Validation of shared parameterisation for cosmic ray neutron sensors measuring snow water equivalent in the Italian Alps

Full Abstract & OSPP Voting

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EGU26 General Assembly 3-8 May 2026, Vienna

Visual summary

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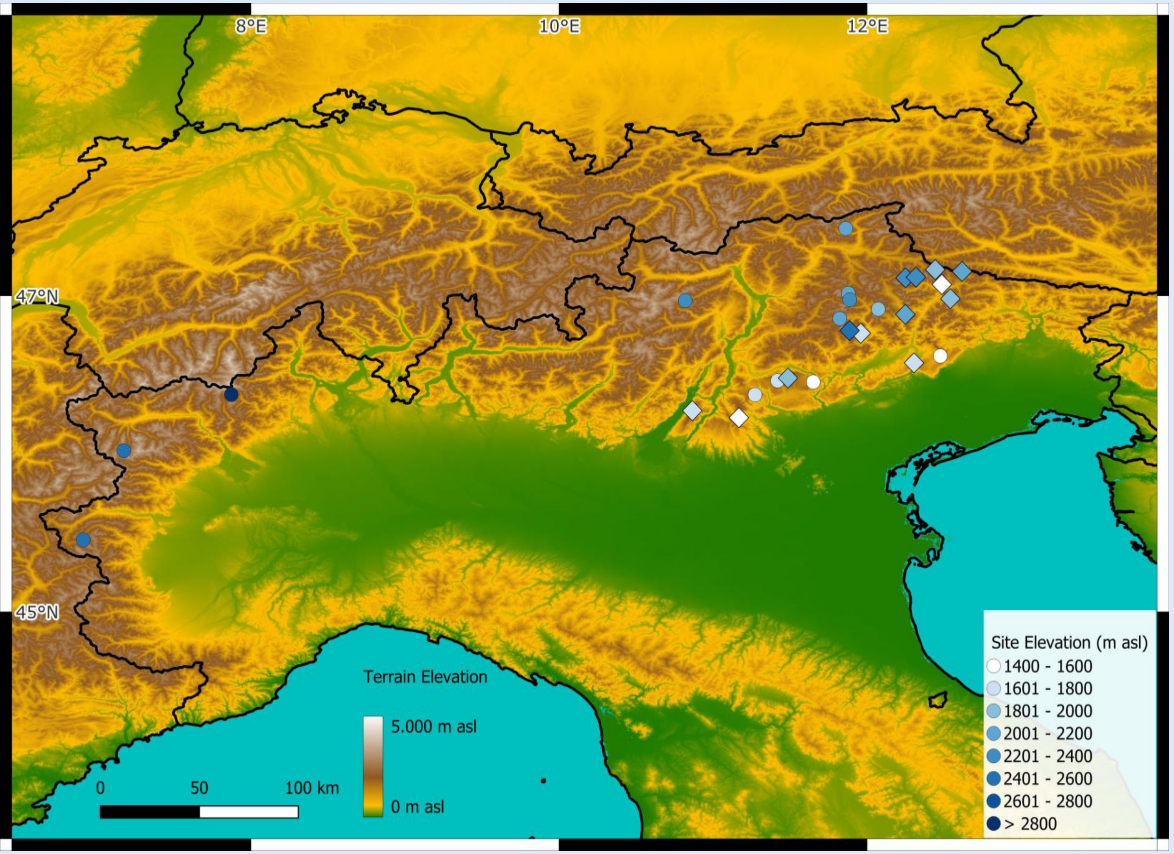
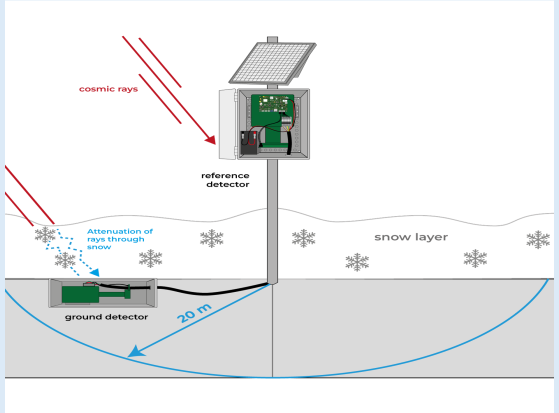
EGU26 GENERAL ASSEMBLY

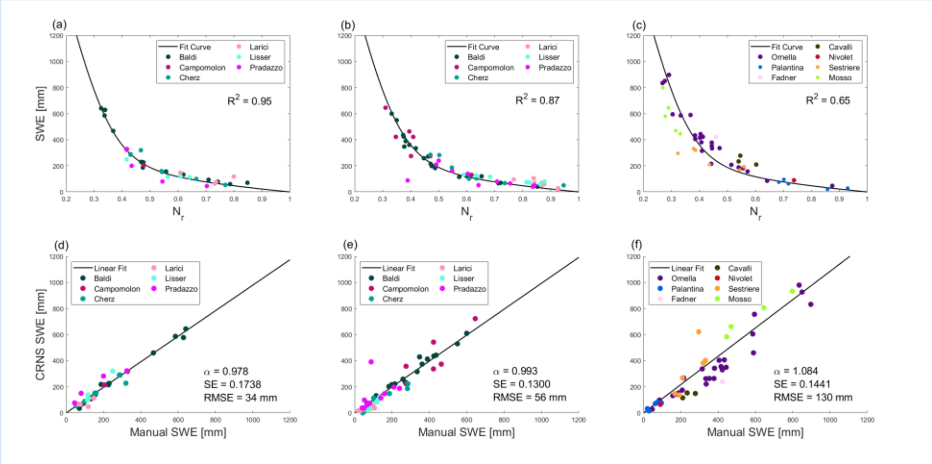
26 sites across the Italian Alps (1422 – 2901 m a.s.l.)





CRNS integrated into AWSs for continuous SWE data

Shared conversion curve



- 146 manual SWE samples
- Two snow seasons
- Transferable method

See you at the touchscreen!

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Session CR6.2 (PICO spot 1a)

PICO Screen 1a.13

Wed 6 May 2026 11:23 – 12:30

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Introduction

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- Traditional measurements of snow water equivalent (SWE) are carried out **manually**
- Manual SWE sampling techniques are **invasive** and require **trained workforce**
- Data from traditional SWE dataset have **limited time density** due to sites **accessibility issues**
- Cosmic Rays Neutron Sensing (**CRNS**) technology offers a **non-invasive and continuous** alternative for measuring SWE
- In recent years, various automated weather stations (**AWSs**) in the Italian Alps saw the **integration of CRNS** probes
- Italy has now **one of the widest CRNS network** for SWE retrieval

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Research Questions

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1. What are the performances of a **shared parameterisation** across the network?
2. Is CRNS only a tool to **increase time coverage** of traditional SWE datasets?
3. Can CRNS probes be deployed in **unmonitored sites** to increase spatial coverage of SWE data

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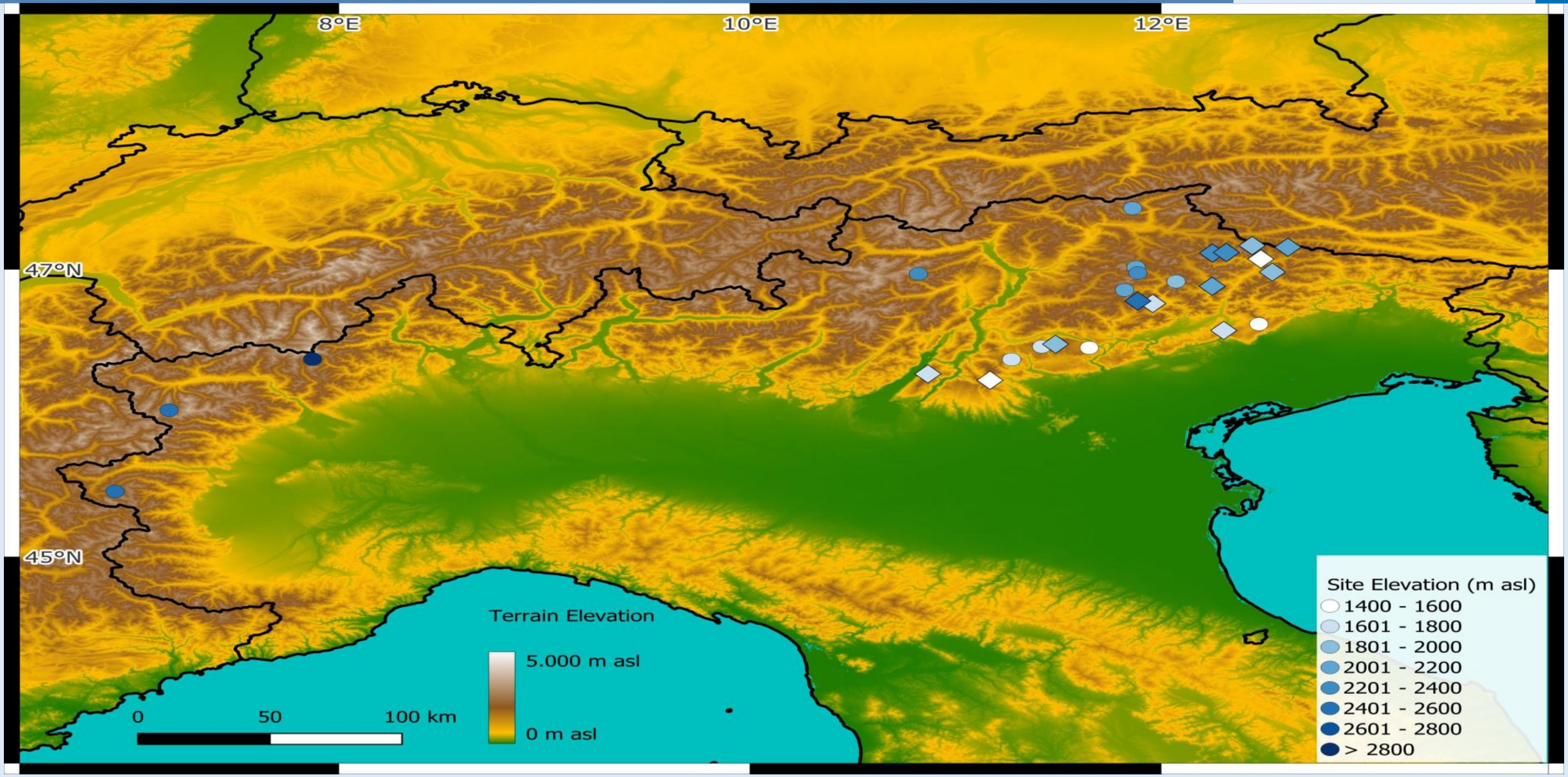
The Italian CRNS Network map



Map of the CRNS network, dots and diamonds represent monitored and unmonitored sites respectively

Abstract

Gallarate, M., et al.: Brief communication: Network-wide parameterisation for estimating snow water equivalent through cosmic ray neutron sensors in the Italian Alps, *EGUsphere* [preprint], doi:10.5194/egusphere-2025-6148, 2026

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The network’s sites

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Name	Elevation [m a.s.l.]	Latitude [° N]	Longitude [° E]	Time Series Lenght
Lisser*	1422	45.9543	11.6510	11/08/2023 - 01/09/2025
Campogrosso	1462	45.7285	11.1684	12/11/2023 - 01/09/2025
Palantina*	1492	46.1189	12.4759	26/09/2023 - 01/09/2025
Sant'Antonio	1495	46.5720	12.4858	21/12/2023 - 01/09/2025
Faverghera	1603	46.0751	12.3013	07/08/2023 - 01/09/2025
Larici*	1606	45.9636	11.4193	10/08/2023 - 01/09/2025
Campomolon*	1732	45.8732	11.2729	10/10/2023 - 01/09/2025
Monte Baldo	1756	45.7731	10.8657	13/09/2023 - 01/09/2025
Malga Losch	1757	46.2624	11.9595	06/10/2023 - 01/09/2025
Casera Doana	1887	46.4812	12.5410	19/09/2023 - 01/09/2025
Baldi*	1913	46.4152	12.0731	21/09/2023 - 01/09/2025
Coltrondo	1929	46.6652	12.4435	20/09/2023 - 01/09/2025
Cima Dodici	1965	45.9790	11.4868	18/07/2024 - 01/09/2025
Val Visdende	2001	46.6538	12.6174	09/11/2023 - 01/09/2025
Cherz*	2010	46.5153	11.8782	01/11/2023 - 01/09/2025
Monte Rite	2013	46.3823	12.2484	09/07/2024 - 01/09/2025
Fadner*	2155	46.9256	11.8614	25/10/2024 - 01/09/2025
Pradazzo*	2195	46.3559	11.8227	25/11/2023 - 01/09/2025
Ornella*	2227	46.4757	11.8863	05/10/2023 - 01/09/2025
Cavalli*	2255	46.4694	10.8194	30/10/2024 - 01/09/2025
Monte Piana	2262	46.6134	12.2503	05/10/2023 - 01/09/2025
Tre Cime	2375	46.6176	12.3178	10/07/2024 - 01/09/2025
Sestriere*	2490	44.9540	6.9111	15/10/2023 - 01/09/2025
Nivolet*	2550	45.5192	7.1714	02/01/2024 - 01/09/2025
San Martino	2580	46.2793	11.8864	11/07/2024 - 01/09/2025
Mosso*	2901	45.8754	7.8717	28/12/2023 - 01/09/2025

- 26 sites:
  - 13 with available manual SWE data (bold)
  - 6 used for calibration (*)
- Four Italian regions
- Managed by research institutions and environmental protection agencies
- Elevation range ~1.5 km (1422 – 2901 m a.s.l.)
- Two snow seasons (2023/24 and 2024/25)

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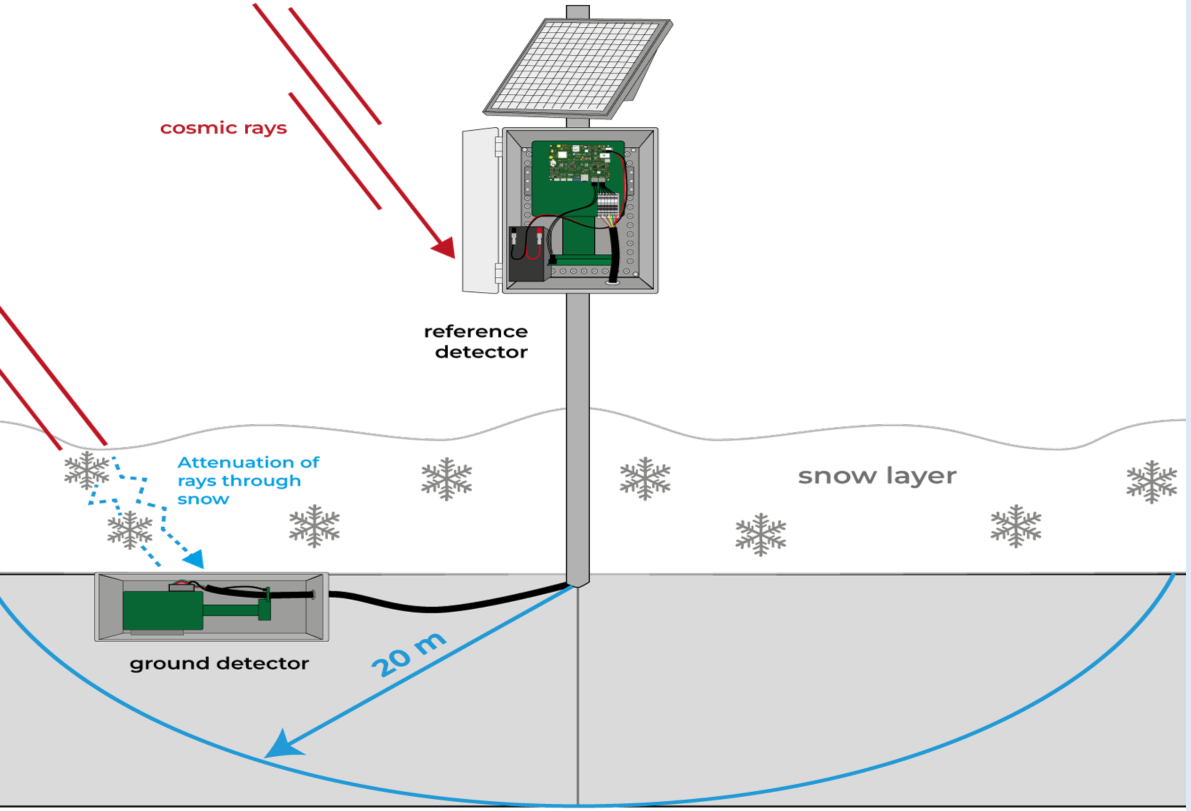
CRNS setup



- Coupled Cosmic Rays (CR) detectors
- Li-doped ZnS(Ag) scintillators
- Ground detector → Neutrons
- Mast detector → Muons for incoming correction
- Integrated barometer for atmospheric pressure correction

Abstract

Atmospheric pressure correction

Hourly raw count rates (C_{raw}) undergo the **atmospheric pressure correction**:

$$C_{apc} = C_{raw} * \exp[\beta(p - p_{ref})]$$

- C_{apc}: atmospheric pressure corrected counts (neutron or muons)
- p: atmospheric pressure
- p_{ref}: site-specific reference atmospheric pressure (elevation dependent)
- β: correction factor different for neutrons and muons

Abstract

Reference count rates

At each site **baseline count rates** are needed for neutrons (N_0) and muons (μ_0)

These values are taken simultaneously over a period with the following characteristics:

- Length of at least **24 hours**
- **Stable** signal (i.e. without discarded data)
- **Absence of snow** cover on the ground

N_0 is strongly **dependent** on each site's **elevation**, **soil composition**, and **morphology**

Before the beginning of each snow season N_0 and μ_0 are **assessed and updated** if needed

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Incoming correction and normalisation

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Neutron counts are scaled with an incoming correction factor **based on the muon flux** measured on the mast:

$$N = N_{apc} * \frac{\mu_0}{\mu_{apc}}$$

Dividing the corrected neutron counts (N) by their reference value (N_0) gives the **normalised neutron count rate** (N_r):

$$N_r = \frac{N}{N_0}$$

Stevanato, L., et al.: An Alternative Incoming Correction for Cosmic Ray Neutron Sensing Observations Using Local Muon Measurement, *Geophys. Res. Lett.*, 49, e2021GL095383, doi:10.1029/2021GL095383, 2022

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Methods and Workflow

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1. Manual SWE measurements
2. Comparison with daily averaged N_r
3. From N_r to SWE through the regression curve
4. Linear regression of CRNS SWE
5. Correlation among sites SWE series

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Manual SWE sampling

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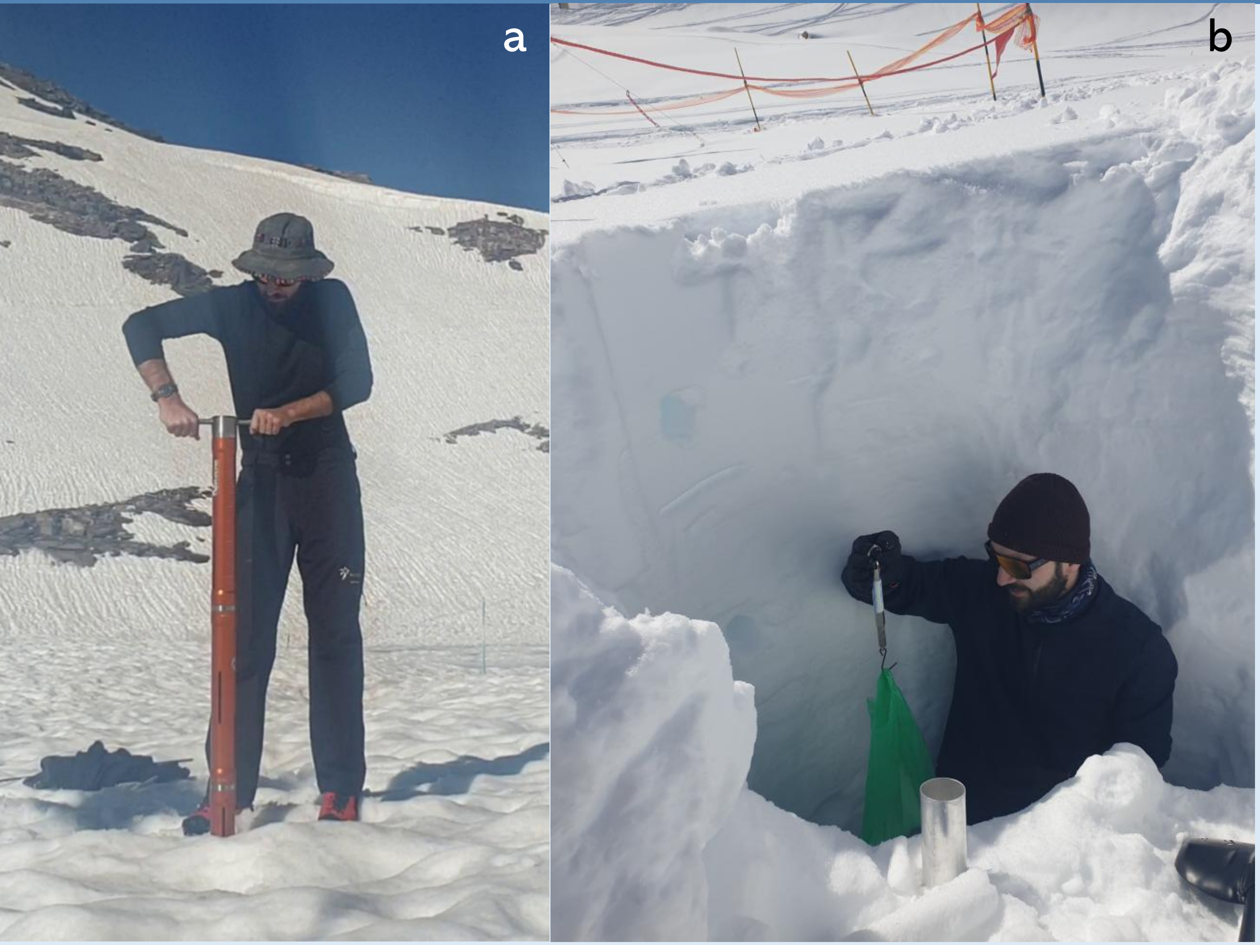

Traditional SWE measures were taken at 13 sites of the network with **two techniques**:

a) **Vertical coring** of the entire snow depth

b) **Horizontal samples** of homogenous snow layers across the **snowpack profile**

Total of **146** manual SWE samples
Range: 20 – 897 mm
Spanning **two snow seasons**

Divided in **calibration** and **validation** subsets

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Regression curve

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SWE is derived from N_r as:

$$SWE = -\frac{10}{\Lambda} log N_r$$

Where Λ is the attenuation length defined as:

$$\Lambda = \frac{1}{\Lambda_{max}} + \left(\frac{1}{\Lambda_{min}} - \frac{1}{\Lambda_{max}}\right) * \left[1 - exp\left(\frac{a_1 - N_r}{a_2}\right)\right]^{-a_3}$$

$\Lambda_{min,max}$: asymptotic values of the attenuation length
a_i: curvature of sigmoidal function

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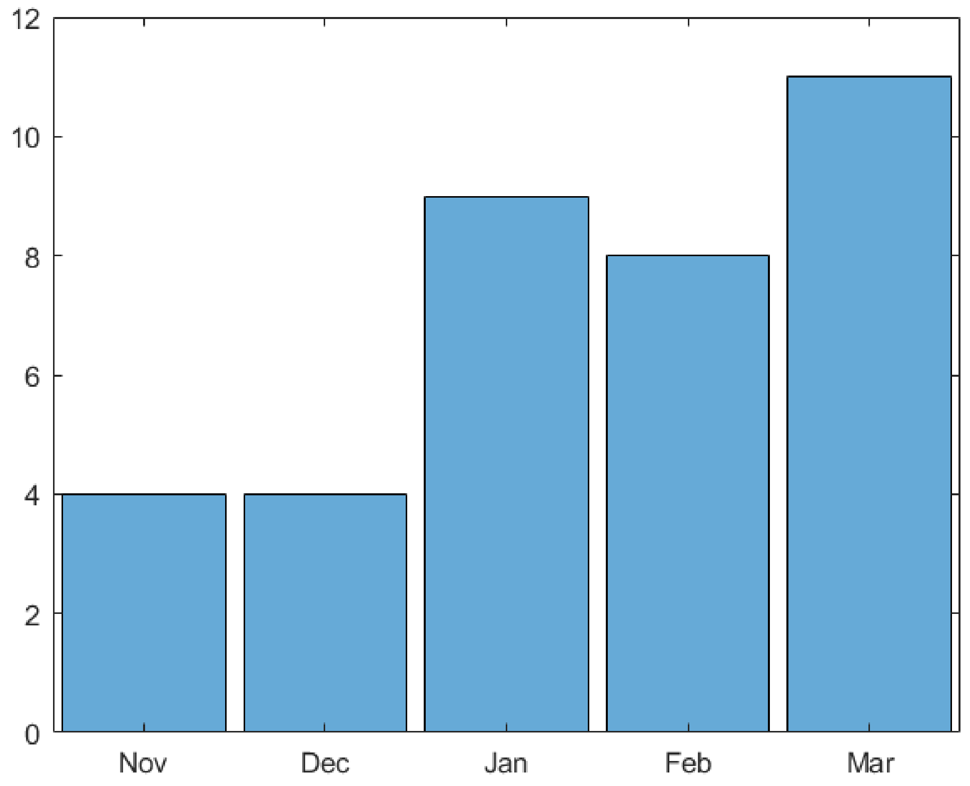
Gugerli, R., et al.: Continuous and autonomous snow water equivalent measurements by a cosmic ray sensor on an alpine glacier, *The Cryosphere*, 13, 3413–3434, doi:10.5194/tc-13-3413-2019, 2019

Abstract

Calibration dataset



Monthly distribution of the manual SWE samples used for calibration

- Data from six sites
- First half of 2023 – 2024 snow season
- 35 manual SWE samples
- Fit of Λ_{min} and a_1
- Regression obtained is shared by all CRNS probes of the network

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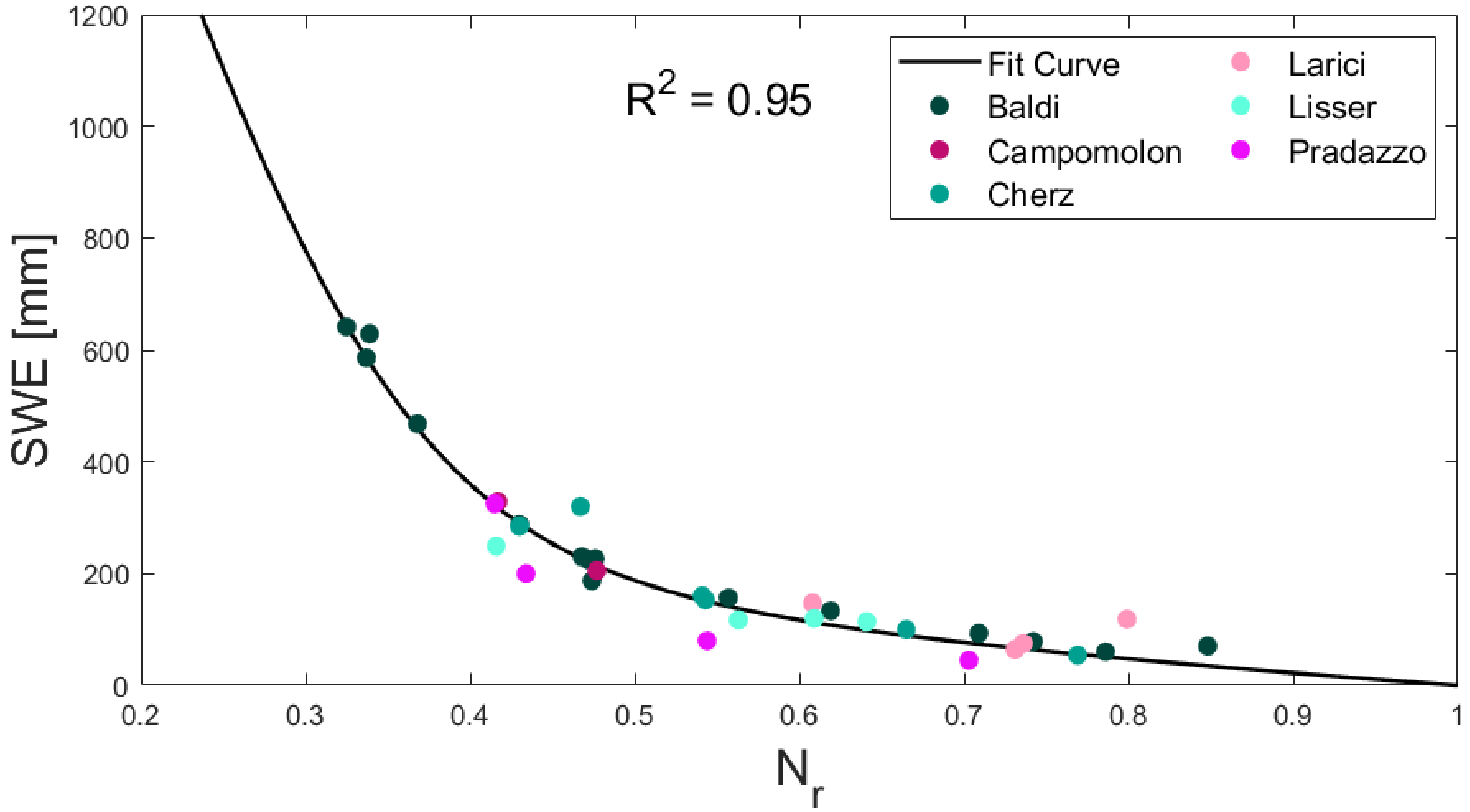
Calibration results



Normalised neutron counts against manual SWE (coloured dots) and regression curve obtained (black line)

Parameters

Λ_{min}	21 cm
Λ_{max}	114 cm *
a_1	0.41
a_2	0.082 *
a_3	1.117 *

* fixed from Gugerli et al. 2019 to avoid overfitting

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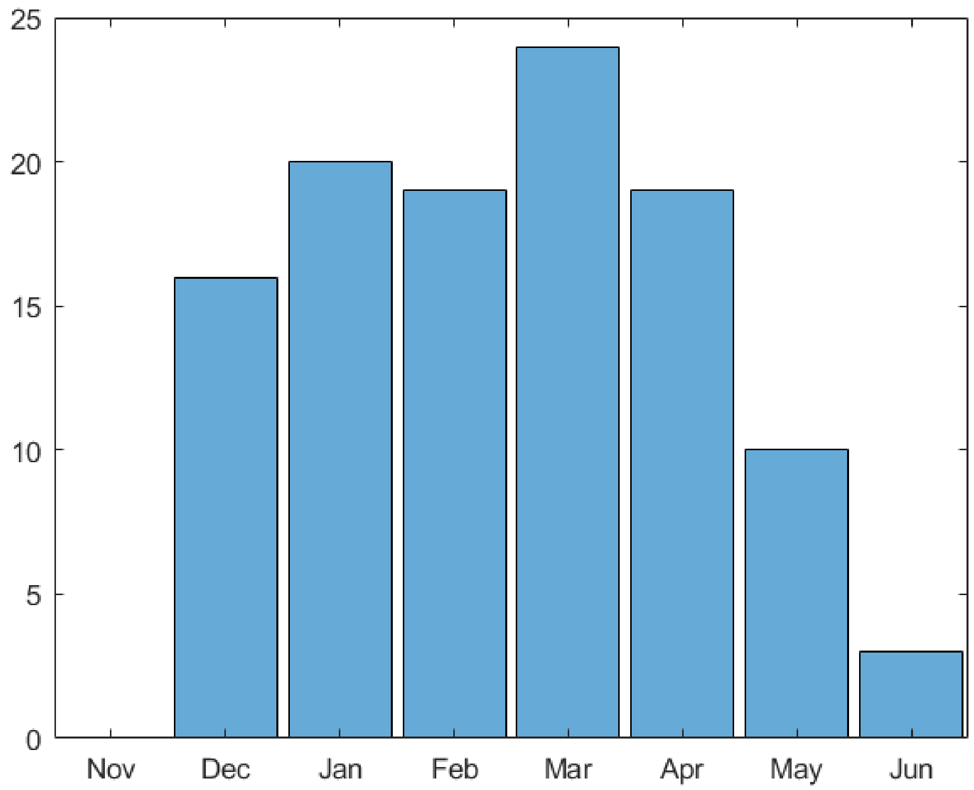
Validation dataset



Monthly distribution of the manual SWE samples used for validation

- Data from 13 sites (6 used for calibration and 7 additional)
- 111 manual SWE samples
- Captures accumulation and melting periods
- Peak of measures (March) coincides with peak SWE at most sites

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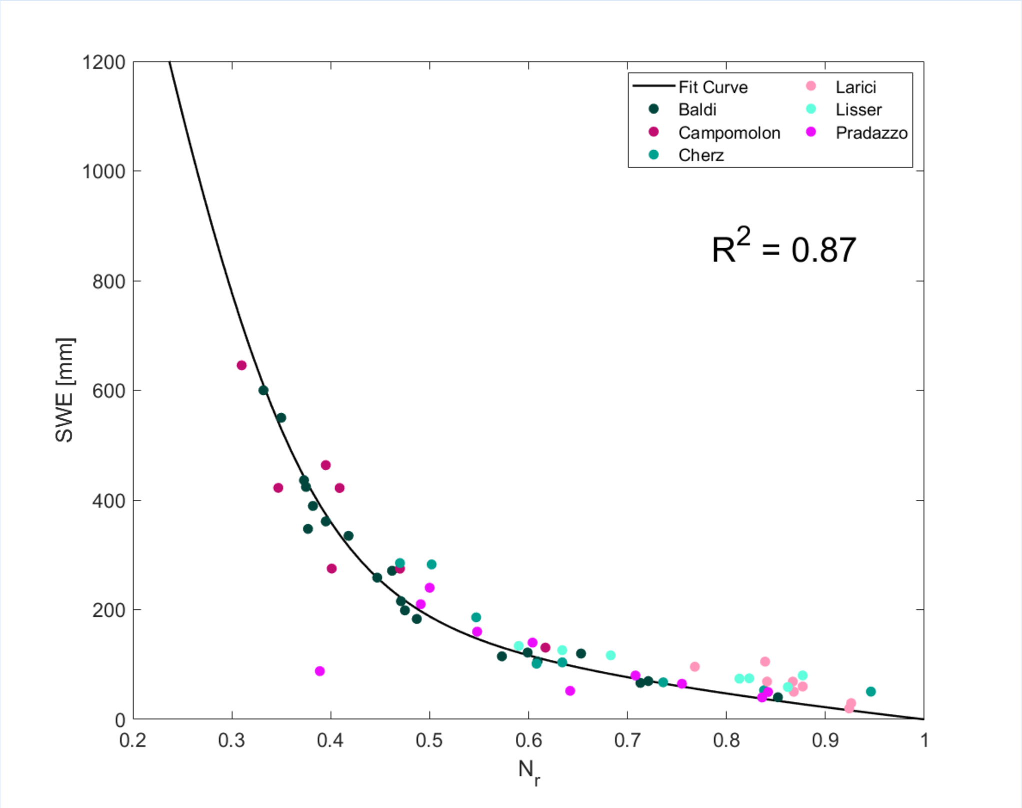
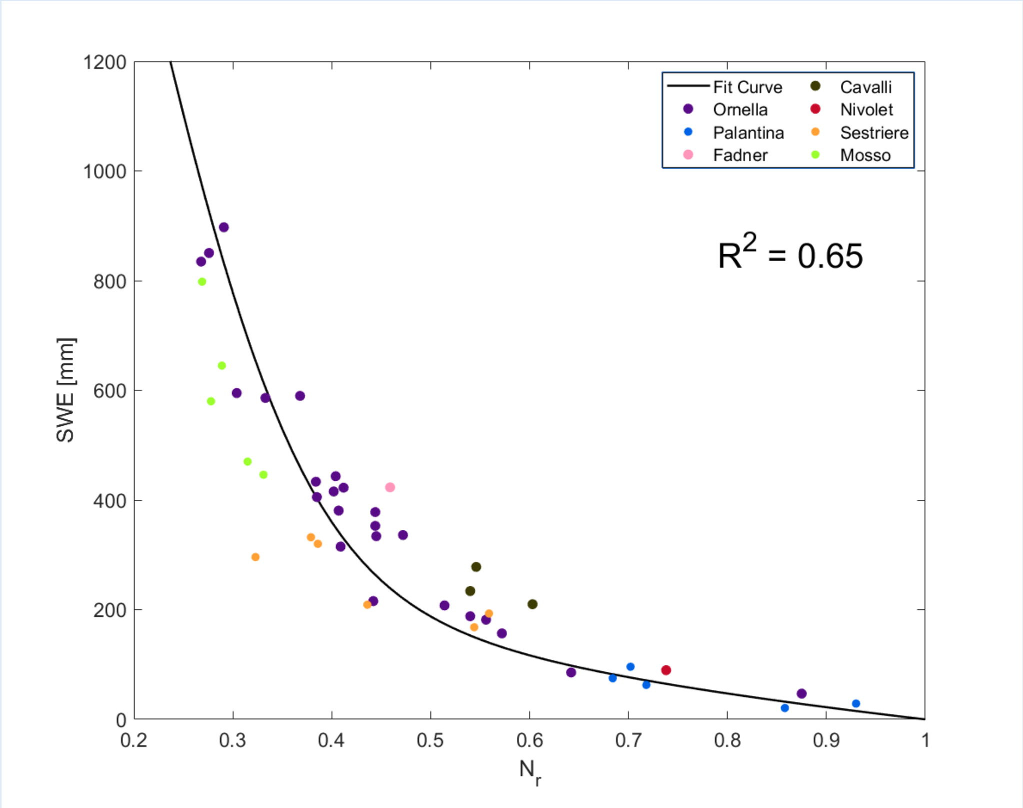
Validation results

Same sites as calibration



Additional sites



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Linear regression of CRNS SWE

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Proposed by Egli et al. (2009) → linear fit of manual SWE vs CRNS SWE

$$SWE_{CRNS} = \alpha \cdot SWE_{manual}$$

- α close to 1 indicates low systematic bias
- Standard Error (SE) of α informs on data dispersion across predictive line
- Root Mean Square Error (RMSE) as estimate of measurement uncertainty

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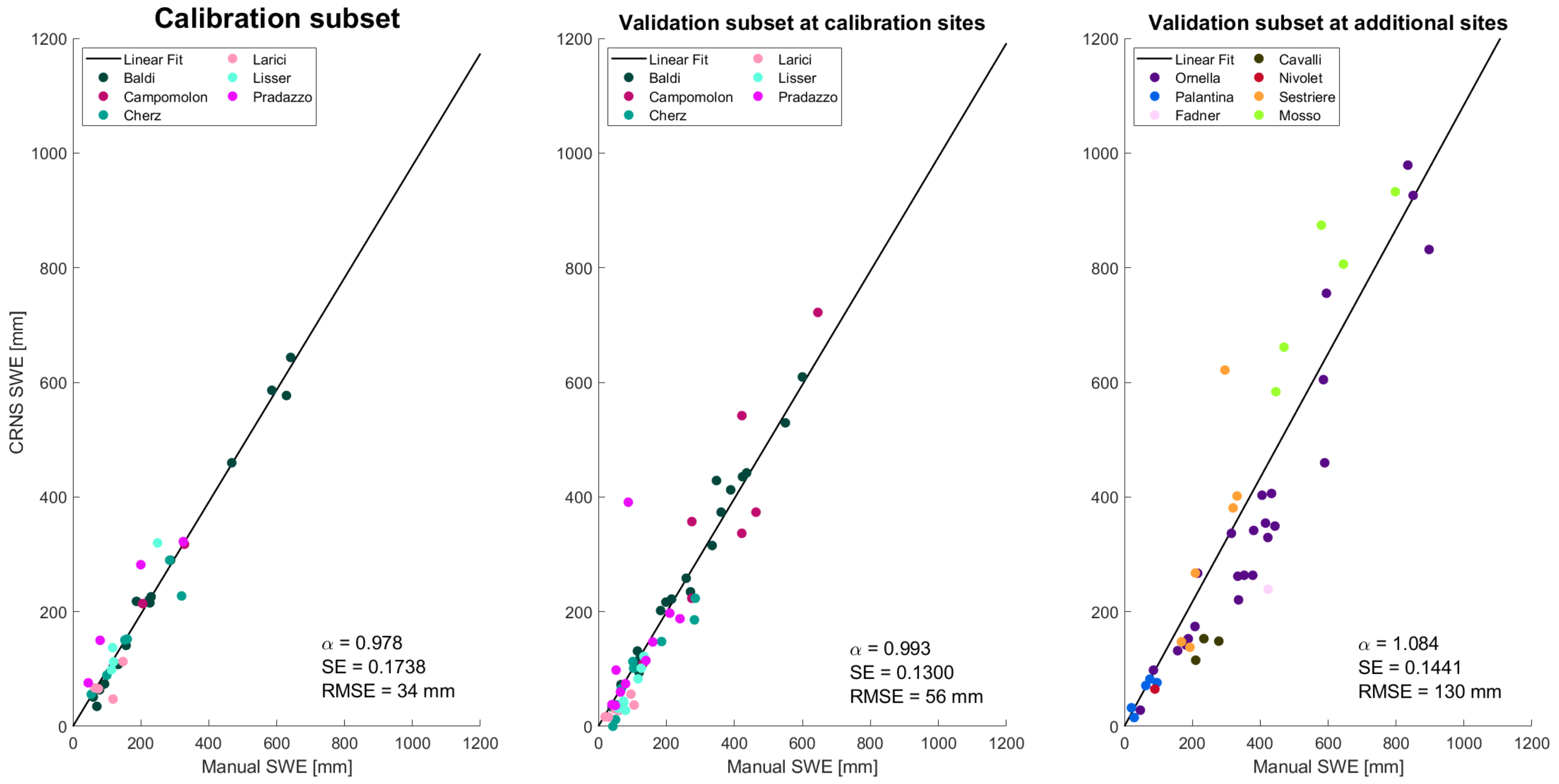
Egli, L., et al.: Comparison of different automatic methods for estimating snow water equivalent, *Cold Reg. Sci. Technol.*, 57, 107–115, doi:10.1016/j.coldregions.2009.02.008, 2009

Abstract

Linear regression results



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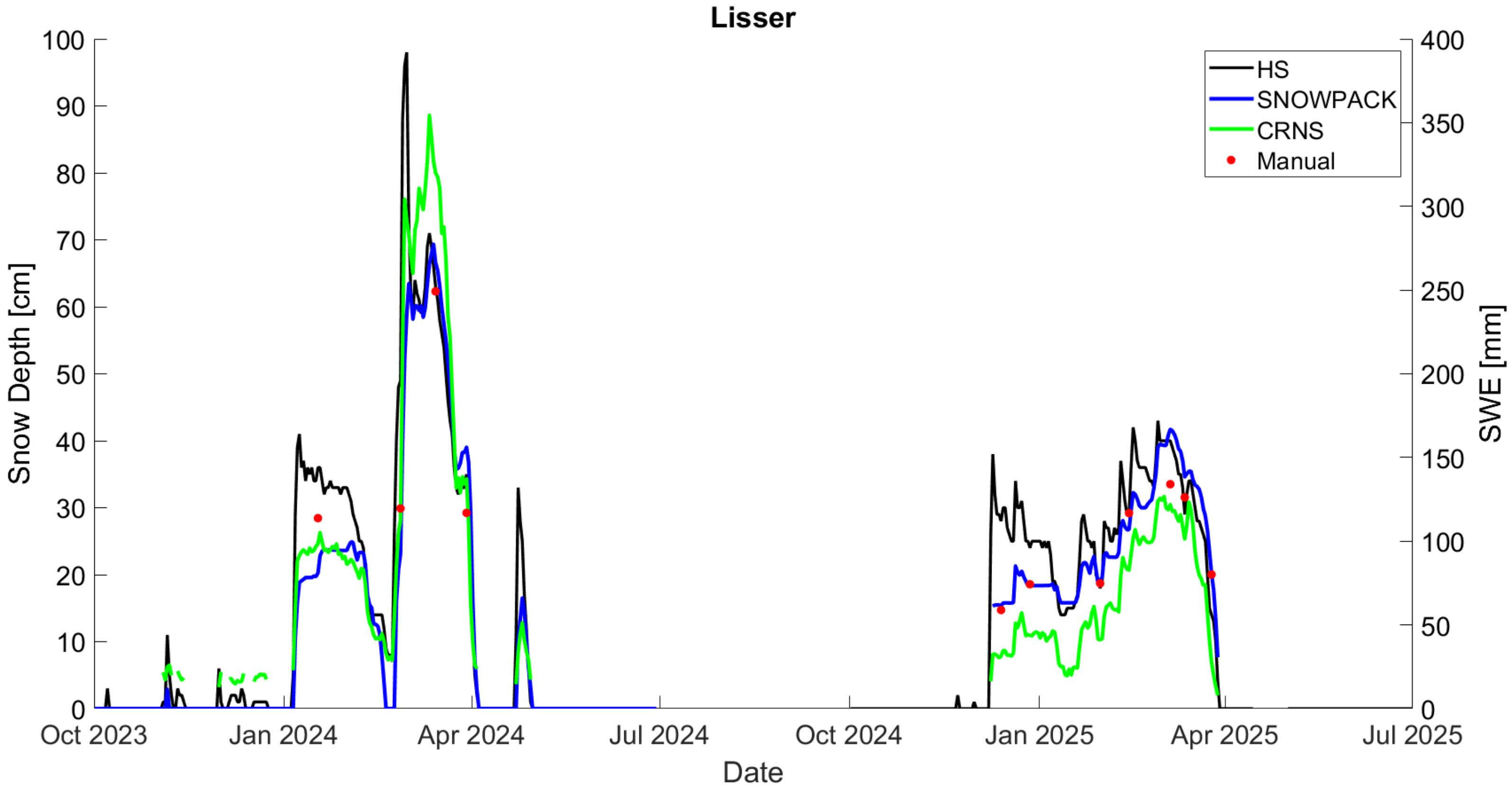
Snow seasons across the network

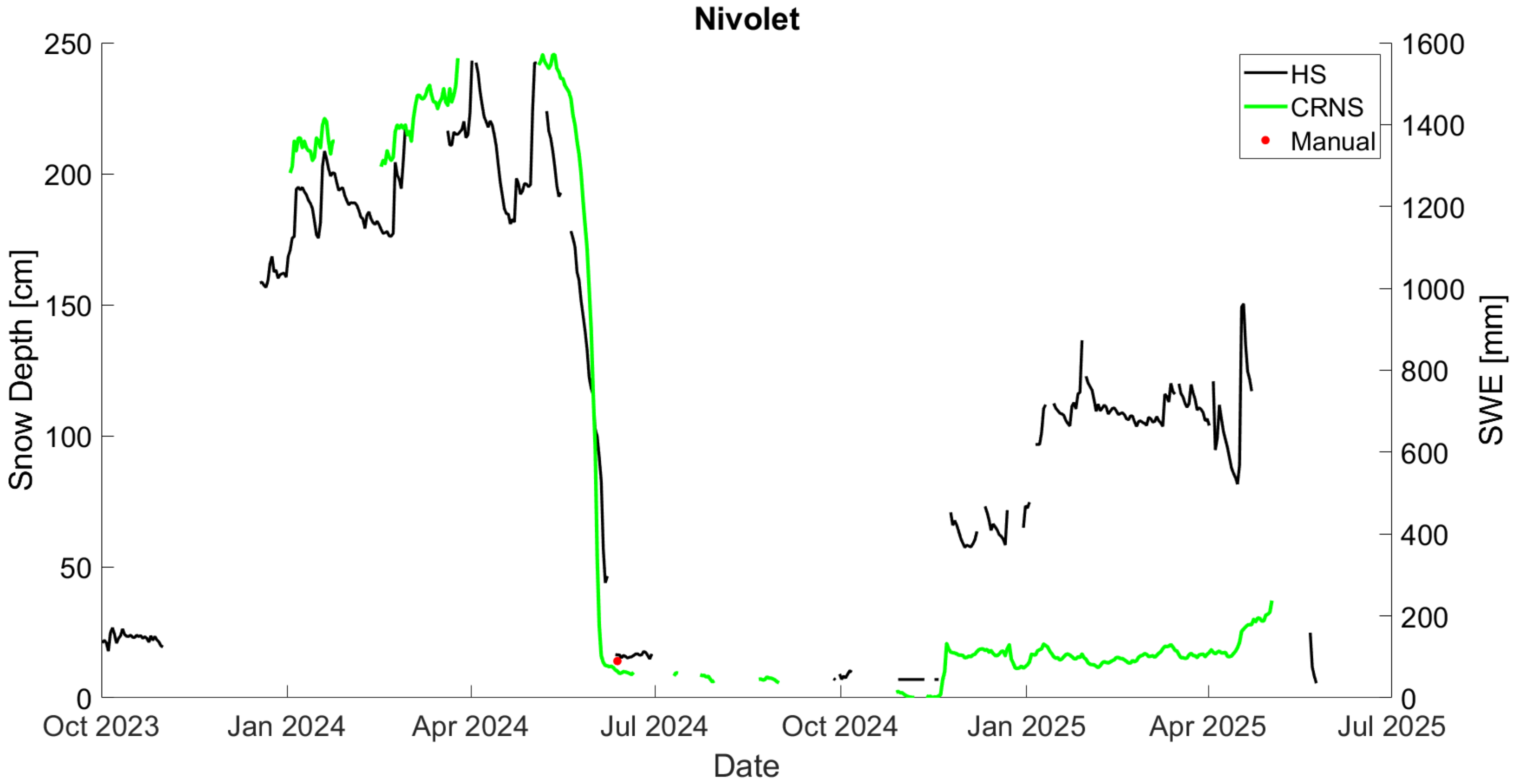


- The lowest site of the network (1422 m asl)
- Part of the calibration subset
- Simulations with the model SNOWPACK
- Short seasonality well depicted
- Possible overestimate of ephemeral snow due to soil moisture contribution

Abstract

Lehning, M., et al.: Snowpack Model Calculations for Avalanche Warning based upon a new Network of Weather and Snow Stations, *Cold Reg. Sci. Technol.*, 30, 145-157,1999

Snow seasons across the network



- Not easily accessible (2550 m asl)
- Only one manual SWE point at the end o 2023-2024 snow season
- CRNS may be used to fill snow depth gaps
- SWE underestimated in the whole 2024-2025 season

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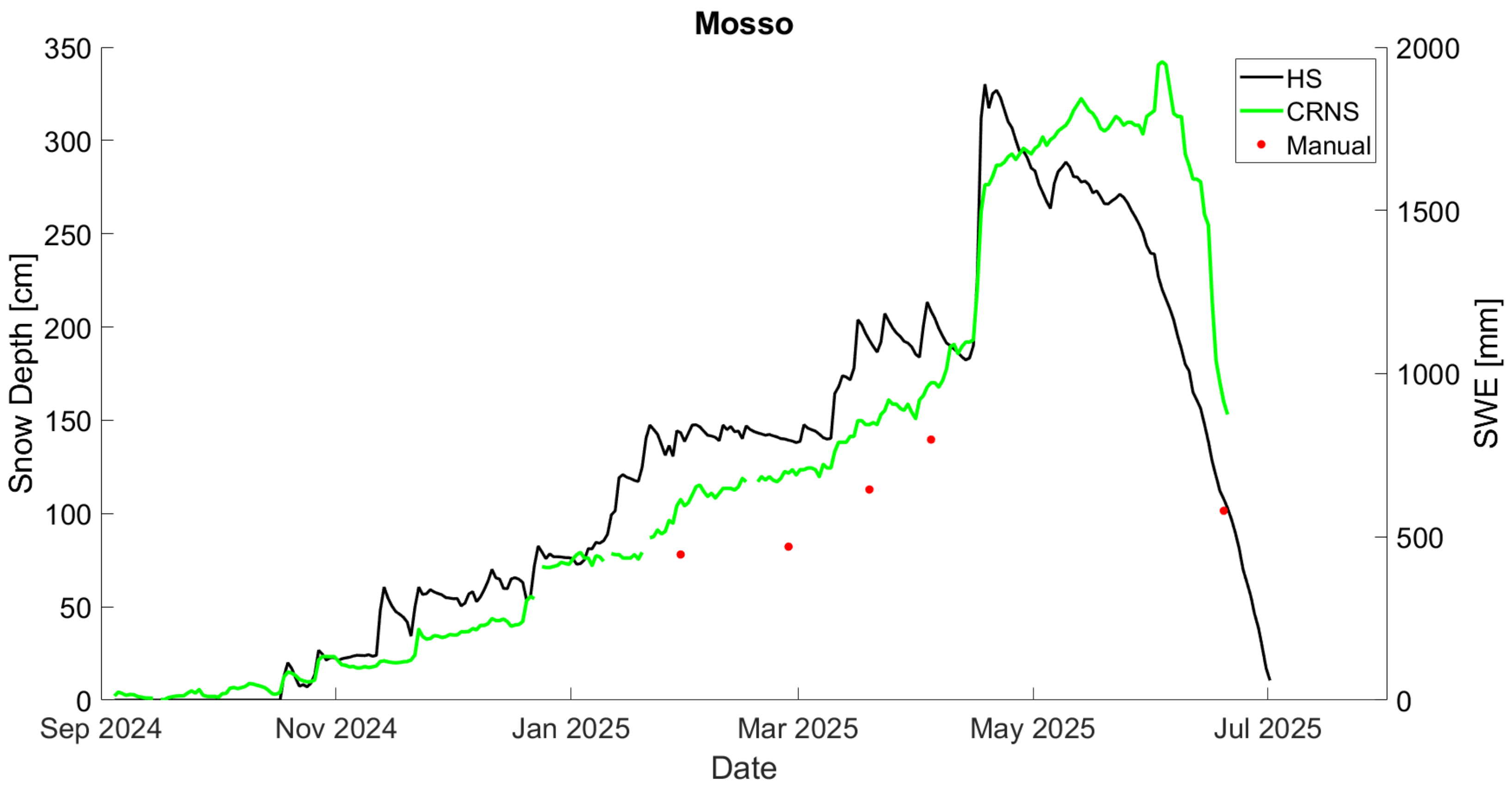
Snow seasons across the network



- The highest site of the network (2901 m asl)
- Only 2024-2025 season available due to late installation and lack of reliable N_0
- Peak SWE measured: 1955 mm

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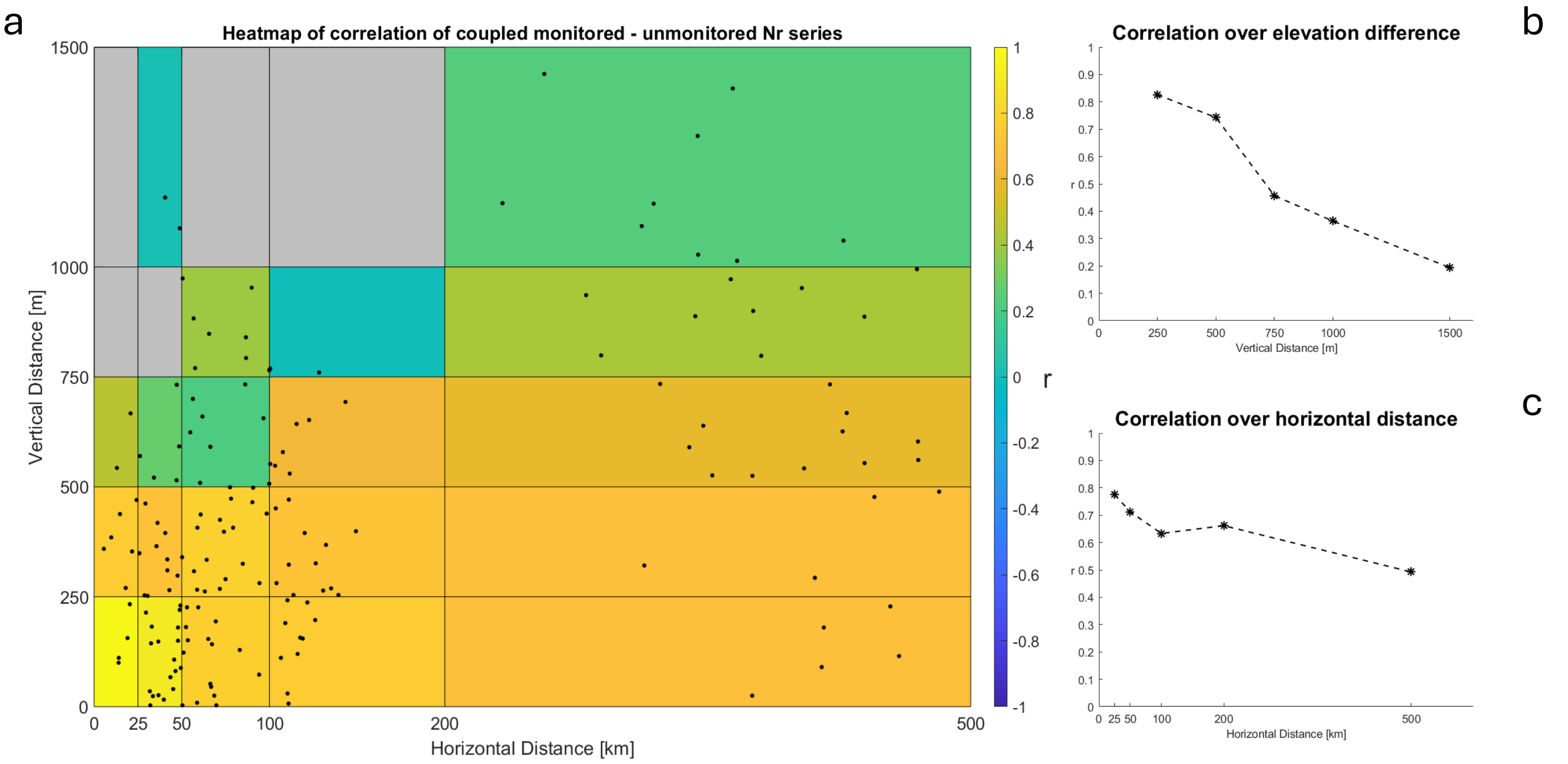
Correlation among sites



- Correlation drops with elevation difference
- Best average correlation (r = 0.98) for coupled sites within 250 m of elevation and 25 km of distance
- Near monitored sites could inform on unmonitored behaviour

(a) Average correlations classified by the horizontal (x-axis) and vertical (y-axis) distances between unmonitored and monitored stations. Black dots represent coupled stations. Average r values depending on vertical (b) and horizontal (c) distances.

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Conclusions

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- The shared parameterisation gives SWE estimates with low biases
- CRNS can be leveraged to increase the spatial coverage of SWE datasets
- Shared parameters derived from monitored sites can be applied to unmonitored locations

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Future perspectives

- Increase the coverage of the network to further improve the parameterisation with additional data
- Define a shared protocol to take SWE measurements intended explicitly for CRNS validation
- Investigate the role of other factors (e.g. soil composition and site's morphology)

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