Snow water equivalent measurement using Muon Radiography

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INTRODUCTION

Muons reach the surface of the earth with an approximately constant flux and deviate their trajectory when crossing matter. These deviations can be measured in order to obtain information or density maps about the inner state of preferably dense and big objects. Previous work done by the company Muon Systems, presenting the capacity of Muon Radiography to help in industrial problems can be consulted in [1]. Here we present a new application of Muon Radiography, the non-destructive measurement of snow water equivalent (SWE), that is, the water content of the snowpack.

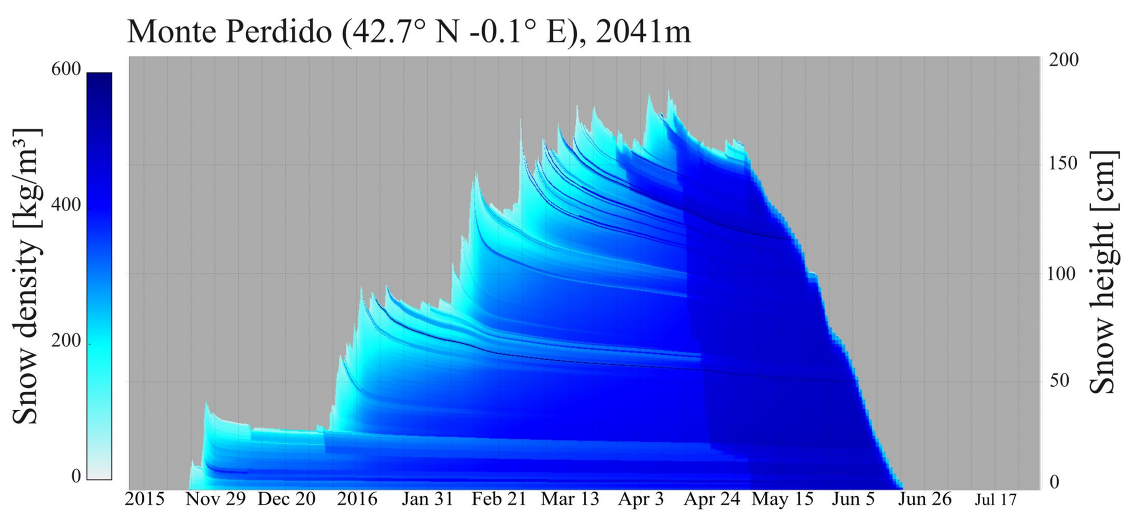

Figure 1. Simulation of the snow structure in a location near Monte Perdido, in the Pyrenees (Aragón, Spain)

In this case study, the measurement target is a column of snow with a base of 1 m^2 and a height varying from 0 to approximately 2 m (Figure 1), suitable for the detection system designed and built by Muon Systems (Figure 2). The density of the snow is low compared to other materials measured in traditional Muon Radiography applications, which makes this challenge more demanding in terms of angular resolution.

OBJECTIVES

Despite its hydrological importance, real time SWE monitoring remains challenging for hydro-meteorological networks. This new application of Muon Radiography would contribute to enhance the SWE monitoring capabilities of the water agencies and land managers, improving the estimation of the mountainous water resources and the river discharge forecast. Nowadays, other technologies are employed to carry out measurements of SWE, but difficulties and uncertainty sources have been noticed [2].

Our goal is to detect SWE changes in an acceptable time frame and explore if Muon Radiography can provide a successful monitoring of SWE.

MATERIALS & METHODS

To analyse this problem using Muon Radiography, firstly the snow has been simulated. We have applied the model *Snowpack* [3], which uses the *ERA5-Land* reanalysis as meteorological forcing, in the Spanish Pyrenees in a location at 2041 meters above sea level in the Monte Perdido massif. The simulations cover one year with a changing number of snow layers, containing information including the density, height and the ice, liquid water and air content of each layer (Figure 1).

Secondly, we have carried out *Geant4* simulations to propagate and measure muons passing through the snow layers previously simulated. The simulated detection system is a virtual copy of real hardware of the company Muon Systems, a hardware based on 2 mm resolution multiwire proportional chambers (Figure 2). In addition, it has to be mentioned that the G*eant4* simulations take into account the location of detection wires and simultaneous hits produced by the same muon, reconstructing the detection process in a realistic way.

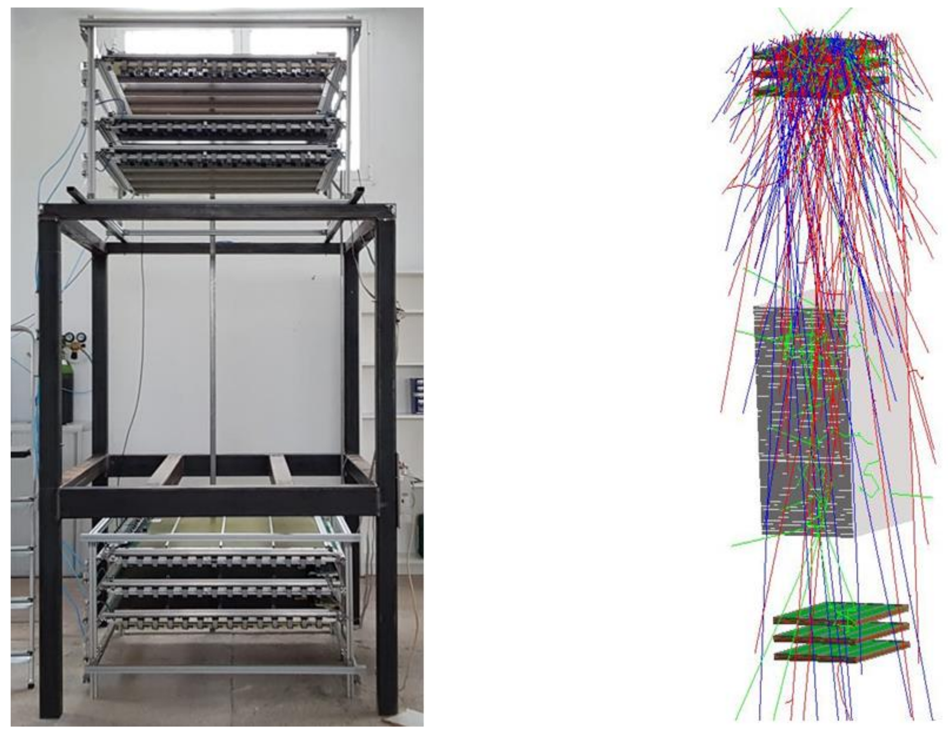

Figure 2. *Left: Detection system designed and built by Muon Systems. Right: Geant4* simulation. Detection structure, snow layers and particle propagation

In order to estimate the SWE, simulations corresponding to 5 hours of data taken have been performed for each week of the hydrologic year 2015/2016 simulated by the Snowpack model.

RESULTS

The RMS of the muon scattering angle for different simulated samples, have been studied as a function of the SWE (Figure 3). As expected, the dependency is compatible with a root square function, since the SWE represents the equivalent water column height, and therefore is proportional to the material thickness. The figure indicates that measurements of about 5 hours allow to clearly monitor and estimate the SWE.

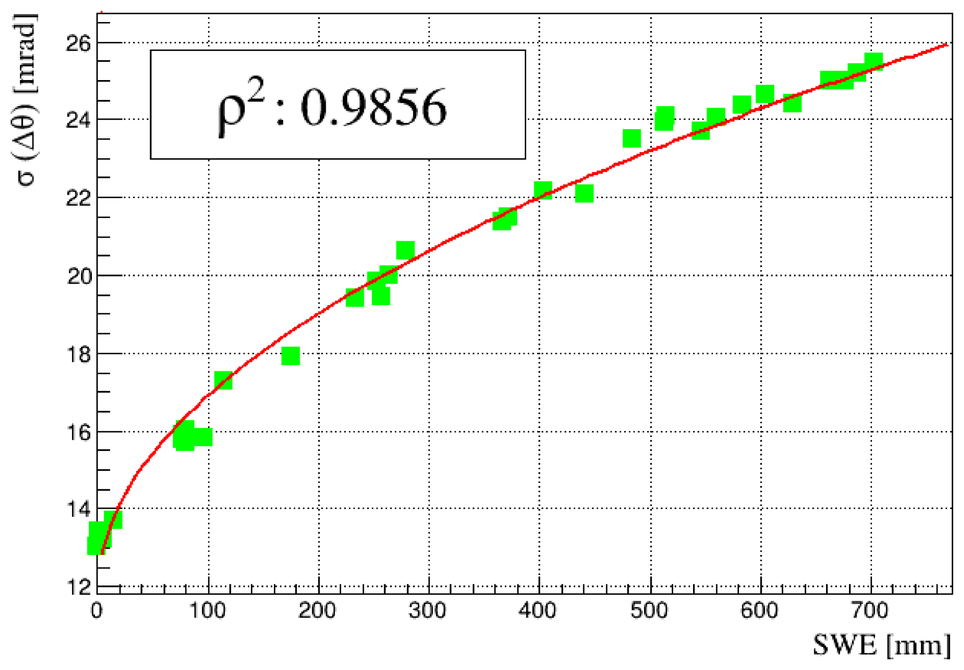

Figure 3. Relation between the standard deviation of muon scattering angles and SWE.

Finally, the time evolution of the generated "true" SWE (blue, "SWE") and the SWE obtained applying the fitted formula to the data already used in the fit (red, "Model SWE") is presented (Figure 4).

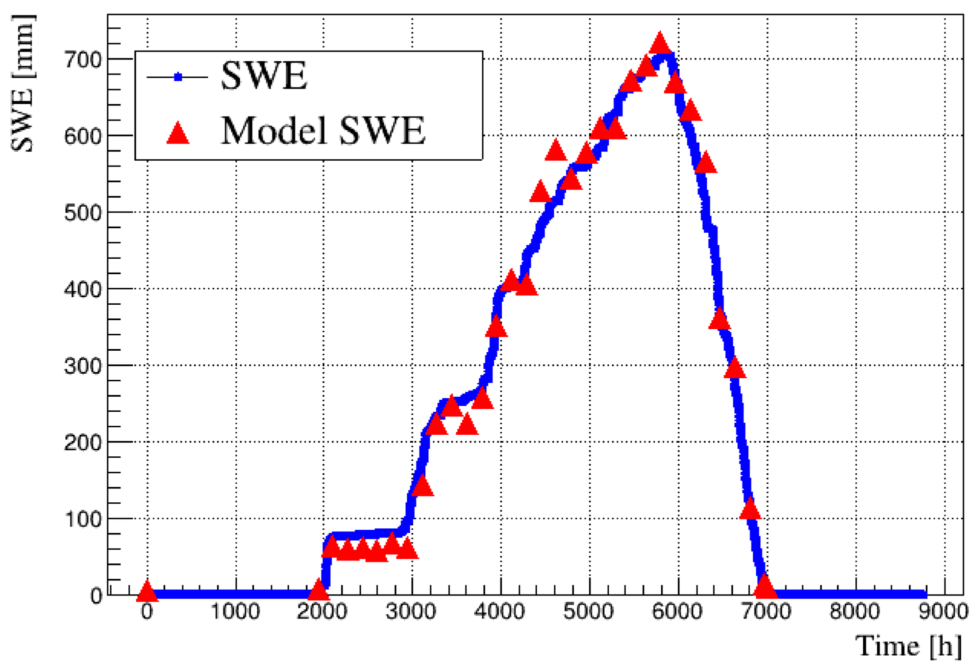

Figure 4. Actual SWE and model SWE in the hydrologic year 2015/2016

CONCLUSIONS

The detection system is valid to discriminate SWE changes and allows to model the SWE evolution successfully.

The next step, is to prove these analysis with real data carrying out snow measurements with the detectors of the company Muon Systems.

Future developments to improve the SWE measurement by muon radiography involve multivariable and advanced models. The implementation of statistical techniques based on machine learning, such as neural networks, and algorithms using maximum likelihood strategy can contribute to improve the precision obtained in this application.

Other interesting objective related to snowpack non-invasive measurements, is to determine the inner structure of the snow layers. This question needs further research, since it is highly demanding in terms of resolution.

Improvements in the muon detectors, like the spatial resolution or muon momentum estimation, also will help to achieve this challenges.

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