Snow water equivalent measured with cosmic-ray neutrons: reviving a little known but highly successful field method

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Motivation

Snow-water equivalent (SWE) depth is inherently difficult to measure. Two popular but not completely satisfactory methods are the snow pillow and gamma probe.

Limitations of the snow pillow:

- must have flat terrain
- requires large volume of antifreeze
- not portable
- susceptible to "bridging"

The gamma method has fewer of these problems, but is only viable up to ~30 cm of SWE. **The cosmic-ray neutron burial method is a potential alternative that can overcome these limitations.** It is more portable than a snow pillow and works over a larger SWE range than the gamma probe.

Theory

Cosmic-ray neutrons continually bombard Earth's surface (**Figure 1**), raining down from the sky. Collisions with hydrogen and oxygen nuclei in snow attenuate this natural source of radiation. The attenuated neutron flux is then measured with a neutron counter tube.

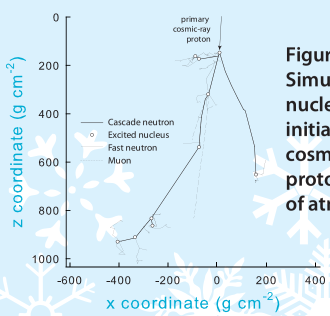

Figure 1. Simulated nucleonic cascade initiated by cosmic-ray proton at top of atmosphere

Counting statistics

The main source of uncertainty is the total number of neutron counts, *N*, which is governed by poisson statistics:

$$\sigma_N = \sqrt{N}$$

The "baseline" (no snow) counting rate is variably in space and time, mainly depending on:

- elevation (**Figure 2**).
- barometric pressure
- solar activity
- soil moisture

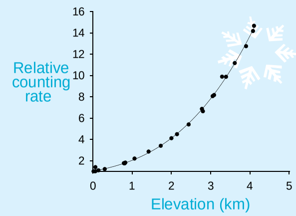

Figure 2. Elevation dependence of cosmic-ray intensity

Field application

A two-channel (bare and moderated) neutron counting system was installed in the Jémez Mountains of New Mexico, elevation 3022 m .

Co-located measurements:

snow pillow
above snow neutrons
below snow neutrons
eddy flux tower
ultrasonic depth sensor

Figure 3.

buried neutron detectors

snow pillow

Results

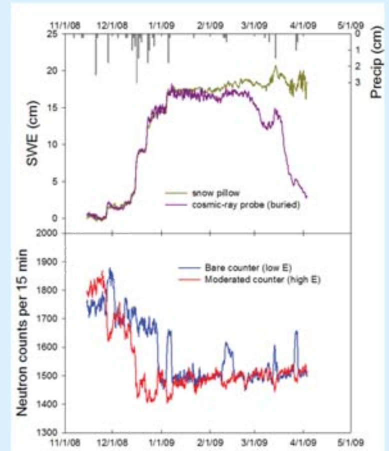

Figure 4. Results are consistent in winter but diverge in spring due to snowpack heterogenetity.

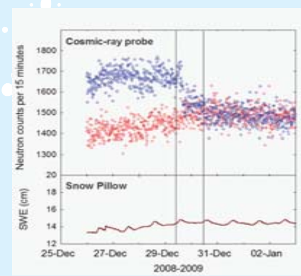

Figure 5. Anomalous counts due to canopy snow?

Conclusions

- Viable, portable method for measuring SWE.
- Works best at high elevations due to better counting statistics.
- Low maintenance (4+ years so far).
- No need for above ground detector for corrections.
- Pressure correction is most important.

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