The EUMETSAT Satellite Application Facility on Land Surface Analysis (LSA SAF)

Algorithm Theoretical Basis Document (ATBD)

Snow Cover (SC)

PRODUCTS: H31 (MSG/SEVIRI SC)

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1. Introduction

Snow can have a high impact on people's everyday lives. Extensive snow accumulation can cause troubles in traffic (cars, trains, airplanes, delivery trucks ...). In certain areas seasonal flooding causes damage to e.g. crop lands and residential areas. Flood forecasting can be done using hydrological models, where snow parameters such as fractional snow cover and snow water equivalent are used as inputs. The hydrological models are used also in hydro power industry for discharge estimation. Albedo of snow is very high and therefore has a big effect in the radiation balance. This in turn is an important parameter in weather forecasting (especially during the melting season, when the changes are rapid) and in climatological models. Snow is used as a tourist attraction, especially in alpine and northern regions. All these aforementioned points have also a direct or indirect economical connection.

With the growing number of satellite platforms and improvements in processing and transmission of digital data obtained from them, it has become possible to obtain frequent snow cover information in near real-time through a variety of different sources. Retrieving snow products from satellite data is still a challenging task. Sparse ground network due to the rough topography, heterogeneity in snow distribution, the effects of slope, aspect, land use, wind and some other factors in the accumulation and melting periods of snow make the retrieving of snow products from satellite data difficult.

EUMETSAT's LSA SAF has been producing daily snow cover product with a baseline algorithm for the areas covered by MSG/SEVIRI instrument since 2007. The first version was based on the cloud mask product of the EUMETSAT's Nowcasting Satellite Application Facility (NWC SAF). The aim of NWC SAF cloud mask is to classify cloud cover. Thus the snow detection was only a rather limited by-product (Derrien, 2005). This approach had some severe limitations; hence version 2 of the snow cover algorithm was developed at the Finnish Meteorological Institute (FMI). Version 2 of the snow cover algorithm has been used to generate the snow cover product of LSA SAF since summer 2007. The algorithm and some validation results are published in Siljamo and Hyvärinen (2011). Further validation and user feedback has shown the value of the product.

This document describes the snow extent product H31 (MSG/SEVIRI SC) v2..

MSG/SEVIRI snow detection algorithm has not been changed since version 2.50. The main reason for the code changes from v2.50 to v2.90 is the upgrade from HDF5 version 1.6 to v1.8 at the LSA SAF production system. A number of minor bug fixes are also included. These do not change the actual algorithm.

The MSG/SEVIRI snow detection algorithm produces snow cover product over the full MSG/SEVIRI disk. The data is available in full disk format and also in regional format in four different geographical regions (Europe, North Africa, South Africa, and South America).

The best reference for satellite product validation would be in situ measurements, but such data is difficult to obtain in large scale. Especially, snow coverage data is almost impossible the get. Snow depth data is available from synoptic weather stations, but there are serious limitations in the way the snow cover is reported in the weather observations. The presence of snow is not reported in many stations, and the absence of snow is usually not reported at all. Snow depth observations can be automatic. For snow extent validation the best available observation type is state of the ground which provides information about snow cover. Unfortunately this is manual observation which is not available from all stations.

Therefore we used NOAA/NESDIS IMS product (Helfrich et al, 2007) as a baseline to which MSG/SEVIRI SC product was compared. NOAA/NESDIS IMS product uses several other data sources which include also microwave instruments. These can be used to detect dry snow under the clouds or in bad lighting conditions. However, the IMS algorithm is not fully automatic.

Since the transfer of he MSG/SEVIRI product to HSAF, the product H31 has been validated as a part of the combined flatland + mountain snow product H10 which is identical in flat land areas. The validation results are available in HSAF.

There is also similar snow extent product for Metop/AVHRR. The details of that product are in Metop/AVHRR ATBD document.

2. Theoretical Background

2.1 Algorithm development in general

The visual and IR channels can be used for snow cover detection only in cloud free conditions. Different surfaces have different reflectance properties which suggest that these differences can be used to separate different surfaces. Typical spectral properties of different surfaces have been measured in laboratory and in situ (see e.g. Baldridge et al, 2008) although these can not be used directly as a basis for satellite algorithms. There is always lots of variability in natural surface types. The grain size of the snow cover changes over time and space, the wetness of snow is changing and the reflecting properties change when the surface is viewed from different angles and in different lighting conditions. Also the vegetation is highly variable even in winter. This natural variability makes it quite difficult to develop a general classification algorithm for snow cover. Finally there is also the atmosphere which must be taken in account when surface and laboratory measurements are compared to satellite measurements.

Figure 1 show as an example three surface types: fine snow, coniferous trees and pale brown silty loam. These are based on laboratory measurements and models. Some commonly used satellite instrument channels are also presented. The figure show that the SEVIRI channels 1, 2 and 3 and AVHRR channel 1, 2 and 3A can be used for snow classification at least if the type of snow is known.

Geostationary satellites are not the best solution for snow detection because the spatial resolution is usually quite low in high latitudes i.e. in the most often snow covered area. However, excellent temporal resolution (15 minutes) is an advantage when the algorithm is based on visual and IR channels of the SEVERI instrument. Polar satellites can produce images from specified regions 2-4 times each day if the area is cloud free about the same time each day. Geostationary instruments such as MSG/SEVIRI produce images every 15 minutes and it is much more likely that at least some of the images are cloud free. If the cloud free period is longer the changing lighting conditions can help the classification.

Cloud cover is also a severe limitation on optical channels. Active and passive microwave methods would be better suited for cloud covered areas, but the spatial resolution of the passive microwave instruments is quite poor when compared to optical channels. Active microwave instruments i.e. radars have better resolution, but unfortunately these instruments need much more processing before the data is in practical form.

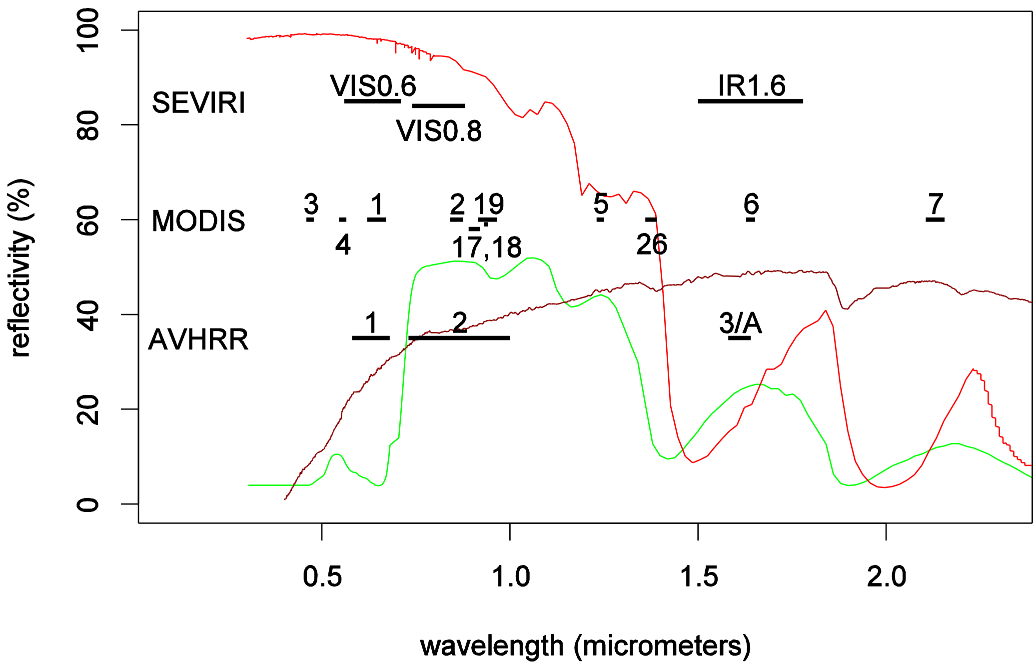

Figure 1 *Example of reflectances of three different surfaces and commonly used satellite instrument channels. Surface reflectances (snow (red), vegetation (green) and bare earth (brown)) based on ASTER Spectral Library v 2.*

2.1.1 MSG/SEVIRI

The algorithm employs six SEVIRI channels (0.6, 0.8, 1.6, 3.9, 10.8 and 12.0 µm), sun and satellite zenith and azimuth angles, land cover type and land surface temperature classification produced by LSA SAF. The capabilities of channels around 1.6 µm and 3.9 µm to discriminate low clouds and snow have been widely reported (Matson 1991, Kidder 1984).

The development of the version 2 of the MSG/SEVIRI snow cover classification algorithm was started by subjective classification of selected areas in representative MSG/SEVIRI images. We used several images between November 2006 and August 2007 from which we selected samples of snow covered and snow free areas, different cloud types and also areas where the surface type could be seen through clouds. Over half a million MSG/SEVIRI pixels were classified to form a data set for algorithm development.

The actual extent of snow cover was determined subjectively using ground observations and MODIS images. Figure 2 and Figure 3 shows two examples of scatter plots demonstrating how the various classes differ from each other. These plots suggest the possibility to automatically classify MSG/SEVIRI images to snow covered and snow free classes.

First version of the new algorithm (v2.00) has been under continuous development since 2007. The empirical nature of the algorithm is the main reason for changes. The development data was collected from a rather limited conditions and time period. There are snow types and snow conditions which were not available during the development period. New versions have been developed to enhance the capabilities of the SC algorithm to classify cloud free pixels and to classify incorrectly classified pixels.

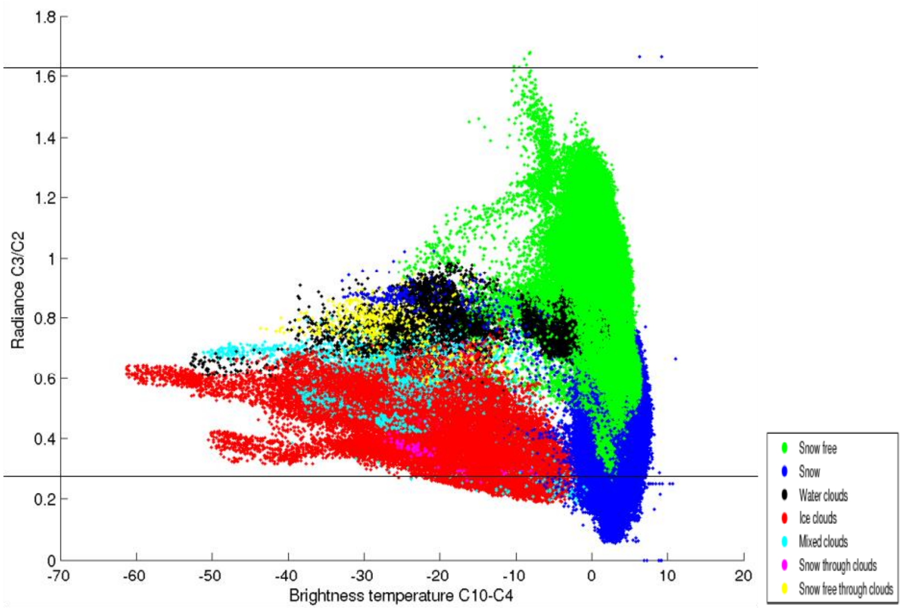

Figure 2 *One example of the scatter plots of the development data set. On the vertical axis both plots show the radiance ratio of SEVIRI channels 2 and 3. On the left the*

horizontal axis is brightness temperature difference of channels 10 and 4. On the right horizontal axis is the sun azimuth angle.

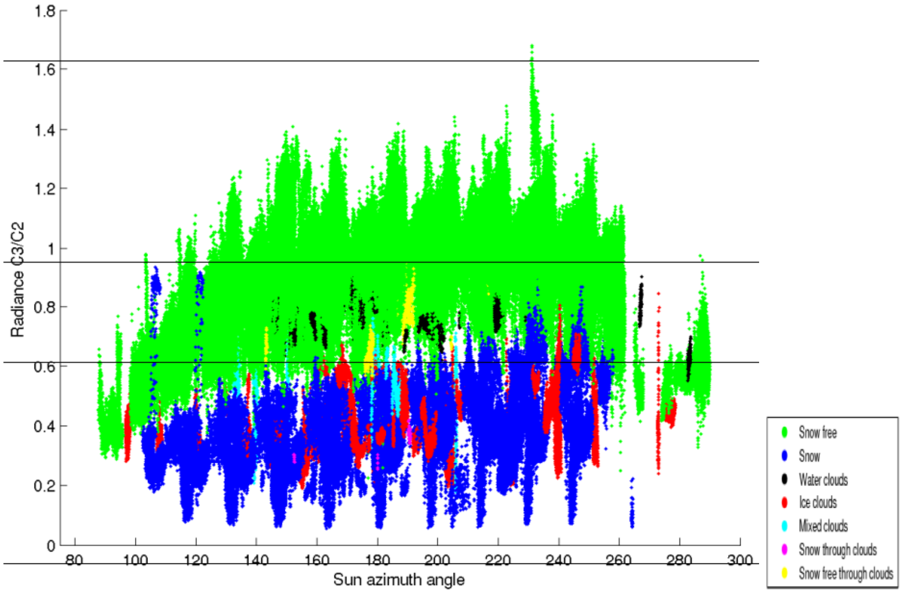

Figure 3 *Second example of the scatter plots of the development data set. On the vertical axis both plots show the radiance ratio of SEVIRI channels 2 and 3. On the left the horizontal axis is brightness temperature difference of channels 10 and 4. On the right horizontal axis is the sun azimuth angle.*

3. Algorithm Description

3.1 MSG/SEVIRI

3.1.1 Algorithm Formulation

The LSA SAF MSG/SEVIRI snow cover algorithm is basically a thresholding method based on the different properties of the snow covered and snow free surfaces and clouds. The LSA SAF MSG/SEVIRI snow cover is a daily product, but it is produced in two separate phases. Phase 1 is the SC1 snow cover product which is based on one cycle of SEVIRI images (every 15 minutes). All of the SC1 products are used to produce the daily LSA SAF snow cover product (SC2).

The calculation of the SC1 product is done every 15 minutes when the new data is available. The plots in Figure 2 and Figure 3 and other similar plots where used to develop a set of thresholding rules. A simplified overview of the SC1 algorithm is presented in the Figure 4 and all the rules in the Table 1.

The classification starts by setting all the pixels as unclassified. Then several tests are applied one by one until all the rules have been applied. As a result each pixel is classified to one of the snow cover (or snow free) classes or remains unclassified. Usually the pixel is unclassified if it is too dark, cloudy or in the area where satellite elevation angle is too low. There are also rules which remove obvious misclassifications such as pixels where the land surface is too warm to contain snow.

The class of partial or in some sense probable snow is used if the pixel is both snow free and snow covered during the same day or if the snow cover in the pixel is patchy or otherwise partial. This class is not yet well defined, because there are only a very limited number of reliable surface observations which could be used to estimate the accuracy of this classification.

Once per day the daily Snow Cover (SC2) product is calculated using the SC1 products of the day. Again the system classifies each pixel as snow free, partially snow covered or totally snow covered. For the daily LSA SAF snow cover product, all snow cover maps which are produced every 15 minutes are combined. The algorithm counts the number of different classifications for each pixel and then determines the final daily classification if there have been reasonable amount of cloud free observations during the day. A simplified structure of the algorithm is presented in Figure 5 and the actual rules in Table 2.

An example of the daily MSG/SEVIRI snow cover product in Europe is presented in the Figure 6. Snow detection is challenging during the spring when the last remains of the snow cover in Europe is in the extreme edge of the MSG/SEVIRI disk.

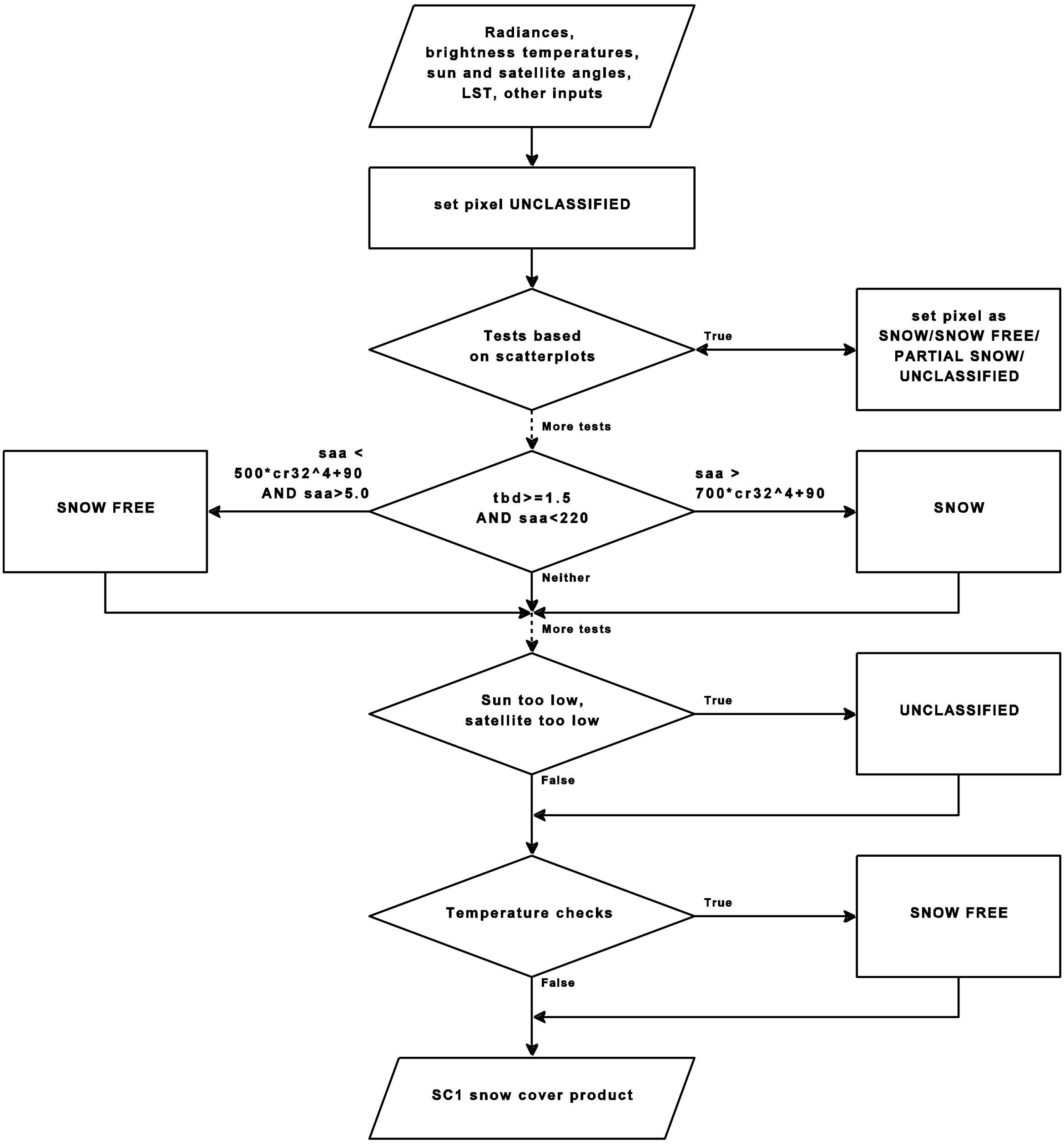

Figure 4 *Simplified structure of the single image part (SC1) of the LSASAF MSG/SEVIRI snow cover algorithm.*

Table 1 *List of classification rules of the LandSAF MSG/SEVIRI SC1 snow cover algorithm. These rules are applied one by one. If the condition is true the snow cover status is set to the defined value. The final snow cover status is the value set after all the rules are checked. Some definition tbd =* $T_{B10} - T_{B4}$*, cx = radiance in channel x, cr32 = c3/c2, lst= LSASAF MSG/SEVIRI LST, LC = land cover type, SC current classification etc.*

RULE	COVER TYPE
	UNCLASSIFIED
tbd >= 0 AND cr32 < 0.6	PARTIAL
tbd >= 2.5	PARTIAL
tbd <= -2.5 AND cr32 < 0.90	UNCLASSIFIED
cr32 < 0.96 AND cr32 >= 0.62 AND cr31 < 1.22 AND cr31 >= 0.77 AND cr21 < 1.49 AND cr21 >= 1.15	UNCLASSIFIED
tbd >= 1.5 AND saa < 220 AND saa > 700*cr32^4 + 90	SNOW
tbd >= 1.5 AND saa < 220 AND saa < 500*cr32^4 + 90 AND saa > 5.0	NO SNOW
tbd >= 1.5 AND saa >= 220 AND cr32 >= 0.82	NO SNOW
tbd >= 1.5 AND saa >= 260 AND cr32 >= 0.30	NO SNOW
cr32 < 0.18	SNOW
tbd >= -2.0 AND tbd <= 1.5 AND cr32 < 0.5	SNOW
tbd >= -2.0 AND tbd <=20.0 AND cr32 < 0.290	SNOW
tbd >= 5.8	SNOW
cr31 >= 1.50 AND tbd > -25	NO SNOW
cr32 >= 1.05 AND tbd > -15	NO SNOW
sza > 80.0	UNCLASSIFIED
vza > 85.0	UNCLASSIFIED
sza > 70.0 AND (saa < 90.0 OR saa > 270.0	UNCLASSIFIED
(t9+t10)/2 >= 278.0 AND (SC = PARTIAL OR SC = SNOW) AND LC >= 6 AND LC <= 14	NO SNOW
during summer (month>=6 AND month <=10):	
(t9+t10)/2 >= 278.0 AND (SC = PARTIAL OR SC = SNOW) AND LC >= 1 AND LC <= 5)	NO SNOW
c1<0.001 OR c2<0.001 OR c3<0.001 OR c4<0.001 OR c9<0.001 OR c10<0.001	UNCLASSIFIED
lst >= 10.0	NO SNOW

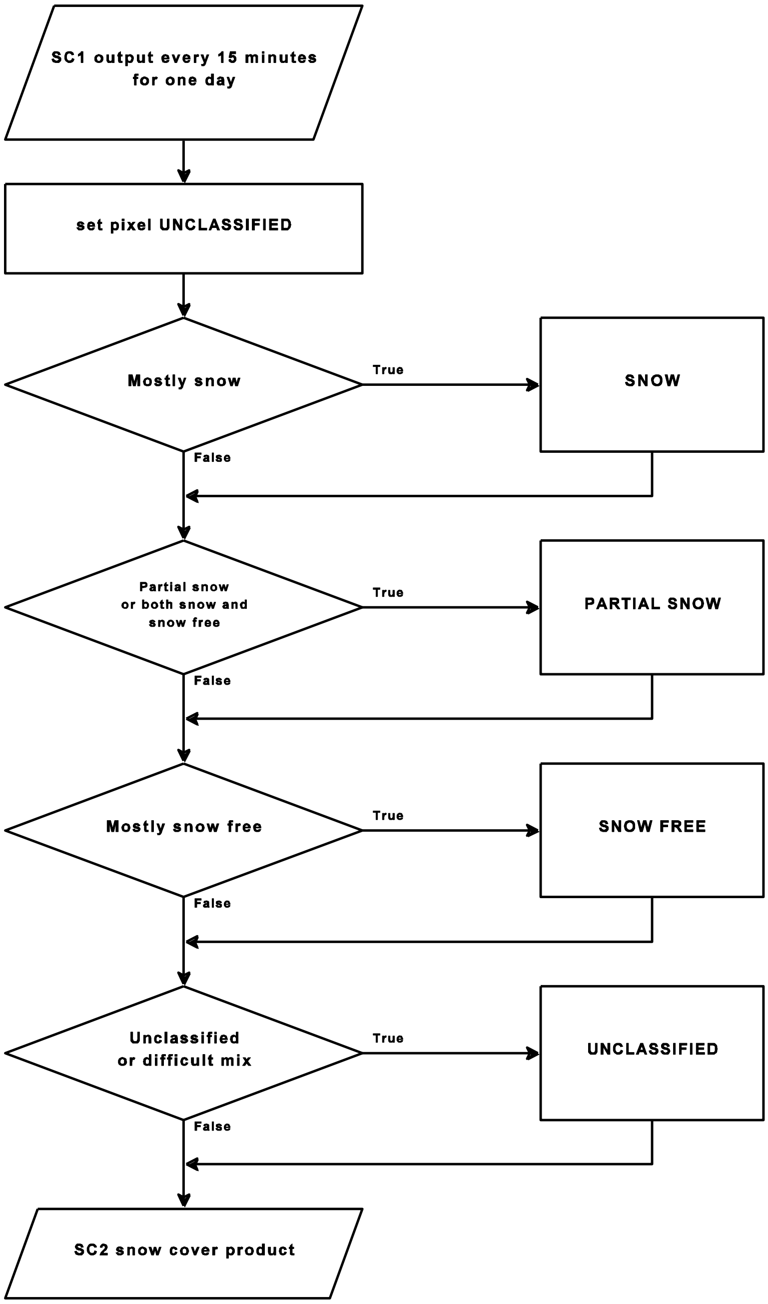

Figure 5 *Simplified structure of the daily part of the LSASAF MSG/SEVIRI snow cover algorithm (SC2).*

Table 2 *List of the rules for daily MSG/SEVIRI SC product. N is the total number of classified observations during the day in each pixel. S, P and F are the numbers of snow covered, partially snow covered and snow free observations, respectively. These rules are used one after the other from the top and the classification is set when the conditions match first time. If none of the rules match, the default classification is used.*

Rules	Classification
S>N/3 AND S>7 AND F<N/4 AND F<4	SNOW
F>N/3 AND F>7 AND S<N/4 AND S<4	NO SNOW
F>2 AND F≤8 AND S>2 AND S≤8	PARTIAL SNOW
F≥4 AND S≤1 AND P≤1	NO SNOW
S≥4 AND F≤1 AND P≤1	SNOW
P>N/3 AND P>3 AND:	
F=0 AND S>4 or	SNOW
F=0 AND S>1 AND S≤4 or	PARTIAL SNOW
F>1 AND F≤6 AND S>1 AND S≤6 or	PARTIAL SNOW
F≥P AND S=0 or	NO SNOW
2F<P AND S=0 or	PARTIAL SNOW

3.1.2 Input Data

The algorithm employs six SEVIRI channels (0.6, 0.8, 1.6, 3.9, 10.8 and 12.0 µm), sun and satellite zenith and azimuth angles, land cover type and land surface temperature (LST) classification produced by LSA SAF. This data is used for every 15 minute cycle of the SEVIRI instrument. Input data is either pre-processed by LSA SAF or they are other LSA SAF products in HDF5 file format.

3.1.3 Snow Cover Quality Control

Currently the quality flags of the snow cover algorithm are based on the previous version (version 1) of the SC algorithm. Some of the rules have been changed. Improved and more reliable quality flags will be developed when there are reliable surface observations of snow coverage, but currently the flags try to provide an estimate of the accuracy.

Validation of snow cover product H31 is performed through comparisons with independent data (e.g., NOAA/NESDIS IMS). A discussion of validation results may be found in the SC Validation Report.

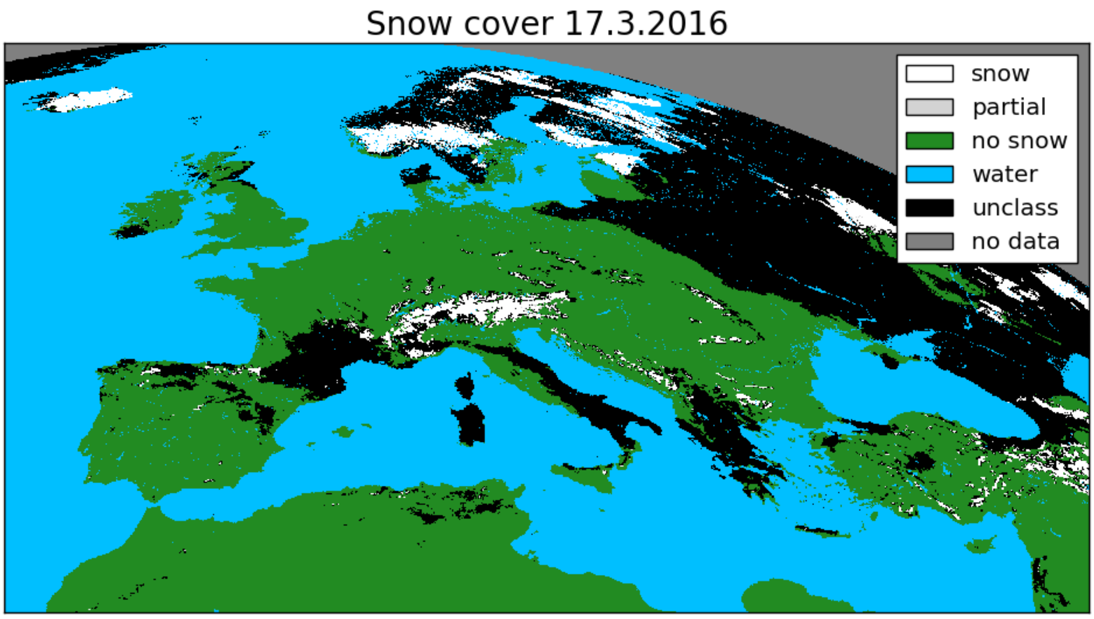

Figure 6 *Snow cover in Europe in the MSG/SEVIRI daily snow cover product on March 17, 2016. The data is presented in the original product grid..*

4. Summary and outlook

The H-SAF is producing snow cover classification products in LSASAF system based on MSG/SEVIRI data and Metop/AVHRR data for the HSAF. Both products employ an empirical thresholding algorithm which is used to classify single images of both instruments.

Based on the 15 minute SC classifications a daily MSG/SEVIRI snow cover product is generated for the full MSG disk.

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