Field observations of rapid midwinter recharge in a seasonally frozen bedrock aquifer

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Introduction

- Climate change predictions indicate warmer and wetter winters in the northern hemisphere

  → Greater potential for winter recharge

- Seasonally frozen bedrock aquifers have received little attention in the study of winter recharge processes
- The impact of increased midwinter warming and rain-on-snow (ROS) events on winter recharge is uncertain:
  - Increases from greater rainfall and more frequent snowmelt?
  - Decreases due to reduced permeability from refreezing of melt water?
  - Decreases from snowpack basal ice creating a low permeability layer?

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Motivation

- A greater understanding of <u>recharge processes</u> is needed to better inform climate change models for water resources in seasonally frozen environments.
- There is a lack of understanding regarding the impacts of midwinter melts and ROS on bedrock recharge.

Objectives

1. Identify the antecedent conditions responsible for permitting or inhibiting winter recharge in fractured rock.
2. Conceptualize the mechanisms for midwinter recharge in fractured rock.

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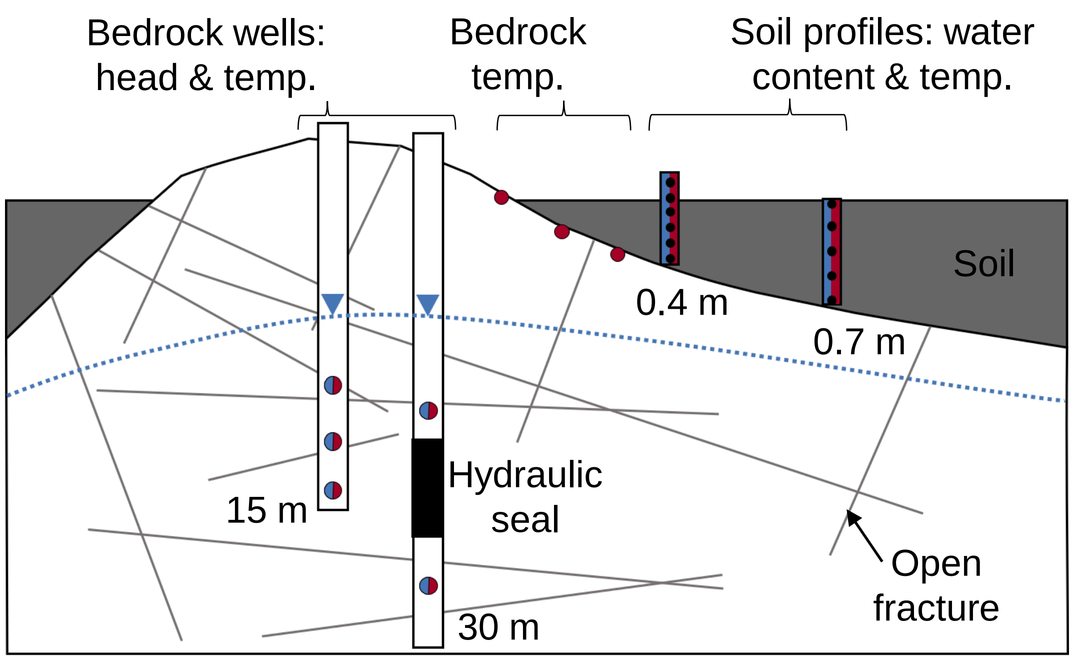
Methods

- Instrumented a fractured bedrock outcrop located in eastern Ontario, Canada
- Monitoring of winter 2019–2020 (15-min measurement interval)
- Hydrological sensors:
  - Two soil profilers (SP1, SP2) measuring volumetric water content and temperature
  - Two bedrock wells (TW3, TW20) with pressure transducers and temp. profile
  - Three thermistors in bedrock
- Atmospheric sensors:
  - Snow depth
  - Rain and snow
  - Air temperature and humidity
  - Wind speed and direction
  - Solar radiation



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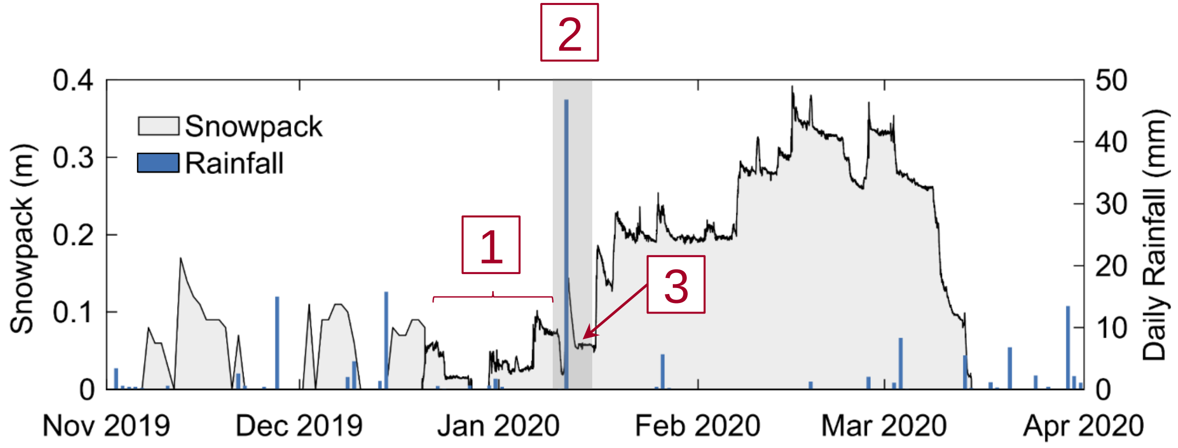
Climate

- Average daily temperature for January, February and March 2020 were warmer than 30-year average
- January and March received 2.2X and 1.5X more rainfall than average, respectively.
- Multiple small snowmelt and ROS events throughout February



Midwinter warming/ROS example:

1. Antecedent conditions – repeated melts and rain in December resulted in a 1-3 cm basal ice layer
2. 47 mm rain event January 11 resulted in 14 cm of ponded water
3. Not all ponded water drained before freezing temps → froze as 6 cm ice layer

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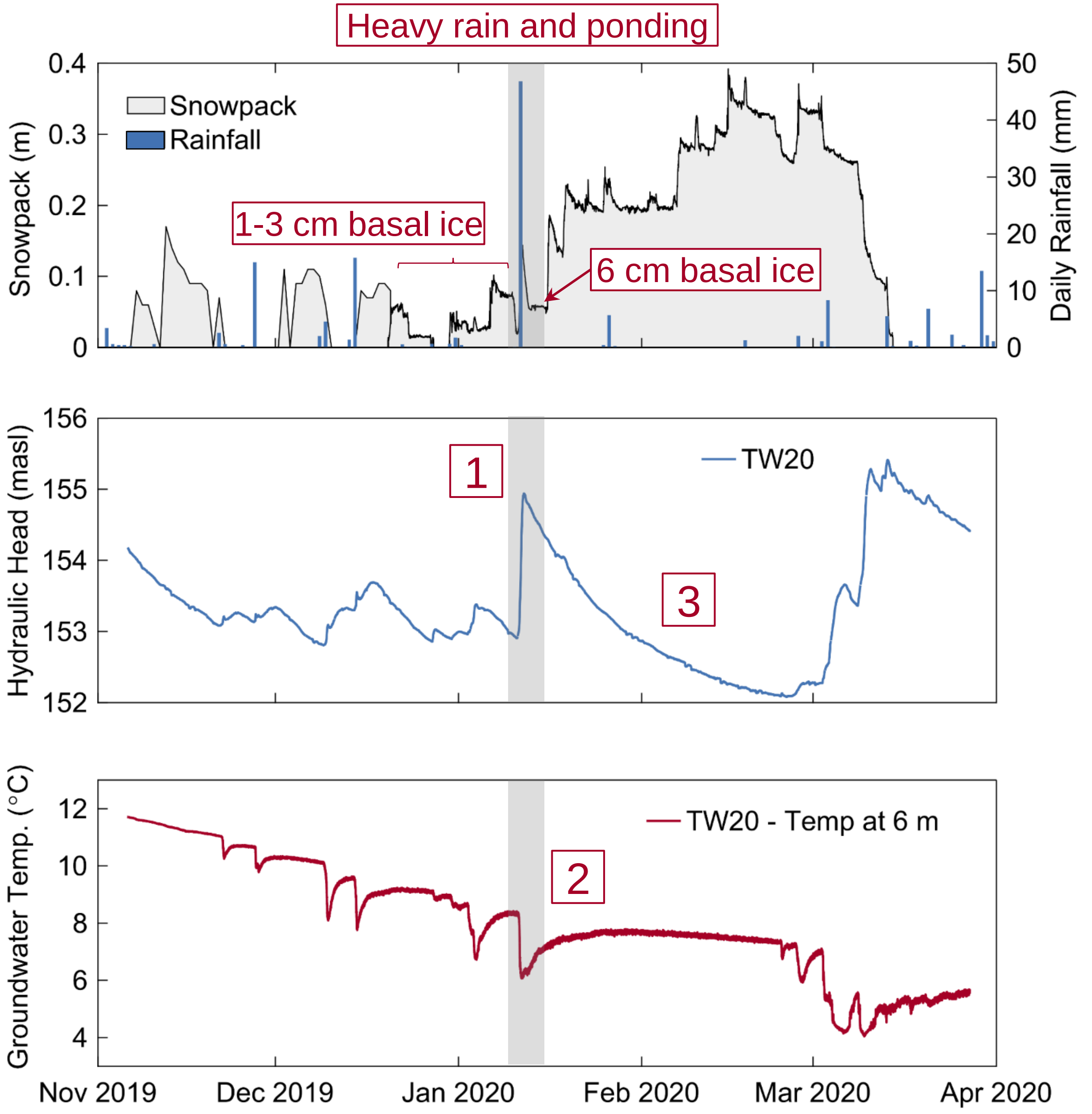
Groundwater

- Multiple recharge events occurred prior to Jan. 11 despite frozen ground and thin basal ice
- Rain-on-snow events were more effective at recharging groundwater than snowmelt or rainfall alone
- Midwinter recharge example:
  1. Rapid hydraulic head rise of 2.2 m
  2. Rapid drop in groundwater temperature (2 °C) indicating cold recharge
  3. Groundwater recession despite multiple snowmelt and ROS events in February



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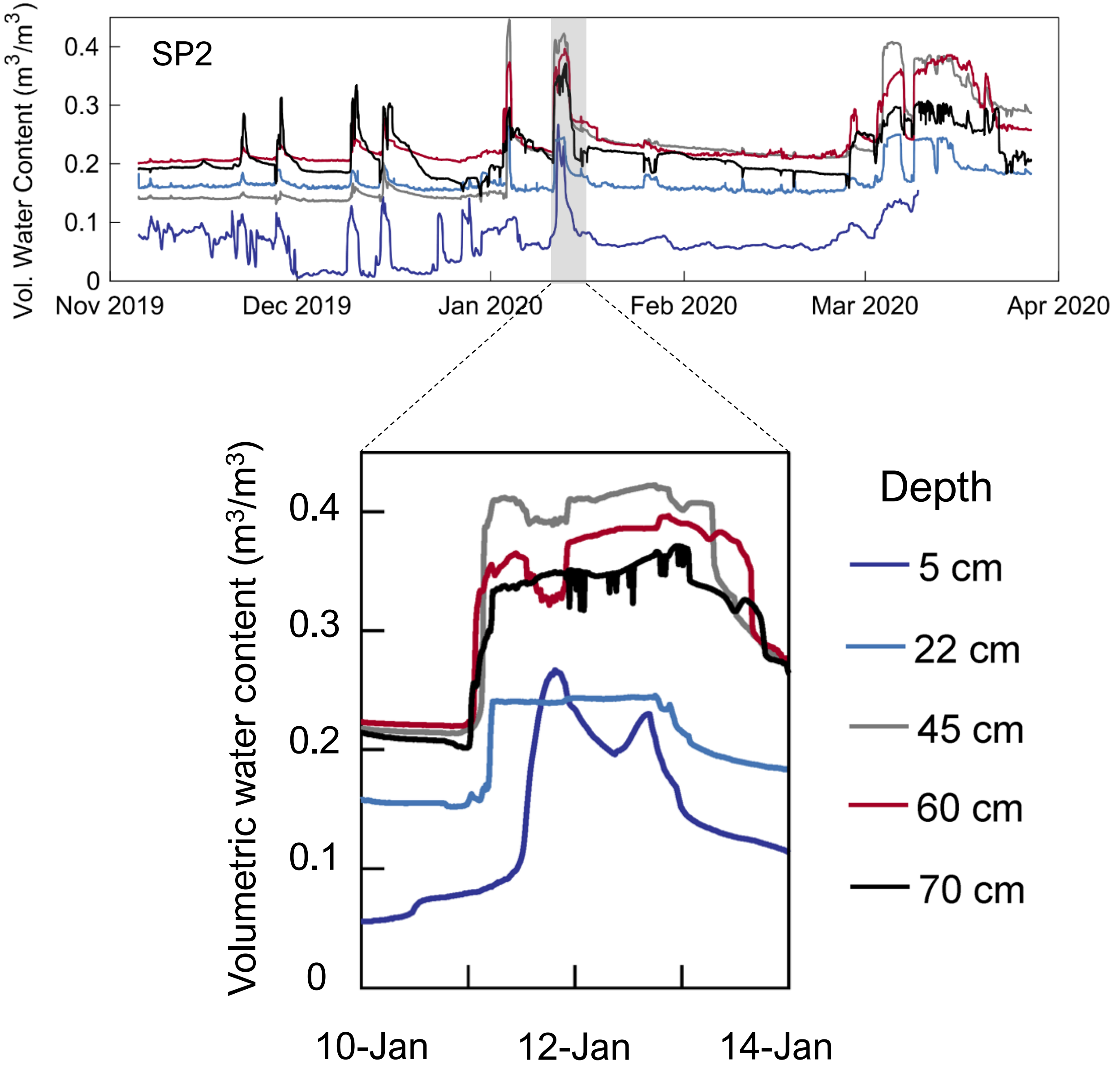
Soil water content

- Midwinter recharge example:
  - Deepest soil sensor (70cm) along soil-bedrock contact responds first followed by next deepest sensor
  - Shallowest sensors responds last
- In other events when basal ice or frozen soil is present, shallow sensor does not respond at all but deep does

Indicates infiltrating water is bypassing frozen surface layer along soil-bedrock contact



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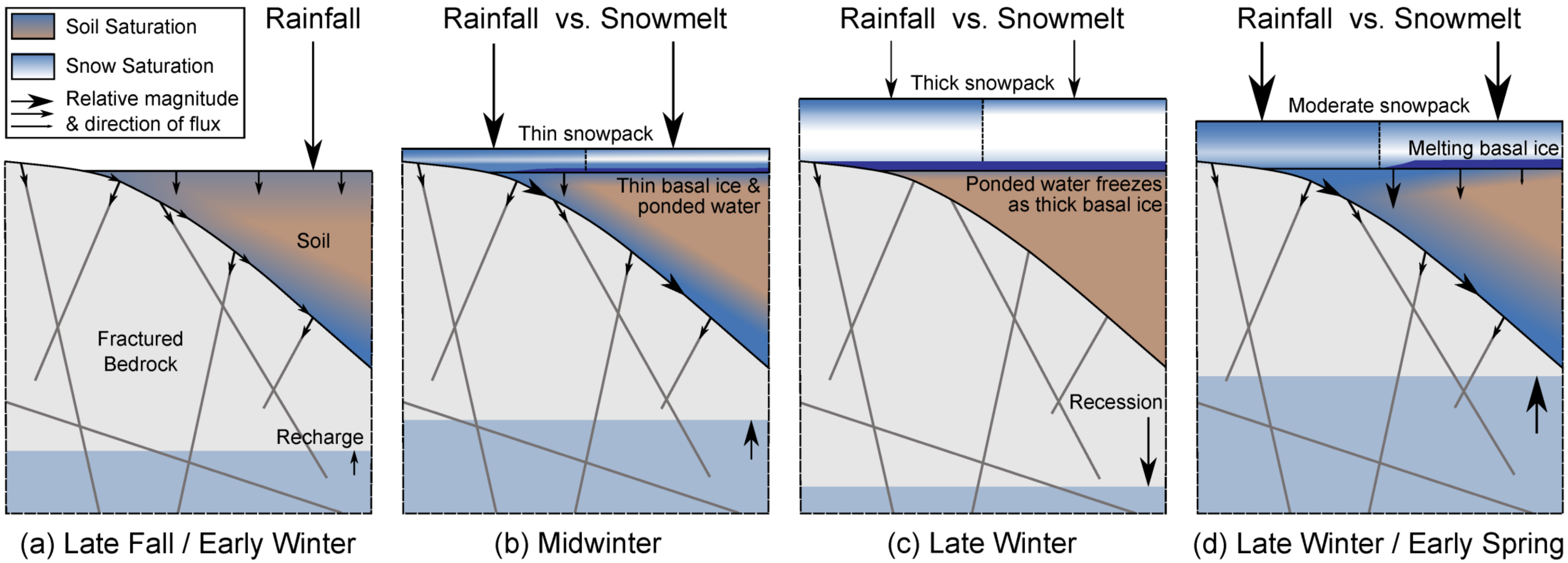
Conceptual models for midwinter recharge



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Conclusions

- Rapid midwinter recharge can still occur in seasonally frozen bedrock despite thin basal ice and frozen ground
  - Recharge is enhanced by ROS
- Recharge can be inhibited by extreme midwinter rainfall that subsequently refreezes, forming a low permeability surface layer
- Main mechanism allowing midwinter recharge is along soil-bedrock contact

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