GMES Service Snow and Land Ice

Reporting

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<th>Project Information</th>
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<tbody>
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Final Report Summary - CRYOLAND (GMES Service Snow and Land Ice)

Executive Summary:
In the FP7 project CryoLand services on snow and land ice monitoring have been developed and implemented in order to match the needs of a broad user community. The products and services build upon data from a variety of Earth Observation satellites. They are ready to fully exploit the potential of the new European Copernicus Sentinel satellite constellation. Fully validated products on snow cover, glaciers and lake/river ice from local to continental scales, conforming to the INSPIRE/GEOSS standards, are delivered to the stakeholders in near real time. In CryoLand concepts and tools have been also developed for operational Copernicus Snow and Land Ice Services, including the option to extend the services to global monitoring of snow and ice.

The CryoLand services on accurate and timely observations of snow and land ice by means of satellites are supporting many environmental and resource management activities in Europe. Seasonal snow cover and glaciers are important resources, supplying major parts of Europe with fresh water for human consumption, agriculture, hydropower generation, and other economic activities. On the other hand, there are natural hazards directly or indirectly arising from snow, glaciers and lake / river ice, including avalanches, snowmelt floods, water outbreak from glacier lakes, and ice jams on rivers. The users of the CryoLand services include organisations operating in the field of water resources management, hydropower production, energy trading, natural hazards mitigation, transportation, construction activities, climate monitoring and modelling, weather prediction, agriculture, tourism, and environmental agencies.

Specifications for snow and ice products and for the CryoLand Geoportal were elaborated together with the CryoLand User Group, comprising more than 60 organisations from 15 European countries and Greenland, and 3 European Institutions. The primary snow products are pan-European and regional maps of snow extent (including fractional coverage) from optical satellite data (MODIS, future Sentinel-3), maps of melting snow from imaging radar (Radarsat-2, Sentinel-1), and low resolution maps of snow water equivalent (from microwave radiometry). Regional snow products, optimized for the users’ needs, include spatially detailed maps of snow extent from optical satellite data for the Alps, Scandinavia and the Baltic region and snowmelt area for mountainous regions derived from radar imagery. Lake and river ice products for northern Europe are generated in near real time from optical satellite data and radar images. The primary lake / river ice products are the extent and concentration of lake ice, and ice cover on rivers.
Glacier services, operating on user request, have been provided for various glacier regions using high resolution satellite imagery (SPOT-5, Quickbird, Ikonos, Landsat, Sentinel-2). Products include glacier area and outlines, maps of snow/ice areas on glaciers, ice surface motion, and glacier lakes. Within CryoLand products on glaciers in the Alps, Scandinavia, Greenland, Kyrgyzstan, and Bhutan were generated for individual users. Several of the services are being carried on after the lifetime of the project, in order to enable a smooth transition to upcoming Copernicus pan-European snow services.

The developed services and methods are capable to immediately utilize data from the various satellites of the European Copernicus Sentinel satellite constellation. The first satellite, Sentinel-1A, was launched in April 2014. Demonstration products on snow cover and glaciers have been generated already in the ramp-up phase after satellite launch. The Sentinel satellite missions will offer an excellent and comprehensive database for climate monitoring and operational applications with long-term continuity.

In order to ensure timely and efficient delivery of CryoLand snow and land ice products, a powerful service infrastructure has been developed and implemented, based on interoperable and standardised Web services. It enables interactive viewing, selection and downloading of single products and time series, and provides also automatic download options for operational user applications. The CryoLand products and services are freely accessible at the CryoLand project Web page http://www.cryoland.eu.

CryoLand Services were advertised at many international conferences. The dissemination activities have been supported by more than 50 printed articles and oral presentations. In several dedicated sessions user organisations were trained on access to the services and the integration of the products into various application environments. Dissemination Workshops with more than 50 participants were held in Oslo and Innsbruck in 2014, attracting also new user organisations. The CryoLand project partners elaborated an exploitation plan, taking into account existing users as well as the attraction of new customers, outlining a commercial business model, and planning extended exploitation activities within the project consortium and with users.

Project Context and Objectives:

BACKGROUND

Snow and land ice are key elements of the water cycle and are important resources, supplying major parts of Europe (but also in many other regions in the world) with water for human consumption, agriculture, hydropower generation, and other economic activities. The presence of snow and ice affects the radiation and energy balance of the Earth’s surface and has an important role in regulating the climate on Earth. Seasonal snow is present in Europe for 30 days to more than 150 days in Alpine regions and for 150 to 300 days in Scandinavia. Therefore, accurate characterisation of snow extent and snow conditions is important for weather prediction and climate monitoring. The variations at daily to seasonal time scales are superimposed to long term trends for all the parameters of the land cryosphere which have been observed during the last decades and are attributed to climate change. Glaciers are located in mountain regions, but they are having wider socio-economic impact as resource as fresh water supplies, especially during warm dry periods, providing headwaters to several large river systems in Central and Eastern Europe which transport water downstream into lowland regions where water is needed for human water consumption, irrigation etc. UNEP (2007) reports that 1.5 to 2 billion people are living in regions, where reduced water flow due to retreat of the seasonal snow cover and glaciers could cause major water shortages. Beside
this, glaciers and especially their temporal changes give also an important insight into climate change.

Various natural hazards are directly or indirectly related to the seasonal snow, glaciers and lake / river ice, including snowmelt flooding, droughts, avalanches, river ice jams and related floods, etc. Seasonal snow has also an impact on the availability of water for irrigation and agricultural activities. Snow load is an important safety and operation issue concerning construction activities for buildings, hydropower reservoirs and power lines. Additionally, transport and logistics are affected by snow conditions in the European regions of seasonal snow cover; this includes such economically important activities as timber collection from woodlands, where the presence of snow enables the manoeuvring of forestry machinery and wood transport.

Snow, lake ice and river ice are characterized by high temporal variability. At short time scale the extent and properties of snow cover and freshwater ice are driven by meteorological events. The year to year variability of these cryospheric parameters is also very high. Due to this high spatial and temporal variability, satellite sensors are the optimum tool for snow and ice monitoring. Accurate observations of snow cover extent and physical properties are not only of interest for climate change research, but are of great socio-economic importance. Snow and glacier melt is a dominating source of runoff in many parts of northern Europe, as well as in the Alps and other European mountain ranges.

The FP7 project CryoLand addressed the continuous and accurate monitoring of snow, glaciers, lake ice and river ice, a theme which is of high socio-economic relevance to the European citizen. A self-sustainable service was developed and implemented in order to support the better management and realisation of a wide range of economic and ecologic activities related to snow and land ice being major natural resources and essential elements of the environmental and climate system. CryoLand capitalized on the high investments in the space sector made in Europe and world-wide by utilizing data from the flagship of the European Earth observation satellites, the Sentinel satellite family.

OBJECTIVES

The primary CryoLand project objectives were to develop, implement and validate an operational sustainable service for monitoring snow and land ice as a Downstream Service within Copernicus in a value added chain with the Land Monitoring Core Services. CryoLand provided geospatial products on the seasonal snow cover (snow extent, snow mass, melt state), glaciers (area, snow / ice extent, ice velocities, glacier lakes), and lake / river ice (extent) derived from Earth observation satellite data in response to user needs. Processing lines and service infrastructure for various product types were adapted to match the user needs. Snow and land ice products at near-real time delivery were supplied with pan-European coverage, as well as with national and regional coverage in Europe and on other continents as required by the users.

To reach the overall aim several sub-objectives were specified:
• Definition of a framework and specifications for the snow and land ice monitoring services and products based on requirements of users from different application fields. The objective was to define in detail the products and services needed by specific user groups as well as by individual clients. The user needs
were collected in workshops, a web survey and by direct consultations and took into account previous and other satellite snow and land ice monitoring activities. This guided the development of geospatial infrastructure, of snow and land ice products and of related services in the project.

• Design, development and implementation of a system for CryoLand services with interoperability of the infrastructure by compliance with INSPIRE and GEOSS. CryoLand was implemented on top of existing Web service environments (decentralized business process architectures) supporting the publication, provision and chaining of geospatial data services according to INSPIRE and GEOSS und integrating Copernicus Land Monitoring Core Services.

• Design, development and implementation of Internet based interfaces to integrate the geospatial infrastructure developed in the project, in order to allow for efficient user interaction and access to the products. User information services offering interactive maps, search and order functions via Web browsers were designed in a corporate “CryoLand Geoportal”. The objective was to provide virtually centralised access to services provided by the cooperation among partners for the delivery of products at different levels of geophysical product generation and of Enterprise System Interfaces for CryoLand service integrations into external user applications.

• Augmentation and improvement of the portfolio of snow and land ice products and services tailored to specific customer needs. The objective was to develop and validate products and processing lines for tailored snow, glaciers and lake / river / ice products and services as requested by user groups and individual users.

• Development and implementation of tools for integration of snow and land ice products from satellite data with non-space-based data (in-situ measurements, model output) in order to improve the quality of the CryoLand services. The aim was to develop, implement, and validate tools for integrating data and products from different sources and to make them accessible through the CryoLand Geoportal. This included tools for the integration of CryoLand products into hydrological and glaciological process models.

• Support and train users for accessing and using the CryoLand Geoportal and Products. The objective was to inform and train the users in the frame of workshops, training sessions or bilateral trainings, on the access and use of the CryoLand Geoportal and products and support the integration of CryoLand Services into their applications.

• Perform thorough testing, validation and qualification of the snow and land ice monitoring system in pre-operational environment. The objective was to perform full end to end system tests of the various components of the CryoLand system and verification in pre-operational environment.

• Development of tools for utilization of Sentinel satellite data for snow and ice monitoring services. The aim was to prepare the software and processing lines for generating snow, glaciers and lake / river ice products using EO data from Sentinel-1 (SAR), Sentinel-2 (high resolution optical) and Sentinel-3 (medium resolution optical) satellites. After operationalisation Sentinel satellites will provide the main EO data for running the services.

• Preparation and initiation of a self-supportive operational snow and land ice monitoring system: A final objective of the project was the transition to an operational self-supportive snow and ice monitoring service before the end of the project by running full performance demonstration of the system, by promotion and dissemination work. The project aimed to perform demonstration of the services during 2 winter periods.

Project Results:

REQUIREMENTS AND SPECIFICATIONS OF SNOW, GLACIERS AND LAKE / RIVER ICE

PRODUCTS AND SERVICES
An important role in the project was the establishment of links to potential users of the CryoLand system. The interaction with the user group was important not only for assessing requirements and tailoring products and services to user needs, but also to encourage and support users in the exploration and evaluation of the CryoLand system, and eventually contribute to a future interest in the CryoLand system.

CryoLand applied multiple approaches to obtain requirements on products and services from the users from a wide application field, which guaranteed that the products and services match the user needs. First the specifications of products and services of previous user surveys and user recommendations for snow, glacier and lake/river ice products and services as specified by international working groups and organisations as well as from projects carried out since 2000, including GCOS, IGOS, EC and ESA projects were reviewed.

The preliminary product and service requirements were presented and discussed at 4 user requirements workshops held in Vienna, Oslo, Helsinki and Bucharest in May and June 2011. Parallel a web survey was initiated asking for input on the organisation itself, the present use of snow and ice information in their application field, specific requirements for various products and technical information on services and interfaces. The User Group was officially formed after the user requirement questionnaire following the initial workshops held in the first period of the project. Users involved in this process formed the core of the CryoLand user group, where further organisation joined during the life time of the project.

The product specifications were consolidated at a User Coordination Meeting held in May 2012 in Stockholm. The basis for the workshop was a first CryoLand Pilot Snow Service running for the period February to March 2012. The updated products and services were provided to users in the second Pilot Services held in the period December 2012 to June 2013, which enabled the users to test and evaluate the concept of the CryoLand System and to provide feedback to Service developers. At the Interim User Validation Workshop, held in Copenhagen in June 2013, users provided feedback and a first evaluation of the services which was used for final adjustment of the services and products. The user group interaction was concluded by the 2 Dissemination workshops held in Oslo and Innsbruck in October and December 2014, respectively.

In preparation for the demonstration phase in winter 2013/14 the CryoLand team organized and held user trainings at various places in Europe (Norway, Finland, Austria, Romania, Sweden) for accessing and downloading CryoLand products and they supported the various users for integrating CryoLand Services in their applications. The user support also includes a written user guideline (“CryoLand for Newbies”) and extensive help documentation at the CryoLand data portal.

The CryoLand User Group includes in total more than 60 organisations from 15 nations in Europe (Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Italy, Norway, Romania, Slovenia, Sweden, Switzerland, and United Kingdom) plus Greenland, and 3 European Agencies. A core group of about 30 individual users have been actively involved in the evaluation of the CryoLand system, presenting their experiences at the workshops held by the project. The data download statistics indicate additional user activity in Australia, Belgium, Canada, China, Estonia, France, Germany, Japan, Kenya, Switzerland, Taiwan, and United Kingdom. The national institutes, universities and private companies
represents user interest within space/remote sensing, environmental protection, weather and hydrological services, climate change, natural hazards, infrastructure, and energy/hydropower.

CRYOLAND SYSTEM ARCHITECTURE AND INTERFACES

The CryoLand System Architecture and the Interfaces of the geospatial infrastructure were designed in a way to match the system requirements collected during the user workshops but also to follow the guidelines of international standards like INSPIRE / GEOSS and OGC and, in the case of glacier products, the GLIMS specifications. This allowed the user to access the CryoLand products and datasets online in a seamless way, and the direct integration of the provided products and datasets into the user’s application system (e.g. GIS, modelling environment, etc.).

The system and geoportal design was based on the infrastructure, data-interface requirements and the product specifications collected and consolidated in the user workshops and contributions from CryoLand partners. This phase was followed by the definition of the required Internet Interfaces and Functionalities to fulfil the user requirements but also to ensure that CryoLand used advanced technologies providing a modern geospatial infrastructure anticipating future needs. The definition and the architectural software design of the Network services of CryoLand has been documented in detail in the Architectural Design Document.

The implemented CryoLand System builds on widely proven Open Source Software Tools (e.g. Python, MapServer, GDAL, PostgreSQL/PostGIS, EOxServer, etc.). These tools were complemented by new implementations to cover system requirement of the user, which were not covered by pre-existed software tools. This includes also the set of software routines implemented to innovatively integrate existing Open Source software tools to form the CryoLand Server System.

A design decision towards the full exploitation and implementation of OGC web service standards for all external interfaces has been agreed upon. For the internal product exchange between project partners and the CryoLand Server, the FTP protocol has been chosen as already established distribution channels existed between the CryoLand partners. The processes between the CryoLand Product and Service Providers and the CryoLand Project Server have been fully automated. Once a product was made available by the Product Provider the product was automatically collected, registered and pre-processed to optimize viewing experience in the webGUI. The high degree of automated data handling led to an overall high availability of the CryoLand Service interfaces since the beginning of its operation.

In order to enable potential users to evaluate CryoLand products and services as early as possible the consortium initiated an additional effort and started with an early operation of the prototype system and products already in the winter season 2011/2012. This early setup of the CryoLand service was intended primarily for internal testing of work-flows and as a limited, first evaluation access point for certain users. It allowed to gather first user responses and helped to evaluate, streamline, and verify some of the requested user requirements. Additional input from the users was included in version 1 of the software release.

Starting with March 2012 the CryoLand GeoPortal Version 0.9 was brought online and is since then fully
accessible for anybody interested in Snow and Land Ice Information Products over the Pan-European region. The GeoPortal access offers fully interoperable interfaces based on the internationally widely used OGC standards WMS and WCS. Two access points, both based on these OGC services were implemented:

- a webGUI providing a viewing/portrayal (WMS) and downloading service (WCS), mainly intended for direct interactive usage
- an access for Enterprise usage (e.g. for direct data integration into customers GIS or modelling environments), mainly intended for customers who either need to access large volumes of data (e.g. longer time-series) or need regular access e.g. daily dataset) to test the services in a pre-operational environment.

To provide initial support to customers for usage of the Enterprise access point demonstration scripts (in python, or IDL) were provided to users. The specifications a user can provide to customize the CryoLand products of interest include

- selection of the desired Dataset Series
- selection of the desired Area Of Interest (AOI)
- selection of the desired Time Of Interest (TOI)
- selection of the desired output file-format
- selection of the desired output coordinate reference system (CRS, projection)

The user provided information is integrated into the WCS request and the GeoPortal generates the customized datasets on-the-fly and provides them to the user. During various User Workshops this functionality of the CryoLand GeoPortal, of automatizing and customizing the access has been demonstrated and received wide positive interest in the user community. Automatizing and customizing access to geospatial information (and remote sensing images) data products has been recognized as innovative and very helpful, especially by users with regular data needs or the requirement to analyse a time-series of a product.

Despite the consolidated user requirements the webGUI interface of the GeoPortal has undergone three development and release cycles which where all influenced by user experience and user feedback (mostly collected during user workshops). This finally resulted in a lean, agile and highly streamlined webGUI with an optimized interface.

In April 2013 the CryoLand team, following a request by EEA, decided to immensely extend the time period for which Pan-European snow products. This resulted in a considerable increase in the number of datasets to be provided via the CryoLand GeoPortal causing performance problems at the server and the interfaces alike. CryoLand provided three daily datasets starting from 1 November 2000 and the project team agreed to extend the production of these products also after the official end of the project in January 2015 until 2016/17. The additional requirements for the larger number of products demanded an update of the GeoPortal (server and webGUI). Concurrently the initially offered OGC interfaces (WMS and WCS) had to be changed to utilize the EO Application profile of the corresponding service (EO WMS and EO WCS) since the result generated by a basic WMS-GetCapabilities exceeded 16MB and the time effort for such a request easily reached 20 minutes. This was caused by the fact that the basic WMS standard was not designed for such a number of datasets. Therefore, the EO-Application protocol has been
standardized to take care of these cases. The upgrade of the Server and webGUI and the general utilization of the EO-Application profile (EO WMS and EO WCS) resulted in a significant performance boost.

The final upgrade of the CryoLand Server improved the performance in handling large data sets and updated the navigation on the Geoportal webGUI interface. Especially the selection of time series of products has been optimized. The webGUI (shown in Figure 2.4) was extended by the following features:

- Zoomable Time-Slider - for pleasant navigation
- Dataset indicators – zoom to dataset extent
- Refined Dataset grouping, together with overlay masks
- Datasets intuitively sortable in layer menu
- Streamlined download procedure
- Additional output file formats
- Additional output projections
- Capability to store/reload AOIs as GeoJSON files
- OGC support optimized to EO-WMS and EO-WCS

By project end in January 2015 the CryoLand GeoPortal offered about 20,000 snow and lake/river ice as well as glacier products (http://neso.cryoland.enveo.at/cryoclient).

CRYO LAND SNOW PRODUCTS AND SERVICES

The snow products generated and delivered in the project are based on optical (radiometer) and microwave (synthetic aperture radar, SAR, and passive microwave radiometer, PMR) satellite imagery. The snow variable retrieval approaches are using single, dual and multi-sensor algorithms. The project partners have been working on advanced retrieval methodologies in many years and made important contributions to innovative algorithms. The project consortium stands internationally at the leading edge of this development. The specifications of the CryoLand Snow Products were defined in close collaboration with the CryoLand user group.

The product portfolio includes pan-European snow products from medium resolution optical and passive microwave radiometer data provided daily in near real-time. Regional fractional snow cover products were generated for Scandinavia, Central Europe (Alps) and Baltic Sea region for local and regional users. Beside snow extent from optical data also maps of the snow conditions (wet snow) are specified using SAR data especially for mountain regions. These products were generated applying algorithms adapted to the characteristics of the region (topography, forest, etc.). Prototype products of snow surface wetness and snow surface temperature from optical satellite data were generated for southern Norway.

The Pan-European Fractional Snow Cover (FSC) is a homogenized product for large areas developed by ENVEO in cooperation with SYKE. The product uses medium resolution optical satellite data from Terra MODIS (Sentinel-3 in the future) and extends from Scandinavia in the north to northern Africa in the south, and from Portugal in the west to the Caspian Sea in the east (from 72°N/11°W to 35°N/50°E). The
algorithm compensates for the effects of the forest and estimates the below-tree FSC. The product, and an associated accuracy estimation per pixel, is provided daily with 0.005° spatial resolution (approx. 500 m).

The Snow Water Equivalent (SWE) product is based on the combination of satellite-based passive microwave radiometer and ground-based weather station data applied in a SWE model. Nimbus-7 SMMR (1980–1987), DMSP SSM/I (1987 to present) and Aqua AMSR-E are the main data sources.

Non-mountainous areas within the pan-European domain are covered by the CryoLand implementation of the SWE service. The pan-European domain SWE maps are provided with 0.1° spatial resolution (approx. 10 km).

Reprocessing of pan-European fractional snow cover product and the snow water equivalent product back to 2000 has been done in order to support European users.

CRYOLAND GLACIER AND LAKE RIVER ICE SERVICES

Glacier products were generated and provided on users’ demand for their particular areas of interest. The glacier product portfolio included glacier outlines, snow and ice areas on glaciers, glacier lake extent, and ice surface velocity on glaciers. For the product generation very high resolution optical and radar satellite data are used, which were ordered especially according to user needs and received through the Data Warehouse system of EC. The applied processing lines for the glacier products generation available at ENVEO and GAMMA are in general operational, but were adapted to the very high resolution satellite imagery, which enabled the products generation with a high spatial accuracy. The products, meeting the internationally accepted format standards for glacier products identified by the Global Land Ice Measurements from Space (GLIMS) project, were directly provided to the interested users.

Lake Ice and River Ice Services were provided by the project partners SYKE and NORUT. SYKE has renewed its Lake Ice algorithm and accordingly the products. Previously the lake ice was mapped with Snow on Ice algorithm, which provided fractional snow cover over lake ice. The difficulty with the earlier algorithm was in distinguishing between snow and clear ice or snow-ice partially covered with snow. Another algorithm providing binary ice extent was in development stage. Based on these two prototype products an advanced algorithm, providing information on four classes (full snow cover, partial snow/white ice, clear ice and open water) was developed. The method uses Terra/MODIS 250m reflectance data as input. In the development phase, the extensive in-situ monitoring network of SYKE was exploited. The method can also be transferred easily to other optical satellite sensors. SYKE conducted in-situ observations of ice cover, ice thickness and thickness of snow cover over lake ice at several sites in Finnish inland waters. Finding the reference reflectances for the algorithm was based on comparing time series of MODIS/Terra reflectances to the snow thickness over selected monitoring sites.

An improved automated processing line for SYKE’s Lake Ice Extent with Optical EO Data product was developed and implemented. The new processing line arrangement was implemented in collaboration with FMI. Automated pre-processing of optical EO data for the Lake Ice Extent product was carried out at FMI.

This included cloud detection from MODIS/Terra data (500m and 1km channels) to create the cloud mask.
The MODIS/Terra 250m channel 2 (841 – 876 nm) was used for lake ice interpretation. The generated product was passed on to SYKE’S processing chain where it was packaged and further distributed via web-services and archived. The initial validation of the product gave overall accuracies of 86% and 74% for two high-resolution datasets from Landsat TM and SPOT-4, respectively.

For the Lake Ice Extent with SAR Data, River Ice Extent and Flood Inundation Area products NORUT has completed automated processing chains in IDL utilizing processing tools for SAR geocoding and classification, along with a long series of in-house NORUT developed processing tools (image reading, geocoding, classification, product export, etc.). The main step in the processing chain for the lake Ice Extent product from SAR Data is the lake ice classification module. This module uses state of the art imaging processing algorithm to identify pixels that are covered by ice and pixels not covered by ice (binary classifier).

River ice extent (RIE) is a product derived from SAR images that gives a binary classification (ice / open water) of river stretches. The classification algorithm for RIE is the same as the lake ice extent algorithm, but since rivers are more narrow, higher resolution SAR data (<25m or better) are preferred as they provide more accurate products. The automated algorithm for flood inundation area detection depends on accurate maps for water bodies. Areas outside the water bodies are subsequently classified into water or not-water based on the same statistical algorithm that is used for lake ice classification. First examples of lake ice maps using Sentinel-1A data was produced in January 2015 during the ice development period.

INTEGRATION OF IN-SITU DATA INTO CRYOLAND SERVICES

In-situ data was an essential part of the development of CryoLand services and in the generation of products. The wider use of in-situ data required that the data sets were available through standardized interfaces following a harmonized data model. These requirements meet also the principles of the INSPIRE directive. In CryoLand, recommendations for commonly used data model and standard interfaces were elaborated. The acceptance and wider implementation of the recommended data model requires national and institutional level discussion and decisions.

The CryoLand data model and interfaces follow the specifications of the INSPIRE directive, which strongly supports and provides guidelines for the interoperability of spatial datasets. The defined data model is capable to store single in-situ measurements (e.g. snow height at a certain location at a certain time), but also modelled values and their representative spatial features. Starting point of the development of the data model was carried out by analysing the current snow monitoring in CryoLand partners’ Institute. The description of snow course networks and current data models were obtained from SYKE, Meteo Romania, and SMHI. Based on a brief study concerning delivered metadata the snow course data contain at least the information of snow depth, snow water equivalent, snow density and snow cover in the area (patchiness) at a certain time. Snow courses were identified by its name and id-code. Location information was always known for a representative point, but location information of snow courses was available for multiple points along a track.

The proposed CryoLand data model was designed to store snow information. Beside the mandatory
attributes, additional attributes widen the information of the site if available. The code lists can be extended to include other phenomena if needed. The measuring methods and description of the sensor varies by different data providers and need to be described in the procedure table. The defined CryoLand data model and guidelines for harmonization were and are important for the users of in-situ data, but also for the provider of the data. The data model and the interfaces for accessing in situ data within CryoLand were documented in Deliverable D7.1 - Description of Data Models, Guidelines for Harmonizing and Publishing Datasets.

The snow parameter list has been specified to support the implemented CryoLand products, but can be extended for upcoming products. For each parameter a recommended unit, the describing feature, the sensor type, the data type of the measurements and the short description is given. For several parameters, key words need to be defined. The proposed data model was tested by transforming SYKE’s snow course data into the CryoLand data model. The overall harmonisation process including the ETL (extract, transform and loading) process to be used by data providers.

Spatial location is crucial information connected to in-situ measurement data. Usually measurements take place each time at same locations. When the coordinates of these sampling points are known, a spatial data set can be created using this information and then publish via WMS (Web Map Service) and WFS (Web Feature Service) interfaces. These standard interfaces allow easier access to data. WFS provides access to vector-based geographic features encoded in GML. It enables among other things querying the data based on coordinates and attributes of features. The data on WFS interface can be exploited as an input data source for analysis processes, which require to use this kind of data. Using WFS, the data can also be exported to the user’s computer in a different format like ESRI Shapefile, if the user’s application is capable to import that. In addition to visualization and querying spatial features and their attributes the user might like to query observations and get for example time series of observations. SOS (Sensor Observation Service) interface is developed for sensor data, but it can be also used for publishing other kind of observation data.

In the CryoLand project spatial locations of Finland’s snow courses were published via WMS and WFS. Also the SOS interface was implemented for observational data of them. The publishing was based on following software: MS SQL Server, ArcGIS for Desktop, ArcGIS for Server and SOS extension for ArcGIS Server. The implementation process in SYKE is described in Deliverable D7.1 Description of Data Models, Guidelines for Harmonizing and Publishing Datasets. Besides the above described commercial software used in SYKE, there are also different Open Source software tools available, which are widely used for publishing data via WMS/WFS interfaces (GeoServer, MapServer, degree, etc.) and SOS interface (52N-SOS-3.2.0 etc.). Spatial data can likewise be stored in Open Source relational database management system like PostgreSQL/PostGIS.

**CRYOLAND SYSTEM VALIDATION AND QUALITY ASSESSMENT**

The validation and testing activities performed for the CryoLand services and products were defined based on the general objectives and structured according to the Reference Model of Open Distributed Processing (RM-ODP1) (ISO/IEC 10746-1:19982). This model is an international standard for designing
open, distributed processing systems. It provides an overall conceptual framework for building distributed systems in an incremental manner. The key fundamental aspect of this model is that it provides a framework for assessing system conformance with the initial requirements. In the model, the viewpoints (a view is a representation of a whole system from the perspective of a related set of concerns) identify the top priorities for architectural specifications and provide a minimal set of requirements to ensure system integrity. They address different aspects of the system and enable the ‘separation of concerns’. Hence, it was identified as a viable approach for identifying the requirements to be validated and verified.

The CryoLand system testing and validation activity was coordinated by NMA. Using the general RM-ODP1 recommendations, the team structured and documented a CryoLand oriented set of procedures, principles and models for system validation and qualification. The documentation was complemented with the feedback and requests received during the User Validation Workshop, held in Copenhagen on 5 June 2013. For an independent assessment of the CryoLand system, relevant user communities (15 experts from 9 institutions) were taught before the start of the CryoLand qualification phase. Several meetings and interactions have been conducted in the second half of the project period. The scope was to create a team of professionals willing to use the test procedures and tools prepared for the system validation and qualification. The team had a one day face to face meeting at the NMA headquarters for introducing the validation procedure to the group. Hands-on workshops were given by CryoLand project members to show the testing team members the operation of the the CryoLand system and the usage of the testing infrastructure. In the following months, the testing team provided feedback on the (i) predefined test procedures and (ii) the overall system evaluation based on questionnaires and interviews.

The test procedures had the following structure:
- Purpose;
- Test platform;
- Actions to be performed;
- Expectations to be verified;
- Status after execution: OK if the final result corresponds with the defined expectation, KO otherwise;
- Feedback: text description of the encountered problems.

Each Test Procedure contained a number of Test Cases specific for each method of access. All Test Cases need to be executed in the order specified in the Test Procedure, as they were usually connected one with another and assure a normal execution flow for the user operations. If specified, the pre-requisite of a Test Case had to be respected; otherwise a false KO may be generated. A web tool was used to define the test cases and gather the results for each individual test case. A fully automated testing procedure (autotest) for the CryoLand software modules was developed and run automatically after every change which is submitted into the system repository, as well as prior to any release version. In the end, a total of 991 test cases were defined for the entire functionality of the CryoLand system:
- automatic tests: 919
- manual test cases: 66
- integration cases: 6 test cases

A total number of 990 OKs were obtained:
- automatic tests: 766 test cases OK, 153 test cases OK but skipped (regarding functionalities disabled on
• manual test cases: 65 OK. Minor errors on one test case regarding a browser specific error that does not affect the normal behaviour of the geoportal.
• integration cases: 6 tests cases OK. Some very minor errors/warnings/slow system responses that do not affect the normal behaviour of the system were registered.

Therefore, the global status of the verification gives a percentage close to 100% of OK results. The registered errors are mostly minor errors, the global functionality of the system is the one defined and planned in the initial project documents. A number of upgrades were implemented after the initial results of the testing phase, based especially on the feedback received from the users (e.g. new functionalities and improvements of the GeoPortal WebGUI). The full description of the process is the subject of the deliverable D8.2 (Final System Qualification of Services and Acceptance).

For demonstration purposes, a technical integration of CryoLand data services with NMA existing geoportal (hosting mainly climatic and meteorological forecast data) was setup. Conceptually, the main CryoLand service was seen as a “mother service” and the NMA as a lighter “child service”, focussed on a specific geographic area, with domain specific functionalities. The CryoLand snow products are integrated using two methods:
• Directly, by connecting to the main CryoLand EO-WMS service. This approach was used for product visualization.
• Indirectly, some products are mirrored on the NMA server. This approach was used mainly for data processing and other operations not permitted by the CryoLand service (e.g. product reprojection to Stereo70, the official Romanian coordinate system).

SNOW AND LAND ICE PRODUCTS FROM SENTINEL-1 DATA

CryoLand Services were developed and implemented for using Sentinel data as main input for their services. The Sentinel satellites are a new family of missions specifically for the operational needs of the Copernicus programme. Each Sentinel mission is based on a constellation of two satellites to fulfil revisit and coverage requirements, providing robust datasets for Copernicus Services. These missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring. CryoLand Services were designed to make finally use of data from Sentinel satellites.

Sentinel-1 (launched on 3 April 2014) is a two satellite constellation with the prime objectives of Land and Ocean monitoring. The mission provides C-Band SAR data continuing ERS-2 SAR and Envisat ASAR. Sentinel-2 (launch planned for June 2015) is a high resolution optical land monitoring mission, and will be composed of two polar-orbiting satellites. Sentinel-3 (launch planned for Q1 2016) is composed of three satellites, operating multiple sensors. Relevant for CryoLand services are the medium resolution optical sensors SLSTR (Sea and Land Surface Temperature Radiometer) and OLCI (Ocean and Land Colour Instrument).

Within the timeframe of CryoLand project the first satellite of the Sentinel satellite series, Sentinel-1A, has
been launched in April 2014. Commissioning Phase was successful and ended in early October 2014. Thereafter the Sentinel-1 Scientific Data Hub, a rolling archive hosting the data of the last 2 months, became operational. Within CryoLand it was possible to take advantage of the first Sentinel-1 data that were made available through the Science Data Hub in October and November 2014. As Sentinel-1 is an active radar sensor, only products that are based on SAR data could be produced. For the products depending on Sentinel-2 and Sentinel-3 preparatory work was done using existing sensors with similar characteristics.

The Sentinel-1 based services for snow and glacier products were implemented and tested. The main snow product was the extent of wet snow from multi-temporal SAR data. The glacier products cover glacier velocity products as well as glacier lake outline maps of Europe, Himalayas and Antarctica.

The Sentinel-1 Scientific Data Hub was the only access for Cryoland Partners to get Sentinel data (ESA, 2012, 2013a, 2013b). The Sentinel-1 Scientific Data Hub Rolling Archive maintained at least the latest 2 months of products for download via HTTP. No data tasking or ordering is possible through the data hub. The Scientific Data Hub has a web interface that allows browsing the archive and an Open Data Protocol (OData) interface for machine-to-machine data catalogue access. OData was used for the creation and consumption of REST (representational state transfer) application programming interfaces (API), which allowed resources, identified using uniform resource locators (URL) and defined in a data model, to be published and edited by Web clients using simple Hypertext Transfer Protocol (HTTP) messages. At this stage the ground segment is in ramp up phase, that means only limited data is made available.

Wet snow maps (SCAW product) were generated from time series of SAR following an algorithm from Nagler and Rott (2000). The method applied hinges on using a reference SAR image acquired under dry conditions (either snow free or snow covered). The method segments wet snow by applying a threshold (typically -3 dB) on the ratio between the current SAR image and the reference data. Within CryoLand processing lines for wet snow products were implemented at Norut within the GSAR software environment and within ENVEO’s wet snow processor.

Several pairs of 12 day repeat pass Sentinel-1 images over different locations in Europe were processed and analysed by Norut. The EU DEM was used for precision geocoding. During the ramp-up phase of Sentinel-1, with limited data, it was decided to use several sources of data for inter-comparison with the wet snow map, and also to evaluate the reference dataset. The sources used were modelled snow conditions for Norway (from http://www.senorge.no) meteorological data (temperature, precipitation, snow depth), MODIS based snow cover maps and wet snow map from other high resolution SAR satellite data.

The principal method to measure ice flow velocity of fast moving glaciers and over longer time intervals is offset tracking (OT). This method determines the surface velocity field by detecting and tracking identifiable features that move with the ice (e.g. crevasses) and that remain stable in sequential pairs of co-registered images. OT represents a method that delivers two components of the velocity vector (in slant range and along track direction) and is less sensitive or insensitive to temporal decorrelation of the radar signal than InSAR, although at lower accuracy. Two OT processors were implemented within CryoLand, the GAMMA OT processor and the ENVEO OT processor. The GAMMA glacier velocity processor is based on SAR offset-tracking procedures (Strozzi et al., 2002) and the methodology
developed within ESA Glaciers_cci (Paul et al., 2013). Preliminary examples and validation of ice surface velocity maps on glaciers from Sentinel-1 data were generated by GAMMA and ENVEO for Arctic and Antarctic Glaciers. Results were validated against existing velocity information and the quality of the co-registration by matching stable ground. Existing information included the Greenland Ice Sheet Velocity Map from InSAR Data by Joughin et al. (2010) and the Ice Velocity Map from Rignot et al. (2011).

Glacier lake extent products: Among glacier hazards, glacier lake outburst floods (GLOF) are especially devastating and represent the glacial threat with the farthest potential reach, up to hundred kilometres and more downstream of the glacier lake that burst out. Typically, glacier lake outbursts are a part of complex chain reactions and process interactions, for instance when sudden slope failures above a lake cause impact waves that trigger destabilization of a lake dam that would otherwise remained stable. The CryoLand glacier lake mapping service provides outlines of the glacier lake under observation. The service was run upon user request and the products are directly delivered to the user. The methodology makes use of the very low backscatter coefficient of smooth water surfaces compared with other land types. Two glacier lake mapping processors are available within CryoLand, the GAMMA processor (Strozzi et al., 2012) and the ENVEO processor. The quality of the products is assessed by comparison with the DEM and if applicable earlier products or other auxiliary data. Within the CryoLand project Sentinel-1 glacier lake maps were produced for lakes in Greenland and the Himalayas.

Operational Fractional Snow Cover monitoring was based on single sensor approaches. The synergistic usage of the spectroradiometer ‘Ocean and Land Colour Instrument’ (OLCI) and the ‘Sea and Land Surface Temperature Radiometer’ (SLSTR) on board of the future Sentinel-3 will provide a new data base enabling an improved snow monitoring and snow and cloud discrimination system. Processing lines for mapping fractional snow cover and improving the cloud screening based on these new sensors have been developed and tested by ENVEO using synergistically archived Envisat MERIS and AATSR data, which have very similar spectral and geometric characteristics as the instruments on-board of Sentinel-3. The resulting snow maps have a significantly improved spatial resolution, and the synergistic usage of the two sensors enables an improved snow and cloud discrimination, which is a critical issue for an operational snow monitoring service.

INTEGRATION OF CRYOLAND SERVICES INTO HYDROLOGICAL RUNOFF MODELS

One of the main user applications of satellite based snow information was in hydrological models for stream flow predictions and hydropower reservoir management. In general, snow (and ice) data can be integrated in hydrological models either through calibration and evaluation procedures for model development, or for model state initialization in forecast simulations using so-called data assimilation. In both cases, the raster based satellite information need to be transformed into the spatial representation used in the hydrological model, which usually is sub-basins representing the catchment area of a specific point in the watershed. The satellite snow information can further be used to calculate sub-basin averages or distributions as function of for instance elevation, aspect, and vegetation type, which is then compared to the equivalent model variables.

The integration of CryoLand Product and Services in hydrological modelling was assessed using the
The hydrological model HYPE developed and operated at the project partner SMHI for basins and sub-basins in Sweden. A template production chain was developed, including automatic scripted download from the CryoLand Geoportal, pre-processing of the satellite products into time series of hydrological sub-basin averages, assimilation of satellite snow data in the hydrological model, and publishing of the model output on WMS interfaces following the CryoLand data model. The suggested processing chain has been developed with the CryoLand products and services and the SMHI hydrological models in mind, but could easily be adapted to other combinations of products from satellite data and hydrological model systems.

The Swedish application of the HYPE model (Strömqvist et al., 2012) is used operationally by SMHI for simulation of the water quality and together with the HBV model (Hydrologiska Byråns Vattenbalansavdelning; Bergström, 1995) for the operational flood forecasting. The current version (S-HYPE 2012) has 36693 sub-basins with a median size of 18 km², and covers the Swedish mainland, all major islands along the coast and contributing areas in Finland and Norway. A routine for data assimilation has been implemented based on the Ensemble Kalman filter method (Evensen, 1994).

Simulation and data assimilation experiments were conducted with the objective to compare the CryoLand SWE and FSC products with the S-HYPE model, and to assess impact of assimilation of the satellite products on the snowmelt runoff simulations, respectively. The Pan-European FSC and SWE products, as well as the Scandinavian multi-temporal and multi-sensor FSC product were included in the study, using data from the second Pilot Service 2011-2013. The results showed firstly a good agreement between the S-HYPE model and the Pan-European SWE products in the major inland part of Sweden, except for the mountainous region in the north-western border to Norway and along the east-coast. The discrepancies were most likely attributed to issues in the microwave based satellite product related to spatial variability of snow in the mountains and influence of the sea along the coast. The Pan-European FSC product and the model simulations compared well with the model simulations in most of Sweden, except for the most northern alpine parts. The multi-sensor/multi-temporal FSC product on the other hand was in good agreement with the model in the mountain areas, but underestimatred largely the maximum snow cover in the forest areas, which constitutes the larger part of Sweden. The differences in the agreement between the simulated FSC and the two satellite products were logical, since the Pan-European optical FSC product takes into account the effect of vegetation, and the Scandinavian multi-sensor FSC product was optimized to correct for shading and clouds in the Scandinavian mountain areas.

The impact on the simulation of stream flows by assimilation of the CryoLand snow products was studied in smaller river basins representing non-regulated rivers in different parts of Sweden. The Pan-European products SWE and FSC improved and reduced the performance of the stream flow simulations in about 1/3 of the experiments, respectively. The largest improvement was achieved in a sub-basin to the Tornionjoki river basin above the tree-line in northern Sweden. The largest reduction in the stream flow simulation performance was experienced in the sub-basin in the central eastern coastal area, where the initial comparison of the CryoLand snow products from satellite data and the S-HYPE model indicated large biases. The assimilation experiments illustrate both the potential of satellite snow data for improving hydrological model simulations/forecast and some typical problems related to systematic biases and other errors in the satellite data.
REFERENCES


ACRONYMS

AOI Area Of Interest
API Application Programming Interfaces
CRS Coordinate Reference System
EC European Commission
EO Earth Observation
ESA European Space Agency
ETL extract, transform and loading
FSC Fractional Snow Cover
FTP File Transfer Protocol
GCOS Global Climate Observing System
GEOSS Global Earth Observation System of Systems
GIS Geographic Information System
GLIMS Global Land Ice Measurements from Space
HTTP Hypertext Transfer Protocol
IGOS Integrated Global Observing Strategy
INSPIRE Infrastructure for Spatial Information in the European Community
LIE Lake Ice Extent
MODIS Moderate Resolution Imaging Spectroradiometer
OData Open Data Protocol
OGC Open Geospatial Consortium
REST Representational State Transfer
RIE River Ice Extent
SAR Synthetic Aperture Radar
SCAW Wet Snow Covered Area
SOS Sensor Observation Service
SWE Snow Water Equivalent
TM Thematic Mapper
TOI Time Of Interest
URL Uniform Resource Locators
WCS Web Coverage Service
WFS Web Feature Service
WMS Web Map Service

Potential Impact:

IMPACT
The CryoLand service on accurate and timely observations of snow, and land ice by means of satellites is very relevant to supporting environmental and resource management activities in Europe. The seasonal snow cover and glaciers are important resources, supplying major parts of Europe with water for human consumption, agriculture, hydropower generation, and other economic activities. The presence of snow and ice effects the radiation and energy balance of the surface so that accurate characterisation of snow and ice properties is important for numerical weather prediction and climate monitoring. Various natural hazards are directly or indirectly related to snow, glaciers and lake / river ice, including avalanches, flooding from sudden snow melt, water outbreak from glacier lakes, ice jams on rivers. Snow load is also an important safety and operation issue concerning construction activities for roofs or power lines. Thus snow and ice services developed in CryoLand are of high relevance for water resources management (irrigation, water quality, water supply), hydropower energy production and energy trading, natural hazards mitigation (snow and glacier related floods, avalanches), transportation (roads, rivers, lakes) and construction activities, insurance and re-insurance companies, climate monitoring and modelling, numerical weather prediction, carbon accounting and biodiversity, living conditions of northern indigenous people, ecosystem, agricultural management, and tourism.

CryoLand services are also relevant to EU strategies and directives:
• DG ENV and EEA: Water Information System for Europe (WISE). Water supply from snow and ice is crucial for river basin management, groundwater recharge, and water quality in many parts of Europe.
• DG ENER: European Strategic Energy Technology Plan - SET. Climate protection requests to make the most efficient use possible of the available energy sources. Hydropower is by far the dominating renewable source for electricity. Improved information on snow and glacier runoff is needed for increasing the efficiency of hydropower production.
• DG ECHO and EEA: The Community Civil Protection Action Programme. Significant improvements for hazard forecasting can be expected from the CryoLand Service: Snow cover information is essential for forecasting avalanches and snow-melt related floods. Up-to date glacier information is important for predicting and mitigating floods in high alpine regions. Glacier dammed lakes may cause sudden floods, and the increased glacier runoff in warm summers tends to amplify floods caused by rainfall in Alpine basins. Snowmelt floods in Nordic rivers may be aggravated by ice jams.
• EEA: Support of Environmental Policy in Europe. Snow cover is relevant for water quality and water availability and has an important function in surface/atmosphere exchange processes, thus being very relevant to air pollution control.
• DG AGRI: Rural Development Policy. Snow melt water is essential for agriculture in many parts of Europe.
• DG CLIMA: European Climate Change Programme (ECCP). Adapting to Climate Change: Snow and glaciers and lake / river ice are sensitive indicators for climate change.
• DG ENTR – European Space Policy - Copernicus: CryoLand aims at developing a service based on EO data, which is of high socio-economic relevance to the European citizens. This is a key objective of Copernicus.

DISSEMINATION
Main dissemination activities of CryoLand include:

- Project information Web Portal, continuously updated during the project lifetime.
- ~50 publications, conference participation and presentations promoting the CryoLand-project (2011-2014).
- Three Policy Briefs.
- Promotional Material and Brochures (CryoLand for Newbies; Brochures; Journal Articles).
- Defining Interfaces with Copernicus Land Monitoring Core Service.
- Proposal (White Paper) on Potential Snow and Glacier Services within Copernicus, in the frame of the Copernicus Land Monitoring Core Services.
- 2 Dissemination workshops: Oslo 8 Oct 2014 and Innsbruck 4 Dec 2014, with ca ~50 participants in total. 17 user presentations on the use of CryoLand Products/services in their application domain were held, showing the high interest on Cryoland Services.
- Direct communication with users

EXPLOITATION

During the CryoLand project all partners have taken part in the exploitation activities. As part of this the CryoLand partners were in contact with users and potential future customers of snow and land ice products developed and provided within CryoLand. In general all the CryoLand-partners will continue work actively to increase interest, knowledge and demand for satellite derived snow information to further extending the user group, either it is among the public bodies, commercial partners or R&D partners. SMHI is one of the users who started to integrate CryoLand-products into their normal operations to support prediction of flood warning, water management and also for hydropower customers. The stakeholders may be graded in key stakeholder ("champions", key funding partners), important stakeholders (typically governmental support or partly funding), and others. The stakeholders may act as user of data or service, funding source, governmental regulator, organisation defining industry standards, or as a general supporter of the service benefitting from service. Identified Key stakeholders are Large hydropower companies. Important stakeholders include Hydrological services, Energy traders, Meteorological services, Environmental agencies. Others include Avalanche warning centres, Road, Railway and River Authorities, Climate monitoring institutions, Geotechnical & Construction companies, Ecologists, Reindeer herders, Recreation (e.g. fishery, skiing), Forestry companies.

Results of CryoLand-project are found appropriate to carry on in 3 different business models:

- Public Union Model: Pan-European Snow Service within Copernicus Land Monitoring Services
- National / Regional Model: Regional products developed serving support of governmental mandates based on public funding (internal department budgets and resources)
- Commercial service: Downstream snow products and services provided on commercial basis, e.g. for hydropower companies and governmental agencies

Three models are applied to serve the three service stakeholder groups, where one group exists and the two others have to be established. SYKE and FMI will use the (public) national/regional model to improve services to the people of Finland. As part of the second model Snow and glaciers have to be included as services in the Copernicus Land Core services, which is an ongoing process where partners and the
CryoLand project have given input to EC how these services could be established and operated. The third model addresses snow monitoring products and services which are regarded as mature enough to be run operationally. User interest is significant, and hence assumed having a potential commercial basis for the operational service provider organisations willing to take risk.

COMMERCIAL OPERATION AND MARKET SEGMENTS

During the CryoLand development and demonstration period, there has been strong interest in the products from close to 100 different user organisations, both from commercial and governmental institutions. Especially the provided snow monitoring services generated high interest among innovative hydropower companies, representing the main commercial market. Governmental authorities, which had already been involved in EO based snow monitoring, demonstrated the benefit of using these products e.g. in flood forecasting, especially at the Finnish and Swedish institutions.

The potential market is divided into following user segments, where focus is on commercial operation of snow monitoring services:

• Hydropower companies, and other actors in the hydropower market
• Energy brokers, analysis and consultancy services
• Public authorities responsible for water and energy management
• Meteorological Offices (and other organizations doing Numerical Weather Predictions)
• Geotechnical Engineering Companies

The proposed services have several documented significant advantages for the potential users. However, the user barriers have to be overcome by adaption and integration opportunities into user environment and systems to be compliant with existing run-off models used in the industry.

PLANNED EXPLOITATION AT PROJECT PARTNERS

ENVEO IT GmbH

ENVEO is a SME with skills and interests acting as an R&D company for EO products and as Service provider for satellite based snow and glacier products. The project enabled to install communication links of ENVEO with key users of snow and glacier information in Europe, European organisations and various DGs at the European Union. ENVEO performs R&D development of new methods and algorithms and is exploiting the capabilities of new EO sensors for snow and land ice monitoring. Beside this ENVEO acts also as a service provider for EO products making use of the R&D results.

Exploitation opportunities ENVEO include:

• Downstream Service Activities: ENVEO is operationally providing snow products in mountain regions as a downstream service. The technological improvements on the product side (long time series, high resolution, quality assessment) and the service side are the basis for enhancing the customer base in
traditional application fields (hydrological services hydropower, meteorology, climate) but also opening new applications (traffic, etc). There is an opportunity to extend the services to other organisation / companies which are not using EO snow products so far.

- Copernicus Snow and Glacier Service: The need for European snow and glaciers services are clearly stated in the recent Copernicus Implementation Plan. In response to the related EC Call ENVEO (together with other CryoLand service partners) will apply for running these services.
- The R&D developments carried out in the project strengthened ENVEO’s position for upcoming activities and projects related to product and service improvements. This is especially the case for using Sentinel data for snow and ice monitoring, but also for developing new products which make use of the advanced imaging capabilities of the Sentinel satellite series.

FINNISH METEOROLOGICAL INSTITUTE (FMI)

FMI will continue to utilize the snow and lake ice products offered within the CryoLand service, although most of the data available on the CryoLand GeoPortal is also available on FMI’s internal servers, as FMI and SYKE are the primary producers of the data. For FMI the CryoLand portal currently serves as a show case to tool / visual aid in promoting more wide spread use of Cryosphere products and in demonstrating data availability to potential public and private enterprises.

Exploitation opportunities of FMI include:

- Hydropower; reservoir inflow forecasting research
- Operational flood forecasting research activity

FINNISH ENVIRONMENT INSTITUT (SYKE)

SYKE is a governmental R&D institute, one of its tasks being the development and implementation of EO services for environmental monitoring. For snow mapping SYKE has developed the SCAmod algorithm, which is in the core of the Pan-European and the regional Baltic snow products in CryoLand. The algorithm is also constantly developed further at SYKE. With the experience of running the Baltic regional service for almost 10 years, SYKE aims at exploiting the widely recognised algorithm to provide both European wide (together with CryoLand partners) and national snow services. The main application areas for snow products are seen in hydrological forecasting and in providing information for hydropower industry. The optical lake ice extent (LIE) product is foreseen to provide essential information for regional weather forecasting and for hydrological modelling and forecasting. Opportunities are also seen in the safety domain. SYKE aims at exploiting the following resulting opportunities:

- Application 1: Snow products in hydrological modelling and forecasting; Benefits expected: Improvement of forecasts
- Application 2: Lake ice product in hydrological modelling & forecasting and in lake ice monitoring related to safety; Benefits expected: Improvement of forecasts

SWEDISH METEOROLOGICAL AND HYDROLOGICAL INSTITUTE (SMHI)
Within the CryoLand-project SMHI has been involved in the user interaction, as well as in the development and evaluation of data assimilation tools for integration of satellite based snow and ice information in hydrological models. There are good opportunities for further exploitation of the knowledge and developed tools with regard to assimilation of satellite snow and ice information in hydrological models, both for research and operational forecast purposes. However, this relies on the availability of satellite snow information either from a future CryoLand service or other service providers. An alternative strategy would be that SMHI develops in-house production of satellite snow information, which of course could be made in collaboration with any of the CryoLand partners. It should be noted that both the numerical weather prediction service and the sea ice service at SMHI already are producing their own satellite based information. The end-users in the SMHI exploitation plans are mainly Swedish governmental agencies or international organisations (for instance EFAS and WMO), as well as commercial companies (mainly hydropower companies).

SMHI aims at exploiting the following resulting opportunities:
• Assimilation of satellite snow information in Swedish applications of the HBV model / Decision support for Swedish hydropower companies.
• Assimilation of satellite snow and ice information in the Swedish S-HYPE model / Decision support for SMHI flood forecasting service.
• Assimilation of satellite snow and ice information in the Pan-European E-HYPE model / Input to the EFAS system.
• Assimilation of satellite snow information in the Pan-Arctic Arctic-HYPE model / Decision support in the WMO Arctic-HYCOS program.
• Monitoring of ice break-up conditions in the Torne River: Decision support for Swedish and Finnish agencies for civil protection.

NATIONAL METEOROLOGICAL ADMINISTRATION OF ROMANIA (NMA)

The CryoLand project addresses a challenge of national interest, namely the accurate and timely knowledge of the seasonal snow distribution and characteristics. The socio-economic impact of snow in Romania is significant, ranging from water management and hydropower, to agriculture, transport, tourism, urbanism and emergency situations management.

The monitoring of ice and snow is extremely important for the management of natural resource, extreme event prediction such as snowmelt floods, avalanches and the impact of global warming. Due to this, it is important to measure the snow state variables, such as Fractional Snow Cover (FSC) and Snow Water Equivalent (SWE) which are useful inputs for hydrological models that can assist in the decision making process of water resources management. Furthermore, combined with other variables like Snow Depth (SD), Snow Density (SDE) and Snow Surface Wetness (SSW) are useful inputs for the modelling of avalanche hazards. Moreover, knowledge of the snow water content is vital for flash flood forecasting during fast rising air temperature events.
KONGSBERG SATELLITE (KSAT)

KSAT has run a seasonal Scandinavian snow cover map (FSC) since 2006. This service is based on a multi-sensor technology on licence from NORUT and NR. The KSAT Snow service has been improved continuously; including the capability of addition of Radarsat 2 SAR (as a replacement of the lost ENVISAT ASAR) imagery as a supplement to the MODIS data. The service is now planned to be offered as a downstream service for specific users in cooperation with partners NORUT and NR, and also finds this service prepared as a core service as part of the future Copernicus Land Monitoring Services, where snow service is also expected to be included. During the CryoLand project the service has been even more operational and regular, supporting especially Norwegian hydropower companies with input to their decision support in the production planning process. Based on these results KSAT aims for being involved in preparing and delivering the future Copernicus Land Monitoring Services. KSAT and the partners will include Sentinel-1 data into the existing service chain which will make the service even more regular and reliable, which has been requested by the users in the demonstration phase. KSAT aims at exploiting services developed in cooperation with NORUT and NR (licence agreement):

• Multisensor FSC map, Scandinavia
• Wet snow product based on Sentinel-1 and RS2
• Additional products indicating start of snow melt based on snow surface temperature and wetness

NORWEGIAN COMPUTING CENTRE (NR)

NR has together with Norut developed the regional FSC product for Scandinavia. NR’s role has been to develop the optical part (algorithm) of the product, and NR developed the multi-sensor multi-temporal (optical + SAR) together with Norut. Opportunities for further improvements will come up with the Sentinel-1 and -3 satellites. NR believes that the product has a larger potential user group, and that the potential will increase with implementation of improvements related to the Sentinel satellites.

NR has also developed the two demonstration products Surface Temperature Snow (STS) and Snow Surface Wetness (SSW), both characterising the current physical state of the snow surface. Parts of the hydrological user community are moving into the use of distributed hydrological modelling. Spatially distributed observations can be used as model input or for calibration and validation. Temperature and liquid water content in the snow are model parameters. The satellite products STS and SSW are therefore of interest to the hydrological community and now being tested.

Therefore, NR aims at exploiting the following resulting opportunities in applications where improved hydrological modelling is expected:

• Contribute to exploitation of the regional Fractional Snow Cover (FSC) product for Scandinavia
• Surface Temperature Snow (STS)
• Snow Surface Wetness (SSW)

NORUT
Norut has developed the regional SCAW product into operational status for Scandinavia based on Radarsat-2. The processing chain has been running on KSAT in 1.5 year. A pre-operational processing chain has also been developed for Pan-European scale and tested out for Envisat ASAR for 2008-2009. Based on these experiences, we aim at developing the SCAW service at Pan European scale as soon as Sentinel-1 data becomes available, and make it operational together with KSAT. Norut has also developed the regional multisensory FSC product together with NR and KSAT. This product will be improved when Sentinel1- and Sentinel-3 becomes available.

Norut has also developed the two demonstration products Lake ice extent (LIE) and River Ice Extent (RIE) based on C-band SAR. These products are useful for monitoring ice formation and break up at high latitudes. Governmental agencies in the Nordic countries have expressed interest in the products.

Therefore, Norut aims at exploiting the following resulting opportunities:
- Exploitation of Pan-European wet snow extent product (SCAW) based on SAR
- Fractional Snow Cover (FSC) based on multi-sensor approach using SAR and optical satellite
- Lake and River ice extent (LIE/RIE) mapping using SAR

EOX IT GmbH

CryoLand provided a good opportunity to gather and consolidate user requirements and apply them in a bottom-up approach during the development of the CryoLand GeoPortal, in a field which was new to EOX. The continuous user feedback greatly helped to improve the GeoPortal's usability.

The resulting GeoPortal represents a strong basis which EOX continues to exploit as an opportunity for further exploration and investments. EOX already now continues the development of EOxServer and EOxClient, the software system components used for the GeoPortal implementation, and their usage within other projects. Beside the developments to cover the new requirements from these projects, the developments are focused on a generalization and broader applicability of the modules for a wider use. Some features, asked for by users, but which were not in the scope to be implemented within the frame of CryoLand, are now being translated into requirements and are on their way to be implemented for a new version of EOxClient and EOxServer.

Compared to the traditional FTP based distribution systems, which do not allow any kind of user defined specification (e.g. subsetting) the current GeoPortal already represents a big step forward in enabling the users to select and receive the data according to their needs. Beside the product itself, users can select their Area of Interest, their Time of Interest, their favourite download data format and their required geographic projection and will receive the requested information already created according to their specification. There is no need on the user side to do any further basic processing which would require capabilities outside their scope of expertise. Especially the possibility to utilize the above described features from within an automated work-flow has been highly welcomed by the user community.

GAMMA REMOTE SENSING AG
GAMMA is a Swiss SME active in active and passive microwave remote sensing, R&D, software and hardware development and a service provider for EO based products. Through the project GAMMA gained close contact to key users of snow and glacier information in Europe.

Within the CryoLand project GAMMA was responsible for the Sentinel related technology development and the provision of glacier products. GAMMA improved existing algorithms and processing lines for snow and glacier services and implemented code and production lines for the new Sentinel SAR satellite generation. Based on these developments products had been provided to the community.

• The R&D activities in CryoLand improved GAMMAs position for upcoming activities and projects. Especially for snow and glaciers services as well as Sentinel-1 related services.
• Within downstream services GAMMA can adapt and extend its processing lines regionally but also thematically. Glacier Lake services are further developed through the ESA GLOF-DM project.
• Copernicus Snow and Glacier Service: The need for European snow and glaciers services are clearly stated in the recent Copernicus Implementation Plan.
• Software sales: The need for processing software for the new Sentinel-1 data will result in an increase of software sales and maintenance contracts.
• Combination with terrestrial measurements: GAMMA is heavily involved in terrestrial measurements for avalanche protection and research. There is good potential for combined VHR SAR, terrestrial radar services. Additional R&D is necessary and industry funds are assessed.

SUMMARY

Below is a summary of the potential users of Cryoland products, with the main focus on snow products:
• Public national bodies – national responsibility and funding serving national interests, especially flood warning
• European level – European initiatives like EFAS, also involving national public bodies in providing flood and drought warning, funded by public European instruments.
• Industry / commercial companies – Some companies in the start-up phase to serve hydropower users with FSC and SCAW products, trying to develop mechanisms to integrate results into existing hydrological models being used as industry standards.
• Meteorological institutes – continue using the CryoLand products for intercomparison and validation activities with their NWP model output, and research on options for snow product integration into meteorological and radiative models is ongoing. Glacier products from satellite data as provided by CryoLand will be a supplementary dataset for climate studies, providing information with an added value for many remote and hardly accessible regions worldwide.
• R&D institutes – continue to use results gained in the CryoLand project to improve algorithms, and develop new systems based on the general knowledge and infrastructure acquired during the CryoLand project. Trying to achieve the goal of improved spatial resolution of SWE-product, when new appropriate sensors will be available; this is to be used as base for improved services also within the other sectors.

List of Websites:
Project Web Page: www.cryoland.eu

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