VISITING SCIENTIST ACTIVITY FOR A FEASIBILITY STUDY ON SENTINEL-2 FOR AUTOMATED VALIDATION OF H-SAF SNOW COVER PRODUCTS

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VSA Final Summary

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Document Table

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Document Modification Table

Version	Modified By	Date	Modification
V1.0	Burak Simsek	30.09.2017	Initial Version
v.1.1	Burak Simsek	04.10.2017	Acknowledgment added
v.1.2	Ali Nadir Arslan	09.10.2017	Reviewed & Feedbacks given
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First, I would like to thank Finnish Meteorological Institute (FMI for their hospitality and friendly environment. It was a great experience to work and collaborate with FMI staff and management.

Second, as the work would not be possible without their contributions, I would like to thank Ali Nadir Arslan, Cemal Melih Tanis, Matias Takala and Terhikki Männinen. Working with them had such a positive impact on the progress of the study.

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ABBREVIATIONS

ACC: Accuracy
AC: Atmospheric Correction
ATBD: Algorithm Theoretical Basis Document
BOA: Bottom of Atmosphere
ESA: European Space Agency
FAR: False alarm rate
HSS: Heidke Skill Score
L1C: Level 1C
L2A: Level 2A
MODIS: Moderate-resolution imaging spectroradiometer
MSI: Multi Spectral Instrument
NDSI: Normalized-Difference Snow Index
POD: Possibility of detection
PVR: Product Validation Report
S2: SENTINEL-2
SC: Scene Classification
SNAP: Sentinel Application Platform
SWIR: Short Wave Infrared
TOA: Top of Atmosphere
VNIR: Visible and Near-Infrared

1. INTRODUCTION

This report presents the work conducted under EUMETSAT H-SAF Project Visiting Scientist Activity between November 2016 and May 2017 for the duration of 6 months at Finnish Meteorological Institute, Helsinki. Work was done under the supervision of Ali Nadir Arslan and Matias Takala with the contribution of Cemal Melih Tanis.

Validation for snow cover products with in-situ data has certain issues such as data availability, frequency, coverage and standardization of measurements between different organizations and countries. Thus, using complementary data for validation processes has a positive impact on validation results. Hence the need for a feasibility study on using Sentinel-2 data as complementary data for validation purposes.

SENTINEL-2 is a wide-swath high-resolution, multi-spectral imaging mission. With twin satellites flying in same orbit and phased at 180°, it has a revisit frequency of 5 days at the Equator. Equipped with Multi Spectral Imager (MSI), SENTINEL-2 covers 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution. (Drusch et al., 2012)

As Drusch et al., (2012) states, with its 13 spectral bands, 290 km swath width and high revisit frequency, SENTINEL-2's MSI instrument supports a wide range of land studies and programmes, and reduces the time required to build a European cloud-free image archive. SENTINEL-2 will provide data for land cover classification, atmospheric correction and cloud/snow separation.

According to Drusch et al., (2012), SENTINEL-2 data are acquired on 13 spectral bands in the VNIR and SWIR:

- Four bands at 10 m: 490 nm (B2), 560 nm (B3), 665 nm (B4), 842 nm (B8)
- Six bands at 20 m: 705 nm (B5), 740 nm (B6), 783 nm (B7), 865 nm (B8a), 1 610 nm (B11), 2190 nm (B12)
- Three bands at 60 m: 443 nm (B1), 945 nm (B9) and 1 375 nm (B10).

The fact that SENTINEL-2 provides high resolution global cover data with ease of access as well as being free, including SENTINEL Application Platform (SNAP) - visit ***http://step.esa.int/main/toolboxes/snap/*** for more information- strongly suggests the use of SENTINEL-2 data for validation purposes.

According to product validation report (PVR) of H10 and H12, current common validation methodology of H-SAF project is based on case study analyses and producing large statistic (multi-categorical) by comparison with ground data. Both large statistics and case study analysis are used to assess the accuracy of the implemented algorithm(s). It is stated that, As case studies helps determining the root of pathological behaviors, large statistics helps identifying the existence of pathological behaviors. The main steps of the validation procedure are listed in PVR as:

1. Check for consistency of both observation and satellite data series,
2. Comparison between the snow observation and the satellite data,
3. Mountain mask application,
4. Large statistical analysis: multi-categorical scores evaluation,
5. Case study analysis.

The steps have to be taken for the validation of H10 and H31 products are:

1. Observation data containing snow cover measurements have to be gathered.
2. Satellite product needs to be acquired.
3. Both observation and satellite data series need to be checked for consistency.
4. Comparison between the observation data and the product has to be performed.
5. Results of the comparison need to be presented.

The steps have to be taken for the validation of H12 product are:

1. Observation data containing e-codes or snow course data with visual estimates of snow covered area with values from 0 to 100 have to be gathered.
2. Satellite products need to be acquired.
3. Both observation and satellite data series need to be checked for consistency.
4. Comparison between the observation data and the product has to be performed.
5. Results of the comparison need to be presented.

The primary objective of this research study is to make a feasibility study on SENTINEL-2 for an automatic validation of the H-SAF snow cover products (H10, H12, H31). Steps of this research can be listed as below;

- Reviewing the existing snow algorithms, already applied or can be applied for SENTINEL-2.
- Implement selected snow algorithms of SENTINEL-2 to the Finnish Meteorological Institute image PROcessing Toolbox (FMIPROT).d
- Making a feasibility study on an automated validation process for the H-SAF snow cover products (H10, H12, H31) using FMIPROT.
- Publish results at a conference/workshop or a possibly a journal paper.

The objectives listed above were implemented via the tasks given in the table below;

TASK		Month (M)	Milestone
Task 1	Review existing algorithms on snow, already applied or can be applied for SENTINEL-2	M2	All snow algorithms reviewed and listed. Algorithms for Sentinel-2 are selected
Task 2	Implement selected snow algorithms of SENTINEL-2 to the Finnish Meteorological Image PROcessing Tool FMIPROT	M3	Selected snow algorithms are implemented to FMIPROT
Task 3	Making a feasibility study on an automated validation process for the H-SAF snow cover products (H10, H12, H31) using FMIPROT	M6	Automated validation process results presented at project meeting and OR 2017

Fig. 1. Table of the tasks and expected timeline

2. METHODS AND MATERIALS

2.1. ALGORITHMS

Different algorithms on snow cover mapping is reviewed to use for the validation study. Applicability by using only SENTINEL-2 data is chosen as the criteria to determine which algorithm will be used.

2.1.1. Algorithm used in this study, SC

Algorithm used in this study is the algorithm designed by DLR/Telespazio for SENTINEL-2. As it is stated by Richter et al., (2011), this algorithm takes Level 1C (TOA Reflectance) data, which is the data distributed by Copernicus from their Data Hub, as input and gives Level 2A (BOA Reflectance) data as output.

As it is stated in algorithm theoretical basis document (ATBD) of SENTINEL-2 Level 2A Products, process is split into two parts:

1. Scene Classification (SC): Creates maps with pixels classified, such as cloud, snow, vegetation, bare-soil. SC uses valid and non saturate pixels -such information is part of the metadata input- from bands 2, 3, 4, 8, 10 and 12. All bands are resampled to 60m for performing this step.

2. Atmoshperic Correction (S2AC): Converting TOA reflectances to BOA reflectances as well as giving an aerosol optical thickness map (AOT) and a water vapour map.

The cloud/snow detection/discrimination algorithm is based on series of threshold filtering steps:

1. Brightness Thresholds on Red (Band 4)
2. Normalized Difference Snow Index (NDSI)
3. Snow Detection / Snow Confidence Mask
4. Snow Filter 1: Normalized Difference Snow Index (NDSI)
5. Snow Filter 2: Band 8 thresholds
6. Snow Filter 3: Band 2 thresholds
7. Snow Filter 4: Ratio Band 2 / Band 4
8. Processing of Snow Boundaries Zones

Where Normalized Difference Snow Index, NDSI is as follows;

$$\text{Normalised Difference Snow Index } (NDSI) = \frac{Band\,3 - Band\,11}{Band\,3 + Band\,11}$$

The fact that only snow is very bright in the visible but dark in SWIR is the basis of NDSI and was introduced by Jeff Dozier (1989) for Landsat TM.

Flow of the cloud/snow detection algorithm is shown below in Figure 2.1

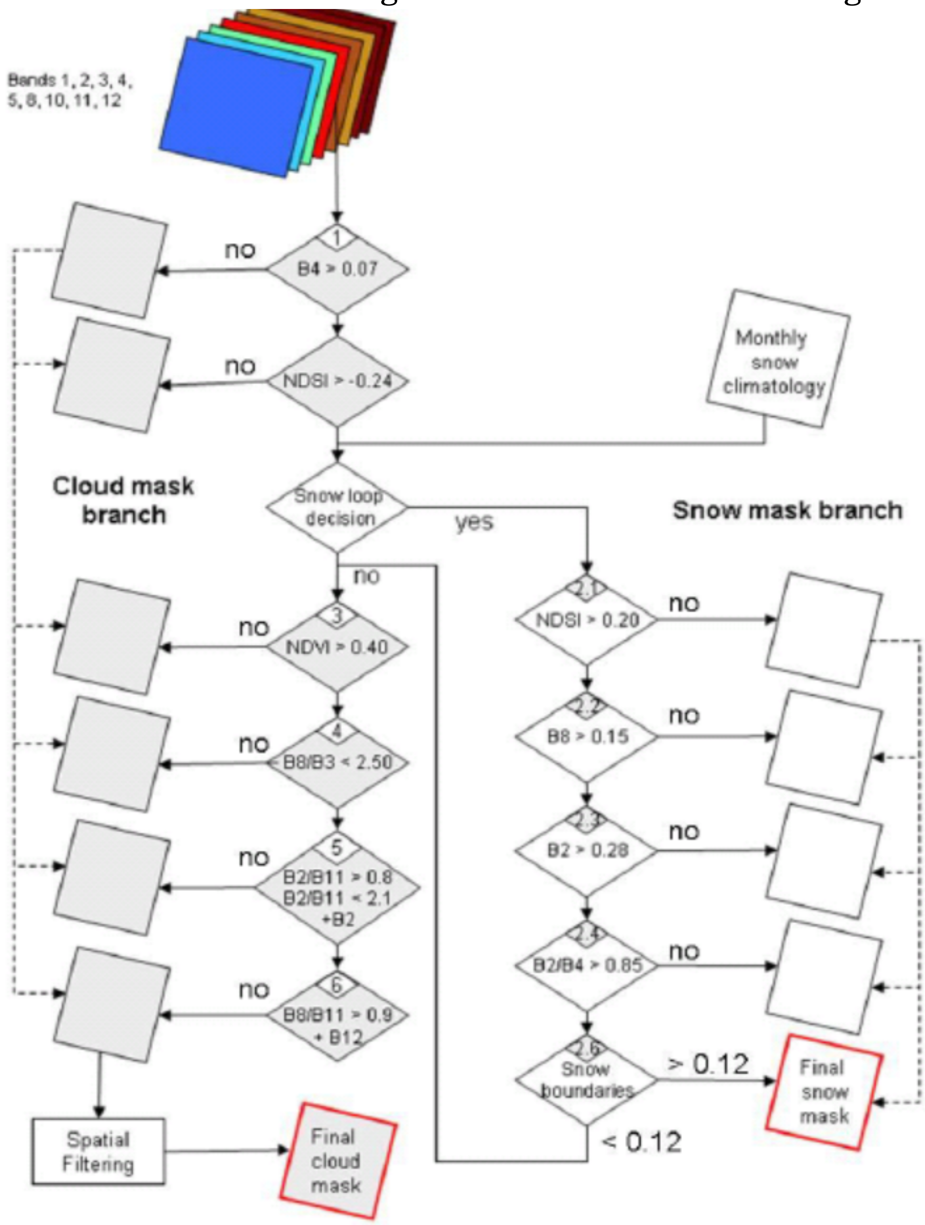

Fig. 2.1. Cloud/snow detection algorithm shown step by step (SENTINEL-2 MSI ATBD)

Level 2-A processing of SENTINEL-2 data is done via Sen2Cor which is a module developed by European Space Agency (ESA) that is applying the algorithm mentioned above (Mueller-Wilm, 2017). Due to version changes and temporary implementation issues, Sen2Cor is applied both from command line or through implementation in SNAP.

2.2. Other algorithms reviewed

2.2.1.1. MODIS SnowMap

According to MODIS snow algorithm ATBD, SnowMap uses NDSI thresholding criteria tests similar to SC and using characteristics of snow in NIR and SWIR. In addition to thresholding tests, brightness temperature difference is also used in order to improve discrimination of snow/cloud and thus, an improved cloud mask.

Therefore, using SnowMap with using solely SENTINEL-2 data is not possible. Auxiliary data/masks are required since bands that are required to provide brightness temperature difference are not available in SENTINEL-2 data.

2.2.1.2. SCAmod

As Metsämäki et al., (2012) states, “The method (*SCAmod*) is based on a semi-empirical model, where three reflectance contributors (wet snow, snow-free ground and forest canopy), interconnected by an effective canopy transmissivity and SCA, constitute the observed reflectance from the target area. Given the reflectance observation, SCA is solved from the model.”

Since the effective forest transmissivity is a model parameter in SCAmod algorithm, this algorithm can not be used as only depending on SENTINEL-2 data.

2.2.1.3. LAND SAF Snow Cover Algorithm

The LSA SAF snow cover algorithm uses SEVIRI channels (0.6, 0.8, 1.6, 3.9, 10.8 and 12.0 µm) as well as sun and satellite zenith and azimuth angels, land cover type and land surface temperature classification produced by LSA SAF (*LAND-SAF Snow Cover ATBD).*

As Sentinel-2 MSI does not have all of these channels and the requirement of land surface temperature, this algorithm can not be performed as only depending on Sentinel 2 data.

2.2. METHODS FOR THE TEST CASE STUDY

2.2.1. Area of Interest

For the test case study, area of interest is chosen as tile T33TVG, located in Italy and shown in the figure below. Due to variation of snow/no snow on the land and sufficient illumination, image from the day 2017.01.31 is used. Process of determining this particular data is done by visual inspection of the quick views on the Copernicus Data Hub and/or by downloading and visually inspecting the downloaded data if the preview is not conclusive. All of the steps of the processing chain which will be explained in the next section is done in Sentinel Application Platform (SNAP) except calculating statistics such as possibility of detection and false alarm rate.

Fig 2.2. Showing the location of the test case study tile

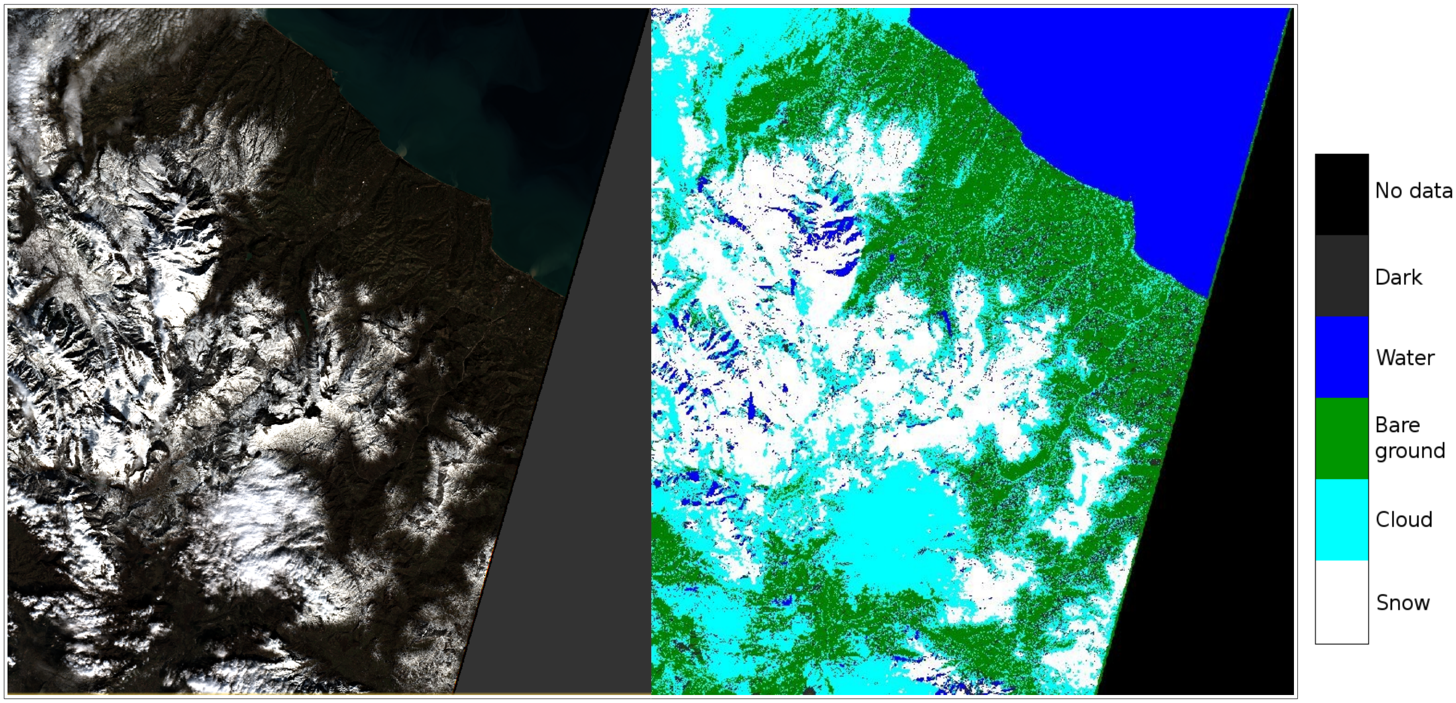

Fig. 2.3. On the left, RGB true color composite image of the SENTINEL-2 data tile. On the right, image of the tile where pixels are classified by using sen2cor process and colored as same as H10.

2.2.2. Methodology

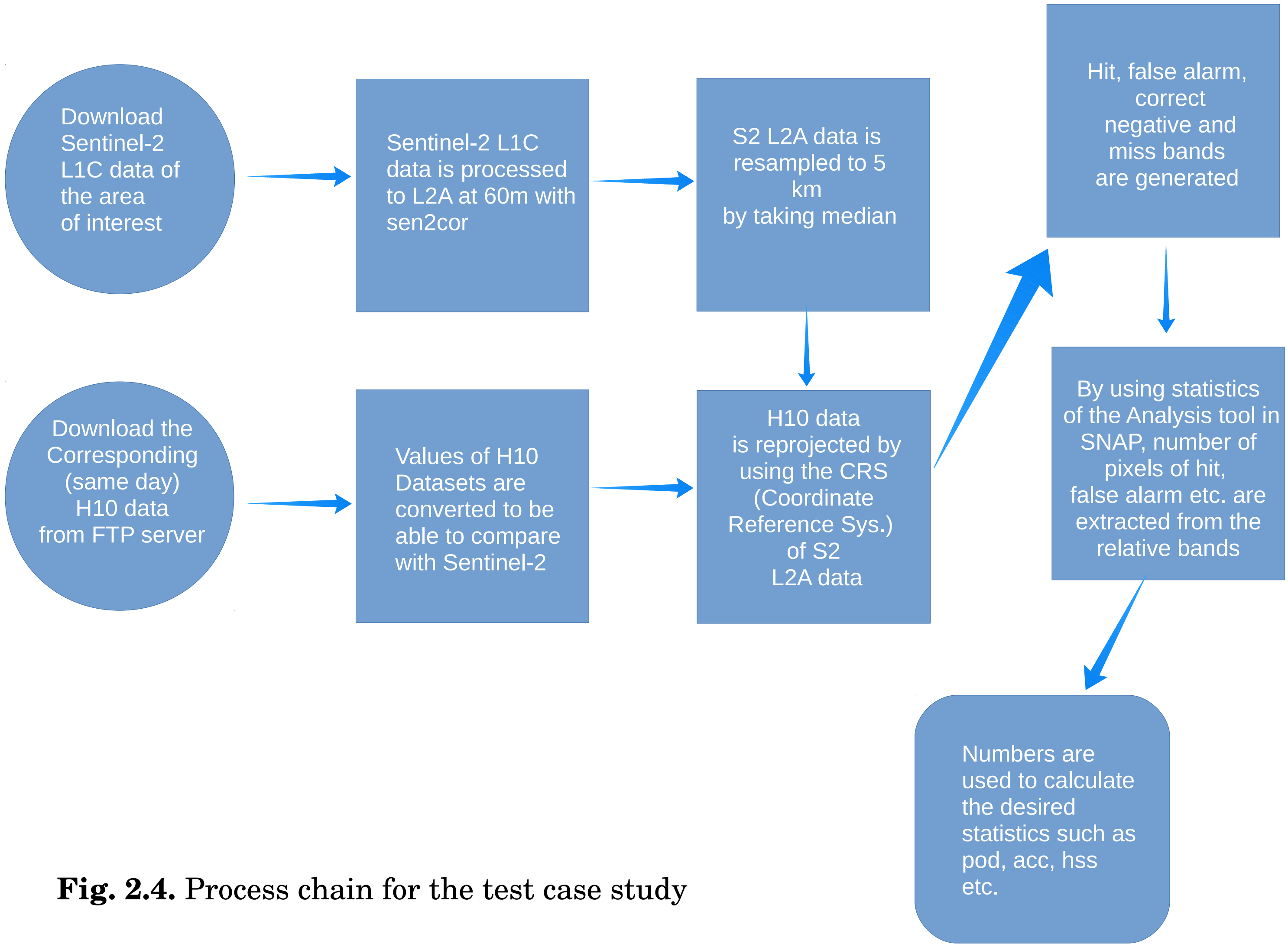

Fig. 2.4. Process chain for the test case study

Data is downloaded from Copernicus Data Hub and processed via sen2cor to L2A. After processing the data, 5 km resampling is applied by taking median to set the S2 data to the H10 resolution. Corresponding H10 data file is downloaded and LAT/LON bands are adjusted for the process. Next, H10 data is reprojected to the Coordinate Reference System of S2 L2A data as reprojection operation also applies collocation. So the H10 data is reduced to the S2 data file coverage with the same projection. After that, by assuming Sentinel-2 L2A data as “truth”, hit, miss, false alarm and correct negative bands are created by band math operations. Then in the final step, pixel counts of these bands are extracted by using analysis tools in SNAP and contingency table is created.

2.3. METHODS FOR VALIDATION STUDY OF H10 WITH SENTINEL-2

2.3.1. Study area

Study area is chosen as shown below, scattered in 33N, 34N, 35N, 36N UTM zones. Initially, all SENTINEL-2 data that involves Sodankylä area is selected. As SENTINEL-2 data for the time frame is in the form of union of several military grid tiles through more than one UTM zones, it is decided to use all parts of these data for validation. All of the data used can be approximately bordered as in the picture below.

Fig. 2.5. Area of Interest boundaries

2.3.2. Time frame

2015-2016 winter that is 01.10.2015 - 01.05.2016 is chosen as validation period due to the fact that it is the first and only winter data available for SENTINEL-2.

2.3.3 Data

Since it is completely dark for some part of the winter, SENTINEL-2 data is not available as frequently in northern regions. Due to low illumination and clouds, some portion of the available data was not usable. In order to pick the data that is sufficiently illuminated and clear from clouds, all the gathered data is processed and visually inspected by using SNAP.

2.3.4. Methodology

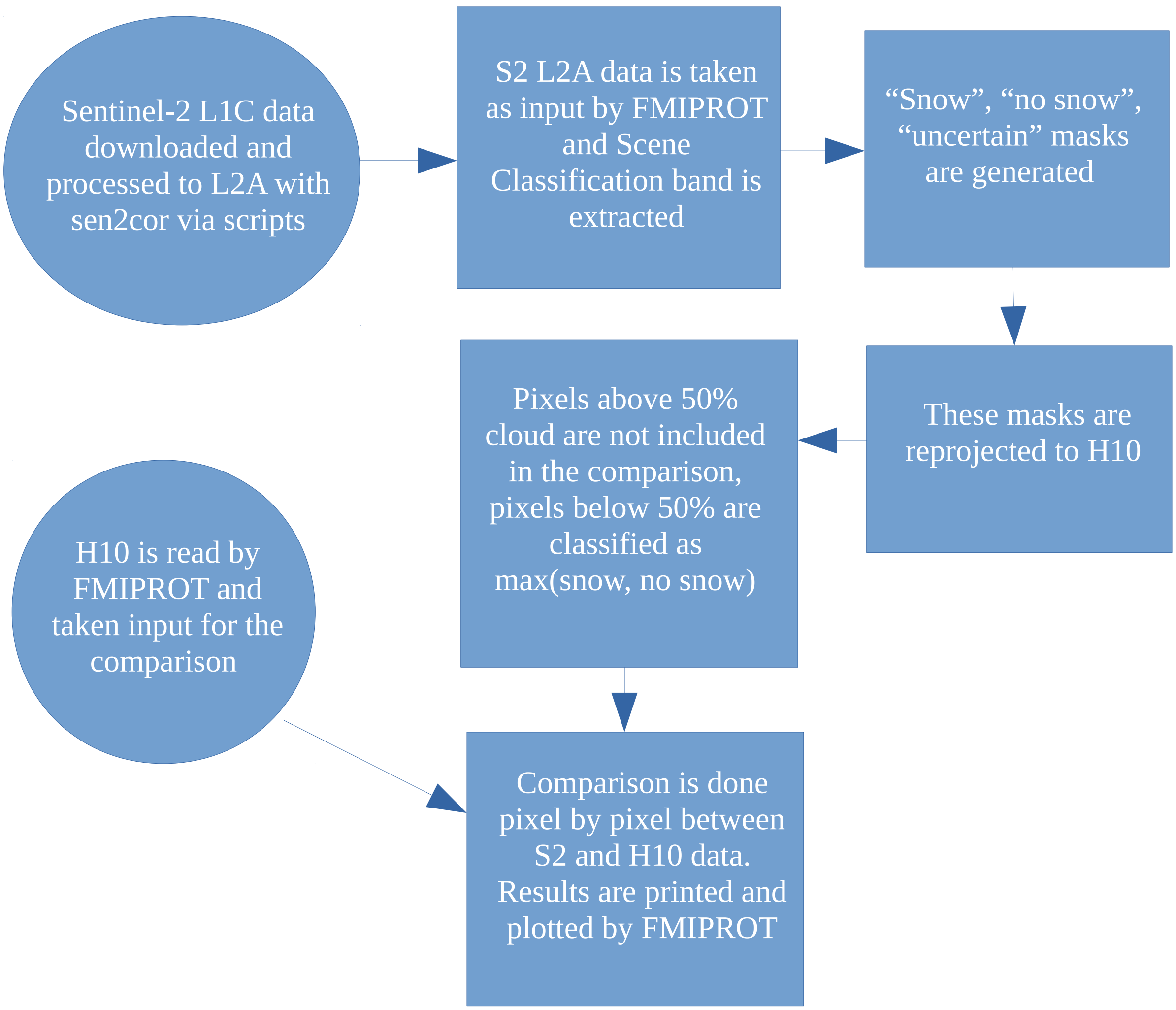

Fig. 2.6. Process chain for the automated validation of H10 with SENTINEL-2 L2A data.

”Validation Tool” is designed and implemented into FMIPROT which automatically compares the data pixel by pixel and prints and plots the results. Data input is handled by setting reference folder paths for the used data. As it requires processed L2A data from SENTINEL-2, first, data is downloaded from Copernicus Data Hub as a batch for the selected area of interest and processed to L2A with sen2cor via scripts. Downloading is allowed only 2 files at a time so it is done in a way that, whenever the download of a file finishes sen2cor processing starts and this goes as a chain until all data is downloaded and processed. Next, corresponding H10 files are downloaded manually due to the fact that there is not a service to allow fetching archived H10 data automatically. By setting the reference folder paths for the data that is downloaded and processed, FMIPROT is ready to do the comparison.

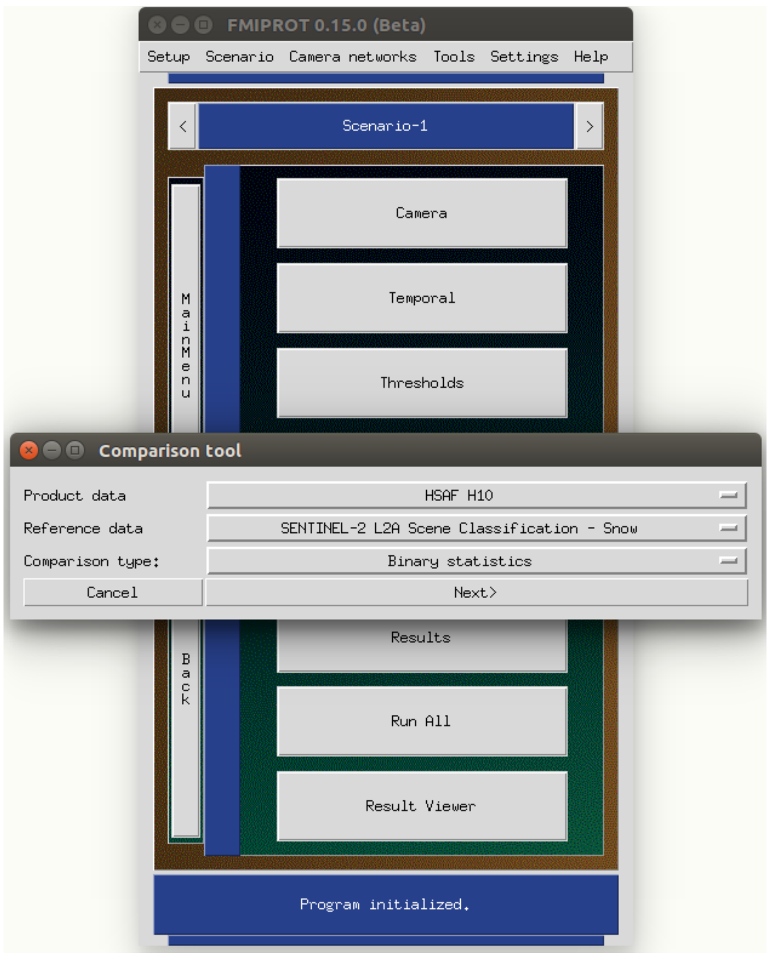

Fig. 2.7. Comparison tool window

After S2 L2A data is taken as input by FMIPROT, Scene Classification band which has the classified pixels is extracted and “snow”, “no snow” and “uncertain” masks are created. Uncertain mask includes high possibility cloud, medium possibility cloud, low possibility cloud, thin cirrus, dark area, no data, saturated pixels and cloud shadows. Since it is not known what is in the pixel in all of these classes, they are grouped as “uncertain”.

Next, these bands are reprojected to geostationary satellite view projection of H10. Pixel values are determined by resampling using Gaussian weighting (See, Pyresample Documentation). Parameters for the resampling can be adjusted by the user in the tool menu.

After resampling, pixels that has above and equal to 50% cloud coverage are not included in the comparison while pixels with below 50% cloud coverage are classified as maximum of snow percentage and no snow percentage.

All of these values can be adjusted by the user as the comparison tool asks for the “true”, ”false”, ”uncertain” and “uncertain threshold” values. As can be seen below;

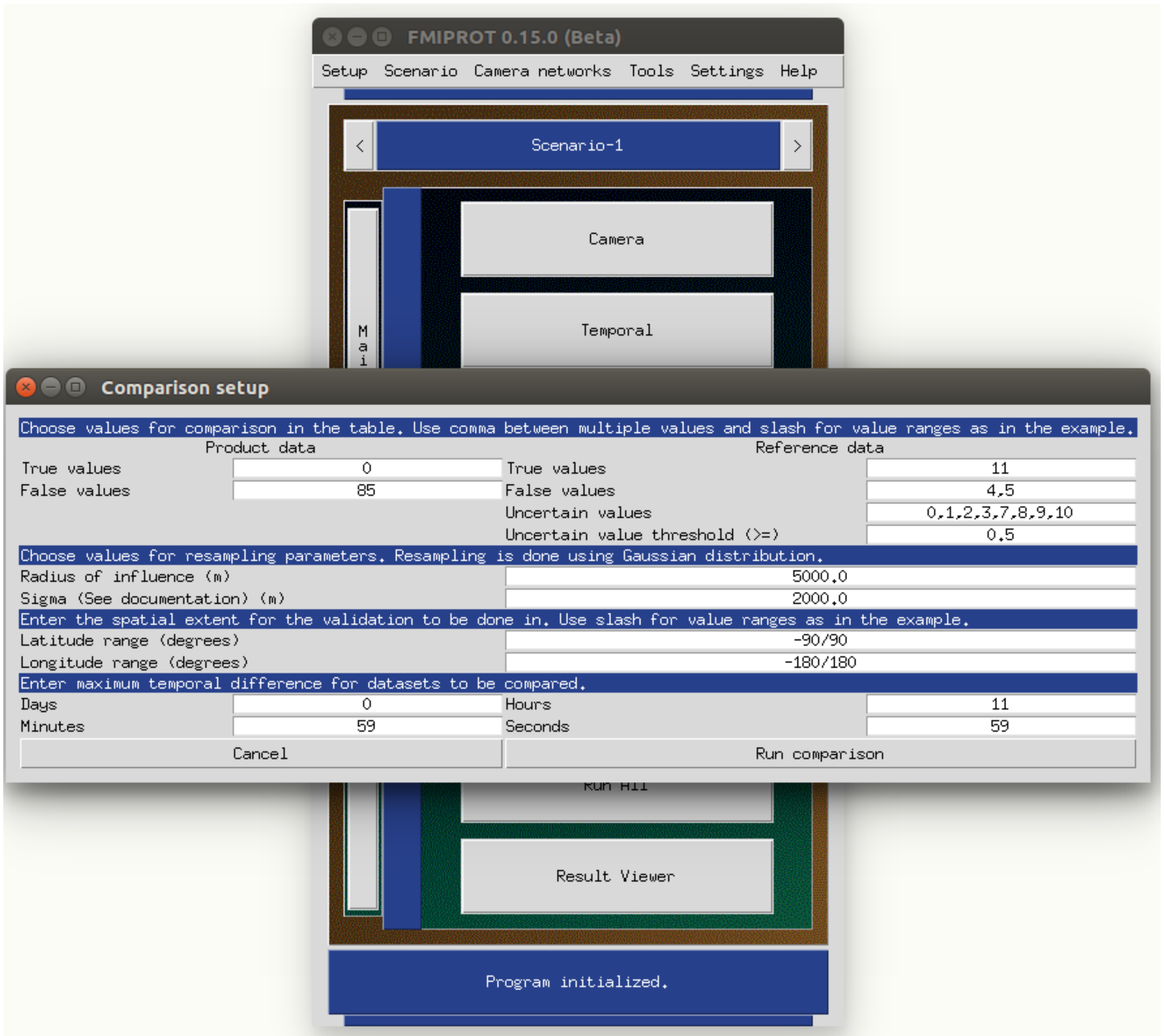

Fig. 2.8. Window that user can adjust the values for various parameters.

In the final step, comparison is done pixel by pixel and results are printed and plotted both by day and as total.

2.4. METHODS FOR VALIDATION STUDY OF H12 WITH SENTINEL-2

2.4.1. Study area

Study area is chosen as shown below, scattered in 33N, 34N, 35N, 36N UTM zones. Initially, all SENTINEL-2 data that involves Sodankylä area is selected. As SENTINEL-2 data for the time frame is in the form of union of several military grid tiles through more than one UTM zones, it is decided to use all parts of these data for validation. All of the data used can be approximately bordered as in the picture below.

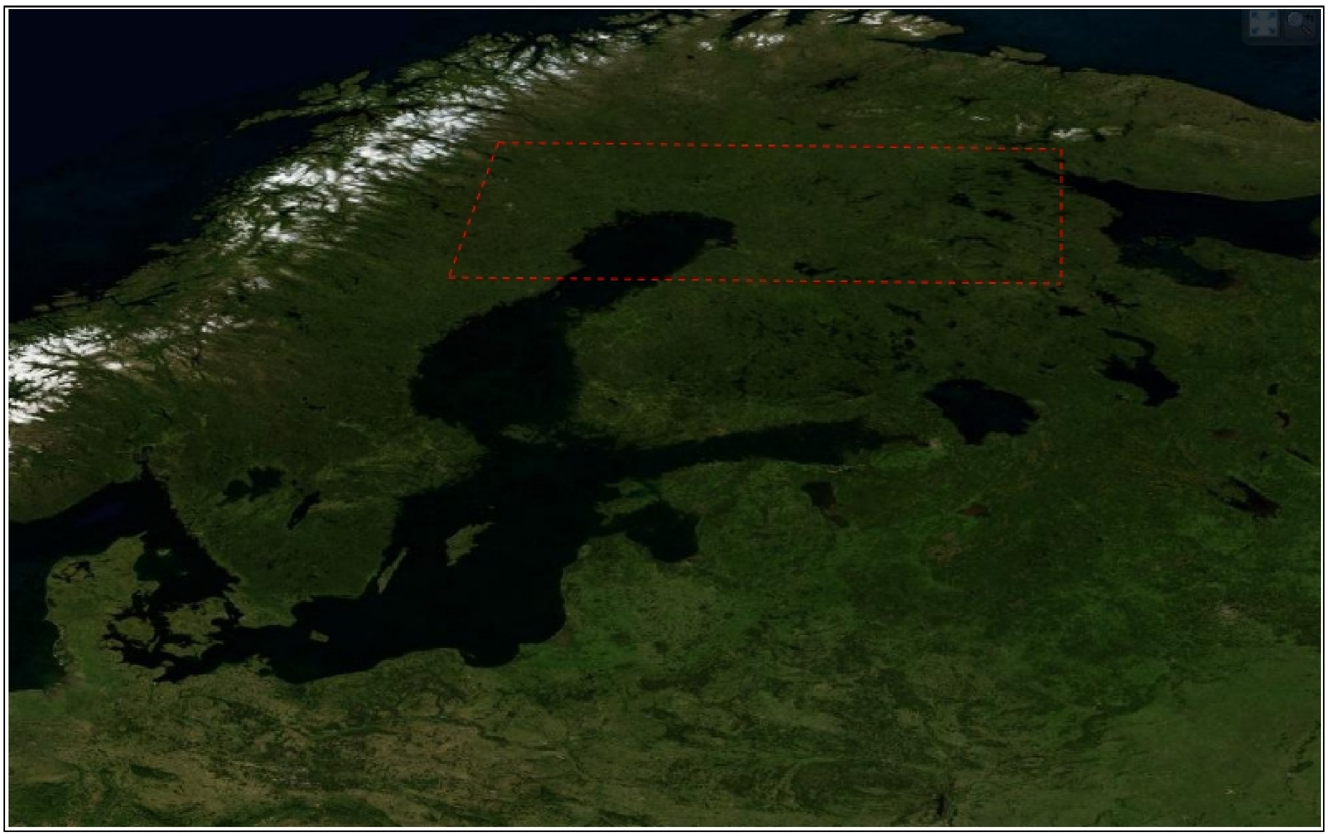

Fig. 2.9. Area of Interest boundaries

2.4.2. Time frame

2015-2016 winter (01.10.2015- 01.05.2016) is chosen as validation period due to the fact that it is the first and only winter data available for SENTINEL-2.

2.4.3 Data

Since it is completely dark for some part of the winter, SENTINEL-2 data is not available as frequently in northern regions. Due to low illumination and clouds, some portion of the available data was not usable. In order to pick the data that is sufficiently illuminated and clear from clouds, all the gathered data is processed and visually inspected by using SNAP.

2.4.4. Methodology

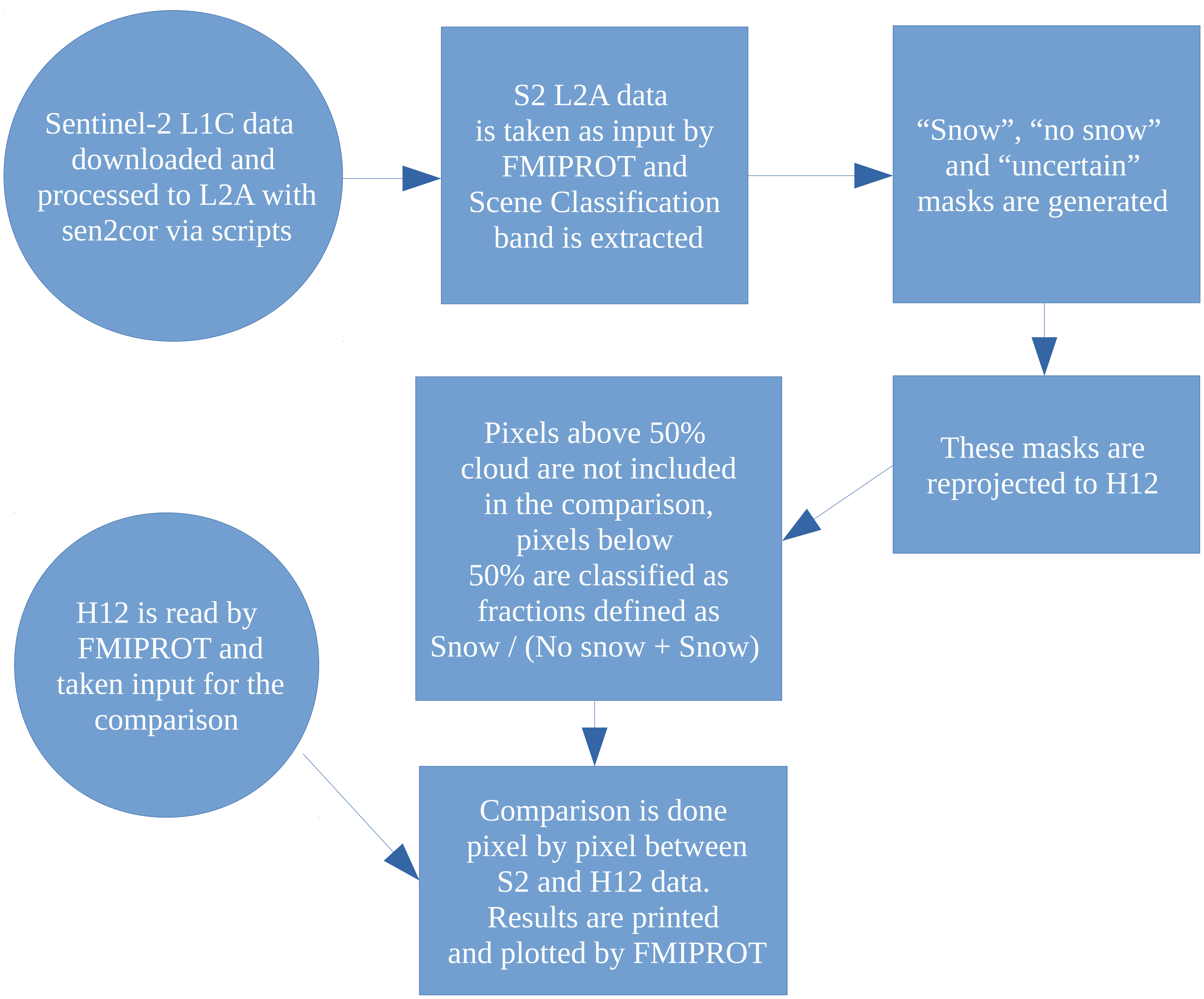

Fig. 2.10. Processing chain for the automated validation of H12 with SENTINEL-2 L2A data.

”Validation Tool” is designed and implemented into FMIPROT which automatically compares the data pixel by pixel and prints and plots the results. Data input is handled by setting reference folder paths for the used data. As it requires processed L2A data from SENTINEL-2, first, data is downloaded from Copernicus Data Hub as a batch for the selected area of interest and processed to L2A with sen2cor via scripts. Downloading is allowed only 2 files at a time so it is done in a way that, whenever the download of a file finishes sen2cor processing starts and this goes as a chain until all data is downloaded and processed. Next, corresponding H12 files are downloaded manually due to the fact that there is not a service to allow fetching H12 data automatically. By setting the reference folder paths for the data that is downloaded and processed, FMIPROT is ready to do the comparison.

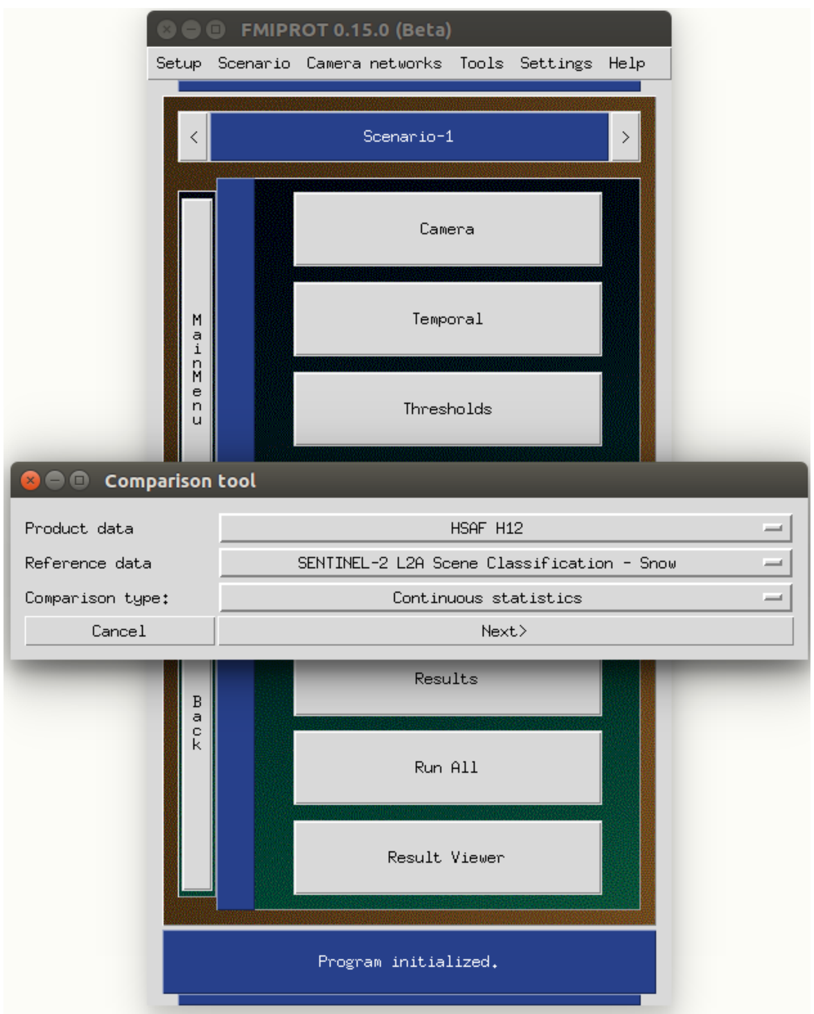

Fig. 2.11. Comparison tool window

After S2 L2A data is taken as input by FMIPROT, Scene Classification band which has the classified pixels is extracted and “snow”, “no snow” and “uncertain” masks are created. Uncertain mask includes high possibility cloud, medium possibility cloud, low possibility cloud, thin cirrus, dark area, no data, saturated pixels and cloud shadows. Since it is not known what is in the pixel in all of these classes, they are grouped as “uncertain”.

Next, these bands are reprojected to the projection of H12. Pixel values are determined by resampling using Gaussian weighting function (See, Pyresample Doc.).

Parameters for the resampling can be adjusted by the user in the tool menu.

After resampling, pixels that has above and equal to 50% cloud coverage are not included in the comparison while pixels with below 50% cloud coverage are classified as fractional snow cover defined as Snow / (No Snow + Snow).

All of these values can be adjusted by the user as the comparison tool asks for the "true", "false", "uncertain" and "uncertain threshold" values. As can be seen below;

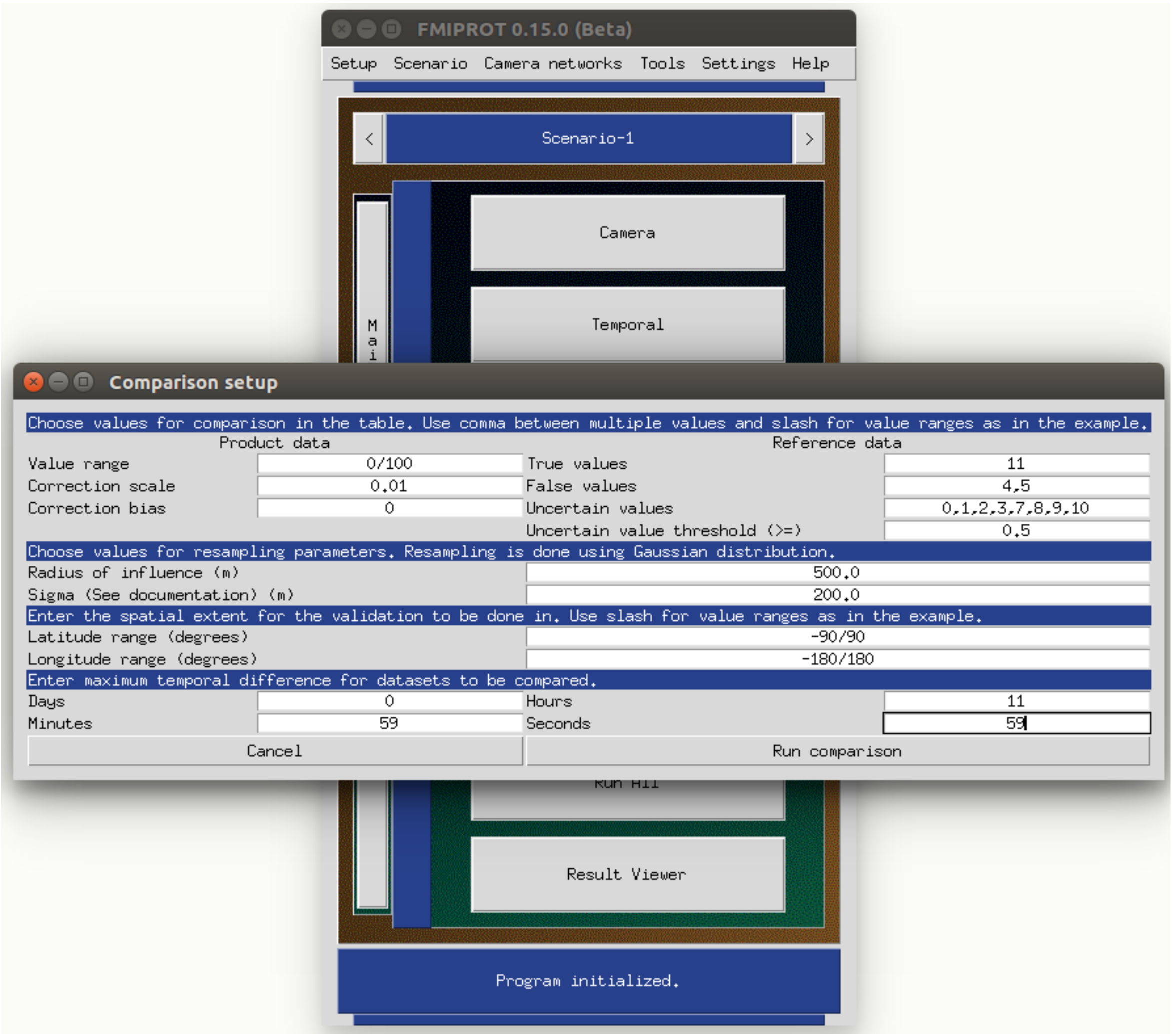

Fig. 2.12. Window that user can adjust the values for various parameters.

In the final step, comparison is done pixel by pixel and results are printed and plotted both by day and as total.

3. RESULTS

3.1. Results for the Test Case Study

Side by side visual comparison of H10 and SENTINEL-2 Level-2A shown in figure 3.1. below.

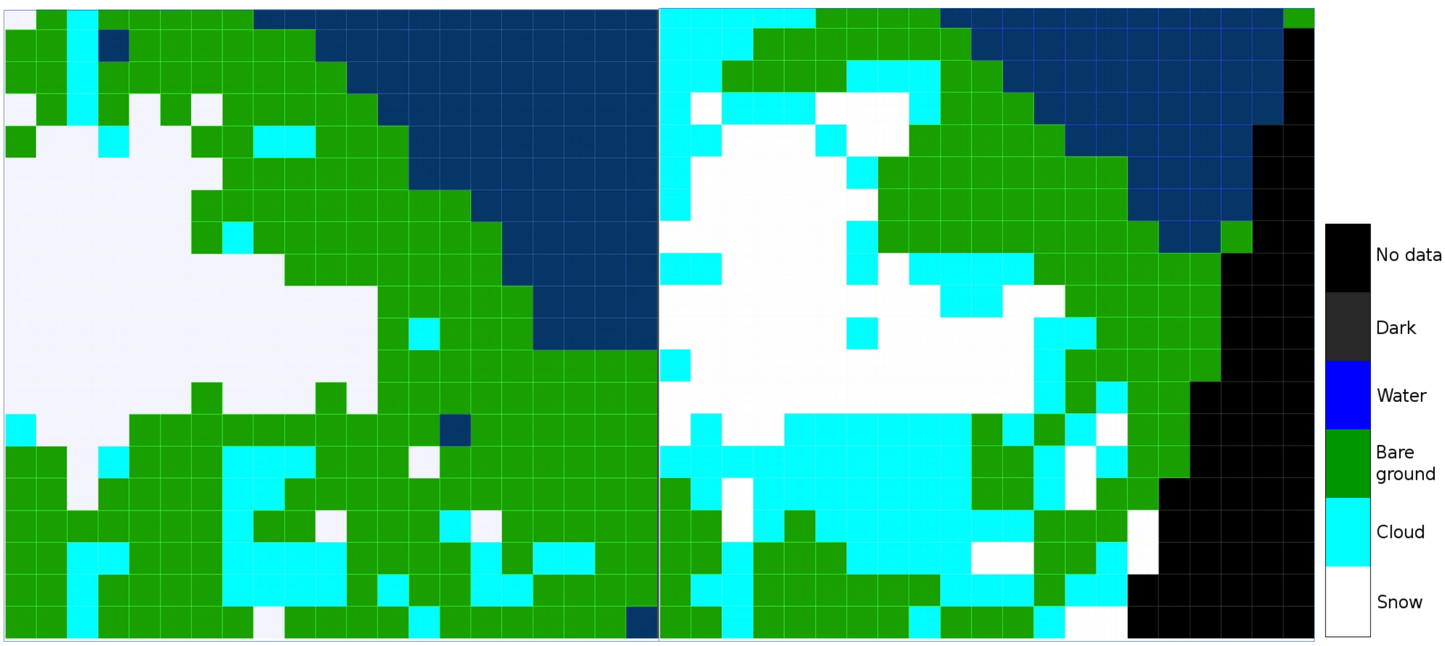

Fig. 3.1. H10 on the left, SENTINEL-2 resampled to 5km on the right

Resulting Statistics

Hit	73
False alarm	0
Miss	14
Correct Negative	101
Number of observations	188
Possibility of detection(POD)	**0.839**
False alarm rate(FAR)	**0**
Accuracy(ACC)	**0.925**
Heidke Skill Score(HSS)	**0.848**

Fig. 3.2. Table showing the resulting statistics

Results shown above indicates high performance with 0.925 accuracy and 0 false alarm rate according to H-SAF snow product requirements stated in the PVR of H10. (reference to the document which has product requirements)

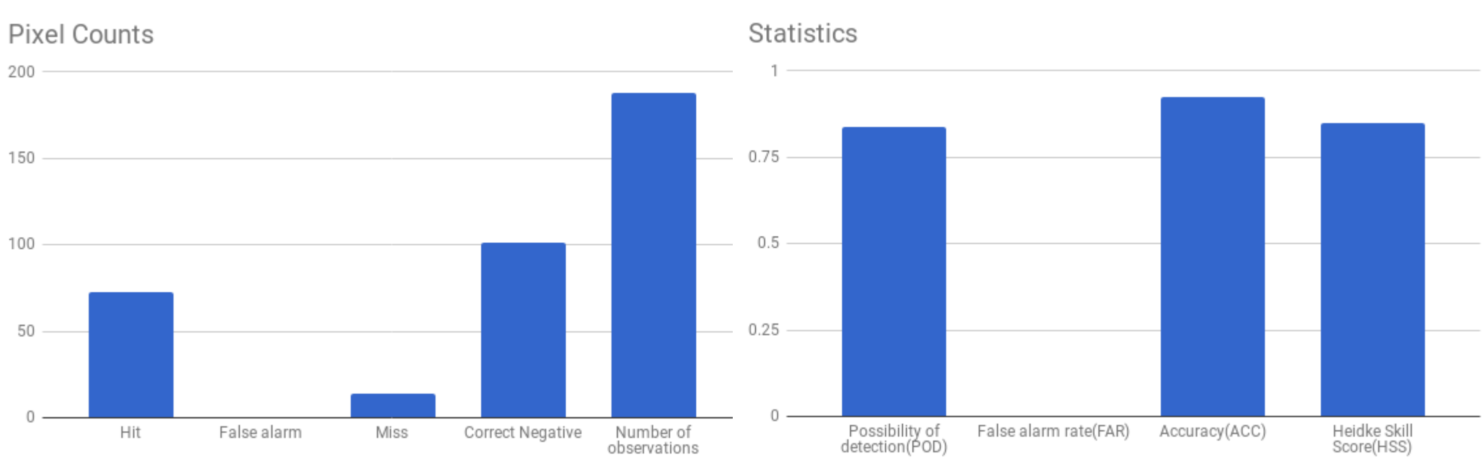

Fig. 3.3. Graphs for pixel counts and statistics of the case study

3.2. Results of the Validation Study with H10

Total of 3947 pixels are compared between SENTINEL-2 L2A data and H10 data. As it can be seen from the table below, possibility of detection of 0.990 and false alarm rate of 0.042 are in optimal ranges according to product validation reports.

Hit	3264
False alarm	32
Miss	144
Correct Negative	507
Number of observations	3947
Possibility of detection(POD)	**0.990**
False alarm rate(FAR)	**0.042**
Accuracy(ACC)	**0.955**
Heidke Skill Score(HSS)	**0.826**

Fig. 3.4. Table showing resulting statistics for the total of the analysis

Date	Hit	Miss	False Alarm	Correct Negatives	POD	FAR	ACC	Number of Observ.
2015.10.06	0	0	133	497	NaN	1	0.788	630
2016.02.15	136	0	0	0	1.00	0	1	136
2016.02.16	355	0	3	0	1.00	0.008	0.991	358
2016.03.23	581	20	0	0	0.966	0	0.966	601
2016.04.02	1587	0	4	0	1.00	0.002	0.997	1591
2016.04.09	242	3	1	10	0.987	0.004	0.984	256
2016.04.12	177	3	3	0	0.983	0.016	0.967	183
2016.04.22	186	6	0	0	0.968	0	0.968	192

Fig. 3.5. Table showing results of H10 validation study for each date in the data

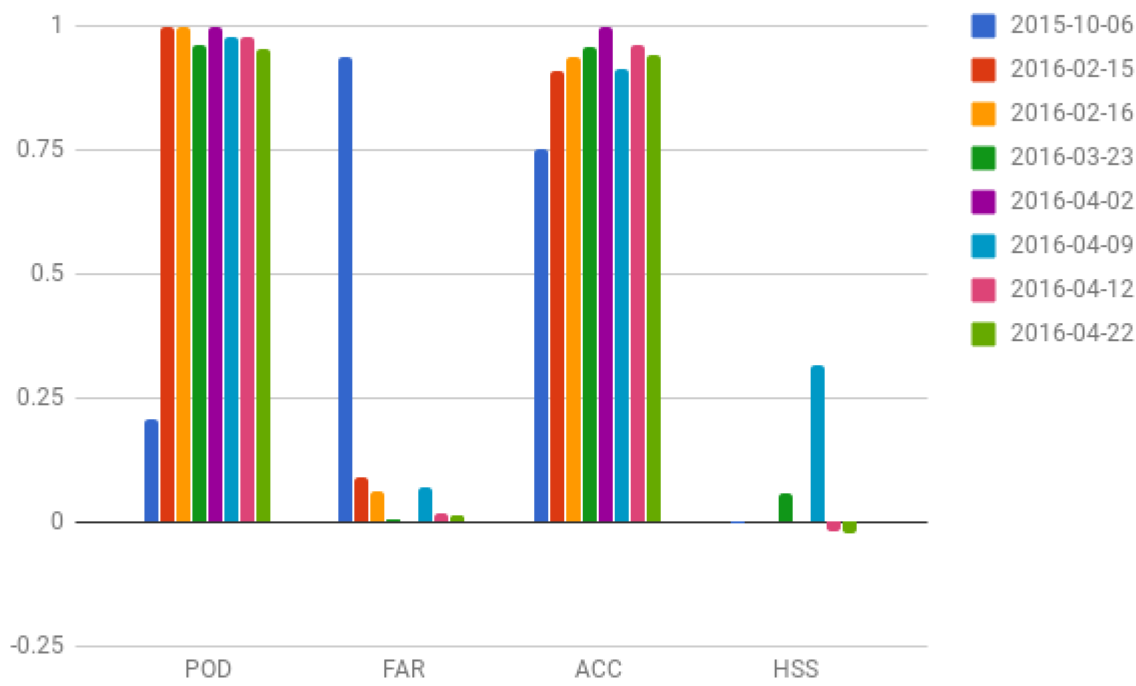

Fig. 3.6. Chart shows the results of H10 validation study for each day.

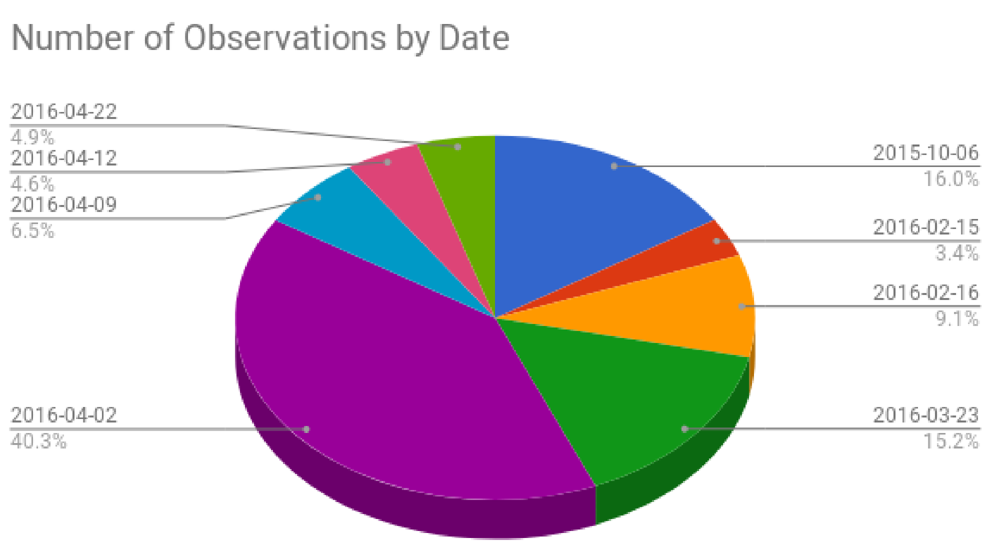

Fig. 3.7. Number of observations of H10 validation study for each date in the data

3.3. Results of the Validation Study with H12

Total of 164644 pixels are compared between SENTINEL-2 L2A data and H12 data. As it can be seen from the table below, according to PVR of H12, RMSE of 0.0831 is in optimal range.

Total pixels compared	164655
RMSE	0.0831
MAE	0.0188

Date	RMSE	MAE	Number of Observations
2015.10.06	0.044	0.003	867
2016.03.23	0.068	0.014	35619
2016.04.02	0.078	0.017	116280
2016.04.09	0.333	0.218	1711
2016.04.12	0.067	0.012	8728
2016.04.22	0.112	0.044	1439

Fig. 3.8. Table of exact values of H12 validation study for each date in the data

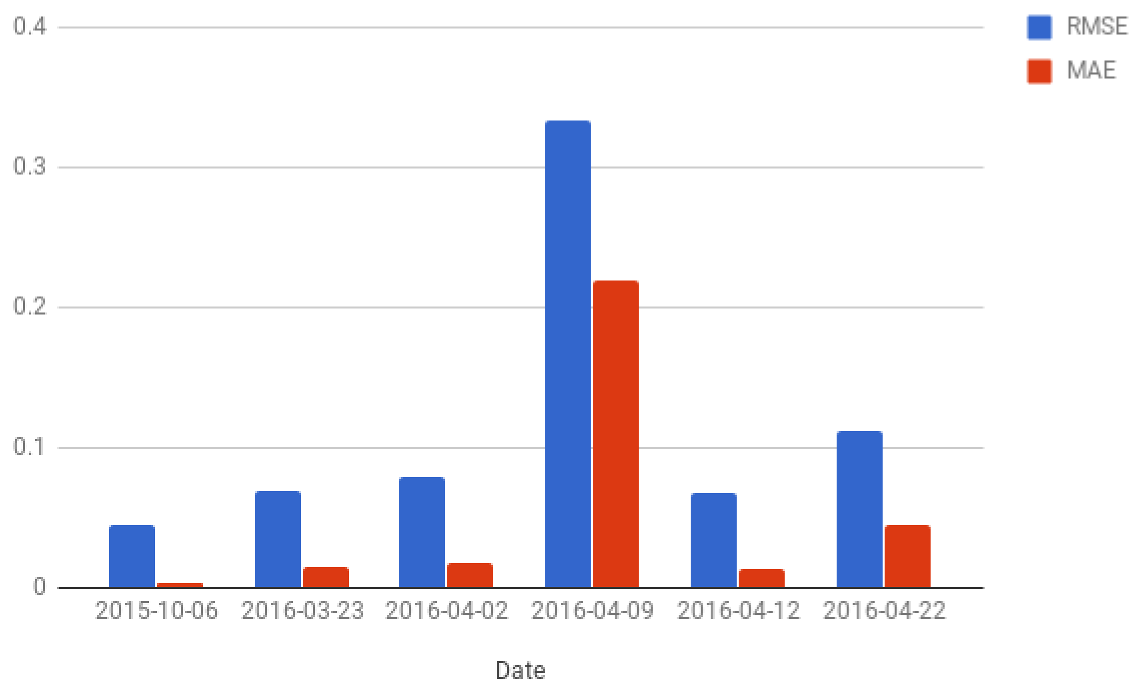

Fig. 3.9. Chart of RMSE and MAE values for each date in the data

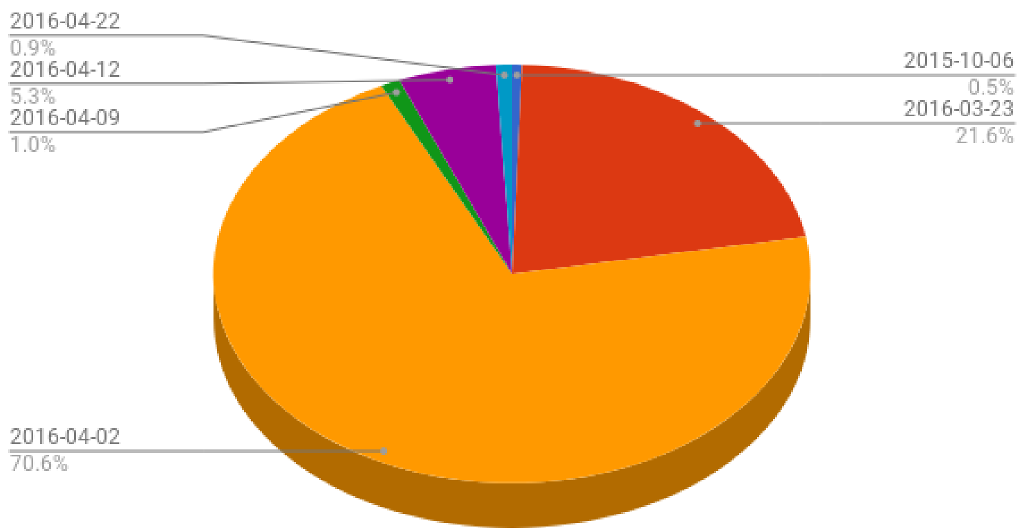

Fig. 3.10. Number of observations of H12 validation study for each date in data

4. CONCLUSION & FUTURE WORK

- Results of the study are in desired levels according to H-SAF product requirements. As it shows high accuracy with low false alarm rate as well as high possibility of detection.
- Automated validation of H10 and H12 products with SENTINEL-2 data is achieved and implemented into FMIPROT.
- As extraction of snow cover from webcam data by using FMIPROT is studied by Arslan et al., in near future it can be extended to usage of SENTINEL-2 data and webcam data for validation of various snow products.
- Automated batch validation using SNAP Desktop application is not feasible due to the stage of development of SNAP. It can be done by using Python module of SNAP for binary snow product. For continuous fractional snow cover, it is not possible due to issues such as problems in ”not a number (NaN)” value handling in resampling operation.

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