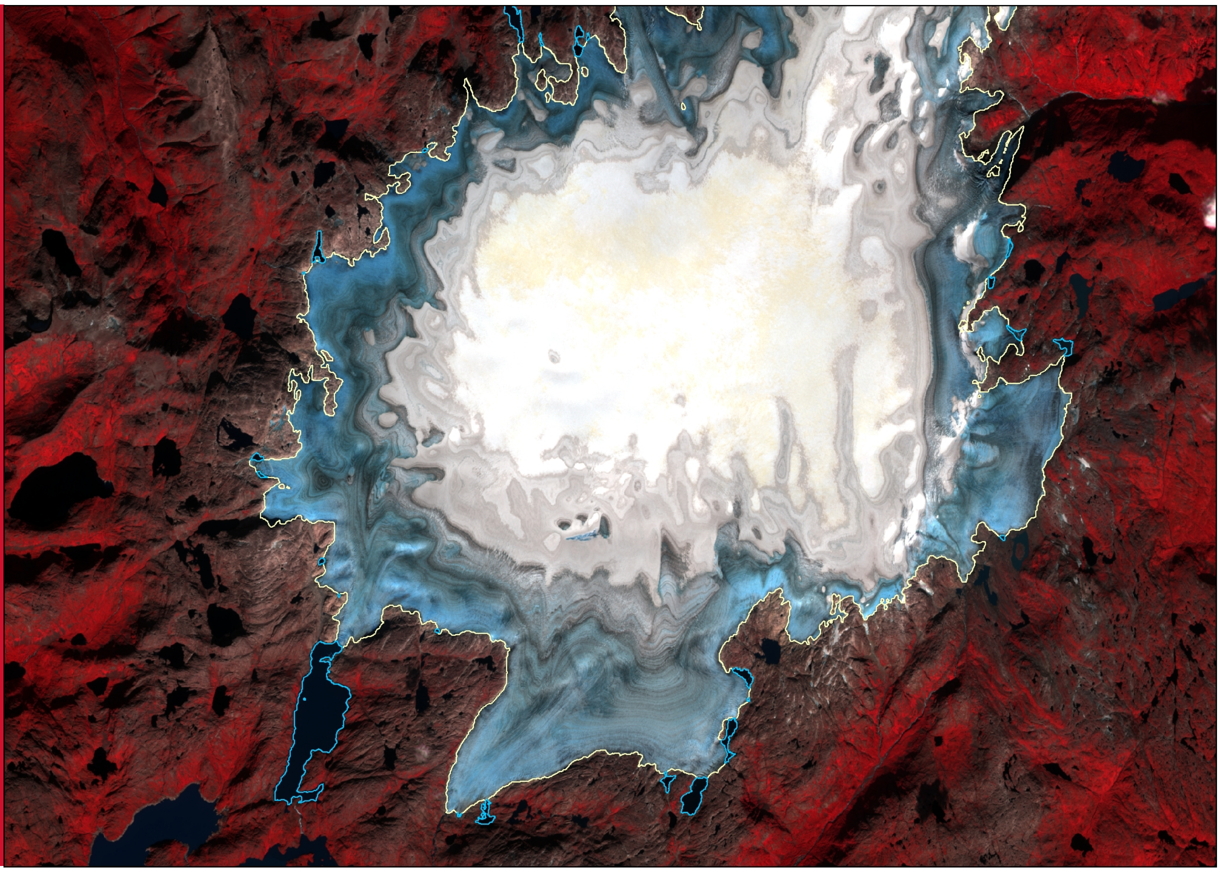
RAPPORT

Nr. 13/2022

CryoClim glacier product documentation

CryoClim glacier sub-service by NVE

Liss M. Andreassen and Solveig H. Winsvold



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Authors: Liss M. Andreassen and Solveig H. Winsvold

Cover photo: Sentinel-2 image of 27 August 2019 showing southern part of Søndre Folgefonna, Vestland, displayed in false 8-4-3 (NIR-Red-Green) colours and mapped glacier area outlines (GAO) in yellow and glacier lake outlines in light blue. Photo: Copernicus Sentinel data 2019

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Abstract: The CryoClim service provides cryospheric climate products, primarily based on satellite observations. Glacier products from mainland Norway in the CryoClim service consist of Glacier Area Outline (GAO), Glacier-dammed Lake Outlines (GLO), Climate Indicator (CI) products, Glacier Lake Outburst floods (GLOF) and Glacier Periodic Photo series (GPP) products. This report describes these products.

Key words: Sentinel-2, Landsat, glaciers, Copernicus

Norwegian Water Resources and Energy
Directorate Middelthuns gate 29
P.O. Box 5091 Majorstuen
N-0301 Oslo

Telephone: 22 95 95 95
Email: nve@nve.no
Internet: www.nve.no

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Norwegian Water Resources and Energy Directorate
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Contents

Preface

The CryoClim service www.cryoclim.net provides cryospheric climate products, primarily based on satellite observations. This document is an update of the Norwegian Water Resources and Energy directorate (NVE) CryoClim glacier service documentation. CryoClim was a European Space Agency (ESA) PRODEX project funded by the Norwegian Space Agency. The CryoClim work has continued in the Copernicus Glacier Service (2016-2021) and in NVE's new Copernicus project (2022-2027), co-funded by the Norwegian Space Agency.

Previously the NVE CryoClim documentation included three documents:

- Product documentation for GAO and GLO
- Algorithm theoretical basis document for the GAO and GLO products
- GCOS compliance statements for the GAO and GLO products

The first two documents are now merged into one updated document for NVE's CryoClim glacier service and published in NVE's report series. The previous documents are available in NVE's Handle collection for CryoClim: https://nve.brage.unit.no/nve-xmlui/handle/11250/2830933

The CryoClim work in NVE has been conducted by Liss M. Andreassen (project leader for NVE in CryoClim) and Solveig H Winsvold who write the original reports and updated the new report. George Stanley Cowie assisted in merging, updating, and proof-reading the new report. Jon Endre Hausberg, Sindre Engh, Ferdinand Klingenberg, Nils Kristian Orthe and Teodor Nagy have also worked on NVE's CryoClim products, services or applications in the period described in this report.

We thank project coordinator Rune Solberg from the Norwegian Computing Center and the partners Norwegian Meteorological Institute (MET Norway) and Norwegian Polar Institute in the CryoClim project for cooperation since the start of the CryoClim project.

Oslo, March, 2022

Hege Hisdal

Director, Department of Hydrology

Rune V. Engeset

Head, section for Glacier, Ice and Snow

Acronyms and definitions

ADC Arctic Data Centre

ESA European Space Agency

ETM+ Enhanced Thematic Mapper plus

GAO Glacier Area Outline

GCOS Global Climate Observing System

GLO Glacier Lake Outline

GLOF Glacier Lake Outburst Flood

GPP Glacier Periodic Photo series

MET Norwegian Meteorological institute

MS Multi-Spectral

MSI Multi-Spectral Instrument

N50 The most detailed of the national map data bases in Norway

NDWI Normalized Difference Water Index

NVE Norwegian Water Resources and Energy Directorate

PAN Panchromatic Band

RGB Red Green Blue

TM Thematic Mapper

UTM Universal Transverse Mercator

WGS World geodetic system

WMS Web Map Service

1 Introduction

CryoClim is an Internet service providing cryospheric climate products, primarily based on satellite observations. The service is delivered through a web service (www.cryoclim.net) and a data portal, the Arctic Data Centre (adc.met.no). The portal includes manual searching, viewing and downloading capabilities. CryoClim is an operational and permanent service for long-term systematic climate monitoring of the cryosphere. The product production and the product repositories are hosted by mandated organisations. The databases are connected over the Internet in a seamless and scalable network, open for inclusion of more databases/sub-services. CryoClim provides sea ice and snow products of global coverage and glacier products covering Norway (mainland and Svalbard) and the Greenland ice sheet. The service was developed by CryoClim project (2008–2013) by the Norwegian Computing Center (project coordinator), Norwegian Meteorological Institute, Norwegian Water Resources and Energy Directorate (NVE) and Norwegian Polar Institute.

Glacier products from mainland Norway in the CryoClim service consist of Glacier Area Outline (GAO), Glacier-dammed Lake Outlines (GLO), Climate Indicator (CI) products, Glacier Lake Outburst floods (GLOF) and Glacier Periodic Photo series (GPP) products. The GAO and GLO products are derived from Sentinel-2, Landsat TM/ETM+/OLI, and topographic maps using image analysis and GIS techniques. We have used Pléiades orthoimages and aerial orthophotos for validation. As of 2022 the most up-to-date products use Sentinel-2 as the main data source with supplementary images from Landsat-8.

New glacier and glacier lake outline products developed through the project Copernicus glacier service (Andreassen et al., 2021) are also a contribution to the CryoClim service.

2 Satellites and sensors

A variety of sensors and satellites have been used to derive the products in CryoClim. The sensors vary between collections as satellites become decommissioned or outdated or by new sensors with increased resolution. In this section we briefly introduce the different satellites, sensors, their capabilities and usage in CryoClim.

2.1 Sentinel-2

Sentinel-2 is a constellation of two polar-orbiting, multispectral high-resolution imaging satellites for land monitoring. Sentinel-2A was launched on 23 June 2015 and Sentinel-2B followed on 7 March 2017. The Sentinel 2A-2B constellation yields an observation every five days at the equator and more frequently in higher latitudes from the same nominal orbit. The satellite sensors have a multi-spectral instrument (MSI) with 13 spectral channels. These includes the visible/near infrared (VNIR) and short-wave infrared spectral range (SWIR) needed for glacier mapping. Sentinel-2 provides a ground resolution of 10m with a swath width of 290 km. Data from Sentinel-2 is freely available (ESA, 2022a).

2.2 Landsat

The Landsat program is a series of multispectral satellites provided by the U.S. Geological Survey (USGS). The first satellite was launched in 1972 and Landsat has the longest continuous global record of the Earth's surface (USGS, 2022a). The newest contribution to the Landsat satellites, Landsat-9, was launched 27 September 2021.

Landsat-8
Landsat-8 that has relatively similar properties as Sentinel-2. It carries an operational land imager (OLI) and thermal infrared sensor (TIRS) and has nine reflective wavelength bands designed for land use, with the highest ground pixel resolution being 15m for the panchromatic band (PAN) (Loveland and Irons, 2016). The revisit time is 16 days.

Landsat-7 ETM+
The Landsat 7 satellite orbits the Earth in a sun-synchronous, near-polar orbit. The satellite has a 16-day repeat cycle. Landsat 7 carries the Enhanced Thematic Mapper Plus (ETM+) sensor, an improved version of the Thematic Mapper instruments that were onboard Landsat 4 and Landsat 5, with a maximum resolution of 15 m in the PAN (USGS, 2022b). This satellite was decommissioned when Landsat-9 was launched and activated.

Landsat-5 TM
The Landsat 5 satellite orbited the Earth in a sun-synchronous, near-polar orbit. The satellite had a 16-day repeat cycle. Landsat 5 carried the Multispectral Scanner (MSS) and the Thematic Mapper (TM) sensors with a maximum resolution of 30 m (USGS, 2022c). This satellite was decommissioned in 2013.

Table 1. Comparison of Landsat and Sentinel-2 parameters. Table modified from Andreassen et al. (2021) that was adapted from Loveland and Irons (2016) and Li and Roy (2017).

Parameter	Landsat-5	Landsat-7	Landsat-8	Sentinel-2
Highest resolution band	30 m	15 m	15 m	10 m
Number of bands of highest resolution	6	1	1	4
Revisit time	16 days	16 days	16 days	5 days (S2A and S2B)
Altitude	705 km	705 km	705 km	786 km
Ground swath width	185 km	185 km	185 km	290 km
Release year - Decomissioned	1984 - 2013	1999-2021	2013 -	2015 - (S2A), 2017 - (S2B)

2.3 Pléiades

Pléiades is a constellation of two high resolution earth imaging satellites launched in 2003. The spatial resolution of the satellites is 0.5 m for PAN, 2 m for MS bands. The swath width of the satellites is 20 km at nadir and can collect imagery within an 800 km ground strip. The repeat cycle of the constellation is 26 days. Pléiades was used mainly for validation of Sentinel-2 and Landsat-8 mappings due to its high resolution (ESA, 2022b; Andreassen et al., 2022)

2.4 Orthophotos

Orthophotos are orthorectified aerial imagery and were used for validation and testing. 'Norge i bilder' means 'Norway in imagery' and is a website displaying orthorectified aerial imagery over mainland Norway: norgeibilder.no. The orthophotos were used directly as a web map service (wms) or for viewing and downloading from norgeibilder.no. The imagery was useful for validation purposes, especially for glacier lake and glacier outline mapping products.

3 Products

This section describes the products provided by CryoClim. Products include Glacier Area Outlines (GAO), Glacier Lake Outlines (GLO) and climate indicator products (CI). The covered time periods and sensors used for the different products can be viewed in Table 2.

Table 2. Time series information of CryoClim and Copernicus glacier service products.

Time period	Sensor	Platform	Comments
GAO			
2018-2019	MSI, OLI	Sentinel-2	Orthophotos and Pleiades used for validation.
1999-2006	TM,ETM+	Landsat-5,7	
1988-1997	TM	Landsat-4,-5	
1947-1985	Topographic maps	N50	Main map series of Norway
1895-1907	Topographic maps	Gradteigskart	Historical topographical maps
GLO			
2018-2019	MSI	Sentinel-2	Orthophotos used for validation
2018	MSI	Sentinel-2	
2014	OLI	Landsat-8	
1999-2006	TM/ETM+	Landsat-5,7	
1988-1997	TM	Landsat-5	

3.1 Glacier Area Outline (GAO)

Glacier outlines and associated attribute data, jointly referred to as a glacier inventory, are baseline data for a range of glaciological and climatological applications, as well as for standard topographic maps. They are input data in local-to-global models of glacier mass balance and hydrology, and for satellite-based assessments of glacier volume changes and contribution to sea level rise. Glacier outlines, area changes and position of calving fronts are being mapped by NVE for glaciers in mainland Norway using Sentinel-2 and Landsat. CryoClim has several datasets of GAO developed through the CryoClim and Copernicus glacier service projects.

3.1.1 GAO 2018-2019

The glacier outlines of mainland Norway 2018-2019 were produced using Sentinel-2 imagery from the summers of 2018 (northern Norway) and 2019 (southern Norway) and are described in detail in Andreassen et al. (2022), see also Andreassen et al. (2021) and Andreassen (2022).

The first phase of data collection was to select suitable Sentinel-2 imagery, preferably from a selection of years with minimal snow cover during the summer and extended periods of clear weather. After selecting suitable images for each region, the next step was to apply a band-ratio thresholding method to produce an initial set of automatically generated glacier masks/outlines. The blue band 2 (B2_blue), red band 4 (B4_red) and shortwave infrared band 11 (B11_swir) were used to make a binary glacier mask which was converted to vector outlines that were further edited. The initial steps were:

- Make initial binary glacier mask: B4_red / B11_swir > ratio_threshold (e.g. 2.4)
- Apply threshold based on the blue band: B2_blue > blue_threshold (e.g. 1100)
- Apply median filter (3x3 pixels) to reduce noise
- Convert to vector outlines (polygon shapefile)

This automated procedure was repeated for all selected Sentinel-2 images to generate a catalogue of different glacier outlines. The best outlines for each glacier region were then used as starting point for manual checking and editing based on the source imagery as well as other suitable scenes from the image catalogue. Lake and ocean polygons were removed or edited and a size threshold applied.

Higher resolution orthophotos from different times were used to aid the manual interpretations in difficult areas such as steep terrain with shadows, areas obscured by cloud and areas with debris-covered ice, which are often misclassified in the automated procedure. Previous glacier inventories and maps/DTMs were also used as supporting data. The further inventory process consisting of manual editing, outline validation and drainage divide delineation.

Sentinel-2 was found suitable to map also smaller glaciers and ice patches (Andreassen et al., 2020). As a result, many more ice patches and smaller glaciers have been mapped in the new inventory.

The Sentinel-2 derived data was compared with high-resolution orthophotos from aerial orthophotos and Pléiades satellite data (Fig. 1).

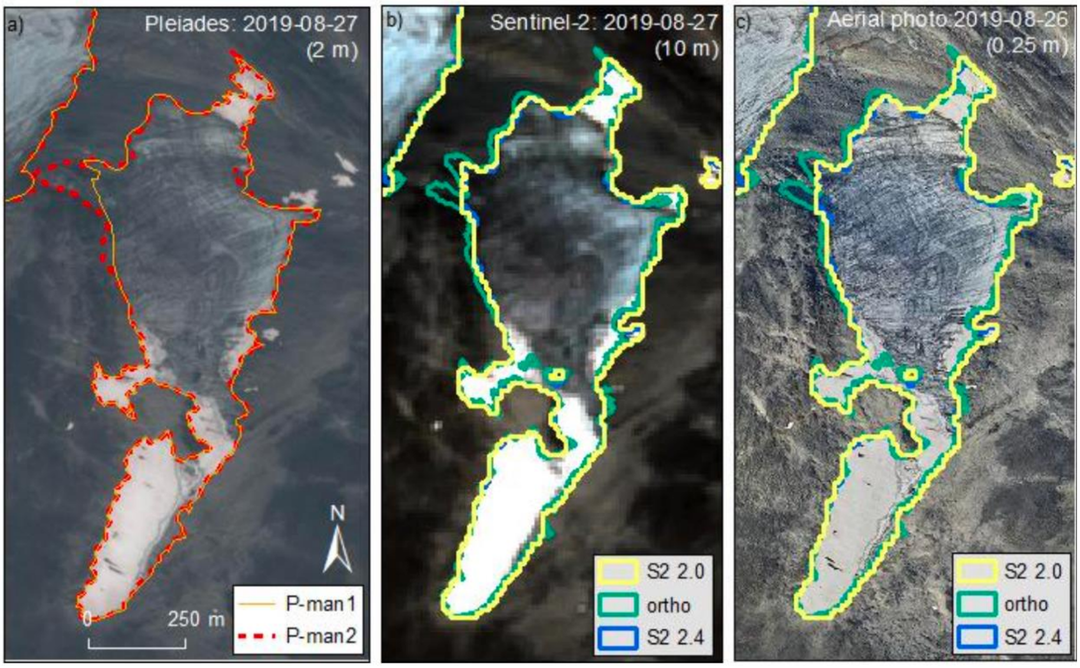


Figure 1. Comparison of GAO on Gråsusnippen using (a) Pléiades manual digitization, (b) Sentinel-2 semiautomatic digitization and (c) an aerial photo manual digitization. The largest difference is in the interpretation of dark ice in the north-western parts (Figure modified from Andreassen et al. (2022)). /Pléiades © CNES 2019, Distribution Airbus DS. /Copernicus Sentinel data 2019/

3.1.2 GAO 1999-2006

The glacier outlines of mainland Norway 1999-2006 were produced using Landsat-5 and 7 and are described in detail in Andreassen et al. (2012), Winsvold et al. (2014) and in the previous CryoClim documentation (Andreassen and Winsvold, 2013).

Ratio images were computed from the raw digital numbers for bands TM3/TM5 for all scenes and made binary using different threshold values. The resulting glacier outlines for each scene were compared with a false color composite (bands 5, 4, and 3 as RGB) of the Landsat image to find the most suitable threshold value. An optimal threshold value was chosen, and pixels were finally classified as ice or snow. As a next step, we applied a median filter (3 by 3 kernel) to the classified binary image to reduce noise in shadow regions and remove isolated pixels outside the glaciers (usually snow patches). The median-filtered glacier map was raster-to-vector converted within ArcGIS and glacier polygons were obtained. Then, all mapped snow and ice polygons were visually inspected using RGB composites of satellite image bands as background. Validation of the glacier products was also done by comparison of the results with orthophotos from http://www.norgeibilder.no where available.

Manual corrections for debris cover, glacier-lake interfaces, clouds, cast shadow and snow were done when necessary. Some small glaciers located in shadow in the Landsat image were not included in the glacier classification. The glacier outlines were in these cases manually digitized based on orthophotos (where available) or Landsat images. For a further method description see Andreassen et al. (2008; 2012).

3.1.3 GAO 1988-1997

The glacier outlines of mainland Norway 1988-1997 were produced using Landsat-4 and Landsat-5 and are described in detail in Winsvold et al. (2014). It was derived using a method similar to the 1999-2006 GAO.

3.1.4 GAO 1947-1988

The 1947-1988 GAO data set was derived by digitizing glacier outlines from 168 first-edition 1:50 000 topographical maps from the Norwegian Mapping Authority based on aerial photographs acquired between 1947 and 1985. The paper maps were scanned and georeferenced using ground control points in a reference map (from European datum zone 32, 33, and 34 to WGS 84 UTM zone 33). The glacier outlines were then digitized on-screen. See further description in Winsvold et al. (2014).

3.1.5 GAO 1895-1907

The 1895-1907 GAO data set was derived using analogue maps. The method was tested in the two northernmost glacier regions in Norway (Seiland and Øksfjord). The analogue maps consisted of quadrangle maps constructed from land surveys conducted in the period 1895-1907 (map scale 1:100 000). The map sheets include the five largest ice caps in the two regions: Nordmannsjøkelen, Seilandsjøkelen, Øksfjordjøkelen, Svartfjelljøkelen, and Langfjordjøkelen. The map sheets were scanned and georeferenced using local transformation methods. The glacier outlines were manually digitized from the georeferenced maps. See further description of the dataset in Winsvold et al. (2014).

Old analogue maps can have severe planimetric distortions due to complex topography, and, in certain cases, glacier extents are known to be overestimated (Winsvold et al., 2014). The glacier area for Langfjordjøkelen are found to be overestimated (Weber et al., 2020).

3.2 Glacier Lake Outline (GLO)

A jokulhlaup or Glacier Lake Outburst Flood (GLOF) is a sudden release of water from a glacier. GLOFs are the major hazard directly related to glacier lakes and can often lead to fatalities and material losses. The water source can be a glacier-dammed lake, a pro- glacial moraine-dammed lake or water stored within, under or on the glacier. With continuing glacier shrinking, existing lakes can change, and new lakes can develop or disappear. Glacier lakes are sensitive to climate change and their mapping and monitoring improves our understanding of regional climate change and glacier-related hazards. Mapping of glacier lakes with optical satellite sensors has become common and has been applied to detect both proglacial and supraglacial lakes (Andreassen et al., 2021).

Glacier lakes in mainland Norway have long posed a threat due to frequent outburst floods (Liestøl, 1956; Jackson and Ragulina, 2014). CryoClim has several collections of glacier lake outlines for mainland Norway: 1988-1997 (Landsat-5), 1999-2006 (Landsat 7), 2014 (Landsat 8), 2018 (Sentinel-2) and 2018-2019 (Sentinel-2). The methods used for the glacier lake products has varied and the methods used for each product is described.

Ideally, for lake outline mapping, the glacier lake surface should be observed at its areal maximum, with no surface snow and ice cover. The lake perimeter should be snow free to avoid misrepresentation of the snow-covered perimeter as water or vice versa. Cloud cover as well as cloud and terrain induced shadowing should be minimal. All images used for the GLO products were visually inspected prior to selection (Andreassen et al., 2021).

3.2.1 GLO 2018-2019

A GLO product for 2018-2019 was produced to match the 2018-2019 glacier outlines described in chap. 3.1. The mapping is described in Andreassen et al. (2021; 2022). The GLO2018 (section 4.2.2) was used as reference. Lakes were mapped that appeared to be in direct contact with glaciers that had an area >0.05 km^2. For northern Norway, the glacier lakes were used as in the GLO2018 product, with some corrections and additions of lakes at glaciers below the 0.25 km^2 glacier size threshold. The images used for southern Norway were the same ones used for the GAO 2018-2019 product and were mainly from 27 August, but imagery from 4 August and 15 August was also used.

The semi-automatic method used for glacier outline mapping often requires manual edits to detach glacier lakes connected to the glacier outlines and this was used to make an updated product for 2019 for southern Norway. The glacier lake was detached from the glacier by splitting the mapped polygon with the digitized line. The full glacier lake outline for larger lakes not fully mapped by this method was derived by merging with the GLO2018 product, or with lakes from the topographic map series 1: 50 000 of Norway, or the remaining outline just digitised manually on screen. Orthophotos from norgeibilder.no were used for validation (Andreassen et al., 2022). Larger lakes were often easy to detect, but smaller newly formed lakes were more difficult to identify and were more uncertain.

3.2.2 GLO 2018

This product is described in detail in Nagy and Andreassen (2019) and Andreassen et al. (2021). The image acquisitions used for the GLO 2018 inventory were from the period 3 July 2018 - 8 September 2018. For the GLO2018 product a semi-automatic approach was used, calculating the Normalized Difference Water Index (NDWI) and applying a threshold. The NDWI maximizes the water body reflectance in the green band and minimizes its reflectance in the NIR band and is calculated as:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

The NDWI is commonly used for mapping lakes and was also used for the previous GLO 1999-2006 product (section 3.2.4). Sentinel-2, however, provides improved details of glacier lake outlines with its 10 m resolution of the green and NIR bands compared to Landsat bands at 30m ground resolution.

A threshold value of 0.23 was selected to separate the NDWI map pixels into the water and non-water based on analysis of a subset of nine lakes with orthophoto as training data. This threshold was found to be the best compromise of minimizing the need for manual lake outline digitization and maximize the inclusion of the ‘true’ water pixels. Still, manual editing was needed for many of the lakes. An uncertainty in glacier lake area of ±4% was estimated for the GLO2018 product.

In the GLO 2018 inventory, lakes larger than 0.001km^2 (1000m^2) that were within ca. 100 m of the glacier perimeter, by glacier units at least 0.25 km^2 in size, were included. All lakes were visually inspected and categorized based on glacier-lake contact and nature of damming.

3.2.3 GLO 2014

The Landsat-8 image acquisitions used for GLO 2014 were from 9 August - 24 September 2014 and had favourable lake outline mapping conditions due to a warm summer and early onset of snow and ice melting. Manual digitisation was used to map the lake outlines. The 1999-2006 lake outlines were used as basis for the mapping. Glacier lake outlines were identified as water bodies that either intersected, were within <50 m, or completely within the glacier area outlines of 1999-2006 (Andreassen et al., 2021).

3.2.4 GLO 1999-2006

The product is described in detail in the previous product documentation (Andreassen and Winsvold, 2013). The 1999-2006 GLO was derived using the Landsat TM. The GLO were defined as water bodies that either intersected, were within a distance of < 50 m or were completely within the glacier boundary (GAO). Lakes were identified using the Normalized Difference Water Index (NDWI) computed from TM1 and TM4 for all scenes (NDWI = (TM4-TM1)/(TM4+TM1), made binary using different threshold values. The resulting glacier lake maps for each scene were compared with a natural color band combination (bands 3, 2 and 1 as RGB) of the Landsat image, and 1:50 000 maps to find at least two suitable threshold values. The next step involved corrections on the two selected NDWI threshold values. Lakes smaller than 0.001 km^2 were removed. The GLO was further edited to eliminate shadow and to generate a smooth transition between the lake and the glacier. The lakes were further validated with aerial photographs, 1:50 000 maps, and earlier registered lakes from edits made to the GAO product.

3.2.5 GLO 1988-1997

The product is described in detail in the previous product documentation (Andreassen and Winsvold, 2013). The GLO product for 1999-2006 was used as basis for creating the 1988-1997 GLO product. Only lakes mapped in the product from 1999-2006 were included. Other possible lake locations were not checked or mapped for the 1988-1997 product. Whereas NDWI was used to find lakes in the GLO 1999-2006 product, this product was as the GLO2014 product created using manual digitization of the lakes directly from the Landsat satellite image. On some occasions the GAO threshold classified glacier lakes as glacier ice. Outlines from the GAO product were then used for mapping these lakes.

3.3 Glacier applications

The applications listed here were developed by NVE as part of the CryoClim project.

3.3.1 Climate Indicator products (CI)

The Climate Indicator products (CI) application display NVE's records of surface mass balance and length and area for glaciers in mainland Norway. The data are read directly from NVE's database and the displayed data can be downloaded from: [http://glacier.nve.no/Glacier/viewer/CI/en/cc.](http://glacier.nve.no/Glacier/viewer/CI/en/cc)

Mass balance

NVE's glacier surface mass balance series contain annual (net), winter and summer balances (Fig. 2). The annual balance is the sum of winter balance and summer balance. Area-averaged values for winter and summer balances are calculated by inter- and extrapolating point measurements of snow density, snow depths and ablation. The series are categorized as 'original' (as published in 'Glasiologiske undersøkelser i Norge/Glaciological investigations in Norway, e.g. Kjøllmoen et al., 2021), ‘homogenized’ (for selected or all years) or ‘calibrated’ (periods are calibrated with geodetic observations). An area-weighted annual mass balance signal reflects a year’s weather directly. However, for longer time series changes in glacier area will also influence the annual balance.

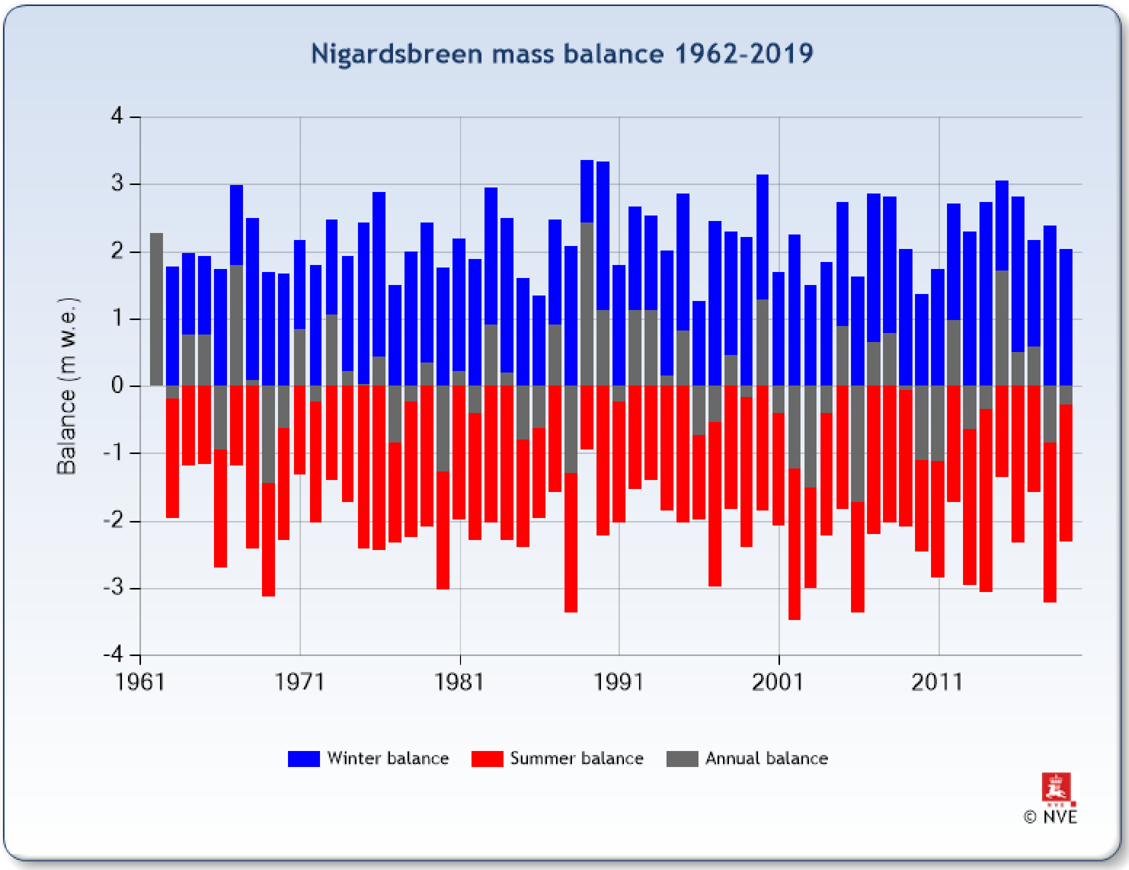


Figure 2. Example of a mass balance product from Nigardsbreen.

Length

Glacier length change is derived from annual, repeated measurements of distance between the glacier terminus and fixed landmarks. It should be noted that in contrast to mass balance measurements, length change does not require annual measurements to have a continuous series. If one year’s data is absent, length change is derived from two years instead of one, maintaining the cumulative signal. The application provides length change between observations and cumulative length change (Fig. 3).

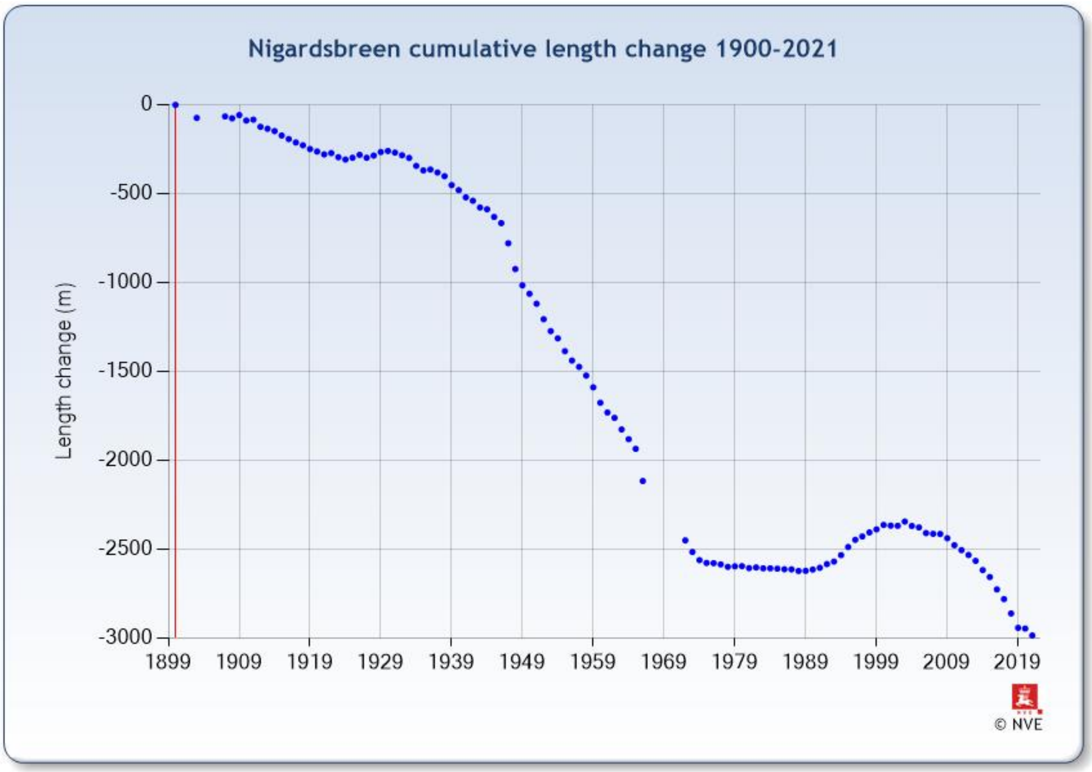


Figure 3. Example of a length change product from Nigardsbreen.

Area
Glacier area changes are calculated from detailed glacier maps, and from the NVE/CryoClim glacier area outline data. It should be noted that there will be several uncertainties in the area change assessments since glacier areas are derived from different sources (Landsat, topographic maps, aerial photos or tabular data), often with different snow conditions. Each method has its specific uncertainties and area changes may partly be due to differences in methods, snow conditions, ice divides or human interpretation rather than real glacier changes (Andreassen et al., 2008).

3.3.2 Glacier Periodic Photo (GPP)

The Glacier Periodic Photo (GPP) series show photos of selected glaciers in mainland Norway. The photo series illustrates how a selection of Norwegian glaciers have changed. The earliest photos are from 1869. The majority of the pictures are from the last 20 years. The number of photos varies between the glaciers. Please note that the photos are not necessarily taken from the same location. The photo angle, view and line of sight will vary (Fig. 4). For each glacier it is possible to see a comparison of two photos. The source of the data is NVE’s photo archive, with contributions from NVE collaborators.

http://glacier.nve.no/Glacier/viewer/gpp/en/cc/

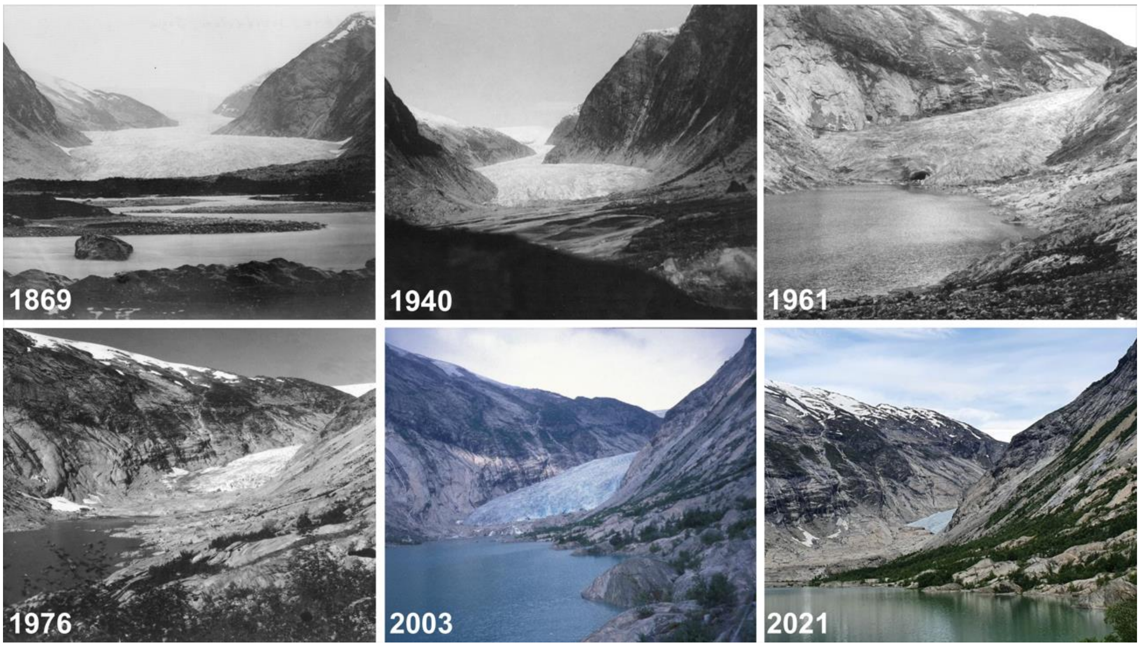


Figure 4. Selected photos from the Nigardsbreen GPP series.

3.3.3 Glacier lake outburst floods (GLOF)

The GLOF application gives an overview of registered glacier lake outburst floods (GLOFs) from glaciers in mainland Norway.
http://glacier.nve.no/Glacier/viewer/GLOF/en/cc

Information about registered events in NVEs database are retrieved directly from NVEs database. In addition, it is also possible to view photos of the affected glaciers.
The glacier lake outburst flood locations can be viewed in NVE's digital glacier atlas (section 3.5).

3.4 The CryoClim portal

The CryoClim portal is now part of the Arctic Data Centre, a service hosted and provided by the Norwegian Meteorological institute (MET):
https://adc.met.no/

The Arctic Data Centre is a legacy of the International Polar Year when MET coordinated operational data streams internationally and research data nationally.

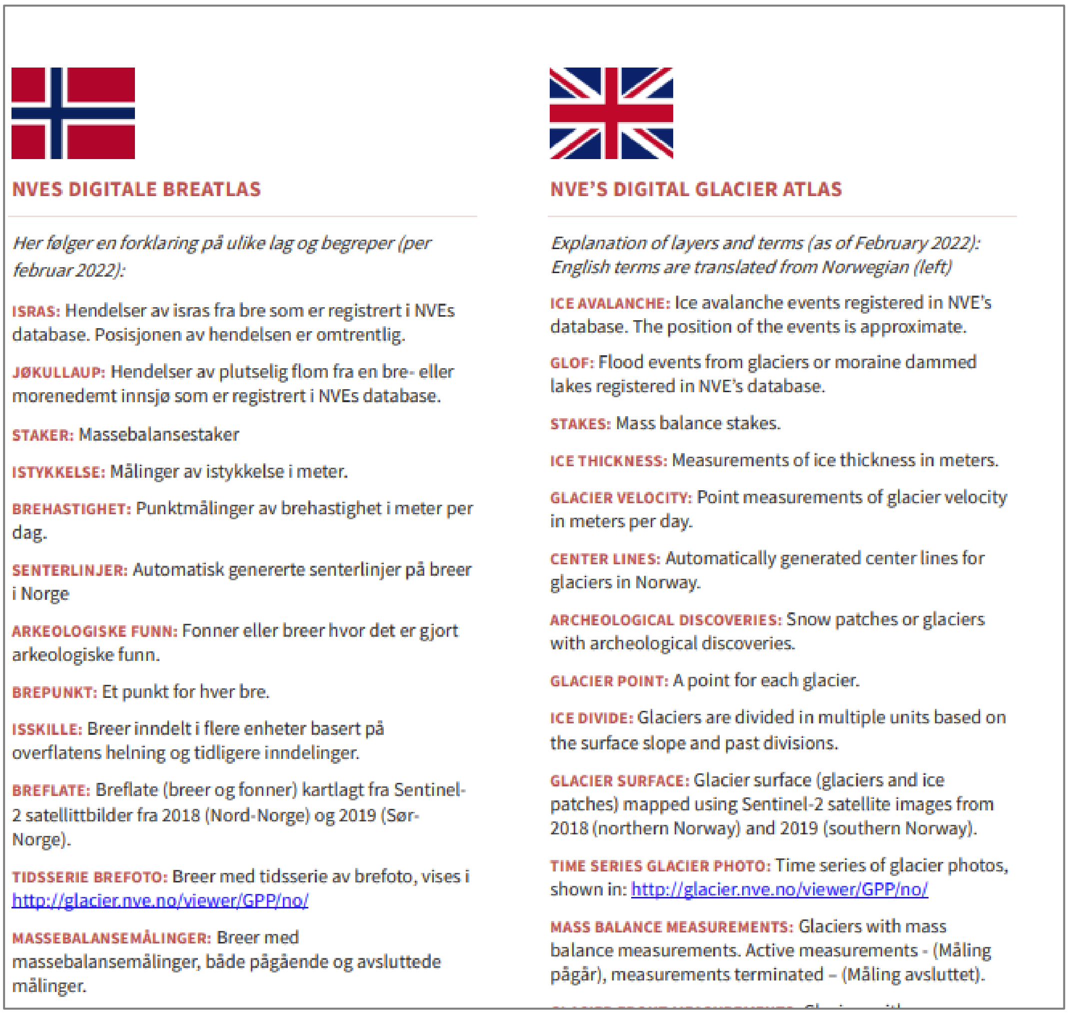
3.5 NVE's digital glacier atlas

NVE's digital glacier inventory (NVEs Breatlas) is part of NVE's map catalogue.

https://temakart.nve.no/tema/breatlas

The digital inventory shows the most recent GLO and GAO products as well as historical products. It also displays the location of GLOFs and other glacier data. The map interface is so far only available in Norwegian, but a Norwegian-English description is available (Fig. 5).

Figure 5. NVE's digital glacier atlas has a Norwegian interface, but a Norwegian-English description is available. The figure shows part of this description.



NVES DIGITALE BREATLAS

Her følger en forklaring på ulike lag og begreper (per februar 2022):

ISRAS: Hendelser av isras fra bre som er registrert i NVEs database. Posisjonen av hendelsen er omtrentlig.

JØKULLAUP: Hendelser av plutselig flom fra en bre- eller morenedemt innsjø som er registrert i NVEs database.

STAKER: Massebalansestaker

ISTYKKELSE: Målinger av istykkelse i meter.

BREHASTIGHET: Punktmålinger av brehastighet i meter per dag.

SENTERLINJER: Automatisk genererte senterlinjer på breer i Norge

ARKEOLOGISKE FUNN: Fonner eller breer hvor det er gjort arkeologiske funn.

BREPUNKT: Et punkt for hver bre.

ISSKILLE: Breer inndelt i flere enheter basert på overflatens helning og tidligere inndelinger.

BREFLATE: Breflate (breer og fonner) kartlagt fra Sentinel-2 satellittbilder fra 2018 (Nord-Norge) og 2019 (Sør-Norge).

TIDSSERIE BREFOTO: Breer med tidsserie av brefoto, vises i http://glacier.nve.no/viewer/GPP/no/

MASSEBALANSEMÅLINGER: Breer med massebalansemålinger, både pågående og avsluttede målinger.

NVE'S DIGITAL GLACIER ATLAS

Explanation of layers and terms (as of February 2022): English terms are translated from Norwegian (left)

ICE AVALANCHE: Ice avalanche events registered in NVE's database. The position of the events is approximate.

GLOF: Flood events from glaciers or moraine dammed lakes registered in NVE's database.

STAKES: Mass balance stakes.

ICE THICKNESS: Measurements of ice thickness in meters.

GLACIER VELOCITY: Point measurements of glacier velocity in meters per day.

CENTER LINES: Automatically generated center lines for glaciers in Norway.

ARCHEOLOGICAL DISCOVERIES: Snow patches or glaciers with archeological discoveries.

GLACIER POINT: A point for each glacier.

ICE DIVIDE: Glaciers are divided in multiple units based on the surface slope and past divisions.

GLACIER SURFACE: Glacier surface (glaciers and ice patches) mapped using Sentinel-2 satellite images from 2018 (northern Norway) and 2019 (southern Norway).

TIME SERIES GLACIER PHOTO: Time series of glacier photos, shown in: http://glacier.nve.no/viewer/GPP/no/

MASS BALANCE MEASUREMENTS: Glaciers with mass balance measurements. Active measurements - (Måling pågår), measurements terminated – (Måling avsluttet).

4 Detailed product description

4.1 Product structure

The glacier products contain zipped shapefiles per time epoch containing Glacier Area Outlines (GAO) or Glacier Lake Outlines (GLO) for mainland Norway. We now store them in two handle data collections:

CryoClim data collection:
https://nve.brage.unit.no/nve-xmlui/handle/11250/2830933

Copernicus bretjeneste (Copernicus Glacier service) collection:
https://nve.brage.unit.no/nve-xmlui/handle/11250/2828121

4.2 Metadata

Each zipped file contains a readme.txt describing the data. The file contains abstract and explanation of variables and with references where available.

4.3 Known limitations of the product

No major limitations known.

4.4 Software and tools

The files can be used by any GIS software capable of reading shapefiles.

4.5 Web Map Service (WMS)

The NVE glacier area outlines and glacier lake outlines and other product are available as WMS (per February 2022):
https://nve.geodataonline.no/arcgis/services/Bre2/MapServer/WMSServer?request=GetCapabilities&service=WMS

4.6 Quality assessment

The glacier area outlines have been validated based on visual analysis of orthorectified high-resolution orthophotos and Pleiades satellite images (Andreassen et al., 2008; 2012; 2022) and sensitivity analysis (Winsvold et al., 2014; Andreassen et al; 2022). Misclassification on debris-covered glaciers and boundaries covered by snow patches may occur in some places. The glacier lake outlines from 2018 and 2019 have been validated using orthophotos (Nagy and Andreassen, 2019; Andreassen et al., 2022).

4.7 Citing products

When CryoClim and Copernicus Glacier Service products are used in a publication, the data set is required to be cited. Follow the citation as recommended in the readme.txt files or when no publication is listed refer to the current report:

L.M. Andreassen and S.H. Winsvold. 2022. CryoClim glacier product documentation. CryoClim glacier sub-service by NVE. NVE Rapport 13-2022, 22 pp. https://publikasjoner.nve.no/rapport/2022/rapport2022_13.pdf

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NVE

Norwegian Water and Energy Directorate

MIDDELTHUNS GATE 29
P.O. BOX 5091 MAJORSTUEN
N-0301 OSLO
TELEPHONE: (+47) 22 95 95 95

www.nve.no