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

Validation Report

Snow Cover (SC)

PRODUCTS: H31 (MSG/SEVIRI SC), H32 (METOP/AVHRR SC)

Reference Number:	SAF/LAND/FMI/VR_SC/1.9
Issue/Revision Index:	Issue 1.9
Last Change:	10/07/2017

DOCUMENT SIGNATURE TABLE

	Name	Date	Signature
Prepared by:	Land SAF Project Team – FMI		
Approved by:	Land SAF Project Manager (IM)	30/03/2016	

DOCUMENTATION CHANGE RECORD

Issue / Revision	Date	Description:
Version 0.0	3/12/2007	Version delivered to IM
Version 1.0	3/12/2007	Version edited and revised by Isabel Trigo
Version 1.1	5/12/2007	Version revised by Niilo Siljamo
Version 1.2	14/02/2008	Version revised by Niilo Siljamo
Version 1.3	30/03/2009	Version revised by Niilo Siljamo
Version 1.4	29/06/2009	Revised version
Version 1.5	30/11/2011	Revised: MSG/SEVIRI SC v2.50, EPS/AVHRR SC v1.00
Version 1.6	30/03/2016	Revised: MSG/SEVIRI SC v2.90, Metop/AVHRR SC v1.41
Version 1.7	23/06/2016	Revised: MSG/SEVIRI SC v2.90, Metop/AVHRR SC v1.43
Version 1.8	16/12/2016	Revised: MSG/SEVIRI SC v2.90, Metop/AVHRR SC v1.43
Version 1.9	10/07/2017	Revised: MSG/SEVIRI SC v2.90, Metop/AVHRR SC v1.43 (longer validation period)

DISTRIBUTION LIST

Internal Consortium Distribution		
Organisation	**Name**	**No. Copies**
IPMA	Isabel Trigo	
IPMA	Sandra Coelho e Freitas	
FMI	Niilo Siljamo	
	H-SAF Project Manager	
	H-SAF Project Team	
IPMA	Carla Barroso	
IPMA	Isabel Monteiro	
IPMA	João Paulo Martins	
IPMA	Pedro Diegues	
IPMA	Pedro Ferreira	
IDL	Carlos da Camara	
IDL	Teresa Calado	
KIT	Folke-S. Olesen	
KIT	Frank Goettsche	
MF	Jean-Louis Roujean	
MF	Gregoire Jacob	
MF	Dominique Carrer	
RMI	Françoise Meulenberghs	
RMI	Arboleda Alirio	
RMI	Nicolas Ghilain	
UV	Joaquin Melia	
UV	F. Javier García Haro	
UV/EOLAB	Fernando Camacho	
UV	Aleixander Verger	

External Distribution		
Organisation	**Name**	**No. Copies**
EUMETSAT	Frédéric Gasiglia	
EUMETSAT	Dominique Faucher	
EUMETSAT	Lorenzo Sarlo	
EUMETSAT	Lothar Schueller	
EDISOFT	Teresa Cardoso	
EDISOFT	Joana Rosa	
EDISOFT	Joaquim Araújo	
GMV	Mauro Lima	

Steering Group Distribution		
Nominated by:	**Name**	**No. Copies**
IPMA	Pedro Viterbo	
EUMETSAT	Lothar Schueller	
EUMETSAT	Christopher Hanson	
EUMETSAT	Harald Rothfuss	
STG/AFG	Francesco Zauli	
MF	Jean-François Mahfouf	
RMI	Rafiq Hamdi	
KIT	Johannes Orphal	
VITO	Bart Deronde	

Table of Contents

List of Figures

List of Tables

1. Introduction

The H-SAF has two different snow extent product originally developed for LSA SAF. There is an algorithm and product for MSG/SEVIRI instrument which provides daily snow extent for full MSG/SEVIRI disk. There is also an algorithm and product for Metop/AVHRR instrument which provides daily global snow extent in 0.01 degree grid. This document describes the snow extent products H31 (MSG/SEVIRI SC) v2.90 and H32 (Metop/AVHRR SC) v1.43.

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 and the product.

Metop/AVHRR snow detection algorithm has been changed substantially since version 1.00. The detection algorithm in the phase 1 (single Product Dissemination Unit (PDU) product) has been rewritten and production of the daily global product has been introduced.

The algorithms used in the generation of these snow cover product classify each pixel in three classes (snow free, partially snow covered or totally snow covered) based on MSG/SEVIRI or Metop/AVHRR data. Pixels which are cloud covered or cloud contaminated or poorly lit are not classified.

The MSG/SEVIRI SC product is available from 1st of February 2005. Version 1 developed by SMHI was based on NWCSAF Cloud mask product. Version 2 uses pre-processed satellite data directly and has been available since 2008. The global Metop/AVHRR snow product has been available via LSA SAF since February 2016, although the single PDU based Metop/AVHRR product has been available earlier for internal use.

In this report we show validation results based on different validation methods for various versions of the algorithms. There are validation results of the H-SAF product H10, which uses product H31 for flat land areas. The products should be identical in these areas. And finally, there are validation results for H32 based on weather station snow depth and state of the ground observations between January 2015 and October 2016.

The challenge in snow extent product validation is the lack of good quality in situ measurements of snow coverage. Especially, observations of snow free surface has been very difficult to obtain, because many weather stations do not measure or report snow cover data and, especially, the stations do not report the lack of snow. Reliable, stable sources of surface observation data in global scale do not exist. However, a combination of snow depth and state of the ground observations (when available) provide a reasonably useful data about snow cover.

2. Examples of the SC products

To show the limitations and strengths of the MSG/SEVIRI SC products some examples are shown. As an example January 26th, 2007 was chosen (Figure 1). The day was cloudy in many areas, but there were large snow covered areas in cloud free parts of central and southern Europe.

There are some interesting features worth noting in this image and snow cover maps in the Figure 1. For example the northern part of the Jutland Peninsula (Denmark) is snow free as can be confirmed by MODIS images. In the IMS product this area is snow covered. There are also differences in the edge of the snow cover in central Europe.

The v2 of the MSG/SEVIRI SC and IMS are quite similar, but there are some differences apart from the obvious lack of the unclassified pixels in the IMS. When these two products are compared to satellite images (SEVIRI and MODIS), it seems that the v2 of the MSG/SEVIRI SC is about as realistic as the IMS.

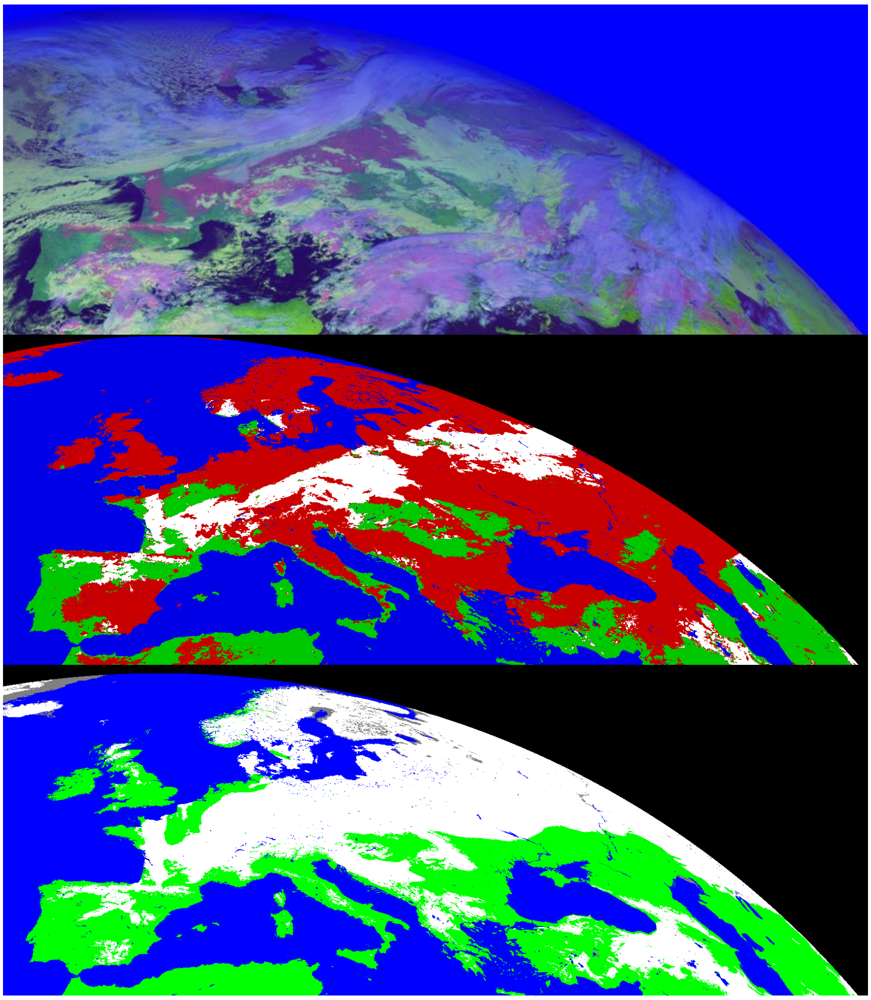

Figure 1 *Top: RGB-composite image of the 26th January, 2007, 1200 UTC, channels 1, 3, 10i. It can be seen, that there are large snow covered areas (dark magenta). Snow free is green and different clouds are purple or pink. Middle: Fully automatic version 2 of the H31 (MSG/SEVIRI SC), white is snow, green snow free and read unclassified. Bottom: IMS snow analysis which is based on the analysis of several data sources.*

It should be noted the LSASAF SC products has been designed for flat areas, although mountain ranges are not excluded from the product. In practice, this means the product can be used also in mountain regions, but the accuracy of the product is not validated.

The MSG/SEVIRI snow product was originally generated and delivered for four different geographical regions (Europe, North Africa, South Africa, South America). In 2015 the product generation started for full MSG/SEVIRI disk, although regional products are still available from some sources (see an example of the full disk product in Figure 2).

In addition to the MSG/SEVIRI SC product a new daily global Metop/AVHRR SC product has been developed to enhance the snow cover analysis in the polar regions which are near the edge of the MSG/SEVIRI disk and where the low satellite viewing angle is add new challenges especially in forests. The same principles are used in development of the SEVIRI and AVHRR products, but these two instruments do not employ the same channels and two different algorithms have to be developed. An example is shown in the Figure 3.

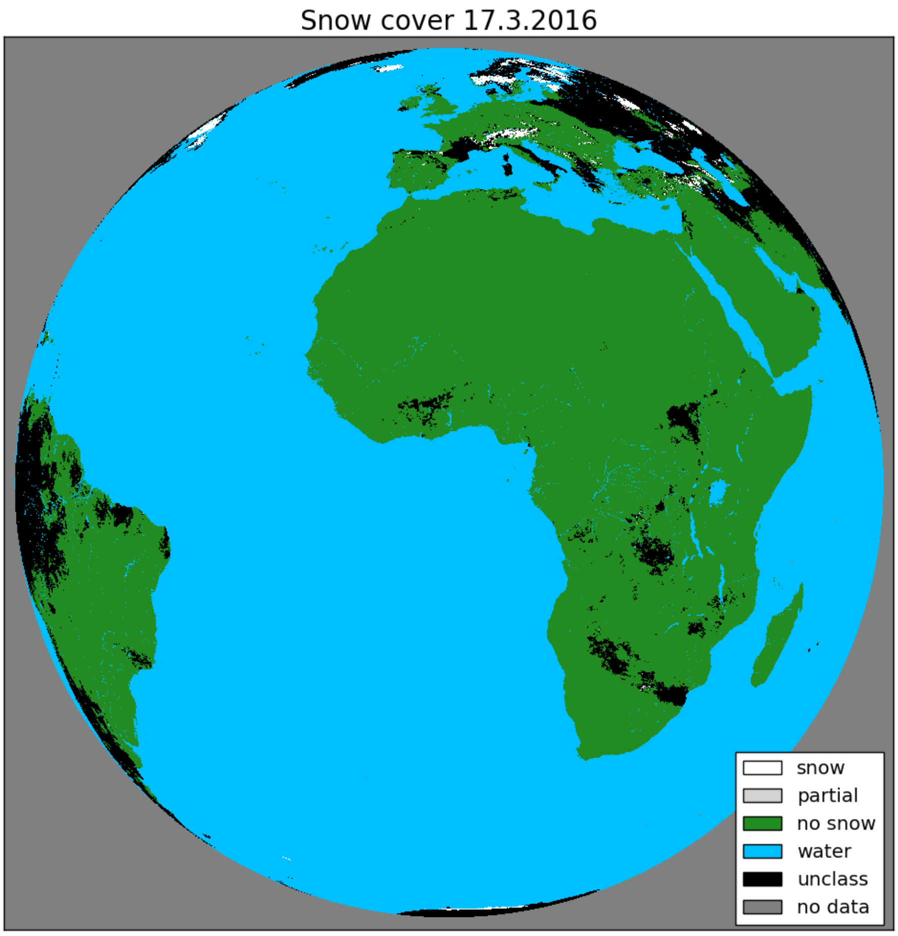

Figure 2 *Snow product H31 (MSG/SEVIRI) on March 17, 2016. Most of the snow is extreme edge of the MSG/SEVIRI disk and in mountain regions.*

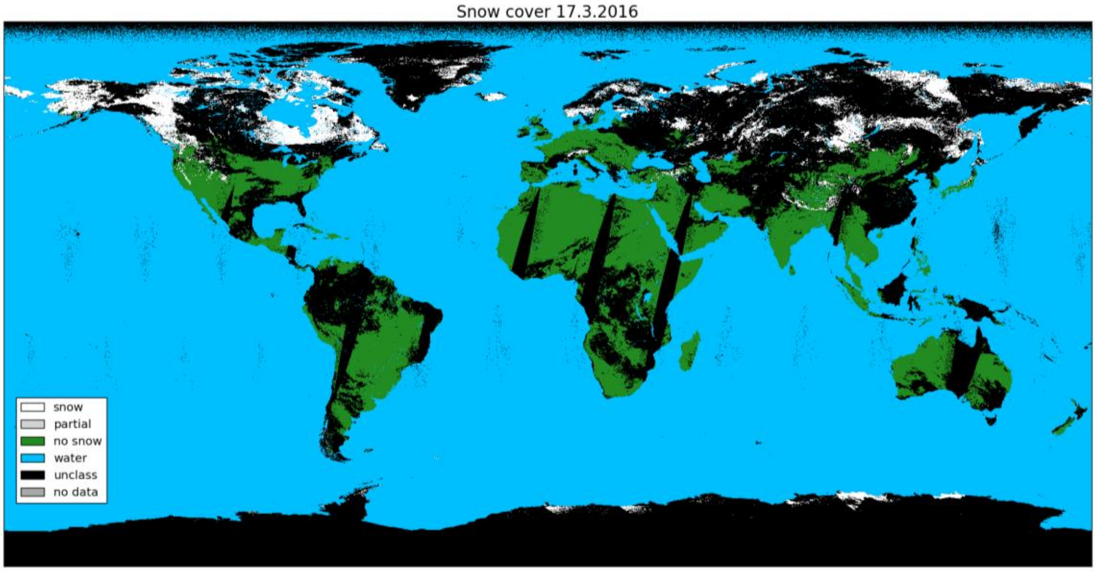

Figure 3 *Snow product H32 (Metop/AVHRR) on March 17, 2016. Practically full globe is covered*

3. Validation measures

The best option for satellite product validation would be in situ measurements. Unfortunately such data has been practically impossible to collect in large scale. For this reason we have used IMS product as baseline to which MSG/SEVIRI product can be compared although it is known that IMS is not perfect and it has some limitations. On the other hand IMS product uses several other data sources which include also microwave instruments. These can be used to detect the snow under the clouds or in bad lighting conditions. LSA SAF MSG/SEVIRI SC product and its validation have been discussed in Siljamo and Hyvärinen (2011).

The IMS snow product limitations can be seen in Figure 1, where e.g. Jutland Peninsula is snow free in the IMS product, but clearly snow covered in the RGB image and MSG/SEVIRI product. Other similar differences can be seen in France. On the other hand, in Eastern Europe the edge of the snow covered region is unnaturally smooth. In an internal snow observation analysis at FMI, the IMS product was shown to have a tendency to not detect the changes of snow cover in several days or even weeks, see Figure 4, even though the IMS product is generated to every pixel each day. Other products compared did not show this feature, but the number of classified pixels was significantly lower, mainly due to polar night and clouds. (Hyvärinen et al, 2015)

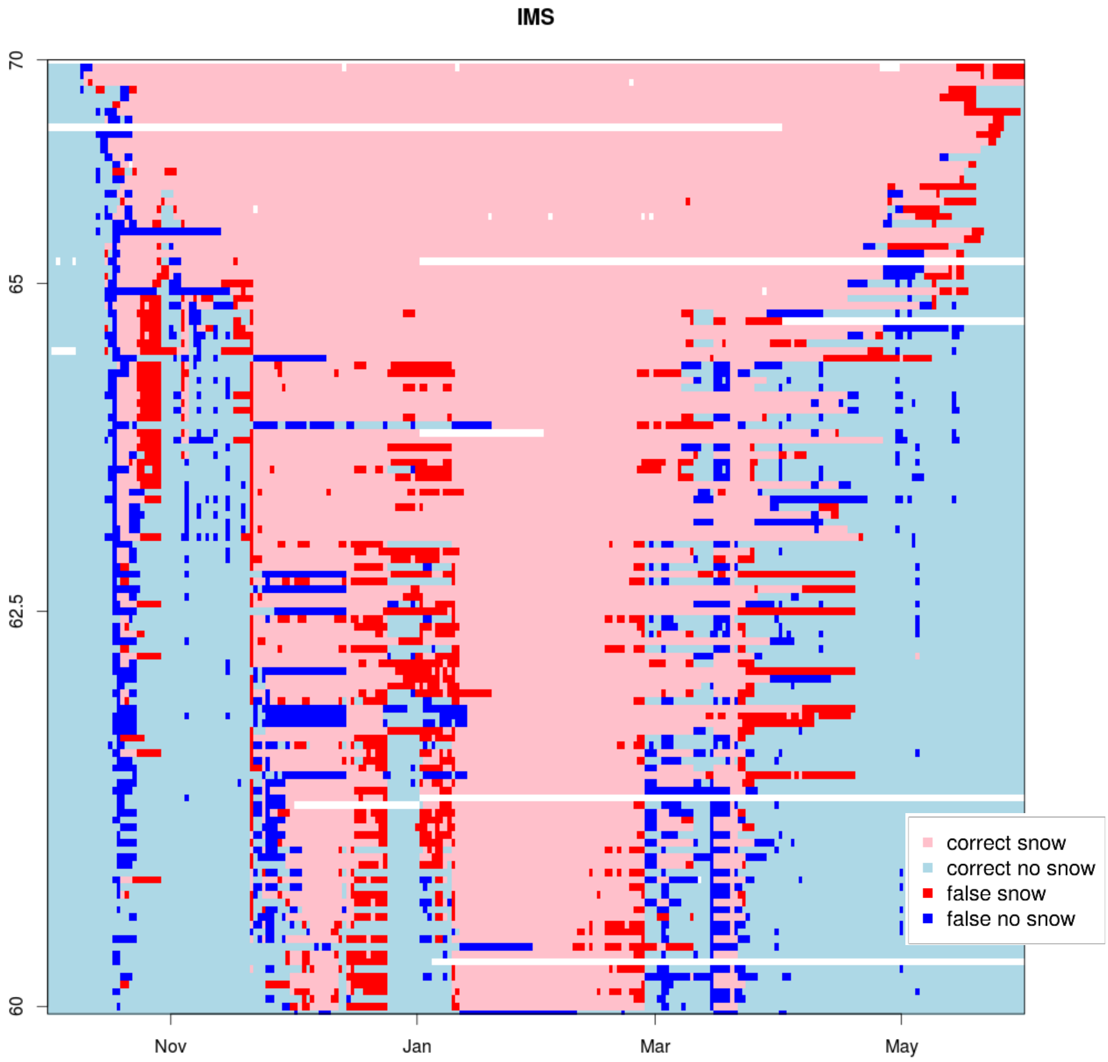

Figure 4 *IMS snow product compared with the in-situ state of the ground observations in Finnish rain stations 2013—2014 ordered by latitude. Light blue and red mark correct values in the IMS product. Dark blue and red mark misclassifications which are quite persistent (several days or even weeks) in some stations. (Hyvärinen et al, 2015).*

For the Metop/AVHRR snow product developed several years later global set of surface observations could be used as baseline.

The validation measures used here follow the terminology of Jolliffe and Stephenson (2003). The Table 1 shows the contingency table used for the calculation of these measures.

Table 1 *Contingency table used for the statistical measures. Hits (a) and correct negatives (d) represent the correctly detected snow cover. Misses (c) and false alarms (b) are the two represent the two misclassification possibilities.*

	Observation: snow	Observation: no snow
Satellite product: snow	a	b
Satellite product: no snow	c	d

The contingency table gives the joint distribution of analyses. From the contingency table the following conditional distributions can be constructed for use as validation measures. In all Metop/AVHRR calculations +1 is added to the nominator and denominator to prevent division by zero errors, e.g. in cases when all satellite observations are correctly snow free (a = b = c = 0). The first measure is the bias:

$$BIAS = \frac{a+b}{a+c}$$

the ratio of the number of snow pixels in the Metop/AVHRR or MSG/SEVIRI analysis to the number of snow pixels in the IMS analysis or surface observation. The best value for bias is 1; less than 1 means underestimation and more than 1 means overestimation.

The hit rate H or probability of detection (POD) is

$$H = \frac{a}{a+c}$$

and in the perfect analysis this should be 1. The false alarm rate F or probability of false detection (POFD) is

$$F = \frac{b}{b+d}$$

and in the perfect analysis this should be 0. The false alarm ratio (FAR) is

$$FAR = \frac{b}{a+b}$$

and in the perfect analysis this should be 0. A simple measure of accuracy is proportion correct (PC, also ACC):

$$PC = \frac{a+d}{a+b+c+d}$$

the fraction of items classified the same way in both analyses. The best value for PC is 1 and the worst is 0. PC alone is insufficient, particularly in cases where one of the categories dominates. An alternative measure is the critical success index

$$CSI = \frac{a}{a+b+c}$$

which ignores correct rejections. Its best value is 1 and the worst is 0.

Skill scores measure the relative skill by comparing the results with the reference. Random hits are often used as reference. When the reference is the random hits, from PC we can define the Heidke skill score:

$$HSS = \frac{2(ad-bc)}{(a+c)(c+d)+\ (a+b)(b+d)}$$

its best value being 1 and its worst being -1.

4. MSG/SEVIRI SC Validation

We have calculated several statistical measures for European Region of the MSG/SEVIRI snow product which can be used to analyse the quality of the snow cover product. For these only those pixels were included which the algorithm can classify to either snow covered or snow free. Figure 5 shows a time series of the several validation measures from January 2009 to August 2011. Black colour is used for operational version during the time series (v2.10). At the end of the period another run using the version 2.50 was made using the data from January to April 2011 and these are shown in red. In the current version 2.90 the classification algorithm is the same which was used in the earlier version 2.50.

The LSASAF MSG/SEVIRI SC algorithm can classify roughly 20–75% of the surface. The main reasons for this are clouds, inadequate lighting and algorithm limitations in areas which are difficult to classify.

Validation results for the version 2.50 compared to IMS product has been calculated to Table 2 and Table 3 for 113 day period from January to April 2011. Further validation of the MSG/SEVIRI snow cover product has been performed as part of the H-SAF validation effort. The results in the Table 4 are based on the validation of the HSAF product H10 which is identical (direct copy) to H31 in flat land regions.

The current MSG/SEVIRI snow algorithm is quite conservative and it does not try to classify pixels in possibly cloudy and poorly lighted areas, where misclassifications are much more probable. The aim is to produce as reliable classification as possible.

Figure 6 shows the spatial distribution of different skill scores. Heidke Skill Score and PC show that in most parts of the Europe MSG/SEVIRI SC v2.10 is in good agreement with IMS. Bias shows that there is some difference in accuracy between Southern and Northern Europe.

For the current algorithm version (v2.50 and later) similar statistical comparison to IMS product has not been calculated. Instead of comparing to different satellite based snow cover products, our preference is in the validation based on surface observations.

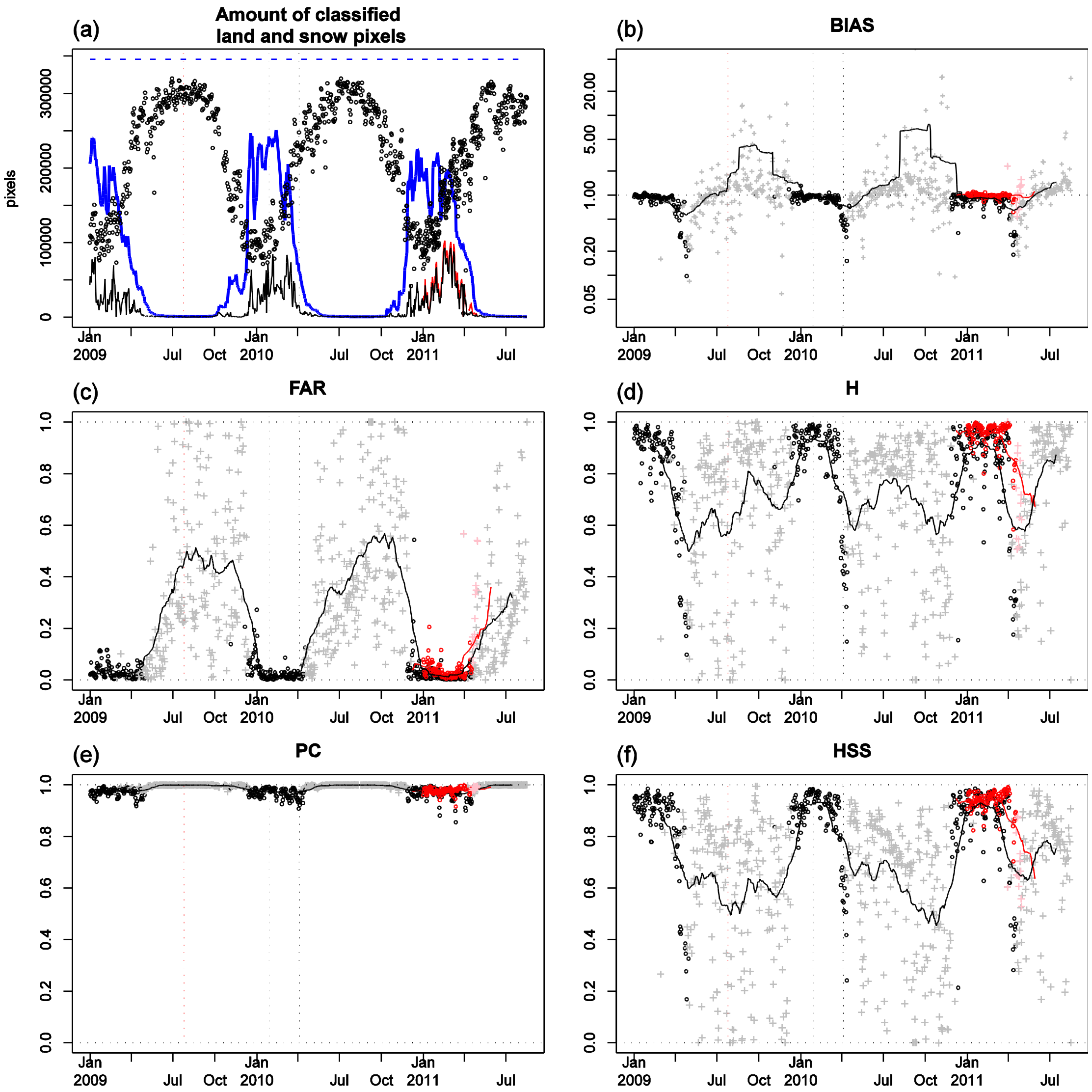

Figure 5 *(a) Amount of cloud-free land pixels (blue dashed line, IMS; red circle, version 2.50; black circle, version 2.10), and amount of snow-covered pixels (blue line, IMS; red line, version 2.50; black line, version 2.10). (b) Bias, (c) FAR, (d) H, (e) PC, and (f) HSS for version 2.50 (red circle) and version 2.10 (black circle) when compared with the IMS product. When the correct rejections exceed the other classes by more than 20 times, version 2.50 is shown in pink and version 2.10 in grey crosses. Curves show the two-month moving average of the data.*

Table 2 *Contingency table of the LSASAF SEVIRI SC v2.50 and the IMS snow (n=17801493), Europe, test period from January to April 2011.*

MSG/SEVIRI SC v2.50	IMS snow	IMS no snow
LSASAF Snow	4699687 (26.4%)	138998 (0.8%)
LSASAF No snow	227146 (1.3%)	12735662 (71.5%)

Table 3 *Comparison of algorithm performance measures of both SC algorithm versions, Europe, January to April 2011 compared with the IMS.*

	MSG/SEVIRI SC v2.50
PC (ACC)	0.9794
BIAS	0.9821
H (POD)	0.9539
FAR	0.0287
F (POFD)	0.0108
CSI	0.9277
HSS	0.9483

Table 4 *Validation results for the MSG/SEVIRI snow product (H31) from H-SAF validation reports for the product H10 (identical to H31 in flat land regions) in Finland during the winter season (October – May).*

	2011-2012	2012-2013	2013-2014	2014-2015
PC (ACC)	0.95	0.95	0.88	0.90
H (POD)	0.97	0.98	0.92	0.95
FAR	0.04	0.05	0.20	0.13
F (POFD)	0.06	0.09	0.13	0.16
CSI	0.93	0.93	0.75	0.83
HSS	0.90	0.90	0.76	0.80

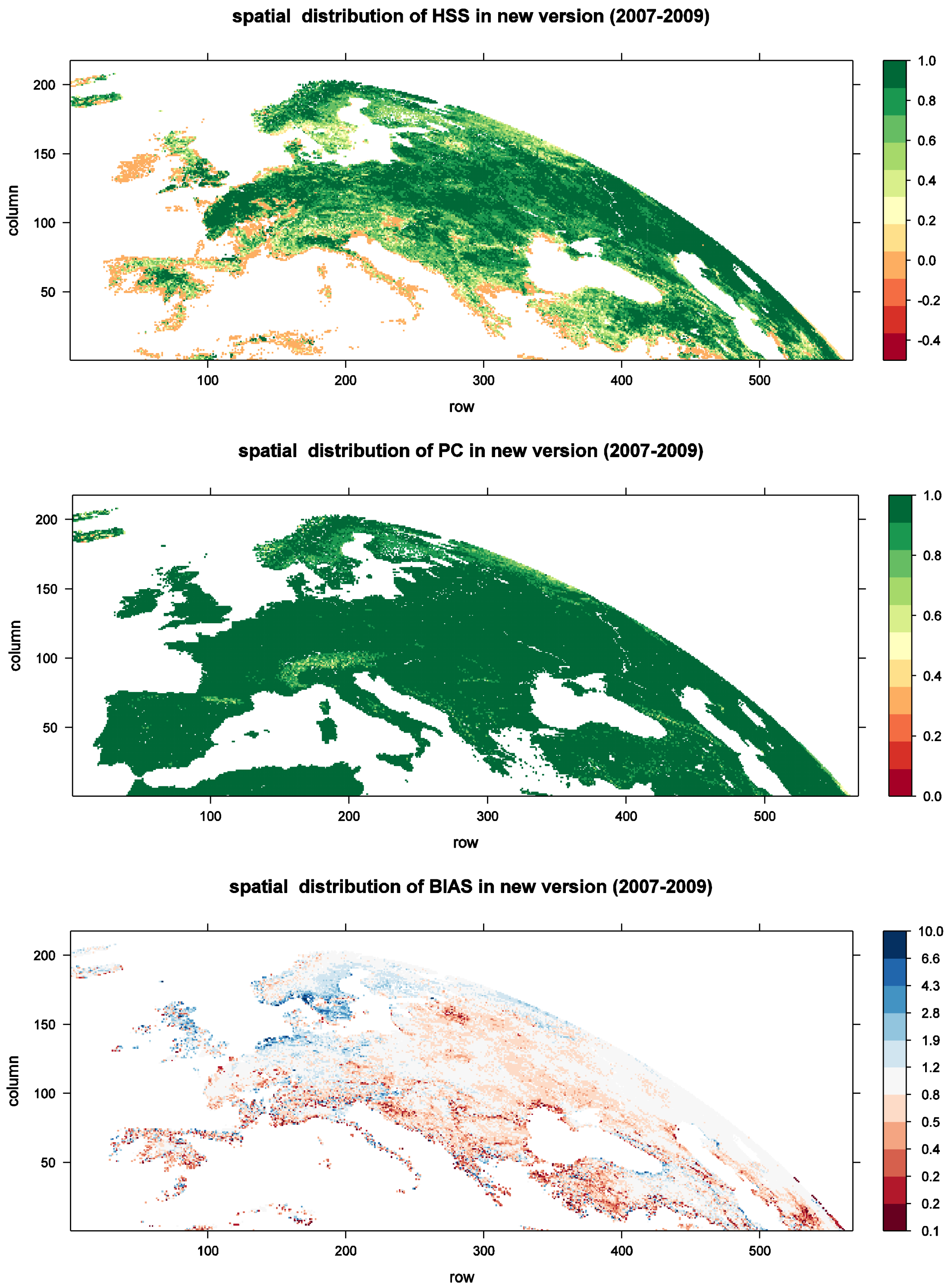

Figure 6 *Spatial distribution of PC, HSS and BIAS in the LSA SAF SC version 2.10 from July 2007 to February 2009. HSS and BIAS cannot be computed in areas where the denominator is zero.*

4.1 Independent validation of the MSG/SEVIRI product

In addition of the normal H-SAF validation, MSG/SEVIRI snow product was part of the H-SAF associated & visiting scientist activity (Kilpys, 2016). In this validation work product H31 was compared to Lithuanian surface observations of the snow cover. The results very good and in some station even exceptional.

Table 5 *Validation results in Lithuania for winter months from November 2012 to February 2016. Observations are from 49 stations. (Kilpys 2016).*

	N	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
Total/Average	7448	1.37	0.98	0.25	0.14	0.89	0.73	0.63	0.76

5. EPS/AVHRR SC validation

The development work of the global daily Metop/AVHRR snow product algorithm and processing code was finished 2015. The code was developed for the new LSA SAF processing environment, which was not operational during the first half of the winter 2015-2016. Testing in the operational environment started at February 2016.

The time span of the data available from the operational system at this moment is not adequate for reliable validation and therefore the LSA SAF reprocessed the data from the beginning of 2015. For this validation the data from January 2015 to May 2017 was used.

For the Metop/AVHRR snow product validation FMI could provide surface observations from surface weather stations. FMI observations database does not contain all global weather station observations, but the spatial coverage is still quite good, although there are large regions without surface observation. Observations of the snow depth and state of the ground were used for the analysis. Also air temperature observations were retrieved for the stations which were selected for the validation.

There is a lot of variation in the surface observations. Some stations provide only one observation per day (either snow depth, state of the ground or both). Automatic weather stations can measure snow depth every minute, but for this work at most hourly observations were used. Many weather stations report only positive snow depth values (i.e. they report snow, but not the lack of snow), but others have special values for snow free conditions or thin snow layers.

State of the ground is a manual observation, although there has been some discussion about limited scale automatic observations. It is not available from all weather stations, but when available state of the ground provides very good estimate of the snow coverage near the weather station. Table 6 shows the WMO coding of the state of the ground. This coding is used in most of the weather station data and similar local coding is used for Finnish weather stations in the FMI observation database.

Table 6 *WMO state of the ground values. Codes 0-9 represent snow free, codes 13-19 snow covered and 10-12 partially snow covered cases. Similar local coding is used in Finnish weather stations and similar reclassification to snow free, snow covered and partial classes was used.*

code	Meaning
0	surface or ground dry (without cracks and no appreciable amount of dust or loose sand), without snow or measurable ice cover
1	surface of ground moist, without snow or measurable ice cover
2	surface of ground wet (standing water in small or large pools on surface, without snow or measurable ice cover
3	flooded, without snow or measurable ice cover
4	surface of ground frozen, without snow or measurable ice cover
5	glaze on ground, without snow or measurable ice cover
6	loose dry dust or sand not covering ground completely, without snow or measurable ice cover
7	thin cover of loose dry dust or sand covering ground completely, without snow or measurable ice cover
8	moderate or thick cover of loose dry dust or sand covering ground completely, without snow or measurable ice cover
9	extremely dry with cracks, without snow or measurable ice cover
10	ground predominantly covered by ice, with snow or measurable ice cover
11	compact or wet snow (with or without ice) covering less than one-half of the ground, with snow or measurable ice cover
12	compact or wet snow (with or without ice) covering at least one-half of the round but ground not completely covered, with snow or measurable ice cover
13	even layer of compact or wet snow covering ground completely, with snow or measurable ice cover
14	uneven layer of compact or wet snow covering ground completely, with snow or measurable ice cover
15	loose dry snow covering less than one half of the ground, with snow or measurable ice cover
16	loose dry snow covering less than one-half of the ground (but not completely), with snow or measurable ice cover
17	even layer of loose dry snow covering ground completely, with snow or measurable ice cover
18	uneven layer of loose dry snow covering ground completely, with snow or measurable ice cover
19	snow covering ground completely; deep drifts, with snow or measurable ice cover
31	missing value

For this validation analysis, only weather stations which had at least 20 snow depth and/or state of the ground observations in the database during the validation period were selected. This limit was chosen to remove possibly poor quality data (coding errors, transmitting errors, database errors) from the analysis. This limitations left 3709 weather stations and 33361767 observations in the analysis. Figure 7 shows the locations of the weather stations in the global analysis.

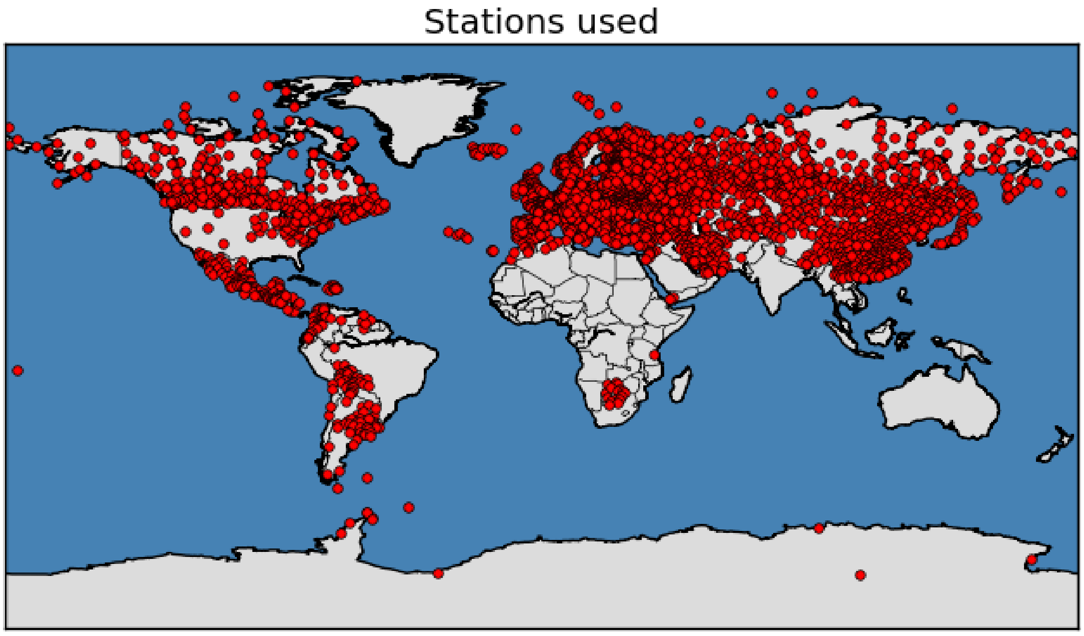

Figure 7 *Locations of the 3709 weather stations used for the Metop/AVHRR snow product validation. Although there are no observations in large areas in Africa, Oceania and South America, the observations cover most of annually snow covered area and there are also some observations from practically snow free regions.*

For the validation, all observations of one day from each station were collected and generalized snow status was calculated based on state of the ground (E) and snow depth (SD). Each day highest value of snow depth was selected and that was used to determine the SD snow status. Some stations report no snow by negative values (typically -1) and these were classified as no snow. Positive values of at least 1 cm were classified as snow covered. 0 cm and other values specifically used to indicate very thin or partial snow cover were classified as partial snow. Highest daily value of state of the ground was used to determine E snow status (no snow, snow, partial snow). These snow status values are used to create daily snow coverage observation for each station. If the SD snow status and E snow status disagree the observation is ignored. This method produced 3156180 daily weather station observations which can be used in the actual validation of the daily satellite product.

The reduce the different classifications from three to two for the analysis the partial snow cover class must be reclassified either as snow free, snow covered or it can be excluded. This reclassification was applied both to the surface observations and satellite observations. The relative number of partially snow covered pixels in the satellite product is very low (about 0.05% or less of all pixels). Currently available surface observations do not allow reliable estimation of partial snow coverage and even the best widely available snow cover data (state of the ground) provides only rough figures (code values 10, 11 and 12).

Many weather stations do not report the lack of snow. To create enhanced data set, air temperature measurements were used to generate snow free observations for the stations included in the analysis. No snow observation can be created if both snow depth and state of the ground observations are missing. If the minimum air temperature is at least 5 °C and the maximum temperature is at least 10 °C, the snow status of the station is changed to snow free. The validation measures are calculated both for original surface observations and for enhanced data set.

Finally, the satellite observations are retrieved based on the station coordinates. These coordinates are usually reliable, but in some rare cases the indicated coordinates are probably incorrect based on rough checks made for limited number of semi-randomly selected stations using Google Maps aerial images and Google Streetview images.

The Figure 8 shows the daily classification counts during the validation period (Jan 1, 2015 – May 31, 2017). There are still a small number of missing days (vertical light grey stripes) and missing PDU (grey spikes) but in general this dataset is almost complete. This figure is best suited for general overview of the global data. The grey spikes (usually caused by missing PDU scenes) seem to coincide quite well with outliers in the time series plots presented in later figures. This indicates that the outliers are caused by unrepresentative coverage of PDU images and not by misbehaving snow detection algorithm.

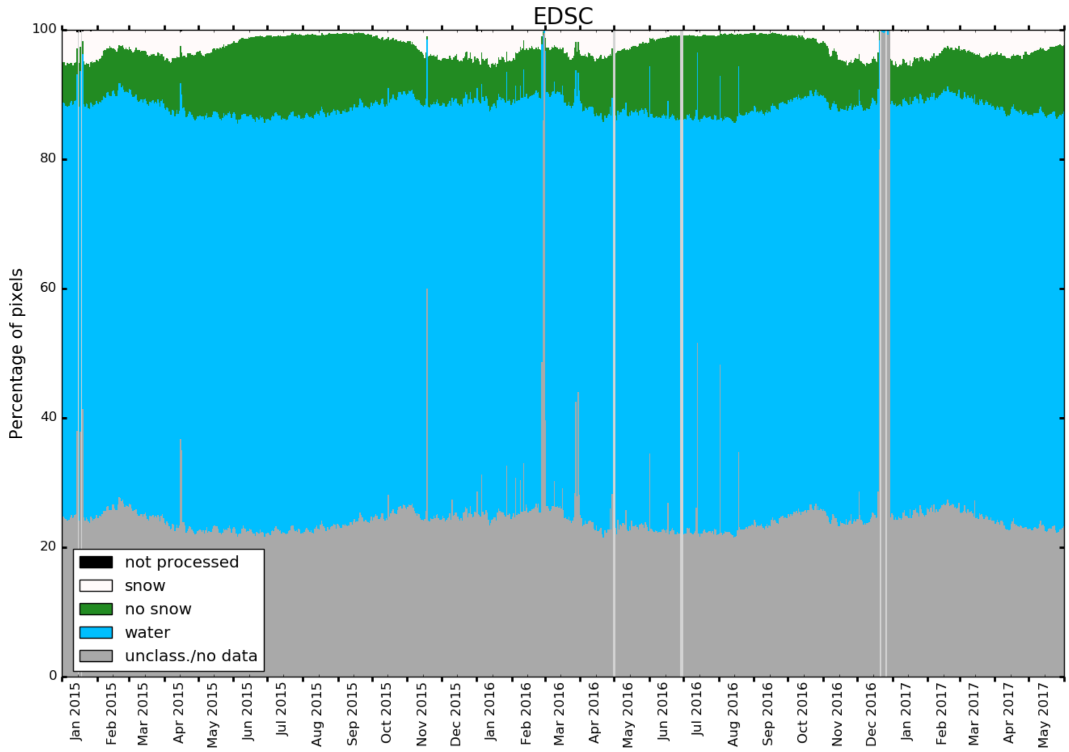

Figure 8 *Pixel classification counts in the reprocessed Metop/AVHHR snow product. There are some data gaps. Missing days are shown as vertical stripes) and missing PDU data as grey spikes. The annual cycle of the snow cover can still be seen quite well although in this global analysis the polar nights and uneven distribution of land between northern and southern hemispheres complicate the analysis. About 25 percent of the pixels are cloudy or night pixels (unclassified).*

The most general validation statistics are those calculated for the full validation period for different regions. In Table 7 these statistics are presented for three different regions: Global, Europe and Variable, which includes only those weather stations which have observed both snow and snow free conditions during the validation period.

Table 7 shows that the results for all three regions are not significantly different, although the results seem to be slightly better when only those stations which have observed both snow free and snow covered cases are used. The use of enhanced temperature based no snow observations does not seem to change the results.

The greatest differences can be seen between different treatments of partial snow cover class. We get best results when we exclude partial snow cover class, but the results are almost the same when we reclassify partial snow cover as snow free. Only treating partial snow cover as full snow cover seem to give slightly worse results. This might suggest that observed partial snow resembles snow free surface rather than full snow cover.

Validation results for the full period shows that the Metop/AVHRR snow product meets the product requirements: hit rate is better than the required optimal hit rate 90% (92.6 % when partial snow is excluded and 93.7% when partial snow is reclassified as no snow) and false alarm ratio is less than target value of 15% and almost reaches the optimal requirement of 5% (4.8% when partial snow is excluded and 6.6% when partial snow is reclassified as no snow).

However, global full period validation measures do not tell much about regional or temporal variations of the product quality. For this purpose daily validation measures were calculated for the validation period (see Figure 9, Figure 10 and Figure 11). In these figures colour coding has been used to show the reliability of the analysis. This kind of binary analysis has a tendency to emphasize rare events such as snow during the summer when in general most of the pixels are snow free. Then even a single classification mistake can change the validation measures significantly. Therefore, dark green has been used to mark those days which have at least 1/20 of hits, false alarms and misses (a, b and c). Light green marks those days which do not match this condition and orange marks the most extreme cases where correct snow free observations (d) are at least 200 more common than other cases. Especially those cases where almost all or all visible pixels are correctly classified as snow free, these validation measures can produce peculiarly extreme values (note the addition of +1 to remove division by zero errors). However, in these cases PC and F show that most of the pixels are classified correctly. The grey line which shows the 20 day moving average gives a general view of the changes of the validation measures during the validation period.

Some outliers can be seen in the time series images. These coincide with the strongest grey spikes in the Figure 8 when almost all PDU scenes are missing. E.g. the spike around February 29, 2016 can been in the data.

In general, Metop/AVHRR snow product recognizes the snow covered pixels very well especially during the northern winter and spring when large seasonally snow covered areas in the northern hemisphere and most of the Antarctic can be seen. When the number of visible snow covered pixels decline during the northern summer the validation measures begin to deteriorate, because the asymmetric land distribution of northern and southern hemispheres means that there is very little seasonal snow in the southern hemisphere to balance the melting northern seasonal snow.

Table 7 *Metop/AVHRR snow product validation statistics treatment in three regions (Global, Europe, Variable). Variable region includes those stations which have observed both snow and snow free during the validation period. Partial snow is treated as snow free (Pns), snow covered (Ps) or excluded (Poff). Statistics are calculated using only snow depth and state of the ground observations (obs) and with added air temp based snow free observations (T2m). Green shading marks the best values for each region (obs only).*

	Nstat	Nobs	a	B	c	d	Bias	H	F	FAR	PC	CSI	HSS
Global, Pns, obs	3709	679239	83047	5846	5629	584717	1.002	0.937	0.010	0.066	0.983	0.879	0.926
Global, Pns, T2m	3709	946675	83047	6693	5629	851306	1.012	0.937	0.008	0.075	0.987	0.871	0.924
Global, Ps, obs	3709	684185	90074	5118	11066	577927	0.941	0.891	0.009	0.054	0.976	0.848	0.904
Global, Ps, T2m	3709	951621	90074	6226	11066	844255	0.952	0.891	0.007	0.065	0.982	0.839	0.902
Global, Poff, obs	3709	679135	88241	4469	7007	579418	0.973	0.926	0.008	0.048	0.983	0.885	0.929
Global, Poff, T2m	3709	946503	88241	5327	7007	845928	0.982	0.926	0.006	0.057	0.987	0.877	0.927
Europe, Pns, obs	1853	375389	23704	2144	1625	347916	1.020	0.936	0.006	0.829	0.990	0.863	0.921
Europe, Pns, T2m	1853	470921	23704	2395	1625	443197	1.030	0.936	0.005	0.092	0.991	0.855	0.917
Europe, Ps, obs	1853	377070	26249	1937	4439	344445	0.918	0.855	0.006	0.069	0.983	0.805	0.883
Europe, Ps, T2m	1853	472602	26249	2277	4439	439637	0.930	0.855	0.005	0.080	0.986	0.796	0.879
Europe, Poff, obs	1853	374470	25348	1481	2461	345180	0.965	0.912	0.004	0.055	0.989	0.865	0.922
Europe, Poff, T2m	1853	470072	25348	1740	2461	440523	0.974	0.912	0.004	0.064	0.991	0.858	0.919
Variable, Pns, obs	1754	411823	46854	2843	1042	361984	1.038	0.978	0.008	0.057	0.991	0.923	0.954
Variable, Pns, T2m	1754	458511	46854	2972	1042	407643	1.040	0.978	0.007	0.060	0.991	0.921	0.954
Variable, Ps, obs	1754	415688	52027	2244	4394	357023	0.962	0.922	0.006	0.041	0.984	0.887	0.931
Variable, Ps, T2m	1754	462376	52027	2436	4394	403519	0.965	0.922	0.006	0.045	0.985	0.884	0.930
Variable, Poff, T2m	1754	412327	50708	1745	2046	357828	0.994	0.961	0.005	0.033	0.991	0.930	9.959
Variable, Poff, T2m	1754	459077	50708	1882	2046	404441	0.997	0.961	0.005	0.036	0.991	0.928	0.958

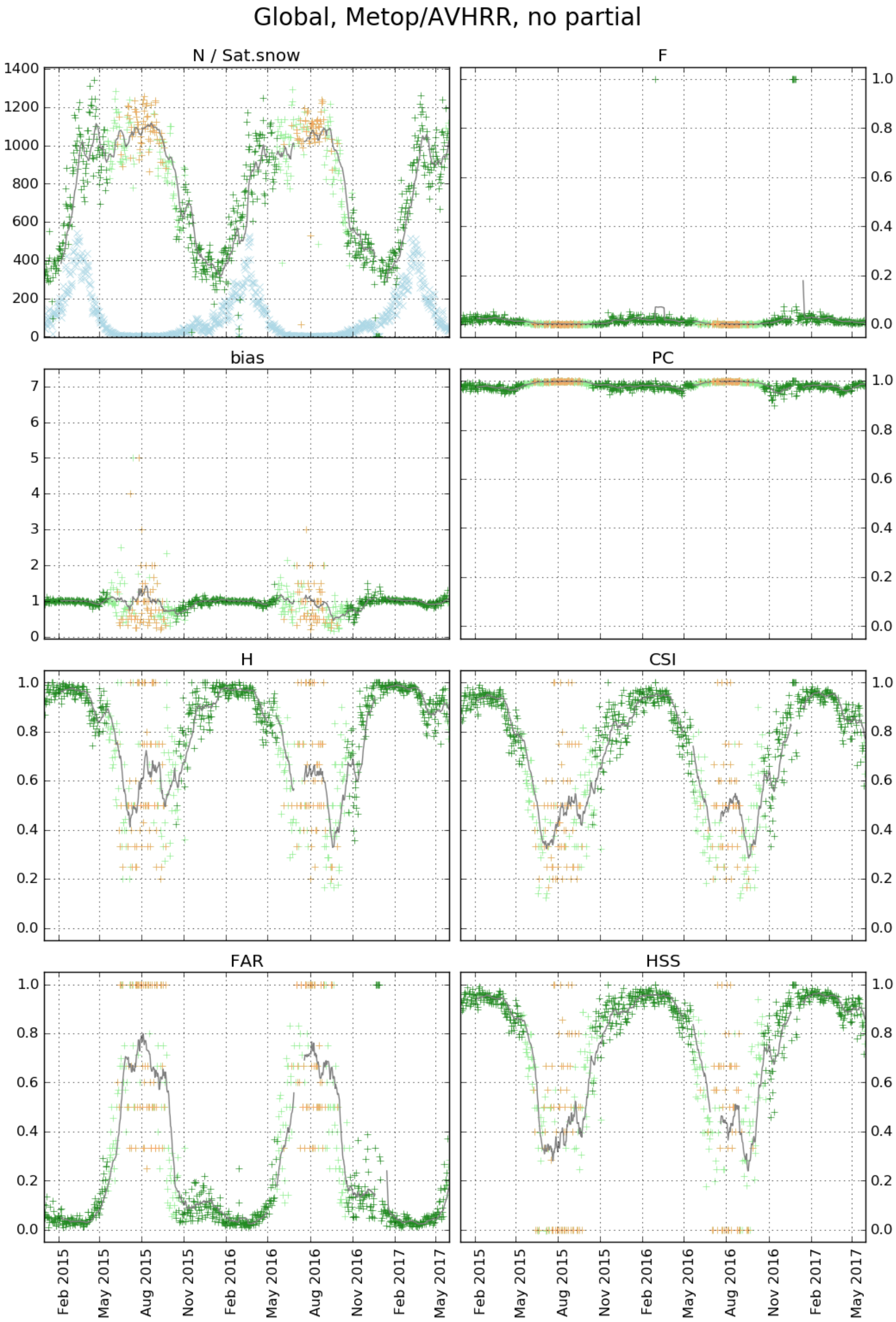

Figure 9 *Time series of global validation measures. All subplots use the same colour coding (see text for details). On top left panel green and orange colour shows the total number of observation pairs and blue colour shows the number of satellite snow pixels in observation pairs. When the correct rejections exceed the other classes by more than 20 (200) times light green (orange) marker is used. In these days the highly skewed distribution of pixels emphasize the misclassifications of very rare snow covered pixels*

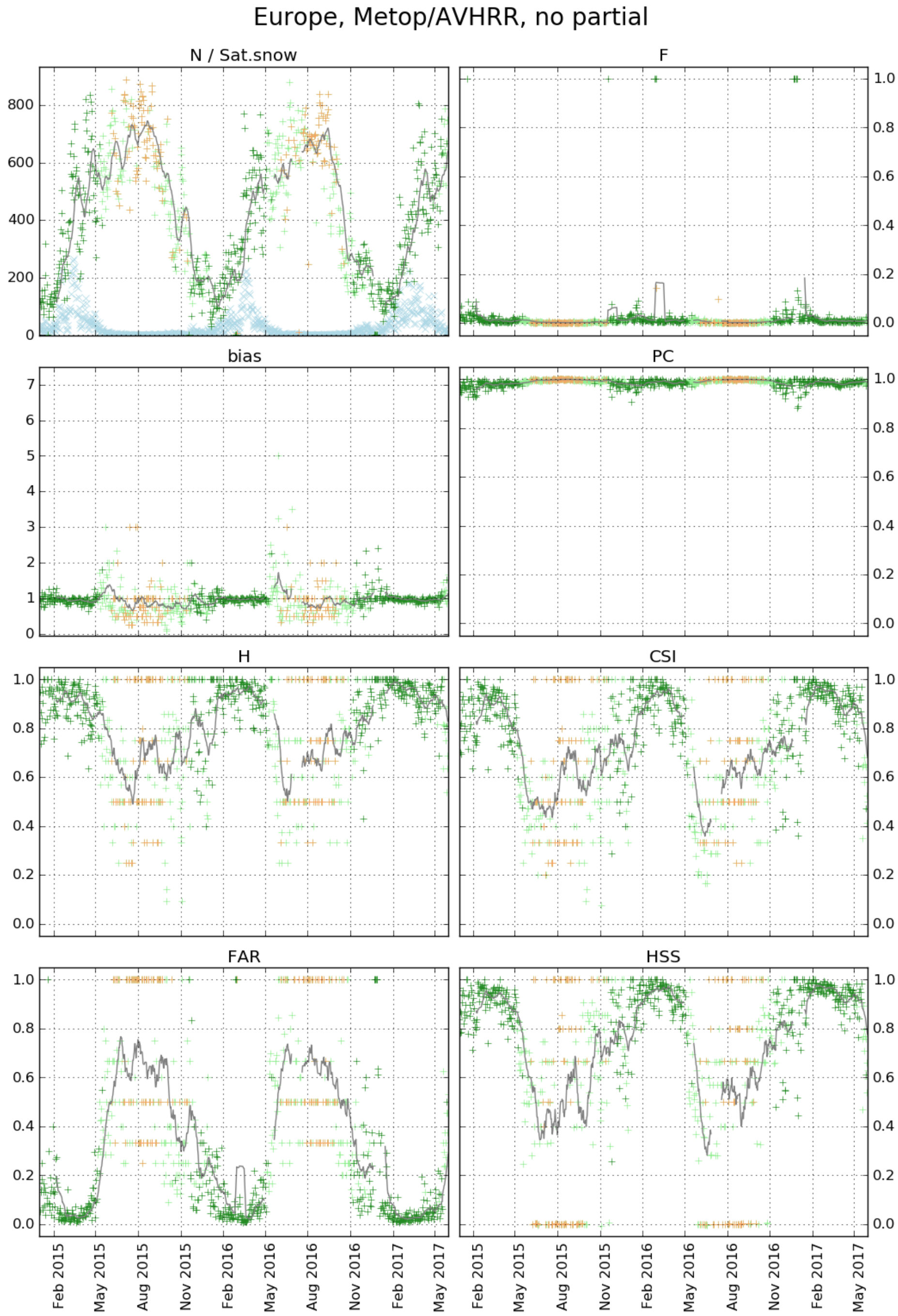

Figure 10 *Time series of validation measures in Europe. All subplots use the same colour coding (see text for details). On top left panel green and orange colours shows the total number of observation pairs and blue colour shows the number of satellite snow pixels in observation pairs. When the correct rejections exceed the other classes by more than 20 (200) times light green (orange) marker is used. In these days the highly skewed distribution of pixels emphasize the misclassifications of very rare snow covered pixels.*

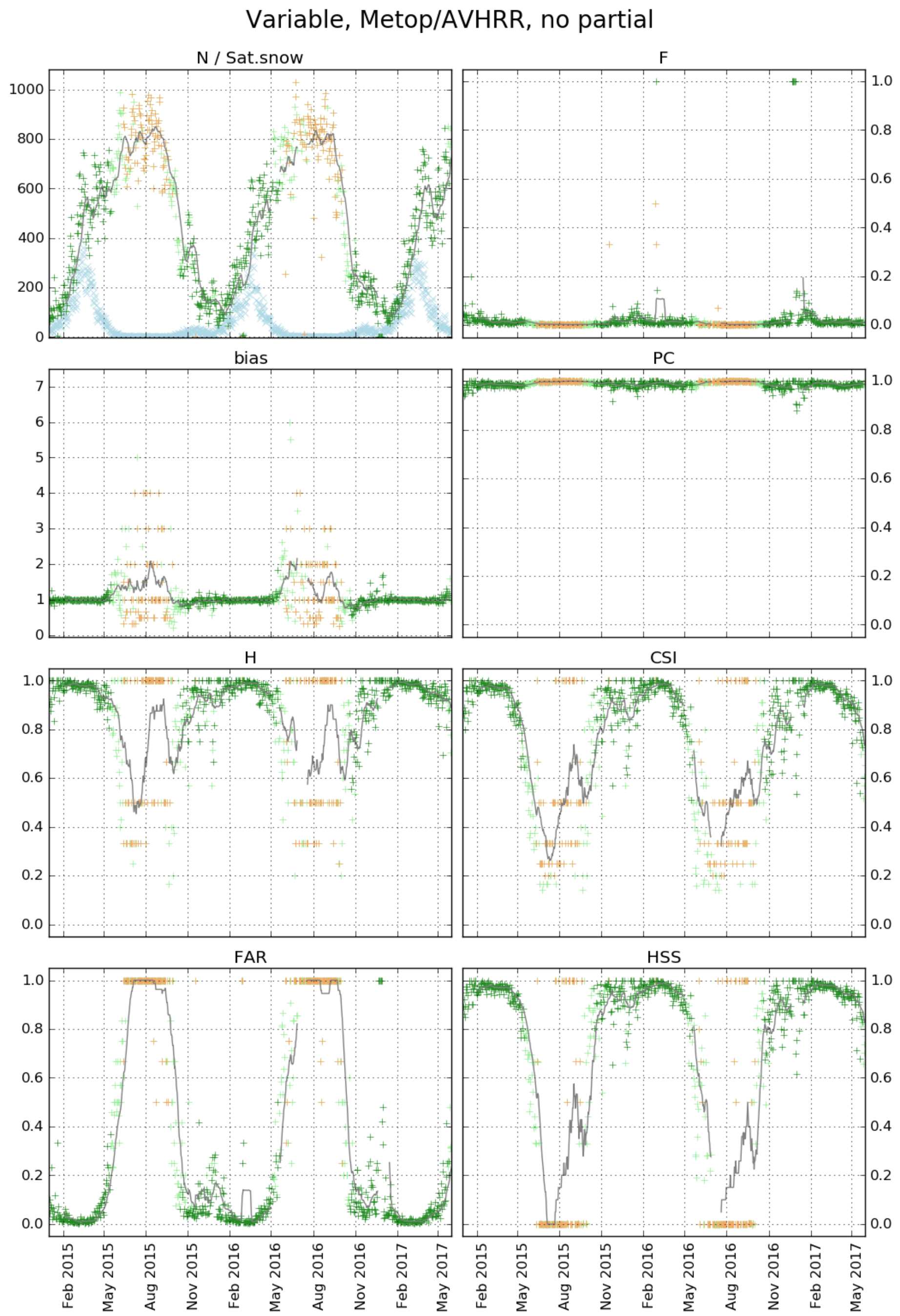

Figure 11 *Time series of validation measures in variable snow region. All subplots use the same colour coding (see text for details). On top left panel green and orange colours show the total number of observation pairs and blue colour shows the number of satellite snow pixels in observation pairs. When the correct rejections exceed the other classes by more than 20 (200) times light green (orange) marker is used. In these days the highly skewed distribution of pixels emphasize the misclassifications of very rare snow covered pixels.*

6. Summary

MSG/SEVIRI snow product (H31) is in good agreement with a widely known global snow product (IMS). Validation results based on surface observations in weather stations and other measuring stations show very good agreement. The results of an independent validation are in good agreement with the HSAF-validation results of the identical (flat lands) H-SAF product (H10).

Validation based on reprocessed Metop/AVHRR snow product (H32) between January 2015 and October 2016 gives very good results.

7. Future work

Conventional snow cover observations campaigns seems to be one possibility to obtain validation data. The SEER campaign provided surface observations of the snow coverage in Finland during one week in April 2011. There is also an ongoing study at the FMI which use social media, i.e. Flickr images with GPS location, to obtain data of the surface condition in similar fashion as Saltikoff and Hyvärinen (2010). These images can be classified to different snow cover classes to get reference data. First tests of this method suggests that the social media has potential as a validation data source, but there are no results available at this moment. Another promising approach can be small unmanned aerial vehicles (UAV) i.e. drones which can be used to take high resolution images suitable for snow coverage analysis. At the moment this method seems to be labour intensive and not suitable for large scale validation.

8. References

Hyvärinen, Otto, Niilo Siljamo, Ari Aaltonen, Janne Kotro, Panu Lahtinen and Anu Petäjä, 2015, Can satellite-based snow products help in quality control of automatic in-situ snow observations in Nordic region?, Proceedings for the 2015 EUMETSAT Meteorological Satellite Conference.

Jolliffe, Ian T. and Stephenson, David B., 2003, Forecast Verification: A Practitioner's Guide in Atmospheric Science, John Wiley & Sons

Kilpys, Justinas, 2016, Independent validation of the H-SAF snow cover products (H10, H12, H31), H-SAF Associated & Visiting Scientist Activity, Final report.

Siljamo, Niilo and Hyvärinen, Otto, 2011, New geostationary satellite-based snow cover algorithm, Journal of Applied Meteorology and Climatology, **50** (June 2011), 1275–1290, American Meteorological Society. DOI: 10.1175/2010JAMC2568.1

Saltikoff, Elena and Hyvärinen, Otto, 2010, Social media as a source of meteorological Observations, Monthly Weather Review 138, 3175–3184, American Meteorological Society. DOI: 10.1175/2010MWR3270.1