The Cryosphere Discussions

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Comment on tc-2021-152

Anonymous Referee #2

Referee comment on "Assessment of neutrons from secondary cosmic rays at mountain altitudes – Geant4 simulations of environmental parameters including soil moisture and snow cover" by Thomas Brall et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-152-RC2, 2021

The authors Brall et al. present in their paper "Assessment of neutrons from secondary cosmic rays at mountain altitudes (...)" a Monte-Carlo-based study with the motivation to better understand the neutron spectrometer at their experimental site and therefore improve the reliability of the data. The simulations provide key insights into the scaling of the CRN intensity with respect to SWE and partially environmental water. The study seems to some extent however to be incomplete as if the results would not have undergone internal revision. The data comparison to the simulations suggests that the initially simulated soil water contents (<5%) underestimate the actual situation. The range calculations do not extend beyond 150 m although the simulations appear to extend beyond that. Therefore the reviewer is wondering why these iterations have not been carried out if the authors have to conclude that they might not have simulated an appropriate topology.

Scientific value:
- Although the authors focus mainly on their own experimental site their results for the understanding of CRN fluxes are relevant and new. Most calculations in the field have not been carried out using GEANT4. Furthermore the topic of snow height measurements is of upcoming interest.

General:
- The study limits itself to very low hydrogen contents in limestone. The reviewer does not know the particular geology at the Zugspitze, but nevertheless wants to mention that there is alawys a small fraction of chemically bound water, so 0 % is unrealistic, and in general limestone can take more than just 5 % of soil moisture. In the discussion the authors mention the fact as well as a possible reason for their observations, but the initial assumption that limestone contains no water at all is already not correct. This should have been at least used as a primary assumption for the data being so far off from the simulations for example for the thermal neutrons.
- the US Standard Atmosphere 1976 does not contain argon. The thermal capture cross section of argon however is not negligible for thermal neutron studies. Furthermore there seems to be no air humidity involved, which is also relevant for the overall neutron flux.
- The fact that the high-energy neutron flux changes in the slanted geometry as well, it

seems that the 'flux reduction' is an entirely cos(angle) geometrical effect due to inclining the flat scorer. Or do you state that a volumetric detector would still measure that difference?
- why have the homogeneous calculations not been carried out with periodic boundary conditions?
- There are no statements about statistical uncertainties. This should be corrected.
- There is a conceptual problem in the distance contribution calculations: Firstly, neutrons scatter in the atmosphere - soil interface several times. Placing a circle in a vacuum is not equal to analyzing the distance contribution in an infinite scenario. Neutrons might originate from a distance within 5 m scatter around and then reach the scorer. If you replace everything around the radius of interest with vacuum you inhibit this process. That may be less relevant for 100 m or 200 m but for small radii it is definitely a misrepresentation. Secondly, as the cited literature values provide significantly larger origin distance values for the 86 % quantile it seems incorrect that the authors simply stop their analysis at 150 m and normalize that to 1. It is not clear how much the flux would increase beyond 150 m and the provided data points already by optical inspection clearly show a trend which indicates that 150 m is definitely not 100 %. Therefore the authors should extend their distance calculation at least by a factor of 2 or 3 and/or use an 'infinite' soil as a reference value for 100%.

Misc:
- in section "3 Results and Discussion" there is a 3.1 with subsequent subsections but no 3.2
- the differential neutron flux is stated in units of per cm^2 not per cm as most plots show
- why do the authors set variables like in the polynomials in italic whereas others like the energy E is not?
- the term intensity is used in the introduction but not in the rest of the manuscript. In the later sections the terms flux, fluence and fluence rate (which equals flux) are used in a maybe not so clearly distinguishable way.
- the plots are tiny (!). The reviewer would be surprised if the authors can read values properly from the graphs when printed on A4.

References:
- some previous works which are relevant to this study are missing, that might be seen optional, however, the authors seem to be quite keen on citing their own works, so a more balanced reference list would be advised. The following works can be taken into account:
- Hendrick 1966 10.1103/PhysRev.145.1023 - probably the first source to discuss the neutron flux relation with respect to soil moisture
- Kodama 1980 10.1016/0165-232x(80)90036-1 - first application of CR neutrons to measure snow
- Schattan 2017 10.1002/2016WR020234 and Schattan 2019 10.1029/2019WR025647 - above-ground neutron measurements of snow water
- Desilets 2010 10.1029/2009WR008726, Franz 2013 10.5194/hess-17-453-2013, Koehli 2021 10.3389/frwa.2020.544847 above-ground neutron intensity relation
- Desilets 2013 10.1002/wrcr.20187 followed by the mentioned Koehli 2015 for the CR footprint
- Sato 2006 10.1667/RR0610.1, Sato 2015 10.1371/journal.pone.0144679 and Sato 2016 10.1371/journal.pone.0160390 for CRN flux above the ground (PHITS)
- maybe Nesterenok 2013 10.1016/j.nimb.2012.11.005 for CRN flux using GEANT4

Abstract:
- L4: "To investigate the impact of these parameters, Geant4 Monte Carlo simulations were carried out." - It should be mentioned that in particular 'these parameters' are snow cover.

Introduction:
- L30: "due to its large elastic scattering cross section" - and equal mass of projectile and target
- L43: as a sidenote: it was not just Hess, in the years 1910-1914 a series of balloon flight radiation measurements were carried out by Wulf, Gockel and Hess
- L45: It is unclear which reference the author means, but the IGY was presented as early as 1953 (10.1103/PhysRev.90.934)

Simulation Geometries:
- L113: Sentence incomplete

Difference between horizontal and slanted soil:
- Fig. 3 might be omitted. The influence of a snow water layer is shown more clearly in Fig. 4 and the slanted geometry has no other effect than changing the rates.

Influence of snow height on neutron flux spectra:
- L148: There is a vagabond "Simulations" which may in combination with the later appearing "Interpretation in terms of thickness of water layer" be meant as a section. As your section layout in 3. is anyway not carried out properly, see above, subsubsection might be introduced here.
- L159: "In contrast, for high-energy cascade neutrons, this decrease is small and amounts only to about a few percent" - shouldn't the high energy part be nearly entirely be oriented in forward direction? At such high kinetic energies the backward direction is heavily suppressed - which might be represented by the data as well.
- the results presented in Fig. 5 are indeed quite relevant to the field. They should be discussed in more detail. However, it would be more appropriate to plot the results from for example the 5 % soil moisture runs as 0% water in soil and air constitutes an extreme and unrealistic scenario.
- L210: Schattan 2017 and 2019 showed that homogeneous and inhomogeneous snow distributions do not show the same response. That means that for patchy snow cover the SWE values you state might correspond to an effective SWE but not to the actual one.

Humidity of Limestone:
- it should be more correctly called moisture instead of humidity
- Fig. 12 (right) the y-axis range should be reduced in order to stretch the scaling of the presented values.
- It would be interesting to see a comparison of the neutron flux results presented here to those already published in literature. At least the reviewer is aware of the fact that Sato 2006 already presented analytical function for the CR intensity depending on the soil water fraction.
- It can be expected that the thermal neutrons do not only show this 'anomaly' for their scaling with respect to SWE but likewise to soil moisture as well. The reviewer however is aware of the fact that the authors might not have conducted such runs as well.

Conclusions:
- L262: "systematic analysis of the influence of environmental parameters" - as pointed out above, the main focus is set on snow.
- L280: as stated above, those SWE values might not be too reliable considering the arguments brought up.
- L299: The issue of computing time is brought up here out of the blue. How many neutrons do you simulate and how long does it take?