Local scale sea ice surface small drone -based aerial surveys conducted during Nansen Legacy cruises to the northern Barents Sea and the area north of Svalbard in 2021-2022.

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Adam Steer, Dmitry V. Divine

Norwegian Polar Institute, Tromsø, Norway

1. Data summary

The data set presents some preliminary results of local scale sea-ice surveys from the aerial imagery collected by a small remotely piloted aircraft ANAFI USA (https://www.parrot.com/en/drones/anafi-usa).

The small drone aerial surveys were conducted during the four Nansen Legacy cruises in 2021 and 2022 with the Norwegian ice-going research vessel *Kronprins Haakon* (KPH) 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 cruises where drone surveys were conducted are listed in **Table 1** below. The goal behind the small drone flights was to collect the high-resolution imagery of sea ice surface and capture various details of sea ice topography on a local scale.

Table 1: Nansen Legacy cruises where local scale aerial surveys using a small drone were conducted. For more details on the cruise program and timelines please see the respective cruise reports (links provided).

Cruise ID	Dates	Cruise report DOI
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
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 as an example for ice station's locations for the 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, the 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

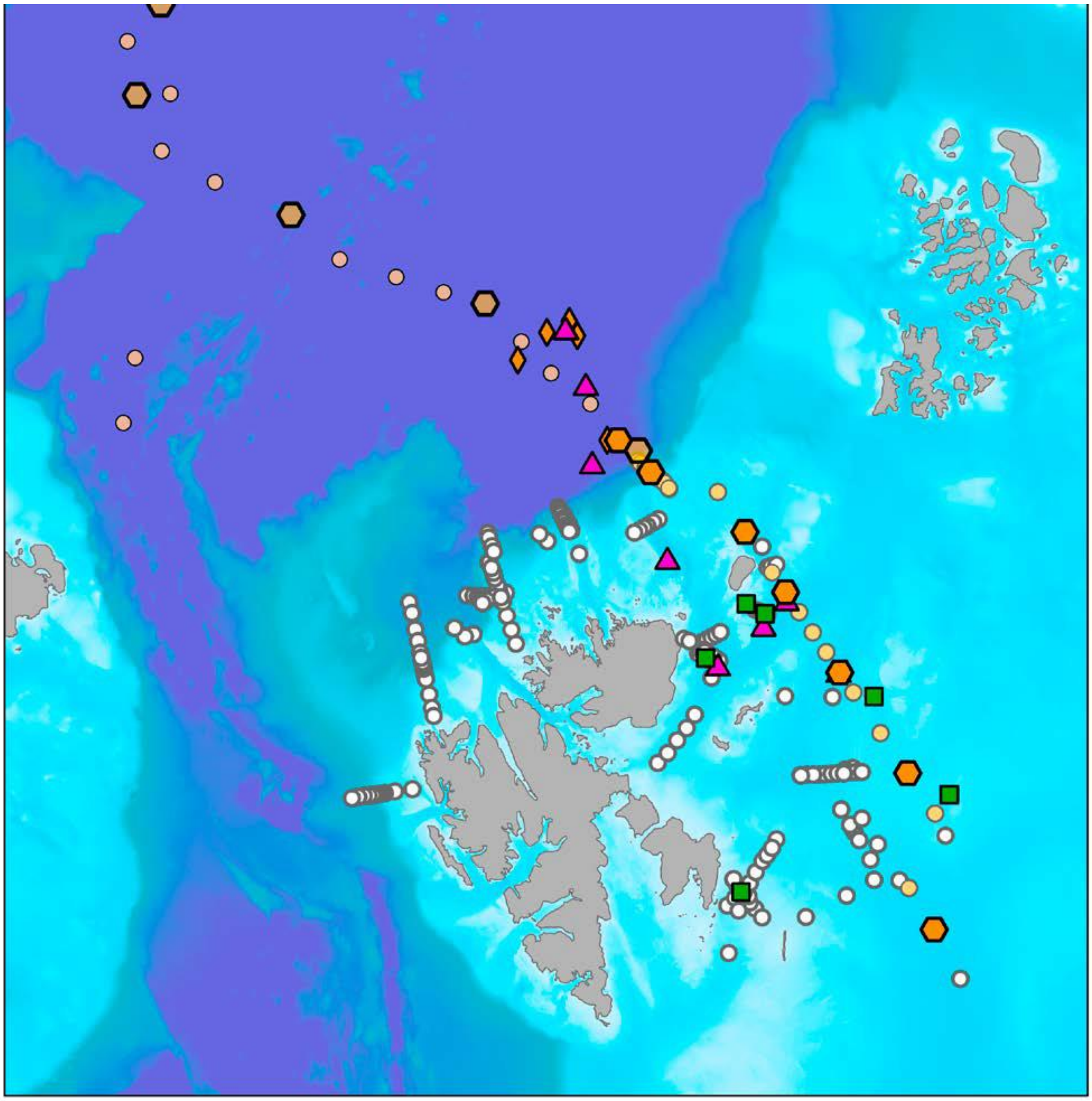

Figure 1: Sampling locations during 2021 Nansen Legacy cruises. Hexagons represent process stations with cross-disciplinary sampling including large-scale sea ice stations where on-ice sampling and research program for sea ice physics was conducted. Map: Ingeborg Reigstad; from Nansen Legacy annual report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

3. Small drone work during sea ice stations

On some ice stations during the seasonal Q1, Q2, JC2-2 and JC3 cruises, when time and weather conditions allowed, we used a small drone ANAFI USA to collect aerial imagery for mapping the area of at least 150 x 150m of ice around core sampling sites. The drone carried a dual 21 MP Sony sensor, one dedicated to wide angle imagery and one dedicated to zoomed in imagery. The imagery was used to generate orthophotos, ice station maps and digital elevation models of the station area in a resolution high enough for subsequent analysis of local sea ice surface properties and topographic features at the spatial scale of up to a few hundred meters.

The acquired image sequences were sea ice drift corrected using an ice-stationed GPS/GNSS tracking unit (**Divine et al., 2024a**). The image sets were further manually filtered to remove any low oblique images such as shots which showed horizon, ensuring that images were taken with the camera facing mostly downwards. Due to the effects of sea ice drift, all mapping flights were manually piloted. A combination of flight velocity and altitude were generally chosen to provide at least a 60% overlap between successive images and ensure a capability to reconstruct a surface topography. Using a flight pattern with a few standard elevations from relatively low 10 m up to 80 m flight altitude enabled a balance between a desired spatial coverage and pixel ground resolution yielding high quality orthophoto and DEM with either 2 cm or 5cm resolutions. All image processing and site area reconstruction procedures were implemented in the open-source structure-from-motion photogrammetry toolkit “OpenDroneMap” (https://www.opendronemap.org/).

The derived data products are useful for inferring several crucial parameters of sea ice surface topography at a local scale, such as surface roughness, melt pond coverage, ridge fraction etc. In addition, the generated orthophotos were also used to document the ice station work. Maps with locations of main activity sites, such as ice coring locations, ice and snow thickness transects were created for a number of ice stations in order to aid future multidisciplinary research work.

Figure 2 shows an example orthophoto of the station area for ice station P4 conducted on 09.05.2021 during the Q2 Seasonal cruise, while **Figure 3** demonstrates a calculated Digital Surface Model (DSM).

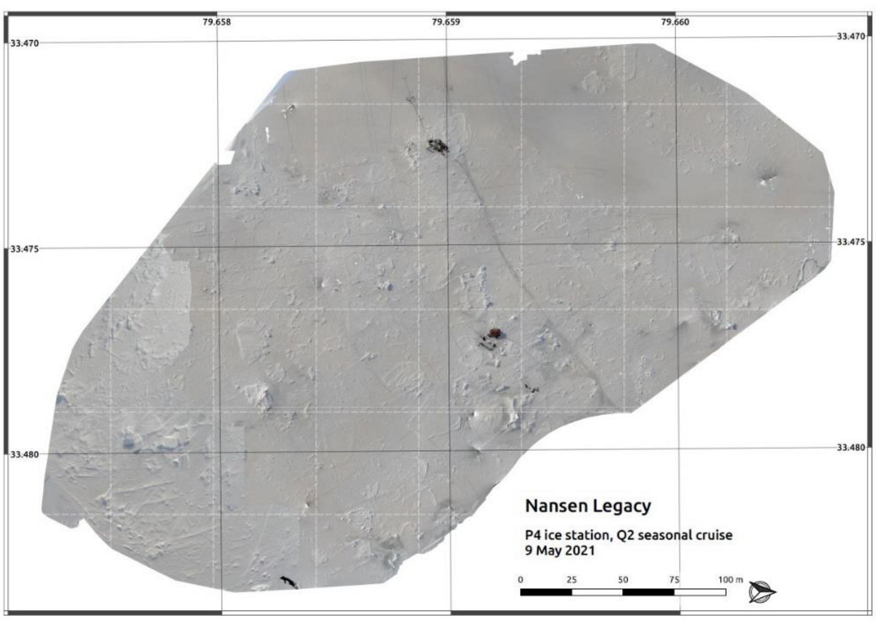

Figure 2: An orthophoto of the area around ice station P4 in the northern Barents Sea conducted on 09.05.2021 during the Q2 Seasonal cruise. The reconstructed scene has an area of about 60000 m2 and accommodates all major components of the ice station supersite. Orthophoto captures well the structure of the ice station floe that consists of a refrozen conglomerate of previously broken up level ice with a typical flow size of less than 25 m and a newly formed level ice between.

4. Data acquisition and processing.

Data (imagery and flight data) were collected using an ANAFI USA small remotely piloted aircraft (https://www.parrot.com/en/drones/anafi-usa).

Flight planning notes, strategies and operating guides can be found here:
https://gitlab.com/adamsteer/aen/-/tree/main/anafi-operations

https://gitlab.com/npolar/aen/sea-ice/-/tree/main/anafi-operations

Resulting images were used to make a site reconstruction using Opendronemap (https://opendronemap.org).

4.1. Image preparation:

The ANAFI USA collected RAW images in Adobe DNG format, and onboard-converted JPG images. RAW images are compressed for archiving, and JPG versions are used in further processing.

Image camera centers were extracted to a CSV file using exiftool. See:
https://gitlab.com/adamsteer/aen/-/blob/main/helper-scripts/getcameracentres.sh

These were drift-corrected, using an ice-stationed GPS / GNSS unit. See, for example:
https://gitlab.com/adamsteer/aen/-/blob/main/jupyter-notebooks/JC2-2-P10-drift-correction.ipynb

The drift-corrected camera centers were written to image sets using exiftool by:

```
#> exiftool -csv=/path/to/csv/file/driftcorrected-cameracenters.csv ./jpg
```

..where ./jpg is a folder containing JPG imagery. The folder name *must match* the path given in the input CSV file.

Next, image sets were manually filtered to remove any low oblique images (shots which showed horizon), ensuring that most images were shot with the camera facing mostly downwards. This was done using the Geequie utility - a fast image previewer - on Linux.

For some ice stations, a "height above ground" dataset is also present. For these images, the GPS positions are replaced by drift corrected latitudes and longitudes, and the GPS altitude of camera position centers is replaced by the aircraft height above pilot. This was done as an experiment to see if height above pilot (difference between controller GPS height and aicraft GPS height) gave better processing results. It was found that it usually made no difference.

4.2. Processing with Opendronemap:

Data were processed on a Linux laptop with 64GB RAM and up to 24 threads. Usually parallelized processes were throttled to 4-8 threads, to keep memory usage inside available limits.

Opendronemap was installed via docker:

```
#> docker pull opendronemap/odm
```

A shell script was created to run Opendronemap, showing all the options used. Each station folder contains the script used to generate mapping products from images.

In general, either 2cm or 5cm orthophoto resolutions were chosen, and processing was done using high quality or ultra quality features and point clouds. Adjusting the number of features and the number of matcher neighbors probably has the largest impact on processing results. The ANAFI USA GNSS accuracy is usually sub-1m, however it generally worked better to let Opendronemap estimate positioning accuracy.

The folder structure resulting from Opendronemap processing is described here: https://docs.opendronemap.org/outputs/

All geospatial data products (orthophotos, raster elevation models, point clouds) are standard formats which contain their own CRS data. Textured mesh models are also standard formats (.obj and jpeg).

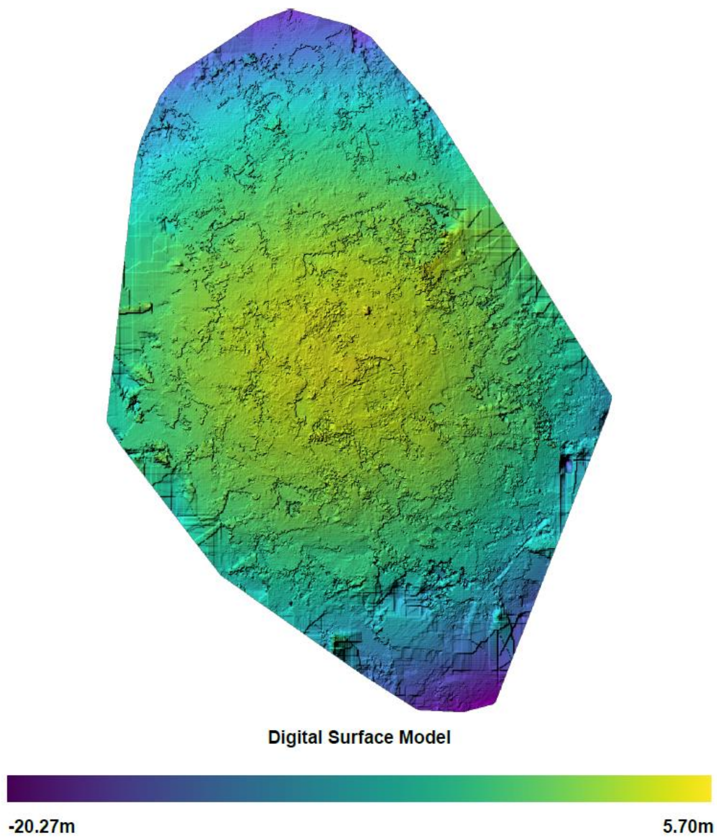

Figure 3: Digital Surface Model (DSM) of the area around ice station P4 in the northern Barents Sea conducted on 09.05.2021 during the Q2 Seasonal cruise (See Figure 2 for orthophoto). The elevations of

camera position centers are calculated relative to the pilot (see Sec 4.2). The DSM is calculated from 540 images of the surface and has an area of about 75000 m^2 with an average ground sampling distance/resolution (GSD) of 0.8 cm. More details on the product are found in the Opendronemap report in the respective folder of the dataset.

Example DSM of the area around ice station P4 from the Q2 Seasonal cruise is shown in **Figure 3**. Since no Z-control points (points with a priori known surface elevation) were seeded in the matched image bundle before calculating a 3D model of the surface, this led to a pronounced dome-shaped bias in surface elevation throughout the scene. This can however be corrected, if required, by fitting and subtracting a 3-D polynomial to the calculated DSM.

4.3. Recreating results

To modify or re-run processing using Opendronemap or other structure-from-motion mapping software (e.g. Agisoft Metashape), grab the 'images' directory from any Opendronemap product set and start processing. If you prefer, unpack the zipped DNG images and start over from scratch.

It is strongly recommended to use current versions of whatever software you use. Any results derived from the processing done here should be robust against improvements in processing. That is, any future processing improvements should serve to tighten error bars rather than change the fundamental stories these data tell.

Important note on the content of the data that were made publicly available:

Due to the big size of the original dataset (about 170 Gb) the publicly available data contains only final output of the data processing, namely orthophotos and digital elevation models (DEM). Potential users who are interested in recalculating the presented results are encouraged to contact NPI persistent contacts for this dataset (see below) in order to be granted access to the full dataset.

5. Data organization and formats

Data are organized in the following conceptual structure:

\\voyage-name\station-name\

In each station folder one finds subfolders with the three aforementioned data categories:

\driftcorrected for Opendronemap data products with camera position centers corrected for sea ice drift

\heightaboveground for Opendronemap data products with camera position centers corrected for sea ice drift and the GPS camera position altitude replaced by the aircraft height above pilot.

The computed DEMs, orthophotos and Opendronemap reports with data summaries are stored in the following subfolders (see https://docs.opendronemap.org/outputs/ for more details on the structure of outputs):

\odm_dem store Digital Surface Models and Digital Terrain Models

\odm_orthophoto store calculated orthophotos of the area

\odm_report contain the Opendronemap reports on the calculations output

\ AeN_site-maps in addition accommodates ice station maps created from the respective orthophotos.

The DEMs are

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

Contacts:

For questions on the dataset contact Adam Steer: adam.d.steer@gmail.com

NPI persistent contacts: Sebastian Gerland, sebastian.gerland@npolar.no and Dmitry Divine, dmitry.divine@npolar.no

References:

Divine, D.V., Steer, A., Cristea, A., Itkin, P., Gerland, S., Granskog, M. (2024a). Metadata on selected sea ice stations of Nansen Legacy cruises to the northern Barents Sea and the area north of Svalbard during 2018-2022. [Data set]. Norwegian Polar Institute. https://doi.org/10.21334/npolar.2024.d5ee950d