

Historical climate warming in the White Mountains of New Hampshire (USA): implications for snowmaking water needs at ski areas.

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The backstory:

- Temperatures globally and in our region have warmed
- Winters have warmed faster than most other times of year
- All evidence suggests that winters (and year-round temps) will continue to warm through this century.



The backstory:

- In the past 50 years the AVERAGE WINTER TEMPERATURE has increased by around 3 degrees Fahrenheit
 - Average ANNUAL TEMPERATURE increase has been around 1.8 degrees F
- Climate models predict that in the next 50 years, winter temperatures will increase by 1.8 – 7.2 degrees Fahrenheit

We wondered:

- What the historic winter temperature increases would have meant for snowmaking (using today's technology)
- Whether understanding that would help understand the challenges ski areas will face in the coming years



What can LIMIT snowmaking?

- Energy
- Temperatures
- Water

What we did:

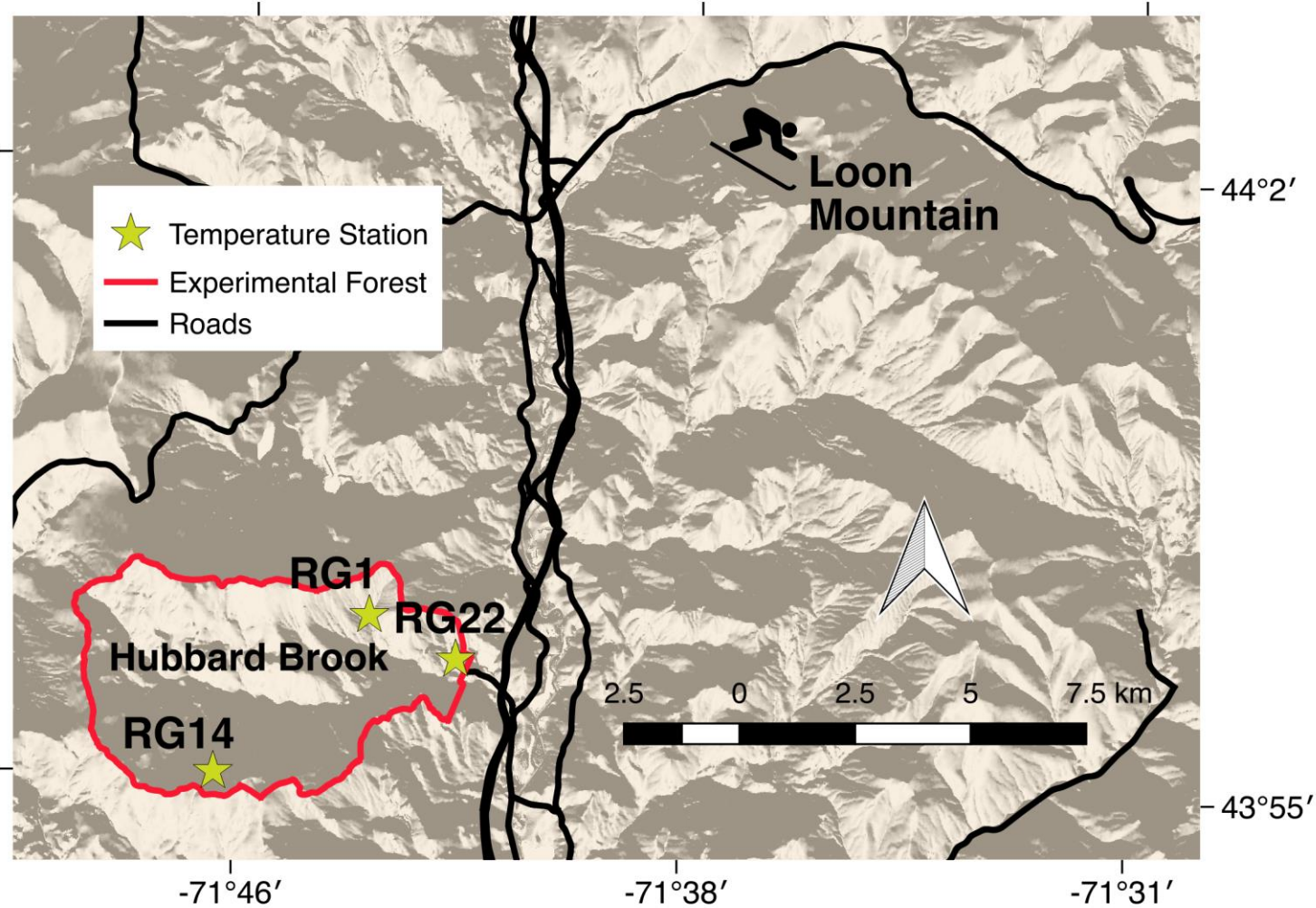
- Defined important snowmaking windows of time
 - Nov1- Thanksgiving
 - Nov1 – Christmas
 - Dec1 – Christmas
 - Nov1-Feb 28
 - (entire snowmaking season)
- Defined snowmaking thresholds
 - Daily average temperatures -2°C



What we did:

- Analyzed 50 years (1965-2015)
 - 3 weather stations at Hubbard Brook
 - Loon opened in 1966 and installed first snowmaking in 1970
- Sorted the days into “good” and “bad” snowmaking days





3 weather stations with different ASPECTS and ELEVATIONS

Location	coordinates	Elevation (m)	aspect
Loon Mountain Resort	44.0564° N -71.6299°W	290 (base) to 930 (summit)	NW (primarily)
HB Rain gage #1	43.952121° N -71.724838 °W	525	S
HB Rain gauge #14	43.920799 ° N -71.765606 ° W	728	N
HB Rain Gauge #22	43.945733 ° N -71.700975 ° W	253	SE

Figure 1.

What we found:

- The snowmaking season has warmed by 2.7 degrees F

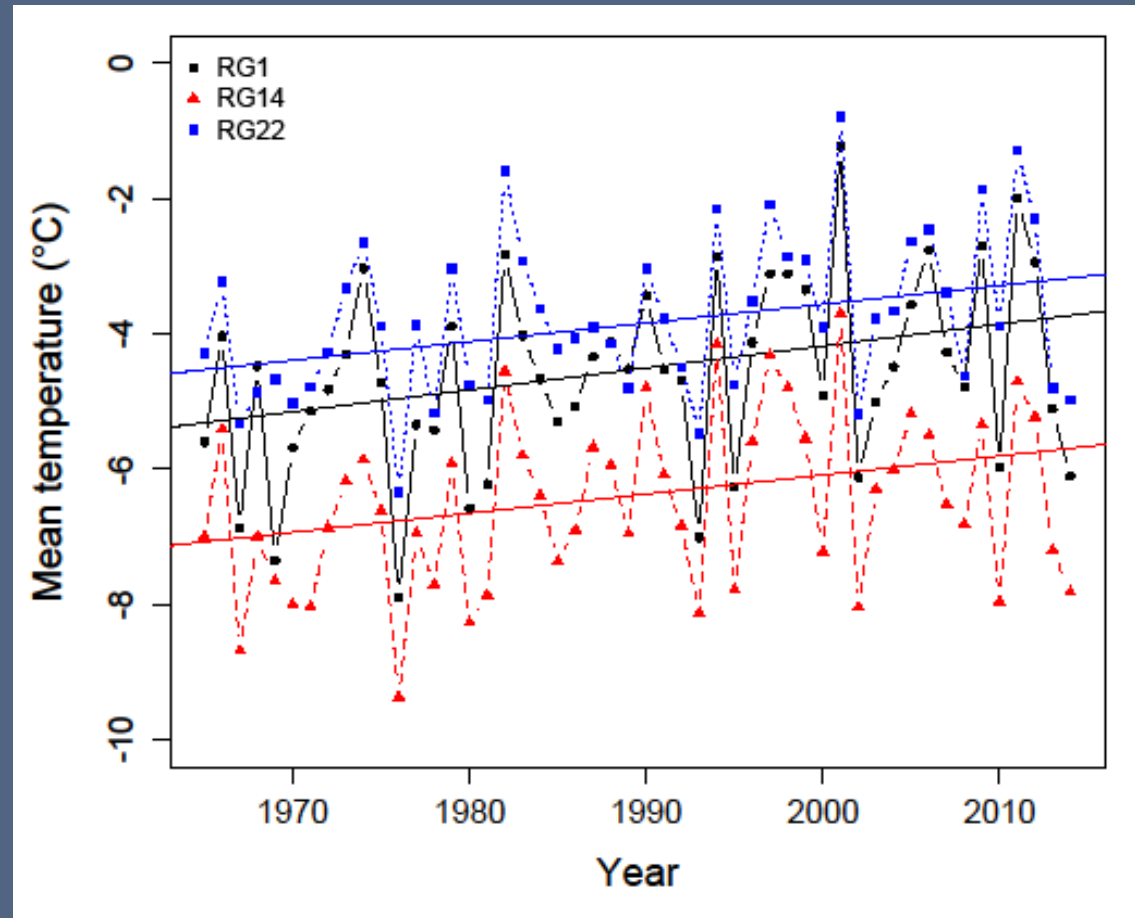


Figure 2. Snowmaking season (Nov. 1 to Feb. 28) mean temperatures, 1965-2015. Sen's slope estimates shown with solid lines.

What we found:

- Each weather station shows the same thing
- Warming is more severe before Christmas

Snowmaking Period	Average Temperature Trend (°C/decade)		
	Gauge #1	Gauge #14	Gauge #22
Nov. 1 – Thanksgiving	n.s.	n.s.	n.s.
Dec. 1 – Dec. 25	0.5*	0.5*	0.5*
Nov. 1 – Dec. 25	0.4*	0.4*	0.3*
Nov. 1 – Feb. 28	0.3*	0.3*	0.3*

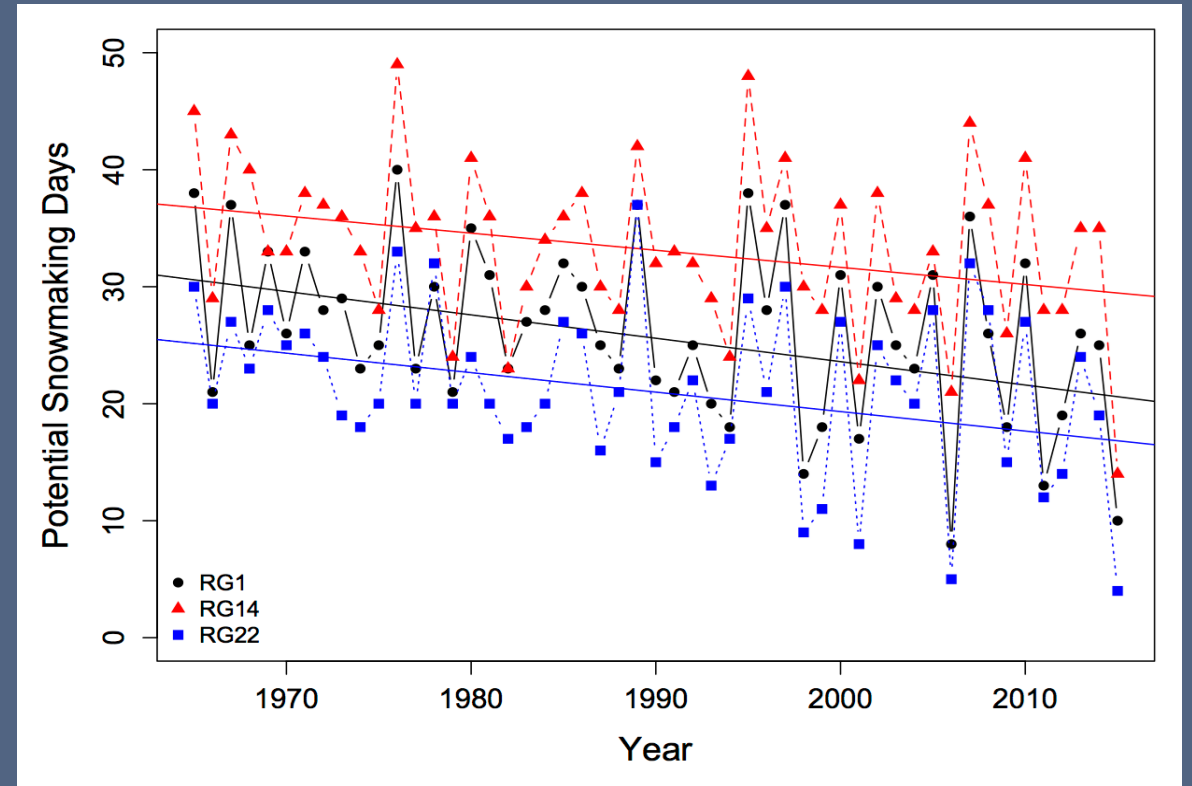
From Table 2: Average temperature trends per decade at three different weather stations.

Time period	Slope of temperature change (°C/decade)	Implied change in snowmaking days using -2°C threshold (implied % reduction)	Implied change in snowmaking days using -5°C threshold (implied % reduction)
1 Nov – 28 Feb	0.3*	-8.1^{\dagger} (-8.5%)	-11.25^* (-15%)
1 Nov – Thanksgiving	n.s.	n.s.	n.s.
1 Nov – 25 Dec	0.4*	-7.3^* (-20%)	-8.5^* (-33%)
1 Dec – 25 Dec	0.5*	n.s.	-4.5^{\dagger} (-26%)

Table 3: Translation of temperature change to snowmaking days using two different criteria and the north-facing weather station

What we found:

- Converting the warming to snowmaking opportunity highlights the business challenges involved
- A reduction of snowmaking opportunity of 8.1 days during the Nov 1 - Feb 28 snowmaking season.
 - 7.3 of those days occur before Christmas
 - **20% reduction!**



Days of good snowmaking opportunity in the Nov 1 - Dec 25 time period, 1965-2015. Sen's slope shown with solid line.

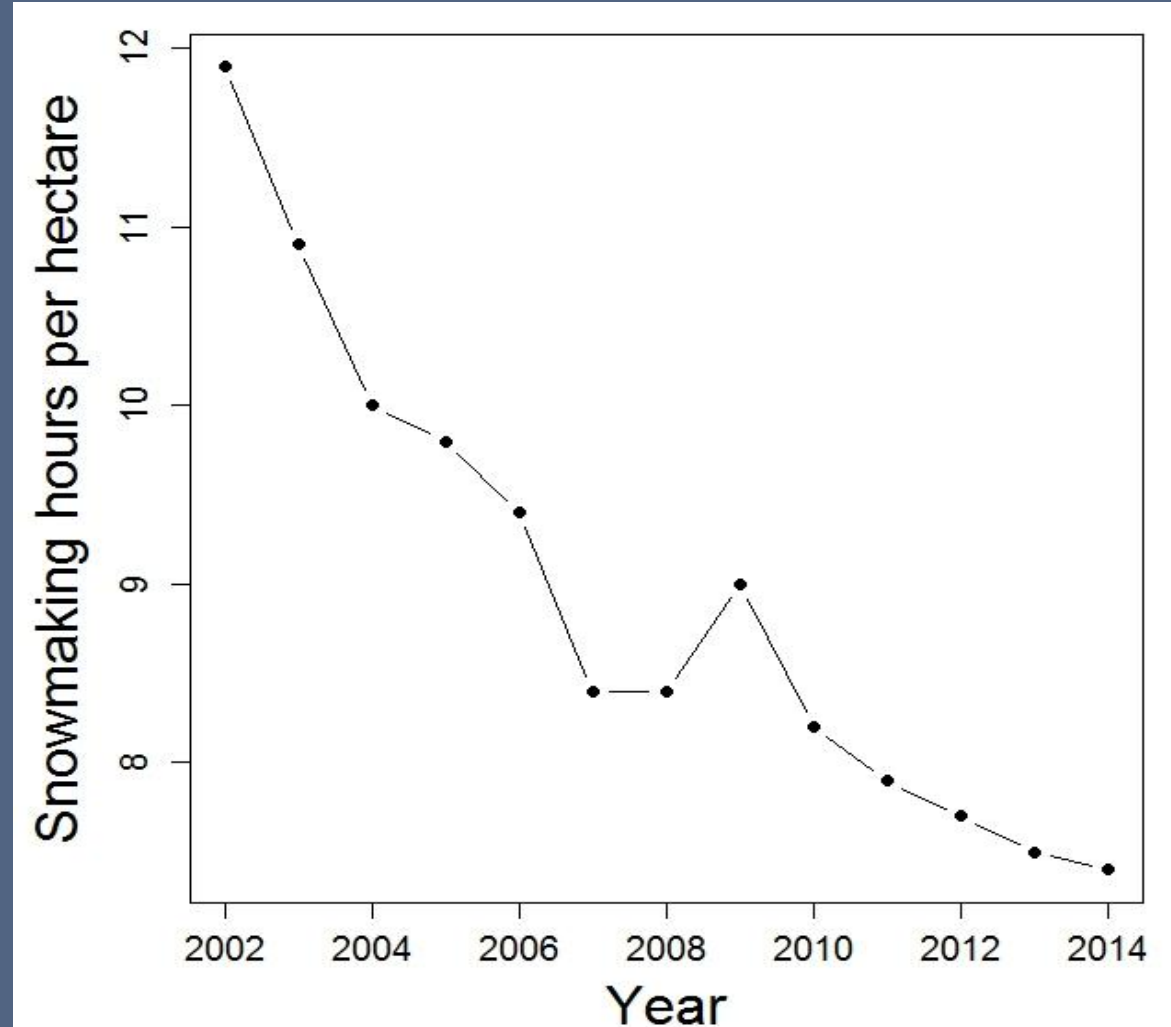
Does a 20-30% reduction in snowmaking opportunity before Christmas matter?

Energy:

- 2004 electricity budget was \$1,000,000
- Current electricity budget under \$700,000.

Water:

- 1993: 3,400 gal/min
- 2012: 7,000 gal/min
- 2013- present: 10,000 gal/min, or between 250 and 300,000,000 gallons/year



Concluding thoughts.

- If snowmaking opportunities continue to decline, water infrastructure will become more important, regardless of total water needs.
 - Pumping capacity per minute
 - Reservoirs
- Water availability at regional ski areas varies widely
 - Upstream drainage areas vary by over 250-fold

