Cross-country assessment of H-SAF snow products by Sentinel-2 imagery validated against in-situ observations and webcam photography

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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.

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- 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

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Goals

- 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
**H10 – Snow detection (SN-OBS-1)**

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 (SN-OBS-3)**

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 to 5 km

*Dissemination*: By dedicated lines to centres connected by GTS - By EUMETCast – by HSAF ftp
The "EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H SAF)" started on 2005 as part of the EUMETSAT SAF Network

http://hsaf.meteoam.it

H SAF objectives are:

• to provide satellite-derived products from existing and future satellites to satisfy the needs of operational hydrology. Products: precipitation - soil moisture - snow
• to perform independent validation of the usefulness of the products
• to assess the impact of the satellite products on hydrological applications.
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

Sentinel-2 L1C data downloaded from the Copernicus Open Access Hub. L1C image product consists of a series of 100 km²-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.
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    | 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
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

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

Contingency table results

|             | POD  | FAR  | POFD | ACC  | CSI  | HSS  |
|-------------|------|------|------|------|------|------|
| Probability of detection: $POD = \frac{a}{(a + c)}$ |
| False alarm ratio: $FAR = \frac{b}{(a + b)}$ |
| Accuracy: $ACC = \frac{(a + d)}{(a + b + c + d)}$ |

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                     |

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%
- 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

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

Probability of detection: \( POD = \frac{a}{a + c} \)

False alarm ratio: \( FAR = \frac{b}{a + b} \)

Accuracy: \( ACC = \frac{(a + d)}{(a + b + c + d)} \)
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.

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

| Region      | RMSE |
|-------------|------|
| Finland     | 0.15 |
| Italian Alps| 0.33 |
| Turkey      | 0.21 |
Conclusions

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.
Thank you for your attention