EUMETSAT Satellite Application Facility on
Support to Operational Hydrology and Water Management

Product Validation Report (PVR-12) for product H12 (SN-OBS-3)

Effective snow cover by VIS/IR radiometry

Reference Number:	SAF/HSAF/PVR-12
Issue/Revision Index:	1.2
Last Change:	31 October 2012
About this document	This Document has been prepared by the Product Validation Cluster Leader, with the support of the Project Management Team and of the Validation and Development Teams of the Snow Cluster

DOCUMENT CHANGE RECORD

Issue / Revision	Date	Description
1.0	16/01/2012	Baseline version prepared for ORR1 Part 3.
1.1	31/05/2012	Updated release for CDOP2 ORR1 Part3 Close-out: Correction of editorial errors (RID12)
1.2	31/10/2012	Version delivered for ORR1 Part 3 close out, added Section 6.4.

Index

List of tables

List of figures

1 The EUMETSAT Satellite Application Facilities and H-SAF

The "*EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF)*" is part of the distributed application ground segment of the "*European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)*". The application ground segment consists of a "*Central Application Facility (CAF)*" and a network of eight "*Satellite Application Facilities (SAFs)*" dedicated to development and operational activities to provide satellite-derived data to support specific user communities. See next figure.

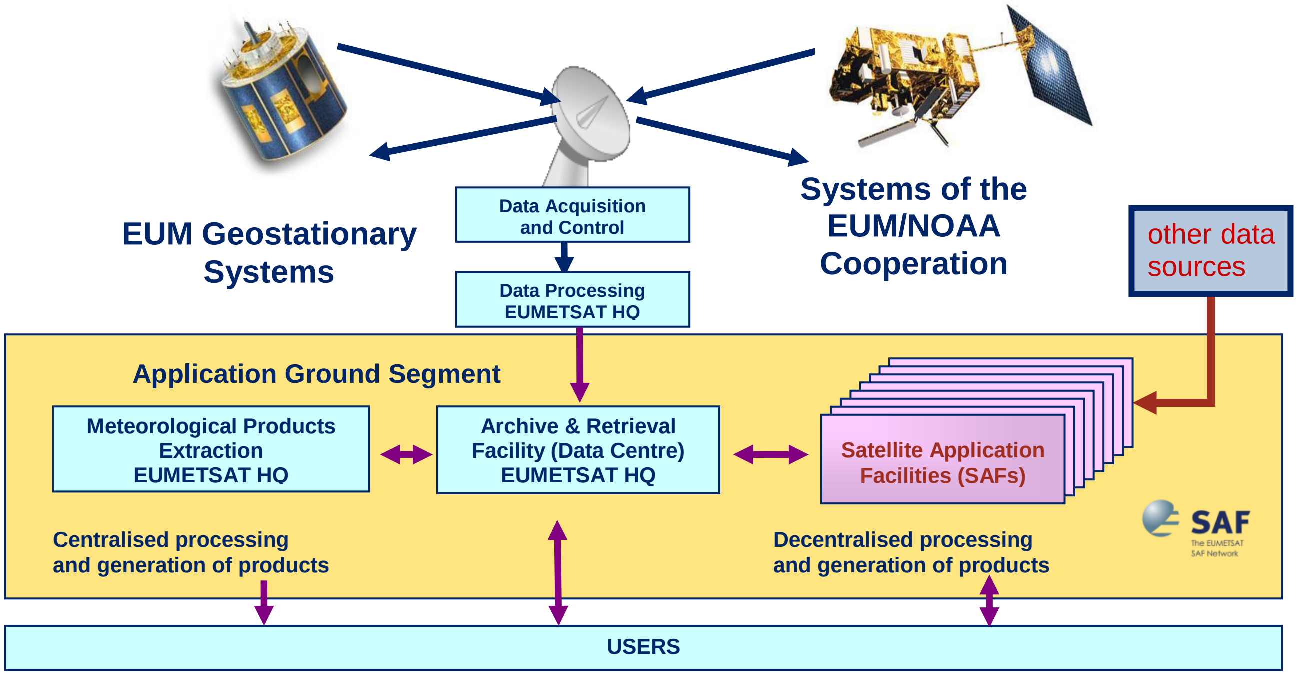


Figure 1 Conceptual scheme of the EUMETSAT application ground segment

Next figure reminds the current composition of the EUMETSAT SAF network (in order of establishment).

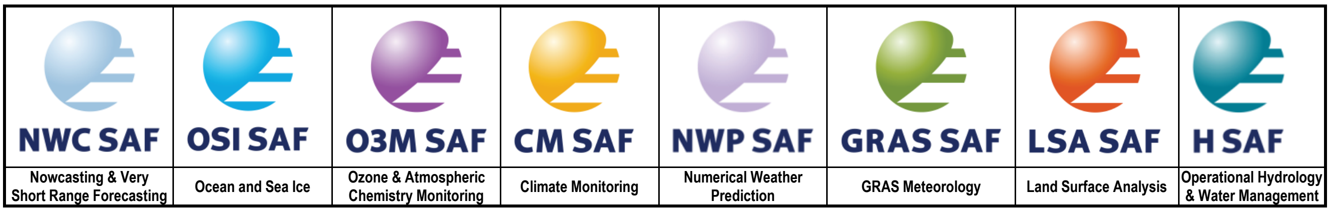


Figure 2 Current composition of the EUMETSAT SAF network (in order of establishment)

The H-SAF was established by the EUMETSAT Council on 3 July 2005; its Development Phase started on 1st September 2005 and ended on 31 August 2010. The SAF is now in its first Continuous Development and Operations Phase (CDOP) which started on 28 September 2010 and will end on 28 February 2012 The list of H-SAF products is shown in the next table.

Acronym	Identifier	Name
PR-OBS-1	H-01	Precipitation rate at ground by MW conical scanners (with indication of phase)
PR-OBS-2	H-02	Precipitation rate at ground by MW cross-track scanners (with indication of phase)

Acronym	Identifier	Name
PR-OBS-3	H-03	Precipitation rate at ground by GEO/IR supported by LEO/MW
PR-OBS-4	H-04	Precipitation rate at ground by LEO/MW supported by GEO/IR (with flag for phase)
PR-OBS-5	H-05	Accumulated precipitation at ground by blended MW and IR
PR-OBS-6	H-15	Blended SEVIRI Convection area/ LEO MW Convective Precipitation
PR-ASS-1	H-06	Instantaneous and accumulated precipitation at ground computed by a NWP model
SM-OBS-2	H-08	Small-scale surface soil moisture by radar scatterometer
SM-OBS-3	H-16	Large-scale surface soil moisture by radar scatterometer
SM-DAS-2	H-14	Soil Moisture profile index in the roots region by scatterometer assimilation method
SN-OBS-1	H-10	Snow detection (snow mask) by VIS/IR radiometry
SN-OBS-2	H-11	Snow status (dry/wet) by MW radiometry
SN-OBS-3	H-12	Effective snow cover by VIS/IR radiometry
SN-OBS-4	H-13	Snow water equivalent by MW radiometry

Table 1 H-SAF Product List

2 Introduction to product SN-OBS-3

2.1 Sensing principle

Product SN-OBS-3 (*Effective snow cover by VIS/IR radiometry*) is based on multi-channel analysis of the AVHRR instrument onboard NOAA and MetOp satellites. The AVHRR radiometer has an IFOV of 1.1 x 1.1 km^2 at nadir degrading to ~ 2 x 6 km^2 at the edge of the 2900 km cross-track swath. Computing fractional cover would in principle require segmenting the image in arrays of pixels (typically ~ 32 x 32) and counting those classifies as snow. This would lead to unacceptable product resolution. For H-SAF, fractional cover is generated at pixel resolution, by exploiting the brightness intensity that is the convolution of the snow signal (highest) and the fraction of snow within the pixel ("effective" cover").

The retrieval algorithm is somewhat different for flat or forested area and for mountainous regions. SN-OBS-3 is generated in Finland by FMI and in Turkey by TSMS. The products from FMI and from TSMS both cover the full H-SAF area, but thereafter are merged at FMI by blending the information on flat/forested areas from the FMI product and that one on mountainous areas from the TSMS product, according to the mask shown in next figure:

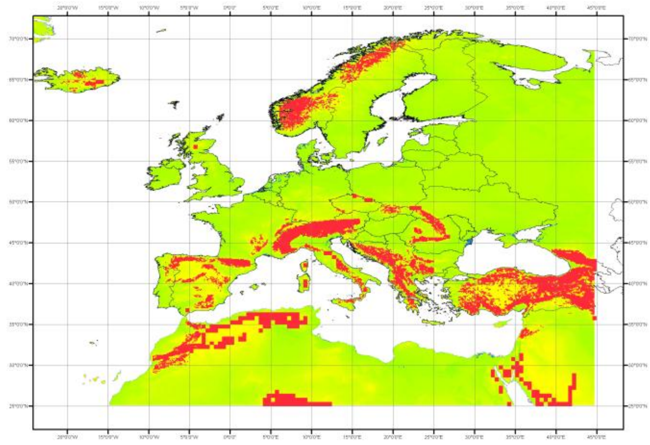


Figure 3 Mask flat/forested versus mountainous regions

The observing cycle of the complex of NOAA and MetOp satellites over Europe is about 3 h. For a single satellite pass, several areas in the scene would provide no useful measurements because of clouds. Therefore, the complex of passes is multi-temporally analysed to search for time instants of cloud-free conditions in a given time interval (e.g., 24 h). However, since short-wave channels play an essential role in the retrieval algorithm, the useful range of hours is in daylight.

For more information, please refer to the Products User Manual (specifically, volume PUM-12).

2.2 Algorithm principle

The baseline algorithm for SN-OBS-3 processing is described in ATDD-12. Only essential elements are highlighted here.

Next chart illustrates the flow chart of the SN-OBS-3 processing chain, valid for flat/forested areas, but also significant of mountainous areas. The offline activity shows the parts consisting of semi-static databases. The forest canopy obscuring the full visibility to the ground is accounted for by applying certain *a priori* “transmissivity” information, that is pre-estimated by means of a high-resolution instrument (MODIS on EOS Terra and Aqua) ensuring high probability of cloud-free pixels with homogeneous dry snow. Snow cover results are added in the effective snow cover time series database for use in mosaic processing snow cover area maps (SCA) from different areas, if needed. The transmissivity map is essential input to the SCA-model, and has to be generated from reflectance data acquired at full dry snow cover conditions for each unit-area of the product. The algorithm for mountainous areas introduces a number of corrections for topographic effects and sun elevation angle.

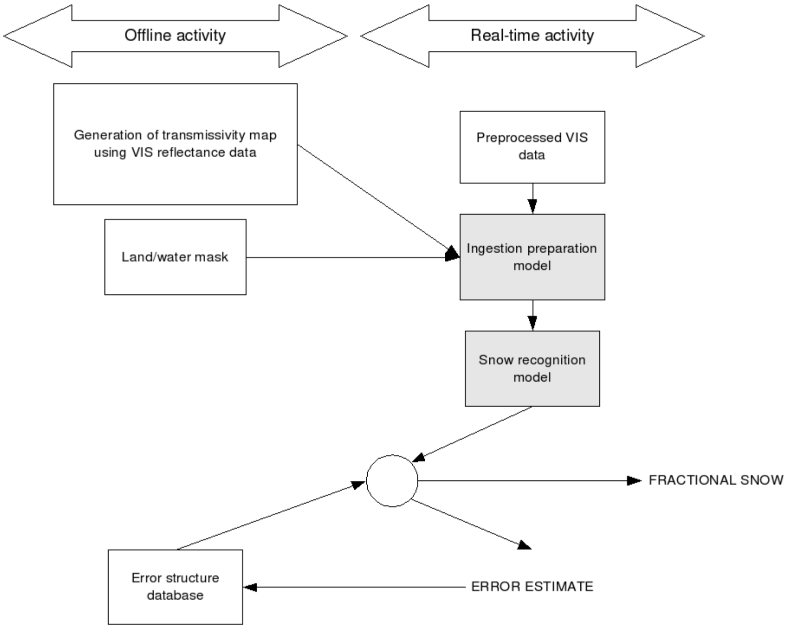


Figure 4 Snow covered area generation chain for flat/forested areas

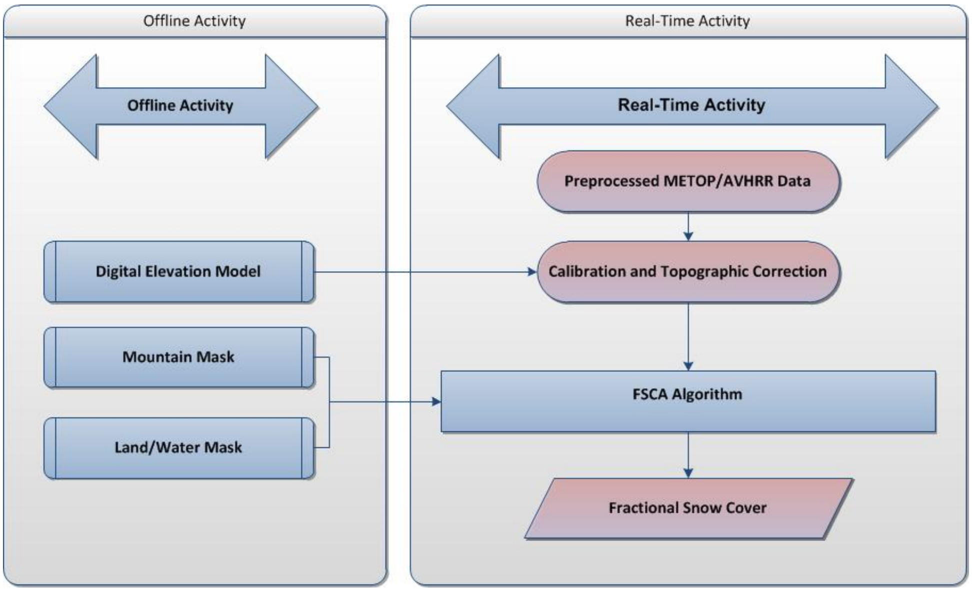


Figure 5 Snow covered area generation chain for mountainous areas

2.3 Main operational characteristics

The operational characteristics of SN-OBS-3 are discussed in PUM-12. Here are the main highlights.

__The horizontal resolution (Δx)__ descends from the instrument Instantaneous Field of View (*IFOV*), the sampling distance (*pixel*), the Modulation Transfer Function (*MTF*) and the number of pixels to co-process for filtering out disturbing factors (e.g. clouds) or improving accuracy. The average IFOV of AVHRR is ~ 2 km. Sampling is made at 0.01-degree intervals, i.e. ~ 1 km intervals, Conclusion:

- resolution Δx ~ 2 km - sampling distance: ~ 1 km.

The *observing cycle (Δt)*. Although the complex of NOAA and MetOp satellites and the 2900 km instrument swath provide global coverage each ~ 3 hour, in order to collect as many cloud-free pixels as possible, multi-temporal analysis over 24 hours is performed. Thus:

- observing cycle: Δt = 24 h.

The *timeliness (δ)* is defined as the time between observation taking and product available at the user site assuming a defined dissemination mean. For a product resulting from multi-temporal analysis disseminated at a fixed time of the day, the time of observation may change pixel by pixel (some pixel may have been cloud-free early in the time window, e.g. in the early morning, thus up to 12-h old at the time of dissemination; some very recently, just before product dissemination in the late afternoon). The average timeliness is therefore:

- timeliness δ ~ 6 h.

The *accuracy (RMS)* is the convolution of several measurement features (random error, bias, sensitivity, precision, …). To simplify matters, it is generally agreed to quote the root-mean-square difference [observed - true values]. The accuracy of a satellite-derived product descends from the strength of the physical principle linking the satellite observation to the natural process determining the parameter. It is difficult to be estimated *a-priori*: it is generally evaluated *a-posteriori* by means of the validation activity.

3 Validation strategy, methods and tools

3.1 Validation team and work plan

To evaluate the satellite precipitation product accuracy a Validation Group has been established from the beginning of the Validation Phase and enlarged in the last CDOP-1 phase. The Snow Product Validation Group (SVG) is composed of experts from the National Meteorological and Hydrological Institutes of Belgium, Bulgaria, Finland, Italy, Poland, and Turkey (figure below). Hydrologists, meteorologists, and precipitation ground data experts, coming from these countries are involved in the product validation activities (table below).

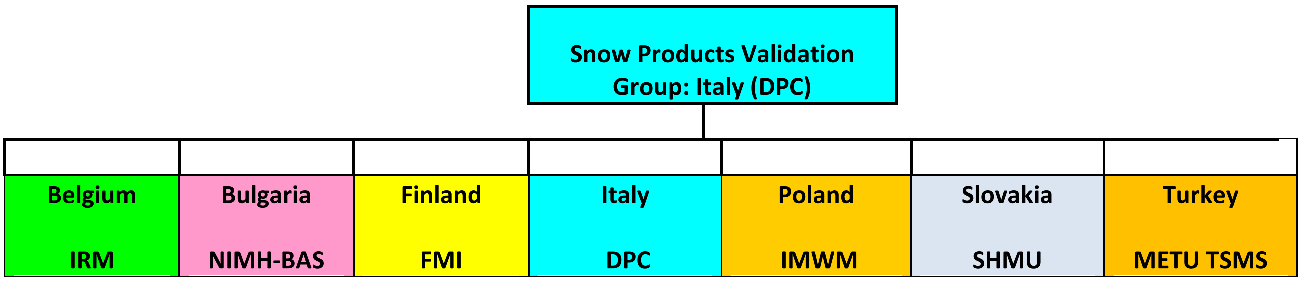


Figure 6 Structure of the Snow products validation team

Reference person	Institute	Country	Email address
Silvia Puca (Leader)	Dipartimento Protezione Civile (DPC)	Italy	silvia.puca@protezionecivile.it
Mario Barbani	Dipartimento Protezione Civile (DPC)	Italy	mario.barbani@protezionecivile.it
Gianfranco Vulpiani	Dipartimento Protezione Civile (DPC)	Italy	gianfranco.vulpiani@protezionecivile.it
Emmanuel Roulin	Institut Royal Météorologique (IRM)	Belgium	Emmanuel.Roulin@oma.be

Angelo Rinollo	Institut Royal Météorologique (IRM)	Belgium	angelo.rinollo@oma.be
Nadejda Petkova	National Institute of Meteorology and Hydrology Bulgarian Academy of Sciences (NIMH-BAS)	Bulgaria	nadejda.petkova@meteo.bg
Hristo Hristov	National Institute of Meteorology and Hydrology Bulgarian Academy of Sciences (NIMH-BAS)	Bulgaria	hristo.hristov@meteo.bg
Panu Lahtinen	Finnish Meteorological Institute (FMI)	Finland	panu.lahtinen@fmi.fi
Bozena Lapeta	Institute of Meteorology and Water Management (IMWM)	Poland	Bozena.Lapeta@imgw.pl
Monika Pajek	Institute of Meteorology and Water Management (IMWM)	Poland	Monika.Pajek@imgw.pl
Pawel Przeniczny	Institute of Meteorology and Water Management (IMWM)	Poland	pawel.przeniczny@imgw.pl
Ján Kaňák	Slovenský Hydrometeorologický Ústav (SHMÚ)	Slovakia	jan.kanak@shmu.sk
Aydin Erturk	Turkish State Meteorological Service (TSMS)	Turkey	agerturk@dmi.gov.tr
Ibrahim Sonmez	Turkish State Meteorological Service (TSMS)	Turkey	isonmez@dmi.gov.tr
Serdar Surer	Middle East Technical University (METU)	Turkey	serdarsurer@gmail.com
Zuhal Akyurek	Middle East Technical University (METU)	Turkey	zakyurek@metu.edu.tr

Table 2 Validation team for H-SAF snow products

The Snow products validation programme started soon after the H-SAF Requirements Review (26-27 April 2006). The first activity was to lay down the Validation plan, which was finalised as first draft early as 30 September 2006. After the first Workshop, other ones followed, at least one per year to exchange experiences, problem solutions and discuss possible improvement of the validation methodologies. The results of the Snow Validation Programme are reported in this Product Validation Report (PVR). A snow product validation section of the H-SAF web page is under development. This validation web section will be continuously updated with the last validation results and studies coming from the Snow Product Validation Group (SPVG).

In the last Validation Workshop held in Antalya, 1-2 December 2010 it has been decided to introduce several Working Groups (WG), to solve specific items of validation procedure and to develop software used by all members of the validation cluster. The coordinators and the participants of the working groups are members of the SPVG or external experts of the institutes involved in the validation activities. The first results obtained by the Working Groups are here reported.

3.2 Validation objects and problems

The products validation activity has to serve multiple purposes:

- to provide input to the product developers for improving calibration for better quality of baseline products, and for guidance in the development of more advanced products;
- to characterise the product error structure in order to enable the Hydrological validation programme to appropriately use the data;
- to provide information on product error to accompany the product distribution in an open environment, after the initial phase of distribution limited to the so-called “beta users”.

Validation of snow observation from space is a hard work, especially because ground systems are essentially based on in-field measurements, very sparse. Comparison with results of numerical models obviously suffer of the limited skill of NWP in predicting snow parameters (a very downstream product that passes through quantitative precipitation forecast, that certainly is not the most accurate product of NWP). The validation results are sensitive to the climatic situation and the status of soil.

During the Development phase some main problems have been pointed out. First of all to have a wide validation with the involvement of several countries. Secondly to define a common validation methodology and to develop the software for all steps of this validation procedure; software available to all the members of the SPVG. The Snow Validation workshop hosted by Turkish State Meteorological Service (TSMS) in Antalya, 1-2 December 2010, gave the opportunity to organize a wider validation inside the H-SAF and to set up working groups for defining the validation procedures. A first simple procedure to validate H11 inside the SPVG has been identified by WG-1 (annex 1). In this document all the main steps and necessary information to perform the H11 validation are reported. The document has been written by the Polish team, and it has been shared and accepted by all the members of the SPVG. The Finish team has developed the related software (See chapter 4). The idea has been to define a simple validation procedure in order to involve several countries and to report all the information necessary to apply the described validation procedure.

3.3 Validation methodology

From the beginning of the project it was clear the importance to define a common validation procedure in order to make the results obtained by several institutes comparable and to better understand their meanings. This methodology has been identified for all the steps in CDOP-1 inside the validation group, in collaboration with the product developers, and with the support of ground data experts. The common validation methodology is based on ground data comparison to produce **large statistic** (multi-categorical), and **case study analysis.** Both components (large statistic and case study analysis) are considered complementary in assessing the accuracy of the implemented algorithms. Large statistics helps in identifying existence of pathological behaviour, selected case studies are useful in identifying the roots of such behaviour, when present. During the Validation workshop held in Antalya has been fixed the period 1.10.2009 – 31.09.2010 as reference period for validation activities.
The main steps of the validation procedure are:

1. check for consistency of both observation and satellite data series,
2. comparison between the snow observation and the satellite data,
3. mountain mask application,
4. large statistic analysis: multi-categorical scores evaluation,
5. case study analysis.

A complete description of validation method is reported in annex.

3.4 Ground data and tools used for validation

From the data collected by ground network, a subset containing snow cover depth for the *reference season* (1.10.2009 – 31.09.2010) is extracted and a local database is created.
The data is stored in plain text. Each file contains the data from all reporting stations for one day of the reference season. For each station the following fields are assigned:

- date and time of measurement,
- number and name of the station or snow course as well as it's coordinates (Latitude(degrees), Longitude(degrees) and height (m) asl.,
- a flag indicating whether the observation site is located in mountainous or flat/forested area. The masking is performed by applying the mountain mask. The file “mountainmask_fsc.h5” is in TSMS ftp site at /OUT/h12/mountainmask
  address:

ftp://hsaf.meteoroloji.gov.tr
username: *snowtur*
password: *rs37kar*

- e-codes: The e-codes are values given by visual inspection for the state of the snow cover. The values used in the validation are shown in Table 1.
- snow course data: while measuring the snow course (snow depth, swe) a visual inspection of the snow cover is made.

e -code	Explanation
0	Ground predominantly covered by ice
1	Compact or wet snow(with or without ice) covering less than one-half of the ground
2	Compact or wet snow (with or without ice) covering at least one-half of the ground but ground not completely covered
3	Even layer of compact or wet snow covering ground completely
4	Uneven layer of compact or wet snow covering ground completely
5	Loose dry snow covering less than one-half of the ground
6	Loose dry snow covering at least one-half of the ground but ground not completely covered
7	Even layer of loose dry snow covering ground completely
8	Uneven layer of loose dry snow covering ground completely
9	Snow covering ground completely; deep drifts

Table 3 The description of the e-codes

3.5 Data consistency check

The first data check of the validation procedure consist in verify the availability of both observation data and satellite product, for all days of the reference season (1.10.2009 – 31.09.2010).

3.6 Mountain mask description

The mountain mask that has been developed by METU to be used in HSAF Project depends on two main features of topography. One is the slope and the other one is the elevation of the terrain. For the mountain mask development GTOPO Digital Elevation Model (DEM) which has 1 km of spatial distribution has been used. The GTOPO DEM covering the domain of HSAF Project which is between latitudes from 25 to 70, and longitudes from -20 to 45 has been used as the base layer. A vector layer that is formed of parallel polylines with 0.05*0.05 degree intervals was developed to make pixel wise calculations in each individual cell of this mesh. Using this mesh onto the GTOPO DEM slope and elevation values of each cell have been calculated. After obtaining this cell wise DEM values an algorithm has been run over this layer in order to create a binary true or false map with the rule given below:
("Mean Elevation of Cell" >=1000m) **OR** ("Std_Dev of Slope of Cell" >=2% **AND** " Mean Elevation of Cell " >=700m) **OR** ("Range of Elevation" >=800m **AND** " Mean Elevation of Cell " >=500m).

After applying this rule, a binary mountain mask which is depicted in figure below is obtained and used in HSAF Project snow products generation. It can be found at ftp site of Turkish State Meteorological Service

(212.175.180.253) under /OUT/h1X/mountainmask directory in .hdf file format (Username: *snowtur* , Password: *rs37kar).*

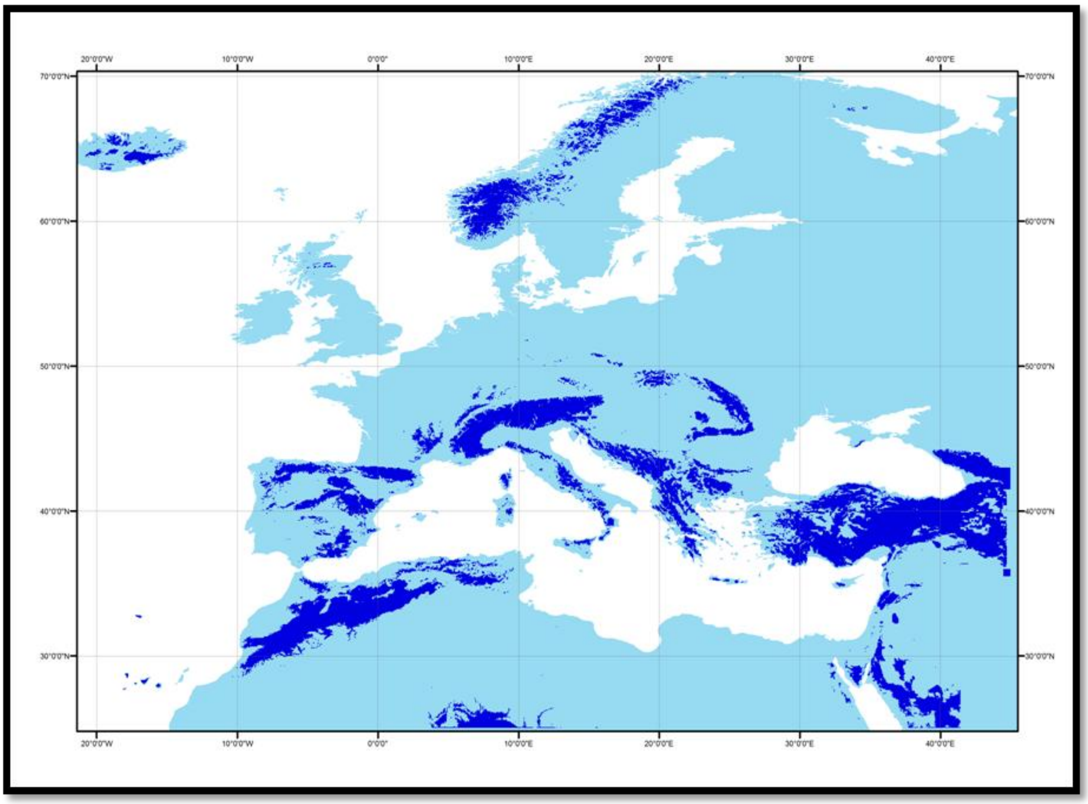


Figure 7 Mountain mask used in HSAF Project

3.7 Comparison between the observation data and the product for large statistical analysis

The nearest e-code extracted for the pixel is used in the validation. The snow cover fraction (FSCA) and the e-code values must be classified as follows:

H12 product:
FSCA=0%,
0%< FSCA< 50%,
50%=<FSCA< 100%,
FSCA=100%.

ecodes:
No snow=0%,
0%< ecodes(1,5)< 50%,
50%=<ecodes(2,6) < 100%,
ecodes(9,8,7,4,3) =100%.

The following contingency matrix is evaluated for e-codes.

Data set	Reference data											
Snow map	Classes	0%		0-50%		50-100%		100%		Total (#)	Commission errors	
		%	#	%	#	%	#	%	#		%	#
	0%	**A0/(A0+A1+A2+A3)**	A0	**B0/(**B0+B1+B2+B3)	B0	**C0/(**C0+C1+C2+C3)	C0	**D0/(**D0+D1+D2+D3)	D0	A0+B0+C0+D0	(B0+C0+D0)/(A0+B0+C0+D0)	B0+C0+D0
	0-50%	**A1/(**A0+A1+A2+A3)	A1	**B1/(B0+B1+B2+B3)**	B1	**C1/(**C0+C1+C2+C3)	C1	**D1/(**D0+D1+D2+D3)	D1	A1+B1+C1+D1	(A1+C1+D1)/(A1+B1+C1+D1)	A1+C1+D1
	50-100%	**A2/(**A0+A1+A2+A3)	A2	**B2/(**B0+B1+B2+B3)	B2	**C2/(C0+C1+C2+C3)**	C2	**D2/(**D0+D1+D2+D3)	D2	A2+B2+C2+D2	(A2+B2+D2)/(A2+B2+C2+D2)	A2+B2+D2
	100%	**A3/(**A0+A1+A2+A3)	A3	**B3/(**B0+B1+B2+B3)	B3	**C3/(**C0+C1+C2+C3)	C3	**D3/(D0+D1+D2+D3**	D3	A3+B3+C3+D3	(A3+B3+C3)/(A3+B3+C3+D3)	A3+B3+C3
Total (#)			A0+A1+A2+A3		B0+B1+B2+B3		C0+C1+C2+C3		D0+D1+D2+D3	A0+B0+C0+D0+A1+B1+C1+D1+A2+B2+C2+D2+A3+B3+C3+D3	(B0+C0+D0+A1+C1+D1+A2+B2+D2+A3+B3+C3)/(A0+B0+C0+D0+A1+B1+C1+D1+A2+B2+C2+D2+A3+B3+C3+D3)	B0+C0+D0+A1+C1+D1+A2+B2+D2+A3+B3+C3
Omission errors		**A0/**(A0+A1+A2+A3)		**B1/**(B0+B1+B2+B3)		**C2/**(C0+C1+C2+C3)		**D3/**(D0+D1+D2+D3)				

Table 4 Contingency matrix evaluated for e-codes

Where the parameters A, B, C and D are defined as follow:

A0 number of correct 0% observations,
A1 number of 1-50% FSCA in the snow products corresponding to 0% in the observations,
A2 number of 51-99% FSCA in the snow products corresponding to 0% in the observations,
A3 number of 100% FSCA in the snow products corresponding to 0% in the observations,
B0 number of 0% observations in the snow product corresponding to 1-50% in the observations,
B1 number of correct 1-50% observations,
B2 number of 51-99% FSCA in the snow products corresponding to 1-50% in the observations,
B3 number of 100% FSCA in the snow products corresponding to 1-50% in the observations,
C0 number of 0% observations in the snow product corresponding to 51-99% in the observations,
C1 number of 1-50% FSCA in the snow products corresponding to 51-99% in the observations,

C2 number of correct 51-99% observations,
C3 number of 100% FSCA in the snow products corresponding to 51-99% in the observations,
D0 number of 0% observations in the snow product corresponding to 100% in the observations,
D1 number of 1-50% FSCA in the snow products corresponding to 100% in the observations,
D2 number of 51-99% FSCA in the snow products corresponding to 100% in the observations,
D3 number of correct 100% observations.

The main statistical scores evaluated are Overall Accuracy (OA) and Root Mean Square Error (RMSE) so defined:

$$OverallAccuracy(\%) = \frac{(A0+B1+C2+D3)}{A0+B0+C0+D0+A1+B1+C1+D1+A2+B2+C2+D2+A3+B3+C3+D3)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(sat_k - true_k)^2}$$

3.8 Case study analysis

Each Institute, in addition to the large statistic verification produces a case study analysis based on **the knowledge and experience of the Institute itself**. Each institute, following a standard format decides whether to use ancillary data such as SEVIRI images, output of numerical weather prediction and nowcasting products.

The main sections of the standard format are:

- description of the case study;
- ground data and product used;
- comparison;
- score evaluated;
- conclusions.

For each case study quantitative analysis in the same manner like for the longer period (explained above) should be performed. Additionally, qualitative analysis by comparing pictures of H12 product with different satellite products (e.g. NOAA-AVHRR RGB composites, MODIS snow products, classified Landsat images) should be performed.

More details on case study analysis will be reported in the Chapter 5.

3.9 Structuring the results of the validation activity

To make the validation fluent and to assure the feedback from validation activities some procedures and tools have to be defined beforehand. The aim is to use the existing database and retrieval structures as far as possible. The H-SAF archive will be logically connected to the databases of the validation sites. Most advanced validation site, Helsinki Testbed (HTB, http://testbed.fmi.fi/), has a xml interface for scientific use, which can be simply combined with H-SAF snow products using map server technology. The validation results will be made available as reports via web interface with possibility to give feedback. Calibration methods and product characterization as well as quality indicators are part of the meta data content, but also available as web documents with time line showing the evolution of the products. The product validation is as iterative process throughout the project affecting the algorithm development work.

3.10 Definition of statistical scores

It is appropriate to deploy the definitions of the statistical scores utilised in H-SAF product validation activities. Some apply to "continuous statistics", some to "dichotomous statistics". Although no ground observing system can be considered a very accurate ground truth, we assume as "true" these observations, thus the departures of satellite observations will be designated as "errors"

3.10.1 Scores for continuous statistics

- Mean Error (ME) or Bias
- Standard Deviation (SD)
- Correlation Coefficient (CC)
- Root Mean Square Error (RMSE)
- Root Mean Square Error percent (RMSE %), used for precipitation since error grows with rate.

$$ME \text{ or } bias = \frac{1}{N}\sum_{k=1}^{N}(sat_k - true_k)$$

$$SD = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(sat_k - true_k - ME)^2}$$

$$CC = \frac{\sum_{k=1}^{N}\left(sat_k - \overline{sat}\right)\left(true_k - \overline{true}\right)}{\sqrt{\sum_{k=1}^{N}\left(sat_k - \overline{sat}\right)^2 \sum_{1}^{N}\left(true_k - \overline{true}\right)^2}}$$

with $\overline{sat} = \frac{1}{N}\sum_{k=1}^{N} sat_k$ and $\overline{true} = \frac{1}{N}\sum_{k=1}^{N} true_k$;

$$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(sat_k - true_k)^2}$$

$$RMSE\ \% = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\frac{(sat_k - true_k)^2}{true^2{}_k}}$$

3.10.2 Scores for dichotomous statistics

Stemming from the contingency Table:

Contingency Table

		Observed (ground)		
		yes	no	total
Forecast (satellite)	yes	hits	false alarms	forecast yes
	no	misses	correct negatives	forecast no
	total	observed yes	observed no	total

where:

- hit: event observed from the satellite, and also observed from the ground
- miss: event not observed from the satellite, but observed from the ground
- false alarm: event observed from the satellite, but not observed from the ground
- correct negative: event not observed from the satellite, and also not observed from the ground.

A large variety of scores have been defined. The following are used in H-SAF

- Frequency BIas (FBI)
- Probability Of Detection (POD)
- False Alarm Rate (FAR)
- Probability Of False Detection (POFD)

- Fraction correct Accuracy (ACC)
- Critical Success Index (CSI)
- Equitable Threat Score (ETS)
- Heidke skill score (HSS)
- Dry-to-Wet Ratio (DWR).

$$FBI = \frac{hits + falsealarms}{hits + misses} = \frac{forecast\,yes}{observed\,yes}$$ Range: 0 to ∞. Perfect score: 1

$$POD = \frac{hits}{hits + misses} = \frac{hits}{observed\ yes}$$ Range: 0 to 1. Perfect score: 1

$$FAR = \frac{falsealarms}{hits + falsealarms} = \frac{falsealarms}{forecast\,yes}$$ Range: 0 to 1. Perfect score: 0

$$POFD = \frac{falsealarms}{correct\,negatives\ + falsealarms} = \frac{falsealarms}{observed\ no}$$ Range: 0 to 1. Perfect score: 0

$$ACC = \frac{hits + correct\,negatives}{total}$$ Range: 0 to 1. Perfect score: 1

$$CSI = \frac{hits}{hits + misses + falsealarm}$$ Range: 0 to 1. Perfect score: 1

$$ETS = \frac{hits - hits_{random}}{hits + misses + falsealarm - hits_{random}}$$ with $$hits_{random} = \frac{observed\ yes * forecast\,yes}{total}$$

ETS ranges from -1/3 to 1. 0 indicates no skill. Perfect score: 1.

$$HSS = \frac{(hits + correct\,negatives) - (expected\ correct)_{random}}{N - (expected\ correct)_{random}}$$ with

$$(expected\ correct)_{random} = \frac{1}{N}\left[(observed\ yes)(forecast\,yes) + (forecast\,no)(observed\ no)\right]$$ HSS ranges from -1 to 1. 0 indicates no skill. Perfect score: 1.

$$DWR = \frac{false\ alarm + correct\ negative}{hits + misses} = \frac{observed\ \ no}{observed\ yes}$$ Range: 0 to ∞. Perfect score: n/a.

4 Ground data used for validation activities

4.1 Ground data in Belgium (IRM)

4.1.1 Snow data

Snow is observed on operational basis at the 18 synoptic stations. An increasing number of climatological stations will provide information about snow including snow depth and with a short delay. Two telemetric stations are equipped with acoustic nivometers.

4.1.2 Hydrological validation

The semi-distributed hydrological model SCHEME will be used for snow product validation. This model comprises a conceptual snow module based on the energy balance (e.g. Bultot et al. 1994[1], Gellens et al. 2000[2]). Snow products will be compared with snow simulated by the hydrological model. The assimilation of the snow products is being investigated. The usefulness of the satellite products for operational hydrology will be tested in a way similar to the other products.

4.2 Ground data in Finland (FMI)

The main validation site in Finland is the Sodankylä-Pallas region in northern Finland representing boreal and sub-arctic zones. Another intensive reference area is the southern-boreal Helsinki Testbed site that contains considerable fractions of agricultural and urban regions in addition to forests. Moreover, this site is located at the coastal zone (Gulf of Finland), which enables the investigation of the effect of coastline to the performance of H-SAF snow products. In certain validation activities, the reference data available through FMI and SYKE will be applied from the ground-based snow observation networks and weather stations covering the whole country, see next two figures:

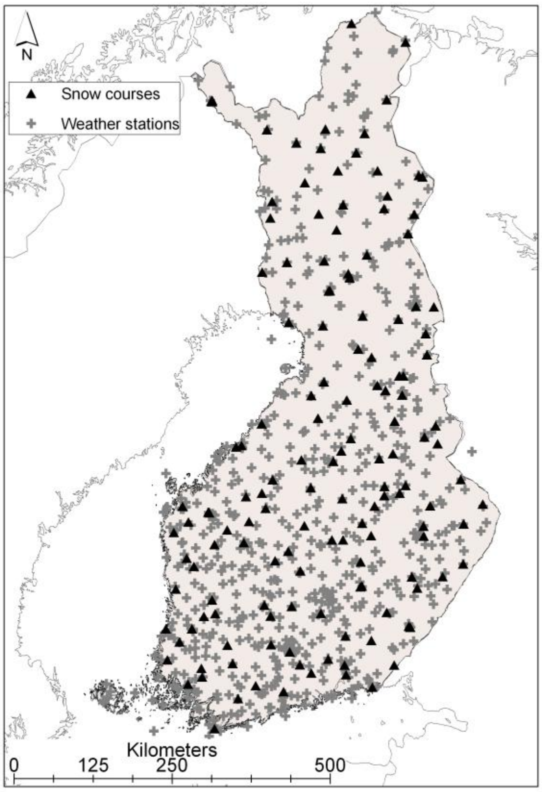


Figure 8 Snow measurement courses (SYKE) and weather stations (FMI) in Finland

[1] Bultot F., D. Gellens, B. Schädler and M. Spreafico, 1994: "Effects of climate change on snow accumulation and melting in the Broye catchment (Switzerland)". *Climatic change*, 28, 339-363.

[2] Gellens D., K. Barbieux, B. Schädler, E. Roulin, H. Aschwanden and F. Gellens-Meulenberghs, 2000: "Snow cover modelling as a tool for climate change assessment in a Swiss alpine catchment". *Nordic Hydrology*, 31, 73-88.

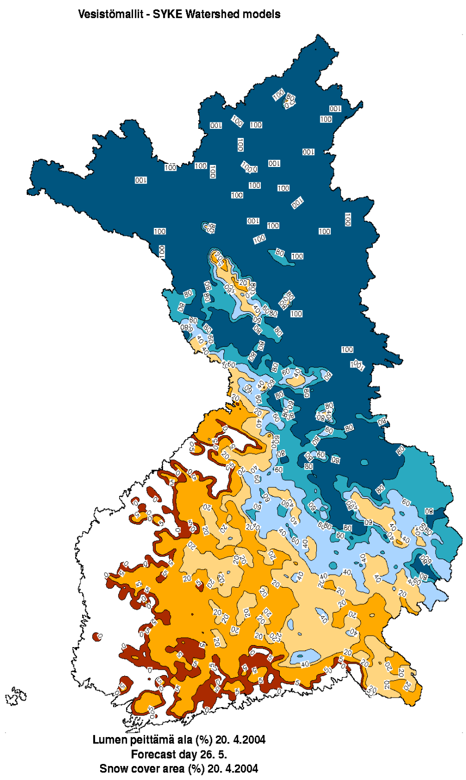


Figure 9 SCA from SYKE watershed simulation and forecasting system (WSFS)

4.2.1 Snow Measurement Courses

A snow course is a 2 - 4 km long trail through various terrains typical of the locality. Measurements on snow depth and snow water equivalent are made regularly along the trail at 40-80 locations, shown in Figure 8, interconnected with information on land cover type at each measurement point. The applied land cover types are open place, open place in forest, pine-dominated forest, spruce-dominated forest, deciduous tree-dominated forest and swamp. In the validation, SCA instead of patchiness will be used: SCA=1-patchiness. One average SCA representing the whole course may be calculated by using percentage of different terrain/vegetation types as weights. These average values represent the *in situ* SCA in the validation. Measurements from each snow course are made typically once a month. The snow course network covers the whole country.
The validation data set includes daily H-SAF Fractional snow (H12) products from melting period 2010 and the concurrent at-ground Fractional snow observations from snow courses managed by the Finnish Environment Institute (SYKE).
80 observations on snow patchiness (=100-FSC) is recorded along the line. For validation an average on these observations is taken and compared with an average FSC from H12 pixels overlaying the trail.
The snow course network by SYKE consists of ~150 active snow courses. Since each course is visited only once per month – around the 15th day – the number of available data is limited, particularly for AVHRR acquisitions with cloud cover.

Finland's 162 snow courses are managed by the Finnish Environment Institute.

4.2.2 Hydrological simulation and forecasting system

The operative hydrological simulation and forecasting system of SYKE (WSFS) simulates the hydrological cycle for the all land area of Finland and cross border watersheds. Forecasts for discharge and water level are made separately for 5845 sub-basins with a mean acreage of 60 km^2. The basic component of the system is a conceptual hydrological model simulating runoff using precipitation, potential evaporation and temperature as input. The output of the model includes water level, discharge and snow water equivalent (SWE). Regular *in situ* observations on these three are also used for correcting the model simulation during the snow melting period. Accordingly, they have been used for model calibration. SCA serves as an important state variable in the model. In addition to daily forecasts for discharge, water level and SWE, displayed as evolving graphs for the whole melting period, daily maps of SCA, and SWE (and many other hydrological parameters) over the whole Finland are produced.

4.2.3 The Sodankylä-Pallas validation region

The Sodankylä-Pallas site is a typical representative of Eurasian taiga belt characterized by a mosaic of sparse conifer-dominated forests and open/forested bogs. The landscape is generally relatively flat or gently rolling although small mountain regions (fjelds) are typical. The land use map of the region provided by SYKE is shown in ***Fig. 08*** (land cover and forest characteristics with a spatial resolution of 25 m). The map shows the location of the site with intensive research stations at the town of Sodankylä and Pallas Mountain indicated.

Figure 10 Land cover map of the Sodankylä-Pallas site

Coniferous forests on mineral soil are depicted by dark green colour. Light green colour depicts sparse coniferous dominated forests (mainly on peat soil) and open bogs are depicted by grey. Open rock and barren areas (fjelds) are shown by brownish colours and open water by blue. Buildings and urban regions are depicted by red. The data sets available for the Sodankylä-Pallas region include the weather and atmospheric parameter monitoring data from the Finnish Meteorological Institute (FMI), land cover characteristics and hydrological monitoring and modelling data from the Finnish Environment Institute

(SYKE), and selected data sets form other Finnish research institutes and universities. Intensive stations equipped with a large variety of atmospheric sampling, profiling and automatic surface parameter measurement systems are located near the town of Sodankylä (Arctic Research Centre of FMI with a permanent staff of around 30 persons), and at/in the vicinity of Pallas Mountain. Additional data sets are available from *in situ* and aerial monitoring campaigns, e.g. brightness temperature and reflectance data sets by Helsinki University of Technology (TKK).

4.3 Ground data in Germany (BfG)

In Germany there are currently about 1000 stations in operation which provide near-real-time data of snow cover depth to Germany's National Meteorological Service (Deutscher Wetterdienst, DWD). Snow cover depth measurements are conducted daily at the least at 6 UTC. About 500 stations can deliver near-real-time snow water equivalent information if the snow cover depth is higher than 5 cm. Snow water equivalent measurements are conducted on Monday, Wednesday and Friday at 6 UTC.

4.3.1 SNOW3-Model

During the winter half year (November-April), SNOW3-model is run operationally for the area of Southern Germany by DWD. It provides daily analyses and forecasts of snow water equivalent and water release from snow cover resulting from melt and precipitation. Next two figures show the spatial coverage of the SNOW3-model, and an example of performance, respectively.

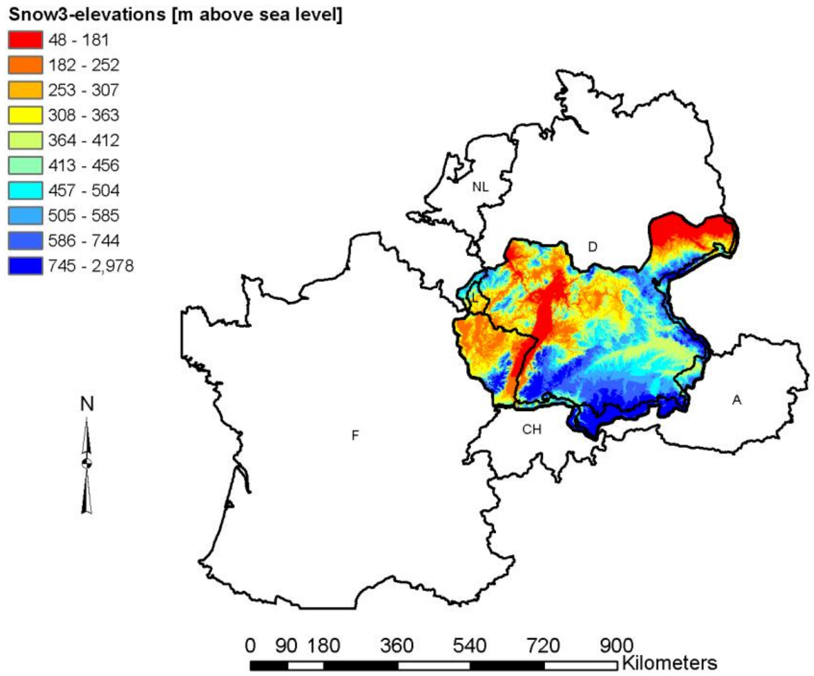


Figure 11 Coverage of SNOW3-model of DWD in Europe

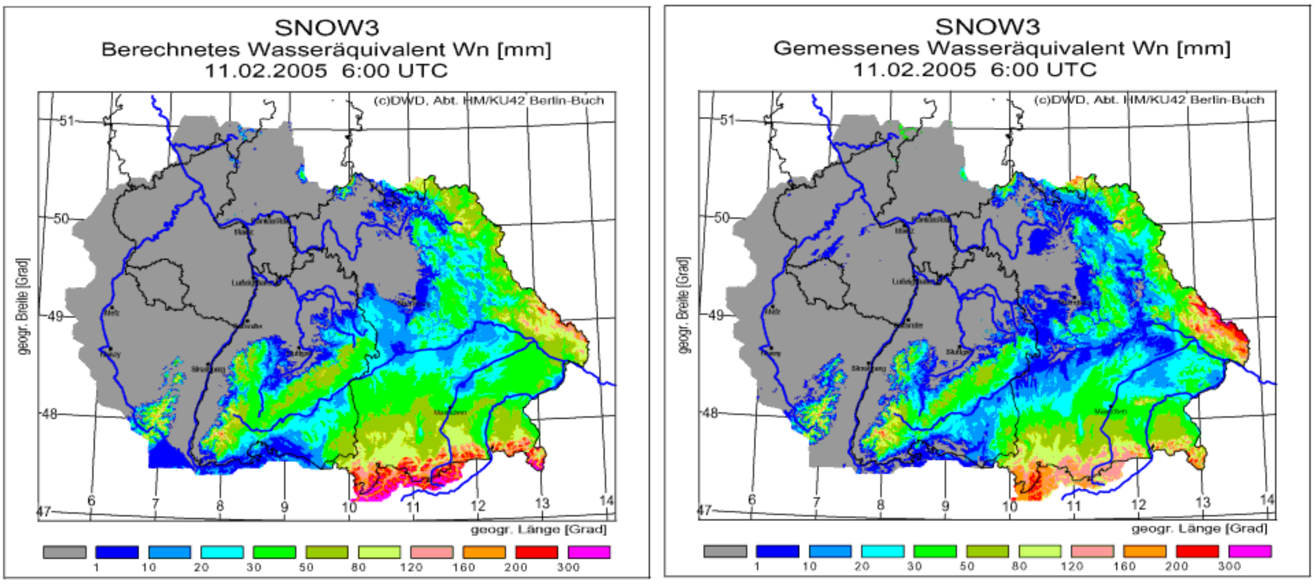


Figure 12 Results from SNOW3: left panel: Calculated snow water equivalent, right panel: Interpolation of measured snow water equivalent

(For figure above, see: http://www.dwd.de/de/wir/Geschaeftsfelder/Hydrometeorologie/Leistungen/Schneeschmelzvorhersage/Schneeschmelzvorhersage.htm).

Forcing terms of the model are regionalized measurements (period of analysis: past 30 h, regionalisation via Kriging) and forecasts (forecast period Lokal Model DWD: 72 h) of following data (Blümel et al. 2003[3], Blümel et al. 2005[4]):

- air temperature
- air humidity (dew point, vapour pressure)
- short wave radiation
- precipitation
- wind velocity

Apart from water release from snow cover resulting from melt and precipitation and snow water equivalent SNOW3 calculates as well:

- snow cover depth
- surface and mean snow temperature
- sensible and latent heat flows

Measurements of snow cover depth (daily) and specific snow water equivalent (three times a week) are used for the verification of model results.

Internal calculation time step is one hour, model results are updated every 6 hours, spatial resolution is 1 km x 1 km. A special feature of the SNOW3-model is its capability to realize simulations at single stations.

---

[3] Blümel K., G. Schneider and T. Günther / Deutscher Wetterdienst, Abteilung Hydrometeorologie, 2003: „Abschlussbericht SNOW2, Winter 2002/2003“, Band 1&2. Berlin.

[4] Blümel K., G. Schneider and T. Günther / Deutscher Wetterdienst, Abteilung Hydrometeorologie, 2005: „Abschlussbericht SNOW3, Winter 2004/2005“, Band 1&2. Berlin.

The distribution of elevation zones in the SNOW3 area, their mean slope, the number of near-real-time stations observing snow cover, and their mean slope, are recorded in next tablem where calculation of mean slopes based on whole-number slope classes and it is derived from 1 km DEM (In addition: number of stations observing snow cover and mean slope at the station).

elevation zone [m amsl]	mean slope [%]	% of SNOW3 area	number of stations	mean slope at station
0-100	3.0	1.1	10	0.2
101-200	3.1	10.5	73	1.3
201-300	3.4	17.4	75	2.1
301-400	3.6	19.2	114	1.7
401-500	3.8	21.4	148	1.8
501-600	4.5	12.0	80	2.3
601-700	5.6	6.5	46	3.5
701-800	6.4	4.1	40	3.2
801-900	8.2	2.2	19	7.3
901-1000	10.4	1.2	11	7.9
1001-1500	16.4	2.7	9	8.9
1501-2000	20.9	1.2	1	18.3
2001-2500	17.5	0.5	0	N/A
2501-3000	13.5	0.1	1	39.4

Table 5 Elevation zones and mean slopes of the area covered by SNOW3

When we apply the elevation criteria of the mountain mask for H-SAF snow products (MeanAltitude ≥ 2000 m or MeanAltitude ≥ 700 m and STDSlope ≥ 2) (source: Snow cluster Meeting Helsinki, 18-19 January 2007), most of the SNOW3 area would be attributed to flatland terrain. It is planned for the winter half-year 2008/2009 to run an updated version of SNOW-model which will cover the whole territory of Germany as well as those parts of foreign river catchments which are of interest for water management tasks in Germany (river Elbe, river Oder).

4.3.2 Validation methodology for snow products

SNOW3-model includes a sophisticated approach for the interpolation of snow station data. Therefore it seems to be the best available product in Germany to be used for H-SAF snow parameter validation.

Additionally, it is planned to use snow station data in the area covered by SNOW3. Snow parameters provided from H-SAF production centres to be used for validation are summarized in next table:

H-SAF product	SNOW3 raster product	Station data (point data)
Snow detection	Regionalized snow cover depth	Snow cover depth
Effective snow cover	Regionalized snow cover depth	
Snow water equivalent	Specific snow water equivalent	Specific snow water equivalent

Table 6 Snow parameters to be used for validation task

In that way, validation of H-SAF snow parameters will be based on:

- raster (satellite product) – point (station data) comparison
- raster (satellite product) – raster (SNOW3) comparison
- comparisons using spatial aggregated products: e.g. elevation zones, (sub-)catchments

Temporal and spatial patterns of snow parameters, e.g. with respect to topography and land use, will be investigated more detailed during the validation procedure.

For efficiency reasons, it is strongly recommended to harmonize snow validation methodologies with precipitation and soil moisture validation methodologies. Verification statistics such as mean absolute error, RSME, correlation coefficient, standard deviation as well as statistics based on contingency tables seem to be appropriate tools for validation tasks.

4.4 Ground data in Poland (IMWM)

Poland's total surface area is 322,500 sq km (including 1,200 sq km of inland waters). Poland is a relatively flat country - 91.3 percent of its territory lies below 300 m above sea level. There are two main mountain ranges in southern part of Poland: the Carpathians (including Tatra – Alpine type mountains covering about 175 sq km) and the Sudetan Mountains.

Poland has a moderate variable climate with both maritime and continental elements. It is characterized by substantial weather changes in consecutive years, caused by disturbances in the pattern of main air masses coming to the country. As a result, the seasons may look quite different in consecutive years. This is particularly true for winters, which are either warm/wet, of the oceanic type, or cold/sunny, of the continental type.

Mean multiannual dates of first and last day with snow cover in winter season in Poland (excluding mountains areas) are respectively in November and March/April, but due to substantial spatial and season-to-season variability it is rough approximation. During this period the snow cover is no stable and relatively high variability of temperature occurs during winter season hitting values below and above 0 deg C. These are situations when the thinnest and patchiest snow cover exist, so snowfall and snow melt have the largest impact on the spatial extent of the snow cover and their density. Maximum snow cover depth of 3.55 m was reported at Kasprowy Wierch in April 1996.

4.4.1 Available snow data measurements and observations in Poland

After modernization of the Polish National Hydrological and Meteorological Service in the years 2000-2005 density of the post network with measured snow characteristics increased and this process is still going on. Main information on snow observation network is presented in next table:

Snow Characteristics	Number of stations		
	SYNOP stations	Climatological stations and Meteorological posts	Rain posts (still in development)
Depth of snow	57	210	1027
Depth of newly fallen snow	57	210	1027
Snow type	57	210	1027
State of ground	57	210	1027
Snow Water Equivalent/ Snow density	57	71	72

Table 7 Number of stations providing snow characteristics measurements and observations Polish Hydrological and Meteorological Network (IMWM) – status at the end of 2005

At SYNOP stations all measurements are made once a day at 0600 UTC. In some cases (i.e heavy snowfall), measurements are repeated at 1800 UTC.

At other remaining stations, measurements are made once a day at 0600 UTC, except Snow Water Equivalent, which is computed - on the base of snow volume/weight measurements - every 5 days at 0600 UTC (more frequent during snowfall and melting time).

The information about State of ground gives information about snow condition (dry or wet) and extension (completely or patchy).

4.4.2 Quality and Accessibility

The SYNOP observations and measurements are performed by high quality personnel and supplies high quality snow information, although sparse located – especially in mountainous region - only three SYNOP station are located in such area (according to the rule “Mean altitude ≥ 1000m or Mean altitude ≥ 600m and STDSlope ≥ 2”). Information from the other posts should be verified due to recent changes of snow measurements performed by this network. Necessary skill is still in development.

All data from SYNOP station are available in Central Historical Database – with quality control but with substantial delay (about half year). Archival of data concerning snow cover in digital form from lower level posts is still in development. Actual availability differs in individual IMWM Branch Offices.

Krakow Branch established “Klimat” database covering one forth of Poland with different topography easily accessible in IMWM network. Remaining area delivers data mainly to Hydrological System database.

Next figure shows the SYNOP stations network in Poland (left part) and the map of IMWM Branches’ area coverage (right part):

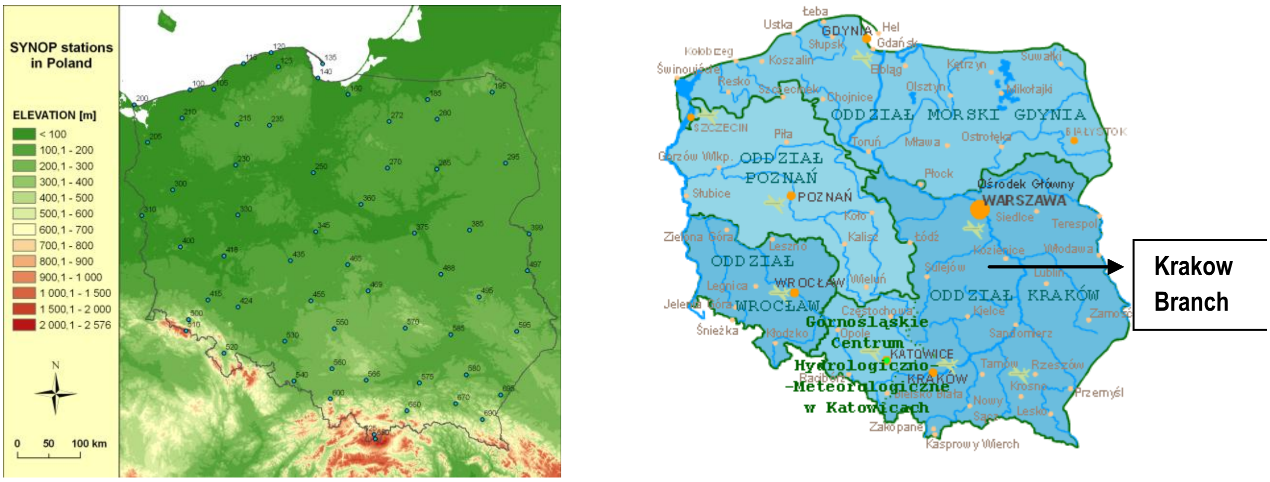


Figure 13 SYNOP stations network in Poland (left part) and the map of IMWM Branches’ area coverage (right part)

Since the H-SAF kick-off, snow data are collected from available on-line sources. From last winter season, selected data from 353 posts are already archived locally by IMWM H-SAF team. They include snow characteristics and air temperature (without SWE).

4.4.3 Validation

Validation methodology must be the same among all partners participating in this task. As a result Cluster 4 coordinator has to define details: methodology, retrieved statistical parameters, number of post required and types of observations taken into account. One validation algorithm should be established to make process of validation comparable.

Following steps will be takes during validation process performed by Poland:

- ground data need to be collected and verified,
- database with ground and satellite measurement will be created for local purposes of IMWM,
- comparison of satellite products with ground measurements/observations will be performed – for this purpose suggested by coordinator method for localisation/interpolation or spatialisation of data to fit different spatial and temporal character will be implemented.

Results of comparison with selected statistical parameters, contingency tables, selected indices (POD, FAR etc.) will be delivered in form of report.

4.5 Ground data in Turkey (TSMS)

Modelling and algorithm developed for product generation imply calibration and validation activity as an integral part. The routine generation includes a certain amount of on-line re-calibration/validation to monitor product quality stability and continuously improve error structure characterisation. Snow cover mapping in mountainous areas is demanding due to the interfering topography and the heterogeneous ground properties.

Various types of observations from different institutions will be used as the auxiliary data for the preparation of data set to be used in cal/val process. For instance, State Hydraulic Works will be in charge of providing discharge and ground truth observations in the basins selected as test sites. Meteorological observations will be mainly provided by the currently operational sites in the basins and those planned to be deployed by TSMS in a near future. In addition, other observation sites located in the vicinity of the basins will be used whenever needed. The snow product calibration and validation in Turkey will be performed using independent snow course measurements, and higher resolution satellite images.

The selected stations have all reported snow depth at 06 UTC for synoptic stations. The e-codes are also available for some synoptic stations (Figure 1). The data are co-located with the H12 data and the corresponding pixel values are recorded into a table. This table is filtered to several categories based on the existence/absence of snow and e-code values and the values in the H12 product.

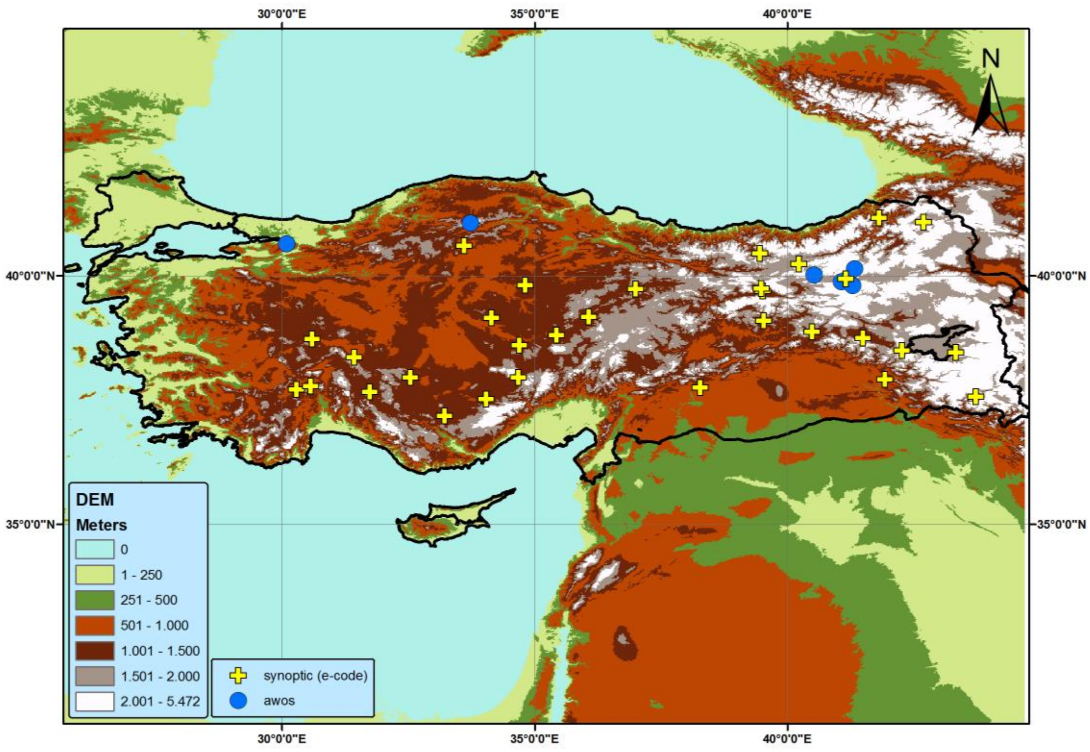


Figure 14 TSMS climate stations reporting ecodes and snow depths

It is very difficult and expensive to collect hydro-meteorological data at higher altitudes especially in extreme climatic conditions. However, it is essential to characterize climate conditions over the rough topography of the remote mountainous catchments in Eastern Turkey where large portion of the water to the large dams originates from snowmelt during spring and early summer months.

There are:

- 5 Automated Weather Operating Stations (AWOS)
- 2 Synoptic Stations
- 5 Climatologic Stations
- 3 Automated Stream Gauging Stations
- 5 Snow Courses

in and around the basin selected as the medium scale test site.

Automated Weather Operating Stations (AWOS) collect 2-hour data (temperature, precipitation, radiation, albedo, wind speed and direction, relative humidity, air pressure, soil temperature, snow depth, snow density, snow lysimeter) that are in real-time format. Synoptic stations collect 1 to 3 hour data (temperature, precipitation, radiation, wind speed and direction, relative humidity, air pressure, evaporation, soil temperature, snow depth) that are received with 1-day delay. Climatologic stations collect data hourly (temperature, air pressure, wind speed and direction) and three times a day (relative humidity, evaporation and precipitation) that are received with 1-month delay. Stream Gauging Stations (SGS) collect 15 to 60 minute data (stream depth converted into discharge) that are in real-time format. Finally, manual snow courses are conducted every two to three weeks during the period with snow cover and data can be transferred with 1-week delay.

The snow cover area validation was performed by Tekeli et al. 2005[5] using the moderate-resolution imaging spectroradiometer (MODIS) images during the accumulation and ablation periods of 2002-2003 water year and as well during the winter period of 2003-2004. Over the ablation period of 2004, daily snow albedo values retrieved from MODIS Terra were compared with ground-based albedo measurements (Tekeli et al., 2006[6]).

Hydro-meteorological data are provided from the stations operating at various locations and altitudes in Upper Euphrates Basin. But since ground based observations can only represent a small part of the region of interest, spatially and temporally distributed snow data are needed. Distribution of the ground data using a proper interpolation technique suffer of the limitations of the interpolation methods in predicting snow parameters for rough terrain. Therefore higher spatial resolution data (e.g. Landsat, Quickbird, Ikonos images) will be also used for validation of the snow recognition and effective snow cover products. The cloud problem will be encountered by performing monitoring during melting period.

For snow water equivalent product, besides ground observations, snow water equivalent values obtained as the output of outputs from snowpack surface energy balance model will be used. Net energy fluxes are calculated for each pixel using the snowpack surface energy balance model that operates at a 1-km spatial resolution. The output from the snow hydrology model is snow depth, density, grain size, and temperature. These parameters are determined for each pixel on an hourly basis.

[5] Tekeli E., Z. Akyürek, A.A. Şorman, A. Şensoy and A.Ü. Şorman, 2005: “Using MODIS Snow Cover Maps in Modeling Snowmelt Runoff Process in the Eastern Part of Turkey”. *Remote Sensing of Environment*, 97, 216-230.

[6] Tekeli E., A. Şensoy, A.A. Şorman, Z. Akyürek and A.Ü. Şorman, 2006: “Accuracy assessment of MODIS daily snow albedo retrievals with in situ measurements in Karasu basin, Turkey”. *Hydrological Processes*, 20(4), 705-721.

5 Validation results: case study analysis

5.1 Case Study analysis in Finland

Two main issues with the H12 product quality are misinterpreted clouds and georeferencing errors of the NOAA/AVHRR data. As examples of these two issues we present the following two cases.

5.1.1 Case Study 1: georeferencing

The case study 1 is from 4th of March 2010 (figure 4). It demonstrates the errors with georeferencing, which can be best seen in the snow covered area between the Black Sea and the White Sea (Ukraine, Belarus and Russia). This area is magnified in figure 5. In the area the merging of different overpasses with slightly different georeferencing cause the duplication of fractional snow cover features. Figure 6 shows the SEVIRI composite area of the same day where pink can be interpreted as snow.

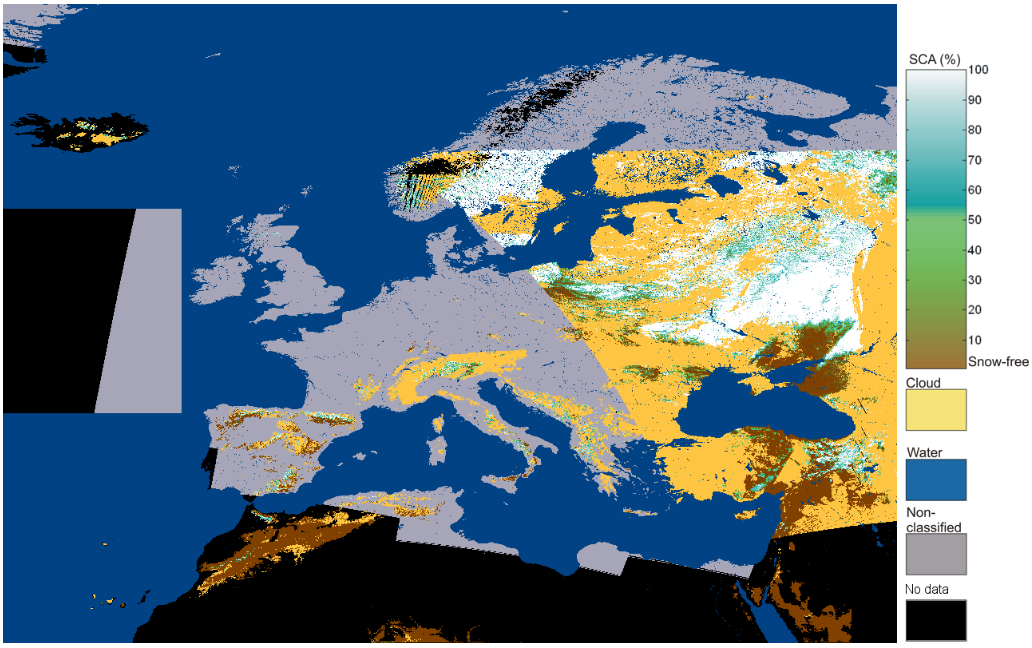


Figure 15 H12 product for 4th March 2010

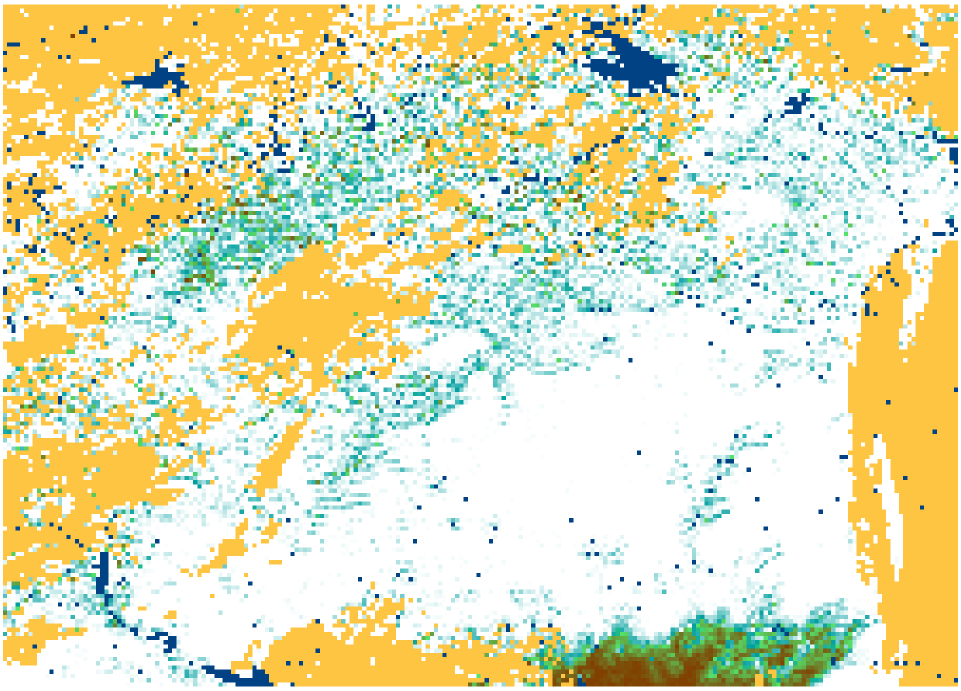


Figure 16 A magnification of the problem area of H12 product for the 4th March 2010

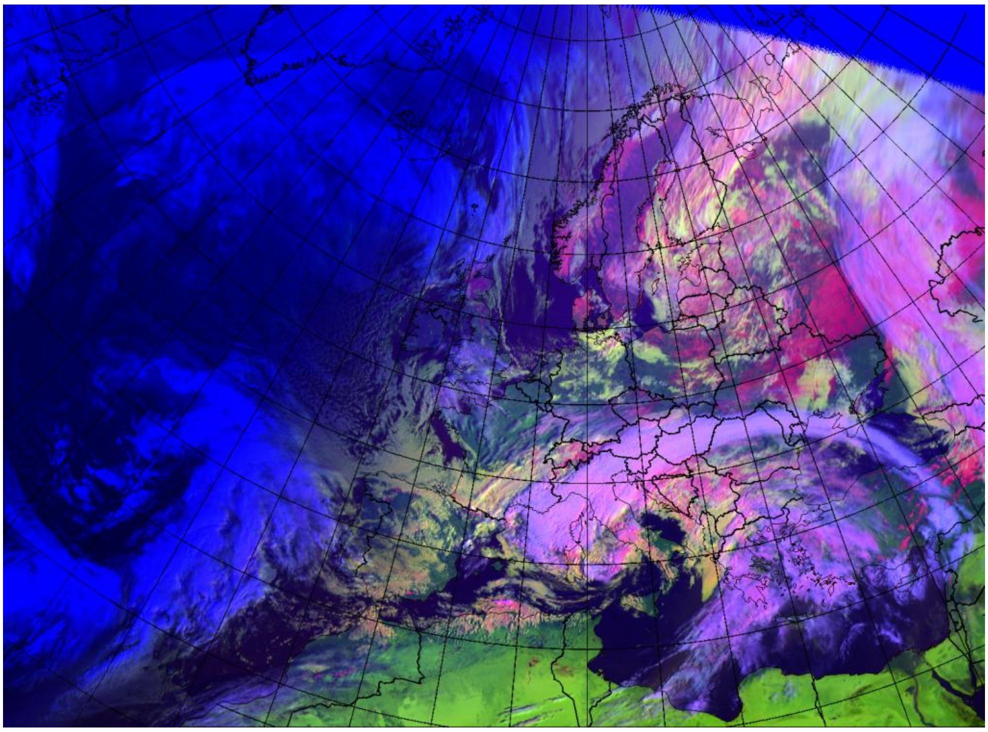


Figure 17 A SEVIRI composite for channels 0.6, 1.6 and 10.8 with country borders for 4th March 2010. The dark pink areas are snow covered

5.1.2 Case Study 2: misinterpreted clouds

The case study 2 is from 14th June 2010 (Figure 15). It demonstrates the problems with cloud masking, this time in Finland and Russian Karelia. The area is magnified in Figure 16. There was no snow cover in Finland during the day of the case study. The FSC>0 values of the area are mostly misinterpreted clouds or areas with scattered clouds.

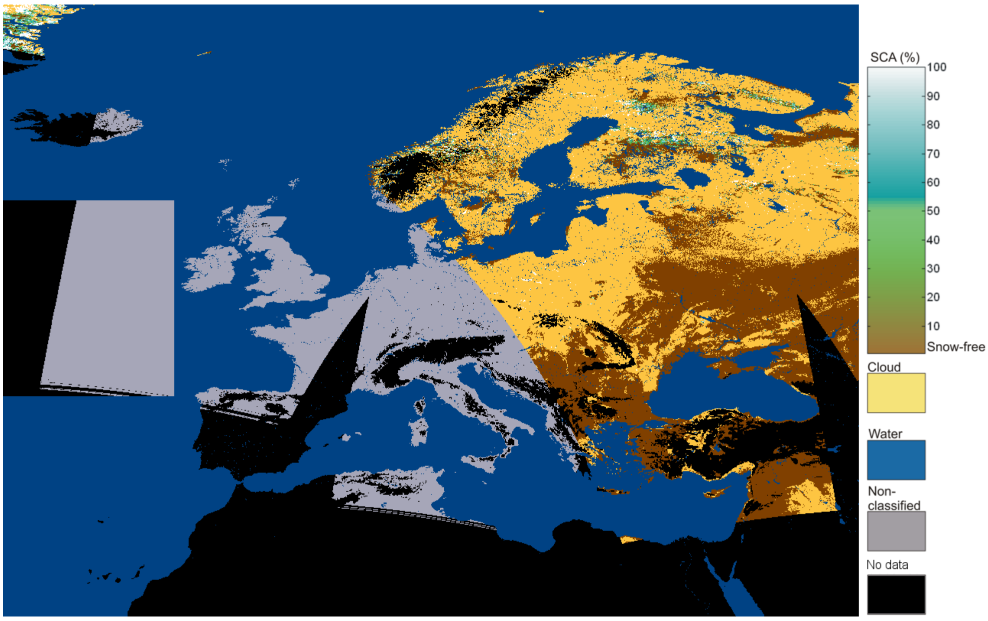


Figure 18 H12 product for 14th June 2010

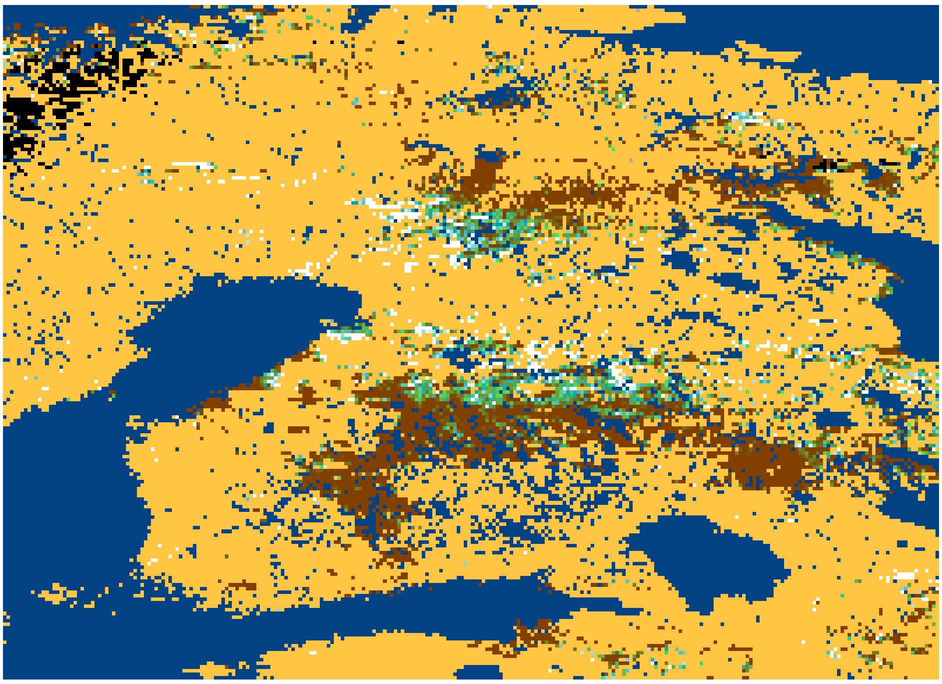


Figure 19 A magnification of the problem area of H12 product for the 14th June 2010

5.2 Case study analysis in Turkey

Three case studies have been performed. The comparison of H12 product with RGB composite of METOP-AVHRR data have been done visually. In the comparison Karasu basin, which is used in hydrological impact studies is used. H12 product has been also compared with MODIS snow product (MOD10A1) in quantitative way. The RGB composites, H12 products, MODIS products are presented in next figures. The quantitative comparison results are given in Table 8 and Table 9.

5.2.1 Case study for 27.01.2010

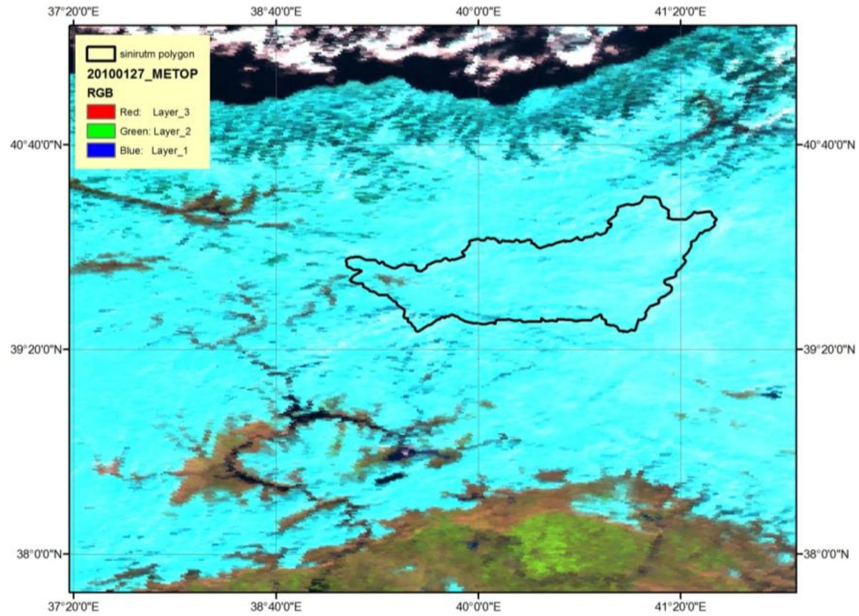


Figure 20 The RGB (Red: Band 3, Green: Band 2, Blue: Band 1) composite of METOP-AVHRR data for 27.01.2010

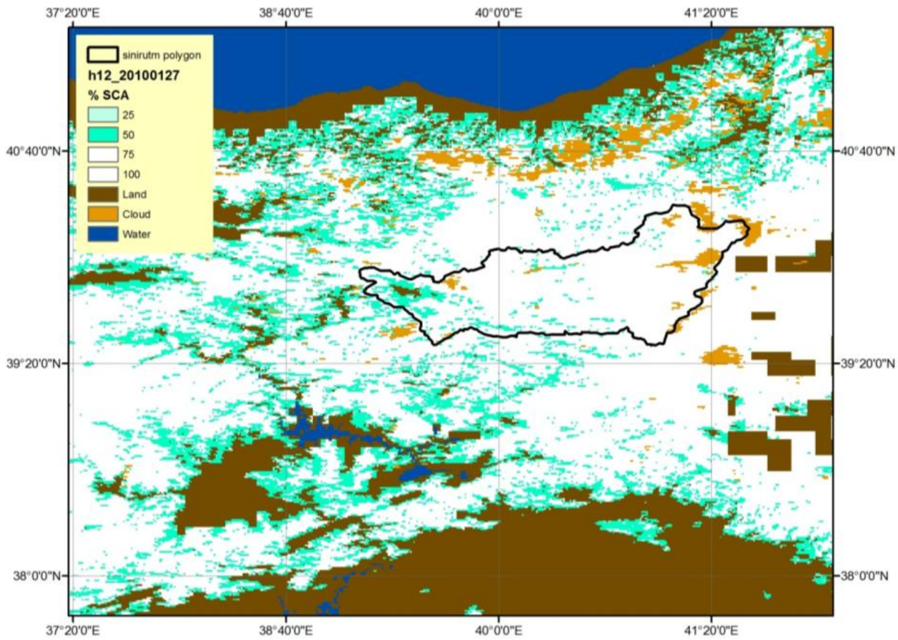


Figure 21 H12 product for 27.01.2010

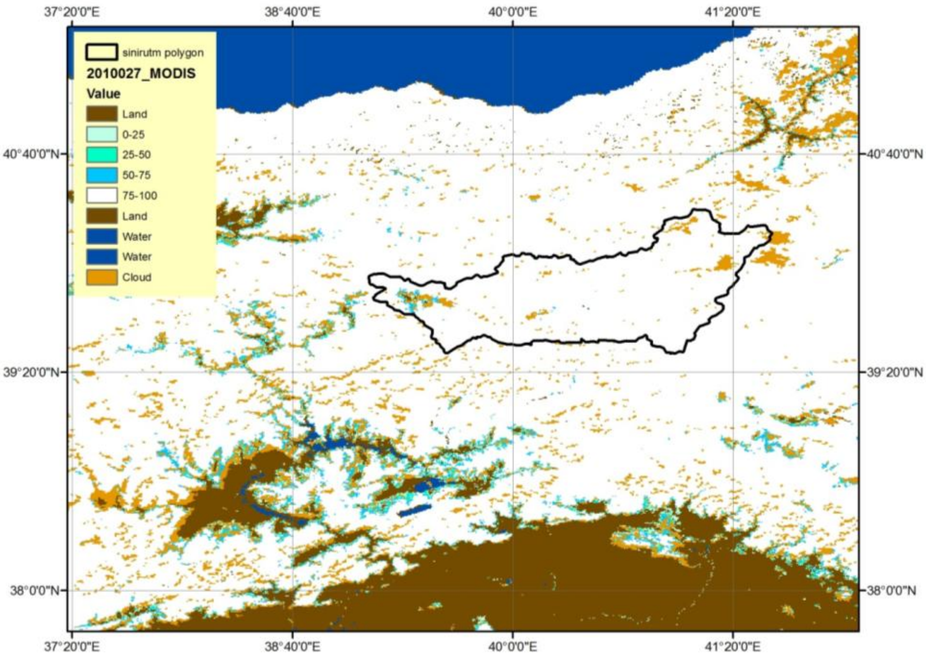


Figure 22 MODIS product for 27.01.2010

H12 \ MODIS	0%	0%-50%	50%-100%	total	User's Acc. (%)
0%	13	17	142	172	7.6
0%-50%	4	5	1559	1568	0.3
50%-100%	0	1	19295	19299	99.9
total	17	23	20996	21036	
Producer's Acc.(%)	76.5	21.7	91.9		

Table 8 The accuracy table obtained for 27.01.2010

Overall accuracy=91.81%

5.2.2 Case study for 13.03.2010

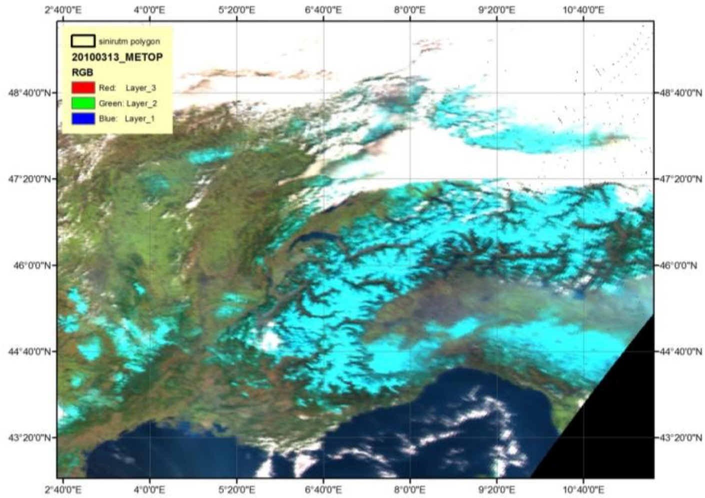


Figure 23 The RGB (Red: Band 3, Green: Band 2, Blue: Band 1) composite of METOP-AVHRR data for 13.03.2010

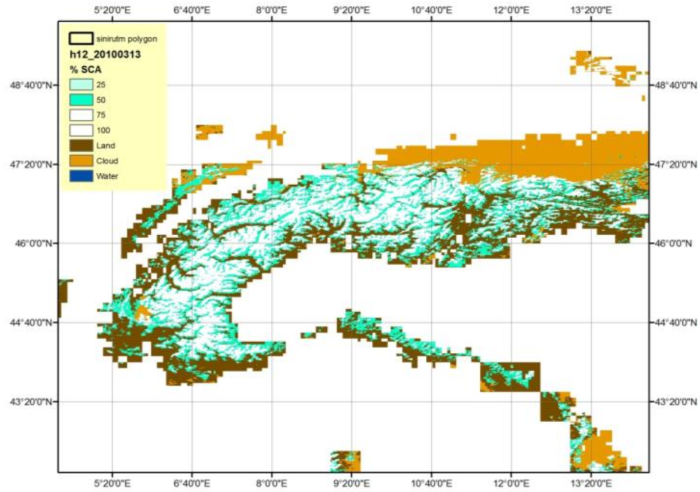


Figure 24 H12 product for 13.03.2010 (flat areas are masked with mountain-mask)

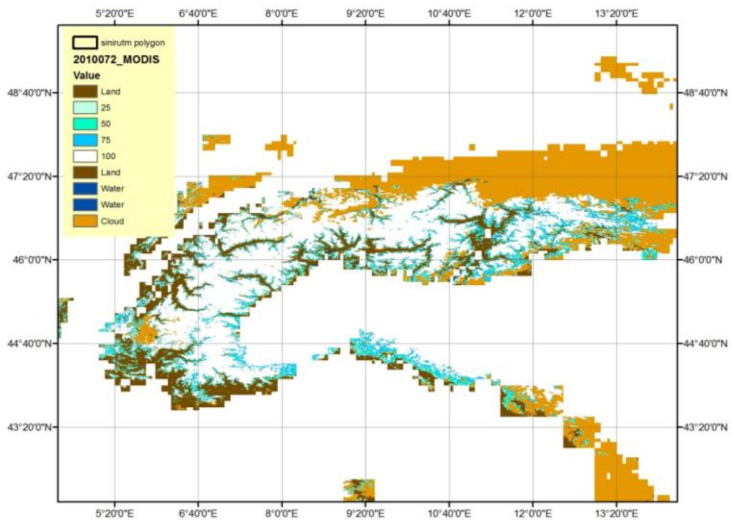


Figure 25 MODIS product for 27.01.2010 (flat areas are masked with mountain-mask)

5.2.3 Case study for 26.03.2011

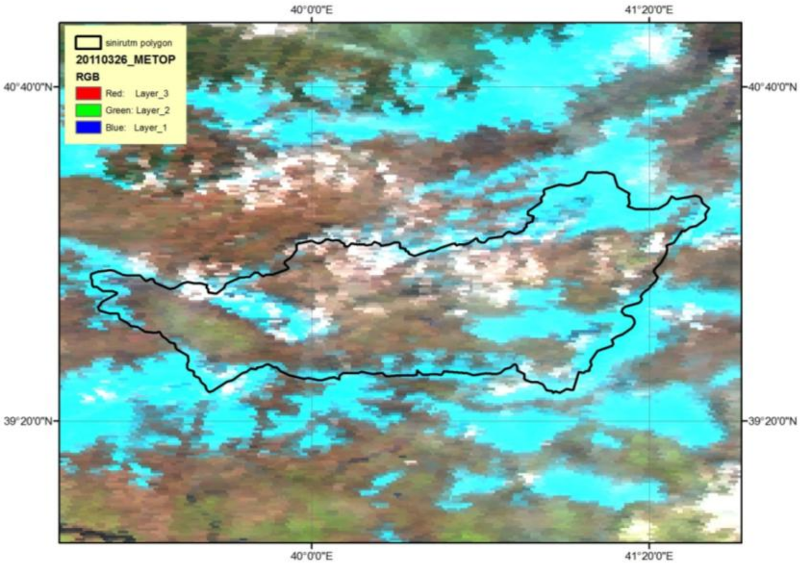


Figure 26 The RGB composite of METOP-AVHRR data for 26.03.2011

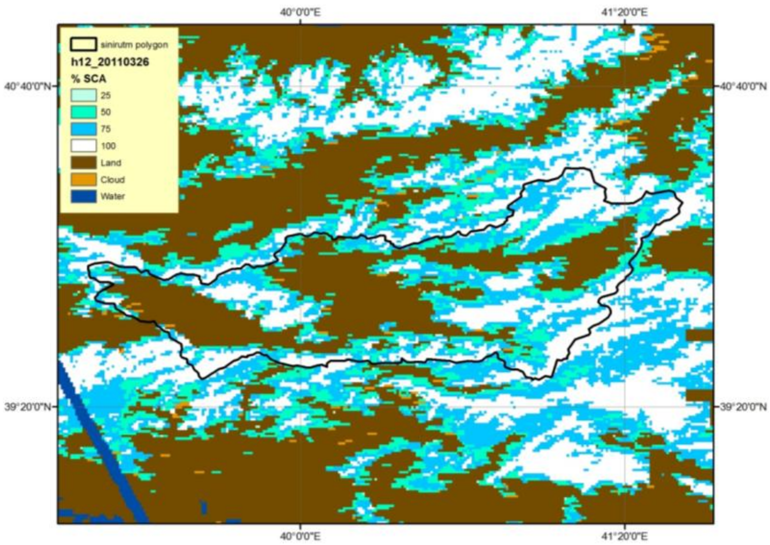


Figure 27 H12 product for 26.03.2011

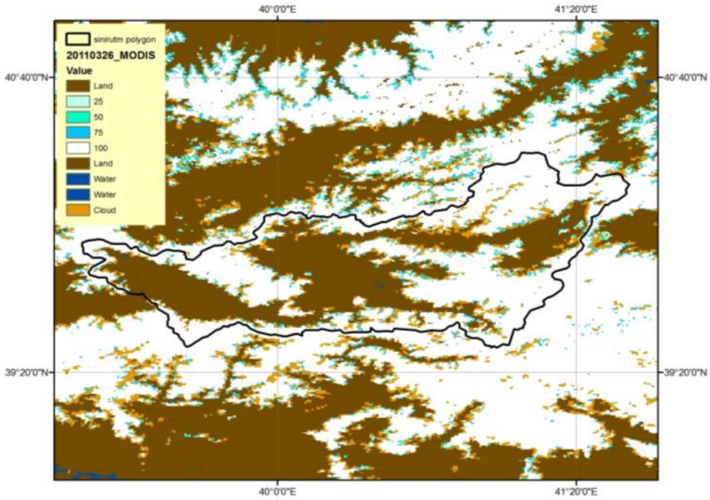


Figure 28 MODIS product for 26.03.2010

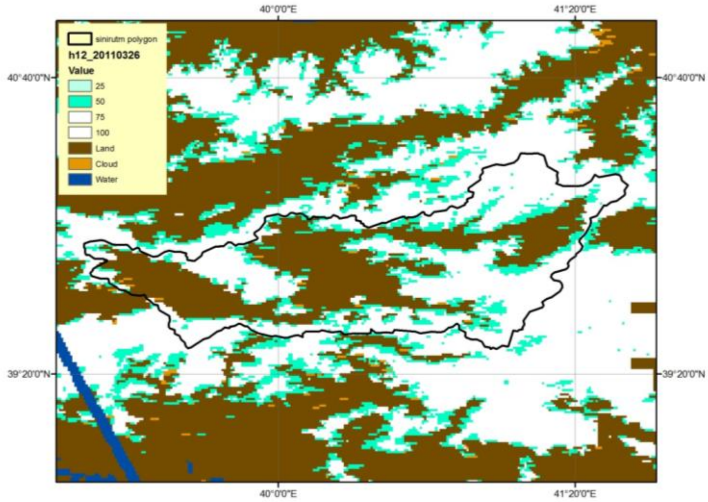


Figure 29 The fractional classes greater than 50% were merged into one class

MODIS H12	0%	0%-50%	50%-100%	Total	User's Acc. (%)
0%	6480	177	1066	7723	83.9
0%-50%	1054	102	1252	2408	4.2
50%-100%	603	151	9375	10129	92.5
Total	8137	430	11693	20260	
Producer's Acc.(%)	79.6	23.7	80.2		

Table 9 The accuracy table obtained for 26.03.2011

Overall Accuracy=78.8%

5.2.4 Conclusions

In case studies H12 product is compared with RGB composites of METOP-AVHRR data. The snow cover area classification performance of the product can be visually interpreted. The algorithm sometimes misclassifies high clouds as snow. The cloud/snow discrimination in operational snow products is still a very challenging subject. H12 product is also compared with another snow product, namely MODIS snow product. MODIS-Terra has better spatial resolution compared to METOP-AVHRR. From the results it is observed that both products are consistent. The consistency is high during full snow coverage in January (over all accuracy=92%), it decreases in melting season (March, over all accuracy =79%). It is observed that MODIS finds more 100% snow cover compared to fractional snow cover compared to H12 snow product. The user's and producer's accuracies for March 26, 2011 are high for no snow and snow 50%-100% classes, whereas for January 27, 2010 the user's accuracy for 0% snow cover class is low. 142 pixels of 50%-100% snow cover in MODIS product was classified as no-snow in H12 product. As the number of the samples in each class increases the accuracies also increases.

6 Validation results: long statistic analysis

6.1 Introduction

In this Chapter the validation results of the H12 large statistic analysis are reported for the period (10.2009 – 09.2010). The validation has been performed on the product release currently in force at the time of writing.
Finland and Turkey contributed to this Chapter by providing the overall accuracy on national territory. The ground data used for the validation have been described in Chapter 4.
To assess the degree of compliance of the product with product requirements (see [RD2]) all the PPVG members provided the long statistic results following the validation methodology reported in Chapter 3.

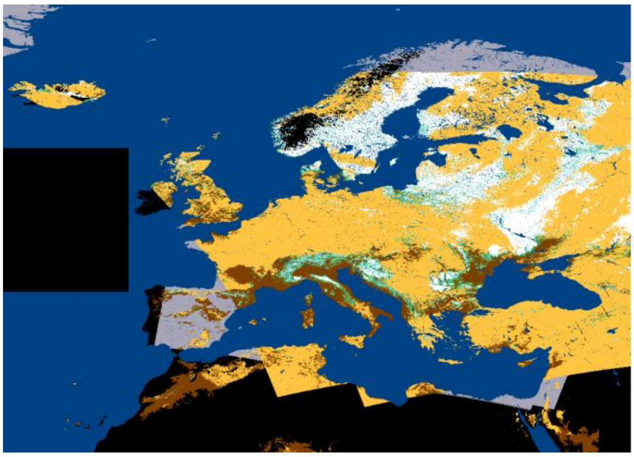
For product H12 the Product requirements are recorded in next table:

score	threshold	target	optimal
flat	40 % (RMSE)	20 % (RMSE)	10 % (RMSE)
mountain	45% (Overall accuracy	65% (Overall Accuracy)	95% (Overall Accuracy)

Table 10 Accuracy requirements for product SN-OBS-3

This implies that the main score to be evaluated has been the RMSE for flat areas and Overall Accuracy for mountainous areas. These scores have been defined in Chapter 3.
The long statistic results obtained in Finland and Turkey will be showed in the next sections.

6.2 Validation results in Finland



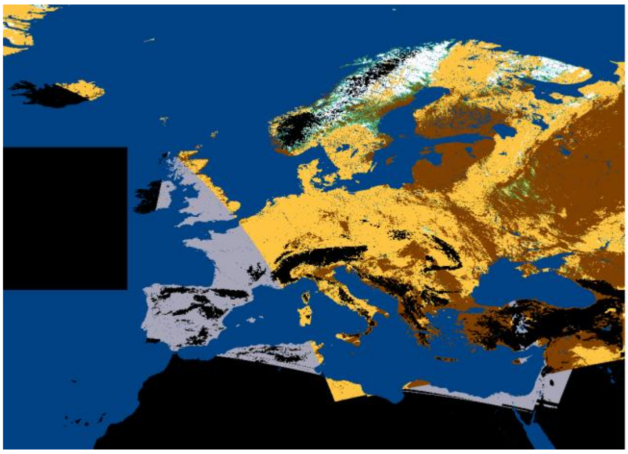


Figure 30 A sample of H12 products validated. March 14th 2010 (left) and May12th 2010 (right)

The validation data set includes daily H-SAF Fractional snow (H12) products from melting period 2010 and the concurrent at-ground Fractional snow observations from snow courses managed by the Finnish Environment Institute (SYKE)

The snow course network by SYKE consists of ~150 active snow courses. Since each course is visited only once per month – around the 15th day – the number of available data is limited, particularly for AVHRR acquisitions with cloud cover.

However, 117 comparison pairs for melting period 2010 were found. The dates of H12 products are listed in next table.

Dates for H12 products validated (at least one match with concurrent at-ground observation)
14-March-2010
15-March-2010
16-March-2010
17-March-2010
18-March-2010
19-March-2010
31-March-2010
14-April-2010
15-April-2010
16-April-2010
17-April-2010
18-April-2010
19-April-2010
01-May-2010
02-May-2010
10-May-2010
13-May-2010
14-May-2010
16-May-2010
18-May-2010

Table 11 Dates for H12 products validated

The validation result is shown in Figure 31. The RMSE of 17.6 %-units was gained; however this result is affected by the high number of matches at full snow cover. Since we wanted to address the SCAmod performance at fractional snow cover, the RMSE for cases less than 100% snow cover was calculated. This leaves us 69 cases giving RMSE of 23.0 %-units.

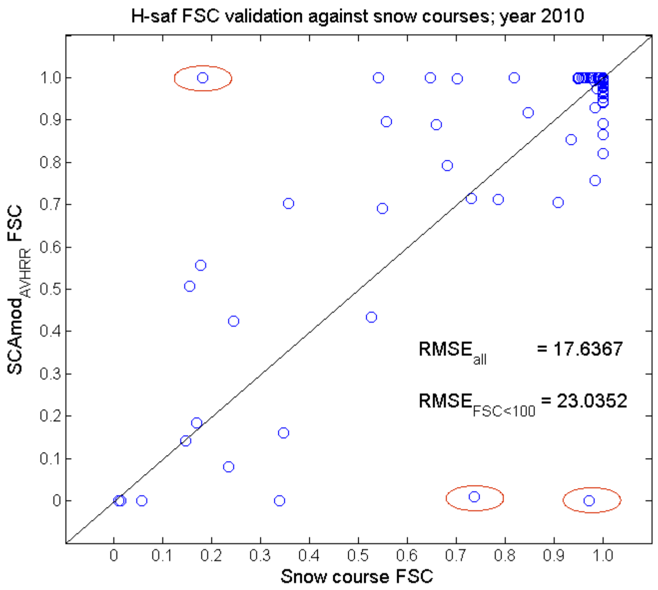


Figure 31 FSC from H12 against FSC from at-ground snow courses

The possible outliers included in the analysis are marked with red, in the above figure.

From figure above it's likely that there is three outliers in the dataset, probably caused by an unrecognized cloud or georeferencing error of the imagery. The removal of these cases will give us an RMSE of 11.2 %-units for all 88 cases and 15 %-units for cases less than 100% snow cover.

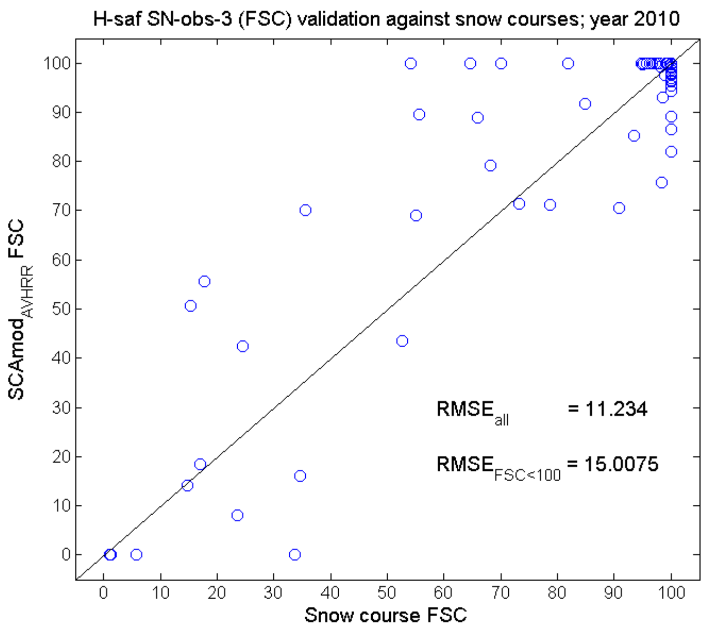


Figure 32 FSC from H12 against FSC from at-ground snow courses

In the figure here above, the possible three outliers are removed from the analysis.

The validation indicates that in principle, H12 product meets the pre-defined requirements of estimation accuracy < 20%. The occasional errors in georeferencing (case study 1) of the AVHRR sets a serious problem as the SCAmod method behind the product is related to a georeferenced background data (the apparent forest transmissivity). It should also be noted that the current product is based on averaging the FSC-estimates from several acquisitions on a certain day. Using large scale angles may weaken the accuracy of an individual estimate, which reflects to the daily average.

H12 product / Ground obs.	0%	0%-50%	50%-100%	100%	total	User's Acc. (%)
0%	0	4	1	0	5	
0%-50%	0	5	2	0	7	
50%-100%	0	3	13	17	33	
100%	0	1	18	53	72	
total	0	13	34	70	117	
Producer's Acc. (%)						
Overall Accuracy:	60.68%					

Table 12 Accuracy table for validation period October, 2010 – September, 2011 evaluated in Finland

6.3 Validation results in Turkey

The validation of effective snow cover detection from VIS and IR imagery from METOP-AVHRR (merged H12 product) is performed against synoptic stations, which have e-code values and snow depth measurements in Turkey. The in-situ data falling in the mountainous mask are included in the validation analysis. The validation dataset covers the period of October 2009-April 2010 and October 2010-April 2011 with 3626 in-situ measurements.

6.3.1 Validation with synoptic weather station data and e-codes

H12 product / Ground obs.	0%	0%-50%	50%-100%	100%	total	User's Acc. (%)
0%	854	5	0	150	1009	84.6
0%-50%	106	3	0	138	247	1.2
50%-100%	54	0	1	218	273	0.4
100%	13	0	0	83	96	86.4
total	1027	8	1	589	1625	
Producer's Acc. (%)	83.2	37.5	100	14.1		
Overall Accuracy:	57.91%					

Table 13 Accuracy table for validation period October, 2009 – April, 2010 evaluated in Turkey

H12 Ground	0%	0%-50%	50%-100%	100%		User's

product obs.					total	Acc. (%)
0%	1298	2	0	88	1388	93.5
0%-50%	69	0	2	38	109	0
50%-100%	104	0	1	71	176	0.6
100%	52	0	0	11	63	17.5
total	1523	2	3	208	1736	
Producer's Acc. (%)	85.2	0	33.3	5.2		
Overall Accuracy:		75.46%				

Table 14 Accuracy table for validation period October, 2010 – April, 2011 evaluated in Turkey

6.4 Validation reference Data

Remote sensing methods mostly classify Earth features on a binary way such as identifying a pixel as “snow” or “not snow”. But the need for detailed information caused scientists to develop sub-pixel classification methods. Considering that the hydrological models require detailed information of snow cover in order to accurately provide estimates of snow covered area, and snowmelt runoff values, sub-pixel algorithms for snow covered area determination have been started to be widely used since 1990’s (Nolin et. al 1993, Rosenthal & Dozier 1996, Hall et. al. 2002, Salomonson and Appel 2004, Metsamaki et. al. 2005). Those methods mostly utilize the spectral properties of the snow and perform different methods such as spectral mixture analysis or regression with tree-based models, which are explained in detail by Rosenthal and Dozier 1996.

Regardless of the method that has been used for the production of fractional snow cover maps, the methods used for validation of these maps do not differ a lot. Since the resultant product is not a binary map but detailed fractional information on snow cover, the measurements and observations made by ground stations are not possible to use for the validation of fractional snow cover maps. Although e-code measurements which give information about the percentage of the snow cover on land has been used for a while during the HSAF H-12 product validation, due to cancellation and unavailability of those measurements all over the world, now it is not possible to use them. Ground observations depending on personal observations contain subjectivity and especially for the rough terrain the observed classes are not homogenously distributed. Using another satellite sensor imagery that has a better spatial resolution is quite preferential and widely applied method for validation of sub-pixel satellite image products. Foppa et. al. 2007 used ASTER (90 m spatial resolution) data for the validation of NOAA-AVHRR (1.1 km spatial resolution) sub-pixel snow cover products, and Dobreva and Klein 2011 used maps from Landsat Enhanced Thematic Mapper Plus (30 m spatial resolution) for the validation of Terra-MODIS (500 m spatial resolution) fractional snow cover products. The subjectivity of snow classification from satellites having better spatial resolution can be eliminated by human interpretation rather than automatic classification methods.

References:

1) Rosenthal W. and Dozier J., 1996. Automated mapping of montane snow cover at subpixel resolution from the Landsat Thematic Mapper. WATER RESOURCES RESEARCH, VOL. 32, NO. 1, PAGES 115-130.
2) Hall DK., Riggs GA., Salomonson VV., DiGirolamo NE., Bayr KJ., 2002. MODIS snow-cover products, Remote Sensing of Environment, Volume 83, Issues 1–2, Pages 181-194
3) V.V Salomonson, I Appel, 2004. Estimating fractional snow cover from MODIS using the normalized difference snow index, Remote Sensing of Environment, Volume 89, Issue 3, Pages 351-360.
4) Metsämäki SJ., Anttila ST., Markus HJ., Vepsäläinen JM., 2005. A feasible method for fractional snow cover mapping in boreal zone based on a reflectance model, Remote Sensing of Environment, Vol. 95, Issue 1.

5) Foppa N., Hauser A., Oesch D., Wunderle S., Meister R., 2007. Validation of operational AVHRR subpixel snow retrievals over the European Alps based on ASTER data. International Journal of Remote Sensing Vol. 28, Iss. 21.
6) Dobreva ID. and Klein AG., 2011. Fractional snow cover mapping through artificial neural network analysis of MODIS surface reflectance, Remote Sensing of Environment, Volume 115, Issue 12, 3355-3366.
7) Nolin, A., Dozier, J. and Mertes, L., 1993. Mapping alpine snow using a spectral mixture modeling technique. Annals of Glaciology, 17, pp. 121–124.

6.5 Some conclusions

The overall accuracy has been evaluated for the period October, 2010 – April, 2011 in Finland and Turkey. The averaged overall accuracy obtained is equal to 66%.
As shown in the Table 16 the statistical scores obtained by the validation of H12 in SPVG are really close to the thresholds stated in the Product requirements (see [RD2]).

Between target and optimal	Between threshold and target	Threshold exceeded by < 50 %	Threshold exceeded by ≥ 50 %

Table 15 Simplified compliance analysis for product H12

Product requirements			H12
threshold	target	optimal	total
45%	65%	95%	66%

Table 16 H-SAF Accuracy requirements for H12 (Overall Accuracy)

Some general consideration when comparing the results from the validation activity with the stated product requirements:

a. Product requirements - There are reasons to believe that the current set of H-SAF Product requirements have been overstated. Therefore new requirements are proposed in the last project meeting.
b. The results obtained by the current validation procedure represent the convolution of at least three factors: the satellite product accuracy, the accuracy of the ground data used and the limitations of the comparison methodology (e.g., errors of space and time co-location, representativeness changing with scale, etc.). Therefore, the results currently found are by far pessimistic in respect of what is the real product performance.

7 Conclusions

The main problem in the validation of the H12 product is the number and subjectivity of the ground observations. Less number of synoptic observations records the e-code values and these values are too subjective, there are cases at zero snow depth some snow cover area fractions are reported. In the recorded values the number of observations in mid classes namely snow cover greater than 0 % and lower than 50 %, snow cover greater than 50% and lower than 100%, are limited. The e-codes are measured visually and they cover a relative small area whereas the measuring unit in the product is approximately 1 km x 1 km. Therefore it is unlikely that the snow cover is similar in the whole resolution unit as it is in the area used in the e-code determination. The e-code values are most reliable with snow free ground and fully

snow covered areas. Therefore the validation of the product turns to be the validation of a binary product. With the available data, the results are promising.
They are already satisfying the threshold value of the product requirement (see [RD2]). Since the mid-class observations are limited, the performance of the product in classifying these classes cannot be discussed. High producer's accuracy for the no-snow class indicates that the algorithm can find the no-snow on the ground. The producer's accuracy for the 100% snow class is low. 100% snow recorded on the ground is not mapped properly by the product. The algorithm tends to find snow first, then cloud and land. If the snow is missed in the classification, it may be due to the shallow depth of snow recorded by the ground observation which cannot be classified by the algorithm. Another reason can be the location of the ground observations which do not represent the pixel of the METOP-AVHRR instrument in a mountainous area. It is known that one of the difficulties in evaluating satellite snow maps with ground observations is the spatial representativeness of ground observations. When the 50%-100% class is considered together with 100% class, the producer's accuracy increases to 50%. This highlights the importance of the ground observations in validating the effective snow coverage.

8 Reference documents

[RD1] http://www.wmo.int/pages/prog/www/WMOCodes/Manual/WMO306_Vol-I-1-PartA.pdf

[RD2] Product Requirement Document, SAF/HSAF/PRD/1.3

Annex 1. Validation methodology for H12 – Effective snow cover by VIS/IR Radiometry

Zuhal Akyurek, zakyurek@metu.edu.tr, Kati Anttila, Kati.Anttila@fmi.fi

This document describes the methodology applied when validating H-SAF snow product H12 – Effective Snow Cover by VIS/IR Radiometry

Validation procedure

To properly validate H12 product, the following steps have to be taken:

6. Observation data containing e-codes or snow course data with visual estimates of snow covered area with values from 0 to 100 have to have to be gathered.
7. Satellite products need to be acquired.
8. Both observation and satellite data series need to be checked for consistency.
9. Comparison between the observation data and the product has to be performed.
10. Results of the comparison need to be presented.

Observation data

From the data collected by ground network, a subset containing snow cover depth for the *reference season* (1.10.2009 – 31.09.2010) is extracted and a local database is created.
The data is stored in plain text. Each file contains the data from all reporting stations for one day of the reference season. For each station the following columns (separated by whitespace) are assigned:

- date and time of measurement,
- number and name of the station or snow course as well as it's coordinates (Latitude(degrees), Longitude(degrees) and height (m) asl.,
- a flag indicating whether the observation site is located in mountainous or flat/forested area. The masking is performed by applying the mountain mask. The file “mountainmask_fsc.h5” is in TSMS ftp site at /OUT/h12/mountainmask
  address:
  ftp://hsaf.meteoroloji.gov.tr
  username: *snowtur*
  password: *rs37kar*
- e-codes: The e-codes are values given by visual inspection for the state of the snow cover. The values used in the validation are shown in Table 1.
- snow course data: while measuring the snow course (snow depth, swe) a visual inspection of the snow cover is made.

e -code	Explanation
0	Ground predominantly covered by ice
1	Compact or wet snow(with or without ice) covering less than one-half of the ground
2	Compact or wet snow (with or without ice) covering at least one-half of the ground but ground not completely covered
3	Even layer of compact or wet snow covering ground completely
4	Uneven layer of compact or wet snow covering ground completely
5	Loose dry snow covering less than one-half of the ground
6	Loose dry snow covering at least one-half of the ground but ground not completely covered
7	Even layer of loose dry snow covering ground completely
8	Uneven layer of loose dry snow covering ground completely
9	Snow covering ground completely; deep drifts

Table 17 he description of the e-codes

Satellite product

H-SAF H12 product is available at the FMI ftp server, ftp://ftp.fmi.fi.

An ftp client (e.g. FileZilla, WinSCP) is required to log in and retrieve the product, which is stored in the binary HDF5 files.

Data consistency check

To guarantee high quality of the validation it is advised to check if both the observation data and the satellite product are available for all days of the reference season.

Comparison between the observation data and the product

The nearest e-code extracted for the pixel is used in the validation. The snow cover fraction (FSCA) and the e-code values must be classified as follows:

H12 product:

FSCA=0%,

0%< FSCA< 50%,

50%=<FSCA< 100%,

FSCA=100%.

ecodes:

No snow=0%,

0%< ecodes(1,5)< 50%,

50%=<ecodes(2,6) < 100%,

ecodes(9,8,7,4,3) =100%.

Data	Reference data

set												
Snow map	Classes	0%		0-50%		50-100%		100%		Total (#)	Commission errors	
		%	#	%	#	%	#	%	#		%	#
	0%	**A0/(A0+A1+A2+A3)**	A0	**B0/(** B0+B1+B2+B3)	B0	**C0/(** C0+C1+C2+C3)	C0	**D0/(** D0+D1+D2+D3)	D0	A0+B0+C0+D0	(B0+C0+D0) / (A0+B0+C0+D0)	B0+C0+D0
	0-50%	**A1/(** A0+A1+A2+A3)	A1	**B1/(B0+B1+B2+B3)**	B1	**C1/(** C0+C1+C2+C3)	C1	**D1/(** D0+D1+D2+D3	D1	A1+B1+C1+D1	(A1+C1+D1) / (A1+B1+C1+D1)	A1+C1+D1
	50-100%	**A2/(** A0+A1+A2+A3)	A2	**B2/(** B0+B1+B2+B3)	B2	**C2/(C0+C1+C2+C3)**	C2	**D2/(** D0+D1+D2+D3	D2	A2+B2+C2+D2	(A2+B2+D2) / (A2+B2+C2+D2)	A2+B2+D2
	100%	**A3/(** A0+A1+A2+A3)	A3	**B3/(** B0+B1+B2+B3)	B3	**C3/(** C0+C1+C2+C3)	C3	**D3/(D0+D1+D2+D3**	D3	A3+B3+C3+D3	(A3+B3+C3) / (A3+B3+C3+D3)	A3+B3+C3
Total (#)			A0+A1+A2+A3		B0+B1+B2+B3		C0+C1+C2+C3		D0+D1+D2+D3	A0+B0+C0+D0+A1+B1+C1+D1+A2+B2+C2+D2+A3+B3+C3+D3	(B0+C0+D0+A1+C1+D1+A2+B2+D2+A3+B3+C3) / (A0+B0+C0+D0 + A1+B1+C1+D1+A2+B2+C2+D2+A3+B3+C3+D3)	B0+C0+D0+A1+C1+D1+A2+B2+D2+A3+B3+C3
Omission errors		**A0/** (A0+A1+A2+A3)		**B1/** (B0+B1+B2+B3)		**C2/** (C0+C1+C2+C3)		**D3/** (D0+D1+D2+D3				

Table 18 Contingency matrix prepared for e-codes

A0 number of correct 0% observations,
A1 number of 1-50% FSCA in the snow products corresponding to 0% in the observations
A2 number of 51-99% FSCA in the snow products corresponding to 0% in the observations,
A3 number of 100% FSCA in the snow products corresponding to 0% in the observations,
B0 number of 0% observations in the snow product corresponding to 1-50% in the observations,
B1 number of correct 1-50% observations
B2 number of 51-99% FSCA in the snow products corresponding to 1-50% in the observations,
B3 number of 100% FSCA in the snow products corresponding to 1-50% in the observations
C0 number of 0% observations in the snow product corresponding to 51-99% in the observations,
C1 number of 1-50% FSCA in the snow products corresponding to 51-99% in the observations,
C2 number of correct 51-99% observations
C3 number of 100% FSCA in the snow products corresponding to 51-99% in the observations
D0 number of 0% observations in the snow product corresponding to 100% in the observations,
D1 number of 1-50% FSCA in the snow products corresponding to 100% in the observations,
D2 number of 51-99% FSCA in the snow products corresponding to 100% in the observations
D3 number of correct 100% observations

$$OverallAccuracy(\%) = \frac{(A0 + B1 + C2 + D3)}{A0 + B0 + C0 + D0 + A1 + B1 + C1 + D1 + A2 + B2 + C2 + D2 + A3 + B3 + C3 + D3)}$$

For snow course data RMSE will be calculated.

$$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(sat_k - true_k)^2}$$

To complement the validation, 3 case studies for the reference season should be presented.

For each case study quantitative analysis in the same manner like for the longer period (explained above) should be performed. Additionally, qualitative analysis by comparing pictures of H12 product with different satellite products (e.g. NOAA-AVHRR RGB composites, MODIS snow products, classified Landsat images) should be performed.

For each case study teams are welcome to introduce their own additional analysis or algorithms.

Reference:

http://www.wmo.int/pages/prog/www/WMOCodes/Manual/WMO306_Vol-I-1-PartA.pdf

Annex 2. Mountainous Area Mask Determination for HSAF Project

In the study "Environment of mountainous areas (Mountain Areas in Europe-Final Report)" altitude and slope data are used in order to obtain mountainous areas for Europe (10 o W- 45 o E, 25 oS - 75 o N).
GTOPO30 DEM, obtained from Eurostat/GISCO, is used as altitude data (Figure 49).
The slope map is derived from GTOPO30 DEM (Figure 52). The mesh grid with 0.5 degrees interval is generated for whole area. The grid interval is decreased to 0.25 o for the areas where altitude is greater than 700m. Since The H-SAF snow products will be generated in 5 and 10 km spatial resolution, 0.25o (around 25km) interval is considered to be a suitable interval due to storage and processing limitations. The mean, standard deviation, range, minimum and maximum altitude for each grid are calculated. The mean elevation and standard deviation in elevation are given in Figures 51-52. The roughness of the terrain is also a critical factor in many regards. Therefore the mean, standard deviation, range, minimum and maximum slope for each grid are calculated. The mean elevation and standard deviation in slope are given in Figures 53-54. 1000 m is considered to be a threshold to classify the mountainous areas. For the transitional areas altitude and slope variations are also considered. The mask for mountainous areas is given in Figure 7. The mountainous areas are determined according to the following rule Mean altitude >=1000m or Mean altitude >=600m and STDSlope >=2 In order to analyse the land cover variation in mountains areas the GLC2000 land cover database is used.
The overlay operation is performed and the area percentages for each class in the database belonging to Europe, North Europe and Southeast Europe are obtained (Table below). Forest is the main land cover class in the mountains areas in Europe.

Land use class	Europe (%)	North Europe (%)	East Europe (%)
Forest	51.99	27.22	42.63
Tundra		46.29	
Shrub	8.53	23.18	2.39
Cropland	29.97	0.34	17.09
Grassland	4.33	1.55	
Hardpan and Consolidated			20.51
Others	5.18	1.42	17.38

Table 19 Land use/cover classes in mountainous areas

Annex 3. Acronyms

AMSU	Advanced Microwave Sounding Unit (on NOAA and MetOp)
AMSU-A	Advanced Microwave Sounding Unit - A (on NOAA and MetOp)
AMSU-B	Advanced Microwave Sounding Unit - B (on NOAA up to 17)
ATDD	Algorithms Theoretical Definition Document
AU	Anadolu University (in Turkey)
BfG	Bundesanstalt für Gewässerkunde (in Germany)
CAF	Central Application Facility (of EUMETSAT)
CDOP	Continuous Development-Operations Phase
CESBIO	Centre d'Etudes Spatiales de la BIOsphere (of CNRS, in France)
CM-SAF	SAF on Climate Monitoring
CNMCA	Centro Nazionale di Meteorologia e Climatologia Aeronautica (in Italy)
CNR	Consiglio Nazionale delle Ricerche (of Italy)
CNRS	Centre Nationale de la Recherche Scientifique (of France)
DMSP	Defense Meteorological Satellite Program

DPC	Dipartimento Protezione Civile (of Italy)
EARS	EUMETSAT Advanced Retransmission Service
ECMWF	European Centre for Medium-range Weather Forecasts
EDC	EUMETSAT Data Centre, previously known as U-MARF
EUM	Short for EUMETSAT
EUMETCast	EUMETSAT's Broadcast System for Environmental Data
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FMI	Finnish Meteorological Institute
FTP	File Transfer Protocol
GEO	Geostationary Earth Orbit
GRAS-SAF	SAF on GRAS Meteorology
HDF	Hierarchical Data Format
HRV	High Resolution Visible (one SEVIRI channel)
H-SAF	SAF on Support to Operational Hydrology and Water Management
IDL©	Interactive Data Language
IFOV	Instantaneous Field Of View
IMWM	Institute of Meteorology and Water Management (in Poland)
IPF	Institut für Photogrammetrie und Fernerkundung (of TU-Wien, in Austria)
IPWG	International Precipitation Working Group
IR	Infra Red
IRM	Institut Royal Météorologique (of Belgium) (alternative of RMI)
ISAC	Istituto di Scienze dell'Atmosfera e del Clima (of CNR, Italy)
ITU	İstanbul Technical University (in Turkey)
LATMOS	Laboratoire Atmosphères, Milieux, Observations Spatiales (of CNRS, in France)
LEO	Low Earth Orbit
LSA-SAF	SAF on Land Surface Analysis
Météo France	National Meteorological Service of France
METU	Middle East Technical University (in Turkey)
MHS	Microwave Humidity Sounder (on NOAA 18 and 19, and on MetOp)
MSG	Meteosat Second Generation (Meteosat 8, 9, 10, 11)
MVIRI	Meteosat Visible and Infra Red Imager (on Meteosat up to 7)
MW	Micro Wave
NESDIS	National Environmental Satellite, Data and Information Services
NMA	National Meteorological Administration (of Romania)
NOAA	National Oceanic and Atmospheric Administration (Agency and satellite)
NWC-SAF	SAF in support to Nowcasting & Very Short Range Forecasting
NWP	Numerical Weather Prediction
NWP-SAF	SAF on Numerical Weather Prediction
O3M-SAF	SAF on Ozone and Atmospheric Chemistry Monitoring
OMSZ	Hungarian Meteorological Service
ORR	Operations Readiness Review
OSI-SAF	SAF on Ocean and Sea Ice
PDF	Probability Density Function
PEHRPP	Pilot Evaluation of High Resolution Precipitation Products
Pixel	Picture element
PMW	Passive Micro-Wave
PP	Project Plan
PPVG	Precipitation Products Validation Group (sometimes also PVG, Precipitation Validation Group)
PR	Precipitation Radar (on TRMM)
PRD	Product Requirements Document
PUM	Product User Manual
PVR	Product Validation Report
RMI	Royal Meteorological Institute (of Belgium) (alternative of IRM)
RR	Rain Rate
RU	Rapid Update
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager (on Meteosat from 8 onwards)
SHMÚ	Slovak Hydro-Meteorological Institute

SSM/I	Special Sensor Microwave / Imager (on DMSP up to F-15)
SSMIS	Special Sensor Microwave Imager/Sounder (on DMSP starting with S-16)
SYKE	Suomen ympäristökeskus (Finnish Environment Institute)
T_{BB}	Equivalent Blackbody Temperature (used for IR)
TKK	Teknillinen korkeakoulu (Helsinki University of Technology)
TMI	TRMM Microwave Imager (on TRMM)
TRMM	Tropical Rainfall Measuring Mission UKMO
TSMS	Turkish State Meteorological Service
TU-Wien	Technische Universität Wien (in Austria)
U-MARF	Unified Meteorological Archive and Retrieval Facility
UniFe	University of Ferrara (in Italy)
UTC	Universal Coordinated Time
VIS	Visible
ZAMG	Zentralanstalt für Meteorologie und Geodynamik (of Austria)