Advancing Snow Accumulation Models in Needleleaf Forests

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Overview

This document links proposed thesis objectives to thesis chapters and proposed papers within each chapter.

Thesis Summary

Purpose: To better understand the processes that govern snow accumulation in forested environments.

Thesis objectives and research questions:

1. Evaluate the suitability of existing snow interception and ablation parameterizations for application in needleleaf forests with differing canopy structure and meteorology.
    a. What are the theoretical underpinnings and assumptions behind existing snow interception and ablation parameterizations?
    b. Are the theories and assumptions of existing snow interception parameterizations supported by field measurements collected across diverse canopy structures and meteorological conditions?
    c. Are the theories and assumptions of existing canopy snow ablation parameterizations supported by field measurements collected across diverse canopy structures and meteorological conditions?
2. Quantify the performance of current snow interception parameterizations against field observations in differing forest structures and climates.

    - For what climatic conditions and forest structures are predictions from current snow interception models most uncertain?
    - How do the assumptions of existing snow interception parameterizations influence model performance?

3. Determine how the modifications of existing snow interception parameterizations could improve process representations that are important for snow accumulation and redistribution in mountain forests.
    - What is the change in simulated snow accumulation model error associated with revised canopy snow interception parameterizations across mountain forests of differing forest structure and climate?
    - What is the change in simulated streamflow model error associated with revised canopy snow interception parameterizations across forested mountain basins of differing forest structure and climate?

Organization of Chapters

This thesis contains 4 chapters, the first chapter includes an introduction and research plan while, the remaining chapters 2-4 each correspond to a journal article which aims to answer each of the research questions.

Thesis Chapters

Chapter 1

This chapter includes background information about the study. Including the following subsections:

Introduction

This subsection of Chapter 1 will introduce background information, motivation, hydrological significance of the study topic, research gaps, and methods used in the study.

Research Plan

This subsection of Chapter 1 will describe the overall purpose of the thesis and links the individual thesis objectives to research gaps.

Chapter 2

This chapter corresponds to objective 1 of the thesis, to evaluate the suitability of existing snow interception parameterizations for application in mountain forests with differing climate and forest structure. To achieve this objective three draft journal articles have been written:

Paper 1: The Theoretical Underpinnings of Existing Snow Interception and Ablation Parameterizations

This paper aims to answer the first research question of Objective 1 which is "What are the theoretical underpinnings and assumptions behind existing snow interception parameterizations?". This advanced review will provide the context necessary for interpreting whether the theories and assumptions of existing parameterizations are true for the field observations collected in this study in the second part of objective 1. This paper is an advanced review which has been invited for submission to the journal WIREs Water.

WIREs Water Deadline: June 28, 2024

Abstract:

In needleleaf forests, up to half of annual snowfall may be lost due to sublimation of snow intercepted in the canopy. However, a comprehensive understanding of snow interception and ablation processes has been constrained by a lack of observations. Existing parameterizations for snow interception and ablation have been developed in locations with distinct climate and forest structures, resulting in differing and incomplete process representations. Consequently, their transferability across diverse landscapes and climates remains uncertain. This review article aims to elucidate the theoretical foundations and assumptions underlying the current snow interception and ablation parameterizations in the literature. The theory and methods behind snow interception and ablation studies are also reviewed to provide the context necessary for examining the applicability of current parameterizations across diverse environments. Some gaps in the literature include challenges in differentiating throughfall measurements from unloading and drip, the assumption of vertical snowflake trajectories, the difficulty in partitioning unloading rates and canopy snow melt drainage, the absence of a wind resuspension parameterization, and the inadequate validation of parameterizations in wind exposed subalpine forests. By reviewing the theory, methods and assumptions of existing snow interception and ablation parameterizations this article aims to inform future model-decision makers in selecting appropriate parameterizations and guiding future field-based observational studies.

1. Introduction

2. The Mass and Energy Balance of Snow in the Canopy

Section 2 begins with discussing the symbology used to represent mass fluxes, energy fluxes and states of snow intercepted in the canopy. This section is written in the context of a winter needleleaf forest environment.

2.1 Mass Balance

Section 2.1 contains a mass balance equation for canopy snow load followed by a description of each of the terms in the equation. A figure is also shown which gives a visual of the mass balance processes important for canopy snow load. Coupled mass and energy equations for the calculation of melt and sublimation of snow intercepted in the canopy are also shown.

2.2 Energy Balance

Section 2.2 contains an energy balance equation for snow intercepted in the canopy followed by a description of the terms. A figure showing a visual representation of the energy balance processes is shown. A discussion of some of the simplifications made with this energy balance representation is then provided.

3. Measuring Snow Interception and Ablation

Section 3 covers the common methodologies used to measure snow interception and ablation. A description of the principle behind each method is given and any uncertainties related to the method are also discussed. The methodologies described include, weighed tree, mass balance methods, snow surveys, subcanopy lysimeters and remote sensing techniques.

3.1 Weighed Tree

3.2 Mass Balance Methods

3.2.1 Snow Surveys

3.2.2 Subcanopy Lysimeters

3.3 Remote Sensing

4. Methods of Determination

Section 4 discusses the parameterizations available in the literature for the determination of the mass and energy balance processes discussed in Section 2. For each parameterization a description the study environment, climate, and methodologies used to derive it is provided. Section 4.1 discusses snow interception parameterizations followed by section 4.2 which discusses snow ablation parameterizations for sublimation, unloading and drip.

4.1 Snow Interception Parameterizations

4.2 Canopy Snow Ablation Parameterizations

4.2.1 Sublimation

4.2.2 Unloading and Drip

5. Discussion

In Section 5 the theories and assumptions of the parameterizations listed above are compared. Research gaps are also listed to give insight on where current snow interception and ablation parameterizations theories and assumptions may be invalid and where new observations and theoretical development is required. Advice for informing model-decision makers on choosing parameterizations is also given

6. Conclusion

Paper 2: Combined effects of wind, air temperature and snowfall on snow interception in a subalpine forest

This journal article aims to answer part of the second research question of Objective 1, "Are the theories and assumptions of existing snow interception parameterizations true for field measurements collected across diverse forest structures and climates?". This will be achieved by presenting observations of interception from a study site few researchers have focused on, a subalpine discontinuous forest and contrast these results with existing theory developed in maritime and continental climates. This journal article is in progress for submission to the Hydrological Processes special issue "Canadian Geophysical Union 2023".

1. Introduction

2. Methods

2.1 Study Site

2.2 Automated Interception Measurements

2.3 Snow Surveys

2.3.1 In-Situ Measurements

2.3.2 UAV-LiDAR Measurements

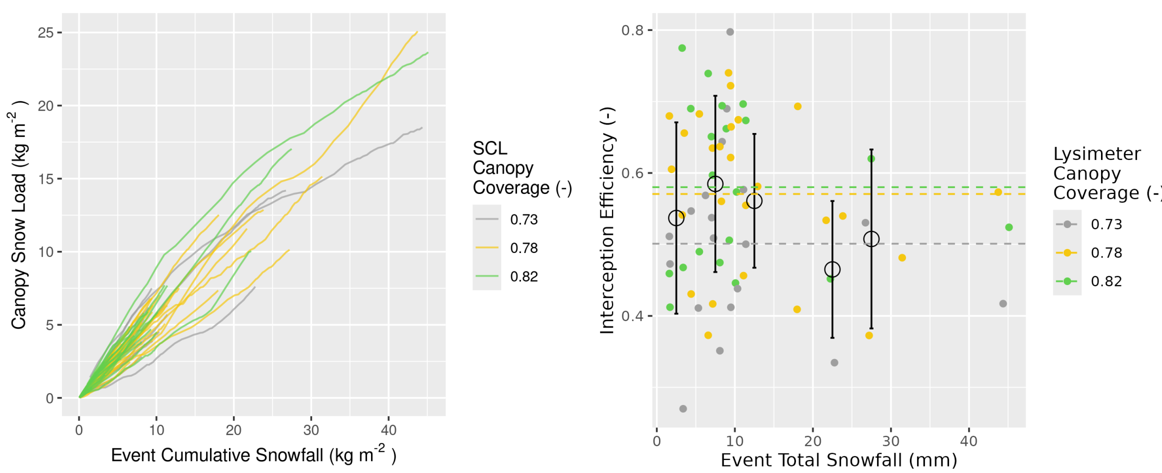
2.3.4 Discrete Event Interception Measurements

2.3 Canopy Structure Products

3. Results

3.1 The influence of meteorology on snow interception

- The accumulation of canopy load over 26 snowfall events shown in Figure **??** measured using the subcanopy lysimeters, exhibits the variability in I/P between and within the different events. The relatively low variability in I/P across and within the different events is attributed to variances in meteorological conditions.
- Frequency distribution of meteorological variables observed over the 26 snowfall events (**?@fig-hist-met-ip**).
- **?@fig-lai-met-ip** shows 15-minute average variables including: air temperature, relative humidity, wind speed, initial canopy snow load, hydrometeor diameter, hydrometeor velocity, versus 15 minute average snow interception efficiency for all 26 snowfall events.



(a) (b)

Figure 1: Two plots showing the relationship between snowfall and interception. Plot (a) shows the cumulative event snowfall versus the corresponding state of canopy snow storage for each of the 26 snowfall events. Plot (b) shows total event snowfall versus the average interception efficiency for each event. Snowfall data was measured using the snowfall gauge at Powerline Station while throughfall data was measured using the three subcanopy lysimeters used for the calculation of canopy storage and interception efficiency. These lysimeters, each denoted by a distinct color (black, red, and green), correspond to varying canopy coverage (0.73, 0.78, and 0.82, respectively).

3.2 The influence of forest structure on snow accumulation

- Snow interception efficiency observed across the study site after a 24 hour snow accumulation event reveals the influence of forest structure on snow accumulation.

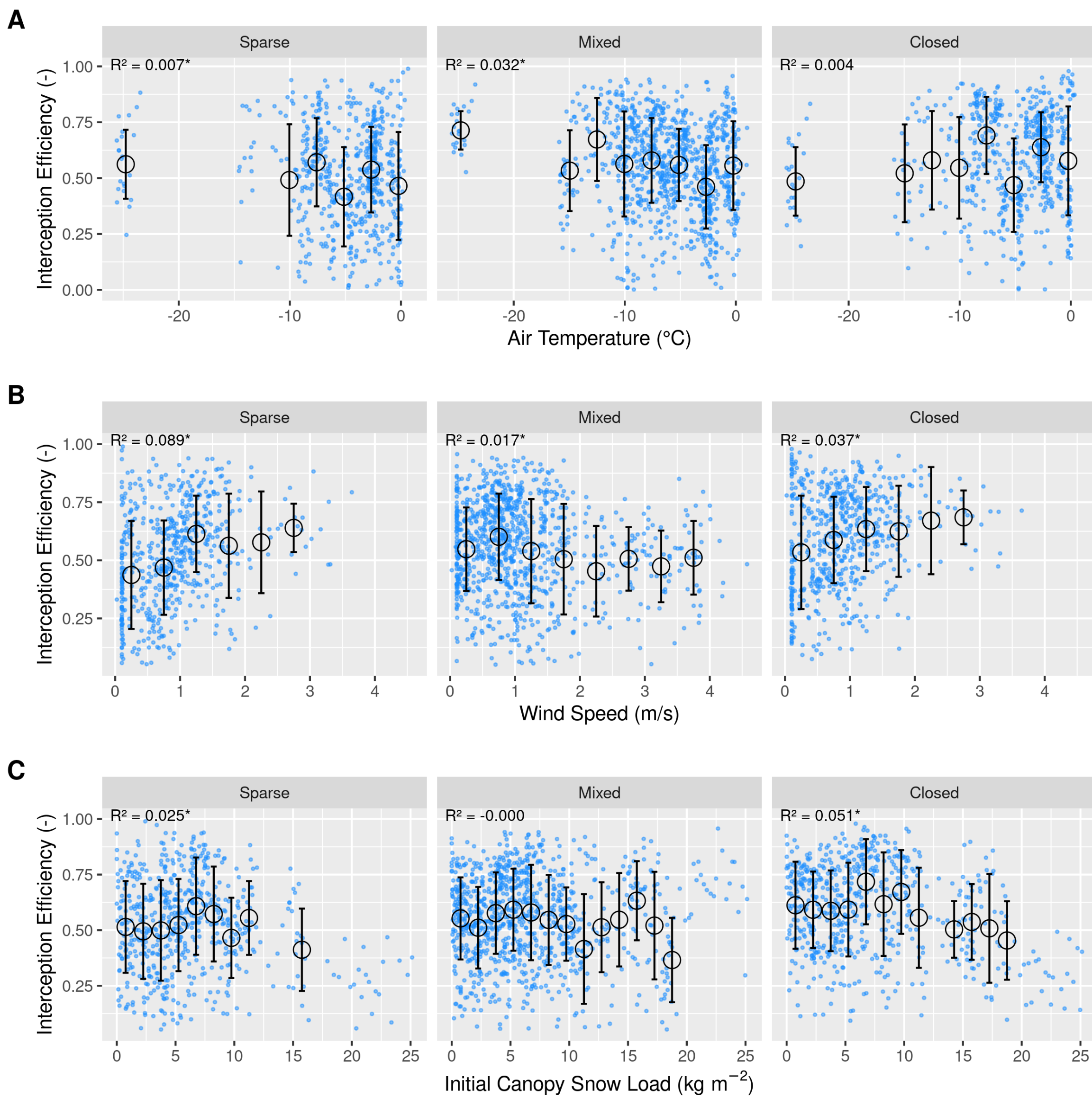


Figure 2: Scatter plots of discrete observations (green) of snow interception efficiency observed at 15 minute intervals using the subcanopy lysimeter and snowfall gauge against and binned data (black). Panels show (A) air temperature, (B) wind speed, (C) initial canopy snow load (the snow load observed at the beginning of the timestep), (E) hydrometeor diameter, (F) hydrometeor velocity. The black open circles show the mean of each bin and the error bars represent the standard deviations. The data were filtered to include observations with a snowfall rate $>$ 0 mm/hr and a snowfall rate $>$ the subcanopy lysimeter throughfall rate to minimize observations with unloading. Periods of unloading and melt were also removed through careful analysis of the weighed tree, subcanopy lysimeters, and timelapse imagery.