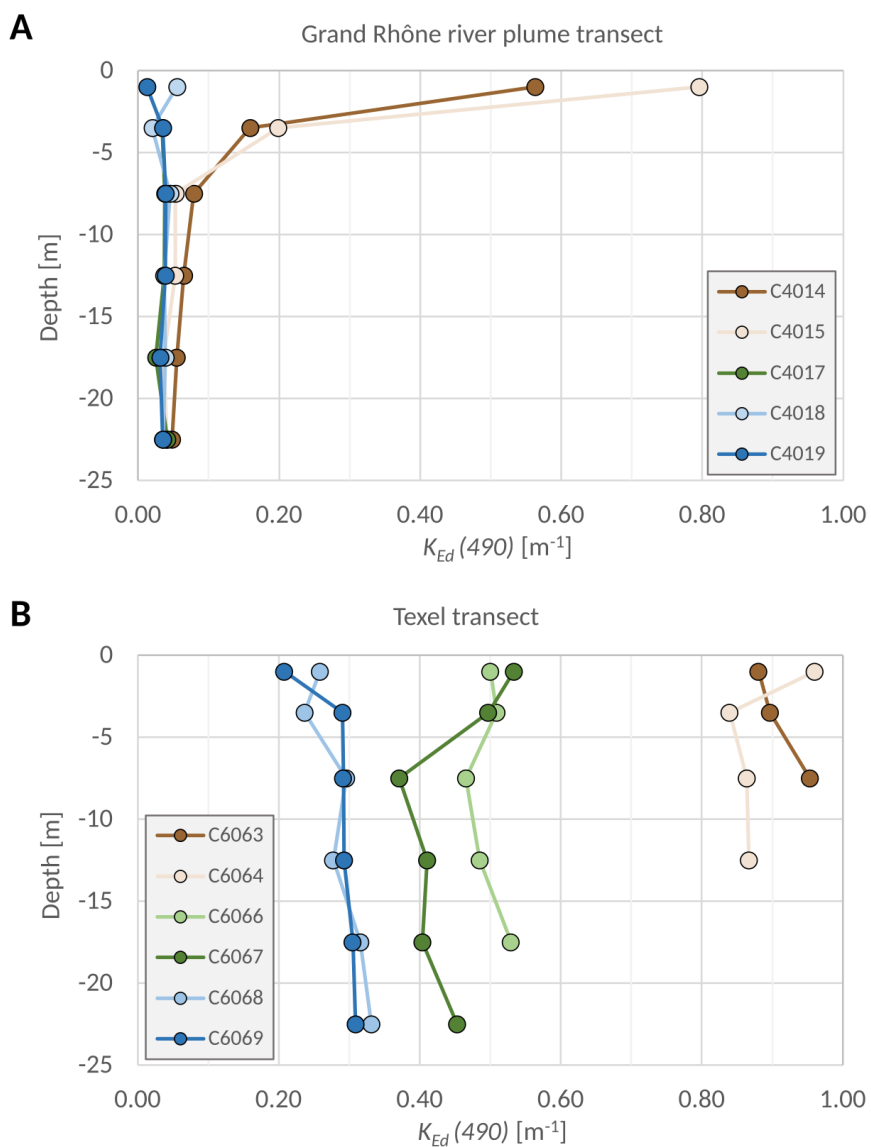
Figure 8. (A) $K_{Ed}(490)$ profiles taken in the Lion's Gulf on 30. Sept. 1997 along a transect extending from site C4014 located ca. 5 km to the west of the mouth of the main Rhône branch (Grand Rhône) to site C4019 located some 20 km further south in clear Mediterranean waters. (B) $K_{Ed}(490)$ profiles taken in the North Sea on 12. Sept 1998 along a transect extending from site C6063 close to the western shore of the island of Texel to site C6069 located ca. 22 km further west in the open North Sea.
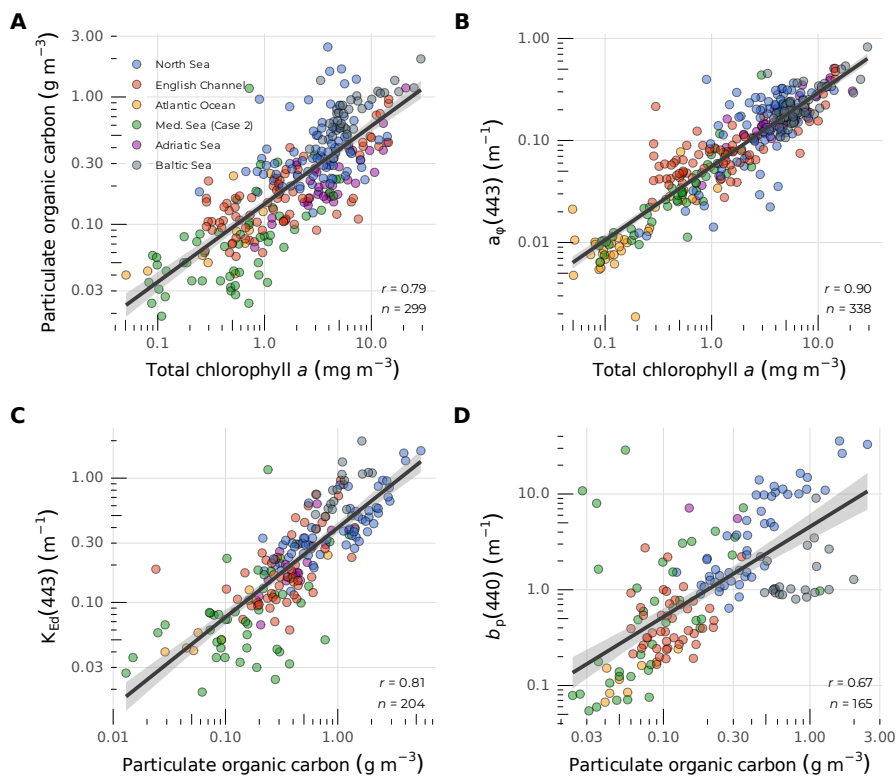
Figure 9. Scatterplots showing relationships among different selected variables. (**A**) Particulate organic carbon (POC) and (**B**) phytoplankton absorption at 443 nm ($a_\phi(443)$) against total chlorophyll *a*. (**C**) Downward irradiance at 443 nm ($K_{Ed}(443)$) and (**D**) particulate scattering at 440 nm ($b_p(440)$) against particulate organic carbon. The red lines show the linear relationships between the variables. The shaded gray areas represent the 95% confidence intervals around the fitted models.

Table 1: List of measured parameters

Source file	Variable	Units	Description
absorption.csv	wavelength	nm	
absorption.csv	a_p_m1	m⁻¹	Total particulate absorption
absorption.csv	a_nap_m1	m⁻¹	Non-algal absorption
absorption.csv	a_nap_adjusted_m1	m⁻¹	Non-algal absorption adjusted for...
absorption.csv	a_cdom_m1	m⁻¹	Chromophoric dissolved organig matter absorption
absorption.csv	a_cdom_adjusted_m1	m⁻¹	Chromophoric dissolved ~~organig~~ matter absorption with background baseline removed

Table 1: List of measured parameters *(continued)*

Source file	Variable	Units	Description
absorption.csv	a_phy_m1	m^{-1}	Phytoplankton absorption
absorption.csv	background_a_p_m1		Baseline background of total particulate absorption
absorption.csv	background_a_cdom_m1		Baseline background of chromophoric dissolved organig matter absorption
absorption.csv	background_a_nap_m1		Baseline background of non-algal absorption
ac9.csv	a_m1	m^{-1}	Total non-water absorption coefficient
ac9.csv	c_m1	m^{-1}	Total non-water attenuation coefficient
ac9.csv	bp_m1	m^{-1}	Particle scattering coefficient
bathymetry.csv	longitude	Degree decimal	Longitude of the pixel used to extract the bathymetry
bathymetry.csv	latitude	Degree decimal	Latitude of the pixel used to extract the bathymetry
bathymetry.csv	bathymetry_m	m	Bathymetry depth at the sampled stations
irradiance.csv	eu_w_m2_um	$w\ m^{-2}\ \mu m^{-1}$	Upward irradiance just beneath the water surface (Eu0-)
irradiance.csv	ed_w_m2_um	$w\ m^{-2}\ \mu m^{-1}$	Downward irradiance just beneath the water surface (Ed0-)
irradiance.csv	k_eu_m1	m^{-1}	Attenuation coefficient for upward irradiance (just beneath the water surface)
irradiance.csv	k_ed_m1	m^{-1}	Attenuation coefficient for downward irradiance (just beneath the water surface)
reflectance.csv	measured_reflectance_percent	Percent	Surface water reflectance
spectral_slopes.csv	s_cdom_nm1	nm^{-1}	Spectral slope that describes the approximate exponential decrease in aCDOM
spectral_slopes.csv	s_nap_nm1	nm^{-1}	Spectral slope that describes the approximate exponential decrease in aNAP
spectral_slopes.csv	a_cdom443_m1	m^{-1}	
spectral_slopes.csv	a_nap443_m1	m^{-1}	
stations.csv	station		Unique ID of the sampled station. Can be used as unique key to merge the data across other files.
stations.csv	date		Date at which the measurement was made
stations.csv	depth_m	m	Depth at which the measurement was made
stations.csv	longitude	Degree decimal	Longitude of the sampling station
stations.csv	latitude	Degree decimal	Latitude of the sampling station

Table 1: List of measured parameters *(continued)*

Source file	Variable	Units	Description
stations.csv	area		Region where the measurement was made. One of: (1) North Sea, (2) English Channel, (3) Atlantic Ocean, (4) Med. Sea (Case 2), (5) Adriatic Sea, (6) Baltic Sea
stations.csv	system		
stations.csv	gmt_time		
stations.csv	solar_zenith_angle	degree	Angle of the sun from the vertical
pigments.csv	chlorophyll_a_mg_m3	mg m^{-3}	Chloropyll-a
pigments.csv	chlorophyll_b_mg_m3	mg m^{-3}	Chloropyll-b
pigments.csv	chlorophyll_c_mg_m3	mg m^{-3}	Chloropyll-c
pigments.csv	pheopigment_mg_m3	mg m^{-3}	Pheopigment
pigments.csv	fucoxanthin_mg_m3	mg m^{-3}	Fucoxanthin
pigments.csv	hexanoyloxyfucoxanthin_19_mg_m3	mg m^{-3}	Hexanoyloxyfucoxanthin-19
pigments.csv	butanoyloxyfucoxanthin_19_mg_m3	mg m^{-3}	Butanoyloxyfucoxanthin-19
pigments.csv	alloxanthin_mg_m3	mg m^{-3}	Alloxanthin
pigments.csv	zeaxanthin_mg_m3	mg m^{-3}	Zeaxanthin
pigments.csv	prasixanthin_mg_m3	mg m^{-3}	Prasixanthin
pigments.csv	neoxanthin_mg_m3	mg m^{-3}	Neoxanthin
pigments.csv	violaxanthin_mg_m3	mg m^{-3}	Violaxanthin
pigments.csv	diatoxanthin_mg_m3	mg m^{-3}	Diatoxanthin
pigments.csv	diadinoxanthin_mg_m3	mg m^{-3}	Diadinoxanthin
pigments.csv	peridinin_mg_m3	mg m^{-3}	Peridinin
pigments.csv	carotene_mg_m3	mg m^{-3}	Carotene
pigments.csv	lutein_mg_m3	mg m^{-3}	Lutein
carbon.csv	suspended_particulate_matter_g_m3	g m^{-3}	Suspended particulate matter
carbon.csv	particulate_organic_nitrogen_g_m3	g m^{-3}	Particulate organic nitrogen
carbon.csv	total_particulate_carbon_g_m3	g m^{-3}	Total particulate carbon
carbon.csv	particulate_organic_carbon_g_m3	g m^{-3}	Particulate organic carbon
carbon.csv	dissolved_organic_carbon_g_m3	g m^{-3}	Dissolved organic carbon
SPMR	Cast	1	Processed cast number

Table 1: List of measured parameters *(continued)*

Source file	Variable	Units	Description
SPMR	Depth	m	Depth of vertical bin, e.g. -1.00 representing the depth bin [-0.90, -1.10 m]
SPMR	TmpWat	Degree celcious	Water temperature
SPMR	Cond	ms cm^{-1}	Conductivity
SPMR	Salin	PSU	Salinity
SPMR	SigmaT	1	Density of sea water
SPMR	TiProf	Degree	Tilt of profiling radiometer
SPMR	TiRef	Degree	Tilt of reference radiometer
SPMR	VSpeed	m s^{-1}	Vertical speed
SPMR	Altim	m	Altimeter sounding of distance from the ocean ground
SPMR	N_OBS	1	Number of observations within depth bin
SPMR	EUnnn	w m^{-2} μm^{-1}	In-water upwelling irradiance at wavelength nnn
SPMR	EDnnn	w m^{-2} μm^{-1}	In-water downwelling irradiance at wavelength nnn
SPMR	ERnnn	w m^{-2} μm^{-1}	In-air downwelling irradiance at wavelength nnn
SPMR	KUnnn	m^{-1}	Diffuse attenuation at wavelength nnn calculated from the upwelling irradiance
SPMR	KDnnn	m^{-1}	Diffuse attenuation at wavelength nnn calculated from the downwelling irradiance
SPMR	PAR_ABS	μmol m^{-2} s^{-1}	Phytosynthetically Active Radiation (PAR)
SPMR	PAR%SRF	Percent	PAR at depth z relative to PAR on the sea surface
SPMR	K_PAR	m^{-1}	Diffuse attenuation for PAR

Appendix A

A1
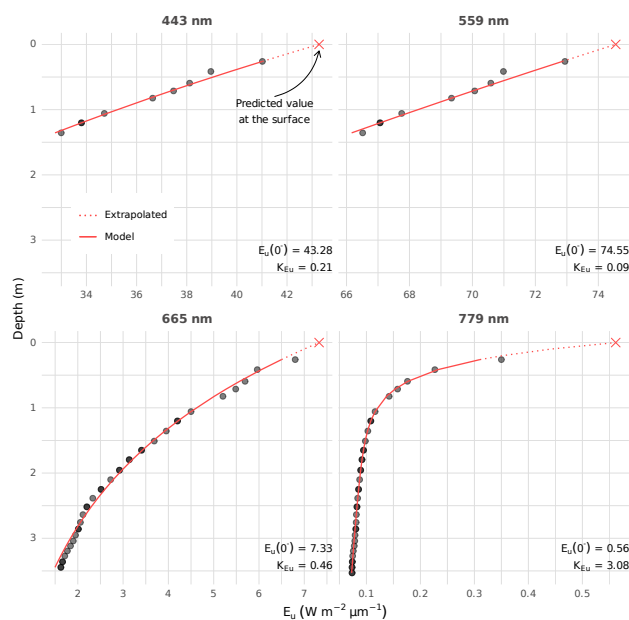
Figure A1. Example of extrapolation of the upward irradiance towards the sea surface. The irradiance values just below the sea surface (red crosses, $E_u\,(0^-)$) and the corresponding diffuse attenuation coefficient for the topmost water layer are specified in the figures. The full lines represent the interpolated values whereas the dashed lines show extrapolation values up to the sea surface.

Table A1: Scientific articles in peer-reviewed journals using or referencing COASTLOOC

Publications
Babin, M., Stramski, D., Ferrari, G. M., Claustre, H., Bricaud, A., Obolensky, G., & Hoepffner, N. (2003). Variations in the light absorption coefficients of phytoplankton, nonalgal particles, and dissolved organic matter in coastal waters around Europe. Journal of Geophysical Research: Oceans, 108(C7).
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Table A1: Scientific articles in peer-reviewed journals using or referencing COASTLOOC *(continued)*

Publications
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Table A1: Scientific articles in peer-reviewed journals using or referencing COASTLOOC *(continued)*

Publications

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Author contributions. Conceptualization: MB, Formal analysis: FF, DD, VSF, MB. Investigation: MB, FF; FF, VFS. Software: DD (AC-9) FF (radiometry), VFS (data acquisition and pre-processing). Writing: PM with support from all co-authors.

Competing interests. The authors declare no competing interests.

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