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Open Access Earth System Science Data Discussions

Artificial Intelligence for Stable Isotope Tracers (AISIT): A Database of δ^{18}O and ancillary data in the Pan-Arctic

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Abstract. The Arctic is undergoing rapid change. Near-surface air temperatures are rising at around four times the global average, ocean temperatures are increasing, sea ice is thinning, retreating rapidly, and growing younger on average, while pan-arctic river run-off and glacial melt are both increasing. The increased fluxes of nutrient-loaded freshwater into the Arctic significantly impact marine systems both locally and globally. Arctic nutrient supplies underpin marine productivity not only within the Arctic Ocean, but also in temperate and tropical regions via oceanic exports. This makes the tracing of freshwater sources from land, the cryosphere and the atmosphere into and throughout the ocean a critical priority for understanding the global consequences of Arctic climate change. When combined with salinity measurements, stable oxygen isotope ratios (δ^{18}O) in seawater are a powerful tracer for distinguishing freshwater contributions from meteoric sources (precipitation, rivers, glaciers) and sea-ice. While major previous efforts have compiled extensive δ^{18}O observations in other regions, no up-to-date, centralised, accessible, and curated pan-Arctic compilation exists, despite the rapid growth in observational coverage over the recent decades. Here, we present a unified pan-Arctic seawater δ^{18}O database comprising observations collected north of 60° N, compiled from public repositories, peer-reviewed literature, and datasets contributed directly by colleagues across the scientific community. To unify these records, we harmonised metadata, applied standardised quality-control procedures, and integrated records into a single Artificial Intelligence (AI) compatible dataset adhering to FAIR (Findable, Accessible, Interoperable, and Reusable) data principles. We further added available barium (Ba) concentration data as another freshwater tracer, capable in some conditions of further de-convolving Arctic river run-off into separate sources. The resulting database comprises 45,714 unique δ^{18}O measurements, paired with salinity measurements for non-freshwater samples, and 5531 unique Ba measurements spanning 1967–2025 (Thorpe-Morgan et al., 2026). This dataset provides a useful resource for quantifying sources of freshwater in the Arctic Ocean, in a format which facilitates data-driven and machine-learning approaches to spatio-temporally-sparse environmental datasets.

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1 Background and Synopsis

The Arctic is warming faster than any other region on Earth, with near-surface air temperature increases occurring about four times more rapidly than the global average, a phenomenon known as Arctic amplification (Rantanen et al., 2022; Serreze et al., 2026). Over the past century, this accelerated warming has paralleled a marked increase in Arctic riverine discharge, which constitutes ca. 10% of global river run-off. (Holmes et al., 2021; Tank et al., 2023; Wang et al., 2025), land and sea ice melt (Poinar et al., 2026; Schroeder, 2016), and precipitation, substantially altering the Arctic hydrological cycle (Klein et al., 2024; Yi et al., 2012). Combined, the freshwater input to the Arctic Ocean is thus increasing (Kopec et al., 2024; Solomon et al., 2021). This change drives fundamental shifts in the physical state of the ocean, modifies ocean circulation and mixing, increases atmospheric humidity, and affects Arctic sea ice, nutrient inputs, inorganic carbon cycling and the biogeochemical structure of Arctic marine systems (Klein et al., 2015; Terhaar et al., 2021). Given the Arctic Ocean's reach via ocean circulation and atmospheric teleconnections, such transformations will have significant consequences globally, affecting Arctic ecosystems and marine ecosystems at lower latitudes, as well as impacting sea-level rise and climate (Koenigk et al., 2020). Understanding the changes in the Arctic freshwater cycle is thus essential for anticipating ecosystem, climate and ocean circulation changes, both regionally (Coupel et al., 2015) and globally (White et al., 2007).

The ratio of stable oxygen isotopes in seawater, δ^{18}O, is a widely-used tracer for quantifying freshwater contributions from meteoric sources (precipitation, river discharge and glacial melt), and sea ice melt (Östlund and Hut, 1984; Tan and Strain, 1996; Meredith et al., 2001; Atwood et al., 2026). The analysis is sometimes complemented by additional tracers such as selected trace metals, rare earth elements, and their isotopes (Laukert et al., 2017), which permit further deconvolution of the freshwater sources into its constituent parts. δ^{18}O is defined as the ratio of the heavier oxygen isotope, ^{18}O (as found in the water molecule $H_2^{18}O$), to the lighter oxygen isotope, ^{16}O (as found in $H_2^{16}O$), relative to a universal standard (Vienna Standard Mean Ocean Water, VSMOW):

$$\delta^{18}\mathrm{O} = \left[\frac{(^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{sample}}}{(^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{standard}}} - 1 \right] \times 1000 \tag{1}$$

In Eq. (1). δ^{18}O – is the oxygen isotope composition of the sample expressed relative to a reference standard in per mil (‰); $(^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{sample}}$ – is the measured ratio of ^{18}O to ^{16}O in the sample; and $(^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{standard}}$ is the corresponding $^{18}\mathrm{O}/^{16}\mathrm{O}$ ratio of the reference standard.

Importantly, δ^{18}O is a conservative tracer, determined at the surface by air-sea-ice interactions and altered in the interior of the ocean only by mixing. In this context, δ^{18}O parallels salinity in that both are shaped by the surface processes that set their values; it is because these processes affect the two tracers differently that paired δ^{18}O/salinity measurements are useful for distinguishing different freshwater inputs. δ^{18}O is determined at the surface by its behaviour during phase changes. During evaporation, the lighter isotope ^{16}O evaporates preferentially and the heavier isotope ^{18}O becomes relatively enriched (Klein et al., 2015). Conversely, the heavier ^{18}O isotope precipitates preferentially from atmospheric water vapour, resulting in a progressive reduction in δ^{18}O as water vapour moves poleward in the general atmospheric hydrological cycle. Typical

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precipitation at the poles thus has very low values for δ^{18}O, alongside zero salinity, making it a distinct freshwater end-member in polar surface waters (Paren and Potter, 1984; Strain and Tan, 1993). The behaviour of δ^{18}O and salinity differ in regions with sea ice formation or melt: surface salinity is strongly affected by freshwater input during sea ice melt or brine rejection during sea ice formation, whereas δ^{18}O is generally less sensitive and can remain comparatively conservative in some settings (Strain and Tan, 1993; Toggweiler and Samuels, 1995; Bauch, 2013). This partial decoupling of δ^{18}O and salinity in the polar regions is what enables the quantitative assessment of sea ice melt inputs separately from meteoric water inputs (Meredith et al., 2013; Geilfus et al., 2021).

Paired δ^{18}O and salinity measurements in the Arctic can thus trace meteoric water inputs separately from sea ice melt, but they cannot easily deconvolve[1] the meteoric water inputs themselves; for example, they cannot easily discern river run-off from precipitation or glacial melt. Further tracers are needed for this. One such tracer that has shown utility is the concentration of Ba (Guay and Kenison Falkner, 1997; Abrahamsen et al., 2009), which enters the Arctic Ocean via river run-off, and which notably has different values in North America and Eurasian rivers. Accordingly, measurement triplets of salinity/δ^{18}O/Ba can identify not just river run-off, but also the continent from which the river run-off derived. Dissolved Ba concentrations differ between freshwater end-members because they are set by distinct source-specific processes, including continental weathering and particle-water desorption in rivers versus exchange with subglacial sediments in glacial meltwater and brine rejection during sea-ice formation. Whilst Ba behaves conservatively on a basin wide scale (Taylor et al., 2003), barite ($BaSO_4$) precipitation can occur within the micro-environments of e.g., sea-ice and organic matter components (especially diatom frustules) (e.g., (Abrahamsen et al., 2009; Thomas et al., 2011; Pyle et al., 2017)). As such, Ba may not be strictly conservative over shorter spatial scales, and its value as a quantitative tracer is thus diminished in regions or at times of significant biological activity (e.g. plankton blooms), in sea-ice environments (e.g., (Hendry et al., 2018)), or in ocean margin settings (Whitmore et al., 2022). Interpretation of Ba data thus requires care to take these factors into account.

Additionally, seawater δ^{18}O values are useful for assisting the interpretation of palaeoclimate proxies, (preserved evidence of past environmental and climatic conditions e.g. ice cores). The calibration of these proxies of historical ocean variability based on the δ^{18}O of marine carbonates (including corals, foraminifera, molluscs, ostracods, and coralline algae) depends on the currently available seawater δ^{18}O data. Compilations of seawater δ^{18}O data thus have value in palaeoclimate data assimilation projects, such as the Last Millennium Reanalysis project (e.g., (Tardif et al., 2019)) allowing better quantification of proxy uncertainty and the training of proxy system models that link environmental variables to proxy measurements, thereby improving the accuracy of palaeoclimate reconstructions derived from these archives.

A major effort to compile global seawater δ^{18}O measurements culminated in the Global Seawater Oxygen-18 Database of the Goddard Institute for the Space Studies (National Aeronautics and Space Administration). The dataset assembled a collection of observations spanning the 1950s to 2008 (LeGrande and Schmidt, 2006). This compilation, later released as a gridded dataset, has been utilised by a broad range of disciplines. However, it has not been updated since 2017, and did not include other freshwater tracers such as Ba. At the regional scale, the PAGES CoralHydro2k Seawater δ^{18}O database was

[1]The δ^{18}O concentration ranges might be indicative of the different meteoric sources, such as land ice melt vs river run-off. However, given substantial regional and seasonal variations in the ranges, the results have a substantial uncertainty in the delineation of the sources.

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recently developed by Atwood et al. (2026), providing a compilation of seawater δ^{18}O with comprehensive coverage across the tropical sub-tropical region (from 35°N to 35°S), as well as previously unpublished global data. While CoralHydro2k represents a major advance for low-latitude regions through its comprehensive data compilation, FAIR-compliant metadata standards, and associated analytical tools and workflows, no equivalent, up-to-date synthesis exists for the Arctic system.

Here, we present an effort to unify existing pan-Arctic seawater δ^{18}O observations into a single, and AI-compatible database. The resulting Artificial Intelligence for Stable Isotope Tracers (AISIT) database adheres to the FAIR principles for scientific data (for more information please see Wilkinson et al. (2016)). To produce the AISIT database, we systematically searched public repositories for measurements collected north of 60° N, harmonised metadata, and applied additional quality control (QC) procedures –harmonised across datasets where necessary–before compiling the records into a single curated dataset. The AISIT database is complemented by a systematic review of published literature and references for the scientific context and observational details of the collected data. The resulting database comprises 45,714 unique δ^{18}O measurements, paired with salinity measurements for non-freshwater samples, and 5531 unique Ba concentration samples. Salinity was added for all non-freshwater δ^{18}O measurements and made a required field because Arctic freshwater partitioning relies on the combined interpretation of salinity and δ^{18}O within established end-member mixing models. Together, these variables allow the relative contributions of meteoric freshwater, sea-ice meltwater and marine end members to be quantified, whereas δ^{18}O alone cannot distinguish between these freshwater sources (Östlund and Hut, 1984; Macdonald et al., 1995; Ekwurzel et al., 2001). Depth was included where possible, as freshwater fractions and isotopic signatures vary substantially through the water column (Strain and Tan, 1993). Temperature was included where available as complementary hydrographic context for water-mass identification and for interpreting δ^{18}O variability, particularly where sea-ice formation and melt influence the structure of the water column (Kopec et al., 2024). The database provides the research community with a valuable resource to investigate freshwater inputs and ocean pathways, water-mass modification, and circulation patterns in the pan-Arctic.

2 Methods

2.1 Data sources

The AISIT database aimed to capture as much pan-Arctic δ^{18}O data as possible, providing users with an up-to-date centralised repository of harmonised, quality-controlled measurements. To achieve this, we conducted a large scale and systematic search, acquiring data from: multiple open repositories, direct contributions by data originators and a systematic review of literature.

Source datasets were identified through a systematic survey of international resources. Open data repositories searched include the NOAA National Centers for Environmental Information (National Centers for Environmental Information, 2026), British Oceanographic Data Centre (British Oceanographic Data Centre, 2026), Goddard Institute for Space Studies (GISS) Global Seawater Oxygen-18 Database (LeGrande and Schmidt, 2006), University of Utah Water isotopes Database waterisotopes.org (Putman and Bowen, 2019), GEOTRACES Intermediate Data Product 2025 (IDP2025) (Group, 2025), PANGAEA (Felden et al., 2023), Laboratoire d'Océanographie et du Climat: Expérimentations et Approches Numériques (LOCEAN) (LOC, 2025), the NSF Arctic Data Center (NSF Arctic Data Center, 2026), Arctic GRO (The Arctic Great Rivers Observatory,

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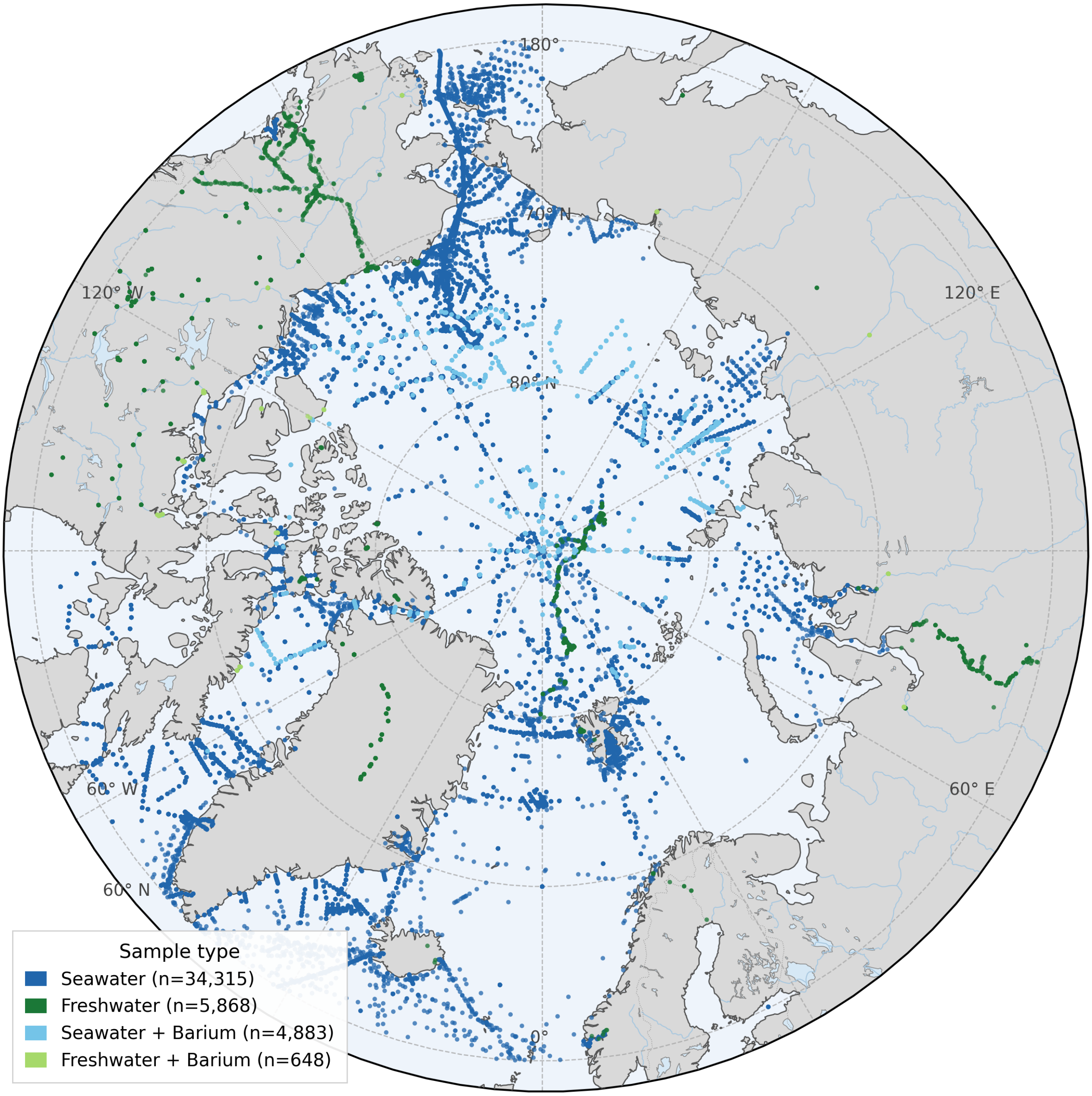

Figure 1. Location of all unique δ^{18}O samples incorporated into AISIT, coloured according to seawater samples (dark blue), freshwater samples, including rivers, sea ice and glaciers (dark green), and samples containing Ba concentration measurements in seawater and freshwater (light blue and light green respectively). Seawater samples will also have an associated salinity measurement, whereas freshwater samples typically were not measured with salinity, though the value has been recorded if present in the original dataset.

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2025; Tank et al., 2023), PAGES CoralHydro2k Seawater δ^{18}O database (Atwood et al., 2026) and Global Ocean Data Analysis Project Version 2 (GLODAP) (Lauvset et al., 2024; Olsen et al., 2016). Due to their QA (Quality Assurance) adjustments to the data over time, we opted not to use data directly from GLODAP in this study. Instead, we used the database to identify additional cruises available to AISIT and then sought the original data from the source. Data were also obtained through direct private communication with data holders. Details and the appropriate citations for these repositories can be found in Appendix 1, and the geographical data coverage is shown in Figure 1.

The Global Network of Isotopes in Precipitation (GNIP) and Global Network of Isotopes in Rivers (GNIR) represent large scale freshwater databases with global coverage (GNIP; IAEA/WMO, 2023)(GNIR; IAEA (2023)). Due to the data use agreement of these repositories, we were unable to incorporate these data into the AISIT database. However, users of the AISIT database conducting scientific studies may wish to examine the GNIP and GNIR surveys.

For the systematic review, Web of Science was used to conduct a title-based search combing δ^{18}O-related terms with Arctic and pan-Arctic as regional key words yielding 44 relevant publications. Additional datasets were also obtained through direct author submissions from existing collaborators.

2.2 Cleaning and compiling data

QC and quality assurance (QA) procedures were applied to all candidate datasets prior to database construction. A set of essential and desirable metadata fields were defined based on Atwood et al. (2026) and adapted for the AISIT project needs by a consortium of subject experts. These included “Collection year”, “Collection month”, “Latitude”, “Longitude”, “Depth”, “δ^{18}O value”, “Reference standard” and “Access date”, as well as a number of their desirable criteria such as “Temperature value” and “Cruise ID”. In addition to the adapted fields, we also added a number of fields that would increase the value of the AISIT database to the end-user and wider community. A full list of all database fields and their descriptions can be found in Table 1. All datasets were evaluated against the ‘essential’ metadata requirements (Table 1). Each metadata field was assigned a classification indicating whether it is essential (1), contributes to an essential criterion (2), contributes to an essential criterion for non-freshwater samples (2a), or is desirable (i.e. included if available; 3). Due to the differences in sampling and analytical protocols, freshwater samples and seawater samples often differed in the availability of the essential fields. For example, some studies marked as freshwater have salinity measurements whereas others omitted this measurement. While not an essential field, we note that freshwater samples often also lacked depth measurements. With this in mind, salinity fields in the database, while essential for seawater samples, was given the category 2a (contributing to essential for non-freshwater samples) and treated as “include if available” in freshwater samples.

In addition to expected essential metadata, such as longitude, latitude, δ^{18}O value and reference standard, only non-freshwater samples with corresponding salinity measurements were retained. This reflects the principle that interpretation of δ^{18}O values in seawater relies on congruent salinity data (MacLachlan et al., 2007). In total, 10 essential metadata elements were required: sample ID or method of unique identification, collection year, collection month, latitude, longitude, δ^{18}O value, δ^{18}O units, reference standard, salinity value and salinity units. We also applied these essential criteria to any Ba concentration measurements reported, where Ba measurements were required to fulfil the essential criteria themselves, as well as have

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a corresponding δ^{18}O value, to be included in the database. Unfortunately a large number of samples did not contain depth measurements in their final data products. Thus, the sparsity of the available depth data meant that a large number of datasets would have had to have been omitted from the database if depth were an essential criterion, leading us to categorise this as a desirable field.

Metadata fields classified as contributing to essential criteria were those needed to enable completion of an essential field. For example, collection month and year were considered essential to populate 'Sample date', whereas datasets were not excluded if the day of collection was missing. When datasets lacked essential metadata, efforts were made to recover missing information by consulting original sources and where possible, contacting lead authors. Datasets for which essential metadata could not be obtained were excluded from the final database.

Table 1: Description of metadata fields in the AISIT database. Classification: essential (1), contributing to essential (2), contributes to essential for non-freshwater samples (2a), desirable (3), see Sec. 2.2 for further details.

Metadata field [table column]	**Classification**	**Units**	**Metadata field description**
Freshwater [Freshwater]	1	No units	A Boolean flag to mark whether a sample is freshwater (True) or not (False)
BIOPOLE [BIOPOLE]	1	No units	A Boolean flag to mark whether a sample was taken on a study associated with (but not necessarily funded by) the BIOPOLE campaign (True), or not (False)
δ^{18}O Standard [O18_Standard]	1	No units	The specified standard against which the O18 measurement was taken, any data entry for which the O18 Standard could not be found is labelled as "VSMOW (assumed)" and should be treated with caution
δ^{18}O [Delta_O18]	1	Per mille [‰]	The delta O18 measurement of a sample as compared to the reference standard listed in the "O18 standard" column
Sample Datetime [ISO8601_Datetime]	1	YYYY-MM-DDT HH:MM:SS	ISO8601 Date time on which sample was taken as reported by the data source (note entries without a day have been assigned YYYY-MM-01 and entries without a time have been assigned 00:00:00) month and year are essential criteria

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Metadata field [table column]	**Classification**	**Units**	**Metadata field description**
Longitude [Longitude_[degree_east]]	1	Degree East	Longitude of sampling position. Positional accuracies varied between datasets but were decimalised with an accuracy of $\pm 0.0001°$ ($-180°$ to $180°$. Negative values indicate longitudes West of the Prime Meridian, and positive values indicate longitudes East of it).
Latitude [Latitude_[degree_north]]	1	Degree North	Latitude of sampling position. Positional accuracies varied between datasets but were decimalised with an accuracy of $\pm 0.0001°$ ($-90°$ to $90°$. Negative values indicate latitudes South of the equator and positive ones indicate latitudes North of it)
Dataset [Dataset]	1	No units	Short name of the dataset or file the data were extracted from
Freshwater Source [Freshwater_Source]	1	No units	A short description of the type of freshwater source for freshwater samples e.g. “River”
Platform [Platform]	2	No units	The name or identifier of a platform from which sampling was taken
Rosette Position [Rosette_Position]	2	No units	An identifier for the position of a bottle on the Conductivity, Temperature, and Depth instrument (CTD) rosette
Event [Event]	2	No units	A unique identifier similar to “Sample ID” that marks the sampling event
Bottle Number [Bottle_Number]	2	No units	The bottle number the sample was measured in
Cast Number [Cast_Number]	2	No units	The cast number the sample was measured in

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Metadata field [table column]	**Classification**	**Units**	**Metadata field description**
Sample ID [Sample_ID]	2	No units	The unique identifier for the sample taken
Site Number/Name [Site_Number_Name]	2	No units	The unique identifier for the site at which the samples were taken (only present for land-based sampling)
Station ID/Name [Station_ID_Name]	2	No units	The unique identifier for the station at which the samples were taken
Cruise ID [Cruise_ID]	2	No units	The cruise name or ID on which the samples were taken
Bottle Salinity [Bottle_Salinity_[dimensionless]]	2a	Dimensionless	The bottle derived salinity for a sample
CTD Salinity [CTD_Salinity_[dimensionless]]	2a	Dimensionless	The sensor/CTD derived salinity of a sample
Land Based [Land_Based]	2	No units	Geographic flag indicating whether the sample location falls on land rather than ocean. Determined using a point-in-polygon test (Gillies, 2025) against the Natural Earth (Natural Earth, 2026) 10 m resolution land polygons. TRUE where the sample's coordinates fall within a land polygon; FALSE otherwise. Used for distinguishing terrestrial samples, river mouths, and shoreline artefacts from open-water observations
Depth From Pressure [Depth_From_Pressure_[meters_below_surface]]	3	Metre	Depth value derived from CTD pressure and latitude using the pressure-to-depth conversion of (Saunders, 1981), as implemented in the Gibbs SeaWater (GSW) Oceanographic Toolbox (McDougall and Barker, 2011; TEOS-10, 2021) function `gsw_z_from_p` (version 3.06.13, 29 July 2021).

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Metadata field [table column]	Classification	Units	Metadata field description
Combined Depth [Combined_Depth_[meters_below_surface]]	3	Metre	Combined column of "Depth_From_Pressure_[meters_below_surfa and "Sample_Depth_[meters_below_surface]" where, if there are values in both columns for a given row, the "Depth_From_Pressure" column value takes precedence
Bottle Salinity WOCE Flag [Bottle_Salinity_WOCE_Flag]	3	No units	WOCE flag for the bottle derived salinity (included where present)
CTD salinity WOCE Flag [CTD_Salinity_WOCE_Flag]	3	No units	WOCE flag for the sensor derived salinity (included where present)
δ^{18}O WOCE Flag Original [Delta_O18_WOCE_Flag_Original]	3	No units	The WOCE flag for the DELO18 column measurement, here datasets with non-standard flags have been left as they were originally listed (included where present)
δ^{18}O WOCE Flag [Delta_O18_WOCE_Flag_Translated]	3	No units	The WOCE flag for the DELO18 column measurement datasets with non-standard flags have been translated into their WOCE alternative (included where present)
CTD Temperature WOCE Flag [CTD_Temperature_WOCE_Flag]	3	No units	QC flag for the temperature (included where present)
Temperature [Temperature_[cel]]	3	Degree Celsius	The sensor derived temperature of the sample, ITS-90
Sample Depth [Sample_Depth_[meters_below_surface]]	3	Metre	Depth (meters below surface) at which samples were taken, increases positively with increasing depth below water's surface
CTD Pressure [CTD_Pressure_[dbar]]	3	Decibar (dbar)	CTD/sensor derived pressure of the sample

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Metadata field [table column]	Classification	Units	Metadata field description
Barium [Barium]	3	(See "Barium Units" column)	The Ba concentration measurement of a sample (included where present)
Barium WOCE Flag [Barium_WOCE_Flag]	3	No units	WOCE flag for the Ba concentration (included where present).
Barium Units [Barium_Units]	3	No units	Units that the associated Ba concentration measurement was reported in.

For datasets passing the initial essential metadata check, samples were limited to those within the targeted pan-Arctic region (north of 60° N). The data were then compiled into a consistent format, harmonising field names and standardising data representations for example, date time in ISO8601 format [yyyy-mm-ddThh:mm:ss], and longitude and latitude in decimal degrees. Automated checks for duplicate records were conducted, and where duplicates were identified, the most recent version of the original dataset was retained.

Data quality flags follow the World Ocean Circulation Experiment (WOCE) convention where generally 2 = good data, 3 = questionable data and 4 = bad data (Table 2) and 9 = no sample. Where non-standard WOCE flags have been used and a key allocated, these have been translated to their WOCE equivalent.

Values are expressed in per mille (‰). In cases where the δ^{18}O standard is not reported, the data has been labelled as VSMOW (assumed) and should be treated with caution.

3 Resulting data set

The AISIT δ^{18}O database comprises 45,714 data points from 99 datasets, paired with salinity measurements for non-freshwater samples, alongside 5531 [Ba] measurements. The temporal coverage of data ranges from 1967–2025. Of 'Freshwater' samples, which constituted 14.3% of the total database, 48.1% were comprised of river or lagoon samples, 40.9% precipitation sampling, and 10.8% snow pit sampling. Seawater samples constituted 85.7% of the total database with depths ranging from the surface to 5201 metres below. A breakdown of the contributions of different water sources can be found in Figure 2. With regards to the Ba data it is important to note that for samples included in the database, no distinction was made in the Ba concentration data in terms of sampling or analytical method.

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Table 2. WOCE quality control definitions for water bottles, water samples and CTD's (GEOTRACES Data Management Office, n.d.)

Flag Value	Definition for water bottles	Definition for water samples	Definition for CTD
1	Bottle information unavailable	Sample drawn but analyses not received	Not Calibrated
2	No problems noted	Acceptable measurement	Acceptable measurement
3	Leaking	Questionable measurement	Questionable measurement
4	Did not trip correctly	Bad measurement	Bad measurement
5	Not reported	Not reported	Not reported
6	Significant discrepancies measured	Mean of replicate measurements	Interpolated over a pressure interval larger than 2 dbar
7	Unknown Problem	Manual chromatographic peak measurement	Despiked
8	Pair did not trip correctly	Irregular digital chromatographic peak integration	Not used for CTD data
9	Samples not drawn for this bottle	Sample not drawn for this measurement from this bottle	Not sampled

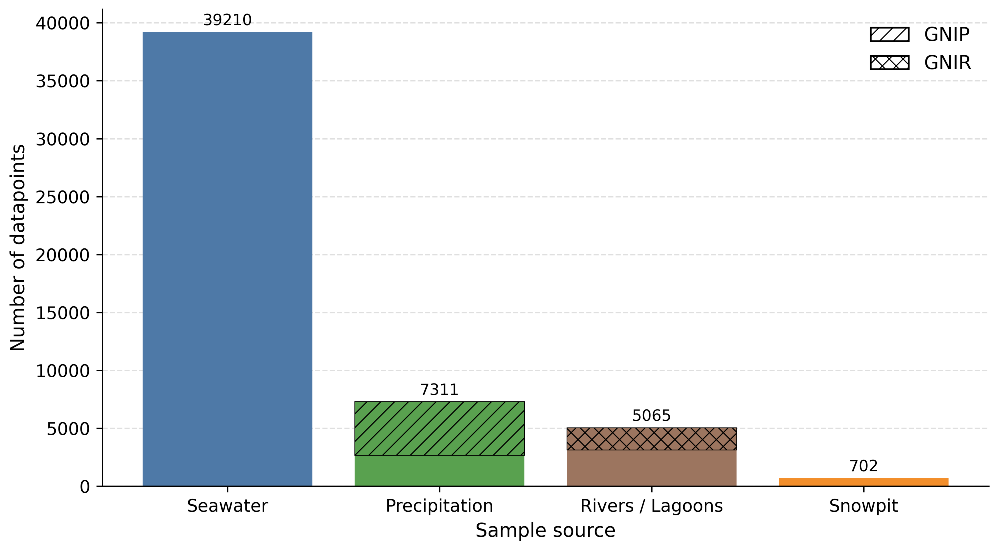

Figure 2. Number of data points by sample type. The "Precipitation" and "Rivers / Lagoons" have been split into those contained within the AISIT database, and data available externally via the GNIP and GNIR projects (International Atomic Energy Agency, 2026a, b). The GNIP /GNIR data are indicated in this plot via the diagonal hatching and cross hatching respectively. The GNIP/GNIR data are not included in the AISIT database (See Sec. 2.1), however these data are available in the GNIP/GNIR portal.

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The AISIT database also comprises samples from a wide range of depths, where 11.7% of measurements were from the surface, and 88.3% of sample were taken from below the surface layer to a maximum depth of 5201 m. Figure 3 depicts the data subdivided into these two categories to show δ^{18}O and sampling year, displaying the variation between these two subsets.

Due to logistical constraints of polar fieldwork, the dataset is biased seasonally towards the Arctic summer (May–October). As shown in Figure 4 88.9% of samples were collected during the Arctic summer months and 11.1% collected during winter (October–May). This effect is also demonstrated spatially in Figure 5, where the vast majority of ocean data points are from the summer months, whereas land-based points show a far greater temporal variation. Figure 4 does, however, show that precipitation sampling is the least seasonally biased as the types collected within AISIT.

Additionally, within the database there is some bias towards more recent years in the number of samples collected, as shown in Figure 3. For example, years prior to ~1990 show fewer samples per year than after this point, with the number of samples per year increasing thereafter. Of note is the year 2016 during which the highest number of samples were recorded: a total of 7975 samples were reported, making up 17.4% of the database. The prevalence of data in 2016 within the AISIT database, is largely due to the "healy_2016" dataset (Klein, 2023), which made up 13.2% of the total database.

Due to the diverse aims of research cruise operation, logistics and geographical areas of interest, the data are also spatially hetrogeneous. This leads to biases in the sampling location and geographical coverage, as illustrated in Figure 1.

Figure 6 shows the distribution of δ^{18}O values across the database and reflects the differing isotopic signatures of Arctic marine and meteoric water sources (water originating from atmospheric precipitation). The AISIT database is strongly dominated by seawater observations, and δ^{18}O values are primarily concentrated between approximately $-12‰$ and $0‰$, consistent with the relatively enriched isotopic composition of ocean water. In contrast, river, precipitation, and snowpit samples are substantially more depleted in ^{18}O, reaching below $-30‰$ and in some cases approaching $-50‰$. These depleted values reflect isotopic fractionation associated with high-latitude atmospheric condensation and continental hydrological processes (White et al., 1988). The logarithmic scale in this figure highlights the strong imbalance in sampling density across the isotopic spectrum, with seawater observations forming the bulk of measurements while meteoric sources contribute fewer data points but substantially broaden the overall isotopic range represented in the database.

Figures 7–9 show the basic relationships between the key parameters temperature, salinity and δ^{18}O. From Figure 7A, the almost linear relationship between ocean salinity and δ^{18}O is evident, reflecting the meteoric water mixing line. The broad range of salinity values at comparatively high values of δ^{18}O (around -5 to 0 ‰) reflects the additional process of sea ice melt/formation shifting the locus of points near-horizontally. Figure 7B shows no such relationship between salinity and Ba, suggesting a more complex connection between the Ba sources and freshwater input. Figure 8 shows a relatively narrow range of Ba values at comparatively high values of δ^{18}O (around -5 to 0 ‰), but a much larger range of Ba values at low δ^{18}O (around -25 to -15 ‰). This greater spread reflects the large range in Ba composition of different meteoric water sources in the Arctic, from which its utility as an addition freshwater tracer derives. Secondary scatter in the Ba-δ^{18}O relationship is likely a result of non-conservative behaviour of Ba e.g., as a result of barite precipitation associated with organic matter. Figure 9A shows that δ^{18}O largely co-varies with salinity across the full range of potential temperatures, with the exception of values close to the freezing point for seawater; this reflects the value of δ^{18}O as a tracer that is able to decouple freshwater

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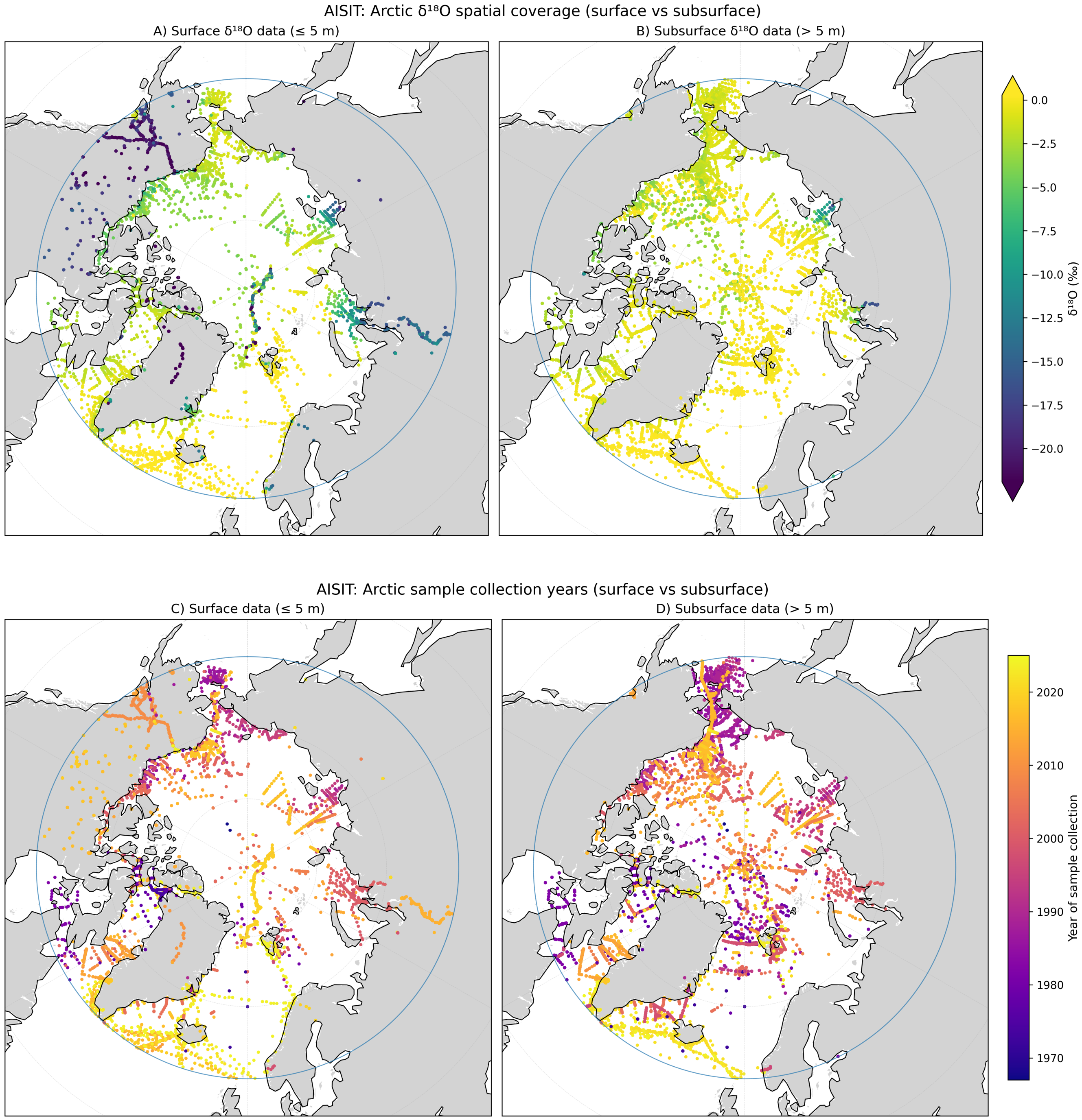

Figure 3. Surface (depth < 5 m) and Subsurface (depth > 5 m) distributions of the data, coloured according to δ^{18}O value [A,B] and year [C,D]. In all plots freshwater data has been excluded. In plots [A,B] the δ^{18}O colour scale is clipped to the 5th–95th percentile range; arrows indicate values beyond the displayed limits.

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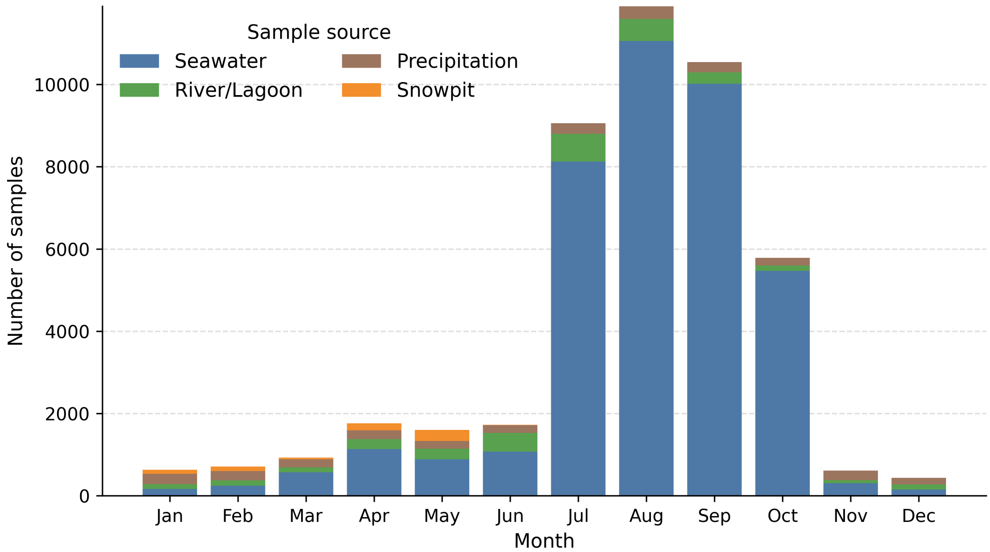

Figure 4. Number of data points per month over the whole dataset, displayed quantitively.

influences from sea ice from those due to meteoric water inputs. Comparison of 9A and 9B reveals strong surface-intensified gradients in salinity and δ^{18}O, reflecting the similarity in their behaviour away from the ocean surface

4 Discussion

4.1 Challenges to database compilation

The compilation of the AISIT database required the integration of numerous heterogeneous datasets originating from a wide range of laboratories, repositories, and individual research projects. Although stable water isotope measurements such as δ^{18}O are widely collected in oceanographic and hydrological studies, the absence of consistent reporting standards across datasets presented several technical and organisational challenges during database construction.

One of the earliest challenges concerned the design of the database schema. Establishing the scope and structure of the schema required close coordination between the data acquisition and data management teams to ensure that both user needs and the characteristics of available datasets were adequately captured. Existing isotope repositories and related oceanographic databases provided useful reference templates; however, they were generally designed around different scopes and tracer sets, and required substantial adaptation to accommodate the broader combination of variables, metadata, and quality-control requirements needed for AISIT. Consequently, the schema design process required iterative refinement, informed by an initial survey of available metadata and the structure of incoming datasets. Particular attention was required to identify potential duplication in datasets retrieved through broad repository searches, as overlapping records can occur when data are indexed in

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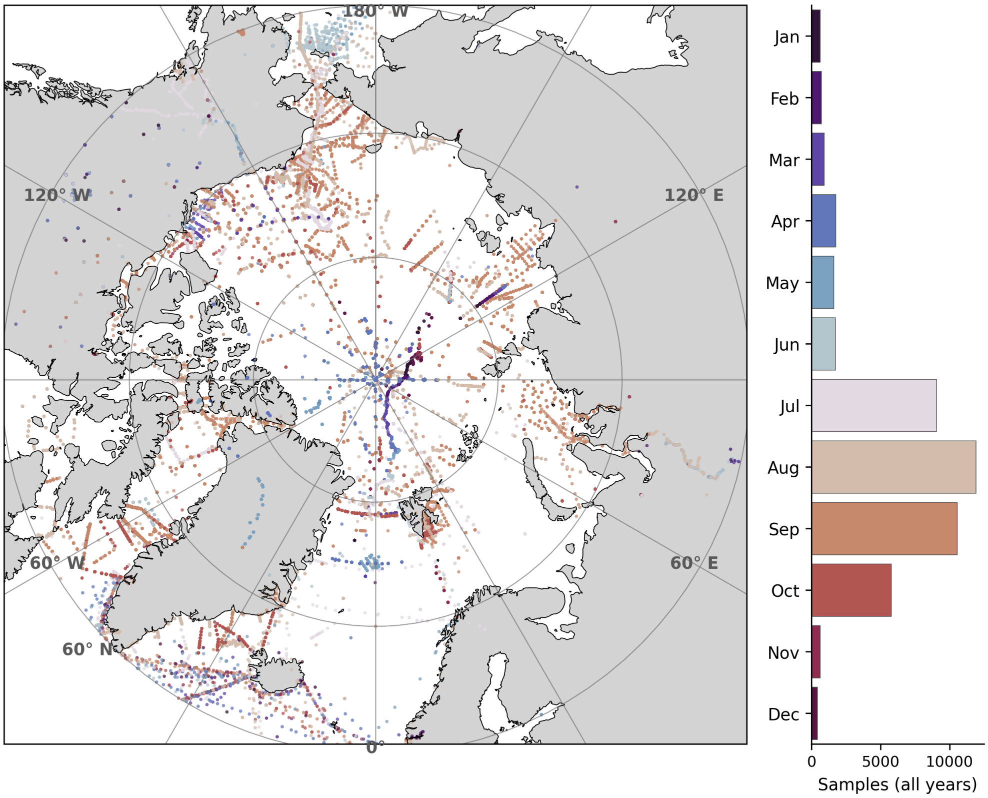

Figure 5. Number of data points per month over the whole dataset, displayed spatially. The histogram inset to the colour bar provides the legend for the colours of the month in the main figure, as well as an indication of the number of samples taken in various months over all years in the dataset.

multiple archives. In addition, clear identification of freshwater sources and their approximate geographic origin was necessary, as these samples play a distinct role in Arctic hydrological analyses and require reliable separation from marine observations.

Data acquisition presented its own set of challenges. While a substantial fraction of isotope measurements is available through established repositories, a significant proportion of relevant data remain embedded within journal articles or supplementary materials and are therefore not readily accessible in machine-readable form.

To capture this "hidden" data, a targeted literature search strategy was developed using the Web of Science database. The search was conducted in accordance with the guidance on the identification of studies described in Higgins et al. (2024). A comprehensive range of search terms representing common expressions of oxygen-18 measurements (e.g., δ^{18}O, δ18O, O-18, and related isotope terminology) was used to maximise retrieval of relevant records. Searches were conducted using the Web of Science Title (TI) field, combining Arctic-related geographic terms (“Arctic”, “Pan-Arctic”, and “Arctic Ocean”) with oxygen-18 isotope terminology using Boolean operators. Retrieval required the presence of at least one Arctic term and one oxygen-18 isotope term within the title record. Searches were conducted as case-insensitive queries. The search used English-language

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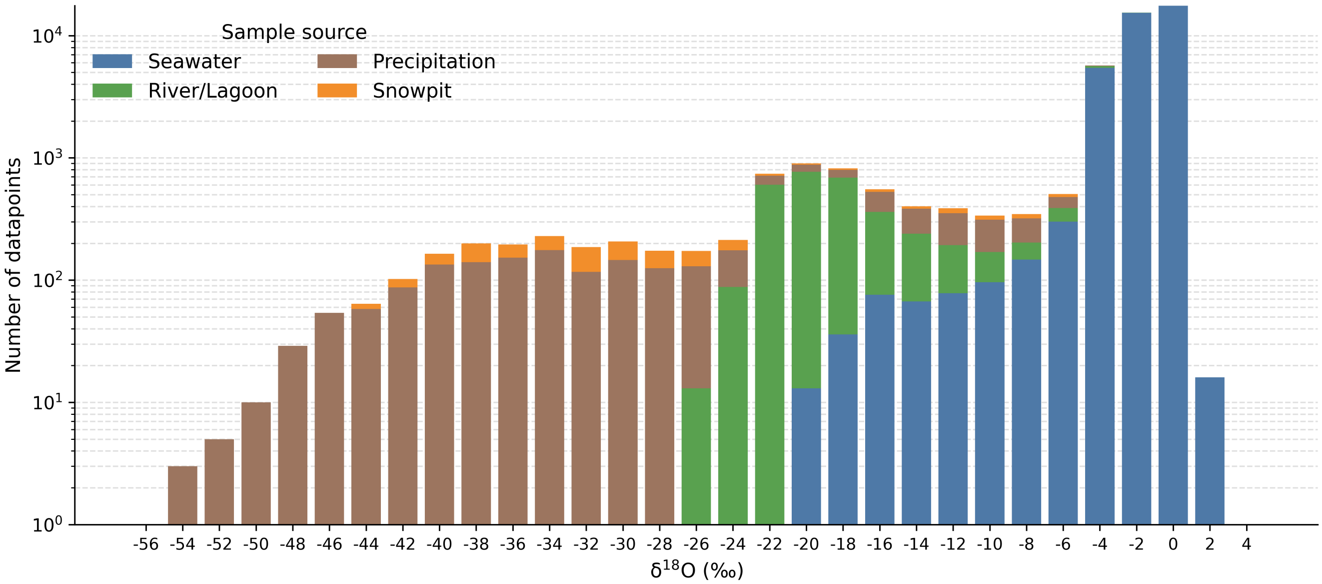

Figure 6. Number of data points by δ^{18}O value (individual bars coloured proportionately to source sample) with binning of 2‰.

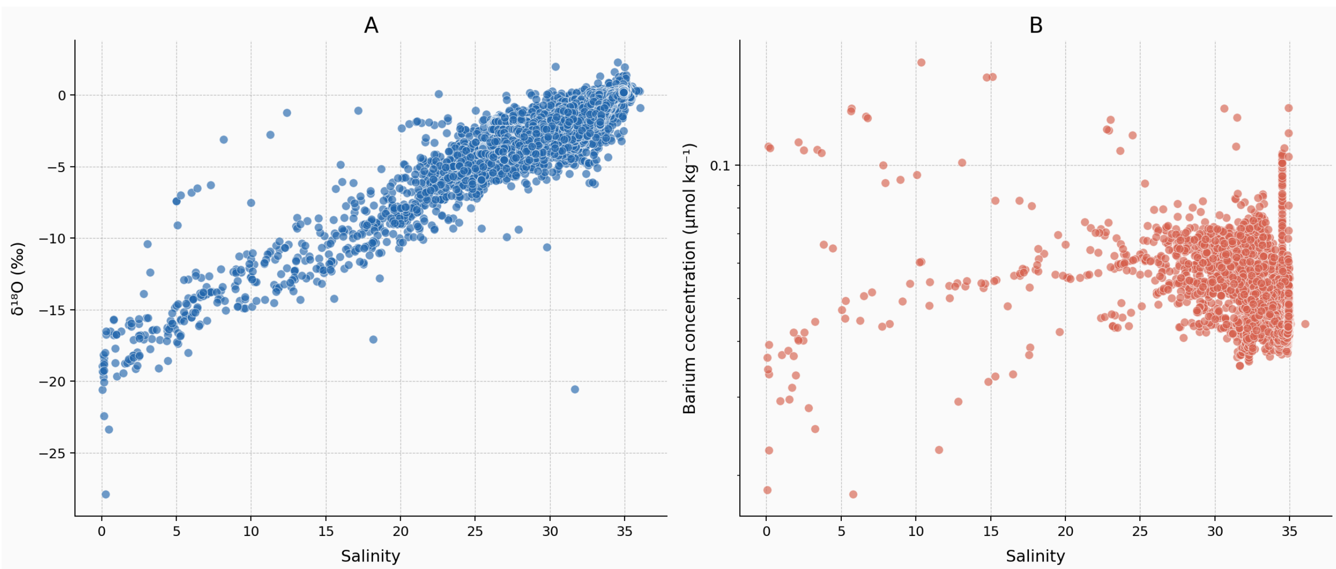

Figure 7. δ^{18}O (left) and Ba concentration (right) plotted against salinity. Data points comprise all non-zero points of the database, and all those that contained Ba concentration for the right-hand plot. Salinity was taken from the bottle salinity measurements if recorded, and CTD salinity was used when it was not.

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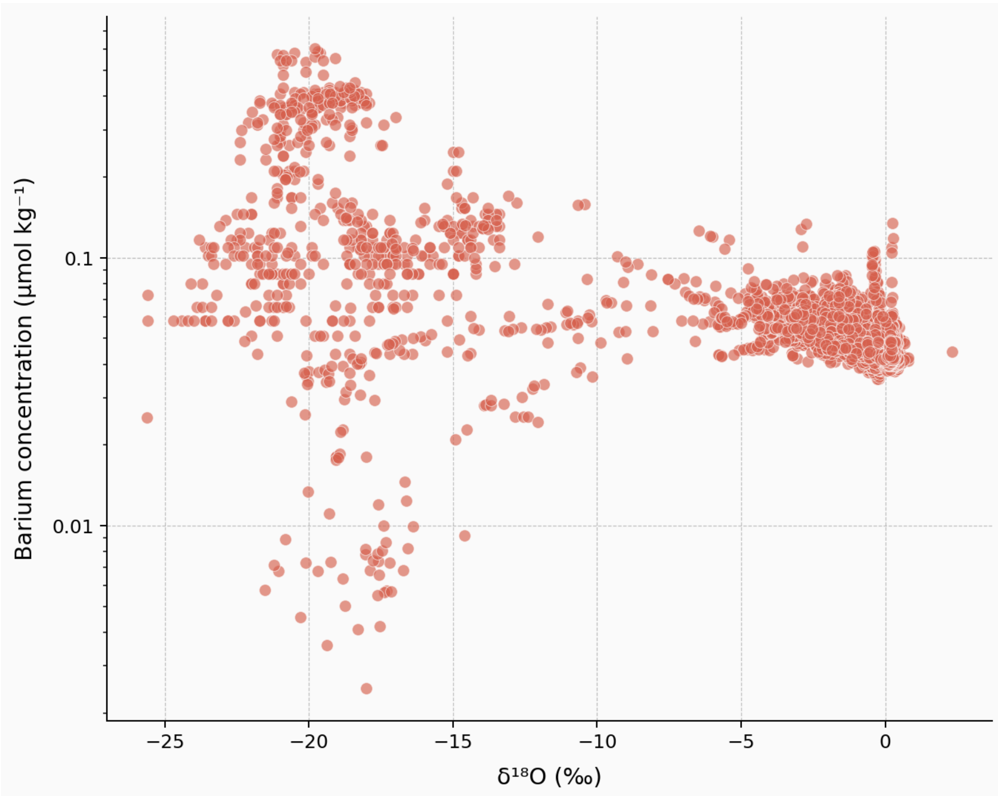

Figure 8. Ba concentration plotted against δ^{18}O. Data points comprise all δ^{18}O points of the AISIT database with a Ba counterpart.

terminology to represent Arctic geographic regions and oxygen-18 isotope measurements. No explicit language restriction was applied during the Web of Science search; however, the use of English search terms may have influenced retrieval of records, particularly for studies without English-indexed metadata. The search was conducted in November 2025. Records identified through the literature search, together with additional datasets obtained through direct correspondence with study authors, were subsequently assessed using the same QC and QA procedures applied to all candidate datasets. Eligibility for inclusion was determined by evaluating each dataset against the predefined essential metadata requirements described in table 1.

Once acquired, the datasets required extensive harmonisation and organisation. Source files were provided in a wide range of formats, including spreadsheets, text files, and repository exports, each with differing conventions for column naming, units, and metadata structure. Consolidating these into a single standardised database format was essential to enable efficient analysis and manipulation. Robust tracking systems were required to monitor dataset status, identify missing information, and record communication with original authors when clarification was needed. Version control and detailed change logs were maintained throughout the process to ensure transparency in the handling of datasets and metadata updates. Particular care was taken to standardise fundamental data formats, such as dates and geographic coordinates, prior to further processing. In

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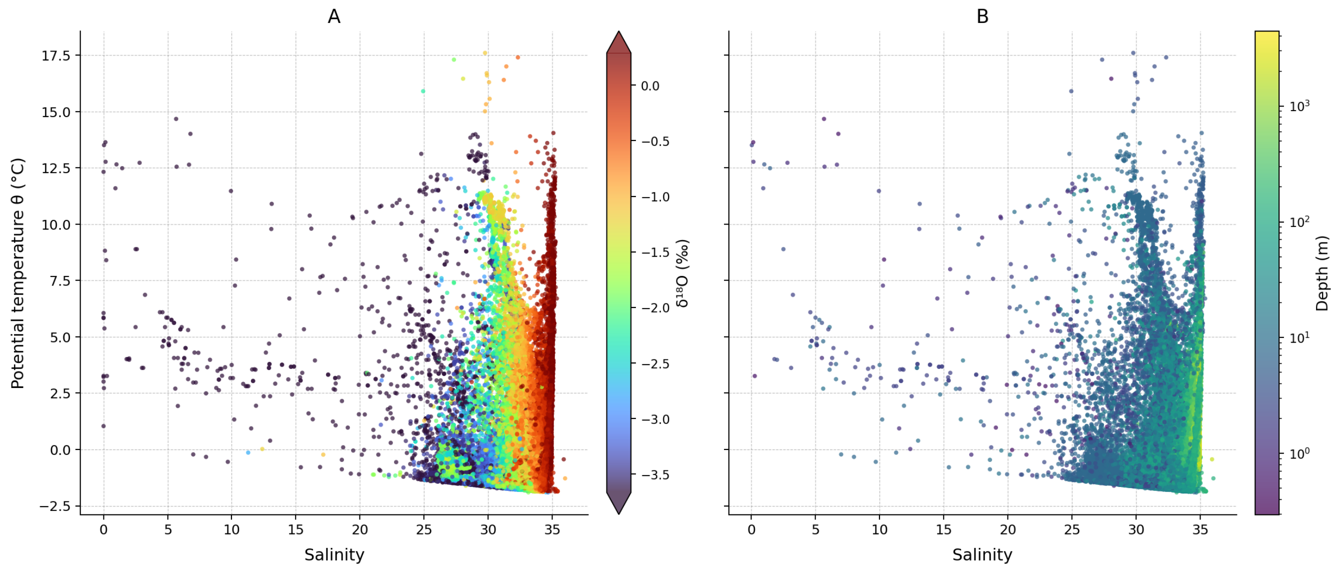

Figure 9. Potential temperature–salinity (T–S) diagrams coloured by [A] δ^{18}O (‰ VSMOW) and [B] water depth (m). Salinity values are derived from bottle measurements where available, with CTD salinity used as a fallback; zero salinity values are excluded. Only data points with valid temperature, salinity, and colour-variable values are plotted. Colour scaling in [A] is a linear scale clipped to the 5th–95th percentile range of δ^{18}O to reduce the influence of outliers (arrows indicate values beyond the displayed limits). Colour scaling in [B] is logarithmic to improve visual separation of shallow water masses.

addition, Boolean indicator fields were implemented to support filtering and categorisation tasks, including the identification of freshwater samples and the distinction between different measurement types.

Quality control and validation represented another significant area of complexity. Different research groups use a wide variety of conventions to represent missing values, including placeholders such as “NaN”, “**”, or sentinel values such as −999. These, therefore, had to be identified and standardised before quality checks could be applied. In developing the AISIT database, best practice guidance was sought from members of the AI and data science community regarding the handling of missing values. Following these consultations, it was determined that missing data should be represented by empty fields rather than sentinel values, ensuring maximum compatibility with a broad range of analytical workflows and machine learning frameworks. Furthermore, the interpretation of quality control (QC) flags varied between datasets. While some repositories adopt standardised flagging systems such as the WOCE scheme, many datasets use local or project-specific QC codes. Each dataset therefore required individual inspection to determine how QC information should be interpreted, translated, or retained within the AISIT framework.

Ambiguity in column naming also posed recurring challenges. Certain variables – particularly those describing depth – were frequently labelled in ways that allowed multiple interpretations. For example, a column labelled “Depth” could refer either to the sampling depth of the water sample or to the depth of the seafloor at the sampling location. Without consulting accompanying documentation or metadata, it was often unclear which definition had been adopted. Such ambiguities required careful cross-checking with source documentation and, in some cases, direct correspondence with data providers.

Overall, the compilation of the AISIT database required substantial effort in harmonisation, documentation, and validation efforts that, however, translate directly into a value-added product for the scientific community. The challenges encountered highlight the need for more consistent reporting standards for stable isotope measurements and associated metadata within the oceanographic and hydrological research communities. At the same time, the processes developed during the construction of AISIT (and described herein) provide a framework for integrating diverse isotope datasets into a unified, analysis-ready resource. To this end, we propose a minimum common reporting protocol for future stable isotope studies, comprising sample metadata (e.g., precise geolocation, date and depth of collection, sampling method), analytical metadata (e.g., analytical method, reference standard, measurement uncertainty), and machine-readable data formatting, in the hope that broader adoption of such standards will reduce the harmonisation burden faced by future compilation efforts and improve integration of datasets into studies by the wider community.

4.2 Data availability

The AISIT database follows the FAIR data principles (Wilkinson et al., 2016) and is released under Open Government Licence v.3 http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/. The data are available from the UK Polar Data Centre[2] (Thorpe-Morgan et al., 2026). The database is also available alongside an interactive map[3], allowing users to visualise the data and apply several filters. To maximise accessibility and findability, we also wanted to ensure that the database was web-hosted and user friendly. To achieve this, we created an Oracle-Apex application on which to host the data[4]. This allows users to perform basic searches and filtering of the database in a web client. As well as this, it provides a place to describe in detail the database, its schema, and host a series of download links to the available data formats and the metadata. To maximise accessibility to the data within this portal, we also provided a small video to act as a guide on how to use the database application.

One of the key goals of the AISIT database was to produce a dataset adhering to the FAIR principles, thus ensuring its longevity and utility for AI and machine-learning communities. To achieve this, extensive metadata were compiled for each source, providing detailed documentation of citation, provenance, and contextual information. We also engaged with multiple machine-learning and AI research teams to better understand requirements for maximising usability of the database. One of the main outcomes of this was that the metadata were stored in both a human-readable format (comma separated values text file) and in a machine-readable format (Croissant JSON file), thus facilitating direct integration with AI and data science workflows and improving interoperability with existing tools and standards.

In accordance with FAIR data management principles, the database is publicly available in multiple formats, including CSV with an extended header (XCSV), netCDF and Parquet, to facilitate accessibility, interoperability, and use in diverse workflows.

[2]https://data.bas.ac.uk/full-record.php?id=GB/NERC/BAS/PDC/02172
[3]To view this map please see: https://experience.arcgis.com/experience/c05c005354c547e191adfbd398fdaae7
[4]https://aisit.data.bas.ac.uk

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The associated metadata have also been released in CSV text and Croissant JSON file formats to provide both a human and machine-readable option to users.

The Croissant metadata specification provides a standardised, machine-readable format for representing dataset metadata that aligns with FAIR principles and supports the needs of AI consumers (Akhtar et al., 2024). Croissant is designed to ensure that dataset contents, structures, and relationships are clearly described in ways that can be understood and utilised programmatically by AI frameworks and libraries, enabling easier dataset discovery, automatic parsing, and integration across platforms such as Python ML toolkits. Use of Croissant helps bridge the gap between varied data access methods and AI workflows by standardising dataset descriptions, enhancing searchability, and supporting downstream machine-learning tasks (Guha et al., 2016; Akhtar et al., 2024). This makes Croissant an appropriate choice for enriching the AISIT database with metadata that not only document datasets for human users but also directly supports machine-oriented processing and analysis.

4.3 Database versioning scheme

The AISIT database is released as Version 1.0.0 alongside this publication. Future iterations may incorporate updates or refinements as the dataset evolves. Versioning follows a structured three-component format (C1.C2.C3), consistent with established data management practices and described in Atwood et al. (2026). In this system, each component is an incrementing integer. The first counter (C1) corresponds to major releases associated with formal publications. The second counter (C2) increments when the set of records changes, such as through the addition or removal of datasets. The third counter (C3) increments when modifications are made to data or metadata without altering the overall record set. When C1 increases, both C2 and C3 reset to zero; when C2 increases, C3 resets to zero.

Updates, refinements, or corrections are incorporated directly into subsequent database versions and documented within the UK Polar Data Centre, British Antarctic Survey. This structured versioning approach ensures transparency, traceability, and reproducibility, enabling users to reference and access specific iterations of AISIT while maintaining a clear record of dataset development over time (Atwood et al., 2026). We hope that future projects will support the continued maintenance and expansion of the database, and we encourage authors with relevant data to contact us regarding potential contributions. We also see potential value in an API and data submission specification that would allow more direct community contributions in future, helping AISIT evolve into a living database over time.

5 Conclusions

The Arctic Ocean occupies a unique position within the global climate system, functioning as both a recipient and exporter of freshwater while experiencing some of the most rapid environmental change on Earth. As such, measurements of δ^{18}O in seawater provide observational constraints on processes that are otherwise difficult to disentangle, including the relative contributions of river run-off, precipitation, sea-ice melt, and oceanic inflow to upper-ocean stratification and circulation. Because many of these processes operate on seasonal to multi decadal timescales and vary markedly between Arctic basins, δ^{18}O sampling offer a means of tracing freshwater redistribution in a way that complements traditional hydrographic measurements.

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The AISIT database has been developed to provide a solution to a long-standing limitation in Arctic research: the fragmentation and uneven accessibility of Arctic δ^{18}O data. By assembling these observations into a standardised, metadata-rich framework, the database reduces barriers to analyses and supports reproducible research across disciplines whilst simultaneously preparing for upcoming and emerging machine learning/AI methods. The compilation provides a standardised foundation for evaluating freshwater storage trends, constraining δ^{18}O–salinity relationships under changing boundary conditions, and benchmarking isotope-enabled model simulations in a region where observational density remains limited relative to climatic importance.

More broadly, AISIT strengthens the observational infrastructure required to interpret Arctic change across temporal scales. It enables improved calibration of proxy records, supports assimilation and model–data comparison efforts, and facilitates synthesis studies that integrate cryospheric, atmospheric, and oceanographic perspectives. In doing so AISIT provides a framework for advancing quantitative understanding of Arctic freshwater dynamics in a rapidly evolving polar environment.

6 Author contributions

CTM - Data curation, Formal Analysis, Software, Methodology, Validation, Visualisation, Writing (original draft preparation), writing (review and editing) ER - Data curation, Writing (original draft preparation),writing (review and editing) PTH - Conceptualisation, data curation, supervision, validation, writing (review and editing) RS - Data curation, validation MM - Conceptualisation, supervision, validation, writing (review and editing) KH - Conceptualisation, supervision, validation, writing (review and editing) YA - Conceptualisation, supervision, validation, writing (review and editing) BE - Conceptualization, Funding Acquisition Writing (Drafting and Reviewing) HP - Conceptualization, Methodology, Conceptualization, Funding Acquisition, Writing (Drafting and Reviewing) BS - Conceptualization, Supervision, Project Administration, Funding Acquisition, Writing (Drafting and Reviewing) AM - Conceptualization, Supervision, Project Administration, Funding Acquisition, Writing (Drafting and Reviewing) GT - Conceptualisation, funding acquisition, supervision, validation, writing (review and editing)

7 Competing interests

The authors declare that they have no conflicts of interest.

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Appendix A: Data sources

Table A1: Data sources

Dataset	Dataset Entries	Data Provenance	Database DOI/Link	License	Version	Access Date	DOI
LOCEAN_Wisotopes-V5	2160	LOCEAN_Wisotopes-V5		CC-BY-4.0	5	2025-11-12T00:00:00	https://doi.org/10.17882/71186
GISS_O18_data_N_of_45N	9436	GISS_O18_data_N_of_45N	https://data.giss.nasa.gov/o18data/	Online Database	1.22	2025-11-12T00:00:00	https://data.giss.nasa.gov/o18data/
healy_2016	6034	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	2	2025-12-12T00:00:00	https://doi.org/10.18739/A2BZ61952
arct_carbn	3988	arct_carbn	https://doi.org/10.3334/cdiac/otg.ios_arct_carbn	CC0	2	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.ios_arct_carbn
Wateriso_Utah_Precip_data_N_of_60N	2364	Wateriso_Utah_Precip_data_N_of_60N	https://wateriso.utah.edu/waterisotopes/pages/spatial_db/SPATIAL_DB.html	Online Database		2025-11-12T00:00:00	https://wateriso.utah.edu/waterisotopes/pages/spatial_db/SPATIAL_DB.html
Wateriso_Utah_River_data_N_of_60N	1920	Wateriso_Utah_River_data_N_of_60N	https://wateriso.utah.edu/waterisotopes/pages/spatial_db/data_use.html	Online Database		2025-11-12T00:00:00	https://wateriso.utah.edu/waterisotopes/pages/spatial_db/SPATIAL_DB.html
GIPY14	106	GEOTRACES 2025	https://doi.org/10.5285/42c92148-8d03-8be6-e063-7086abc09f0c	CC-BY-4.0	1	2025-11-12T00:00:00	https://doi.org/10.5285/42c92148-8d03-8be6-e063-7086abc09f0c
GN02	126	GEOTRACES 2025	https://doi.org/10.5285/42c92148-8d03-8be6-e063-7086abc09f0c	CC-BY-4.0	1	2025-11-12T00:00:00	https://doi.org/10.5285/42c92148-8d03-8be6-e063-7086abc09f0c
GN03	81	GEOTRACES 2025	https://doi.org/10.5285/42c92148-8d03-8be6-e063-7086abc09f0c	CC-BY-4.0	1	2025-11-12T00:00:00	https://doi.org/10.5285/42c92148-8d03-8be6-e063-7086abc09f0c
PACIFICA_32PZ20020819	971	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	2	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.pacifica_32pz20020819
ARKXXII_2	622	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.clivar_arkxxii_2
HLY_0301	566	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.32h120030721

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Table A1: Data sources continued

Dataset	Dataset Entries	Data Provenance	Database DOI/Link	License	Version	Access Date	DOI
Alpha_Helix	482	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-11-25T00:00:00	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0068667
JOIS_2016	542	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/jy88-9n09
DavisStrait_2022	539	Private Communication		Permission given in private communication	0	2025-11-12T00:00:00	Sent by Kumiko Azetsu-Scott
ArcticGRO	526	ArcticGRO	http://www.arcticgreatrivers.org/data	Online Database	20250402	2025-11-25T00:00:00	http://www.arcticgreatrivers.org/data
ArcticNet	523	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-11-12T00:00:00	https://doi.org/10.25921/719e-qr37
Knorr_2013	472	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	3	2025-12-03T00:00:00	https://doi.org/10.25921/35kw-bx29
JOIS_2015	470	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/c35k-0h70
TXF13	155	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	3	2025-11-12T00:00:00	https://doi.org/10.25921/n5dy-h455
SAS_Oden	419	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/eaf4-9658
JOIS_2004	394	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/vwsp-x287
HLY2202-SAS	384	Private Communication		Permission given in private communication	0	2025-12-23T00:00:00	Unpublished
Knorr_2011	369	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v5bz64cq
Water-iso_Utah_Snowpit_data_N_of_60N	351	Water-iso_Utah_Snowpit_data_N_of_60N	https://wateriso.utah.edu/waterisotopes/pages/spatial_db/SPATIAL_DB.html	Online Database		2025-11-12T00:00:00	https://wateriso.utah.edu/waterisotopes/pages/spatial_db/SPATIAL_DB.html

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Table A1: Data sources continued

Dataset	Dataset Entries	Data Provenance	Database DOI/Link	License	Version	Access Date	DOI
MO-SAIC_stable_isotopes_snowpits	351	PANGEA	https://www.pangaea.de/	CC-BY-4.0	1	2026-01-28T00:00:00	https://doi.org/10.1594/PANGAEA.952556
Knorr_2010	346	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v58p5xt9
PACI-FICA_49NZ20020822	343	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.pacifica_49nz20020822
JOIS_2013	338	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/7r17-4q18
JOIS_2014	330	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/jkqw-ya62
Knorr_2007	305	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v5zs2tt5
MO-SAIC_stable_isotopes_ice	303	PANGEA	https://www.pangaea.de/	CC-BY-4.0	1	2026-01-28T00:00:00	https://doi.org/10.1594/PANGAEA.948511
Knorr_2008	296	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v53j3b9v
JOIS_2012	290	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/c5kx-sm59
CARI-NA/77DN19910726	289	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	2	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.carina_77dn19910726
PACI-FICA_49NZ20040901	279	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	2	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.pacifica_49nz20040901
MO-SAIC_stable_isotopes_water_underway	265	PANGEA	https://www.pangaea.de/	CC-BY-4.0	1	2026-01-28T00:00:00	https://doi.org/10.1594/PANGAEA.948291

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Table A1: Data sources continued

Dataset	Dataset Entries	Data Provenance	Database DOI/Link	License	Version	Access Date	DOI
TXS13	111	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	3	2025-11-12T00:00:00	https://doi.org/10.25921/n5dy-h455
CARI-NA/32H120020505	255	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	3	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.carina_32h120020505
HLY1801	247	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	2	2025-12-23T00:00:00	https://doi.org/10.18739/A2JD4PR5B
SWL2017	239	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	1	2025-12-23T00:00:00	https://doi.org/10.18739/A2P843X00
JOIS_2010	233	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/w3rp-tx17
DY081-CTD	156	PANGEA	https://www.pangaea.de/	CC-BY-4.0		2025-11-12T00:00:00	https://doi.org/10.1594/PANGAEA.896543
SWITCHYARD	228	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.3334/cdiac/otg.switchyard_zzic2005swyd
Knorr_2009	226	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v5794304
JOIS_2011	196	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/y1cw-db38
Rysgaard_East_Greenland_Isotopes_KN_2021	188	PANGEA	https://www.pangaea.de/	CC-BY-4.0		2025-11-12T00:00:00	https://doi.org/10.1594/PANGAEA.962781
SWL2016	173	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	1	2025-12-23T00:00:00	https://doi.org/10.18739/A23B5W875
HLY1702	174	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	1	2025-12-23T00:00:00	https://doi.org/10.18739/A2PN8XH4S
SWL2018	172	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	2	2025-12-23T00:00:00	https://doi.org/10.18739/A24X54J4C
Helmer_Hansen	170	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.25921/350g-0y60

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Table A1: Data sources continued

Dataset	Dataset Entries	Data Provenance	Database DOI/Link	License	Version	Access Date	DOI
SWL2019	154	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	3	2025-12-23T00:00:00	https://doi.org/10.18739/A2CR5ND9N
ARK_IV_3	151	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-11-12T00:00:00	https://doi.org/10.3334/cdiac/otg.06aq19870704_ark_iv_3
UNCLOS_2016	149	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	2	2025-11-12T00:00:00	https://doi.org/10.25921/2gj7-e547
Sikuliaq2024	130	Arctic Data Center	https://arcticdata.io/	CC0 1.0	1	2025-11-12T00:00:00	https://doi.org/10.18739/A23J3932S
Knorr_2006	112	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v5v1233j
Hudson_2005	107	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v5df6pj1
DY167_CTD	96	British Oceanographic Data Centre	https://www.bodc.ac.uk/	UK Open Government Licence v3[5]	1	2026-02-03T00:00:00	https://doi.org/10.5285/48e39c93-2405-99f3-e063-7086abc003fa
SWL2021	92	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	1	2025-12-23T00:00:00	https://doi.org/10.18739/A2RF5KH42
SWL2023	84	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	1	2025-12-23T00:00:00	https://doi.org/10.18739/A2D50G02C
UNCLOS_2015	79	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	2	2025-11-12T00:00:00	https://doi.org/10.25921/2gj7-e547
NyAlesund2023/River_Transect	77	Private Communication		Permission given in private communication	0	2025-11-12T00:00:00	Unpublished
DEHEAT	75	Private Communication		Permission given in private communication	0	2025-11-12T00:00:00	Unpublished
KN179_05	73	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	1	2025-12-03T00:00:00	https://doi.org/10.7289/v5j67f79
Sikuliaq2021	50	Arctic Data Center	https://arcticdata.io/	CC0 1.0 Universal	1	2025-12-23T00:00:00	https://doi.org/10.18739/A2XD0R04Q

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[5]https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

Table A1: Data sources continued

Dataset	Dataset Entries	Data Provenance	Database DOI/Link	License	Version	Access Date	DOI
UNCLOS_2014	48	National Centers for Environmental Information	https://www.ncei.noaa.gov/	CC0	2	2025-11-12T00:00:00	https://doi.org/10.25921/2gj7-e547
MOSAiC_Seawater	41	PANGEA	https://www.pangaea.de/	CC-BY-4.0	1	2026-01-28T00:00:00	https://doi.org/10.1594/PANGAEA.966223
NyAlesund2024_130924CA	37	Private Communication		Permission given in private communication	0	2025-11-12T00:00:00	Unpublished
DY167_Underway	22	British Oceanographic Data Centre	https://www.bodc.ac.uk/	UK Open Government Licence v3[6]	1	2026-02-03	https://doi.org/10.5285/48d50e6a-e137-e1e3-e063-7086abc09a72
TU19	29	PANGEA	https://www.pangaea.de/	CC-BY-4.0		2025-11-12T00:00:00	https://doi.org/10.1594/PANGAEA.930217
NyAlesund2023_/Fjord	24	Private Communication		Permission given in private communication	0	2025-11-12T00:00:00	Unpublished
CHARS-2019	20	Private Communication		Permission given in private communication	0	2025-11-12T00:00:00	Unpublished
KQ18	17	PANGEA	https://www.pangaea.de/	CC-BY-4.0		2025-11-12T00:00:00	https://doi.org/10.1594/PANGAEA.930217
DY081-FSH	11	PANGEA	https://www.pangaea.de/	CC-BY-4.0	1	2025-11-12T00:00:00	https://doi.pangaea.de/10.1594/PANGAEA.896539
DY081-ROV	3	PANGEA	https://www.pangaea.de/	CC-BY-4.0	1	2025-11-12T00:00:00	https://doi.pangaea.de/10.1594/PANGAEA.896540
HLY1901	4	Arctic Data Center	https://arcticdata.io/	CC0 1.0	1	2025-12-23T00:00:00	https://doi.org/10.18739/A2F47GW53
R/V_Professor_Shtokman_2014	73	PAGES CoralHydro2k Seawater d18O Database	https://doi.org/10.25921/ap7d-2k16	CC0	1	2026-02-25T00:00:00	https://doi.org/10.1134/S0001437017010040
Sedina_IV	48	PAGES CoralHydro2k Seawater d18O Database	https://doi.org/10.25921/ap7d-2k16	CC0	1	2026-02-25T00:00:00	https://doi.org/10.25921/ap7d-2k16
BLE_LTER	442	Environmental Data Initiative Data Portal	https://portal.edirepository.org/nis/home.jsp	CC0-1.0	1	2026-03-10T00:00:00	https://doi.org/10.6073/pasta/f32c2bdec6f3723e7bf1d45a0fb9c423
NABOS18	1432	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A2FX73Z1F
NPEO2003	19	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X

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[6] https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

Table A1: Data sources continued

Dataset	Dataset Entries	Data Provenance	Database DOI/Link	License	Version	Access Date	DOI
NPEO2005	30	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2001	19	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2007	44	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2006	37	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2015	36	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2002	9	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2004	35	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2011	60	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2013	77	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2008	112	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2000	11	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2012	72	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
NPEO2014	35	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
BG2008	67	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A25T3FZ8X
SCARFS_2014	10	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A2CP8H
SCARFS_2015	172	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A2NZ80Q62
SCARFS_2016	214	Arctic Data Center	https://arcticdata.io/	CC-BY-4.0	1	2026-03-29T00:00:00	https://doi.org/10.18739/A2XG9FB6J