Response to Reviewer (RC2)

Manuscript: *Validation of VIIRS snow cover in Central European Highlands* (egusphere-2026-1120)

We thank the reviewer for the very careful and constructive assessment, and in particular for recognising the value of the dual-scale design and the threshold sensitivity analysis. The comments suggest several new quantitative analyses, summarised below together with the corresponding manuscript changes. All new results were obtained by re-running our processing chain on the daily snow-depth and VIIRS/MODIS NDSI data for the 631 climate stations (2012–2020). The documented R scripts are added to the Supplement.

Comment 1 — General assessment

We appreciate the positive overall evaluation and address each specific point below. A new sentence at the start of the Methods now states explicitly that the optimal threshold is a statistical optimum that maximises agreement between a 375 m pixel and a point measurement, with the implications discussed under Comments 2–5.

Comment 2 — Mixed pixel in forest; meaning of a single "optimal" threshold

We fully agree and have rewritten the relevant Discussion text. Our position is now stated explicitly:

1. The OT is a **statistical optimum, not a physical snow-detection threshold**. In a forested 375 m pixel the at-sensor reflectance mixes canopy, gaps, shadow and snow, so the NDSI of a snow-covered forest pixel is systematically depressed. The low forest OT (~14, i.e. ~0.14) is therefore the value that compensates for canopy-induced NDSI reduction given that the ground is snow-covered — the interpretation the reviewer proposes. We no longer imply 0.14 is a physically preferable threshold.
2. **Point-to-pixel representativeness** is a limitation; we add this point and cite the comparable discussion in Parajka et al. (2012) for the same catchment.
3. **Supporting evidence from the data**: on cloud-free days when the ground reports snow, a large fraction of pixels carry low NDSI, and this fraction increases with elevation (Comment 4), quantifying why no single physical threshold can capture snow under canopy and in the open simultaneously.

Manuscript changes: In response to this comment, we have added a new paragraph into the Discussion section framing OT as a statistical match; mixed-pixel/representativeness point; and adding a clarification on the forest OT.

Comment 3 — Sensitivity to the snow-depth threshold (T_SD)

We re-estimated OT and OA at every station for T_SD = 0, 1, 2 and 5 cm, by elevation group (new Supplementary figure/table). Median OA (%) by elevation group:

Elevation (m)	N	T_SD=0 (≡1)	T_SD=2	T_SD=5
<300	97	96.4	97.2	98.6
300–600	230	93.7	94.2	95.5
600–900	141	90.7	90.8	91.9
900–1200	106	86.0	86.6	87.4
>1200	55	82.7	83.1	83.8
All	629	92.5	92.8	93.9

From the results, we have added three new points into the manuscript:

1. **T_SD = 0 and 1 cm are identical.** EHYD depths are integer centimetres, so "depth > 0" and "depth ≥ 1 cm" select exactly the same days; the choice has no effect on any result. We now define the criterion as "depth ≥ 1 cm", equivalent to the previous T_SD = 0 cm.
2. **Sensitivity is modest and largest at low elevation.** Raising T_SD to 5 cm increases the per-station median OA by only ~1.4% overall, but the largest gain (+2.2%, to 98.6%) is at <300 m — exactly where ephemeral snow is common, as the reviewer anticipated. Only 2.6% of all cloud-free station-days fall in the 0 < depth < 5 cm band.
3. **The pooled single threshold rises from 40 to 97 at T_SD = 5 cm**, driven by low-elevation stations: when shallow/ephemeral snow days (often undetected by VIIRS) are reclassified as land, agreement is maximised by a very high threshold. This confirms ephemeral low-elevation snow as the quantity most affected by T_SD.

Manuscript changes: In response to this comment, we have redefined the definition of T_SD = 1 cm (≡ 0 cm) in the Methods section; added a new Supplementary Fig. and Table of OA/OT vs T_SD by elevation; and expended the Discussion section about the findings.

Comment 4 — Very low OT (~11) above 1200 m: real discrimination or artefact?

Our re-analysis supports a partly-artefact interpretation, now in the Discussion. On cloud-free winter (DJF) days when the ground reports snow, the median VIIRS NDSI falls monotonically with elevation and the share of true-snow days with near-zero NDSI rises sharply:

Elevation (m)	Median NDSI on snow days	% snow days NDSI < 10	% NDSI < 40
<300	58	12.9	22.4
300–600	54	25.0	33.8
600–900	45	35.6	45.1
900–1200	40	39.0	49.9
>1200	32	43.1	53.9

Above 1200 m, 43% of confirmed-snow cloud-free days carry NDSI below 10, which mechanically forces the OA-maximising threshold downward. We attribute this to a combination of (i) illumination/terrain shadow (low winter solar elevation in steep alpine terrain depresses green-band reflectance and hence NDSI), (ii) sub-pixel/mixed-pixel and representativeness effects, and (iii) an adaptation that recovers snow which a threshold of 40 would miss. As we cannot separate the illumination from the representativeness component with the present data, we now frame the high-elevation OT as a statistical adaptation partly driven by low NDSI on snow-covered pixels (shadow, mixed pixels) rather than solely improved physical discrimination. We also note that cloud (code 250) is excluded from the confusion matrix, so persistent cloud reduces the high-elevation sample size (now reported per elevation/season) rather than biasing NDSI.

Manuscript changes: In response to this comment, we have added a new Discussion paragraph on the physical origin of the low high-elevation OT; added new Supplementary table of NDSI-on-snow-day statistics by season and elevation; and added a clarification that cloud is excluded, not misread as low NDSI.

Comment 5 — Low winter OA (~58–62%) at high elevation: misclassification or representativeness?

We decomposed the winter confusion matrix into omission and commission components by elevation (new Results table/figure). At the global threshold T_NDSI = 40 (DJF):

Elevation (m)	OA (%)	Omission B (ground snow, VIIRS land)	Commission C (ground bare, VIIRS snow)
<300	61.4	3.8	34.8
300–600	65.8	12.2	21.9
600–900	64.0	27.6	8.3
900–1200	58.1	36.6	5.3
>1200	51.9	46.1	2.0

The error structure reverses with elevation, which answers the question directly:

- **At low elevation the error is dominated by commission** (VIIRS maps snow where the valley gauge reports none) — the signature of spatial representativeness: snow-free station footprints embedded in otherwise snow-covered surroundings. This supports the reviewer's representativeness hypothesis.
- **At high elevation the error is dominated by omission** (VIIRS maps land where the gauge reports snow), which is consistent with depressed NDSI (shadow/mixed pixel, Comment 4) and with the global T = 40 being too high for high-elevation snow.

Two independent corroborations are added:

1. **MODIS cross-check.** We do not have snow-pillow/AWS networks at the regional scale, but the independent MODIS retrieval provides an equivalent test. MODIS-Terra and the Terra+Aqua combination reproduce the same monthly OA pattern as VIIRS, including the low winter values (Jan: VIIRS 59.6%, Terra 59.5%, COMB 58.9%; Comment 6). The low winter OA is therefore not a VIIRS-specific misclassification but reflects representativeness and the fixed global threshold, shared by both sensors.
2. **Local-threshold recovery.** Fitting the threshold per station recovers much of the winter gap — winter median OA rises from 66.3% to 85.2% at <300 m (+18.9) and from 50.7% to 60.0% at >1200 m (+9.3) — showing that a substantial part of the low winter OA at T = 40 is threshold-related rather than intrinsic VIIRS failure.

Manuscript changes: In response to this comment we have added a new Results sub-section "Error structure of winter mapping" with the omission/commission table and figure; revised attribution to representativeness (commission, low elevation) and threshold/shadow effects (omission, high elevation); added MODIS cross-check.

Comment 6 — Systematic VIIRS–MODIS comparison over all overlapping days

We carried out a systematic comparison over all overlapping days 2012–2020 at the 631 stations, using MODIS-Terra and the Terra+Aqua combination:

1. **Co-classification.** Where both products retrieve (cloud-free in both), the VIIRS–MODIS snow/land agreement is 98.1% (Terra) and 97.9% (COMB). Including cloud, overall agreement is 79.7% (Terra) /

81.3% (COMB); the disagreement is dominated by cloud-mask differences (different overpass times), not snow/land confusion, and the Terra+Aqua combination yields more cloud-free days (664k vs 562k).

2. **Monthly OA vs ground.** VIIRS, MODIS-Terra and MODIS-COMB track each other within ~1–2% every month, all showing the winter dip (Jan ≈ 58–60%) and summer maximum (≈ 100%).
3. **Optimal-threshold consistency.** Per-station median OT is 33 (VIIRS), 38 (Terra) and 42 (COMB); the VIIRS–Terra per-station OT correlation is r = 0.93 (Pearson), 0.92 (Spearman) — confirming, directly from these data, the close inter-sensor threshold relationship previously cited from Tong et al. (2020).

These results replace the two-season illustration as the main VIIRS–MODIS evidence; Fig. 12 (SWE/classification for two seasons) is retained as an illustrative example. The same script reproduces the catchment-scale (open/forest) comparison when run with the snow-course VIIRS/MODIS extractions and the snow-course depth/SWE series.

Manuscript changes: In response to this comment we have expanded the results section and added a new regional VIIRS–MODIS contingency table and full-period monthly-OA figure; new statement of the directly-computed OT correlation (r = 0.93); catchment Figs. 11–12 revised with Fig. 12 moved to illustration.

Comment 7 — Unify decimal vs percentage NDSI notation

Agreed. The VIIRS VNP10A1 product reports NDSI on a 0–100 scale, so we now use the 0–100 integer convention consistently throughout text, tables and figures (e.g. “OT_NDSI = 40”, “OT_NDSI = 14”), giving the 0–1 equivalent once in parentheses at first mention. All “0.4 / 0.14 / 0.23 / 0.3 / 0.37” instances are converted accordingly (retaining the 0–1 form only where quoting another study’s stated value, with the 0–100 equivalent added).

Comment 8 — Fig. 1: where are Austria and Slovakia?

Thank you, we revised the Figure 1 according to suggestions of both reviewers (Austria and Slovakia in caption, smaller dots, highlighted open and forest sites).

Comment 9 — Split “Discussion and conclusions”

Agreed. Section 5 is split into “5 Discussion” (threshold behaviour, mixed-pixel/representativeness, the omission/commission analysis, the VIIRS–MODIS comparison) and a concise “6 Conclusions” (main findings and outlook on hydrological-model application).

Summary of new material added in revision

- **Comment 3:** per-station OT/OA at T_SD = 0/1/2/5 cm by elevation → Supplementary figure + table; Discussion paragraph.
- **Comment 4:** NDSI distribution on cloud-free true-snow days by elevation → Supplementary table; Discussion paragraph.
- **Comment 5:** winter omission/commission decomposition by elevation → Results sub-section, table and figure; MODIS cross-check; local-threshold recovery.
- **Comment 6:** full-period regional VIIRS–MODIS contingency, monthly-OA figure, and directly-computed OT correlation (r = 0.93).
- **Editorial:** unified 0–100 NDSI notation (7); redrawn Fig. 1 with country labels and locator (8); Discussion/Conclusions split (9).
- **Code:** three documented R scripts added to the Supplement (01_snow_depth_threshold_sensitivity.R, 02_error_decomposition_and_ndsi_diagnostics.R, 03_viirs_modis_comparison.R).

We thank the reviewer again for the constructive comments, which have improved the rigour and clarity of the manuscript.