Validation of snow products using Copernicus Sentinel data

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Validation of new snow products using Copernicus Sentinel data

Outline

- Part 1: Cross-Country Assessment of H-SAF Snow Products by Sentinel-2 Imagery Validated against In-Situ Observations and Webcam Photography

- Part 2: Validation of ESC-H (H35) and SE-G-AVHRR (H32) in extra-European areas

Cross-Country Assessment of H-SAF Snow Products by Sentinel-2 Imagery Validated against In-Situ Observations and Webcam Photography

Piazzi et al 2019, Geosciences 9, 129; doi:10.3390/geosciences9030129

The research has been conducted in the framework of the EUMETSAT HSAF Project, thanks to the collaboration among several partner institutes of the validation cluster of snow products.

- CIMA Research Foundation
- Finnish Meteorological Institute
- Middle East Technical University, Department of Civil Engineering
- Çankırı Karatekin University, Faculty of Forestry, Department of Forest Engineering
- Italian National Civil Protection Department

We are also grateful to the European Cooperation in Science and Technology (COST) ES1404 Harmosnow Action.

Goals of the Cross-Country Assessment

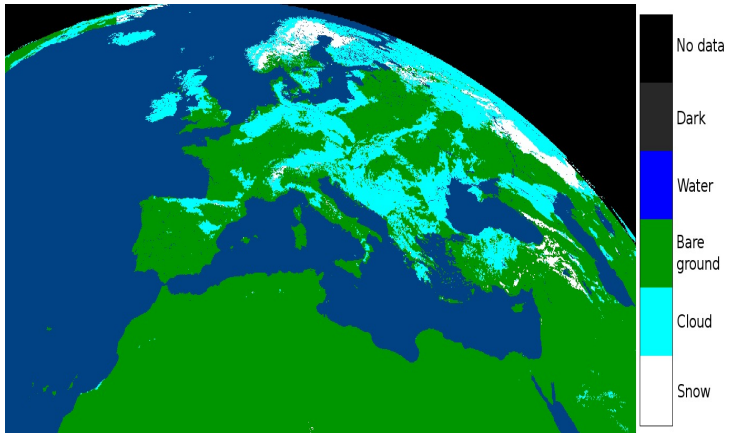
- Validate moderate-resolution H SAF products H10 – Snow detection (SN-OBS-1) and H12 – Effective snow cover (SN-OBS-3) using Sentinel-2
- High-resolution image of Sentinel-2 data are assumed as ground truth
- To guarantee the reliability of the validation analysis the accuracy of Sentinel-2 snow maps validated against in-situ snow measurements and webcam photography.

Three study areas are analyzed: Finland, Italian Alps, and Turkey

Products

H10 – Snow detection (SE-E-SEVIRI)

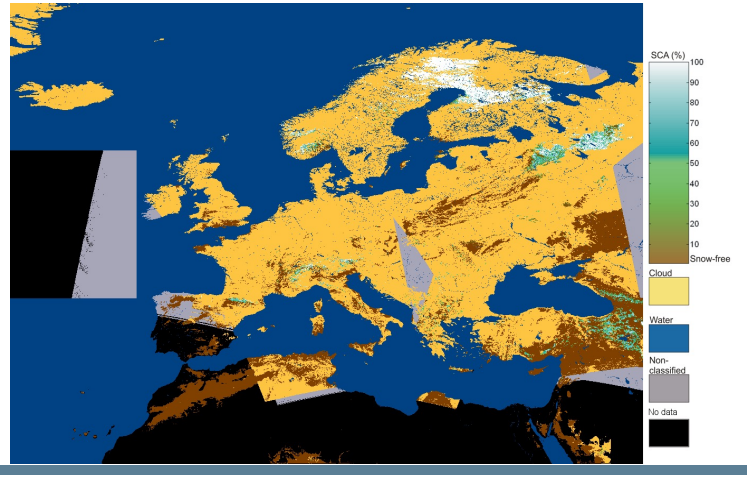
Daily operational product of **snow extent** generated from SEVIRI instrument on board MSG satellites, is derived for a multi-temporal analysis of SEVIRI 15-minutes images,
Consists of four different classes: snow, cloud, bare ground, water
Coverage: The H-SAF area [25-75°N lat, 25°W-45°E long]
Cycle: **Daily**
Resolution: 1 to 5 km
Dissemination: By dedicated lines to centres connected by GTS - By EUMETCast – by HSAF ftp



H12 - Effective snow cover (FSC-E)

Daily operational product of **fractional snow cover** based on multi-channel analysis of the AVHRR on board NOAA and MetOp satellites.

Coverage: The H-SAF area [25-75°N lat, 25°W-45°E long]
Cycle: **Daily**
Resolution: 1 km
Dissemination: By dedicated lines to centres connected by GTS - By EUMETCast – by HSAF ftp



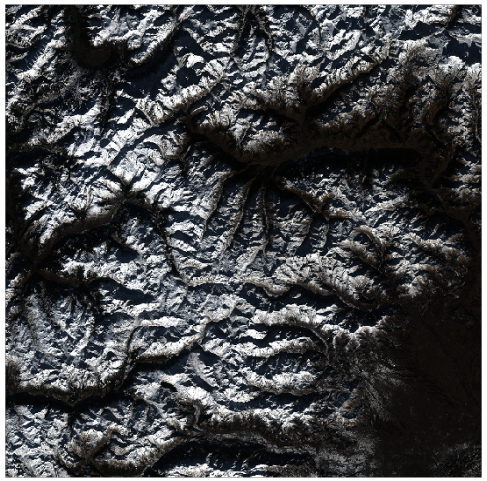
Sentinel-2

High-resolution imagery provided by Multi-Spectral Imager (MSI) instruments (13 bands, no thermal band).

The Copernicus Sentinel-2 mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other - Sentinel-2A (June 23rd 2015) and Sentinel-2B (March 7th 2017).

→ effective revisit time of 5 days at the equator (2-3 days at mid-latitude).

Depending on the spectral band, the spatial resolution varies from 10 m to 60 m → **SCA 20 m**



Sentinel-2 RGB image
December 06, 2017 (Italian Alps).

Sentinel-2

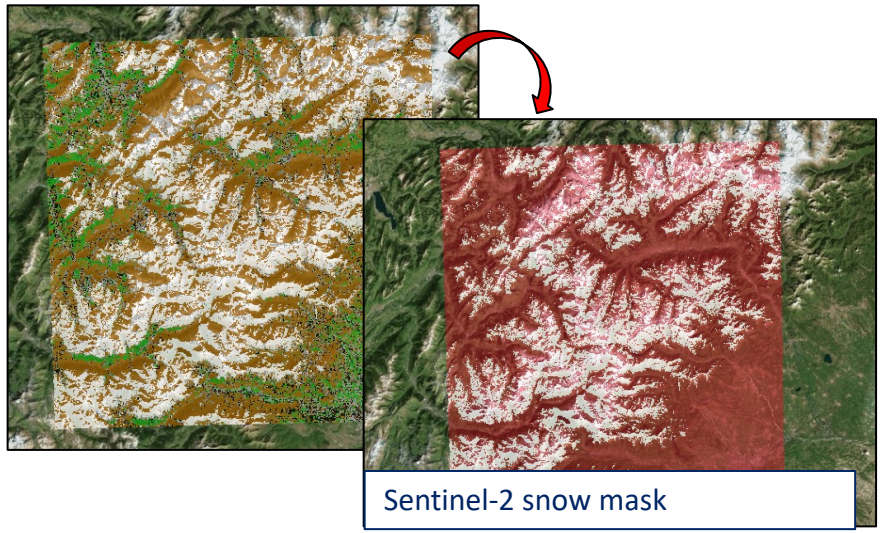
Pre-processing

Sentinel-2 L1C data downloaded from the Copernicus Open Access Hub.
L1C image product consists of a series of 100 km^2-tiles (JPEG-2000 images).

MSI TOA reflectance images processed through **Sen2Cor** 2.5.5, last version of ESA Sentinel-2 Level-2A Prototype Processor. Sen2Cor L2A_SceneClass module used to generate Scene Classification (SCL) maps at a spatial resolution of 20 m.

Binary snow masks (presence/absence of snow cover) derived from Sentinel-2 SCL maps: bare-soil, water and vegetation pixels classified as no-snow pixels

Label	Classification
0	No data
1	Saturated/defective
2	Dark area
3	Cloud shadows
4	Vegetation
5	Not vegetated
6	Water
7	Unclassified
8	Cloud (medium probability)
9	Cloud (high probability)
10	Thin cirrus
11	Snow



Sentinel-2 snow mask

Sentinel-2

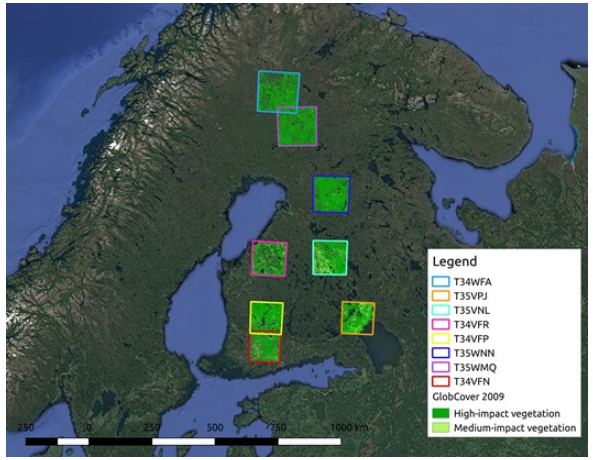
8 Sentinel-2 tiles selected over Finland, Italian Alps and Turkey.

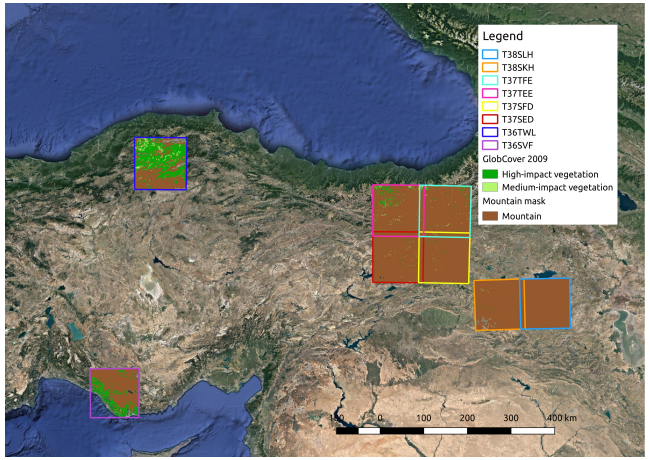
Ancillary information on vegetation cover derived from ESA GlobCover 300-m map

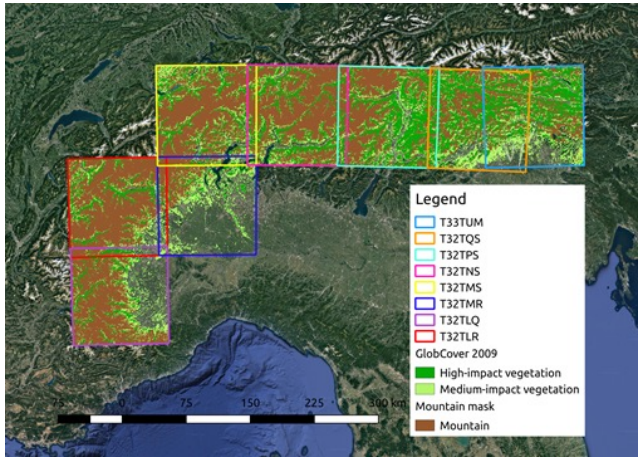
- High-impact vegetation (V_1): evergreen forest
- Medium-impact vegetation (V_2): deciduous forest

Analysis period: winter seasons 2016/2017 and 2017/2018.

Cloud free scenes or scenes with minor cloud cover (lower than 20%) are analyzed.







Data collection

Missing images:

- H10 – Snow detection
  1 (2016/17) & 7 (2017/18)

- H12 - Effective snow cover
  7 (2016/17) & 16 (2017/18) .

Test site	Seasonal number of S-2 images	
	Snow season 2016/17	Snow season 2017/18
Finland	60	193
Italian Alps	133	198
Turkey	37	101

Analysis period: winter seasons 2016/2017 and 2017/2018.

Validation of Sentinel-2 snow maps

Turkey
- In situ measurements of snow depth

Italy and Finland
- Webcam images

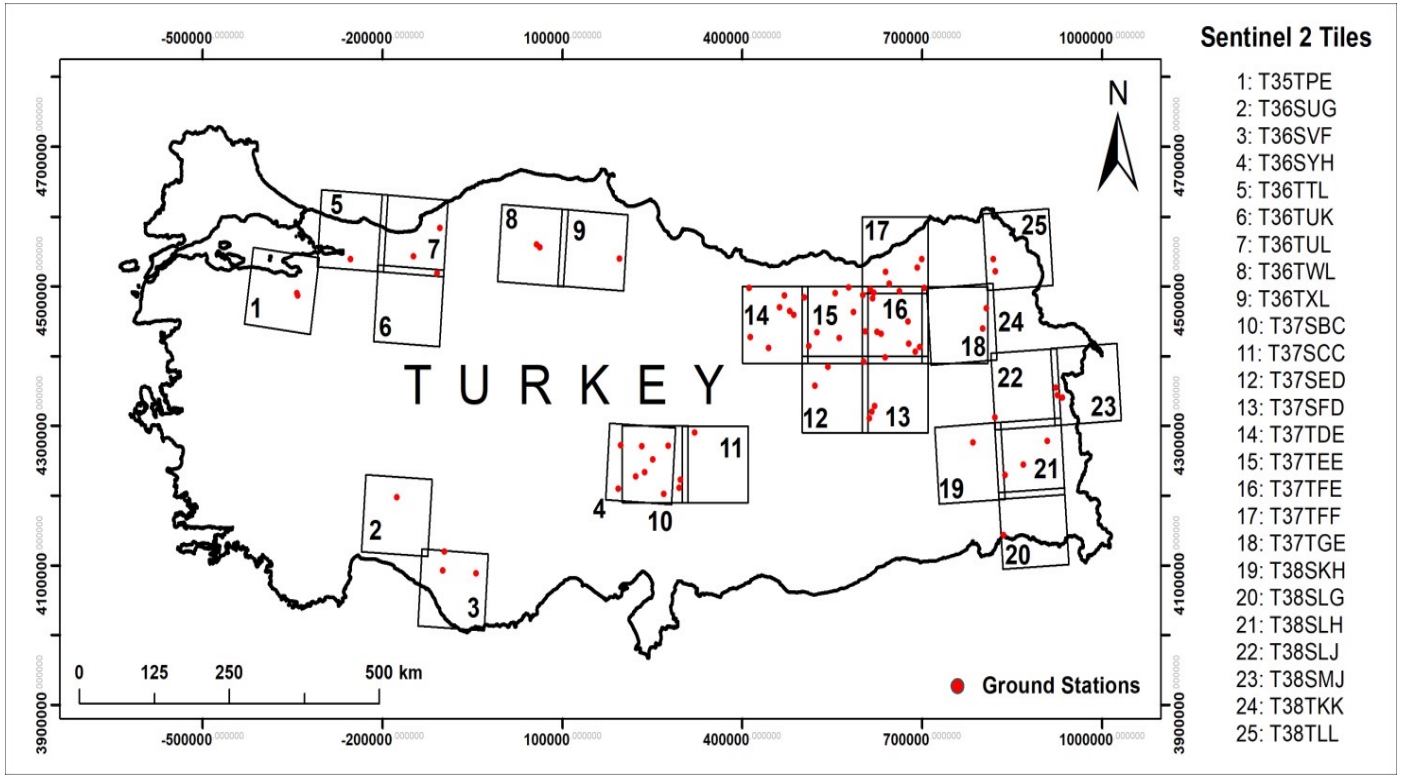
Figure 7. Webcam field of views: (**a**) Kenttärova canopy camera, (**b**) Lompolojankka peatland camera, (**c**) Sodankylä canopy camera, (**d**) Sodankylä peatland camera, (**e**) Torgnon camera.

Validation of Sentinel-2 snow maps in Turkey

Validation of 25 Sentinel-2 tiles against 286 in-situ snow depth observations during winter season 2017/18.

Daily snow depth measurements provided by 75 AWS of Turkish State Meteorological Service.

According to the in-situ measures, the presence of snow is detected whenever a threshold of 5 cm is exceeded.



Validation of Sentinel-2 snow maps in Turkey

Contingency table

Table 8. Contingency table reporting number of HITS (a), number of FALSE ALARMS (b), number of MISSES (c), number of CORRECT NEGATIVES (d).

		Reference Dataset	
		Snow	**No Snow**
Analyzed dataset	**Snow**	*a*	*b*
	No Snow	*c*	*d*

Probability of detection: $POD = {}^{a}/_{(a+c)}$

False alarm ratio: $FAR = {}^{b}/_{(a+b)}$

Accuracy: $ACC = {}^{(a+d)}/_{(a+b+c+d)}$

Contingency table results

	Ground-based measures	
	SD ≥ 5 cm	SD < 5 cm
S-2 binary snow masks	201	17
	43	25

POD	0.82
FAR	0.08
POFD	0.40
ACC	0.79
CSI	0.77
HSS	0.33

Significant consistency of satellite imagery, as evidenced by the highest number of hits and lower values of false alarms and misses

Validation of Sentinel-2 snow maps in Finland and Italy

Validation against in-situ webcam imagery, in terms of fractional snow cover (FSC).

Comparison of daily FSC value pairs derived from camera observations and Sentinel-2-based FSC maps (cloud cover lower than 50%).

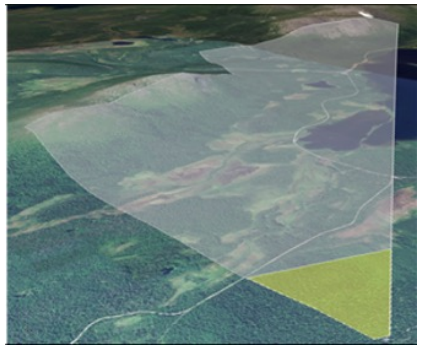
For each webcam an AOI is identified for the comparison with Sentinel-2

The FSC on the AOI by 4 experts through visual inspection

4 webcams selected in Finland (MONIMET)
1 webcam selected over Italian Alps (Phenocam)

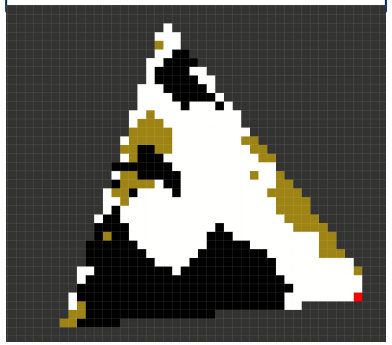
Camera name	No. of analyzed images
Torgnon	24
Sodankylä peatland	22
Sodankylä canopy	22
Lompolojankka peatland	23
Kenttärova canopy	23

Kenttärova camera FOV (white polygon) and AOI (yellow polygon)



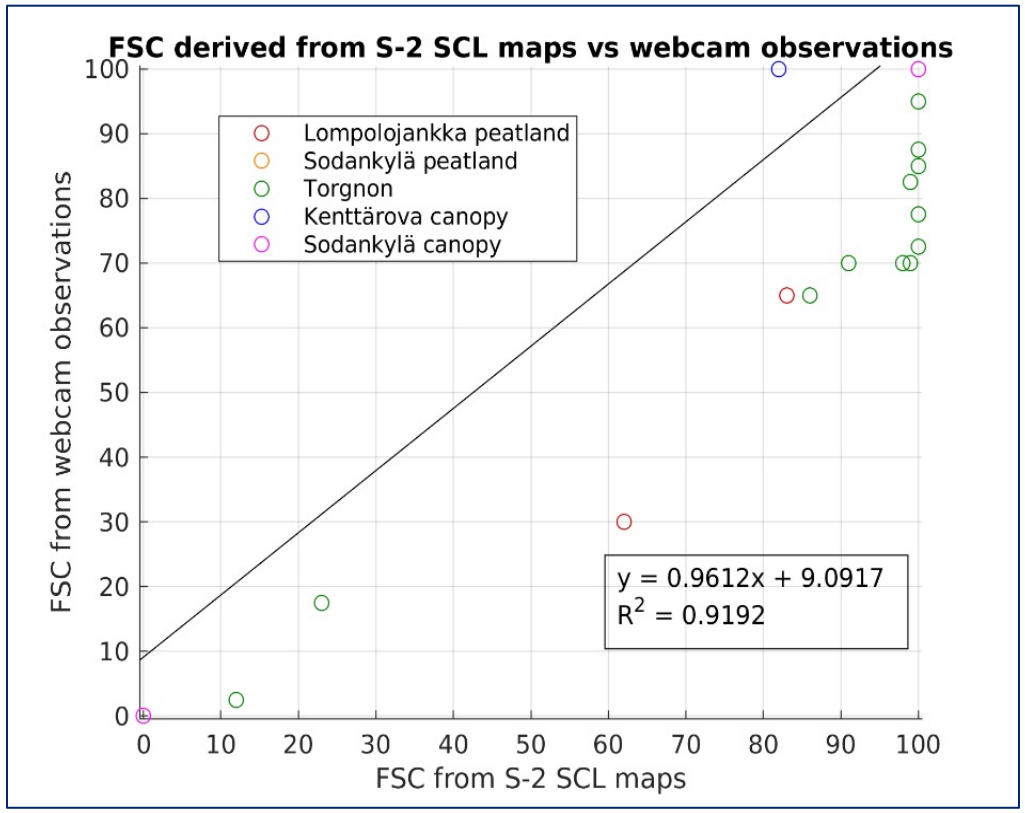
Kenttärova camera AOI (yellow polygon)

633-pixels Sentinel-2 snow cover map



white: snow
brown: no-snow;
black: clouds and unclassified
red: camera location

Validation of Sentinel-2 snow maps in Finland and Italy



- RMSE 12% (all pairs)
- RMSE 19.8% (19 pairs) neglecting full snow and bare soil
- Tendency of S2 to over-estimation
- Scenes having the highest error are those affected by higher cloud cover fraction
- During the melting period (ground covered by meltwater and patchy snow cover) Sentinel-2 data are affected by overestimation in Lompolojankka.

Validation of H10 product by Sentinel-2

Validation performed individually over each Sentinel-2 tile.

Comparison performed at the coarser spatial resolution of the HSAF H10

For each H10 grid cell Sentinel-2-based FSC defined as the number of snow pixels versus the total number in the coarse cell (Sentinel-2-derived FSC map, Binary snow mask restored through 50%-thresholding of FSC)

Coarse resolution pixel with more than the 50% of Sentinel-2 pixels classified as cloud or unclassified are neglected.

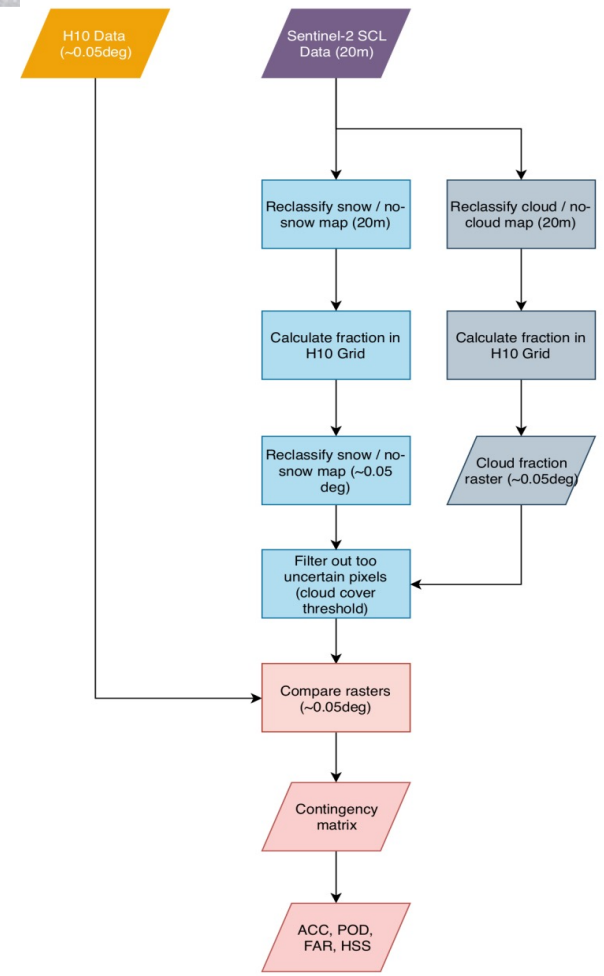
Contingency table

		Reference dataset	
		Snow	No snow
Analyzed dataset	Snow	a	b
	No snow	c	d

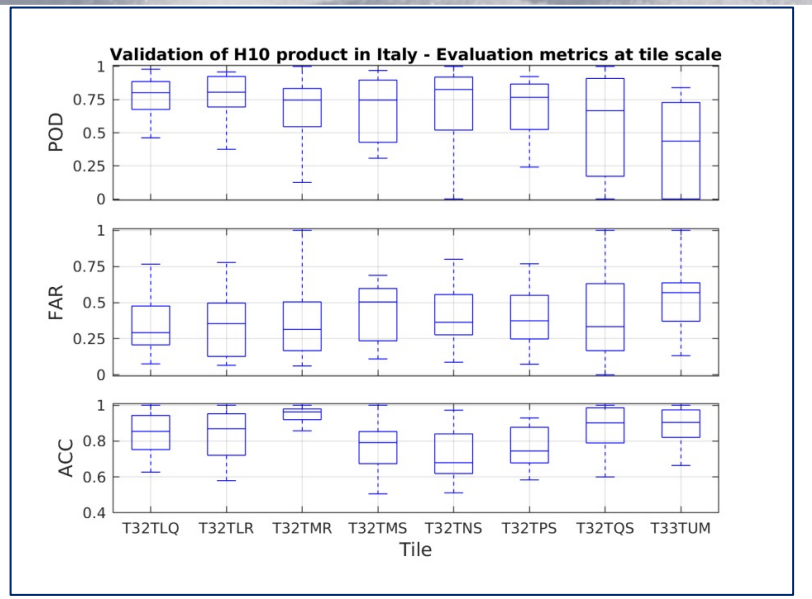
Probability of detection: $POD = {}^{a}/_{(a+c)}$

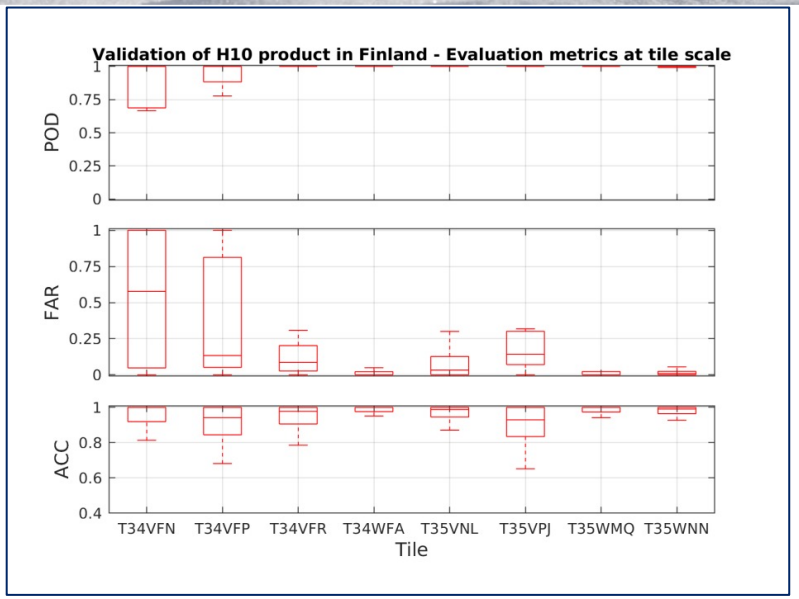
False alarm ratio: $FAR = {}^{b}/_{(a+b)}$

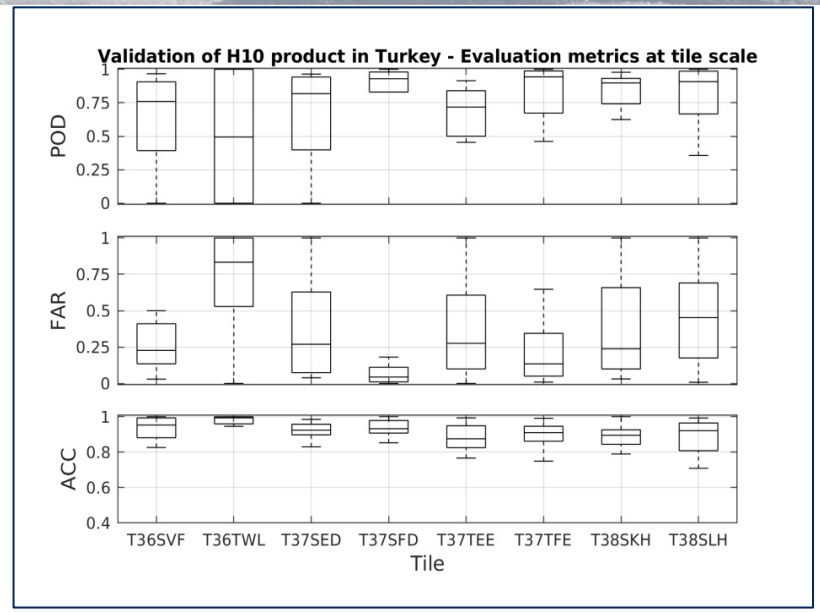
Accuracy: $ACC = {}^{(a+d)}/_{(a+b+c+d)}$



Validation of H10 product by Sentinel-2







- Generally, accuracy greater than 0.8, except for tiles T32TNS and T33TPS over Italian Alps
- Strong impact of complex topography - higher performances over flat areas (Finland), rather than over mountainous regions (Italian Alps and Turkey)
- Vegetation cover results in a lesser impact than topographic factors → greater impact where the local topography is complex, due to overlapping effects.

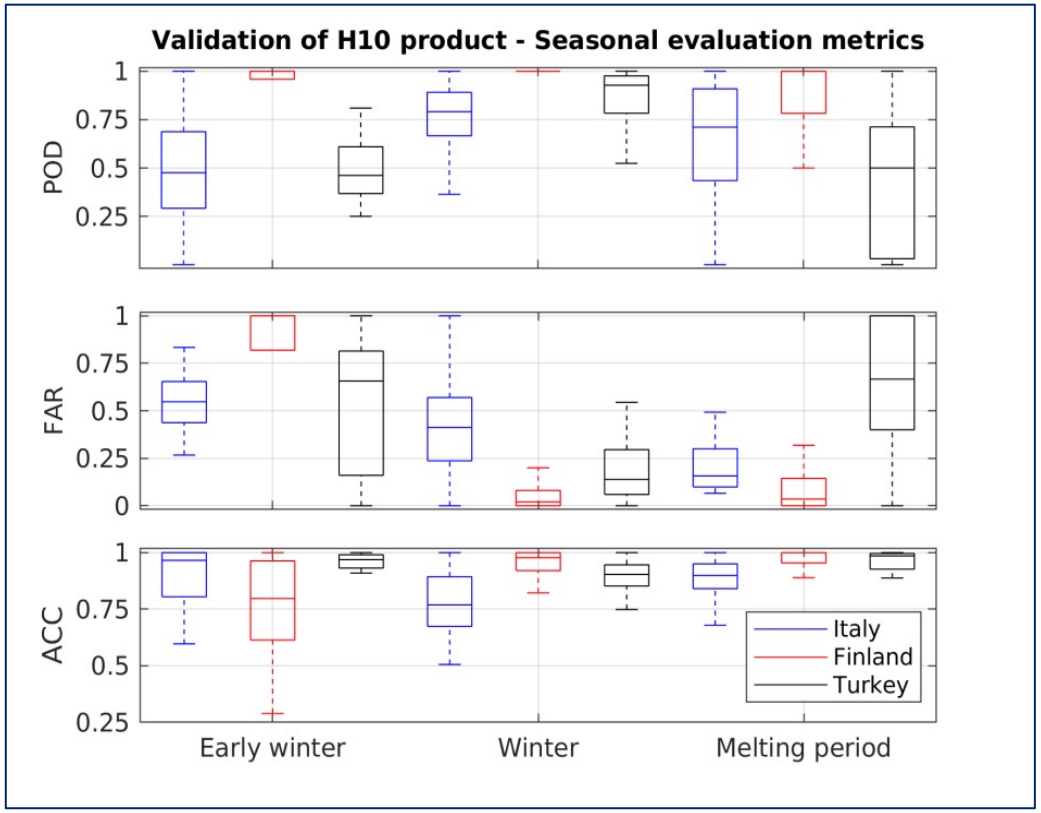
Validation of H10 product by Sentinel-2

Assessment under different snow cover conditions - early winter (October, November), winter (December-March), melting period (April, May).

In early winter lower ACC and higher FAR in Finland due to frequent cloudiness.

Lower performances under conditions of patchy snow cover.

50%-thresholding of FSC derived from S-2 data mainly affect analysis during the transition periods.



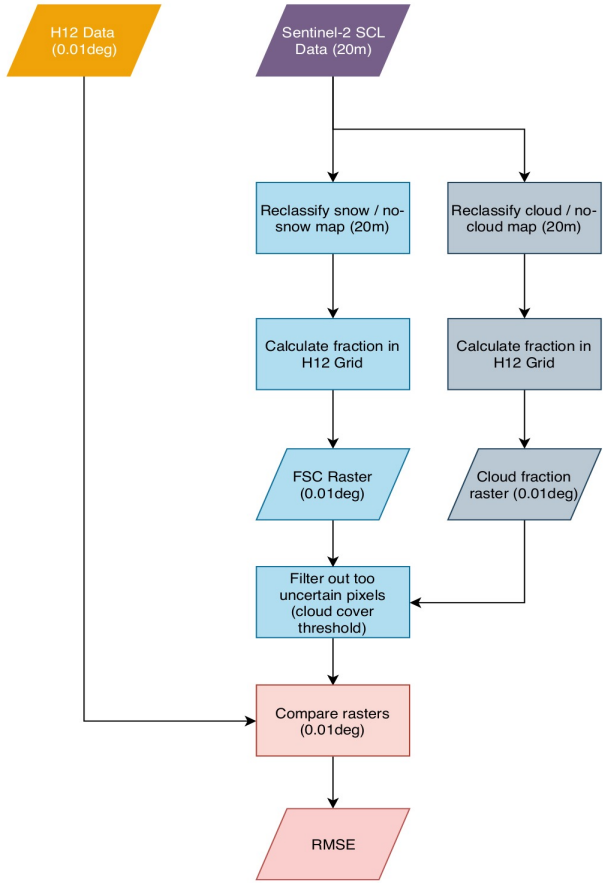
Validation of H12 product by Sentinel-2

Validation performed individually over each Sentinel-2 tile.

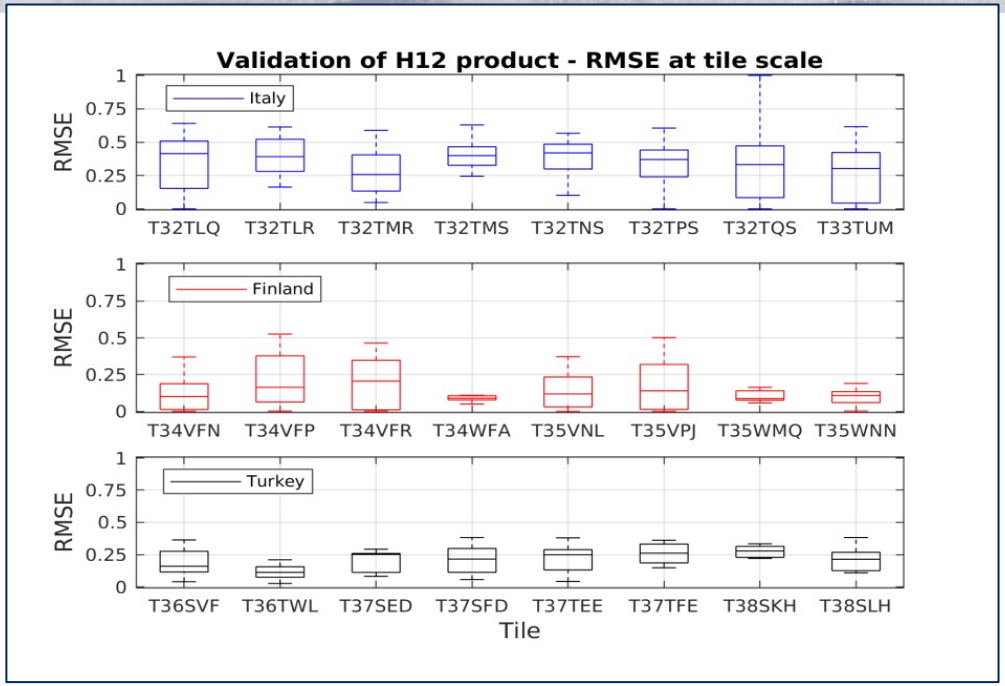
Binary snow masks are derived from both H12 and Sentinel-2 SCL maps (unclassified and cloud-contaminated pixels neglected).

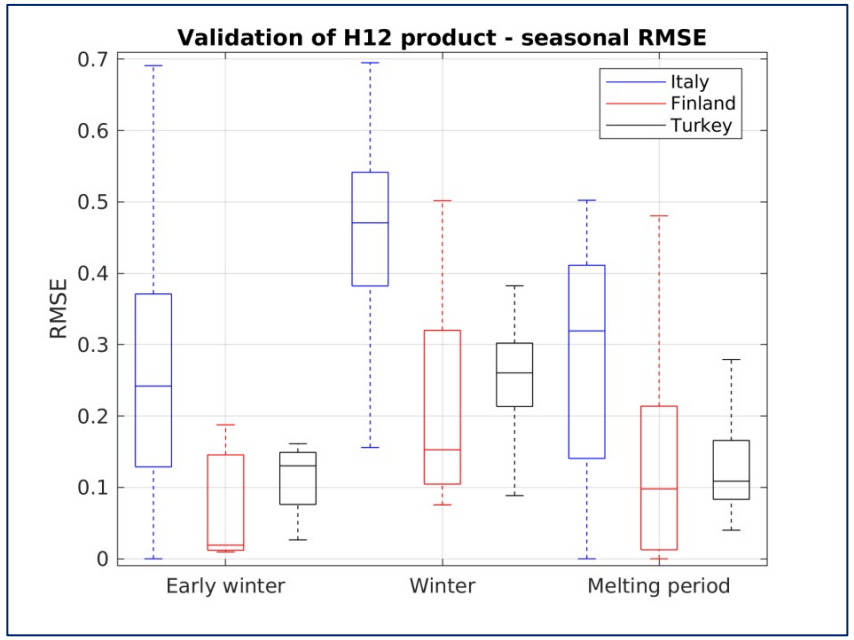
Comparison performed at the coarser spatial resolution of the HSAF H12.
For each H12 grid cell Sentinel-2-based FSC defined as the number of snow pixels versus the total number in the coarse cell
→ Sentinel-2-derived FSC map.

Cells with more than the 50% of Sentinel-2 pixels classified as cloud or unclassified are neglected.



Validation of H12 product by Sentinel-2





- RMSE scores are generally lower than 0.4.
- Complex topography in mountainous areas affects the consistency between H12 product and Sentinel-2 snow maps, especially over the Italian Alps.

Region	RMSE
Finland	0.15
Italian Alps	0.33
Turkey	0.21

higher RMSE in winter (H12 overestimates respect to S2) especially in mountainous region.

Conclusions Part 1

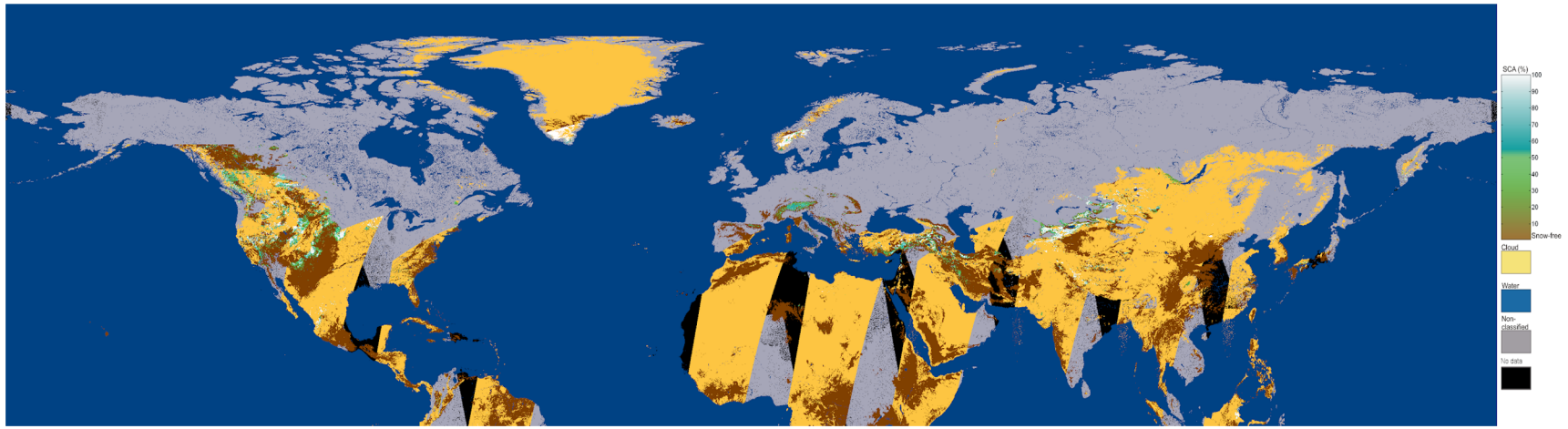
About Sentinel-2

- Can be properly used for continuous validation of medium/coarse resolution satellite snow products, have a significant consistency with both ground-based snow measurements and in-situ webcam photography.
- Dense cloud cover can undermine the reliability of Sentinel-2 snow maps
- Patchy snow cover and melting period may lead to an overestimation of snow cover.

About H SAF snow products

- Are highly consistent with S-2 imagery with a higher agreement over flat areas than in mountainous regions
- Complex topography significantly hinders snow detection.
- Vegetation cover has less relevant impact on the consistency among remotely-sensed observations, even in presence of dense evergreen forest.

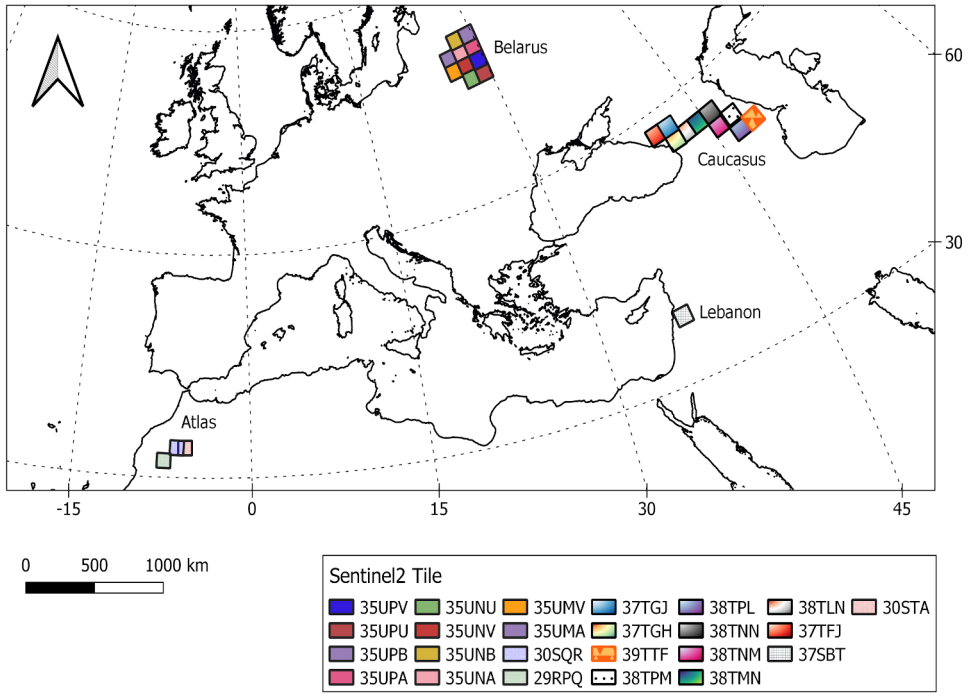
Validation of the ESC-H (H35) snow product



ESC-H (H35): daily FSC maps for the northern Hemisphere, by VIS/IR radiometry is based on multi-channel analysis of the AVHRR instrument onboard MetOp satellites

Validation of the ESC-H (H35) snow product

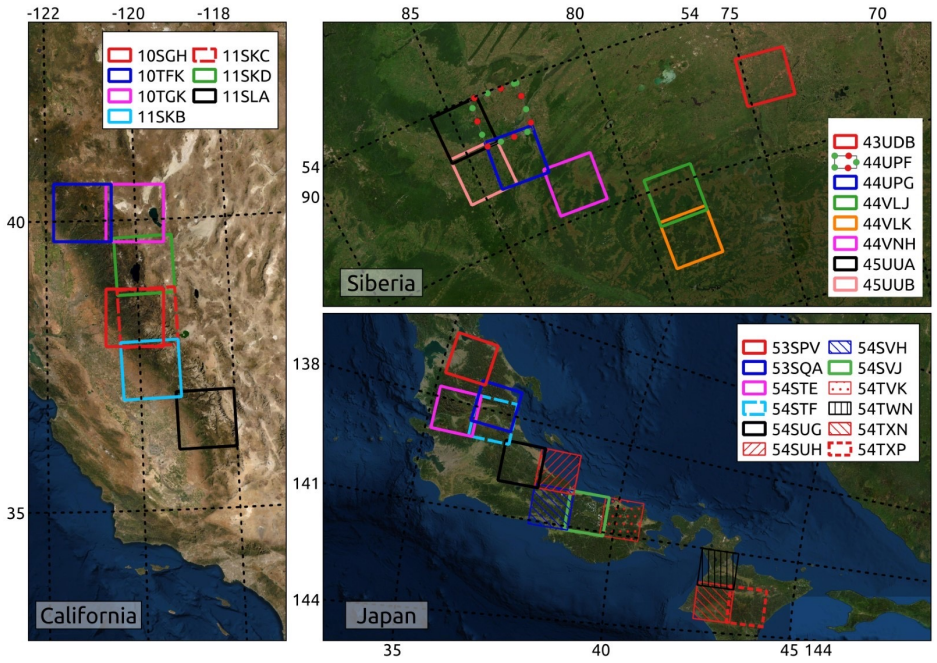
H35: Oct. 1 2019 - Jan. 31 2020



We considered S2 tiles across:

- Siberia
- Japan
- California
- Belarus
- Caucasus
- Lebanon
- Atlas

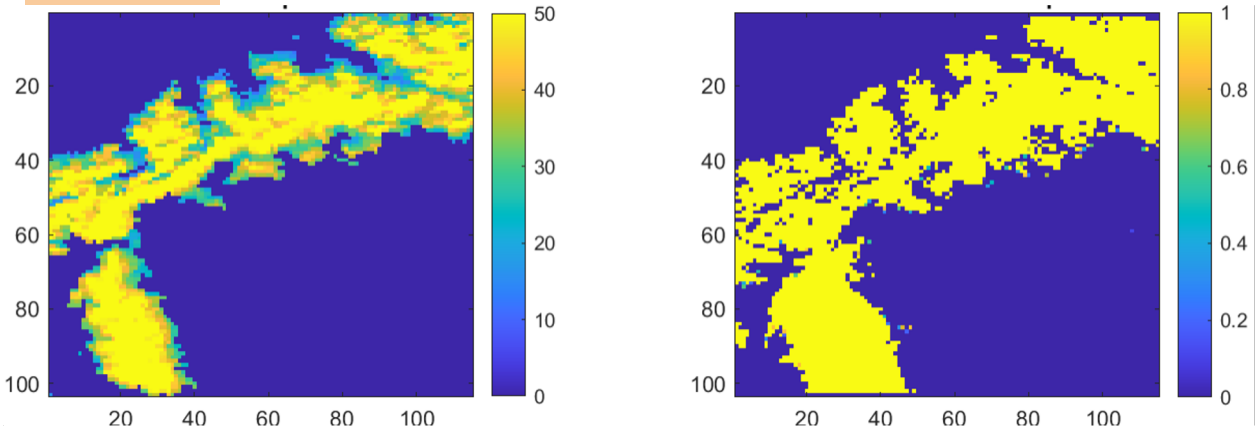
H35: Oct. 1 2019 - May 31 2020



Validation of the ESC-H (H35) snow product

We compared H35 to Sentinel-2 Scene Classification Maps, following results by Piazzi et al. 2019

Atlas



Step 1 — **Download S2 data**

We directly downloaded Level-2 SCL maps

Step 2 — **Resampling S2 data**

For each map-tile, we resampled S2 according to the HSAF grid

Step 3 — **Comparison**

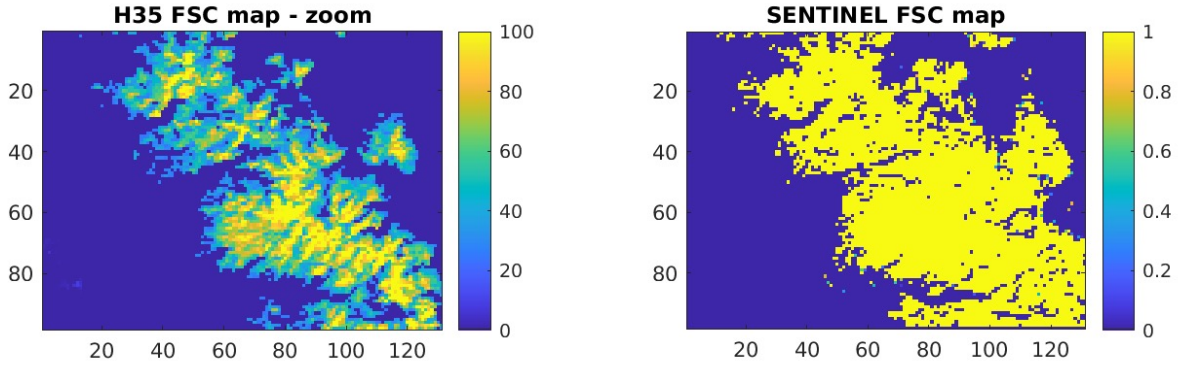
H35, S2 resampled maps were converted to FSC

Step 4 — **Evaluate performance**

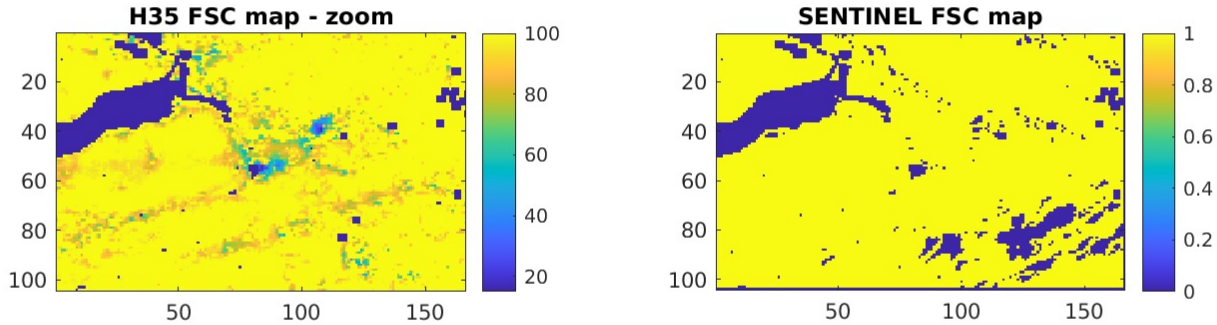
performance for H35 was evaluated using RMSE and bias.

Validation of the ESC-H (H35) snow product

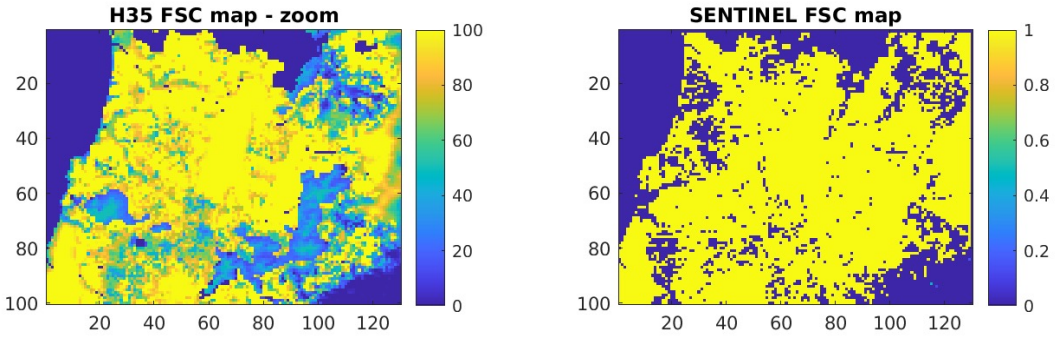
California (February 06, 2020, tile 11SKC)



Siberia (March 23, 2020, tile 44UPF)



Japan (February 12, 2020, tile 54SVJ).



Qualitatively, snow patterns estimated by H35 and by Sentinel 2 are consistent.

Validation of the ESC-H (H35) snow product

H35: Oct. 1 2019 - Jan. 31 2020

Table 1: Considered Sentinel-2 tiles, satellite orbit, and number of images for each area of interest. Images cover the period October 1 2019 through January 31 2020 and were filtered to discard those with overall cloud cover above 20% (Piazzi et al., 2019).

Area of interest	S2 Tile	Orbit	Number of images
Caucasus	37TFJ	78	10
	37TGJ	78	13
	37TGH	78	10
	38TLN	35	9
	38TMN	35	8
	38TNN	135	6
	38TNM	135	7
	38TPM	135	7
	38TPL	92	12
	38TTF	92	12
Belarus	35UMA	136	3
	35UMV	136	2
	35UNB	93	2
	35UNA	93	1
	35UNV	93	2
	35UNU	93	1
	35UPB	93	1
	35UPA	93	1
	35UPV	93	2
	35UPU	50	3
Lebanon	37SBT	121	10
Atlas	29RPQ	137	20
	29SQR	94	15
	30STA	94	14
Total			**171**

171 images Oct. 1, 2019 - Jan. 31, 2020
288 images Oct. 1, 2020 - May 31, 2021

Images with less than 20% clouds

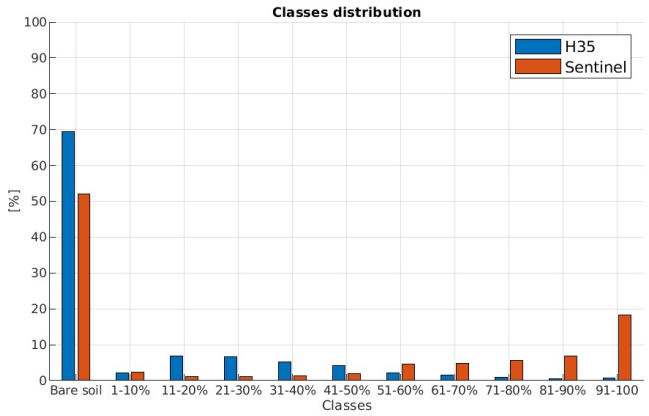
H35: Oct. 1 2019 - May 31 2020

Table 1: Considered Sentinel-2 tiles, satellite orbit, and number of images for each area of interest. Images cover the period October 1, 2019 through May 31, 2020 and were filtered to discard those with overall cloud cover above 20%.

Area of interest	Tile	Orbit	# of images
California	10SGH	70	26
	10TFK	113	13
	10TGK	113	18
	11SKB	70	20
	11SKC	70	24
	11SKD	70	24
	11SLA	70	19
Siberia	43UDB	34	11
	44UPF	5	11
	44UPG	5	9
	44VLJ	134	4
	44VLK	134	4
	44VNH	48	10
	45UUA	5	9
	45UUB	5	9
Japan	53SPV	117	10
	53SQA	117	8
	54STE	74	16
	54STF	117	8
	54SUG	74	5
	54SUH	74	4
	54SVH	74	6
	54SVJ	74	3
	54TVK	74	5
	54TWN	74	4
	54TXN	74	5
	54TXP	74	3
Total			288

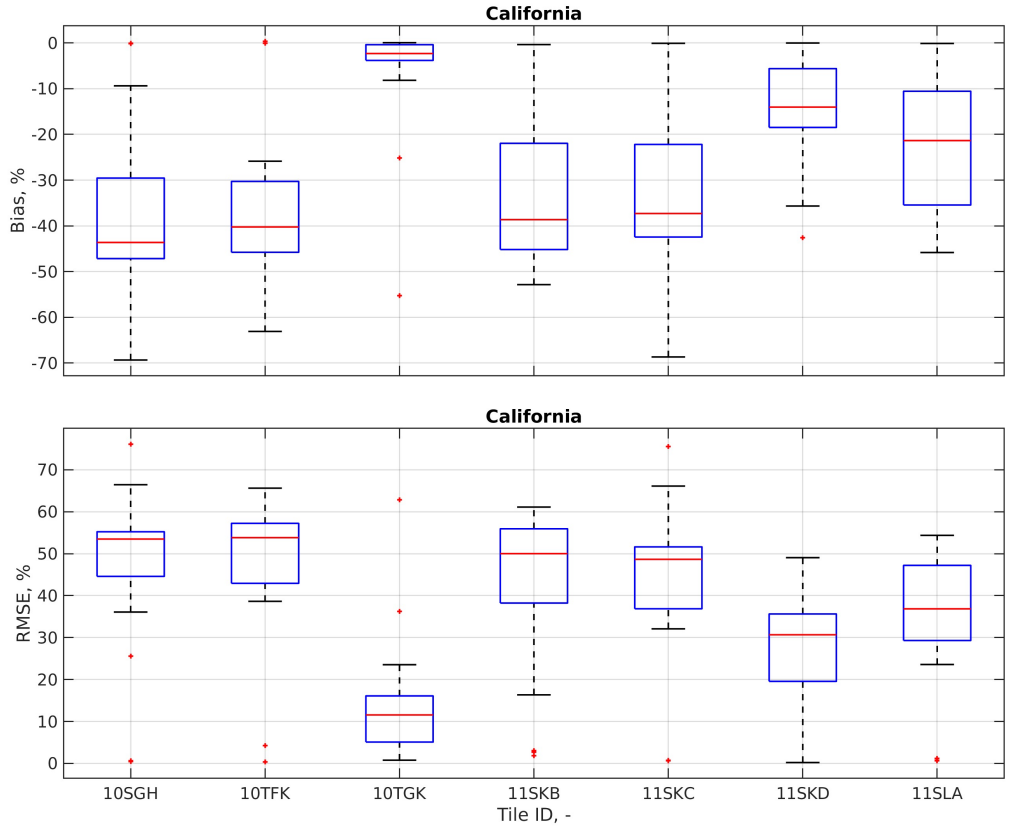
H35: California (mountain region)

RMSE 40%, BELOW THRESHOLD



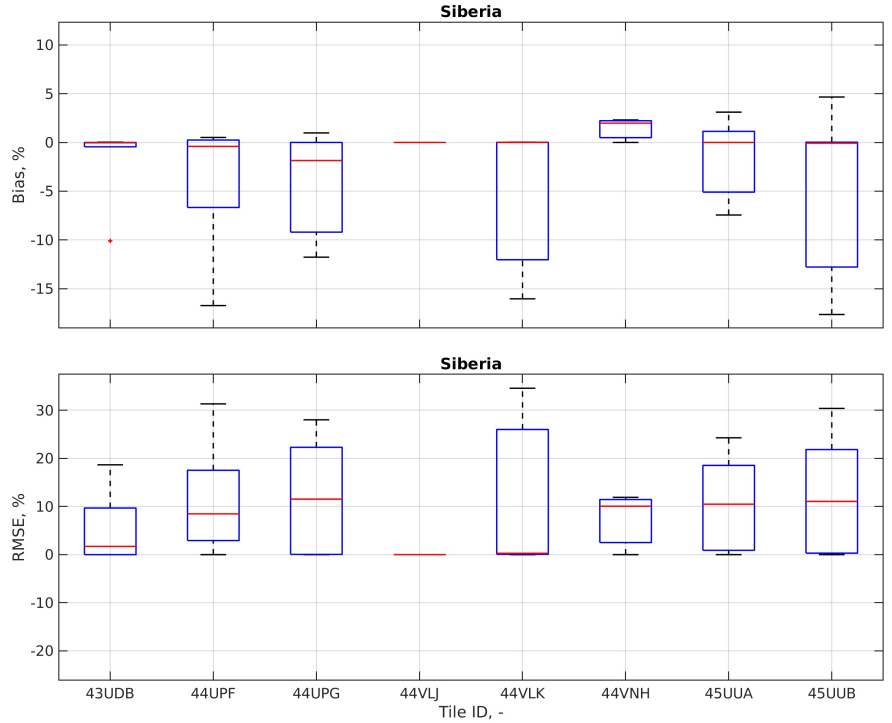
Thresholds for Fractional Snow Cover products (H12, H35)

H-SAF Accuracy requirements FSC Products			
Product requirements *Root Mean Square Error*			
Score	threshold	target	optimal
Flat/ Forested areas RMSE	40%	20%	10%
Mountainous areas RMSE	50%	30%	10%



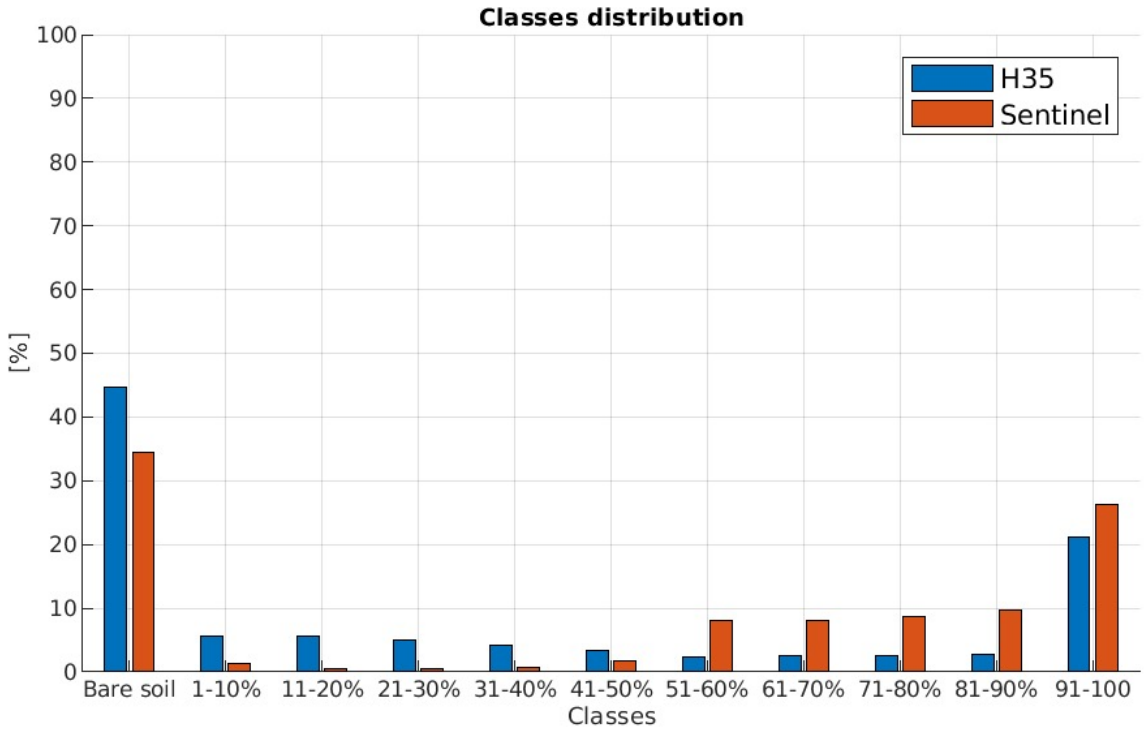
H35: Siberia (flat region)

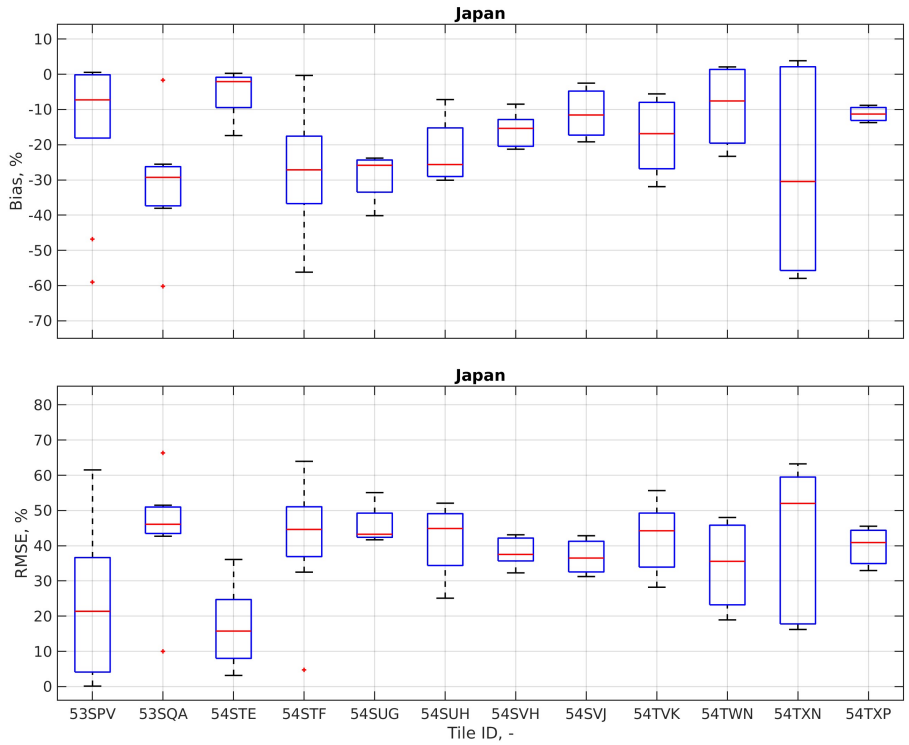
RMSE 17.5%, BETWEEN TARGET AND OPTIMAL



H35: Japan (mountain region)

RMSE 39%, BELOW THRESHOLD

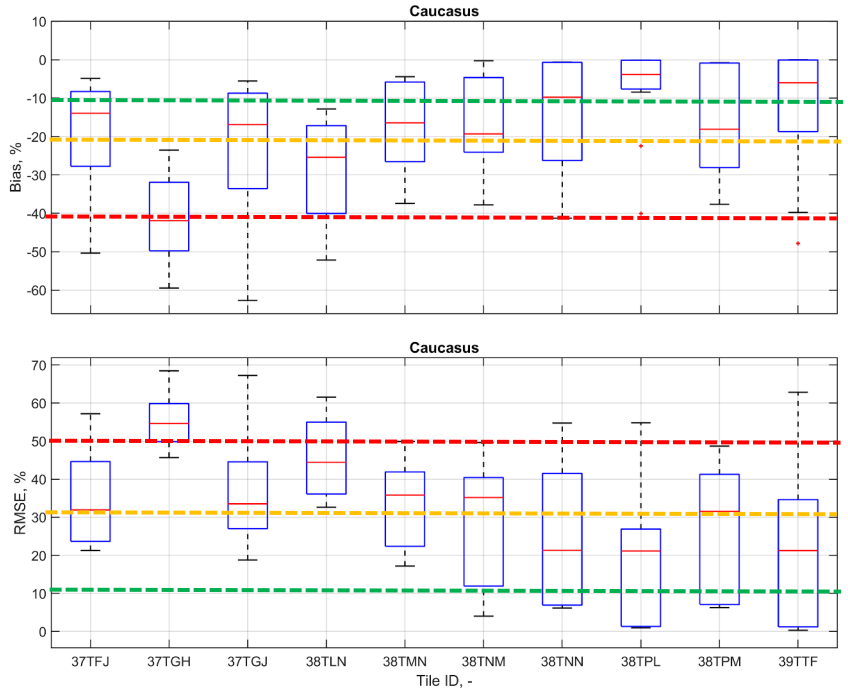




H35: Caucasus

RMSEs and biases for all areas of interest were below thresholds (50% and 40%, respectively).

Area of interest	RMSE	Bias
Caucasus	38%	-20%
Belarus	3%	0.25%
Atlas	19%	-6%
Lebanon	22%	-6%



Bias: 40%, 20%, 10% (threshold, target, optimal)
RMSE: 50%, 30%, 10% (threshold, target, optimal)

H35: Lebanon, Atlas, Belarus

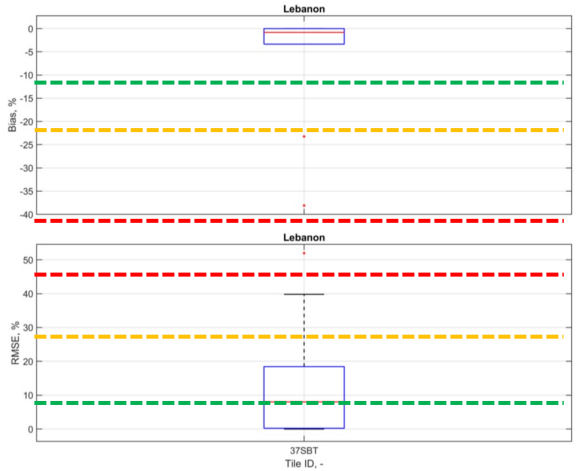


Figure A.7: Lebanon: Distribution of RMSEs and Biases for each image, by tile.

RMSEs and biases for all areas of interest were below thresholds (50% and 40%, respectively).

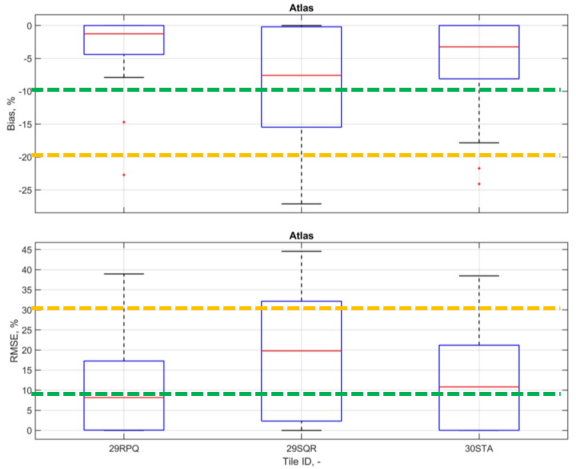


Figure A.8: Atlas: Distribution of RMSEs and Biases for each image, by tile.

Area of interest	RMSE	Bias
Caucasus	38%	-20%
Belarus	3%	0.25%
Atlas	19%	-6%
Lebanon	22%	-6%

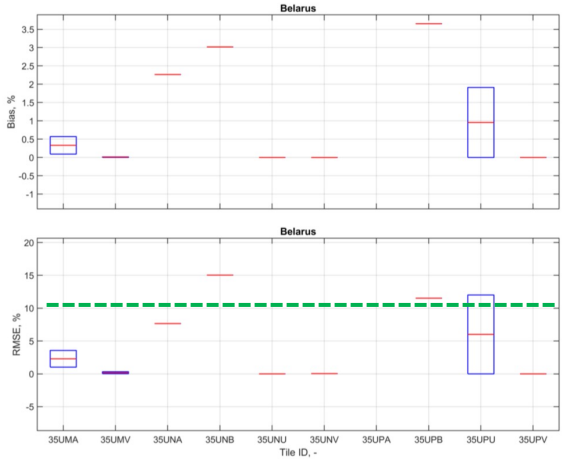


Figure A.6: Belarus: Distribution of RMSEs and Biases for each image, by tile.

Bias: 40%, 20%, 10% (threshold, target, optimal)
RMSE: 50%, 30%, 10% (threshold, target, optimal)

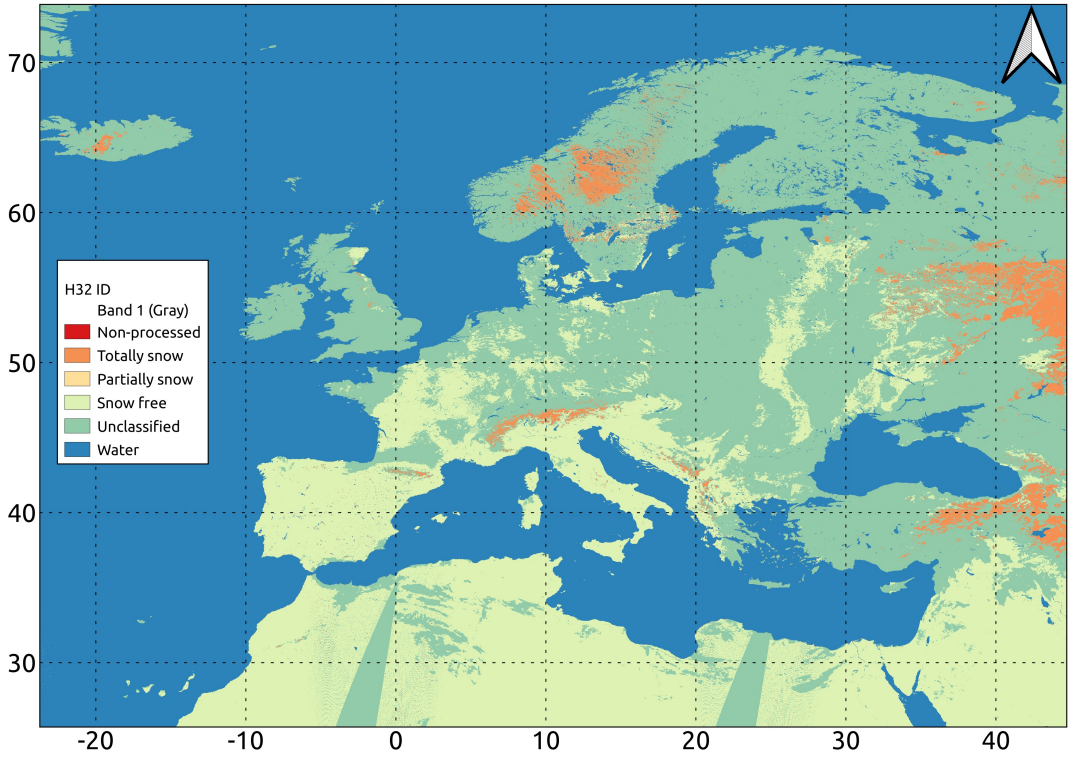
Conclusions ESC-H (H35)

Overall good agreement between H35 and Sentinel 2, with all areas of interest reporting global score below the required thresholds.

Scores are robust to mountain areas but tend to slightly decrease in areas that are likely covered by vegetation ore where snow is more ephimeral

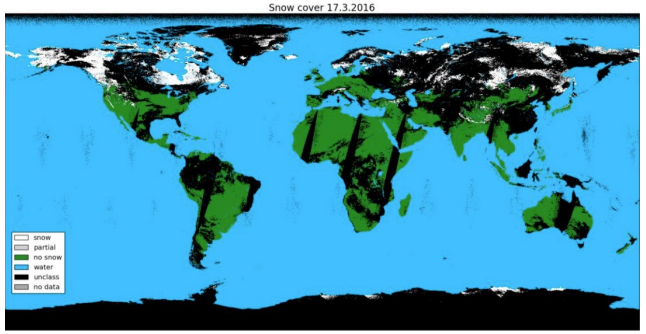
H35 was successfully validated in Siberia, Japan, California, Belarus, Caucasus, Lebanon and Atlas

Validation of the SE-G-AVHRR (H32) snow product



H-SAF H23 map for Europe, February 21, 2020

SE-G-AVHRR (H32): global snow-cover data (SCA) based on measurements from the Advanced Very High Resolution Radiometer (AVHRR) on-board EUMETSAT polar system satellites, the Metop series.
Daily, ~1 km



Validation of the SE-G-AVHRR (H32) snow product

H32: Oct. 1 2019 - May 31 2020

We considered S2 tiles across:

- Siberia
- Japan
- California

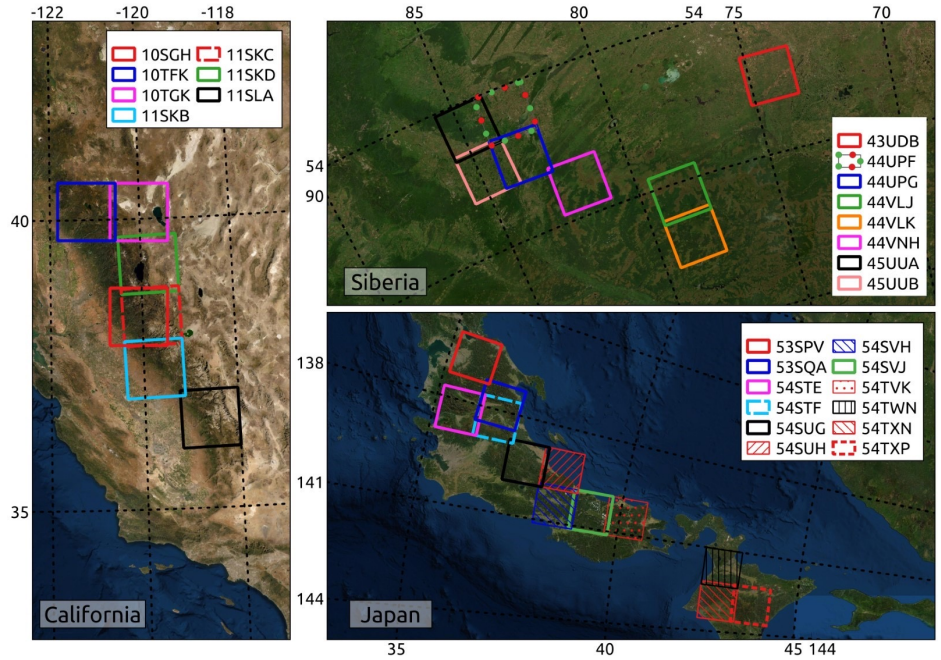


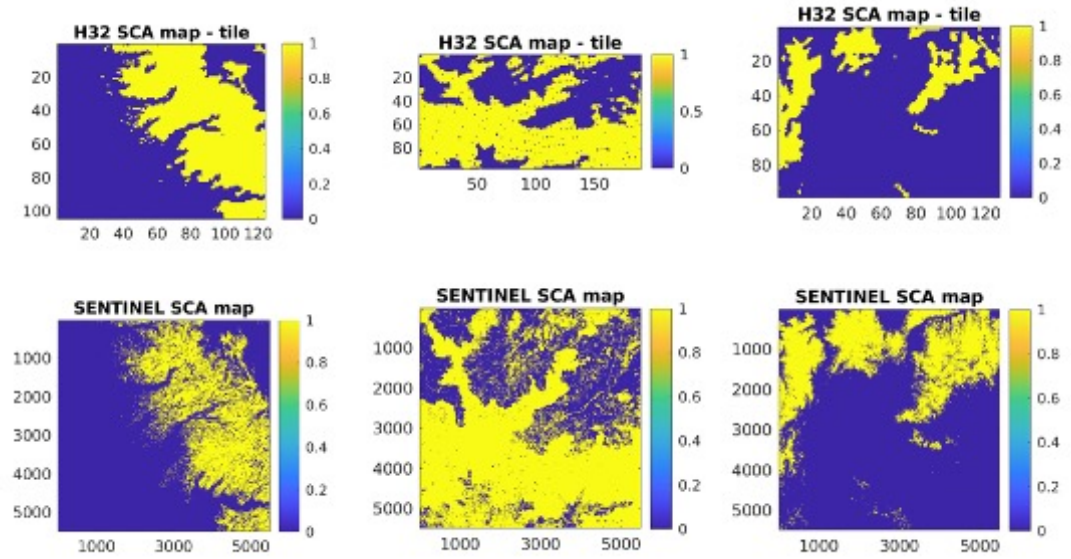
Table 1: Considered Sentinel-2 tiles, satellite orbit, and number of images for each area of interest. Images cover the period October 1, 2019, through May 31, 2020, and were filtered to discard those with overall cloud cover above 20%.

Area of interest	*Tile*	*Orbit*	*# Of images*
California	*10SGH*	*70*	*26*
	10TFK	*113*	*13*
	10TGK	*113*	*18*
	11SKB	*70*	*20*
	11SKC	*70*	*24*
	11SKD	*70*	*24*
	11SLA	*70*	*19*
Siberia	*43UDB*	*34*	*11*
	44UPF	*5*	*11*
	44UPG	*5*	*9*
	44VLJ	*134*	*4*
	44VLK	*134*	*4*
	44VNH	*48*	*10*
	45UUA	*5*	*9*
	45UUB	*5*	*9*
Japan	*53SPV*	*117*	*10*
	53SQA	*117*	*8*
	54STE	*74*	*16*
	54STF	*117*	*8*
	54SUG	*74*	*5*
	54SUH	*74*	*4*
	54SVH	*74*	*6*
	54SVJ	*74*	*3*
	54TVK	*74*	*5*
	54TWN	*74*	*4*
	54TXN	*74*	*5*
	54TXP	*74*	*3*
Total			*288*

288 S2 images

Validation of the SE-G-AVHRR (H32) snow product

We compared H32 to Sentinel-2 Scene Classification Maps, following results by Piazzi et al. 2019



Comparison between H32 and Sentinel-2 snow-covered area in California (February 06, 2020, tile 10SGH), Siberia (February 11, 2020, tile 44VLJ), and Japan (March 26, 2020, tile 54STF).

Step 1 — **Download S2 data**

We directly downloaded Level-2 SCL maps

Step 2 — **Resampling S2 data**

For each map-tile, we resampled S2 according to the HSAF grid

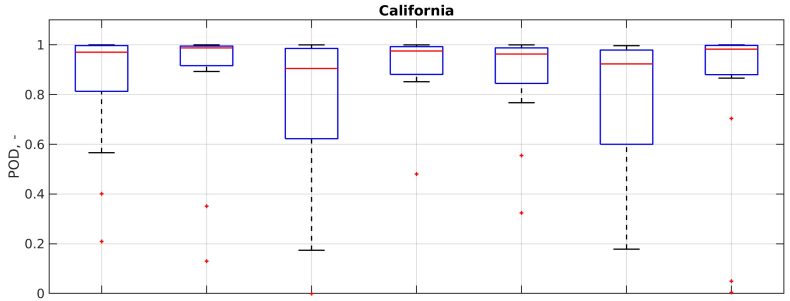
Step 3 — **Comparison**

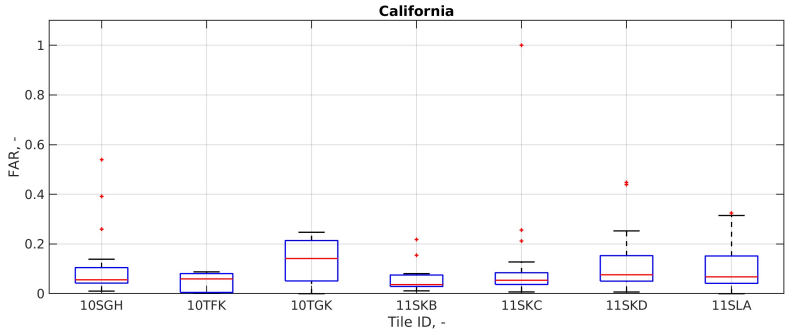
For comparing with H32, S2 resampled maps were converted to SCA

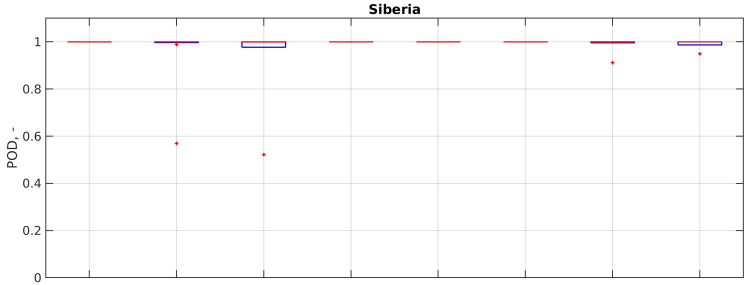
Step 4 — **Evaluate performance**

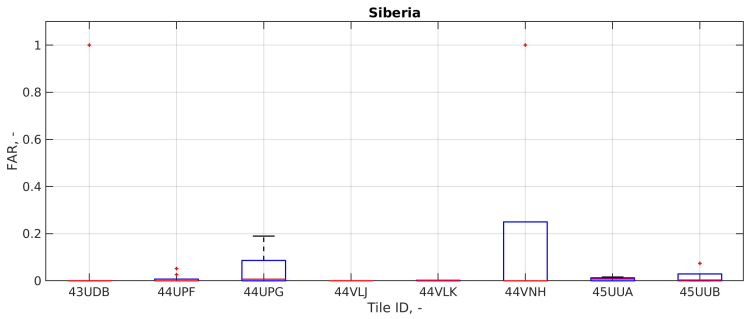
Performance for H32 was evaluated using confusion matrices, PODs and FARs

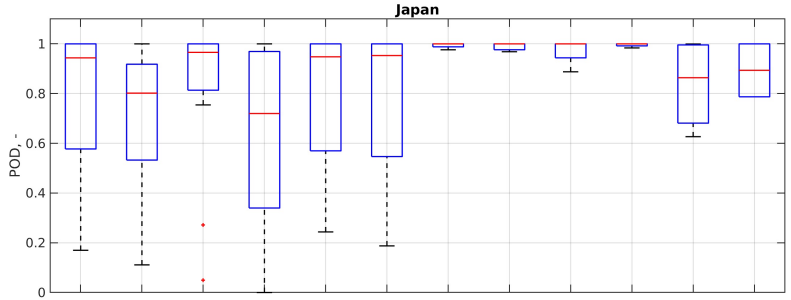
Validation of the SE-G-AVHRR (H32) snow product

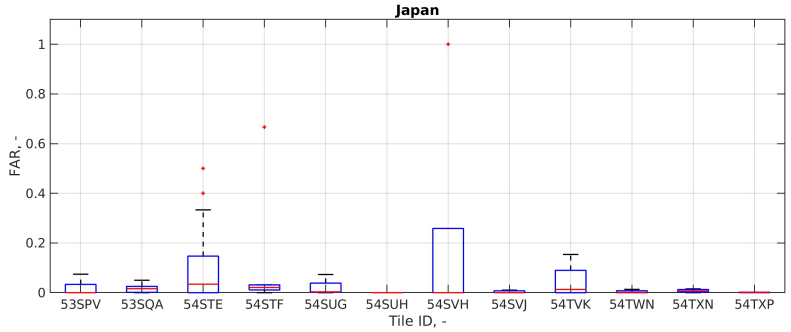












Conclusions SE-G-AVHRR (H32)

All regions of interest show remarkable performances, especially in terms of

- a high proportion of correct negatives in topographically complex, mountainous regions like California and Japan where snow presence is highly seasonal (and so more instances of bare ground)
- a high proportion of correct positive in the arctic region of central Siberia.
- False positives and false negatives are very low in all areas of interest, with particularly low values in the flat Siberia.
- Overall, correctly classified pixels in Siberia are about 99%, but this share is greater than 95% also in mountainous regions.