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

Algorithm Theoretical Basis Document (ATBD)

Snow Cover (SC)

PRODUCTS: H32 (METOP/AVHRR 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 H32 (Metop/AVHRR SC) v1.43. There is also similar snow extent product for Metop/AVHRR. The details of that product are in MSG/SEVIRI ATBD document.

Metop/AVHRR snow detection algorithm has been changed substantially since version 1.00. The detection algorithm in the phase 1 has been rewritten and production of the daily global product has been introduced.

In addition of the operational MSG/SEVIRI SC product, same general principles have been applied to the development of a snow cover algorithm for Metop/AVHRR data. As an older instrument with limited channels, the AVHRR instrument is not as well suited for snow detection as SEVIRI, but it has some advantages. The most important advantage is the polar orbit, which provides global coverage and better viewing angles at high latitudes. The Metop/AVHRR has better spatial resolution than MSG/SEVIRI and that compensates some of the limitations, also. Instead of the six channels used for MSG/SEVIRI SC product the Metop/AVHRR SC algorithm employs all five channels available in the instrument. However, the limitations of the AVHRR instrument may produce a greater number of unclassified pixels and classification errors when compared with the MSG/SEVIRI SC.

The Metop/AVHRR snow cover product is distributed as global daily product which is generated by reprojecting and merging individual Product Dissemination Unit (PDU, produced every 3 minutes) based snow products.

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.

For Metop/AVHRR SC product validation results have been calculated using reprocessed data from January 2015 to October 2016.

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.

Cloud cover is 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.

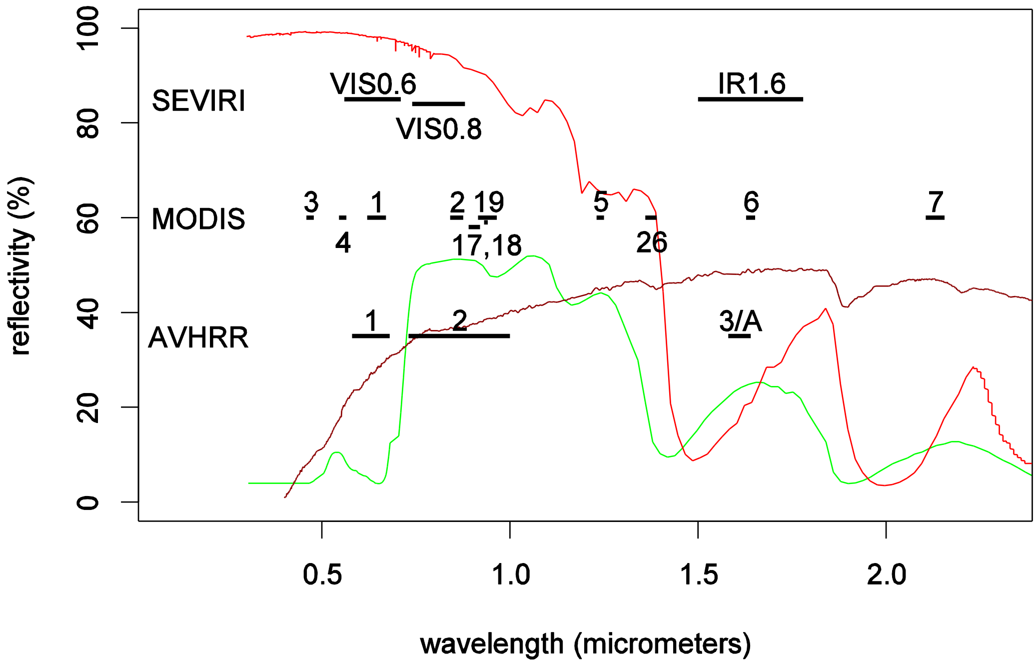

Figure 1 *Example of reflectances of three different surfaces and commonly used satellite instrument channels. Surface reflectances (snow (red), vegetation (green) and bare earth (brown)) based on ASTER Spectral Library v 2.*

2.1.1 EPS/AVHRR

The algorithm employs five AVHRR channels (about 0.6, 0.8, 1.6, 11 and 12 µm), sun and satellite zenith and azimuth angles, land cover type, elevation and land surface temperature classification produced by LSA SAF.

The development of the version 1 of the LSA SAF Metop/AVHRR snow cover classification algorithm was started by subjective classification of selected areas in representative Metop/AVHRR images. We used several AVHRR images during 2008 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 to produce first preliminary version of the algorithm for phase 1 (PDU based product) snow product (SC1).

The actual extent of snow cover was determined subjectively using also ground observations and MODIS images. The data suggest that different snow, snow free and cloudy pixels can be separated using the AVHRR data. Because the first dataset collected was rather limited, more data was collected during the next winter. About 250 thousand Metop/AVHRR pixels were classified to form a data set for algorithm development. When data availability from LSA SAF system improved we were able to finalize the SC1 product using the 2014 and 2015 AVHRR data. No new pixels were classified, but the algorithm behaviour was tested, reasons for misclassifications analyzed and algorithm improved.

Unfortunately, the limited channels available in the AVHRR instrument made it practically impossible to use the same snow detection rules in all regions around the Earth. To reduce this limitation, we had to develop a ruleset where some of the rules are used only in limited geographical region based on coordinates, elevation and landcover types. During the final development work the product was compared to original satellite data around the globe (such as RGB images) to find misclassifications. If the product was found to be making misclassifications, the rules were changes and the earlier results were rechecked. In some cases the best option was to change the algorithm and leave the region unclassified. This removed misclassifications in many common cases, such as tropical ice clouds misclassified as snow.

These changes reduce the number of classified pixels when the risk of misclassification is high. When there is at least one full year of the Metop/AVHRR snow product data (either from operational system or reprocesses data) available, some of these challenging cases of potential misclassifications may be reduced in the further development work.

The final phase of the development work was the reprojection and merging of all PDU SC products of one day to generate one global daily snow cover product (SC2). First all available PDU SC product are analyzed in order from the oldest to the newest. The data is reprojected and merged to global grid. If same pixels is observed again, new data replaces old data unless the pixel is not classified as snow covered, partially snow covered or snow free. The effect of the inherent geolocation errors of the AVHRR instrument is reduced in the last phase of the algorithm by selective smoothing of the product.

AVHRR/3 instrument onboard Metop satellites uses an internal rotating mirror to scan the surface. The Metop satellite position, speed, clock errors and satellite attitude are relatively well known and can be used to automatically improve the accuracy of the pixel location calculations. The exact attitude of the rotating mirror is difficult to measure and minor inaccuracies combined with aforementioned navigational errors can potentially lead to quite large geolocation errors in the images. According the description in the NWP SAF AAPP Documentation Scientific Description (available from: http://nwpsaf.eu/site/software/aapp/documentation/): “With the standard options (daily TBUS bulletins, clock error corrected and default satellite attitude),the expected navigation accuracy is about 3 km, in terms of r.m.s. error" in nadir and in certain conditions even more. This is almost 3 pixels. This can be reduced: "If an automatic adjustment on landmark is used together with AAPP, the expected accuracy is 1.7 km for the passes where this adjustment has been successful". Both citations refer to a paper by P. Brunel and A. Marsouin, 2000. Further discussion with the AVHRR experts of the EUMETSAT secretariat suggest that in practice these errors tend to be less than one AVHRR pixel which is not significant especially considering the selective spatial smoothing in the final daily product.

It would be ideal to use the same classication count based merging method as is used for the daily geostationary MSG/SEVIRI snow product. In an ideal day there are 96 MSG/SEVIRI snow classifications for each pixel which can be used to estimate the surface status. Even if there are some images where some of the pixels are not classified correctly, there are usually many more correct classifications of the same pixel which produce correct classification for the daily product.

This method is not available for the global product pixels of the polar orbit Metop/AVHRR snow product. In large parts of the globe there are only two observations during each 24 hour period and only one during the daylight hours. In polar regions there might be several observations of the same global pixels, but the number of observations is still quite small. Also, using of time variations to distinguish clouds and snow is limited in polar orbits because on each track which cover the same region each pixel still covers slightly different area. Reasonable accuracy is reached be reprojecting the PDU product pixels to corresponding pixel in global grid and smoothing the product based on classifications of the neighboring pixels. This produces good estimate of the snow cover in each global grid point (pixel) considering that the edge of the snow covered region where the misclassifications are most probable is rarely exact and more often quite gradual from snow free to fully snow covered.

3. Algorithm Description

3.1 EPS/AVHRR

3.1.1 Algorithm Formulation

The LSA SAF Metop/AVHRR snow cover algorithm is basically a thresholding method based on the different properties of the snow covered and snow free surfaces and clouds. The current version of the LSA SAF Metop/AVHRR snow cover product is PDU based i.e. every image is classified independently (product H32 SC1). A daily product have been developed based on all the single PDU SC products (H32 SC2). These phases are comparable to the phases of the MSG/SEVIRI SC product.

The calculation of the AVHRR SC1 product is done 3 minute blocks (PDU) when the new data is available. Different scatter plots were used to develop a set of thresholding rules. These rules were then altered by comparing the the resulting snow map to different RGB images of the PDU data and other data sources, such as MODIS images. The definitions used by the rules are in Table 1 and the rules used in the AVHRR SC1 are in the

Table 2.

The small number of channels and their properties limit the capabilities of the AVHRR instrument in snow detection. The differentiation of ice clouds and snow is difficult on many situations for human observers and for computer it is often practically impossible in the limited time frame available for an operationally generated product. Additional channels which are available in e.g. SEVIRI and VIIRS data would provide valuable information which is missing from the AVHRR data. For this reason the rules which produce excellent products in one region can produce large number of misclassifications in others. For example in tropical regions some of the rules would generate snow in cloude pixels. To reduce misclassifications, some of the rules are limited to predefined months or geographical regions. This reduces the number of obvious misclassifications, but does not remove them completely.

The classification starts by setting all the pixels as unclassified. Then the 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 when 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.

Table 1 *List of definitions used in the code. Other definitions used are lst= LSASAF Metop/AVHRR LST, lc = land cover type, lat = latitude, lon = longitude, dem = altitude from sea level etc.*

DEFINITION	VALUE
tx	Brightness temperature, channel x
cx	Radiance, channel x
tbd	t4 – t5
crxy	cx/cy
fixlc	True if lc=2 OR (lc>=5 AND lc<=12) OR lc=14
coldreg0	True if lat< -60 OR lat > 60
coldreg1	True if lat <-45 OR lat >58 OR (lat >45 AND (lon<-30 OR lon>30))
coldreg2	True if dem >= 1500 AND (lat <-35 OR lat>35)

coldreg3	True if dem >=3000
coldreg4	True if month >=1 AND month <=5 AND (lat<-35 OR lat>60 OR (lat>35 AND (lon<-30 OR lon>30)))
coldreg	True if any of coldreg0-3 is true
coldregfix	True if (any coldreg0-2 true AND month >=1 AND month <= 5) OR coldreg3 is true
tropic	True if dem<3000 AND lat<20 AND lat>-20
moderate	True if dev<=2500 AND lat<40 AND lat>-40
forest	True if lc <=6 OR lc=8 OR lc=14
nonforest	True if lc=7 OR (lc >=9 AND lc <>14)

Table 2 *List of classification rules of the LandSAF Metop/AVHRR 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 definitions: lst= LSASAF Metop/AVHRR LST, lc = land cover type, lat = latitude, lon = longitude, dem = altitude from sea level etc.*

RULE	COVER TYPE
Set pixel as	UNCLASSIFIED
nonforest AND cr21 < (-0.2*t5 +57) AND cr31 < 0.002*t5 - 0.45 AND t5 < 272.6 AND cr21 > -0.05*t5 + 15.5	PARTIAL
t4 >290	NOSNOW
nonforest AND cr31>0.134	NOSNOW
coldreg AND nonforest AND cr23 > (-2*t4 + 585) AND t4 < 277	SNOW
coldregfix AND nonforest AND cr23 > (-2*t4 +574) AND t4 > 256.5 AND t4 < 269.7	SNOW
coldregfix AND forest AND cr21 > (-0.1*t5 + 29.5) AND cr21 < 2.86 AND t5 < 280	PARTIAL
cr31<0.045 AND t4>280	NOSNOW
coldreg4 AND (c3-c2)/(c3+c2) < -0.975 AND t4 < 279 AND t4 > 240	SNOW
forest AND cr31 > 0.135	NOSNOW
coldreg AND cr23 > 120 AND t4 < 276	SNOW
coldreg AND forest AND cr23 > 72 AND t4 > 253	SNOW
coldregfix AND forest AND cr23 > 45 AND t4 > 263	SNOW
coldregfix AND ((cr23 > 120 AND t4 < 254) OR (cr23 > 220 AND t4 < 280) OR (cr23 > 50 AND t4 > 267 AND t4 < 276 AND tbd < 1.5))	SNOW
t5 > 280 AND cr21 > 2	NOSNOW
t4 < 242 AND cr23 < 68.8	UNCLASSIFIED
tbd > 4 AND cr31 > 0.09 AND cr31 < 0.11	UNCLASSIFIED
vza > 60	UNCLASSIFIED
sza > 80	UNCLASSIFIED
tropic AND fixlc AND (snow OR partial)	UNCLASSIFIED
moderate AND (t4+t5)/2 < 253 AND (snow OR partial)	UNCLASSIFIED
lst >= 293.15 AND (snow OR partial)	NOSNOW
(snow OR partial) AND c1 < 1.2 AND c2 < 1.2 AND c3 < 0.02	UNCLASSIFIED
water pixel	SEA

When all the daily PDUs are analyzed, the phase 2 can be started. In this phase each PDU product file and associated coordinates files are loaded in order from the oldest to the newest and the the data is reprojected to 0.01 degree global grid. If the same pixel is classified several times the newest value is used in the merging. All PDU based SC files are reprojected and merged to create the daily global product. This preliminary global classification has large number of unprocessed pixels.

When all data from the phase 1 has been read, reprojected and merged, the final product is created by smoothing the data using pixel classification counts in the 3x3 pixels around each pixel. Each pixel is reclassified using the rules in the Table 3.

Table 3. *The rules applied in the smoothing process for the final daily product in each 3x3 pixel regions. W = sea, U = unclassified, P = partial snow, S = snow, N=nosnow, I = nonprocessed.*

Rules	Classification
If pixels is snow, partial, nosnow or unclassified:	
W > 0 AND N>0 and (W+N)>=5	NOSNOW
W>=8	SEA
N>=8	NOSNOW
If pixel is snow/partial AND U>=8	UNCLASSIFIED
If U+I > 4	UNCLASSIFIED
If S+P < 2 AND N<2 AND U>2	UNCLASSIFIED
If W>3 AND S+N+P+U = 0	SEA
If W+I <= 3:	
S+P = 0 AND N >2 AND W+I = 0	NOSNOW
S+P > 3 AND N=0	SNOW
S+P = 0 AND N>2	NOSNOW
S+P > 3 AND N>2	PARTIAL

3.1.2 Input Data

The algorithm employs five AVHRR channels (0.6, 0.8, 1.6, 11 and 12 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 PDU of the AVHRR 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

Quality flags will be developed when there are reliable surface observations which can be used for validation. Currently the flags try to provide an estimate of the accuracy.
Validation of snow cover products is performed through comparisons with independent data (e.g., NOAA/NESDIS IMS, surface observations). A discussion of validation results may be found in the SC Validation Report.

An example of the daily Metop/AVHRR snow cover is presented in the Figure **2**, which shows the snow cover in Europe on March 17, 2016.

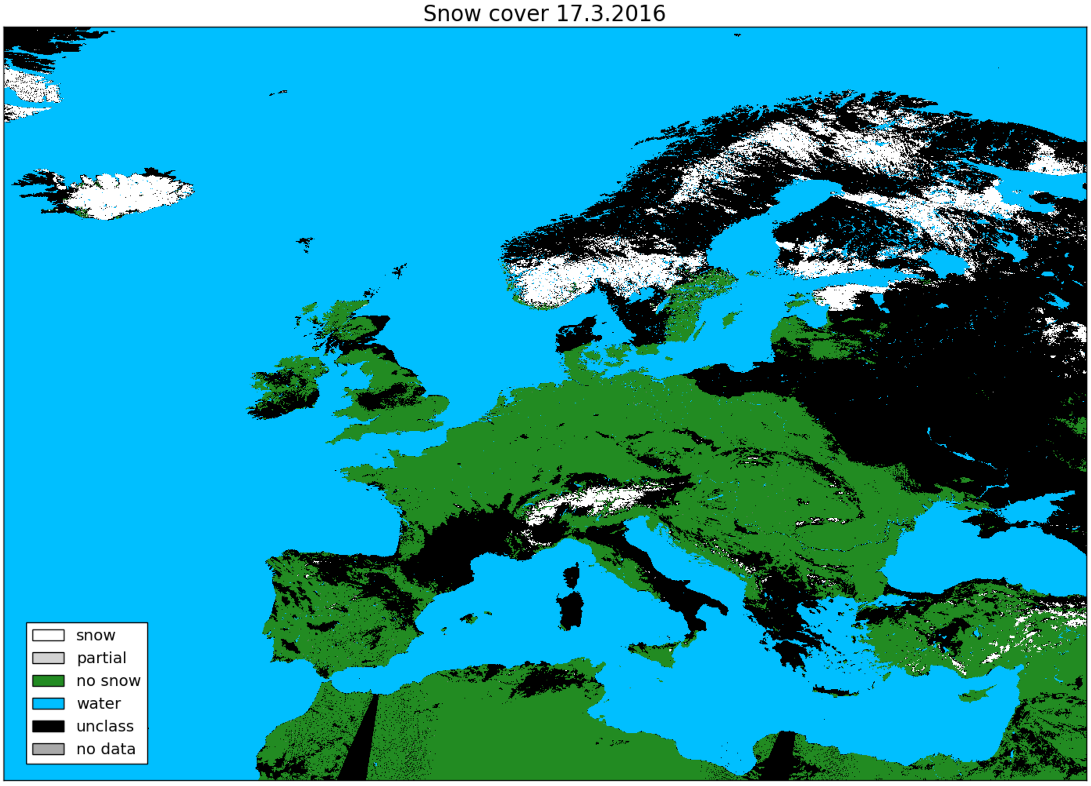

Figure 2 *Snow cover in Europe in the global daily Metop/AVHRR snow cover product on March 17, 2016. The product is merged from several hundred single image PDU snow cover products. When this product is compared to geostationary MSG/SEVIRI product in the* Error! Reference source not found.*, the differences both in resolution and number of classified pixels are easy to recognize.*

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. Similar product for Metop/AVHRR is generated based on the classification of 3 minute PDU data, which is reprojected and merged to generate a global daily snow cover product.

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