CryoClim product documentation

CryoClim sub-service from the Norwegian Polar Institute

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Date	**30 March 2022**
Project ref.	**ESA/NSC PRODEX/Norway, CryoClim**

Norwegian Polar Institute
2022

Report no. 1 – 2022

Published by: Norwegian Water Polar Institute

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Print: Norwegian Polar Institute

Key words: Sentinel-2, Landsat, glaciers

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Contents

Preface

This document is an update and consolidation of NPI's CryoClim documentation. Previously, the CryoClim documentation included three documents:

• Product documentation for GAO and GST

• Algorithm theoretical basis document for the GAO and GST products

• GCOS compliance statements for the GAO and GST products

We have now merged these documents into one updated document for NPI's CryoClim service. The previous and the current documents are available in NPI's datacentre (data.npolar.no)

The work leading to the products and services has been supported by the CryoClim project sponsored by the Norwegian Space Agency and the European Space Agency (ESA).

Acronyms and definitions

DEM	Digital Elevation Model
DTM	Digital Terrain Model
ERS	European Remote-sensing Satellite
ESA	European Space Agency
GAO	Glacier Area Outline
GCOS	Global Climate Observing System
GIS	Geographical Information System
GST	Glacier Surface Type
MSI	Multi-Spectral Instrument
NPI	Norwegian Polar Institute
NR	Norwegian Computing Center
NSC	Norwegian Space Centre
NVE	Norwegian Water Resources and Energy Directorate
PAN	Panchromatic Band
S100	1:100 000 Topographic Map Series of Svalbard
SAR	Synthetic Aperture Radar
SWIR	Short Wave Infrared
TIRS	Thermal Infrared Sensor
VNIR	Visible/Near Infrared
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 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 (NR; project coordinator), Norwegian Meteorological Institute (MET Norway), Norwegian Water Resources and Energy Directorate (NVE) and Norwegian Polar Institute (NPI). CryoClim was an ESA PRODEX project funded by the Norwegian Space Centre.

Glacier products from mainland Norway in the CryoClim service consist of Glacier Area Outline (GAO) and Glacier Surface Type (GST) products. The GAO products are derived from Sentinel-2, Landsat, SPORT-5, ASTER, aerial orthophotos and topographic maps using image analysis and GIS (Geographic Information System) techniques. As of 2022 the most up-to-date products use Sentinel-2 as the main data source with supplementary images from Landsat-8. The GST products are derived using C-band Synthetic Aperture Radar (SAR) sensors.

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 becoming available. 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. Onboard the satellites have a multi-spectral instrument (MSI) with 13 spectral channels in the visible/near infrared (VNIR) and short-wave infrared spectral range (SWIR). 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-7/8

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 2022).

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 15 m for the panchromatic band (PAN) (Loveland and Irons, 2016). The revisit time is 16 days.

2.3 SPOT-5

The SPOT-5 satellite had a high-resolution stereoscopic (HRS) instrument, which was used to generate freely available DTMs and 5 m resolution panchromatic orthophotos as a part of the IPY-SPIRIT project (Korona et al. 2009). The available products for 2007-2009 were used in the 2001-2010 GAO product.

2.4 ASTER

The ASTER instrument is a part of the Terra program which provides high spatial resolution imagery (15 m resolution) in wavelengths ranging from visible to thermal infrared light (TERRA 2022), with an additional backward-looking sensor that allows for stereo photogrammetry and DTM generation. Orthorectified ASTER imagery and the Global ASTER DEM (GDEM) were used to complete the coverage of the Svalbard archipelago in the 2001-2010 GAO product.

2.5 Orthophotos

All of Svalbard was surveyed with high-resolution aerial stereo-imagery during the summer

months of 2008-2012 and forms the basis for the NPI orthophoto products that can be viewed directly on toposvalbard.no or as a WMS product (see http://geodata.npolar.no).

These orthophotos were important supporting information for the GAO2020 product, especially for finer glaciological interpretations in the glacier outline mapping with Sentinel-2. The digital terrain model (DTM) of Svalbard. “SO Terrengmodell” (https://data.npolar.no/dataset/dce53a47-c726-4845-85c3-a65b46fe2fea), is based on these stereo photos, and it was also used as supporting data for GAO2020.

2.6 SAR C-band

The GST product was obtained using the C-band of SAR imagery from the European Remote-sensing Satellite (ERS) (König et al. 2002 and 2004). This is the band of synthetic aperture radar (SAR) that operates in 4-8 GHz and in the 7.5-3.8 wavelength range (Earthdata 2022).

3 Products

This section provides an overview of the products included in CryoClim. The products described are Glacier area Area outlines Outlines (GAO) and Glacier Surface Types (GST). The covered time periods and sensors used for the products can be viewed in Table 1.

Table 1. Time series information of CryoClim and Copernicus glacier service products

Time period	Sensor, sensor	Products	Comments
GAO			
2020	Sentinel-2, Multi Spectral Instrument (MSI)	L1C-DTERRENG or L1C	DTERRENG products corrected with Norwegian DTM (S100)
2020	Landsat 7/8, TIRS		
2007-2008	SPOT-5, High Resolution Stereoscopic (HRS) Sensor	IPY-SPIRIT products	Korona et al. 2009
2001-2010	Terra, ASTER	L1B, DTMs and orthopotos (AST14DMO)	
1990 and 2008-2012	Aerial stereo photography	S100 Topographic Map Series of Svalbard	Technique: automated image matching
1936-1972	Aerial and oblique stereo photography	Historical S100 Topographic Map Series of Svalbard	Technique: Analogue stereoscopic plotter
GST			
1991-2012	ERS, ASAR	C-band SAR	

3.1 Glacier Area Outlines (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 NPI for Svalbard and by NVE for glaciers in mainland Norway using Sentinel-2 and Landsat-8 imagery. CryoClim has several datasets of GAO developed through the CryoClim and Copernicus glacier service projects.

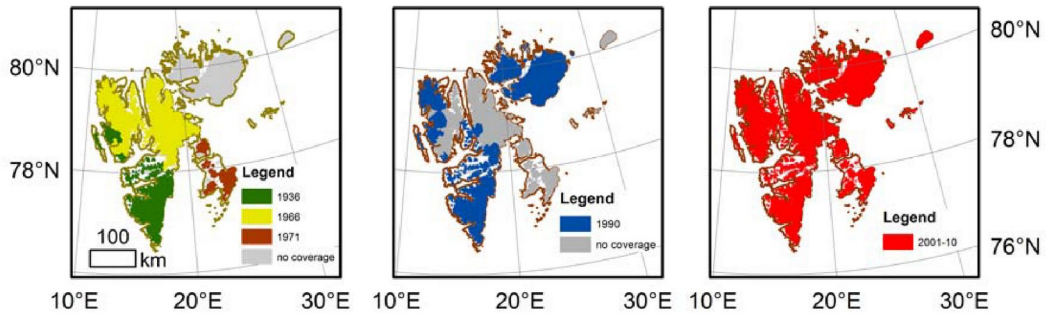

Figure 1 Comparison of GAO on Gråsusnippen using (a) Pléiades manual digitization, (b) Sentinel-2 semiautomatic digitization and (c) an aerial photo manual digitization. The largest difference is in the interpretation of dark ice in the north-western parts (Figure modified from Andreassen et al. (2022)).

3.1.1 GAO 1936-2010

The previous CryoClim documentation as well as the 1936-2010 GAO products and their belonging GCOS compliance statements can be found at:

https://data.npolar.no/dataset/89f430f8-862f-11e2-8036-005056ad0004

3.1.2 GAO 1936-1972

The first GAO product created at the Norwegian Polar Institute (NPI) was derived from the original S100 Topographic Map Series of Svalbard which in turn was based on aerial photography and surveys taken during campaigns in 1936, 1938, 1960, 1966 and 1969-71. The coverage of the product can be seen in Figure 1, and a detailed description and analysis of the dataset is provided by König et al. (2013) and Nuth et al. (2013).

3.1.3 GAO 1990

The 1990 campaign acquired vertical aerial images in the summer of 1990, covering the whole archipelago except for two swaths along the central ridge of the south-eastern coast. Using digital photogrammetric techniques, the S100 Topographic Map Series of Svalbard was improved, reused, where appropriate, or replaced. The 1990 outlines were extracted and modified to generate the GAO 1990 product, with spatial

coverage shown in Figure 1. A detailed description and analysis of the dataset is provided by König et al. (2013) and Nuth et al. (2013).

3.1.4 GAO 2001-2010

The first satellite-based glacier outlines were based on data from the IPY SPIRIT project (Korona et al. 2009) which provided high resolution DEMs (40m/pixel) and orthophotos (5m/pixel), covering approximately 70 % of the archipelago during the summers of 2007-2008. ASTER orthophotos, and in a few cases Landsat-7, were used to fill in the missing areas. Precise georeferencing was performed by co-registering the associated DEMs to ICESat laser altimetry data and applying the horizontal shifts to the orthophotos before digitizing. A further reference was provided by the S100 map data. All glacier outlines were digitized manually and divided into glacier basins following the drainage systems of the analogue "Glacier atlas of Svalbard and Jan Mayen" Hagen et al. (1993). The same basin separation was also implemented in the GAO 1936-1970 and GAO 1990 products. Further details about all these three GAOs are provided by König et al. (2013) and Nuth et al. (2013).

3.1.5 GAO 2020

The most recent GAO product covering the Svalbard archipelago was obtained during the summer months of 2020 using the extensive archive of Sentinel-2 imagery. The process and product are described in detail by Andreassen et al. (2022) and summarized here:

The Sentinel-2 catalogue was searched for suitable imagery, i.e., not too much snow cover and/or clouds. A warm and relatively clear period in July/August 2020 turned out to have many good images and a complete coverage of the archipelago. 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., 5)
- Apply threshold based on the blue band: B2_blue > blue_threshold (e.g., 1700)
- Apply median filter (3x3 pixels) to reduce noise
- Convert to vector outlines (polygon shapefile)
- Remove sea-ice and ocean polygons by land mask
- Remove snow-filled gullies based on area-perimeter ratio

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.

Higher resolution orthophotos from separate times were used to aid the interpretations in difficult areas such as steep terrain with shadows, areas obscured by clouds 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 consisted of manual editing, outline validation and drainage divide delineation.

Before the manual editing, the automated outlines for Svalbard were split up into separate vector layers for the outer perimeter (large polygons), the nunataks (small polygons) and the drainage divides (lines inherited from the previous inventory). The three layers were then edited separately based on the summer 2020 Sentinel-2 imagery as well as supporting data from Landsat-8, orthophotos and DTMs. In some areas, the automated outlines could be used efficiently (Figure 2), while in others, shadows and debris cover made it difficult to interpret the glacier extent from the Sentinel-2 imagery directly.

In difficult areas, land-surface temperatures (LST) derived from the Thermal Infrared Sensor (TIRS band 10, 30 m resolution) of Landsat-8 was used to better separate ice-containing areas and areas without ice. During the summer of 2020, Svalbard experienced a heat wave, resulting in sharp temperature contrasts between atmosphere-heated land surfaces and snow/glacier surfaces near the melting point.

Glacier basins were inherited from GAO 2001-2010 and updated where changes were visible, including splitting up some basins due to glacier retreat.

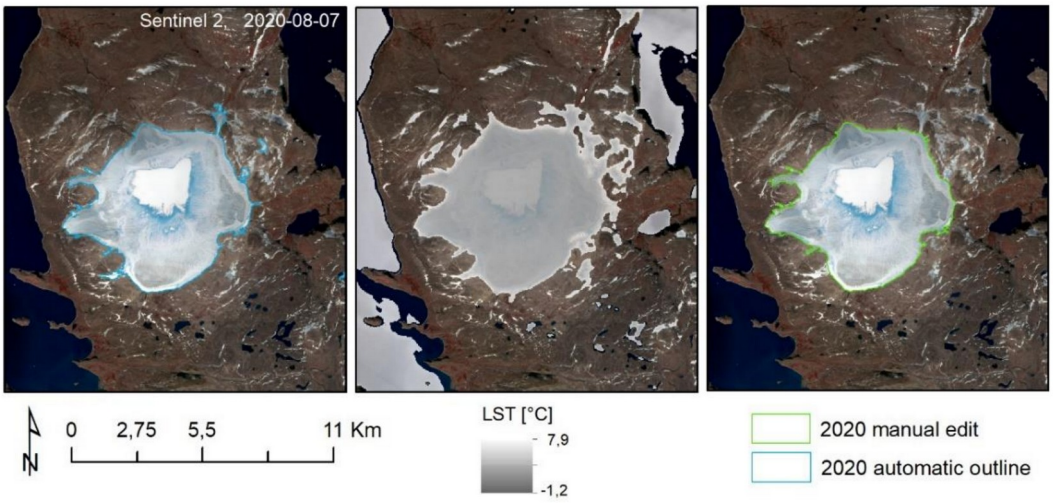

Figure 2 Example of an ice cap, Ahlmannfonna on Nordaustlandet, where the automated method for glacier outlines performs well (left) and few manual adjustments had to be made for the final inventory (right). The middle image shows Landsat-derived land-surface temperatures (LST) below 7.9°C, which was used as a threshold for icy areas, but in this case also including some surrounding areas, as well as lakes and the ocean. Figure taken from Andreassen et al. 2022.

3.2 Glacier Surface Types (GST)

On many glaciers in Svalbard, three surface types are visible on SAR images, the dark glacier ice at the glacier's lower end, the brighter superimposed ice in the middle, and the white firn at the higher elevations. Surface classification of these types is valuable especially since the retreat or advance of the firn area provides information on the status of the glacier. While the snowline reacts immediately to annual changes, the firn area smoothes out these short-term changes and shows, similar to the glacier front, longer-term changes of the glaciers.

GST uses an Otsu three-category algorithm to separate the image into these three surface types for selected Svalbard glaciers. The method works very well on glaciers with distinct surface types, the main weakness is crevasses and rough areas being classified as superimposed ice. A quality number indicates if an individual classification is ideal (1), good (2) or of medium quality (3). The quality number indicates how many crevasses are classified as superimposed ice. The firn area should be displayed correctly for all selected glaciers.

The product and previous CryoClim documentation can be found at: https://data.npolar.no/dataset/d756f766-de33-11e2-8993-005056ad0004.

3.3 The CryoClim portal

The cryoClim portal is now part of the Arctic Data Centre hosted by met.no:

https://adc.met.no/

3.4 Svalbardkartet

NPI's digital glacier inventories, the GAO products, are embedded in the ArcGIS-service, Svalbardkartet:

https://svalbardkartet.npolar.no

Svalbardkartet shows the most recent GAO and GST products as well as historical products.

4 Detailed product description

4.1 Product structure

The glacier products contain shapefiles per time epoch containing glacier outlines (GAO) or glacier surface types (GST) for Svalbard.

GAO 2020 (shapefiles to be published soon, available on request):

https://data.npolar.no/dataset/1b8631bf-7710-449a-a56f-0da1a4fef608

GAO 1936-1797, 1990 and 2001-2010:

https://data.npolar.no/dataset/89f430f8-862f-11e2-8036-005056ad0004

GST:

https://data.npolar.no/dataset/d756f766-de33-11e2-8993-005056ad0004

4.2 Metadata

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

4.3 Known limitations of the product

GAO:

No major limitations, but some misclassifications and errors may occur in alpine areas and where the surface is covered by debris, making it difficult to judge if there is ice underneath.

GST:

The method works only for glaciers with three distinct surface types, namely glacier ice, superimposed ice and firn. More complex surfaces (crevasses, rougher areas etc.) are often misclassified.

4.4 Software and tools

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

4.5 Citing products

When CryoClim and Copernicus Glacier Service products are used in a publication, the data set is required to be cited.

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