

The Feasibility of Over-Summer Snow Storage at the Craftbury Outdoor Center, Craftsbury VT

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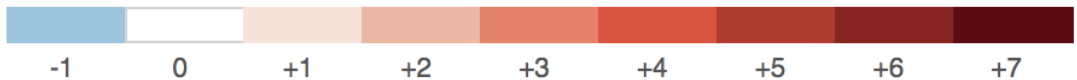
Warming Winters In The U.S., 1896- 2018

Jan, 2020

Less snowfall predicted overall for the northeast (Zarzycki, 2017)

Winter conditions are becoming more unpredictable (Finlayson, 2019)

AVERAGE CHANGE IN TEMPERATURE (°F)



Why skiing?

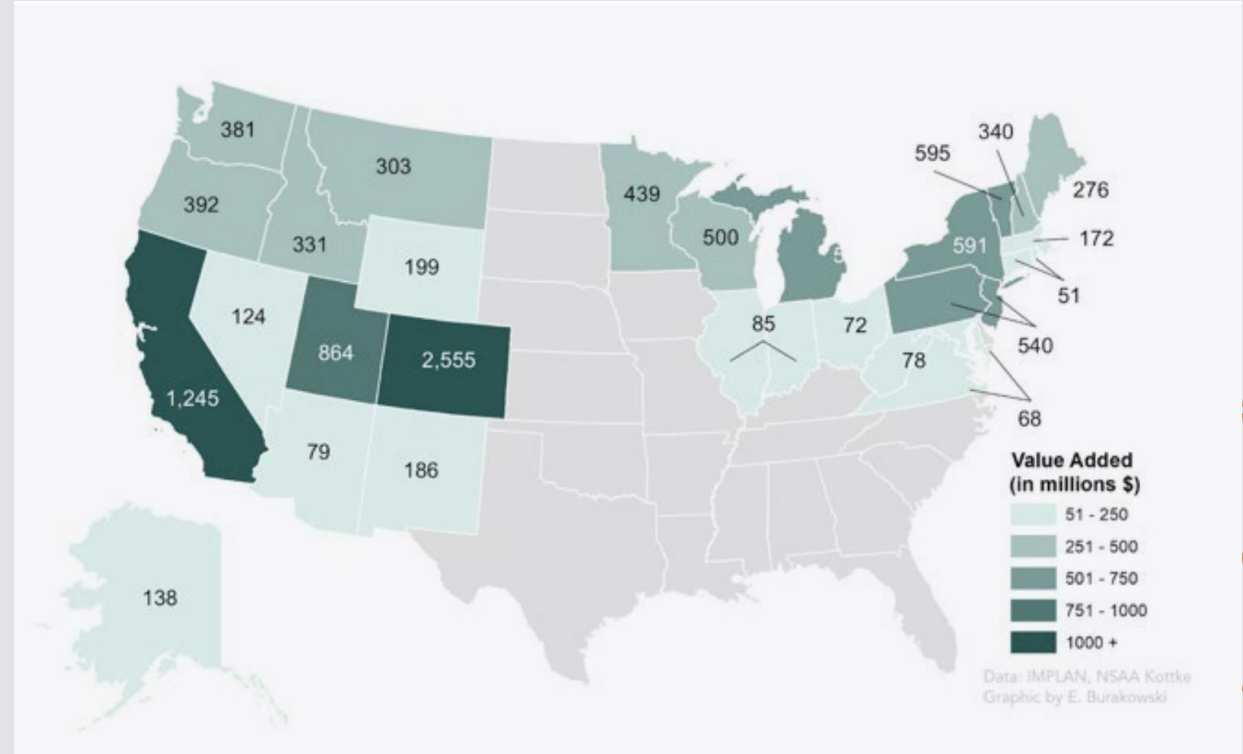
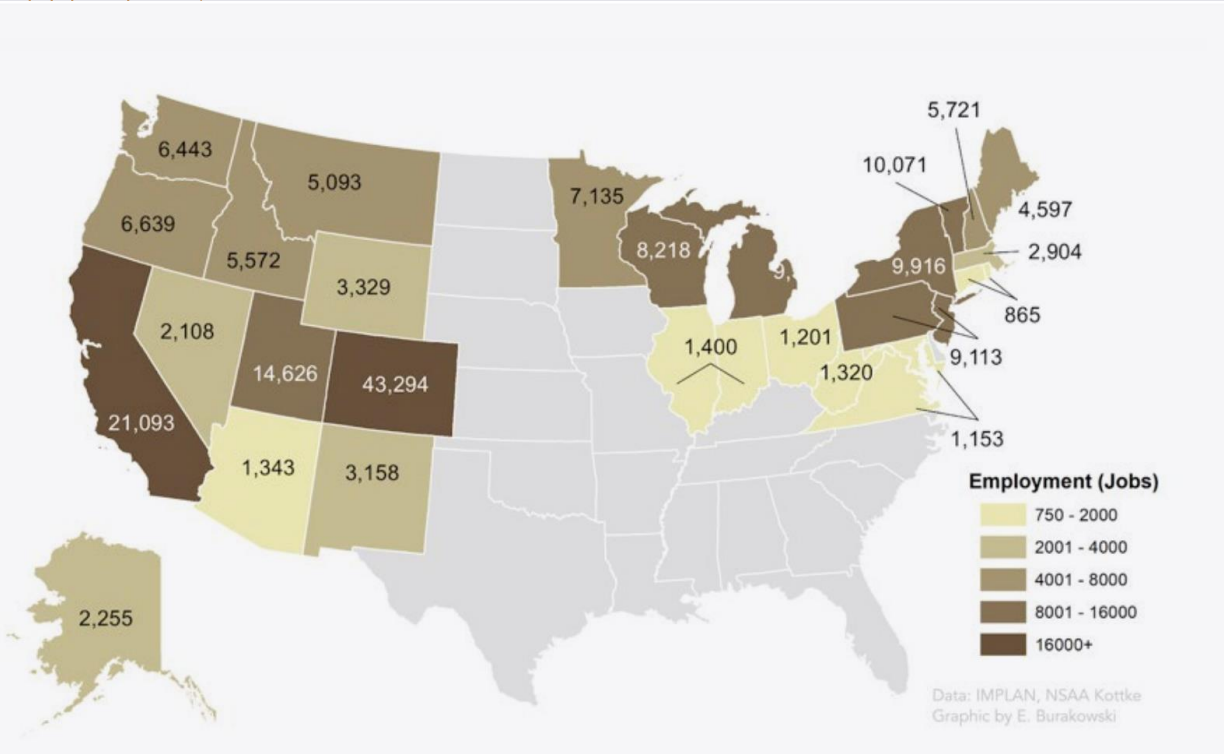


Historical roots (Huntford, 2009; Pedersen, 2013)



Cultural/identity (Allen, 1985) and physical/mental benefits (Sharp, 2011)

Why skiing? Economic impact



Jobs added (left) and value added to economies in 2016 (right) (Hagenstad et. al., 2018)

Employs **3% of employable adults in VT**
 Employs **1.5% of employable adults in CO**

Added **2.2% to VT's 2016 GDP**
 Added **0.8% to CO's 2016 GDP**

Snow-making



Image: <https://www.vtrural.org/programs/climate-economy/innovator/craftsbury-outdoor-center>

Images: <https://www.xcskiresorts.com/resort-features/2016/9/12/snowmaking-pays-off-for-xc-ski-resorts>

What is snow storage?

1

Make a large pile of snow during cold months

2

Cover the snow in insulative layers

3

Let the snow pile sit through spring, summer, and fall

4

Uncover the snow pile at the beginning of the ski season

5

Spread it to create trails

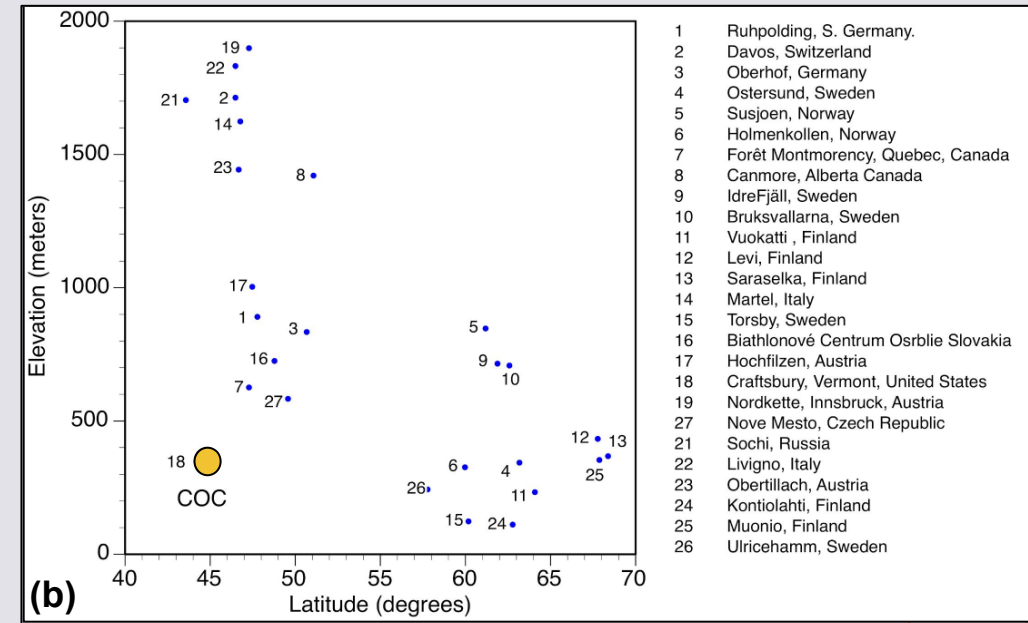
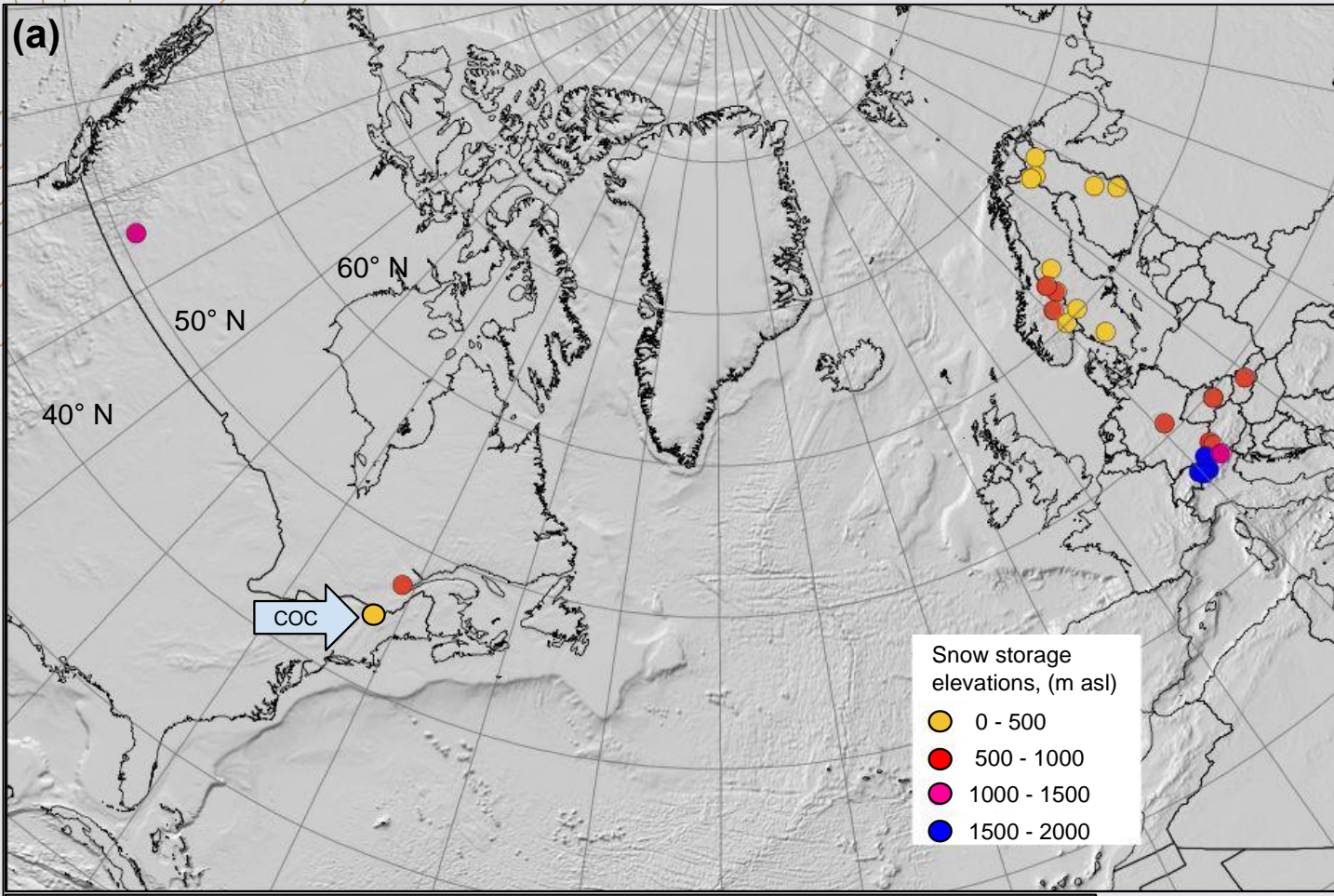


Image: <http://ais.wetter.de/masters/514430/switzerland-snowfarming.jpg>



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Who stores snow?



The Craftsbury Outdoor Center





This research

1. Can we store snow over the summer at the COC?

2. If we can, what is the best way to store snow?

3. Is snow storage financially feasible (\$)?

4. Is snow storage environmentally feasible (kg CO₂)?

This research

2018

1. Can we store snow over the summer at the COC?

2018/
2019

2. If we can, what is the best way to store snow?

2019/
2020

3. Is snow storage financially feasible (\$)?

2020

4. Is snow storage environmentally feasible (kg CO₂)?

Methods: Can we store snow at the COC?

1. Choose locations
2. Create snow piles
3. Cover snow piles in wood chips
4. Monitor change
5. Analyze results

Spring,
2018

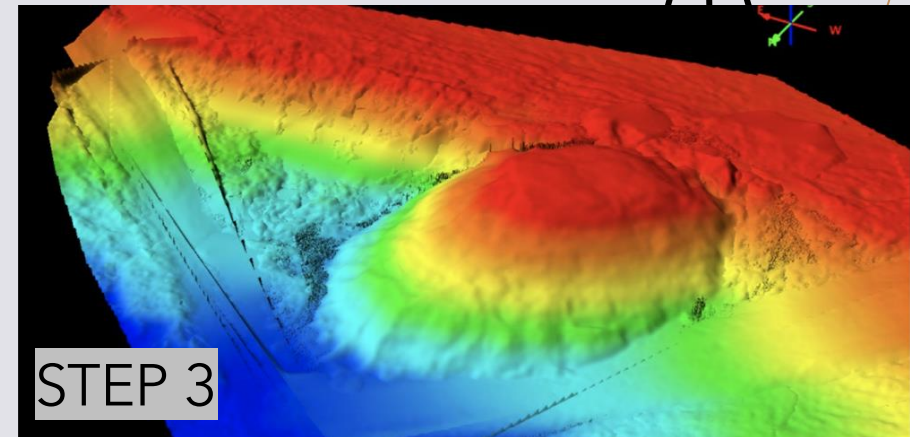
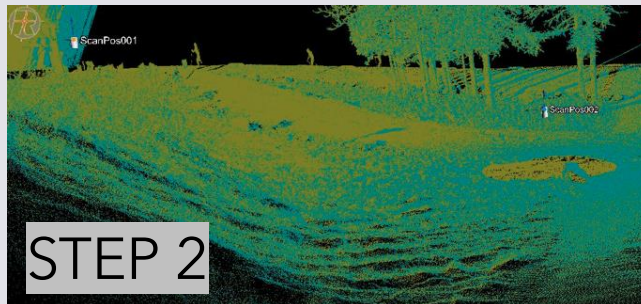
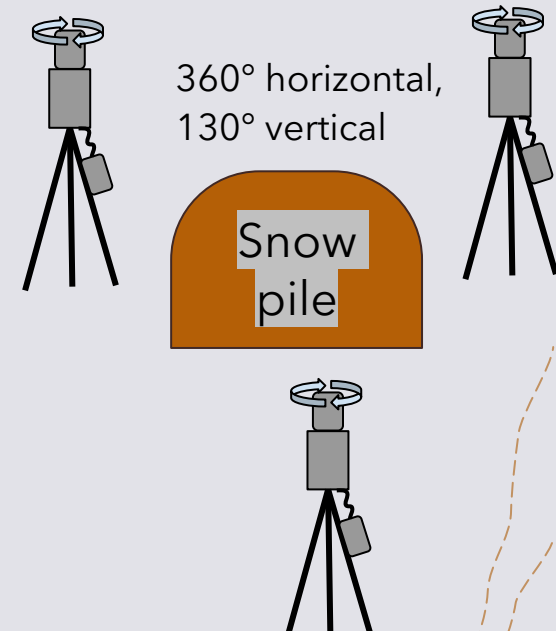
Fall,
2018



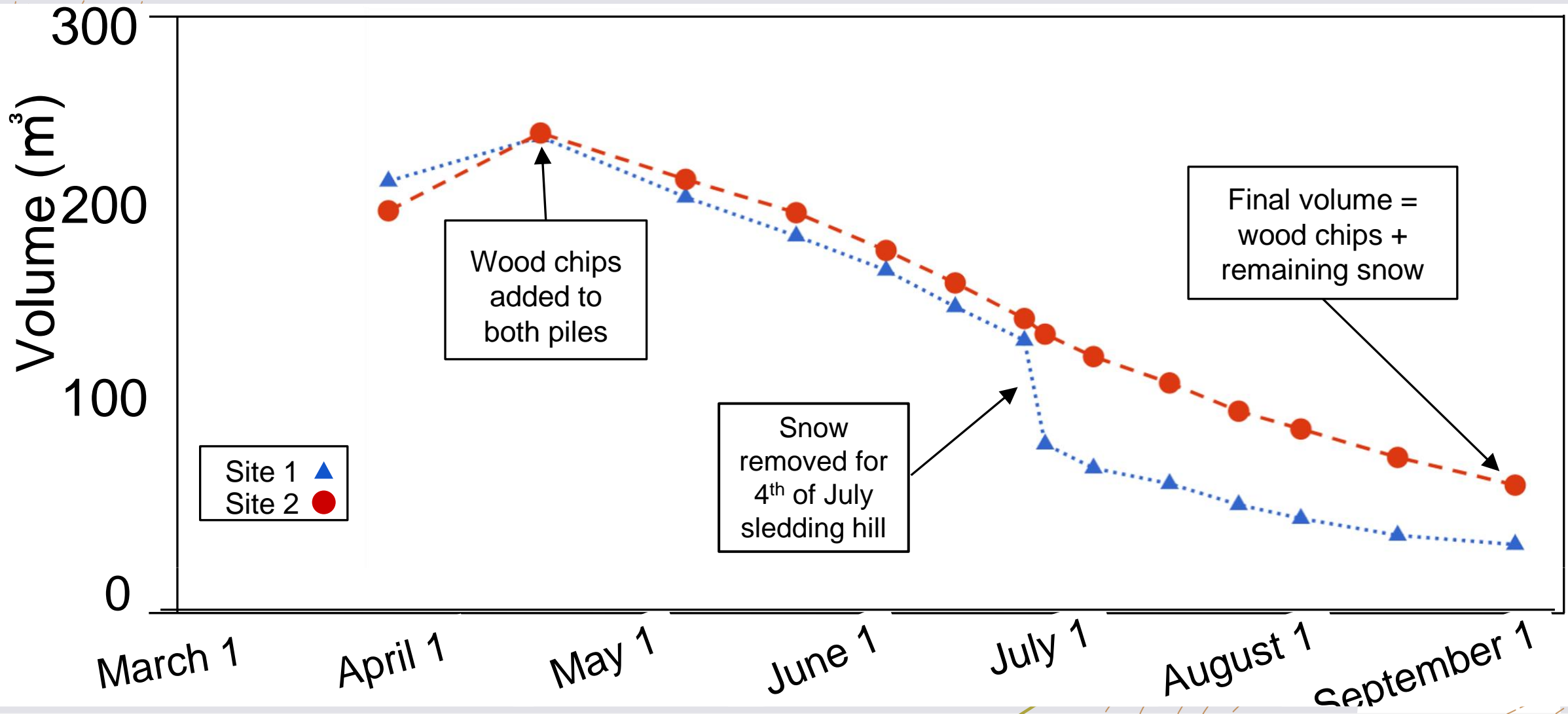
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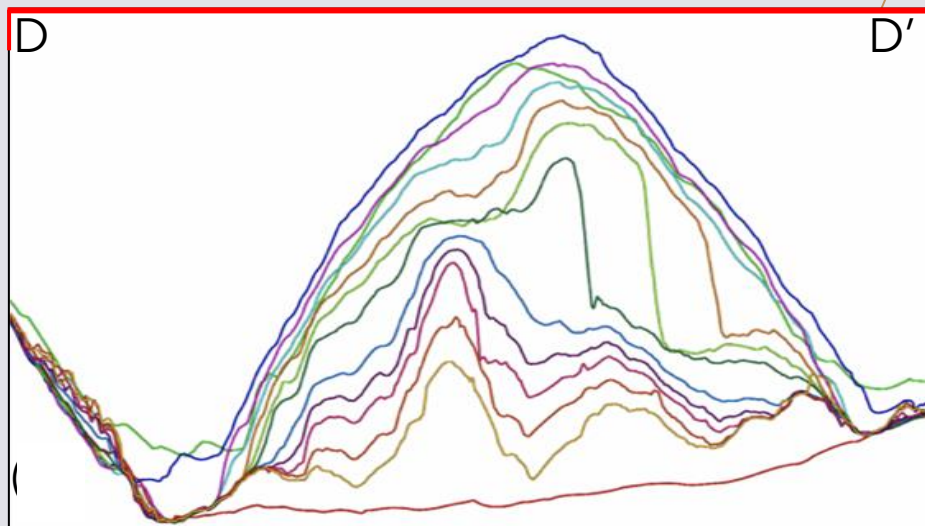
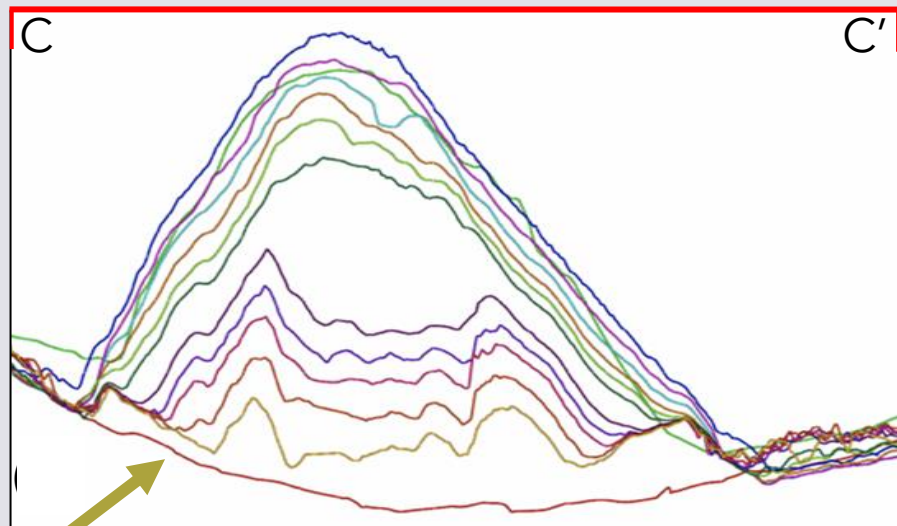
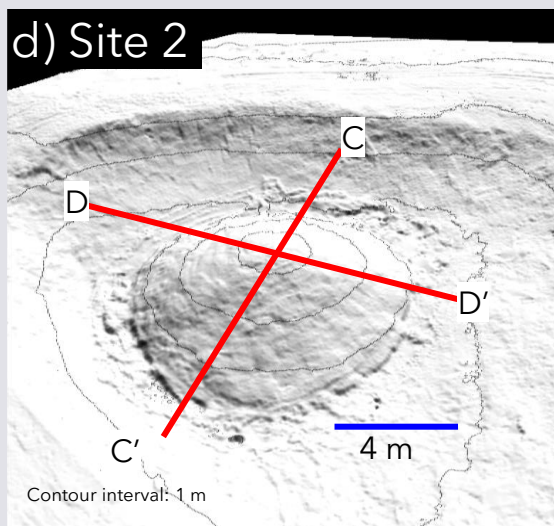
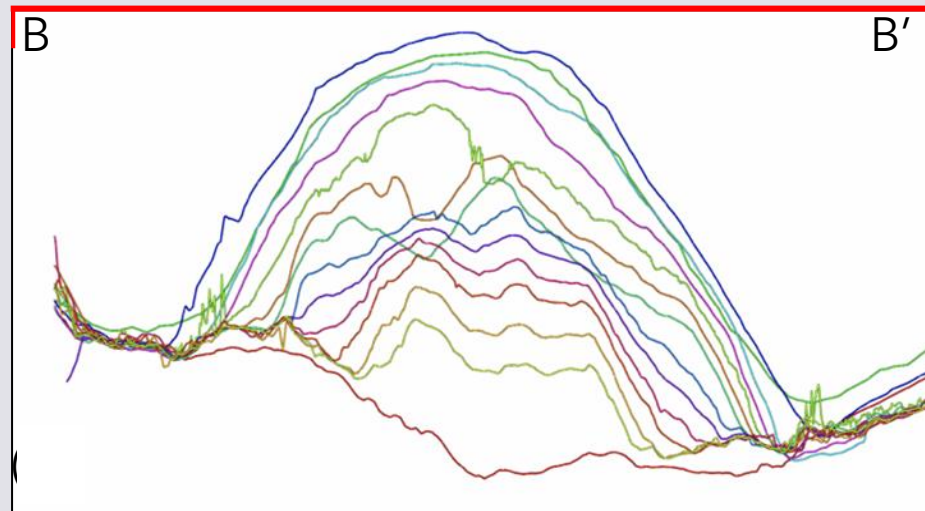
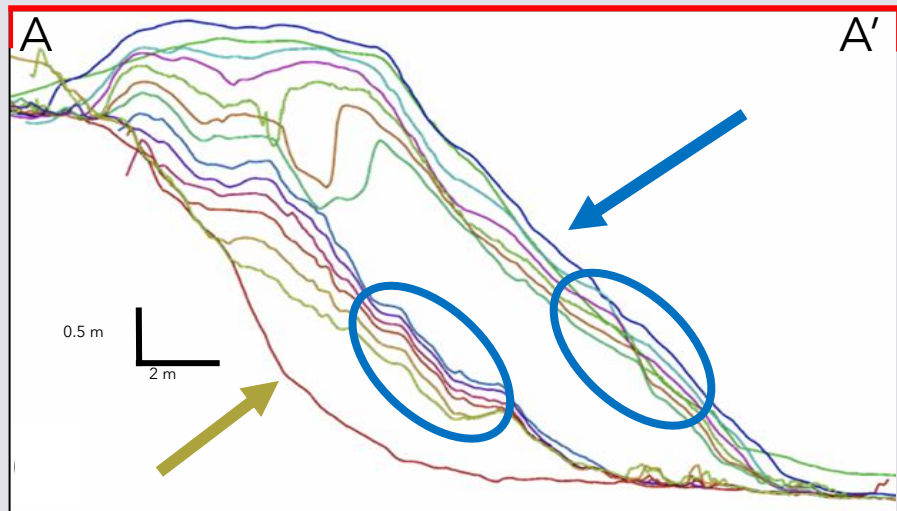
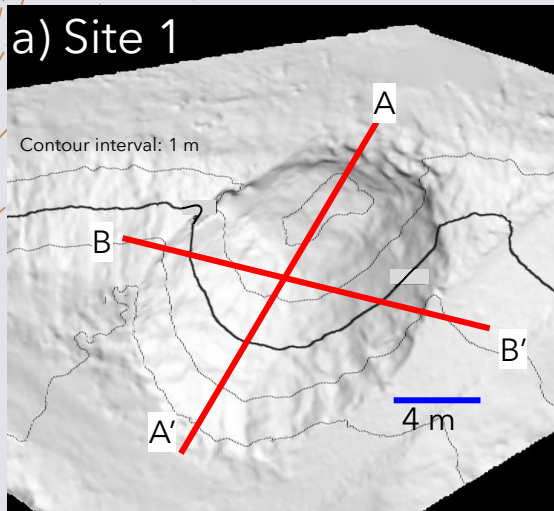
LiDAR



Results



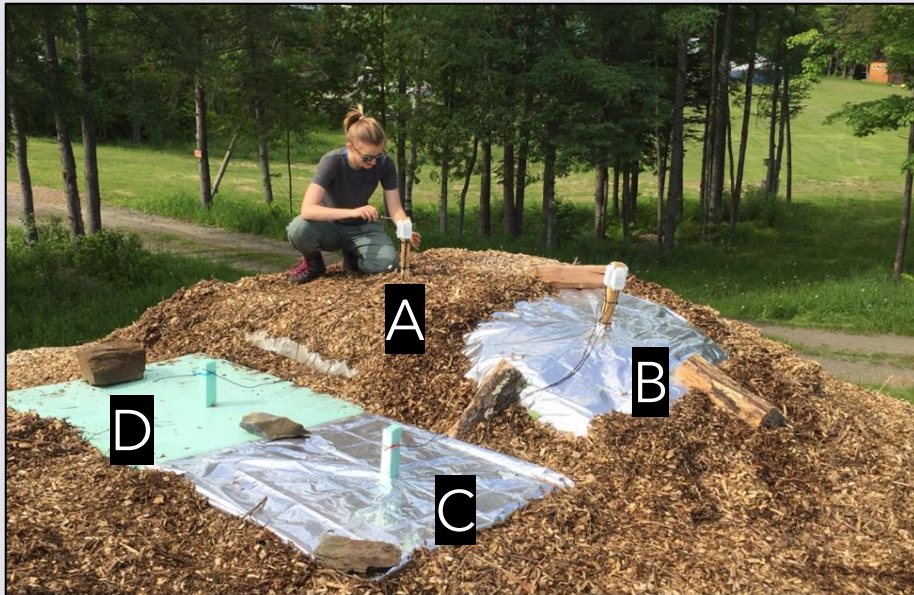
Results



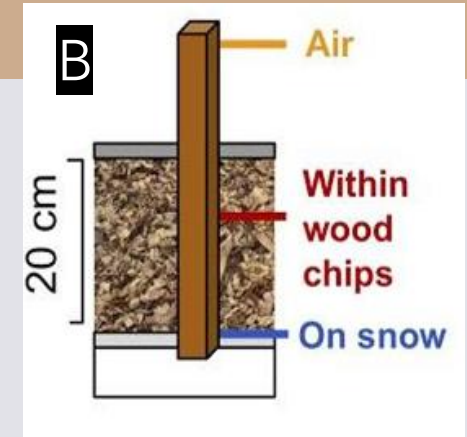
Methods: If we can, what is the best way to store snow?

1. Find different coverings to try
2. Create study plots

Experiment 1

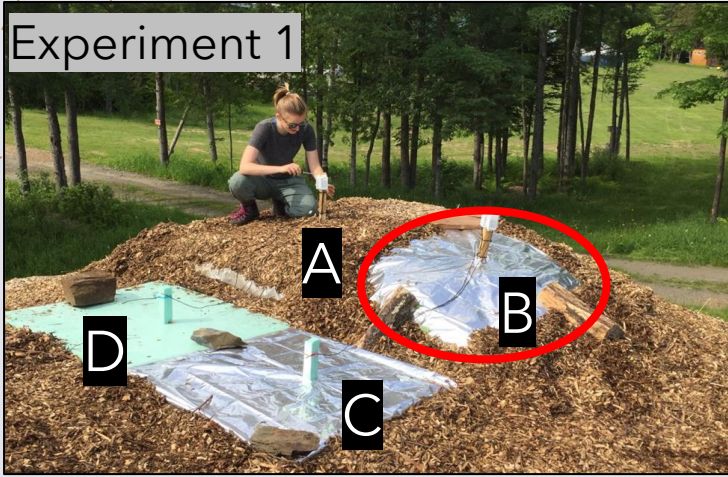


Experiment 2

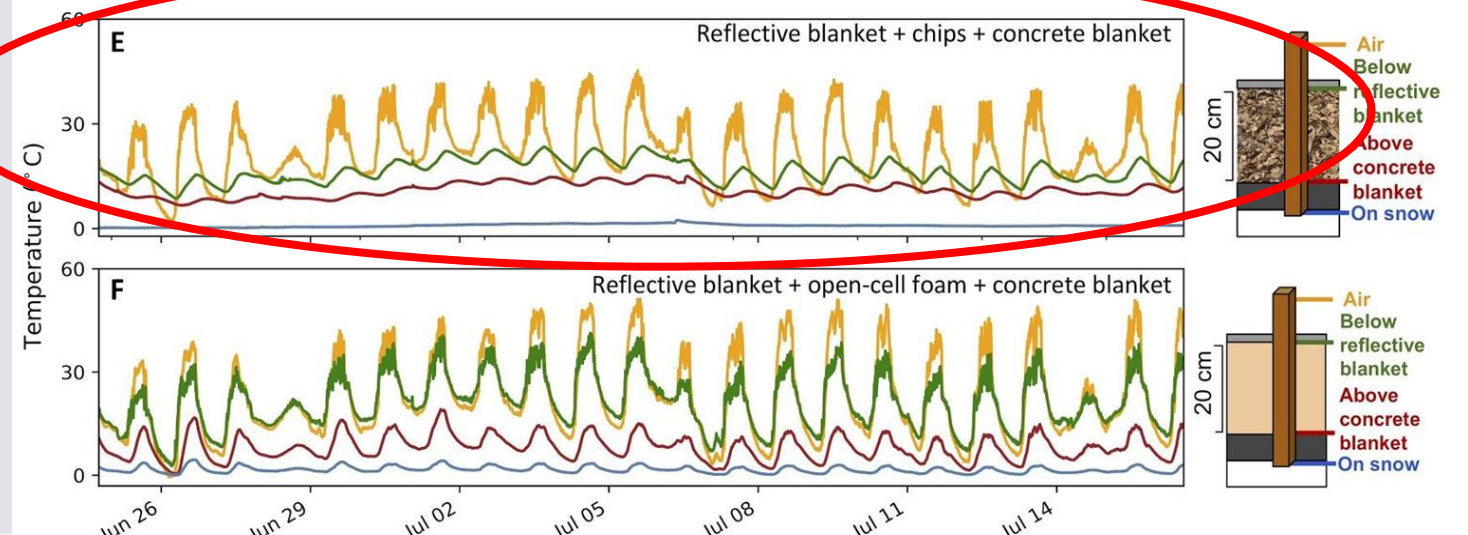
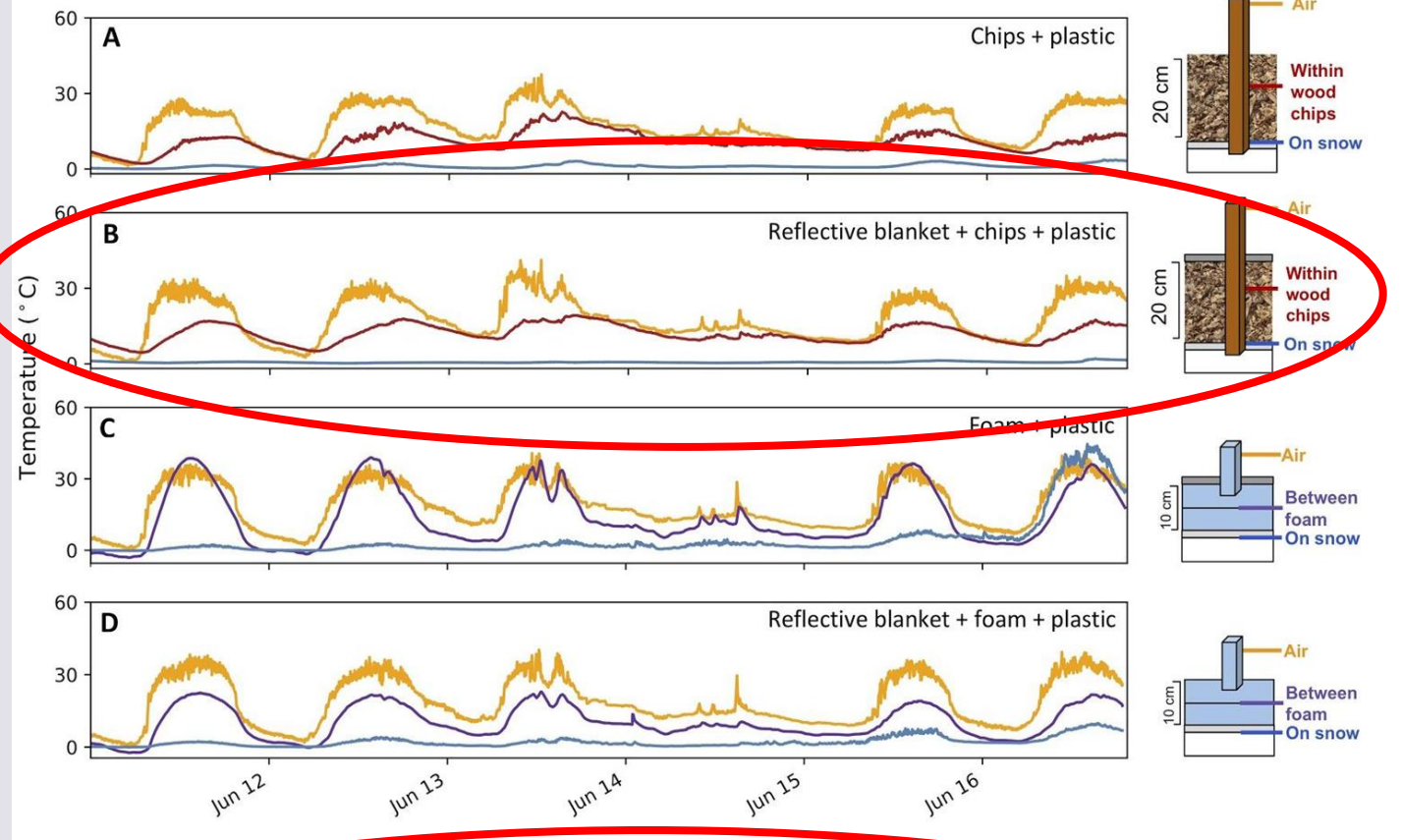
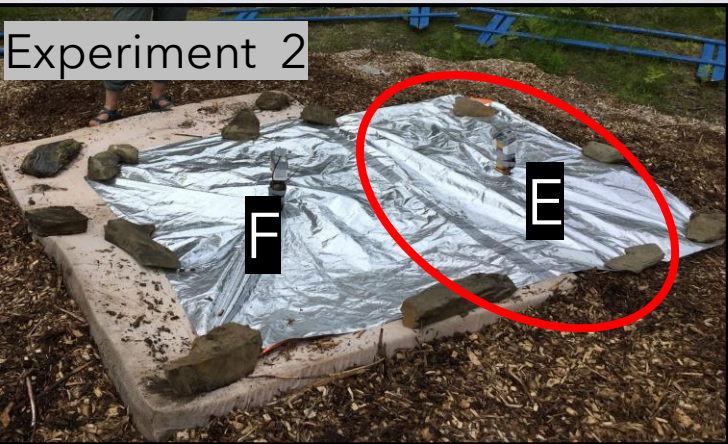


Results

Experiment 1



Experiment 2



Conclusions from summer 2018

- + Gently sloping pile
- + Thick layer of wood chips (20 cm)
- + Reflective surface over top

Results - 2019 pile



9,300 m³ of snow - 3/3/19



Woodchips: 5/19



White covering: 6/7/19

Summer 2019



Summer 2019



Summer 2019 Results

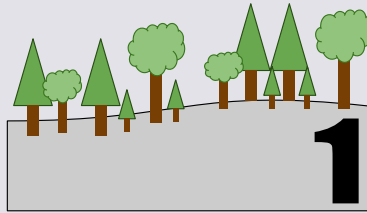


- At the end of the summer, 65% of the pile remained
- Its melt rate was 0.7% per day on average, compared with 1.6% per day from the 2018 piles
- Enough snow to open in November, 2019!

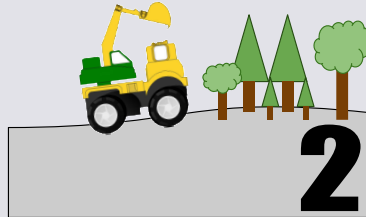
Methods: Is snow storage financially feasible?

1. Compile list of snow storage steps
2. Collect cost data about each step
3. Collect cost data on products purchased for snow storage
4. Sum all costs
5. Contextualize cost (Discussion)

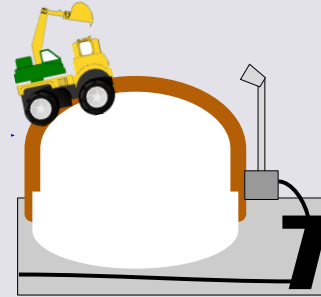
1. Compile list of snow storage steps



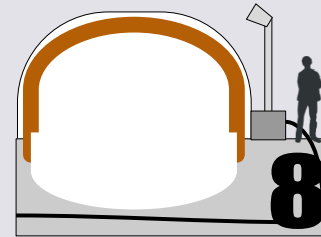
1. Choose location



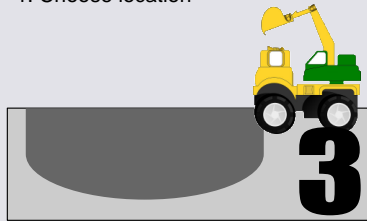
2. Clear existing vegetation



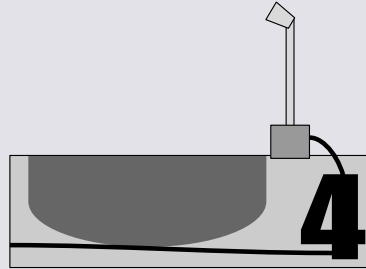
7. Cover pile with a 20 cm layer of wood chips



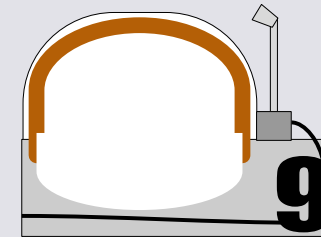
8. Place white tarp over the entire snow pile



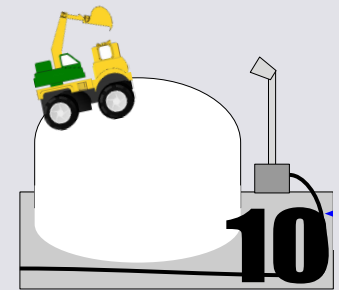
3. Dig/shape the pit



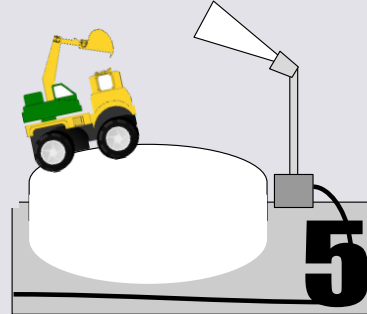
4. Install snow guns, pipeline to lake for water



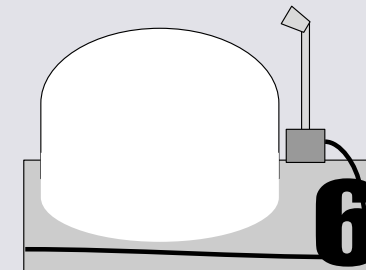
9. Let pile sit throughout the summer and fall



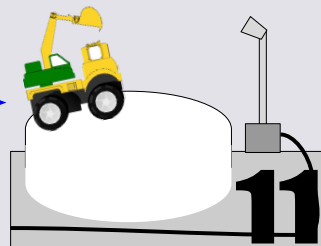
10. When ready to open season, remove tarp and wood chips



5. Make snow, shape pile



6. Allow pile to densify, compact



11. Dig the pile out and spread it on trails



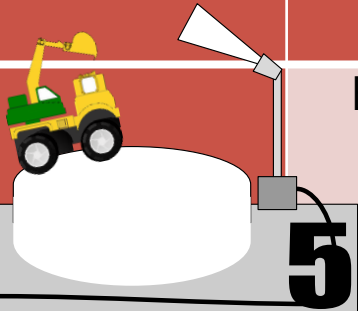
12. Open the season!

2. Collect data about each step

- + How much time did it take?
- + How many people worked on it?
- + What is their average pay per hour?
- + What machinery was used?
- + How much diesel does that piece of equipment burn per hour?



2. Collect data about each step



		(HR)	(W)	(R _G)	(G _T)	(D _T)	(L _T)	Total Cost of step
	Equipment used	Hours spent on task	Number of workers	Gallons diesel/hour used	Total gallons diesel used	Total Diesel Cost (\$)*	Labor cost (\$)	Diesel cost + labor cost (\$)
SHAPE SNOW PILE	CAT 311 CU Excavator	1.5	1	6	9	27.5	31.5	\$102
	PistenBully 100	1.5	1	2.5	3.75	11.5	31.5	

*During Spring 2019, diesel cost on average \$3.06/gallon



3. Collect data on products purchased for snow storage

CAPITAL INVESTMENTS	QUANTITY	UNIT PRICE	TOTAL (\$)
NIVIS ECOSTICKS SNOWMAKING UNITS	3	5840	17520



Zero-energy-snowmaker

Ecostick

The Revolution of snowmaking

Ecostick Mono | Duo | Trio

The Nivis® snow cannons need neither compressed air nor an own compressor unit. They use the enclosed energy in the water pressure and reconvert it to a significant saving of energy on snowmaking systems.

nivis
INNOVATIVE SNOW MAKING

4. Sum all costs

+ Cost of each step + Cost of purchased items = Total cost of snow storage for year 1

YEAR	DOLLARS	NOTES
YEAR 1	\$127,211	Setup cost
Every year after	\$13,101	Baseline cost
Every 4 years, an additional	\$31,263	tarp/woodchip replacement year
Every 20 years, an additional	\$21,520	dump truck/snow gun replacement year

*Note: discounting not included

Discussion: Contextualizing Cost

+ Q: "In terms of revenue, what would lead the center to no longer support Nordic skiing/biathlon?"

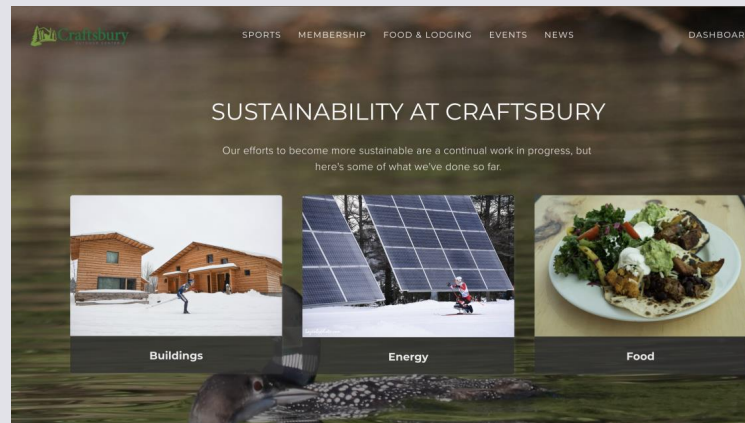
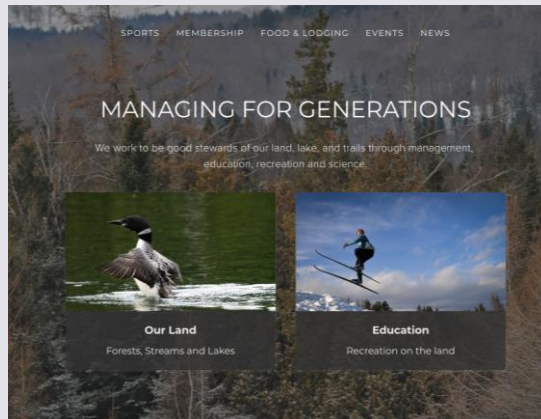
+ Q: "How much impact does revenue have on determining whether the center has experienced "success" or not? What are the other factors?"

+ A: "It's our mission—we will keep doing it regardless. We are different from normal ski areas this way."

+ A: [Revenue] doesn't have an impact- it's more important for us to..."[d]evelop a reputation for holding high quality races, have great skiing, serve lots of kids and families with our programming, and in general achieve our mission."

Discussion: Contextualizing Cost

+ "It's our mission—we will keep doing it regardless. We are different from normal ski areas this way."



Mission

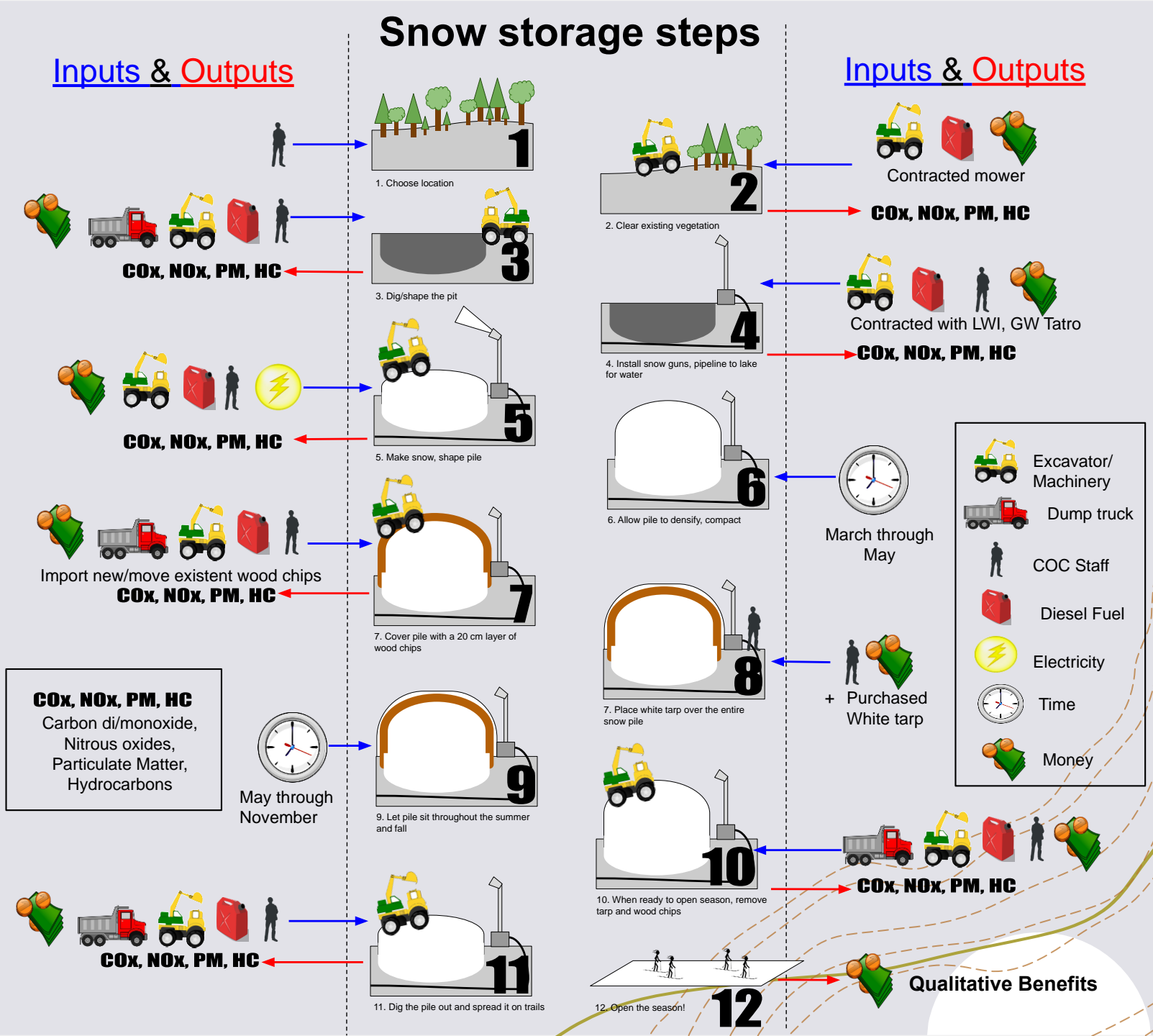
To support and promote participation and excellence in lifelong sports with a special focus on rowing, nordic skiing, biathlon and running; To use and teach sustainable practices; And to protect and manage the surrounding land, lake and trails.

+ Altruistic motivators of sustainable change are powerful (Panda et. al., 2020; Font et. al., 2016; Baston & Powell, 2003)

Methods: Is snow storage environmentally feasible (kg CO₂)?

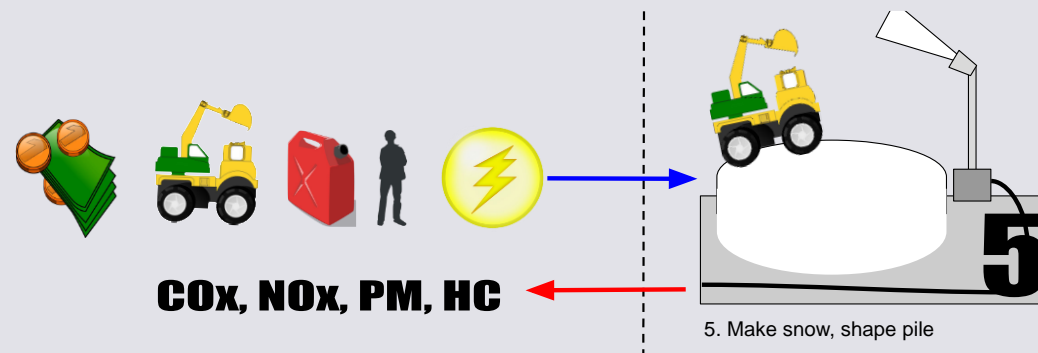
1. What are the inputs (energy used)/outputs (pollution emitted) of each step?
2. Collect these data for snow storage steps
3. Collect these data for transportation of products to the COC
4. Sum quantity of pollution emitted
5. Contextualize CO₂ emitted (Discussion)

1. What are the inputs (energy used) / outputs (pollution emitted) of each step?



2. Collect these data for snow storage steps

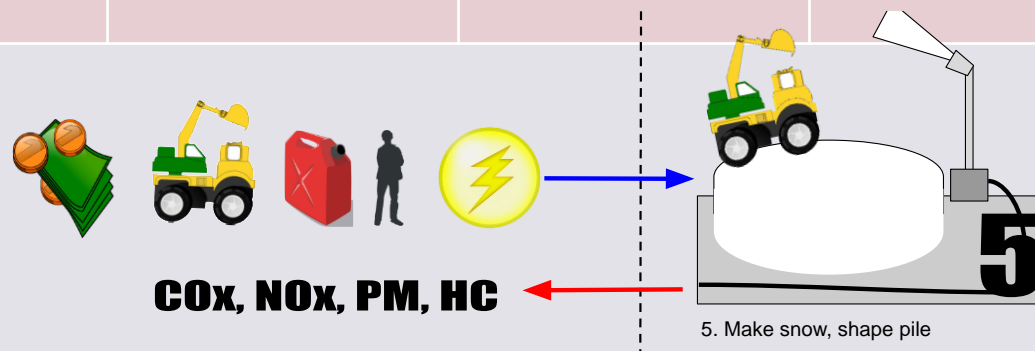
- + How many hours were spent per task?
- + How many gallons were used per hour by the machinery in use?
- + What are the total gallons of diesel used?



2. Collect these data for snow storage steps

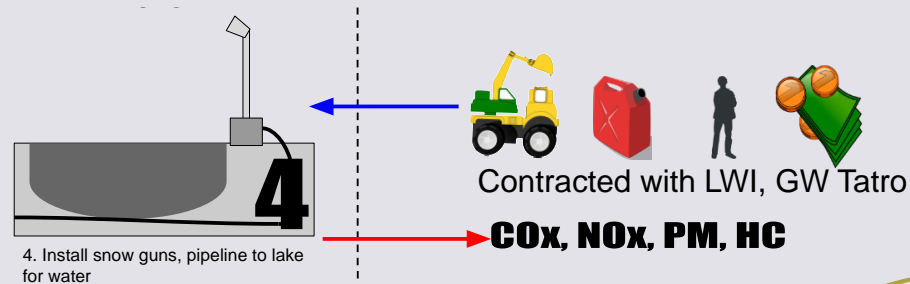
		(HR)	(R _G)	(G _T)
	Equipment used	Hours spent on task	Gallons per hour consumed	Total gallons of diesel used
SHAP E SNOW	CAT 311 CU Excavator	1.5	6	9
	PistenBully 100	1.5	2.5	3.75

ministry in



3. Collect these data for transportation of products to the COC

CARBON FROM TRANSPORTATION OF PRODUCTS			Miles via google earth	X2 or x1 Miles	Per 1 mile-ton (kg per ton-mile)	Miles * kg CO2 produced	Kg -> lbs
PRODUCT	Journey (description)	Method	Legs of journey	One way?	Kg CO ₂ produced	Total Kg CO ₂	Total lbs CO ₂
CULVERTS	Johnson Hardware and Rentals Store -> COC,	Trucked	24	48	0.202	9.696	21.4



4. Sum quantity of pollution emitted

**LBS OF CO₂ FROM
DIESEL YEAR 1**

44549

**LBS OF CO₂ FROM
TRANSPORTATION YEAR 1**

1557.5

TOTAL CO₂ YEAR 1

46,106.5 lbs

How to contextualize
this value?

20.9 metric
tons of CO₂

Equivalent to 4.5
passenger vehicles
driven for 1 year in U.S
(epa.gov)

Equivalent to the
emissions from energy use
of 2.4 homes for 1 year in
U.S (epa.gov)

Discussion: Contextualizing CO₂



- + How does the CO₂ released during snow storage compare with the CO₂ released from an alternative?
- + Alternative: what happens when the COC cannot open due to lack of snow storage
- + Unclear what the COC would do, but there is research about what their guests may do

Discussion: Contextualizing CO₂

- +Q1: What will happen if the COC does not open?
- +Q2: What is most likely to occur at the COC?
- +Q3: Where do skiers travel to if COC is not open?
- +A1: Skier behavior will either follow a temporal, or spatial shift, or change activities¹
- +A2: Competitive skiers - likely will choose spatial
- + A3: Colorado, USA or British Columbia, Canada²

Discussion: Contextualizing CO₂

+ What is the CO₂ produced from one person flying from BVT to either Colorado, USA or BC, Canada?

One Way/Round Trip		Cabin Class		Number of Passengers
Round Trip		Economy		1
Leg	From City/Airport	To City/Airport		
1	BTV	DEN		
Delete All Location(s)		Delete Leg		Add New Leg
Reset		Compute		

Metric (KG / KM)		Standard (LBS / MI)				
Dep Airport	Arr Airport	Number of passengers	Cabin Class	Trip	Aircraft Fuel Burn/journey (KG) ^{ab}	Total passengers' CO ₂ /journey (KG) ^c
BTV	DEN	1	Economy	Round Trip	20677.4	464.4

Flight Stage Detail					
Dep Airport	Arr Airport	Distance (KM)	Aircraft	Aircraft Fuel Burn/leg (KG) ^a	Passenger CO ₂ /pax/leg (KG)
BTV	DEN	2630.0	319, 320	10338.7	232.2
DEN	BTV	2630.0	319, 320	10338.7	232.2

a. Fuel Burn information provided are for 1 aircraft per leg

b. Aircraft Fuel Burn/journey = \sum Aircraft Fuel Burn/leg

c. Total passengers' CO₂/journey = \sum Passenger CO₂/pax/leg×Number of pax

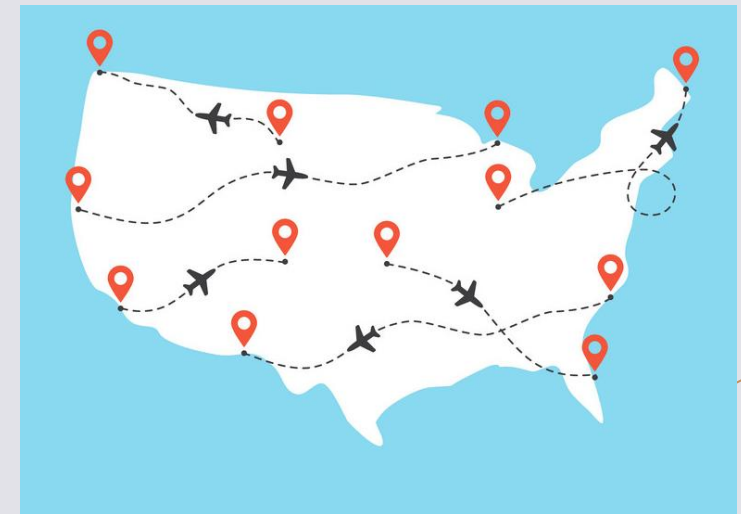
Discussion: Contextualizing CO₂

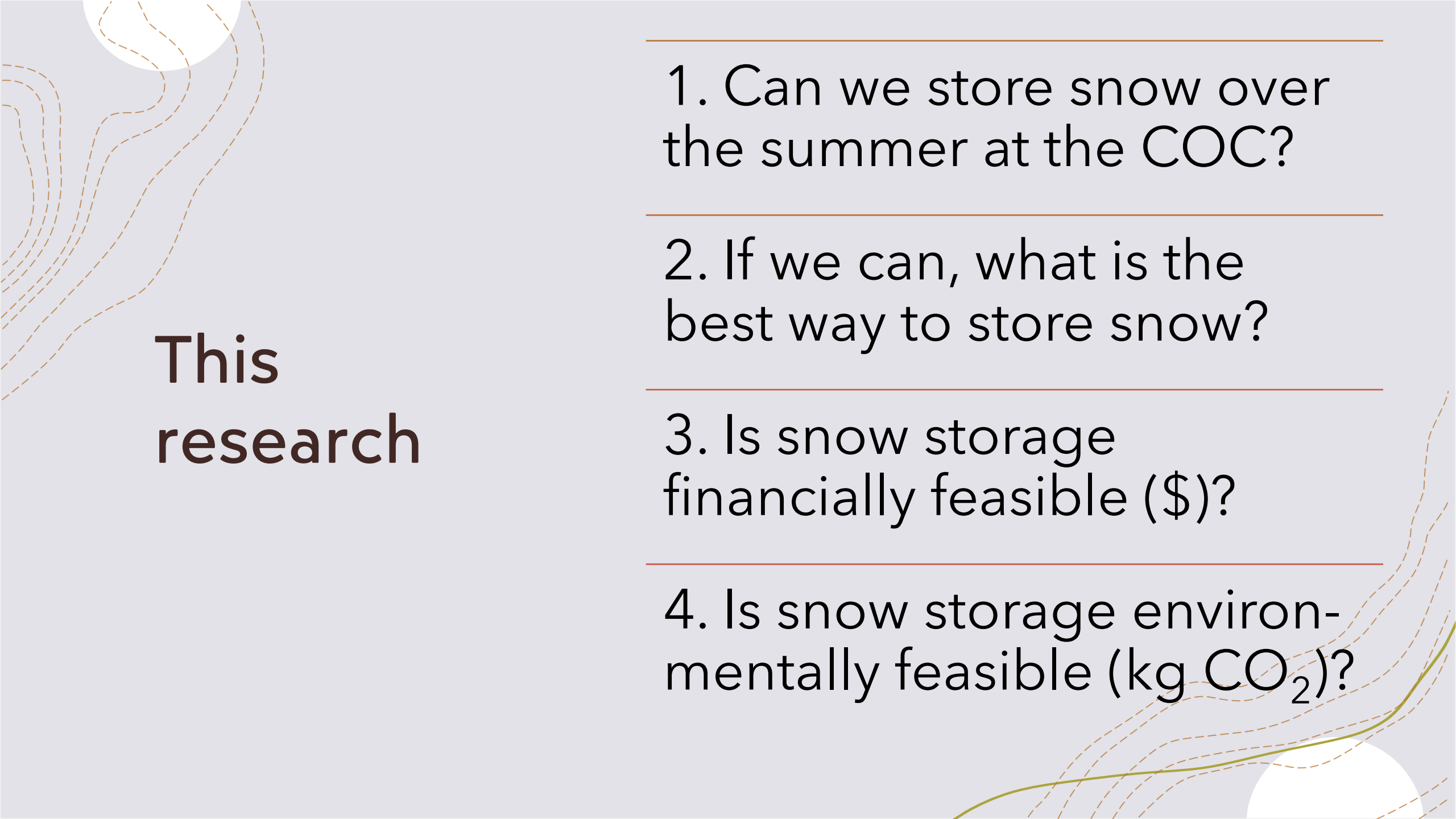
+ How many people would need to be prevented from flying?

$$+ \frac{\text{CO}_2 \text{ from 1 person's flight}}{\text{CO}_2 \text{ from snow storage}} = \# \text{ people to prevent from flying}$$

# of individual flights to offset....	CO ₂ from setup year 1	CO ₂ from baseline year*
BVT -> DENVER, CO, USA	35	29
BVT -> VANCOUVER, CANADA	25	20

*baseline year = non-setup year, non-replacement year





This research

1. Can we store snow over the summer at the COC?

2. If we can, what is the best way to store snow?

3. Is snow storage financially feasible (\$)?

4. Is snow storage environmentally feasible (kg CO₂)?

2018 pile 1



2018 pile 2

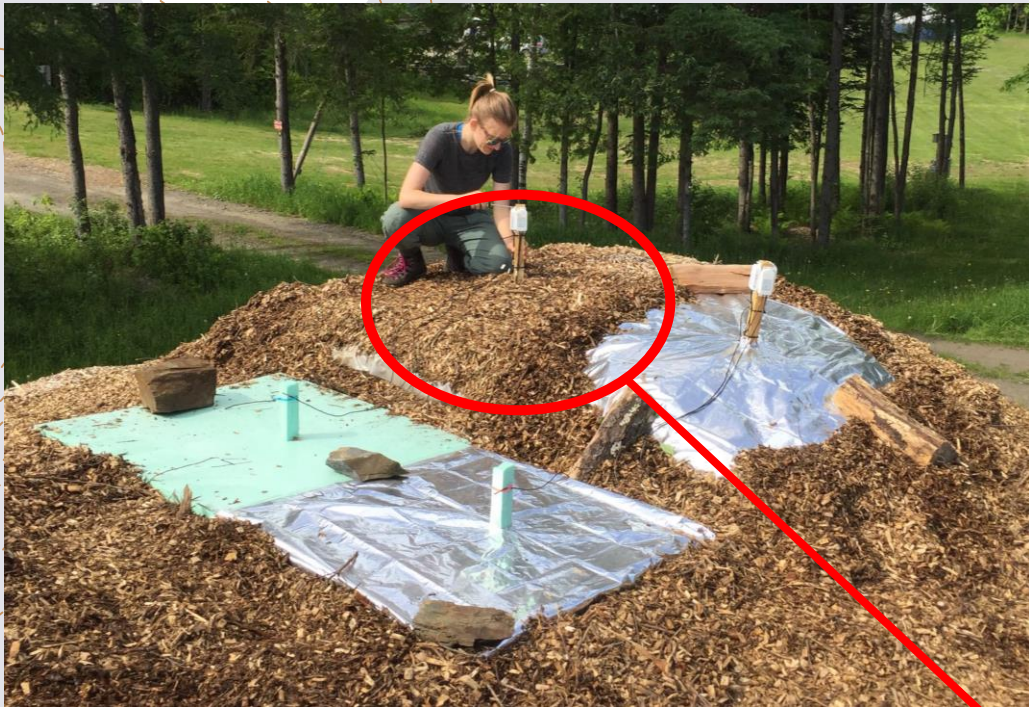


1. Can we store snow over the summer at the COC?

Yes

2019 pile



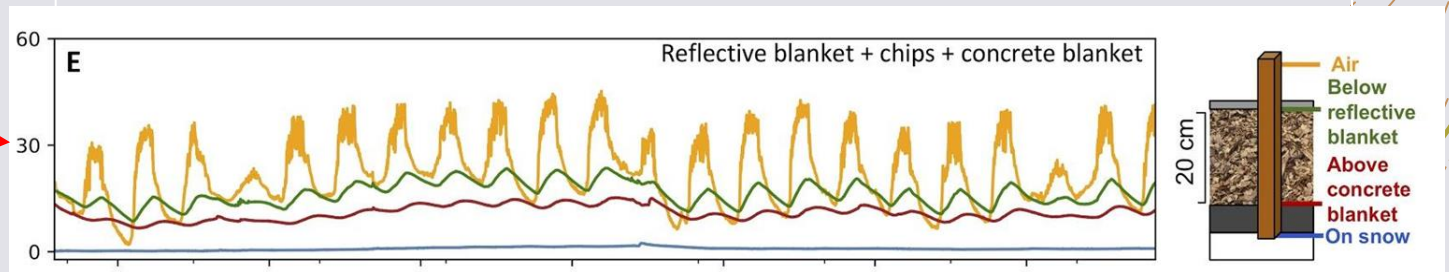
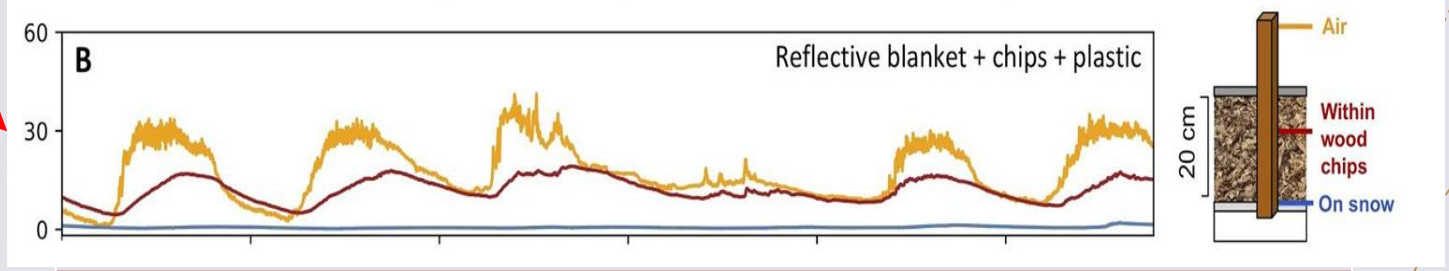


1. Can we store snow over the summer at the COC?

Yes

2. If we can, what is the best way to store snow?

Wood chips, reflective tarp, gentle slopes



To support and promote participation and excellence in lifelong sports with a special focus on rowing, nordic skiing, biathlon and running; To use and teach sustainable practices; And to protect and manage the surrounding land, lake and trails.

1. Can we store snow over the summer at the COC?

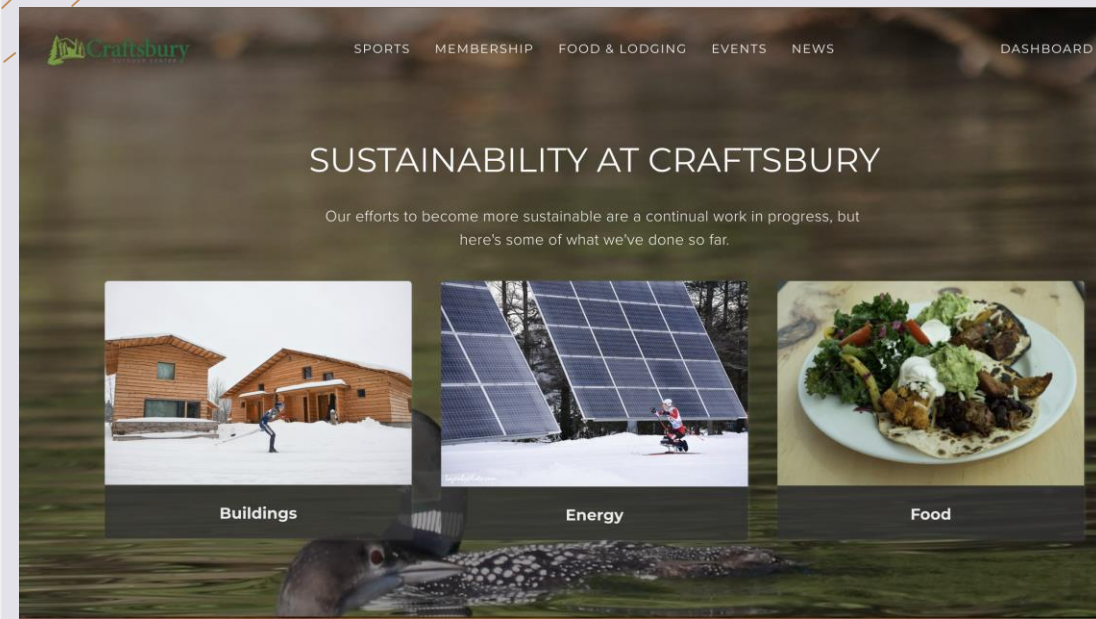
Yes

2. If we can, what is the best way to store snow?

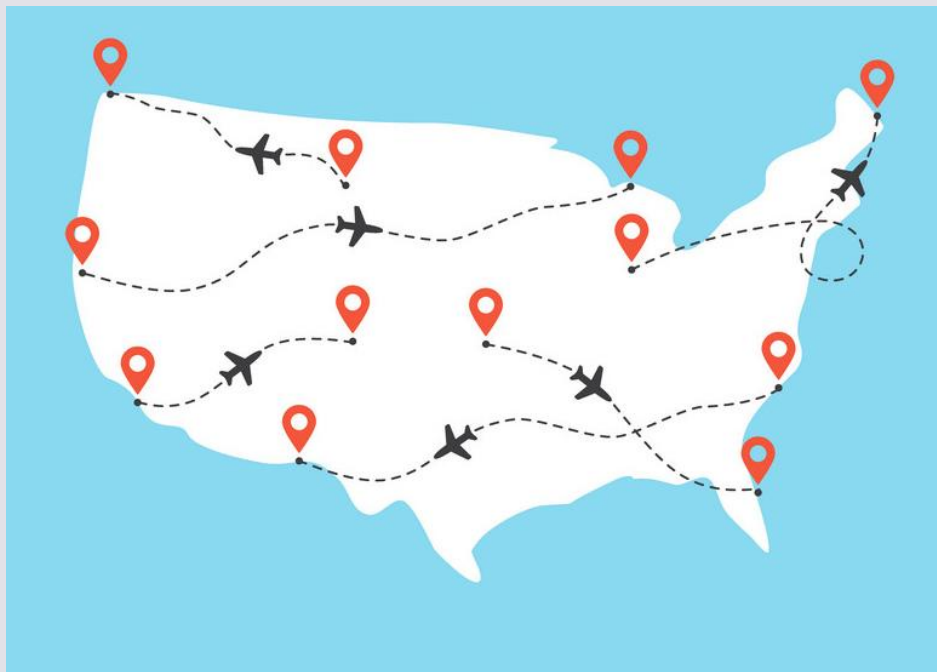
Wood chips, reflective tarp, gentle slopes

3. Is snow storage financially feasible (\$)?

Non-monetary benefits outweigh financial cost



# of individual flights to offset...	CO ₂ FROM SETUP	CO ₂ BASE-LINE
BVT -> DENVER, CO, USA	35	29
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1. Can we store snow over the summer at the COC?

Yes

2. If we can, what is the best way to store snow?

Wood chips, reflective tarp, gentle slopes

3. Is snow storage financially feasible (\$)?

Non-monetary benefits outweigh financial cost

4. Is snow storage environmentally feasible (kg CO₂)?

Yes compared with flying to another ski center

Conclusion

Snow storage is feasible at the COC

Other similarly-located nordic centers could pursue snow storage

Nordic skiing could continue longer into the 21st century

1. Can we store snow over the summer at the COC?



<https://www.craftsbury.com/news/early-thoughts-on-winter-21-at-craftsbury>

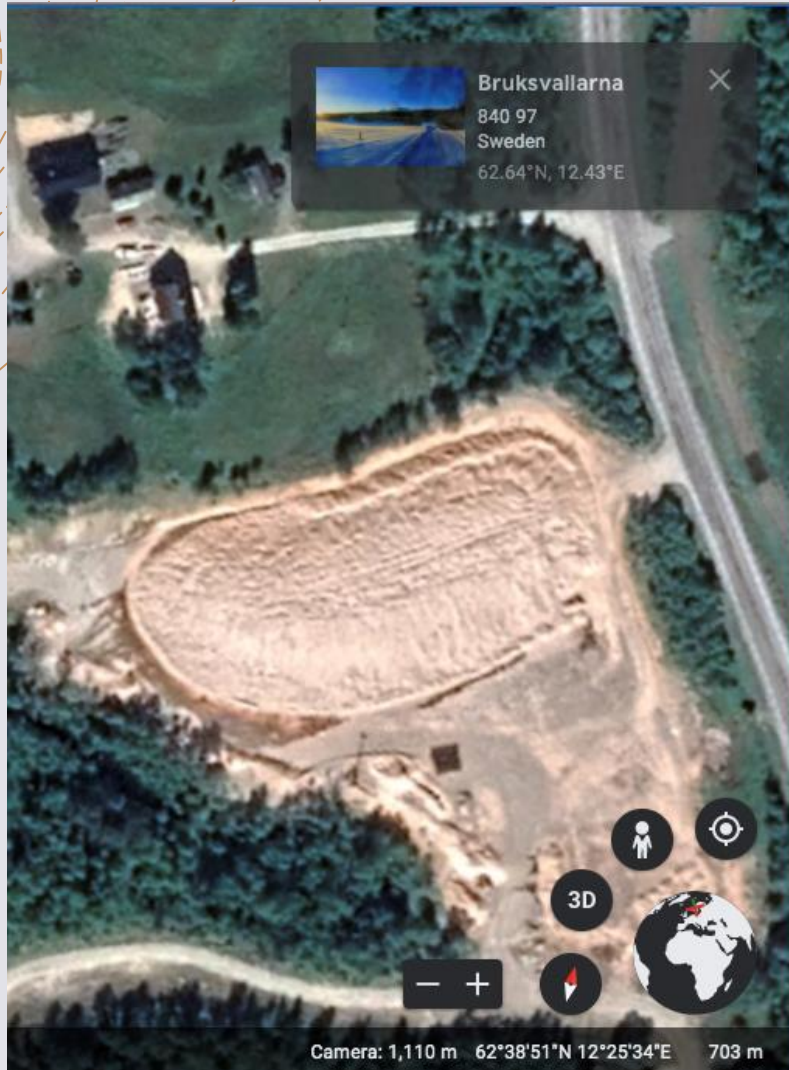
Thanks & Questions

- + Advisor: Paul Bierman, Ph.D
- + Committee: Josh Farley Ph.D, Donna Rizzo Ph.D, Scott Hamshaw Ph.D
- + Coauthors of paper: Paul Bieman, Yves Dubief, and Scott Hamshaw
- + Craftsbury Outdoor Center
- + Funding sources:
 - + Rubenstein School
 - + The Graduate College
 - + UVM Geology Department
 - + UVM Engineering Department
 - + UVM Spatial Analysis Lab
- + Friends and family

Works Cited

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- + Panda, T. K., Kumar, A., Jakhar, S., Luthra, S., Garza-Reyes, J. A., Kazancoglu, I., & Nayak, S. S. (2020). Social and environmental sustainability model on consumers' altruism, green purchase intention, green brand loyalty and evangelism. *Journal of Cleaner Production*, 243, 118575.
- + Jin, C. H. (2020): *How Warming Winters Are Affecting Everything; NPR analysis of NOAA data*. NPR
- + Sharp, J. R. (2011). *The Emotional Calendar: Understanding Seasonal Influences and Milestones to Become Happier, More Fulfilled, and in Control of Your Life*. Macmillan.
- + See full thesis for more

Who stores snow?



Bruksvallarna, Sweden



Ruhpolding, S. Germany.



Idrefjäll, Sweden

Site 2, April 2019



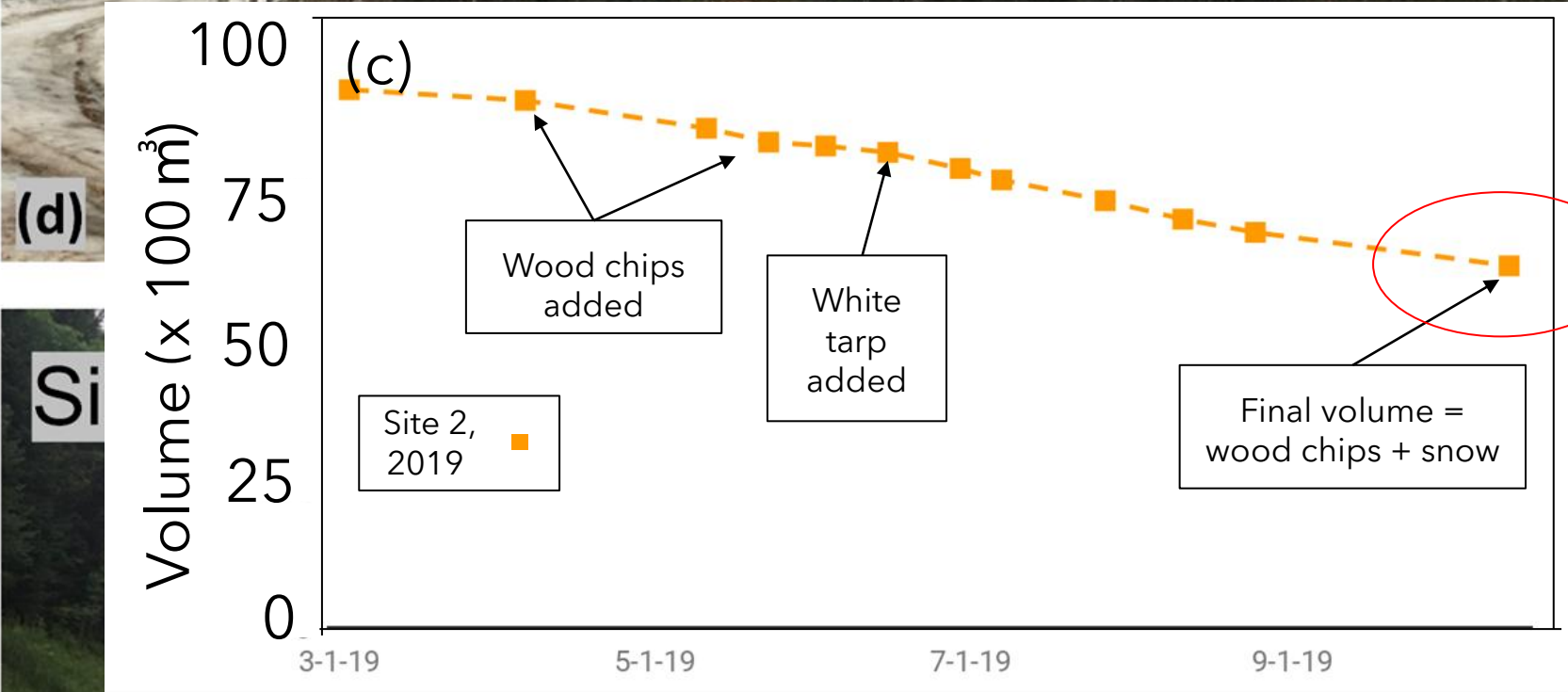
(d)

Site 2, July 2019



(e)

Site 2, April 2019



5600 cubic meters - Enough snow to open the season in November 2019!

(d)

Si

(e)

