Performance assessment of the Snow Products for the Alpine area, and description of the evaluation methodology

Issue 1.0

SEN3APP

Processing Lines And Operational Services Combining Sentinel And In-Situ Data For Terrestrial Cryosphere And Boreal Forest Zone

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Document History

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22/09/2016	Initial document	Gabriele Schwaizer	ENVEO

Table of Contents

Introduction

Daily fractional snow cover over the Alpine area is mapped fully operational by means of medium resolution optical satellite data from Terra/MODIS, as Sentinel-3 data were not available in near-real time during the SEN3APP demonstration phase.

The snow products are of high interest for instance for meteorological or hydrological services, but also for water suppliers or hydropower companies. Information on the uncertainty of the snow products is important for the users for interpreting the provided snow information.

1. Document Identifier

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1. Title

Performance assessment of the Snow Products for the Alpine area, and description of the evaluation methodology

2. Authority and Contact Information

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3. Abstract

The performance assessment of the fractional snow cover products for the Alpine area compared with reference snow maps generated from Landsat data are presented. Fractional snow cover of the product and from the reference snow maps are compared over non-forested areas. In forested areas, the Alpine FSC product classifies snow only binary, using the approach of Dozier. Thus, also the reference snow maps are in forested areas converted to binary snow maps, and then used for intercomparison.

4. Keywords

#fractional snow cover, #Alps, #Alpine area #optical satellite, #MODIS

5. Key terminology

Fractional snow cover	The area of snow in percentage (0 % - 100 %) referred to the area of one pixel (100 %)
Alpine area	The Alpine area covers the region from about 49.56°N/4.66°E – 43.62°N/17.76°E
RMSE	Root Mean Square Error

6. Background, Context and Scope

The Fractional Snow Cover (FSC) products for the Alpine area from existing optical satellite data have been developed during the EU FP7 project CryoLand (No. 262925), and the operational service has been continued during the EU FP7 project SEN3APP (No. 607052). Key users were interviewed in the beginning of the project period to identify if the already existing service still fulfils their requirements or if changes are needed.

15 Landsat 8 scenes acquired at different snow stages in various parts of the Alpine area in 2013 and 2014 are used for the evaluation of the Alpine FSC products. As also the reference snow maps from high resolution satellite data have some uncertainty, which has not yet been sufficiently investigated, we generate snow maps from Landsat data by applying 3 different snow detection algorithms. The Alpine FSC products are then intercompared with all these reference snow maps, to assess the quality of the products. The intercomparison protocols and methods developed and established internationally during the ESA project SnowPEx (lead by ENVEO) are used to evaluate the Alpine snow extent products.

The QA4EO framework was selected as an example of a template for reporting the performance of the Alpine snow products and as an information package for the user to easily assess the suitability of the data for the purpose.

7. Product performance and uncertainty

The mean unbiased RMSE value derived from the intercomparisons with the total areas of the selected Landsat scenes is about 13 %, and mean Bias values are about -2 % for all the algorithm applied on the Landsat scenes for generating the reference snow maps. For non-forested areas, the resulting mean statistical values are a bit smaller, while for forested areas, the mean unbiased RMSE is about 4 % higher, and the mean Bias values are about 2 % lower.

The main validation results derived for the intercomparison of the Alpine FSC products with snow maps generated from Landsat data by applying different algorithms are summarized in Table 7.1.

Table 7.1: Results of the comparison of the Alpine FSC product against snow maps from 15 selected Landsat (LS) scenes generated by different algorithms. Beside the total area covered by each of the Landsat scenes, snow in forested and in non-forested areas are intercompared separately.

	Alpine Fractional Snow Cover					
LS Algorithm	*Dozier*		*Klein*		*Salomonson*	
Classification	*Unbiased RMSE*	*Bias*	*Unbiased RMSE*	*Bias*	*Unbiased RMSE*	*Bias*
Total (FSC)	13,28	-2,14	13,93	-2,80	12,85	-2,06
Total non-forested area (FSC)	12,99	-0,80	13,34	-1,22	12,61	-0,75
Total forested area (binary snow)	16,68	-3,85	17,76	-5,46	16,22	-3,70

8. Inputs

Input	Description	Link
ENVEO Alpine Fractional Snow Cover Products	Daily fractional snow cover maps for the Alpine area	http://neso1.cryoland.enveo.at/cryoclient/
Snow maps from Landsat data	Snow maps generated by applying different snow classification algorithms on selected Landsat scenes, spatially distributed over the Alpine area	http://glovis.usgs.gov
Corine Land Cover 2012 (CLC 2012)	Surface classification by the European Environment Agency (EEA), V16, used for forest and water body masks	http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012/view
EU DEM	Digital Elevation Model provided by the European Environment Agency, used for topographic correction	http://www.eea.europa.eu/data-and-maps/data/eu-dem
Scripts for snow map comparison and statistical analysis	Software developed at ENVEO for a pixel-by-pixel intercomparison of the Alpine FSC product and the snow maps from Landsat data, and for the generation of statistical analyses	

9. Standards and Traceability

Standard/ Documentation	Description	Link
Dozier	Snow detection algorithm applied on Landsat scenes, and used for binary snow classification in Alpine FSC product in forested areas	Dozier & Painter, 2004
Klein	Snow detection algorithm applied on Landsat scenes	Klein, Hall, & Riggs, 1998
Salomonson	Snow detection algorithm applied on Landsat scenes	Salomonson & Appel, 2004, 2006
Topographic correction	Correction of illumination effects and atmospheric propagation due to topography	Ekstrand (1996)

10. Methodology, Processing

1) Select and download snow covered Landsat scenes at nearly clear sky conditions to be used for generating reference snow maps, and associated auxiliary data (DEM, surface classification, water mask, etc.)
2) Pre-process all needed reference data sets, including radiometric calibration of Landsat data, reprojection and resampling of auxiliary data as needed, topographic correction of Landsat top of atmosphere reflectance, generation of reference snow maps by applying different snow detection methods
3) Resample, reproject and aggregate high resolution reference snow maps to fractional (in non-forested areas) or binary (in forested areas) snow maps at the grid size of the Alpine FSC product
4) Run pixel-by-pixel intercomparison between reference snow map and the Alpine FSC product and calculate statistics

11. Evaluation of Performance

A validation data base of 8 Landsat 5 TM scenes acquired between 2003 and 2011 was used for the product evaluation during the EU FP7 project CryoLand. This data base has been extended with additional 15 Landsat 8 OLI scenes acquired in 2013 and 2014.

The following statistical measures are used to describe the product performance:

- the Bias between two products, the number of used pixels, specified by N_{ui}, are used as calculation basis:

$$BIAS = \frac{1}{N_{ui}} \sum_{j=0}^{y} \sum_{i=0}^{x} (FSC_{EXT}(i,j) - FSC_{REF}(i,j))$$

- the root-mean-square error, RMSE, between two products, using all pixels suitable for inter-comparison (N_{ui}):

$$RMSE = \sqrt{\frac{1}{N_{ui}} \sum_{j=0}^{y} \sum_{i=0}^{x} (FSC_{EXT}(i,j) - FSC_{REF}(i,j))^2}$$

- the unbiased RMSE using the same input dataset (N_{ui}) as for the RMSE:

$$unbiasedRMSE = \sqrt{\frac{1}{N_{ui}} \sum_{j=0}^{y} \sum_{i=0}^{x} \left(\left(FSC_{EXT}(i,j) - \overline{FSC_{EXT}}\right) - \left(FSC_{REF}(i,j) - \overline{FSC_{REF}}\right)\right)^2}$$

- the correlation coefficient between two products (EXT = SCF Extent in Product 1, REF = Product 2 or Reference snow map, e.g. from Landsat) using only the valid pixels for the inter-comparison (N_{ui}):

$$CorrCoef = \frac{\sum_{j=0}^{y} \sum_{i=0}^{x} \left(FSC_{EXT}(i,j) - \overline{FSC_{EXT}}\right)\left(FSC_{REF}(i,j) - \overline{FSC_{REF}}\right)}{\sqrt{\sum_{j=0}^{y} \sum_{i=0}^{x} \left(FSC_{EXT}(i,j) - \overline{FSC_{EXT}}\right)^2 \sum_{j=0}^{y} \sum_{i=0}^{x} \left(FSC_{REF}(i,j) - \overline{FSC_{REF}}\right)^2}}$$

$\overline{FSC}$ is the average fractional snow cover value.

During the EU FP7 project CryoLand, the evaluation of the Alpine FSC was performed with snow maps from Landsat data using only the approach of Dozier. These intercomparisons of the Alpine FSC product with snow maps from 8 selected Landsat 5 TM scenes resulted in a mean unbiased RMSE value of about 22.5 % and a mean negative Bias of about -4 %. The derived mean correlation coefficient was 0.80. The results of these intercomparisons are summarized in Error! Reference source not found..

Table 11.1: Results of the Alpine FSC product evaluation with snow maps from 8 Landsat 5 TM scenes derived by the approach of Dozier and Painter (2004) performed during the EU FP7 project CryoLand.

Measure	Number of used pixel	RMSE	unbiased RMSE	Bias	Correlation Coefficient
MEAN	58133	23,39	22,55	-4,10	0,80
Minimum	28005	18,51	18,26	-12,87	0,66
Maximum	98709	29,99	27,09	2,29	0,85
25 %ile	37116	20,81	20,70	-7,58	0,79
75 %ile	72431	25,44	24,77	-0,29	0,84

15 newly selected Landsat 8 OLI scenes acquired in 2013 and 2014 were used to update the evaluation of the Alpine Fractional Snow Cover product for the service operation during SEN3APP.

For the generation of the reference snow maps, the algorithms of Dozier, Klein and Salomonson are applied on the selected 15 Landsat scenes. In open land, all pixels of the Alpine FSC product are compared with all snow maps from the Landsat scenes. For forested areas, the Alpine FSC product classifies snow in forest only binary. On snow maps in forested areas from Landsat scenes, binary snow maps are generated by applying three different thresholds on the aggregated FSC maps: FSC ≥ 0 %, FSC ≥ 3 % and FSC ≥ 15 %.

Further, different discrete intervals of fractional snow cover are intercompared. The aim of this intercomparison is to roughly assess the performance of the Alpine FSC product at different snow cover conditions, i.e. with more and less snow. As the performances of the snow detection algorithms applied on the Landsat scenes are also uncertain due to lack of real validation data, these intercomparison results should be considered more as a qualitative information.

The detailed mean statistical results retrieved from all the snow map intercomparisons for the total areas, as well as for non-forested and forested areas, respectively, are summarized in Table 11.2.

The statistical results derived for the evaluation of the Alpine FSC product within SEN3APP with snow maps from Landsat 8 OLI data used as reference data show a much higher agreement as the results derived within CryoLand using Landsat 5 TM data for generating the reference snow maps. For the former evaluation activities within CryoLand only one algorithm has been applied on the Landsat scenes to generate the reference snow maps.

Table 11.2: Detailed statistical results of the intercomparison of the Alpine FSC product with the selected Landsat scenes for particular snow and surface classes. Results are shown separately for each snow mapping algorithm applied on all the Landsat scenes. For all intercomparisons, all valid pixels, i.e. snow covered and snow free pixels are used.

	Alpine Fractional Snow Cover					
LS Algorithm	*Dozier*		*Klein*		*Salomonson*	
Classification	*Unbiased RMSE*	*Bias*	*Unbiased RMSE*	*Bias*	*Unbiased RMSE*	*Bias*
Total (FSC)	13,28	-2,14	13,93	-2,80	12,85	-2,06
Total non-forested area (FSC)	12,99	-0,80	13,34	-1,22	12,61	-0,75
0 % ≤ FSC ≤ 25 %	6,39	0,36	6,15	0,18	5,97	0,12
26 % ≤ FSC ≤ 50 %	32,19	-5,36	31,66	-9,34	31,14	-7,74
51 % ≤ FSC ≤ 75 %	33,77	-10,38	34,84	-14,05	33,14	-10,75
76 % ≤ FSC ≤ 100 %	20,31	-10,69	21,37	-11,47	19,63	-9,64
Total forested area (binary snow)						
LS FSC ≥ 0 %	16,68	-3,85	17,76	-5,46	16,22	-3,70
LS FSC ≥ 3 %	31,81	1,11	33,36	-2,25	33,55	-1,88
LS FSC ≥ 15 %	32,33	7,51	32,58	4,41	32,85	6,41

For the evaluation activities within SEN3APP the protocols and methods defined in the ESA project SnowPEx (PI: ENVEO) in close collaboration with the international snow community were used. Therefore, the reference snow maps from Landsat data were generated by applying three different algorithms. The statistical results derived within SEN3APP are very similar independently of the algorithm, and thus is assessed to be more reliable. Anyway, the reference snow maps are only snapshots at particular snow conditions. In order to assess also the reliability of the reference snow maps in future, an independent and spatially distributed reference data set of ground truth data, measured concurrently with the acquisition of usable Landsat scenes, would be needed.

12. References

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Klein, A. G., Hall, D. K., & Riggs, G. A. (1998). Improving snow cover mapping in forests through the use of a canopy reflectance model. Hydrological Processes, 12, 1723–1744.

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Document History

Date	Update	Contributor	Organization
22/09/2016	Initial document	Gabriele Schwaizer	ENVEO

Table of Contents

Introduction

For the Alpine area, melting snow areas are observed regularly by means of C-band radar data of Sentinel-1. This demonstration service has been newly developed during the SEN3APP project.

The wet snow products are of high interest for instance for meteorological or hydrological services, but also for water suppliers or hydropower companies. Information on the uncertainty of each of the snow products is important for the users for interpreting the provided snow information.

1. Document Identifier

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2. Title

Performance assessment of the Wet Snow Cover Products for the Alpine area, and description of the evaluation methodology

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4. Abstract

The uncertainty information related to the wet snow products for Alpine area are presented. The performance of the wet snow products is assessed by comparison with snow maps from Landsat data acquired during the melting season.

5. Keywords

#melting snow, #wet snow, #Sentinel-1, #C-SAR, #Alps, #Alpine area

6. Key terminology

Wet snow cover	Melting snow
Alpine area	The Alpine area covers the region from about 49.56°N/4.66°E – 43.62°N/17.76°E
RMSE	Root Mean Square Error
NDSI	Normalized Difference Snow Index

7. Background, Context and Scope

The melting snow product for the Alpine area has been newly developed within the SEN3APP project based on Sentinel-1 data. For this new product, preliminary product specifications were sent to key users at the very beginning of the project period, and they were asked if any changes are needed in the product specifications within the limitations (e.g. spatial or temporal resolution) caused by the raw satellite data.

For evaluating the wet snow cover product, the protocols and methods defined in the ESA project SnowPEx (PI: ENVEO), developed in close collaboration with the international snow community, are used. The wet snow cover service started during the melting season 2015 as demonstration service within SEN3APP. Thus, only preliminary evaluation results are so far available.

Wet snow maps from Sentinel-1 data are generated by applying a threshold on the backscatter ratio, testing the VV-polarized and the VH-polarized backscatter ratios, as well as a combined single channel combining the VV- and VH-polarized ratios (Nagler, Rott, Ripper, Bippus, & Hetzenecker, 2016). The retrieved wet snow cover maps were compared with NDSI based snow maps from Landsat data, generated by applying the threshold 0.40. The generated binary snow maps are aggregated to fractional snow cover maps with the pixel size of the wet snow cover product, and reduced to a binary snow information by using only aggregated FSC pixels ≥ 75 %.

The NDSI based snow information from optical satellite data includes both, melting and dry snow. Thus, the time frame for the acquisition of Landsat scenes to be used as reference data set is very narrow. Landsat scenes were only selected as usable reference data when acquisition is at clear sky conditions, when snow remains at high elevations, and melting occurs at all levels. These conditions limit the availability of usable Landsat scenes significantly, as snow maps from Sentinel-1 data are only generated since the melting season 2015. 3 Landsat scenes acquired over different regions of the Alps in May and June 2015 with only a few days delay to the Sentinel-1 scenes used for the wet snow cover product generation are selected as reference data for the preliminary evaluation.

The QA4EO framework was selected as an example of a template for reporting the performance of the wet snow cover products and as an information package for the user to easily assess the suitability of the data for the purpose.

8. Product performance and uncertainty

The preliminary results for the evaluation of the wet snow cover product show agreement rates ranging between 0.76 and 0.96, with lower agreement rates for VV-polarized backscatter ratios, and highest agreement rates for the combined single channel based on Rvv and Rvh ratios.

Table 8.1: Agreement rates (0 ≤ AR ≤ 1) resulting from the comparison of the Alpine wet snow cover product from Sentinel-1 SLC data with snow maps from 3 selected Landsat (LS) scenes acquired with a few days delay to the S1 acquisition. Different backscatter ratios (Rvv: VV-polarized; Rvh: VH-polarizd; Rc: combined single channel based on Rvv and Rvh ratios) are tested for the generation of the wet snow cover products, and evaluated separately.

Acquisition date		*Agreement rates of Alpine Wet Snow Cover vs Landsat snow maps*			
Landsat scene	*Sentinel-1 scene*	*Region*	*Rvv*	*Rvh*	*Rc*
29.05.2015	29.05.2015	AT, Zillertaler Alps	0,76	0,86	0,90
05.06.2015	02.06.2015	AT, Ötztaler Alps	0,88	0,95	0,96
03.06.2015	07.06.2015	CH, Berne	0,83	0,95	0,95

The main validation results derived for the intercomparison of the Alpine wet snow cover products with NDSI based snow maps generated from Landsat data are summarized in Error! Reference source not found..

9. Inputs

Input	Description	Link
ENVEO wet snow cover products	Multi-temporal maps of melting snow cover (binary information) for the Alpine area	http://neso1.cryoland.enveo.at/cryoclient/
Snow maps from Landsat data	Snow maps generated by applying a threshold on NDSI maps of selected Landsat scenes, spatially distributed over the Alpine area	http://glovis.usgs.gov
Forest and water body masks	Binary masks for forested areas and water bodies	https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html
EU DEM	Digital Elevation Model provided by the European Environment Agency, used for topographic correction	http://www.eea.europa.eu/data-and-maps/data/eu-dem
Scripts for snow map comparison and statistical analysis	Software developed at ENVEO for a pixel-by-pixel intercomparison of the Alpine FSC product and the snow maps from Landsat data, and for the generation of statistical analyses	

10. Standards and Traceability

Standard/ Documentation	Description	Link
NDSI based snow maps	Binary snow classification by applying a threshold on NDSI map from Landsat scenes	Hall et al. (2002)
Wet snow map	Method for retrieving wet snow maps from Sentinel-1 SLC data	Nagler, Rott, Ripper, Bippus, & Hetzenecker, (2016)
Topographic correction	Correction of illumination effects and atmospheric propagation due to topography	Ekstrand (1996)

11. Methodology, Processing

1) Select and download snow covered Landsat scenes acquired during the melting season at nearly clear sky conditions to be used for generating reference snow maps, and associated auxiliary data (DEM, forest mask, water mask)
2) Pre-process all needed reference data sets, including radiometric calibration of Landsat data, reprojection and resampling of auxiliary data as needed, topographic correction of Landsat top of atmosphere reflectance, generation of reference snow maps by applying a threshold on NDSI maps generated from the Landsat scenes
3) Resample, reproject and aggregate high resolution reference snow maps to the grid size of the Alpine wet snow cover product
1) Run pixel-by-pixel intercomparison between reference snow map and the Alpine SCAW product and calculate statistics

12. Evaluation of Performance

The preliminary evaluation of the Alpine wet snow cover product with snow maps generated from Landsat data acquired during the melting season 2015 over three selected test sites show in most cases high agreements between the derived snow maps. While the wet snow cover maps are generated with 100 m pixel size for high alpine terrain excluding forested areas, the Landsat based snow maps used as reference data have originally 30 m pixel size. These reference snow maps are aggregated to fractional snow cover at the same pixel size as the wet snow cover product, and then reduced to a binary snow information considering only fractional snow cover between 75 % and 100 % snow. The resulting snow maps are compared pixel-by-pixel with the wet snow cover products.

All detailed statistical results are shown in Table 12.1. The lowest agreement rates are found for snow maps generated from the S1 backscatter ratio Rvv, while for the ratio Rvh the results show already a significant improvement. Best agreements were found for the wet snow cover maps derived from the single channel based on combining the Rvv and Rvh ratios. Details on this combination are published by Nagler et al. (2016).

Table 12.1: Confusion matrix for snow (SN) and snow free (SNF) derived for three validation sites in the Alps for wet snow classification from Sentinel-1 (S1) compared with snow classification from Landsat (LS) data. S1 results are shown for snow maps based on the backscatter ratios Rvv, Rvh and Rc. AR indicates the overall agreement rate, ranging between 0 and 1.

		Rvv			Rvh			Rc		
Region		S1 SN	S1 SNF	AR	S1 SN	S1 SNF	AR	S1 SN	S1 SNF	AR
AT, Zillertaler Alps	LS SN	0,68	0,32		0,82	0,18		0,87	0,13	
	LS SNF	0,02	0,98		0,03	0,97		0,01	0,99	
	AR			0,76			0,86			0,90
AT, Ötztal Alps	LS SN	0,81	0,19		0,95	0,05		0,95	0,05	
	LS SNF	0,04	0,96		0,05	0,95		0,03	0,97	
	AR			0,88			0,95			0,96
CH, Berne	LS SN	0,73	0,27		0,94	0,06		0,92	0,08	
	LS SNF	0,07	0,93		0,05	0,95		0,03	0,97	
	AR			0,83			0,95			0,95

Although the Landsat scenes are often acquired with a few days delay to the Sentinel-1 scenes, the overall agreement for the Rc based wet snow cover products with the Landsat snow maps is always ≥ 90 %.

Further details on the S1 based wet snow cover product and further validation results are published in Nagler et al., 2016: Advancements for Snowmelt Monitoring by means of Sentinel-1 SAR, Remote Sensing, 2016.

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