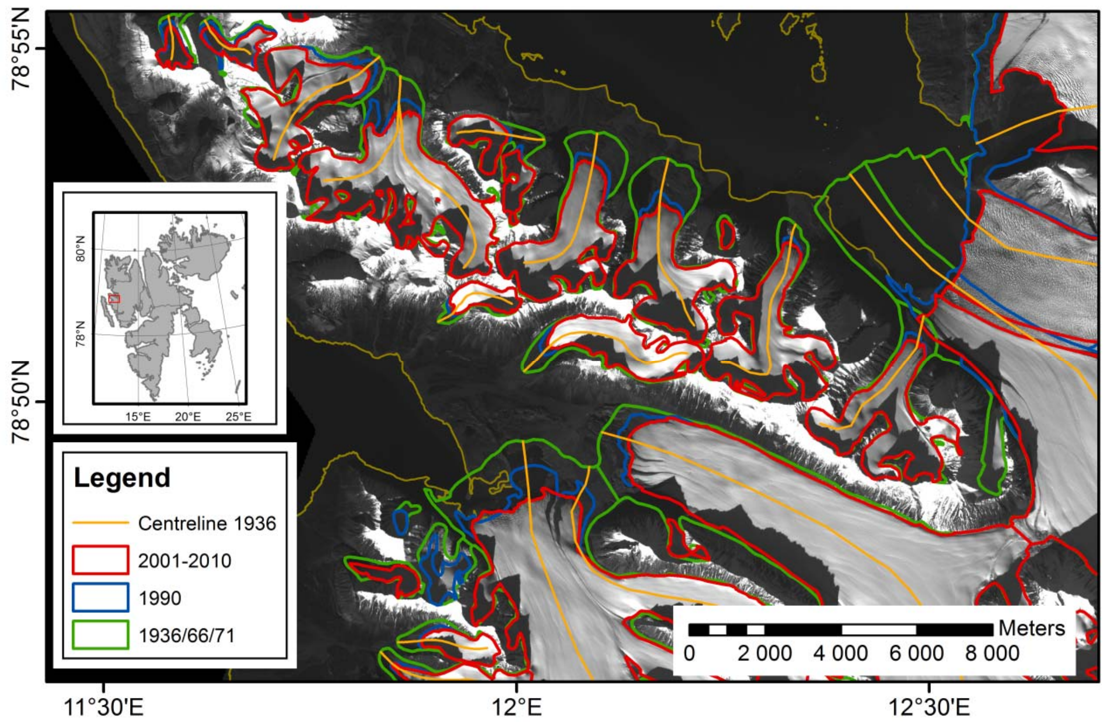
Algorithm Theoretical Basis Document (ATBD) for the GAO product

CryoClim sub-service for glaciers in Svalbard



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1 Introduction

CryoClim is an Internet service providing cryospheric climate products, primarily based on satellite observations. The service is delivered through a web service and web portal (www.cryoclim.net). 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). The service has been 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.

The Glacier Area Outline (GAO) product has been created for the years 1936, 1966-71, 1990 and 2001-10. For most glaciers, outlines are available from more than one year, thus documenting glacier retreat over time. Except for the 2001-10 data, glacier outlines were created using cartographic data from the original NPI topographic map series of Svalbard by delineating individual glaciers and ice streams, assigning unique identification codes relating to the hydrological watersheds, digitizing centre lines, and providing a number of attributes for each glacier mask. The 2001-10 glacier outlines are derived from orthorectified satellite images from SPOT-5 and ASTER sensors.

2 Algorithm description

2.1 Algorithm idea and overview

This product was initially not planned to be delivered by NPI within the CryoClim project, but had been produced within the Global Land Ice Monitoring from Space (GLIMS) project and was decided to be made available through the CryoClim system as well. A more detailed description of this dataset can be found in König et al. (2013).

The first complete glacier inventory of Svalbard was presented by Hagen et al. (1993), (‘H93’) following the instructions of the World Glacier Inventory. This inventory was based upon the original topographic map series of Svalbard derived from aerial photographs taken over multiple years (1936/1966/1971). Attributes such as area and length were directly measured from these maps and documented in tables. The original data (i.e. glacier masks) are not available in digital format, although the original hard-copy atlas can be found as an electronic publication (http://brage.bibsys.no/npolar/).

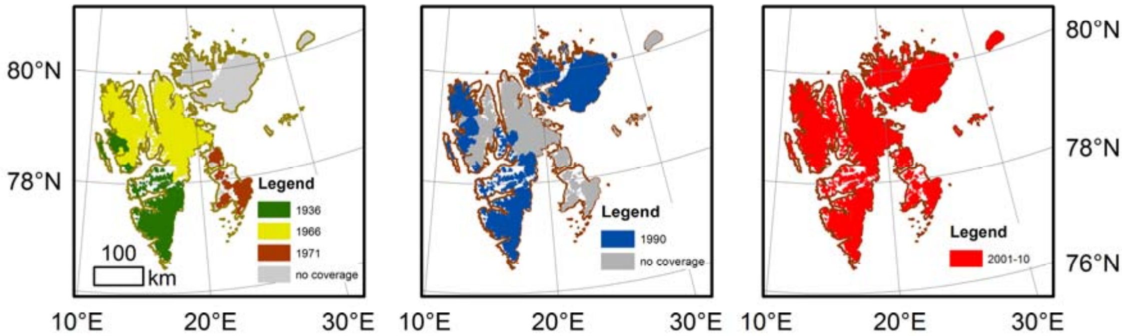

Figure 2.1a-c: Svalbard maps showing the coverage of the three available Shapefiles with glacier outlines derived from cartographic data (1936-1990) and SPOT images (2001-2010).

2.2 Theoretical background and algorithm details

Since the original glacier atlas data were not digital and due to the multiple year compilation of that database, this task required recompiling of all glacier masks. All map data from the Norwegian Polar Institute were digitized in the 1990s, which forms the basis for this glacier inventory re-compilation. Many glaciers in Svalbard are valley-type, which are easily divisible into glacier masks. However, most of the glacier area comprises connected ice fields that drain into separate valleys. To divide these into individual glacier units we follow the principle of hydrological drainage divides based upon surface topography. We use a compilation of older and newer contour lines and Digital Elevation Models (DEM) as well as satellite images to help interpret the border between individual glacier units. The hydrological approach based upon topography does not account for ice flow, i.e. ice may flow in a different direction than what the surface aspect suggests.

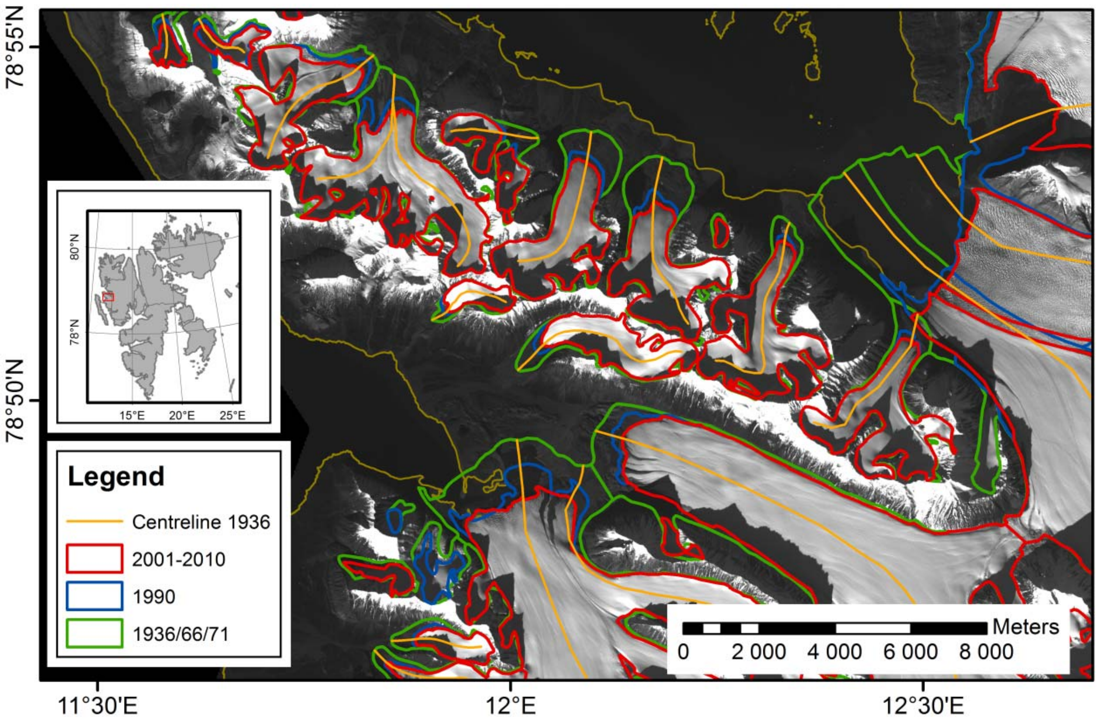

Figure 2.2: A subset of the database shows all available data at Brøggerhalvøya with a 2007 SPOT image (CNES 2008) as background. The colours of the glacier outlines correspond to the colours indicating years in Figure 2.1. Retreat of the glaciers between 1936 and 2007 is clearly seen with a decrease of 3% glaciated area in Kongsfjorden. Centrelines for each glacier are available.

While these masks and divides are derived with the best possible data at the present time, we acknowledge that errors and mistakes may occur, and therefore hope to create a transparent database where mistakes, if found, can be adjusted and corrected for as further information is acquired.

To initiate the transfer of individual glacier identification codes from first inventory to digital media, we began with the earliest cartographic Shapefiles from the S100 map series (Figure 2.1a). Each individual glacier was separated from the conglomerate polygon and metadata, such as glacier name and ID, added as an attribute. For individual valley glaciers not connected to a larger ice mass, the original polygon often needed little adjustment, mainly by removing snow fields connected to the glacier surface that were originally included in the Shapefile by the non-glaciologist cartographer. This was accomplished through visual inspection of orthorectified SPOT, ASTER and georectified Landsat images, but also using hill shades of the DEMs, where the mountain sides can be easily visualized.

The larger interconnected ice masses also needed to be sub-divided into individual glaciers and ice streams. We followed the drainage basin divides as in H93, making only slight adjustments where our objective interpretations differ. Ice divides are manually digitized mainly using contours lines from the more recent DEMs (1990-present). As stated above, this hydrological approach for drainage-basin division assumes ice flow in the direction of the surface slope. If actual ice flow diverges significantly from the apparent surface slope in the area of the basin drainage divides, this might lead to errors. In addition, determining individual glacier basins in the oldest dataset using more recent data can introduce errors. Nonetheless, the greatest changes in Svalbard glaciers occur at the fronts, rather than at basin divides. A subset of the glacier database for the Kongsfjorden area can be seen in Figure 2.2 showing among others the 1936 outlines.

Most of the 1990 data covers glaciers where outlines for 1936-1971 are available as well (Figure 2.1b).

Polygons of individual valley glaciers required little adjustment from the original 1990 cartographic data and were again taken entirely from the original data except for the removal of adjacent snow fields where necessary. For the larger interconnected ice masses, ice divides were not re-analysed, but copied from the previous glacier outline. The glacier identification codes were simply transferred from the older (S100) dataset to the 1990 dataset, where applicable. This method assumes that the accumulation-area divides between ice masses have not changed significantly over the years. Again, most area changes of individual glaciers and ice streams occur at the tongue of the glacier. Figure 2.2 shows frontal changes and outlines for 1990 in the Kongsfjorden area. For all of Svalbard these are discussed in detail in Nuth et al. (2013).

2.3 Climate Change Indicator

The Climate Change Indicator "Glacier Area Change" is derived from GAO and consists of a figure displaying area change of Svalbard glaciers over the years. See http://data.npolar.no/dataset/fff1ccc2-fa7c-11e2-bd10-005056ad0004 for more information.

2.4 Uncertainty estimation

Errors in the glacier outlines depend on the images used to delineate glaciers, i.e. their resolution and quality, sky and ground conditions, and the analyst's ability to digitize and interpret the imagery. Latter errors arise both from the manual interpretation of glacier-land boundaries and from the uncertainty of locating hydrological divides of interconnected ice fields (i.e. based upon surface topography). Errors in ice-field divides are related to the accuracy of the DEM and to the hydrological flow directions derived from it when using automated hydrological GIS algorithms. Interpretation uncertainty may arise, for example, in cases where debris or lateral moraines obscure the glacier outlines, or where seasonal snow in the imagery covers the glacier edge.

A manual digitization experiment (Paul et al., 2013) with 20 participants on 24 glaciers resulted in area uncertainties (expressed as a relative difference) ranging between 2 and 30 %; the largest errors came from sections of glaciers with heavy debris cover. Manual digitization error was found to be on the order of 1–3 pixels at any vertex; relative errors were typically better than 5 %, varying with glacier size and conditions (i.e. debris cover) (Paul et al., 2013). For our digital datasets, we expect errors of this magnitude but also some degree of spatial variability in the uncertainty since, for example, central and north-central areas are less glaciated (i.e. less than 40 % in Figure 2b) and have larger amounts of debris cover and/or ice-cored moraines.

3 Algorithm processing system

3.1 Processing input

The input data are orthorectified satellite images or aerial photography.

3.2 Processing system description

The GAO does not have an automated processing chain. The outlines are derived through manually digitizing optical images or editing existing cartographic Shapefiles. Since GAO is only updated every 5 years or so, this is acceptable and much more accurate than automated algorithms.

Detailed information on the process is found in König et al. 2013.

3.3 Processing output

The output is a Shapefile per time epoch containing the outlines of all Svalbard glaciers.

4 Algorithm validation

The data is visually derived from optical imagery and largely based on careful analysis of professional cartographers and/or glaciologists. It is therefore not based on an unsupervised method which may introduce misclassification. The outlines were overlaid, where available, over various images to see that boundaries indeed coincide with the actual outline.

5 Conclusions

The satellite-derived glacier inventory dataset represents the most complete areal coverage of Svalbard derived within a short time span (Figure 2.1c). For this dataset, we updated front positions (retreat or advance) by clipping or extending glacier outlines from the most recent mask (depending on availability in either the S100 or 1990 inventory). For glaciers experiencing large retreat, which is the case for most glaciers in Svalbard, the valley sides were also updated because there has been concurrent shrinkage. The result for the Kongsfjorden area is seen in Figure 2.2.

The data for Svalbard glaciers are both available through CryoClim as well as GLIMS and at http://data.npolar.no/dataset/89f430f8-862f-11e2-8036-005056ad0004

References

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Acronyms and definitions

AMSR-E	Advanced Microwave Scanning Radiometer - Earth Observing System
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CEOS	Committee of Earth Observation Satellites
CSW	Catalogue Services for the Web
DB	Data Base
DOKIPY	Data handling and coordination service for Norwegian IPY projects
DOS	Dark Object Subtraction
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EEA	European Environment Agency
ERA-40	ECMWF 40 Year Re-analysis
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper plus
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCC	False Colour Composite
FCDR	Fundamental Climate Data Record
FMI	Finish Meteorological Institute
FSC	Fractional Snow Cover
FTP	File Transfer Protocol
GAO	Glacier Area Outline
GBA	Glacier Balance Area
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFL	Glacier Firn Lines
GLO	Glacier-dammed Lake Outline
GLOF	Glacier Lake Outburst Flood
GMES	Global Monitoring for Environment and Security
GPP	Glacier Periodic Photo series
GSL	Glacier Snow Lines
GST	Glacier Surface Type
GSV	Glacier Surface Velocity
HTTP	Hypertext Transfer Protocol
ICT	Information and Communication Technology
IGOS	Integrated Global Observing Strategy
IHS	Intensity-hue-saturation
INSPIRE	Infrastructure for Spatial Information in the European Community
IPY	International Polar Year
ISO 19115	Defines schema required for describing geographic info. and services
ISO 23950	Information retrieval, application service def. and protocol specification
LSA SAF	Land Surface Analysis Satellite Application Facility (EUMETSAT)
N50	The most detailed of the national map data bases in Norway
NASA	National Astronautic and Space Administration
NDWI	Normalized Difference Water Index
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NPI	Norwegian Polar Institute
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NR	Norwegian Computing Center

NRT	Near Real-Time
NSC	Norwegian Space Centre
NTNU	Norwegian University of Science and Technology
NVE	Norwegian Water Resources and Energy Directorate
METNO	Norwegian Meteorological Institute
MODIS	Moderate Resolution Imaging Spectroradiometer
MPI	Max Planck Institute for Meteorology
OAI-PMH	Open Archives Initiative - Protocol for Metadata Harvesting
OGC	OpenGeoSpatial Consortium
OpeNDAP	Open-source Project for a Network Data Access Protocol
OSI SAF	Ocean and Sea Ice Satellite Application Facility (EUMETSAT)
PHP	Originally, scripting language for web pages, now extended functionality
PMR	Passive Microwave Radiometer
PLT	Project Leader Team
PMB	Project Management Board
REST	Representational state transfer
RESTful	Systems following REST principles
RGB	Red Green Blue
SAR	Synthetic Aperture Radar
SCA	Snow Cover Area
SCE	Snow Cover Extent
SCF	Snow Cover Fraction
SCE	Snow Cover Extent
SD	Snow Depth
SIC	Sea Ice Concentration
SIE	Sea Ice Edge
SMMR	Scanning Multichannel Microwave Radiometer
SOA	Service Oriented Architecture
SRU	Search/Retrieve via URL
SSM/I	Special Sensor Microwave/Imager
STAG	Scientific and Technical Advisory Group
SWE	Snow Water Equivalent
THREDDS	Thematic Realtime Environmental Distributed Data Services
TM	Thematic Mapper
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNIDATA	Diverse community vested in sharing data and tools to access and visualize
URL	Uniform Resource Locator
UTM	Universal Transverse Mercator
WCRP	World Climate Research Programme
WCS	Web Coverage Service
Web portal	Presents information from diverse sources in a unified way
Web service	Supports interoperable machine-to-machine interaction over a network
WFS	Web Feature Service
WGS	World geodetic system
WIS	WMO Information System
WMO	World Meteorological Organisation
WMS	Web Map Service
WPS	Web Processing Service
XML	Extensible Markup Language

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