Physical properties of sea ice from ice cores recovered on Nansen Legacy cruises to the northern Barents Sea and the area north of Svalbard during 2018-2022.

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1. Data summary

The data set presents physical properties of sea ice from sea ice cores recovered during Nansen Legacy cruises conducted during 2018-2022 to the northern Barents Sea, area north of Svalbard and further into the central Arctic, namely Nansen and Amundsen basins.

For more details on the Nansen Legacy project (*Norwegian: "Arven etter Nansen"*), research goals, sampling strategy and the associated activities please follow the link https://arvenetternansen.com/.

The dataset includes relevant ice core data from six Nansen Legacy cruises conducted with the Norwegian ice-going research vessel *Kronprins Haakon* where a comprehensive program on sea ice physics was implemented. These cruises are listed in **Table 1** below.

Table 1: Nansen Legacy cruises that involved a significant sea ice physics-directed component. For more details on the cruise program and timelines please see the respective cruise reports (links provided).
* Data from ice cores collected on JC2-1 were also published in Jones et al., (2023).

Cruise ID	Dates	Cruise report DOI
Joint Cruise JC1-2	06.08 - 23.08.2018	https://doi.org/10.7557/nlrs.5628
Seasonal Cruise Q1	02.03 - 24.03.2021	https://doi.org/10.7557/nlrs.6464
Seasonal Cruise Q2	27.04 - 20.05.2021	https://doi.org/10.7557/nlrs.6689
Joint Cruise 2-1*	12.07 - 26.07.2021	n/a
Arctic Basin Joint Cruise JC2-2	24.08 - 24.09.2021	https://doi.org/10.7557/nlrs.6413
Winter Gaps Joint Cruise JC3	19.02 - 11.03.2022	https://doi.org/10.7557/nlrs.6685

2. Ice stations

Nansen Legacy followed a strategy of consistent sampling in the same locations throughout the entire project duration (see **Table 2** below for a list of Nansen Legacy stations and Figure 1 for ice stations locations for 2021 cruises). Most of the multidisciplinary activity was conducted during the so-called Process stations labelled P1 to P11 and sometimes on shorter stations (NLEG-stations) in between the P-stations. The sea ice physics work related activity was generally confined to a subset of stations dictated by the actual cruise plan and sea ice conditions. Since Barents Sea features a seasonal ice cover with high interannual variability in both ice extent and concentration, a number of ice stations made varied between the cruises and years. Note also that due to sea ice drift, the actual locations for sea ice sampling activity could deviate from the locations indicated below.

Table 2. Locations of Nansen Legacy stations. Main stations for multidisciplinary process studies are also denoted *P (for "Process study")*-stations.

Nansen Legacy Station ID	Latitude	Longitude
P1 (NLEG01)	76	31.22
NLEG02	76.5	31.22
NLEG03	77	34
P2 (NLEG04)	77.5	34
NLEG05	78	34
NLEG06	78.5	34
P3 (NLEG07)	78.75	34
NLEG08	79	34
NLEG09	79.25	34
NLEG10	79.5	34
P4 (NLEG11)	79.75	34
NLEG12	80	34
P5 (NLEG13)	80.5	34
NLEG14	81	34
NLEG15	81.3098	31.3487
NLEG16	81.3822	31.2933
NLEG17	81.4107	31.2468

NLEG18	81.4318	31.1448
NLEG19	81.458	31.0775
NLEG20	81.5025	30.9618
P6 (NLEG21/NPAL15)	81.5463	30.8548
NLEG22	81.5895	30.7667
NLEG23	81.6165	30.6647
NLEG24	81.6828	30.5258
P7/ NLEG25	81.8027	30.8846
P7 (NLEG25/NPAL16)	82	30
NLEG26	82.4703	29.5359
NLEG27	82.9469	27.9103
NLEG41	83.1549	-9.6042
NLEG28	83.3821	26.878
NLEG40	83.8515	-9.5361
P8/ NLEG29	83.8994	25.4114
NLEG30	84.1782	22.0896
NLEG31	84.496	17.9159
NLEG32	84.8254	12.3426
P9/ NLEG33	85.3707	7.4551
NLEG34	85.747	-2.5438
NLEG35	86.0051	-10.6921
P10/ NLEG36	86.5052	-16.7077
NLEG39	86.6043	-11.1007
NLEG37	87.0041	-21.5252
P11/ NLEG38	87.5009	-17.3716

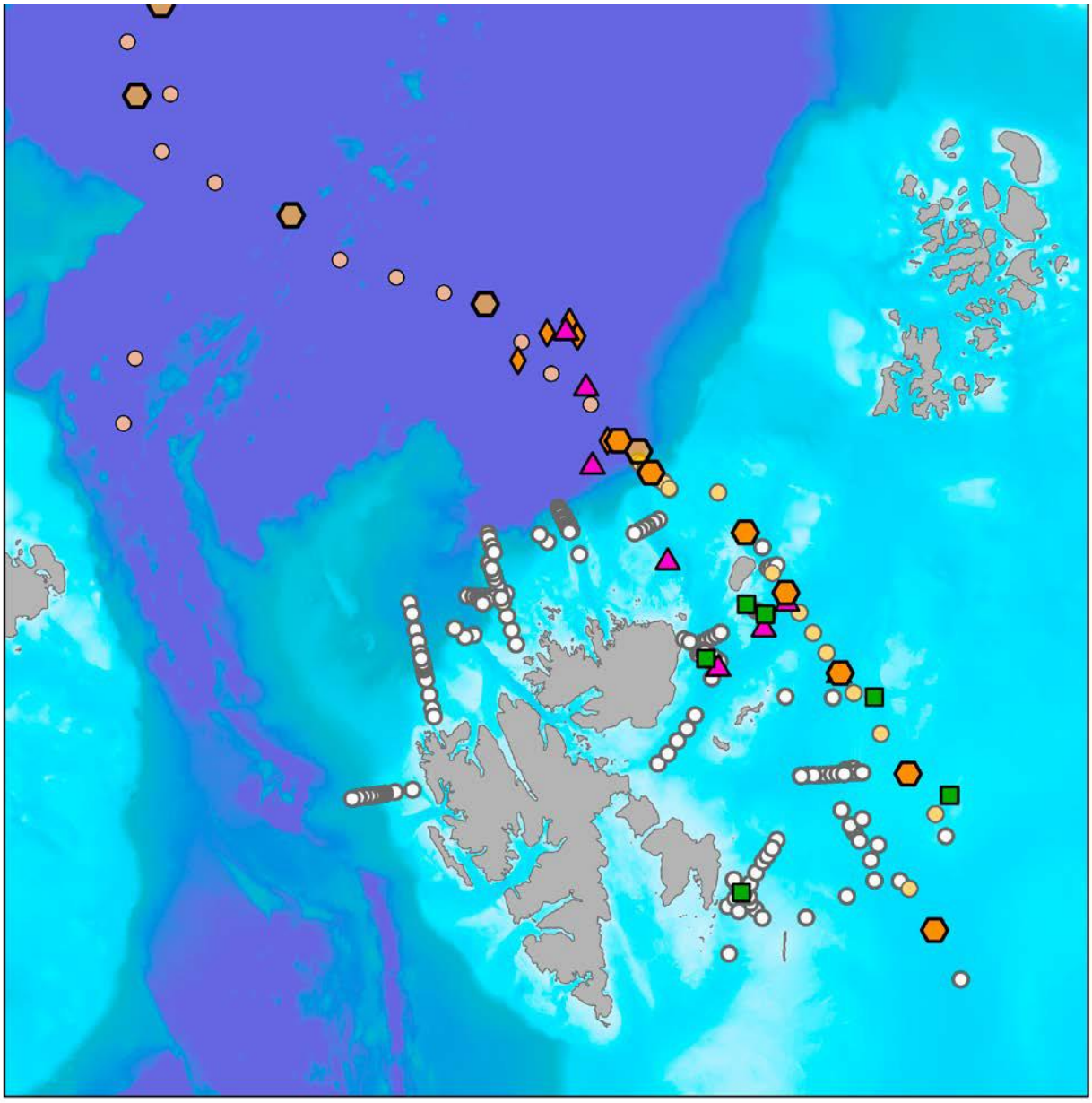

Figure 1: Sampling locations during 2021 Nansen Legacy cruises. Hexagons represent process stations with cross-disciplinary sampling including large-scale sea ice stations where on-ice sampling and research program for sea ice physics was conducted. Map: Ingeborg Reigstad; from Nansen Legacy annual report 2021 (https://doi.org/10.7557/nlrs.6547).

3. Sea ice coring

Acquiring samples of sea ice by coring was an essential component of the sea ice physics program on the Nansen Legacy research cruises. The primary aim of the ice coring work was to capture major physical characteristics of sea ice crucial for its evolution, with implications for sea ice-related studies on biology/ecosystems and biogeochemistry, as well as sea-ice remote sensing applications. At each ice station a standard Nansen Legacy protocol for ice coring was followed, typically in coordination with the

project research teams on sea ice biology, and sea ice and ocean biogeochemistry. All cores were collected from the same site on level ice in the area of approximately rectangular shape of about 10 m size. This would help to minimise a dissimilarity between the basic characteristics of recovered ice cores. These ice samples are labelled as “main coring site” ice cores.

On few occasions additional cores were opportunistically collected from the sites that had distinctly different characteristics (e.g. in ice thickness and/or type of ice) or were associated with other activities, like studies of sea ice optics or ROV work. These samples were labelled accordingly.

The coring for sea-ice physics included recovery of ice cores for sea ice:

1. Temperature
2. Salinity (with optional subsampling for stable water isotopes)
3. Density
4. Stratigraphy
5. Archive/Backup

Ice cores were recovered using a Mark II coring system (9 cm coring barrel diameter) from Kovacs Enterprise, LLC. During Seasonal Q1 and Q2 cruises a Mark III 7.25 cm corer was used to recover cores for density measurements (Core 3), while for cruises JC2-2 and JC3 a Mark II coring system was used for this purpose. No dedicated density cores were collected during the JC1-2 cruise. For each core borehole parameters were registered, sometimes along with basic core metadata such as breaks or distinct texture features. For some ice cores pictures were also taken on site.

We note that a complete set of ice cores was not systematically recovered at all considered cruises and ice stations given various actual limitations, e.g., available time and/or personnel capacity. Cores 1 and 2 were processed on site and onboard, respectively, while Cores 3-5 were packed in plastic tubing and kept frozen to be brought on land for further laboratory analysis/archiving. Core 1 was also in some cases used for chemical analysis in the framework of the BGC studies (Jones et al., 2023).

Sea-ice temperature profiles (Core 1) were measured using a thermistor probe, VWRI620-2000 or Testo-720, into holes drilled at 5 or 10 cm distance, typically within 5 minutes of core extraction to ensure a minimal alteration to initial temperature profile of the ice slab. Additional temperature measurements were conducted on the ice-water and ice-snow(air) interfaces. Expected ice temperature measurement uncertainty was about 0.1°C.

Core 2 was cut on-site in 5 or 10 cm long sections immediately after recovery and brought onboard in sealed containers for analysis. Higher sampling frequency was typically used next to the interfaces (ice-snow/air and ice-water). Bulk salinity of melted ice sections was then measured using a conductivity meter Cond3110 SET3. Note that conductivity and temperature of melted samples was logged along with salinity values. The probe was routinely calibrated on an annual basis to ensure a quality of the measurements with uncertainty within 0.1 psu. Salinity is reported on the practical salinity scale (dimensionless).

Sea ice density was measured from Core 3 in the freeze lab of NPI using the hydrostatic weighing method (Pustogvar and Kulyakhtin, 2016) with paraffin (lamp oil) as the submersion liquid. For analysis we used the “Shimadzu” precision balance UX4200H model, equipped with SMK-101 specific gravity measurement kit for density determination. The typical sampling resolution of the method was 5 cm with a measurement uncertainty of about 0.2% but no worse than 2%. After the density was measured,

the core pieces were melted to determine salinity of the ice using the same procedure as for Core 2. This does not apply to most of the density cores from Q1 and Q2 cruises that were withheld for further microstructure analysis using an X-ray tomography (Solomon et al., 2022).

Core 4 was collected for textural and microstructure analysis using thin sectioning at home laboratories after the expedition. In addition to understanding the local history of sea ice formation and growth, a synthesis of these results allows the calculation of major properties of sea ice as brine content and porosity crucial for the inference on sea ice permeability and gas exchange between the ocean and atmosphere. Due to time constraints, and labour intensity of this analysis it has been applied to selected cores only from Q1 and JC2-2 cruises. Some sea ice cores were processed for thick sections only. An additional sea ice core (Core 5) was also archived as a back-up core for any further analysis to potentially emerge in the future. These cores are stored in the main freezer storage of the Norwegian Polar Institute in Tromsø.

4. Data structure/data organization.

Ice -core data are split so that there is one “csv” file per physical core. Data are organized in the following conceptual structure:

//voyage-name/core-type/

As an example, the density cores data from the Q1 2021 expedition is located in the following folder:

//Q1-2021/density/

/raw - containing csv formatted data read from the cores and density measurement process

/processed - containing csv formatted processed data, with densities computed

/plots - basic plots made while processing data

Other folders may be present if relevant, for example:

/images - containing any relevant imagery of ice cores taken on the ice or later in the lab.

Aggregated data tables about a particular property are found in:

//voyage-name/property

...for example:

//voyage-name/density-aggregate-stats

File names contain necessary information on the core type/location/cruise. File name example for salinity core recovered from the main coring site on P11 station during the JC2-2 cruise is shown below.

JC2-2_2021_P11_main_salinity.csv

For convenience all data are arranged by cruises with all data for a single cruise compressed into one zip file with folder data structure preserved.

5. Data formats

Data are provided as comma delimited text files (.csv). Imagery, where needed, is provided as Canon RAW format or jpeg.

Each ice core file contains a metadata block, up to 25 lines long (see **Table 3** for a detailed list of metadata variables with explanations). It is then followed by one empty row, and the actual core data presented in tabular format.

The metadata/header entries are mainly self-explanatory and comprise:

Cruise specific metadata:

voyage name, voyage ID and the project ID

Site specific metadata:

Timestamp, Latitude and Longitude, site label (main coring site or additional coring location), names of those who did the coring.

Measurement units specific metadata:

Units used for logging core depth, weight, salinity, temperature and conductivity. Note that core depth was measured from the snow(air)-ice interface downwards, with the snow(air)-ice interface set as zero.

Core specific metadata:

core sample id (Nansen Legacy sample identifier), snow depth at the core site, measured borehole parameters such as sea ice thickness, and sea ice freeboard (elevation of snow(air)-ice interface over sea level). Negative freeboard would mean the snow/ice interface to be below sea level. In additional general comments on the core as well as number and length of individual core sections at recovery are provided as well.

Table 3 shows the metadata entries, in the order of their appearance in the files, in details.

voyage_name	Nansen Legacy official voyage name
voyage_id	IMR (Institute of Marine Research, Norway) voyage ID
Timestamp	Approximate timing of ice core recovery (accurate to within a few hours, time UTC
Longitude	Ice station latitude, degrees
Latitude	Ice station longitude, degrees
site_label	Name of the site on ice station
sampled_by	Names of persons who conducted the sampling
project_id	RCN project name and number, (always Arven Etter Nansen RCN 276730)
metadata_scheme	https://septentrio.uit.no/index.php/nansenlegacy/article/view/5800 (link to the NL data management plan)
core_sample_id	Nansen Legacy unique sample ID
depth_units	Measurement units for depth/length (always in meters)

weight_units	Units of weight (always in kg)
density_units	Units for density (always in kg/m^3)
salinity_units	Units for salinity (always PSU)
conductivity_units	Units for conductivity (always milliSiemens)
temperature_units	Units for sample temperature (on ice or in the lab, always degrees centigrade)
ice_freeboard	Measured sea ice freeboard, relative to ice/air(snow) interface (always in meters)
snow_depth	Depth of snow on site (always in meters)
sea_ice_thickness_m	Borehole/corehole sea ice thickness (always in meters)
processing_code	
comments_core	General comments on the core
Segment	Core segment number and length (shown in lines below, always in meters)

The actual core data is presented in a tabular format below the header block. The column names are common for density, salinity and temperature cores. Only columns relevant for a particular core type will contain data.

sample_depth_m	Measurement depth in the core (from ice/snow(air) interface, m
min_depth	Minimum sample depth, m (for bulk samples)
max_depth	Maximum sample depth, m (for bulk samples)
temperature	Measured sample temperature (on site or in the lab), degrees centigrade
salinity	Sample salinity, PSU
conductivity	Sample conductivity, mS
w_air	Weight of sample in air, kg
w_parafin	Weight of sample in paraffin, kg
paraffin_density	Density of paraffin, kg/m^3
extra_weight_air	Weight of sample in air with standard extra weight (only for some samples with density below the density of paraffin)
extra_weight_parafin	Weight of sample in paraffin with standard extra weight (only for some samples with density below the density of paraffin)
p_ice	Calculated density of ice, kg/m^3
comments_samples	Various comments on samples, made in the lab or on ice
NL_subsample_UUID	NL unique sample ID if available (e.g. if the sample was subsampled for any other analyses)

For Temperature cores, additional entries contain measurements of various temperatures measured in situ at the coring site

Air_temperature	Air T at ca. 1 m above the surface of snow or ice
surface_temperature	Surface temperature (snow or ice to air interface)
snow_ice_interface_temperature	Interface temperature between

	snow and ice
sea_water_temperature_borehole	Water temperature at borehole

Cores analyzed for stratigraphy have the following data entries, estimates based on the analysis of thin and thick sections:

ice_type	Type of ice in ice column (granular, columnar etc)
crystal_diameter_mm	Prevalent diameter of crystals in mm
crystal_length_mm	Prevalent length of crystals in mm
pore_diameter_mm	Average diameter of pores in mm
pore_percent	Percent of pores in ice column
discrete_pores	Configuration of pores
breaks	Presence of breaks

Code created by Adam Steer associated with these datasets can be found at:

https://gitlab.com/npolar/aen/sea-ice/

The code is also forked here:

https://gitlab.com/adamsteer/aen/

Note however, that generated files were further modified manually to accommodate additional metadata.

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References:

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