AGU ADVANCING EARTH AND SPACE SCIENCES

Geophysical Research Letters

RESEARCH LETTER

10.1029/2023GL104128

Estimation of the Snow Water Equivalent Using Muon Scattering Radiography

Aitor Orio-Alonso[1,2], Esteban Alonso-González[3], Carlos Díez-González[1], Pablo Gómez-García[1], and Pablo Martínez-Ruiz del Árbol[2]

[1]Muon Tomography Systems S.L., Bilbao, Spain, [2]Instituto de Fisica de Cantabria (IFCA)—UC-CSIC, Santander, Spain, [3]Centre d'Etudes Spatiales de la Biosphère (CESBIO), Université de Toulouse, CNRS/CNES/IRD/INRA/UPS, Toulouse, France

Key Points:

- We test the suitability of Muon Scattering Radiography to infer the Snow Water Equivalent (SWE)
- Numerical simulations show the technique can estimate the SWE with a precision of around 12 mm
- Laboratory measurements confirm the results obtained with simulation

Correspondence to:

P. Martínez-Ruiz del Árbol,
parbol@ifca.unican.es

Citation:

Orio-Alonso, A., Alonso-González, E., Díez-González, C., Gómez-García, P., & Martínez-Ruiz del Árbol, P. (2023). Estimation of the snow water equivalent using muon scattering radiography. *Geophysical Research Letters*, *50*, e2023GL104128. https://doi.org/10.1029/2023GL104128

Received 18 APR 2023
Accepted 12 JUL 2023

Author Contributions:

Conceptualization: Aitor Orio-Alonso, Esteban Alonso-González, Carlos Díez-González, Pablo Martínez-Ruiz del Árbol
Data curation: Aitor Orio-Alonso, Esteban Alonso-González, Carlos Díez-González, Pablo Gómez-García, Pablo Martínez-Ruiz del Árbol
Formal analysis: Aitor Orio-Alonso, Esteban Alonso-González, Pablo Martínez-Ruiz del Árbol
Funding acquisition: Aitor Orio-Alonso, Carlos Díez-González, Pablo Martínez-Ruiz del Árbol
Investigation: Aitor Orio-Alonso, Esteban Alonso-González, Carlos Díez-González, Pablo Gómez-García, Pablo Martínez-Ruiz del Árbol
Methodology: Aitor Orio-Alonso, Esteban Alonso-González, Carlos Díez-González, Pablo Gómez-García, Pablo Martínez-Ruiz del Árbol

Abstract Despite the important hydrological and ecological implications of the snowpack, its real time monitoring remains challenging. This is particularly relevant in relation to the *Snow Water Equivalent* (SWE), as the available technologies which measure it, exhibit a number of limitations that hinder their operational implementation. In this work, we explore the potential of a new technology, *Muon Scattering Radiography*, to infer the SWE. We coupled snowpack simulations generated by the SNOWPACK model, with a muon scattering simulation program based on GEANT4. The SWE is modeled as a function of the muon scattering distributions. Predictions of the SWE along the year are provided showing a *root-mean-square error* of 12 mm for 5 hr continuous measurements. We also performed laboratory measurements using ice samples, confirming the SWE estimation capabilities and the potential of the technique to operate as a SWE monitoring tool.

Plain Language Summary The monitoring of the seasonal snowpack is important to understand and predict the dynamics of the hydrological and ecological processes, but its continuous monitoring is still a scientific challenge. Particularly in relation to the Snow Water Equivalent (SWE). The available technologies to monitor the SWE exhibit a number of limitations that prevent its use in many real world cases. Here we explore the potential of a new technology, Muon Scattering Radiography (MSR), to quantify the SWE. MSR is a technique based in the detection of the natural and innocuous radiation of muon particles. The technique consists in the measurement of muon deviations, which are larger when the muons cross very large or dense materials. In this analysis, we simulated the snowpack evolution itself and its measurement process. Then, we determined the relation between muon deviations and SWE. Finally, we estimated the precision in the determination of SWE comparing the predictions to the ground truth in simulation. The results yielded a precision of about 12 mm. We also performed laboratory measurements with ice samples, using a 4 layer muon detector based on multiwire proportional chambers, confirming the potential of the technique to operate as a SWE monitoring tool.

1. Introduction

The seasonal snowpack plays a key role in the hydrology of the areas where it is present and beyond (Barnett et al., 2005), but its real-time monitoring still represents a big challenge for the scientific community and water management agencies. Real-time monitoring systems strongly rely on remote sensing and numerical modeling. However, to date, there is still no effective approach to retrieving the snow water equivalent (SWE) from orbital sensors, especially over complex terrain (Luojus et al., 2021). In addition, even the most sophisticated physically based snowpack models suffer from the limitations of the quality of the forcing (Raleigh et al., 2016), its parametrizations (Günther et al., 2019), and the uncertainty caused by the wind and avalanche snow redistribution (Vionnet et al., 2021).

Direct observations of the snowpack are very appreciated for water management purposes, long-term climatological studies, as well as for model and remote sensing product validation or data assimilation. However, as a consequence of the difficulties of snowpack monitoring and increased costs, the available SWE time series are often scarce, incomplete, or just inexistent (Alonso-González et al., 2018). In addition, despite nowadays it is possible to retrieve the snow depth using relatively cost-effective techniques (Revuelto et al., 2021), the monitoring of the SWE remains elusive.

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