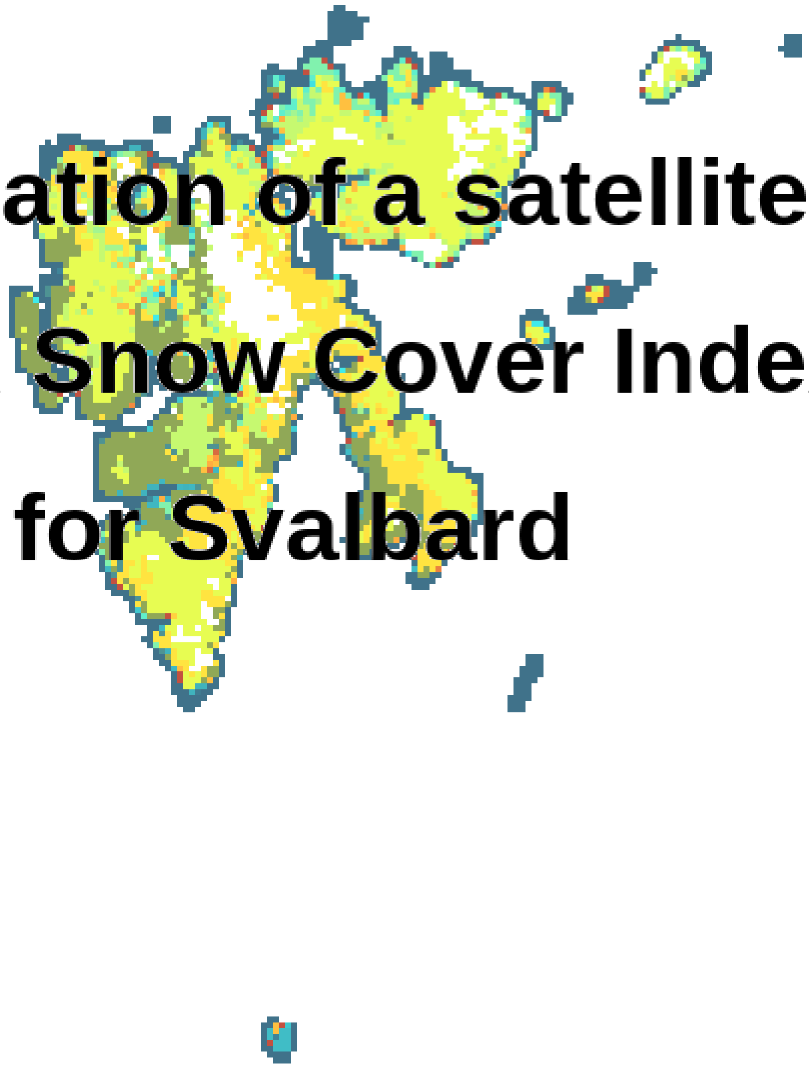
Project report for SIOS ACCESS project 2018_0007

Validation of a satellite based Snow Cover Index for Svalbard



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1 INTRODUCTION

The presence of snow cover has a large impact in many areas such as the Arctic ecosystems, human activities, atmospheric processes and the Earth's surface energy balance. A snow cover index for Svalbard - a time series of total snow-covered area - is thus of interest for a wide range of fields. However, the snow cover is challenging to map for larger regions due to its large spatial and temporal variability and its changing properties influenced by temperature, precipitation and wind. Also the sparse number of weather stations with snow cover measurements contributes to a poor observational base. By using satellite monitoring it is possible to get a better overview of the snow condition on land. Regular satellite observations since the early 1980's give rise to continuous time series of satellite data from which snow cover products can be derived. In this project we aim to generate a long-term data record for the snow cover on Svalbard using a climate calibrated satellite data record from the Advanced Very High Resolution Radiometer (AVHRR) instrument covering 1982 - 2015. AVHRR flies on polar orbiting satellites and can therefore, due to Svalbard's northerly location, observe the archipelago on multiple orbits each day. Svalbard's geographical position brings some disadvantages as well. The polar night makes it impossible for sunlight dependent retrieval algorithms to deliver gap-free products year round, and the polar night is likely to "hide" the onset of the Svalbard wintertime snow cover. On the other hand, the seasonal snow cover typically extends well into the late spring and summer months, and following the Sun's return the daylight hours increases fast, opening again for frequent observations daily and satellite products of high quality. The satellite data based daily snow cover products can be used as basis to derive climate indicators for snow cover extent. Available ground observations of snow depth will be used for validation.

2 GENERATING DAILY SNOW COVER MAPS FOR SVALBARD

2.1 The snow cover algorithm

Through a series of previous projects the Norwegian Meteorological institute (MET Norway) has developed a snow cover algorithm that derives binary snow cover from optical satellite data. The algorithm processes all available swaths from AVHRR (or similar instrument) data. The calculations are based on a probabilistic (Bayesian) approach using a set of *signatures* (instrument channel combinations) and statistical coefficients. For each pixel of the swath, the probabilities for the surface classes *snow*, *land* (snow-free ground) and *cloud* are estimated. The statistical coefficients are derived from pre-knowledge of the typical behaviour of the surface classes in the various parts of the spectrum. Figure 1 shows an example of such a swath product.

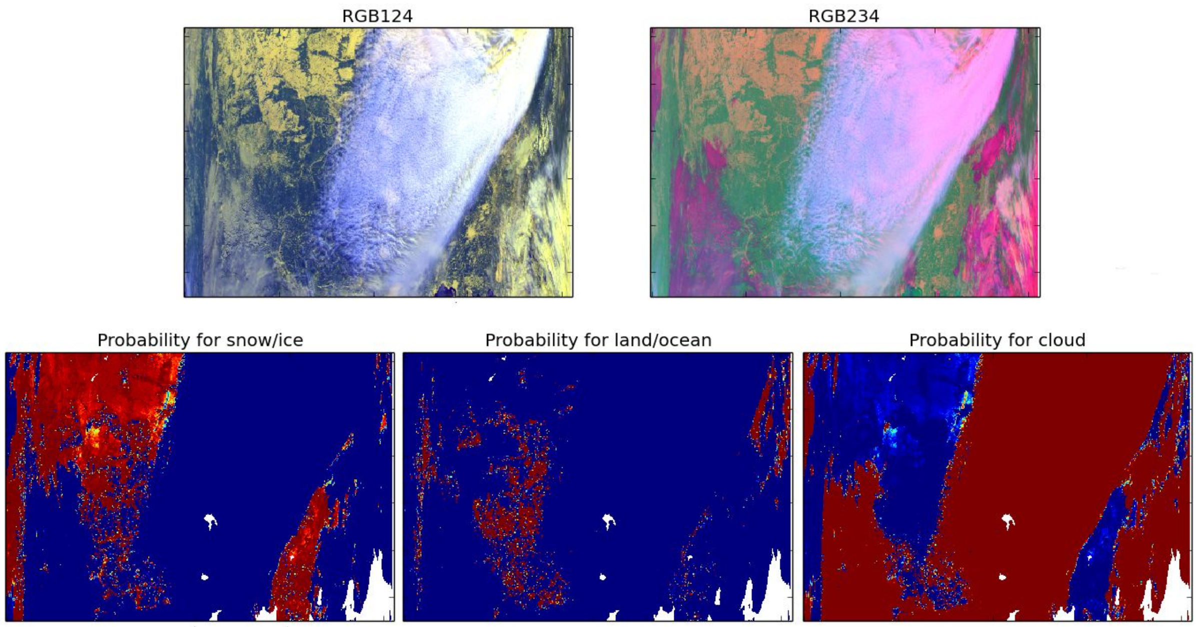

Figure 1: an example of a swath product using the MET Norway snow cover algorithm. The Figure shows a section of a NOAA-19 satellite swath from March 15 2009, 08:50 UTC. The top row shows RGB colour composites using AVHRR channels 1, 2 and 4 (left) and AVHRR channels 2, 3B and 4 (right). The bottom row shows the probabilities for the classes *snow* (left), *land* (middle) and *cloud* (right). Red colour indicates high probability while blue indicates low probability. White shows areas of no product (in this case water pixels).

A set of processed swaths can be averaged and gridded to a product grid covering the area of interest. Swath product pixels with a probability for the class *cloud* larger than 40% are considered cloud-covered and are therefore not used in the averaged product. Averaging all available swath products from a 24-hour period gives daily, gridded, snow cover products containing probabilities for *snow*/*no snow*. A threshold is applied at 50% probability for snow, and a binary *snow*/*no snow* product is the result. Figure 2 shows an example of a gridded product for Scandinavia using the MET Norway snow cover algorithm.

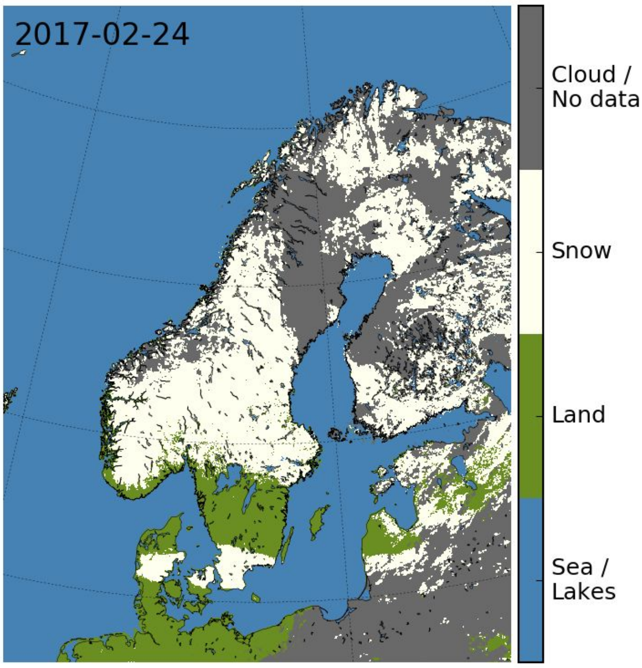

Figure 2: an example of a daily gridded snow cover product for Scandinavia. The product is based on AVHRR and VIIRS data, and is valid for February 24 2017.

As indicated by Figure 2, an aggregation period of 24 hours is normally not sufficient to give a cloud-free product for an extended area. Furthermore, since the algorithm uses satellite measurements of reflected sunlight, there will be areas of no data due to wintertime darkness. A more detailed description of the binary snow cover algorithm can be found in the snow sub-service report for the CryoClim project (Killie et al., 2013).

The AVHRR instrument has ~1 km resolution, but only data at a reduced resolution (~4 km) is permanently archived and available with global coverage. This data record is called AVHRR Global Area Coverage (GAC) data. A fundamental climate data record (FCDR) for AVHRR GAC radiances and brightness temperatures for 1982-2015 is available from the EUMETSAT Climate Monitoring Satellite Application Facility (CM SAF) (Karlson et al., 2017). This" CLARA-A2" data record provides cloud properties, surface albedo and surface radiation parameters derived from the AVHRR sensor onboard NOAA and METOP satellites. Figure 3 shows the satellites contributing to the CLARA-A2 FCDR.

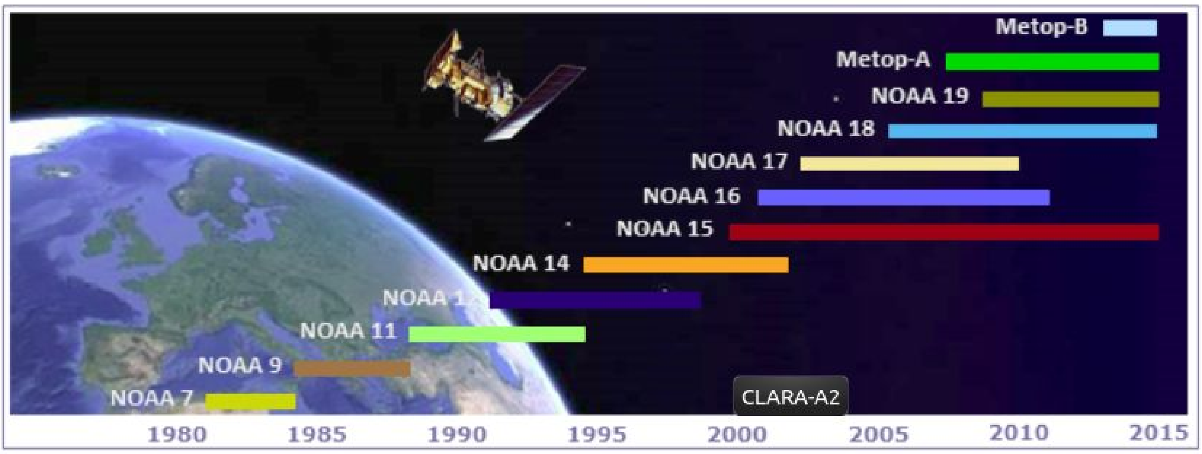

Figure 3: an overview of the NOAA and MetOp satellites used in CLARA-A2. Figure credit: www.cmsaf.eu

CLARA-A2 is previously used as input to the MET Norway snow cover algorithm to produce a time series of global, daily snow cover products for 1982 - 2015 (see project reports for phase 1 and 2 for the project Sentinel4CryoClim: Solberg et al., 2017, Killie et al., 2018). The long term, *daily* snow cover product for Svalbard to be produced in this project will be based on the global *swath* products generated in Sentinel4CryoClim. The existing swath products will be gridded to a product grid of 4 km resolution covering the Svalbard archipelago, and daily products will be generated. Due to polar night no products are generated from October through February. The aggregated products will be the basis from which a snow cover index (total snow covered area as function of time) can be derived. The snow cover index can be used to evaluate the onset of melting as function of year.

2.2 Svalbard land mask

A 4 km landmask covering the Svalbard archipelago has been introduced. The grid is 200x200 pixels, and the projection is Lambert Azimuthal Equal Area grid. Figure 4 shows the fraction of land.

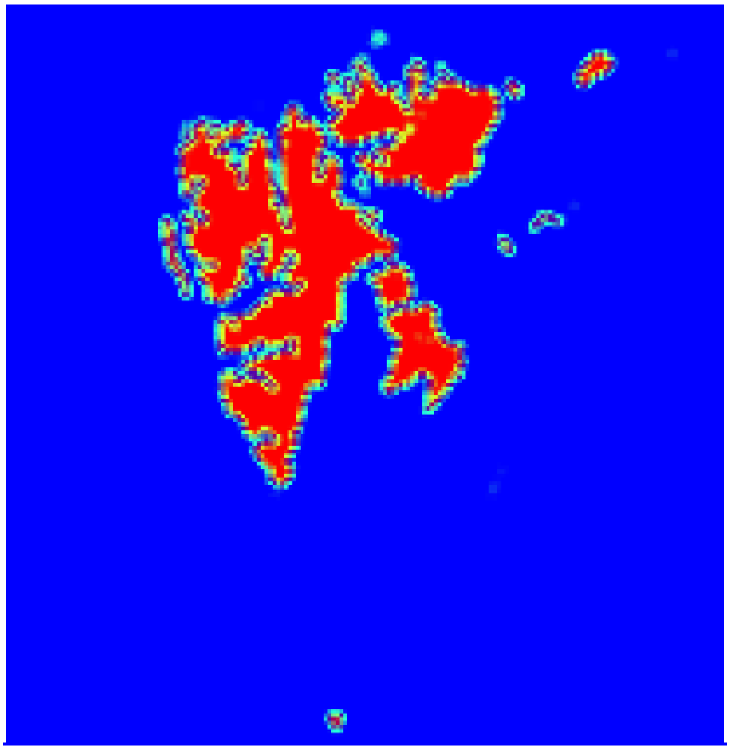

Figure 4: the 4 km land mask used in this project. The figure shows the fraction of land. Red colour: 100% Blue colour: 0%

Note that the island Hopen, with a width of 2 km at the most, is too narrow to be easily seen in the fraction of land field shown in Figure 4.

2.3 Production of daily products

Existing gridding routines have been adapted and scripts set up to generate the time series of daily data for 1982 - 2015. Due to wintertime darkness processing starts on March 1 of each year and ends on September 30. The level 2 swath product files from Sentinel4CryoClim (internal dataset) contain a range of variables, including probabilities for *snow*, *land* and *cloud* for each swath pixel. These snow estimates are averaged and gridded to the product grid shown in Figure 4. An analysis that adds a “gap-free” field (as far as possible) and ensures CF compliance for metadata is then performed. The final product files are on NetCDF format.

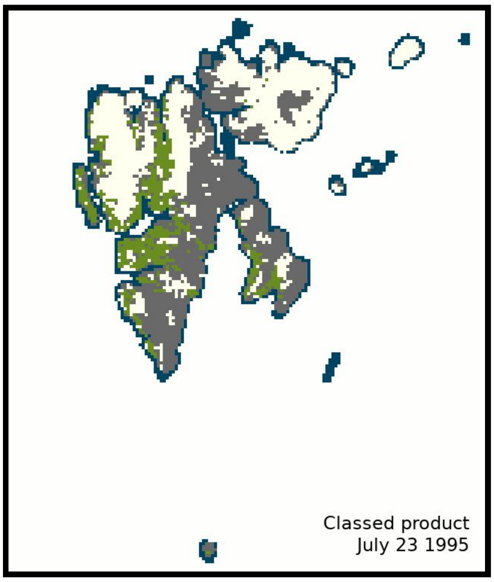

Figure 5: the classed product for July 23 1995. White pixels are snow-covered, green pixels are snow-free land, and clouded pixels are shown in gray. The dark blue along the coast indicates pixels that are unprocessed.

Figure 5 shows the classed field from a typical daily snow cover product for Svalbard. Each unclouded pixel has been allocated to the class *snow* (white) or *land* (green). Clouded areas are represented by gray, and unprocessed pixels along the coast by dark blue.

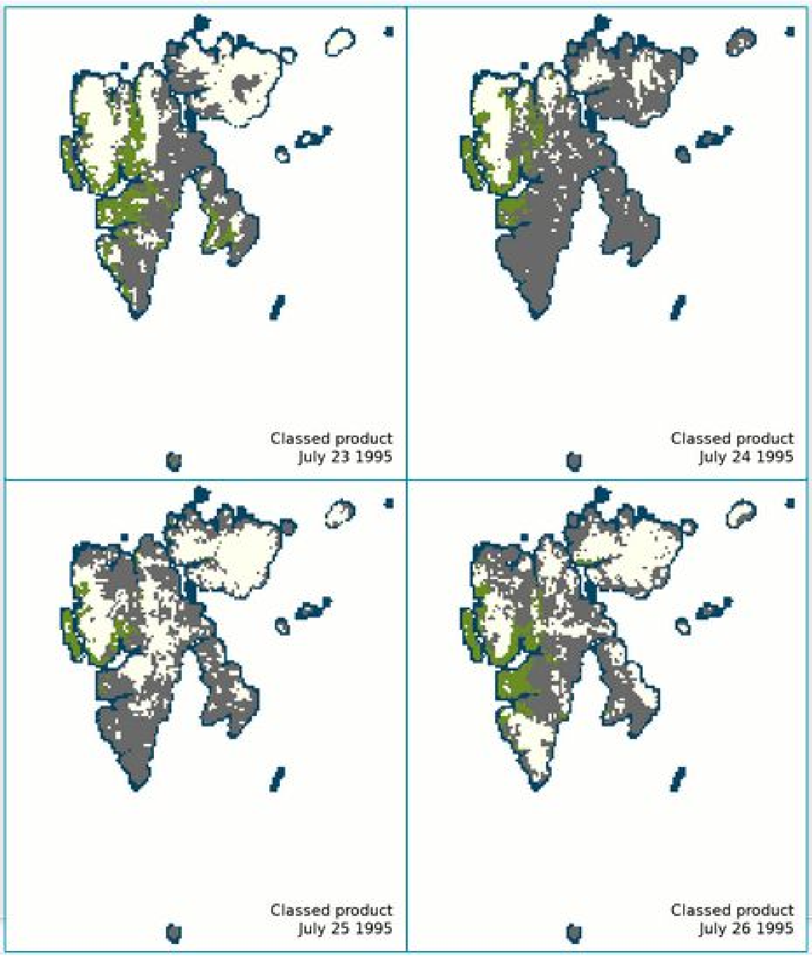

Figure 6: the classed product for four consecutive days during July 1995. Looking carefully at the north-west coast of Spitsbergen, one can see example of pixels that change back and forth between snow-covered (white) and snow-free (green).

Figure 6 shows the classed field for a series of consecutive days. We find that a number of pixels that are unclouded for several consecutive days can change back and forth between the classes *snow* and *land* from one day to the next. This “flickering” is something we have not earlier seen at this scale for the aggregated snow cover maps produced using the MET Norway snow cover algorithm. Whether the change in class actually reflects that the pixel changes from snow-covered dominated to snow-free dominated and back at this rapid pace or if this is an algorithm weakness is not clear at this point. The Svalbard terrain is much more barren than that of mainland Norway, and the weather can be very windy. The MET Norway snow cover algorithm is not tuned particularly for Svalbard conditions, but uses a set of statistical coefficients to estimate the probabilities for the surface classes (*snow*, *land*, *cloud*) that are derived from training data covering much of Scandinavia, including Svalbard. The reflective properties of more vegetated terrain types likely dominate the training data base from which the coefficients are derived, meaning that the coefficients might not be optimal for Svalbard.

2.4 Gap-free maps

As seen in Figures 5 and 6, clouds are typically very much present in the daily aggregated snow cover maps for Svalbard. A "gap-free" field is added to each daily file. For each clouded pixel in the daily gridded product, the nearest in time cloud-free pixel information is used. The method searches up to 9 days backwards or forwards in time for a cloud-free observation. This method removes nearly all clouded pixels for each daily product 1982-2015, with some exceptions. Figure 7 shows an example of the classed product and the gap-free ("cloud-reduced") product for one day.

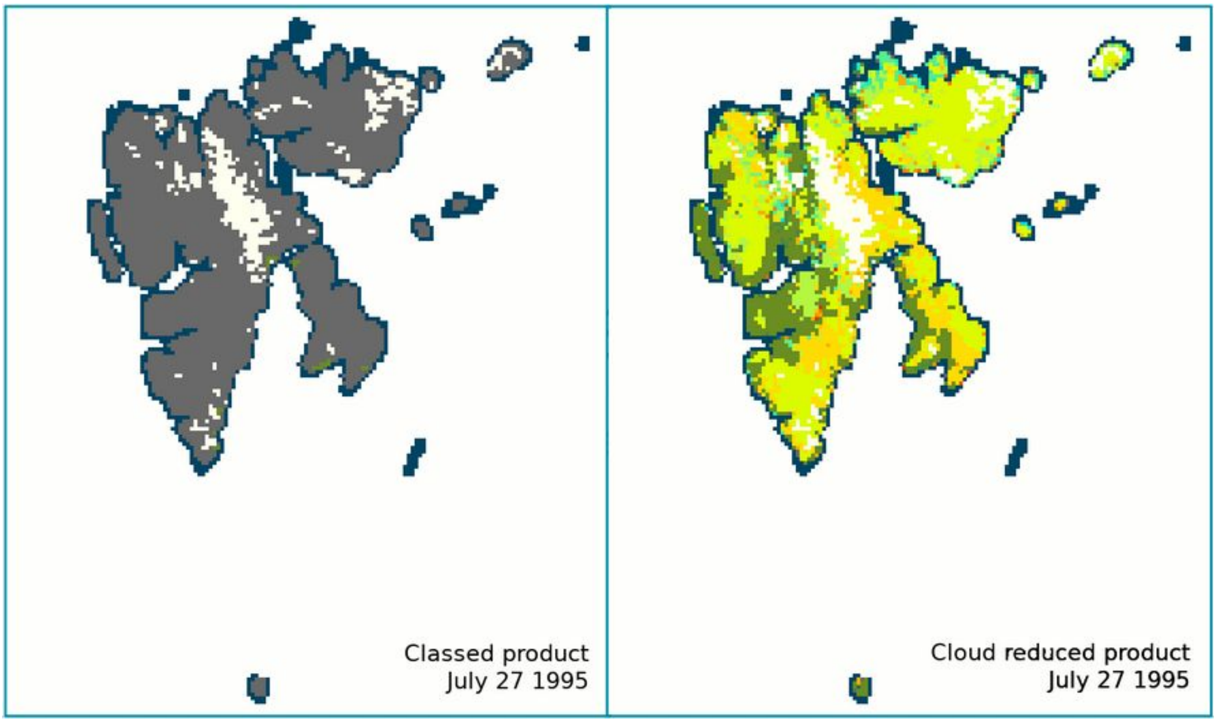

Figure 7: the left panel shows the classed product for July 27 1995. Nearly all of Svalbard was cloud-covered (grey) for this day. The right panel shows the "cloud-reduced" field for the same day. Using data up to +- 9 days, all clouds are "removed". Snow-free land is shown in dark green, while snow-covered areas are shown in white (snow-covered today) or shades of yellow depending on the temporal distance of the unclouded information relative to the product date.

This gap-free product is essential to assess the total daily snow cover and to look for changes in snow cover extent with time. This is further discussed in Chapter 4.

2.5 Extending the dataset to today

The AVHRR GAC FCDR that is the basis for the Svalbard daily snow cover product is currently available for 1982 - 2015. Level 1b AVHRR LAC data covering the Scandinavian areas (including Svalbard) is available in house at MET Norway for most of the period following 2015. In an attempt to extend the dataset for daily snow cover maps for Svalbard until today, we applied the MET Norway snow cover algorithm to these data files, and the resulting swath products of ~1 km resolution were gridded to the 4 km product grid. This was done for March 1 to September 30 for the years 2016-2018.

Whereas the global swath products are processed over land only, the version of the algorithm available for the level 1b AVHRR LAC data processes all pixels of the swath. Due to the difference in resolution between the AVHRR GAC swath products and the AVHRR LAC swath products, gridding to the 4 km product grid using the same gridding routine leads to the effect illustrated by Figure 8.

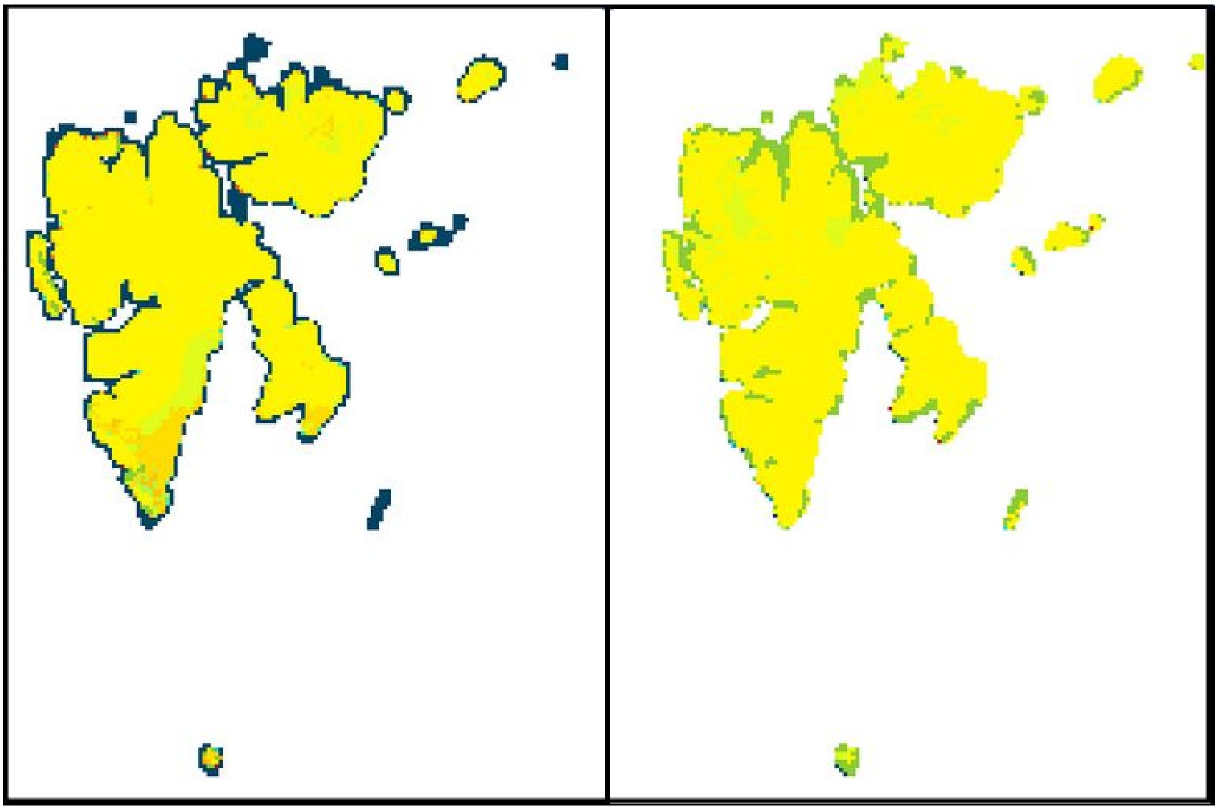

Figure 8: The left panel shows the gap-filled product for May 1 2015, and the right panel shows the gap-filled product for May 1 2016. Here, snow is shown in yellow tones. The AVHRR GAC-based product (left) has a dark blue “belt” of unprocessed pixels along the coast. The AVHRR LAC-based product, on the other hand, has a “belt” of snow-free land pixels (green) along the coast. Notice that

many fjords are filled with apparent land pixels (Wijdefjorden, Woodfjorden, van Mijenfjorden, and Tempelfjorden to name some) in the product for 2016.

Figure 8 shows side by side a gap-filled product from each of the datasets. Whereas the GAC-based snow cover product has unprocessed pixels along the coast, the LAC-based product has a false snow-free belt around the archipelago. A direct comparison of the products is not possible without further work. With more time at hand, AVHRR LAC data for 2015 could be used to inter-calibrate the gridded daily maps from the two data sources. In the following we focus on the 1982 - 2015 period, generated from a climate consistent satellite dataset.

2.6 Product variable description

This chapter contains a description of the most essential fields of the daily snow cover product files. A header dump of an actual NetCDF product file is included in Appendix A.

Aggregated snow probability

The `prob_snow` field gives the averaged probability for the class *snow*. The value is derived using swath product pixels with a probability for cloud below 40%. The value is normalized.

Aggregated land probability

The `prob_nosnow` field gives the averaged probability for the class *snow-free land*. The value is derived using swath product pixels with a probability for cloud below 40%. The value is normalized.

Classed product

This field is derived from the aggregated snow probability and takes binary values:

-1	ocean
0	no data
1	snow-free land
2	snow-covered land
4	clouded

Pixels with aggregated snow probability above 50% is categorized as snow-covered, while a snow probability in the range 0-50% is categorized as snow-free. Product grid pixels that have contributions solely from swath pixels with a probability for cloud above 40% are categorized as clouded. Pixels with a land fraction value of 0% are classified as ocean. Pixels along the coast that has a land fraction value above 0% but no contribution from gridded swath pixels are assigned the value for no data.

Number of swaths available
The `num_pass` field gives the number of satellite swaths passing for each product grid cell pixel. The number includes nighttime passes and clouded situations.

Number of observations used
The `num_obs_used` field gives the number of swath pixels used to derive the normalized, aggregated probabilities for snow / snow free for the product grid pixel.

Gap-free product
The `gapfree_classed_product` field is derived from the `classed_product` and uses data from daily gridded products with a temporal distance of up to 9 days to fill in for clouded pixels. The valid values are:

-1	ocean
0	nodata
0.X	clouded today, snow-free 10-X days earlier (X is in [1,9])
1	snow-free land today
1.X	clouded today, snow-free X days later (X is in [1,9])
2.X	clouded today, snow-covered 10-X days earlier (X is in [1,9])
3	snow-covered today
3.X	clouded today, snow-covered X days later (X is in [1,9])
4	clouded today and for +- 9 days

3 VALIDATION OF PRODUCT

The dataset for daily Svalbard snow cover maps for 1982 - 2015 is derived from global swath products containing snow, land and cloud probabilities based on AVHRR GAC data. These swath products were generated in phase 2 of the previously mentioned project Sentinel4CryoClim (“S4CC2”). In S4CC2 the global swath products were gridded to global daily snow cover products of 5 km resolution, one set for the Northern hemisphere and one for the Southern hemisphere. The Northern hemisphere daily snow cover maps were validated against ground observations of snow depth or snow cover from four different validation datasets. The most extensive of these validation datasets was data from the Global Historical Climatology Network - Daily (GHCN-D) database. Data from the GHCN-D database served as "ground truth", and was compared with the geographically and temporal corresponding satellite product pixel. The full period 1982 - 2015 was validated using data from almost 8000 unique ground stations located in North America, Europe and Asia. In total 11 million cloud-free comparisons were made. For 96% of the cases there was agreement between the satellite product pixel and the ground station. 94% of the cases of ground observed snow cover was correctly identified by the satellite product, as was 97% of the total number of snow-free ground observations. There are however variation with season, and map plots showed large variation with geography as well. More details on previous related validation results can be found in the CryoClim snow sub-service documentation (Killie et al., 2013), and the Sentinel4CryoClim project reports (Solberg et al., 2017; Killie et al., 2018).

A ground-based point measurement of snow depth does not necessarily represent the snow cover condition in an entire 4x4 km satellite product grid cell very well, in particular during melting and first snowfall. There might also be geographical or topographical factors that make the ground observation a poor representative for the entire satellite product pixel, such as large variation in altitude or land use within the pixel. This possibility for representation error is something we must keep in mind when choosing to validate a satellite based product against ground point observations. For the validation work in Sentinel4CryoClim there was no screening of stations based on terrain, and no manual removal of suspicious data. Snow depths in the range 0 to 5 cm however, was removed.

In this project we will follow the same approach as described above. We will use ground observation data from several datasets/sources. We validate the daily (March to September) gridded product, and will also validate the swath products. Although previous validation work shows very good results, we do not expect that the results for Svalbard will match the global (hemispheric) results. The northerly location means that the sun never reaches high in the sky. Low solar elevation is challenging due to cloud shadows, mountain shadows and shadowed landscape. We know from previous work that the algorithm typically has reduced performance for low solar illumination (Solberg et al., 2017). In addition, the statistical coefficients used in the algorithm are static, meaning that there is one set of coefficients to describe each of the classes *land*, *snow* and *cloud* that is used for all terrain types and times of year. The reflective properties of a surface change with illumination and angles, but also with season. Fresh snow reflects much more than old snow. Vegetated land reflects differently than unvegetated land. The training data from which the coefficients are derived was collected mainly using pixels at latitudes between 60 and 70 degrees north. Some samples were collected from the Svalbard archipelago and surrounding ocean areas as well, but the sparse vegetation on Svalbard is not dominating the data on which coefficients for the class *land* is based.

Table 1 shows the four validation data sources used in this project. Some validation data was already available in house from previous projects. The SIOS data portal was also searched to find validation data. The final, daily gridded products - as well as the swath products - have been validated. The geographical coverage for each validation data source can be seen in Figure 9.

Data source	Temporal coverage	Geographical coverage	Comment
Synop snow depth observations from MET weather stations	2013-2015	Barentsburg Ny-Ålesund Hornsund Svalbard Airport	Downloaded through SIOS data portal, marked “SIOS NC” in Figure 9
Synop snow depth observations from GHCN-D	1982-2015	Sveagruva Bjørnøya Ny-Ålesund	Downloaded and prepared in a previous project
Point measurements of snow cover from Möller and Möller 2018	2014-2015	Nordenskiöld Land	Downloaded through SIOS data portal
Snow observations from synoptic and climate stations	2011-2015	Scandinavia	Files available in house, marked “swath validation” in Figure 9

Table 1: a list of the validation datasets used in this project. Each entry in this table is shown in Figure 9.

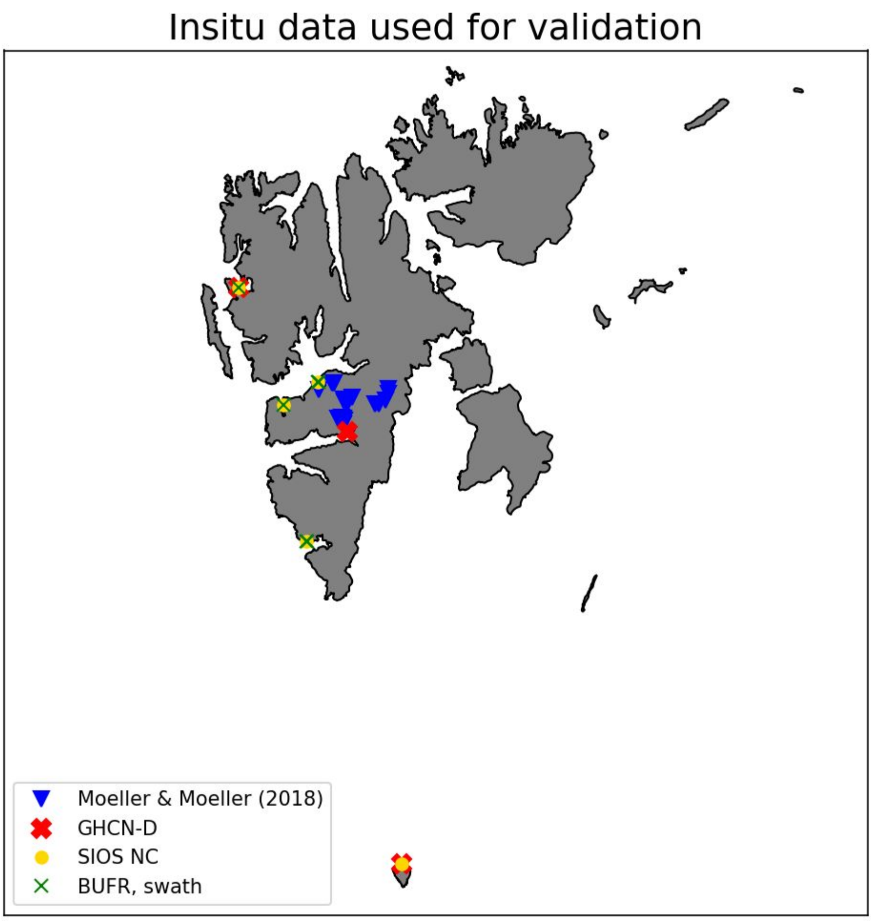

Figure 9: This figure shows the locations for the validation data used in this project. Each symbol type refers to a validation dataset.

3.1 Validation method for swath products and daily gridded products

We follow the validation approach from previous projects mentioned. The ground observation is translated from snow depth if necessary - to a binary snow/no snow value[1]. The ground snow observation (snow, no snow) is compared with the class value (snow, snow-free) of the nearest pixel from the satellite product of the same day. Verification measures such as total accuracy, total hit rate for each class (snow, land), false alarm ratio etc. are computed. Table 2 shows the 2x2 contingency table for matches and mismatches between the snow cover product derived from satellite, and the ground observation of snow.

[1] Samples with snow depths above 0 cm and below 5 cm are removed when validating the gridded products.

	Ground observation: **snow**	Ground observation: **no snow**
Satellite product: **snow**	A (hit)	B (false positive)
Satellite product: **no snow**	C (miss)	D (true negative)

Table 2: 2 x 2 contingency table (confusion matrix) for verification of satellite snow product.

A perfect match between the satellite product and the ground observations would produce only *hits* and *true negatives*, and no cases of alternatives B and C. Statistical scores (verification measures) can be computed from the contingency table values and be used to describe the products' performance. Among these scores are hit rates, false alarm ratio, probability of false detection and bias:

- Total hit rate (accuracy): (A+D)/(A+B+C+D)
- The hit rate (accuracy) for snow: A/(A+C)
- The hit rate (accuracy) for snow-free: D/(B+D)
- The false alarm ratio: B/(A+B)
- The probability of false detection: B/(B+D)
- Bias: (A+B)/(A+C)

Statistical scores are computed for each validation dataset, and confusion matrices along with various tables and plots of the results are shown. The results are presented for each validation dataset source. There might be overlap in the validation data. Data from the same stations may enter in more than one of the validation datasets. Different quality measures may have been performed, meaning that the validation results for one station might not be identical between the datasets.

3.2 Validation against in situ snow observations from the SIOS data portal

Synop snow depth observations from weather stations for 2013-2015 have been downloaded from the SIOS data portal. A total of six stations are included: Hornsund, Ny-Ålesund, Svalbard Airport, Bjørnøya, Hopen and Barentsburg. In a satellite product of this resolution the island Hopen - measuring 2 km across at the widest - is too narrow to be separated from water. Therefore no validations are performed for the station at Hopen. Station locations for the remaining five stations are indicated by yellow circles in Figure 9. Snow depth observations less than 5 cm are removed.

Table 3 shows a confusion matrix for the validation results. 1140 data points are compared, and the overall accuracy is 82%. The total hit rate for each surface class (*snow* and *land*) is 96% and 64% respectively.

	In situ: snow (SD > 5 cm)	In situ: no snow (SD = 0 cm)	Total
Satellite product: snow	607	184	791
Satellite product: no snow	23	326	349
Total	630	510	1140
Hit rates	**Snow: 0.96**	**Land: 0.64**	**Total: 0.82**

Table 3: Summary of validation results against in situ data downloaded from the SIOS data portal.

Table 4 shows the total hit rates for classes *snow* and *land*, the total accuracy and the number of samples for each of the five ground stations contributing to this validation dataset.

Station	Hit rate snow	Hit rate land	Total accuracy	# of samples
Svalbard Airport	0.99	0.84	0.91	251
Ny-Ålesund	0.92	0.43	0.76	282
Bjørnøya	-	0.76	0.76	68
Hornsund	1.0	0.036	0.59	199
Barentsburg	0.97	0.90	0.94	340
All stations	**0.96**	**0.64**	**0.82**	**1140**

Table 4: Some verifications measures shown per station.

There are large variations in the statistical scores for the ground stations. The data record for Bjørnøya contains no observations of snow. Validation using data from the four remaining stations give total hit rates for snow at 92% or higher. The hit rate for land varies between the stations. Svalbard Airport and Barentsburg both have hit rate for land above 80%. The Hornsund data has a very low hit rate for land (3.6%), and 100% hit rate for snow. The low hit rate for land translates to a high probability of false detection (conf. the definitions in Chapter 3.1). The Hornsund station is situated approximately 2 km from the foot of the Hansbreen glacier. We suspect that it is in fact the glacier that causes the poor hit rate for land for this station - as well as the high success rate in identifying snow cover. Without the Hornsund data, the total hit rate for land for this validation dataset would become 76%, and the total accuracy would be 87%, using 941 data points.

Figure 10 shows the monthly total accuracy with one line for each of the five stations contributing to this validation dataset for the years 2013-2015. The figure also shows bars indicating the number of comparisons for each month.

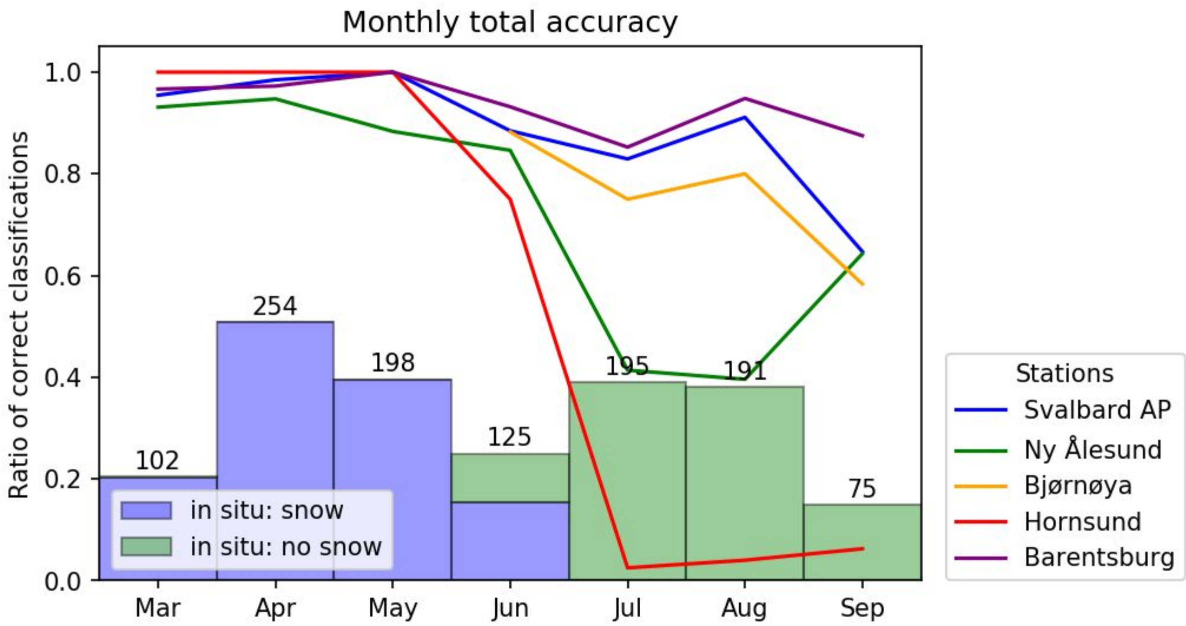

Figure 10: monthly total accuracy for each of the stations contributing data to the validation dataset. The blue and green bars illustrate the type of the inputdata: blue bars for ground observations of snow, and green bars for ground observations of snow-free land. The total number of comparisons for each month is printed at the top of each bar

The coloured bars show that months March to May are dominated by ground observations of snow, while months July to September are dominated by ground snow-free observations. There is a consistently high accuracy during the snow dominated period (approximately 90% or above) for all stations, and lower accuracy during summer (from July). This reflects a high hit rate for snow, and lower hit rate for land. In addition to the previously discussed station Hornsund, Figure 10 shows that validation against data from the Ny-Ålesund station also has a low success rate during summer.

3.3 Validation against data from GHCN-D

GHCN-D is a database of daily climate observations from land surface stations across the globe. The data records in GHCN-D have undergone a common set of quality assurance reviews, and more than 90 000 stations in 180 countries and territories are included. Among the variables are maximum and minimum temperature, total daily precipitation, snowfall and snow depth. Data records of snow depth observations from the GHCN-D dataset were already available in house. The dataset contains data from three unique stations located within the time interval (1982 - 2015) and geographical region of our interest: Bjørnøya, Sveagruva and Ny-Ålesund. These are indicated by red x in Figure 9. Snow depths between 0 and 5 cm are not used.

During analysis of the validation results we found that all of the Bjørnøya data and more than half of the Ny-Ålesund data had to be excluded from the validation dataset. This was due to suspicious amounts of allegedly snow-free observations during spring/early summer. Station Bjørnøya had solely snow-free ground observations for March- September for the full 1982 - 2015 period and was therefore completely removed from the validation dataset. The same was the case for ground observation data from station Ny-Ålesund prior to 2009. The data record contained (solely) snow-free observations, also for the late winter / early spring months. From 2009 the Ny-Ålesund ground observation changed character, and reported snow on the ground for March to June and snow-free ground from June through September. The ground observations from station Sveagruva covers the years 1982 to 2002 and 2014. Figure 11 shows as function of year the distribution of validation data from GHCN-D per category (A-D, Table 2), and the validation data distributed per contributing station.

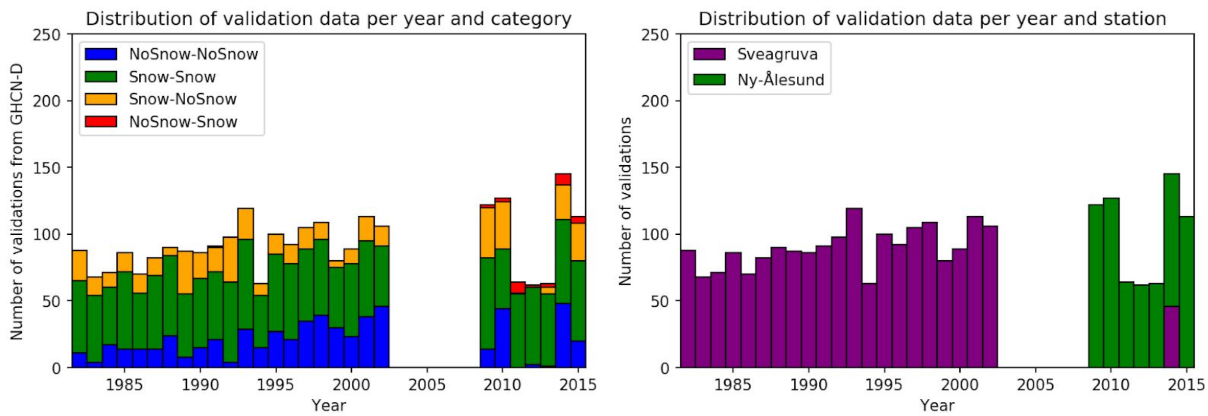

Figure 11: The left panel shows the validation data per category (ref: the confusion matrix in Table 2) as function of year, while the right panel shows the contribution for each of the two ground stations.

There are very few missed snow observations (category C in Table 2, red bars in Figure 11 left), and these occur mostly towards the end of the dataset period. From 2003 to 2008 there are no ground observations available from this dataset. The right panel shows the origin of the validation data. Data from station Sveagruva is available for 1982 to 2002 and then again for 2014. Station Ny-Ålesund contributes with data from 2009 to 2015.

Table 5 shows a confusion matrix for the comparison between the daily snow cover products for Svalbard and snow observations from the GHCN-D dataset. After removing samples for which the satellite product is clouded, dominated by water or for some other reason contains no data (most often due to wintertime darkness), a total of 2589 comparisons remain.

	GHCN-D: snow (SD > 5 cm)	GHCN-D: no snow (SD = 0 cm)	Total
Satellite product: snow	1509	470	1979
Satellite product: no snow	32	578	610
Total	1541	1048	2589
Hit rates	**Snow: 0.98**	**Land: 0.55**	**Total: 0.81**

Table 5: Summary of validation results against GHCN-D.

An overall accuracy of 81% is found. The hit rate for each surface class (*snow* and *land*) is again very different. The satellite product pixel agree with 98% of the ground observations of snow and 55% of the ground observations of land. Table 6 shows the hit rates for each year of the 1982 - 2015 period for which there is validation data.

Year	Hit rate snow	Hit rate land	Total accuracy	# of samples	Year	Hit rate snow	Hit rate land	Total accuracy	# of samples
1982	1.0	0.32	0.74	88	1999	1.0	0.86	0.94	80
1983	1.0	0.22	0.79	68	2000	1.0	0.68	0.88	89
1984	1.0	0.61	0.85	71	2001	1.0	0.68	0.84	113
1985	1.0	0.50	0.84	86	2002	1.0	0.75	0.86	106
1986	1.0	0.50	0.80	70	2003	-	-	-	-
1987	1.0	0.52	0.84	82	2004	-	-	-	-
1988	1.0	0.80	0.93	90	2005	-	-	-	-
1989	1.0	0.20	0.63	87	2006	-	-	-	-
1990	1.0	0.44	0.78	86	2007	-	-	-	-

1991	0.98	0.54	0.79	91	2008	-	-	-	-
1992	1.0	0.11	0.65	98	2009	0.97	0.27	0.67	122
1993	1.0	0.56	0.81	119	2010	0.94	0.56	0.70	127
1994	1.0	0.63	0.86	63	2011	0.87	0	0.86	64
1995	1.0	0.64	0.85	100	2012	0.97	1.0	0.97	62
1996	1.0	0.60	0.85	92	2013	0.95	0.17	0.87	63
1997	1.0	0.69	0.85	105	2014	0.89	0.65	0.77	145
1998	1.0	0.75	0.88	109	2015	0.92	0.42	0.71	113

Table 6: Hit rates and total accuracy for each year.

The yearly hit rate for class *snow* is consistently very high, and above 90% for all years except for 2011 (87%) and 2014 (89%). The hit rate for class *land* varies between 0% (2011 - one observation of snow-free ground, which was missed by the satellite product) and 86% (1999).

Station	Hit rate snow	Hit rate land	Total accuracy	# of samples
Sveagruva	1.00	0.58	0.82	1939
Ny-Ålesund	0.93	0.44	0.77	650
Total	**0.98**	**0.55**	**0.81**	**2589**

Table 7: Summary of validation results against in situ data downloaded from the SIOS data portal.

Table 7 shows the total hit rates for classes *snow* and *land*, the total accuracy and the number of samples for both of the stations contributing to this validation dataset. 100% of the ground snow observations from Sveagruva are classified as snow in the satellite product, while 58% of the observations of snow-free land are identified as land in the satellite product. With nearly 2000 samples, Sveagruva is the main contributor for this validation dataset, and also the one with the highest success rate. Snow observations from station Ny-Ålesund are also very often identified as snow in the satellite product (93%), but the hit rate for land is only at 44%.

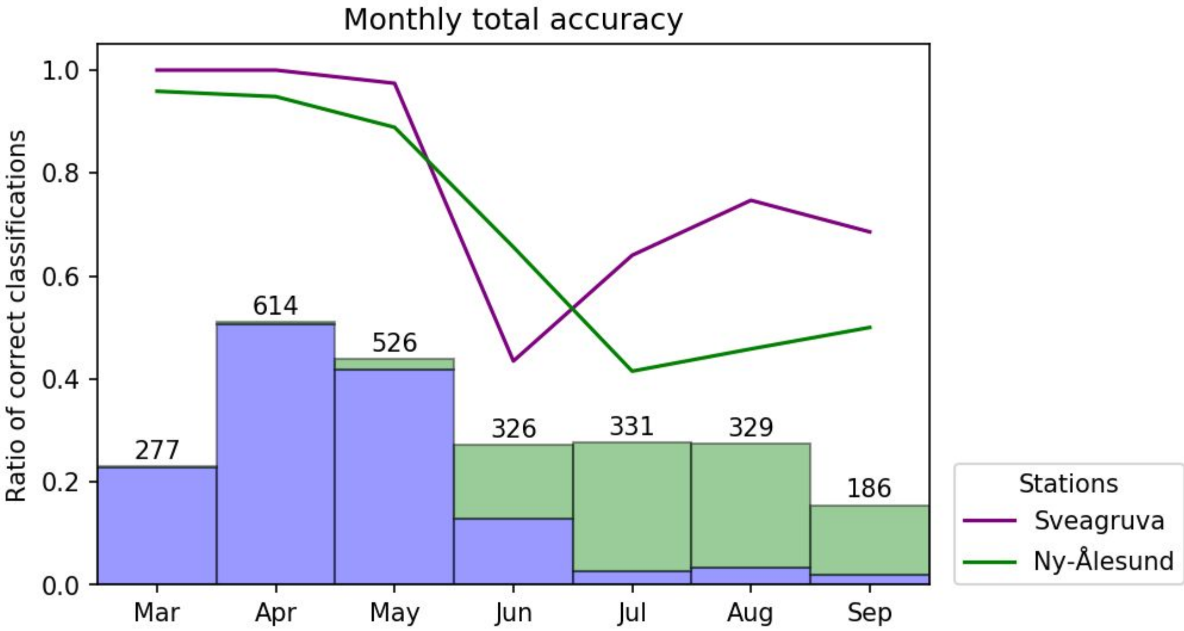

Figure 12: monthly total accuracy for each of the stations contributing data to the validation dataset. The blue and green bars illustrate the type of the inputdata: blue bars for ground observations of snow, and green bars for ground observations of snow-free land. The total number of comparisons for each month is printed at the top of each bar.

Figure 12 is similar to Figure 10 and shows monthly total accuracy for the two stations contributing to the validation data from GHCN-D. The coloured bars show the number of ground observations of snow (blue) and snow-free (green) for each month.

3.4 Validation against snow depth measurements from glaciers across Nordenskiöld Land

The Möller and Möller (2018) dataset contains snow cover data from a series of point measurements made across Nordenskiöld Land during 2014-2016. Snow depths was measured at 69 different locations on 17 individual glaciers during the spring seasons. We use data for 2014 and 2015. Several of the samplings are gridded to the same satellite product pixel, and one of the snow ground measurements is assigned to a clouded satellite product pixel. This leaves 19 unique comparisons between the snow depth measurements and the satellite product, spread over 6 dates. All have snow on the ground and snow in the satellite product, i.e., 100% accuracy. We keep in mind that the number of comparisons is low. On the other hand, this dataset contributes with validation data that are collected inland / away from the coast. The locations for the samplings are listed in Table 8 and indicated by blue triangles in Figure 9.

Date	Event label from Möller and Möller (2018)	Ground snow observation coordinates	Satellite product value
20140329	Svalbard_A-04	78.25 16.10	snow
	Svalbard_A-05	78.25 16.06	snow
	Svalbard_A-06	78.25 16.01	snow
20140330	Svalbard_B-01	78.15 16.82	snow
	Svalbard_B-06	78.10 16.64	snow
	Svalbard_B-08	78.11 16.55	snow
	Svalbard_B-10	78.13 16.50	snow
20140331	Svalbard_C-01	78.19 15.53	snow
20140406	Svalbard_D-01	78.14 18.10	snow
	Svalbard_D-04	78.19 18.20	snow
	Svalbard_D-06	78.23 18.20	snow
20140406	Svalbard_E-01	78.11 17.85	snow
	Svalbard_E-02	78.11 17.71	snow
20150329	Svalbard_H-01	77.98 16.32	snow
	Svalbard_H-03	77.99 16.45	snow
	Svalbard_H-04	77.98 16.52	snow
	Svalbard_H-05	77.97 16.56	snow
	Svalbard_H-09	77.94 16.54	snow

Table 8: the samplings from Möller and Möller (2018) used for validation.

3.5 Swath product validation

Ground snow observations from synoptic and climate stations are available on bufr files stored locally at MET. The archives contain data back to 2011. Swath products from 2011-2015 are validated against snow depth observations from this data record. For each swath product file, the data records are searched for ground observation within the Svalbard archipelago. For each ground observation that is found, observed snow depths and other variables are collected. Then - using the latitude and longitude of the ground observation, a selection of satellite product variables for the nearest 7*7 satellite product pixels are collected. For each ground observation a “matchup” like this is collected. We remove matchups that are clouded, above water, immersed in polar night or showing suspicious behaviour. In the end a total of 5020 matchups remain.

	Ground station: (SD > 0 cm)	Ground station:no snow (SD = 0 cm)	Total
Satellite product: snow	3799	418	4217
Satellite product: no snow	343	460	803
Total	4142	880	5020
Hit rates	**Snow: 0.92**	**Land: 0.52**	**Total: 0.85**

Table 9: Summary of validation results for swath products.

Table 9 summarizes the total hit rates and accuracies for the validation of swath products for 2011 - 2015. The total hit rate for snow is 92%, the total hit rate for land is 52%, and the overall accuracy is 85%. These summarized results are along the same lines as those seen in Chapters 3.2 and 3.3 (tables 3 and 5).

In Table 10 below the results are sorted on coordinates.

Coordinates (lat,lon)	Location	Hit rate snow	Hit rate land	Total accuracy	# of samples
(77.0,15.50)	Hornsund	0.81	0.52	0.75	114
(77.0,15.54)		0.87	0.58	0.78	203
(78.05,14.22)	Barentsburg	0.70	0.93	0.80	162
(78.25,15.47)	Svalbard	0.95	0.35	0.83	762

(78.25,15.5)	Airport	0.92	0.54	0.66	721
(78.92,11.93)	Ny-Ålesund	0.92	0.40	0.91	3058
Total		**0.92**	**0.52**	**0.85**	**5020**

Table 10: Verification measures shown per geographical location.

We see that the total hit rate for snow ranges from 70% (Barentsburg) to above 90% (Svalbard Airport), while hit rates for land are in the range 35% (Svalbard Airport) to 93% (Barentsburg).

Figure 13 shows the monthly values for accuracy and hit rates for snow and land. The figure also shows bars indicating the number of comparisons for each month.

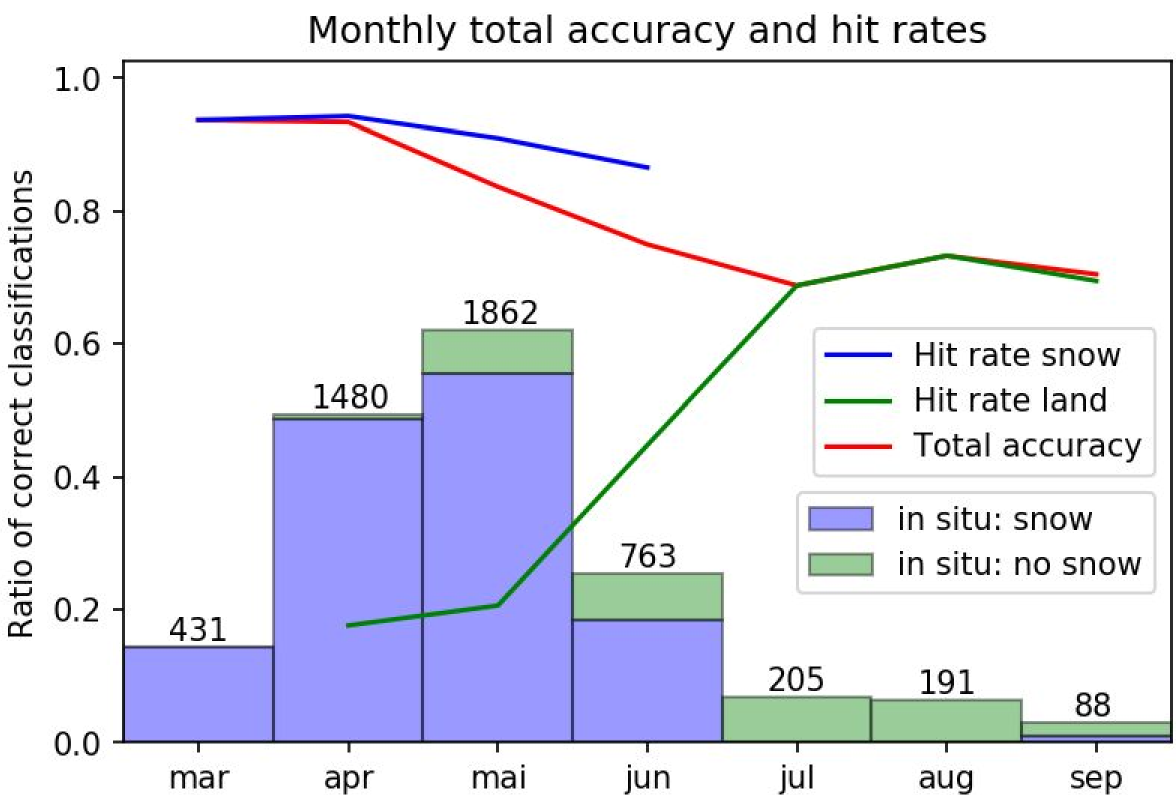

Figure 13: Monthly total values for hit rate snow, hit rate land and total accuracy. The figure also shows the distribution of validation data with time of year. Blue bars show ground observations of snow, and green bars show the number of ground observations of snow-free land. The total number of comparisons for each month is printed at the top of each bar.

3.6 Summary of validation results

Hit rates for classes *snow* and *land* for the three largest validation datasets are summarized in Table 11 below. Due to the limited size of the Möller and Möller (2018) data we do not include that dataset in this summary.

Validation dataset	Temporal coverage	Hit rate snow	Hit rate land	Total accuracy	# of samples
SIOS NC	2013 - 2015	0.96	0.64	0.82	1140
GHCN-D	1982 - 2015	0.98	0.55	0.81	2589
BUFR	2011 - 2015	0.92	0.52	0.85	5020

Table 11: Summary of total verification numbers for three of the validation datasets. Remember that data from GHCN-D covers 1982 - 2002 and 2009 - 2015.

The agreement between the summarized validation results is easily seen. The total hit rates for snow are generally above 90%, and the total hit rates for land are around 50-60%. Remember that the two first entries in Table 11 are validation of the daily gridded files, while the third entry comes from validation of the swath products on which the daily products are based. The SIOS NC and GHCN-D data overlap in time and to some extent in location. GHCN-D contains data from Sveagruva and Ny-Ålesund. Ny-Ålesund data appears also in the SIOS NC dataset, while ground data from Sveagruva does not. Sveagruva is the dominating part of the validation dataset, contributing with 76% of the 2589 validations. There is a large overlap in stations between SIOS NC and BUFR files (ref. Tables 4 and 10). Given that the BUFR files are used for validation of the swath product, it is valuable to include both results in this report.

Validation dataset ->	Daily product validation:SIOS NC		Daily product validation: GHCN-D		Swath product validation: BUFR	
Ground station	Hit rate snow	Hit rate land	Hit rate snow	Hit rate land	Hit rate snow	Hit rate land
Svalbard Airport	0.99	0.84			0.94	0.49
Ny-Ålesund	0.92	0.43	0.93	0.44	0.92	0.40

Hornsund	1.0	0.036			0.85	0.57
Barentsburg	0.97	0.90			0.70	0.93

Table 12: Summary of validation results for the stations contributing to more than one validation dataset.

Table 12 lists the hit rate for snow and land for ground stations appearing in more than one of the validation datasets. Svalbard airport has a high success rate for identifying snow on the ground, but shows very different results when it comes to identifying snow-free land. Validation of the daily products gives a hit rate land at 84%, while validation of the swath products give 49%. Figure 14 shows a comparison of the snow depth measurements contained on the BUFR files (left) and NetCDF file from SIOS (right). Whereas the BUFR datafile has two sections of 0 m snow depth, the SIOS NetCDF file has value -1, which means that is it excused from the validation. Traditionally 0 cm snow depth and missing observation of snow depth is reported in the same way, and it is not obvious whether the ground is snow free or if no observation was performed for that day. Quality measures have been applied to the NetCDF file, but not to the BUFR files. The period in early May - for which apparently no observations where made - will for the validation against BUFR likely produce false cases of false positives. The quality of the validation data has a large influence on the validation results.

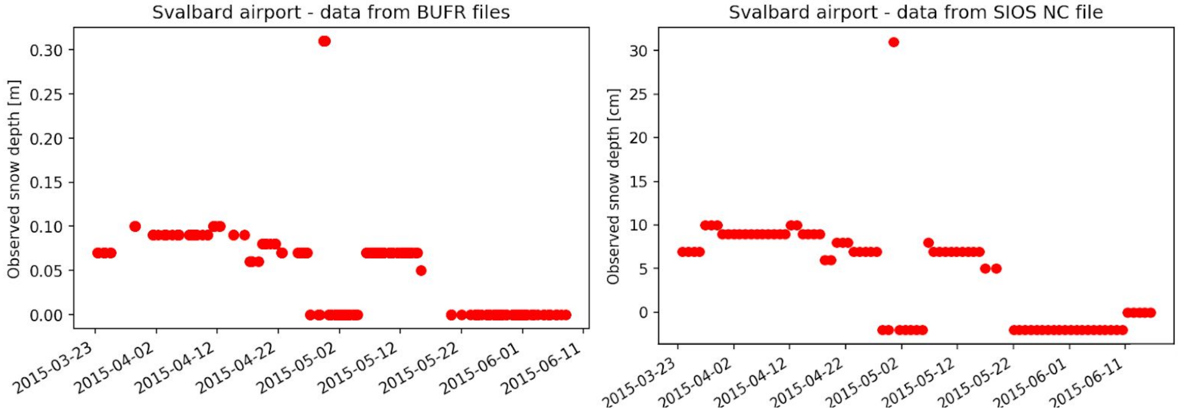

Figure 14: the ground snow observations for Svalbard Airport for 2015 from BUFR files used for swath validation (left) and from the NetCDF files downloaded from SIOS data portal used for validation of the daily product (right).

Ny-Ålesund has high success rate for identifying snow for all three validation exercises summarized in Table 12. The hit rate for land is consistently low at 40-43%, and in particular low during summer (ref. Figures 10 and 12). A low hit rate for land means that the station reports snow-free ground, while the satellite product pixel is classified as snow-covered. Ny-Ålesund is located on the north shore of Brøggerhalvøya, a peninsula that is ~10 km wide. The peninsula is dominated by mountains, with several tops at 600-800 m a.s.l. Just south of Ny-Ålesund is the Zeppelin mountain reaching 475 m a.s.l.

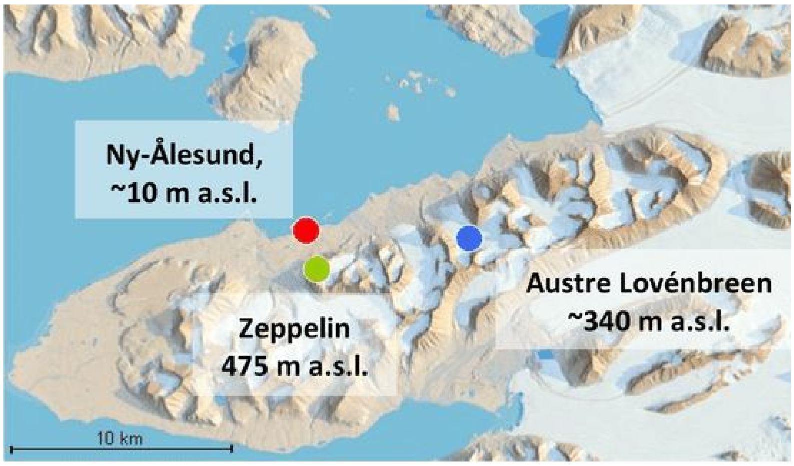

Figure 15: a map of Brøggerhalvøya (copyright: Norwegian Polar Institute)

Remembering that each pixel of the satellite product grid is 4x4 km it is very likely that the product pixel containing Ny-Ålesund also contains a large fraction of mountain areas. It is therefore likely that the ground station in Ny-Ålesund at an elevation of ~10 m a.s.l. can become snow-free much sooner than the majority of the grid cell area, which will naturally lead to poor hit rate values for the class *land*. In addition, mountain shadows and cloud shadows can also influence the results.

As mentioned in Chapter 3.2, the location of the Hornsund station close to Hansbreen is very likely the reason for the 100% hit rate for snow and the very poor hit rate for snow-free land when validating the *gridded* products. Validation of the *swath* products on the other hand gives 85% hit rate for snow and 57% hit rate for land. Figure 16 shows a map of Hornsund with the station included.

Figure 16: a Google map of Hornsund. Notice the 5 km distance bar in the lower right corner.

We believe that the difference in validation results is that for the gridded product the ground station is (permanently) allocated to a product pixel dominated by glacier areas, while for the validation of the swath product this is not necessarily the case.

4 SNOW COVER INDEX

A main goal for this project is to derive a snow cover index - a value for the snow covered area as function of time for 1982-2015. Gap free maps described in Chapter 2.4 is achieved for March to October of each year. As described in Chapter 2.5 it was not possible within this project to extend the dataset beyond 2015 by combining with AVHRR LAC data. The fluctuations from day to day described in Chapter 2.3 prohibit looking at variations with geographical location. The onset of the seasonal snow cover typically happens too late in the year to be detectable from this satellite product which needs a solar zenith angle of 80 degrees or less to process data. The onset of melting on the other hand starts at a time of year for which the Sun has returned. In this chapter we will investigate the onset of snow melt from the gap-free daily snow cover maps.

4.1 Method

The gap-free field described in Chapter 2.4 is used. For each day from March 1 to September 30 each year, the total number of snow-covered (/snow-free) pixels are counted. Dividing by the total number of land pixels, the ratio of snow-covered (/snow-free) pixels as function of time is found. Looking at one particular day, the total number of snow-covered pixels for this day is the sum of pixels that are snow-covered on this day and pixels that are clouded on this day but has snow-covered as the nearest in time cloud-free state. Conversely, the total number of land-covered pixels for a given day is the sum of the pixels that are cloud-free and snow-free on this day and pixels that are clouded on this day but has snow-free as the nearest in time cloud-free state. This is illustrated by Figure 17 using data for the year 2000.

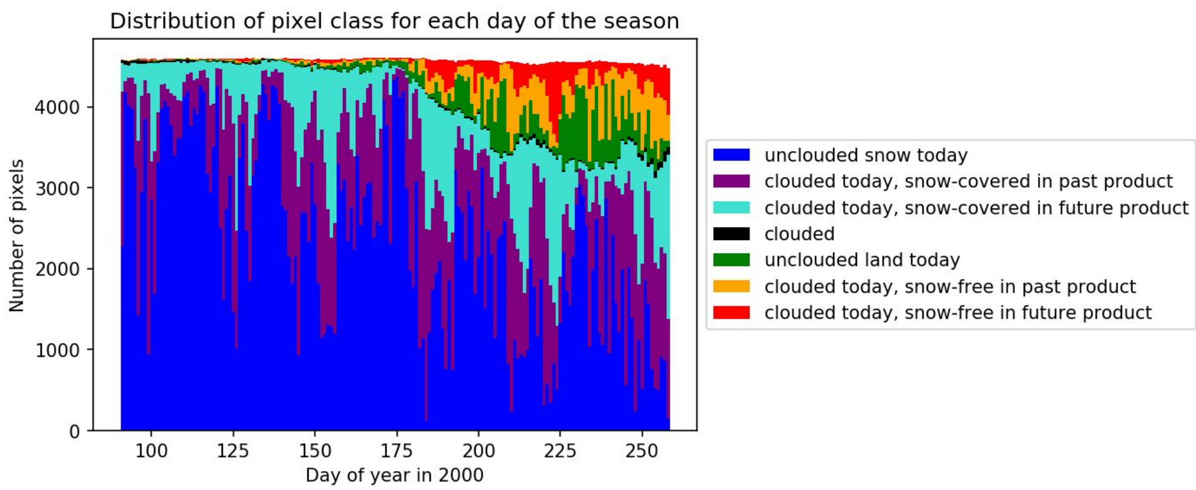

Figure 17: for each day of year the coloured bars show the origin of the gap-free classified data.

The development seen in Figure 17 is representative for the dataset. At the start of the year more or less all pixels are snow-covered (dark blue, purple or light blue in Figure 17). Around day of year 170 (mid-June) an increasing number of pixels become snow-free (green, yellow or red in Figure 17). Note that there are some black sections in the figure. These represents pixels that are clouded for that daily product even when looking as much as 9 days backwards or forwards in time.

To reduce noise we average over a 9 days moving window. Figure 18 shows some selected years from 1982 - 2015.

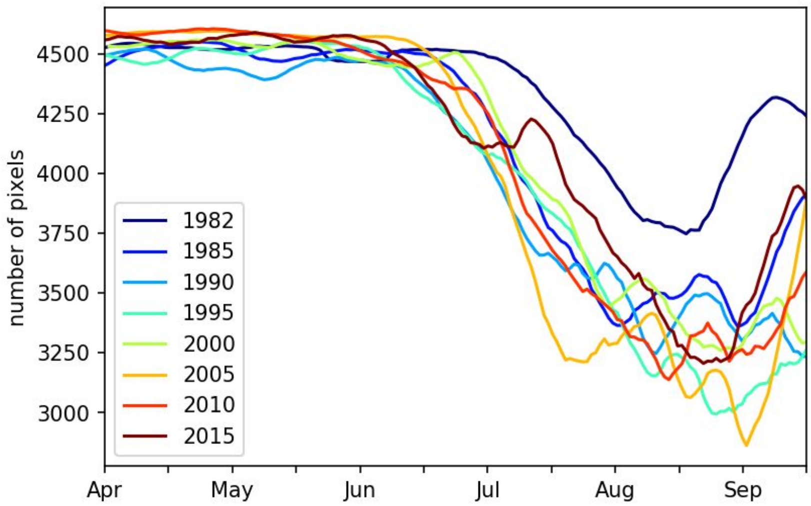

Figure 18: averaged number of snow covered pixels for some selected years.

We will assess whether there is a temporal change in the melting onset and if a larger total area melts and becomes snow-free during the summer season. Figure 19 shows a heatmap of the snow-covered area for each summer season during 1982 - 2015.

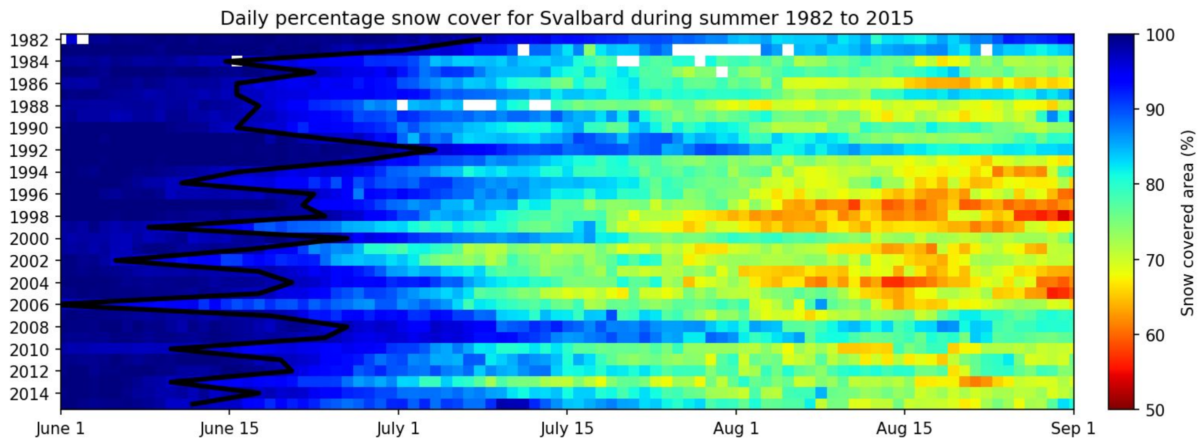

Figure 19: a heatmap for the daily percentage snow cover for Svalbard 1982 - 2015. White squares are days of missing satellite data product.

Each square refers to one day. The colour of a square shows the percentage of snow cover for that day. Red colour indicates a low fraction of snow covered area, while blue indicates a high (100%) value for the total snow covered area. To extract a date we can “define” as onset of melting for the total product, we calculate an averaged plateau value for each year (left sections of the plots seen in Figures 17 and 18), and collect the date for which the number of snow-covered pixels drops below 95% of the plateau level. The black line in Figure 19 indicates this date. Figure 20 shows a scatterplot of the “melt onset” date as function of year.

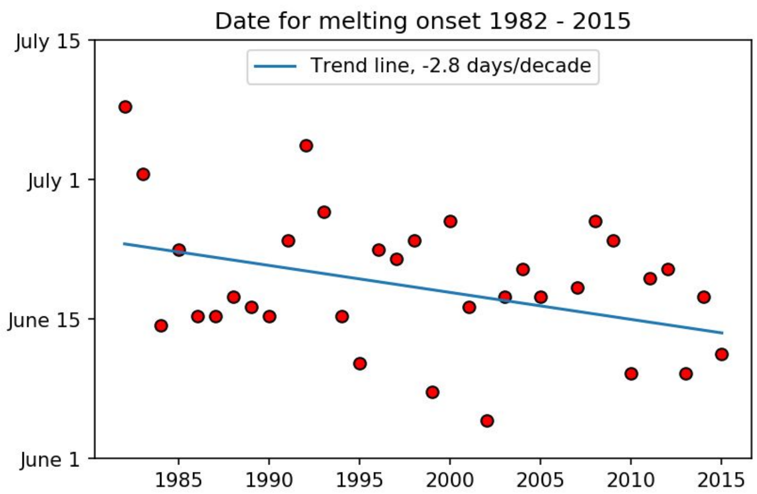

Figure 20: scatterplot for melt onset date.

A linear regression trend line has been fitted to the plot (blue line), and the slope of this line corresponds to -2.8 days/decade. The p-value is -0.038 meaning that the trend of -2.8 days/decade change in melt onset date is statistically significant at the

0.05 level.

Osuch & Wawrzyniak (2017) presents temporal variability of snow-cover indicators such as snow onset date, snow disappearance date, snow-cover duration and maximum snow depth over 32 years using observational data for Barentsburg and Hornsund stations. Among their results are trend lines for snow disappearance date at -1.5 days/decade for Barentsburg and −4.0 days/decade for Hornsund. The authors study *snow disappearance* for two well defined stations, which is not directly comparable with our method to derive melt onset of Svalbard using the satellite data based snow cover maps. Still, the results compare well.

5 SUMMARY AND CONCLUSION

A daily gridded dataset of snow cover maps for Svalbard covering 1982 to 2015 has been generated from an AVHRR GAC FCDR. The daily files contain probabilities for snow and snow-free, a classified snow cover field, and a gap-filled snow cover field. The latter is developed using data for up to 9 days backwards and forwards in time. Due to polar night conditions, maps are produced only for March 1 to September 30. The dataset will be available through the SIOS data portal.

A substantial part of this project has been to validate the satellite product in its environment. The daily snow cover products have been compared with ground snow depth observations from weather stations and other available snow observations on Svalbard. We keep in mind that representation error can have a large influence on the validation results when validating a satellite product of 4 km resolution with a ground point observation. Overall results show a total hit rate for snow in the range 92-98%, and total hit rate for snow-free land in the range 52-64%. As discussed in Chapter 3.6, many of the false positives (ref. Table 2) can be attributed to either representation error or error in the validation dataset, which means that the hit rate for land should in fact be higher for some of the data.

The gap free field is used to derive and analyse a snow cover index for Svalbard. By defining melt onset as the day of year for which the snow covered area drops below 95% of full snow cover, we find indications of a trend in melt onset of -2.8 days earlier melt onset per decade.

One aim of the project was to use level 1b AVHRR LAC data to continue the time series of snow cover maps from 2015 to today. This was not possible within the frame of this project. Some work must be done to inter-calibrate snow maps from the two different satellite data sources. If this comes in place, scripts can be set up for continuously updates of the satellite based snow cover maps.

6 REFERENCES

Karlsson, Karl-Göran; Anttila, Kati; Trentmann, Jörg; Stengel, Martin; Meirink, Jan Fokke; Devasthale, Abhay; Hanschmann, Timo; Kothe, Steffen; Jääskeläinen, Emmihenna; Sedlar, Joseph; Benas, Nikos; van Zadelhoff, Gerd-Jan; Schlundt, Cornelia; Stein, Diana; Finkensieper, Stephan; Håkansson, Nina; Hollmann, Rainer; Fuchs, Petra; Werscheck, Martin (2017): CLARA-A2: CM SAF cLoud, Albedo and surface RAdiation dataset from AVHRR data - Edition 2, Satellite Application Facility on Climate Monitoring, DOI:10.5676/EUM_SAF_CM/CLARA_AVHRR/V002, https://doi.org/10.5676/EUM_SAF_CM/CLARA_AVHRR/V002.

Killie, M. A., Eastwood, S., Solberg, R., Rudjord, Ø. and Salberg, A. B., 2013 Snow sub-service development: Report on CryoClim WP 3 progress and results. Project deliverables no. D3.1-D3.10, CryoClim Phase 4, ESA/NSC PRODEX. Norwegian Computing Center and Norwegian Meteorological Institute.

Killie, M. A., Eastwood, S. and Sørensen, A., 2018 Improvement and Validation of the Optical Component Used for Snow Mapping in CryoClim. Sentinel4CryoClim Phase 2 Project Report.

Möller, Marco; Möller, Rebecca (2018): Snow cover data across Nordenskiöldland, Svalbard, from point measurements during 2014-2016. PANGAEA, https://doi.org/10.1594/PANGAEA.896581, Supplement to: Möller, M; Möller, R (in review): Snow cover variability across glaciers in Nordenskiöldland (Svalbard) from point measurements in 2014–2016. Earth System Science Data Discussions, 1-16, https://doi.org/10.5194/essd-2018-158

Osuch, M., & Wawrzyniak, T. (2017). Variations and changes in snow depth at meteorological stations Barentsburg and Hornsund (Spitsbergen). *Annals of Glaciology, 58*(75pt1), 11-20. doi:10.1017/aog.2017.20

Solberg, R., Rudjord, Ø., Salberg, A. B., Killie, M. A., Eastwood, S. and Breivik, L. A., 2017 Advancement of global snow mapping in CryoClim. Sentinel4CryoClim Phase 1, Deliverables 1-6.

APPENDIX A

This appendix contains a header dump of a netCDF data product file.

```
netcdf daily-avhrr-sce-Svalbard_200007111200_c {
dimensions:
    time = 1 ;
    bounds = 2 ;
    xc = 200 ;
    yc = 200 ;
variables:
    double time(time) ;
       time:axis = "T" ;
       time:long_name = "reference time of product" ;
       time:standard_name = "time" ;
       time:units = "seconds since 1978-01-01 00:00:00" ;
       time:calendar = "standard" ;
       time:bounds = "time_bounds" ;
    double time_bounds(time, bounds) ;
       time_bounds:units = "seconds since 1978-01-01 00:00:00" ;
    double xc(xc) ;
       xc:axis = "X" ;
       xc:long_name = "x-coordinate in Cartesian system" ;
       xc:standard_name = "projection_x_coordinate" ;
       xc:units = "m" ;
    double yc(yc) ;
       yc:axis = "Y" ;
       yc:long_name = "y-coordinate in Cartesian system" ;
       yc:standard_name = "projection_y_coordinate" ;
       yc:units = "m" ;
    float lon(yc, xc) ;
       lon:long_name = "longitude coordinate" ;
       lon:standard_name = "longitude" ;
       lon:units = "degrees_east" ;
    float lat(yc, xc) ;
       lat:long_name = "latitude coordinate" ;
       lat:standard_name = "latitude" ;
       lat:units = "degrees_north" ;
    float land_area_fraction(yc, xc) ;
       land_area_fraction:long_name = "fraction_of_land" ;
       land_area_fraction:standard_name = "land_area_fraction" ;
       land_area_fraction:units = "1" ;
    short prob_snow(time, yc, xc) ;
       prob_snow:units = "%" ;
       prob_snow:long_name = "Aggregated snow probability" ;
       prob_snow:_FillValue = -32767s ;
       prob_snow:valid_min = 0s ;
       prob_snow:valid_max = 10000s ;
       prob_snow:coordinates = "time xc yc" ;
       prob_snow:scale_factor = 0.01f ;
    short prob_nosnow(time, yc, xc) ;
```

```
        prob_nosnow_o:units = "%" ;
        prob_nosnow:long_name = "Aggregated land probability" ;
        prob_nosnow:_FillValue = -32767s ;
        prob_nosnow:valid_min = 0s ;
        prob_nosnow:valid_max = 10000s ;
        prob_nosnow:coordinates = "time xc yc" ;
        prob_nosnow:scale_factor = 0.01f ;
   byte classed_product(time, yc, xc) ;
        classed_product:units = "1" ;
        classed_product:long_name = "pixel class: -1=ocean, 0=nodata, 1=no
snow, 2=snow, 4=cloud" ;
        classed_product:coordinates = "time xc yc" ;
    short num_pass(time, yc, xc) ;
        num_pass:units = "1" ;
        num_pass:long_name = "number of swaths available" ;
        num_pass:_FillValue = -32767s ;
        num_pass:coordinates = "time xc yc" ;
    short num_obs_used_o(time, yc, xc) ;
        num_obs_used_o:units = "1" ;
        num_obs_used_o:long_name = "number of satellite passages used" ;
        num_obs_used_o:_FillValue = -32767s ;
        num_obs_used_o:coordinates = "time xc yc" ;
    short gapfree_classed_product(time, yc, xc) ;
        gapfree_classed_product:_FillValue = -32767s ;
        gapfree_classed_product:units = "1" ;
        gapfree_classed_product:long_name = "-1: ocean, 0: nodata, 0.x: snow
free 1-0.x days later 1: snow free today , 1.x: snow free x days earlier,
2.x: snow covered 3-2.x days later, 3: snow covered today, 3.x: snow covered
x days earlier" ;
        gapfree_classed_product:coordinates = "time xc yc" ;
        gapfree_classed_product:grid_mapping = "Lambert_Azimuthal_Grid" ;
        gapfree_classed_product:add_offset = 0. ;
        gapfree_classed_product:scale_factor = 0.1 ;

// global attributes:
        :title = "Daily aggregated snow cover product for Svalbard" ;
        :product_name = "Fmsnowcover Svalbard snow cover product" ;
        :product_status = "offline" ;
        :abstract = "Daily averaged snow cover product based on processed
AVHRR GAC swaths from Sentinel4CryoClim phase 2" ;
        :topiccategory = "ClimatologyMeteorologyAtmosphere" ;
        :keywords = "Snow Cover, Terrestrial Snow, Cryosphere, Meteorology,
Climate, Remote Sensing" ;
        :gcmd_keywords = "Cryosphere > Snow/Ice > Snow Cover\n",
              " Terrestrial Hydrosphere > Snow/Ice > Snow Cover\n",
              " Geographic Region > Arctic > Svalbard and Jan Mayen\n"
              " Vertical Location > Land Surface\n",
              " AVHRR > Advanced Very High Resolution Radiometer\n" ;
        :easternmost_longitude = 41.76429f ;
        :westernmost_longitude = -11.76122f ;
        :northernmost_latitude = 73.85917f ;
        :southernmost_latitude = 52.30252f ;
        :area = "Svalbard" ;
```

```
        :activity_type = "Space borne instrument" ;
        :instrument_type = "AVHRR GAC" ;
        :start_date = "2000-07-11 00:00:00" ;
        :stop_date = "2000-07-11 23:59:59" ;
        :project_name = "SIOS SvalSCE" ;
        :institution = "Norwegian Meteorological Institute" ;
        :PI_name = "Mari Anne Killie" ;
        :contact = "m.killie@met.no" ;
        :distribution_statement = "Free" ;
        :history = "2019-03-22 created" ;
        :netcdf_version = "3.6.3" ;
        :Conventions = "CF-1.3" ;
}
```