Response Letter

Validation of VIIRS snow cover in Central European Highlands

Patrik Sleziak[1], Michal Danko[1], Martin Jančo[1], Ladislav Holko[1], Juraj Parajka[2]

[1]Institute of Hydrology, Slovak Academy of Sciences, Bratislava, 841 04, Slovakia

[2]Institute of Hydraulic Engineering and Water Resources Management, TU Wien, Vienna 1040, Austria

The authors are grateful to the reviewer for careful evaluation of the manuscript. Our responses (given in italics) are given below.

Response to reviewer:

This is a potentially useful paper on regional evaluation of VIIRS snow cover products to replace MODIS, but it will require major revision. An uninformed reader could be left with the impression that the VIIRS snow cover is new and largely untested. In fact, a cursory search reveals more than twenty published evaluations going back to 2013. The information from Overall Agreement optimized for the entire dataset will be limited; is it possible to divide the data into periods or elevation bands with evaluation against observations that are not used in the optimisation?

Response: We want to thank the reviewer for her/his positive assessment of the manuscript. We acknowledge that several studies have evaluated VIIRS snow cover products since 2013. However, our analysis is based on a large dataset of 631 climate stations across Austria, complemented by a detailed catchment scale evaluation including forest and open sites, which is rare in the literature. In the revised manuscript, the Introduction will be expanded to include additional relevant literature.

The aim of our study is to identify the optimal NDSI threshold for VIIRS and to assess the resulting snow cover mapping accuracy across a comprehensive dataset and multiple spatial scales. We agree that evaluating the results on independent subsets of the data can provide additional insight into the robustness of the optimal threshold. However, this approach is beyond the scope of the study. In our study, the robustness is assessed through stratification by different elevation zones and land cover types.

Abstract

Comment 1: "MODIS" is not a dataset or a snow cover product (M*D10 is), and it is misleading to say that it is expected to be replaced by VIIRS in the near future; VIIRS snow cover products have been available since 2012.

Response: *Thank you for this clarification. In the revised manuscript, we will correct the terminology. The first sentences of the abstract will read: "The Moderate Resolution Imaging Spectroradiometer (MODIS) is a sensor on board the Terra and Aqua satellites providing one of the most attractive remote sensing datasets used for mapping snow cover. Data collection from both is expected to end in 2027. The VIIRS (Visible Infrared Imaging Radiometer Suite) sensor on board the Suomi NPP satellite provides a continuation of MODIS observations. Therefore, a reliable and accurate evaluation of this product is needed for future hydrological applications".*

Introduction

Comment 2: MODIS is on both Terra and Aqua, which are now in drifting orbits and data collection from both is expected to end in 2027.

Response: *Thank you for this note. This information will be added to the Introduction.*

Data

Comment 3: Smaller dots in Figure 1 would give a better impression of the distribution of stations. The open and forest sites with fortnightly measurements should be identified.

Response: *Thanks, we will modify the Figure 1 as suggested.*

Comment 4: How dense is the canopy at the forest site?

Response: *The average tree height is approximately 26.0 meters and the average diameter at breast height is 38.0 cm; the stand density index (stocking density) is low, approximately 0.6. The tree density of conifers (Norway spruce) at the forest was estimated to be 638 trees.ha^{-1} (Jančo et al., 2026). These sentences will be added to the Study area subsection of the Data section.*

Jančo, M., Škvarenina, J., Škvareninová, J., Danko, M., Sleziak, P.: Influence of total interception on the surface runoff in a decline mountain spruce forest, Front. Environ. Sci, 14, 1757503, https://doi.org/10.3389/fenvs.2026.1757503, 2026.

Comment 5: The VIIRS Snow Cover Products User Guide lists eight products; the one used should be stated.

Response: Thank you for this comment. The VIIRS snow cover dataset tested in the study is VNP10A1. This will be clarified in the revised manuscript.

Comment 6: The VIIRS visible channel used for NDSI isn't 0.55 microns and isn't green.

Response: Thank you for this correction. In response to this comment, we will add the following explanation to the paragraph regarding "VIIRS snow cover dataset: "The NDSI is calculated using the VIIRS image bands I1 (0.64 μm, visible red) and I3 (1.61 μm, shortwave near-infrared) (Eq. 1)".

$$NDSI = (B1 - B3)/(B1 + B3) \qquad (Eq. 1)$$

where, B1 is the VIIRS red light band and B3 is the VIIRS shortwave near-infrared band I3 (Riggs et al., 2016).

Snow has a high reflectance in visible band and a low reflectance in shortwave infrared, which allows it to be distinguished from snow-free land. A water mask is applied distinguish snow from inland water. The NDSI values from 0 to 100 are within the possible range of snow. More details of the VIIRS snow cover data are described in the VIIRS Snow Products User Guide (Riggs et al., 2016; Riggs et al., 2019).

Riggs, G. A., Hall, D. K., and Román, M. O.: VIIRS Snow Products User Guide: Collection 1 (Version 1.0, 9 September 2016). NASA. https://viirsland.gsfc.nasa.gov/PDF/VIIRS_snow_products_user_guide_version_1.pdf, 2016.

Riggs, G. A., Hall, D. K., and Román, M. O.: VIIRS/NPP Snow Cover Daily L3 Global 375m SIN Grid, Version 1. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/VIIRS/VNP10A1.001, 2019.

Comment 7: NDSI does not distinguish snow from inland water; a water mask is used.

Response: We agree. In response to this comment, we will improve the paragraph regarding "VIIRS snow cover dataset" (see comment above).

Comment 8: How many stations are there in each of the elevation groups? How representative are the point measurements of surrounding 375 m areas?

Response: Thank you for these questions. Information regarding the number of stations in each group (see below) will be added to the manuscript.

Stations above 1200 m a.s.l. (98 stations)
900 – 1200 m a.s.l. (230 stations)
600 – 900 m a.s.l. (142 stations)
300 – 600 m a.s.l. (106 stations)
Station below 300 m a.s.l. (55 stations)

Point measurements represent a single location within a 375 m pixel and may not fully represent conditions within the surrounding area due to spatial variability. Our study uses a large dataset of measurements across Austria, and validation using satellite pixel values is a standard approach in evaluating satellite snow products (e.g., Parajka et al., 2012; Tong et al., 2020).

Parajka, J., Holko, L., Kostka, Z., and Blöschl, G.: MODIS snow cover mapping accuracy in a small mountain catchment–comparison between open and forest sites, Hydrol. Earth Syst. Sci., 16, 2365–2377, https://doi.org/10.5194/hess-16-2365-2012, 2012.

Tong, R., Parajka, J., Komma, J., and Blöschl, G.: Mapping snow cover from daily Collection 6 MODIS products over Austria, J. Hydrol., 590, 125548, https://doi.org/10.1016/j.jhydrol.2020.125548, 2020.

Methods

Comment 9: Numerator of Equation 2 should be A + D.

<u>Response:</u> Yes, that is correct, thank you for the comment. In the R code (see "Supplement_Rcode") it is implemented correctly, we will correct it in Equation 2 in the manuscript.

Comment 10: If T_SD = 0 cm, "Station snow depth >= T_SD (SNOW)" in Table 1 does not make sense.

<u>Response:</u> Thank you for this comment. Table 1 has been corrected (see below).

Tab. 1 Confusion matrix defining the snow cover mapping accuracy (OA). T_{NDSI} is the VIIRS NDSI threshold and T_{SD} represents the snow depth threshold at the climate stations/snow profiles.

	VIIRS NDSI > = T_{NDSI} (SNOW)	VIIRS NDSI < T_{NDSI} (LAND)
Station snow depth > 0 cm (SNOW)	A	B
Station snow depth = 0 cm (LAND)	C	D

Results

Comment 11: Fraction of measurements with snow cover would be a useful addition to figures. 100% accuracy for a 100% NDSI threshold in snow-free months is trivial.

<u>Response:</u> Thank you for this comment. Following reviewer suggestion, we have added the fraction of measurements with snow cover to the figures (see below). In a similar way, we will prepare it for Austria and include it in the revised manuscript.

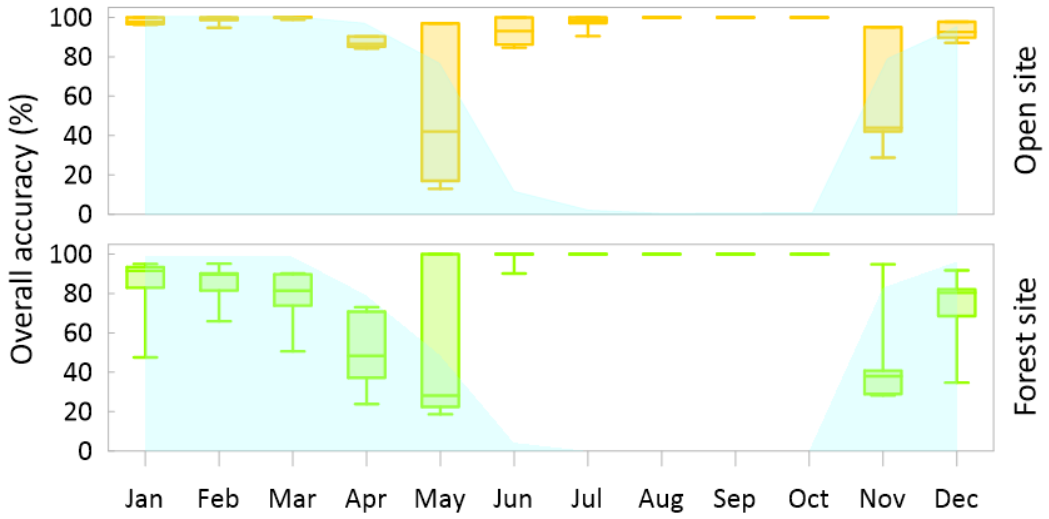

Figure 9: Accuracy of VIIRS snow cover maps with optimal NDSI threshold for different months and land cover classes (open and forest sites) in the period from January 2012 to December 2020. The shaded area represents the fraction of snow-covered days (%).

Discussion and conclusions

Comment 12: Zhang et al. (2020) and Dietz and Rossler (2025) used different metrics to select thresholds; does this make a difference?

<u>Response:</u> Thank you for this point. Dietz and Rossler (2025) selected the NDSI threshold based on comparison with 381 classified Landsat images by maximizing the F1 score. Zhang et al. (2020) determined the optimal NDSI threshold as the one with the highest averaged Cohen's Kappa and F-Score for 330 stations in China. In our study, based on daily observations of snow depth from 631 climate stations and 9 snow profiles, the optimal NDSI threshold with the highest mapping accuracy is determined through a detailed sensitivity test.

We agree that different performance metrics may lead to slightly different optimal thresholds. In our study, overall accuracy index (OA) was selected as the primary metric due to its suitability for large scale evaluation across diverse topographic and climatic conditions (Tong et al., 2020). While the F1 score emphasize the balance between precision and recall for the snow class, OA reflects the overall agreement between observed and mapped snow cover across both snow and snow-free conditions. This will be discussed in the Discussion and conclusions section of the revised manuscript.

Tong, R., Parajka, J., Komma, J., and Blöschl, G.: Mapping snow cover from daily Collection 6 MODIS products over Austria, J. Hydrol., 590, 125548, https://doi.org/10.1016/j.jhydrol.2020.125548, 2020.

Minor corrections:

Comment 13: l. 24: "differences are found"

Response: This will be corrected.

Comment 14: l. 44: "existing global snow cover products" here refers to MODIS products.

Response: This will be corrected.

Comment 15: l. 131: "along an approximately"

Response: This will be corrected.

Comment 16: l. 144: "each of the categories of the confusion matrix"

Response: This correction will be made.

Comment 17: l. 160: "The optimal NDSI threshold"

Response: Thank you, it will be fixed.