Estimating Density from Hand-Held Snow Penetrometers

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A Brief History of Microstructure from Penetrometers:

In Proksch et al. (2015), a method was developed for using the SnowMicroPenetrometer to measure snow density, specific surface area, and correlation length. Since then, coefficients have been re-calibrated (Calonne 2020), and the SnowMicropyn open-source library has undergone significant enhancements. Additionally, new relationships between penetrometers and snow density have been proposed (Kaur Satyawali 2017).

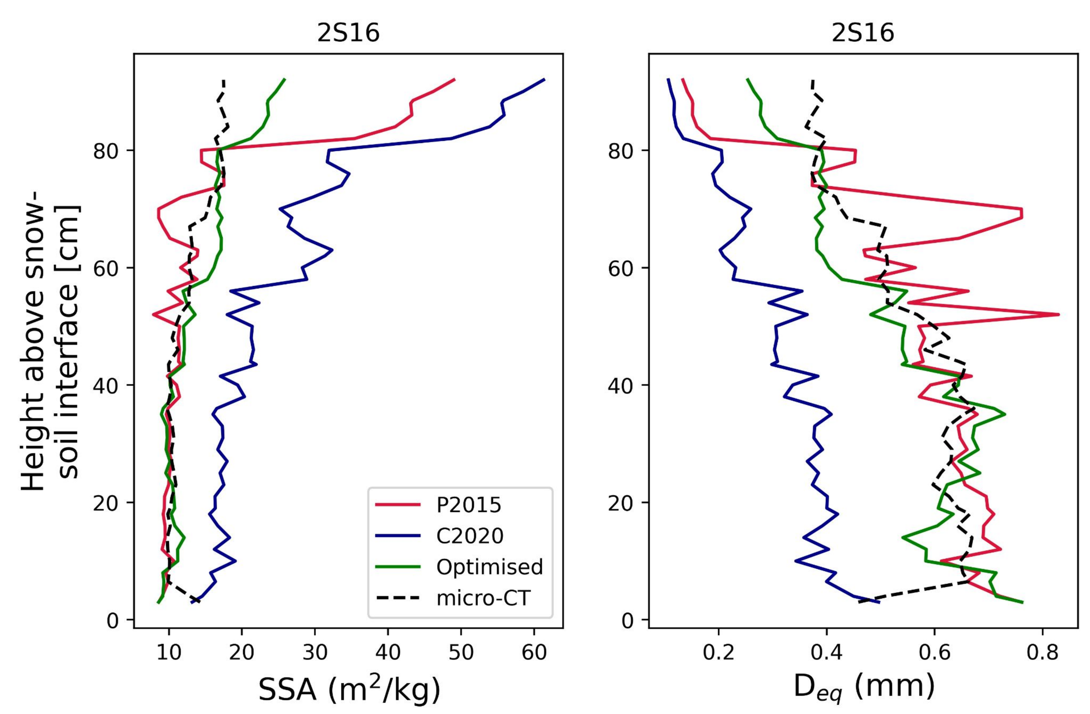


Figure 1. SSA and equivalent grain diameter estimations derived from an SMP profile (SnowEx 2021) using various coefficient models, including a model calculated for SnowEx 2021. (Many thanks to my SnowEx Hackweek 2022 Microstructure group for this figure)

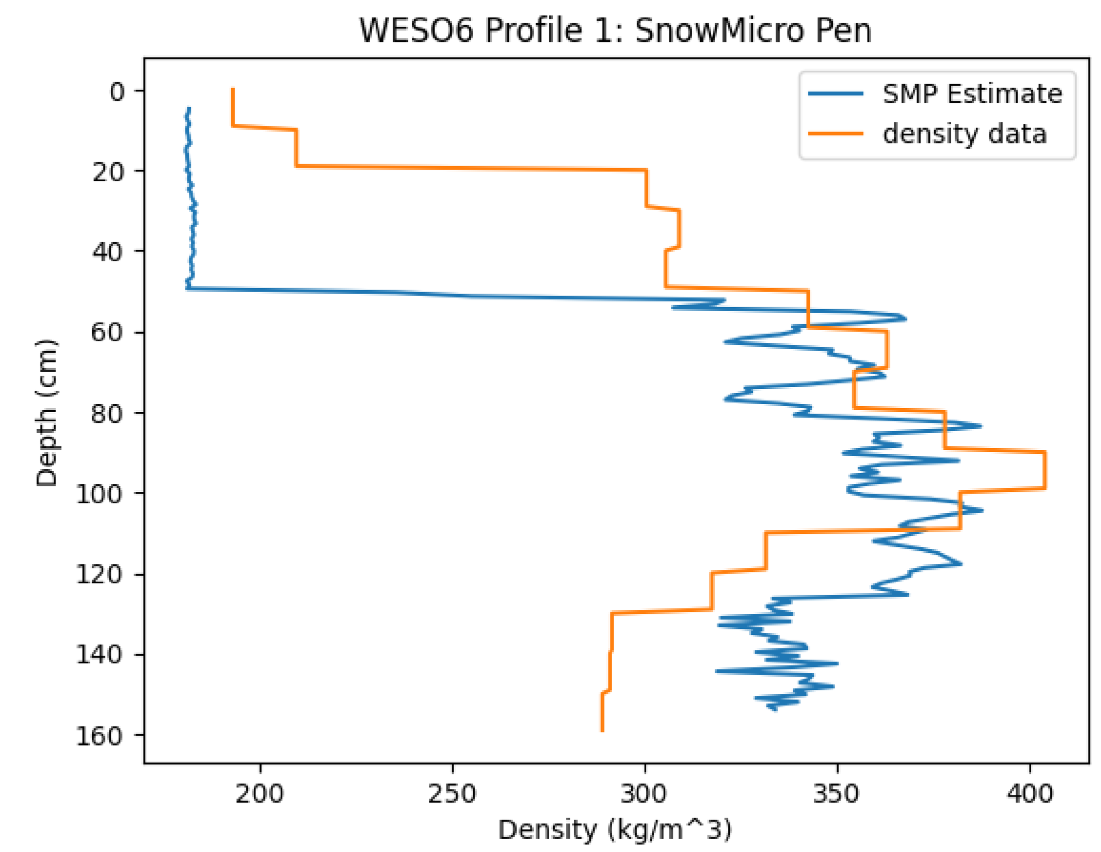
This project examines the application of established relationships to lower-cost hand-held probes that, like the SnowMicroPenetrometer, measure penetration resistance through the snow profile. These probes are non-motorized and equipped with less precise sensors. The objective is to assess their feasibility for field use in determining snow density.

Advantages to Handheld Probes:

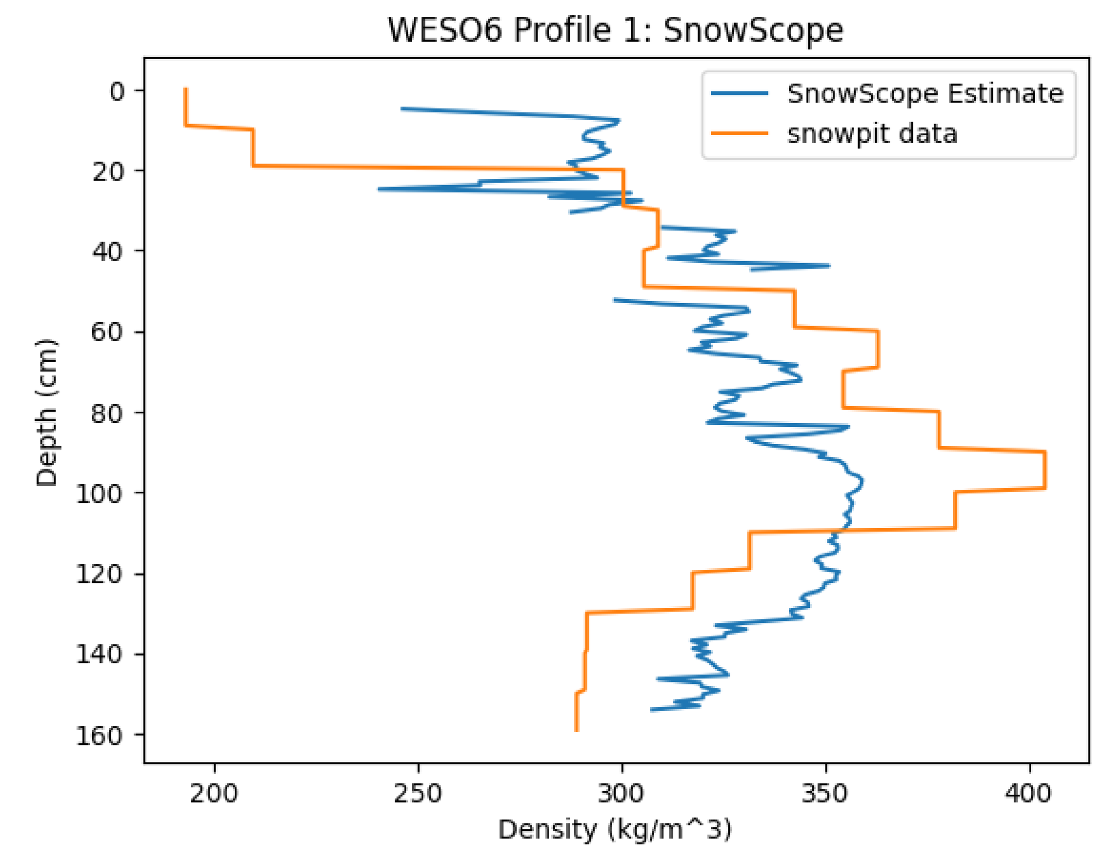
- **Low-Cost** Compared to the SMP from SLF, both on-market hand-held probes are significantly cheaper to buy ($2-3k).
- **Durability** In the field, the hand-held probes have been tough and don't require regular maintenance.
- **Fast Measurements** Measurements take around 3o seconds.

Probes are pushed into snow quickly by the user, and the acceleration is measured by the probe. Software is used to detect the snow surface and ground and the profile is cropped and ready for interpretation.

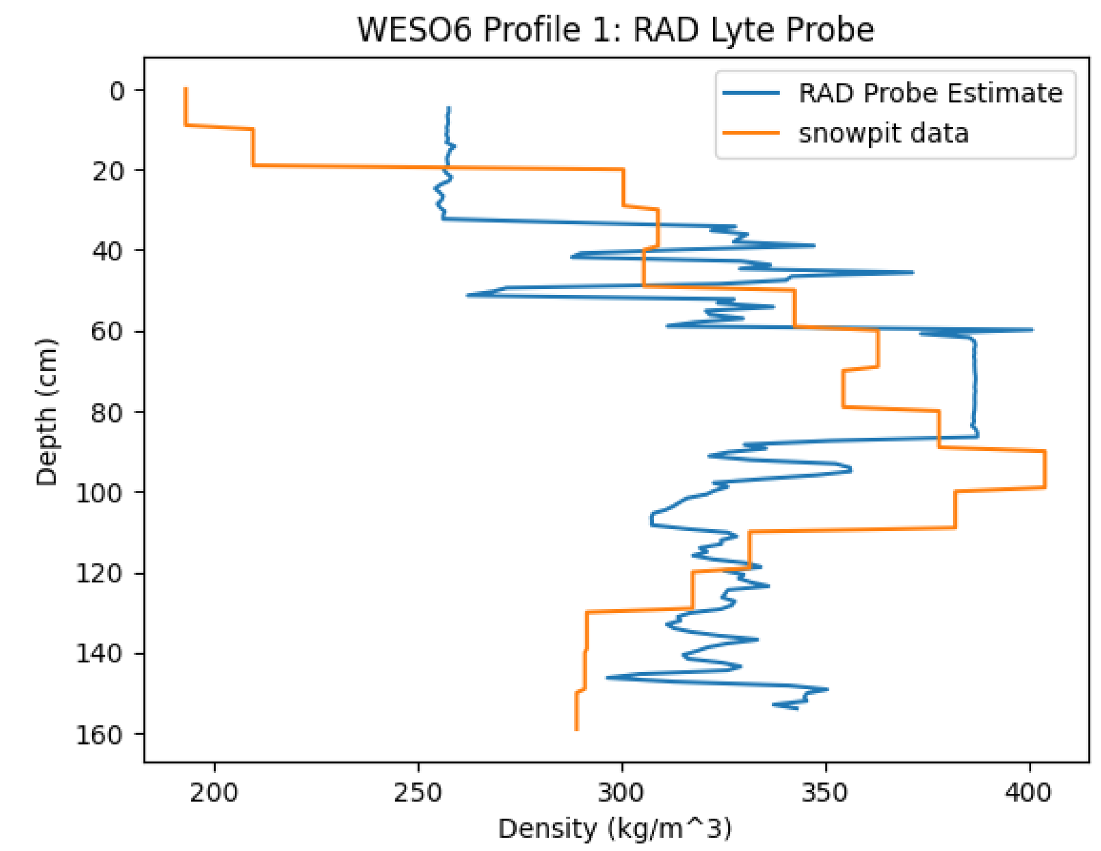
SnowMicroPenetrometer (SLF):



SnowScope (Propagation Labs):



Lyte Probe (Realtime Adventure Data):

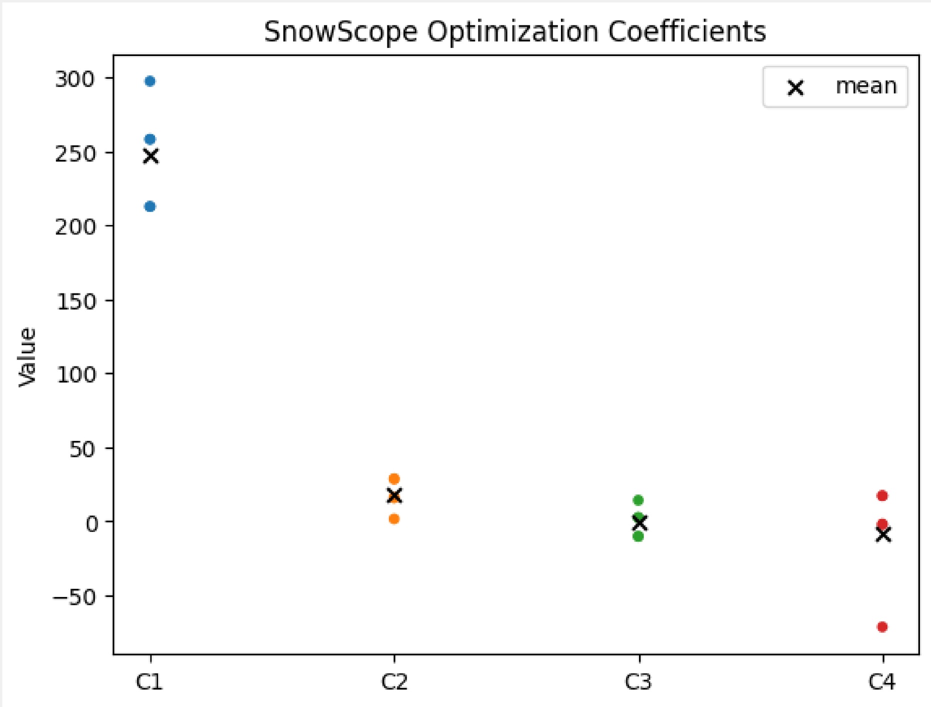


Methods

The following relationship was used to calculate density, as proposed in Proksch (2015).

$$\rho = c_1 + c_2 ln(\widetilde{F}) + c_3 ln(\widetilde{F})L + c_4 L)$$

Where $\widetilde{F}$ is the median penetration force of a given window and L is the structural element size.



Optimization of Coefficients

The example above depicts determining the mean coefficients for each instrument given coefficients calculated by optimizing the relationship defined above for snowpits with coincident density and probe measurements. For this project, these coefficients are being calculated by analyzing profiles from both winter and spring field campaigns conducted in Grand Mesa, CO, during the 2023/24 season.

Future Work:

- **Near-Infrared:** In the future, hand-held probe devices could incorporate both active and ambient side-looking near-infrared (NIR) measurements. Given that near-infrared has been shown to correlate with snow microstructure, integrating this data into a new algorithm that combines penetration resistance with NIR measurements could enhance the accuracy of density estimates.
- **Data Availability:** To accurately calibrate coefficients, a broader dataset encompassing various snow stratigraphies is required. The data presented in this poster is at risk of overfitting, which may compromise the reliability of the calibration.
- **Depth Retrieval:** A major limitation of hand-held penetrometer devices is their imprecision in depth measurements during insertion into the snow. Non-motorized devices, while optimizing time, durability, and cost, provide depth measurements only within a few centimeters. This limited precision can complicate coefficient calibration and lead to inaccuracies in estimating the total snow water equivalent.

References

[1] Sukhdeep Kaur and P. K. Satyawali.
Estimation of snow density from snowmicropen measurements.
COLD REGIONS SCIENCE AND TECHNOLOGY, 134:1–10, FEB 2017.

[2] Martin Proksch, Henning Loewe, and Martin Schneebeli.
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Github: https://github.com/annavalentine

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