6.2: Snow depth downstream added value services

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Acronyms and Abbreviations

ALS	Airborne Laser Scanning
CF	NetCDF Climate Forecast
ESA	European Space Agency
FTP	File Transfer Protocol
GIS	Geographic Information System
NetCDF	Network Common Data Format
NRT	Near Real Time
NTC	Non Time Critical
PolSAR	Polarimetry Synthetic Aperture Radar
QA	Quality assessment
SAR	Synthetic Aperture Radar
SRAL	Synthetic Aperture Radar Altimeter
STC	Slow Time Critical
SWE	Snow Depth Equivalent

1. Abstract

This document describes the snow depth service based on Sentinel-3 SAR altimeter data defined in the scope of the LOTUS project.

The study of snow is a key parameter, especially for regions where fresh water is mainly supplied by snowmelt and runoff. Monitoring the amount of snow provides essential information for different topics such as water supply, flooding prediction, weather forecast, and climate changes.

Snow has been characterized as snow pack defined from snow density and snow depth. The Snow Water Equivalent (SWE) defines the quantity of water that would results of the melt of the snow packs. It appears to be the best parameter to monitor amount of snow.

One of the best parameter used to characterize the snow pack is the Snow Water Equivalent (SWE), defined as the quantity of water that would results from the melt of a given quantity of snow. Snow Water Equivalent can be computed as a combination of two parameters: snow depth and snow density.

Unfortunately up to now there is no sensor able to directly infer SWE from space. This could be solved using information from different sensors, i.e. snow density can be obtained from Synthetic Aperture Radar (SAR) data, while snow depth can be retrieved from radar altimeter.

The scope of the LOTUS project is to prepare the operational life of Sentinel-3. As a spacecraft that carry on-board SAR altimeter instrument, thus this service will focus on snow depth delivery.

2. Review of user needs and requirements

The user requirements have been defined in the previous document "Preparing Land and Ocean Take Up from Sentinel-3 (LOTUS)' Work Package 2 'Processing of SRAL SAR mode waveforms over land", Deliverable 2.2.

Snow melt provides the majority of annual groundwater recharge, so monitoring of snow water equivalent is an important part of water resource management, especially for hydrological companies. In that scope, Snow Water Equivalent (SWE) is the common measurement for snow storage. SWE represents the amount of water contained in the snow pack per unit area. Its estimation is still investigated by the scientific community and not any satellite can perform its direct measurement. Nevertheless, SWE is defined as a product of two snow parameters: snow depth and snow density. Then, providing snow depths estimation from altimeter data would be a first step to retrieve it, in combination with snow density estimation from other sources (numerical models, SAR).

Surface irradiative exchange and heat transfer investigators are also interested in snow depth information due to its different impacts on surface energy balance. Snow affects frozen ground, permafrost distribution, and moisture recharge. In this context, snow estimation is an important input to climate evolution studies.

Currently, on-site instruments such as snow rulers or ultrasonic ranging sensors essentially measure snow depth. Such instruments produce single point location measurements, which are interpolated and extrapolated spatially to cover wider areas. From our side, space-borne sensors can cover wide swath with repeat data. Space altimeters also permit access to difficult to reach areas, or not likely to be covered by snow areas. Then, they are perfectly suited to complete and extend the in situ measurements of snow depth estimation for scientific and users' communities.

Table 1: User requirements for low topography snow depth monitoring.

	Minimum requirement for radar altimetry snow depth product
Temporal resolution	Tens of days
Spatial resolution	Hundreds of meters
Accuracy	0.1 m
Coverage	Local scale

3. Review of the state of the art technologies

3.1.In situ instruments

Actually, the way to retrieve snow depth remains to be in situ measurements: snow rulers and ultrasonic ranging sensors.

Snow ruler is certainly the oldest snow depth acquisition instrument. It requires human reading of the measurements, and has to be in accessible areas. The instrument cannot be located in high mountain peaks. More the reading cannot be done in hard weather condition, or over instable amount of snow. The accuracy of such a system is quite good, but requires the contribution of a human person.

Ultrasonic ranging system is the remote instruments on site to measure snow depth. Ultrasonic sensors have a wide beam so it is hard to focus them on a particular area. They need to be mounted perpendicular to the snow surface. The speed of sound changes with the temperature, so for accurate readings the sensor must be temperature compensated. Ultrasonic sensors have a good range and recently several low-cost ultrasonic sensors have become available.

In situ measurements reveal to be local and often together located. They do not provide global coverage as Earth observation from space is able to.

More, they are located where snow is expected. There are not any in situ instruments where snow falls only once every ten years. This snow coverage remains to be an important source of imbalance in the water resource management.

3.2.Airborne laser scanning

Airborne laser scanning (ALS) during flying campaigns can also retrieve snow depth. ALS, often referred to lidar or laser altimetry, is a remote sensing technique which measure the round-trip time of emitted laser pulses to determine the topography of the earth's surface. This technology employs pulsed lasers that repetitively emit short infrared pulses towards the Earth's surface. The waveforms reflect on the snow surface. Some of the energy is scattered back to the sensor where it is measured with an optical receiver.

Airborne laser scanning measures the snow elevation, but the snow depth cannot be retrieve directly from this acquisition. Then, always two phase in the acquisition campaigns are needed to estimate the variation of snow depth. The campaigns are performed before the start and at the end of accumulation season of winter, Mott et al. (2011), or Helfricht et al. (2012).

Such technology is used only for study campaigns. This kind of technology cannot operate on repetitive acquisitions and for global scales.

3.3.Statistical Models

To address this issue, models has been developed to produce wider coverage. Models application aims to cover large areas like model from Golding (1974), Chang and Li (2000), Marchand and Killivingtveit (2005), and Pomeroy et al. (2002), or smaller catchments (1 to 30 km^2) such as Jost et al. (2007), and Plattner et al. (2006).

All these models previously mentioned are limited by the small amount and spatial coverage of snow depth observations available for the analysis. Most are based on manual snow depth measurements and tens to few hundreds of samples could be used for the regression modelling. Only in the recent years, some studies (Grünewald et al., 2010, Lenhning et al., 2011) used snow depth data obtained by terrestrial and airborne laser scanning. These technologies produce high resolution and high quality snow depth data. But, ALS data is only available from study campaigns, and would never be an operational service.

These models require high level input, including meteorological data, sometimes detailed flow field, and sometimes high-resolution digital elevation model. They are, then, very expensive in required information and calculation resources, and have not been apply for very large areas or longer time frames. All large areas studies remains to be on restricted areas that do not cover a complete mountain range.

The “Global” model, combining all the data from all areas investigated could only explain 23% of the snow depth variability. Better results are obtained from models that are calibrated to local conditions at the single study areas, explaining from 30 to 91% of the snow depth variability. However, it appears that local statistical models cannot be applied to different regions. On the contrary, the statistical models developed for one year, can be well applied to other years.

4. Service architecture definition and description

4.1.Global Architecture of the Service

From the Sentinel-3 SRAL Level 1B data, the stacks of waveforms are extracted for each location. Each stack is then retracked to retrieve the waveforms parameter such as the range, and the backscatter coefficient. Snow depth is computed through a model from the backscatter coefficient. Finally, to provide a user-friendly product, the data is formatted in a common climate format: NetCDF CF.

To ensure the quality of the product, a quality assessment process is performed. The access point for end user to get the data is an ftp server. Through a free registration, the end user is providing with a login to download the final L3 product.

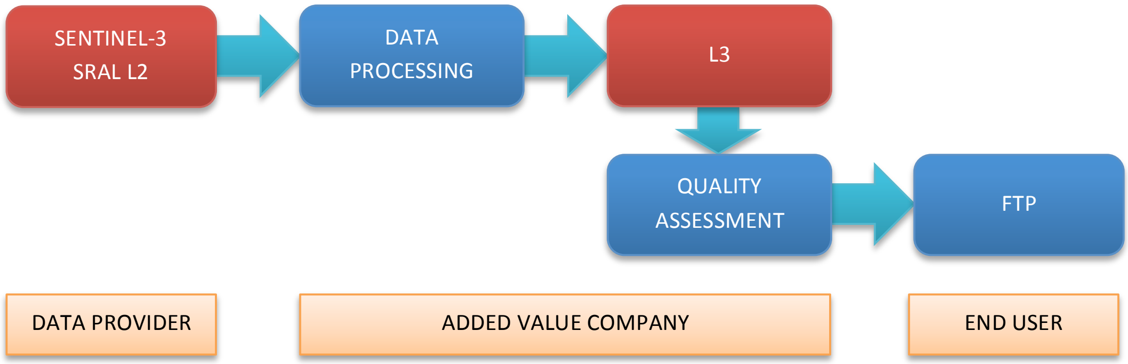

Figure 1: Service architecture

4.2.Service inputs

ESA proposes different levels of data for Sentinel-3 SRAL instruments. Unfortunately, the Level 1B product is an internal product. It is not available to users and is considered only as an input to Level-2 processing.

A level-2 SRAL complete product contains three files in NetCDF format: “reduced” containing a subset of the main 1 Hz Ku band parameters, “standard” containing the standard 1 Hz and 20 Hz Ku and C-band parameters, and “enhanced” containing the standard 1 Hz and 20 Hz Ku and C-band parameters, the waveforms and the associated parameters necessary to reprocess the data. The processing chain needs waveforms to compute snow depths.

Different data types depending on delivery time to users and the available consolidated auxiliary or ancillary data: “Near Real Time (NRT)”, delivered less than 3 hours after acquisition, “Slow Time Critical (STC)”, delivered within 48 hours after data acquisition due mainly to the consolidation of auxiliary and ancillary data, and “Non-Time Critical (NTC)”, delivered about 1 month after data acquisition, with precise orbit. From the requirements, the service does not provide critical time dataset.

To summarize, the data chosen, as input for the snow depth service is the Sentinel-3 SRAL Level-2 Enhanced NTC, using the 20Hz Ku-band waveform datasets.

The data is free, full, and accessible through the data policy adopted for the Copernicus programme foresees access after pre-registration.

4.3.Processing chain

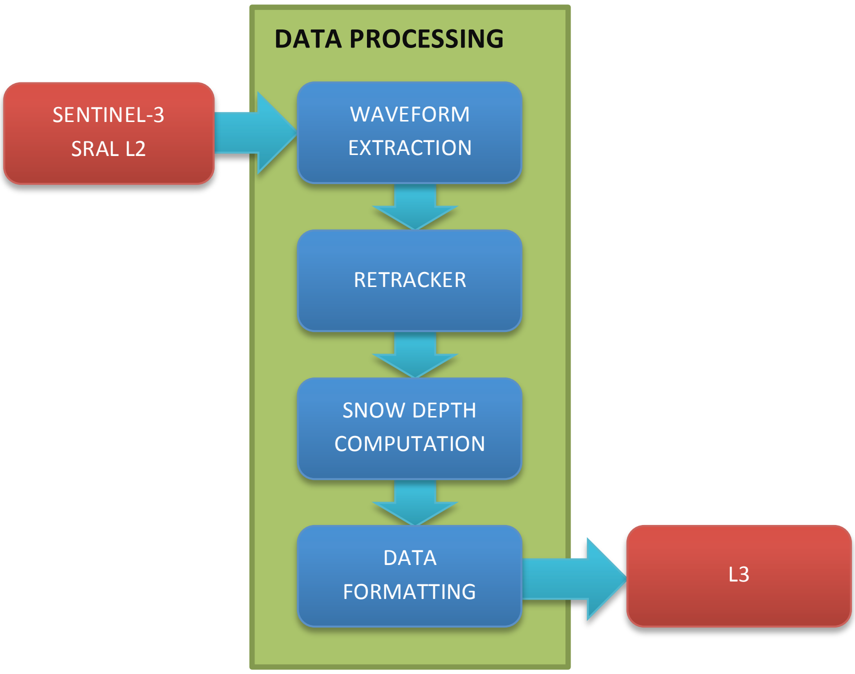

Figure 2: Data processing architecture

From the input products Sentinel-3 SRAL Level-2 Enhanced, the stacks of waveforms corresponding to the 20 Hz Ku band acquisitions are extracted using a NetCDF reader.

These waveforms are retracked using a land retracker to retrieve waveform parameters. The retracker estimates different parameters of the waveform. From Papa et al. studies (2002), the backscattering coefficient was found to be the most sensitive to the presence of snow. The mean value of the backscattering coefficient decrease as the snow cover thickened through the winter.

Following the approach developed by Papa et al. (2002) a model to estimate snow depth has been set-up. The averaged backscattering coefficient over the altimeter radar footprint is the sum of three different effects: the reflection from the snow surface, the volume-scattering effect of the entire snow layer, and the two-way attenuation of the ground return signal. The model estimate the backscattering coefficient of the ground without snow coverage as a reference and a total backscattering coefficient including snow depth estimation. The temporal evolution of the backscatter with respect to the reference backscatter gives information on the snow pack characteristics such as snow depth during winter season.

The product is formatting in a user-friendly format, respecting the ESA recommendations: NetCDF CF.

4.4.Product definition

The L3 product contains snow depth estimation located on satellite tracks. The data is time indexed, and located with latitude and longitude coordinates on a daily basis. The snow estimation covers same area as the topography coverage of Sentinel-3 from -81,5N to 81,5N. The frequency of the measurements is based on a 27-day repeat cycle, with a 4-day sub-cycle. This definition is built considering only the Sentinel-3A spacecraft.

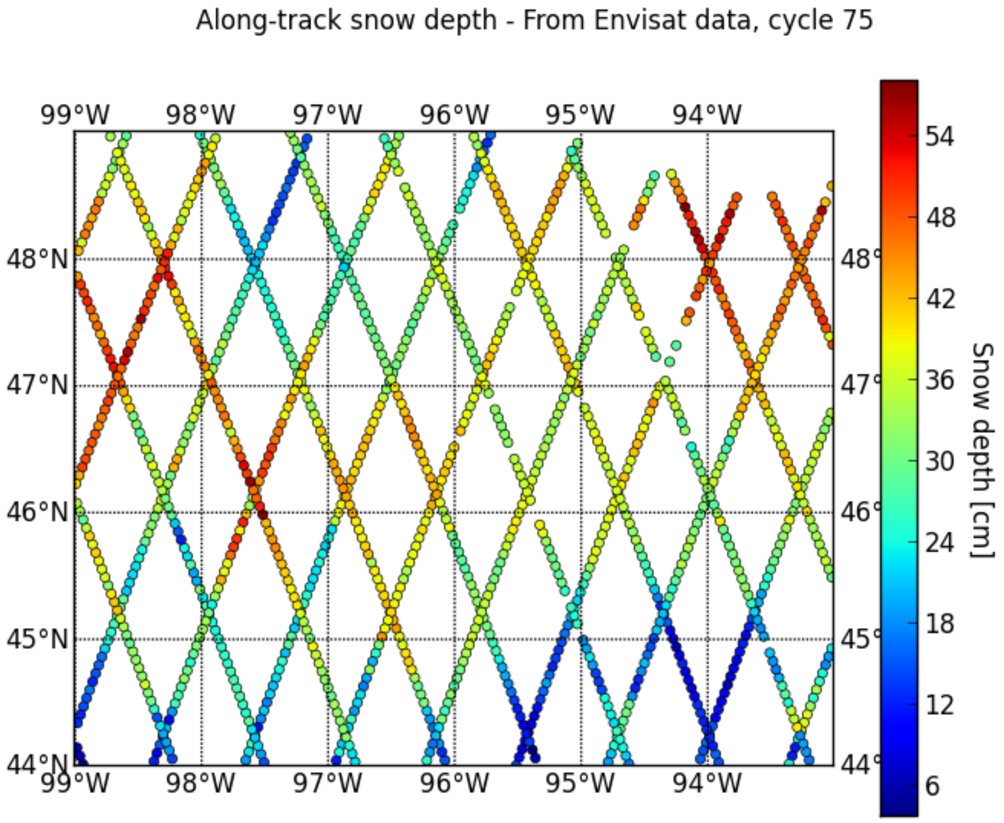

Figure 3: Snow depth along track product for EnviSat cycle 75 in a focused area

The product is formatting in (Network Common Data Format) NetCDF format and convention. The NetCDF is commonly used in climatology, meteorology, oceanography and GIS applications. Several conventions to write and present data into the NetCDF format have been defined. The convention used for the snow depth product is the Climate and Forecast (CF) Metadata Convention. The metadata defined by the CF convention is included in the same file as the data, making the file "self-describing". The convention provides a definitive description of what the data values found in each NetCDF variable represents, and of the spatial and temporal properties of the data. Such convention produces a common format easily opened and read by software applications such viewers.

Table 2: Final product definition

Product	Snow depth
Type of information	Snow depth over tracks

Delivery format	Network Common Data Format – Climate and Forecast metadata conventions (NetCDF CF 1.6)
Inputs needed to elaborate the product	Sentinel-3 – SRAL Level 2 Enhanced – 20 Hz Ku band SAR mode
Geographical coverage	Global coverage, -81.5N – 81.5N
Time coverage	Daily product
Geographic projection - Coordinate reference system	Along-track product - Latitude/Longitude coordinates
Frequency	27-day repeat cycle, with a 4-day sub-cycle

4.5.Quality assessment

Establishing an efficient quality assessment concept will guarantee the overall quality of the service implementation and of the final deliverables

Table 3: Key element of a QA concept

QA concept element	Additional details	Responsibility
Data format verification	Detect inconsistencies in the format	Value adding specialist
Data content verification	Detect missing values, wrong values	Value adding specialist
Statistical and scientific evaluation	Evaluate datasets to record outliers	Value adding specialist

4.6.Data packaging and delivery platform

The data is made available for the end user through an ftp platform. As soon as the data is processed, verified, and validated, the files are uploaded to the ftp server. The access is free of charge, but a previous registration is needed to get a login to the platform.

Data Format and delivery
Delivery channel: on-line via FTP **Spatial (geographical) data**: NetCDF CF 1.6 data **Reports, statistics**: MS Office (word, excel, powerpoint) and PDF format

5. Service requirements and specifications

The service specifications are directly linked to the user requirements defined in section 2.

5.1.Requirements convention and acronyms

- "SHALL" is used to indicate a mandatory requirement
- "SHOULD" indicates a preferred solution but is not mandatory
- "MAY" indicates an option
- "WILL" indicates a statement of fact or intention.
- "N.A. " for Non Applicable.

The trace code will be compiled as follow:

R-XXX-NNN,

where XXX is a two/three letter acronym for the service section (see Table xxx), and NNN is the requirement number in this category.

Table 4: This table provides the service section trace codes.

Targeted Service Sections Trace Codes	Label
IN	Service inputs
DP	Data processing
OUT	Output product
QA	Quality assessment
DEL	Delivery platform

5.2.Service inputs

Table 5: Service input requirements

Trace Code	Service requirement
R-IN-001	Sentinel-3 SAR L2 products shall contain time indexed data
R-IN-002	Sentinel-3 SAR L2 products shall contain geolocated data (latitude, longitude)
R-IN-003	Sentinel-3 SAR L2 products shall contain stack of waveforms acquired for a single location

5.3.Data processing

Table 6: Data processing requirements

Trace Code	Service requirement
R-DP-001	The data processing unit shall run on a server
R-DP-002	The data processing unit shall have a Matlab/IDL license.

5.4.Output product

Table 7: Output product requirements

Trace Code	Service requirement
R-OUT-001	The output products should be delivered in a user-friendly format
R-OUT-002	The output products shall have a time resolution of tens of days
R-OUT-003	The output products shall have a spatial resolution of hundreds of meters
R-OUT-004	The output products shall have a snow depth accuracy of 0,1 meter

5.5.Quality assessment

Table 8: Quality assessment requirements

Trace Code	Service requirement
R-QA-001	The quality assessment processing shall check the readability of the data
R-QA-002	The quality assessment processing shall check the format
R-QA-003	The quality assessment processing shall check the scientific quality of the data

5.6.Delivery platform

Table 9: Delivery platform requirements

Trace Code	Service requirement
R-DEL-001	The delivery platform should be free of charge access
R-DEL-002	The delivery platform should support registration

R-DEL-003	The delivery platform should be available worldwide
R-DEL-004	The delivery platform shall be support daily data updates
R-DEL-005	The delivery platform shall be able to store all the complete dataset

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