Optimizing over-summer snow storage at low latitudes and low altitudes

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Abstract

Climate change is forcing the ski industry to modify snow-making strategies and facility operations. Over-summer snow storage is an adaptation successfully employed by high-elevation and/or high-latitude ski centers in Europe, Canada, and Asia. The process involves stockpiling winter snow and storing it beneath insulation (e.g., wood chips) through summer. Current methods are empirically-based with few studies quantifying snowmelt through summer or comparing insulation strategies. In this project, we evaluate the feasibility of over-summer snow storage in Vermont, northeastern North America. Soil temperatures were recorded since June 2017 with sensors 5, 20, 50 cm and 1 m below the ground surface. In March 2018, two, 200 m3 snow piles were covered in plastic and wood chips; we monitored their volume bi-weekly through the melt season using terrestrial LiDAR. We also measured air to snow temperature gradients under various insulation materials: rigid foam, open cell foam, and wet wood chips, all with and without reflective coverings. Away from snow piles, ground temperatures at 1 m depth were ˜7C in spring 2017, rising to 12C in summer, and falling to just above 0C in winter. As depth decreased, ground temperature became more responsive to air temperature; ground temperature lagged air temperature at all depths. Below summer snow piles, soil temperature at all depths remained near freezing through the summer as cold meltwater percolated into the ground. Snow was lost from each pile at a similar rate (˜1.3 m3 day-1) from late March to mid-June; melt then accelerated slightly in response to increased air temperature, solar radiation, and humidity. Large crevasses formed in both piles along the edge of the plastic sheeting which exposed snow to direct sunlight. Temperature was at or above 10C over the snow below both rigid foam and open-cell foam with a strong diurnal variation, regardless of the addition of a reflective blanket. Beneath wet wood chips covered with a reflective blanket, temperature remained close to freezing even though air temperature was > 30C. There was no diurnal variation, indicating that wood chips effectively buffered thermal swings. It appears that a reflective surface over >20cm of wet wood chips is most effective at minimizing summer snow melt in humid, northeastern North America.

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Summary

- As winters become shorter, & warmer, the winter tourism industry needs adaptation strategies.
- Globally, ski centers are turning to over-summer snow storage to begin their season on-time.
- The Craftsbury Outdoors Center in northeastern VT will be the lowest latitude/elevation location to attempt snow storage.
- Summer '18 was the pilot test with two, ~200 m³ piles of snow emplaced.
- We tested a variety of insulation strategies and found a promising one.

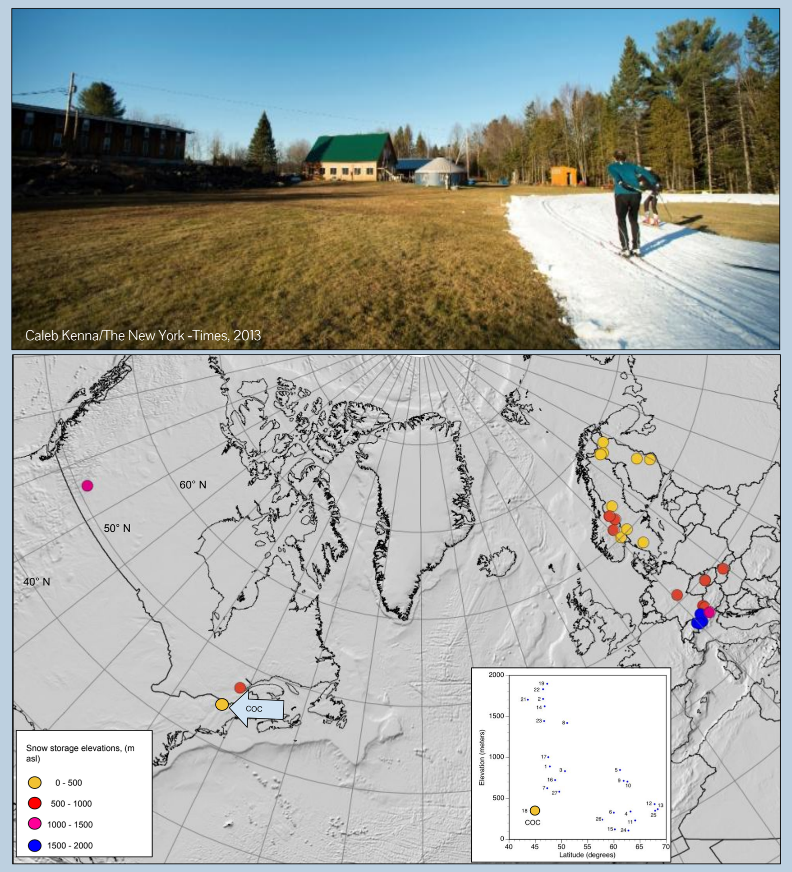


Figure 1: (Top) Skiers using an artificial snow loop at the COC for Thanksgiving races in 2013. (Bottom) Known global locations of over-summer snow storage, colored by elevation. The Craftsbury Outdoors Center (COC) is identified.

How Saving Snow Works

Figure 2: (Left/Right) A wood chipper covers piles of snow at two nordic ski centers in Europe.

1. Make a large pile of artificial snow outdoors during cold months
2. Cover the pile in insulating materials (i.e., wood-chips)
3. Let it sit over the summer
4. Remove the insulation and spread snow out on trails to open the ski season

Location of this study

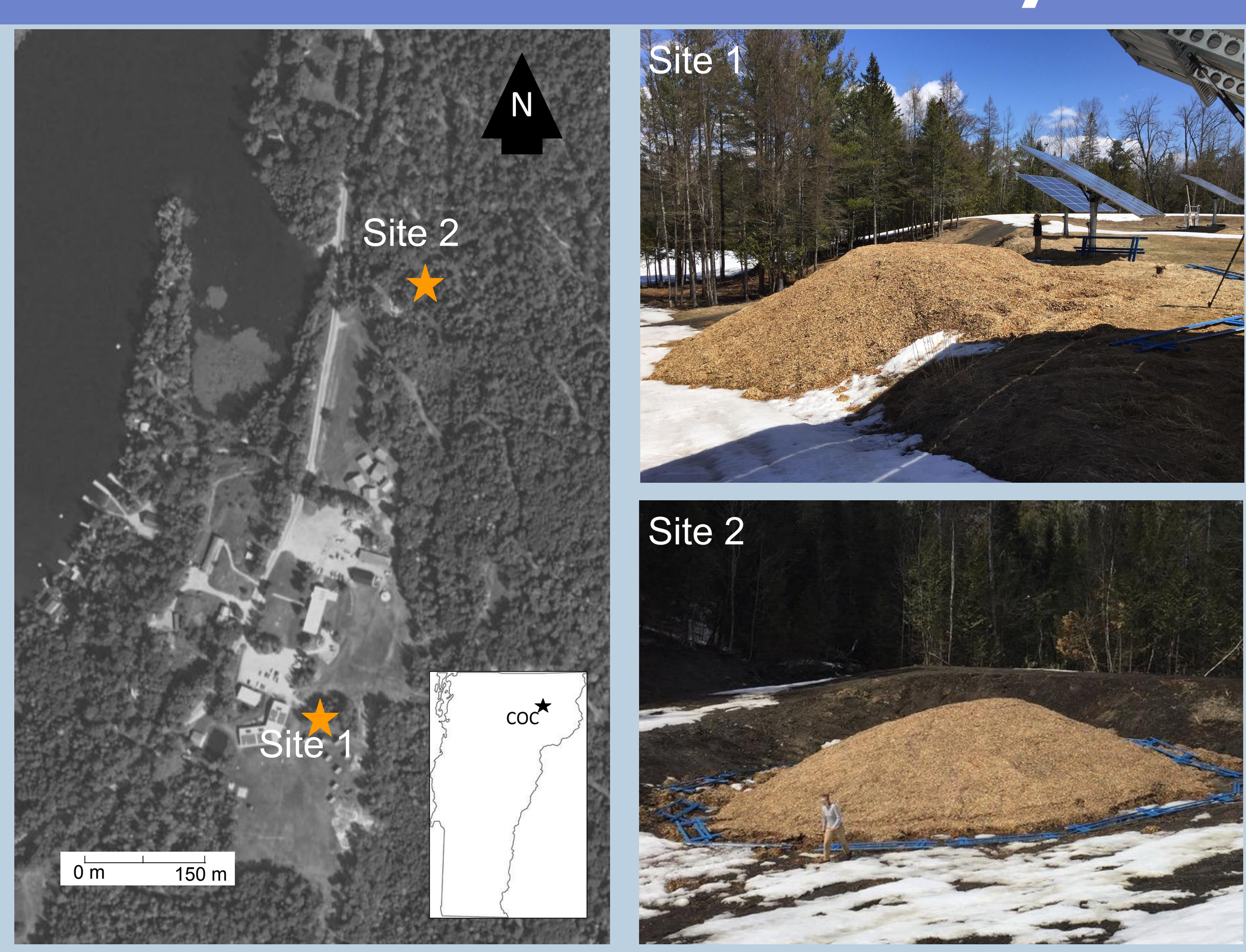
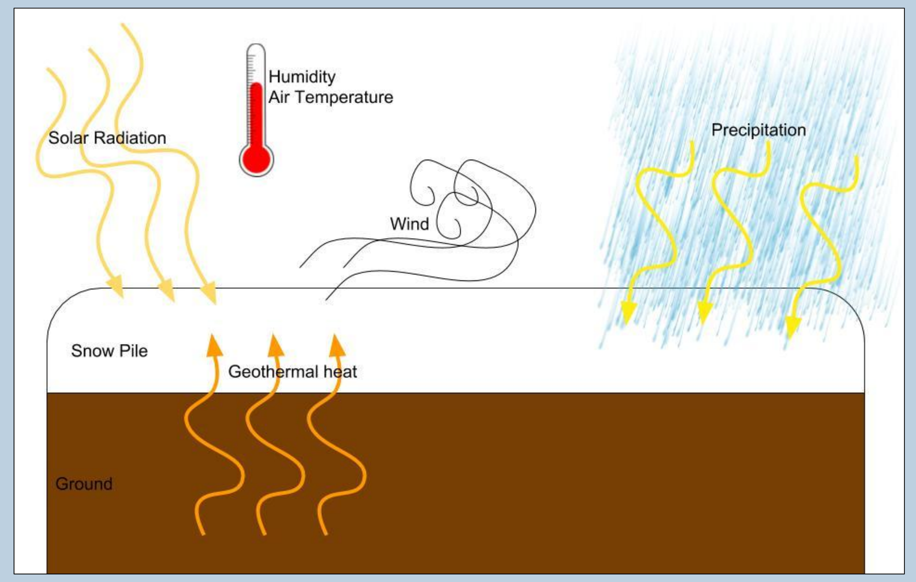


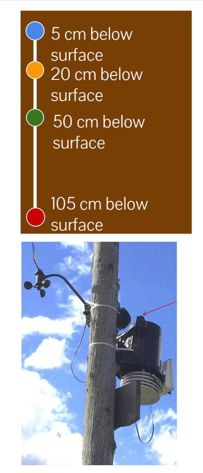
Figure 3: (Left) The location of the Craftsbury Outdoors Center in Vermont. (Right, top) Site 1's pilot snow pile covered in wood chips (225 m³ snow + 24m³ wood chips). (Right, bottom) Site 2's pilot snow pile covered in wood chips (209 m³ snow + 42 m³ wood chips). Photos taken by Paul Bierman on 4/21/18.

Our methodology

1) What affects snowmelt?



- Installed HOBO ground temperature sensors, recorded 4 different ground temperatures depths since June, 2017 at 20 minute intervals
- Recorded other weather conditions in the above diagram through the local Davis weather station at the COC



2) How do the piles melt over time?

- Created two pilot piles (Fig. 3), covered them in a layer of plastic and wood chips
- Surveyed with terrestrial LiDAR (RIEGL VZ-2000i) and tracked volume change over the summer
- Surveyed and processed scans every 10-14 days for 14 scans of each pile between February and September, 2018

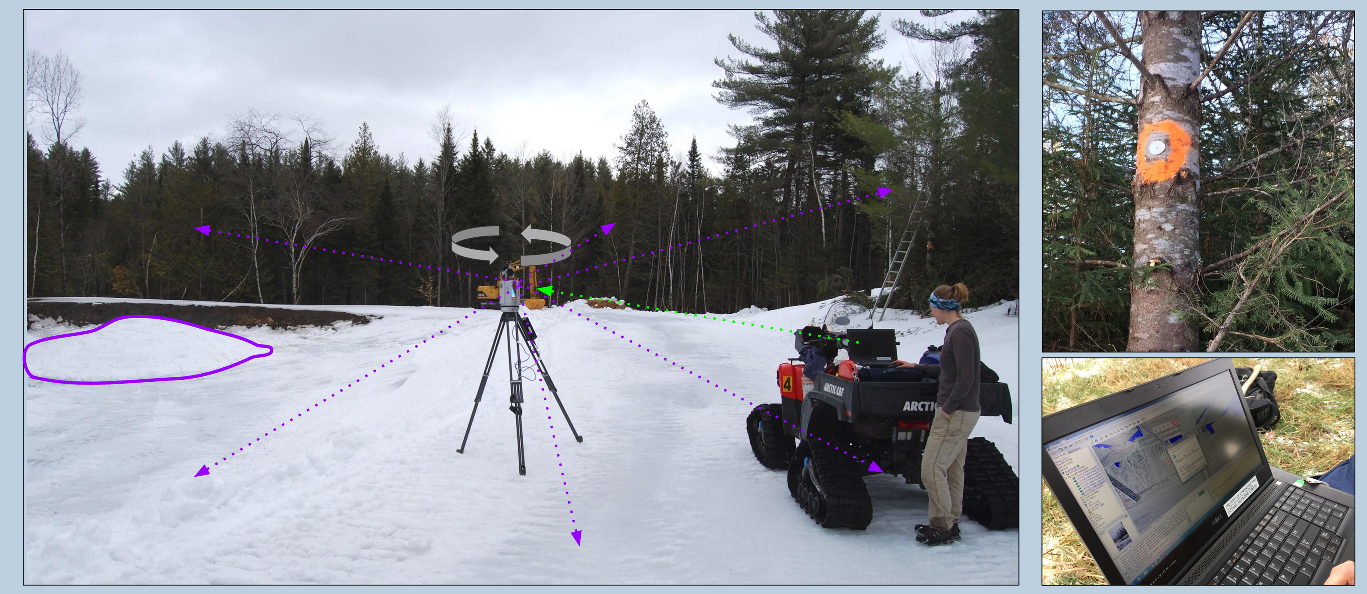
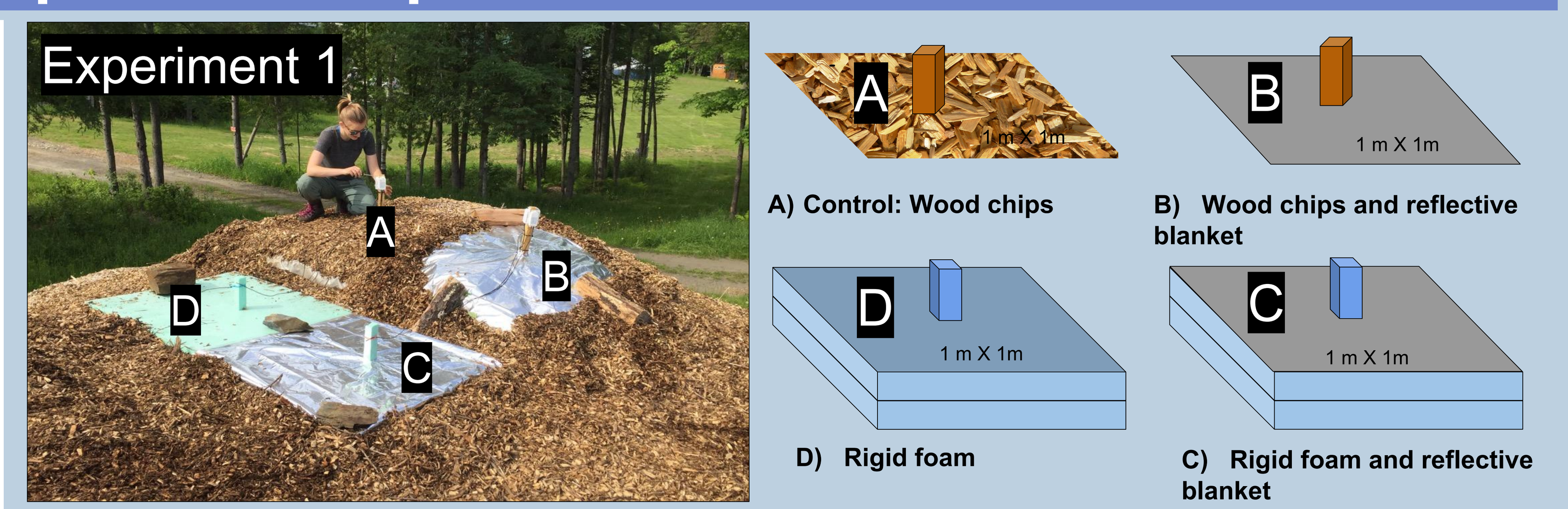


Figure 4: (Left) LiDAR scans a snowpile before wood chips have been emplaced. LiDAR is controlled via a computer (green arrow, right bottom picture), and then emits infrared laser pulses in a 360° scan. The goal is to determine the volume of the snowpile (outlined in purple). We took scans from at least three different locations per pile and merged them together through LiDAR recognizing "tie-points" (right, top picture) or reflectors that stay in the same place throughout all the scans.

3) What insulation keeps snow temperatures closest to 0° at surface?

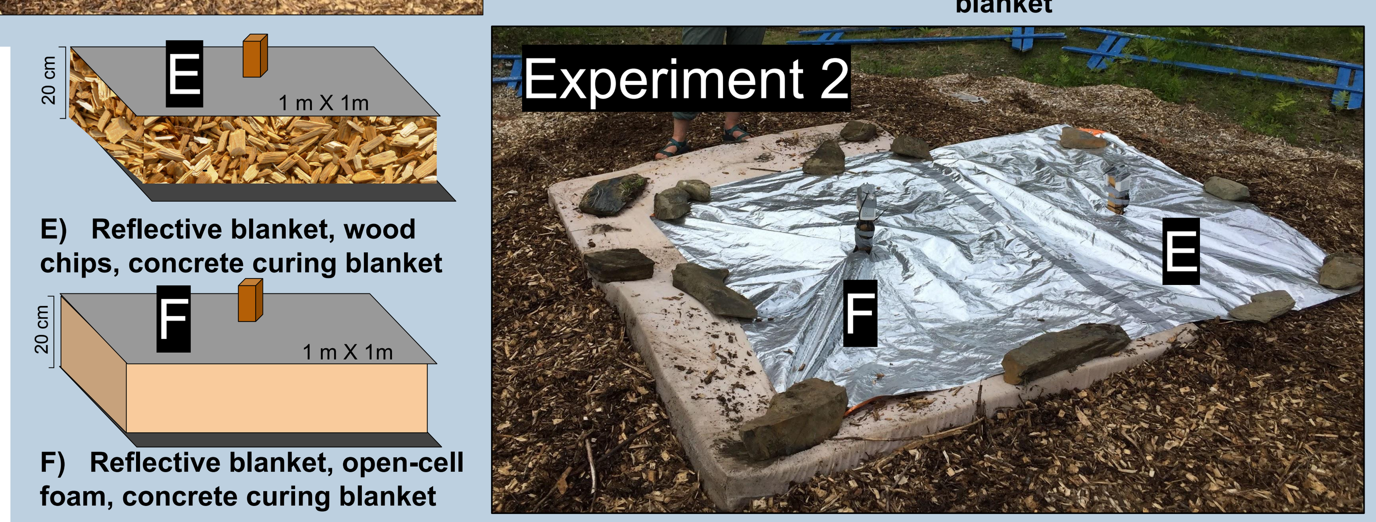
Experiment 1:

- Tested rigid foam and a reflective blanket using four different 1 m x 1m subplots
- Three temperature sensors in each plot recorded 1) temperature at snow level, 2) temperature within the insulation and 3) air temperature above at 5 minute intervals for 1 week



Experiment 2:

- Tested open-cell foam, a reflective blanket, and concrete curing blanket through two different 1 m x 1m subplots
- Three temperature sensors in each plot recorded 1) temperature at snow level, 2) temperature within the insulation 3) temperature below the reflective blanket, and 4) air temperature at 5 minute intervals for 1 week



Results - How do the piles melt over time?

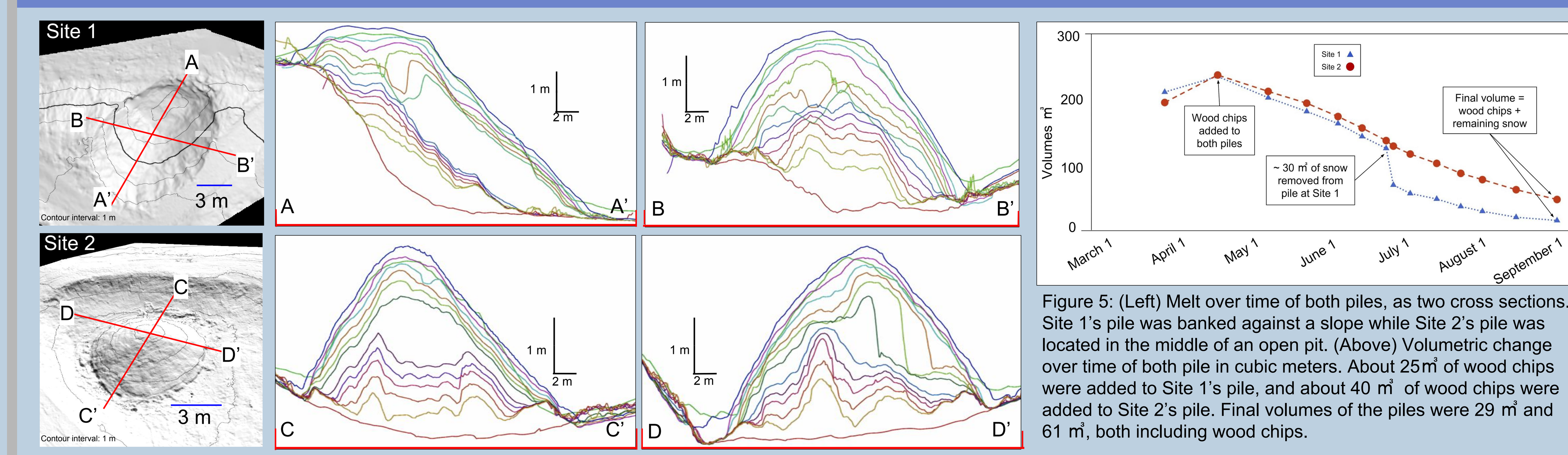


Figure 5: (Left) Melt over time of both piles, as two cross sections. Site 1's pile was banked against a slope while Site 2's pile was located in the middle of an open pit. (Above) Volumetric change over time of both pile in cubic meters. About 25m³ of wood chips were added to Site 1's pile, and about 40 m³ of wood chips were added to Site 2's pile. Final volumes of the piles were 29 m³ and 61 m³, both including wood chips.

Results - Weather/Environment

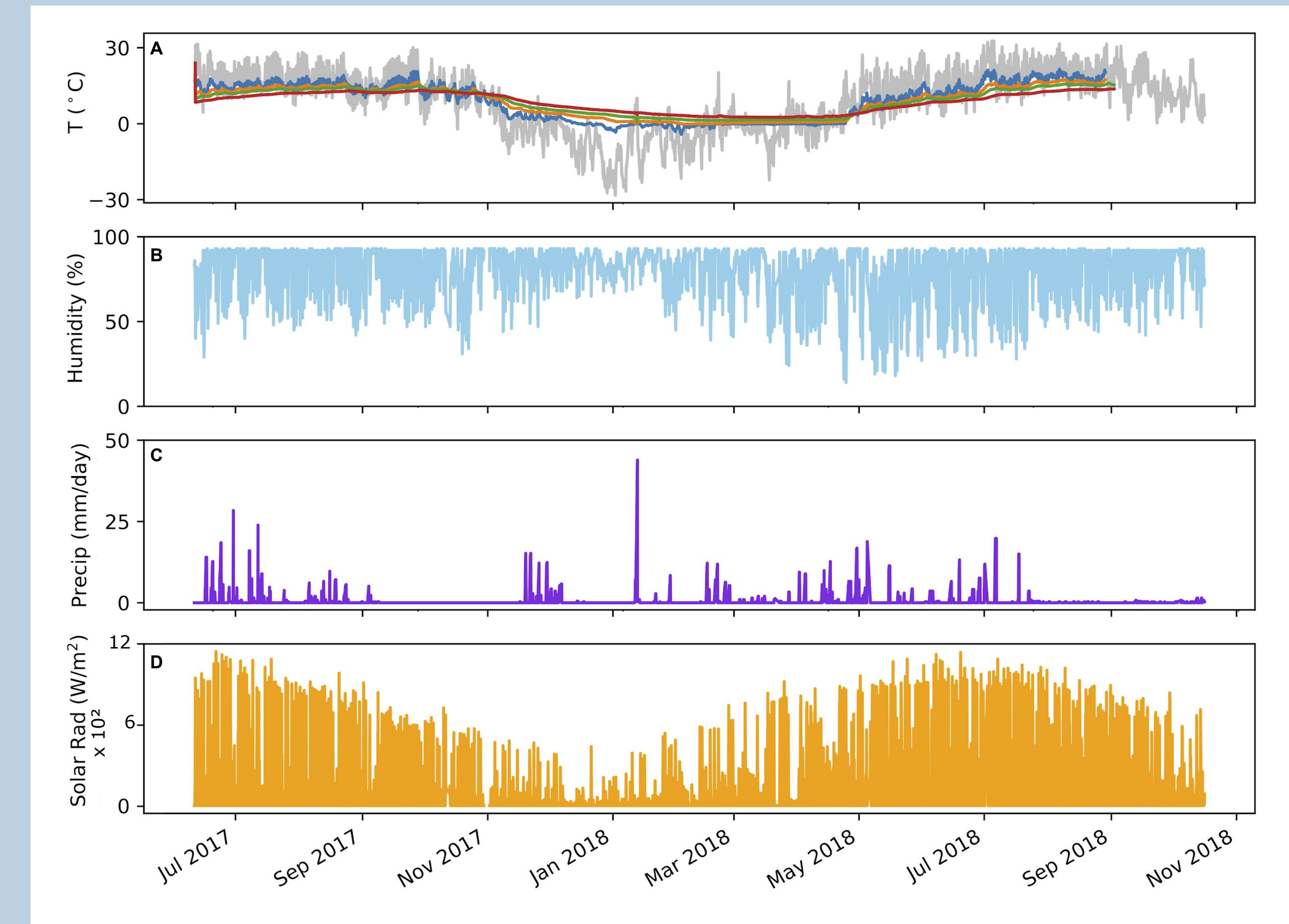


Figure 6: Key variables monitored from June, 2017 through October, 2018. Seasonal change is noted in panels A, B, and D as these variables respond to changing seasons.

Results -Insulation Experiments

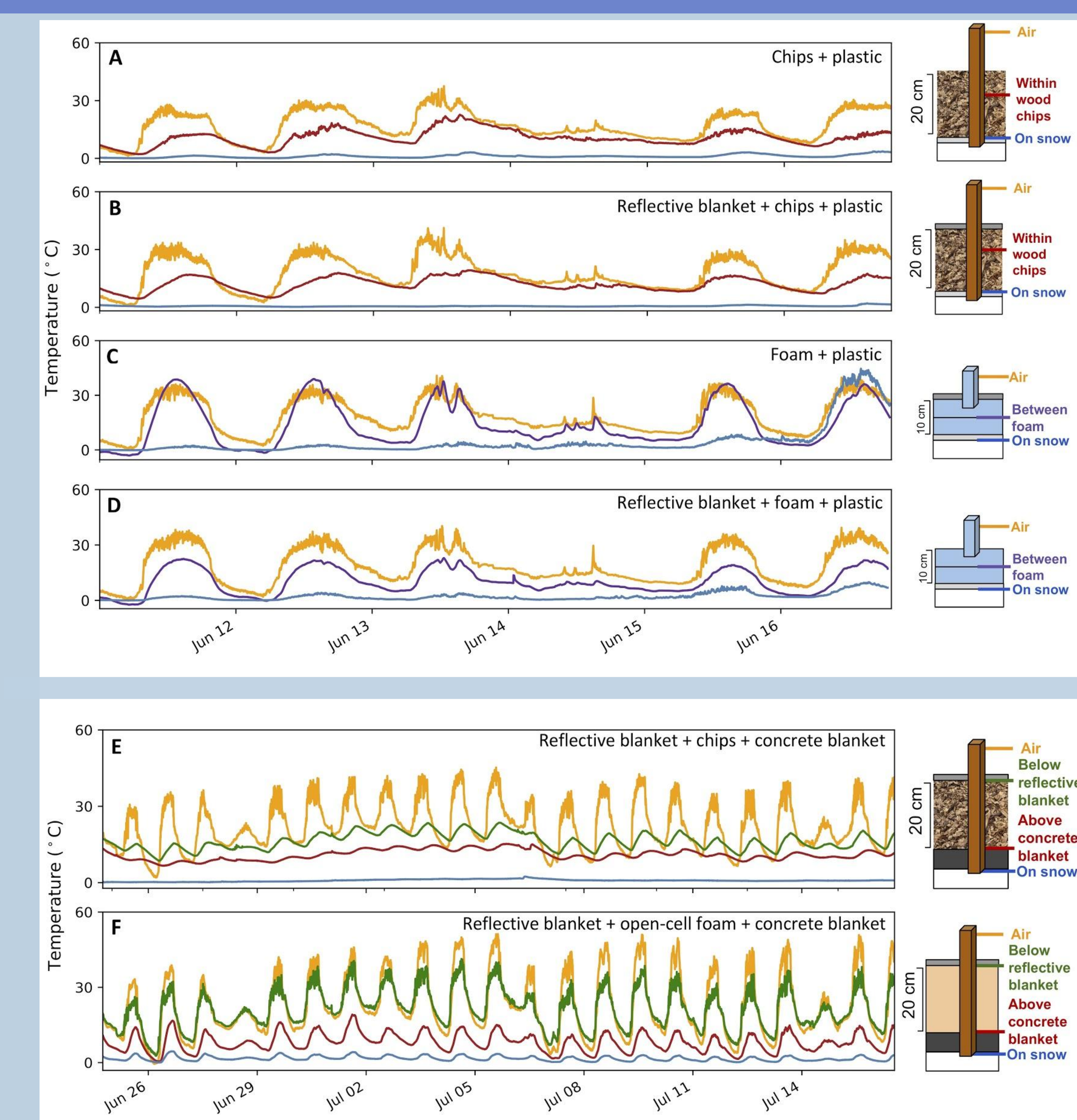


Figure 7: (Top) Temperature results from Experiment 1 reveal that a reflective blanket and wood chips keep surface snow temperatures closest to 0° (Panel B). (Bottom) Temperature results from Experiment 2 reveal that a reflective blanket, wood chips, and a concrete blanket keep snow temperatures closest to 0° (Panel E).

Key takeaways

- A reflective blanket, wood chips, and a concrete blanket are the preferable insulation combination to reduce snow melt
- Snow storage is possible at low latitudes and low elevations

Looking ahead: Summer 2019 will incorporate what we've learned in 2018 and apply it to a 7,000 cubic meter snow pile at the COC.