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Open Access Earth System Science Data Discussions

# The marine carbonate system in the northwest European shelf seas: a quality-controlled data product (NWESDAP)

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**Abstract**

Continental shelf seas play an important role in the global carbon cycle. At the interface between the land and deep open ocean, shelf seas are typically highly biologically productive, major sites of organic carbon burial in sediments, and are also highly impacted by human activities. To investigate the marine carbon cycle and its variability through space and time, consistent and quality-controlled data products of marine carbonate system variables, such as the Global Ocean Data Analysis Project (GLODAP), are needed. However, GLODAP focuses on the open ocean, limiting its utility for understanding the marine carbonate system in shelf seas. The northwest European shelf (NWES) seas are of particular interest because of their

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biogeochemical heterogeneity and expected capacity to absorb, export and bury carbon. Here, we present a new data product for this region called the Northwest European Shelf Data Analysis Product (NWESDAP). NWESDAP includes discrete measurements of marine carbonate system variables (total alkalinity, dissolved inorganic carbon and pH) as well as physical and other biogeochemical variables between 43.6°N and 70°N on the NWES and down to 1,000 m depth. NWESDAP is a compilation of datasets of discrete observations (i.e., laboratory measurements of seawater samples, rather than autonomous sensor measurements) from research cruises and time-series stations from 1975 to 2026. Data from rivers, estuaries and fjords are also included. NWESDAP consists of 46,545 data points (of which 5,221 were in GLODAPv2.2023) from around 500 different expeditions and platforms, merged into a consistent format. Data quality flags corresponding to quantified systematic and random uncertainties have been assigned to each dataset depending on the measurement method used and other available metadata provided. Since GLODAP-style quality control (QC) based on deep ocean cross-over analysis is not possible in the shallow NWES seas (mostly < 200 m), a secondary QC based on variable distributions and relationships has been developed to identify suspected erroneous data points and check for systematic biases in specific datasets, aiming to assess the internal consistency of the entire product with respect to the Global Ocean Acidification Observing Network (GOA-ON) climate and weather quality goals so it can be used to investigate the highly variable marine carbon cycle of the NWES. Of the 46,545 datapoints, 24,822 are of at least weather quality, but the rest has been retained as they can still provide important historical context. The data product and associated metadata are available online at https://doi.org/10.5281/zenodo.23555137 (Brandon et al., 2026b). We expect this data compilation to facilitate studies of marine carbonate system variability through space and time across the NWES and support the assessment of carbon stocks and fluxes. NWESDAP will also provide a foundation for evaluating the impact of climate change and anthropogenic activities on the carbonate system as well as for validating regional biogeochemical models.

## 1 Introduction

Continental shelves represent 7-10 % of the global ocean surface area (Laruelle et al., 2013; Harris et al., 2014). However, their impact on the carbon and nutrient cycling is of greater importance, representing 10-30 % of the global primary productivity and around 80 % of the total organic carbon burial in sediments (Bauer et al., 2013). At the interface between land, atmosphere and the open ocean, continental shelves are a key regions for the exchange of carbon and nutrients between these different reservoirs. Due to their proximity to land and the numerous resources they provide, shelf seas are also heavily impacted by human activities (Regnier et al., 2013). The diversity of processes at play in these regions results in high uncertainties in the quantification of the carbon fluxes within the shelf seas and between them and the open ocean (Chen and Borges, 2009; Bauer et al., 2013; Fennel et al., 2019; Legge et al., 2020). Moreover, the role of shelf seas in the future global carbon cycle under the increasing impact of climate change and ocean acidification remains poorly constrained.

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The northwest European shelf (NWES) seas are of interest because of their capacity to export carbon through the continental shelf pump (Thomas et al., 2004; Bozec et al., 2005; Legge et al., 2020). Through a combination of high biological activity and seasonal stratification, the continental shelf pump transfers dissolved inorganic carbon (DIC) and total alkalinity (TA) from the shallow waters of the shelves to the deeper layer of the open ocean (Tsunogai et al., 1999; Thomas et al., 2004; Holt et al., 2009). While the NWES is known to be a net sink of $CO_2$ from the atmosphere (Hartman et al., 2019; Becker et al., 2021), the fate of this carbon on longer time scales remains highly uncertain, with 0-40 % thought to be exported to the Atlantic Ocean in the water column and the remaining 60-100 % deposited in seafloor sediments (Legge et al., 2020). Numerous processes influence the carbonate system on the NWES, such as biological activity, water column stratification and tidal currents (Thomas et al., 2004; Clargo et al., 2015; Kossack et al., 2024; Macovei et al., 2025; Ourradi et al., 2026). At the boundary between the terrestrial and oceanic domains, the carbon cycle of the NWES is also affected by inputs from rivers, fjords and the Baltic Sea (Hydes et al., 1999; Thomas et al., 2005; McGrath et al., 2016; Hartman et al., 2019). In the near future, the region is expected to be increasingly affected by ocean acidification (Artioli et al., 2014) and by changes in hydrodynamics linked to heatwaves and ocean warming (Holt et al., 2010). These changes will affect the carbon uptake capacity of the NWES and could have an impact at the global scale. The NWES has been widely studied, with numerous cruises every year measuring carbonate system variables through individual projects or monitoring programmes. However, no collective efforts have been put in place to gather all these discrete observations, preventing a more complete overview of the carbon cycle and its evolution through time in this region.

To assess the marine carbonate system in shelf seas and their role in the global carbon cycle, access to internally consistent in situ observations is key. In the past two decades, efforts have been made to merge existing biogeochemical data from the full water column into internally consistent and quality-controlled databases. GLODAP (Global Ocean Data Analysis Project) is the reference database for discrete in situ measurements of inorganic carbon variables, oxygen, nutrients and other biogeochemical variables (Key et al., 2004; Olsen et al., 2016; Lange et al., 2026). In GLODAP, internal consistency is ensured by a multi-step QC of the data, regardless of their origin. A primary QC is done on all individual cruises through a property-property check to identify outliers (Sabine et al., 2005; Tanhua et al., 2010). A secondary step is based on a crossover and inversion analysis, performed on data deeper than 1,500 or 2,000 m, which allows the detection and correction of possible offsets between cruises crossing or in close proximity to each other (Gouretski and Jancke, 2001; Johnson et al., 2001; Tanhua et al., 2010; Humphreys et al., 2026a). This depth criterion, however, excludes the possibility of using crossover analysis on cruises that took place entirely in shelf seas (< 200 m water depth). While differences found between cruises in the deep ocean can be linked to cruise-level measurement biases, strong temporal variations in coastal oceans make it difficult to separate actual cruise biases from natural variability. The number of data points in shelf seas is therefore limited and these have not gone through secondary QC. The use of GLODAP in understanding the marine inorganic carbonate system and its evolution in shelf seas is therefore limited (Olsen et al., 2016). SOCAT (Surface Ocean $CO_2$ Atlas; Bakker et al., 2016) is a compilation of surface ocean seawater $CO_2$ fugacity measurements with a similar limitation to that of NWESDAP: no deep ocean data for

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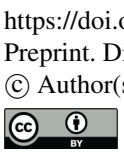
105 direct cross-over analysis. In the SOCAT QC process, datasets are compared if they pass within a small space and time window of each other (on the order of tens of kilometres and a day or two). But this occurs only for a very limited number of datasets, so this approach cannot be used to ensure internal consistency of the entire data product.

Several quality-controlled databases of inorganic carbon variables in coastal regions or including coastal data have been
110 published in recent years (Jiang et al., 2026), such as CODAP-NA (Coastal Ocean Data Analysis Product in North America) for the North American continental shelves (Jiang et al., 2021; Yoo et al., 2026), Cocori$CO_2$ for the French coasts (Petton et al., 2024, 2026) or CARIMED for the Mediterranean Sea (Álvarez et al., 2026). Other datasets include observations from both open and coastal oceans, such as SNAPO-$CO_2$ (Service National d'Analyses des Paramètres Océaniques du $CO_2$, Metzl et al., 2024, 2025). These data products are assumed to be internally consistent either because their measurements all come from a
115 single laboratory or project (Petton et al., 2024; Metzl et al., 2025) or from a small number of connected laboratories with recognised measurement quality (Jiang et al., 2021). However, this approach may lead to valuable data from other sources such as national programmes or individual cruises being excluded.

Although the possibilities for secondary QC are limited in shelf seas, the high variability generally observed in these regions
120 offers some mitigation, meaning that greater uncertainties can be tolerated for a data product to be considered internally consistent. In the Global Ocean Acidification Observing Network (GOA-ON) guidelines for target uncertainties in marine carbonate system observations, a distinction is made between 'climate quality' and 'weather quality' uncertainty levels (Newton et al., 2015). The climate quality target is intended for detecting long-term (e.g., decadal) trends in open ocean datasets driven by anthropogenic $CO_2$ uptake, which is one of the main goals of GLODAP. The weather quality target is less strict,
125 recognising that greater uncertainties in the data do not necessarily hinder investigations of processes that drive much greater changes in conditions, such as those driving seasonal cycles and spatial variability in shelf seas.

Here, we present the Northwest European Shelf Data Analysis Product (NWESDAP), a new, quality-controlled data product for the marine carbonate system in the NWES seas based on discrete in situ samples collected during cruises and at fixed time-
130 series stations from 1975 to 2026. NWESDAP includes measurements of TA, DIC and pH as well as temperature, salinity, dissolved oxygen and nutrients (total inorganic nitrate, nitrite, ammonium, silicate, and phosphate). In total, 46,545 distinct measurement points have been compiled into a consistent format. Uncertainties have been assessed and outliers were flagged based on metadata evaluation, statistical analysis and offset diagnosis between cruises. This also allowed systematic biases in specific datasets to be identified, assessing the internal consistency of the data product with respect to the GOA-ON climate
135 and weather quality goals. We describe the spatial and temporal distribution of the compiled dataset and present an overview of possible future use cases.

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## 2 Methods

### 2.1 Defining the boundaries

The latitudinal boundaries of NWESDAP have been defined to the south by the Capbreton Canyon at 43.6°N, and to the north at 70°N, where there is the shortest distance between the coast and the continental slope along the Norwegian Shelf, which we consider to be the boundary with the Barents Sea (Figure 1). The Danish islands of Fyn and Sjælland at the southern end of the Kattegat sets the boundary between the NWES and the Baltic Sea. To enable the study of continental runoff influence on the NWES, we included measurements from rivers, estuaries and fjords.

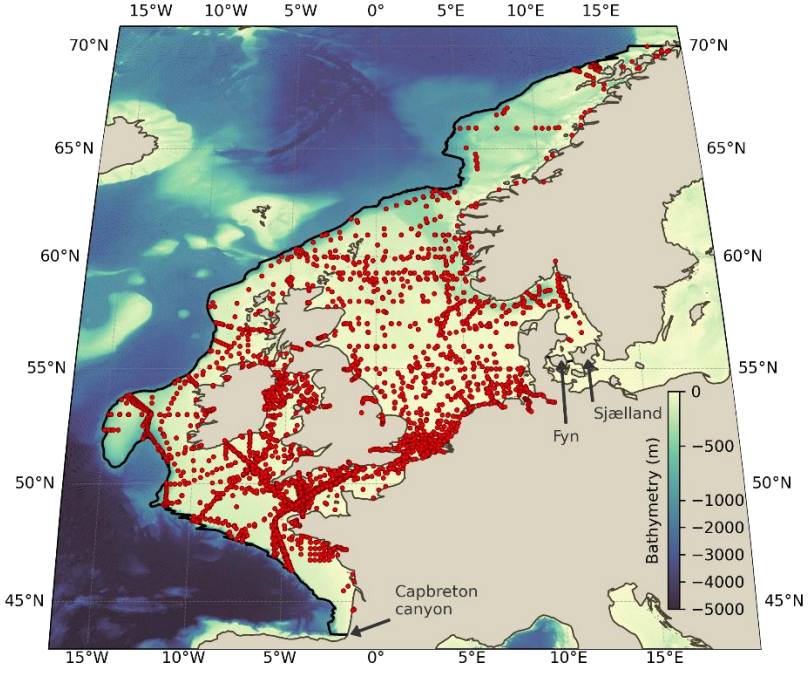



**Figure 1. Location of all sampling sites in NWESDAP (red dots). 1000 m isobath and boundaries with land are represented by the black line. Bathymetry from GEBCO 2026 (GEBCO Bathymetric Compilation Group 2026).**

The boundary between the continental shelf and the open ocean can be defined in several different ways, for example based on the distance to shore or the bathymetry. In previous studies on continental shelves, different limits have been used such as 200 nautical miles (Jiang et al., 2021), the furthest from the coast between a distance to shore of 300 km or a 1,000 m isobath (Roobaert et al., 2024), or alternatively the 200 m (Legge et al., 2020), 500 m (Becker et al., 2021) or 1,000 m isobaths (Laruelle et al., 2013). In the case of the NWES, the distance between the coast and the shelf slope is highly variable, from less than 50

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km around the Lofoten Islands to up to 1,000 km in the North Sea between the Wadden Islands and the boundary between the North Sea and the North Atlantic. This irregularity makes it unsuitable to use a constant distance to shore as the limit between the shelf and the open ocean. We used the 1,000 m isobath as the outer limit of the NWESDAP to allow an overlap with open-ocean data and to cover the beginning of the continental slope. Where a cruise had datapoints falling inside and outside of the area, only the data points inside the defined zone were kept for the final product.

### 2.2 Variables

NWESDAP includes inorganic carbon variables (TA, DIC and pH) from the surface and water column, as well as the associated salinity and temperature values. Where available, dissolved oxygen and nutrients (total inorganic nitrate, nitrite, ammonium, silicate, and phosphate) were also included. Seawater $fCO_2$ ($CO_2$ fugacity) measurements were not included as they fall under the scope of SOCAT (Bakker et al., 2016).

All inorganic carbon and nutrient data in NWESDAP are from discrete measurements and were sampled either from water-sampling bottles mounted on a rosette, manual sampling with a bucket from the side of a boat or from a jetty for rivers and estuaries, or from the ship's flowthrough near-surface seawater (underway) system. For samples collected using a rosette, temperature, salinity, pressure and dissolved oxygen were measured by CTD (conductivity–temperature–depth) and oxygen sensors mounted on the frame. For underway samples, temperature, salinity and dissolved oxygen were recorded by the ship's underway sensors. Discrete salinity and dissolved oxygen samples were frequently measured to calibrate the respective sensors (see Section 2.4 for details). All variables included in the data product are described in Table 1. The measurement methods and uncertainties of the inorganic carbon variables for each dataset are detailed in the metadata file.

**Table 1. Variables included in NWESDAP with their abbreviations, description and units (detailed description in Section 2.4).**

| Column name | Description | Unit |
|---|---|---|
| Dataset_origin | Origin of dataset | - |
| Name_ID | Name of the dataset or Quality Control Unit | - |
| Unit_ID | Quality Control Unit identification number | - |
| Sample_ID | Sample identification number | - |
| EXPOCODE | Expedition code | - |
| Cruise_ID | Cruise name or code | - |
| Ship | Ship name | - |
| Station_ID | Station number or name | - |
| Cast_number | Cast number | - |
| Bottle_ID | Bottle or Niskin number | - |
| Year_UTC | Year in UTC | - |

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| | | |
|---|---|---|
| Month_UTC | Month in UTC | - |
| Day_UTC | Day in UTC | - |
| Time_UTC | Time in UTC (hh:mm:ss) | - |
| Datetime | Datetime in YYYY-mm-dd hh:mm:ss (UTC) | - |
| Datenum | Decimal days since 1st January 0000 | day |
| Latitude | Latitude in decimal degrees north | ° N |
| Longitude | Longitude in decimal degrees east | ° E |
| Depth_bottom | Bottom water depth at the sampling location | m |
| Sampledepth_max | Maximum depth sampled in the water column, when applicable | m |
| Distance_to_shore | Distance to the shore | km |
| CTDPRES | Pressure at sampling depth | dbar |
| Depth | Sampling depth | m |
| CTDTEMP | Temperature | °C |
| Theta | Potential temperature | °C |
| CTDSAL | Practical salinity | - |
| Absolute_Salinity | Absolute salinity | g $kg^{-1}$ |
| DIC | Dissolved inorganic carbon | µmol $kg^{-1}$ |
| TA | Total alkalinity | µmol $kg^{-1}$ |
| pH_T_measured | pH on Total Scale at lab temperature and pressure | - |
| pH_T_insitu | pH on Total Scale at in situ temperature, salinity and pressure | - |
| TEMP_pH | Temperature at which pH was measured in the lab | °C |
| CTDOXY | Calibrated oxygen value from sensor | µmol $kg^{-1}$ |
| Oxygen | Oxygen from discrete sample measured using Winkler titration | µmol $kg^{-1}$ |
| Recommended_Oxygen | Oxygen from discrete sample measured using Winkler titration completed by calibrated oxygen value from sensor | µmol $kg^{-1}$ |
| AOU | Apparent oxygen utilisation calculated with potential temperature, following (García and Gordon, 1992) | µmol $kg^{-1}$ |
| Nitrate | Nitrate ($NO_3^-$) content | µmol $kg^{-1}$ |
| Nitrite | Nitrite ($NO_2^-$) content | µmol $kg^{-1}$ |
| Nitrate_and_Nitrite | Nitrate + nitrite content | µmol $kg^{-1}$ |
| Ammonium | Ammonium ($NH_4^+$ and $NH_3$) content | µmol $kg^{-1}$ |
| Phosphate | Total dissolved inorganic phosphate content | µmol $kg^{-1}$ |
| Silicate | Total dissolved inorganic silicate content | µmol $kg^{-1}$ |

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### 2.3 Data origin

Data included in NWESDAP were obtained from publicly accessible archives or by contacting researchers known to collect carbonate system data from the NWES seas. The data originate from individual research cruises, monitoring programs, voluntary observing ships and fixed stations (Appendix A). A metadata file with a list of all cruises and stations is provided
180 with the NWESDAP dataset. The metadata file contains the links to access the original datasets when available, the start and

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end dates, ship names and names of principal investigators (PIs), agencies or programmes responsible for the data. Where available, information on the measurement methods for TA, DIC and pH was added, with reported uncertainty, precision and/or accuracy values.

### 2.4 Data formatting and unit conversions

All datasets have been merged into a consistent format. Column names were standardised following Jiang et al. (2022) except for temperature and salinity, with CTDTEMP_ITS90 replaced by CTDTEMP and CTDSAL_PSS78 replaced by CTDSAL, because information on temperature and salinity scales was not always available in the metadata for all cruises.

Measured variables that did not fall within the scope of NWESDAP were removed. Only measured rather than calculated values of TA, DIC and pH were included in the data product.

Datapoints where no carbonate system variables were measured, as well as those with missing temperature or salinity values, were removed. All missing values are indicated with "-999", as used in GLODAP and recommended by Jiang et al. (2022). Missing depth values were calculated from pressure using the GSW-Python conversion functions based on the Thermodynamic Equation of Seawater 2010 (TEOS-10) (McDougall and Barker, 2011; Roquet et al., 2015). When depth values were already reported in the original dataset, they were replaced by the values calculated from pressure. When no pressure values were available in the original file, they were calculated from depth.

Bottom depth (Depth_bottom) for each location was derived from EMODnet Bathymetry (v2024) (EMODnet Bathymetry Consortium, 2024). When datapoints fell outside of the area covered by EMODnet, the bottom depth was instead derived from the GEBCO bathymetry (v2026, GEBCO Bathymetric Compilation Group 2026). The distance to the nearest coastline (Distance_to_shore) was calculated using the Python package Dreamcoat (Humphreys, 2024, v0.3-green) based on the 1:10 million resolution coastline map from Natural Earth Data. Absolute salinity and potential temperature (Theta) were calculated for all samples using GSW-Python (McDougall and Barker, 2011). Dates and times are presented in Coordinated Universal Time (UTC). However, for some datasets, the time standard was not explicitly stated in the available metadata; this is indicated in the NWESDAP metadata file.

Dissolved oxygen can be measured either using a sensor or from Winkler titration of discrete samples. For the majority of oxygen datasets, only the sensor-calibrated values were available. The calibrated sensor values are stored in the column CTDOXY and the discrete Winkler values are reported in the Oxygen column. For some datasets originating from NMDC, the oxygen sensor values stored in the bottle files were not calibrated. When available in the metadata, the calibration equation was used to calculate the calibrated values. When no calibration equation was available, the sensor data were removed from the dataset. For three cruises (KB2023006004, GOS2023001003 and HB2024009051), both sensor and discrete oxygen data

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were removed because of concerns raised in the metadata about the quality of the Winkler data (first two cruises) or because of values outside of the expected range (third cruise, Winkler values > 5000 µmol $kg^{-1}$) and because no calibration equation was available. A "Recommended_Oxygen" column was created following the same method as described in Jiang et al. (2021). Apparent oxygen utilization (AOU) was calculated from CTDOXY, absolute salinity and theta, with saturated oxygen calculated using the "combined-fit" parametrisation constants from García and Gordon (1992, 1993).

The pH value is reported under in situ conditions and on the total scale (pH_T_insitu). When pH was reported only at laboratory temperature (pH_T_measured) in the original files, in situ pH was calculated at in situ temperature and pressure using PyCO2SYS v1.8.3.3 (Humphreys et al., 2022, 2024), based on the laboratory temperature given in the dataset or described in the metadata. For PyCO2SYS calculations, we used the parameterisations of Lueker et al. (2000) for the carbonic acid equilibria, Dickson (1990) for bisulfate ion dissociation, Dickson and Riley (1979) for hydrogen fluoride dissociation, and the borate to salinity ratio of Uppström (1974). DIC was used preferentially as the second carbonate system variable to calculate in situ pH. When not available, TA was used and when neither DIC nor TA were available, the mean DIC value for the cruise was used.

TA, DIC, oxygen and nutrients are reported in micromoles per kilogram of seawater (µmol $kg^{-1}$). Variables reported in µmol $L^{-1}$ in the original files were converted to µmol $kg^{-1}$ using GSW-Python density functions (McDougall and Barker, 2011). Absolute salinity and potential temperature (theta) used for unit conversions were calculated for all samples using GSW-Python (McDougall and Barker, 2011), assuming a laboratory temperature of 22°C and a hydrostatic pressure of 0 dbar. Oxygen values reported in mL $L^{-1}$ or µg $L^{-1}$ and nutrient values reported in µg $L^{-1}$ were converted to µmol $kg^{-1}$ using the same procedure described above for the conversion from $L^{-1}$ to $kg^{-1}$ and using the following factors and molar masses: 44.66 µmol $mL^{-1}$ and 31.999 g $mol^{-1}$ for oxygen, 14.007 g $mol^{-1}$ for nitrate, nitrite and ammonium, 30.974 g $mol^{-1}$ for phosphate, 28.0855 g $mol^{-1}$ or 60.0843 g $mol^{-1}$ for silicate depending on if it was reported in µg $L^{-1}$ Si or µg $L^{-1}$ SiO2 respectively.

To identify the different datasets and specific datapoints, unique identifiers were assigned at different levels of the data product. The origin of each dataset can be found in the column Dataset_origin. This refers to the 17 data products, monitoring programmes, unique cruises and stations listed in the column "Dataset_origin" of Annex A. A second identifier differentiates the cruises or stations within each Dataset_origin and is indicated in the column Name_ID. Research cruises are often identified using an expedition code (expocode), but this is not the case for all cruises and monitoring stations. The Name_ID is based on either the expocode if available, or the station name or the dataset number if not, as in the case of the SDG14.3.1 database where each dataset is identified with a number. Each Name_ID was associated with a unique number (Unit_ID) that links to the corresponding metadata in the metadata file. For simplicity, cruises and stations are hereafter referred to as quality control units (QCUs). A QCU is a subset of data with the same Name_ID that can be considered internally consistent due to having been produced by one laboratory over a constrained time period or during one expedition and can therefore be quality

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controlled together. Finally, a unique identifier was also assigned to each measurement point in each QCU. This identifier, labelled Sample_ID, is used to identify each individual row (e.g., one water sampling bottle on a CTD rosette) in the data product and is used during the QC process to flag individual datapoints. The following equation was applied:

$$\text{Sample_ID} = \text{Unit_ID} * 100000 + \text{row number} \quad (1)$$

where the row number is a number from 1 to the total number of rows for each unique Unit_ID.

### 2.5 Quality Control

#### 2.5.1 Primary QC

Our primary QC assessed the quality of each dataset based only on the dataset itself, without reference to other datasets in the product. We followed the World Ocean Circulation Experiment (WOCE) convention for this base level of QC. When datasets were originally flagged using another system than WOCE, such as SEADATANET and NMDC flag schemes, we converted the flags to the WOCE convention for consistency. For datasets with original flags following SEADATANET flag scheme, flag 1 (good value in SEADATANET) was replaced by the WOCE flag 2, flags 3 and 4 in SEADATANET (probably bad value and bad value respectively) were kept the same as they correspond to the same flags in WOCE. For the NMDC flag scheme, flag 0 (good value in NMDC) was replaced by WOCE flag 2 while flags 2 and 3 in NMDC (data outside of calibration range or below detection limit and bad value) were replaced by WOCE flag 4. Among the 179 QCUs, 133 contained flags in the original datasets and 46 did not. All data flags assigned to variables in the original datasets by their PIs were kept in the data compilation. When no flags were submitted with the original dataset, they were assigned a flag of 10.

All QCUs underwent primary QC following a method similar to the one described by Tanhua et al. (2010), adapted to better suit the statistics of the NWESDAP dataset, as described in the following paragraphs. The QC was performed on TA, DIC and pH_T_insitu. No additional QC was performed on oxygen and nutrient variables other than the original QC from the PIs.

To avoid overwriting the original flags (stored with the name of the variable followed by "_flagPI") and thereby losing information on the different QC steps, new flag columns were created to report the flagged datapoints following the QC carried out for NWESDAP. For each quality-controlled variable, a column with the name of the variable followed by "_QC" was added to the dataset. The flags used for primary QC are summarised in Table 2. A flag 0 was first assigned to all carbonate system values. A flag 1 was assigned to all values flagged as questionable (flag 3 in the "_flagPI" column) or bad (flag 4 in the "_flagPI" column) in the original dataset and a flag 9 was assigned to missing values. The following QC steps were performed only on datapoints flagged as good data in the original dataset or datapoints with no flag.

We identified questionable values for TA, DIC and pH using statistical analysis and property-property plots. For each QCU, the median and the spread estimator $S_n$ (Rousseeuw and Croux, 1993) of each carbonate variable were calculated. The estimator

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$S_n$ is more suitable for this application than the standard deviation because $S_n$ is much less sensitive to the presence of outliers. Datapoints falling outside of ± 4 $S_n$ of the median were manually checked and flagged as questionable unless their unusual values could plausibly form part of the natural variability of the region. Data falling within the 4 $S_n$ window were checked for values falling outside the usual patterns of variability, and if found, these were flagged as questionable. These manual checks were done using property-depth and property-property plots as well as histograms. For the property-property plots, multiple combinations were made to inspect the relationships between the variables and to determine if the identified outliers were related to biogeochemical or hydrological processes. TA, DIC and pH were plotted against each other and against temperature, salinity, depth, distance to shore and datetime. When needed, the location of the sample and/or oxygen and nutrient values were used to confirm the presence of a questionable datapoint. A flag 2 was assigned in the variable_QC column to all questionable data identified through this primary QC. A detailed description of the reasons for each flagged datapoint can be found in the Supplementary Data.

### 2.5.2 Secondary QC

Secondary QC assesses the quality of each dataset by comparing with surrounding datasets in NWESDAP. It aims to identify biases in the datasets, as well as possible offsets between QCUs. We developed a method combining multiple linear regression (MLR) analysis and crossover identification, hereafter referred to as the MLR-crossover method, to identify questionable values not identified during primary QC as well as biases between QCUs. For each QCU, MLRs were fitted to calculate each of TA, DIC and pH from temperature, salinity, datenum, depth, latitude, longitude and distance to shore using the equation

$$y = \alpha + \sum_i \beta_i X_i + \sum_{i=S,T,z,d} \gamma_i X_i^2 + \delta ST \quad (2)$$

where $y$ is the target variable (TA, DIC or pH); $X_i$ is predictor variable $i$; $S$ is practical salinity; $T$ is temperature in °C; $z$ is depth in m; $d$ is distance to shore in km; and $\alpha, \beta_i, \gamma_i$ and $\delta$ are the fitted coefficients associated with the constant, linear, squared and combined terms respectively. MLRs were performed on QCUs containing a minimum of 50 data points to prevent overfitting. Predictors were included in the MLR only if they covered a minimum range of values, as follows. Longitude and latitude were used as predictors for QCUs with a minimum range of 0.1° for each coordinate variable. Depth and datenum were used only for QCUs with at least 2 different depths of 1 m apart and within a time window longer than 1 day. Distance to shore was considered as a predictor for QCUs with at least 5 km between the closest and furthest datapoints to shore. No minimum ranges were defined for salinity and temperature.

The offsets between the measured and MLR-predicted variables were calculated for each QCU. As in the primary QC, a limit of ± 4 $S_n$ was used to identify the suspicious points within each QCU. A manual verification was performed to confirm or not the presence of questionable data within the outliers identified, accounting for the environmental context to avoid flagging outliers linked to natural variability rather than questionable quality.

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For each QCU, surrounding QCUs were then identified to perform an MLR-crossover analysis and diagnose biases between datasets. While in GLODAP, a distance of up to 2° arc (approximately 200 km) is used to identify the crossovers (Olsen et al., 2016; Lange et al., 2026), a smaller distance is needed on continental shelves to account for the strong spatial variability compared to the deep open ocean. As for the crossover definition in SOCAT, sampling date and time was also taken into account. In total, the same 7 variables used to calculate the MLR were used to identify crossovers. Longitude, latitude and datenum were used to identify the neighbouring QCUs, with cut-offs of ±1° for longitude and latitude and ±30 days for datenum. Only values from neighbouring QCUs within ±10 meters of the depth range covered by the selected QCU were considered for the crossover. Because of the strong influence of continental inputs on the carbonate system variables, distance to shore was also considered in the selection of neighbouring QCUs, with a cutoff of 5 km under the minimum distance to shore of the selected QCU and 20 km above the maximum distance to shore. Finally, salinity and temperature were also used to account for the strong seasonal and spatial variability of these variables in the region, with cutoffs of ±2 °C and ±2 for salinity.

Here, we filtered the MLR-crossovers using the windows of values describe for each of the variables listed above. All the datapoints from QCUs other than the one selected for QC and falling within the window for all the variables were selected to perform the MLR-crossover analysis with the selected QCU. When needed, the windows were adjusted per QCU to account for the natural variability and the location of the samples (distance to shore, depth, location, temperature and salinity range, temporal variability).

The MLR defined for a QCU was applied to all datapoints selected for crossover and the offsets between the calculated and observed values for each of TA, DIC and pH were analysed. A flag 3 was assigned in the "_QC" column to datapoints identified as questionable from the secondary QC. Contrary to GLODAP, no adjustments were made to the values when an offset was detected between QCUs as it is difficult to estimate the correction necessary depending on the natural variability, even when stations are close in space and time. Instead, if the analysis clearly indicated which QCU was responsible for the offset, the data from this QCU were flagged as questionable (Table 2).

**Table 2. Flags used for QC at the datapoint level in NWESDAP (columns "_QC").**

| Flag value | Definition |
|---|---|
| 0 | Good data |
| 1 | Flagged as questionable or bad data in the original dataset |
| 2 | Flagged as questionable following the primary QC |

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| | |
|---|---|
| 3 | Flagged as questionable following the secondary QC (MLR-crossover) |
| 9 | Missing value |

340

### 2.5.3 Uncertainties

The datasets compiled in this product were selected based on the availability of discrete measurements of carbonate system variables in the NWES seas, regardless of their origin. Different methods were used to measure the carbonate system variables in this data product, each with its own uncertainty. To assess the consistency of the data product and allow intercomparison of 345 the carbonate system between the different QCUs, the measurement methods of TA, DIC and pH and their related uncertainties are reported in the NWEDAP metadata file based on the original metadata given by each dataset's PI.

Flags were assigned at the QCU level to indicate whether datasets were assessed to meet the GOA-ON (Newton et al., 2015) climate quality uncertainty goals (2 µmol $kg^{-1}$ for TA and DIC, 0.003 for pH) or the weather quality goals (10 µmol $kg^{-1}$ for 350 TA and DIC, 0.02 for pH) (Table 3). For DIC, datasets from coulometric or infra-red based systems that explicitly used CRMs for calibration were in the first instance considered to be climate quality (flag C); datasets without CRMs or based on continuous flow-through analysis (CFA) or potentiometric methods were considered to be weather quality (flag W); datasets with uncertainties reported as or assessed in our QC processes to be greater than the weather quality goal were identified separately (flag X). Analogously for TA, datasets from potentiometric systems with CRM calibration were considered to be 355 climate quality; datasets based on CFA were considered weather quality, unless the uncertainty was greater. For pH, datasets from spectrophotometric systems were considered climate quality, and potentiometric or other measurement systems were considered weather quality or worse. For any dataset, if the uncertainty reported by the data provider was greater than the climate- or weather quality cutoff assumed above based on the methodology, then the flag was assigned based on the provided uncertainty instead.

360

**Table 3. Flags assigned at the QCU level in NWESDAP (column name "_QCU_flag" in the dataset and metadata).**

| Flag value | Definition |
|---|---|
| **C** | QCU meeting the climate quality uncertainty goals (2 µmol $kg^{-1}$ for TA and DIC, 0.003 for pH) |
| **W** | QCU meeting the weather quality uncertainty goals (10 µmol $kg^{-1}$ for TA and DIC, 0.02 for pH) |
| **X** | QCU with uncertainties greater than the weather quality goal or with no methods detailed in the metadata |
| **Z** | Variable not measured |

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### 2.5.4 Carbonate system calculations

Where three carbonate system variables are known, the internal consistency of the carbonate system can be evaluated by calculating one carbonate system variable from the other two. We investigated the difference between the calculated and measured values of TA, DIC and pH for the 30 QCUs containing data for all three. The calculations were done using PyCO2SYS v1.8.3.3 with the settings described in Section 2.4. When available, nutrient values were included in the calculations. In datasets such as GLODAPv2 or CODAP-NA, the results of the internal consistency were used to flag or correct pH data only, and not TA or DIC (Olsen et al., 2016; Jiang et al., 2021), although internal consistency was no longer assessed in GLODAPv3 (Lange et al., 2026). In NWESDAP, no flags were assigned to the data following this step, but the results of these calculations and the implications for the internal consistency of NWESDAP are discussed in Section 3.3.

## 3. QC results

### 3.1 Primary QC evaluation

From the primary QC, a total of 164 TA, 133 DIC and 206 pH data points were assigned a flag 2 for questionable data following the statistical analysis (Section 2.5.1). QCU NorwegianWestCoast_2020_2021 provides an example of the importance of manual verification (Figure 2). While multiple datapoints fall outside of the 4 $S_n$ window, the low DIC values were all located in the surface waters and a clear relationship with salinity and DIC can be observed. They were therefore not identified as questionable in the dataset. On the contrary, the datapoint marked as a yellow star on Figure 2 was identified as questionable despite falling within the 4 $S_n$ window. It was identified as such as it was falling outside of the main linear relationships between DIC and other variables (depth, salinity, TA).

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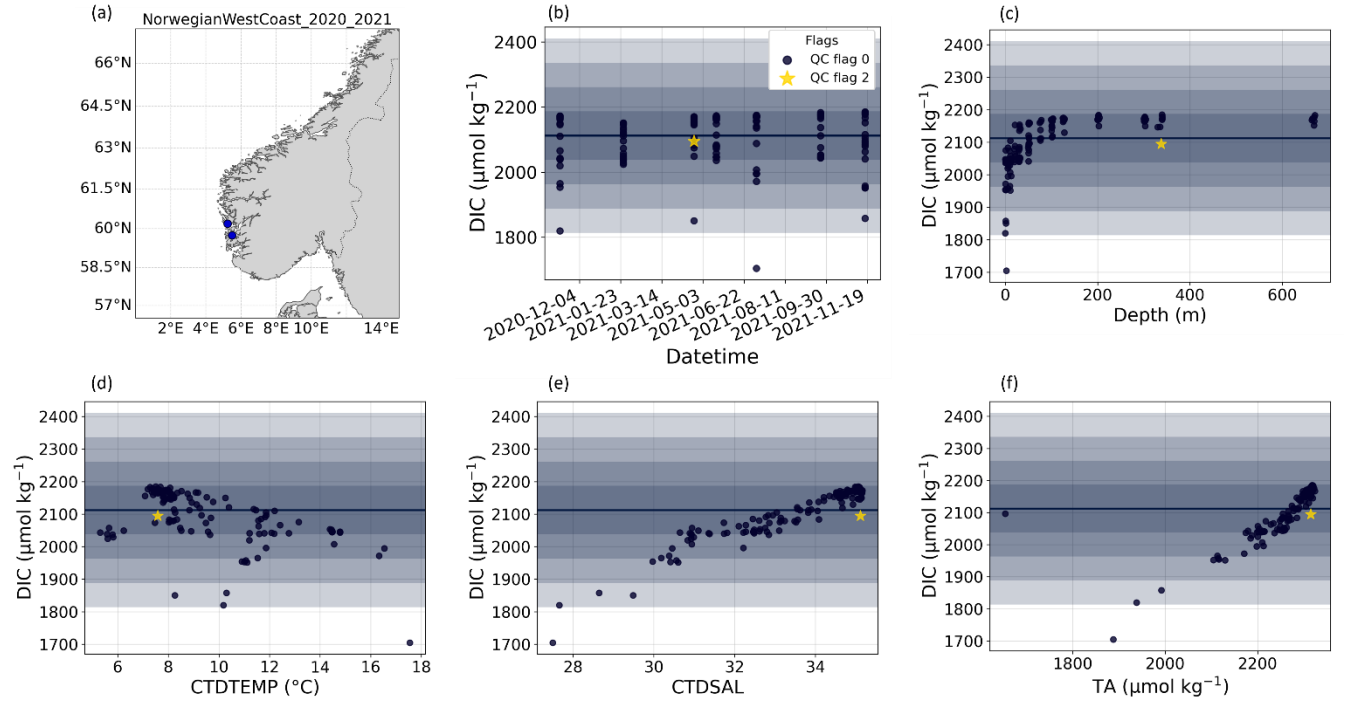



**Figure 2. Case study of primary QC for QCU (Name_ID) NorwegianWestCoast_2020_2021 for DIC. (a) Map and (b-f) property-property plots of DIC against other variables. In b-f, the black horizontal lines represent the median values and the grey horizontal shaded bars represent 1-4 $S_n$ deviations from the median. The back dots represent the datapoints flagged as good data (flag 0) and the yellow star represents the datapoint flagged as questionable during primary QC (flag 2). The outlier with low TA in (f) is flagged as questionable for TA but not for DIC, hence why it is not referenced as a flag 2 datapoint here for DIC graphs.**

For some stations close to harbours, high DIC and TA values were identified. These datapoints, potentially affected by anthropogenic activities, were not flagged as suspicious but were reported in the NWESDAP metadata file. Processes such as biological activity, freshwater inputs from rivers or fjords, and sedimentary processes were taken into account during the manual check to avoid incorrect flagging in this highly variable environment. For example, careful review of the location and season was made. The salinity range and depth above the seafloor were also investigated before deciding whether to flag each datapoint. However, it is possible that some of the flagged datapoints are due to natural variability or specific processes occurring at the station location, and some questionable datapoints may not have been flagged during the primary QC.

### 3.2. Secondary QC evaluation

From the secondary QC based on the MLR-crossover method, 91 of 164 QCUs for TA, 79 of 158 for DIC and 36 of 52 for pH were QCed to identify questionable datapoints. From this step, a total of 48 TA, 5 DIC and 9 pH datapoints were flagged as questionable and were assigned a flag 3. The first part of the MLR-crossover method allowed us to identify datapoints with large offsets between the calculated and measured value, highlighting discrepancies that could not be identified through the

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statistical analysis. As described in the Methods, the MLR was defined for the carbonate system variables of each QCU using temperature, salinity and other core variables. While temperature and salinity are often sufficient to predict TA with a reasonable uncertainty in the surface open ocean (Lee et al., 2006), this is not the case for DIC and pH, nor for TA in shelf seas. In the coastal ocean, TA and DIC can be influenced by river and fjord inputs or by sedimentary inputs (Borges and Frankignoulle, 1999; Thomas et al., 2009; Gypens et al., 2011; Hydes and Hartman, 2012). Salinity and temperature also have a higher variability compared to the open ocean, linked with the freshwater inputs but also caused by extreme meteorological events. As the MLR-crossover method was not only applied on surface samples but also on samples in the water column, other processes such as remineralization or sedimentary inputs can also influence the distributions of TA, DIC and pH (Thomas et al., 2009; Brenner et al., 2016). The samples' depth and their proximity to the seafloor were considered during the manual verification. All these processes can lead to a decoupling of the relationship between the carbonate system and hydrographic variables. For these reasons, the offset between calculated and measured values was evaluated with caution. A manual review of all the offsets was conducted to avoid flagging outliers impacted by the high variability and natural processes in the region.

Figure 3 provides an example of the performance of the secondary QC for pH_T_insitu in QCU 11BG20070510. A datapoint was identified as questionable following the MLR-crossover method, showing a large offset between a calculated and measured pH_T_insitu value. The datapoint was given a flag of 3.

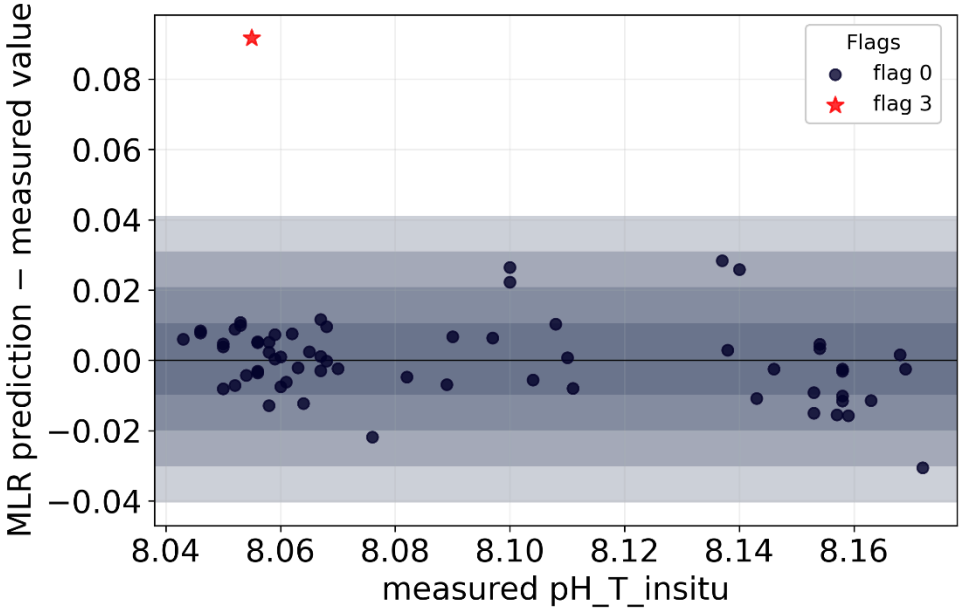



**Figure 3. Case study of secondary QC for QCU (Name_ID) 11BG20070510. Identification of an outlier based on the offset between MLR predicted and measured pH_T_insitu. The outlier identified through secondary QC is flagged questionable (flag 3, red star). The black dots represent the datapoints flagged as good data (flag 0).**

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The secondary QC was also used to identify offsets between MLR-crossovers (Section 2.5.2). For TA, 140 QCUs were QCed for crossover. Of these 140 QCUs, 91 of them contained at least 50 TA datapoints and each MLR equation determined in the step above was used to calculate the TA values for the surrounding QCUs. Based on this method, 49 QCUs could be QCed for TA while having less than 50 datapoints. For DIC, a total of 124 QCUs were checked, 79 of them having more than 50 datapoints. For pH_T_insitu, 44 QCUs underwent the MLR-crossover approach, based on the MLR of 36 units.

### 3.3 Internal consistency of the carbonate system variables

4,569 datapoints (9.8 % of the total number of datapoints in NWESDAP) had values for all of TA, DIC and pH and thus could be used for the internal consistency analysis. Important discrepancies between calculated and measured carbonate variables were observed during the internal consistency evaluation, with offsets of up to several hundreds of µmol $kg^{-1}$ for TA and DIC and up to 1.65 for pH (Figure 4a-c). The majority of the datapoints affected by these important offsets had already been flagged as questionable (Flag 1 to 3) or came from a QCU flagged X in the metadata. These results highlight the importance of carrying out several QC steps, at the datapoint level but also at the QCU level, to assess the consistency of the data product.

For the next step of the internal consistency evaluation, we focused on the datapoints with a flag 0 and a flag C or W at the QCU level (4007 datapoints). We observed a good agreement between the calculated and measured values, with 76.7 % and 78.8 % of TA and DIC offsets within 10 µmol $kg^{-1}$ and 75.3 % of pH offset within 0.02 (Figure 4d, e, f). These results show that the majority of the carbonate system data within this subset are internally consistent within the weather quality goal (Newton et al., 2015). The number of datapoints meeting the climate quality criteria was however very low, with only 21.5 %, 22.7 % and 16.6 % of TA, DIC and pH_T_insitu data respectively under the threshold of 2 µmol $kg^{-1}$ for TA and DIC and 0.003 for pH_T_insitu.

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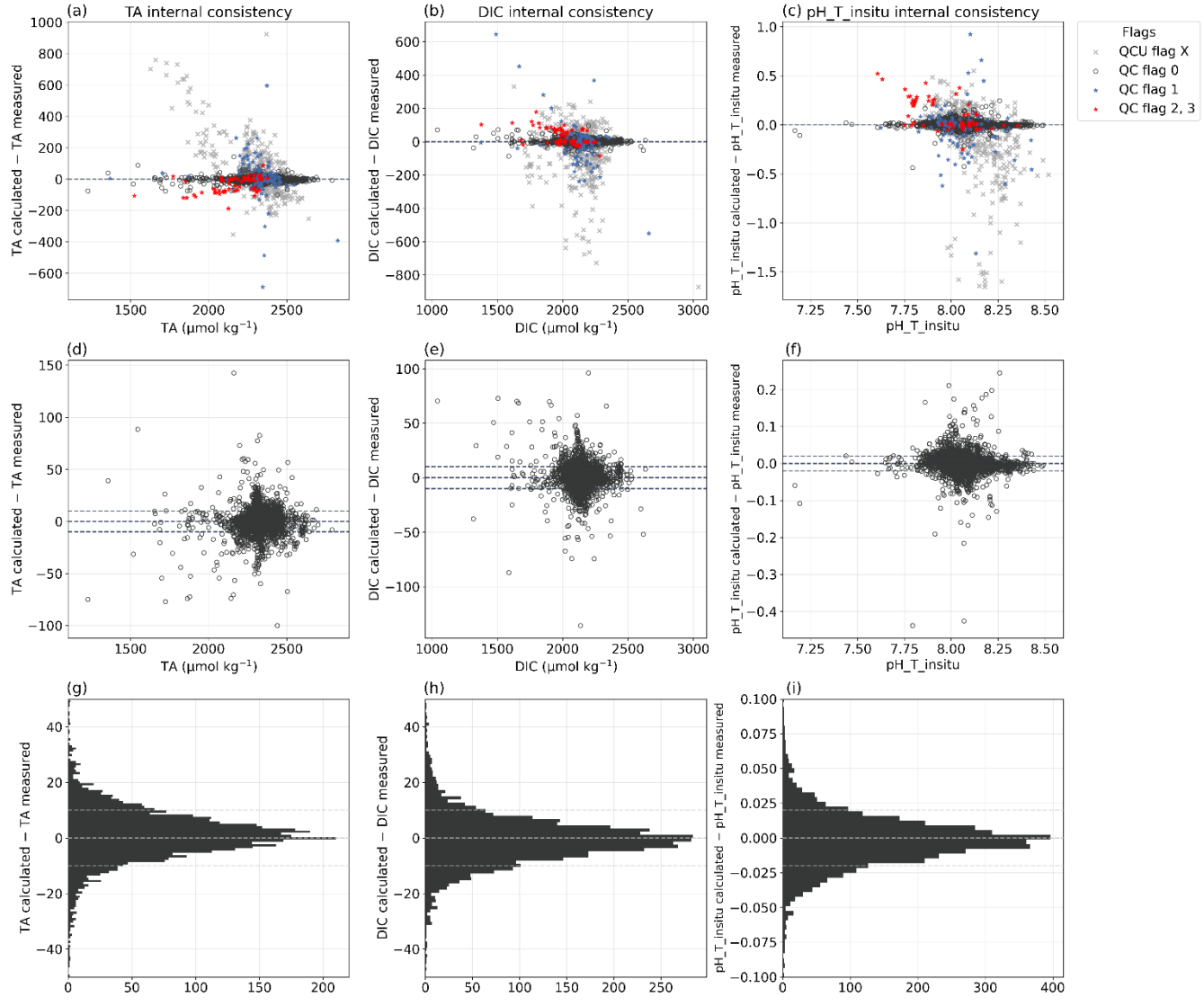



**Figure 4. Internal consistency of the carbonate system variables for TA (a, d, g), DIC (b, e, h) and pH_T_insitu (c, f, i) for the 30 QCUs with the three variables. Dots with dark grey edges are the datapoints flagged 0. The stars represent the datapoints with at least one of the three variables flagged 1 (in blue), 2 or 3 (in red) and datapoints from QCU flagged X (in light grey) in the metadata based on the measurement method and uncertainty. In the upper panels (a-c), all datapoints from the 30 QCUs are plotted. In the middle (d-f) and lower panels (g-i), only the datapoints flagged 0 were retained to observe the internal consistency of the good datapoints in the data product. The dotted lines in the middle panels show the weather quality uncertainty levels of 10 µmol kg$^{-1}$ for TA (d) and DIC (e) and 0.02 for pH (e). The bottom panels (g-i) show the distribution of the datapoints shown in panels (d-f) with a zoom on the y axis.**

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Several sources of uncertainty contribute to the discrepancies between calculated and measured values. The analytical precision and accuracy of the measurements (Orr et al., 2018; Carter et al., 2024b), which can be observed through the poor agreement between calculated and measured values for datapoints originating from datapoints flagged 1-3 and from QCUs flagged X (Figure 4a-c). The use of the TA-DIC pair to calculate pH can also lead to higher uncertainties than other pairs in the coastal ocean (Orr et al., 2018; Raimondi et al., 2019; Aguado Gonzalo et al., 2026).

The input constants used to calculate the variables and in particular the equilibrium constants $K_1$ and $K_2$ (Mojica Prieto and Millero, 2002; Millero et al., 2006; Orr et al., 2018; Carter et al., 2024a) also lead to uncertainties in the calculations. Here, we used the set of constants from Lueker et al. (2000), designed for seawater with salinities greater than 19 and temperatures above 2°C. The use of this set of constants for waters fresher than 19 or colder than 2 °C, as is the case in NWESDAP, can therefore result in higher uncertainties in the calculated values. Within the subset of data used for the internal consistency and flagged 0 at the datapoint level and C or W at the QCU level, only 2 datapoints had a salinity < 19 and 32 datapoints had a temperature < 2°C. From these datapoints, 1 out of the 2 datapoints with 19 < S was outside of the weather quality goals for the three carbonate system variables and 22, 23 and 17 datapoints out of 32 for pH, TA and DIC respectively were outside for the datapoints with temperature lower than 2°C. To account for the high variability in salinity and temperature in coastal oceans, other sets of equilibrium constants with a wider range of salinity and temperature values can be used. We compared the results obtained using Lueker et al. (2000) with the calculated values using Waters et al. (2014), which is validated for a salinity range of 0 < S < 45 and a temperature range of 0 < T < 45°C. However, because of the small amount of data with low salinity and temperature, the difference between the two methods was not significant, with less than 1 µmol $kg^{-1}$ difference for TA and DIC and 0.002 for pH between the median offsets for each method.

The computation of the carbonate system variables is affected by the nutrient concentrations through the contribution of silicate, phosphate, ammonia and bisulfide to TA. Aguado Gonzalo et al (2026) reported a small influence of ignoring these contributions on carbonate system calculations (up to a 1.9 % increase in the absolute uncertainty) for coastal waters. However, the uncertainty scales with nutrient concentrations, so this effect would be greater in samples from more nutrient-rich areas.

Finally, in the coastal ocean, the contribution of organic alkalinity to total alkalinity can be significant (Cai et al., 1998; Kuliński et al., 2014; Yang et al., 2015; Kerr et al., 2021), but the organic components are omitted from TA calculations, potentially leading to substantial uncertainties (Kuliński et al., 2014; Orr et al., 2018; Carter et al., 2024b). The highest differences between calculated and measured carbonate system variables were found along the coasts, in fjords and in the southern North Sea, suggesting a potential impact of terrestrial organic material and/or sedimentary processes in shallow waters on the internal consistency of the carbonate system (Brenner et al., 2016; Voynova et al., 2019; Meyer et al., 2025).

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While the internal consistency of the carbonate system could be performed on only 9.8 % of the data, this subsample of the data product already shows the complexity of predicting the carbonate system in the NWES seas. The low number of datapoints meeting the climate quality goals highlights the limitation that calculating carbonate system variables risks substantial propagation errors in many of the coastal waters represented by NWESDAP.

## 4. Data product description

NWESDAP consists of 46,545 carbonate system datapoints from 179 research cruises, monitoring programmes and stations collected between 1975 and 2026. 5,221 datapoints were already available in GLODAPv2.2023, representing 11.22 % of the datapoints included in NWESDAP. The period covered by GLODAPv2.2023 is shorter, with data from 1989 to 2019. NWESDAP contains 26,426 TA, 24,524 DIC and 26,358 pH measurements (Table 4). 43.72 % (20,351 datapoints) of the measurement points have values for one carbonate system variable, 46.46 % (21,625 datapoints) have two carbonate system variables and 9.82 % (4,569 datapoints) have three carbonate system variables. Among the 179 QCUs, TA measurements are included in 164 of them, DIC measurements in 158 and pH in 52.

**Table 4. Number of observations per variable.**

| Variable | Number of observations |
|---|---|
| CTDTEMP | 46,545 |
| CTDSAL | 46,545 |
| TA | 26,426 |
| DIC | 24,524 |
| pH_T_insitu | 26,358 |
| CTDOXY | 24,039 |
| Oxygen | 1,037 |
| Nitrate | 31,579 |
| Nitrite | 25,423 |
| Ammonium | 22,815 |
| Silicate | 34,259 |
| Phosphate | 35,113 |

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The interannual distribution of the carbonate variables is uneven, with less than 1 % of TA and DIC data before 2000 and more than half of the datapoints (62.94 % for TA and 59.96 % for DIC) from 2015 onward (Figure 5). The majority of TA and DIC datapoints up to and including 2005 come from GLODAPv2.2023, with most of the data during this period being measured in 2001, 2002 and 2005 in the North Sea (Bozec et al., 2006). The lack of data in the oldest part of the period covered by NWESDAP could be attributed to the lack of measurement of carbonate system variables or the difficulty to access the data, or both. For pH, the interannual distribution is different, with more than a third of the datapoints before 1985 (38.09 %) and 28.14 % of the data from 2015. The interannual pH distribution before 2018 is mostly driven by one dataset in the Dutch North Sea (Name_ID = DutchOA), with 18,224 pH measurements between 1975 and 2018 (87.3 % of the total number of pH datapoints over this period in NWESDAP). From 2005, the number of available datapoints per year in NWESDAP increased for the three carbonate system variables and reached a peak in 2022/2023 before decreasing. The decreasing number of carbonate system observations in recent years has also been observed in SOCAT (Bakker et al., 2024). In SOCAT, this decrease is attributed to the decline in observing efforts. In NWESDAP, while the reduction in observing efforts may partially account for the decline, another possible explanation is the delay between collection and publication of the data for the most recent years. One notable feature is the increasing availability of pH measurements this past decade. Again, this increase could come from the increasing accessibility of these data in the different databases, but there may also have been an increase in pH observations due to the recommendation for coastal states to monitor the progression of ocean acidification under the UN Sustainable Development Goals (Target 14.3.1, United Nations General Assembly, 2015).

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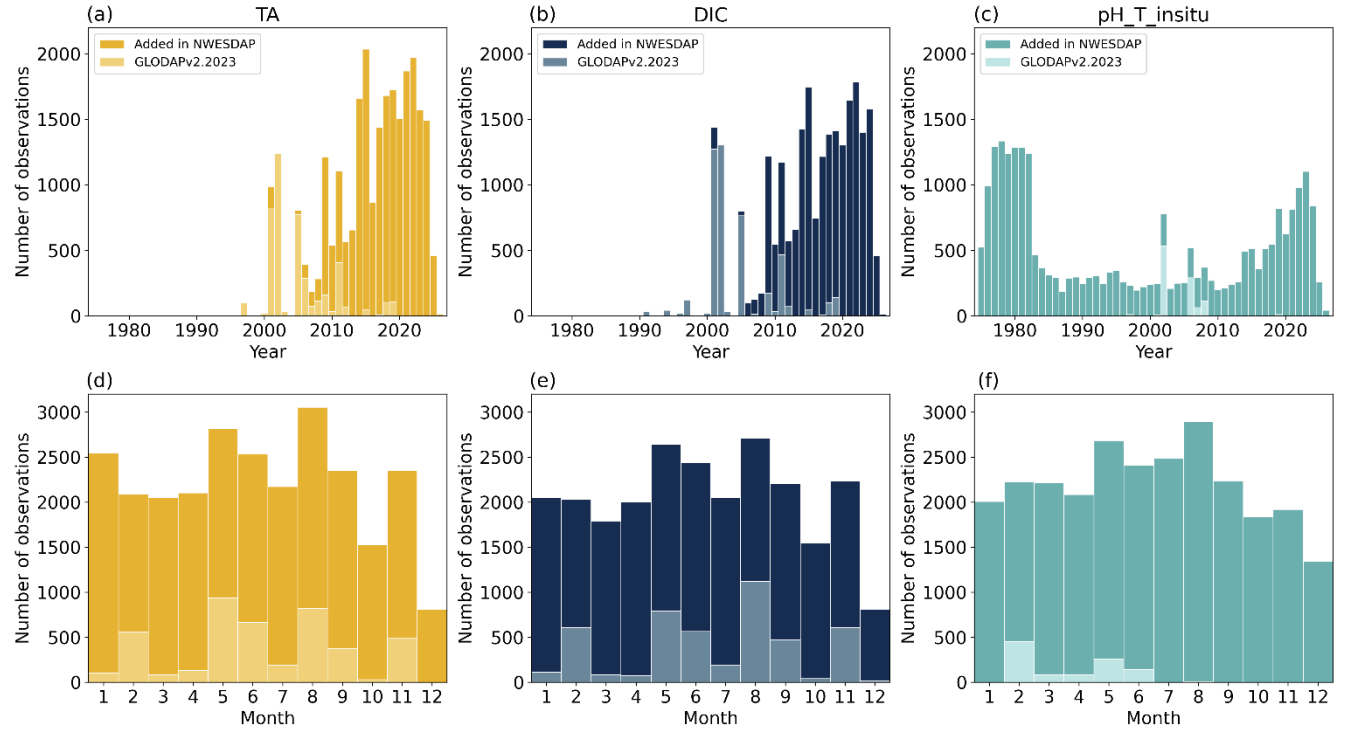



**Figure 5. Yearly and monthly distributions of the carbonate system variables. Number of observations per year and month for TA (a, d), DIC (b, e), and pH_T_insitu (c, f). The total height of each bar shows the number of observations in NWESDAP, with the lighter colour in the lower part of each bar representing the subset of data that are also in GLODAPv2.2023.**

In NWESDAP, the data are evenly spread throughout the year, with 26.1 %, 29.8 %, 23.9 % and 20.2 % of the data for spring (March to May), summer (June to August), autumn (September to November) and winter (December to February) respectively. This is an improvement compared to GLODAPv2.2023, where data available for the NWES are biased towards the summer months for TA and DIC (respectively 38.1 % and 40.0 % of the data) and towards the winter and spring for pH (41.6 % and 43.8 % respectively). The relative differences in the number of observations between the most- and least-sampled months is also significantly less in NWESDAP than in GLODAP. Indeed, several months had no data at all for some variables in GLODAP, whereas all months are represented in NWESDAP. The comprehensive temporal coverage of NWESDAP is therefore an asset to support studies of the seasonal variability of the carbonate system on the NWES.

In addition to a uniform temporal coverage, the spatial representativeness of the entire region is also important to capture the regional and local heterogeneity and to facilitate accurate and unbiased carbon budgets of the region. While NWESDAP includes observations from the surface to the bottom of the water column, they are unevenly distributed, with more than two-thirds of the datapoints (71.2 %) within the first 10m (Figure 6). The stations with observations at different depths along the water column are however well distributed within the continental shelf.

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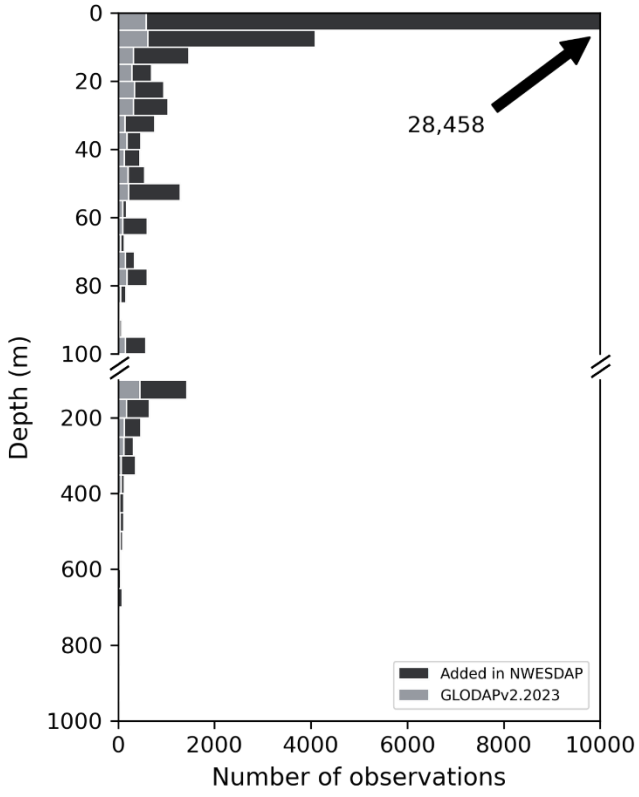



**Figure 6. Depth distribution of the observations in NWESDAP. Note the change in vertical axis at 100 m, with bars every 5 meters for the first 100 m, and every 50 m from 100 m. The total length of each bar shows the number of observations in NWESDAP, with the lighter colour in the lower part of each bar representing the subset of data that are also in GLODAPv2.2023.**

In general, the datapoints are well-distributed across the NWES, with more than 3,900 different stations (Figure 1). The Norwegian Sea has the least spatial coverage, with most of the data located in the fjords, along repeated monitoring transects at the southern boundary (Svinøy), north of 68°N (Gimsøy) and along a unique transect at 66°N. The density of the data in space and time ensures a good representation of all seas of the NWES across all four seasons (Figure 7), especially for TA and DIC (Figures S1 and S2). The oxygen and nutrients also have a good spatial coverage (Figure 8). pH is less evenly distributed across the shelf, with most of the observations located in the North Sea and along the French coast (Figure S3).

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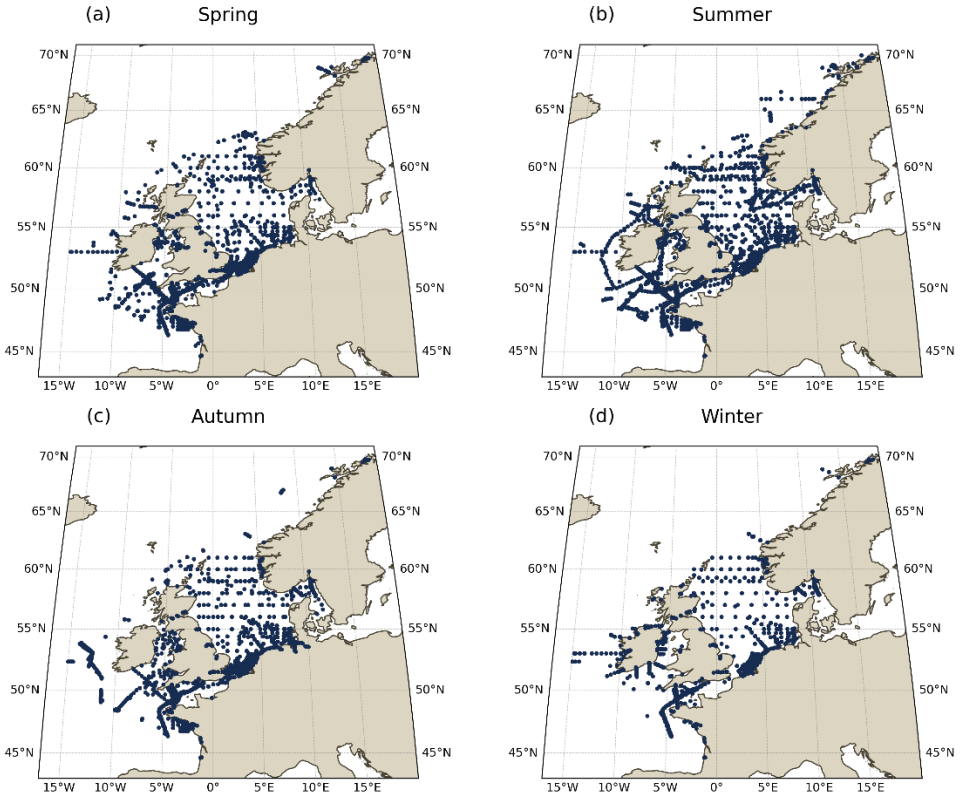



**Figure 7. Seasonal distribution of NWESDAP for all carbonate system variables. Spring from March to May, Summer from June to August, Autumn from September to November and Winter from December to February.**

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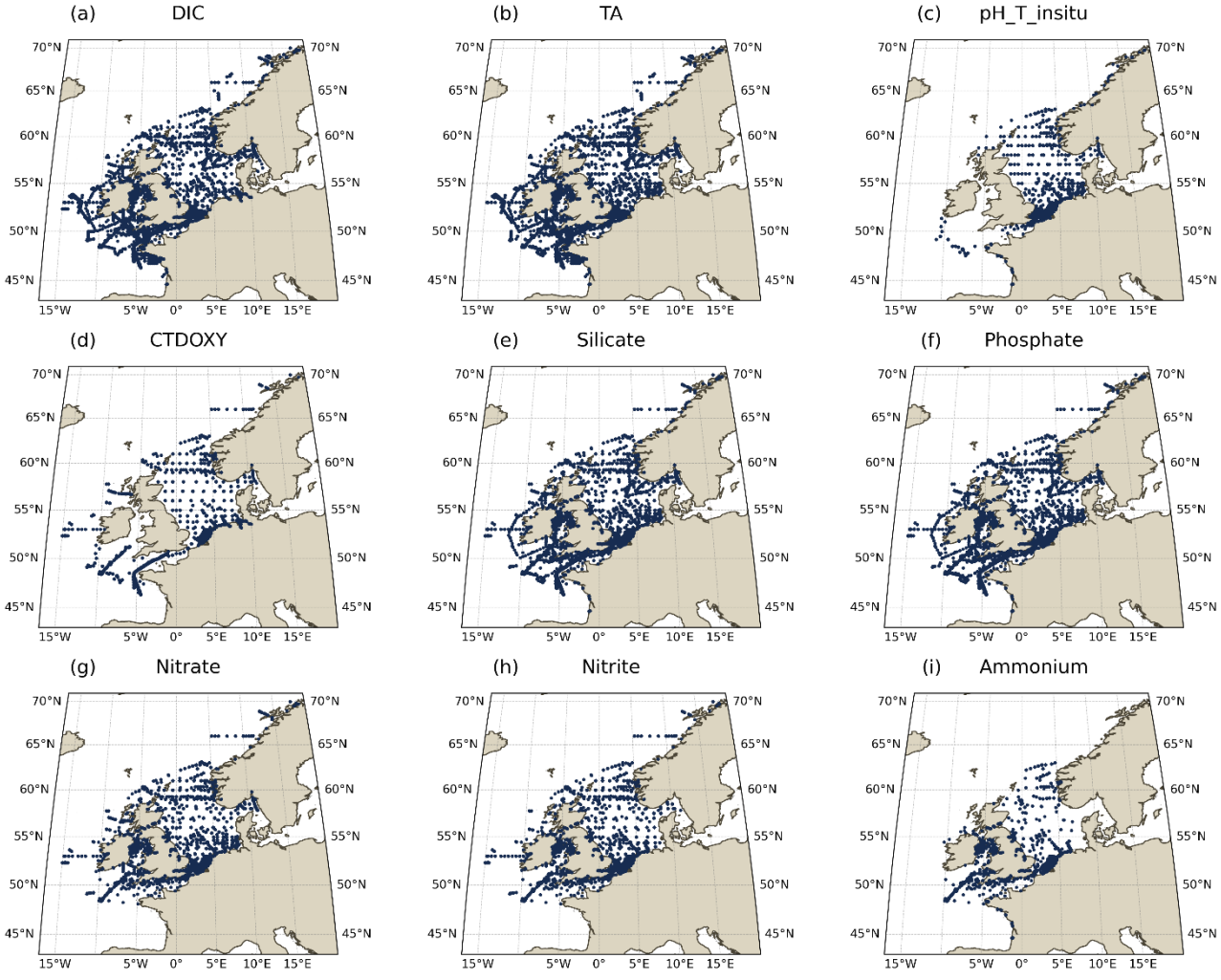



**Figure 8. Spatial distribution of the carbonate system variables, oxygen and nutrients in NWESDAP.**

Although the spatial coverage seems reasonably complete for each season and parameter in Figures 7-8, the aggregation of all years into a single figure masks the much less uniform coverage for any particular year. Given the high interannual variability in shelf seas like the NWES, this could be restrictive for some applications, and continued collection of year-round data across the region is still very much needed.

Rivers, estuaries and fjords are also represented, with datasets covering rivers and estuaries in Ireland, the United Kingdom, France, the Netherlands and Germany and fjords in Norway. These datapoints facilitate the understanding of the impact of continental inputs on the carbonate system of the shelf, for example allowing zero-salinity TA and DIC endmember values to be calculated. The presence of several datasets from monitoring programmes, with repeated cruises every year sometimes

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during multiple months per year, is an asset to study the interannual evolution of the carbonate system in the relevant regions as well as the seasonal variability. These datasets are mainly located in the southern part of the North Sea along the coast of Belgium, the Netherlands in the German Bight, and along transects in the Norwegian Sea.

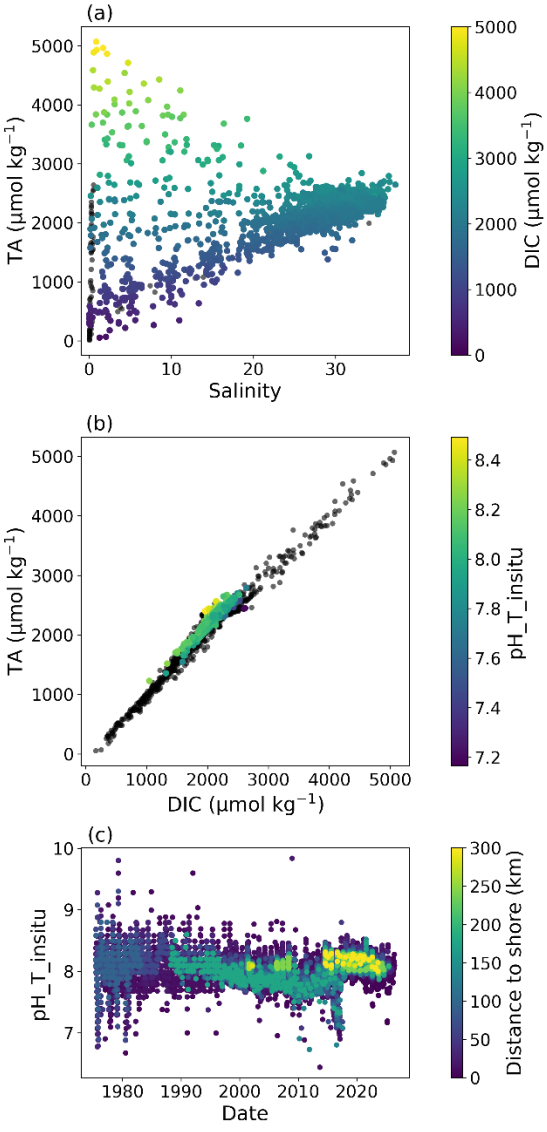



**Figure 9. Relationships between the carbonate system variables and their dependencies on other variables in NWESDAP. (a) Distribution of TA (y axis) and DIC (colour) depending on salinity. (b) Relationship between DIC and TA, with pH_T_insitu in coloured dots. (c) pH_T_insitu through time with distance to shore in colour. For (a) and (b), the grey dots correspond to data for which DIC and pH_T_insitu were not measured, respectively. Only datapoints with Flag 0 and QCU flags C and W are shown here, except for panel (c) where pH values of Unit_ID 76 (Flag X) are also shown.**

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NWESDAP features a wide range of values of carbonate system and hydrographic variables, reflecting the high variability of processes in the NWES seas. Temperature values range from -0.91 to 25.38 °C, with salinity values between 0 and 37.3 (Figure 9a); high salinities > 36 are found at Ifremer Bouin oyster growth facility). TA and DIC show high variability, with values between 9 and 5067 µmol $kg^{-1}$ for TA and between 168 and 5069 µmol $kg^{-1}$ for DIC (Fig. 9a-b), and a strong correlation between the two parameters for the entire dataset. The strongest variability in TA and DIC is observed at the lowest salinities, linked to the heterogeneity of freshwater sources. pH values also show a wide range of values, with the highest variability observed close to the coast (Fig. 9c).

## 5. Data availability

The data product and associated metadata are available online (Brandon et al., 2026b; https://doi.org/10.5281/zenodo.23555137). The metadata consists of two Excel files: one file with the list of all QCUs with information related to the origin of the datasets and to the measurement methods of the carbonate system variables, and another file with the lists of all the flagged datapoints for primary and secondary QC as well as datapoints that were potentially suspicious but ultimately not flagged 2 or 3 following the primary and secondary QC and a comment explaining the reason. The code and data used to generate the figures and statistics presented in this manuscript are also available online (Brandon et al., 2026a; https://doi.org/10.5281/zenodo.23573432).

## 6. Conclusion

NWESDAP is the first quality-controlled compilation of inorganic carbon, hydrographic and biogeochemical measurements for the northwest European shelf seas. It includes discrete measurements of TA, DIC and pH as well as temperature, salinity, oxygen and nutrients (nitrate, nitrite, ammonium, silicate, phosphate) for the entire water column in the NWES seas down to 1,000 m depth between 1975 and 2026. The internal consistency of the data product is assessed through a rigorous quality control developed for the high variability of the carbonate system on continental shelves and to overcome the limitations arising from the impossibility to use deep crossovers. This multi-step QC was carried out to allow the high variability of the marine carbon cycle in the NWES seas to be investigated at least within the GOA-ON weather quality uncertainty target.

With more than 40,000 additional datapoints on top of those already available in GLODAPv2.2023 (a 791.5 % increase), NWESDAP offers an increased spatial and temporal coverage of the marine carbonate system in the NWES seas, from rivers and fjords to the shelf edge connecting to the North Atlantic Ocean. By providing an open access, high-quality inorganic carbon data product, NWESDAP opens new possibilities for better understanding the marine carbonate system in coastal environments and for constraining the carbon sources and sinks in a region where the uncertainties remain high. In a region strongly influenced by anthropogenic activities and climate change, and to better quantify their effect on the continental shelf,

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NWESDAP aims to highlight the importance of continuous monitoring and long-term observations on the NWES. NWESDAP can also be used for training mapped data products and for validating the distributions of inorganic carbon variables in models and reconstructions (Gregor and Gruber, 2021; Chau et al., 2024; Roobaert et al., 2024), helping to improve the representations of underlying processes and guiding where and when new observations are needed to resolve the remaining knowledge gaps.

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Appendix A: Supplementary table

Table A1. Sources of data included in NWESDAP

| Source | Dataset_origin | Reference |
|---|---|---|
| GLODAPv2.2023 | GLODAP | Lauvset et al., 2024 |
| SNAPO-$CO_2$-v2 | SNAPO_CO2 | Metzl et al., 2025 |
| Cocori$CO_2$ | CocoriCO2 | Petton et al., 2024, 2026 |
| SDG14.3.1 | SDG14_3_1 | SDG 14.3.1 data portal, 2026 |
| Ocean Carbon and Acidification Data System – OCADS | OCADS | Ocean Carbon and Acidification Data System (OCADS), 2026 |
| Vannmiljø | VANN | Vannmiljø data portal, 2026 |
| Norwegian Marine Data Center – NMDC | NMDC | NMDC data portal, 2026 |
| Shelf Sea Biogeochemistry research programme – SSB | SSB | Hartman et al., 2019; Humphreys et al., 2019 |
| Land-Ocean Carbon Transfer – UK LOCATE (Land Ocean CArbon TransfEr) programme | LOCATE | Matthews, 2022 |
| Dutch North Sea (Rijkswaterstaat-NIOZ) ocean acidification monitoring programme | NIOZ_OA | Humphreys et al., 2025 |
| Dutch water management agency Rijkswaterstaat (RWS) long-term monitoring program | RWS | Provoost et al., 2010 |
| NIOZ Jetty | NIOZ_jetty | Ourradi et al., 2026 |
| NoSE cruises | NoSE | Humphreys et al., 2026a, b |
| Carmaflux | Carmaflux | Obtained directly from the PIs |
| WCO (Western Channel Observatory) stations L4 and E1 | WCO, SDG14_3_1 | Western Channel Observatory website Data obtained from BODC data portal (British Oceanographic Data Centre (BODC), 2026) and SDG14.3.1 |
| UK Ocean Acidification research programme cruise | UK_OA | Ribas-Ribas et al., 2014 |

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| | | |
|---|---|---|
| VLIZ datasets | VLIZ | Obtained directly from the PIs |
| Rockall Trough and Irish coast and shelf cruises | GLODAP, SDG14_3_1 | McGrath et al., 2012, 2016, 2019; Daly et al., 2024, data from GLODAP and SDG14.3.1 data portal |
| Monitoring the Belgian Continental Shelf and the Scheldt estuary (MONIT) | SDG14_3_1 | Obtained from the SDG14.3.1 data portal |
| Bundesamt für Seeschifffahrt und Hydrographie (BSH) | SDG14_3_1 | BSH, Obtained from the SDG14.3.1 data portal |
| Norwegian seas ocean acidification monitoring programme (IMR, NIVA, NORCE Research, University of Bergen) | NMDC, VANN, SDG14_3_1 | Obtained from NMDC, Vannmiljø and SGD14.3.1 data portals or directly from the PIs |

**Author contributions**. Subject to update through review process before submission

M.Br.: conceptualization, data curation, formal analysis, investigation, methodology, software, validation, visualization, writing – original draft, writing – review and editing.

M.P.H.: conceptualization, funding acquisition, investigation, methodology, resources, software, writing – review and editing.

A.C.K.: methodology, software, writing – review and editing.

M.Be.: conceptualization, writing – review and editing.

H.C.B.: conceptualization, writing – review and editing.

All other co-authors: resources, data curation, writing – review and editing.

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