An Analysis of Snowpack Temperature, Density, and Cold Content Across the Western United States

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Background

- Change in the western U.S. snowpack is influenced by warming temperature.
- Trillion dollar science question; requires more direct observation
- 1818 snowpits digitized; profiles of temperature, density, and cold content
- Repurposed data from a USGS chemistry study
- SWE isn't the whole story

Science question

How are ***cold content*** vertical profiles shaped by the relative roles of ***temperature*** and ***density***?

What is cold content and why is it important?

- CC is the energy required to raise the snowpack to its melting point—relates to snowmelt timing
- Studying CC demonstrates the value of internal snow temperature monitoring
- Modeling and remote sensing validation and training for Rocky Mountains
- Relevant to applied water resource management; snowmelt timing

Cold Content Equation

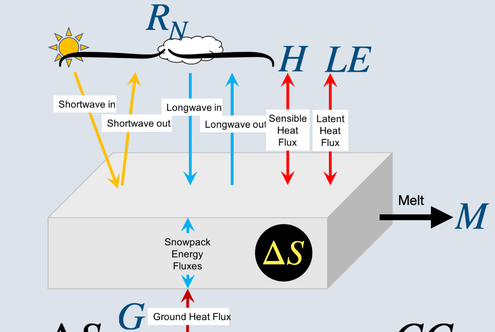
$$C \cdot \rho \cdot SWE \cdot (T_m - T_s) = CC$$

C = heat capacity of ice (1895-2067 $MJ\ kg^{-1}{}^{\circ}C^{-1}$)
ρ = density of ice ($917 kg\ m^{-3}$)
SWE = Snow Water Equivalence (cm)
T_m = Melt Temperature ($0^{\circ}C$)
T_s = Snow Temperature ($^{\circ}C$)
CC = Cold Content ($J\ m^{-2}$)

Snow Cover Energy Balance Equation

$$R_N + H + LE + G + M = \Delta S$$

Energy Storage Change



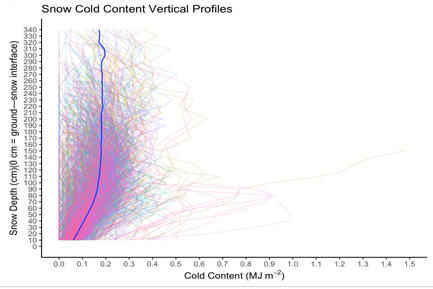
ΔS is synonymous with CC

Interpreting Cold Content in Snowpits

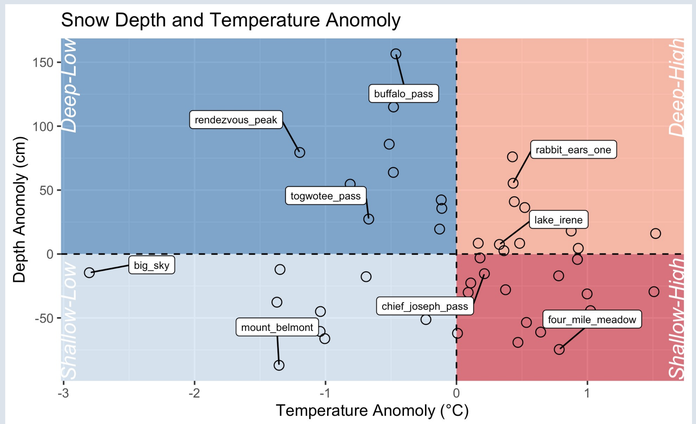
Relative Spread Around Mean from all Locations

Variables	*CV*	*SD*	*Mean*
Depth (cm)	33.0	54.5	165.0
Temperature (K)	0.3	0.9	270.6
Density (kg m^{-3})	8.3	25.2	304.0
SWE (mm)	38.7	191.7	494.7
Cold Content (MJ m^{-2})	50.4	1.3	2.6

Coefficient of variation as a percentage of the mean (CV), standard deviation (SD)

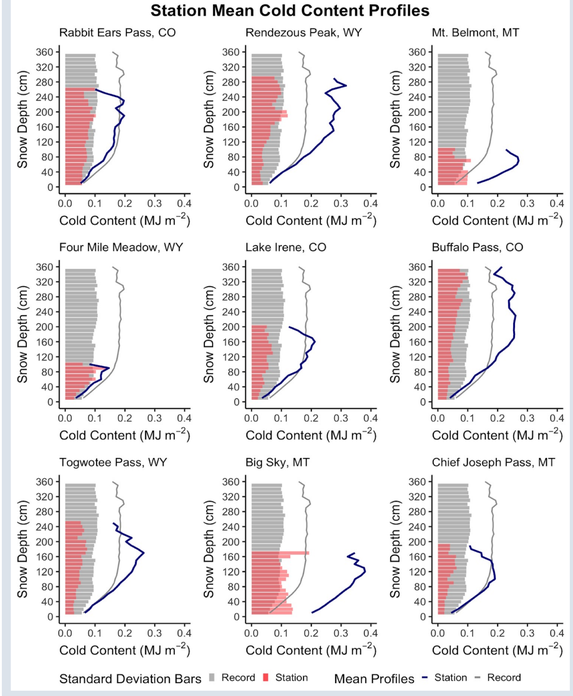


Selection of Nine Stations

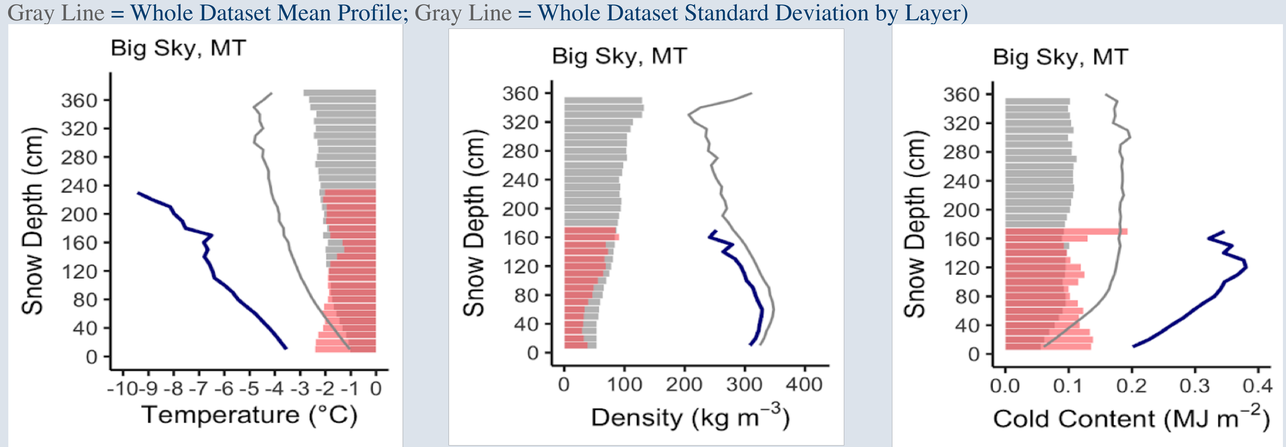


This study points to the value of monitoring snowpack temperature to alert planners of when CC will delay snowmelt timing and when it will not.

Mean Vertical Profiles and Standard Deviation of CC



Big Sky, MT Case Study (Blue Line = Big Sky Mean Profile; Red Bars = Big Sky Standard Deviation by Layer; Gray Line = Whole Dataset Mean Profile; Gray Line = Whole Dataset Standard Deviation by Layer)



At Big Sky snow temperature influences CC vertical profile variability more than density.