CryoLand

Copernicus Service Snow and Land Ice

Collaborative Project funded by the European Union under the 7th Framework Programme
Project Number: 262925

Upgraded Pan-European Snow Services

Prepared by

Gabriele Schwaizer, Elisabeth Ripper and Thomas Nagler, ENVEO, Austria

Jaakko Ikonen, Kari Luojus, Timo Ryyppö, Mwaba Hiltunen and Jouni Pulliainen, FMI, Finland

Sari Metsämäki, SYKE, Finland

Issue / Revision: 1 / 1.1

Date: 10.03.2017

Document controlled by: T. Nagler

CryoLand Report

Grant Agreement Nr:	**Subject:**	**Project Coordinator:**
262925	Pan-European Snow Products, Algorithms and Processing Lines	ENVEO
Issue / Revision: 1 / 1.1	**Contractor's Ref:** ID4.6 / A	

The purpose of this report is to present the pan-European snow products, algorithms and processing chains developed for the CryoLand pan-European snow services. The project has successfully developed pre-operational pan-European snow services for fractional snow cover and snow water equivalent. Fractional snow cover is based on optical sensors, while snow water equivalent is based on passive microwave radiometers. These two services were tested and delivered to users since the winter season 2012/13. A time series of Fractional Snow Cover products from archived optical satellite data since winter 2000/01 has been generated. The products are provided through the CryoLand GeoPortal (http://neso1.cryoland.enveo.at/cryoclient/).

This project was funded by the 7th Framework Programme of the European Commission. Responsibility for the contents resides in the author or organisation that prepared it.

Authors: G. Schwaizer, E. Ripper, T. Nagler, J. Ikonen, K. Luojus, T. Ryyppö, M. Hiltunen, J. Pulliainen, S. Metsämäki.

This page is intentionally left blank.

DOCUMENT CHANGE LOG

Issue/ Revision	Date	Modification	Modified pages	Observations
0.1	07.11.12	Template/outline	All	Gabriele Bippus
0.2	17.01.13	Initial contributions from ENVEO	Ch. 2, 3 and 4	Gabriele Bippus
0.3	18.01.13	Initial contributions from FMI	Ch. 3	Jaakko Ikonen
0.4	25.01.13	Updates of most sections	All	All
0.5	11.02.13	Editing and corrections	All	Gabriele Bippus
0.6	01.10.13	Updates for v. 1.0	Ch. 3	Jaakko Ikonen
0.7	07.10.13	Updates for v. 1.0	Ch. 2	Sari Metsämäki
0.8	10.10.13	Updates for v. 1.0	All	Gabriele Bippus
0.9	14.10.13	Collating and proofs of contributions	All	Gabriele Bippus
1.0	25.10.13	Final updates and proofs	All	Gabriele Bippus
1.1	10.03.17	Update of FSC documentation	Ch. 2	Gabriele Schwaizer (maiden name: Bippus)

This page is intentionally left blank.

TABLE OF CONTENTS

This page is intentionally left blank.

1. INTRODUCTION

1.1 Purpose of the document

The main purpose of the document is to report on the upgraded pan-European snow services. This includes a description of the products (specifications), algorithms and processing chains. The described pan-European snow services are available through the CryoLand service.

This document is updated based on the internal deliverable ID4.6.

1.2 Outline

Chapter 2 presents the operational pan-European snow service for fractional snow cover. Chapter 3 describes the operational pan-European snow water equivalent service based on passive microwave data.

1.3 Acronyms

AMSR-E	Advanced Microwave Scanning Radiometer
CLC	Corine Land Cover (2000, 2006, 2012)
DEM	Digital Elevation Model
DUE	Data User Element
EASE-Grid	Equal-Area Scalable Earth Grid
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency
ENVEO	ENVironmental Earth Observation IT GmbH
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper Plus, sensor on board of Landsat 7
FMI	Finnish Meteorological Institute
FSC	Fractional Snow Cover
FTP	File Transfer Protocol
GDAL	Geospatial Data Abstraction Library
GeoTIFF	Geographic Tagged Image File Format
GLIMS	Global Land Ice Measurements from Space
GSGRDA	Initial GMES Service for Geospatial Reference Data Access
HDF	Hierarchical Data Format
HR	High Resolution

HUT	Helsinki University of Technology (now Aalto University TKK)
LAADS	Level 1 and Atmosphere Archive and Distribution System
MODIS	Moderate Resolution Imaging Spectrometer
NASA	National Aeronautics and Space Administration
NDSI	Normalized Difference Snow Index
netCDF	Network Common Data Form
NRT	Near-Real Time
RMSE	Root-Mean-Square Error
SD	Snow Depth
SMMR	Scanning Multichannel Microwave Radiometer
SRTM	Shuttle Radar Topography Mission
SSM/I	Special Sensor Microwave Imager
SWE	Snow Water Equivalent
SYKE	Finnish Environment Institute
TKK	Aalto University, Teknillinen korkeakoulu (formerly HUT)
TM	Thematic Mapper, Sensor on board Landsat 5
VHR	Very High Resolution

2. PAN-EUROPEAN SNOW COVER SERVICE

2.1 *Fractional snow cover*

The development of the pan-European snow cover service is aimed at providing a homogeneous fractional snow cover product for the area extending from 72°N/11°W to 35°N/50°E with a spatial resolution of 0.005° x 0.005°. The product uses Terra MODIS data distributed by NASA as input. The final product is provided to the users daily in the late afternoon via FTP and the CryoLand web service, only a few hours after the last image acquisition over the area of interest. The product specifications and an example of the pan-European snow map are provided in Table 2.1 and Figure 2.1, respectively.

Table 2.1:
Description of pan-European fractional snow cover product.

Parameter	***Specification***
Thematic variable	Fractional Snow Cover (FSC)
Thematic resolution	1% FSC
Thematic range	[1, 100] FSC
Thematic accuracy	~20%
Thematic uncertainty estimate	Daily RMSE per pixel over land areas
Spatial coverage	Pan-European region: 72°N 11°W – 35°N 50°E
Delivery time period	Year-round
Temporal frequency	Daily
Spatial resolution	0.005° × 0.005°
Geometric accuracy	< 1 pixel aiming at 0.5 pixel
Projection/Datum	Geographical (lat/lon) / WGS84
Sensor	Terra MODIS
File format	GeoTIFF
Developed by	CryoLand
Service provider	CryoLand
CryoLand priority	1 (primary product)
CryoLand status	Operational

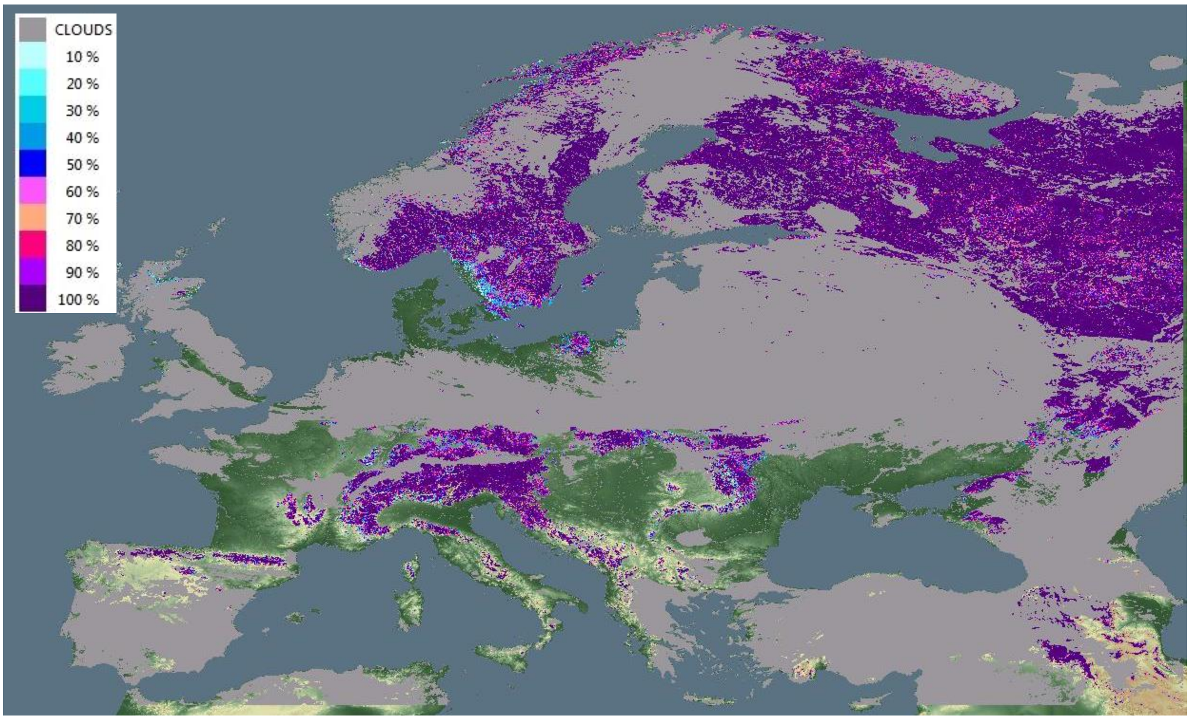

Figure 2.1: Example of the pan-European fractional snow cover map from Terra MODIS data of 3 March 2013 using the SCAmod algorithm. The cloud mask from MODIS cloud product (MOD35_L2) is only shown over land areas.

2.2 *The algorithm*

Various algorithms are currently available for the retrieval of fractional snow cover from optical satellite imagery. Most of these methods are optimized for particular areas and surface conditions. After testing two algorithms, the SCAmod (Metsämäki et al. 2005, 2012) and multi-spectral unmixing, and intercomparison with the MODIS snow product provided by NASA (Hall et al. 2002), snow maps derived from very-high resolution satellite data and in-situ measurements, the SCAmod has been selected for generating the pan-European fractional snow cover product. The results of these intercomparisons are summarized in Section 2.5.

Before the SCAmod is applied, a strict binary snow classification is made to identify snow free pixels with similar reflectance characteristics as snow covered pixels. The brightness temperature and the Normalized Difference Snow Index (NDSI), which is based on the different reflectivity of snow and other surfaces in the visible and mid-infrared wavelengths (Crane & Anderson 1984), are used for this pre-classification. The SCAmod is applied on all pixels classified as snow by the pre-classification.

SCAmod is based on a reflectance model, using a transmissivity map (providing information on forest “transparency”) derived from GLOBCOVER data as input (Metsämäki et al. 2012). Fractional snow cover is retrieved from earth-observation data by using the following equation:

$$FSC = \frac{\frac{1}{t_\lambda^2} * \rho_{\lambda,obs} + (1 - \frac{1}{t_\lambda^2}) * \rho_{\lambda,forest} - \rho_{\lambda,ground}}{\rho_{\lambda,snow} - \rho_{\lambda,ground}}.$$

$P_{\lambda,obs}$	observed reflectance from unit area
$P_{\lambda,snow}$	reflectance for wet snow
$P_{\lambda,forest}$	reflectance for forest canopy
$P_{\lambda,ground}$	reflectance for snow-free ground
t_λ^2	apparent forest canopy two-way transmissivity for the unit area
FSC	fraction of snow covered area percentage

Typical reflectance values to use in the SCAmod algorithm for snow-free ground, wet snow and forest canopy are given in the next section.

2.3 *The processing chain*

Terra MODIS data (Version 6) is retrieved from the LANCE FTP site of NASA. The Level-1B calibrated radiance product with 1 km and 500 m spatial resolution, and the geo-location product are downloaded daily for the area of interest. Until February 2016, also the MODIS cloud product (MOD35_L2) was downloaded daily.

Of the MODIS cloud product with 500 m pixel size all classes with probable occurrence of clouds were used for the cloud mask. Only confident clear pixels were excluded. The MODIS cloud product was checked for data gaps, which were filled by averaging neighbouring pixels. No other filter or pre-processing operation was applied on the MODIS cloud product. The reliability of the MODIS cloud product was partly limited, especially in case of clouds over snow covered areas. Therefore, the NDSI pre-classification described further below was useful for distinguishing inter alia snow and cloud pixels. Since February 2016, cloud screening is based on the simple cloud detection algorithm, developed by Metsämäki et al. (2015).

Additional to the calibrated MODIS bands, the following auxiliary data are needed for the processing chain:

- Digital Elevation Model (DEM)
- Surface classification (Corine Land Cover, GLOBCOVER 2009)
- Transmissivity map

Over European countries, the digital elevation model used for the processing of the pan-European snow map has been generated by the Initial GMES Service for Geospatial Reference Data Access (GSGRDA) from ASTER GDEM, corrected with data from SRTM, NEXTMap, Landsat and other data sets. For the remaining areas, a combined DEM based on elevation data from SRTM (Shuttle Radar Topography Mission, Version 4; Jarvis, Reuter, Nelson, & Guevara, 2008) for the latitude range 60°N – 35°N, and on the ASTER GDEM V2, a joint product of METI and NASA, for the northern latitudes, between 60°N and 72°N is used.

For the surface classification, the Corine Land Cover (CLC) data set, Version 18.5, published by the European Environment Agency (EEA) in October 2016 is used over large areas in Europe. The CLC data set is currently available for the years 2000, 2006 and 2012. The CLC data set of 2006 was selected to generate a homogeneous time series of the Fractional Snow Cover product. For regions not covered by the CLC product, the GlobCover 2009, Version 2.3, released by the DUE GlobCover project of ESA in December 2010, is used. The GlobCover product has a lower spatial resolution compared to the CLC data set, but is available globally. Based on these land-cover classifications a homogeneous surface mask using CryoLand coding was generated, including the following classes:

- Water (sea, lake, river)
- Bare ground
- Glacier (updated with data from GLIMS and Austrian Glacier Inventory of 1997-1999)
- Forest
- Urban area

The transmissivity describes the transparency of the forest canopy and is related to crown coverage. The mandatory transmissivity map is created based on MODIS and GlobCover data. For regional test sites, transmissivity is generated from MODIS reflectance (550 nm) observations acquired at the full snow cover (FSC=100%). These transmissivity data are combined with GlobCover data. Statistics on their relationship are derived in order to provide the transmissivity based on GlobCover (Metsämäki et al., 2012). Transmissivity can thus be generated for extensive areas where it is not possible to find appropriate cloud-free MODIS observation for full snow cover conditions. Water bodies are classified by the value “-1” in the transmissivity map. This code is used additionally to the water mask of the Land Cover data when the SCAmod is applied. As the transmissivity map is partially based on the GlobCover product, some differences regarding water and land classifications compared to the CLC surface classification can occur, in particular along coast lines, small inland water bodies and rivers.

The SCAmod algorithm is very sensitive to the transmissivity map used as input. As the transmissivity map is derived from GlobCover data, boreal forests in Scandinavia and forests in southern latitudes have similar transmissivity values in this map.

To avoid misclassifications due to similar transmissivity values in different climate zones, a spatially and temporally variable NDSI threshold map is used for the strict preliminary binary classification of definitely snow free and potentially snow covered pixels. By default, in the winter months, January, February, March, November and December, the NDSI threshold north of 58°N is set to a minimum of -0.10. For these months, a linear gradient is applied on the NDSI threshold to change between 58°N and 38°N from -0.10 to +0.50. South of 38°N, the NDSI threshold is set constant to +0.50 in this period. In these winter months, a NDSI threshold of +0.70 is allotted to areas classified in the CLC data set as rice fields, permanent irrigated lands, salt marshes, saline or intertidal flats to avoid misclassifications due to very-high reflectivity of these areas.

Additional to the geographic latitude the NDSI thresholds change with the surface elevation derived from the digital elevation model used as auxiliary data. For altitudes above 500 m a.s.l. the NDSI threshold decreases linearly about 0.01 per 100 m elevation interval. Thus, for example high altitudes in the main alpine mountain ridge have also the minimum NDSI threshold of -0.10.

Further, the NDSI thresholds are set variable with time, as the reflectivity of vegetation and other surfaces changes during the year. The spatially variable NDSI thresholds are increased during the spring, summer and autumn months. The spatially and temporally variable NDSI values used for the pre-classification of definitely bare ground pixels and potential snow pixels are given in Table 2.2.

Table 2.2:
Temporal adaptation of NDSI thresholds in order to correct for annual reflectivity changes.

Region	***Jan/Feb/Mar/ Nov/Dec***	***Apr/Oct***	***May***	***Jun/Jul/ Aug/Sep***	***Altitudes >500 m a.s.l.***
>58°N	-0.10	0.00	+0.15	+0.20	-0.01 / 100 m
58°N – 38°N	-0.10 – +0.50 (linear change)	0.00 – +0.60 (linear change)	+0.15 – +0.75 (linear change)	+0.20 – +0.80 (linear change)	-0.01 / 100 m
<38°N	+0.50	+0.60	+0.75	+0.80	-0.01 / 100 m
CLC06 classes: Rice fields, permanent irrigated lands, salt marshes, saline, intertidal flats	+0.70	+0.80	+0.95	+1.00	-0.01 / 100 m

To avoid misclassifications of pixels located in small cloud gaps, the information of a brightness temperature (T_B) band is used. As the land surface is usually warmer than cloud temperature, and misclassifications of snow in pixels surrounded by clouds were mainly observed when the land surface temperature was already far above freezing temperatures, the following classification rule is applied on the emissive MODIS band 31 (10.780 µm - 11.280 µm) with 1 km grid size:

$$IF\ (T_B(11\mu m) >= 283.0\ K)\ THEN\ FSC = 0$$

The effect of using the brightness temperature as an additional criterion for classifying snow or no snow is illustrated in Figure 2.2.

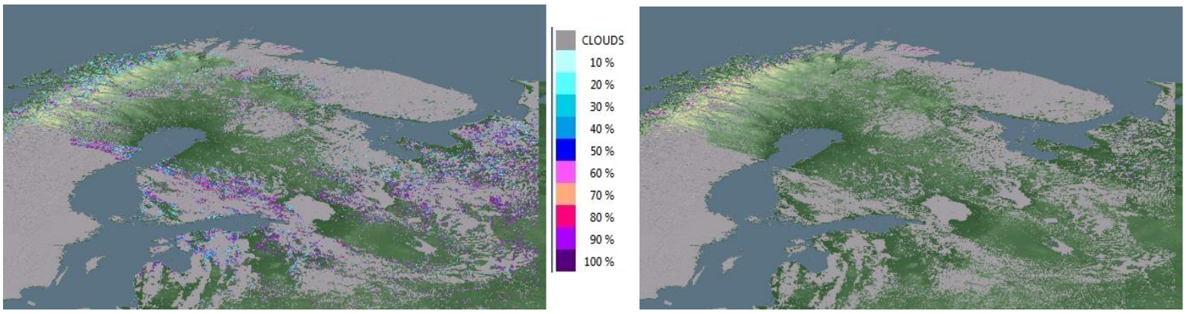

Figure 2.2: Comparison of the fractional snow map of 13 June 2013 derived without (left) and with (right) the brightness temperature criteria. The difference of misclassified snow in the left image and the snow free pixels in the right image is distinctive.

For all pixels classified as snow by the pre-classification using the NDSI and the additional threshold on the brightness temperature, the SCAmod algorithm is applied. Pre-defined typical reflectance values for forested areas, bare ground and wet snow are needed for the SCAmod algorithm. According to Metsämäki et al. (2012) these reflectance values are set as:

- $\rho_{wet\ snow} = 0.65$
- $\rho_{forest\ canopy} = 0.08$
- $\rho_{snow\text{-}free\ ground} = 0.10$

The snow classification is applied on each of the scenes needed for a complete coverage of the pan-European area. As soon as the generation of the particular snow maps is completed, the product is merged to one large snow map. For overlapping snow-free pixels on image boundaries the pixels with the steepest local sensor incidence angle are used for the merged product in order to get the best available information. If a pixel of the overlapping image part is classified as cloud in one scene, and as any other class in another scene, the classification of the cloud-free pixel is used.

During the polar night, a snow classification is not possible in the northern latitudes of the pan-European area. All pixels with solar zenith angle greater than 84° are classified as "polar night".

The resulting fractional snow cover map meets the CryoLand product specifications defined in the Product Design Document (D2.2, available online from http://cryoland.enveo.at/downloads/CryoLand_No262925_D02.2_PDD_v1.6.pdf). Additional to the product, an associated metadata file is generated daily, containing information about the product, the used input data and contact information. The full product data set is saved in a compressed archive format (.tgz), uploaded to the CryoLand server and automatically integrated into the CryoLand web interface. The interested user can access the pan-European snow product of the current day in the late afternoon.

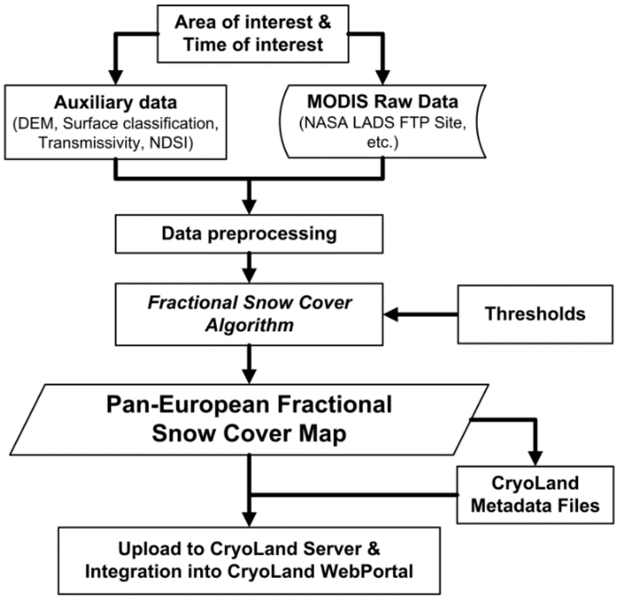

Figure 2.3: Conceptual processing chain for the pan-European fractional snow map.

2.4 *Implementation of the service*

The full processing chain for the generation of the daily pan-European fractional snow cover product based on Terra MODIS data is implemented into ENVEO's in-house developed software system, which is written in C code and runs currently in a Linux environment. Auxiliary maps – like the digital elevation model, the surface classification, the transmissivity map and the NDSI map – have to be prepared according to the spatial requirements of the product before the processing chain can be run. If all required auxiliary data sets are available the processing chain can be executed fully automated.

The automated processing chain starts with searching for new raw data (Collection 6) in near real time on the LANCE-MODIS data system of NASA for the area of interest. The area of interest can be easily changed via an input file. As soon as new data are available for the requested area, the required data sets are automatically downloaded. Beside others, particular modules of ENVEO's software are available for orthorectification, radiometric calibration, topographic correction, generation of cloud masks, and the application of a selected algorithm for the generation of the fractional snow cover map. As soon as the final fractional snow-cover products from the individual scenes are available for the full coverage of the area of interest, a further module is used for generating a composite based on the individual fractional snow cover maps. All modules required for the snow-map generation are linked by Python scripts, which are executed successively and controlled via cron jobs.

When the final pan-European snow product is available the additional files requested for the CryoLand product data set, including at least a preview and associated metadata files are generated based on the raw input data. All data are stored in one compressed archive file, which is uploaded on the CryoLand FTP site and from there integrated into the CryoLand web system. The preparation of the CryoLand specific formats and the generation of the additional files are also executed regularly and controlled via a cron job.

Figure 2.4 shows a conceptual diagram of the pan-European snow service implemented at ENVEO.

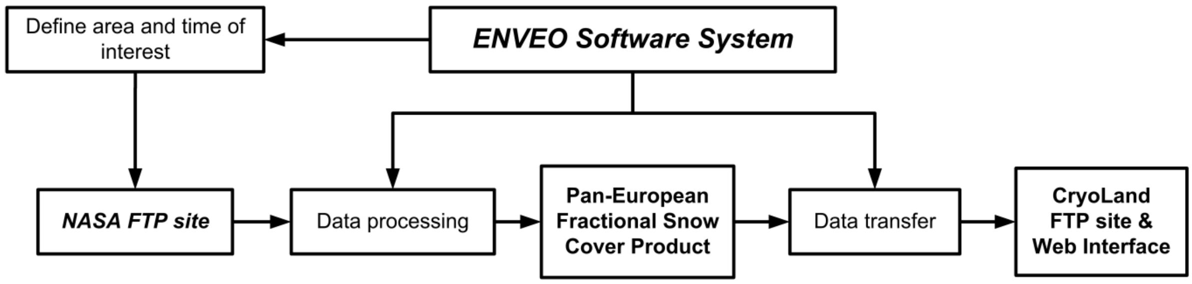

Figure 2.4: Concept of pan-European snow service implemented at ENVEO.

2.5 *Product/service validation*

The product validation results described in the following are derived for the prototype version of the pan-European FSC product. Based on these results the algorithm has been selected for the demo version of the pan-European FSC product.

2.5.1 *Product validation against in situ data*

The product evaluation is carried out in order to find the best algorithm for the pan-European fractional snow map by comparing the FSC from 1) ENVEO-method 2) SCAmod-method and 3) NASA MOD10_L2 fractional product. The FSC from a snow course (average from ~80 observations along the 2-4 km transect) is compared against average FSC from pixels overlaying the ground-projected route of the transect. An RMSE is provided to describe the accuracy of the FSC estimation.

$$RMSE = \sqrt{\frac{1}{N}\sum (FSC_{estimated} - FSC_{reference})^2}$$

The results are shown in Figure 2.5. For each product type, altogether 205 cases were included in the analyses, the majority of them observed at 100% snow cover. Therefore, the RMSE is provided also for fractional snow only (i.e. case where snow course FSC <1). SCAmod gives a lowest RMSE < 0.15 (15%), while the ENVEO method strongly underestimates the FSC with RMSE of 0.36 (36%). Mod10_L2 gives an RMSE between these two, still showing clear underestimation which is in line with results presented in Metsämäki et al. (2012). For NASAmod10_L2, the underestimations at 100% snow cover were expected as it was already reported in Metsämäki et al. (2012) that the FSC-retrieval method behind the product (Salomonson et al., 2004) cannot catch full snow cover in moderate or dense forests. This seems to be the problem with ENVEO method as well.

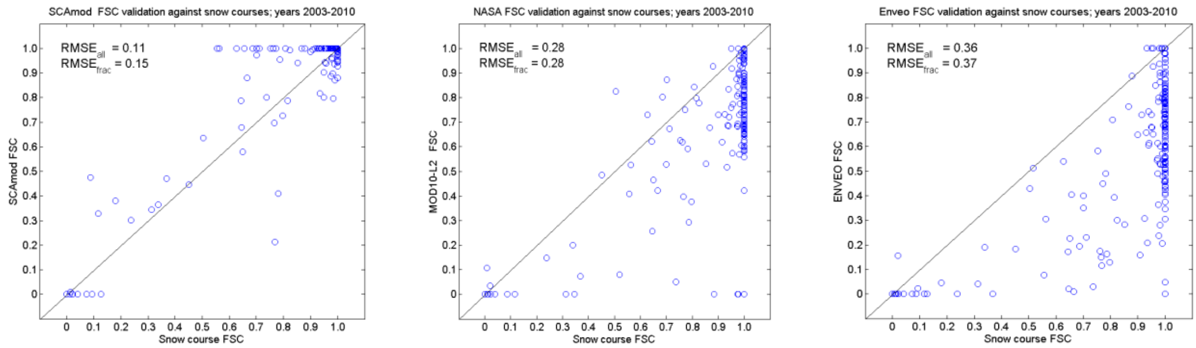

Figure 2.5: Validation against Finnish (SYKE) snow course observations. Left: SCAmod-method; Centre: NASA MOD10_L2 fractional product; Right: ENVEO method.

The performance of FSC estimation is demonstrated also using a priori information on full snow cover conditions. The test scene is from 15 March 2003 over Finnish-Russian border featuring also dense forests. According to weather station observations, the Snow Water Equivalent product and to general climatology, the whole scene area is fully snow covered. Figure 2.6 shows the results: The redder colour, the better result. Grey colour stands for water areas or no-data.

The estimated average scene FSC is lower than 100% for all methods, but SCAmod gives distinctively better results (FSC = 96%) compared to the ENVEO method (FSC = 57% and MOD10_L2 (FSC = 62%).
RMSE is calculated as a deviation from 100%:

$$RMSE = \sqrt{\frac{1}{N}\sum(FSC_{estimated} - 100\%)^2}$$

The obtained RMSE is 59% for ENVEO method, 14% for SCAmod and 50% for MOD10_L2. This result supports the conclusion that ENVEO FSC strongly underestimates the FSC, both in moderate and dense forests (the blue-coloured area in ENVEO product is very dense forest).

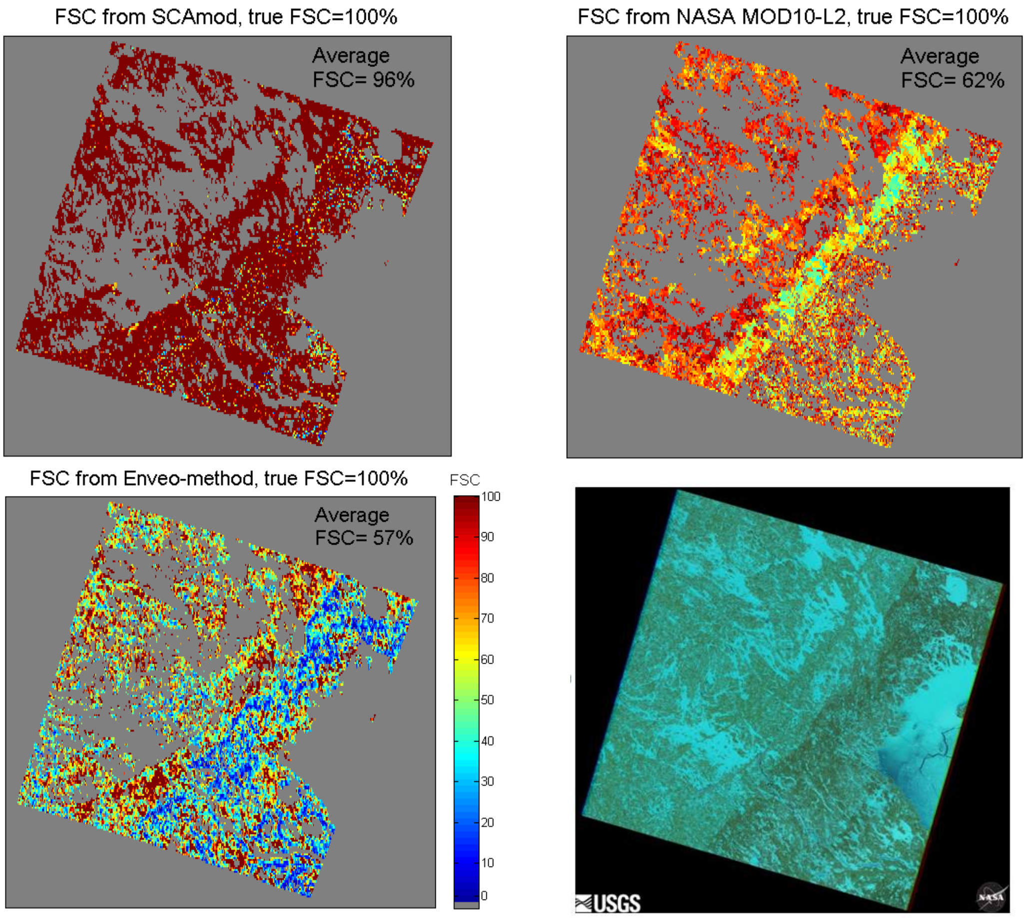

Figure 2.6: Fractional Snow cover-maps against a priori known full snow coverage (FSC=100%) for Finnish-Russia borderline area. Top left: SCAmod; Top right: NASA MOD10_L2 fractional product; Bottom left: ENVEO's spectral un-mixing; Bottom right: Browse-image for TM-scene 186/017, 15 March 2003.

2.5.2 *Product validation against high-resolution data*

Comparison against high-resolution data is carried out using Landsat-TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper+) data providing observations at 25 m spatial resolution and at optical wavelengths suitable for fractional snow detection. The idea is to derive binary (snow / no snow) information for 25 m pixels and then aggregate those into FSC (by averaging binary data) with spatial resolution of 0.01° coinciding with CryoLand FSC product. The binary snow retrieval is based on the approach by (Klein et al., 1998) using NDSI (Normalized Difference Snow Index) and NDVI (Normalized Difference Vegetation Index) as major criteria to decide if pixel is snow or snow-free. After aggregating binary data, the resulting FSC is compared to CryoLand FSC using *two set of metrics: binary and fractional*. Fractional metric is a result of direct pixel-to-pixel comparison of FSC from two sources: for each scene RMSE (Root Mean Square Error).

Binary metrics describe the algorithm's ability to correctly discriminate snow pixels and snow-free pixels. Following the approach by Painter et al. (2009), a pixel is first classified as snow if its FSC exceed 15% (FSC range is 0-100%), otherwise it is classified snow-free. Then a set of three metrics is provided:

- *Recall*: the percentage of true snow pixels correctly predicted.
- *Accuracy*: the ratio of correctly predicted (snow and snow-free) pixels to the total number of pixels
- *Precision*: percentage of correctly identified snow out of all pixels predicted as snow

A set of 13 Landsat-TM/ETM+ scenes from years 2000-2003 in different parts of Europe was selected for comparisons. These represent different landscapes (tundra, steppe, boreal forest) and different stages of snow melt (FSC ranges from nearly zero to 100%). For each TM-scene, the FSC for every cloud-free 0.01° × 0.01° pixel is then compared to FSC from 1) ENVEO method and 2) SCAmod, resulting to fractional metrics. For binary metrics, pixels are classified as snow/no snow using FSC of 15% as a threshold and the binary metrics are calculated. All comparisons are made separately for forests pixel, non-forest pixels and all pixels. An example of FSC comparison for one scene is presented in Figure 2.7. All pixels, i.e. forests and non-forests, are included.

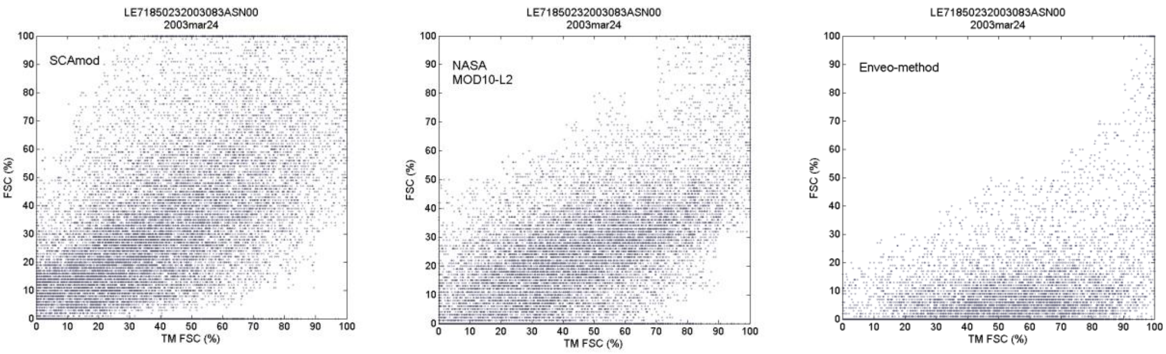

Figure 2.7: Example of direct comparison between TM-FSC and CryoLand FSC. *Left*: FSC from SCAmod, RMSE = 20%. *Centre:* FSC from MOD10_L2, RMSE=22% *Right:* FSC from ENVEO's method (spectral un-mixing), RMSE = 32%.

The results from comparisons for all 13 scenes are presented in the following. The average FSC for each scene is presented in Figure 2.8. It can be seen that the ENVEO method strongly underestimates the areas covered by snow, underestimation being stronger for forests. MOD10_L2 gives slightly lower FSC than SCAmod for most scenes, particularly for forests. Considering that forests cover a significant fraction of the pan-European area, the better performance of SCAmod is of relevance. For the 13 TM scenes, the average forest fraction is 52%, ranging from 34% to 74%.

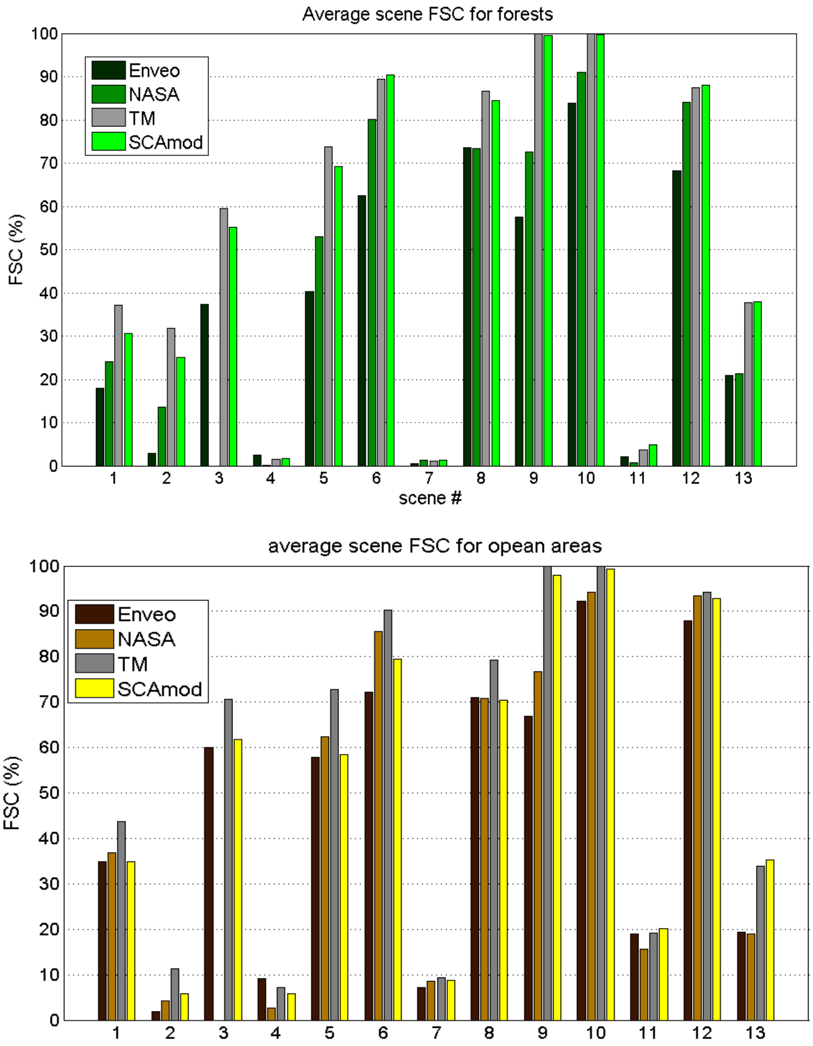

Figure 2.8: Average scene FSC for forest (top) and non-forests (bottom) for ENVEO method and SCAmod-method, with respect to FSC from TM data (MOD10_L2 for scene #3 is missing so far).

The fractional and binary metric are presented Table 2.3. An average from scene-level metrics are shown, scene-level results are listed in Appendix 1. The results clearly indicate that in terms of RMSE, SCAmod is superior to the ENVEO method and also better than MOD10_L2. On average, SCAmod RMSE is below 0.16 both for forest and non-forest pixel, whereas ENVEO's is distinctively higher, particularly for forests. Also MOD10_L2 performs poorer for forests. From *Recall* it can be seen that the ENVEO method as well as MOD10_L2 tend to omit snow both in forests and non-forests. SCAmod performs clearly better, particularly in forest where MOD10_L2 method finds only 65% of snow pixels while SCAmod finds 89% of them. The *Precision*, in turn, is high for ENVEO method and even higher for MOD10_L2. This is because it is false commissions not false omissions that are driving the Precision as the ENVEO method and MOD10_L2 constantly underestimates the snow. There are very few false commissions. In other words, *Precision* should be looked at together with *Recall* so that if only both are high, the product performs well. This is the case with SCAmod.

Table 2.3:
Fractional and binary metrics for comparisons against Landsat TM. The best value is presented with bold.

Measure (%)	SCAmod-method			ENVEO-method			NASA mod10_L2 fractional		
	all	forests	open areas	all	forests	open areas	all	forests	open areas
RMSE	**15.80**	**15.96**	**15.79**	27.91	31.88	23.43	20.01	22.73	17.72
Recall	**94.73**	**89.20**	**89.91**	74.98	66.04	78.33	74.49	65.54	75.56
Precision	92.44	**89.01**	92.58	93.30	88.13	94.06	**96.93**	85.72	**97.64**
Accuracy	**94.94**	**95.10**	**94.73**	88.76	85.62	90.92	91.85	91.15	92.14

The validation of the pan-European fractional snow product is continuously ongoing and extended to further evaluation sites, depending on the availability of reference data.

2.5.3 *Service validation*

The technical validation of the pan-European snow service was continuously done during the development of the service implementation at ENVEO. In a first step, all auxiliary maps are prepared for the area of interest with the required CryoLand formats and projections specified in the Product Design Document (Del. 2.2). The final auxiliary maps were imported into the format of ENVEO's in-house developed software system.

An input file for an already well-tested existing script for downloading raw MODIS data was adapted in order to get data covering the full pan-European area. For downloading the raw data, which needs a total of about 5 GB local disk space per day, a high-speed internet connection is advisable.

ENVEO's software modules for data download, data integration and pre-processing are well tested and used operationally before.

The individual modules of ENVEO's in-house developed software for the processing of fractional snow mapping were upgraded to retrieve optionally products meeting the CryoLand specifications. The individual modules written in C code as well as the Python scripts used for controlling the various commands for an automated processing chain were successively verified, validated and tested using

MODIS data of long-term and rolling archives provided by NASA. The processing chain starts by default automatically several times per day, searching for new raw data and executing the full processing chain if new satellite images are found. The system environment at ENVEO can handle parallel processing of multiple scenes at the same time. The processing chain can also be executed for a selected date or period, for example if reprocessing of one particular date is needed.

As the individual software modules of the processing chain are independent of each other, upgrades or revisions of single software modules, or the development of a new module can be done at any time. Each adapted module can be verified and validated individually, and can be integrated into the executing script controlling the processing chain after successful testing.

For running the pan-European snow service from Terra MODIS data, about 60 GB local disk space is needed per day for executing the processing chain. A RAM of minimum 8 GB is mandatory in order to keep the computational time low and provide the product only a few hours after the final image acquisition.

The validation of the pan-European Fractional Snow Cover Service is summarized in Table 2.4.

Table 2.4:
Service validation summary.

Type	***Comments***
Requirements	Auxiliary data, full ENVEO software package (current Version 2.1.00), high speed internet connection, ~60 GB local disk space, minimum 8 GB RAM
Use Cases	Fractional snow cover mapping from optical satellite imagery
Test Cases	FSC processing from MODIS/Terra of winter 2012/13
Applicable Standards	CryoLand; INSPIRE
Unit Tests	Independent testing of individual software tools for multiple test cases.
Integration Tests	Step by step execution of script controlling the full processing chain for multiple test cases.
System Tests	Multiple executions of the processing chain at the same time and automated product generation running over a full winter period
Acceptance Tests	Output controlling
Processing Performance	Processing chain is automated
Developed by	ENVEO, CryoLand
Service provider	ENVEO
Service status	Operational

3. PAN-EUROPEAN SNOW WATER EQUIVALENT SERVICE

The Finnish Meteorological Institute (FMI) has developed a service for pan-European snow water equivalent products. A SWE product time series covering the period 2011 until present has been produced and is available (http://erdas-apollo.fmi.fi/apollo-client/index.jsp?nocombo=true and http://neso.cryoland.enveo.at/cryoland/cryoclient/). Precursor products have undergone extensive tests and improvements through a series of projects. The most recent effort has taken place in the European Space Agency (ESA) Data User Element (DUE) GlobSnow project aiming at creating a global database of snow parameters for climate research purposes and updating the database regularly.

3.1 *The snow product*

The SWE product is based on the combination of satellite-based microwave radiometer and ground-based weather station data. Nimbus-7 SMMR (1980–1987), DMSP SSM/I (1987 to present) and Aqua AMSR-E are the main data sources. Non-mountainous areas within the pan-European domain are currently covered by the CryoLand implementation of the SWE service. The pan-European domain SWE maps are generated from FMI's Northern Hemisphere (EASE 25 km grid) SWE product by re-projecting to WGS84 lat/lon geodetic projection (EPSG: 4326) and by resampling to 0.1 degree grid.

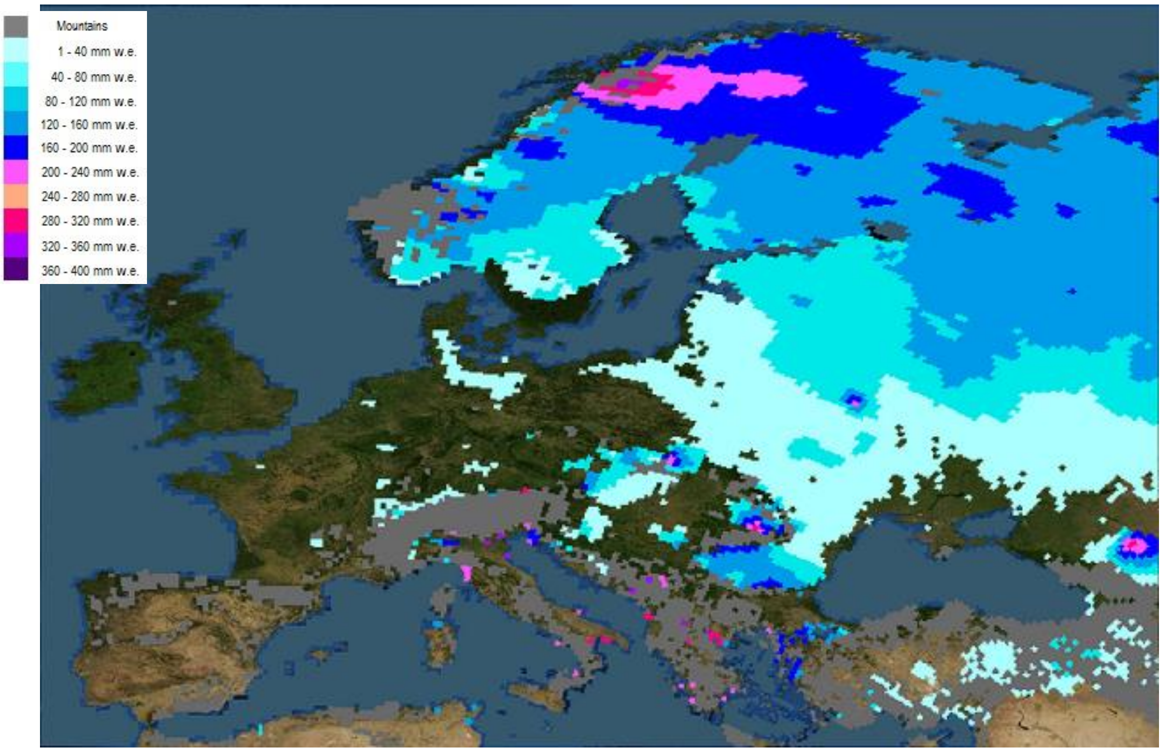

Figure 3.1: CryoLand SWE map example (pan-European domain) for 3 March 2013. Mountainous areas are excluded from the SWE retrieval.

Table 3.1:
Description of the snow water equivalent product.

Parameter	***Specification***
Thematic variable	Snow Water Equivalent (SWE)
Thematic resolution	4% SWE up to 400 mm
Thematic range	[0, 200] SWE
Thematic accuracy	-
Thematic uncertainty estimate	32–43 mm SWE
Spatial coverage	Pan-European Area: 72°N 11°W – 35°N 50°E
Delivery time period	Winter Season: October - June
Temporal frequency	Daily
Spatial resolution	0.1° × 0.1°
Geometric accuracy	< 1 pixel aiming at 0.5 pixel
Projection/Datum	Geographical (lat/lon); WGS84
Sensor	SSMI/S Radiometer Data
File format	GeoTIFF
Developed by	FMI within EC CryoLand
Service provider	FMI
CryoLand priority	1 (primary product)
CryoLand status	Operational

3.2 *The algorithm*

Retrieval of snow water equivalent (SWE) from passive microwave data traditionally relies on direct inversion algorithms relying on an empirically determined relationship between SWE and emitted brightness temperature (e.g. Chang et al., 1987).

The emission measured from a dry snowpack originates largely from the underlying ground, with frequency-dependant scatter occurring in the snowpack. The total scatter is governed by the combined interaction of snow depth, density and grain size (i.e. the scattering particles), as identified by Kelly et al. (2003). Lower frequencies penetrate the snowpack to a larger extent, while scatter increases at higher frequencies. This creates an observable negative spectral gradient between microwave frequencies, which can be used to determine SWE.

Increasing the performance of passive microwave retrieval algorithms by means of data assimilation has been investigated. Assimilation can include other remote sensed data, such as optical or radar imagery, or available ground information. Pulliainen (2006) presents an assimilation technique which weighs passive microwave data driving a semi-empirical radiative transfer model, and prior snow information from ground measurements, with their respective statistical uncertainties. The study indicates that the assimilation technique can address effects of saturation related to high values of SWE, as well as reduce systematic errors related to satellite-only based SWE retrievals. This methodology was further refined and is published along an extensive inter-comparison of different SWE retrieval approaches in Takala et al. (2011).

The processing system applies passive microwave observations and weather station observations collected by ECMWF in an assimilation scheme to produce maps covering all land-surface areas with the exception of mountainous regions and Greenland. 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 retrieval methodology (Pulliainen, 2006) is complemented with a time-series melt-detection algorithm (Takala et al., 2009). The two algorithms are combined to produce snow water equivalent maps incorporated with information on the extent of snow on coarse resolution (25 km × 25 km) grid cells. The SWE estimates are complemented with uncertainty information at a grid-cell level.

Estimates of snow depth (SD) based on emission-model inversion of two frequencies, 18.7 and 36.5 GHz, are first calibrated over EASE-Grid cells with weather station measurements where SD is available. Snow grain size is used in the model as a scalable model input parameter (being determined from the input radiometer and weather station data). These values of grain size are used to construct an interpolated background map of the effective grain size using Kriging, including an estimate of the effective grain size error. The map is then used as input in model inversion over the span of available radiometer observations, providing an estimate of the SD. In the inversion process, the effective grain size in each grid cell is weighed with its respective error estimate. A snow density value is applied to each grid cell to connect SD to SWE. Areas of wet snow are masked according to observed brightness temperature values using an empirical equation, as model inversion of SD/SWE over areas of wet snow is not feasible due to the saturated brightness temperature response. The weather-station observations of SD are further interpolated to provide a crude estimate of the SD (or SWE) background. The SWE estimate map and SD map from weather-station observations are combined using a Bayesian spatial assimilation approach to provide the final SWE estimates.

The snow emission model applied is the semi-empirical HUT snow emission model (Pulliainen et al., 1999). The model calculates the brightness temperature from a single layer homogenous snowpack covering frozen ground in the frequency range of 11 to 94 GHz. Input parameters of the model include snowpack depth, density, effective grain size, snow volumetric moisture and temperature. There are separate modules to account for ground emission and the effect of vegetation and atmosphere. The model has been validated against tower-based and airborne reference radiometer observations (see e.g. Pulliainen et al., 1999; Lemmetyinen et al., 2009).

The detection of the snow extent is based on a time-series melt-detection approach described in (Takala et al., 2009). The algorithm can be used to determine the onset of the snowmelt season using the available radiometer observations on a hemispherical scale covering the product time-series up to present day. The methodology has been calibrated against a vast pan-Arctic dataset covering most of the land areas of northern Eurasia between the years 1979 to 2001. The areas that are identified as snow covered with the melt detection algorithm, but for which a SWE estimate is not produced, are given a marginal SWE value (0.001 mm) in the final SWE product. This information can be used to determine the extent of snow cover. The areas with a SWE value of 0 mm are bare ground, and areas with SWE of 0.001 mm or above are snow covered.

3.3 *The processing chain*

A flowchart of the processing chain is presented Figure 3.2. There are four primary steps to the retrieval scheme:

- *Estimating the snow depth field*: SD observations from synoptic weather stations are obtained for the northern hemisphere from ECMWF. The stations located in mountainous areas are filtered out, as are the deepest 1.5% of reported snow depth values in order to avoid spurious or erroneous deep snow observations. Once this filtering is performed, an '*observed SD'* field is produced from the synoptic weather station observations by ordinary Kriging interpolation to 5 km spatial resolution.
- *Forward modelling of brightness temperature*: The available synoptic weather station measurements of SD are used as input to forward model simulations of brightness temperature (T_B) using the single-layer HUT snow emission model. Additionally, the approach takes into account atmospheric effects to space-borne observed T_B. The model is fit to spaceborne observed T_B values at the locations of weather stations by optimizing the value of effective snow grain size.
- *Estimating effective snow grain size*: A spatially continuous background field of the effective snow grain size (including a variance field) is interpolated by Kriging from the snow grain size estimates produced for the weather station locations in the previous step
- *Assimilating snow depth*: A map of spatially continuous '*assimilated SD*' is produced through forward T_b simulations with the HUT model using the interpolated effective grain size produced and land cover information. The simulations are compared via a cost function at each grid cell with spaceborne radiometer measurements. The assimilation adaptively weighs the space-borne brightness temperature observations and the '*observed SD*' field from the first step to estimate a final SD and an estimate of statistical uncertainty (in the form of a variance) on a grid-cell basis.

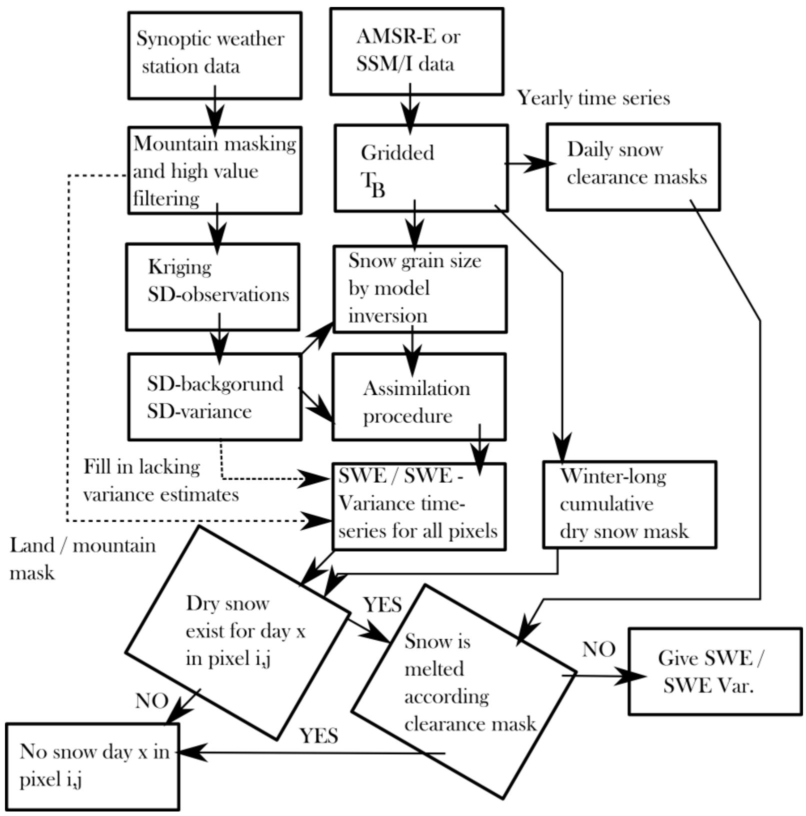

Figure 3.2: Processing chain SWE retrieval.

3.4 *Implementation of the service*

There are six primary steps in the implementation of the Northern Hemisphere SWE service:

- *FMI Pre-processing*: Snow depth observations from weather stations across the Northern Hemisphere provided by ECMWF and stored in FMI's climate database are used to interpolate spatially continuous HDF5-grids. These grids are transferred via FTP protocol to FMI's snowflake.fmi.fi server with an in-house built program written in C.
- *FTP Cronjob / Conversion to EASE Grid*: The latest SSMI/S images are retrieved from MeteoAM's FTP server and converted from swath-geometry to EASE-grids by an in-house built program written in C. The current swath-geometry conversion program will in the near future be replaced with PyTROLL (Python-based data processing) modules.
- *Conversion to CSV*: A MatLab script is used to convert the snow-depth HDF5 grids to CSV-formatted matrices, which in turn are used in the snow-depth assimilation scheme.
- *Calculate dry snow mask and snow-melt mask*: Areas of wet snow, i.e. areas of melting snow, are masked according to observed brightness-temperature values using an empirical equation based on Takala et al. (2009). Dry-snow areas are determined through a cumulative process whereby the masked area is increased incrementally for each time step from the beginning of

the snow season. In contrast, during the spring season, the snow melt mask is used to clip the dry snow masked areas. These masking procedures are handled with a MatLab script.

- *Processing / Post-Processing*: A series of MatLab scripts are used to compile the final SWE product. Brightness-temperature derived SWE-estimate grids, interpolated continuous snow depth, CSV matrices and the dry/wet snow masks are combined to form continuous SWE-estimate grids and SWE variance grids for the Northern Hemisphere.
- *Packaging and FTP Upload*: Raw binary MatLab format SWE data are converted to NetCDF grids. Metadata is provided for each grid with an associated ASCII formatted text file. These files are packed (.gzip) and uploaded to the litdb.fmi.fi long term file storage system with an in-house built Unix-bach script.

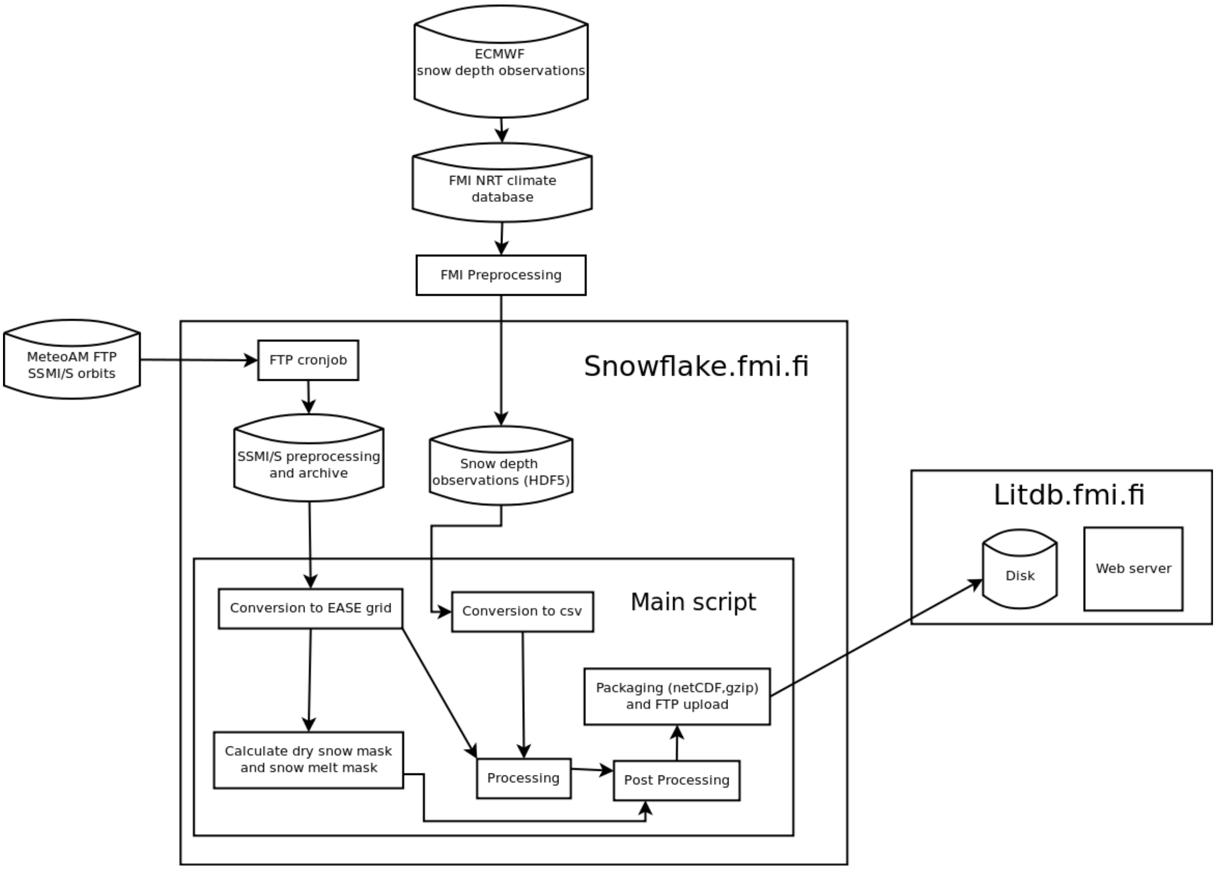

Figure 3.3: System-level flowchart of the Northern Hemisphere SWE service implementation.

For the pan-European CryoLand SWE service, an operational NRT service has been implemented. The SWE product is packaged according to CryoLand SWE specifications. This package is delivered in parallel via the EOX server and FMI Erdas Apollo Service. A compressed package (tar.gz) is uploaded to the EOX FTP server geoportal directory, which is then added to the CryoLand geoportal.

There are five primary steps in the service production chain:

- *Re-projection:* The Northern Hemispheric 25 km EASE-grid SWE maps are re-projected to geodetic Lat/Lon WGS-84 grid using nearest-neighbour interpolation to preserve the original data accuracy as far as possible. This task is handled with the Geospatial Data Abstraction Library (GDAL) calls within a Unix-bash script.
- *Re-sampling and Clipping:* The re-projected grids are clipped to correspond to the CryoLand SWE service domain and resampled to a resolution of 0.1 degrees (approx. 10 km) using nearest-neighbour interpolation. Resampling and clipping is handled by SAGA (System for Automated Geoscientific Analysis) GIS library modules controlled by Unix-bash script.
- *Reclassification:* The resampled grid values are reclassified according to CryoLand SWE service encoding. Reclassification of absolute SWE values to CryoLand SWE service encoding is similarly handled by utilizing SAGA GIS library modules within a Unix-bash script.
- *Product packing:* Service-product packages containing a data file, XML metadata files, a snap-shot file and a product-generation text file are generated based on input from the SWE-retrieval processing chain. This task is handled with an in-house post-processing Unix-bash script.
- *Uploading:* Completed packages are simultaneously uploaded to FMI's Erdas Apollo Map server and EOX server. Compressed packages (tar.gz) are uploaded to the EOX FTP-server geoportal directory, which has automated routines to upload the product and associated metadata to the CryoLand geoportal. Data uploading is also handled as part of the post-processing Unix-script.

3.5 *Product/service validation*

The SWE algorithm validation reported within Takala et al. (2011) evaluate the GlobSnow SWE data record 1979–2010 with distributed snow transect data collected from the former Soviet Union and Russia covering the period 1979–2009. The reference dataset contains snow path measurements carried out within 517 different snow-path locations, ranging from 35° to 85° northern latitude and 14° to 179° of eastern longitude. This vast dataset (285,300 samples) is compared against the SWE data acquired for the same period and gives a thorough view on the algorithm performance in different seasonal and geographical domains.

The comparison shows that the RMSE for SWE values range between 0 and 150 mm for the years 1979–2009 (consisting of 144,959 samples) was 32.1 mm. The bias for the same dataset was +8.5 mm. The use of all the samples of the full data set (all SWE values, consisting of 161,684 samples) gave a bias of +1.1 mm and RMSE of 43.4 mm (both values represent a significant improvement over the alternative evaluated algorithms). Also, the RMSE for the different years show a rather consistent behaviour with no significantly outlying years.

The SWE processing and service chain consists of several in-house built programs and scripts which perform format and geographic reference system conversions, file transfers and derivation of new variables from input data. These processes are handled by two primary scripts; 1 for producing the Northern Hemisphere SWE grids in EASE-grid, and 1 for the production of CryoLand formatted SWE grids for the pan-European domain. In the past, the outputs and inputs of all secondary processing programs and scripts have been subjected to periodic visual inspection by the product developers. For the coming winter of 2013-2014 and beyond, the SWE product will be subjected to regular, daily, visual inspection by dedicated FMI NRT operators. As the CryoLand SWE service has only been online since the 23 December 2012, full-fledged automatic or semi-automatic operational service validation/notifications of possible service break downs or issues regarding product validity have proven to be difficult to implement. In the future however, automatic (or at least semi-automatic) service validation routines will be developed and implemented as soon as more experience on the types of errors that usually can occur is gained.

4. CONCLUSIONS

The current pan-European snow products, developed and validated for the *CryoLand* service, were presented. This includes a description of the products (specifications), algorithms and processing chains available from the project partners. These pan-European snow services are available through the *CryoLand* service.

The project has successfully developed operational pan-European snow services for fractional snow cover and snow water equivalent. Fractional snow cover is based on optical sensors, while snow water equivalent is based on passive microwave radiometers. These two services have been tested and are delivered to users in near-real time since the spring season 2013. A time series of Fractional Snow Cover products from archived optical satellite data since winter season 2000/01 was generated and is available from the CryoLand GeoPortal.

This page is intentionally left blank.

5. REFERENCES

Chang, A. T. C., J. L. Foster, and Dorothy K. Hall, 1987. Nimbus-7 Derived Global Snow Cover Parameters. *Annals of Glaciology* 9: 39-44.

Crane, R.G. & Anderson, M.R., 1984. Satellite discrimination of snow/cloud surfaces. *International Journal of Remote Sensing*, 5(1), pp.213–223. Available at: http://dx.doi.org/10.1080/01431168408948799.

Hall, D.K. et al., 2002. MODIS snow-cover products. *Remote Sensing of Environment*, 83, pp.181–194.

Jarvis, A. et al., 2008. Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database. Available at: http://srtm.csi.cgiar.org.

Kelly, R., A. Chang, L.Tsang, and J. Foster, 2003. A prototype AMSR-E global snow area and snow depth algorithm. *IEEE Transactions on Geoscience and Remote Sensing*. 41(2): 230-242.

Lemmetyinen, J., C. Derksen, J. Pulliainen, W. Strapp, P. Toose, A. Walker, S. Tauriainen, J. Pihlflyckt, J.-P. Kärnä, and M. T. Hallikainen, 2009. A comparison of airborne microwave brightness temperatures and snowpack properties across the boreal forests of Finland and western Canada. IEEE Transactions on Geoscience and Remote Sensing, 47: 965–978, 2009.

Metsämäki, S. et al., 2005. A feasible method for fractional snow cover mapping in boreal zone based on a reflectance model. *Remote Sensing of Environment*, 95(1), pp.77–95.

Metsämäki, S. et al., 2012. An optical reflectance model-based method for fractional snow cover mapping applicable to continental scale. *Remote Sensing of Environment*, 123, pp.508–521. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0034425712001794 [Accessed November 6, 2012].

Metsämäki, S. et al., 2015. Introduction to GlobSnow Snow Extent products with considerations for accuracy assessment. *Remote Sensing of Environment*, 156, pp.96–108. Available at: http://dx.doi.org/10.1016/j.rse.2014.09.018.

Painter, T. H., Rittger, K., McKenzie, C., Slaughter, P., Davis, R. E., & Dozier, J. (2009). Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. Remote Sensing of Environment, 113, 868-879.

Pulliainen, J, 2006. Mapping of snow water equivalent and snow depth in boreal and sub-arctic zones by assimilating space-borne microwave radiometer data and ground-based observations. *Remote Sens. Environ.*, vol. 101, pp. 257-269, 2006.

Pulliainen, J., J. Grandell, and M. T. Hallikainen, 1999. HUT Snow Emission Model and its Applicability to Snow Water Equivalent Retrieval. IEEE Transactions on Geoscience and Remote Sensing. 37: 1378-1390, 1999.

Takala, M., Pulliainen, J., Metsämäki, S. and Koskinen, J., 2009. Detection of Snowmelt Using Spaceborne Microwave Radiometer Data in Eurasia from 1979 to 2007. IEEE Transactions on Geoscience and Remote Sensing, vol. 47, no. 9, pp. 2996-3007.

Takala, M., Luojus, K., Pulliainen, J., Derksen, C., Lemmetyinen, J., Kärnä, J.-P., Koskinen, J. and Bojkov, B., 2011. Estimating northern hemisphere snow water equivalent for climate research through assimilation of space-borne radiometer data and ground-based measurements", Remote Sensing of Environment (2011), doi:10.1016/j.rse.2011.08.014.

APPENDIX: GUIDELINES FOR THE GENERATION OF REFERENCE ("GROUND TRUTH") SNOW MAPS

The pan-European snow maps to be evaluated (algorithm comparison) or validated (product validation) will be compared pixel-by-pixel with the reference ("ground truth") snow maps based on data from high resolution (HR) or very high resolution (VHR) sensors. Therefore, the geometry, coding and procedures for inclusion of other thematic data (like clouds, water bodies and urban area) have to result in equivalent product characteristics. The guidelines below are to assist that.

The specification of the pan-European product is:

- Domain: 35°N-72°N 11°W-50°E
- Projection: LatLon / WGS84
- Pixel size: 0.01° × 0.01° and 0.0025° × 0.0025° (i.e., product in two versions)
- Grid position: coordinates refer to the upper left pixel corners, not the pixel centre
- File format: GeoTIFF

Procedure:

1. Based on the HR or VHR data, classify into "snow", "no snow", "clouds" (including cloud shadows), "dense forest" (coniferous forest so dense that it cannot be determined or inferred whether the ground is snow covered or not) and "unclassified" (like cast shadows where no classification could be done). Procedures followed for the classification, including exception handling and tailoring, are to be documented. (Classification guidelines are not within the scope of this document.)
2. The resulting snow map is archived (for reference) in the geometry applied for the classification.
3. The resulting snow map is transformed to geographical coordinates (lat/lon) with a spatial resolution corresponding approximately to the original full resolution.
4. Water bodies (freshwater), ocean and urban areas (from common CryoLand masks) are mapped into the snow map. If the mask resolution does not correspond, pixels overlapping fractions of the mask are set to the mask value (conservative approach masking out all pixels fully or partly affected by mask values).
5. The snow map is then aggregated to the pan-European product grids (in two versions corresponding to 0.01° and 0.0025° grid resolution). If a product grid cell corresponds to "snow" and "no-snow" pixels only, the average snow cover is calculated (number of "snow" pixels divided by the total number of pixels within the grid cell). The grid cell is assigned the

corresponding fractional snow cover (FSC) value (in the range 0-100%). Otherwise, if at least one high-resolution pixel is of the other classes (“cloud”, “dense forest”, “unclassified”, “water”, “ocean” or “urban”), the product cell is assigned to the dominating other class (if all are equal in number, it is assigned the value of “unclassified”). For border pixels where the grid cell in the product is partly outside the domain of the high-resolution snow map, the grid value is set to “outside area of interest”.

The class values are to follow the CryoLand standards as given in the table below.

Class	**Value**
Snow	210
Snow free	50
FSC	100-200
Cloud	30
Unclassified	255
Outside area of interest	0
Water body*	22 or 21
Ocean	20
Urban	90
Dense forest	81

*) See explanation below.

Note that coordinates are specified to refer to the upper left pixel corners, not the pixel centre. If your software tools are handling pixel centre coordinates only, this has to be notified such that it can be compensated for when performing the evaluation and validation analysis (by shifting the coordinates corresponding to 0.5 grid cell).

ENVEO has prepared masks for water and urban areas for the pan-European area with 0.0025° × 0.0025° pixel size based on Corine (V18, 2016) and GlobCover (2009) data. The mask coding follows in general the definitions of the Product Design Document (D2.2). But we had to make a compromise: rivers are only coded as “22” where Corine data are available, as GlobCover does not differentiate between lakes and rivers, for all areas outside the Corine coverage lakes and rivers are both coded as “21”.

The VHR snow maps have to be delivered to the CryoLand FTP Server. The snow maps are needed with original pixel size of the VHR image (e.g. 0.00025 deg for SPOT-5), and with the two aggregated pixel sizes, 0.01 deg and 0.0025 deg.