

SHELDA: Sub-hourly European Quality Controlled Sea Level Dataset

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Abstract.

10 Freely accessible sea level databases often contain time series measured with hourly or even longer sampling step, or they contain high-frequency data that have not undergone quality control procedures. To address this gap, the SHELDA (Sub-Hourly European Quality Controlled Sea Level DAtaset) has been created. This dataset comprises 257 individual tide gauge records in NetCDF format (<https://doi.org/10.14284/764>, Balić and Šepić, 2025), each representing quality-controlled sea level time series sampled at intervals between 1 and 15 minutes, along with residual time series derived by removing tidal components. The duration of individual records ranges from a minimum of one month to a maximum of 13 years. This manuscript outlines the rigorous quality control procedures (i.e., removal of out-of-range values, application of an automatic spike detection algorithm, visual inspection) implemented and discusses the procedures that were not implemented (i.e., corrections of datum shifts). The manuscript further describes the spatial and temporal coverage of the dataset, along with technical specifications. All data are distributed under the CC BY 4.0 licence. SHELDA enables precise identification and analysis of sea level variability at timescales ranging from minutes to seasonal and longer, depending on the stability of the long term series along the European coasts and along the coasts of Greenland, Canary Islands, Israel, Lebanon and Türkiye.

1 Introduction

Sea level variations are affected by a combination of various physical processes encompassing a broad spectrum of time scales. These processes, typically distinguished by their period, wavelengths, amplitudes, repeatability, and manifestation, include short-term phenomena like surface gravity waves lasting from 1 to 20 seconds, infragravity waves, long ocean waves, seiches, and tsunamis with periods ranging from minutes to over an hour, tidal oscillations peaking at $\sim 1/2$ day and ~ 1 day, and other sea level variations which occur due to meteorological, hydrological and circulation effects that last from several days to years (including interannual and decadal fluctuations), as well as long-term changes of mean sea level due to planetary, geological and climatological factors (IOC, 2006; Pugh and Woodworth, 2014). To accurately distinguish and analyse these processes, it is essential to measure sea level using sampling intervals and instruments appropriately suited to the specific temporal and spatial scales of interest.

The first sea level measurements were conducted in 1679 at Brest, France (Picard and de la Hire, 1680) and later at various locations across northern Europe such as Amsterdam in 1682 (van Veen, 1954), Liverpool in 1768 (Woodworth, 1999) and Stockholm in 1774 (Ekman, 1988), using either visual observations of graduated markings on stone walls of docks (Woodworth et al., 2015) or wooden graduated rods, called tide poles, with both of these located at points where observers could read off the instantaneous sea level height at any given time (Woppelmann and Pirazzoli, 2019). Initially, sea level measurements were conducted with sampling intervals between one reading per month and one per week. In the mid-19th century, the sampling interval of these measurements increased to 1-2 times per day, focusing specifically on high and low water levels and their respective timings (Cartwright, 1999). Naturally, sea level variations occurring at periods shorter than 2-4 days were not distinguishable by such measurements.

The development of the first automatic or “self-registering” tide gauge in the UK around 1830 (Palmer, 1831) marked a significant milestone in sea level measurement history, enabling the production of continuous sea level traces for the first time. These traces were, at best, digitized with an hourly resolution allowing for the analysis of tides, storm surges, and long term mean sea level changes. However, oscillations occurring at periods shorter than 2 hours, including wind waves, infragravity waves, tsunamis, and other long ocean waves, could not be discerned from hourly values (IOC, 2006). To assess these shorter period oscillations, one had to digitize sea level traces with a higher resolution - a strenuous procedure which was only sporadically applied on episodes of high interest (e.g., Šepić et al., 2012). The wind waves, though, could not be obtained by this procedure, as they are filtered out from the sea level records during the measurement phase. This is because traditional float tide gauges typically measure sea level in stilling wells in which oscillations of the shortest periods are dumped. Modern sea level measuring instruments (such as radar gauges) also usually do not measure wind waves due to averaging or filtering procedures implemented in the instrument’s software.

For more than two decades, various new technologies have been developed to accurately and reliably measure sea levels with a minute and even shorter time steps. These technologies include floats connected to digital converters, bottom pressure recorders, and acoustic and radar systems (IOC, 2006; IOC, 2016). Nonetheless, measuring sea level with an hourly time step endured as a standard approach in most countries, in accordance with the GLOSS program’s initial requirements (IOC, 1990; IOC, 1997), at least until the catastrophic Indian ocean tsunami in 2004 (Lay et al., 2005). In response to this devastating event, the Intergovernmental Oceanographic Commission (IOC) of UNESCO took swift action and established multiple Intergovernmental Coordination Groups to implement effective tsunami warning systems and advised the installation of new sensors with a higher sampling frequency (1 minute or less). In addition to greatly improving tsunami warning services, it also enabled enhanced research of high-frequency sea level oscillations, encompassing tsunamis (including meteotsunamis), infragravity waves, and seiches (IOC, 2006). The upgrade was facilitated by advancements in technology, particularly the further improvement and development of measuring sensors and communication links (Pérez et al., 2013).

Nowadays, sea level data can be found in various databases. These include global, regional and national databases, some of which are freely available, while others are accessible under specific conditions. Unfortunately, certain databases are

unavailable due to data ownership restrictions, which strictly limit data exchange (e.g., indicated in Pérez Gómez et al., 2022 for the Mediterranean). The following data centres and databases contain freely available global sea level data acquired from tide gauge observations:

1. Permanent Service for Mean Sea Level (PSMSL; <https://www.psmsl.org/>, last access: 15 June 2026) collects and publishes monthly and annual mean sea level values from the global network of tide gauges operated by local and national authorities (Holgate et al., 2013);
2. University of Hawaii Sea Level Centre (UHSLC; <https://uhslc.soest.hawaii.edu/>, last access: 15 June 2026) provides fast delivery (4-6 weeks) of preliminary quality controlled hourly sea level data and delayed mode research quality hourly sea level data through the Joint Archive for Sea Level (JASL) (Caldwell et al., 2001);
3. Intergovernmental Oceanographic Commission Sea Level Station Monitoring Facility (IOC SLSMF, <https://www.ioc-sealevelmonitoring.org/>, last access: 15 June 2026) hosted by the Flanders Marine Institute (VLIZ), provides a web-based global sea level station monitoring service for a quick inspection of the real time raw data from individual stations and offers information on the tide gauge network's operational status; available data is mostly of 1 minute sampling frequency, but data measured with shorter and longer sampling intervals can also be found within this database;
4. Global Extreme Sea Level Analysis dataset (GESLA; <https://gesla787883612.wordpress.com/>, last access: 15 June 2026) contains higher-frequency (i.e., hourly or more frequent) sea level records obtained from many international data suppliers providing data with different levels of quality control (Haigh et al., 2022);
5. Système d'Observation du Niveau des Eaux Littorales (SONEL; <https://www.sonel.org/>, last access: 15 June 2026) offers daily, monthly, and annual mean sea levels and integrates tide gauge data with GNSS (Global Navigation Satellite System);
6. Minute Sea Level Analysis dataset (MISELA; <https://www.vliz.be/en/imis?dasid=6673&doiid=457>, last access: 15 June 2026) comprises of 1-minute high-pass filtered (cut off period of 2 hours) sea level records of nonseismic (tsunamis) sea level oscillations from 331 tide gauges worldwide (Zemunik et al., 2021).

Among the databases and datasets mentioned, as it collects data in real time, the IOC database stands out as the most frequently updated one. However, the real time collection of data often results with issues with data quality - the problem that is further examined in Section 2.2. PSMSL, UHSLC, and SONEL databases are also actively maintained and receive regular updates. In comparison, GESLA is updated less often, with new releases occurring every 5 or 6 years (Menéndez and Woodworth, 2010; Woodworth et al., 2017; Haigh et al., 2022; GESLA-4, <https://gesla787883612.wordpress.com/downloads/>, last access: 15 June 2026) and the MISELA dataset covers a period of 2004–2019, and has not yet been updated.

In addition to the previously mentioned data portals and databases, sea level time series are also available through integrated repositories. Notable examples include the European Marine Observation and Data Network (EMODnet; <https://emodnet.ec.europa.eu/en/physics>, last access 15 June 2026), which offers global coverage and the Copernicus Marine

100 Environment Monitoring service in Situ TAC (CMEMS INS TAC; <https://marineinsitu.eu/>, last access 15 June 2026) which primarily covers Europe. The tide gauge intercomparison tool, TGCAT (Tide Gauge CATalogs; <https://www.sonel.org/tgcat>, last access 15 June 2026), serves as a valuable resource for the comparison of fundamental tide gauge information (e.g., coordinates, names) across diverse data repositories, especially given the increasing number of such repositories. Sea level data can be accessed, not only from global and regional databases, but also through the websites of national data providers.

105 For instance, in the USA, sea level data measured at 1-minute, and 6-minute time step is freely available on the National Oceanic and Atmospheric Administration (NOAA) website (<https://tidesandcurrents.noaa.gov/products.html>, last access 15 June 2026).

One of the main challenges with the databases mentioned earlier, as well as sea level measurements in general, is data quality and latency. Often, real time and near real time data, which are indispensable for navigation, port management, storm surge forecasting, and tsunami warning systems, are of unverified quality. In these situations, immediate data transmission and data sampling intervals of one minute or less (IOC, 2006) are more important than rigorous quality control, which is often not feasible. However, real time monitoring can include simple checks such as detecting when a tide gauge stops transmitting data (UNESCO/IOC, 2020). Real time data are, e.g., available through the IOC SLSFM website and the National Tidal and Sea Level Facility (NTSLF) website (<https://ntslf.org/data/uk-network-real-time>, last access 15 June 2026) for the UK Tide Gauge Network.

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Higher quality data includes fast mode data, which is required on timescales of days to weeks, and is subject to mostly automatic quality control procedures, such as identifying and correcting obvious spikes. Such data is essential for the calibration of satellite altimeter data (Mitchum, 2000) and for forecasting ocean circulation and properties. These data are, e.g., available through the University of Hawaii Sea Level Center. On the other hand, delayed mode data is generally considered to be of the highest quality. It is primarily used for scientific research and subsequently for practical applications and is available at various time steps, through e.g., MISELA (for 1-min data, although only filtered series containing only sea level oscillations at periods shorter than 2 hours), UHSLC, JASL, GESLA (all three primarily hourly data, with some higher resolution data in GESLA), PSMSL (monthly and annual data), and through national data providers.

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Out of the listed datasets MISELA is the only one that contains 1-min sea level records that were thoroughly quality controlled (Zemunik et al., 2021). However, sea level records in MISELA contain only high-pass filtered series obtained after tidal signal was removed from the original series, and after the residual series were high-pass filtered with a 2-hour Kaiser-Bessel window. Accordingly, quality control in MISELA is limited to high-frequency component. This methodological approach introduces a practical gap by restricting subsequent analysis strictly to short period sea level oscillations ($T < 2$ h). Consequently, a comprehensive, sub-hourly quality-controlled dataset that preserves the total, unfiltered signal is essential. Such data is required to investigate both short- and long- period processes, as well as to quantify the contribution of the short-period oscillations to total sea level variations, particularly during extreme events.

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While such high-resolution framework is ideally needed worldwide, managing a global scale was unfeasible to us given the resources required for the quality control of 1-min data, hence we decided to base SHELDA on the European sea level

records. In addition to feasibility, choice of the European coast is supported by: (1) length and number of available records – longest and spatially most densely distributed time series of 1-15 minute sea level data are available for the European and North America coasts; (2) extraordinary sea level variability, encompassing a wide range of tidal regimes as well as both low- and high- frequency oscillations is recorded along the European coast, allowing for research of multitude of processes of scientific and practical interest.

In this manuscript and related dataset, we present the delayed mode dataset of sea level series measured with a time step of 1-15 minutes along the European coasts and Greenland, Canary Islands, Israel, Lebanon and Türkiye. Our dataset originates entirely from the IOC SLSMF dataset of real-time sea level data. Prior to publishing the dataset, all data were subjected to strict automatic and visual quality control procedures. This was deemed necessary as real time data are prone to various quality issues, such as mean and date shifts, artificial spikes, gaps, and others (e.g., Šepić et al., 2015; Vilibić and Šepić, 2017; Woodworth, 2017; Zemunik et al., 2021). Ultimately, our objective was to establish a high-quality dataset that enables the precise identification and analysis of sea level variations occurring at periods from minutes to seasonal and longer, depending on the stability of long term series along the majority of European coastline.

This paper is structured as follows. Section 2 describes the data source for the SHELDA dataset and outlines the quality control procedures implemented. Section 3 presents the dataset itself, detailing the spatial and temporal coverage of the quality-controlled time series, along with the technical specifications of the dataset. The paper subsequently includes a data availability statement and concludes with a discussion on the applications of the dataset and potential areas for improvement.

2 Data and methods

2.1 Data source

The Intergovernmental Oceanographic Commission Sea Level Station Monitoring Facility (IOC SLSMF), established in 2006, was developed in collaboration between Flanders Marine Institute (VLIZ) and the ODINAFRICA project of IODE (The International Oceanographic Data and Information Exchange) (Flanders Marine Institute (VLIZ) and Intergovernmental Oceanographic Commission (IOC), 2025). The service began with an emphasis on operational monitoring of sea level stations in Africa and was later expanded to stations involved in the IOC programs, including the Global Sea Level Observing System Core Network and the networks under the regional tsunami warning systems in the Indian Ocean (IOTWS), North East Atlantic, the Mediterranean and adjacent seas (NEAMTWS), Pacific (PTWS), and Caribbean and adjacent regions (CARIBE-EWS).

The IOC database contains sea level data acquired in real time at sampling intervals ranging from less than a minute to 15 minutes. To ensure accuracy, redundancy, and cross-calibration, many tide gauge sites, from which data are provided to the IOC SLSMF database, have duplicate or multiple sensors (Aarup et al., 2019). For instance, the Italian national tide gauge network Rete Mareografica Nazionale is fitted with both float and radar sensors (Nardone et al., 2020). Other national tide gauge networks incorporating multiple sensors include, for example, the UK National Tide Gauge Network, the Swedish Sea

Level Network, the Spanish National Geographic Institute Sea level network. Data suppliers are not required to provide data from multiple sensors to the IOC SLSMF, so in most cases, only data from the primary sensors are available, however, for certain stations, data from multiple sensors can be downloaded as well. Additionally, some stations are equipped with both internet and satellite real-time transmission systems, which can result in duplicate series from the same station in the IOC SLSMF database.

The IOC SLSMF offers a display service designed to enable quick visual examination of real time data from a specific station over user-selected timeframes (i.e., 12 hours, 1 day, 7 days, or 30 days). Each station's profile includes essential details such as a unique identifier, geographical coordinates of the tide gauge location, and its respective country. Furthermore, contact details for the local agency responsible for station management are provided, alongside technical specifications regarding sensor type and sampling frequency.

2.1.1 Data acquisition

Sea level time series from 299 tide gauges along the European coasts, with a sampling resolution ranging from 1 second to 15 minutes, were obtained from the IOC SLSMF website for the period from the beginning of station activity until 00:00 on 1 January 2021 (or until the end of station activity, if it occurred prior to 1 January 2021). The data were retrieved using an automated process developed by Ruić et al. (2023). The code downloads sea level time series by fetching one month at a time, reformats the data by stripping away extraneous content, and continues this process until all the data is collected. Ultimately, it merges all the monthly files into a single file in the desired format.

Total of 26 SHOM (French Naval Hydrographic and Oceanographic Service) stations from the RONIM network are each listed twice on the IOC SLSMF website – this is due to the fact that these stations are equipped with dual real-time transmission systems (Pérez Gómez et al., 2022) and thus deliver same data twice to the IOC SLSMF website (e.g., ptve and ptve2). For such stations which have two available time series of sea level measurements, covering the same temporal range, we downloaded both series, but kept, for further analyses, the longest series with the lowest percentage of data gaps. Similarly, there are relatively few stations (21) that have data from duplicate sensors which are all given with same coordinates. For those stations we also opted for the longest time series with the lowest percentage of data gaps. Next, we excluded from further analysis 42 tide gauges for which we estimated time series to be of unacceptable quality. Following these initial modification, we ended up with 257 time series in the SHELDA dataset. Each of these series has at least 30 days of measurements, the minimum required for deriving harmonic tidal constituents and validating numerical models (Fig. 1). From here on, the term “record” refers exclusively to the total set of time series of sea levels measured by a specific tide gauge.

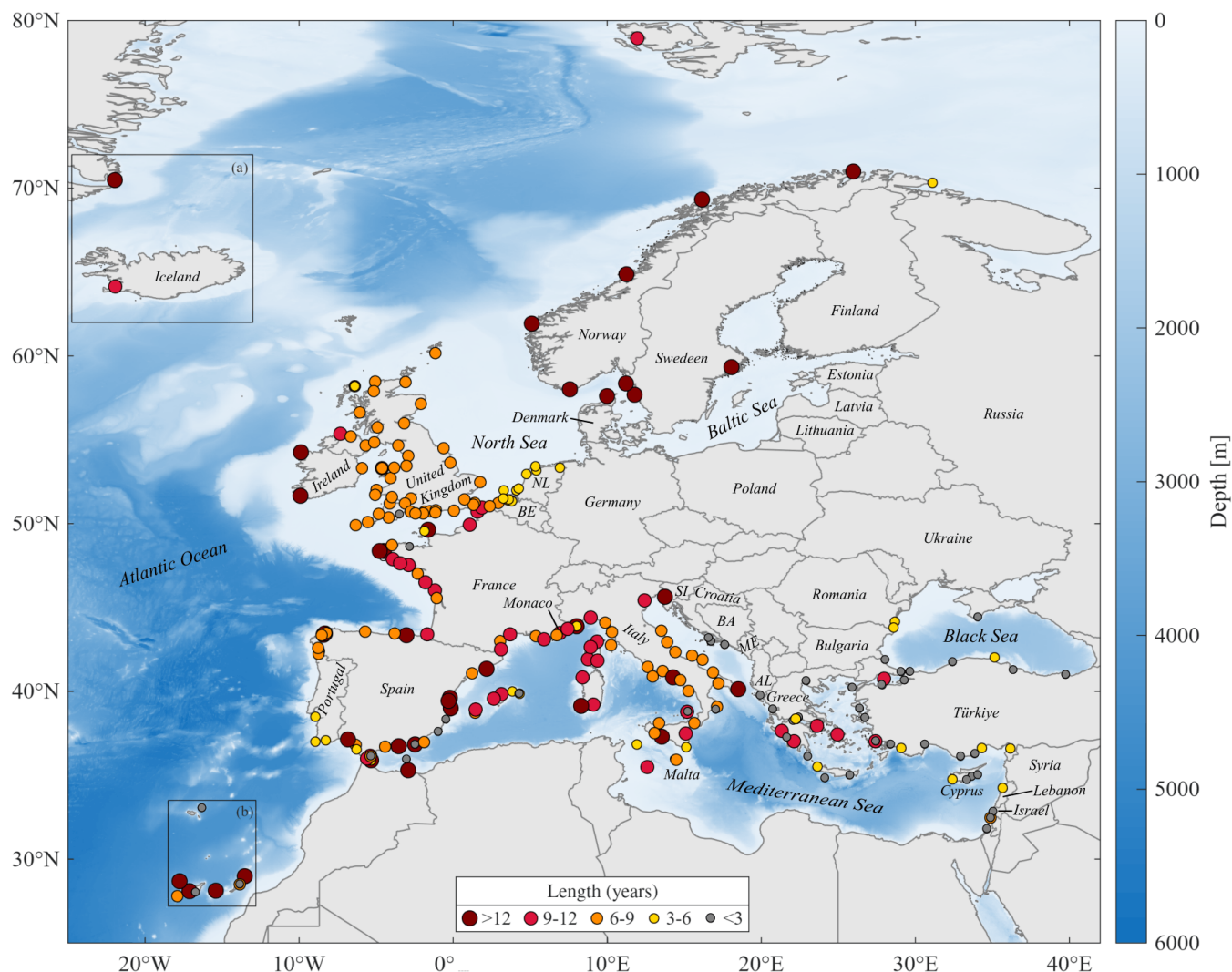


Figure 1. Map of SHELDA station locations. The length of the time series is represented by the size and colour of the circle. Iceland and Greenland are highlighted with frame (a), and Canary Islands with frame (b). Bathymetry is plotted using GEBCO 2024 grid (GEBCO Bathymetric Compilation Group, 2024). Following country abbreviations are used: AL for Albania, BA for Bosnia and Herzegovina, BE for Belgium, ME for Montenegro, NL for Netherlands and SL for Slovenia.

2.2 Quality control procedures

As stated on their website, the IOC SLSMF data are not subjected to any quality control procedure and are archived and available for download to interested individuals and organizations in the IOC specified format. The quality and reliability of sea level measurements are occasionally impacted by common errors present in tide gauge sea level data (Fig. 2), including out-of-range values, gaps, flat lines, isolated and clustered spikes, drifts, vertical shifts, time errors, and datum changes. Thus, further processing must be conducted before data can be utilized for research. The errors are caused by various factors such as electronic noise in measurements, problems in sensor calibration, stabilization, clock failures, instrumental drifts,

transmission mistakes, etc (UNESCO/IOC, 2020). Among these, there are gradual and sudden changes: e.g., a drift manifests as a gradual change of the sea level signal (attenuation, increase or decrease of background sea level, and similar, commonly due to instrumental issues); and a vertical shift manifests as a sudden change in the data mean, which is in sea level time series often suspected to be due to a possible datum shift - a specific vertical change tied to reference benchmark alternations or gauge relocations. However, due to the lack of detailed information on the IOC SLSMF website to confirm this, all sudden changes in the mean value are referred to as vertical shifts.



Figure 2. Examples of errors commonly encountered in raw sea level time series: (a) vertical shifts; (b) spikes; (c) gaps and spikes; (d) spurious data, flat lines, and clustered spikes.

We next explain pre-processing and quality control procedures applied to downloaded SHELDA data, but first, we note that 71 records obtained from the IOC SLSMF database were previously partially quality controlled by Vilibić and Šepić (2017) and Zemunik et al. (2021) (up to June 2018). Quality control flags from the MISELA dataset (Zemunik et al., 2021) were employed to remove spurious/false values from these records which we downloaded from the IOC SLSMF website. In this

study, these records have been further extended up to 1 January 2021 (00:00 UTC) and additionally processed in accordance with the QC procedures outlined here.

2.2.1 Pre-processing

To ensure consistency across the dataset, the raw sea level records underwent a four-step pre-processing procedure:

225 1. Handling variable sampling frequencies

A total of 17 records exhibited changes in sampling frequency over time (e.g., the record's first segment was sampled every 10 or 15 minutes, whereas the last segment was sampled every minute). To accommodate the variable sampling frequencies of these records and enable separate pre-processing and quality control tailored to specific frequencies, these 17 records were split into 35 segments (e.g., one record was split into three segments) each representing a period of continuous sampling
230 frequency. Each segment underwent separate pre-processing and quality control. Once processed, segments were recombined into their original single files. Further details on these records can be found in the Appendix A.

 2. Temporal resampling

To ensure consistency with one-minute intervals, 37 records with a sampling frequency higher than one minute were averaged to a 1-minute series.

235 3. Mean value removal

Removal of mean values was done as sea level heights, depending on the country/station, are given with respect to a different reference level, which is furthermore not indicated in the IOC SLSMF database. Mean values are stored in the SHELDA dataset for each station and, for records composed of segments with different sampling frequencies, also for each individual segment, allowing for reproduction of original sea levels.

240 4. Creating records with a regular time step

Occasional missing timesteps and sea level values occur, likely due to factors like system errors or problems with data transmission. In cases where timestamps were missing, regular time records were created, and the associated missing sea level measurements were marked with a NaN (Not a Number) value. In case of records which are constituted of segments of different sampling frequency, this procedure was performed independently for each segment to preserve the original
245 sampling characteristics.

2.2.2 Removing spurious data

Significant portions of the raw dataset had various data quality issues (i.e. spikes, shifts, drifts) so a five-step quality control procedure was implemented:

 1. Correction of major vertical shifts

250 Noticeable vertical shifts caused by inconsistencies in measurements were visually identified and dealt with by subtracting the mean value computed for the specific period affected by the vertical shift. Although this procedure minimises the

artificial shift between two parts of the records, we acknowledge that it does not completely remove it – as two parts of the series might not have the same mean value.

2. Removal of out-of-range values

255 Values that were out of range, i.e., values with a 50 cm difference from a neighbouring value and a 30 cm difference from both neighbouring values, were eliminated as part of the automatic quality control. These thresholds were chosen to identify physically unrealistic spikes while preserving genuine, short duration sea level variability. This approach follows the procedure and thresholds already used on the IOC SLSMF data by Vilibić and Šepić (2017) and Zemunik et al. (2021), whose analyses demonstrated that these criteria successfully eliminate most, but not all, unphysical spikes, making additional
260 automatic and visual controls necessary. The procedure was applied specifically to the 1-minute data. For the remaining data with sampling intervals greater than 1 minute, a 1-meter threshold from the neighbouring value was used to avoid overly strict criteria that might exclude high-quality data.

3. Application of spike detection algorithms

Automatic spike detection procedures, developed by Williams et al. (2019), were applied exclusively to 1-minute records.
265 Following the author's recommendation, the procedures were applied twice, as a single run does not account for all spurious spikes. The Williams et al. (2019) algorithms eliminate all values that deviate more than three standard deviations from a spline fitted to sea level time series using the least squares method. Although highly effective, these automated quality control procedures did not solve all data quality issues. The main remaining problems included: (a) identifying spikes in the proximity of other spikes, (b) detecting clusters of spikes, and (c) accounting for minor vertical shifts and constant sea level
270 values over time.

4. Visual inspection

To address the remaining issues, a visual inspection of all records was conducted. Each record was visually examined using a series of 10-day consecutive windows. The visual inspection resulted with identification and removal of spurious values that were missed by automatic quality control procedures.

275 5. Buddy checking

In specific records (11 in total), particularly those with 10- and 15-minute sampling frequencies, larger portions of potentially inaccurate data were noticed during the visual inspection, including attenuated signals, and variations in phase and amplitude. However, as we could not with certainty confirm that these data were “false” just from looking at a single time series, we also performed “buddy checking”, whereby measurements were compared with those from the two nearest
280 tide gauges (Fig. 3). Based on this comparison, it was determined whether the observed oscillations were caused by an event that propagated along a coastline or were they non-physical and thus required to be removed.

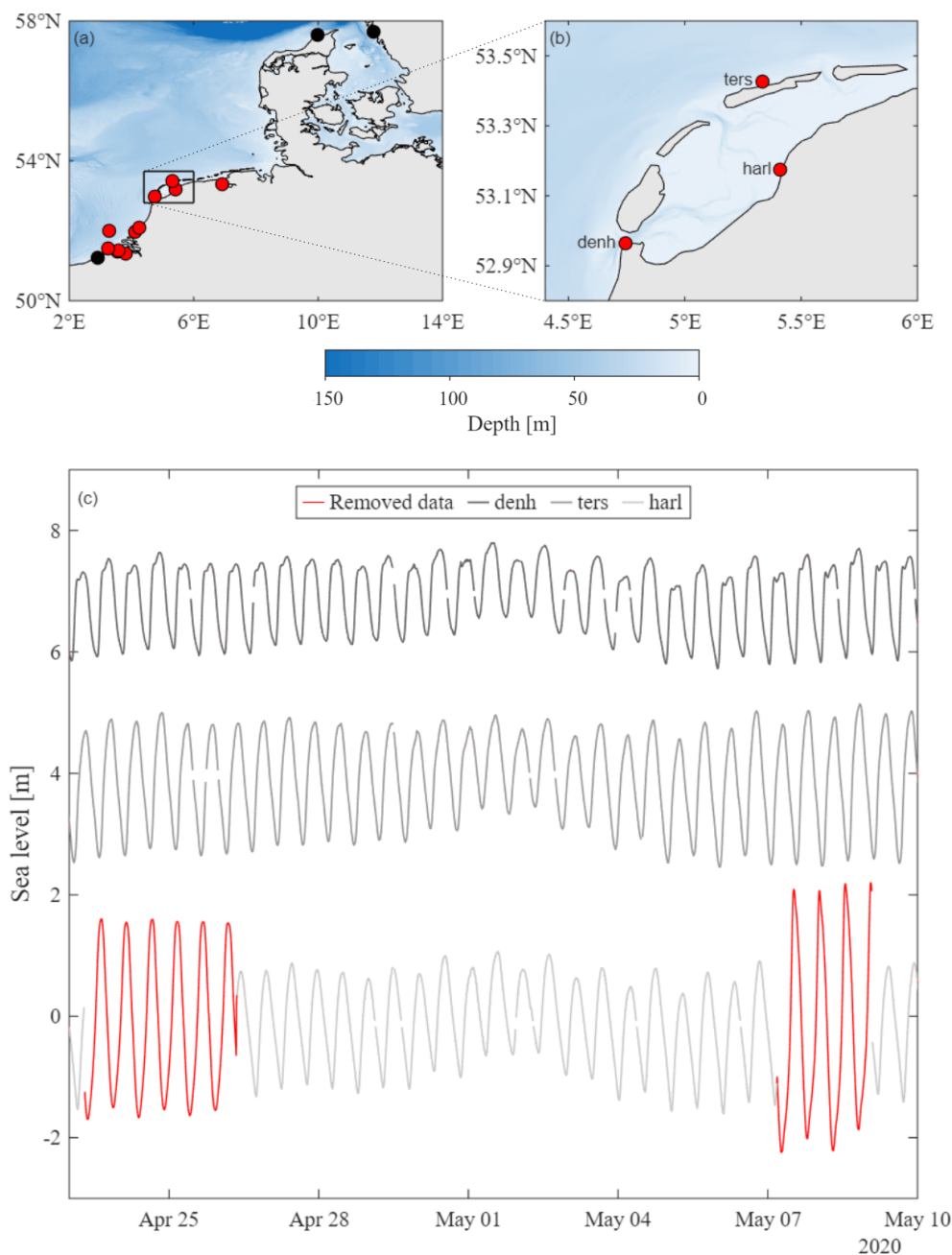


Figure 3. (a) Bathymetric map of the North Sea region showing the distribution of tide gauge stations, with red markers indicating Dutch stations that underwent buddy checking and black markers representing stations in neighbouring countries. The rectangular box highlights the area of interest containing three stations selected as examples for buddy checking; (b) Closer view of three stations: Den Helder (denh), Harlingen (harl), and Terschelling Noordzee (ters); (c) Records for three stations harl, ters (vertically offset for 4m to allow for clearer representation) and denh (vertical offset 7m), with red segments indicating problematic data identified through cross-comparison.

2.2.3 Tidal analysis

Following automatic and visual detection and removal of erroneous data, the MATLAB software package T_Tide (Pawlowicz et al., 2002) was used to estimate the tidal signal. An estimate was made for all significant tidal components.

295 However, analysis of the residual signal (the original records minus the tidal signal) revealed that the tidal signal was not estimated/removed properly at seven Norwegian stations. Additionally, these stations exhibited a vertical offset that had been mentioned previously.

Our initial analyses suggested that the issue was mainly due to a time shift (from standard time to daylight saving time, and vice versa) occurring twice a year and not accounted for by some providers. Further investigation, in collaboration with the
300 Norwegian data provider Kartverket, confirmed that although the data were reported as being in UTC on the IOC portal, they were in reality in UTC+1 during standard time and UTC+2 during Daylight Saving Time.

Temporal corrections were applied and time stamps adjusted based on daylight saving time status (−2 hours during DST, −1 hour during standard time). Corrections were applied only to data between the onset of the vertical offset and 17 March 2020, 22:50 UTC, which marks the point when Kartverket started transmitting records in the correct UTC reference frame to
305 the IOC. The correction procedure was validated by comparing the corrected time series for two stations with observations directly downloaded from the Kartverket web service (https://vannstand.kartverket.no/tideapi_en.html, last access: 15 June 2026), confirming the reliability of the applied temporal adjustments.

The comprehensive quality control procedure is illustrated in Fig. 4, and some key steps in the data processing workflow are demonstrated using a portion of the record from one tide gauge, as shown in Fig. 5.

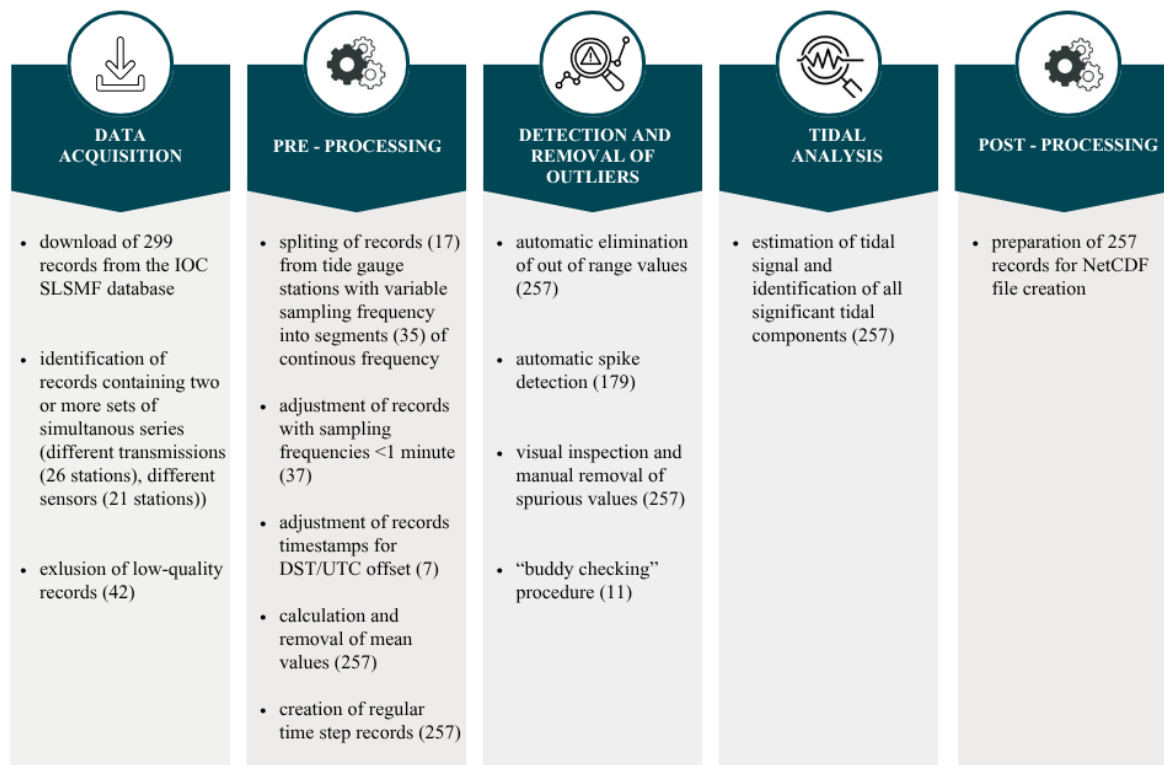


Figure 4. Flow chart of data processing. The numbers in parentheses indicate how many records have passed each step. Automatic spike detection (179) was applied only to 1-minute time series.

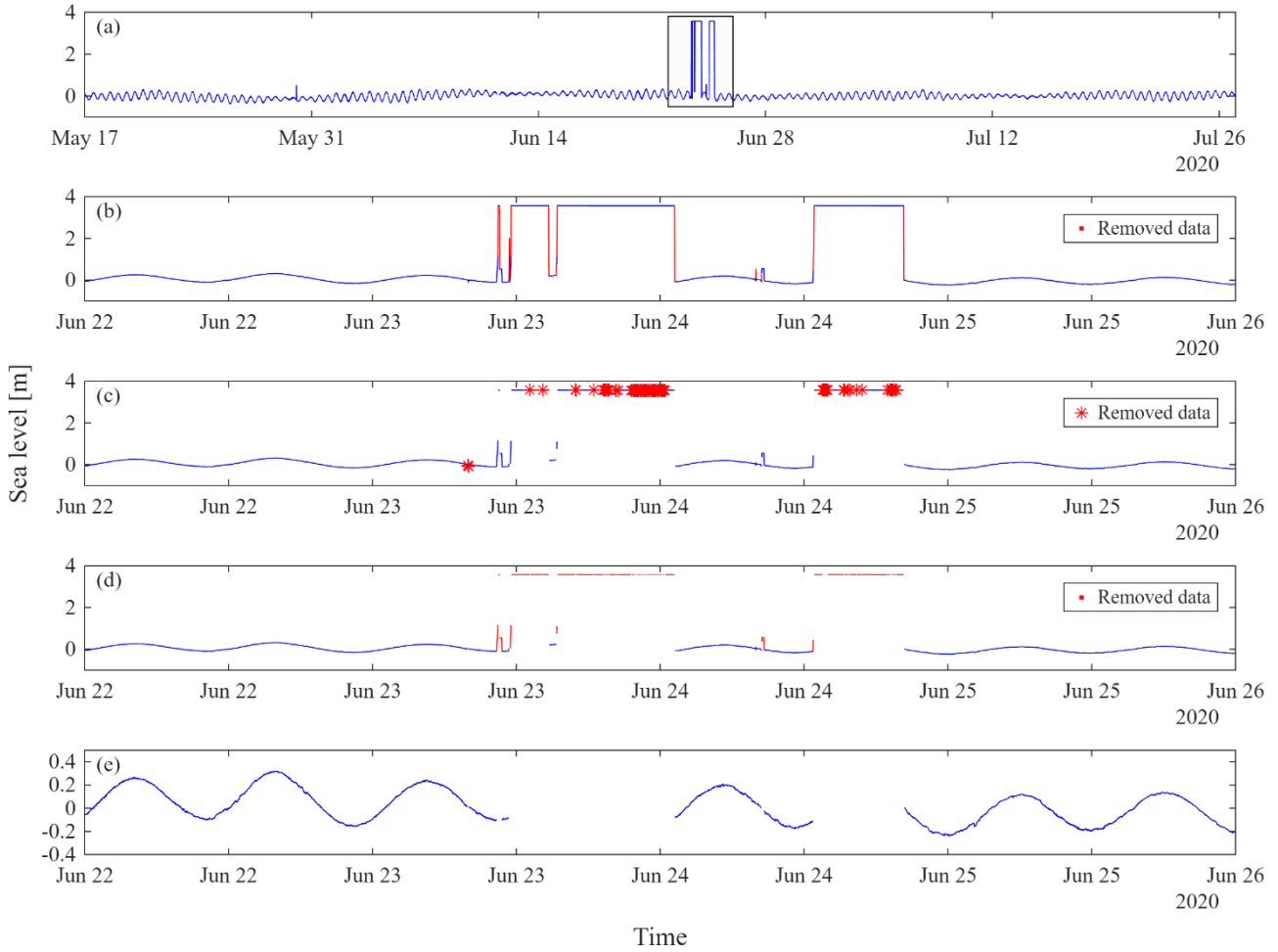
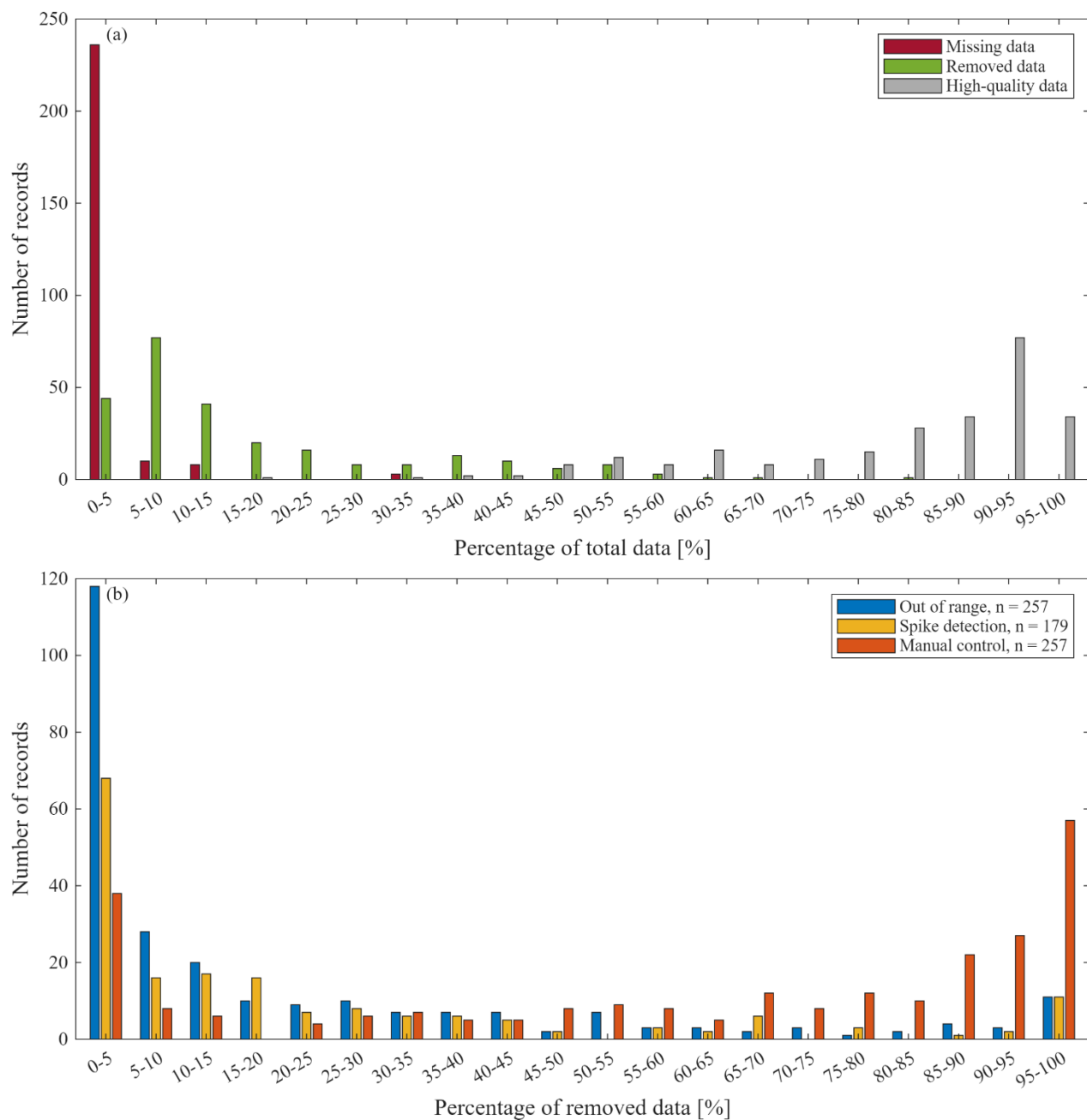


Figure 5. The key steps involved in data processing using the example of Aigio station in Greece. (a) The raw record adjusted to a regular time interval, with the mean value subtracted. The portion of the record that is zoomed in in (b)-(e) is indicated within the rectangle. Erroneous data points, indicated in red, are identified during the following procedures: (b) the out-of-range correction method, (c) the automatic spike detection and (d) visual inspection. (e) The final record after quality control steps.

2.2.4 Quality control statistics

To get a clear picture of the SHELDA dataset's quality we further discuss how much data was considered "high-quality", and how much data was missing or removed across 257 records. Percentages are given with respect to the length of the time series. The results, as illustrated in Fig. 6a, demonstrate that the majority of stations had reliable records. About 240 records had less than 5% missing data during their observation periods, and 121 records had less than 10% of their data removed. When it comes to the percentage of high-quality data, around 77 records contained between 90% and 95% of high-quality data, and an additional 34 records exceeded 95% of high-quality data. On average, 79.64% of the total data in the dataset is classified as high-quality, 18.75% as missing, and only 1.61% has been removed during the quality control.

In Fig. 6b, we show the proportions of data removed during (ii) – (v) quality control steps: out-of-range value detection, spike detection, and visual control (including buddy checking). The percentages are given with respect to the removed data, and not with respect to the length of the total time series. For the 71 stations for which quality control flags were obtained from the MISELA database, information regarding the number of data points removed at each stage of the quality control process is unavailable. Consequently, statistical analyses for these stations were conducted using data from 15 June 2018 until the end of the respective time series. Most records have a low percentage (0–5%) of removed data for both automated methods. In contrast, visual control shows more diverse distribution: there are lots of records with either very little (0–5%) or almost all (95–100%) of their excluded data removed during this step. This suggests that for some records, almost all the erroneous data is detected and removed during visual checks, while for others, the automated steps detect and remove most spurious data, and visual control isn’t necessary. Looking at the overall contribution of each step to the total amount of data removed, visual control accounts for 55.31%, spike detection for 23.38%, and out-of-range value detection for 21.31% of removed data. It is also important to mention that most of the data removed following visual control is due to specific issues previously discussed in Section 2.2.3.



340 **Figure 6. (a) Distribution of records by percentage of data quality categories: missing data, removed data and high-quality data; (b) Distribution of records by percentage of data removed during each of three quality control steps with each step represented by a distinct colour, as shown in the legend. The percentages in (b) are given with respect to removed data, and not with respect to total length of time series. The number of records (n) processed in each quality control step is indicated in the legend.**

3 Dataset description

345 The dataset consists of 257 quality-controlled sea level time series in the NetCDF format, each representing data from an individual tide gauge station along the European coastlines. Each file is named according to the station code specified on the IOC SLSMF website and contains four variables: (i) “time” - expressed in seconds since 1 January 2000 00:00:00 UTC; (ii) “sea_level_qc” - the quality-controlled sea level time series; (iii) “residual” - quality-controlled record minus the tidal signal; (iv) “qc_flags” - quality control flags, where 1 indicates high-quality data, 2 denotes missing data and 3 removed data. For
350 records which are split into segments of various sampling frequencies all four variables are given separately for each of the segments.

The global attributes include metadata on the station name (IOC code and full station name), geographic location (country, latitude, and longitude), sampling interval and temporal coverage of the quality-controlled records. Additional attributes specify the mean value removed from the raw data, number of segments contained in each file, the original data source (i.e.,
355 the IOC SLSMF portal where data is hosted), the data provider (i.e., the data owner or the institution responsible for maintaining the station) and contact information of the dataset compiler. When applicable (e.g. in cases involving variable sampling frequencies in the raw data or corrections for vertical shifts), a disclaimer is included to explain the additional global attributes. A simplify example of the NetCDF file structure used in the SHELDA dataset is provided in Table 1.

SHELDA dataset contains nearly 1816 station years of sea level data of 1-15 minute frequency, coming from 257 records
360 across 22 different countries (Fig. 1). These records cover the period from 2 December 2007 to 1 January 2021, depending on station, with an overall average record length of 7.1 years. However, the duration of individual records varies significantly among stations, ranging from 1 month (amas, erdek, igne, ista, ment, sile and yalo in Türkiye) to as long as 13 years (smog, sthm and goto in Sweden).

The distribution of sea level monitoring stations (for which data is available in the IOC database) across European coastal
365 regions shows significant geographical differences (Fig. 1). The United Kingdom, France, Spain, and Italy have high station coverage with records of various lengths. Despite their extensive coastlines, Norway and Sweden show low station density in the IOC database. Similarly, along the coastlines of Ireland, Iceland, Portugal, Croatia, and the Black Sea, there is limited data availability within the IOC database. Notable gaps are evident across several European countries, with Finland, Estonia, Latvia, Lithuania, Poland, Slovenia, Montenegro, Albania, and Bulgaria completely absent from the IOC database, while
370 Germany, although present in the IOC database, is excluded from the SHELDA dataset due to insufficient data quality (i.e. presence of numerous non-physical oscillations appearing throughout the time series). The lack of data from specific countries does not necessarily imply that sea level measurements are not conducted or are conducted only sparsely in these countries, but often that data (or parts of data) are not shared via the IOC SLSMF web portal. E.g., Pérez Gómez et al. (2022) in their study on the coastal sea level monitoring stations in the Mediterranean list 17 tide gauge stations measuring with 1-
375 min time step along the Croatian coast of the Adriatic Sea – however, data from only three of these stations are available at the IOC SLSMF web portal.

Analysis of record durations shows that stations with longer records (over 10 years) are predominantly found in the Baltic region, France, Italy, and Spain. In contrast, those with shorter records (less than 4 years) are mainly located in the Eastern Mediterranean and the Black Sea. The longest records in the SHELDA dataset are from 3 tide gauges in Sweden. Stations with shorter time series may be newer installations, may have only operated for a short period, or may have been recently added to the IOC database. In some cases, records are shorter than the available raw data because numerous erroneous data points were removed during extensive quality control, particularly at the beginning and/or end of the records.

Table 1. Example of SHELDA NetCDF file

File name: ball.nc

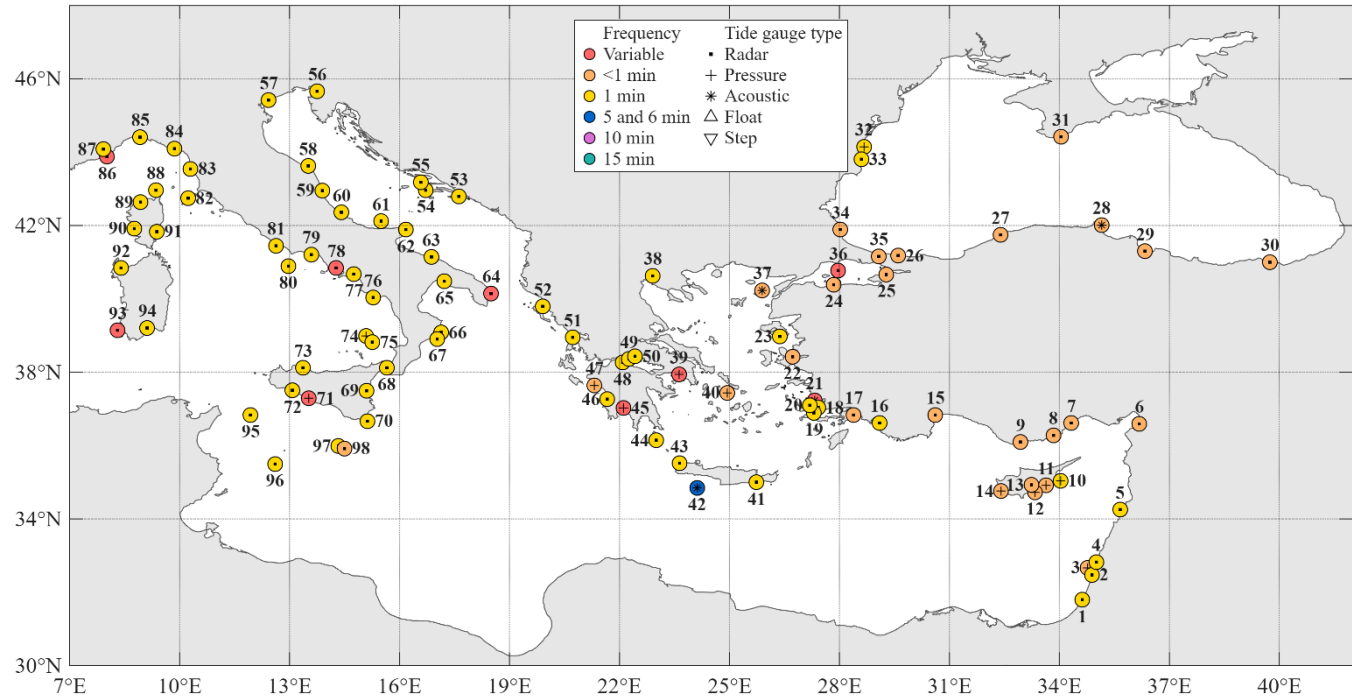
Global attributes:	
IOC station code	ball
Station full name	Ballyglass pier, Belmullet
Country	Ireland
Latitude	54.25 degree N
Longitude	9.89 degree W
Disclaimer	The original tide gauge record was divided into two segments due to a change in sampling frequency. Each segment was individually processed and quality controlled, with corresponding start and end dates, sampling frequencies, and mean values documented. The final NetCDF file merges both segments into a continuous record.
Number of segments	2
Start date segment 1	2008-06-11 10:06:00
End date segment 1	2018-03-13 08:54:00
Sampling interval segment 1	6 min
Mean value segment 1	0.0368 m
Start date segment 2	2018-03-13 09:00:00
End date segment 2	2020-10-24 02:20:00
Sampling interval segment 2	5 min
Mean value segment 2	0.0827 m
Types of erroneous data	Out of range values, spikes, drift
Original data	http://www.ioc-sealevelmonitoring.org/bgraph.php?code=ball
Data provider	Marine Institute (Ireland)
Contact person	Marijana Balić, Faculty of science, University of Split, Split, Croatia mbalic@pmfst.hr balic.marijana@hotmail.com
Dataset information	This file is a part of the SHELDA (Sub-hourly European quality-controlled sea level dataset) dataset, providing quality-controlled sea level records and corresponding residual time series at 1–15 minute intervals from 257 tide gauges along European coastlines. The dataset enables the precise identification and analysis of sea level variations occurring at periods from minutes to months along the majority of European coastlines.

Variables:

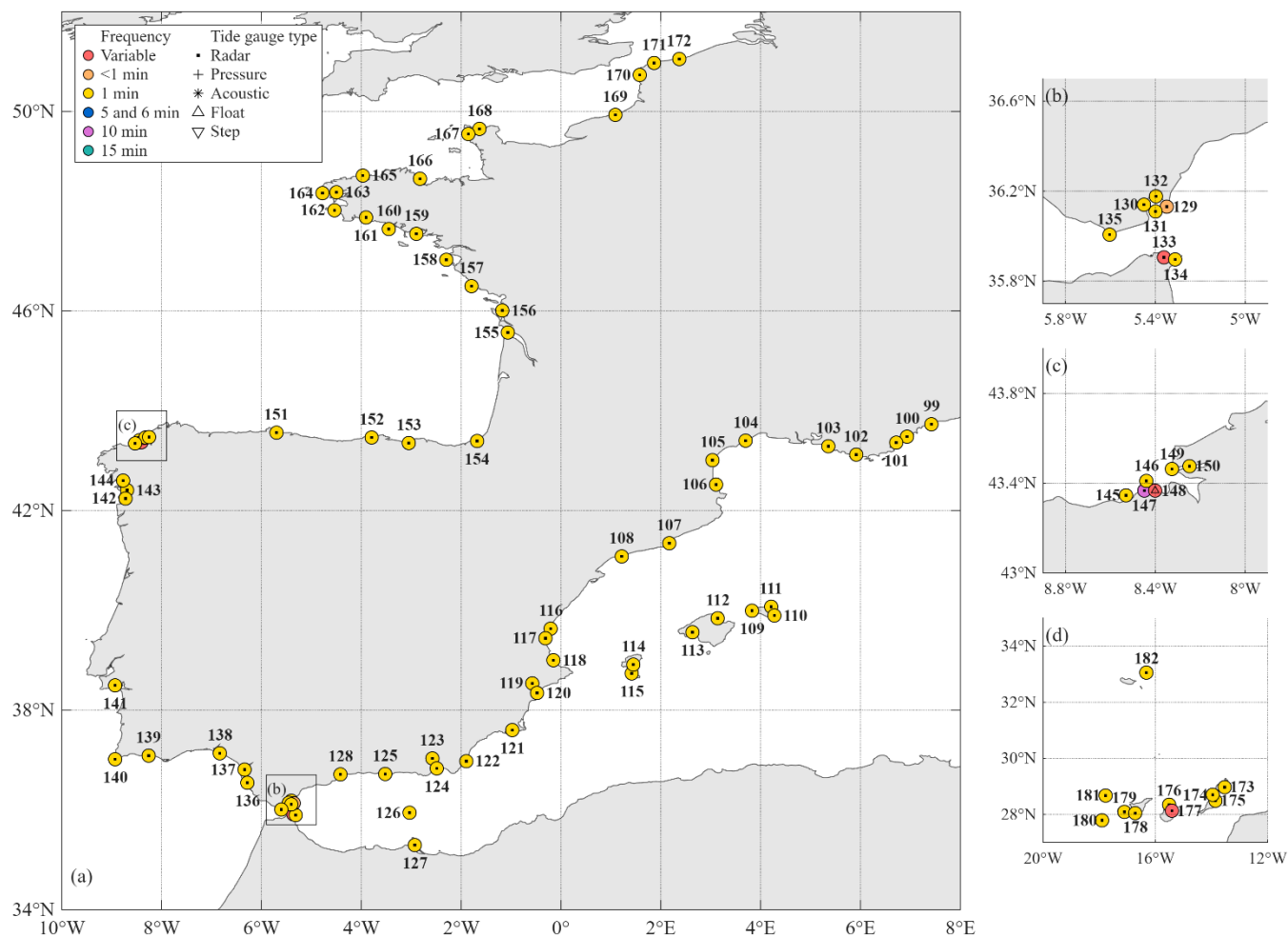
time	long name = Time units = seconds since 2000-01-01 00:00:00 UTC
sea_level_qc	long name = Quality-controlled sea level time series units = m
residual	long name = Residual time series units = m
qc_flags	long name = Quality control flags flag meaning = 1 High-quality data 2 Missing data 3 Removed data

385

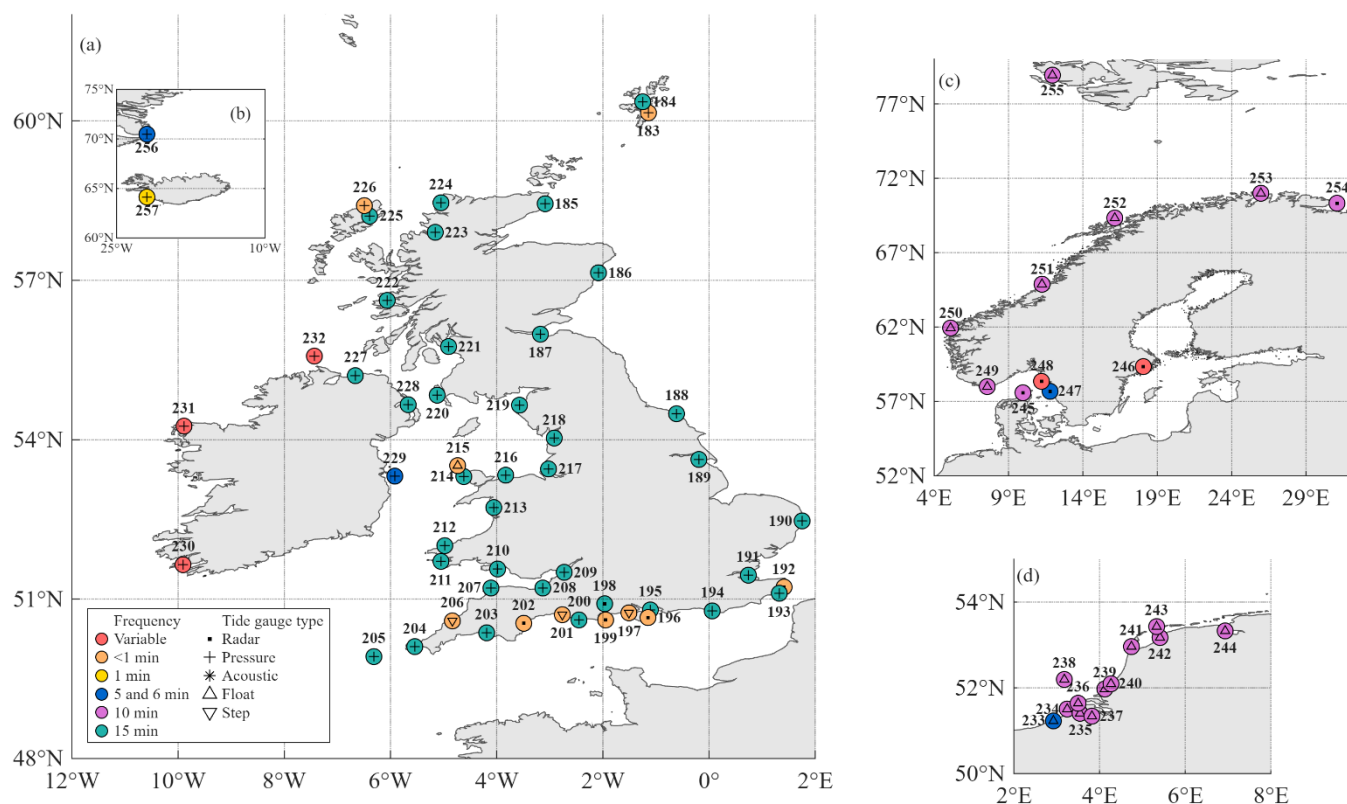
Besides spatial distribution, the following regional close-up views (Fig. 7-9) reveal detailed insights about the infrastructure supporting sea level monitoring. The figures show locations, technological preferences (i.e. type of sensor) and operational characteristics (i.e. sampling frequency) of stations in three regions: a) Region 1: Central and Eastern Mediterranean Sea and Black Sea regions (98 stations; Fig. 7); b) Region 2: Western Mediterranean, Western European coasts, and Canary Islands (84 stations; Fig. 8); c) Region 3: Northern European coasts, including the United Kingdom, Ireland, Iceland, Greenland, Norway, Sweden, Denmark, the Netherlands, and Belgium (75 stations; Fig. 9).



395 **Figure 7. Distribution and characteristics of tide gauge stations in the Central and Eastern Mediterranean and Black seas as of January 2021. Marker colours indicate sampling frequency while internal symbols denote the type of tide gauge instrumentation. Station names and metadata are provided in Appendix A, table A1. Note that stations 3, 13, 20, 21, 74, and 87 are slightly repositioned from their true geographical coordinates to improve visibility on the map.**



400 **Figure 8.** Same as in Figure 7 but for (a) the Western Mediterranean and western European coasts, with panels (b) and (c) displaying zoomed-in views of selected regions, and (d) the Canary Islands (precise location is indicated in Figure 1). Station names and metadata are provided in Appendix A, table A2. Note that stations 111, 119, 123, 130, 131, 133, 146, 147, 174 and 176 are slightly repositioned from their true geographical coordinates to improve visibility on the map.



405 **Figure 9.** Same as in Figure 7 but for (a) UK and Ireland, (b) Iceland and Greenland (precise location is indicated in Figure 1), (c) Norway, Sweden and Denmark, (d) The Netherlands and Belgium. Station names and metadata are provided in Appendix A, table A3. Note that stations 184, 198, 215, 226, 232, 236 and 238 are slightly repositioned from their true geographical coordinates to improve visibility on the map.

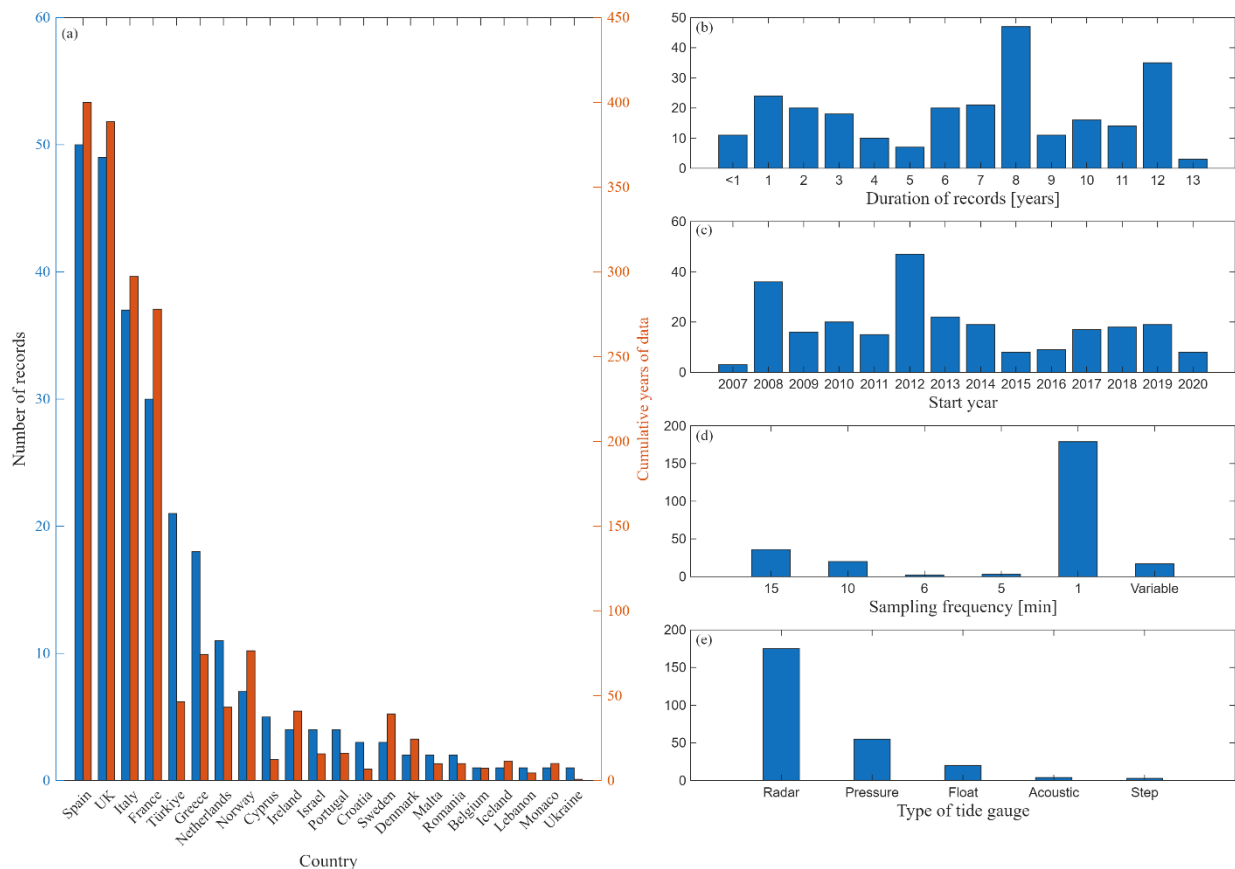
The bar charts in Fig. 10 give an overview of the distribution of records across different countries, showing the cumulative
 410 years of data available for each country, the periods those records cover, the starting year of records, and specific technical information about the tide gauges featured in the dataset. As shown in Fig. 10a, Spain stands out as the top contributor, with 50 records and just over 400 years of accumulated data, closely followed by the United Kingdom. Italy and France contribute fewer records (30 – 37) but still exceed 270 years of accumulated data. When comparing the number of records to the total years of data collected for each country, significant differences are found. For instance, Türkiye and Greece have a
 415 relatively high number of records but shorter cumulative durations, indicating shorter records. Other countries have considerably less data, highlighting regional differences in data accessibility.

The temporal distribution of records shows variation in time series length (Fig. 10b); while some records span over a decade (altogether 68 records), there are also numerous records shorter than three years (altogether 55 records). Additionally, information on the starting year of records (Fig. 10c) provides important context for understanding the development and
 420 expansion of the IOC database over time. Peaks in 2008 and 2012 correspond to the addition of Italian stations (16 of 36) and UK stations (42 of 47) to the network, respectively.

From a technical point of view, a 1-minute sampling frequency is the most common temporal resolution in the final processed dataset, accounting for 69.6% of all records, as illustrated in Fig. 10d. This frequency aligns with modern oceanographic standards and international protocols. It is the dominant sampling frequency observed in Region 1 (Fig. 7) and Region 2 (Fig. 8). In contrast, in Region 3 (Fig. 9), instruments with sampling frequencies of 10 and 15 minutes are predominantly used. The final chart presents information about instrumentation choices and categorizes records based on the tide gauge type (Fig. 10e). A significant portion of the network is equipped with radar sensors, which account for 68.1% of all sensors. This aligns with the IOC recommendations for upgrading tide gauge networks. The analysis of tide gauge types shows that radar sensors are the dominant choice in both Region 1 (Fig. 7) and Region 2 (Fig. 8), while bottom pressure recorders and float tide gauges are more commonly used in Region 3 (Fig. 9). There are also stations equipped with step gauges. A step gauge represents a specific type of tide gauge that measures water level using a vertical array of evenly spaced metal electrodes. It operates by electronically scanning the electrodes to identify the lowest dry one, which by definition marks the actual water level.

The distribution of sampling frequencies and sensor types in the SHELDA dataset reflects a combination of the hydrodynamic characteristics of European sea basins, the primary objectives of national tide gauge networks, and their historical development. Different coastal regions require different temporal resolutions depending on the hydrodynamic processes that dominate them. In micro-tidal regions, such as the Mediterranean and Black Seas, high-frequency sampling (1 minute or less) is necessary to capture short-period oscillations, including seiches and tsunamis, as well as meteotsunamis. In contrast, macro-tidal regions such as the North Sea and the English Channel have traditionally relied on 10- to 15-minute sampling intervals, which are generally sufficient for capturing long-period oscillations, such as astronomical tides and storm surges.

These regional differences are closely linked to the development and modernization of national tide gauge systems. Monitoring networks in the Mediterranean and Black Sea regions (Regions 1 and 2) have undergone substantial upgrades in recent decades, largely driven by the implementation of tsunami warning systems since the mid-2000s. As a result, there has been a widespread transition toward radar sensors, particularly in countries such as Spain, France, Italy, Croatia and Türkiye (Pérez Gómez et al., 2022). By contrast, many Northern European networks (Region 3) continue to rely on established infrastructure, including float gauges in stilling wells and bottom pressure sensors. This persistence reflects their proven long-term reliability and resilience to harsh environmental conditions. Some national agencies plan to preserve existing sensors to ensure continuity of long-term data records, while simultaneously upgrading systems to modern standards (e.g., the United Kingdom's National Tide Gauge Network; <https://www.oceanwise-global.com/article/oceanwise-to-maintain-and-upgrade-the-uks-national-tide-gauge-network/>, last access: 26 June 2026).



455 **Figure 10. (a) The total number of records (blue bars) and the cumulative years of data (red bars) available for each country; (b)**
Number of records categorized by duration in years; (c) Number of records with data starting in a specific year; (d) Distribution
of records based on sampling frequency; (e) Distribution of records according to tide gauge type.

4 Data availability

Data described in this paper can be accessed through the Marine Data Archive of the Flanders Marine Institute (VLIZ) at
460 <https://doi.org/10.14284/764> (Balić and Šepić, 2025). This dataset is licensed under a Creative Commons Attribution 4.0
International License (CC BY 4.0).

5 Discussion and conclusions

The Sub-Hourly European Sea Level Dataset (SHELDA) provides a valuable resource for analysis of sea level variations
occurring at periods from minutes to seasonal and longer, depending on the stability of long term series along European
465 coastlines. The utilization of such data for research purposes requires the previous implementation of rigorous quality control
procedures to ensure the prevention of misinterpretation of findings and dissemination of inaccurate conclusions. By

performing quality control procedures on raw sea level time series from the IOC SLSMF database, we have created a high-quality research dataset containing nearly 1816 stations years of sea level data sampled with a 1–15-minute time step and originating from 257 tide gauge stations across 22 European countries. The procedures used for quality control of the
470 SHELDA dataset involved several steps that combined both automated and visual control methods. Automated methods were used so the same criteria could be easily and quickly applied across all data, and visual inspection had to be included because there were some erroneous data that the automated processes missed. Particularly challenging were spurious data points, such as flat lines and clustered spikes, and special issues like attenuated signals. Statistical analysis of the quality control process indicated that visual inspection remains essential despite automated procedures, accounting for 55.31% of
475 the total data removals. This underscores the limitation of our automated quality control algorithm and highlights the potential for developing techniques that will automatically detect the aforementioned problems. The development of those advanced algorithms will significantly improve and accelerate quality control, making visual inspection less time consuming compared to our previous experience.

A comparison of SHELDA with similar existing datasets, GESLA (Haigh et al., 2022) and MISELA (Zemunik et al., 2021),
480 shows the differences between them. While GESLA mainly consists of global hourly sea level measurements with different levels of quality control, SHELDA focuses on European sea level records sampled with a 1-15 minute time step, implementing rigorous quality control procedures. Compared to MISELA, which provides 1-minute high-pass (2-hour cut-off period) quality-controlled records, SHELDA is more appropriate for the analysis of sea level processes across a wider range of timescales because it preserves the full spectral content of measurements. Access to high-quality sea level data of a
485 1–15-minute time step is important for improving our understanding of coastal flooding hazards, which often result from complex interactions between different sea level components across multiple timescales (Woodworth et al., 2019; Idier et al., 2019). The SHELDA dataset is particularly valuable for investigating contribution of high-frequency phenomena to flooding.

Several limitations of the SHELDA dataset must be acknowledged. First, the spatial distribution of tide gauges remains
490 uneven across the European coasts. Expanding geographical coverage could involve adding more stations in underrepresented regions, which might require incorporating additional data sources beyond the IOC SLSMF database and collaborating with regional monitoring programs to improve data sharing. Second, the temporal coverage of the dataset is currently limited to the end of 2020, primarily due to the extensive time and effort required for performing rigorous quality control, particularly the visual inspection step. We recognize that the inclusion of more recent data would significantly
495 enhance the value of SHELDA so we plan to extend the dataset in the future as resources allow. There is also significant potential for expansion, as at least 70 new stations have been added to the IOC database since January 2021 (e.g., 50 Swedish and 21 Norwegian sea level stations, added to the system in October 2021 and June 2023, respectively). Third, the temporal coverage varies significantly between stations, with 55 of them having records that span less than three years (up to 2021). This is particularly evident for the Croatian Adriatic coast and the eastern Mediterranean and Black Sea regions.
500 While the availability of short time series, especially when they are new records, is welcome, short series resulting from

discontinued tide gauge operations are concerning. Therefore, in addition to recommending the targeted addition of new tide gauges to the European sea level monitoring network and advocating for open data and free data access where data exists but is not shared due to local regulations (e.g., Pérez Gómez et al., 2022 for the Mediterranean), it is also necessary to focus on the maintenance of existing tide gauges to ensure that they continue to operate effectively in the future.

505 To ensure that the dataset remains useful for both operational and research purposes, it will need to be updated regularly. Addressing the current temporal limitation will depend largely on improving the efficiency of the quality control workflow. In this context, the development of more advanced automated quality control methods would be particularly helpful. A promising step in this direction is the VLIZ API (Application Programming Interface) web service for the SLSMF, introduced in spring 2025, which provides access to automatically quality-controlled sea level data ([https://api.ioc-](https://api.ioc-sealevelmonitoring.org/v2/doc)
510 [sealevelmonitoring.org/v2/doc](https://api.ioc-sealevelmonitoring.org/v2/doc), last access: 15 June 2026). Using this service could significantly simplify and accelerate our data processing workflow, as the automated quality control methodology is compatible with our existing procedures. However, it is important to note that the API does not include visual inspection, so, if the highest data quality is required, an additional visual quality control step may still be necessary.

Extreme sea levels (Vousdoukas et al., 2017) and coastal flooding (IPCC, 2014; Hinkel et al., 2014) are growing threat to
515 European coastlines, largely due to rising mean sea levels driven by climate change (Oppenheimer et al., 2019; Hamlington et al., 2024). In recent decades, the frequency of extreme sea level events has increased at many locations (Menéndez and Woodworth, 2010; Haigh et al., 2010). To predict these hazards, researchers use global models of tide, storm surges, and wave setup to obtain projections of episodic coastal flooding over the coming century (Kirezci et al., 2020). These models are validated against tide gauge data, highlighting the critical need for reliable, high-quality datasets like SHELDA. By
520 sharing this quality-controlled dataset openly with researchers, we hope to make it easier to analyse the complex sea level phenomena behind coastal flooding, particularly in regions where high-frequency processes may dominate or significantly contribute to overall extremes. This improved ability to study processes across different timescales will be crucial for creating effective adaptation strategies and helping coastal areas become more resilient.

APPENDIX A: Tide gauge stations metadata

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Table A1. Tide gauge station metadata for Region 1. Station index (see Fig. 7), IOC code, full name, country, data provider, latitude, longitude, start and end dates for quality controlled records, the sampling interval of raw data (min), sensor type and data issues are provided for all stations as of January 2021. Data issues refer to types of erroneous data identified in the raw data: 1 = Out of range values, 2 = Spikes. 3 = Drift, 4 = Vertical shift, 5 = Attenuated signals, variations in phase and amplitude.

No.	IOC code	Full name	Country	Data provider	Lat	Long	Start	End	Sampling interval	Sensor	Data issues
1	ashd1	Ashdod Marina	Israel	Joint Research Centre (Europe) Israel Oceanographic and Limnological Research Ltd	31,80	34,63	2.2.2018 5:02	8.6.2020 21:25	1	Radar	1, 2
2	hade2	Hadera Port	Israel	Joint Research Centre (Europe) Israel Oceanographic and Limnological Research Ltd	32,47	34,88	31.1.2018 4:47	14.6.2020 14:21	1	Radar	1, 2
3	hade	Hadera	Israel	Israel Oceanographic and Limnological Research Ltd	32,47	34,86	10.5.2010 7:51	24.6.2018 21:02	< 1	Pressure	1, 2
4	haif	Haifa	Israel	Joint Research Centre (Europe) Israel Oceanographic and Limnological Research Ltd	32,82	35,01	29.1.2018 4:42	1.1.2021 0:00	1	Radar	1, 2
5	batr	Batroun	Lebanon	Joint Research Centre (Europe) National Centre for Geophysical Research	34,25	35,66	30.6.2016 6:47	9.6.2020 23:00	1	Radar	1, 2
6	iske	Iskenderun	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	36,59	36,18	17.8.2016 7:25	1.1.2021 0:00	< 1	Radar	1, 2, 4
7	erdem	Erdemli	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	36,61	34,33	16.8.2016 10:52	23.5.2020 22:55	< 1	Radar	1, 2
8	tasu	Tasucu	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	36,28	33,84	26.11.2019 22:03	1.1.2021 0:00	< 1	Radar	1, 2
9	bozy	Bozcaada	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	36,10	32,94	16.8.2016 11:22	25.12.2017 21:16	< 1	Radar	1, 2
10	para	Paralimni	Cyprus	Cyprus Oceanography Center	35,04	34,04	8.5.2013 9:56	24.3.2015 8:43	1	Pressure	1, 2
11	larn	Larnaca	Cyprus	Cyprus Oceanography Center	34,92	33,64	8.5.2013 11:12	5.11.2014 19:57	< 1	Pressure	1, 2
12	zygy	Zygi	Cyprus	Cyprus Oceanography Center	34,73	33,34	7.9.2011 12:42	11.12.2013 4:37	< 1	Pressure	1, 2
13	zygy1	Zygi	Cyprus	Cyprus Marine and Maritime Institute Joint Research Centre (Europe)	34,73	33,34	16.3.2018 4:20	17.12.2020 9:49	< 1	Radar	1, 2
14	papho	Paphos	Cyprus	Cyprus Oceanography Center	34,76	32,41	9.3.2011 14:58	18.3.2015 1:42	< 1	Pressure	1, 2
15	anta	Antalya	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	36,84	30,61	26.11.2019 22:03	1.1.2021 0:00	< 1	Radar	1, 2

16	feth	Fethiye	Türkiye	Joint Research Centre (Europe) Kandilli Observatory and Earthquake Research Institute	36,62	29,09	21.12.2015 9:16	9.5.2020 22:02	1	Radar	1, 2
17	mrms	Marmaris	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	36,84	28,38	26.11.2019 22:04	1.1.2021 0:00	< 1	Radar	1, 2
18	bodri	Bodrum (IDSL)	Türkiye	Joint Research Centre (Europe) Kandilli Observatory and Earthquake Research Institute	37,03	27,43	29.10.2019 5:48	1.1.2021 0:00	1	Radar	1, 2, 4
19	kos2	Kos Marina	Greece	National Observatory of Athens	36,89	27,30	16.9.2019 4:28	1.1.2021 0:00	1	Radar	1, 2
20	kos1	Kos	Greece	National Observatory of Athens	36,90	27,29	10.7.2018 6:54	17.12.2020 12:00	1	Radar	1, 2
21	bodr	Bodrum	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	37,03	27,42			Variable	Acoustic	1, 2, 4
							27.11.2010 10:30	17.11.2011 14:15	15		
							16.8.2016 10:53	1.1.2021 0:00	< 1		
22	ment	Mentes	Türkiye	General Directorate of Mapping	38,43	26,72	4.11.2020 21:11	1.1.2021 0:00	< 1	Radar	
23	plom	Plomari	Greece	National Observatory of Athens	38,97	26,37	18.12.2019 16:32	1.1.2021 0:00	1	Radar	1, 2
24	erdek	Erdek	Türkiye	General Directorate of Mapping	40,39	27,85	4.11.2020 21:05	1.1.2021 0:00	< 1	Radar	1, 2
25	yalo	Yalova	Türkiye	General Directorate of Mapping	40,66	29,28	4.11.2020 21:11	1.1.2021 0:00	< 1	Radar	2
26	sile	Sile	Türkiye	General Directorate of Mapping	41,18	29,60	4.11.2020 21:16	1.1.2021 0:00	< 1	Radar	1, 2, 4
27	amas	Amasra	Türkiye	General Directorate of Mapping	41,74	32,39	4.11.2020 21:06	1.1.2021 0:00	< 1	Radar	
28	sino	Sinop	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	42,02	35,15	6.3.2017 14:00	1.1.2021 0:00	< 1	Acoustic	1, 2
29	sams	Samsun	Türkiye	Joint Research Centre (Europe) Kandilli Observatory and Earthquake Research Institute	41,29	36,34	26.11.2019 22:03	26.12.2020 19:14	< 1	Radar	1, 2
30	trab	Trabzon	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	41,00	39,74	26.11.2019 22:04	1.1.2021 0:00	< 1	Radar	1, 2
31	kaci	Kaciveli	Ukraine	Marine Hydrophysical Institute	44,42	34,05	28.1.2011 8:26	3.11.2011 8:34	< 1	Radar	1, 2
32	csta2	Constanta	Romania	National institute for Earth Physics	44,15	28,67	5.12.2015 7:34	10.11.2020 10:52	1	Pressure	1, 2
33	mang	Mangalia	Romania	National institute for Earth Physics	43,80	28,60	5.12.2015 7:34	1.1.2021 0:00	1	Radar	1, 2
34	igne	Igneada	Türkiye	General Directorate of Mapping	41,89	28,02	4.11.2020 20:58	1.1.2021 0:00	< 1	Radar	
35	ista	Istanbul	Türkiye	General Directorate of Mapping	41,16	29,07	4.11.2020 21:11	1.1.2021 0:00	< 1	Radar	
36	maer	Marmara Ereglisi	Türkiye	General Directorate of Mapping Kandilli Observatory and	40,77	27,97			Variable	Radar	1, 2
							16.2.2011	17.11.2011	15		

				Earthquake Research Institute			5:15 17.11.2011 12:42	7:15 1.1.2021 0:00	1		
37	gokc	Gokceada	Türkiye	General Directorate of Mapping Kandilli Observatory and Earthquake Research Institute	40,23	25,89	24.11.2019 21:57	1.1.2021 0:00	< 1	Acoustic	1, 2
38	thes	Thessaloniki	Greece	National Observatory of Athens	40,63	22,91	28.10.2018 20:49	13.10.2020 6:40	1	Radar	1, 2
39	peir	Peiraias	Greece	Hellenic Navy Hydrographic Service	37,93	23,62			Variable	Pressure	1, 2
							20.11.2009 16:59	21.1.2018 4:15	1		
							26.1.2018 8:10	1.1.2021 0:00	5		
40	syro	Syros	Greece	Hellenic Navy Hydrographic Service	37,44	24,94	20.11.2009 17:00	1.1.2021 0:00	< 1	Pressure	1, 2
41	iera	Ierapetra	Greece	National Observatory of Athens	35,00	25,74	24.10.2018 8:44	1.1.2021 0:00	1	Radar	1, 2
42	gvd9	Gavdos	Greece	National Technical University of Athens	34,85	24,12	12.9.2012 8:06	21.5.2015 13:18	6	Acoustic	1
43	kast	Kasteli	Greece	National Technical University of Athens	35,51	23,64	28.6.2010 12:38	16.5.2016 18:24	1	Radar	1, 2
44	kaps	Kapsali	Greece	National Observatory of Athens	36,14	23,00	26.10.2017 17:30	29.1.2018 3:03	1	Radar	1, 2
45	kala	Kalamata	Greece	Hellenic Navy Hydrographic Service	37,02	22,11			Variable	Pressure	1, 2
							20.11.2009 17:00	17.11.2014 5:15	1		
							15.10.2017 21:50	1.1.2021 0:00	5		
46	kypa	Kyparissia	Greece	National Observatory of Athens	37,26	21,66	21.10.2018 19:01	1.1.2021 0:00	1	Radar	1, 2
47	kata	Katakolo	Greece	Hellenic Navy Hydrographic Service	37,64	21,32	20.11.2009 17:00	1.1.2021 0:00	< 1	Pressure	1, 2
48	aigi	Aigio	Greece	National Observatory of Athens	38,26	22,08	21.10.2018 20:29	1.1.2021 0:00	1	Radar	1, 2
49	pano	Panormos	Greece	National Observatory of Athens	38,36	22,25	23.11.2017 15:49	1.1.2021 0:00	1	Radar	1, 2
50	itea	Itea	Greece	National Observatory of Athens	38,43	22,42	21.10.2018 20:20	1.1.2021 0:00	1	Radar	1, 2
51	prev	Preveza	Greece	National Observatory of Athens	38,95	20,73	20.7.2020 15:31	1.1.2021 0:00	1	Radar	1, 2
52	corf	Kerkyra, Corfu	Greece	National Observatory of Athens	39,79	19,91	28.10.2018 20:49	25.11.2020 9:01	1	Radar	2
53	sobr	Sobra	Croatia	Institute of Oceanography and Fisheries	42,79	17,62	2.10.2018 21:01	1.1.2021 0:00	1	Radar	1, 2, 4
54	vela	Vela Luka	Croatia	Institute of Oceanography and Fisheries	42,96	16,72	2.10.2018 21:01	1.1.2021 0:00	1	Radar	1, 2, 4
55	stari	Stari Grad	Croatia	Institute of Oceanography and Fisheries	43,18	16,58	2.10.2018 21:01	1.1.2021 0:00	1	Radar	1, 2, 4
56	TR22	Trieste	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	45,65	13,76	29.9.2008 6:21	1.1.2021 0:00	1	Radar	1, 2

57	VE19	Venice	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	45,42	12,43	17.2.2010 20:46	1.1.2021 0:00	1	Radar	1, 2
58	AN15	Ancona	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	43,63	13,51	15.12.2013 14:11	1.1.2021 0:00	1	Radar	1, 2
59	SB36	S.Benedetto Del Tronto	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	42,96	13,89	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
60	OR24	Ortona	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	42,36	14,41	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
61	IT45	Isole Tremiti	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	42,12	15,50	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
62	VI12	Vieste	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	41,89	16,18	15.12.2013 14:11	1.1.2021 0:00	1	Radar	1, 2
63	BA05	Bari	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	41,14	16,87	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
64	OT15	Otranto	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	40,15	18,50			Variable	Radar	1, 2
							27.9.2008 7:30	17.2.2010 6:10	10		
							17.2.2010 6:11	1.1.2021 0:00	1		
65	TA18	Taranto	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	40,48	17,22	15.12.2013 14:11	1.1.2021 0:00	1	Radar	1, 2
66	CR08	Crotone	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	39,08	17,14	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
67	lcst	Le Castella	Italy	Joint Research Centre (Europe) Istituto Nazionale di Geofisica e Vulcanologia	38,91	17,03	10.7.2016 7:07	9.5.2019 21:16	1	Radar	1, 2
68	RC09	Reggio Calabria	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	38,12	15,65	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
69	CT03	Catania	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	37,50	15,09	13.9.2010 23:25	1.1.2021 0:00	1	Radar	1, 2
70	ppcp	Portopalo di Capo Passero	Italy	Joint Research Centre (Europe) Istituto Nazionale di Geofisica e Vulcanologia	36,67	15,12	21.3.2016 15:44	29.11.2020 7:09	1	Radar	1, 2
71	PE09	Porto empedocle	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	37,29	13,53			Variable	Pressure	1, 2
							27.9.2008 7:30	14.9.2010 12:10	10		
							14.9.2010 12:11	1.1.2021 0:00	1		
72	SC43	Sciacca	Italy	Istituto Superiore per la Protezione e la Ricerca	37,50	13,08	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2

				Ambientale							
73	PA07	Palermo	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	38,12	13,37	15.6.2014 7:21	1.1.2021 0:00	1	Radar	1, 2
74	GI20	Ginostra (Isola di Stromboli)	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	38,78	15,19	14.11.2010 16:46	1.1.2021 0:00	1	Pressure	1, 2
75	ST44	Strombolicchio	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	38,82	15,25	15.12.2013 14:11	13.1.2015 21:45	1	Radar	1, 2
76	PL14	Palinuro	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	40,03	15,28	1.2.2014 14:31	1.1.2021 0:00	1	Radar	1, 2
77	SA16	Salerno	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	40,68	14,75	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
78	NA23	Napoli	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	40,84	14,27			Variable	Radar	1, 2
							27.9.2008 7:30	17.2.2010 6:10	10		
							17.2.2010 6:11	1.1.2021 0:00	1		
79	GA37	Gaeta	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	41,21	13,59	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
80	PO40	Ponza	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	40,90	12,97	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
81	AZ42	Anzio	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	41,45	12,64	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
82	MC41	Marina Di Campo	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	42,74	10,24	15.12.2013 13:56	1.1.2021 0:00	1	Radar	1, 2
83	LI11	Livorno	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	43,55	10,30	10.6.2014 12:15	1.1.2021 0:00	1	Radar	1, 2
84	LA38	La Spezia	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	44,10	9,86	19.11.2013 0:00	1.1.2021 0:00	1	Radar	1, 2
85	GE25	Genova	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	44,41	8,93	13.9.2010 23:13	1.1.2021 0:00	1	Radar	1, 2
86	IM01	Imperia	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	43,88	8,02			Variable	Radar	1, 2
							27.9.2008 7:30	17.2.2010 6:10	10		
							17.2.2010 6:11	1.1.2021 0:00	1		
87	im02	Imperia 2	Italy	Joint Research Centre (Europe)	43,88	8,02	12.2.2015 20:35	1.1.2021 0:00	1	Radar	1, 2
88	cent2	Centuri 2	France	Service hydrographique et océanographique de la marine	42,97	9,35	11.1.2011 5:27	1.1.2021 0:00	1	Radar	1, 2

89	rous2	Ile Rousse 2	France	Service hydrographique et océanographique de la marine	42,64	8,94	29.8.2011 14:05	1.1.2021 0:00	1	Radar	1, 2
90	ajac	Ajaccio	France	Service hydrographique et océanographique de la marine	41,92	8,76	18.9.2009 10:31	29.12.2020 14:22	1	Radar	1, 2
91	sole	Solenzara	France	Service hydrographique et océanographique de la marine	41,84	9,37	2.11.2010 23:58	30.10.2020 8:57	1	Radar	1, 2
92	PT17	Porto Torres	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	40,84	8,40	12.9.2010 16:01	1.1.2021 0:00	1	Radar	1, 2
93	CF06	Carloforte	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	39,14	8,31			Variable	Radar	1, 2
							27.9.2008 7:30	17.2.2010 6:10	10		
							17.2.2010 6:11	1.1.2021 0:00	1		
94	CA02	Cagliari	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	39,21	9,11	13.9.2010 23:25	1.1.2021 0:00	1	Radar	1, 2
95	pant	Pantelleria	Italy	Joint Research Centre (Europe) Istituto Nazionale di Geofisica e Vulcanologia	36,83	11,94	21.3.2016 15:45	13.4.2020 18:54	1	Radar	1, 2
96	LA23	Lampedusa	Italy	Istituto Superiore per la Protezione e la Ricerca Ambientale	35,50	12,60	12.9.2010 16:01	1.1.2021 0:00	1	Radar	1, 2
97	malt	Malta	Malta	University of Malta,Oceanography Malta Research Group within the Department of Geosciences	35,99	14,33	29.10.2019 5:58	17.12.2020 18:59	1	Radar	1, 2
98	ptma	Portomaso	Malta	University of Malta,Oceanography Malta Research Group within the Department of Geosciences	35,92	14,49	16.2.2011 13:48	4.12.2019 16:02	< 1	Radar	1, 2

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Table A2. Tide gauge station metadata for Region 2. Station index (see Fig. 8), IOC code, full name, country, data provider, latitude, longitude, start and end dates for quality controlled records, the sampling interval of raw data (min), sensor type and data issues are provided for all stations as of January 2021. Data issues refer to types of erroneous data identified in the raw data: 1 = Out of range values, 2 = Spikes. 3 = Drift, 4 = Vertical shift, 5 = Attenuated signals, variations in phase and amplitude.

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No.	IOC code	Full name	Country	Data provider	Lat	Long	Start	End	Interval	Sensor	Data issues
99	monc	Monaco, Fontvieille harbour	Monaco	Principauté de Monaco - Direction de l'Environnement	43,73	7,42	30.11.2010 23:58	31.12.2020 23:59	1	Radar	1, 2
100	figu	La Figueirette	France	Service hydrographique et océanographique de la marine	43,48	6,93	31.5.2011 23:57	31.12.2020 23:54	1	Radar	1, 2
101	ptfe2	Port Ferréol 2	France	Service hydrographique et océanographique de la marine	43,36	6,72	5.4.2012 13:40	1.1.2021 0:00	1	Radar	1, 2
102	toul2	Toulon 2	France	Service hydrographique et océanographique de la marine	43,12	5,91	9.4.2010 8:57	1.1.2021 0:00	1	Radar	1, 2

103	mars	Marseille	France	Service hydrographique et océanographique de la marine	43,29	5,36	27.10.2010 11:39	22.1.2019 2:32	1	Radar	1, 2
104	sete	Sète	France	Service hydrographique et océanographique de la marine	43,40	3,70	1.7.2011 9:18	31.12.2020 23:59	1	Radar	1, 2
105	ptln	Port-La-Nouvelle	France	Service hydrographique et océanographique de la marine	43,01	3,04	29.5.2013 12:04	31.12.2020 23:59	1	Radar	1, 2
106	ptve	Port-Vendres	France	Service hydrographique et océanographique de la marine	42,52	3,11	7.3.2011 0:00	31.12.2020 23:59	1	Radar	1, 2
107	barc	Barcelona	Spain	Puertos del Estado	41,34	2,17	27.2.2008 11:12	1.1.2021 0:00	1	Radar	1, 2
108	tarr	Tarragona	Spain	Puertos del Estado	41,08	1,21	10.1.2014 18:53	1.1.2021 0:00	1	Radar	1, 2
109	ciut	Ciutadella	Spain	Joint Research Centre (Europe) Instituto Geográfico Nacional	39,99	3,83	26.10.2017 8:38	1.1.2021 0:00	1	Radar	1, 2
110	maho	Mahon	Spain	Puertos del Estado	39,89	4,27	15.6.2018 5:33	1.1.2021 0:00	1	Radar	1, 2
111	lmma	La Mola de Mahon	Spain	Joint Research Centre (Europe) Instituto Geográfico Nacional	39,87	4,31	26.10.2017 13:04	1.1.2021 0:00	1	Radar	1, 2
112	alcu	Alcudia	Spain	Puertos del Estado	39,84	3,14	11.10.2009 21:45	1.1.2021 0:00	1	Radar	1, 2
113	palm	Palma de Mallorca	Spain	Puertos del Estado	39,56	2,64	15.10.2009 8:43	1.1.2021 0:00	1	Radar	1, 2
114	ibiz	Ibiza2	Spain	Puertos del Estado	38,91	1,45	11.10.2009 21:46	1.1.2021 0:00	1	Radar	1, 2
115	form	Formentera	Spain	Puertos del Estado	38,73	1,42	10.1.2014 18:59	1.1.2021 0:00	1	Radar	1, 2
116	sagu	Sagunto	Spain	Puertos del Estado	39,63	-0,21	25.3.2008 14:04	1.1.2021 0:00	1	Radar	1, 2
117	vale	Valencia	Spain	Puertos del Estado	39,44	-0,31	25.3.2008 14:04	1.1.2021 0:00	1	Radar	1, 2
118	gand	Gandia	Spain	Puertos del Estado	39,00	-0,15	27.2.2008 11:11	1.1.2021 0:00	1	Radar	1, 2
119	alac1	Alicante 1	Spain	Instituto Geográfico Nacional	38,34	-0,48	1.12.2019 0:00	13.12.2020 6:02	1	Radar	1
120	alac2	Alicante 2	Spain	Instituto Geográfico Nacional	38,34	-0,48	1.12.2019 0:00	13.12.2020 6:00	1	Radar	1
121	murc2	Murcia	Spain	Instituto Geográfico Nacional	37,60	-0,97	1.12.2019 0:00	13.12.2020 6:02	1	Radar	1, 2
122	carb	Carboneras	Spain	Puertos del Estado	36,97	-1,90	10.1.2014 18:59	31.12.2020 23:58	1	Radar	1, 2
123	alme	Almeria	Spain	Puertos del Estado	36,83	-2,48	27.2.2008 11:12	1.1.2021 0:00	1	Radar	1, 2
124	alme2	Almeria 2	Spain	Instituto Geográfico Nacional	36,83	-2,49	1.12.2019 0:00	13.12.2020 6:02	1	Radar	1, 2
125	motr	Motril2	Spain	Puertos del Estado	36,72	-3,52	25.3.2008 14:04	1.1.2021 0:00	1	Radar	1, 2
126	albo	Alboran Island	Spain	Instituto Geográfico Nacional Puertos del Estado	35,94	-3,03	1.12.2019 0:03	13.12.2020 6:02	1	Radar	1, 2
127	meli	Melilla	Spain	Puertos del Estado	35,29	-2,93	27.2.2008 11:09	1.1.2021 0:00	1	Radar	1, 2
128	mal3	Malaga	Spain	Puertos del Estado	36,71	-4,42	10.1.2014	31.12.2020	1	Radar	1, 2

							18:59	23:40			
129	gibr	Gibraltar (tsunami)	UK	National Oceanography Centre	36,13	-5,35	10.2.2009 16:21	7.1.2014 7:32	< 1	Radar	1, 2
130	gibr2	Gibraltar	UK	National Oceanography Centre	36,13	-5,35	17.9.2010 0:00	10.1.2019 9:53	1	Radar	1, 2
131	gibr3	Gibraltar	UK	National Oceanography Centre	36,13	-5,35	15.1.2019 10:14	1.1.2021 0:00	1	Radar	1, 2
132	alge	Algeciras	Spain	Puertos del Estado	36,18	-5,40	15.10.2009 8:41	1.1.2021 0:00	1	Radar	1, 2
133	ceut	Ceuta	Spain	Instituto Español de Oceanografía	35,90	-5,31			Variable	Radar	1, 2
							18.8.2008 0:00	27.9.2018 7:10	10		
							18.10.2018 9:24	31.12.2020 21:59	1		
134	ceut1	Ceuta 2	Spain	Joint Research Centre (Europe) Instituto Geográfico Nacional	35,90	-5,31	7.9.2017 20:50	1.1.2021 0:00	1	Radar	1, 2
135	tari	Tarifa	Spain	Puertos del Estado	36,01	-5,60	11.10.2009 21:45	1.1.2021 0:00	1	Radar	1, 2
136	cadi	Cadiz	Spain	Joint Research Centre (Europe) Instituto Geográfico Nacional	36,54	-6,28	1.1.2016 0:01	30.12.2020 17:21	1	Radar	1, 2
137	bon2	Bonanza 2	Spain	Puertos del Estado	36,80	-6,34	15.1.2014 3:13	1.1.2021 0:00	1	Radar	1, 2
138	huel	Huelva5	Spain	Puertos del Estado	37,13	-6,83	31.3.2008 16:00	1.1.2021 0:00	1	Radar	1, 2
139	albu	Albufeira	Portugal	Joint Research Centre (Europe) Instituto Português do Mar e da Atmosfera	37,08	-8,26	1.1.2016 0:01	1.1.2021 0:00	1	Radar	1, 2
140	sagr	Sagres	Portugal	Joint Research Centre (Europe) Instituto Português do Mar e da Atmosfera	37,01	-8,93	11.10.2015 15:57	1.1.2021 0:00	1	Radar	1, 2
141	setu	Setubal	Portugal	Joint Research Centre (Europe) Instituto Português do Mar e da Atmosfera	38,49	-8,93	20.2.2015 8:49	28.5.2018 8:34	1	Radar	1, 2
142	vig2	Vigo	Spain	Puertos del Estado	42,24	-8,73	14.1.2014 4:48	1.1.2021 0:00	1	Radar	1, 2
143	mari	Marin	Spain	Puertos del Estado	42,41	-8,69	16.1.2014 8:53	1.1.2021 0:00	1	Radar	1, 2
144	vil2	Villagarcia	Spain	Puertos del Estado	42,60	-8,77	14.1.2014 4:48	1.1.2021 0:00	1	Radar	1, 2
145	lang	Langosteira	Spain	Puertos del Estado	43,35	-8,53	16.1.2014 9:25	1.1.2021 0:00	1	Radar	1, 2
146	cor2	Acoruna	Spain	Puertos del Estado	43,36	-8,39	16.1.2014 9:41	1.1.2021 0:00	1	Radar	1, 2
147	acor1	A Coruña	Spain	Instituto Geográfico Nacional	43,36	-8,40	12.1.2019 0:00	4.2.2020 3:30	10	Radar	
148	coru	La Coruña	Spain	Instituto Español de Oceanografía	43,37	-8,40			Variable	Float	1, 2
							18.8.2008 0:00	3.6.2019 7:50	5		
							3.6.2019 7:51	1.1.2021 0:00	1		

149	fer1	Ferrol1	Spain	Puertos del Estado	43,46	-8,33	1.4.2008 16:58	1.1.2021 0:00	1	Radar	1, 2
150	fer2	Ferrol2	Spain	Puertos del Estado	43,48	-8,25	10.1.2014 18:59	1.1.2021 0:00	1	Radar	1, 2
151	gij2	Gijon	Spain	Puertos del Estado	43,56	-5,70	16.1.2014 9:25	1.1.2021 0:00	1	Radar	1, 2
152	san2	Santander	Spain	Puertos del Estado	43,46	-3,79	10.1.2014 18:59	1.1.2021 0:00	1	Radar	1, 2
153	bil3	Bilbao3	Spain	Puertos del Estado	43,35	-3,05	1.4.2008 9:22	1.1.2021 0:00	1	Radar	1, 2
154	scoa2	Socoa	France	Service hydrographique et océanographique de la marine	43,40	-1,68	8.6.2011 10:32	31.12.2020 23:59	1	Radar	1, 2
155	port	Port-Bloc	France	Service hydrographique et océanographique de la marine	45,57	-1,06	2.7.2012 10:05	31.12.2020 23:59	1	Radar	1, 2
156	iaix	Ile d'Aix	France	Service hydrographique et océanographique de la marine	46,01	-1,17	23.5.2011 9:54	7.12.2020 7:17	1	Radar	1, 2
157	leso	Les Sables d'Olonne	France	Service hydrographique et océanographique de la marine	46,50	-1,79	1.4.2010 8:14	31.12.2020 23:59	1	Radar	1, 2
158	herb	L'Herbaudière	France	Service hydrographique et océanographique de la marine	47,03	-2,30	13.6.2014 10:19	31.12.2020 23:59	1	Radar	1, 2
159	lecy	Le Crouesty	France	Service hydrographique et océanographique de la marine	47,54	-2,90	27.5.2010 23:58	31.12.2020 23:59	1	Radar	1, 2
160	tudy	Port-Tudy (Groix island)	France	Service hydrographique et océanographique de la marine	47,64	-3,45	26.4.2011 23:56	31.12.2020 23:59	1	Radar	1, 2
161	conc	Concarneau	France	Service hydrographique et océanographique de la marine	47,87	-3,91	3.2.2010 0:00	31.12.2020 23:54	1	Radar	1, 2
162	audi2	Audieme 2	France	Service hydrographique et océanographique de la marine	48,02	-4,54	3.7.2018 14:09	1.1.2021 0:00	1	Radar	1, 2
163	bres	Brest	France	Service hydrographique et océanographique de la marine	48,38	-4,50	12.12.2008 0:01	31.12.2020 23:59	1	Radar	1, 2
164	leco	Le Conquet	France	Service hydrographique et océanographique de la marine	48,36	-4,78	12.12.2008 0:03	31.12.2020 23:59	1	Radar	1, 2
165	rosc	Roscoff	France	Service hydrographique et océanographique de la marine	48,72	-3,97	2.7.2012 10:05	31.12.2020 23:59	1	Radar	1, 2
166	stqy2	Saint-Quay- Portrieux 2	France	Service hydrographique et océanographique de la marine	48,65	-2,82	10.10.2018 4:58	1.1.2021 0:00	1	Radar	1, 2
167	diel	Dielette	France	Service hydrographique et océanographique de la marine	49,55	-1,86	30.9.2015 23:57	31.12.2020 23:59	1	Radar	1, 2
168	cher	Cherbourg	France	Service hydrographique et océanographique de la marine	49,65	-1,63	20.12.2008 12:03	31.12.2020 23:59	1	Radar	1, 2
169	diep	Dieppe	France	Service hydrographique et océanographique de la marine	49,93	1,09	15.4.2009 0:00	31.12.2020 23:59	1	Radar	1, 2
170	boul	Boulogne- Sur-Mer	France	Service hydrographique et océanographique de la marine	50,73	1,58	1.4.2010 0:01	31.12.2020 23:59	1	Radar	1, 2
171	cala	Calais	France	Service hydrographique et océanographique de la marine	50,97	1,87	22.10.2009 23:56	31.12.2020 13:00	1	Radar	1, 2
172	dunk	Dunkerque	France	Service hydrographique et océanographique de la marine	51,05	2,37	9.2.2012 19:41	31.12.2020 23:59	1	Radar	1, 2
173	arre	Arrecife	Spain	Puertos del Estado	28,97	-13,53	4.8.2008 21:47	1.1.2021 0:00	1	Radar	1, 2
174	fuer2	Fuerteventura	Spain	Instituto Geográfico Nacional	28,50	-13,86	1.12.2019	13.12.2020	1	Radar	1, 2

							0:00	6:02			
175	fue2	Fuerteventura	Spain	Puertos del Estado	28,49	-13,86	20.2.2014 16:53	1.1.2021 0:00	1	Radar	1, 2
176	lasp	LasPalmas2	Spain	Puertos del Estado	28,14	-15,41	14.10.2009 21:47	1.1.2021 0:00	1	Radar	1, 2
177	pluz	Puerto de la Luz	Spain	Instituto Geográfico Nacional	28,13	-15,41			Variable	Radar	1, 2
							18.8.2008 0:00	28.4.2010 0:00	10		
							8.2.2011. 9:50	25.6.2015 9:10	5		
							25.6.2015 9:15	31.12.2020 7:05	1		
178	tn031	Arona, Tenerife	Spain	Instituto Geográfico Nacional	28,05	-16,72	1.12.2019 0:00	9.12.2020 11:56	1	Radar	1, 2
179	lago	LaGomera	Spain	Puertos del Estado	28,09	-17,11	18.4.2008 12:51	1.1.2021 0:00	1	Radar	1, 2
180	hie2	ElHierro	Spain	Puertos del Estado	27,78	-17,90	16.1.2014 9:25	1.1.2021 0:00	1	Radar	1, 2
181	lapa	LaPalma	Spain	Puertos del Estado	28,68	-17,77	31.3.2008 21:11	1.1.2021 0:00	1	Radar	1, 2
182	posa	Porto Santo	Portugal	Joint Research Centre (Europe) Instituto Português do Mar e da Atmosfera	33,06	-16,31	11.5.2018 6:13	1.1.2021 0:00	1	Radar	1, 2

Table A3. Tide gauge station metadata for Region 3. Station index (see Fig. 9), IOC code, full name, country, data provider, latitude, longitude, start and end dates for quality controlled records, the sampling interval of raw data (min), sensor type and data issues are provided for all stations as of January 2021. Data issues refer to types of erroneous data identified in the raw data: 1 = Out of range values, 2 = Spikes. 3 = Drift, 4 = Vertical shift, 5 = Attenuated signals, variations in phase and amplitude.

No.	IOC code	Full name	Country	Data provider	Lat	Long	Start	End	Interval	Sensor	Data issues
183	lerw	Lerwick (tsunami)	UK	National Oceanography Centre	60,16	-1,15	6.3.2009 17:31	24.2.2018 19:32	< 1	Pressure	1, 2
184	lerw2	Lerwick2	UK	National Oceanography Centre	60,16	-1,15	27.4.2012 10:15	1.1.2021 0:00	15	Pressure	1
185	work	Workington	UK	National Oceanography Centre	58,44	-3,09	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
186	abed	Aberdeen	UK	National Oceanography Centre	57,14	-2,08	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
187	leit	Leith	UK	National Oceanography Centre	55,99	-3,18	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
188	whit	Whitby	UK	National Oceanography Centre	54,49	-0,61	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
189	immi	Immingham	UK	National Oceanography Centre	53,63	-0,19	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1, 3
190	lowe	Lowestoft	UK	National Oceanography Centre	52,47	1,75	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1

191	shee	Sheerness	UK	National Oceanography Centre	51,45	0,74	4.9.2012 13:15	1.1.2021 0:00	15	Pressure	1
192	dlpr	Deal Pier	UK	Channel Coastal Observatory	51,22	1,41	5.10.2012 9:09	21.12.2020 21:27	< 1	Radar	1, 2
193	dove	Dover	UK	National Oceanography Centre	51,11	1,32	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
194	nhav	Newhaven	UK	National Oceanography Centre	50,78	0,06	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
195	ptmt	Portsmouth	UK	National Oceanography Centre	50,80	-1,11	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
196	sdpr	Sandown Pier	UK	Channel Coastal Observatory	50,65	-1,15	5.12.2012 0:06	25.9.2020 18:18	< 1	Radar	1, 2
197	lymg	Lymington	UK	Channel Coastal Observatory	50,74	-1,51	5.10.2012 9:04	11.10.2020 10:24	< 1	Step	1, 2
198	bour	Bournemouth	UK	National Oceanography Centre	50,71	-1,87	3.9.2012 20:15	1.1.2021 0:00	15	Radar	1
199	swpr	Swanage Pier	UK	Channel Coastal Observatory	50,61	-1,95	20.9.2012 19:57	19.3.2020 12:50	< 1	Radar	1, 2
200	weym	Weymouth	UK	National Oceanography Centre	50,61	-2,45	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
201	wbhb	West Bay Harbour	UK	Channel Coastal Observatory	50,71	-2,76	4.10.2012 11:23	16.3.2020 1:36	< 1	Step	1, 2
202	tnpr	Teignmouth Pier	UK	Channel Coastal Observatory	50,54	-3,49	20.9.2012 18:01	3.2.2014 8:28	< 1	Radar	1, 2
203	plym	Plymouth	UK	National Oceanography Centre	50,37	-4,19	10.9.2012 16:00	1.1.2021 0:00	15	Pressure	1
204	newl2	Newlyn	UK	National Oceanography Centre	50,10	-5,54	5.10.2011 19:00	14.6.2020 7:15	15	Pressure	1
205	stmr	St Marys	UK	National Oceanography Centre	49,92	-6,32	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
206	ptis	Port Isaac	UK	Channel Coastal Observatory	50,59	-4,83	5.10.2012 9:09	19.12.2020 18:32	< 1	Step	1, 2
207	ilfa	Ilfracombe	UK	National Oceanography Centre	51,21	-4,11	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1, 3
208	hink	Hinkley Point	UK	National Oceanography Centre	51,21	-3,13	3.9.2012 20:15	7.12.2020 14:00	15	Pressure	1
209	avon	Avonmouth Portbury	UK	National Oceanography Centre	51,50	-2,73	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1, 3
210	mumb	Mumbles	UK	National Oceanography Centre	51,57	-3,98	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1, 3
211	mhav	Milford Haven	UK	National Oceanography Centre	51,71	-5,05	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1, 3
212	fish	Fishguard	UK	National Oceanography Centre	52,01	-4,98	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
213	barm	Barmouth	UK	National Oceanography Centre	52,72	-4,05	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
214	holy2	Holyhead2	UK	National Oceanography Centre	53,31	-4,62	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
215	holy	Holyhead (tsunami)	UK	National Oceanography Centre	53,31	-4,63	22.1.2009 13:37	19.2.2019 15:18	< 1	Float	1, 2
216	llan	Llandudno	UK	National Oceanography Centre	53,33	-3,83	3.9.2012	1.1.2021	15	Pressure	1, 3

							20:15	0:00			
217	live	Liverpool	UK	National Oceanography Centre	53,45	-3,02	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
218	heys	Heysham	UK	National Oceanography Centre	54,03	-2,92	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1, 3
219	wick	Wick Harbour	UK	National Oceanography Centre	54,65	-3,57	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
220	porp	Portpatrick	UK	National Oceanography Centre	54,84	-5,12	3.9.2012 20:15	31.12.2020 23:45	15	Pressure	1
221	mill	Millport	UK	National Oceanography Centre	55,75	-4,91	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
222	tobe	Tobermory	UK	National Oceanography Centre	56,62	-6,06	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
223	ulla	Ullapool	UK	National Oceanography Centre	57,90	-5,16	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
224	kinl	Kinlochbervie	UK	National Oceanography Centre	58,46	-5,05	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
225	stor	Stornoway	UK	National Oceanography Centre	58,21	-6,39	9.4.2012 13:30	1.1.2021 0:00	15	Pressure	1
226	stor2	Stornoway (tsunami)	UK	National Oceanography Centre	58,21	-6,39	12.12.2013 13:29	12.2.2019 9:20	< 1	Pressure	1, 2
227	prus	Portrush	UK	National Oceanography Centre	55,21	-6,66	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1, 3
228	bang	Bangor	UK	National Oceanography Centre	54,66	-5,67	3.9.2012 20:15	1.1.2021 0:00	15	Pressure	1
229	kis1	Kish Bank Lighthouse	Ireland	Marine Institute	53,31	-5,92	12.6.2008 22:00	12.3.2015 19:54	6	Pressure	1
230	cast	Castletownbere	Ireland	Department of Agriculture, Fisheries and Food Marine Institute	51,65	-9,90			Variable	Pressure	1, 2
							16.6.2008 12:45	21.3.2018 9:00	15		
							21.3.2018 11:35	1.1.2021 0:00	5		
231	ball	Ballyglass pier, Belmullet	Ireland	Marine Institute	54,25	-9,89			Variable	Pressure	1, 2, 3
							11.6.2008 10:06	13.3.2018 8:54	6		
							13.3.2018 9:00	24.10.2020 2:20	5		
232	mali	Malin Head Peninsular	Ireland	Marine Institute	55,37	-7,33			Variable	Pressure	1, 2, 3
							26.8.2011 13:06	12.3.2018 10:00	6		
							12.3.2018 11:10	1.1.2021 0:00	5		
233	oste	Ostend	Belgium	Maritieme Dienstverlening en Kust	51,23	2,92	6.9.2013 0:00	1.1.2021 0:00	5	Float	1
234	vlnr	Vlakte v/d Raam	Netherlands	Rijkswaterstaat	51,50	3,24	11.1.2017 19:50	1.1.2021 0:00	10	Float	1, 5
235	brsk	Breskens Handelshaven	Netherlands	Rijkswaterstaat	51,40	3,55	9.3.2017 9:10	1.1.2021 0:00	10	Float	1, 5
236	vlis	Vlissingen	Netherlands	Rijkswaterstaat	51,44	3,60	14.1.2017 14:40	1.1.2021 0:00	10	Float	1, 5

237	trnz	Terneuzen	Netherlands	Rijkswaterstaat	51,34	3,82	11.1.2017 20:10	1.1.2021 0:00	10	Float	1, 5
238	euro	Europlatform	Netherlands	Rijkswaterstaat	52,00	3,27	11.1.2017 19:50	1.1.2021 0:00	10	Float	1, 5
239	hoek	Hoek van Holland	Netherlands	Rijkswaterstaat	51,98	4,12	14.1.2017 14:50	1.1.2021 0:00	10	Float	1, 5
240	sche	Scheveningen	Netherlands	Rijkswaterstaat	52,10	4,26	11.1.2017 20:20	1.1.2021 0:00	10	Float	1, 5
241	denh	Den Helder	Netherlands	Rijkswaterstaat	52,96	4,74	14.1.2017 14:50	1.1.2021 0:00	10	Float	1, 5
242	harl	Harlingen	Netherlands	Rijkswaterstaat	53,18	5,41	14.1.2017 14:50	1.1.2021 0:00	10	Float	1, 5
243	ters	Terschelling Noordzee	Netherlands	Rijkswaterstaat	53,43	5,33	7.3.2017 11:20	1.1.2021 0:00	10	Float	1, 5
244	delf	Delfzijl	Netherlands	Rijkswaterstaat	53,33	6,93	14.1.2017 15:00	1.1.2021 0:00	10	Float	1, 5
245	hirt	Hirtshals	Denmark	Danish Meteorological Institute	57,60	9,97	3.8.2008 12:20	1.1.2021 0:00	10	Radar	1
246	sthm	Stockholm	Sweden	Swedish Meteorological and Hydrological Institute Swedish Maritime Administration	59,33	18,07			Variable	Radar	1, 2, 4
							2.12.2007 0:00	26.6.2019 11:25	5		
							27.6.2019 13:49	1.1.2021 0:00	1		
247	goto	Goteborg Torshamnen	Sweden	Swedish Meteorological and Hydrological Institute	57,68	11,78	2.12.2007 0:00	1.1.2021 0:00	5	Radar	1
248	smog	Smogen	Sweden	Swedish Meteorological and Hydrological Institute Swedish Maritime Administration	58,35	11,22			Variable	Radar	1, 2, 4
							2.12.2007 0:00	20.3.2019 8:55	5		
							20.3.2019 10:52	1.1.2021 0:00	1		
249	treg	Tregde	Norway	Norwegian Hydrographic Service	58,01	7,57	16.12.2008 23:00	31.12.2020 0:50	10	Float	4
250	malo	Måløy	Norway	Norwegian Hydrographic Service	61,93	5,12	17.12.2008 23:00	31.12.2020 0:40	10	Float	1, 4
251	rorv	Rørvik	Norway	Norwegian Hydrographic Service	64,87	11,25	16.12.2008 23:00	31.12.2020 0:30	10	Float	1, 4
252	ande	Andenes	Norway	Norwegian Hydrographic Service	69,32	16,15	16.12.2008 23:00	31.12.2020 0:40	10	Float	1, 4
253	honn	Honningsvåg	Norway	Norwegian Hydrographic Service	70,98	25,98	17.12.2008 23:00	31.12.2020 0:40	10	Float	1, 4
254	vard	Vardø	Norway	Norwegian Hydrographic Service	70,33	31,10	12.5.2015 6:00	31.12.2020 0:50	10	Radar	1, 4
255	nyal	Ny Ålesund	Norway	Norwegian Hydrographic Service	78,93	11,95	5.4.2010 22:10	31.12.2020 0:40	10	Float	1, 4
256	scor	Ittoqqortoormii, Scoresbysund	Denmark	Danish National Space Centre, Technical University of Denmark	70,48	-21,96	3.12.2008 12:15	31.12.2020 23:55	5	Pressure	1, 4
257	reyk	Reykjavik	Iceland	Icelandic Coast Guard, Hydrographic Department	64,15	-21,93	1.9.2008 0:00	20.3.2020 12:28	1	Pressure	1, 2

Author contribution

JŠ supervised and led the development of the quality control methodology, MB implemented and performed the quality control procedures, MB and JŠ conceptualized the paper, MB wrote the initial draft of the text, and JŠ commented on, revised, and approved the final manuscript.

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgments

The authors sincerely thank the Intergovernmental Oceanographic Commission (IOC) Sea Level Station Monitoring Facility, along with all contributing data providers, station operators, and everyone involved in the collection, transmission, and maintenance of sea level data. We are deeply grateful to Leon Čatipović, Ivica Vilibić and Petra Zemunik Selak for performing initial quality control of 71 time series. Special thanks are extended to Krešimir Ruić for generously sharing his code for downloading IOC SLSMF data with us. We gratefully acknowledge Oda Roaldsdotter Ravndal from Kartverket for providing valuable information and clarifications regarding the Norwegian sea level data. The authors also thank the data team at VLIZ for their assistance with data storage and management, with particular appreciation to Carolien Knockaert (VLIZ) and to Bart Vanhoorne (IOC SLSMF team) for their guidance and support throughout this step. We highly appreciate the suggestions from both reviewers, Ivan Haigh and an anonymous reviewer, which significantly improved the paper.

Financial support

The research has been supported by the ERC 853045 SHExtreme, the ERC PoC 101213756 MeD-Track, the Croatian Science Foundation projects IP-2019-04-5875 StVar-Adri and IP-2022-10-4144 CroClimExtremes, the STIM-REI 2.0 project (PK.1.1.10.0005), the ZMAJ project funded by the European Union - NextGenerationEU, the "VAL" project (PK.3.4.17.0021) funded by the European Regional Development Fund (ERDF), and the BioRes&App programme (1477-1-1/2025) supported by Javna ustanova za upravljanje Park šumom Marjan, Split.

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