Hydrological SAF

Associated & Visiting Scientist Activity

INDEPENDENT VALIDATION OF THE H-SAF SNOW COVER PRODUCTS (H10, H12, H31)

Final Report

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V1.2	21/03/2016	J. Kilpys (LHMS)	Final version

Table of Contents

Objectives

The main objective of this Associated Scientist activity was to perform independent validation study of three HSAF snow products (H10, H31, H10). Satellite based products were validated against the snow measurements at the meteorological stations in Lithuania.

Abstract

Monitoring of snow cover parameters is very important for hydrological and climate applications. In many parts of the world snow-melt is the main source of freshwater. However, accurate assessment of snow cover is a challenging task.

The HSAF (EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management) provides several satellite based snow products. In this study three HSAF products were compared against the ground measurements in Lithuania: H10 – snow mask (MSG-SEVIRI); H12 – effective snow cover (AVHRR, NOAA and Metop); H31 – snow detection for flat land (MSG-SEVIRI). Validation study covered four winters from 2012 to 2016. Ground snow depth and snow fraction data were obtained from the observational network of Lithuanian Hydrometeorological Service. HSAF snow mask products (H10, H31) when compared with in situ measurements showed very high agreement. However, number of available satellite based observations was limited due to the low sun elevation angle and dominant cloudy weather in winter. Rate of agreement of H10, H31 snow products with in situ data varies during the cold season. The lowest validation scores were determined at the beginning of cold season (November–December) and the highest in January and April. A tendency of overestimation was determined for the HSAF snow mask products. Inter-comparison of H10 and H31 data showed that there is a spatial shift between these products and it could be due to the remaping or changing the geolocation information after merging H31 product with snow mask for mountains.

Analysis of HSAF effective snow cover product (H12) indicated that the main limitation is the availability of satellite data. Due to the low sun elevation angle, no H12 data is available for the territory of Lithuania from November till the beginning of February. This limits the potential of H12 product application for snow monitoring. Validation of H12 product showed worse results for coastal stations than for continental stations. The exceptional case was Nida meteorological station at the Curonian Spit. For this location the rate of agreement between in situ and HSAF snow products was lowest. But it was anticipated, as the spatial resolution of HSAF snow products is too low to capture high variation of the surface conditions in the narrow 1–3 km wide spit.

Overall agreement of HSAF snow products (H10, H12, H31) and in situ data was very high. The main limitation of HSAF snow data application for snow monitoring is low data availability, especially at the beginning of the cold season.

Introduction

Snow cover is an important climate variable on both local and global scales. It affects the planetary radiation budget through high albedo values (Levis et al., 2007). It influences the hydrological cycle globally and locally, and for many locations it is an important source of water (Barnett et al, 2005). Monitoring snow cover is an essential part of Global Climate Observing System (GCOS) (Seiz et. al., 2011; WMO, 2011). Snow cover is monitored by different methods, e.g. point measurements at ground stations or spatial measurements using satellite instruments. The main advantage of satellite measurements is that they enable snow monitoring on a large scale.

The HSAF provides satellite based products on snow detection (snow mask), snow status (dry/wet), effective snow cover and snow water equivalent. The snow detection (H10 and H31) is based on visible (VIS) and infrared (IR) radiometry of SEVIRI instrument on-board of Meteosat satellites (LSA SAF 2008a ;HSAF, 2011a; Siljamo, Hyvärinen, 2011). Snow fraction product (H12) of HSAF is based on multi-channel analysis of the AVHRR instrument onboard NOAA and MetOp satellites (HSAF, 2012a). The snow status (H11) and snow water equivalent (H13) products are based on the AMSR-E microwave radiometer data which flies on EOS-Aqua satellite (HSAF 2012c; HSAF 2013).

Validation of satellite products is important for assessing accuracy, identifying possible product errors and providing input for improvements. Validation studies describe advantages and limitations of products and help users to use data appropriately. The main objective of this study is to asses the accuracy of three HSAF products H10, H31 and H12. The accuracy of satellite based snow products was evaluated against the in situ measurements in Lithuania.

1. Data

The validation was based on data from period November 2012 – February 2016. The analysis covered months from November till April as this is snow season in Lithuania. Three HSAF products were used in this validation study:

1. H10 (SN-OBS-1) – snow detection (snow mask) by VIS/IR radiometry. H10 product is based on SEVIRI data and it is operational product.
2. H12 (SN-OBS-3) – effective snow cover by VIS/IR radiometry. H12 product is based on multi-channel analysis of the AVHRR instrument on-board of NOAA and MetOp satellites (pre-operational product).
3. H31 (SN-OBS-0G) – snow detection for flat land by VIS/NIR of SEVIRI. H31 product has a MSG disk coverage with SEVIRI pixel resolution and is based on multi-channel (VIS, NIR, IR) analysis (it is operational product and was handed over from LSA SAF).

Ground data was obtained from the observational network of Lithuanian Hydrometeorological Service (LHMS). Data from 50 stations were used (Fig. 1), including 18 meteorological stations (MS) and 32 water gauging stations (WS) (full list is in Annex 1). In all stations snow measurements are done manually by the observers. Snow depth is determined by the measuring stick and snow fraction is determined visually. The snow fraction is described using points from 1–10, were 10 points represent the area which is 100 % covered with snow. If there is no snow, no SYNOP messages or monthly summaries are provided. In this study, on the date when there was no message about the snow, the in situ value was considered “no snow”.

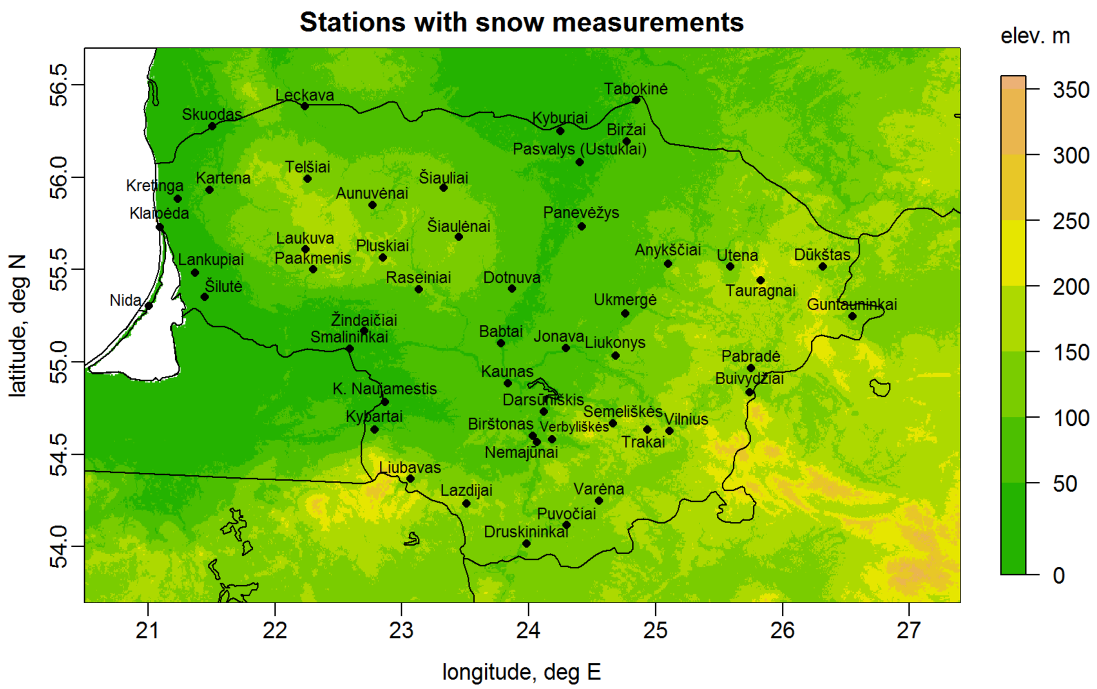


Fig. 1. Stations in Lithuania which are measuring the snow cover (50 stations).

In addition to the daily snow depth measurement, snow courses are performed every 10 days in 39 stations. Starting from February snow courses are done every 5 days. During the snow courses observer makes a field trip and measures the snow cover in an open areas and forests. During the snow courses different characteristics of the snow pack are measured:

- snow depth (measurement accuracy 1 cm);
- snow fraction (1-10 points);
- snow conditions (dry, wet, fresh, old, etc.);
- snow drift (is it uniform or not);
- surface conditions under the snow (land with permafrost, water under the snow, ice, etc.).

A snow course is a 1–2 km long trail through the open field or forest (in forest, the trail can be shorter, 0.5 km). 100 observations on snow depth and patchiness are recorded along the trail.

The day with snow was considered when more than 50% of surrounding area is covered with snow (6–10 points). Snow depth was not used as criteria, because there are frequent events, when snow depth is less than 1 cm, but all area is covered with snow, especially at the beginning of cold season.

2. Validation methodology

The snow mask products (H10, H31) were validated using contingency table statistics, which are the most common technique for dichotomous variables ("yes" or "no" events).

Contingency Table

		Observed from ground		
		Yes	No	Marginal Total
Observed from satellite	Yes	*hits*	*false alarms*	*Satellite determined yes*
	No	*misses*	*correct negatives*	*Satellite determined no*
	Marginal Total	*Observed yes*	*Observed no*	*Total*

The categories of contingency table are:

- hits – snow was determined from satellite data, and also observed on the ground;
- misses – snow was not determined from the satellite data, but observed on the ground;
- false alarm – snow was determined from the satellite data, but not observed on the ground;
- correct negative – snow was not determined from the satellite data, and also not observed on the ground.

The contingency table categories were used to calculate different categorical statistical scores (Table 1).

Table 1. *Validation scores, which were calculated using the contingency table statistics.*

Statistical Score	Formula	Description
1. Frequency Bias (FBI)	$FBI = \frac{hits + falsealarms}{hits + misses}$	How satellite derived snow cover frequency compare with snow observed in situ? Range: 0 to ∞. Perfect score: 1.
2. Probability Of Detection (POD)	$POD = \frac{hits}{hits + misses}$	What fraction of the in situ snow events were determined by satellite data? Range: 0 to 1. Perfect score: 1.
3. False Alarm Ratio (FAR)	$FAR = \frac{falsealarms}{hits + falsealarms}$	What fraction of the satellite derived snow cover was false (no snow was observed in situ)? Range: 0 to 1. Perfect score: 0.
4. Probability of false detection (POFD)	$POFD = \frac{falsealarms}{correctnegative + falsealarms}$	What fraction of the observed “no snow” events were determined as snow in satellite data? Range: 0 to 1. Perfect score: 0.
5. Accuracy / Rate of agreement (ACC)	$ACC = \frac{hits\ +\ correctnegatives}{total}$	What fraction of satellite derived snow cover was correct? Range: 0 to 1. Perfect score: 1.
6. Critical success index (CSI)	$CSI = \frac{hits}{hits + misses + falsealarms}$	How well did the satellite derived snow cover correspond to the observed snow cover in situ. Range: 0 to 1. Perfect score: 1.
7. Equitable Threat Score (ETS)	$ETS = \frac{hits - hits_{random}}{hits + misses + falsealarms - hits_{random}}$ $hits_{random} = \frac{(Observed\ yes) * (Satellite\ derived\ yes)}{Total}$	How well did the satellite derived snow cover events correspond to the observed snow in situ (accounting for hits due to random chance)? Range: -1/3 to 1. 0 indicates no skill. Perfect score: 1.
8. Heidke Skill Score (HSS)	$HSS = \frac{(hits + correctnegatives) - (expectedcorrect)_{random}}{Total - (expectedcorrect)_{random}}$ where *(expected correct)*$_{random}$: $(expectedcorrect)_{random} = \frac{1}{Total}[(Observed\ yes) * (Satellite\ determined\ yes) + (Satellite\ determined\ no) * (Observed\ no)]$	What is the accuracy of satellite derived snow cover relative to that of random chance. Range: -∞ to 1. 0 indicates no skill. Perfect score: 1.

Categorical statistics used in this study was also used in HSAF Product Validation Reports for H10 and H12 products (HSAF 2011c, 2012b), so the results of this study can be compared to the previous studies. For the H12 fractional snow cover product additional statistics were calculated:

1) Bias:

$$bias=\frac{1}{N}\sum_{k=1}^{N}\left(sat_k-true_k\right)$$

2) Standard deviation (SD):

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

3) Correlation coefficient (CC):

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

4) Root mean square error (RMSE):

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

Contingency table statistics for H12 product were calculated considering “hit” when rounded H12 snow fraction value was equal to the value provided by the observer in situ (e.g. H12 values 45–54% and 5 points by the observer was considered to be “hit”). Rounded H12 values above the observed values in situ were considered to be “false alarm”, and lower H12 values were classified as “misses”.

HSAF snow product validation was based on point to pixel comparison. The respective pixel was determined using closest neighbour method. Cloudy and data-missing (“dark”, “space”) pixels were removed from validation.

For H31 product additional analysis was made to compare the results when partly snow covered values (binary value = 2) were considered as snow or as snow free.

3. Validation results of the H10 product

Results show that there is good agreement between H10 (snow mask) and in situ observations in Lithuania. The mean rate of agreement (ACC) was 0.89; the average Probability of Detection (POD) was 0.98; False Alarm Rate (FAR) was 0.24 and Critical Success Index (CSI) was 0.74. Scores are averaged for the 49 stations in Lithuania, excluding Nida MS (which is very specific location) (Table 2). FBI values higher than 1 indicate the tendency of H10 product to overestimate the snow cover.

The availability and accuracy of the H10 snow product varies during the cold season (see Table 3). The number of available satellite observations increases from the beginning of cold season to the end of it. In November and December the availability of H10 data is reduced due to the low sun angle and dominant cloudy weather patterns. Also in the first half of cold season (November-January) there are higher number of cases with false alarms (Fig. 2).

Table 2. *Validation scores for the H10 snow mask product (full list of stations and scores is provided in Annex II).*

Station	N	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
Biržai MS	156	1,00	1,00	0,00	0,00	1,00	1,00	1,00	1,00
Dotnuva MS	160	1,00	1,00	0,00	0,00	1,00	1,00	1,00	1,00
Dūkštas MS	130	0,95	0,93	0,02	0,01	0,96	0,91	0,85	0,92
Kaunas MS	148	1,03	0,97	0,06	0,05	0,96	0,91	0,85	0,92
Klaipėda MS	151	0,96	0,96	0,00	0,00	0,99	0,96	0,96	0,98
Kybartai MS	177	1,12	1,00	0,11	0,04	0,97	0,89	0,86	0,92
Laukuva MS	157	1,02	0,95	0,06	0,04	0,96	0,90	0,83	0,91
Lazdijai MS	154	1,13	1,00	0,12	0,07	0,95	0,88	0,82	0,90
Nida MS	120	3,80	1,00	0,74	0,56	0,53	0,26	0,12	0,21
Panevėžys MS	157	1,07	0,97	0,10	0,06	0,95	0,88	0,81	0,89
Raseiniai MS	149	1,26	0,96	0,24	0,14	0,89	0,74	0,62	0,77
Šiauliai MS	160	1,00	0,99	0,01	0,01	0,99	0,97	0,95	0,97
Šilutė MS	141	1,00	0,93	0,07	0,02	0,97	0,87	0,84	0,91
Telšiai MS	154	1,20	1,00	0,16	0,15	0,92	0,84	0,71	0,83
Trakai WS	152	1,25	0,96	0,23	0,15	0,89	0,75	0,62	0,77
Ukmergė MS	158	1,25	1,00	0,20	0,12	0,92	0,80	0,70	0,82
Utena MS	156	1,06	0,98	0,07	0,05	0,96	0,91	0,85	0,92
Varėna MS	140	1,10	0,96	0,12	0,08	0,94	0,84	0,76	0,86
Vilnius MS	142	0,98	0,97	0,02	0,01	0,98	0,95	0,92	0,96
Total / Average (except Nida MS)	7421	1,36	0,98	0,24	0,14	0,89	0,74	0,64	0,76

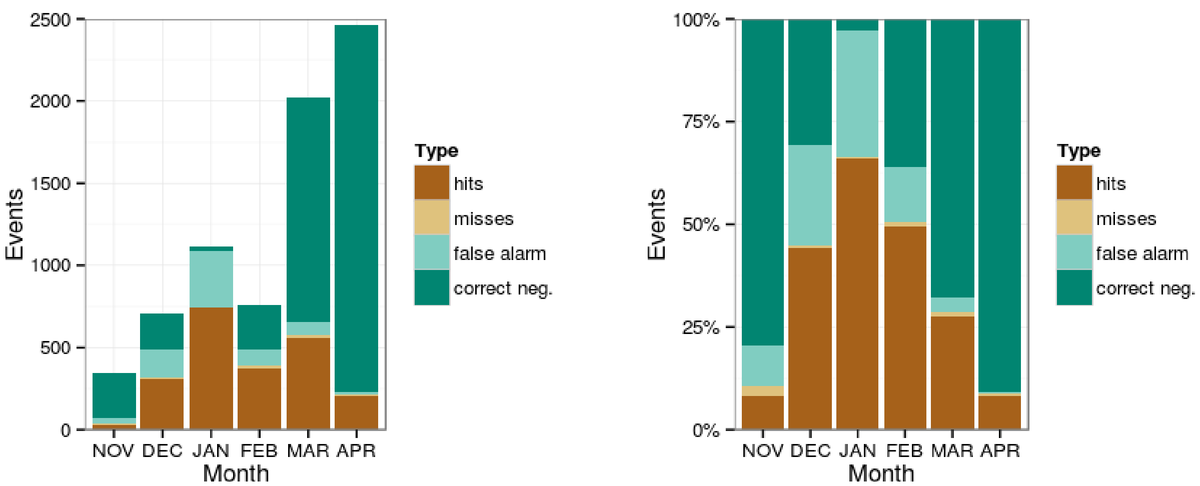


Fig. 2. *Left – number of cases with available H10 data on different months and distributions; right – the contingency table categories in percent (2012–2016).*

Table 3. *H10 product validation results on different months.*

Scores	NOV	DEC	JAN	FEB	MAR	APR
hits	29	310	740	376	559	206
misses	8	5	2	10	17	10
false alarm	35	172	345	101	77	14
correct neg.	276	217	31	275	1367	2239
total	348	704	1118	762	2020	2469
FBI	0,34	1,83	1,58	1,48	1,09	1,01
POD	0,26	0,99	1,00	0,97	0,84	0,9
FAR	0,40	0,33	0,31	0,21	0,21	0,06
POFD	0,15	0,37	0,73	0,27	0,05	0,01
ACC	0,84	0,75	0,69	0,85	0,95	0,99
CSI	0,23	0,66	0,69	0,77	0,73	0,84
ETS	0,30	0,47	0,12	0,58	0,71	0,87
HSS	0,31	0,57	0,15	0,69	0,76	0,91

It was presumed that there will be differences in validation results between coastal stations and continental stations. However, comparison did not show any distinction between coastal and continental areas or stations at lowlands and uplands (Fig. 3).

The exceptional case was Nida MS. This meteorological station is located in the Curonian Spit which is only 1–3 km wide and separates the Baltic Sea and Curonian Lagoon. Specific location of this station makes it difficult to correctly determine snow cover using satellite data. For Nida MS the ACC was 0.53, FAR was 0.74 and CSI was 0.26 (lowest scores from all the station).

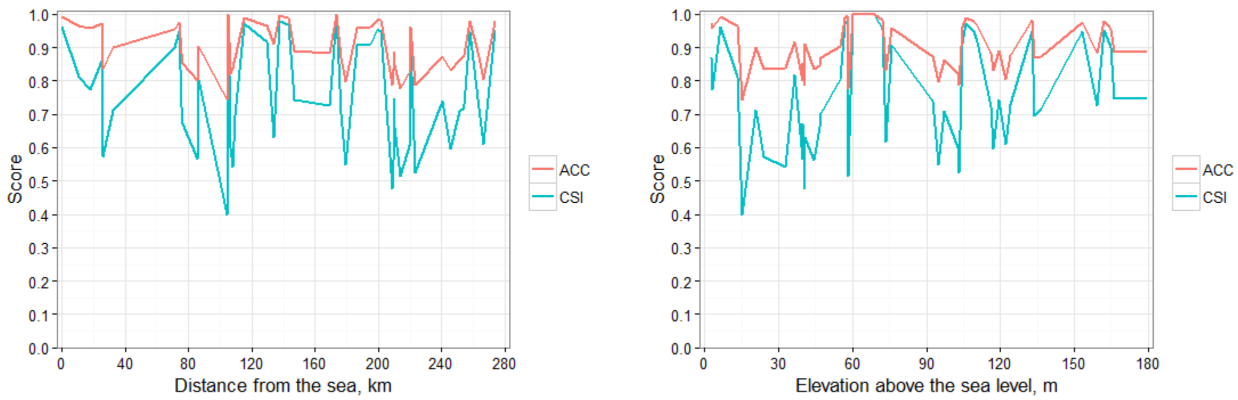


***Fig. 3**. The relation between H10 validation scores of Accuracy (ACC) and Critical Success Index (CSI) and distance from the sea (left) and elevation (right).*

During the validation it was determined that Curonian Spit is missing in the H10 and H31 product land mask from 29th December 2012 till the 4th March 2013 (Fig. 4). This period corresponds to the transition from MSG-2 (Meteosat-9) to MSG-3 (Meteosat-10) as the main operational satellite. The MSG-3 satellite completed its in-orbit testing on 12th December 2012 and on 21st January 2013 it was moved to 0° and became the prime operational geostationary satellite. The Land SAF message system indicates that the final tests of LSA SAF system working with MSG3 was performed on the 18th February 2013.

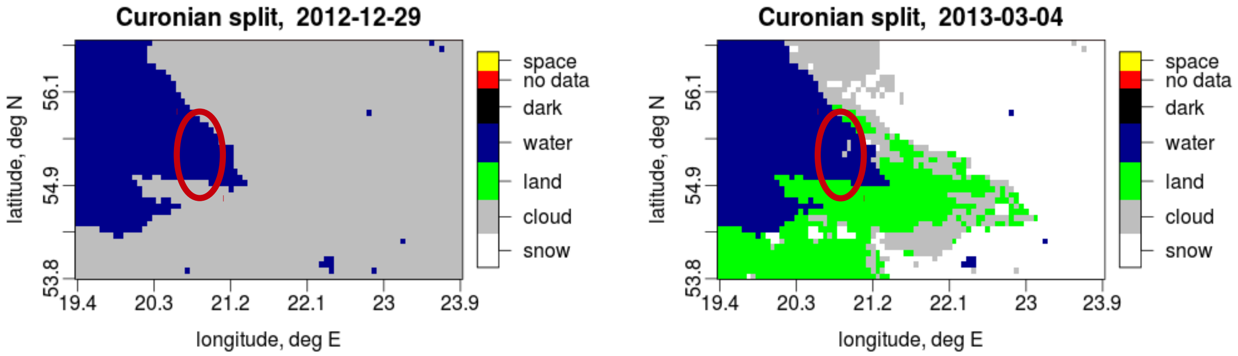


***Fig. 4**. The representation of Curonian Spit in H10 and H31 products. Spit is missing in the land mask from 29th December 2012 till the 3th March 2013.*

4. Validation results of the H31 product

The comparison of the H31 product against the ground observations at 50 stations in Lithuania showed that mean rate of agreement (ACC) was 0.89, average POD was 0.98, FAR 0.25 and CSI 0.73. At some stations (Kaunas MS, Lazdijai MS) H31 product had a perfect scores, indicating that when it is cloud free, HSAF snow products can be very accurate (Table 4). The average FBI value was 1.18, revealing the tendency of H31 product to overestimate the snow cover. The poorest results were determined for Nida MS, but this is due to the very specific location of this station in the Curonian Spit (described in detail in Chapter 3).

***Table 4.** Validation scores of H31 snow detection over the flat land product (full list of stations and scores is provided in Annex III).*

Station	N	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
Biržai MS	168	1,00	0,99	0,01	0,01	0,99	0,97	0,95	0,98
Dotnuva MS	163	0,99	0,99	0,00	0,00	0,99	0,99	0,97	0,99
Dūkštas MS	147	0,96	0,94	0,02	0,01	0,97	0,93	0,87	0,93
Kaunas MS	138	1,00	1,00	0,00	0,00	1,00	1,00	1,00	1,00
Klaipėda MS	152	0,88	0,88	0,00	0,00	0,98	0,88	0,85	0,92
Kybartai MS	153	1,38	1,00	0,28	0,11	0,92	0,72	0,64	0,78
Laukuva MS	160	1,00	0,93	0,07	0,06	0,94	0,87	0,78	0,87
Lazdijai MS	152	1,08	0,98	0,09	0,05	0,96	0,89	0,84	0,91
Nida MS	163	6,00	1,00	0,83	0,74	0,36	0,17	0,04	0,08
Panevėžys MS	163	1,12	0,96	0,14	0,08	0,93	0,83	0,75	0,86
Raseiniai MS	153	1,17	0,94	0,20	0,10	0,91	0,76	0,66	0,79
Šiauliai MS	153	1,03	0,98	0,05	0,03	0,97	0,94	0,90	0,95
Šilutė MS	153	1,00	0,91	0,09	0,03	0,96	0,84	0,80	0,89
Telšiai MS	165	1,14	0,97	0,15	0,11	0,92	0,82	0,72	0,84
Ukmergė MS	146	1,21	0,98	0,19	0,11	0,92	0,79	0,70	0,82
Utena MS	151	1,05	0,98	0,06	0,04	0,97	0,92	0,87	0,93
Varėna MS	137	1,45	1,00	0,31	0,25	0,84	0,69	0,52	0,68
Vilnius MS	141	1,02	0,98	0,03	0,03	0,98	0,95	0,92	0,96
Total / Average (except Nida MS)	7448	1,37	0,98	0,25	0,14	0,89	0,73	0,63	0,76

H31 product has a “partly snow” pixel category, which when merging snow detection over the flat land an over the mountains to one product (H10) is considered to be “no snow”. In this study “partly snow” pixels were considered both “snow” and “no snow” and analysed as separate cases. Although number of “partly snow” pixels is very low (67 cases in total) analysis showed that in 61% cases “partly snow” pixels were actually snow free (snow fraction on the ground was less than 50%) (Fig. 5). Later in the study “partly snow” pixels were considered as “no snow” – the same as it is done for H10 product.

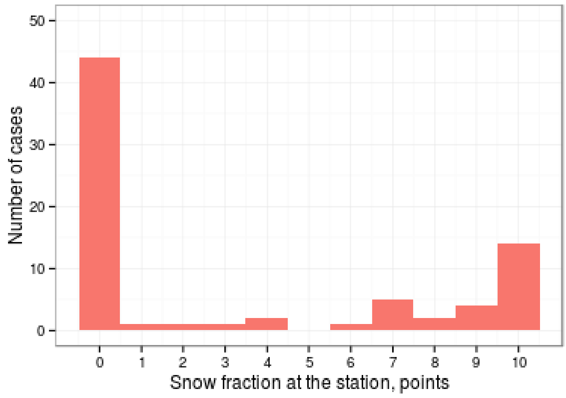


Fig. 5. *Number of cases when “partly snow” pixels correspond to different snow fraction determined in situ. In most cases when pixel is categorized as “partly snow” there is no snow at the meteorological stations.*

Because there are no mountains in Lithuania, H31 and H10 products should be identical, however the inter-comparison showed that there are differences (Fig. 6). The difference could be caused by different geolocation information. Then specific region is examined there is an evident shift in coastlines, water bodies or snowline between the products. The shift can be caused by different geolocation or remaping of H10 product after merging snow detection product for flat land (FMI) and for mountains (TSMS).

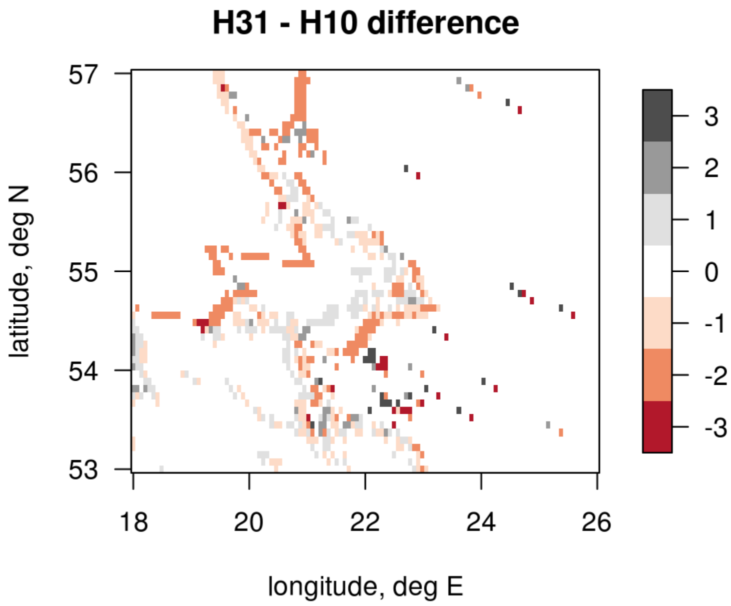
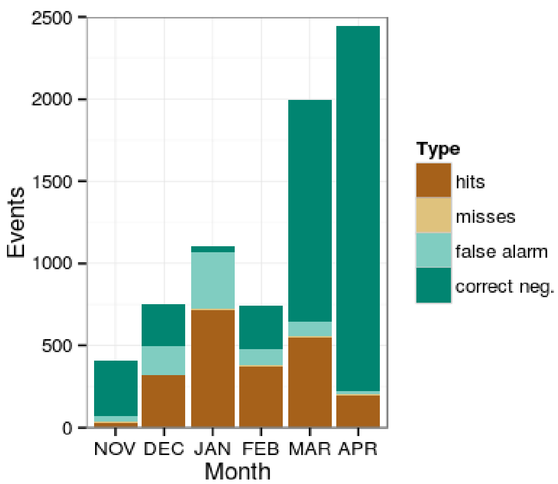


Fig. 6. *Difference between the H31 and H10 products on 4^th^ March 2013. There is an evident shift in snowline, coastlines and water-bodies.*

The accuracy of H31 snow mask product changes during the cold season (Table 5). In November and December the availability of H31 data is limited due to the low sun elevation and dominant cloudy weather patterns. The highest scores (ACC=0.99, POD=0.94, FAR=0.07, CSI=0.73) were determined for April, when the dominant category is "no snow" and number of available satellite observations is highest (Fig. 7).

Table 5. *H31 product validation results on different months.*

Scores	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
hits	29	318	716	374	547	199
misses	7	5	6	11	15	6
false alarm	36	171	347	97	81	15
correct neg.	333	260	32	264	1353	2226
total	405	754	1101	746	1996	2446
FBI	0,34	1,72	1,59	1,33	1,12	1,08
POD	0,30	0,99	0,99	0,97	0,85	0,94
FAR	0,35	0,32	0,32	0,20	0,22	0,07
POFD	0,11	0,35	0,75	0,27	0,05	0,01
ACC	0,88	0,77	0,68	0,85	0,95	0,99
CSI	0,27	0,67	0,67	0,77	0,73	0,87
ETS	0,39	0,47	0,12	0,57	0,72	0,90
HSS	0,40	0,58	0,15	0,69	0,77	0,93



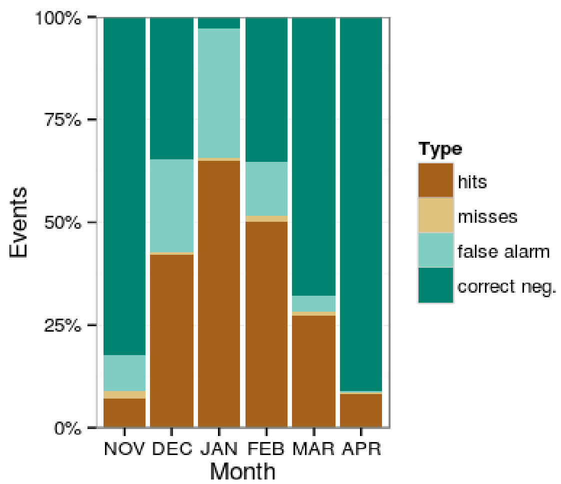


Fig. 7. *Left – number of cases with available H31 data on different months and distributions; right – the contingency table categories in percent (2012–2016).*

H31 product validation results did no show any link between the station's distance to the sea or elevation and validation scores (Fig. 8). Overall H31 products show a good agreement with in situ data both in coastal and continental areas.

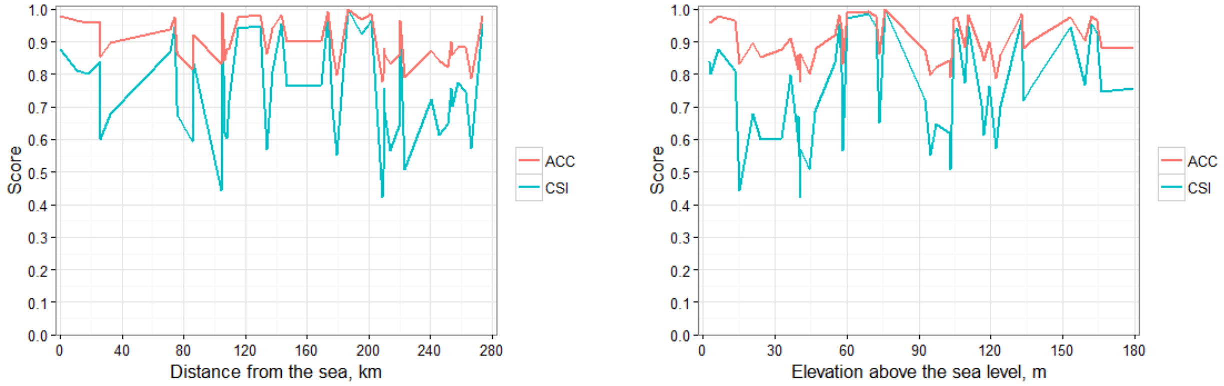


Fig. 8*. The relation between H31 validation scores of Accuracy (ACC) and Critical Success Index (CSI) and distance from the sea (left) and elevation (right).*

5. Validation results of the H12 product

The comparison of ground observations and satellite based observations showed that HSAF effective snow cover product (H12) has a tendency to overestimate snow fraction. For all locations H12 product exhibits the positive bias (average 24.5%) and average RMSE is 51% (Table 6). RMSE values in this study far exceeds the H12 product target requirement of 20% RMSE (HSAF, 2012b). The lowest correlation coefficients were determined for the coastal stations (Nida MS and Klaipėda MS), 0.36 and 0.55 respectively. In other stations the correlation coefficient were higher, varying from 0.64 to 0.99. Average ACC was 0.71, POD was 0.64, FAR 0.63 and CSI 0.28.

Table 6*. Validation scores of H12 fractional snow product (full list of stations and scores is provided in Annex IV).*

Station	N	Bias	SD	CC	RMSE	RMSE, %	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
Biržai MS	67	32,7	41,9	0,96	53,1	0,60	1,25	0,92	0,27	0,19	0,85	0,69	0,53	0,69
Dotnuva MS	56	25,6	38,8	0,99	46,5	0,55	1,43	0,93	0,35	0,17	0,86	0,62	0,50	0,67
Dūkštas MS	61	34,2	40,8	0,95	53,2	0,65	0,73	0,58	0,21	0,11	0,75	0,50	0,32	0,48
Kaunas MS	55	17,1	27,8	0,95	32,6	0,54	0,67	0,27	0,60	0,15	0,69	0,19	0,07	0,13
Klaipėda MS	67	17,2	27,0	0,55	32,0	0,21	8,33	0,33	0,96	0,38	0,61	0,04	0,00	-0,01
Kybartai MS	60	16,8	30,5	0,93	34,8	0,43	1,56	0,67	0,57	0,16	0,82	0,35	0,26	0,41
Laukuva MS	56	28,5	41,2	0,95	50,1	0,60	1,00	0,79	0,21	0,11	0,86	0,65	0,52	0,68
Lazdijai MS	61	30,0	40,6	0,98	50,5	0,59	2,36	1,00	0,58	0,30	0,75	0,42	0,30	0,46
Nida MS	83	23,7	32,4	0,36	40,2	0,31	9,25	0,25	0,97	0,46	0,53	0,02	-0,02	-0,04
Panevėžys MS	62	32,5	40,3	0,98	51,7	0,62	2,91	0,91	0,69	0,43	0,63	0,30	0,16	0,27
Raseiniai MS	61	21,1	35,1	0,94	41,0	0,50	2,30	0,90	0,61	0,27	0,75	0,38	0,26	0,41
Šiauliai MS	72	26,8	37,3	0,93	45,9	0,53	1,65	0,90	0,45	0,29	0,76	0,51	0,34	0,51
Šilutė MS	60	4,4	12,5	0,91	13,2	0,22	3,67	0,33	0,91	0,18	0,80	0,08	0,04	0,07
Telšiai MS	62	25,2	37,5	0,91	45,2	0,58	1,92	0,58	0,70	0,32	0,66	0,25	0,11	0,20
Ukmergė MS	63	21,0	31,6	0,97	37,9	0,52	0,65	0,18	0,73	0,17	0,65	0,12	0,00	0,00
Utena MS	59	37,2	42,5	0,93	56,5	0,64	1,40	0,90	0,36	0,26	0,80	0,60	0,41	0,59
Varėna MS	55	12,7	21,2	0,88	24,8	0,57	0,22	0,17	0,25	0,03	0,71	0,16	0,10	0,17
Vilnius MS	52	30,6	37,9	0,95	48,7	0,64	0,84	0,42	0,50	0,24	0,63	0,30	0,10	0,18
Total / Average (except Nida MS)	2940	24,5	34,2	0,90	42,2	0,51	3,43	0,64	0,63	0,26	0,71	0,28	0,18	0,26

Number of available H12 data was very low compared to H10 and H31 products. For the territory of Lithuania H12 data is available only from February (Fig. 9). In November, December and January (for the period 2012–2016) all H12 product pixels over the Lithuania were classified as “dark” or “no data“. The half of snow season with missing data is the main limitation for H12 application in snow monitoring. Validation scores for February, March and April are comparable to each other (Table 7). Scatter plot of H12 snow fraction data and fraction measured at the meteorological station shows that when there is no snow at the station, pixel in H12 product still can be classified as 100% covered with snow (Fig. 10). This shows the tendency to overestimate the snow fraction. On the other hand, there was no cases when area in situ was fully snow covered (10 points) and there was no snow (0 %) in H12 product (Fig. 10). If ground is fully covered with snow satellite data will determine at least some fraction of snow in the pixel.

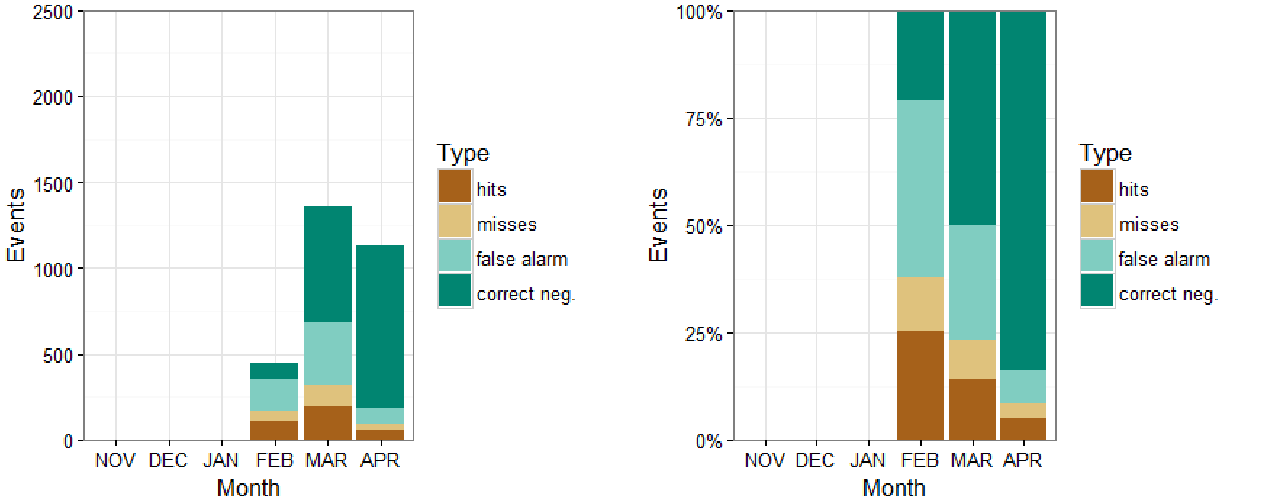


Fig. 9. *Number of cases with available H12 data on different months and distributions of contingency table categories (2012–2016).*

Table 7. *H12 product validation results on different months.*

Score	NOV	DEC	JAN	FEB	MAR	APR
hits	-	-	-	112	194	57
misses	-	-	-	56	122	37
false alarm	-	-	-	183	362	90
correct neg.	-	-	-	94	683	949
total	-	-	-	445	1361	1133
Bias	-	-	-	44,0	30,9	8,22
SD	-	-	-	33,1	35,0	21,8
CC	-	-	-	0,87	0,9	0,94
RMSE	-	-	-	56,4	46,8	23,4
RMSE_%	-	-	-	11,5	10,5	10,5
FBI	-	-	-	2,04	2,71	1,14
POD	-	-	-	0,61	0,51	0,47
FAR	-	-	-	0,61	0,64	0,58
POFD	-	-	-	0,63	0,31	0,09
ACC	-	-	-	0,46	0,65	0,89
CSI	-	-	-	0,30	0,28	0,29
ETS	-	-	-	0,04	0,18	0,25
HSS	-	-	-	0,04	0,23	0,34

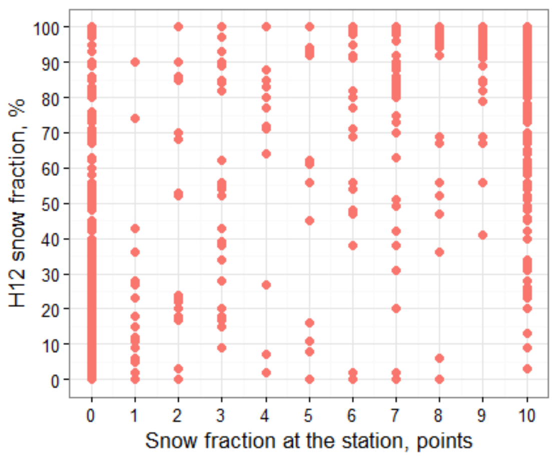


Fig. 10. *Scatter plot of H12 snow fraction values (%) against the snow fraction in situ (in points).*

H12 product for the coastal stations had lower validation scores than stations further from the Baltic Sea (Fig. 11). However some continental stations also had low validation scores. Snow cover at the coast is ephemeral, there are frequent thaws and area covered with snow can change rapidly. In these climatic conditions it is difficult to precisely determine snow fraction using satellite based observations.

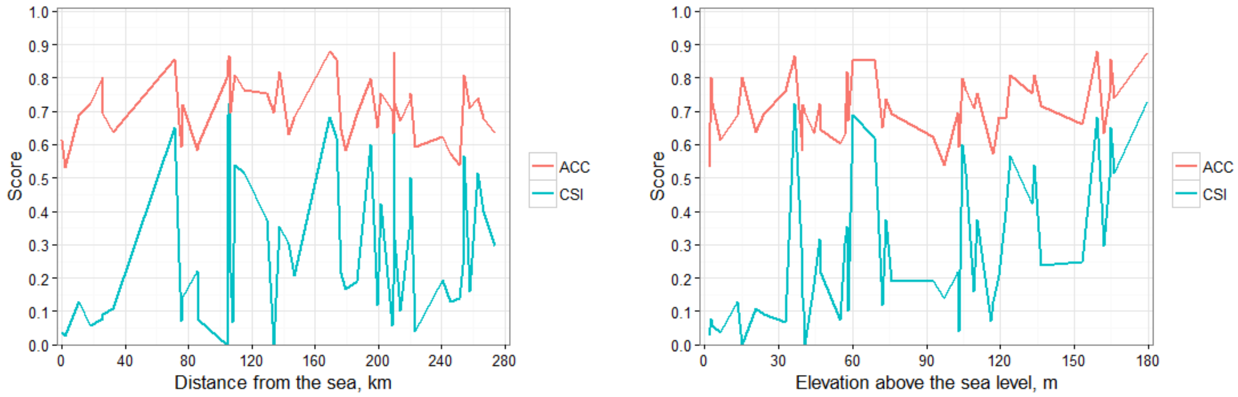


Fig. 11*. The relation between H12 validation scores of Accuracy (ACC) and Critical Succes Index (CSI) and distance from the sea (left) and elevation (right).*

6. Snow courses case studies

The snow courses in the field and forest are performed in the vicinity of the meteorological station. In most cases trails of the snow courses fall in the same HSAF snow product pixel as the point measurements at the station (Fig. 13).

Snow cover fraction and average depth determined from the snow courses in the open field often match observations at the meteorological station (Fig. 12). Values determined in the forest trail can differ from the observations in the field and station. The snow courses in the forest are not performed if the snow fraction at the station is less than 5 points (≤ 50 %), so the number of available observations in the forest is smaller than in the open field.

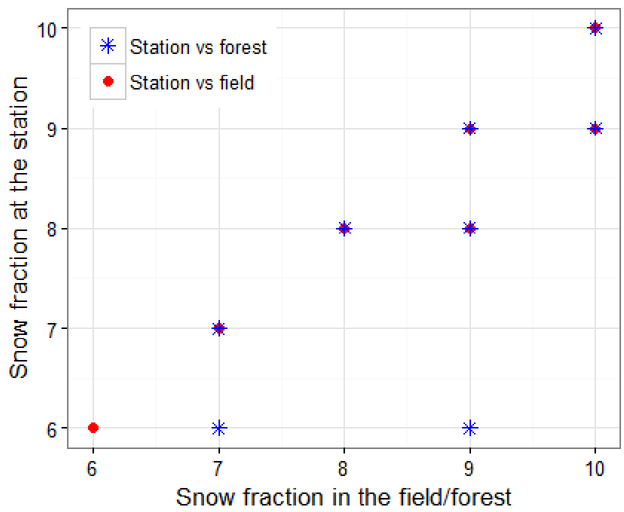


Fig. 12. *Comparison of snow fraction (in points) observed at Vilnius MS. Observations are done on the same day at the station and in the open field and forest. Snow fraction in the forest is the same or higher than at the station.*

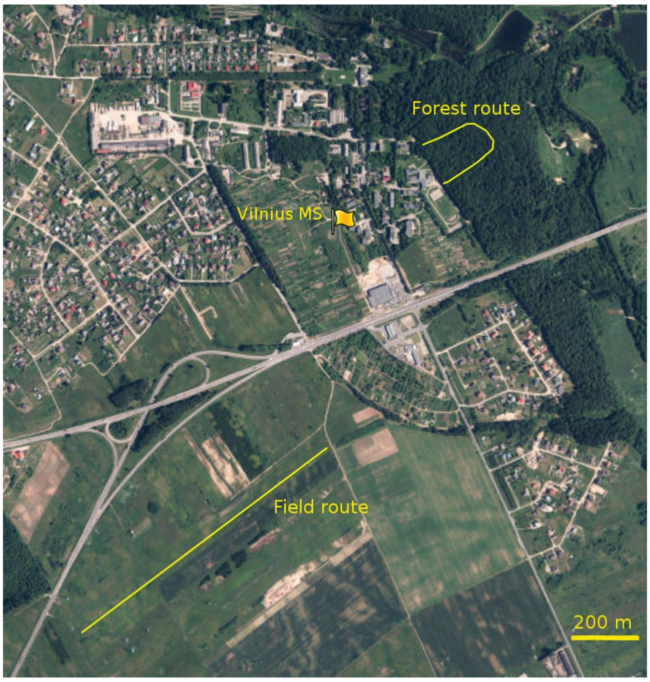


Fig. 13. *Snow survey measurements at Vilnius MS. Snow course measurements are done every 10 days in the forest and in the open field. The trails are in vicinity of the station and in most cases fall in the same pixel as meteorological station.*

H10 and H31 product validation scores over the snow courses in the open field were very similar (Table 8 and Table 9). These products should be identical, but due the spatial shift there are some differences. Comparison of H10 and H31 with the snow courses in the forest, showed that H31 product is better in detecting snow: false alarm rate (FAR) for the H10 product was 0.79, while for the H31 product it was 0.14. Number of available snow course measurements in the forests in Lithuania in 2012–2016 was limited, so the validation results should be treated with caution.

Table 8. *The mean validation scores for the H10 snow product and snow courses.*

Location	**N**	**FBI**	**POD**	**FAR**	**POFD**	**ACC**	**CSI**	**ETS**	**HSS**
Open field	935	1,23	0,99	0,12	0,04	0,97	0,87	0,84	0,90
Forest	173	1,43	0,43	0,79	0,13	0,87	0,21	0,20	0,24

Table 9. *The mean validation scores for the H31 snow product and snow courses.*

Location	**N**	**FBI**	**POD**	**FAR**	**POFD**	**ACC**	**CSI**	**ETS**	**HSS**
Open field	930	1,23	1,00	0,14	0,05	0,96	0,86	0,83	0,89
Forest	174	1,20	0,96	0,14	0,03	0,97	0,82	0,79	0,87

HSAF snow fraction product H12 showed better agreement with ground measurements in the forest snow course than in the open field. However, the number of available cases for comparison in open field and forest differ by 6 times and thus the statistical scores should be compared with reservation (Table 9).

Table 10. *The mean validation scores for the H12 snow product and snow courses.*

Station	N	Bias	SD	CC	RMSE	RMSE, %	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
Open field	458	15,2	27,5	0,90	31,51	0,33	1,65	0,49	0,73	0,23	0,76	0,20	0,14	0,21
Forest	84	13,7	24,0	0,88	27,69	0,29	0,56	0,34	0,48	0,12	0,83	0,26	0,22	0,32

6. Conclusions

In this study H-SAF products H10, H12 and H31 were validated against the in situ snow observations in Lithuania.

When compared with in situ measurements HSAF snow mask products (H10, H31) showed very good agreement. Number of available satellite based surface observations in Lithuania is limited due to the low sun elevation angle and dominant overcast weather conditions in winter. Rate of agreement of H10 and H31 snow products with in situ data varies during the cold season. The lowest validation scores were determined at the beginning of cold season (November–December) and the highest were in April. Both HSAF snow mask products showed a tendency to overestimate the snow cover.

Inter-comparison of H10 and H31 snow mask products showed that there is a spatial shift between the products, although for the flat land areas these products should be identical. The spatial shift could be due to the remapping or different geolocation used in H10 product after merging H31 and snow mask product for mountain areas. It was determined that H10 and H31 product land/water mask is not consistent and in period December 2012 – March 2013 the Curonian Spit is missing from land mask. Also, validation results in Lithuania showed that H31 “partly snow” pixels in 61% of cases were “no snow” events.

The main limitation of HSAF effective snow cover product (H12) is the availability of satellite data. Due to the low sun elevation angle, no H12 data is available for the territory of Lithuania from November till the end of January. This limits the potential of H12 product application for snow monitoring. The validation results showed that H12 have a positive bias and tend to overestimate the snow fraction.

Validation results of H10 and H31 products did not indicate any differences between coastal and continental stations, while H12 had lower validation scores in coastal areas. The exceptional case was Nida meteorological station at the Curonian Spit. In this location the rate of agreement between in situ and HSAF snow products was lowest. It was anticipated, as the spatial resolution of HSAF snow products is too low to capture high variation of the surface conditions in the narrow, 1-3 km wide spit.

Overall agreement of HSAF snow products (H10, H12, H31) and in situ data was very high and results from this study is consistent with the HSAF validation reports. The main limitation of HSAF snow products application for snow monitoring is data availability, especially at the beginning of the cold season.

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Annex I

List of stations with snow measurements in Lithuania: MS – meteorological station, WS – water gauging station.

No	Station	Latitude (deg. N)	Longitude (deg. E)	Elevation, m	Distance from the sea, km
1	Anykščiai WS	55,533	25,100	94,8	179,2
2	Aunuvėnai WS	55,850	22,767	102,8	106,3
3	Babtai WS	55,102	23,784	47,2	176,4
4	Birštonas WS	54,600	24,033	46,6	210,4
5	Biržai MS	56,193	24,774	60,2	104,8
6	Buivydžiai WS	54,837	25,741	122,0	266,6
7	Darsūniškis WS	54,733	24,117	44,6	209,5
8	Dotnuva MS	55,396	23,866	69,1	173,7
9	Druskininkai WS	54,017	23,983	92,6	240,3
10	Dūkštas MS	55,518	26,316	164,2	220,6
11	Guntauninkai WS	55,247	26,555	136,7	253,8
12	Jonava WS	55,075	24,292	40,9	208,5
13	Kartena WS	55,933	21,483	24,1	26,1
14	Kaunas MS	54,884	23,836	76,1	186,7
15	Klaipėda MS	55,731	21,092	6,2	0,09
16	K. Naujamestis WS	54,783	22,867	40,9	133,8
17	Kretinga WS	55,883	21,233	13,4	11,0
18	Kybartai MS	54,633	22,783	57,7	137,4
19	Kyburiai WS	56,250	24,250	39,6	85,7
20	Lankupiai WS	55,483	21,367	3,1	17,6
21	Laukuva MS	55,609	22,239	165,0	71,0
22	Lazdijai MS	54,232	23,511	133,0	201,5
23	Leckava WS	56,383	22,233	40,0	76,3
24	Liubavas WS	54,367	23,067	159,0	169,2
25	Liukoniai WS	55,033	24,683	103,0	223,0
26	Nemajūnai WS	54,567	24,067	58,1	241,1
27	Nida MS	55,302	21,007	2,0	1,95
28	Paakmenis WS	55,500	22,300	116,2	75,6
29	Pabradė WS	54,967	25,750	124,1	254,0
30	Panevėžys MS	55,735	24,417	57,1	143,4
31	Pasvalis (Ustukiai) WS	56,081	24,399	36,3	106,1
32	Pluskiai WS	55,567	22,850	133,7	109,4
33	Puvočiai WS	54,117	24,300	97,2	251,2
34	Raseiniai MS	55,395	23,133	110,7	129,4
35	Semeliškės WS	54,667	24,666	117,2	245,3
36	Šiaulėnai WS	55,677	23,449	119,4	147,0
37	Šiauliai MS	55,942	23,331	105,9	115,3
38	Šilutė MS	55,352	21,447	2,7	25,9

No	Station	Latitude (deg. N)	Longitude (deg. E)	Elevation, m	Distance from the sea, km
39	Skuodas WS	56,277	21,508	20,8	32,3
40	Smalininkai WS	55,073	22,587	15,4	104,5
41	Tabokinė WS	56,417	24,85	55,0	86,3
42	Tauragnai WS	55,443	25,826	179,4	210,2
43	Telšiai MS	55,991	22,257	153,3	73,8
44	Trakai WS	54,633	24,933	166,1	262,5
45	Ukmergė MS	55,264	24,760	72,1	199,4
46	Utena MS	55,515	25,590	104,8	195,2
47	Varėna MS	54,248	24,552	109,1	258,0
48	Verbyliškės WS	54,583	24,183	73,5	220,0
49	Vilnius MS	54,626	25,107	162	273,4
50	Žindaičiai WS	55,171	22,704	32,7	108,1

Annex II

H10 (snow mask) validation scores.

No	Station	N	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
1	Anykščiai WS	157	1,82	1,00	0,45	0,27	0,80	0,55	0,40	0,57
2	Aunuvėnai WS	157	1,60	0,98	0,39	0,24	0,82	0,60	0,45	0,62
3	Babtai WS	145	1,37	0,98	0,29	0,18	0,87	0,70	0,57	0,72
4	Birštonas WS	148	1,51	1,00	0,34	0,22	0,84	0,66	0,51	0,68
5	Biržai MS	156	1,00	1,00	0,00	0,00	1,00	1,00	1,00	1,00
6	Buivydžiai WS	138	1,58	0,98	0,38	0,27	0,80	0,61	0,44	0,61
7	Darsūniškis WS	153	1,78	1,00	0,44	0,21	0,84	0,56	0,45	0,62
8	Dotnuva MS	160	1,00	1,00	0,00	0,00	1,00	1,00	1,00	1,00
9	Druskininkai WS	141	1,25	0,94	0,24	0,18	0,87	0,72	0,57	0,73
10	Dūkštas MS	130	0,95	0,93	0,02	0,01	0,96	0,91	0,85	0,92
11	Guntauninkai WS	163	1,40	1,00	0,28	0,19	0,87	0,72	0,58	0,73
12	Jonava WS	156	2,10	1,00	0,52	0,26	0,79	0,48	0,35	0,52
13	Kartena WS	139	1,74	1,00	0,43	0,21	0,83	0,57	0,45	0,62
14	Kaunas MS	148	1,03	0,97	0,06	0,05	0,96	0,91	0,85	0,92
15	Klaipėda MS	151	0,96	0,96	0,00	0,00	0,99	0,96	0,96	0,98
16	K. Naujamestis WS	154	1,30	0,89	0,31	0,09	0,91	0,63	0,56	0,72
17	Kretinga WS	164	1,07	0,93	0,13	0,03	0,96	0,81	0,78	0,87
18	Kybartai MS	177	1,12	1,00	0,11	0,04	0,97	0,89	0,86	0,92
19	Kyburiai WS	165	1,70	0,98	0,43	0,26	0,80	0,57	0,41	0,58
20	Lankupiai WS	162	1,04	0,89	0,14	0,03	0,96	0,77	0,73	0,85
21	Laukuva MS	157	1,02	0,95	0,06	0,04	0,96	0,90	0,83	0,91
22	Lazdijai MS	154	1,13	1,00	0,12	0,07	0,95	0,88	0,82	0,90
23	Leckava WS	164	1,44	0,98	0,32	0,20	0,85	0,67	0,53	0,69

No	Station	N	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
24	Liubavas WS	164	1,33	0,98	0,26	0,16	0,88	0,72	0,60	0,75
25	Liukoniai WS	146	1,83	0,97	0,47	0,27	0,79	0,52	0,38	0,55
26	Nemajūnai WS	148	1,94	1,00	0,49	0,29	0,78	0,51	0,36	0,53
27	Nida MS	120	3,80	1,00	0,74	0,56	0,53	0,26	0,12	0,21
28	Paakmenis WS	156	1,38	1,00	0,28	0,17	0,88	0,72	0,60	0,75
29	Pabradė WS	138	1,32	0,98	0,26	0,18	0,88	0,73	0,59	0,75
30	Panevėžys MS	157	1,07	0,97	0,10	0,06	0,95	0,88	0,81	0,89
31	Pasvalis (Ustukiai) WS	155	1,22	1,00	0,18	0,13	0,92	0,82	0,71	0,83
32	Pluskiai WS	152	1,38	0,98	0,29	0,18	0,87	0,70	0,56	0,72
33	Puvočiai WS	144	1,19	0,91	0,23	0,17	0,86	0,71	0,56	0,71
34	Raseiniai MS	149	1,26	0,96	0,24	0,14	0,89	0,74	0,62	0,77
35	Semeliškės WS	149	1,68	1,00	0,40	0,22	0,83	0,60	0,46	0,63
36	Šiaulėnai WS	154	1,35	1,00	0,26	0,16	0,89	0,74	0,62	0,77
37	Šiauliai MS	160	1,00	0,99	0,01	0,01	0,99	0,97	0,95	0,97
38	Šilutė MS	141	1,00	0,93	0,07	0,02	0,97	0,87	0,84	0,91
39	Skuodas WS	152	1,41	1,00	0,29	0,13	0,90	0,71	0,62	0,76
40	Smalininkai WS	129	2,50	1,00	0,60	0,31	0,74	0,40	0,28	0,43
41	Tabokinė WS	136	1,20	0,98	0,18	0,15	0,90	0,80	0,68	0,81
42	Tauragnai WS	159	1,30	0,98	0,24	0,16	0,89	0,75	0,62	0,76
43	Telšiai MS	154	1,20	1,00	0,16	0,15	0,92	0,84	0,71	0,83
44	Trakai WS	152	1,25	0,96	0,23	0,15	0,89	0,75	0,62	0,77
45	Ukmergė MS	158	1,25	1,00	0,20	0,12	0,92	0,80	0,70	0,82
46	Utena MS	156	1,06	0,98	0,07	0,05	0,96	0,91	0,85	0,92
47	Varėna MS	140	1,10	0,96	0,12	0,08	0,94	0,84	0,76	0,86
48	Verbyliškės WS	154	1,62	1,00	0,38	0,23	0,83	0,62	0,47	0,64
49	Vilnius MS	142	0,98	0,97	0,02	0,01	0,98	0,95	0,92	0,96
50	Žindaičiai WS	137	1,74	0,96	0,45	0,19	0,84	0,54	0,43	0,60
	Total / Average (except Nida MS)	7421	1,36	0,98	0,24	0,14	0,89	0,74	0,64	0,76

Annex III

H31 (snow mask) validation scores.

No	Station	N	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
1	Anykščiai WS	149	1,81	1,00	0,45	0,27	0,80	0,55	0,40	0,58
2	Aunuvėnai WS	159	1,55	0,98	0,37	0,21	0,84	0,62	0,49	0,66
3	Babtai WS	150	1,38	0,98	0,29	0,16	0,88	0,69	0,58	0,73
4	Birštonas WS	152	1,46	1,00	0,31	0,20	0,86	0,69	0,55	0,71
5	Biržai MS	168	1,00	0,99	0,01	0,01	0,99	0,97	0,95	0,98
6	Buivydžiai WS	136	1,68	0,98	0,42	0,29	0,79	0,57	0,40	0,57
7	Darsūniškis WS	160	1,97	1,00	0,49	0,25	0,80	0,51	0,38	0,55
8	Dotnuva MS	163	0,99	0,99	0,00	0,00	0,99	0,99	0,97	0,99
9	Druskininkai WS	140	1,18	0,90	0,23	0,16	0,86	0,71	0,56	0,72
10	Dūkštas MS	147	0,96	0,94	0,02	0,01	0,97	0,93	0,87	0,93
11	Guntauninkai WS	151	1,32	1,00	0,24	0,14	0,90	0,76	0,65	0,79
12	Jonava WS	148	2,38	1,00	0,58	0,27	0,78	0,42	0,31	0,47
13	Kartena WS	149	1,67	1,00	0,40	0,19	0,85	0,60	0,49	0,65
14	Kaunas MS	138	1,00	1,00	0,00	0,00	1,00	1,00	1,00	1,00
15	Klaipėda MS	152	0,88	0,88	0,00	0,00	0,98	0,88	0,85	0,92
16	K. Naujamestis WS	160	1,76	1,00	0,43	0,17	0,86	0,57	0,47	0,64
17	Kretinga WS	166	1,15	0,96	0,16	0,04	0,96	0,81	0,78	0,87
18	Kybartai MS	153	1,38	1,00	0,28	0,11	0,92	0,72	0,64	0,78
19	Kyburiai WS	166	1,63	0,98	0,40	0,25	0,81	0,59	0,44	0,61
20	Lankupiai WS	148	1,25	1,00	0,20	0,05	0,96	0,80	0,76	0,86
21	Laukuva MS	160	1,00	0,93	0,07	0,06	0,94	0,87	0,78	0,87
22	Lazdijai MS	152	1,08	0,98	0,09	0,05	0,96	0,89	0,84	0,91
23	Leckava WS	157	1,49	1,00	0,33	0,20	0,86	0,67	0,54	0,70
24	Liubavas WS	158	1,31	1,00	0,23	0,14	0,91	0,77	0,66	0,80
25	Liukoniai WS	149	1,88	0,97	0,48	0,26	0,79	0,51	0,37	0,54
26	Nemajūnai WS	155	1,76	1,00	0,43	0,21	0,83	0,57	0,44	0,62
27	Nida MS	163	6,00	1,00	0,83	0,74	0,36	0,17	0,04	0,08
28	Paakmenis WS	154	1,37	0,98	0,28	0,18	0,87	0,71	0,57	0,73
29	Pabradė WS	136	1,37	0,98	0,29	0,20	0,86	0,70	0,55	0,71
30	Panevėžys MS	163	1,12	0,96	0,14	0,08	0,93	0,83	0,75	0,86
31	Pasvalis (Ustukiai) WS	158	1,25	1,00	0,20	0,14	0,91	0,80	0,69	0,82
32	Pluskiai WS	148	1,39	1,00	0,28	0,18	0,88	0,72	0,59	0,74
33	Puvočiai WS	140	1,44	0,96	0,33	0,25	0,82	0,65	0,47	0,64
34	Raseiniai MS	153	1,17	0,94	0,20	0,10	0,91	0,76	0,66	0,79
35	Semeliškės WS	153	1,63	1,00	0,39	0,21	0,84	0,61	0,48	0,65
36	Šiaulėnai WS	168	1,31	1,00	0,24	0,15	0,90	0,76	0,65	0,79
37	Šiauliai MS	153	1,03	0,98	0,05	0,03	0,97	0,94	0,90	0,95
38	Šilutė MS	153	1,00	0,91	0,09	0,03	0,96	0,84	0,80	0,89
39	Skuodas WS	165	1,47	1,00	0,32	0,13	0,90	0,68	0,59	0,74

No	Station	N	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
40	Smalininkai WS	148	1,95	0,91	0,53	0,18	0,83	0,44	0,35	0,52
41	Tabokinė WS	136	1,16	0,98	0,15	0,13	0,92	0,84	0,72	0,84
42	Tauragnai WS	143	1,24	0,96	0,22	0,17	0,88	0,76	0,61	0,76
43	Telšiai MS	165	1,14	0,97	0,15	0,11	0,92	0,82	0,72	0,84
44	Trakai WS	144	1,34	1,00	0,25	0,18	0,88	0,75	0,61	0,76
45	Ukmergė MS	146	1,21	0,98	0,19	0,11	0,92	0,79	0,70	0,82
46	Utena MS	151	1,05	0,98	0,06	0,04	0,97	0,92	0,87	0,93
47	Varėna MS	137	1,45	1,00	0,31	0,25	0,84	0,69	0,52	0,68
48	Verbyliškės WS	152	1,48	0,98	0,34	0,18	0,86	0,65	0,53	0,69
49	Vilnius MS	141	1,02	0,98	0,03	0,03	0,98	0,95	0,92	0,96
50	Žindaičiai WS	155	1,66	1,00	0,40	0,15	0,88	0,60	0,51	0,68
Total / Average (except Nida MS)		7448	1,37	0,98	0,25	0,14	0,89	0,73	0,63	0,76

Annex IV

H12 (effective snow cover) validation scores.

No	Station	N	Bias	SD	CC	RMSE	RMSE, %	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
1	Anykščiai WS	60	29,4	37,2	0,91	47,4	0,59	0,94	0,28	0,71	0,29	0,58	0,17	0,00	-0,01
2	Aunuvėnai WS	59	22,2	34,9	0,98	41,4	0,57	2,11	0,56	0,74	0,28	0,69	0,22	0,10	0,19
3	Babtai WS	62	30,1	39,4	0,90	49,6	0,54	3,25	0,75	0,77	0,37	0,65	0,21	0,11	0,19
4	Birštonas WS	54	30,6	40,6	0,92	50,9	0,58	1,90	0,70	0,63	0,27	0,72	0,32	0,19	0,32
5	Biržai MS	67	32,7	41,9	0,96	53,1	0,60	1,25	0,92	0,27	0,19	0,85	0,69	0,53	0,69
6	Buivydžiai WS	56	34,3	39,8	0,83	52,5	0,53	2,00	0,86	0,57	0,38	0,68	0,40	0,22	0,36
7	Darsūniškis WS	63	27,2	37,7	0,78	46,5	0,44	5,60	1,00	0,82	0,40	0,63	0,18	0,11	0,19
8	Dotnuva MS	56	25,6	38,8	0,99	46,5	0,55	1,43	0,93	0,35	0,17	0,86	0,62	0,50	0,67
9	Druskininkai WS	56	24,0	33,9	0,83	41,5	0,63	0,41	0,23	0,44	0,12	0,62	0,19	0,07	0,12
10	Dūkštas MS	61	34,2	40,8	0,95	53,2	0,65	0,73	0,58	0,21	0,11	0,75	0,50	0,32	0,48
11	Guntauninkai WS	56	26,3	37,0	0,96	45,4	0,60	0,37	0,26	0,29	0,05	0,71	0,24	0,14	0,25
12	Jonava WS	54	20,5	32,0	0,64	38,0	0,38	8,00	0,50	0,94	0,29	0,70	0,06	0,02	0,05
13	Kartena WS	65	16,4	26,7	0,75	31,4	0,30	11,0	1,00	0,91	0,32	0,69	0,09	0,06	0,12
14	Kaunas MS	55	17,1	27,8	0,95	32,6	0,54	0,67	0,27	0,60	0,15	0,69	0,19	0,07	0,13
15	Klaipėda MS	67	17,2	27,0	0,55	32,0	0,21	8,33	0,33	0,96	0,38	0,61	0,04	0,00	-0,01
16	K. Naujamestis WS	59	18,4	32,3	0,81	37,2	0,37	0,00	0,00	1,00	0,31	0,69	0,00	0,00	0,00
17	Kretinga WS	64	10,5	20,4	0,86	23,0	0,25	5,50	0,75	0,86	0,32	0,69	0,13	0,08	0,14
18	Kybartai MS	60	16,8	30,5	0,93	34,8	0,43	1,56	0,67	0,57	0,16	0,82	0,35	0,26	0,41
19	Kyburiai WS	67	37,2	42,1	0,98	56,2	0,63	3,89	0,89	0,77	0,47	0,58	0,22	0,11	0,19
20	Lankupiai WS	58	6,8	15,5	0,92	16,9	0,19	8,00	0,50	0,94	0,27	0,72	0,06	0,03	0,05
21	Laukuva MS	56	28,5	41,2	0,95	50,1	0,60	1,00	0,79	0,21	0,11	0,86	0,65	0,52	0,68
22	Lazdijai MS	61	30,0	40,6	0,98	50,5	0,59	2,36	1,00	0,58	0,30	0,75	0,42	0,30	0,46
23	Leckava WS	64	20,8	33,6	0,87	39,5	0,50	2,43	0,43	0,82	0,25	0,72	0,14	0,06	0,11

No	Station	N	Bias	SD	CC	RMSE	RMSE, %	FBI	POD	FAR	POFD	ACC	CSI	ETS	HSS
24	Liubavas WS	58	28,3	39,9	0,98	48,9	0,56	1,47	1,00	0,32	0,16	0,88	0,68	0,57	0,73
25	Liukoniai WS	59	30,4	40,9	0,97	50,9	0,55	25,0	1,00	0,96	0,41	0,59	0,04	0,02	0,05
26	Nemajūnai WS	55	20,7	32,4	0,95	38,4	0,50	2,67	0,33	0,88	0,29	0,67	0,10	0,01	0,03
27	Nida MS	83	23,7	32,4	0,36	40,2	0,31	9,25	0,25	0,97	0,46	0,53	0,02	-0,02	-0,04
28	Paakmenis WS	64	26,7	39,0	0,95	47,2	0,54	14,0	1,00	0,93	0,42	0,59	0,07	0,04	0,08
29	Pabradė WS	52	31,4	39,4	0,99	50,3	0,60	1,00	0,72	0,28	0,15	0,81	0,57	0,40	0,58
30	Panevėžys MS	62	32,5	40,3	0,98	51,7	0,62	2,91	0,91	0,69	0,43	0,63	0,30	0,16	0,27
31	Pasvalis (Ustukiai) WS	60	34,5	42,6	0,98	54,8	0,61	1,38	1,00	0,28	0,21	0,87	0,72	0,58	0,73
32	Pluskiai WS	62	28,7	39,7	0,96	48,9	0,60	1,35	0,82	0,39	0,20	0,81	0,54	0,39	0,56
33	Puvočiai WS	54	23,5	32,8	0,83	40,4	0,64	0,50	0,18	0,64	0,22	0,54	0,14	-0,02	-0,04
34	Raseiniai MS	61	21,1	35,1	0,94	41,0	0,50	2,30	0,90	0,61	0,27	0,75	0,38	0,26	0,41
35	Semeliškės WS	63	34,0	41,1	0,89	53,3	0,55	7,75	1,00	0,87	0,46	0,57	0,13	0,07	0,13
36	Šiaulėnai WS	60	27,2	38,5	0,93	47,1	0,55	2,22	0,56	0,75	0,29	0,68	0,21	0,10	0,17
37	Šiauliai MS	72	26,8	37,3	0,93	45,9	0,53	1,65	0,90	0,45	0,29	0,76	0,51	0,34	0,51
38	Šilutė MS	60	4,4	12,5	0,91	13,2	0,22	3,67	0,33	0,91	0,18	0,80	0,08	0,04	0,07
39	Skuodas WS	69	10,2	20,7	0,93	23,1	0,24	9,33	1,00	0,89	0,38	0,64	0,11	0,07	0,12
40	Smalininkai WS	65	3,4	8,9	0,89	9,6	0,21	3,33	0,00	1,00	0,16	0,80	0,00	-0,04	-0,08
41	Tabokinė WS	63	22,3	30,0	0,88	37,3	0,63	0,16	0,08	0,50	0,05	0,60	0,07	0,02	0,03
42	Tauragnai WS	57	38,1	44,0	0,92	58,2	0,62	1,37	1,00	0,27	0,18	0,88	0,73	0,60	0,75
43	Telšiai MS	62	25,2	37,5	0,91	45,2	0,58	1,92	0,58	0,70	0,32	0,66	0,25	0,11	0,20
44	Trakai WS	58	35,6	41,2	0,92	54,4	0,60	1,47	0,84	0,43	0,31	0,74	0,52	0,31	0,48
45	Ukmergė MS	63	21,0	31,6	0,97	37,9	0,52	0,65	0,18	0,73	0,17	0,65	0,12	0,00	0,00
46	Utena MS	59	37,2	42,5	0,93	56,5	0,64	1,40	0,90	0,36	0,26	0,80	0,60	0,41	0,59
47	Varėna MS	55	12,7	21,2	0,88	24,8	0,57	0,22	0,17	0,25	0,03	0,71	0,16	0,10	0,17
48	Verbyliškės WS	57	27,4	38,7	0,78	47,4	0,42	2,67	1,00	0,62	0,31	0,74	0,38	0,26	0,41
49	Vilnius MS	52	30,6	37,9	0,95	48,7	0,64	0,84	0,42	0,50	0,24	0,63	0,30	0,10	0,18
50	Žindaičiai WS	58	8,4	20,7	0,96	22,3	0,39	4,33	0,33	0,92	0,22	0,76	0,07	0,02	0,04
	Total / Average (except Nida MS)	2940	24,5	34,2	0,90	42,2	0,51	3,43	0,64	0,63	0,26	0,71	0,28	0,18	0,26