CryoClim - A New System for Cryospheric Climate Monitoring

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Abstract – The development of the CryoClim system and its associated web service was started in 2008 by a group of Norwegian organisations. When the system becomes operational, it will perform long-term systematic climate monitoring of the cryosphere. The system and service are designed to be integrated with the international system of systems for global monitoring (GEOSS) as a contribution to the Global Climate Observing System (GCOS). Based on scientific and technological results from several past and current projects, a network-based system is developed based on international standards for interoperability. The network of processing chains and databases (the nodes) will be hosted by mandated organisations in order to ensure long-term and stable operation. In 2008, a system demonstrator was developed, including prototype products for snow, sea ice and glacier variables. When the processing chains are fully implemented, the system will be used to create long time series of climate products based on earth observation data starting from the late 1970s and the beginning of 1980s.

Keywords: Climate monitoring, sea ice, snow, glaciers.

1. INTRODUCTION

Air temperature measurements show a clear trend of global climate warming during the last decades. The Arctic temperature has increased at almost twice the rate compared to that of the rest of the world over the same period. It has been generally agreed internationally that climate monitoring is urgently needed in order to quantify and better understand the climatic changes taking place. Recognising the needs of climate monitoring as stated by UNFCCC and the implementation plan provided by GCOS, the CryoClim project was started with Phase 1 in 2008.

The vision of the CryoClim initiative is to develop new operational services for long-term systematic climate monitoring of the cryosphere. The current project includes plans for development of services for sea ice and snow products of global coverage and glacier products covering Norway (mainland and Svalbard). The project is also aiming at including the glaciers in the Alps and the Greenland ice cap. The system and services proposed will be designed to be integrated into the planned international system of systems for global monitoring (GEOSS) – the part of the system aimed for climate monitoring.

The envisioned service will be provided through web services based on state-of-the-art principles for spatial data. The system tools should be state-of-the-art open solutions following international standards. The product production chains and the corresponding databases will be hosted by mandated organisations, and the service will be free of charge. The databases hosted by the mandated organisations will be integrated over the Internet in a seamless and scalable network, which is open for inclusion of other databases/sub-services in the future.

The CryoClim initiative was proposed by a group of Norwegian organisations: Norwegian Computing Center (NR), Norwegian Meteorological Institute (METNO), Norwegian Water Resources and Energy Directorate (NVE) and Norwegian Polar Institute (NPI). Phase 1 of the project was carried out as an ESA PRODEX project supported by the Norwegian Space Centre (NSC)**.

2. OVERVIEW OF THE SYSTEM TO BE DEVELOPED

2.1 System Architecture and Interoperability

The CryoClim system is a distributed system involving production chains located at several institutions. As such the CryoClim system will be a system of systems, and the focal point of the system architecture is to set up interoperability principles that support the distributed idea of CryoClim as well as the interoperability of the CryoClim system within a global environment as defined by e.g. GEOSS, WIS (WMO Information System) and INSPIRE principles. The architecture of the system to be developed (Figure 1) is fully decentralised and relies on Service Oriented Architecture (SOA) concepts and utilises web services to achieve the service orientation.

A basic design based upon SOA is in line with INSPIRE, WIS and GEOSS requirements and will ensure a potential for future development and addition of web-service interfaces as they become mature enough. Basically, SOA implies that the communication between the data user and the data provider is handled through services that may be used both interactively and as machine-readable interfaces.

The CryoClim production chains have to implement common standards in the following areas: metadata, quality information, file formats, map projections and data access interfaces.

To ensure compatibility with upcoming systems and requirements, standard interfaces will be utilised. This implies that each production chain within the system should publish data and products using OGC (OpenGeoSpatial Consortium) interfaces. Metadata should be published using OGC Catalogue Services for the Web (CSW) (with ISO 23950 binding through SRU (Search/Retrieve via URL) to achieve WIS and GEOSS compatibility). Data should be available through OGC WMS

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(Web Map Service) and WCS/WFS (Web Coverage Service/ Web Feature Service) when technology is mature enough. OAI-PMH (Open Archives Initiative - Protocol for Metadata Harvesting) and OpeNDAP (Open-source Project for a Network Data Access Protocol) will be used to achieve a jump start concerning interoperability. By using THREDDS Data Server (Thematic Realtime Environmental Distributed Data Services), both OpeNDAP, HTTP and WCS access is achieved at least when using some standard file formats. This will increase the interoperability of the system on a global basis as well as link to important communities concerning interoperability development (e.g. UNIDATA, NOAA, NASA, etc). The CryoClim service will be publicly available, and it is planned to implement the required web services using a RESTful approach.

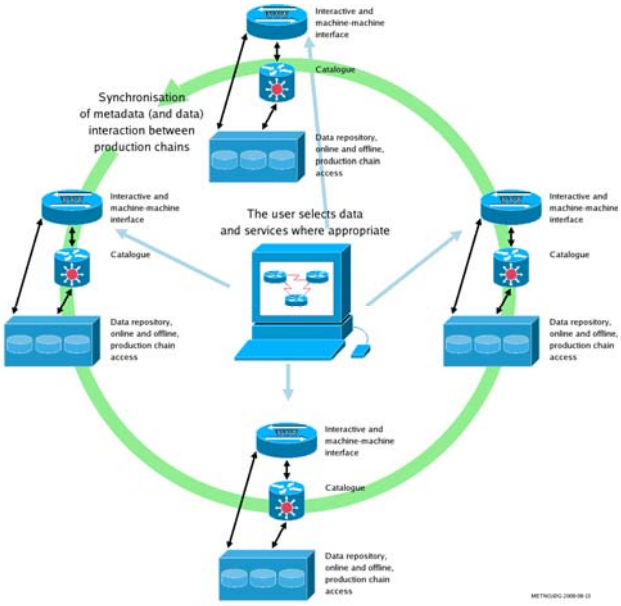

Figure 1: The CryoClim system concept, which is based upon a fully decentralised system concept. Data are not synchronised unless specifically required by some internal or external requirement.

2.2 The Portal

The CryoClim portal will offer searching, previewing and ordering of cryospheric data. The portal will allow users to preview cryospheric data in a map window. Corresponding metadata are displayed textually. In order to locate data for previewing, search queries may be formulated by selecting from lists specific values for individual search criteria. Search results are collected in a list, and may be expanded, allowing individual products to be selected for preview or download.

The CryoClim products are likely to be available through several portals, including GEOSS portals. The CryoClim portal will be developed by METNO and NR, and the operational version will be hosted by METNO.

2.3 Production Chain for Global Sea Ice Products

The sea ice products, i.e., Sea Ice Concentration (SIC) and Sea Ice Edge (SIE), are based upon EUMETSAT OSI SAF re-analysis. The SSM/I brightness temperatures are corrected for contamination arising from atmospheric water vapour content and wind roughening of the open water. The correction is computed using a radiative transfer model and atmospheric input data from ECMWF re-analysis.

The OSI SAF ice concentration algorithm development is based on testing and evaluation of a number of established algorithms. Analysis of atmospheric sensitivity showed that the Bootstrap frequency mode algorithm had the lowest sensitivity to atmospheric noise over open water. Conversely, comparison to high-resolution SAR imagery revealed that of the algorithms using the low-frequency channels (i.e. below 85 GHz), the Bristol algorithm (Andersen et al. 2007) gave the best agreement. Consequently a hybrid algorithm (Breivik et al. 2001) has been established as a smooth combination of two of the tested algorithms, the Bristol algorithm and the Bootstrap frequency mode algorithm. To ensure an optimum performance over both marginal and consolidated ice, the Bristol algorithm is given little weight at low concentrations, while the opposite is the case over high ice concentrations.

The added value of the CryoClim service to the OSI SAF products is the combination of products into aggregated climate products, adding standardised quality information to each product and providing sea ice products that are consistent with the other products delivered by CryoClim. The sea ice production chain will run in the METNO production environment.

2.4 Production Chain for Global Snow Products

The planned snow sub-service will provide various products for Snow Cover Extent (SCE; binary snow/no-snow products) and Fractional Snow Cover (FSC; percentage of snow cover). This sub-service will be developed by applying a similar production chain as for sea ice and by adapting algorithms and algorithm experience from other projects. The longest time series of historical snow products, all of 10 km spatial resolution, will be based on passive microwave data from SMMR (from 1978) and SSM/I (from 1987). An optical product (of 1 km spatial resolution) is also planned, based upon the NOAA AVHRR satellite/sensor series.

The most advanced snow cover product envisioned for the snow sub-service is the multi-sensor time-series product. The idea here is to fuse passive microwave data with optical data through a model for retrieval of the snow cover variable at much higher quality and resolution than is possible with passive microwaves alone. NR has developed such a method combining optical and SAR data (Solberg et al. 2008). A similar approach can be applied for optical and Passive Microwave Radiometer (PMR) data. Such an approach will, hopefully, solve the most significant deficits of snow retrieval algorithms for passive microwave data (often related to wet snow and mountainous terrain). The product will be a novel contribution to global snow monitoring as there is no such high-resolution product available today covering several decades, and no product at all fusing optical and PMR data in a sound way. The snow production chain will run in the METNO production environment.

2.5 Production Chain for Glacier Products Mainland Norway

Glacier products for mainland Norway will consist of Glacier Area Outline (GAO), Glacier-dammed Lake Outlines (GLO) and Glacier Periodic Photo series (GPP) products. In addition glacier products Glacier Snow Line (GSL) and Glacier Firn Line (GFL)

will be considered. All these products, except GPP, are based on Landsat TM/ETM+ imagery using image analysis and GIS techniques.

In a pilot study in the Jotunheimen mountain region, Norway, the applicability of standard glacier mapping methods for deriving GAO were tested using segmentation of ratio images computed from the raw digital numbers for Landsat TM (Andreassen et al., 2008). The results confirmed that the applied method was robust and highly accurate for extracting glacier outlines in Norway. For the CryoClim service, the methods will be tested for all glaciated areas. In each area the algorithm will be tested and adjusted if necessary. The algorithms required to effectively extract glacial variables from satellite images depend upon illumination condition, landscape types and scene conditions. Manual adaption is needed to check the suitability of algorithms for each region and scene. The product processing chain for glacier products covering mainland Norway will be hosted by NVE.

2.6 Production Chain for Glacier Products Svalbard

At Svalbard about 1500 glaciers have been defined with a total area at about 36,000 km^2. To monitor these glaciers efficiently there is a need for methods and algorithms which can be run more or less automatically based on remote sensing data. It is known that most of the glaciers at Svalbard are 'surging glaciers'. This causes very nonlinear changes in mass balance depending on whether a glacier is in a surging period or not. The work will mainly focus on establishing the necessary algorithms and a production chain which can provide useful information about changes in the mass balance.

The glacier products available for Svalbard in the CryoClim service will be Glacier Surface Type (GST) and Glacier Balance Area (GBA). These products are produced with the use of different image classification techniques on C-band SAR images. The historical satellite data we (NPI) have available in C band is from ERS-1/2, Envisat ASAR and Radasat-1/2.

An automatic method for classification of the glacier surface based on texture and the amount of backscatter in SAR images has been developed. This algorithm is also using information from different polarisation to increase the classification accuracy, when available. The work is an extension of the work done earlier at NPI in EuroClim (König et al. 2004). This algorithm is used as baseline for the classification of the facies, but with the possibility for an operator to do manual adjustments of the result. The results look promising for the glaciers where field data is available for validation. A correlation between k-means classification and mass balance for some glaciers in Kongsfjorden at Svalbard has been found in EuroClim (König et al. 2004). This algorithm will be used as a baseline for the GBA product. The glacier production chain will run in the NPI production environment.

3. EXAMPLE PRODUCTS

Demonstration samples of climate products have been developed in the first phase of the project. Their design and content are equivalent to real climate products to be delivered by the operational system, but their content is not necessarily representing the real world as the retrieval algorithms and processing system are not yet developed.

3.1 Global Sea Ice Products

Demonstration products for sea ice have been made for monthly Sea Ice Concentration (SIC) for the northern hemisphere covering the period from 1988 to 2007. The monthly products are based on daily products from the ongoing EUMETSAT OSI SAF reprocessing project for historical SMMR and SSM/I data. The reanalysis produce a consistent data set for sea ice concentration and ice edge, both swath data and daily accumulated data, going back to 1978. The resolution is 10 km.

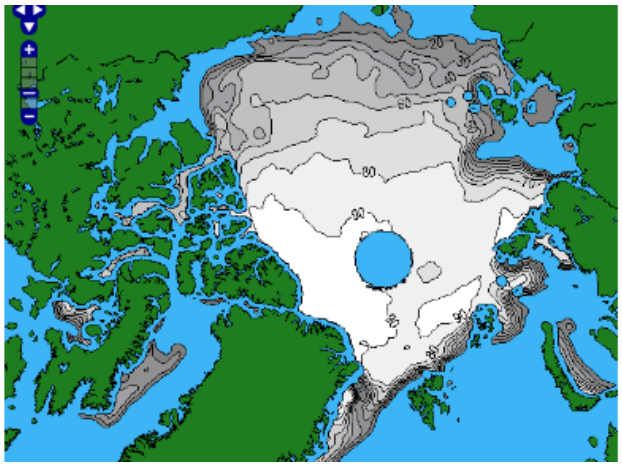

Figure 2: Examples of sea ice concentration product.

3.2 Global Snow Products

Demonstration samples for snow products have been made for Snow Cover Extent (SCE), Fractional Snow Cover (FSC), Snow Water Equivalent (SWE) and Snow Depth (SD). The global products have been separated into three different regions: Northern region (northern part of the northern hemisphere, including USA, the mountains of North Africa and the Himalayas); Equator region (from north of Africa to south of South America) and Southern region (Antarctica). The demonstration products have been made from AMSR-E and MODIS data.

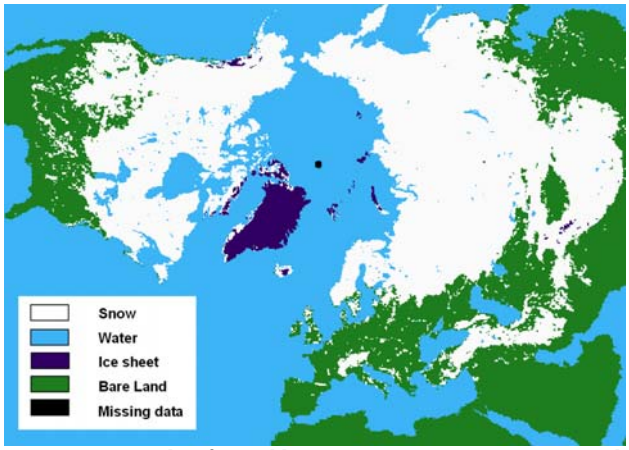

Figure 3: Example of monthly average snow cover area (March 2008). This is a demonstrator product not necessarily showing the actual snow situation at that time.

3.3 Glacier Products Mainland Norway

For mainland Norway, demonstration sample products have been made for Glacier Area Outline (GAO), Glacier Snow Line (GSL), Glacier Firn Line (GFL), Glacier-dammed Lake Outline (GLO) and Glacier Periodic Photo series (GPP). The glacier products for mainland Norway are derived using Landsat images of 30 m resolution.

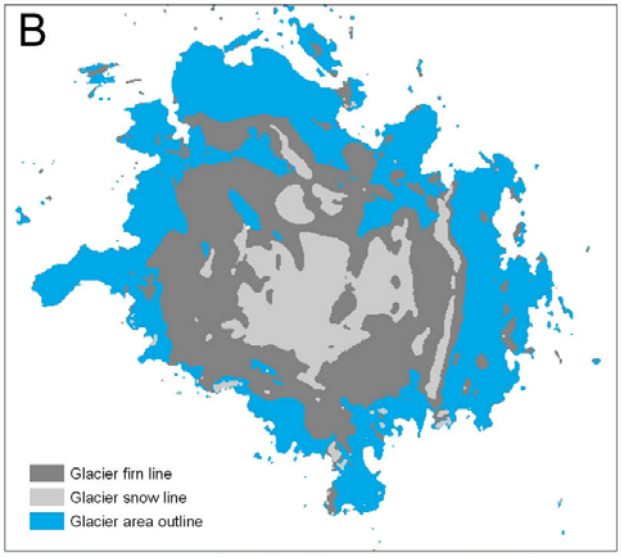

Figure 4: Glacier Area Outline, Snow Line and Firn Line for Hardangerjøkulen glacier in southern Norway.

3.4 Glacier Products Svalbard

For glaciers in Svalbard, demonstration sample products have been made for Glacier Surface Type (GST) and Glacier Balance Area (GBA). The glacier products for Svalbard are derived using SAR images of 10-75 m pixel spacing.

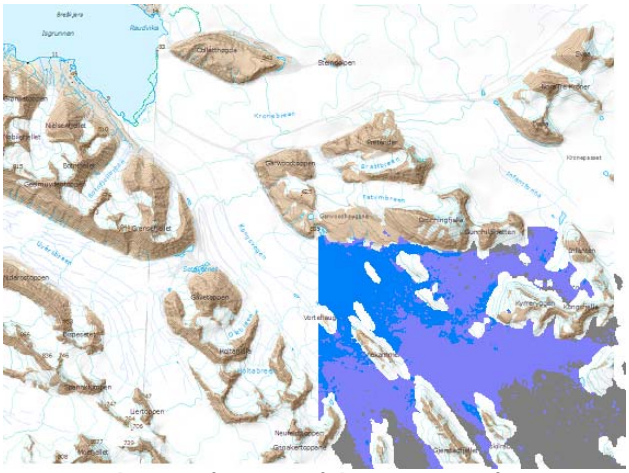

Figure 5: Glacier surface type of the upper part of Kongsvegen (blue = ice, violet = superimposed ice, grey = firn, transparent = no classification area).

4. DISCUSSION AND CONCLUSIONS

The vision of the CryoClim initiative is to develop new operational services for long-term systematic climate monitoring of the cryosphere. The system and services proposed will be designed to be integrated into the planned international system of systems for global monitoring (GEOSS) – the part of the system aimed for climate monitoring. Based on scientific and technological results from several past and current projects, it is proposed to develop a network-based system building on standards and communication languages identified by GMES and GEO for the global system of systems. The network of processing chains and databases (the nodes) will be hosted by mandated organisations in order to ensure long-term and stable operation.

The development of this system will draw on the pool of institutions that has developed the current knowledge and technology base for remote sensing of the cryosphere and data processing and management. Our ambition is that the new system we will develop, including the web-based service and the new and accurate climate products, will represent a significant contribution to the very important task of monitoring the development of the climate on our planet.

The current version of the CryoClim concept consists of world-wide monitoring of sea ice and snow, while glacier monitoring is limited to Norway (the mainland and Svalbard). However, the project vision is to include more land ice. It is recognised that it would be of particular importance to include the monitoring of Greenland – the second larges ice cap on Earth – and the glaciers in the Alps, where climate changes are taking place rapidly.

REFERENCES

Andersen, S., R.T. Tonboe, L. Kaleschke, G. Heygster, L. Toudal, 2007: *Intercomparison of passive microwave sea ice concentration retrievals over the high concentration Arctic sea ice*, JGR, VOL. 112, C08004.

Andreassen, L. M., Paul, F., Kääb, A., and Hausberg, J. E. 2008: Landsat-derived glacier inventory for Jotunheimen, Norway, and deduced glacier changes since the 1930s. *The Cryosphere*, 2, 131-145.

Breivik L.-A., S. Eastwood, Ø. Godøy, H. Schyberg, S. Andersen, R.T. Tonboe, 2001: Sea Ice Products for EUMETSAT Satellite Application Facility. *Canadian Journal of Remote Sensing*, Volume 27, No. 5.

König, M., Winther, J.-G., Kohler J. and König, F., 2004: Two methods for firn area and mass balance monitoring of Svalbard glaciers with synthetic aperture radar (SAR) satellite images. *Journal of Glaciology*, 50, 168, 2004.

Solberg, R, Huseby, R.B., Koren, H. and Malnes, E. 2008. Time-series fusion of optical and SAR data for snow cover area mapping. *Proceedings of* 5th *EARSeL LIS-SIG Workshop*: *Remote Sensing of Land Ice and Snow*, Bern, February 11-13, 2008.