CryoLand – the GMES Downstream Service Snow and Land Ice

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Abstract

Climate change has a strong impact on land ice and snow cover based environments. Rising mean temperatures will lead to retreat of average snow and ice coverage, jeopardizing the supply of fresh water for human consumption, agriculture, and hydropower generation. In addition, changing snow and ice will affect ecosystems and biospheric diversity. Accurate and timely observations of snow and ice are necessary to prepare for these challenges. In order to support the management of snow and ice resources, the project “CryoLand - GMES Service Snow and Land Ice” will develop new services for monitoring snow cover, glacier ice and lake/river ice as a GMES Downstream Service. The CryoLand’s value added chain utilizes the GMES Land Monitoring Service as well as Earth observation satellite data from the GMES Space Component directly as an input. CryoLand is a 4 year project which started in 2011, and is supported by the 7th Framework Programme of EC.

One component of the project is dedicated to snow and glacier services in mountain areas. Accurate and up-to-date information on snow and glacier parameters are highly needed for managing water resources for hydro power production, irrigation, flood forecasting and even for drinking water supply. In order to supply these services and provide the products to the users a service infrastructure will be developed based on interoperable and standardised Web services. To achieved this target the CryoLand service architecture to be developed will follow the recommendations provided by GIGAS (GEOSS, INSPIRE and GMES an Action in Support). These recommendations included the standards developed within OGC which provided mechanisms and interfaces such as CSW, WMS, WFS, WCS, and WPS. They allow providing online services which can be consumed by different clients for a direct integration of CryoLand functions and products into GIS, modelling tools and decision support environments.

This paper discusses the CryoLand architecture with focus on mountain areas mapping applications and on the technology implemented within the Access and Integration Software System (AISS).

1 Introduction

Snow and land ice are key elements of the water cycle in many parts of Europe, as well as in mountain regions and mid- and high-latitude zones of Asia and the Americas. Snow, lake ice and river ice are characterized by highly temporal variability. 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. Melt water from the mountains is also an important water resource downstream for lowland regions of Central and Eastern Europe, as it is for a main part of the Northern hemisphere land masses at large (Barnett et al., 2005). UNEP (2007) reports that 1.5 to 2 billion people live in regions, where reduced water flow, due to retreat of the seasonal snow cover and glaciers, could cause major water shortages.

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. 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 (Lemke et al., 2007; Serreze et al., 2000). Satellite Earth observations (EO) are the only efficient means to deliver accurate and up-to-date information on these key elements of the cryosphere. This has been recognized by scientists and technicians who have been developing methods and processing algorithms to generate satellite-based snow and ice products for scientific, industrial, and institutional applications. The potential of EO data has as well been recognized by users in many different fields, such as hydrological services, meteorological services, environmental agencies, agriculture managers, hydro-power companies, energy traders, tourism industry, avalanche warning centres, and ecologists.

The primary products provided by CryoLand include fractional snow cover extent and melting snow area on a regional scale, both needed on a daily basis and in near real time during winter and during the melting period. Observing glacier parameters (glacier outlines, maps of snow/ice areas, glacier lakes) and their

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seasonal and annual variations are important contributions to climate change monitoring. The generation of glacier products will follow international guidelines provided by the Global Land Ice Measurements from Space (GLIMS) community.

CryoLand manifests itself as a GMES-embedded, pre-operational, Internet-based service infrastructure, which is becoming increasingly visible as new services and products are added and which will be transferred at the end of the project into a sustainable operational multi-provider environment. Applying the GIGAS (GEOSS, INSPIRE and GMES an Action in Support) recommendations and building upon OGC web service standards and implementations is the approach of achieving these goals.

2 CryoLand Architecture

When dealing with the inherent complexity of large distributed information systems individuals can rarely fully comprehend all aspects of the specifications. The concept of RM-ODP (ISO 10746), applied for the CryoLand Architecture definition approach, therefore, provides separate viewpoints into the specification of a given complex system, each satisfying an audience with interest in a particular set of aspects of the system.

The CryoLand team is committed to apply standards like INSPIRE, OGC, and OASIS and is also respecting the HMA and GENESIS frameworks for the implementation of the CryoLand spatial data infrastructure. The recommendations, provided by GIGAS, the basis and interoperability with wider global geospatial infrastructures (e.g. GEOSS, GLIMS), are closely followed.

2.1 Enterprise Viewpoint

This viewpoint asks for the definition of CryoLand’s purpose, scope, policies, and related business which altogether are impacting infrastructure implementation decisions. The implementing organizations (i.e. the FP7 consortium partners – see CryoLand Project Web Page) and some 40 formally committed user organizations are in the process of formulating their different operational mandates, commitments and business expectations related to the future sustained operations of the CryoLand provided services. The objectives of the project are the development, implementation, validation and provisioning of standardized, interoperable and sustainable services on seasonal snow, glaciers, and lake/river ice as a GMES Downstream Service. In addition, the CryoLand Project plans to:

- Generate snow and land ice products tailored to the needs of the different users.
- Achieve a higher degree of automated processing lines, workflows and logistics.
- Provide a coordinated data storage management.
- Provide standardised interfaces for network services and for user access (INSPIRE and GEOSS compliant).
- Achieve services operations in multi-provider environment.
- Develop tools for utilisation of Sentinel satellite data for snow and ice monitoring services and stipulate the validation of Sentinel-1 utility and service lines
- Create production facilities for the European Climate Change Initiative.

The CryoLand project addresses a theme of high socio-economic relevance to the European citizen, namely the continuous and accurate monitoring of snow, glaciers, lake ice and river ice. A self-sustainable service shall be developed in order to support the better management and realisation of a wide range of economic and ecologic activities related to snow and ice being major natural resources and essential elements of the environmental and climate system.

In this paper the emphasis is placed on the following Use Case scenario: Since CryoLand products will be derived from various satellite sensors (MODIS, ASAR and Sentinel-1 / 2 / 3) semi-automatic algorithms will be developed in order to support the better monitoring and realisation of a wide range of economic and ecologic activities related to snow and ice being major natural resources and essential elements of the environmental and climate system.
2.2 Information Viewpoint

This viewpoint focuses on the semantics of products as well as the product generation for the system. The product and service requirements for different applications were specified in cooperation with users from a wide range of applications within in user workshops held by the CryoLand Consortium in Vienna, Oslo, Helsinki and Bucharest in May and June 2011. The outcome of these workshops is being used to generate products tailored towards the various applications taking the characteristics of available and near future GMES Sentinel satellites into account. In this paper the CryoLand snow and glacier products for mountainous areas are described.

The baseline snow product portfolio for mountainous areas include the snow extent, extent of melting snow, snow surface temperature and surface wetness, and statistical snow information for basins and sub-basins, and surface albedo maps. Due to the high temporal changes of the snow extent fully automatic processing lines and well developed data flow lines are needed in order to provide the products in near real time. The snow extent products are includes products at regional to continental scale utilizing high resolution optical satellite data (e.g. Aster, Landsat TM, Sentinel 2) and medium resolution optical sensors (e.g. MODIS, Sentinel 3), respectively, relying on single sensor as well as on dual or multi-sensor algorithms. Automated snow classification methods are applied for the retrieval of snow covered area. Advanced algorithms use spectral unmixing techniques to retrieve fractional snow cover (FSC) (Nolin et al., 1993; Painter at el., 2003). Figure 1 shows as an example of the basin fractional snow extent products for basins derived from MODIS data for April 2, 2011, and statistical snow information for the drainage basin Mittersill.

In spite of significant developments of snow retrieval methods from optical data over the last several years, there are still deficiencies in forested regions and in compensating illumination effects in steep terrain. Within the CryoLand improvements in this respect are made by integrating accurate land cover data of the GMES Land Monitoring Service data bases FSC retrieval algorithms. For hydrology a main interest is the detection and monitoring of melting snow (Nagler et al., 2008). An automatic and mature method for detecting wet snow using SAR data was developed by Nagler and Rott (2000; 2005). The SAR wet snow mapping procedure uses multi-temporal C-band SAR data as input and applies the ratio of the reduced backscattering coefficient of wet snow cover versus snow-free reference. As C-Band SAR is sensitive only to wet snow it provides complementary information to snow maps from optical satellite data which include wet and dry snow areas.

Figure 1: (a) Fractional Snow extent Map for the Alps, 2. April 2011, from MODIS satellite data, generated at ENVEX. (250 m pixel spacing; daily generated; latency time 6 hours); blue lines –drainage basins specified by regional hydrological services in Austria; (b) statistical snow information for drainage basin Mittersill, Alps: snow area / elevation curve, snow extent for aspect classes.

CryoLand will offer a portfolio of glacier products, based on high resolution multi-spectral optical satellite data and SAR data. The baseline products include glacier outline, time series of maps of snow / ice, ice velocity maps and delineation of glacier lakes. The glacier outline (total glacier area) is the basic glacier information and also required to derive other glacier parameters from satellite images. The current baseline technique uses multi-spectral high resolution optical satellite images (SPOT, Landsat ETM+, ASTER, etc.)
(Bishop et al., 2004; Kargel et al., 2005; Rott and Markl, 1989) (a) (b). In the case of debris-covered glaciers visual control is needed, as debris has often a similar spectral signature as the surrounding moraines, which does not allow fully automatic classification. The temporal evolution of snow and ice area extent on a glacier during the melting period is key information for computing the melt water contribution and the glacier mass balance which is an essential climate variable. At the end of summer, the ratio of snow to ice area extent is a proxy of the annual mass balance of a glacier. (Oerlemans, 2001; Rott and Markl, 1989).

The algorithm for mapping snow / ice areas utilises multi-spectral optical and SAR imagery. The automated algorithm developed by ENVEO starts with the top-of-atmosphere albedo in visible channels and applies parametric corrections for atmospheric propagation, and compensates terrain effects on solar illumination (a) (b). Ice motion data are needed to determine and predict the glacier response to climate change. Repeat pass SAR images enable the mapping of ice motion at high accuracy by means of differential processing techniques, separating the phase contributions of surface motion and topography (Rott, 2009). However, decorrelation of the radar phase due to snow fall, wind drift or melt in the time interval between the image acquisitions severely limits the application of repeat pass interferometry (Rott and Siegel, 1997). Correlation of incoherent SAR amplitude images offers an alternative for mapping glacier motion if stable features are apparent on a glacier surface (a) (b).

Figure 2: (a) Late Summer snow / Ice extent, Stubai Alps, 31 August 2009. Snow areas (cyan), Ice areas (blue), Glacier outlines (red) lines. UTM, 30 m pixel size Landsat-5 TM, (R-G-B: TM Band 5-4-3). (b) Ice velocity field from multi-temporal TerraSAR-X data using image cross-correlation, Skeiðarárjökull, Iceland.

2.3 Computational (Service) Viewpoint

This viewpoint shall describe the environment which enables distribution through functional decomposition of the system into objects which interact at interfaces. The CryoLand design follows the recommendations provided by GIGAS of applying the Open Geospatial Consortium Reference Model (OGC 08-062r4), which establishes the principles for Service Oriented Architectures (SOA), and the OGC Abstract Specification Topic 12 - The OpenGIS Service Architecture (OGC 02-112 - also published as ISO 19119:2005). OGC 02-112 provides a framework for developers to create software that enables users to access and process geospatial data from a variety of sources across generic computing interfaces within an open information technology environment.

CryoLand, consisting of different entities (service providers), each with a high level expertise in the snow and ice remote sensing domain, will integrate existing experiences, tools, and services. To integrate and offer the services an Open SOA based system will be establish. OGC provides an internationally accepted set of standards for geospatial web services, which when applied foster interoperability at service interfaces. OGC services are defined using fundamental principles of service-oriented architectures:

- A Service is a distinct part of the functionality that is provided by an entity through interfaces.
An Interface is a named set of operations that characterize the behaviour of an entity.

An Operation is a specification of a transformation or query that an object may be called to execute. Each operation has a name and a list of parameters.

Figure 3 depicts an overview of the CryoLand system indicating the flow of data and information (bottom to top) as well as the duality inside each CryoLand Facility (CLF-), containing the Thematic Production Software System (TPSS) and the Access and Integration Software System (AISS). The interlinked communication between CLFs is indicated by also showing a CLF at the level of an external processing resource.

Figure 3: System overview of CryoLand, its service facilities and the connection to external resources

While the TPSS implements the thematic and scientific expertise to produce the CryoLand products, the AISS is taking care of process communication, data ingestion and delivery as well as security and user management issues. While each TPSS will strongly depend on the thematic expertise and products to be generated the AISS will provide generalized interfaces of similar functionality at each CLF. A detailed view of the architecture of AISS, its services and their associated interfaces is given in Figure 4.

The AISS (Figure 4) will take care of the User Identity Management and the policy enforcement (CL-IDM) to control the access to the CryoLand system. The provision of identities can be realised from inside CryoLand or by an external Identity Provider. By enabling a level of trust Users known at one CryoLand facility may access services and data at another facility, if the access policy doesn’t restrict the user. Once access is granted the AISS will provide a set of interfaces and services (WMS, WPS; WCS, WPS) to the users, either directly or as part of a CryoLand Applications Interface (CL-IA) e.g. as a Web-GUI.

To access external Storage and Processing Resources AISS will offer HTTP, FTP WCS and WPS, respectively, which represent the main pathways for data transport and process invocation. For CryoLand internal communication and data exchange additional services will be provided, namely EO-WMS, EO-WCS, WCS-T, WCPS, as well as an Administration interface. This extended set of OGC services will enable the conformant transfer of EO datasets and derived snow and ice products e.g. by WCS-T (transactional) between the CLFs, including the relevant metadata and processing history by applying the corresponding Earth Observation Application Profiles to the respective services (EO-WMS, EO-WCS).

For the described use case scenario one of the major services involved in the transport of the datasets from the EO data providers to CryoLand, between the CryoLand nodes and partly for data delivery to the users
and is the EO-WCS. The EO Application Profile for the WCS 2.0 standard enables the online access to time-series data, to stitched mosaics and allows the provisioning of EO associated metadata together with the datasets.

Figure 4: System overview of CryoLand, its service facilities and the connection to external resources

The big advantages of using the EO-WCS, especially when compared with a FTP access, are:
- The possibility to subset the data in the time and space dimension, allowing retrieval of only the portion of the data which is relevant.
- To have easy access to dataset series (e.g. time-series).
- Subsetting of large mosaics.
- Data previewing e.g. for cloud cover evaluation.
- Chaining it within web services

The EO-WCS therefore allows gaining the data from the EO providers, and in combination with a WPS (or WCPS) the invocation of further processing steps. E.g. for the snow extent product this will result in a fully automated workflow to generate the maps of the snow extent e.g. covering the entire region of the Alps. But, work within CryoLand is devoted for further automation of the algorithms and processing lines of other products. The resulting coverage of snow maps will be made available to the users via WCS, or directly incorporated into their GIS or Modelling environment, or could be viewed and downloaded as simple image files from the CryoLand Web-Portal. With such a workflow in place the service could then be extended toward user triggered generation of products. The user defines the Area and Time of Interest and invokes the
processing. The service will collect the required data, initiates the product generation and either informs the user to pick up the results when the processing jobs are done or immediately provides access information or presents the results in a Web-GIS interface at the CryoLand Web Portal, respectively.

2.4 Engineering Viewpoint

This viewpoint defines a set of mechanisms and functions that provide the basis for deployment of the CryoLand system in a distributed environment as shown in Figure 5. These engineering components are accessed by services as described in section 2.3. The model foresees a multi-tier architecture with a number of distributed nodes representing CryoLand service partners each acting as processing and service provider. The Spatial Data Infrastructures will link these nodes with the input data providers. These include space EO data acquisition and archiving centres providing Level-1 data (calibrated, swath-based satellite data), e.g. ESA processing and archiving centres (PAFs), the KSAT PAF, etc. and the GMES Land Monitoring Service (LMS) centre. LMS products will be integrated with satellite data for improving the CryoLand satellite derived snow products. Links to in-situ data providers will be set up according to providers and users needs.

![CryoLand Network Diagram](image)

Figure 5: CryoLand multi-provider and distributed network

If required, an additional archiving node, maintaining a consistent Level-2 archive for the production of customized Level-3 data from a coherent input baseline, is foreseen. The interface for the users to the individual CryoLand nodes will be through a portal, providing a virtual centralized access to the decentralized, chained services and the generated products. A security schema common to all CryoLand nodes, managing user access and policy enforcement, will be implemented.

The aim of the CryoLand project is not only to enhance the quality of satellite derived snow and ice products but also to enhance the "Quality of Service" (QoS) towards the users. Since the expertise and IPRs is distributed among different organisations this objective strongly points towards the use of distributed systems, which themselves strongly depend on the underlying geospatial data infrastructure. The new QoS level shall include direct data access according to the users Area and Time of Interest, provisioning of Near-Real-Time data products, and last but not least the on-demand processing of products at the users request.
2.5 Technology Viewpoint

This viewpoint focuses on the choice of technology to be used for the implementation of the CryoLand service components. Concerning the AISS the CryoLand Spatial Data Infrastructure development team is inclined towards the use of Free and Open Source Software (FOSS) since it allows a free mix of software required components and it provides the freedom to adopt the tools to the specific needs to achieve the best possible solution for the project.

At this rather early stage of the project a final decision about the software platforms to be used for the implementation of the AISS has not been taken. However, a group of software tools has been selected for closer consideration. This group currently consists of the following software items:

- Linux, Apache,
- GDAL, OGR,
- MapServer 6.0, EOxServer
- GeoNetwork OpenSource
- PostgreSQL/postGIS, rasdaman, ZOO project
- python, Django
- QGIS, OpenLayers, MapFish, GeoExt, MapBender
- CHARON_SAC_Framework, WebProxy, GeoPrisma

It has to be noted that in recent years especially in the geospatial domain a strong community has matured. Many geospatial software tools are in use at operational level routinely handling enormous amount of data. Systems based on FOSS licensing can be fast and easily adopted and extended to meet the needs of a project resulting in optimized solution.

3 Discussion

Climate change has a strong impact on land ice and snow cover based environments. Rising temperatures will lead to retreat of snow and ice, jeopardizing the supply of fresh water for human consumption, agriculture, and hydropower generation. In addition, changing snow and ice will affect ecosystems and biospheric diversity. Accurate and timely observations of snow and ice are necessary to prepare for these challenges. In order to support the management of snow and ice resources, CryoLand develops new services for monitoring snow cover, glacier ice and lake/river ice.

CryoLand will enhance the methodology to derive and deliver up-to-date spatially detailed information on various land ice and snow parameters. Besides developing high quality products using advanced algorithms it is will make use of modern and efficient mechanisms for timely distribution of products and data access. To generate high quality products in a fast and cost-effective way and to offer them as potent services to a global community interested in these essential climate variables needs a spatial data infrastructure with well defined interfaces.

The standards developed under the auspices of OGC provided such mechanisms. CSW, WMS, WFS, WCS are offered by many operational systems in the geospatial domain. They allow providing online services which can be consumed by different clients. CryoLand will, in addition to FTP and web pages, make its products accessible via services based on these interface standards offering wider functionalities. This allows directly integrating CryoLand results into GIS, modelling tools and decision support environments gathering the information for the area and the time needed, without the additional hassle of downloading large files to extract a rather small area of interest. This service will be performed on the sever side e.g. by an EO-WCS (or EO-WMS) delivering only the data of interest. Additionally the CryoLand service structure will support customers requesting CryoLand products by providing on the fly projection transformation and support of most common GIS data formats.

4 References


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