Final Report

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FMI, SYKE, VTT, GAMMA and ENVEO

SEN3APP

Processing Lines And Operational Services Combining Sentinel And In-Situ Data For Terrestrial Cryosphere And Boreal Forest Zone

FP7 Grant agreement No 607052

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Acronym:

AOD:	Atmospheric Optical Density
ARC:	Arctic Research Centre
BDA:	Bulk Download Application
CAS:	Collaborative Acquisition Station
ColHub:	Collaborative Data Hub
CryoLand:	EU Project: GMES Service Snow and Land Ice
CSV:	Comma Separated Values
DEM:	Digital Elevation Model
DHMS:	Bhutan Department of Hydro-Meteorological Service
DHuS:	Data Hub Services
DWH:	Data WareHouse
ECW:	Enhanced Compressed Wavelet
EDI:	Electronic Data Interchange
EGS :	European Geophysical Society
EGU :	European Geosciences Union
ENVEO:	ENVironmental Earth Observation IT GmbH
EO:	Earth Observation
ERDAS:	Earth Resources Data Analysis System
ESA :	European Space Agency
EU:	European Union
EU FP7:	European Union Seventh Framework Programme
EUG :	European Union of Geosciences
FMI:	Finnish Meteorological Institute
FSC:	Fractional Snow Cover
FTP:	File Transfer Protocol
GAMMA:	Remote Sensing Research and Consulting AG

GIS:	Geographic Information System
GSED:	Growing Season End Date
GSSD:	Growing Season Start Date
HS Tyrol:	Tyrol State Government (Hydrography and Hydrology)
LIE:	Lake Ice Extent
LTA:	Long Term Archive
MAVI:	Agency for Rural Affairs, Finland
MODIS:	MODerate-resolution Imaging Spectrometer
NDWI:	Normalized Difference Water Index
NetCDF:	Network Common Data Form
NOAA:	National Oceanic and Atmospheric Admisntration
NPP:	National Polar-orbiting Operational Environmental Satellite SystemPreparatory Project
NRT:	Near Real Time
NSDC:	National Satellite Data Centre
NWP:	Numerical Weather Prediction
OGC:	Open Geospatial Consortium
OLCI:	Ocean and Land Colour Imager
SAG:	Scientific Advisory Group
SAR:	Synthetic Aperture Radar
SciHub:	Science Data Hub
SLC:	Single-Look-Complex
SLSTR:	Sea and Land Surface Temperature Radiometer
SPOT:	Satellite Pour l'Observation de la Terre
SSD:	Solid State Disk
SYKE:	Finnish Environment Institute
TOPS:	Terrain Observation with Progressive Scans
V2:	Version 2
V3:	Version 3

VIIRS:	Visible Infrared Imaging Radiometer Suite
VTT:	Technical Research Centre of Finland
WCS:	Web Coverage Service
WMO:	World Meteorological Organization
WMS:	Web Map Service
WP:	Work Package
ZAMG :	Zentralanstalt für Meteorologie und Geodynamik
XML:	Extensible Markup Language

1. EXACUTIVE SUMMARY

Development, implementation, operationalization and validation of Sentinel data processing lines for cryospheric (terrestrial) and land cover/phenology applications were main objectives of SEN3APP project. Operational capabilities of the Finnish Meteorological Institute (FMI) Sodankylä National Satellite Data Centre (NSDC) were applied to host part of the infrastructure and also complete processing lines. During the project implementing of Copernicus Collaborative Ground Segment to Sodankylä has been made in order to maximise the utilisation of Copernicus Sentinels for provided services and products of SEN3APP project by the project partners.

Twelve products participated in the SEN3APP demonstration phase. The products were generated by different SEN3APP partners. Several of the operational services are also continued after the official demonstration phase, and are still actively running. Products and services were generated and validated during the demonstration phase of the SEN3APP project.

Product validations were conducted by the service operator/ product developer. The validation datasets were mainly from years 2014-2016. The near real time (NRT) validation was piloted for the Baltic Sea FSC (Fractional Snow Cover) product. The SEN3APP system validation focused on monitoring the data production and dissemination.

Promotional materials brochures were prepared. Dissemination workshops in Helsinki, Finland and Vienna, Austria were successfully organized. Training material, entitled, "EU FP7 SEN3APP Product Descriptions & Data Access" regarding SEN3APP project was prepared. The SEN3APP portal which provides detailed information about how to download and access all the products was provided within the SEN3App project.

Market analysis was conducted using surveys, face to face and other communications such as email, tele-conference, etc. with some of the end-users of the SEN3APP project. Business models, service scenarios, exploitation and business plans were reported.

All SEN3APP products and services are made available to end-users via SEN3APP web portal.

2. INTRODUCTION

The Sentinel- satellite series aims at frequent global coverage of the Earth surface in full spectrum of remote sensing. This enables the use of well-established satellite products, built up with earlier more research oriented satellites, to be used for the benefit of people in six core areas of Copernicus: security, land monitoring, climate change, atmosphere monitoring, emergency management and marine environment monitoring. The SEN3APP- project addressed three of these, namely climate change, land monitoring and security. At the heart of many of the challenges for the global human community lies the climate change. The understanding of the processes requires vast amount of information. The cryosphere, especially seasonal snow cover, frozen ground and permafrost, plays a very important part in the Earth's energy balance system. The inter- and intra-annual changes in the cryosphere, phenology and land cover have proven relevant not only for climate change studies, hydrology, hydropower, traffic etc. but they have an impact to and interact with many other environmental phenomena. For example, changes in the water quality (freshwater and coastal water) are significantly affected by the duration of winter conditions. Snow melting as well as the thawing and freezing of soil, induce and restrain different processes in the aquatic ecosystems. Changes of land cover are relevant in these processes as well.

Main objective of SEN3APP project was to develop and implement operational and validated Sentinel data processing lines for cryospheric (terrestrial) and land cover/phenology applications. Sub-objectives were

- Define a system and applications including interfaces
- Define processing line of optical system
- Define processing line of SAR system
- Develop tools for utilization of Sentinel satellite data for snow, glaciers, lake ice, soil and land cover change/phenology monitoring in boreal forest and sub-arctic zone
- Define external service interaction and access systems for user-controlled - service provision
- The satellite products and services adapted to Sentinel-satellites will be validated using the QA4EO framework.

The scientific and technical approach of SEN3APP were planned to achieve the project goal and objectives in a realistic, measurable and specific manner within 3 years. The work was divided into the following 8 Work Packages.

- WP1 Users' Consultation and feedbacks
- WP2 System Architecture, Data Management and Processing
- WP3 Product and Service Generation
- WP4 Product and Service Validation

- WP5 Demonstration
- WP6 Dissemination and Exploitation
- WP7 Scientific and Technical coordination
- WP8 Management

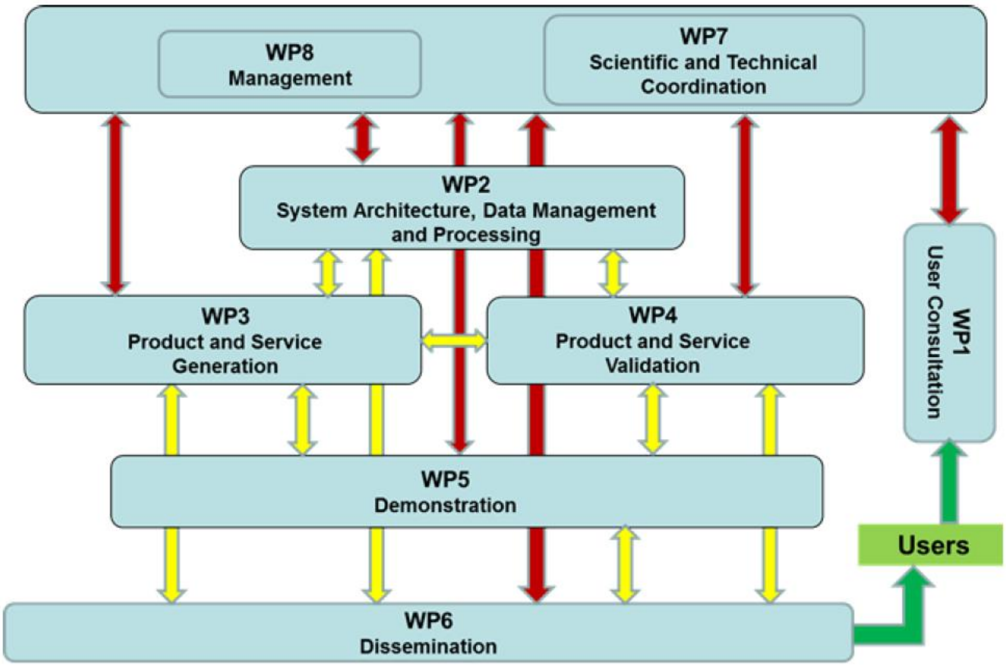


Figure 2.1: Work packages and interdependencies

3. PROGRESSES AND RESULTS

3.1 WP1: USER CONSULTATION AND FEEDBAKS

Relevant governmental organisations and companies in Europe and Bhutan were contacted and invited to complete a questionnaire on SEN3APP snow, glacier, hydrography, land cover / phenology and auxiliary product requirements. In order to assess the user requirements, ENVEO and FMI prepared a questionnaire for SEN3APP products, which was sent to interested users.

All users contacted by ENVEO were very interested in the snow and glacier services provided by ENVEO within the SEN3APP project, and agreed to participate in the SEN3APP user group. Users contacted by FMI were primarily interested in hydrography, land cover/phenology and auxiliary products, with the exception of the Bhutan Department of Hydro-Meteorological Service (DHMS), which was primarily interested in snow, glacier, and hydrography products. Both the surveys conducted by ENVEO and FMI relied heavily on experiences gained from the EU FP7 project CryoLand in which a downstream service for snow, glacier and lake/river ice products was developed.

In addition to existing internal users of SYKEs snow and ice products (fresh water ice monitoring and hydrological service), SYKE started a close collaboration with The Agency of Rural Affairs (MAVI). In two face – to -face user meetings the requirements for land cover/use/change products have been tailored to develop products, which would help in the control of EU agricultural aid mechanism.

Snow, glacier and lake/river ice products currently provided by the CryoLand downstream services are based on sensors with similar properties as the new Sentinel satellites used to produce SEN3APP products. Thus, relevant CryoLand products are used as a baseline to query SEN3APP user requirements.

3.1.1 Collecting end-users' current and future requirements

The SEN3APP user group consists of five public sector users from 4 countries (Finland, Austria, The United Kingdom and Bhutan). The organizations consist of national and regional authorities as well as one national scientific institute.

The Agency for Rural Affairs (MAVI) is predominantly interested in land cover change monitoring and in particular agricultural crop type classification. The primary use of SEN3APP products for MAVI relates to annual monitoring and mapping of areas where farming is practiced and subsequent farming EU subsidies are paid. The most crucial elements regarding MAVI's needs are quick delivery of products, production of products from different dates as well as receiving data at the highest possible spatial resolution. The entire geographic area of Finland (at least all areas where farming is practised / subsidies paid) should be covered by all specified SEN3APP products. The spatial resolution of end products should be at least 15 m or preferably less.

The Department of Hydro-Meteorological Service (DHMS), Bhutan, as a national authority, is predominantly interested in data collection, archival and analysis of hydro-meteorological data in Bhutan. The primary use of SEN3APP products for DHMS relates to multi-hazard early warning systems applications, such as flood and avalanche warning. The DHMS indicated that for them a major consideration besides data quality and specifications relates to the data dissemination system used to provide data access to users. In particular consideration should be placed on how data provided by the SEN3APP project can be connected to databases maintained by the DHMS.

The Hydrological and Hydrographic Service of the Tyrol State Government (HS Tyrol), as a regional authority, is predominantly interested in the fields of hydrography, hydrology and the water cycle within its federal administrative area of responsibility. This includes data collection, archival and analysis of hydro-meteorological data. The primary use of SEN3APP products for HS Tyrol relates to multi-hazard early warning systems applications, such as flood and avalanche warning.

The Central Institute for Meteorology and Geodynamic (ZAMG), as a national scientific authority, has interest in all the snow and glacier products currently provided by ENVEO within the CryoLand project. Highest priorities have the fractional and the melting snow extent products, as well as glacier outlines in particular regions. The requested service includes also a data provisioning chain tailored to the particular needs of ZAMG, The primary use of SEN3APP products for ZAMG relates to meteorological and climatological analyses and forecasts, as well as to scientific research in associated fields.

The UK Meteorological Office (MetOffice UK) as a national authority is predominantly interested in fractional and wet snow extent products, as well as in glacier products. The primary use of SEN3APP products for MetOffice UK relates to numerical weather prediction (NWP) as well as meteorological and climatological studies.

The user MetOffice UK had the following requests for changes in the product specifications:

- All products provided as raster data should be made available in NetCDF format
- Glacier products provided as vector data should be provided also as raster data in NetCDF format
- The wet (melting) snow area product should preferable have a higher temporal resolution than weekly - whatever passes are available for real-time NWP assimilation alongside optical snow cover.

The Freshwater Centre of the Finnish Environment Institute , being responsible for national hydrological modelling and forecasting, is interested in the improving the models through the use of Earth observation based snow parameters. As both FSC and SWE served as model state variables, it is easy to use the EO snow information to verify the state of the model, and correct the model accordingly. This is a part of the Centre's operational activity during the snow season. In contrast to this already established activity, using SWE and FSC directly through data assimilation is not so straightforward, as it would require model systematic calibration. So far, this is under development and is not operationally performed. Freshwater centre also holds long term monitoring of climatological variables from hydrology and cryosphere. Several fresh water lakes and few rivers are observed for formation and disintegration dates of ice cover. Some sites are also observed for thickness of ice cover and snow on ice. To extend the monitoring to cover the numbered freshwater areas of Finland, Fresh water Centre of SYKE is interested in the Lake Ice Extent-product.

Fortum Energy as a participant in the SEN3APP user group is interested in developing Hydropower efficiency and optimization applications through utilization of EO snow observation data products (namely SWE) along with hydrologic forecasting models. The Snow Water Equivalent estimates should be provided for selected Norwegian and Swedish price areas as energy estimations in TWh. An analysis of probable uncertainty would also be considered valuable by Fortum Energy. Fortum Energy requires that the data can be received in a suitable XML and CSV formats and additional to that in EDI messages.

Stora Enso is interested in improving forestry logistics operations through identifying cross country (including small forest roads) mobility factors based on soil bearing capacity. In Finland, as with other boreal zone areas, soil bearing capacity is to a large degree affected by soil freeze/thaw cycles along with soil moisture conditions.

The following snow and glacier products were requested by ENVEO's users (HS Tyrol, ZAMG, MetOffice UK) :

- Daily Fractional Snow Cover (regional, Pan-European area)
- Weekly Wet Snow Extent (regional, Pan-European area)
- Weekly Snow Melt Line (selected regions)
- Annual glacier outlines (regional)
- Annual / seasonal snow / ice areas on glaciers (selected glaciers)
- Annual /seasonal ice surface velocity (selected glaciers)

The specifications for snow products provided by ENVEO were defined in close collaboration with the users in the EU FP7 project CryoLand. The currently provided snow services are already tailored to users' needs regarding temporal and spatial coverage, map projection and data delivery. Thus, the basic requirements for the snow products remain unchanged.

FMI's potential users (Fortum Energy, Bhutan, SYKE Freshwater Centre) have requested a wide range of snow products:

- Snow Covered Area (selected regions / Bhutan)
- Statistical SCA Information (selected regions / Bhutan)
- Fractional Snow Cover (selected regions-Bhutan)
- Statistical FSC Information (selected regions-Bhutan)

- Snow Extent (selected regions-Bhutan)
- Snow Water Equivalent (selected regions/ points-Scandinavia & Bhutan)
- Statistical SWE Information (selected regions-Scandinavia & Bhutan)
- Snow Melt Line (selected regions-Bhutan)

The requirement for the thematic accuracy depends on the application. For instance, SYKE Freshwater Centre's hydrological modelling and forecasting service requires the FSC within the same day, as it is a rapidly changing variable particularly at the end of the melting period. FSC can also be used in near real-time detecting the start of the snow ablation period, as it is sensitive to the small changes in snow patchiness. SWE, in contrast to FSC, is needed to capture the maximum value during the accumulation period, and may be produced with a small 1-3 days delay. The targeted thematic accuracy for SWE is 10 mm, while for FSC, 10% accuracy is required (FSC range is 0-100%).

Mapping of crop fields and plots for the agricultural subsidies of EU sets strict requirements for the satellite products and processing thematically, geometrically as well as temporally. The thematic requirements are mainly dictated by the classification of crops in the EU subsidies system. Classification of crops is therefore the underlying task for the tailored land cover/use product for MAVI. The timeframe of the classification is between April and August. From this period all available images are needed. The timeframe is set by the growing season of crops, but also (mainly shortened) by the timeline of the subsidies application process in Finland. More unpredictable factors affecting the temporal requirements for the data and processing are different timing for planting in same climatic area and, seldom though, sudden loss of crops, that is often followed up by new planting. August is, also, already at the border for being in time for the subsidies process control-mechanism. This also sets tight requirement for the delivery of the images and the final classification. In the most stringent case the imagery are needed in few days after the acquisition.

The agricultural fields in Finland are small and irregular in shape. This sets high demands for the spatial resolution and geometric accuracy of the satellite data. There is no obvious minimum requirement for the spatial resolution, but the order of ~10m is considered a limit, which already captures the majority of the plots: The higher the resolution, the better, but not with the cost of spectral resolution and representativeness (number of channels). Due to the small size and importance of the accuracy in areas (subsidies are based on areas) the accuracy of geometrical correction is highly important.

3.1.2 Collecting end-users' feedback on product and services

A second and final questionnaire was prepared in October 2016 and disseminated to all potential end-users of SEN3APP products. By November 2016, 14 responses were received. The most relevant questions regarding end user feedback and demonstration the following questions were presented:

- Do you use any satellite products and what are they?
- Have you already tested the products provided through the SEN3APP portals?

- Which SEN3APP product(s) is of highest interest for you?
- What is needed that you would start using the products provided by SEN3APP?
- For which application would you use the product(s) provided by SEN3APP portal?
- How long historic records would be needed for the products?
- What is the preferred platform for exploring existing data?
- What is the preferred data download option for SEN3APP products?
- Which data formats do you prefer?
- Have you experienced any issues regarding spatial or thematic accuracies with the SEN3APP product(s) you are using?
- Are some geographic areas that you be interested in that are not currently covered by the SEN3APP products?

In combined total of 20 responses from 17 different institutes were received from the 2 end-user questionnaires. Theses institutes include:

- Institute of Hydrology, Slovak Academy of Sciences (SAS)
- Institute for applied mathematics (CNR-IAC), Italy
- Middle East Technical University (METU), Turkey
- University of Bern, Switzerland
- University of Oslo, Norway
- University of Leuven, Belgium
- University of Silesia, Poland
- University of Oulu, Finland
- alpS Centre for Climate Change Adaptation
- Estonian Environment Agency
- Slovak Hydrometeorological Institute
- Anadolu University, Eskisehir, Turkey
- Zentralanstalt für Meteorologie und Geodynamik (ZAMG)
- National Institute of Meteorology and Hydrology, Bulgaria
- Institute of Geography, Romanian Academy
- alpS Centre for Climate Change Adaptation
- Geological Survey of Spain (IGME)

Summary of response related to what is perceived as being needed to begin operational utilization of the products provided by SEN3APP:

- Lack of knowledge and information on the existence of the products.
- Comparison with reference products and peer-reviewed papers are needed.
- Better resolution products for the Western Carpathians.
- Reliable SWE products for mountainous areas.
- Lack of time to implement new data retrieval procedures and tools.
- Connection with other portals would be beneficial.

The required length of historic records needed for the products ranges considerably (between 50 to 2 years) between end-users and their respective applications. Generally, however, quite unsurprisingly, the longer the historic records the better.

Issues regarding spatial or thematic accuracies with the SEN3APP product(s):

- **University of Silesia, Poland**: The averaged velocity from a set of following products give a good look into tidewater glaciers dynamics and velocity. Although in case of smaller glaciers velocity from one velocity product could be underestimated. Generally, data are useful, especially for looking for local differences between glaciers velocities.
- **alpS Centre for Climate Change: Adaptation**: All products have issues representing the snowline elevation. In the transition zone with snow-free and snow-covered areas, most often no snow cover is mapped (including the fractional products). However, this is the most interesting information for flood forecasting purposes where also modelling is most challenging.

Important geographic areas currently not covered by the SEN3APP products:

- Wet Snow Cover from Sentinel-1 for Slovakia
- Data for eastern part of Turkey is requested
- SWE products for western Carpathians
- Data for Antarctica is requested
- Data for Southern Spitsbergen (Svalbard) is requested
- Wet snow product for Iceland is requested

3.2 WP2: SYSTEM ARCHITECURE, DATA MANAGEMENT AND PROCESSING

Work package 2 concentrated on system and data management aspects and pre-processing of Sentinel data.

3.2.1 System requirement specification and internal interfaces

The SEN3APP system requirement specification covers the satellites and instruments to be utilized and the supported data formats, as well as the functional and non-functional requirements for the system.
Sentinel-1 is used as the Synthetic Aperture Radar (SAR) satellite data source in SEN3APP, offering dual polarisation C-band SAR data from two satellites, in four acquisition modes: Stripmap (SM), Interferometric Wide swath (IW), Extra Wide swath (EW) and Wave mode (WV). The main optical satellites used in the project are Sentinel-2 with its multi-spectral instrument (MSI) and Sentinel-3 with its Sea and Land Surface Temperature Instrument (SLSTR) and Ocean and Land Colour Instrument (OLCI).

For the time period that data streams from Sentinel-2 and Sentinel-3 are not available, replacement satellites were identified: Landsat 8/Operational Land Imager (OLI) for the high-resolution Sentinel-2 images, and Suomi-NPP/Visible Infrared Imaging Radiometer Suite (VIIRS) for the low-resolution Sentinel-3 images.

The functional requirements for the system were mainly derived from the identified user requirements. For data access, the project used the ESA Sentinel Scientific Data Hub, the FMI Sodankylä Collaborative Ground Segment (including the national Sentinel mirror site and the Ground Segment with direct reception of Sentinel data) and the NASA download site for the MODIS atmospheric data.

For input data, the specific product levels required for each instrument were determined.

Spatial requirements for the data were determined as in the following. For snow, lake ice and phenology products based on Sentinel-1 and Sentinel-3: the Pan-European area (72°N/11°W – 35°N/50°E) and also regional coverage (at least the Alpine area and UK). Similar regional coverage requirements apply for Sentinel-2 data. For glacier products based on Sentinel-1 and Sentinel-2 data: selected glaciers or glacier regions all over the world, including Greenland periphery. For land cover products: the area of Finland.

Temporal requirements for the data were determined as in the following. For snow and lake ice products, near-real-time availability and processing of Sentinel-1, Sentinel-2 and Sentinel-3 data is required. Latency time should be no more than 12 hours, preferably in the order of six hours or faster. For snow products, the required temporal availability of data was determined to vary throughout a year. For phenology products, the season covers for Sentinel-3 (and Sentinel-2) from February until November. For glacier products, the requirements for Sentinel-1 depend on the glacier. For Sentinel-2 data, acquisitions are useful only in late summer (August – October) for glacier outline and snow/ice area product generation. For land cover products the period of interest for Sentinel-2 data is from April to July/August. The latency requirement is of 1-2 days.

Data/product provision requirements specified that for automated near-real-time product generation Sentinel products should be accessible via FTP or HTTP. For on demand generated glacier products, Sentinel data should be searchable and selectable via an online Web interface, and downloadable via FTP or HTTP.

Additionally, a number of non-functional requirements for the system were identified and concisely defined, namely for system availability, performance and storage, data throughput and security.

The internal system interfaces are arranged through a common data pool, which serves as an intermediate and as output data storage for the optical and SAR processing lines. The output products of the processing lines are written in GeoTIFF, NetCDF or Shapefile (GLMIS standard) files to the data pool, where they are picked up by the applications. The output of the applications is also written to the data pool, mainly in raster formats. The data is hosted in the data pool and served to end users via OGC WMS/WCS output interfaces.

3.2.2 System deployment and control

The SEN3APP system architecture consists of four primary operating components and a data pool. The components are: Data ingestion processes, Optical and SAR pre-processing, Applications, and Product access interfaces. These are described in respective subsections of this document.
The data pool serves as an intermediate output data storage for the optical and SAR processing lines. It is also used by the applications to ingest and output data, and to serve the data to end users via output interfaces. To allow quick access, the data pool is using disks instead of tapes. Historical and archived data will be fetched from long term archives (LTA) and ingested into the data pool when needed.

A simplified diagram of the SEN3APP system architecture is shown in Figure 3.1.

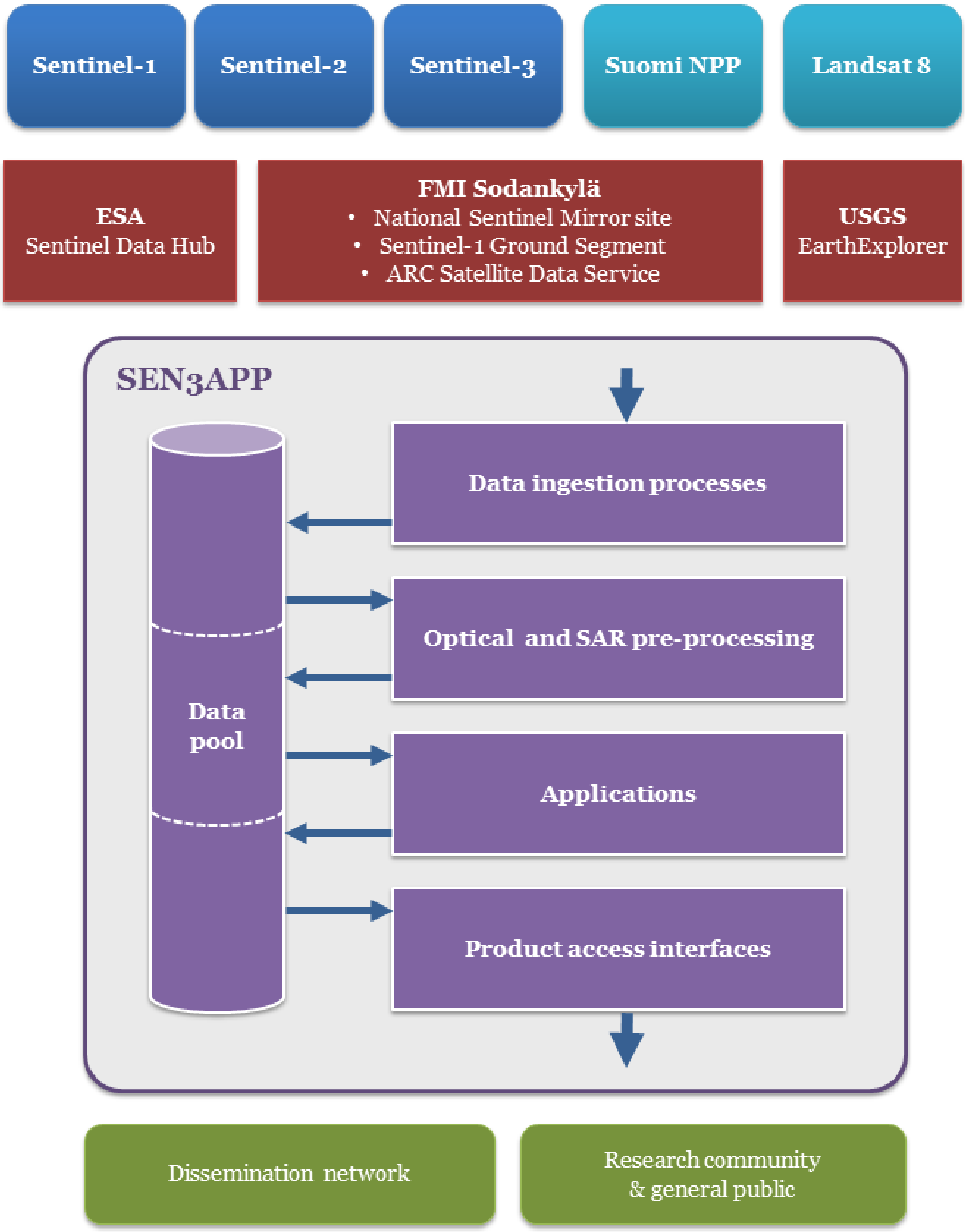


Figure 3.1: Conceptual overview of the SEN3APP components, data sources and the associated data flows. Omitted are additional in-situ and auxiliary data inputs

Deployment options for the SEN3APP system include distributed and centralized approaches, either sufficiently expanding the existing operational systems, or extending highly scalable cloud-based data hosting services. During the project, the system has been deployed at the Sodankylä National Satellite Data Center (NSDC) of the Finnish Meteorological Institute (FMI), using a combination of new and existing infrastructure. The processors and processing chains are partially new developments and partially rely or have a heritage from previously existing software.

A second SEN3APP system deployment with ingestion, data pool and processor components is set up by ENVEO. This system uses Sentinel data that is outside the radius of the Sodankylä receiving station but relevant for product generation within SEN3APP. Regardless of the dual deployment scenario, all products are disseminated from a single source.

To speed up high-volume access to Sentinel data for a high number of concurrent national users, a national long-term archive is set up at the FMI Sodankylä centre. The archiving component consists of Long-Term Archive (LTA), a National mirror as a rolling on-line archive, and a catalogue service that provides metadata of the stored Sentinel data and value added products.

The SEN3APP processes are decentralized within various systems hosted by the Sodankylä NSDC. Depending on each process, it is performed in a virtual environment or in a cluster processing system. The available processing capacity is adequate to host all the defined processing chains.

As part of the NSDC, the Apache Hadoop based Calvalus system is serving as a re-processing and research platform that allows efficient validation of new algorithms and processors and generation of refined long-term time series of physical parameters of interest.

With regard to operating systems, the NSDC uses Red Hat Enterprise based virtual environment, where the users are able to select any operating system (OS) of choice. NSDC prefers UNIX/LINUX systems, and by default the virtual servers are CentOS 7. Calvalus runs on Hadoop 2.4, and Ubuntu 14.04 LTS is the preferred operating system for the processing nodes. Calvalus is capable of running linux-executable and BEAM based processor bundles.

Monitoring of processing systems, networks, infrastructure, services and disk space is arranged at the NSDC through Nagios (http://www.nagios.org/). The system components and processes can be attached to Nagios monitoring system which is maintained by the FMI ICT unit. Nagios sends alerts to specified user groups about identified problems or communication errors and also informs when the problems are solved.

All the SEN3APP processes are monitored during the office hours. Additionally, vital processes can be attached to FMI 24/7 h surveillance which is staffed around the clock daily.

Each process and service writes comprehensive log files. Logs are stored and can be used for problem solving and monitoring the system performance.

On the virtual environment running the SEN3APP Application processes, the processing can be controlled by a stream-based processing system. The Batch Processing System (BPS) allows executing processing jobs sequentially to restrict server workload.

3.2.3 Processing lines for optical system

Pre-processing lines were implemented for Sentinel-2 data and Suomi-NPP/VIIRS data. The Suomi-NPP/VIIRS data were used as a substitute for Sentinel-3 data, which was released for use only during the second last project month of project SEN3APP.
For reading **Sentinel-2 data**, the VTT-developed em_unpack tool was updated to input Sentinel-2 images. This tool:

- uncompressed the JPEG-2000 compressed per-band files of each granule,
- combines the images of each resolution (10, 20, and 60 m) into a multi-band file,
- mosaics together all granules of a UTM zone, and
- combines the sun/satellite angle grids per UTM zone.

When needed, the user can continue to re-projecting and combining the UTM zones with their preferred image processing tools like gdalwarp, ERDAS/ERMapper, ENVI and so forth.

For processing Sentinel-2 images over large areas, a set of tools were implemented for:

- Combination of the sun/satellite angle grids of UTM zones and re-projecting to another projection,
- Combination of Sentinel-2 image files of UTM zones and re-projecting to a chosen UTM zone or the Lambert Equal Area Azimuthal projection, and
- For estimation of a harmonized sun/satellite angle grids.

These tools were tested for a large-area test dataset covering the Boreal zone of Northern Europe (Figure 3.2).

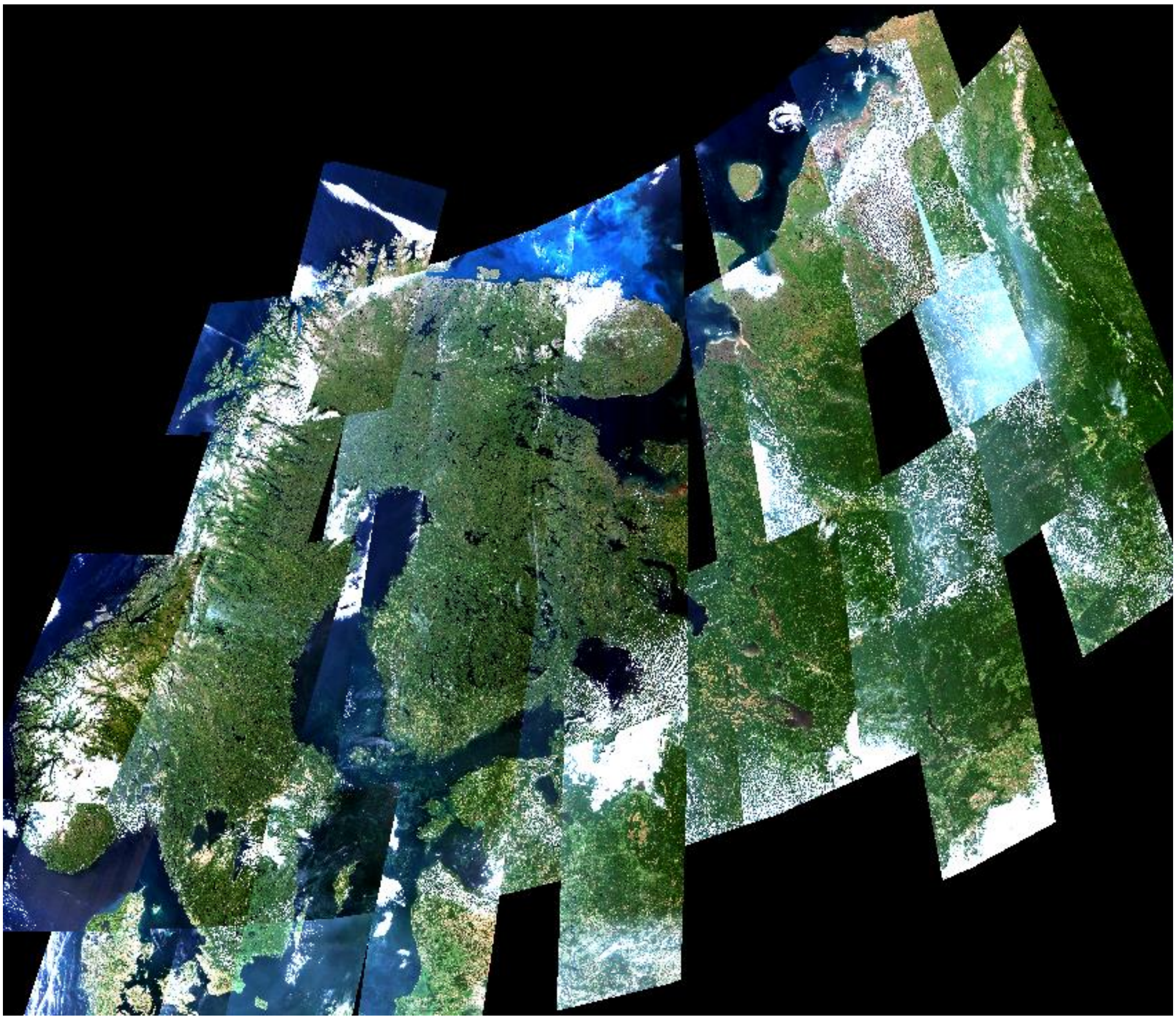


Figure 3.2: Low resolution mosaic of 79 Sentinel-2 images in Northern Europe. Red, green, and blue visible light shown in red, green, and blue, respectively

For **correcting the effects of varying aerosol** in Sentinel-2 type images, a software tool was made for estimating the aerosol in the image. Program comp_aod calculates the Aerosol Optical Density (AOD) field using the blue band in 0.49 µm and the SWIR band in 2.19 µm. In Finland, the Corine-2012 land cover map is used to locate dark dense vegetation (mature forest) in AOD field calculation. AOD values are iterated by the Simplified Method for Atmospheric Correction (SMAC) for those areas and interpolated for remaining pixels. This AOD field is then used in the Envimon tool em_radio to make the atmospheric correction, i.e. to compute surface reflectance values for the pixels of the Sentinel-2 image.
Figure 1.3 shows a sample AOD field which was estimated from a Sentinel-2 image and the effect when using the estimated AOD field in the atmospheric correction instead of one default AOD value. One can see how the highest aerosol optical density locations are corrected to the same radiometric level as in the rest of the image. This is an effect that makes otherwise unusable optical images (especially visible part of the spectrum) usable over large areas.

Corrected with fixed AOD Estimated AOD field Corrected with variable AOD

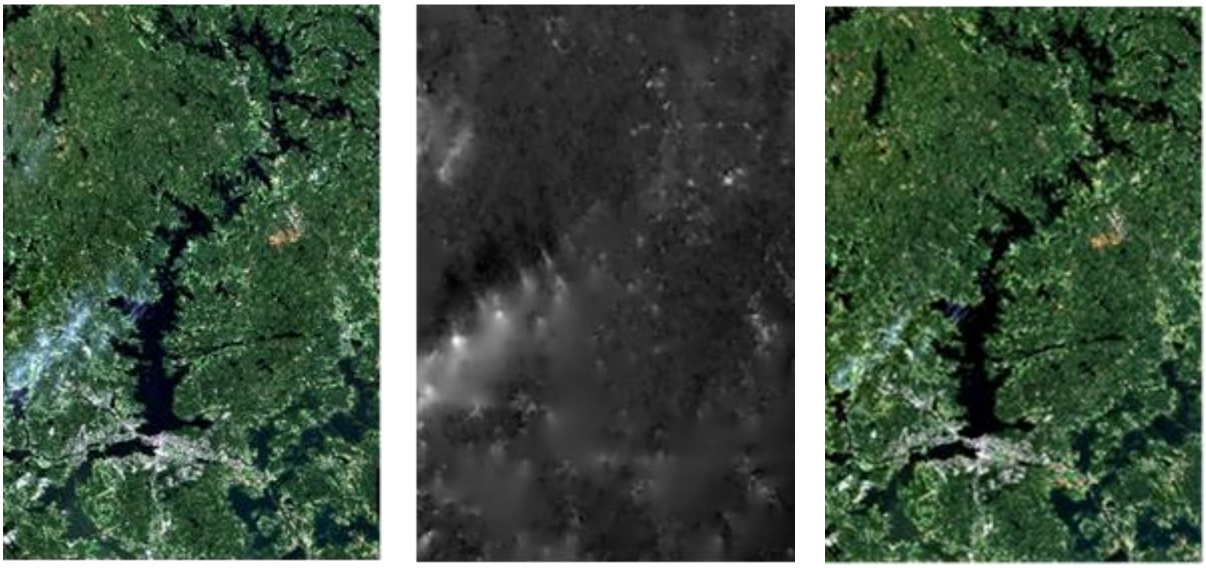


Figure 1.3: Sentinel-2 scene after atmospheric correction with fixed Aerosol optical density (AOD) value of 0.1 (left), AOD field estimated for the Sentinel-2 scene (middle), and Sentinel-2 image after atmospheric correction with variable AOD values from 0.05 to 0.47 (right). The Sentinel-2 scene covers the Tampere and Pyhäjärvi region in Finland. Natural colour version is shown here (blue, green, and red visible bands)

The **pre-processing line for Suomi-NPP/VIIRS** (National Polar-orbiting Operational Environmental Satellite System Preparatory Project/Visible Infrared Imaging Radiometer Suite) data takes as input SDR data (Sensor Data Record). The processing line consists of tools for reading the input hdf5 (Hierarchical Data Format version 5) files, rectification tools, and atmospheric correction tools.

The hdf5 reading programs accept data from the FMI Sodankylä receiving station and data from the archive service CLASS (Comprehensive Large Array-data Stewardship System) of NOAA (National Oceanic and Atmospheric Administration). The rectification tools include resampling alternatives nearest neighbour and Gaussian-weighted average. The atmospheric correction tools utilize the SMAC program of CNES. Both constant AOD (Aerosol Optical Density) and variable AOD (by iteration with SMAC) are supported.

Figure 3.4 shows a sample Suomi-NPP/VIIRS mosaic. Data from 31.5.2015 to 30.9.2016 were used. Image rectification was done daily on a virtual server (vtt-viirs) in the FMI Sodankylä facilities. All 238 images were rectified to 500-metre pixel spacing in the Lambert Azimuthal Equal Area (LAEA) projection. Atmospheric correction was made with a constant AOD. A minimum-NIR (Near InfraRed, 0.865 µm) composite over the whole period was used to generate a water mask. Water areas were taken from the minimum-NIR composite. Land areas were taken from a maximum-NDVI (Normalized Difference Vegetation index, $[I_{0.865} – I_{0.64}]/[I_{0.865} + I_{0.64}]$) composite over the period of 31.5.2015 to 23.8.2016. No external data were used.

Figure 3.4: Sample Suomi-NPP/VIIRS mosaic over Northern Europe. Red = short wavelength infrared (1.61 mm), green = near infrared (0.865 mm), and blue = red visible light (0.64 mm)

Cloud detection and masking methods were developed and implemented for Sentinel-2 and Suomi-NPP/VIIRS type of data. Program comp_cloud_s2 computes cloud and shadow mask from Sentinel-2 images and comp_cloud_VIIRS for Suomi NPP VIIRS images. Both are based on same algorithm and same software. The only difference is that comp_cloud_s2 contains the integration of the 10 m, 20 m, and 60 m Sentinel-2 bands for the processing.
The algorithm uses 3 visible bands (blue in 490 nm, green in 560 nm and red in 665 nm), one near-infrared (NIR) band (0.865 µm) and 3 short-wave infrared (SWIR) bands (1.38 µm, 1.61 µm and 2.19 µm). Cumulus cloud detection is based on high reflectance in the visible bands and the cirrus and high altitude cloud detection is based on high reflectance in cirrus band (1.38 µm). The resulting cloud mask contains also other classes like bare agricultural areas and snow and ice areas. Snow and ice is separated from the clouds by the Normalized Difference Snow Index using bands 1.38 µm and 1.61 µm and the bare agricultural areas are separated from clouds by the ratio between the NIR (865 nm) and the visible bands. Shadow detection is based on the ratio between blue (490 nm) and green (560 nm) bands. The resulting shadow mask contains also other classes like shore and shallow water areas and dark dense vegetation areas. These areas are separated from the shadow mask by differences in the spectral profiles. In post-processing, all one pixel sized objects are removed and the cloud and cirrus objects are dilated by 6 pixels and shadow objects by 4 pixels before the final cloud and shadow mask.

Figure 3.5 shows the result of cloud and shadow detection from a Sentinel-2 image over a Finnish area.

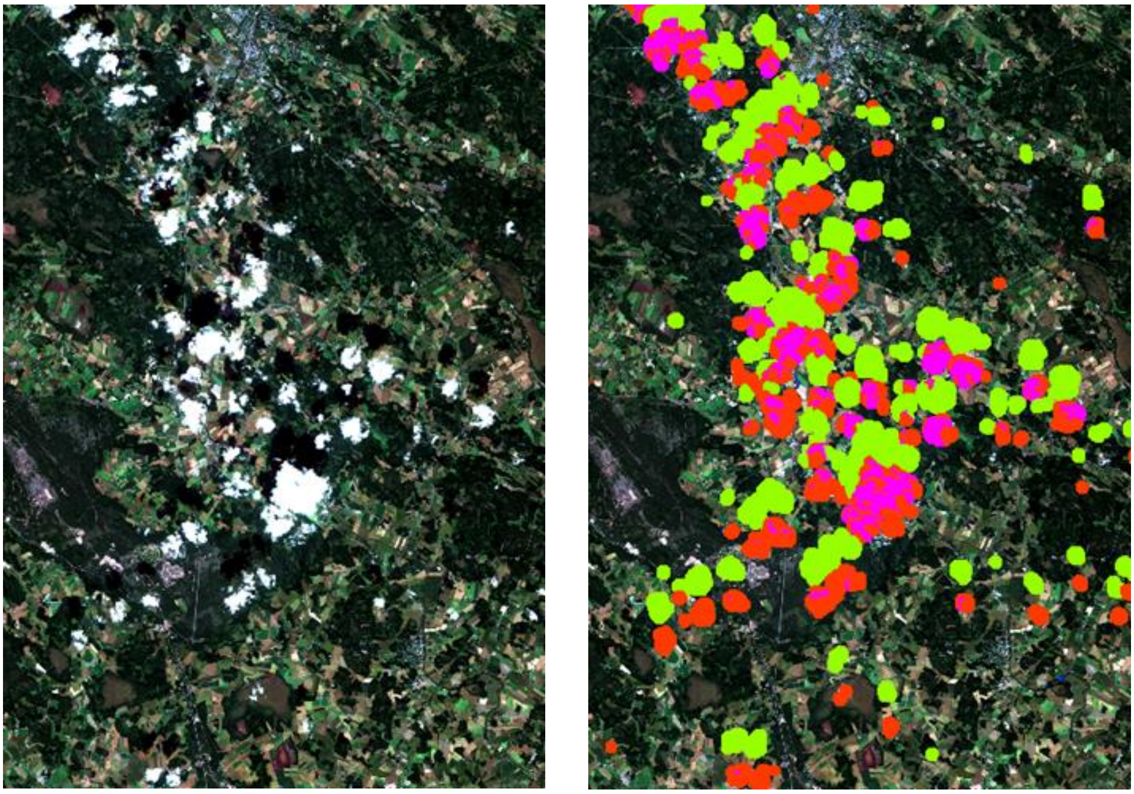


Figure 3.5: Sample Sentinel-2 image (left) and result from cloud and shadow detection (right). Red= cumulus cloud, lilac = cirrus or high altitude cloud, green= shadow

3.2.4 Level 1 processing lines for SAR

The Sentinel-1 (S1) pre-processing consists of a set of shell scripts that are grouped into 2 main modules:

- S1 GRD (Ground Range Detected) Processor and
- S1 SLC (Single Look Complex) Processor.

The scripts steer the processing of common tasks and base on COTS (Commercial Off The Shelf) GAMMA software tools (Table 1) as well as FOSS (Free and Open Source Software) GDAL (Geospatial Data Abstraction Library), and common Linux tools. The shell scripts are designed in a modular way to simplify maintenance and improve reliability of the scripts.

Prerequisites for the Sentinel-1 pre-processing line are:

- Installation of the latest release of the GAMMA Software packages ISP, DIFF, LAT (binaries). The list of Sentinel-1 relevant tools is given in Table 1.
- GDAL >= 1.10

- SEN3APP Sentinel-1 pre-processing shell scripts

Table 1: List of specific Sentinel-1 GAMMA software executables used in the SAR processing system

`par_S1_GRD`	Import S1 GRD data to raster format, apply calibration data, optional conversion to slant range geometry multi looking image.
`OPOD_vec`	Apply precision state vectors from the Sentinel-1 On ground Precise Orbit Determination (POD) solution.
`par_S1_SLC`	Import S1 SLC TOPS (Terrain Observation with Progressive Scans in azimuth) data, and optionally apply calibration data.
`SLC_copy_S1_TOPS`	Copy multiple bursts from a Sentinel-1 TOPS mode SLC.
`SLC_cat_S1_TOPS`	Concatenate adjacent Sentinel-1 TOPS SLC images.
`multi_S1_tops`	Calculate MLI mosaic from Sentinel-1 TOPS SLC burst data.
`SLC_mosaic_S1_TOPS`	Calculate SLC mosaic of Sentinel-1 TOPS burst SLC data.
`SLC_interp_lt_S1_TOPS`	Resample TOPS (Interferometric Wide mode) SLC using a lookup table and SLC offset polynomials for refinement.

The general processing outline is shown in Figure 3.6. For details it is referred to the Pre-Processing Lines: User documentation and guide. All scripts have integrated documentation that can be extracted using the perlpod tools (`pod2man|pod2text scriptname`).

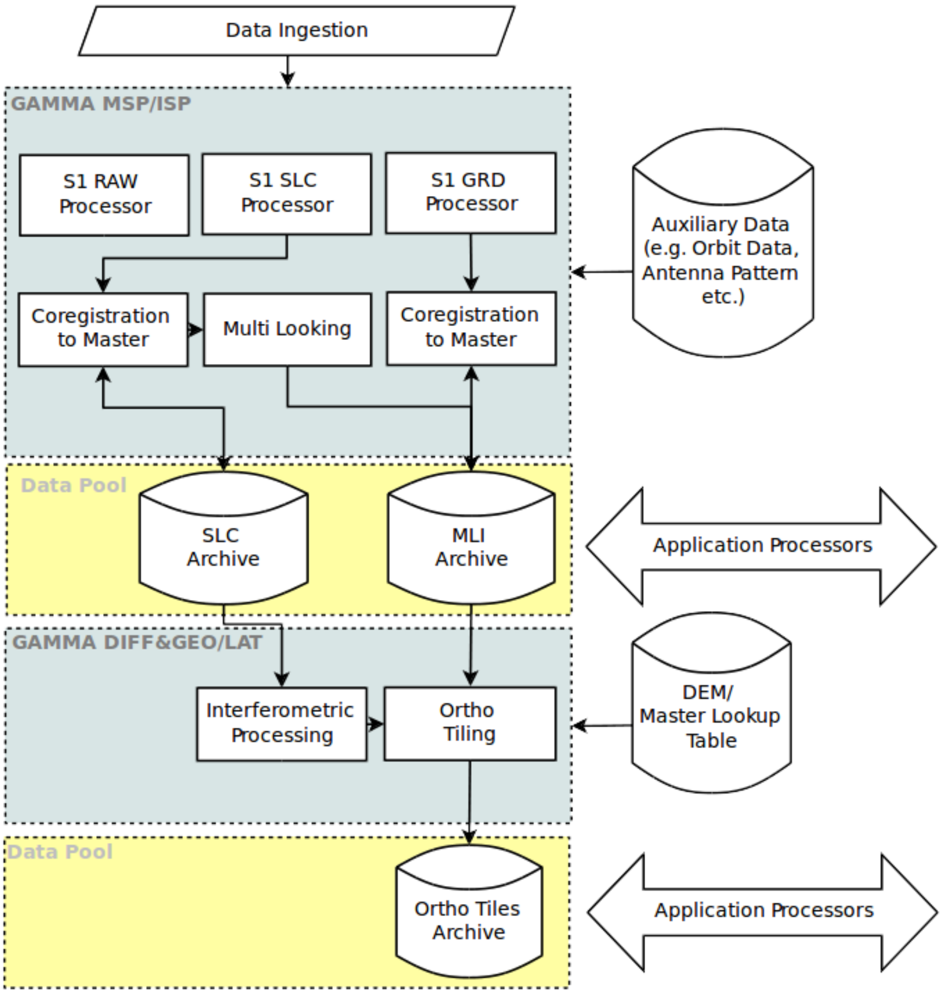


Figure 3.6: Sentinel-1 pre-processor diagram

In a first step, the data coming from the collaborative ground segment are imported into GAMMA software and converted to detected images in slant range (sensor) geometry. This is necessary as the SLC scansar data consist of single burst SLC (Figure 3.7) of 3 swaths (Figure 3.8) that need to be mosaicked to get a continuous image (Figure 3.9). The GRD data on the other hand are in a pre-processed format that includes some height correction that needs to be reversed for proper ortho-rectification later. Images are brought into a common geometry by using a master image as reference.

In a second step, images are filtered (spatially but also multi temporal filtering) and if applicable undergo interferometric processing. Finally images are ortho-rectified including the pixel area normalisation. A process of particular interest in rough terrain as it removes the effect of topography on the backscatter value due to the incidence angle dependant pixel size (Figure 3.10).

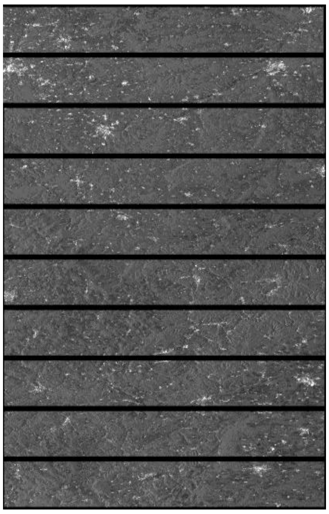


Figure 3.7: IW1 SLC bursts

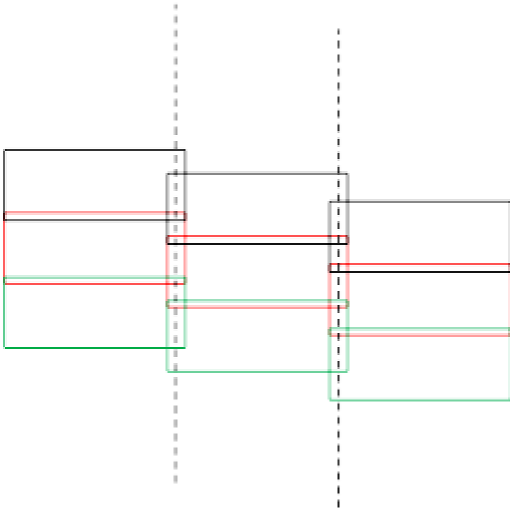


Figure 3.8: S1 burst structure indicating the small overlaps between succeeding bursts and the 3 sub-swaths

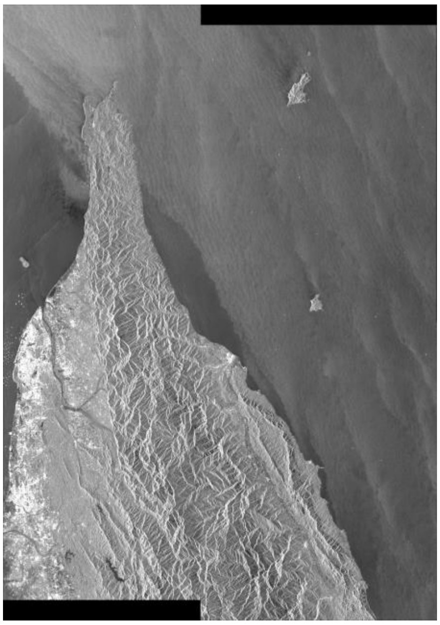


Figure 3.9: S1 TOPS SLC mosaic that includes 2 sub-swaths and 10 bursts. Data is acquired from an ascending orbit, and shown in slant range and azimuth geometry

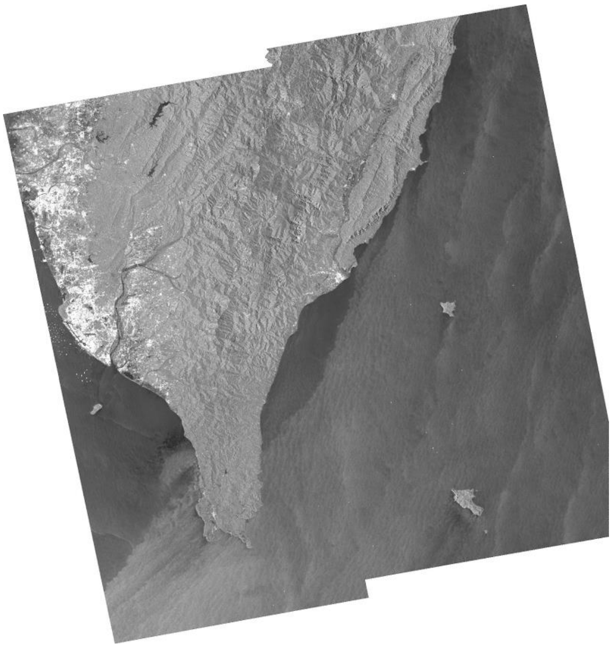


Figure 3.10: Ortho-rectified backscatter image with pixel area correction applied

3.2.5 Data ingestion tools

ESA provides Sentinel data access to users via Data Hub Services (DHuS). There are two different services; Science Data Hub (SciHub) which is open for everyone and Collaborative Data Hub (ColHub) which is only available for Sentinel Collaborative Ground Segments (CGS). FMI, as a CGS, uses ColHub to mirror Sentinel 1, 2, 3 and 5P data to Sodankylä National Satellite Data Center (NSDC).

In addition to the DHuS, Sodankylä NSDC uses the near-real time Sentinel-1 data as a part of the Collaborative Acquisition Station (CAS) activities. The Sentinel-1A and 1B data is received and processed using the existing infrastructure and ingested into the SEN3APP system. Sentinel-3 was launched during the SEN3APP project but the data was not available. Thus, the Suomi NPP (S-NPP) satellite data is used for developing corresponding SEN3APP processing lines and applications. Sodankylä NSDC receives S-NPP on daily basis and the data is provided in near-real time (NRT) through the disk system.

Landsat 8 satellite data was used to demonstrate and develop SEN3APP processing chains until Sentinel 2 data was available. USGS data service is used to fetch Landsat 8 data to Sodankylä NSDC and ingested to SEN3APP system. Currently the service is only available through a semi-automatic bulk download application (BDA). From the beginning of the year 2016, Sentinel-2 data is ingested from ColHub to NSDC to be used in SEN3APP applications.

3.2.6 Product selection and access

ESA has released its DHuS software as an open source that FMI NSDC uses to distribute local Sentinel data to SEN3APP applications and other users. FinHub, available at https://finhub.nsdc.fmi.fi, is open for everyone who has need for faster and non-restricted access (no parallel download limits) to Sentinel data.

The Sodankylä NSDC has built a web portal (http://saana.nsdc.fmi.fi/apollo-portal/) for data distribution (other than Sentinel L1 data) from a single point of access. The SEN3APP products are being made available through the portal linked from the project website. The portal is based on ERDAS APOLLO, an OGC/ISO-based web application that is developed by Hexagon Geospatial and implemented on a geospatial platform that enables high performance OGC web services. The data on the service is accessible with a web browser or with a GIS tool.

The web service allows users to browse and search the data from a catalogue. The data content can be restricted based on the user. Some of the data can be made available only after logging in to the system. The data can be shown on the WMS or downloaded to the user's computer. The data can also be opened directly with 3rd party software such as Google Earth. The WMS service offered allows basic tools to select the user desired data.

The data interfaces offered employ the Open Geospatial Consortium's (OGC) Web Map Service (WMS) and Web Coverage Service (WCS) specifications. Technically, all the metadata interfaces are XML-based and work over the HTTP protocol. The SEN3APP web portal offers example scripts to help users to request the data without using the ERDAS APOLLO GUI. The scripts are similar to those provided by the CryoLand portal and can be used to automate the access to the WCS interface to gather information about the service and receive data.

3.2.7 Interoperability and workflows for user controlled services

User controlled services of SEN3APP are realized by giving external users access to virtual machines hosted on the infrastructure of the Arctic Research Centre (ARC) of the Finnish Meteorological Institute (FMI). The machines can be used to run specialized processing lines for custom applications. In addition to the processing capacity, the machines have a fast connection to the SEN3APP Near-Real Time (NRT) data pool as well as to the data archive.
The processing is mainly done on virtual machines. A typical virtual machine for running the processing has a 64bit Intel dual-core 2,5 GHz CPU and is equipped with 4 GB RAM. The processing capabilities can be easily expanded when using virtualization. Also resources that are not used at the moment can be used by other processors. Depending on the operational level, a virtual machine can be granted higher privileges that allow using more resources compared to other machines.

The processing machines have access to the common storage (Lustre) where users can find the source data and products for processing. This intermediate data storage contains only the latest data of the whole data centre. The NRT data is available for the users from a rolling archive. The data on the rolling archive is staged on the drives for fast access upon request. From the rolling archive the data is moved to a long term archive (LTA) where it is first placed on disks and eventually to tapes. Data from the LTA is also available for users but the recovery from tapes takes more time than from disks. NSDC is currently renewing its storage system. The new storage, planned to be active at the beginning of 2017, will have increased storage capacity and instead of tapes, all the data is stored to Solid State Disks (SSD) that provide faster data access.

Backup will be performed for the processing machines usually once per week or as agreed with the user. The services are targeted to run 99.9 % of time and the users are informed about the outages due to routine maintenance of the computer systems or in case of unexpected malfunctions. External users can access an on-line ticketing service that is used to request for support and report problems regarding the processing services. The used software is JIRA that is developed by Atlassian for issue and project tracking.

3.3 WP3: PRODUCT AND SERVICE GENERATION

A summary of the products and the algorithms and processing line specifications is given in Table 1 sorted by Sentinel sensor. It shows the products and services development status, and gives quick access to the products, basic product algorithm, processor, input and output data and products. In addition the requirements on the production time (latency) are indicated and also production time and memory needs are given as an indication of performance and scaling capability. The processors that are run within the SEN3APP demonstrator are indicated by status "Demo" in Table 2.

The products and the corresponding algorithms and processing lines are discussed in more detail in the following sections. The sections are structured along the product groups defined in the proposal.

The implementation of the processing chains was done by product by the responsible partner. The design for all operational chains is portable so that production can be migrated later to a central or distributed computing solution if necessary. The operational processors that relay on data available in the collaborative ground segment in Sodankylä are run on virtual machines close to the data source in Sodankylä. Available data includes regional VIIRS and Sentinel-1 GRD data. Sentinel-1 SLC and Sentinel-2 data are available through the Science- and API-Hub operated by ESA.

ENVEO has its own processing environment and runs all processing chains in their own facilities.

GAMMA produces the glacier velocity product in-house as it depends on SLC data not available in Sodankylä. However, tests confirmed the portability of the processor to the virtual SAR data processing machine in Sodankylä (gamma-sar).

Table 2: SEN3APP product implementation status

Service/ Product	Status	Algorithm	Processor	Input	Output	Latency / RAM / Production Time / Product Size
Glacier Velocity	Demo On-demand	Offset Tracking (Paul 2013)	SAR, offset tracking module (ENVEO/ GAMMA)	Sentinel-1	Ice surface displacement map as raster (GeoTIFF, NetCDF) and vector (csv). Displacement / year Spacing: 5 – 20 m	< 3 months RAM: ca 20 GB Processing time: ca 30 min per slice Product size: ca 150 MB per track

		Interferometry (Strozzi 2012)	InSAR, displacement module (ENVEO/ GAMMA)	Sentinel-1	Ice surface displacement map as raster (GeoTIFF, NetCDF) Displacement / year Spacing: 5 – 20 m	< 3 months RAM: ca 20 GB Processing time: ca 30 min per slice Product size: ca 150 MB per track
Wet snow cover	Demo Pilot	Change detection (Nagler, 1996, Nagler and Rott (2000, 2001), Nagler et al., 2016)	SAR processor (ENVEO)	Sentinel-1	Melting snow map as raster (GeoTIFF, NetCDF) Binary information Spacing 100 m	< 1 day RAM: ca 20 GB Processing time: ca 30 min per track Product size: ca 1 MB per track
Lake ice state	Research	Multi temporal metric (Wegmuller et. al 2010)	SAR (GAMMA)	Sentinel-1	Binary map of lake ice state (open water, floating ice, grounded and potentially frazil ice) Spacing: 20 m	Seasonal RAM: ca 20 GB Processing time: Minutes from sen3app standard SAR product Product size: ca 200 MB per product
Water Bodies	Research	Multi-temporal metric (cci_landcover)	SAR, WB classifier (GAMMA)	Sentinel-1	Binary map of water and land classification. The water class refers to open and permanent inland water bodies (rivers, lakes, impoundments) Spacing: 20 m	Annual or seasonal RAM: ca 20 GB Minutes from sen3app standard SAR product Product size: ca 200 MB per product
Freeze/Thaw	Research	Multi-temporal metric (Park et al., 2011)	SAR, FT classifier (GAMMA)	Sentinel-1	Time series of backscatter values indicating freeze/thaw for selected points Spacing: 20 m	Annual product RAM: ca 20 GB Processing time: Minutes from sen3app standard SAR product

Snow/Ice areas on Glaciers	Demo On-demand	Threshold-based semi-automated approach (Bippus, 2011) or change detection (wet snow only)	Optical /SAR processor, optional manual post-processing (ENVEO)	Sentinel-1 (wet snow only) /-2 (Landsat 8, SPOT, or similar – depends on availability through DWH) (full snow/ice discrimination)	Snow areas on glaciers as raster (GeoTIFF, NetCDF) or outlines of snow areas on glaciers as vector (Shapefile) Spacing: 10 m	< 3 months RAM: ca 20 GB Processing time: ca 1 hour per scene (if all ancillary data are available, glacier outlines prerequisit) Product size: a few MB (Shapefile) up to a few hundred MB (GeoTIFF)
Glacier Outlines	Demo On-demand	Semi-automated detection	Optical processor, optional manual post-processing (ENVEO)	Sentinel-2 MSI (Landsat 8, SPOT, or similar – depends on availability through DWH)	Outlines of glaciers as vector (Shapefile) Spacing: 10 m	< 3 months RAM: ca 20 GB Processing time: < 3 months (post-processing can be time consuming) Product size: ca 1 MB – 10 MB
Crop/vegetation classification (for MAVI)	Demo Under Development	New methodology developed	(SYKE)	Sentinel-1, Sentinel-2, (Landsat-8, other high-resolution satellite instruments)	Classification of agricultural crops on main level, information about ploughing of parcels for agricultural subsidy control Monthly tables describing if parcel has vegetation cover or not. Crop classification as table for parcels during August. Monthly image mosaics of reflectance, maximum NDVI and SAR backscatter.	Annual product Processing time of the order of 1h
Cloudless Sentinel-2 reflectance	Processor	Intermediate Product of Sentinel-2 Processing chain	(VTT)	Sentinel-2	Surface reflectance map at the resolution of input data.	< 1 day Production time < 1 day Memory/RAM: 8 GB (16 GB recommended) Disk space: 30 GB per Sentinel-2 image.

Lake ice Extent	Demo Under developmen t	Threshold reflectances	(SYKE)	Sentinel-3 [Sentinel-2 optional] (VIIRS/ MODIS/ Landsat-8)	Maps of lake ice extent and four class classification of the lake ice state.	Latency 1 day RAM: 8GB Processing time: 10h (can be reduced to 4h) Product Size: 150 MB
NH Fractional Snow Cover	Demo Pre-operational	SCAmod	(SYKE/FMI)	VIIRS/ Sentinel-3 SLSTR	Fractional snow cover map as raster (GeoTIFF, NetCDF) Spacing: 0.01°	Latency 1 day RAM: 48GB Processing time: 3h Product Size: daily: 1.2GB
Fractional Snow Cover	Demo Operational	Multi-spectral unmixing	Optical processor (ENVEO)	Sentinel-3 SLSTR / OLCI (MODIS, VIIRS)	Fractional snow cover map as raster (GeoTIFF, NetCDF) Spacing: 0.003°	< 1 day *Pan-Europe:* RAM: ca 7 GB Processing time: ca 3 hours Product size: ca 87 MB *Alpine area:* RAM: ca 8 GB Processing time: ca 2.5 hours Product size: ca 8.2 MB
Extended Baltic Sea drainage basin direct broadcast FSC based on NPP VIIRS/ Sentinel-3 SLSTR	Demo Operational	SCAMod	Optical FSC-processor (SYKE/FMI)	Sentinel-3 SLSTR (VIIRS, MODIS)	Fractional snow cover map as raster (GeoTIFF, NetCDF) Spacing: 0.01°	< 1 day RAM:48GB Processing time: 45minutes Product Size: daily: nc 1.2GB (can be reduced)
Phenology	Demo Pre-operational	Threshold time series of vegetation indices/ fractional snow cover information. Function fitting used for time-series gap filling (Böttcher et al. 2013)	Matlab (SYKE)	Sentinel-3 (VIIRS/ MODIS)	Annual maps of growing season start date (GSSD). Spacing: 1 km	Annual data RAM: 8 GB Processing time: Product Size: 250 kB

Combined NH FSC + SWE	Research	SCAmod + FMI GS SWE	(SYKE/FMI)	VIIRS/Sentinel-3 SLSTR + PMW + synop data	Fractional snow cover and SWE map (25 km x 25 km) as raster (GeoTIFF, NetCDF)	< 1 day RAM: 48 GB Processing time 10h Product size: 100 MB
Pan-Europe High resolution SWE	Demo Pre-operational	FMI GS SWE	(FMI)	PMW + synop data + Sentinel-3	Fractional snow cover and SWE map (5 km x 5 km) as raster (GeoTIFF, NetCDF)	< 1 day RAM: 4 GB Processing time: 24h Product Size: 100 MB

3.3.1 Land cover change and phenology for boreal zone

This section covers the services addressing land cover change and phenology for the boreal zone. The following products are produced:

- Crop/vegetation classification
- Phenology Product
- Water Body Map
- Freeze/Thaw

Agricultural crops are classified using statistical non-parametric k-nearest neighbour classifier. Time series of remote sensing data, in other words monthly mosaics of SAR backscatter and maximum NDVI are used as features for classification. Classification requires training areas provided by MAVI. Information about ploughing, in other words vegetation status in winter, is based on thresholding of NDVI and SAR backscatter to provide vegetation / no-vegetation classification.

The phenology product for growing season start date (GSSD) is based on time-series of fractional snow cover (FSC) used for coniferous forests and in normalized difference water index (NDWI) for deciduous forests. The product is in development phase, where methodology is sought for determining growing season end date (GSED) and allowing computing the length of growing season. The product suffers from cloud cover and polar night. The main usage of the data is currently in climate research and the methodology is continuing to develop to allow mapping of end of growing season and length of growing season. Additionally, there is interest in the data in research of species populations and habitats.

The map of water body represents a static classification of inland open and permanent water bodies. The other class is land. This product does not account for temporary water bodies (unless of prevalent water cover during the time period of the Sentinel-1 data). The product shows maximum extent of water in the time frame of the Sentinel-1 data. Dynamics are therefore not mapped.

The aim of the freeze/thaw product is to determine the soil state based on a high frequency stack of Sentinel-1 data. The product depends on a stack of Sentinel-1 SAR acquisitions. The acquisition repeat rate during the melt and freeze periods is crucial for the product processing. The algorithm is based on the detection of the significant drop in soil moisture when the soil freezes.

3.3.2 Snow for boreal forest and mountain zone

In SEN3APP experiences elaborated in previous projects were used to proceed with already running snow services requested by users. For continuity these services were migrated to use Sentinel-2 and Sentinel-3. Based on Sentinel-1 a pre-operational wet snow monitoring service for the Alpine area was implemented. The following products were established within SEN3APP:

- Fractional Snow Cover extent for Northern Hemisphere from optical data
- Combined (2-layer, 25km) Northern Hemisphere snow cover product with optical FSC and PMW SWE –layers
- High resolution (5km) Pan-European SWE product (augmented using optical FSC data)
- Wet snow cover for the Alpine area from Sentinel-1 data
- Regional and Pan-European FSC product from synergistic Sentinel-3 SLSTR/OLCI data
- Extended Baltic Sea drainage basin direct broadcast FSC based on NPP VIIRS/Sentinel-3 SLSTR (FMI&SYKE)

Information about fractional snow cover is of high interest for multiple applications for instance in hydrology, meteorology, geotechnical engineering and climate research. A number of products were developed and implemented for different target areas and spatial resolution. The synergistic Sentinel-3 SLSTR and OLCI data will provide in future a new data base to continue the services providing daily fractional snow cover service for the Alpine region and the Pan-European area.

The Combined (2-layer, 25km) Northern Hemisphere snow cover product with optical FSC and PMW SWE layers addresses the need for Snow Water Equivalent (SWE) information. Retrieval of snow water equivalent (SWE) from passive microwave data is traditionally based on direct inversion algorithms relying on an empirically determined relationship between SWE and observed brightness temperature. The SWE layer of the proposed product is derived using a combination of ground based data and satellite microwave radiometer-based measurements. Due to the nature of the radiometer observations, the SWE product reliably shows areas with seasonal dry snow cover. Areas with sporadic wet snow or a thin snow layer are not reliably detected. Therefore, an additional snow extent analysis mask derived from VIIRS and IMS data is used to constrain SWE layer extents. Although the analysis mask is unable to provide a SWE estimate in areas where the radiometer based algorithm does not detect snow, but snow is otherwise detected, it can filter-out snow free areas. In order to provide additional information to users of the SWE product, a second layer consisting of fractional snow cover is added the final product. Adding a second FSC-layer is particularly useful in areas where the SWE algorithm is unable to reliably determine the presence and/or volume of snow. In practical terms this provides valuable information during snow accumulation, when snow cover typically consists mostly of wet snow, and during snow ablation, when once again the snow cover layer mostly consists of wet snow.

The **wet snow cover product** is of very high interest for hydrological applications, as it provides in combination with the total snow extent from optical satellite data advanced information on the melting status of the snow area. The pilot product aims to cover the full alpine area. Therefore, data of at least four tracks of Sentinel-1A are needed, which are acquired on different dates. In order to meet the user requirement to get the product in near-real time, the wet snow cover product is updated and provided track-wise.

3.3.3 Glaciers

Glacier products from Sentinel data are generated on demand for particular areas of interest identified by users. Users show interest in the following glacier products, each generated from high resolution satellite data, as available from Sentinel-1 and Sentinel-2:

- Glacier outlines
- Snow and ice areas on glaciers
- Ice surface velocity maps

The general products characteristics identified in close collaboration with users in the EU FP7 project CryoLand (2011 – 2015, No 262925), and reconfirmed by SEN3APP users in the beginning of the project period are summarized in Table 3.

Table 3: Overview on glacier products planned to be adapted and tested using Sentinel data as input within SEN3APP

Products	Sensor	Projection / Datum	Spatial Coverage	Spatial Resolution	Temporal Resolution	Delivery period	Latency time	File Format
Glacier Outlines / Area	Sentinel-2 (Landsat)	Geographic / WGS84	Selected regions	10 m	Annually	TBD	< 3 months	Vector (Shapefile, GLIMS Standard)
Snow / Ice Areas on Glaciers	Sentinel-2 (Landsat)	Geographic / WGS84	Selected glaciers	10 m	Seasonally / Annually	TBD	< 3 months	Raster (GeoTIFF), Vector (Shapefile, GLIMS Standard)

Ice Surface Velocity	Sentinel-1	Geographic / WGS84	Selected glaciers	5 m - 20 m	Seasonally / Annually	TBD	< 3 months	Raster (GeoTIFF, netCDF)

Glacier outlines are generated on user request only for selected areas of interest using high resolution optical satellite data, as available from Sentinel-2 MSI. Data from Landsat-8 or SPOT could be used as complementary data base. Glacier outlines are prepared meeting the internationally accepted standards defined by GLIMS (Global Land Ice Measurements from Space) and following the INSPIRE standards. The final product contains beside glacier outlines also other relevant surface types belonging to a glacier, as for instance internal rocks on glaciers including Nunataks, or supra-glacial lakes.

The **snow and ice areas on a glacier** at the end of the ablation period are important parameters which can be used assessing the mass balance of a glacier. Also for hydrological runoff forecasting information on the snow areas on glaciers is relevant, as such areas store a vast amount of water over a season, while the seasonal snow is melting faster, and thus contributes at another time to the runoff. Also with respect to fresh water supply for the population benefiting from water originating from seasonal or permanent snow covered areas the knowledge about the snow areas remaining on glaciers during the summer is important.

Knowledge on glacier ice velocity provides a better understanding of a wide range of processes related to glacier dynamics, for example glacier mass flux, flow modes and flow instabilities (e.g. surges), sub-glacial processes (e.g. erosion), supra- and intra-glacial mass transport, and the development of glacier lakes and associated hazards. In addition, the comparison of the spatio-temporal variations of glacier velocities both within and between regions will improve understanding of climate change impacts. The **ice surface velocity product** is based on repeat pass SAR data, as available from Sentinel-1. An offset tracking procedure results in an ice displacement in slant and azimuth direction.

3.3.4 Lake ice

Two products were developed in the context of lake ice, the SYKE Lake Ice Extent (LIE) and the lake ice state.

SYKE Lake Ice Extent (LIE) is a three class lake ice classification, which can be derived from optical satellite sensors of different resolutions. Initially there were four classes, but as the last stages of melting, before final break-up of the ice, are not as well pronounced other changes the “partial snow/ice covered” and “clear ice” classes were combined. On the other hand the open water areas can be clearly discerned from ice cover using NDVI. Therefore, the product has stronger focus now on the extent of ice on lakes. The fully snow covered ice still remains as a separate class.

Optical satellite sensors are restricted by cloud cover as well as low light conditions during late autumn and early spring. The method is simple and easily applied to data with different sensors. The method is readily transferred to sensors of Sentinel-2 and Sentinel-3, once operational. The accuracy in preliminary validations have provided good results, largely due to calibration of the thresholds simultaneously, therefore more rigorous and independent validation is needed.

The **lake ice state product** distinguished between different possible states of tundra lakes, including at least open water (unfrozen), floating ice, and grounded ice. For rivers frazil ice is an additional state that can be mapped. The lake ice state is varying seasonally and therefore multi-temporal observations are required.

3.4 WP4: PRODUCT AND SERVICE VALIDATION

3.4.1 QA4EO framework for SEN3APP satellite data products

To use the satellite data based products the user needs naturally information about the product itself, but also about its uncertainty. The QA4EO (Quality Assurance for Earth Observations) initiative was established to provide guidelines how to report uncertainty of satellite (and other earth observation) data. Since the start of the project the QA4EO framework has not been actively updated. The framework still provides a good starting point to create documentation to accompany the data, which provides the user enough information to evaluate the suitability of the data to the use.
The QA4EO key principle is stated as: "Data and derived products shall have associated with them a fully traceable indicator of their quality." The two core requirements in this statement are that the dataset has:

- *Quality indicator*: "A Quality Indicator (QI) shall provide sufficient information to allow all ausers to readily evaluate the "fitness for purpose" of the data or derived product."

- *Traceability:* "A QI shall be based on a documented and quantifiable assessment of evidence demonstrating the level of traceability to internationally agreed (where possible SI) standards"

The SEN3APP validation documentation focuses on the quality assurance of the satellite data products. The documentation assumes that the user is familiar with the product content, although references are given to documentation describing the product generation. The validation is presented in a manner that allows the user, also to follow the protocol if the data or similar data is available. The main content of the validation documentation are:

- *General information:* Document ID, contact information etc.
- *Main results of the validation*, i.e. the accuracy of the product
- *Datasets used*
- *Methods used*
- *Additional information on the validation*
- *References*

The following section summarizes the product validations in SEN3APP.

3.4.2 Product validations

The product portfolio used in the validation work package consisted of 12 satellite based products for which the 10 were validated during the course of the project. Vegetation cover data for agricultural products (MAVI) was developed and piloted for summer 2016. The validation scheme was drafted, but focus was given to data delivery and development and therefore validation of vegetation cover will take place later on. The other product, which did not go through validation, was the product Snow and Ice Areas on glaciers. The WorldView-2 image acquired through the Copernicus Data Warehouse process could not be aligned with the data product from Sentinel-2 image, due to considerably different geo-locations. This was likely caused by the underlying DEMs in the ortho-rectification. The geo-correction in alpine areas is highly sensitive to the DEM used.

Product validations were conducted by the service operator/ product developer. The validation datasets were mainly from years 2014-2016. The extensive validation dataset used with Pan-European FSC was further extended with 72 additional Landsat scenes from 2015. The validation was repeated with the full dataset. Lake Ice Extent (LIE) was validated earlier with relatively restricted dataset (few SPOT and Landsat scenes). The LIE product was modified during SEN3APP and archived Terra/MODIS data and in-situ observation data was readily available from the period of 2010-2013. These years were used to run the validation. It should be recognised that validation of the Sentinel-2 based products can be fairly restricted due to short operation period of Sentinel-2 during the project, highly cloudy summer in Scandinavia restricting the imaging and rare overlaps between Sentinel-2 and very high resolution satellite data.

Table 4: SEN3APP product portfolio and respective producers, reference datasets used for validation and main validation results

Product	Producer	Reference dataset	Validation years	Validation metrics	
Agricultural plant type classification (Sentinel-1)	SYKE	Farmers notifications	2015	Overall classification accuracy: Class wise producer's accuracies: Class wise user's accuracies:	93 % 80-100 % 90-98 %
Vegetation cover estimate (Sentinel-2)	SYKE	Aerial images	2016	Validation not yet performed	NA
Extended Pan-European FSC (NPP Suomi/VIIRS)	SYKE, FMI	Binary snow data derived from Snow depth observations. Datasets: ECMWF, RIHMI , Finnish and German weather station networks	Winters: 2014-2016	*Whole year:* F-score: Recall: Precision: False alarm rate: *Only snow period (Oct-Jun):* F-score: Recall: Precision: False alarm rate:	 0.79-0.81 0.78-0.86 0.73-0.85 0.01-0.04 0.80-0.82 0.79-0.86 0.75-0.86 0.02-0.06

Product	**Producer**	**Reference dataset**	**Validation years**	**Validation metrics**	
Pan-European FSC (Terra/MODIS)	ENVEO	Binary snow maps derived from SPOT-5, WorldView-1 and -2 and binary and fractional snow maps derived from Landsat scenes. Validation datasets generated manually from VHR dataset, and from Landsat applying three methods: Dozier, 2004 Klein, 1998 Salomonson, 2004	Winters 2000-2015	*Dozier:* Unbiased-RMSE Bias: *Klein:* Unbiased-RMSE Bias: *Salomonson:* Unbiased-RMSE: Bias:	 15.85 % -0.37 % 16.16 % 3.44 % 15.68 % 0.63 %
High resolution (5km) Pan-European SWE (DMSP F-17/ SSMIS)	FMI	Snow depth data from ECMWF weather station network	Winter 2015-2016	RMSE: Bias: Pearson correlation coefficient r:	37.7 mm (swe) -1.7 mm 0.81
Wet Snow Cover Product for the Alpine Area (Sentinel-1)	ENVEO	Binary snow maps derived from Landsat data NDSI (Normalized difference snow index) threshold	2015	*Overall accuracies:* VV-pol: VH-pol: VV and VH used:	 76 – 88 % 86 – 95 % 83 – 95 %
Fractional Snow Cover Product for Alpine Areas (Sentinel-2)	ENVEO	Binary and fractional snow maps derived from Landsat data. Validation datasets generated with three methods: Dozier, 2004 Klein, 1998 Salomonson, 2004	2013-2014	*Dozier:* Unbiased-RMSE: Bias: *Klein:* Unbiased-RMSE: Bias: *Salomonson:* Unbiased-RMSE: Bias:	 13.28 % -2.14 % 13.93 % -2.80 % 12.85 % -2.06 %

Product	Producer	Reference dataset	Validation years	Validation metrics	
Glacier Outline Product (Sentinel-2)	ENVEO	Glacier outlines of former years from other high resolution data sources	2015	Overall accuracy:	±50m (with 10m resolution of the Sentinel-2 satellite data)
Snow on ice and ice area on glaciers (Sentinel-2)	ENVEO	Orthorectified VHR-satellite data (WorldView-2)	2015	Overall accuracy:	Validation not yet preformed, due to major difference in orthorectification of the Sentinel-2 and WorldView-2 images.
Glacier Ice Velocity Product for Greenland (Sentinel-1) *Two cases:* Single S-1 pass Multiple S-1 passes	ENVEO	Ice velocity products from TerraSAR-X (& ALOS PALSAR)	*S1 and TSX:* 2014-2015 *APS:* 2008-2009	*Single S-1 pass vs.TSX-data:* RMSE: *Multiple S-1 passes vs. TSX-data:* RMSE: *ALOS PALASAR (data from 2008 and 2009)*: Used as reference for temporal development.	 0.068 m d^{-1} (7.4%) 0.047 m d^{-1} (4.8%) NA
Ice Surface Velocity (Sentinel-2)	GAMMA	GPS measurements of ice velocity	2014	*Far from glacier calving fronts and shear zones:* Mean difference: STD: *Close to glacier calving fronts and shear zones:* Mean difference (depending on in-situ datasets): STD (respectively to mean differences):	 8 m/y 22m/y 38, 77 and 118 m/y 64, 76 and 49 m/y

Product	**Producer**	**Reference dataset**	**Validation years**	**Validation metrics**	
Lake Ice Extent (Terra/MODIS)	SYKE	In-situ observations of ice disappearance from field of view in Finnish lakes	2010-2013	*Difference in days between satellite ice-off and in-situ ice-off:* Mean: Median: STD:	 3.3 days 2.0 days 5.2 days

3.4.3 NRT-validation

The near real time (NRT) validation was piloted for the Baltic Sea FSC (Fractional Snow Cover) product. The product is operationally created from Terra/MODIS data. The algorithm is the SCAMod algorithm, which is also the basis of the Extended Baltic Sea FSC (based on NPP Suomi/VIIRS satellite data) and Pan-European FSC products (which is also based on Terra/MODIS data). The service can be found at:

http://wwwi4.ymparisto.fi/i4/eng/snow/fsc_baltic_eng.html

The service has been running since 2007 and was selected for the pilot testing of NRT-validation since SYKE had full control over and existing platform to create web-based service: Control of databases used for in-situ and satellite data products, control of data flow and control of visualizing the results in browser environment in a web-service.

The NRT-validation is based on snow observations from the weather station network of Finnish Meteorological Institute (FMI). Both the satellite data product, which is processed at the Finnish National Satellite Data Center in Sodankylä, and the in-situ data are delivered to SYKE and subsequently stored.to web accessible folder and to an SQL-database, respectively.

The snow measurements and observations are performed daily at 6:00 am (GMT +2). Snow data is available from 110 sites of the FMI weather station network. The data consists of:

- Snow depth measurements from sonic sounders with accuracy ±2 cm and manual measurements with accuracy ±1 cm
- E-code observations (operator made, WMO Manual on Codes 2011), giving information about the surface conditions, including snow, at the weather station. The E-code classification is described in Table x.

The timeline for the NRT-validation is as follows:

1. Observations are made at the weather stations at 6:00 am
2. Satellite data is collected from overpasses between 7:00 – 11:30 am
3. Satellite data is processed and delivered to SYKE around 5:00 pm
4. In-situ observation data from FMI arrives to SYKE at 10:00 am the morning after the in-situ observations were made.
5. The validation is scheduled to run each day at 20:45 to avoid

The validation against snow depth measurements is based on binary metrics. Therefore, both the FSC information from the satellite data and the snow depth from weather stations need to be converted to snow/no-snow data. The following criteria were used:

- Weather station snow depth > 0 cm → is snow
- FSC < 25% is → no snow

Further details on the effects of selecting the threshold values can be found in the Validation Report for Extended Baltic Sea FSC from VIIRS data (SEN3APP Deliverable 4.3).

Table 5: E-code observations coding and descriptions

E-code	Description
0	Dry snow free terrain, vegetation can be covered by moisture from dew or fog
1	Wet snow free terrain
2	Snow free terrain with water ponds
3	Terrain frosted or covered with surface ice
4	Open terrain snow free, some snow in forested areas
5	Snow covering over 0%, but less than 50% of the terrain
6	Wet or re-frozen snow covering over 50% but less than 100% of the terrain
7	Wet or re-frozen snow covering 100% of the terrain
8	Dry, loose snow covering over 50%, but less than 100% of the terrain
9	Dry, loose snow covering 100% of the terrain

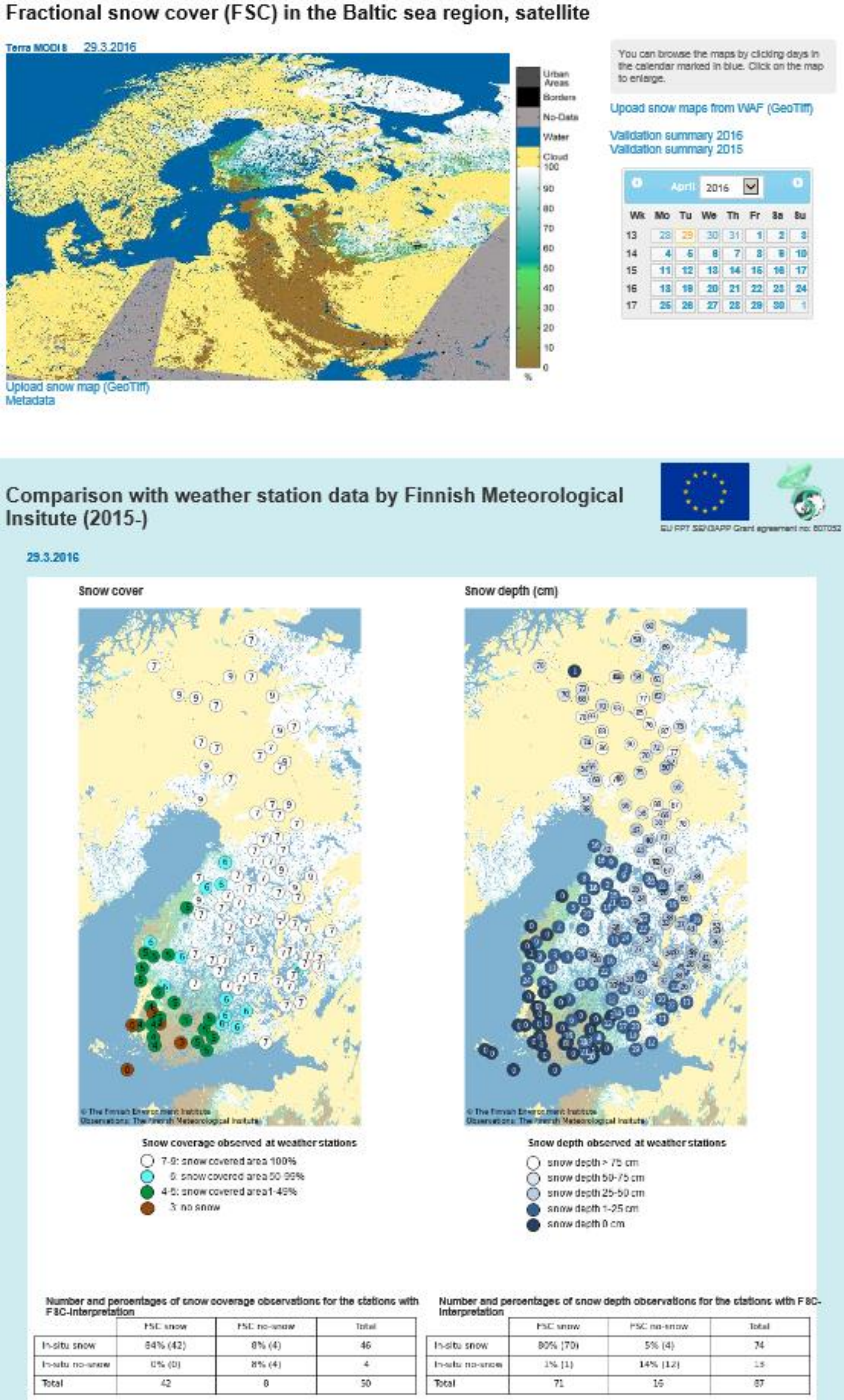
In order to compare FSC and E-code, the FSC data is binned to following classes:

- 100% snow cover
- 50-99% snow cover
- 1-49% snow cover
- Snow free ground

Following validation results and metrics are produced for each daily satellite product and for both in-situ datasets:

- *Confusion matrices* (in-situ vs. satellite FSC), both number of data pairs as well as % of all data pairs
- *Precision* (0-100%): Describes how precisely the 'snow' in the FSC-interpretation reflects the truly existing snow
- *Recall* (0-100%): Describes the ability of FSC -interpretation to recognize truly existing snow
- *False Alarm Rate* (0-100%): Describes the tendency of FSC-product to interpret snow-free areas as snow
- *F-Score* (0-100%): Describes the ability of FSC -interpretation to recognize truly existing snow, and a the same time, the ability to avoid interpreting snow-free areas as snow

Additionally information is provided for total number of Satellite FSC estimates – In-situ observation pairs and percentage of weather stations covered with available FSC information (i.e. non-cloudy image pixels) for each image. The live NRT-validation (Figure 3.11) can be found at: http://wwwi4.ymparisto.fi/i4/eng/snow/fsc_baltic_eng.html
The validation summary and validation metrics for 2016 (Figure 3.12) at:
http://wwwi4.ymparisto.fi/i4/eng/snow/validation/FSC_validation_report.html



	FSC snow	FSC no-snow	Total
In-situ snow	84% (42)	8% (4)	46
In-situ no-snow	0% (0)	8% (4)	4
Total	42	8	50

	FSC snow	FSC no-snow	Total
In-situ snow	80% (70)	5% (4)	74
In-situ no-snow	1% (1)	14% (12)	13
Total	71	16	87

Figure 3.11: The main product page for SYKE Baltic FSC product and associated NRT-validation

Validation report 2016

In the following, truly *existing snow* or *truth* refers to the snow information from weather stations. *Interpretation* refers to the Earth observation-based snow information (FSC). All the metrics are derived from comparison pairs of weather stations observations (truth) and of FSC provided over its location (interpretation). The metrics are designed to described FSC-product in general although they are calculated from the comparison pairs only.

NTOT: Number of weather station observations for which satellite data-based FSC is available.

EO-COVERAGE (0-100%): Percentage of weather stations for which FSC interpretation is available.

PRECISION (0-100%): Describes how precisely the 'snow' in the FSC-interpretation reflects the truly existing snow (more information).

RECALL (0-100%): Describes the ability of FSC -interpretation to recognize truly existing snow (more information).

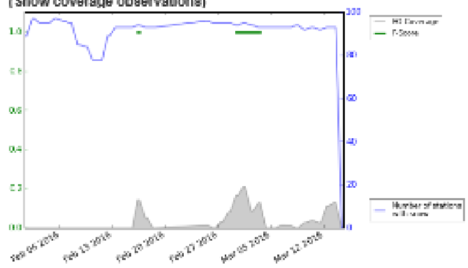
FALSE ALARM RATE (FAR 0-100%): Describes the tendency of FSC-product to interpret snow-free areas as snow (more information).

F-SCORE (0-100%): Describes the ability of FSC -interpretation to recognize truly existing snow, and a the same time, the ability to avoid interpreting snow-free areas as snow (more information).

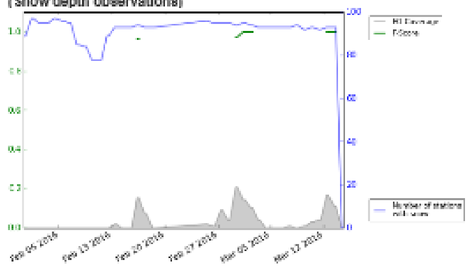
SYKE is using Creative Commons BY 4.0 International licence for open datasets. This licence applies to SYKE's satellite data.

Summary

Time-series of FSC product performance (Snow coverage observations)



Time-series of FSC product performance (Snow depth observations)



FSC vs. E-code, product list

PRODUCT	NTOT	EO-COVERAGE	RECALL	PRECISION	FALSE ALARM RATE	F-SCORE	Validation date
2016-11-14	0	0 %	-	-	-	-	2016-11-14
2016-11-10	0	0 %	-	-	-	-	2016-11-10
2016-11-09	0	0 %	-	-	-	-	2016-11-10
2016-11-08	0	0 %	-	-	-	-	2016-11-10
2016-11-07	0	0 %	-	-	-	-	2016-11-10
2016-11-06	0	0 %	-	-	-	-	2016-11-10
2016-11-05	0	0 %	-	-	-	-	2016-11-10
2016-11-04	0	0 %	-	-	-	-	2016-11-10
2016-11-03	0	0 %	-	-	-	-	2016-11-10
2016-11-02	0	0 %	-	-	-	-	2016-11-10
2016-11-01	0	0 %	-	-	-	-	2016-11-10
2016-10-31	0	0 %	-	-	-	-	2016-11-10
2016-10-30	0	0 %	-	-	-	-	2016-11-10
2016-10-29	5	6 %	-	-	-	-	2016-11-10
2016-10-28	0	0 %	-	-	-	-	2016-11-10
2016-10-27	0	0 %	-	-	-	-	2016-11-10
2016-10-	[illegible]	3 %	-	-	-	-	[illegible]

FSC vs. snow depth, product list

PRODUCT	NTOT	EO-COVERAGE	RECALL	PRECISION	FALSE ALARM RATE	F-SCORE	Validation date
2016-11-14	0	0 %	-	-	-	-	2016-11-14
2016-11-10	0	0 %	-	-	-	-	2016-11-10
2016-11-09	0	0 %	-	-	-	-	2016-11-10
2016-11-08	0	0 %	-	-	-	-	2016-11-10
2016-11-07	0	0 %	-	-	-	-	2016-11-10

Figure 3.12: The validation summary page for 2016, from the SEN3APP NRT-validation pilot

3.4.4 SEN3APP system validation

The SEN3APP data production and dissemination facilities consist of two parts: Infrastructure of National Satellite Data Center (NSDC) of the Finnish Meteorological Institute (FMI) and data production and dissemination facilities of ENVEO. Both platforms host capabilities of processing, archiving and dissemination of satellite data. The SEN3APP system validation focused on monitoring the data production and dissemination.
Monitoring FMI data production and dissemination

The servers, where the satellite data pre-processing and derived data production, of NSDC FMI are monitored by following components:

Hewlett and Packard Integrated Light Out (iLO)	Software to manage the HP servers providing the virtual environment for data production. The software capabilities consists of: • Server resetting in case of no response • Remote powering up of servers • Remote system control • Access Integrated Management Log
Nagios	Monitoring system network and infrastructure: • Monitoring performance of network services protocols • Monitor host processor and disk usage resources • Monitor other hardware connected to the system • Development of services checks • Visualization of the performance
Check_MK	Nagios extension – Increasing configuration options and scalability: • Replacing Nagios Standard GUI for administration to allow centralized view of all Nagios instances

The FMI data dissemination facility runs on Hexagon ERDAS Apollo system. That provides graphical user interface for searching and downloading satellite data products. The platform is also used to monitor the data production. The platform offers the following facilities for monitoring satellite derived data production:

- Portal data and service management tools for manual checks on server, catalogue and WMS services
- Auto notifications in the form of quicklooks for manual scan of faults in the processing lines
- Log –files: Records the activity in the portal

Hexagon has run exhaustive benchmark testing on the ERDAS Apollo to test the performance of the system (Hexagon ERDAS Apollo Benchmarking, http://hexgeo.co/2gmacEA). The benchmarking has been done using their own Enhanced Compressed Wavelet (ECW) file format, but it gives the underlying maximum performance characteristics for the system:

- *Response time* (WMS service):
  - Using different datasets (256px, 600px or 2048px): Mean between 10-300 ms, depending on the test dataset, with STD from 7.5-42.3 ms.
  - With increased number of users (0-20) using 600px data: Mean 25-150 ms

- *Data transfer rates* (WMS service): 6-650 request/sec, corresponding to 5700-12000 KB/sec

*Monitoring ENVEO data production and dissemination*The CryoLand system has in-house built software for running the back-end pre-processing of satellite data and generation of data products.

The front-end dissemination facility CryoLand GeoPortal is running on a virtual machine hosted by ENVEO using the EOxServer software. During the FP7 CryoLand project (2011-2015, No.262925), an extensive performance test was run on the system. The testing consisted of:

- Running the automated testing-scripts for the back-end software functionality (919 cases)
- Running manual execution of predefined test cases for the EOxServer based front-end (66 cases)
- Running integration service tests for the EOxServer based front-end (6 cases)

The overall performance during the testing is close to 100%. Summary of the testing is given in table a, based on the CryoLand –documentation (CryoLand - Final system qualification of services and acceptance. CryoLand, available upon agreement from ENVEO).

Table 6: Summary of the testing of CryoLand GeoPortal during CryoLand – project

System part	*Test case*	*Number of executed tests*	*Number of successful tests*	*Comments*
Backend, Network service	Automated scripts for testing the software and the backend system	919	919	766 test cases fully OK; 153 test cases OK, but skipped, as functionalities were disabled on purpose.
Frontend, GeoPortal	Manual execution of predefined test cases	66	65	Minor errors on one test case regarding a browser specific error that does not affect the normal behaviour of the GeoPortal.
Frontend, GeoPortal	Integration of CryoLand service into a user's system	6	6	Some very minor errors/warnings/slow system responses that do not affect the normal behaviour of the system were registered.
TOTAL		**991**	**990**	

When updates or developments are made to the underlying software there are automated test-scripts that can be run to test the functionality. Since the final release of the CryoLand Geoportal, the portal has not gone through major changes, and therefore the previous test results are still considered valid.

3.5 WP5: DEMONSTRATION

Twelve products, listed in Table 7, participated in the SEN3APP demonstration phase from July 2015 – May 2016. The products are generated by different SEN3APP partners. Several of the operational services were also continued after the official demonstration phase, and are still actively running. More details on the participating products are provided in the following subsections.

Table 7: SEN3APP services and products participating in the demonstration phase

Category	Product	Spatial resol.	Temp. resol.	Satellite / Sensor	Service status	Service provider	End-user
LAND COVER	Crop / vegetation classification	10 m – 25 m	Annually	Sentinel-1 C-SAR / -2 MSI, Landsat 8 OLI	Pilot	SYKE	MAVI (Finland)
	Phenology Product	5 km	Annually	Terra MODIS	Under development	SYKE	SYKE, FMI
SNOW	Fractional Snow Cover (FSC) for NH	1 km	Daily	NPP VIIRS, Sentinel-3 SLSTR	Operational	SYKE & FMI	Community using snow cover information in hydrological, NWP and climate change studies
	High resolution Pan-European SWE product	5 km	Daily	SSMI/S (PMW) & synoptic snow depth data	Operational	FMI	Fortum, SYKE, MetOffice UK, ECMWF
	Regional wet snow cover	100 m	Multi-temporal, 12 days per track	Sentinel-1 C-SAR	Pilot	ENVEO	ZAMG, HS Tyrol (Austria), MetOffice UK (UK)
	Regional FSC	250 m	Daily	Terra MODIS, NPP VIIRS, Sentinel-3 SLSTR & OLCI	Operational	ENVEO	ZAMG, HS Tyrol (Austria), MetOffice UK (UK)
	Pan-European FSC	500 m					
	Extended Baltic Sea drainage basin direct broadcast FSC	1 km	Daily	NPP VIIRS, Sentinel-3 SLSTR	Operational	FMI & SYKE	Hydrological community
GLACIER	Glacier outlines	10 m – 30 m	Annually (depends on availability of satellite data)	Sentinel-2 MSI	On demand	ENVEO	ZAMG, HS Tyrol (Austria), MetOffice UK (UK), DHMS (Bhutan)
	Glacier ice surface velocity	50 m – 250 m	12 days	Sentinel-1 C-SAR / -2 MSI	On demand	ENVEO, GAMMA	ZAMG (Austria), MetOffice UK (UK), DHMS (Bhutan), NPI (Norway), Department of Geosciences, Univ. of Oslo (Norway), Univ. of Silesia, Katowice (Poland)

Cate-gory	Product	Spatial resol.	Temp. resol.	Satellite / Sensor	Service status	Service provider	End-user
	Snow / ice areas on glaciers	10 m – 30 m	Annually (depends on availability of satellite data)	Sentinel-2 MSI / -1 C-SAR	On demand	ENVEO	ZAMG, HS Tyrol (Austria), MetOffice UK (UK), DHMS (Bhutan)
LAKE ICE	Lake ice extent	250 m	Daily	Sentinel-2 MSI / -3 SLSTR & OLCI, Terra MODIS, Landsat 8 OLI	Operational	SYKE	SYKE Freshwater centre (Finland)

The SEN3APP products and services are provided to users through two geoportals: the FMIARC GeoPortal, installed at FMI, and the CryoLand GeoPortal hosted by ENVEO. Both portals are accessible through the SEN3APP Portal (http://sen3app.fmi.fi/index.php?style=main&page=Products).

The following products are distributed through FMIARC GeoPortal, and are available using WCS and WMS.

- Fractional Snow Cover Extent for Northern Hemisphere from Optical Data
- High Resolution (5km) Pan-European SWE Product (Augmented Using Optical FSC)
- Extended Baltic Sea Drainage Basin Direct Broadcast FSC Based on NPP VIIRS/Sentinel-3 SLSTR
- Phenology
- Crop / Vegetation Classification
- Ice Velocity

Some of the products are distributed through the CryoLand GeoPortal, but sample products can also be accessed from the FMIARC GeoPortal:

- Regional Wet Snow Cover from Sentinel-1 Data
- Regional and Pan-European Fractional Snow Cover Product from Synergistic Sentinel-3 SLSTR/OLCI Data

For some key end users, products are tailored to their needs and provided directly via file transfer protocol (FTP), or sent via e-mail. This includes also products generated only on demand.

3.5.1 Demonstration of land cover change and phenology

3.5.1.1 Crop/vegetation classification

Service provider: *SYKE*

The crop / vegetation classification is a new product developed within the SEN3APP project for the Agency for Rural Affairs (MAVI, Maaseutuvirasto). MAVI is responsible for control of EU agricultural subsidies, and need tools and processes to decrease the work-load of control and shorten the time used for control. Specific needs include plant classification, at least in general level, and information of ploughing of agricultural parcels.

The test area is in South-Western Finland. The images (Sentinel-1, Landsat-8, Sentinel-2) have been processed for area which upper left corner is lat. 61° 38'N long. 21° 25'E and lower right lat. 60° 6'N long. 25° 15'E. MAVI provided the shapefile of agricultural parcels for summer 2016 and more precise area of interest with farmer's plant information during early June. This information is used as training data for plant classification.

The aim of this service is to provide information for agricultural parcels that can be used to aid agricultural subsidy control of farmers, and is tailored to the needs of MAVI.

The annual deadline for data delivery for MAVI is the early August. Therefore, the plant and ploughing classification is based on Landsat-8, Sentinel-1 and -2 time series of images from late March to late July. Also, late autumn images from previous season can be used. The reliability of service depends on the availability of Sentinel-1 IW-images. EW-images could also be used but they have poorer resolution decreasing accuracy.

Product development and piloting were done during summers 2015 and 2016. Due extensive cloud cover during summer 2015 the development focused on Sentinel-1 data. Plant and ploughing classifications were made using Sentinel-1 SAR images. Plant classification (winter cereal, spring cereal, peas, potato, rapeseed, and grasses) was successful, with overall accuracy around 93%. Summer 2016 was the service pilot phase, where data was delivered in tables. The product development continues and further funding is sought for to establish more operational service. The concept of dataflow is presented in Figure 3.13.

The service characteristics for crop/vegetation classification are provided in Table 8.

Table 8: Crop/vegetation classification service characteristics

Service status	Pilot. Summer 2015 was used for development and testing of service, summer 2016 will be pilot phase.
Service limitations	Heavy rain before and during image acquisition may limit the usefulness of image.
Spatial extent	60°6'N – 61°38'N, 21°25'E – 25°15'E
Spatial resolution	Sentinel-1 images are resampled to 20 m pixel, Sentinel-2 10 m, Landsat-8 25 m. These are used to compute parcel wise mean backscatter or reflectance values.
Temporal resolution	Growing season, from April to October.
Map projection	ETRS TM35FIN (EPSG 3067)
Satellite instrument	Sentinel-1, Landsat-8, Sentinel-2
Latency time	MAVI needs information about agricultural parcels in early August.
Length of service	Summer 2015 development phase, summer 2016 pilot.
Service operator	SYKE
Data access	Shapefile table using email, images using FTP, WMS under consideration.

Products are provided directly to the end user MAVI via e-mail or FTP, and are also accessible through the FMI-ARC GeoPortal (http://saana.nsdc.fmi.fi/fmiarc-geoportal/).

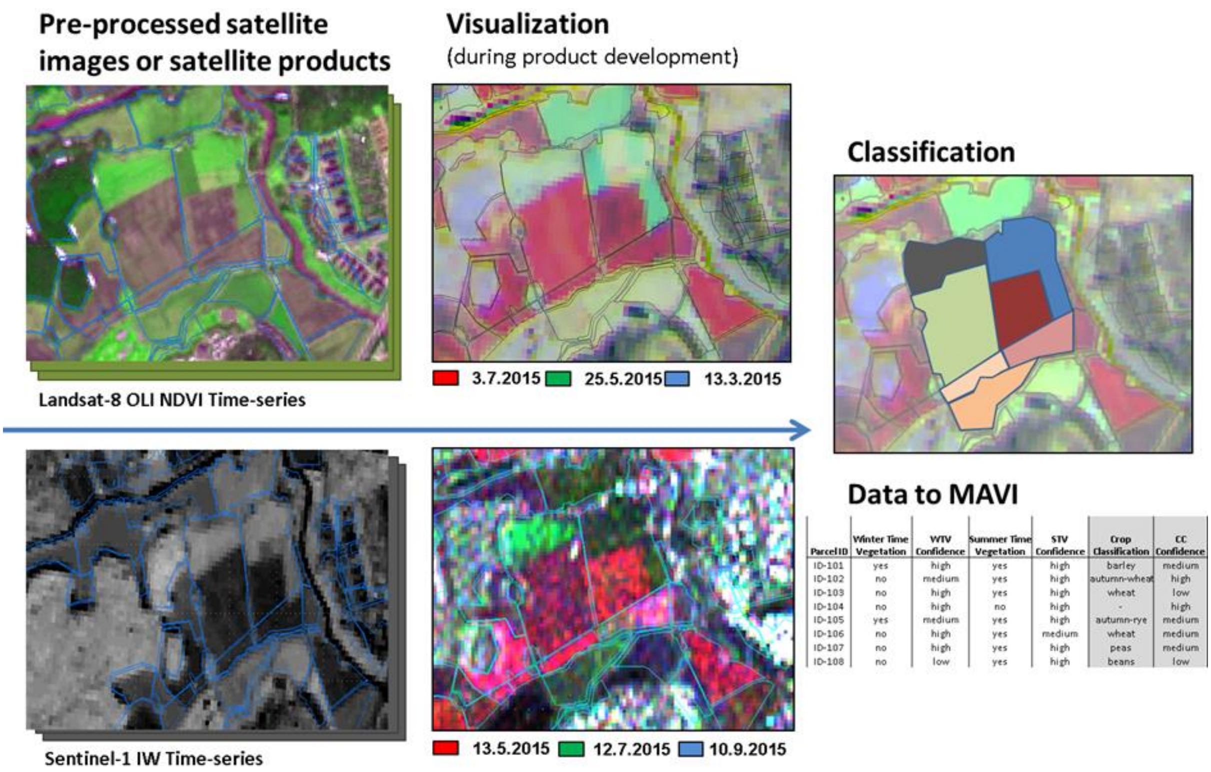


Figure 3.13: The concept of data delivery to MAVI. Satellite derived data products and time-series are used to produce final classification to MAVI, addressing individual subsidies control requirements. The data to MAVI is delivered in table, relating the classifications to individual agricultural parcels.

3.5.1.2 Phenology product

Service provider: *SYKE*

The phenological events derived from optical satellite data are largely a product under development. There is strong interest towards the product in the research community and it has had applications in the estimation of CO_2- fluxes (Böttcher et al., 2014) and in estimating the moth peak flight period (Costa et al., 2014, CLIPC Deliverable 7.2.).

The product comprises currently the onset of vegetation active period for boreal coniferous and deciduous forests. With the application of optical satellites, the determination of end of vegetation active period suffers from low light conditions in the high Northern latitudes. The research for methodology for determining these is ongoing.

The product was compared to CO_2 -flux measurements and phenological field observations (Böttcher et al., 2014). The comparison shows a good agreement between the product and in-situ data. The calibration of satellite indicators to start of vegetation active period from CO_2

flux measurements provides possibility to evaluate the spatial distribution of land-surface model-derived beginning of growing season against satellite observations.

The cloud cover and polar night are the main constraints for optical satellite products and services. As the phenology products are based on time-series of indices based on satellite data, they are not so sensitive to individual days of clouds. On the other hand, long cloudy periods are not uncommon in Northern latitudes during spring time, and therefore the product can suffer from weather conditions. Polar nights are making the development of methodology for extracting the end of vegetation active period from the time-series more challenging, due to low light conditions in the high Northern latitudes. Preliminary efforts have been made, but the full methodology is still under research and development.

Sample products from the years 2013, 2014 and 2015 are available in the FMI-ARC Geoportal (http://saana.nsdc.fmi.fi/fmiarc-geoportal/). Sample product is shown in Figure 3.14.

Table 9: The main characteristics of the phenology product and service

Service status	Under development
Service limitations	Currently onset of vegetation active period available for deciduous and coniferous vegetation separately. Cloud cover and polar night (low light conditions). These restrictions apply to the underlying indices datasets (FSC, NDVI, NDWI), but as the product is fundamentally based on time-series the effect of the restrictions are less effective.
Spatial extent	Finland
Spatial resolution	0.05° (~5km)
Temporal resolution	Annual maps
Map projection	Geographical, WGS-84
Satellite instrument	MODIS
Latency time	Annual
Length of service	2001 – ongoing
Service operator	SYKE
Data access	Upon request (Kristin.bottcher@ymparisto.fi) FMI-ARC GeoPortal: http://saana.nsdc.fmi.fi/fmiarc-geoportal/ (sample products)

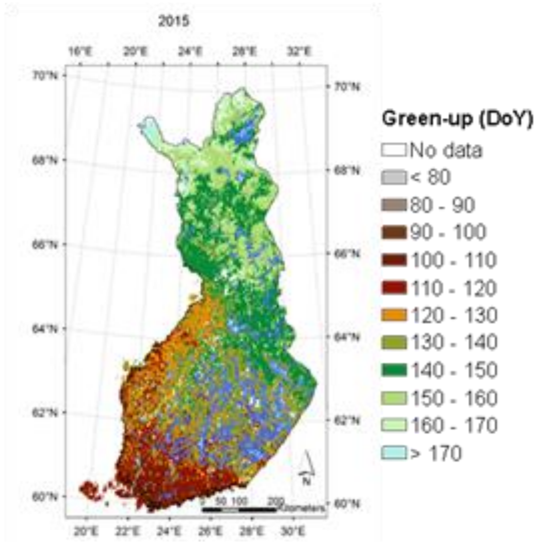


Figure 3.14: Sample phenology product in 2015. Green-up i.e. start of vegetation active period of deciduous forests in Finland. Day of year from start of the year

3.5.2 Demonstration of Sentinel-1, -3 snow mapping service

Six different snow mapping services are provided during the SEN3APP demonstration phase, operated by different partners for different spatial extents and from different satellite data sources. Each service is briefly described in the following subsections.

3.5.2.1 Fractional snow cover extent for northern hemisphere from optical data

Service provider: *SYKE & FMI*

The near real time fractional snow cover service for the northern hemisphere is currently based on NPP VIIRS data, and is provided daily with 0.01° x 0.01° pixel size. The processing chain for the product generation can be transformed to use Sentinel-3 SLSTR data as input as soon as these data will become available in near-real time. The service is operational and daily with a 3-6 hours latency time. Products are provided through the FMIARC GeoPortal (Figure 3.15). The detailed product and service characteristics are summarized in Table 10.

Table 10: Service characteristics for northern hemisphere fractional snow cover extent

Service status	operational
Service limitations	polar night, clouds
Spatial extent	25°N–84°N, 168°W–192°E
Spatial resolution	0.01°, ~ 1 km
Temporal resolution	daily, thorough the years

Map projection	Geographical, WGS-84
Satellite instrument	VIIRS at the moment, transition to S3 SLSTR whenever available
Latency time	3-6 hours after satellite overpass
Length of service	Service running as a legacy of GlobSnow NH Snow Extent product
Service operator	FMI & SYKE
Data access	FMI-ARC GeoPortal: http://saana.nsdc.fmi.fi/fmiarc-geoportal/, FTP

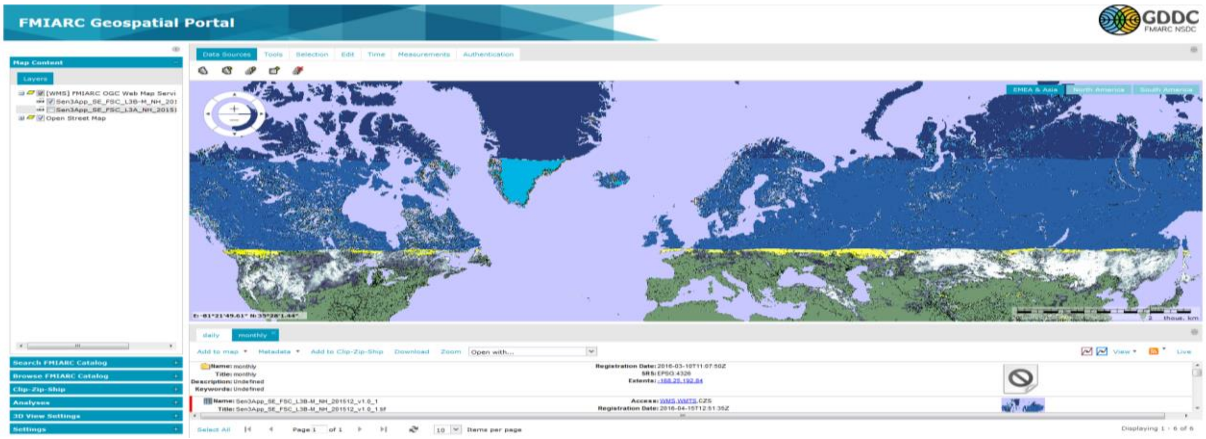


Figure 3.15: An example of the Fractional Snow Cover extent for Northern Hemisphere from optical data product from December, 2015, as shown in the FMIARC GeoPortal

3.5.2.2 High resolution (5km) pan-european SWE product (augmented using optical FSC data)

***Service provider:** FMI*

Documentation of service demonstration

The Snow Water Equivalent (SWE) product is based on passive microwave observations and SYNOP weather station snow depth observation. The product is generated by an assimilation process resulting in maps of SWE estimates (0.05 degrees, WGS84 grid) over the Pan-European region, covering all land surface areas with the exception of mountainous regions. A semi-empirical snow emission model is used for interpreting the passive microwave (radiometer) observations through model inversion to the corresponding SWE estimates. The SWE product is provided in spatial resolution of about 5 km on a daily basis covering the Pan-European area. The methodology provides the snow water equivalent in millimetres which can also be used to determine snow depth and snow mass.
The high resolution Pan-European SWE product is an operational product, provided with about two days latency time. The products are provided through the FMIARC geoportal as shown in Figure 3.16.

The detailed service characteristics are summarized in Table 11.

Table 11: Service characteristics for the high resolution Pan-European SWE product

Service status	operational since 2016
Service limitations	mountains are excluded from the product
Spatial extent	25°N–84°N, 168°W–192°E
Spatial resolution	0.05°, ~ 5 km
Temporal resolution	daily
Map projection	Geographical, WGS-84
Satellite instrument	DMSP F18 (before breakup F17), SSMI/S, ECMWF synop Snow Depth
Latency time	< 2 days
Length of service	Service running since Feb 2015
Service operator	FMI
Data access	FMI-ARC GeoPortal: http://saana.nsdc.fmi.fi/fmiarc-geoportal/

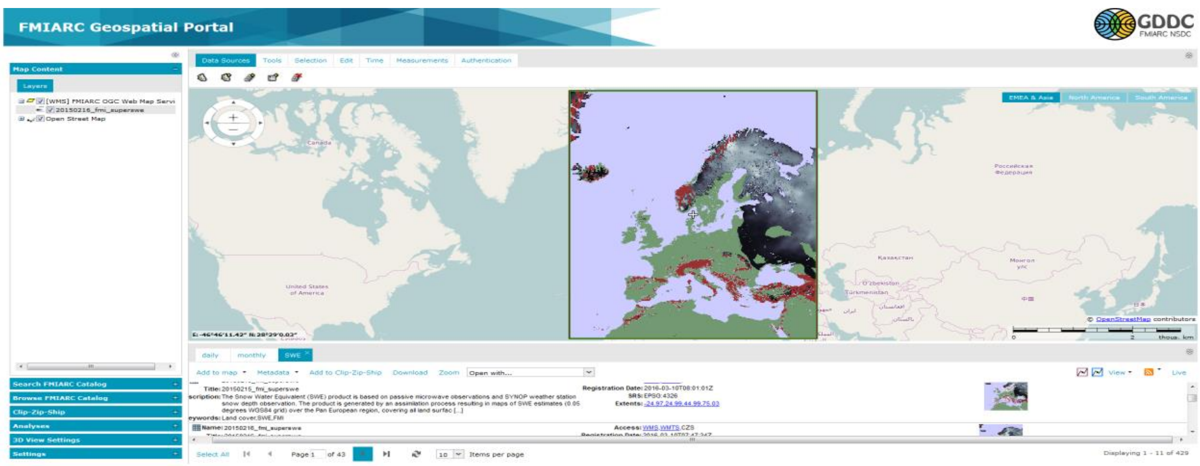


Figure 3.16: An example of the High resolution (5km) Pan-European SWE product (augmented using optical FSC data) on 16 February 2015, as shown in the FMIARC GeoPortal

3.5.2.3 Regional wet snow cover from Sentinel-1 data

Service provider: *ENVEO*

The Wet Snow Cover product is generated for the Alpine area (49.5°N/4.5°E – 43.5°N/17.0°E) with 0.001° x 0.001° pixel size from Sentinel-1 C-SAR data. Demonstration products were generated for the melting seasons 2015 and 2016. The detailed service characteristics are summarized in Table 12.

The wet snow cover service for the Alpine area is currently running as a pilot service. Products are generated during the melting season in the Alpine area. So far, the production is performed at irregular intervals, as the processing chain is still under improvement. A more regular and thus more reliable service, transforming the current pilot service to a pre-operational service is planned for the melting season 2017.

The products are provided through the SEN3APP portal, and accessible via the CryoLand GeoPortal. Figure 3.17 shows an example of the Alpine Wet Snow Cover product as shown in the CryoLand GeoPortal.

Table 12: Service characteristics for alpine wet snow cover

Service status	pilot
Service limitations	radar shadow, radar layover, forested areas and water bodies are masked. Dry (cold) snow has very similar backscatter signals as bare ground; thus, these surfaces types are combined in one class.
Spatial extent	43.5°N – 49.5°N, 4.5° E – 17.0° E
Spatial resolution	0.001°, ~ 100 m
Temporal resolution	Melting season, multi-temporal (6 days repeat time per track)
Map projection	Geographical, WGS-84
Satellite instrument	Sentinel-1A/B C-SAR
Latency time	Currently irregular product generation, aimed on < 1 day
Length of service	Demonstration products available since the melting season 2015
Service operator	ENVEO
Data access	CryoLand GeoPortal: http://neso1.cryoland.enveo.at/cryoclient/, FTP

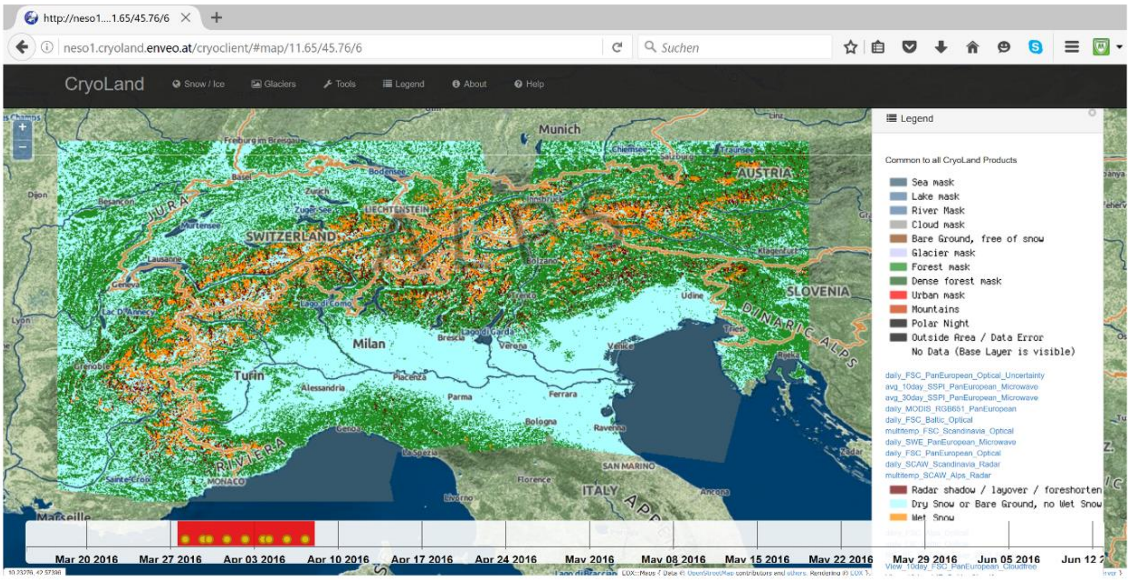


Figure 3.17: Example of the wet snow cover product over the Alpine area. For full coverage of the area, Sentinel-1 tracks from multiple days are needed. The example shows the wet snow from S1A tracks acquired from 28 March till 7 April 2016, as presented in the CryoLand GeoPortal

3.5.2.4 Regional and pan-european FSC product from synergistic Sentinel-3 SLSTR/OLCI data

Service provider: *ENVEO*

The Fractional Snow Cover product for the Pan-European area (72°N/11°W – 35°N/50°E) with 0.005° x 0.005° pixel size, and for the Alpine area (49.57°N/4.66°E to 43.62°N/17.77°E) with 0.0025° x 0.0025° pixel size, each from MODIS Terra data was developed within the EU FP7 project CryoLand, and is provided daily in near-real-time since 2012 by ENVEO. The products are based on different snow algorithms. The service has been continued based on MODIS Terra data within SEN3APP, as Sentinel-3 data were not available within the SEN3APP demonstration phase.

The Pan-European and the Alpine snow services run fully operational and products are provided daily all the year round in near-real time whenever the required input satellite data are available in near-real time. The Pan-European FSC products and an associated uncertainty layer, providing the (non-biased) error standard deviation for each clear-sky pixel, are provided within 7 hours after the image acquisition over the full area is completed. The products of the regional snow extent service for the Alpine area from optical satellite data are provided with only 3 – 6 hours latency time after image acquisition.

The service characteristics are summarized in Table 13.

Table 13: Service characteristics for Pan-European fractional snow cover

	Pan-European FSC service	***Alpine FSC service***
Service status	operational	operational
Service limitations	Pixels affected by polar night, cloud cover and water bodies are masked	Pixels affected by cloud cover and water bodies are masked, snow in forested in classified binary
Spatial extent	25°N – 72°N, 11.0°W – 50.0°E	43.62°N – 49.57°N, 4.66°E – 17.77°E
Spatial resolution	0.005°, ~ 500 m	0.0025°, ~ 250 m
Temporal resolution	Daily, full year	Daily, full year
Map projection	Geographical, WGS-84	Geographical, WGS-84
Satellite instrument	MODIS Terra, in future Sentinel-3 SLSTR/OLCI	MODIS Terra, in future Sentinel-3 SLSTR/OLCI
Latency time	< 7 hours	< 3 - 6 hours
Length of service	Service online since 2012, products available from Dec 2000 - present	Service online since 2012, products available from Oct 2011 - present
Service operator	ENVEO	ENVEO
Data access	CryoLand GeoPortal: http://neso1.cryoland.enveo.at/cryoclient/, FTP	CryoLand GeoPortal: http://neso1.cryoland.enveo.at/cryoclient/, FTP

The products are provided through the SEN3APP portal, and accessible via the CryoLand GeoPortal. Figure 3.18 shows examples of the Pan-European and the Alpine Fractional Snow

Cover products as shown in the CryoLand GeoPortal. For particular end-users these products are tailored to specific needs, and provided directly via FTP.

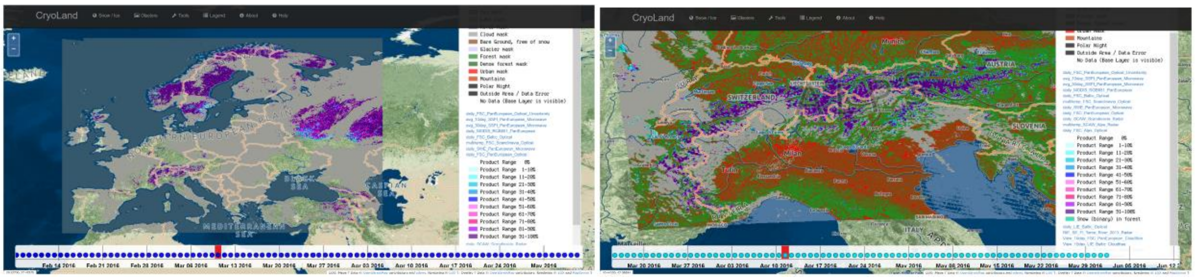


Figure 3.18: Left: Example of the Pan-European Fractional Snow Cover product of 11 March 2016, as provided in the CryoLand GeoPortal. Right: Example of the Alpine Fractional Snow Cover product of 11 April 2016, as provided in the CryoLand GeoPortal

3.5.2.5 Extended Baltic Sea drainage basin direct broadcast FSC based on NPP VIIRS/Sentinel-3 SLSTR

Service provider: *SYKE & FMI*

The extended Baltic Sea drainage basin direct broadcast Fractional Snow Cover (FSC) service is currently based on NPP VIIRS data, but the processing chain is ready to use Sentinel-3 data as input as soon as these data will become available in near-real time. Products are currently generated daily with 0.01° x 0.01° pixel size, but the spatial resolution will soon be improved to ~500 m as planned. As cloud cover is often affecting the daily products, composites of multiple days are provided, showing the most recent clear sky pixel information. Thus, the current status of the snow extent can be better visualized. An example of such a composite is shown in Figure 3.19.

The service is a fully automatized, ready established operationally running system. Gaps in the spatial map are mostly due to the cloud coverage, although some missing data may occur (with VIIRS). Products provide daily sub-pixel Fractional Snow Cover (FSC) with an accuracy < 20%. The products are provided through the FMIARC geoportal.

The detailed service characteristics are provided in Table 14.

Table 14: Service characteristics for extended Baltic Sea drainage basin direct broadcast FSC

Service status	operational
Service limitations	Pixels affected by polar night, clouds, or open water bodies are masked
Spatial extent	38°N-72°N, 11°W-65°E
Spatial resolution	(0.01^{0} , ~ 1 km)

Temporal resolution	daily, thorough the years
Map projection	Geographical, WGS-84
Satellite instrument	VIIRS at the moment, transition to S3 SLSTR whenever available
Latency time	3-6 hours after satellite overpass
Length of service	Service running from February 2016 in its current form (extended area)
Service operator	SYKE & FMI
Data access	FMI-ARC GeoPortal: http://saana.nsdc.fmi.fi/fmiarc-geoportal/, FTP

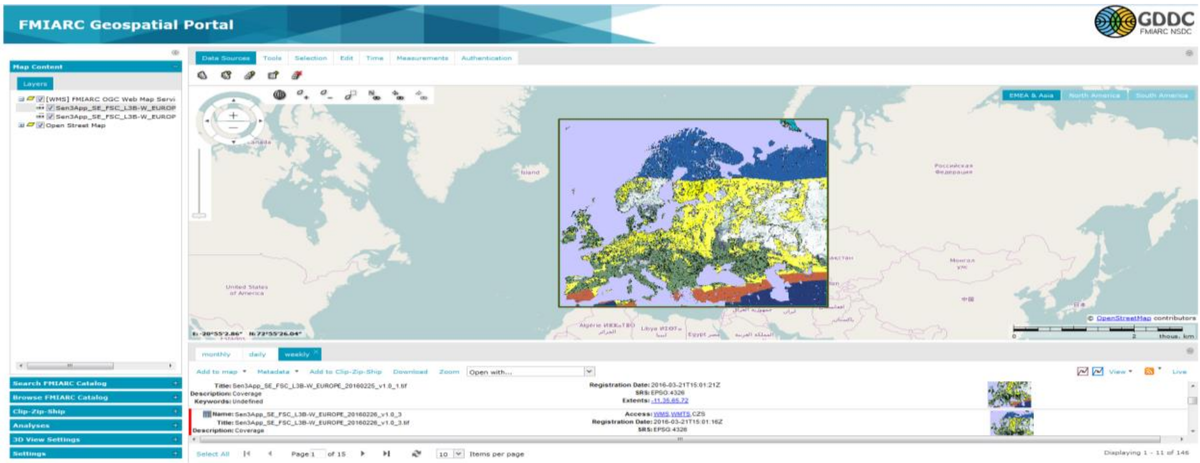


Figure 3.19: An example of the Extended Baltic Sea FSC product, as shown in the FMIARC GeoPortal. This is a weekly composite containing contributions from the last seven days' maps, in this example from 19 to 26 February 2016

3.5.3 Demonstration package for Sentinel-1 and Sentinel-2 glacier products

3.5.3.1 Glacier outlines

Service provider: *ENVEO*

The glacier outline service is only active on demand for selected regions identified by the interested user. The service depends strongly on the availability of useful satellite images. The product is generated with 10 m x 10 m pixel size from Sentinel-2 data acquired as close as possible to the date with maximum ablation area, and at clear sky conditions over the glaciated areas. The glacier outline products generated within the SEN3APP project meet the internationally accepted standard defined by GLIMS (Global Land Ice Measurements from Space), as well as the INSPIRE standards. Figure 3.20 shows an example of the glacier outline product. The product is delivered directly to the user requesting the service for a particular region via FTP or per e-mail.

The service characteristics are summarized in Table 15.

Table 15: Service characteristics for glacier outlines

Service status	On demand
Service limitations	Satellite image for product generation must be acquired as close as possible to the date with maximum ablation area, with clear sky conditions over the glaciers of interest. Glaciers affected by cloud cover or extensive seasonal snow have to be excluded from product generation. Also rock glaciers are excluded from this service.
Spatial extent	Selected glacier regions, as requested
Spatial resolution	10 m
Temporal resolution	Depends on availability of satellite data meeting the acquisition requirements
Map projection	UTM, WGS-84
Satellite instrument	Sentinel-2 MSI
Latency time	< 3 months
Length of service	Service only active on demand
Service operator	ENVEO
Data access	FTP, e-mail

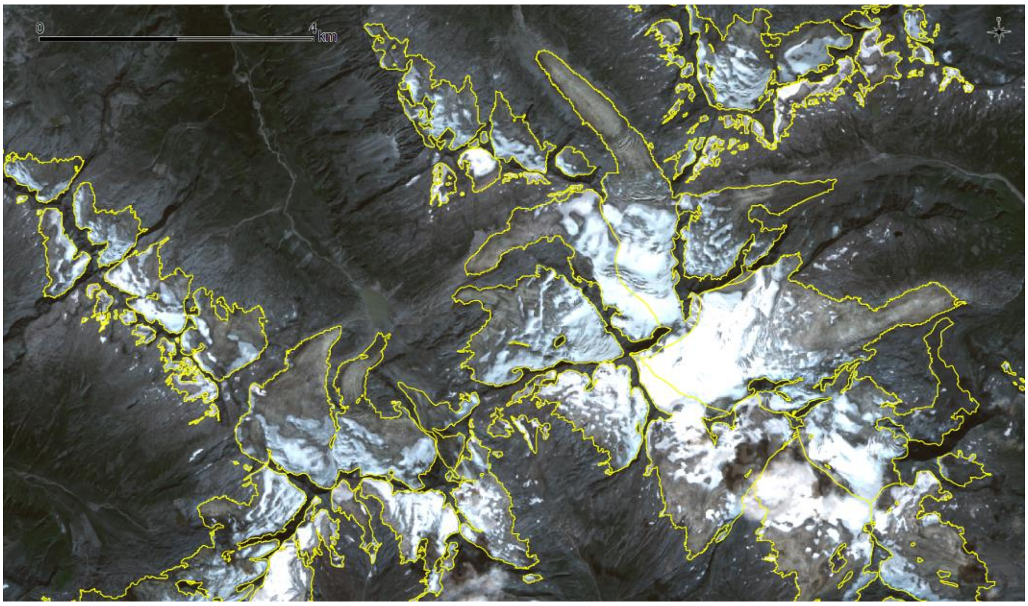


Figure 3.20: Example of glacier outlines mapped from Sentinel-2 scene of 13 August 2015 over the mountain group Venedigergruppe in Austria

3.5.3.2 Glacier ice surface velocity

Service provider: *GAMMA*

The glacier ice surface velocity service provided by GAMMA is a operational service based on Sentinel-1 C-SAR data. Currently products over Svalbard are generated every 6 days with 100 m x 100 m pixel size. Other areas can be processed upon request.

The service characteristics are summarized in Table 16. Figure 3.21 shows a time series of ice surface velocities over Svalbard derived from Sentinel-1 data from 4 March 2016 till 16 May 2016.

The products are provided through the FMIARC geoportal, or via the GAMMA dropbox .

Table 16: Service characteristics of glacier ice surface velocity over Svalbard

Service status	Pre-operational service
Service limitations	N/A
Spatial extent	Demonstration for 76.4°N – 80.9°N, 10°E – 30°E (upon request)
Spatial resolution	100 m
Temporal resolution	6 days, All year around (subject to Sentinel-1A and B data acquisition)
Map projection	UTM 33N, WGS-84 (upon request)
Satellite instrument	Sentinel-1 C-SAR
Latency time	< 5 days
Length of service	Mid of April 2016 – present
Service operator	GAMMA
Data access	SFTP at dropbox.gamma-rs.ch

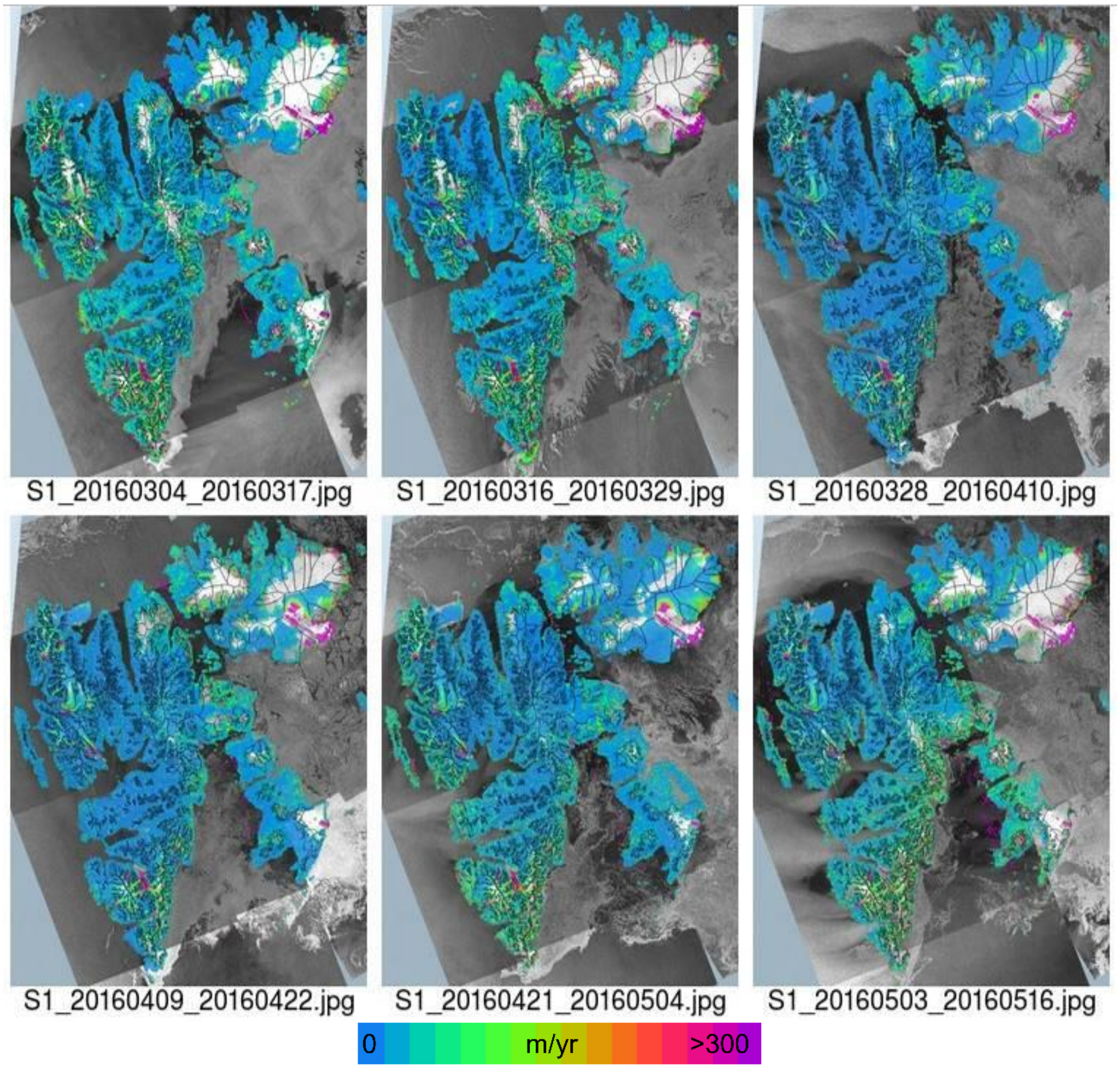


Figure 3.21: Time series of ice surface velocities over Svalbard from Sentinel-1 data

3.5.3.3 Glacier ice surface velocity

Service provider: *ENVEO*

Documentation of service demonstration

The glacier ice velocity service is only active on demand for selected regions identified by the interested user. The SEN3APP demonstration products for selected glaciers in northern Greenland were generated with 250 m x 250 m pixel size from repeat-pass Sentinel-1 IW SLC data. Observed glaciers areas must have a minimum size of about 1 km in line of sight, and a minimum ice velocity of about 0.10 m d^{-1}. The product is delivered directly to interested users via FTP or per e-mail.

The service characteristics are summarized in Table 17.

Table 17: Service characteristics for glacier ice velocity

Service status	On demand
Service limitations	The characteristics of the used SAR data (e.g. acquisition mode, temporal base line) determine the detectable glacier size and ice motion. For offset tracking from S1A IW SLC data the size of the observed glacier region (e.g. tongue) should be larger than 1 km in line of sight of the SAR beam, and ice velocity should be minimum 0.10 cm d^{-1}.
Spatial extent	Demonstration for selected glaciers in northern Greenland (79°N – 82°N, 33°W – 70°W)
Spatial resolution	250 m
Temporal resolution	12 days
Map projection	Geographical, WGS-84
Satellite instrument	Sentinel-1A C-SAR
Latency time	< 3 days
Length of service	January 2015 – present, service for other regions active on demand
Service operator	ENVEO
Data access	FTP, e-mail

Figure 3.22 shows an example of the glacier ice velocity product, and Figure 3.23 presents the analysis of a time series for the ice velocity along the flowline of the Petermann glacier in northern Greenland.

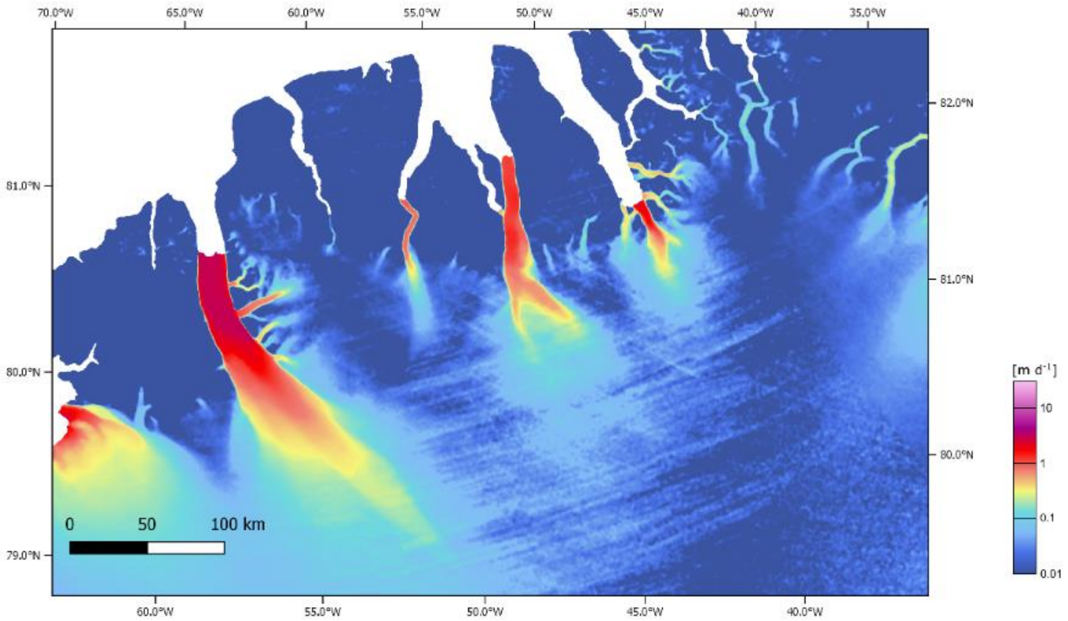


Figure 3.22: Example of glacier ice surface velocity product from multiple Sentinel-1 data of 2015 and 2016 over northern Greenland

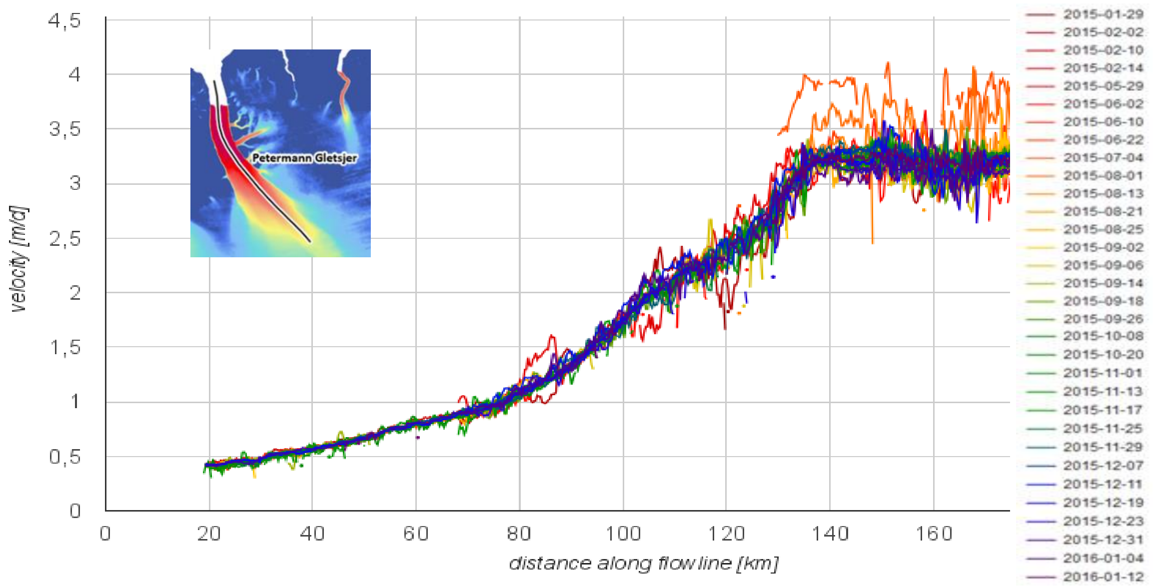


Figure 3.23: Time series of ice velocity along a profile of the glacier tongue of Peterman glacier in northern Greenland

During the SEN3APP demonstration phase, a time series of ice velocity products since January 2015 has been generated for outlet glaciers of northern Greenland. This time series has also been continued after the end of the demonstration phase.

The latency time for the products depends on the area of interest, but can be usually provided in less than 3 days for a selected glacier when repeat pass Sentinel-1 IW SLC data are available. On user demand, the service can be run every 12 days for a pre-defined area of interest meeting the spatial and motion requirements.

3.5.3.4 Snow / Ice areas on glaciers

Service provider: *ENVEO*

The snow / ice areas on glaciers service is only active on demand for selected regions identified by the interested user. The product is generated with 10 m x 10 m pixel size from Sentinel-2 data acquired as close as possible to the date with maximum ablation area, and at clear sky conditions over the glaciated areas. Glacier outlines are mandatory input for this product. The service is limited by the availability of useful satellite data, as an image has to be acquired as close as possible to the date with maximum ablation area, and the glaciated areas of interest have to be free of clouds or cloud shadows.

The products generated within the SEN3APP project meet the internationally accepted standard defined by GLIMS (Global Land Ice Measurements from Space), as well as the INSPIRE standards. The product is delivered directly to the user requesting the service for a particular region via FTP or per e-mail.

The service characteristics are summarized in Table 18. Figure 3.24 shows an example of the snow and ice areas on glaciers.

Table 18: Service characteristics for snow and ice areas on glaciers

Service status	On demand
Service limitations	Satellite image for product generation must be acquired as close as possible to the date with maximum ablation area, with clear sky conditions over the glaciers of interest. Glaciers affected by cloud cover or extensive seasonal snow have to be excluded from product generation. Also rock glaciers are excluded from this service.
Spatial extent	Selected glacier regions, as requested
Spatial resolution	10 m
Temporal resolution	Depends on availability of satellite data meeting the acquisition requirements
Map projection	UTM, WGS-84
Satellite instrument	Sentinel-2 MSI
Latency time	< 3 months
Length of service	Service only active on demand
Service operator	ENVEO
Data access	FTP, e-mail

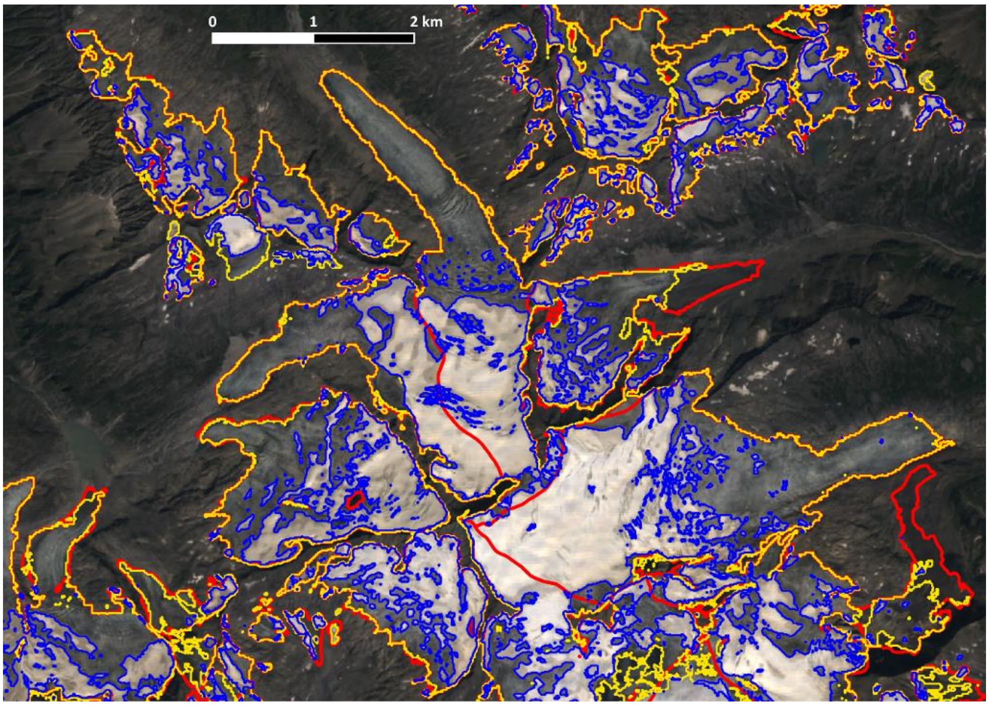


Figure 3.24: Example of snow and ice areas on glaciers from Sentinel-2 scene of 13 August 2015 over the mountain region Venedigergruppe in Austria. Blue: snow; yellow: bare ice; red: debris covered glacier areas

3.5.4 Demonstration service and compilation of products package for lake ice products

3.5.4.1 *Lake Ice Extent*

Service provider: *SYKE*

Lake ice extent (LIE) is an operational product for monitoring the ice coverage on fresh water lakes. Currently the product covers the Baltic Sea drainage area. The main interest groups currently for the product are hydrological services and numerical weather prediction community (Pour et al., 2014), especially in the Finland and Scandinavia, with large number of lakes (from Finnish land cover 10% are lakes).

Industries with some economic value, such as freshwater fishing, reindeer herding and transport are also among the interest groups for lake ice coverage. Especially in Northern Finland, Scandinavia and Northern-Russia are affected by the seasonal ice cover. The ice conditions also have strong effect on leisure activities in these areas (e.g. skiing).

Table 19: The main characteristics of the lake ice extent product and service

Service status	Operational
Service limitations	Cloud cover and polar night (low light conditions)
Spatial extent	Baltic Sea drainage basin [45°N – 71°N, 5°E – 45°E]
Spatial resolution	0.0025° (~250 m)
Temporal resolution	Daily coverage
Map projection	WGS-84
Satellite instrument	MODIS
Latency time	12 hours
Length of service	2011 – ongoing
Service operator	SYKE & FMI
Data access	CryoLand GeoPortal: http://neso1.cryoland.enveo.at/cryoclient/ FMI-ARC GeoPortal: http://saana.nsdc.fmi.fi/fmiarc-geoportal/ (sample products)

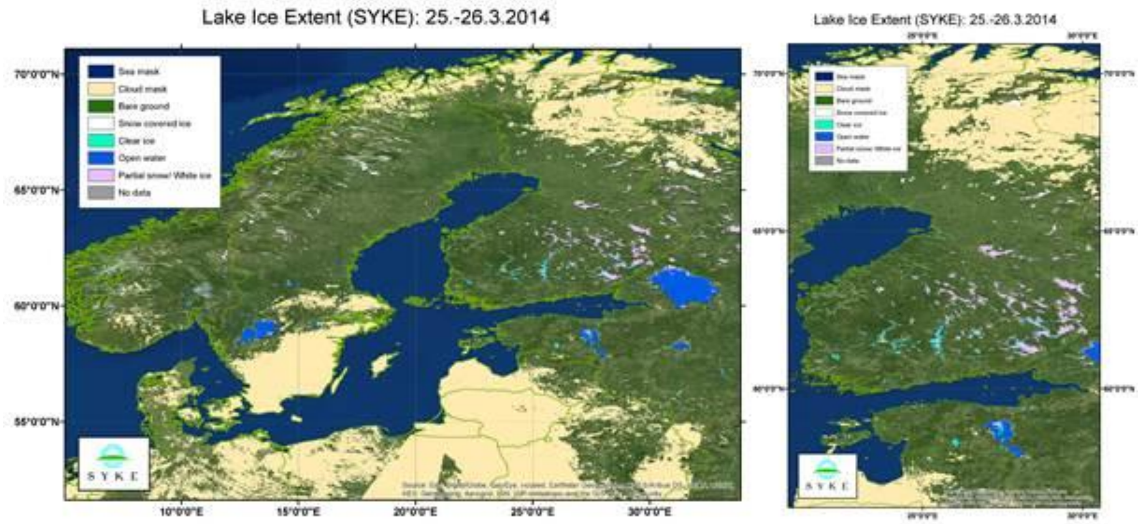


Figure 3.25: Sample LIE -product. Composite of 25th and 26th March 2014

The product is a 0.0025° raster (e.g. around spatial resolution around 250 m) in WGS-84 coordinate system. This makes the dataset fairly large and therefore requires heavy computing power for applications. The raster can be easily extended to cover larger areas and more lakes. The aim in developing the product is to make selection of lakes and produce focused lake ice maps for these regions, excluded the uninteresting land areas.

The product is currently produced from MODIS satellite data from FMI Sodankylä ground station. The latency time for the product is around 12 hours. This can be considerably reduced, but currently the best overpasses are sought for to generate the product. Sample products are made available through SEN3APP portal (the data is delivered through the CryoLand GeoPortal (http://neso1.cryoland.enveo.at/cryoclient/).

The product is also considered to be included in the Copernicus Global Land portfolio for operative global lake ice detection method.

3.6 WP6: DISSEMINATION AND EXPLOITATION

3.6.1 Promotion activities

Promotional materials brochures were prepared. These brochures were distributed thorough meetings, workshop and conferences by the project partners.

2 Dissemination workshops in Helsinki, Finland and Vienna, Austria were successfully organized.

1st Dissemination workshop was held on November 19, 2016 at the FMI in Helsinki, Finland. The participants of workshop were mainly from Finland as focus on two end-users MAVI and FORTUM and the position of the Sodankyla NSDC in the project. However the whole workshop is broadcasted online on YouTube during the day. About 25–30 persons have participated the workshop in person and about 6 viewers in average have followed the broadcast with a peak of ten viewers.

2nd dissemination workshop was held April 18, 2016 at the ZAMG in Vienna, Austria. 33 people has participated to the workshop in person. The objectives of 2nd dissemination workshop were as follow

1. To disseminate products and services provided by SEN3APP project to wider end-user community possible future end-users which has scope of interest as same as SEN3APP project
2. To present demonstrated services and products of SEN3APP project
3. To give hands-on training to use services and products provided by SEN3APP project.

In order to achieve the objectives above listed we selected Vienna and timing during the same week EGU (egu.eu) general assembly was held. We co-organized with the COST Action ES1404 (harmosnow.eu) which has over 100 persons from 28 countries. The idea of co-organizing 2nd dissemination workshop with this COST Action and during EGU conference was to increase number of participation and interest international level.

3.6.2 Product and service support and training for users

We prepared training material, entitled, "EU FP7 SEN3APP Product Descriptions & Data Access" regarding SEN3APP project. In that training document, the products generated within the EU FP7 project SEN3APP are described and information on how to access the products is provided. Downloading of SEN3APP products via the FMIARC GeoPortal (http://saana.nsdc.fmi.fi/fmiarc-geoportal) and the CryoLand GeoPortal (http://neso1.cryoland.enveo.at/cryoclient/) is described.

3.6.3 Dissemination of SEN3APP products and SEN3APP portal

SEN3APP products are disseminated from two interfaces, FMI Erdas Apollo system and CryoLand system. The FMI Erdas Apollo system is a data dissemination instance of the Finnish National Satellite Data Centre located in Sodankylä. The CryoLand system is powered by the EOxServer software which was developed within the EU FP7 project CryoLand (2011-2015). The CryoLand system is hosted by ENVEO.

Sodankylä site now hosts the Finnish Collaborative Ground Segment which is providing ESA Sentinel data. Sodankylä National Satellite Data Centre focuses on fast delivery remote sensing product generation for scientific and commercial uses. The data centre's high performance computer arrays are capable of processing vast amounts of satellite data to value adding products to various users. The products can be delivered directly to customer or to large data archives for bulk use. Satellite data and products can be transferred to users with no delays using high speed optical fibre.

The FMI Erdas Apollo System is powered by Erdas Apollo. Erdas Apollo is an interoperable OGC/ISO-based commercial application that implements an out-of-the-box service-oriented architecture (SOA). It is implemented on a geospatial platform that enables high performance OGC web services from the FMIARC catalog. Users can interact with the FMIARC catalog directly using a Web Coverage Service (WCS) interface, a Web Map Service (WMS) interface, the Web Feature Service (WFS) interface, and the Web Registry Service (WRS) interface. All of these interfaces are compliant with the standards established by the Open Geospatial Consortium (OGC).

The CryoLand GeoPortal is the online data access point for snow and land ice services developed and established during the EU FP7 project CryoLand (No. 262925, 2011 - 2015). Products in the CryoLand system are generated and provided by different operators based on freely available satellite data, but for the end-user, all products are accessible via a centralized portal. The CryoLand system has a basic FTP Server hosted by ENVEO for storing most of the generated snow and land ice products. Some products are only made available via the FTP server of other product providers. These external FTP servers are also linked with the CryoLand system. The integration of the different products into the CryoLand system and the user interfaces are controlled via the Open Source EOxServer software (http://eoxserver.org) running on a virtual machine hosted by ENVEO.

The SEN3APP portal provides detailed information about how to download and access all the products that are provided within the SEN3App project. SEN3App products page is created under the SEN3App webpage (http://sen3app.fmi.fi/) and available from http://sen3app.fmi.fi?page=Products. In the page, the products generated within the project, are described and information on how to access the products is provided. For each product, a specific page, where the detailed information and previews can be found, is created and available from the links in the product page.

3.6.4 Business model and service scenarios

Preliminary stakeholders defined at the beginning of the project and can be listed as follow

- Agency for Rural Affairs (MAVI)
- Tyrol State Government (Hydrography and Hydrology)
- Central Institute for Meteorology and Geodynamics (ZAMG)
- MetOffice (United Kingdom)
- Fortum Energy
- Freshwater Centre of the Finnish Environment Institute

During the project time, especially during 2nd dissemination workshop possible stakeholders identified as follow:

- Institute of Hydrology, Slovak Academy of Sciences (SAS)
- Institute for applied mathematics (CNR-IAC), Italy

- Middle East Technical University (METU), Turkey
- University of Bern, Switzerland
- University of Oslo, Norway
- University of Leuven, Belgium
- University of Silesia, Poland
- University of Oulu, Finland
- alpS Centre for Climate Change Adaptation
- Estonian Environment Agency
- Slovak Hydrometeorological Institute
- Anadolu University, Eskisehir, Turkey
- WSL Institute for Snow and Avalanche Research SLF, Switzerland
- National Institute of Meteorology and Hydrology, Bulgaria
- Institute of Geography, Romanian Academy
- alpS Centre for Climate Change Adaptation
- Geological Survey of Spain (IGME)

The SEN3APP project is designed to lead to a set of long-term operational services. SEN3APP services will appear as a feasible extension of the current business of the project partners. The current business portfolio of preoperational and operational services delivered by project partners includes

- Snow cover mapping and monitoring for the hydropower industry (production and energy trading)
- Snow cover and glacier mapping and monitoring for hydropower planning and geotechnical work
- Snow cover monitoring for hydrological services
- Snow extent and water equivalent monitoring for ecosystem management
- Glacier monitoring for natural hazard assessment and mitigation (glacial lakes and glacier instabilities)
- Lake ice and river ice products including flood extent during ice jams

In SEN3APP, project partners gain further knowhow in (1) developing methods for processing and using of Sentinel data (2) providing services and products based on Sentinel data. This knowhow and extended service and product portfolio will support project partners' current and future businesses. New applications are expected to open up through the SEN3APP developments.

Users will have access to various service layers. Free (at the point of access) layers would be supported by public organizations. Individual users or organizations requiring more detail would pay for a subscription service, while specialized companies (particularly those involved in the energy market and in water management) would pay more for tailored solutions.

In SEN3APP, we developed a system which is (a) capable of ingesting the extremely high-volume data of the Sentinel-1,-2 and -3 satellites provided by the Sodankylä ground segment interfaces (b) process the data to create value added product and services (c) integrate the products and services with data from other external sources, and offer both the raw and the processed data to users, via an accessible user interface and standard-based data interfaces, which provide intelligent search mechanisms and allow ordering of customized products and services. Sodankylä National Satellite Data Centre (NSDC) is in the centre of the SEN3APP system. Business scenarios of the developed system are planned to be

1. Customer oriented services
    a. Customized high performance processing in processing clusters, Long-term archiving of the data and high speed data delivery.
    b. Flexible product generation and hosting of external processing chains in virtual environments
    c. Platform as a Service (Paas) and Infrastructure as a Service (IaaS)
    d. Imaging and acquisition planning service
2. Direct broadcast and near real time services
    a. Copernicus Collaborative Acquisition Station to downlink Sentinel-1 pass-through for quasi.real-time-applications like Baltic Sea Ice service
3. Applications
    a. Terrestrial Cryosphere (e.g. Snow and ice maps generation)
    b. Meteorological applications
    c. Research and development

The activities and tasks of the Sodankylä National Satellite Data Centre (NSDC) is being developed in various projects such as SEN3APP. Overall goal is to develop the NSDC as the centre for satellite data and products in Finland. The centre that serves Sentinel data users with free Sentinel data and provides processing services and data products for national satellite data users and international partners developed during SEN3APP project. Figure 3.26 depicts the graphical representation of the development steps foreseen.

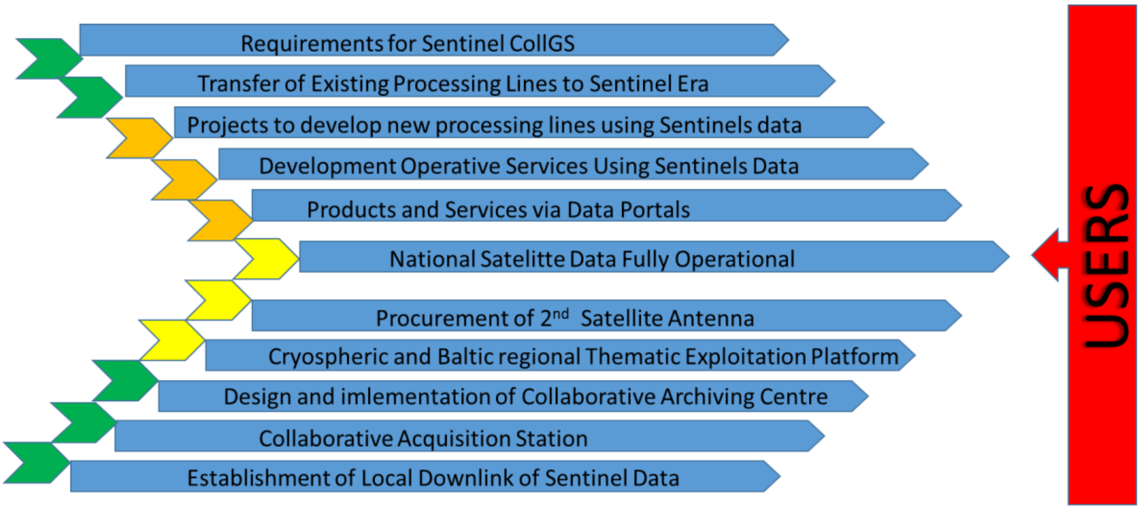


Figure 3.26: Development steps towards to fully operational satellite products and services

3.6.5 Barriers and critical risks

The main barrier for establishing an operational service based on the pilot products developed in SEN3APP is the lacking funding for finishing the development work and establishing the operational service (i.e. setting up sustainable technology, work flow, administration, contracts etc.). The funding opportunities are constantly sought for. There are no other evident obstacles for the development of the operational service. The stakeholder, i.e. MAVI, has strong interest to develop the methodology; the expertise for service development exists and the technology is ready.

Critical factors for the service are:

- The renewal of the platform and process for subsidies control does not support the uptake of the remote sensing data.
- Timely and spatially extensive (covering entire Finland) delivery of the Sentinel-1 and -2 data.
- Contractual agreement on the division of responsibilities and sustained resources.

Efficient use of remote sensing is strongly connected to the reform in the subsidies control process. The advancement in remote sensing is therefore also dependent on the success of the other process.

Sentinel satellites are still young and e.g. the Sentinel-1 imaging program has gone through some changes in the first couple of years and is still under review. With the launch of Sentinel-1b the temporal coverage was improved. The current bottleneck for the commercialisation of Sentinel-1 based NRT services is the ground segment that struggles to provide the data on a reliable base. Use of the optical data is dependent also on the successful launch of the Sentinel-2B satellite as, especially in the northern latitudes, the constraints from the cloud cover are significantly reduced with two operating satellites. Agreement on by the contributing parties needs to be signed to ensure the sustainability of the service.

4. FUTURE LOOK

.**Creation of an Analytical Snow Data Comparison Tool:** In order to create an analytical snow data comparison tool, further bilateral meetings are required to ascertain exactly which data sources Fortum Oyj is currently using and how does Fortum Oyj access this data. The comparison tool could do the following:

- Maps of absolute and relative difference between sets of data (pixel based and area based).
- Maps of deviation from long term average for each data set (pixel based and area based).
- Comparison of snow condition evolution over time with all available data (pixel based and area based).

Proceeding the SEN3APP project FMI will continue to work together to Fortum Oyj to create a prototype of the suggested comparison tool to further advance an understanding of common goals, as during the bilateral discussion such an understanding was not clearly reached. The comparison tool will address the question of data reliability and comparison through an analytical approach, instead of a purely visual assessment from various sources, which Fortum Oyj has indicated as being challenging at times to do.

Providing satellite data products to support the agricultural subsidies control mechanism: In SEN3APP first prototype products were developed to support the monitoring of agricultural land parcels. Higher level discussion and work is needed to establish the administrative and economic frameworks and to setup practices for sustained operational service. There is also further potential for product development in making use of remote sensing in agriculture and strong incentive to provide information for the farmers benefit as well (crop yield prediction, plant disease monitoring, guidance of fertilization etc.). The key development steps are:

- Re-thinking of subsidies control mechanism by MAVI
- Finding financing for further development of the products and continuation of piloting in summer 2017 (MAVI and SYKE)
- Establishing pre-operational service (MAVI, SYKE, FMI)
- Establishing administrative and funding framework for the service (MAVI)
- Establishing operational service

The timing of these activities is highly dependent on finding the funding for further development of the products and on the digitalization activities of MAVI.

Providing global coverages of fractional snow cover (FSC), Snow Water Equivalent (SWE) and lake ice extent (LIE) in the framework of Copernicus Global Land component: These products will be provided as global services under a contract administrated by Joint Research Centre (JRC). The service provision is scheduled to start as soon as the data dissemination procedures and infrastructure are in place and connections to the services established. The consortium providing the services consists of FMI, ENVEO and SYKE.

Developments in the FSC data products are continually disseminated to the SYKE's hydrological modelling unit. Further integration of the data to the hydrological forecasting is dependent on the modelling group.

Use of LIE in weather prediction would need separate research and development funding, both for development of the product (to incorporate Sentinel-1) and also for the uptake of the data by the model.

ENVEO will continue running the GeoPortal services established during the EU FP7 project CryoLand (2011 – 2015) to further disseminate the SEN3APP products and extended snow and land ice services.

Providing Sentinel-1 processing software:

GAMMA will continue to sell its COTS software tools for SAR, SAR interferometry and land applications. Within SEN3APP GAMMA software was tested in the frame of a Software as a Service (SaaS). This model will be further investigated and followed. In particular for providing specific processing solutions as e.g. done within SEN3APP to produce Ice Velocity Maps but also Snow related applications.

- Remaining gaps (wish list) to be addressed in future can be listed as follow:
- Snow products from Sentinel-2 and -3 / operational products
- Sentinel-2 data distribution using OGC wms service
- Further balancing of cloud-masking and atmospheric correction algorithms between a) efficiency and automation, and b) amount of lost areal coverage
- More geographic area coverage
- Increase usage of SEN3APP's services and products; more promotion
- More use of SEN3APP products and services at events such as hackathons which give the public easy access
- Reliability of services and products

Needs for further research or product development to meet user needs can be given below:

- Automatic, cost-efficient tools for cloud-detection and atmospheric correction of optical imagery
- Increase accuracy and resolution on satelitte products
- New sensors and multi-sensor approaches
- New technologies