Sea ice extent variability in Kongsfjorden, Svalbard during 2003-2021, based on visual observations from the mountain Zeppelinfjellet.

Sebastian Gerland, Olga Pavlova, Marika Marnela, Dmitry V. Divine, Jack Kohler, Angelika Renner, Anders Skoglund

Norwegian Polar Institute, Fram centre, Tromsø, Norway

This archive presents the results of sea ice extent observations in Kongsfjorden - the Arctic fjord located in the west coast of Spitsbergen, Svalbard archipelago at approximately 79° N, 12° E (**Figure 1**). The permanent presence of Norwegian Polar Institute's staff at Ny-Ålesund Research Station, and daily visits to the observatory on the mountain Zeppelinfjellet (474ma.s.l., south of Ny-Ålesund) enable regular visual sea ice observations in the fjord, which have been done systematically since 2003 (Gerland and Renner, 2007, Pavlova et al., 2019). The observations are weather- and visibility permitting and typically conducted several times a week from February to June: from the onset of daylight conditions sufficient for visual observations and lasting until the end of ice season in the fjord. The archive covers years 2003 – 2021 and contains 668 ice charts evenly distributed over the period, on average 36 per ice season. Since some of the charts represented a few days of observations in a row, reporting "similar ice conditions", the digitized archive comprises 887 ice observation days in total. This dataset is a detailed extension of previously published monthly values for sea ice extent in the inner part of Kongsfjorden, Svalbard 2003-2019 (Gerland&Pavlova, 2020), compiling in one archive the original observations of sea ice conditions in the fjord back to 2003.

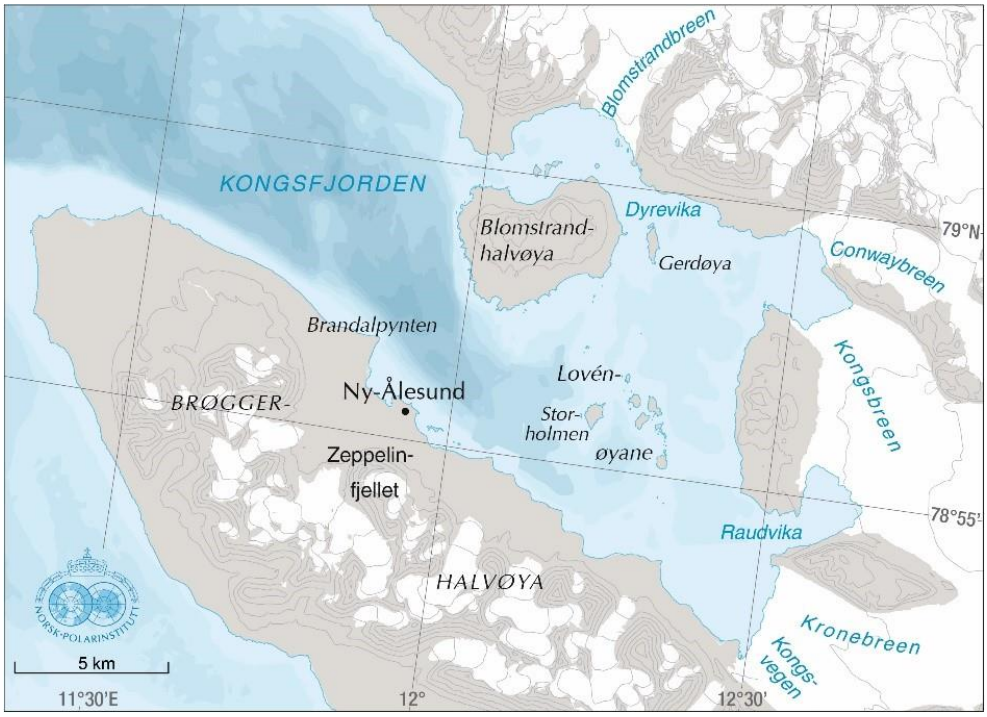

Figure 1*. Map of Kongsfjorden, Svalbard Archipelago, showing locations referred to in the text. Map credits: Oddveig Øien Ørvoll, Norwegian Polar Institute.*

Ice extent observations

Sea ice-extent data are derived mainly from hand-drawn ice maps and photography. During the time of year with daylight hours and good visibility, near-daily manual ice maps are produced on standard A4 ice chart templates. The ice charts are produced during visits to Zeppelinfjellet station, by visually assessing the ice edge position in the fjord using landmarks such as islands to support the chart making procedure. **Figure 2a** shows an example ice chart from the 13th of April 2021.

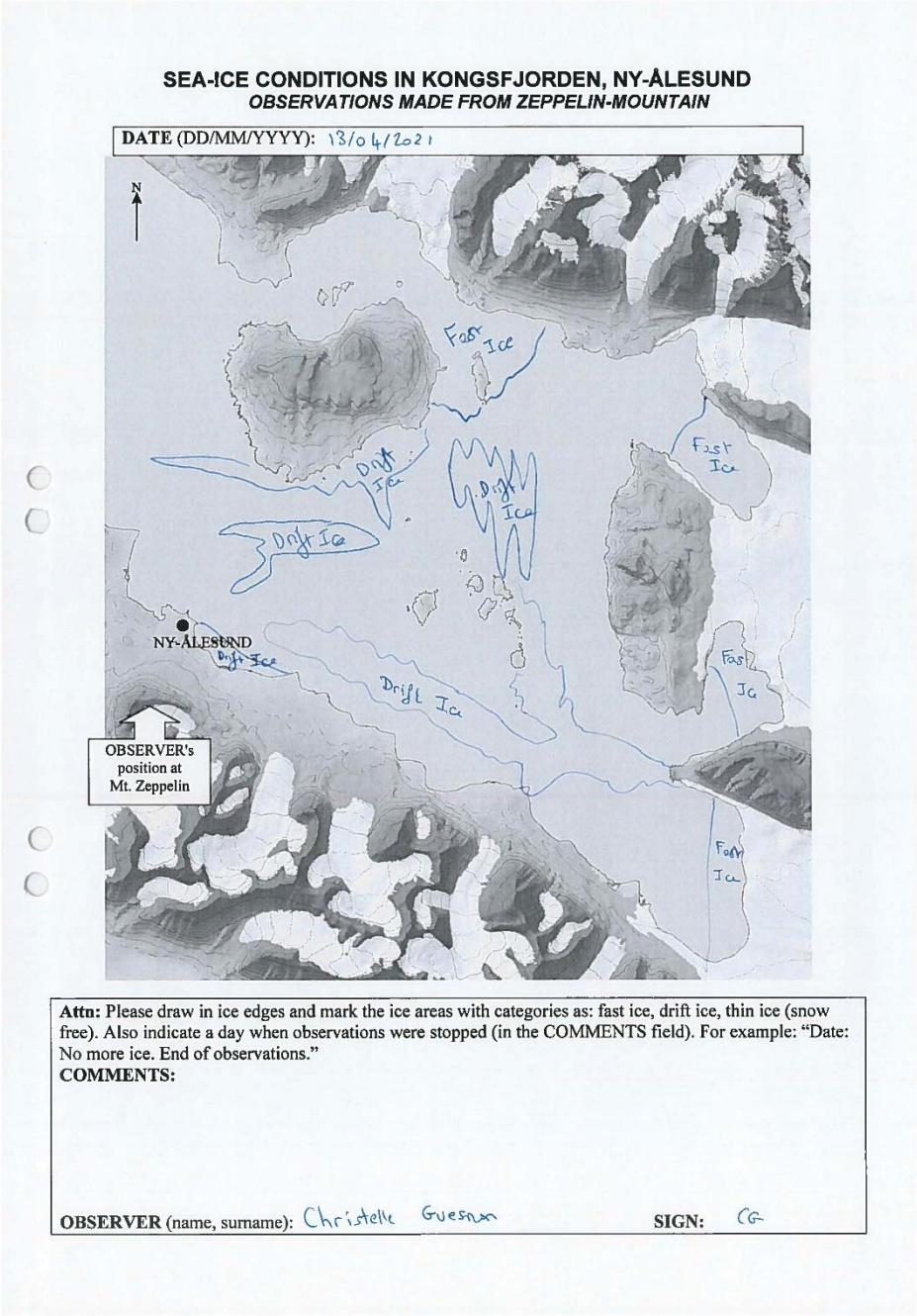

Figure 2a: Example ice chart of ice conditions in Kongsfjorden from 13.04.2021 showing fast ice areas in Raudvika, Dyrevika around Gerdøya and east Dyrevika, as well as patches of drift ice in the fjord.

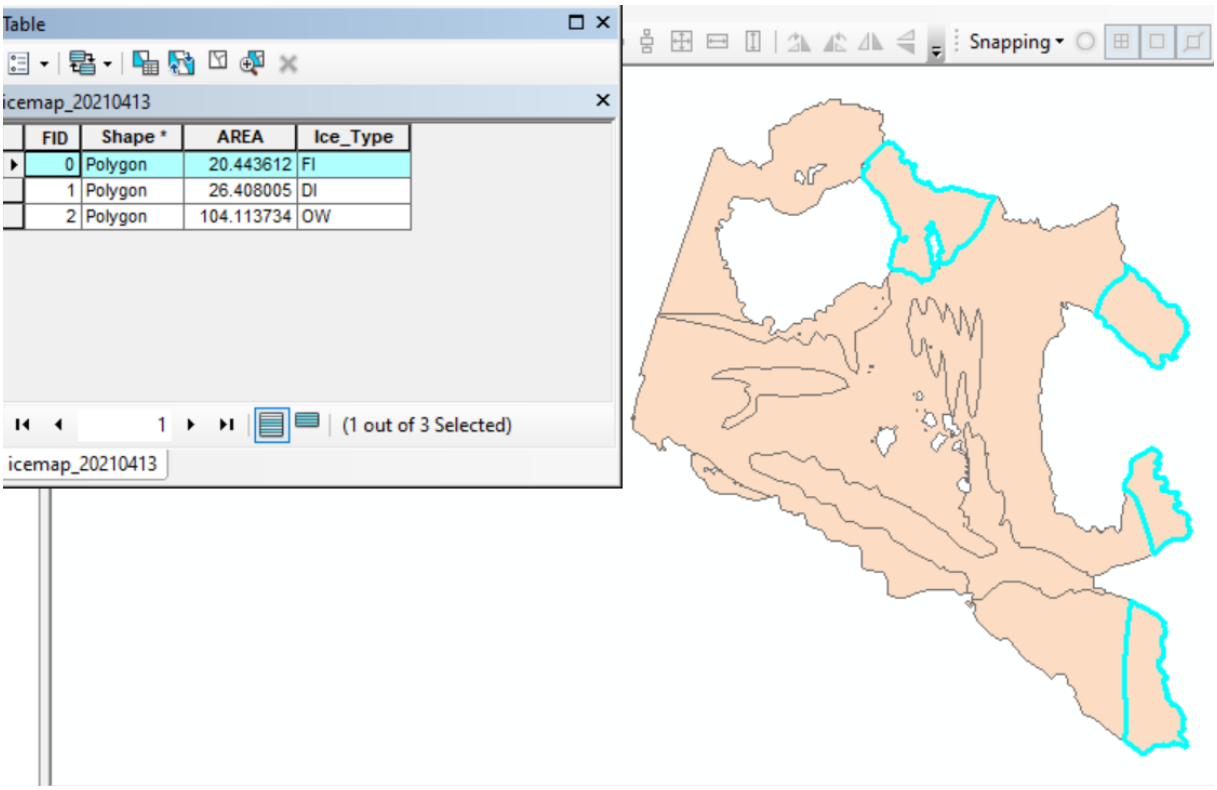

Figure 2b: Digitized ice chart of ice conditions in Kongsfjorden for 13.04.2021 from Figure 2a, as displayed in ArcView. Green lines delimit the areas of fast ice in Raudvika, Dyrevika around Gerdøya and east Dyrevika, and in Kronebukta in from of Kronebreen. Solid black lines outline patches of drift ice in the fjord. Table in the upper left corner shows areas in km^2 for fast ice (FI), drift ice (DI) and open water (OW), respectively.

Additionally, we took into account occasional pictures taken from aircraft. In some cases, the manually drawn maps are complemented by regular visits to the sea ice. During the annual sea ice monitoring campaigns, sea ice thickness, snow thickness and freeboard are sampled among other parameters. Additionally, in 2016–2021 the fast ice edge was traced in some sections using a handheld GPS and a small boat (Negrel et al., 2018, Johansson et al., 2020).

Systematizing and categorizing visual observations of sea ice in Kongsfjorden

Due to practical reasons, a common system for logging sea ice conditions in the fjord using sea ice classes and types as defined in e.g. WMO Sea ice nomenclature (JCOMM, 2014) was not established for Kongsfjorden. Sea ice observations as logged in ice charts, notes on sea ice classes/types are therefore not fully standardized and tend to vary between the observers during the observational period. Depending on an observer, sea ice notes could be made in English or Norwegian languages. However, analysis of this textual information provided in the charts enables categorization of the broad range of notes into the two types of sea ice cover and open water.

Typically, during the direct observations and from photographs, the ice is classified as fast ice and ‘other ice’, usually either pack ice broken off the fast ice, or ice advected from other areas (Krossfjorden and areas outside Krossfjorden/Kongsfjorden). Thin ice areas were registered as well when the presence of this ice type was possible to observe.

Photographs are rectified using landmarks (e.g. capes, islands) to include additional information about the ice edges and integrate it into the final ice charts. However, for the sake of simplicity and practical considerations with respect to possible numerical analysis of the digitized charts, the entire abundance of sea ice information was diminished to two main ice categories of “drift ice” and “fast ice”. Together with “open water” it comprises a three-class categorization of surface conditions in Kongsfjorden.

Processing of ice charts

The derived ice charts are further processed and digitized in the GIS software (ArcGIS v10.8.1.) and ESRI shape files for individual days (.dbf, .shp, .shx, .prj and .cpg associated files) outlining the ice-covered areas are produced for each individual day/observation. For the processing the WGS1984_projection and UTM Zone33N (EPSG:32633) was used. The example visualization of the digitized chart is displayed in **Figure 2b**. included in the archive. Note that ice covered areas are registered as polygons limited by the actual observed ice edge, and whenever relevant, coastlines and glacier front positions.

In accordance with the ice type categorization scheme applied, the "Ice_Type" attribute value list comprises FI (Fast Ice), DI (Drift Ice), OW (Open Water). The “Area" attribute provides the area of each feature in square kilometres (based on a planar calculation). Note that multipart features are aggregated by “Ice_Type” value. Multipart features mean that if there are, say, three separate polygons of drift ice in an individual day shapefile, the polygons are defined and handled in the shapefile as one object rather than three, and so it also lists the sum of individual polygon areas for a specific ice class in the area attribute.

One should note that two areas are located in the visual “shadow” for the observations from Zeppelinfjellet. These are the area north of Blomstrandhalvøya, and the area in the inner Raudvika and inner Dyrevika. In the first case it is not found possible to disambigiously interpret the ice situation in this subarea, even if fast ice is present around Gerdøya. For Raudvika, however, the presence of visible fast ice edge guarantees the presence of fast ice in the inner Raudvika; hence this area is labelled as “fast ice” in the respective ice charts should the fast ice edge outside Raudvika have been observed and registered in the respective ice chart. In addition, observation of areas that are further distant might be more affected by limited visibility.

Coastline and land mask changes during the dataset period

Glacier recession, past surging of Blomstrandbreen and land erosion during the observational period led to corrections of land mask/coastline used in the archive. The dataset over the covered period uses three versions of land coastlines from 1993, 2009 and 2018. The glacier fronts positions of the Kongsfjorden marine terminating glaciers were updated for 2002 and also used for the maps from 2003 and 2004. From 2005 and onwards the glacier front positions for marine terminating glaciers of Kongsfjorden were updated annually.

Table 1 presents an overview of glacier front updates during the dataset period. Note that updates are based on the analysis of optical satellite imagery from the later part of the summer season to capture the maximal annual retreat of the respective glaciers. **Table 2** further presents the effect of changes in landmask and glacier recession on observational area in Kongsfjorden. Updates in landmask (coastline) and glacier fronts led to an increase in the observational area of the fjord from 132 km^2 in 2002 to 151 km^2 in 2021, indicating a total change of about 19 km^2 during 2002-2021.

Year	Blomstrandbreen	Conwaybreen	Kongsbreen Kongsbrebukta	Kongsbreen Raudvika	Kronebreen and Kongsvegen
2002	K	K	K	S 11/07	S 11/07
2005	K	K	K	S 22/06, 08/07	K
2006	K	K	K	S 27/07	S 27/07
2007	K	K	K	K	K
2008	M	M	M	M	K
2009	NPI	NPI	NPI	NPI	NPI
2010	K	S 23/08 (2009)	K	S 23/08	K
2011	K	S 17/08 (2009)	K	K	K
2012	K	M	K	M	K
2013	K	K	K	K	K
2014	K	K	K	K	K
2015	K	K	K	K	K
2016	K	K	K	K	K
2017	K	K	K	K	K
2018	S 21/09	S 21/09	S 21/09	S 21/09	S 21/09
2019	K	K	K	K	K
2020	K	K	K	K	K
2021	M	M	M	M	M

Table 1: Years of updates of glacier fronts positions for the glaciers of Kongsfjorden. The positions of fronts are from Moholdt et al., 2021 (M) and Kohler, unpublished data (K); 2009 data are based on aerial imagery of the area conducted for NPI and (S DD/MM) indicate front positions based on Sentinel-2 imagery produced for this data set.

year	observational area [km^2]
2002	132.43
2005	133.86
2006	134.22
2007	136.13
2008	136.03
2009	136.99
2010	137.52
2011	138.37
2012	139.95

2013	141.58
2014	144.06
2015	144.19
2016	145.65
2017	147.68
2018	148.51
2019	149.28
2020	150.34
2021	150.97

Table 2: Changes in observational area during 2002-2021 associated with changes in coastline (landmask) and glacier recession in Kongsfjorden.

The nearly annual changes in landmask are depicted in Figure 3. The effect of land mask updates on the inferred ice extent should be taken into consideration when working with the archive.

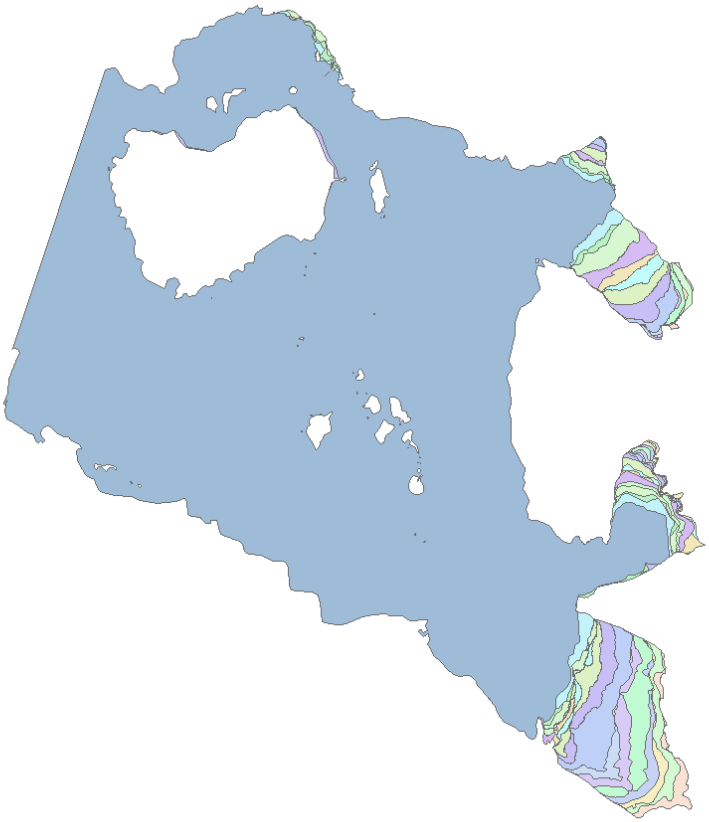

Figure 3: Changes in coastlines (landmask changes) and positions of glacier fronts in Kongsfjorden during the period of 2002, and 2005-2021. The recession of glaciers over the studied period was a continuous process; the legend for the figure is not provided to improve the visualization.

Acknowledgement

We are very grateful to Norwegian Polar Institute's staff at Ny-Ålesund Research Station for performing sea ice observations from Zeppelinfjellet since 2003. The digitizing of ice charts has partly been funded via EU project FACE-IT under grant agreement no. 869154 from the European Union's Horizon 2020 research and innovation programme.

References

Gerland, S., & Renner, A.H.H. (2007): Sea ice mass balance in an Arctic fjord. Annals of Glaciology, Vol. 46, pp. 435-442.

Gerland, S., & Pavlova, O. (2020). Sea ice coverage in inner Kongsfjorden, Svalbard, 2003-2019, version 1.0 [Data set]. Norwegian Polar Institute. https://doi.org/10.21334/npolar.2020.74c7b236

JCOMM Expert Team on Sea Ice (2014) Sea-Ice Nomenclature: snapshot of the WMO Sea Ice Nomenclature WMO No. 259, volume 1 – Terminology and Codes; Volume II – Illustrated Glossary and III – International System of Sea-Ice Symbols). Geneva, Switzerland, WMO-JCOMM, [121pp.]. (WMO-No. 259 (I-III)). DOI: https://doi.org/10.25607/OBP-1515

Johansson, A.M., Malnes, E., Gerland, S., Cristea, A., Doulgeris, A.P., Divine, D., Pavlova, O., and Lauknes, T.R. (2020): Consistent ice and open water classification combining historical synthetic aperture radar satellite images from ERS-1/2, Envisat ASAR, RADARSAT-2, and Sentinel-1A/B. Annals of Glaciology. DOI: 10.1017/aog.2019.52.

Moholdt, G., Maton, J., Majerska, M., & Kohler, J. (2021). Annual coastlines for Svalbard [Data set]. Norwegian Polar Institute. https://doi.org/10.21334/npolar.2021.21565514

Negrel, J., Gerland, S., Doulgeris, A.P., Lauknes, T.R., and Rouyet, L. (2018): On the potential of hand-held GPS tracking of fjord ice features for remote-sensing validation. Annals of Glaciology. DOI: 10.1017/aog.2017.35.

Pavlova, O., S. Gerland and H. Hop (2019): Changes in sea-ice extent and thickness in Kongsfjorden, Svalbard, and related ecological implications. Advances in Polar Ecology. In: Hop H., Wiencke C. (eds.) The Ecosystem of Kongsfjorden, Svalbard. Advances in Polar Ecology 2, 105-136. Springer, Cham. DOI: 10.1007/978-3-319-46425-1_4.

Data archive structure

The archive structure besides this metatada document comprises thwo main components

1) ESRI shape files pooled for each year between 2023 to 2021 with sea ice observations for individual days (.dbf, .shp, .shx, .prj and .cpg associated files) are archived in zip files of the format

   IceMap_KF_year_YYYY.zip

2) Zip file IceMap_KF_2003to2021.zip contains all available sea ice observations for the study period compiled into a single ESRI shape file (.dbf, .shp, .shx, .prj and .cpg associated files).

3) Zip file “Kongsfjord_coast_lines_2002-2021.zip contains ESRI shape files with annual coastlines (.dbf, .shp, .shx, .prj and .cpg associated files) for the period 2002-2021.