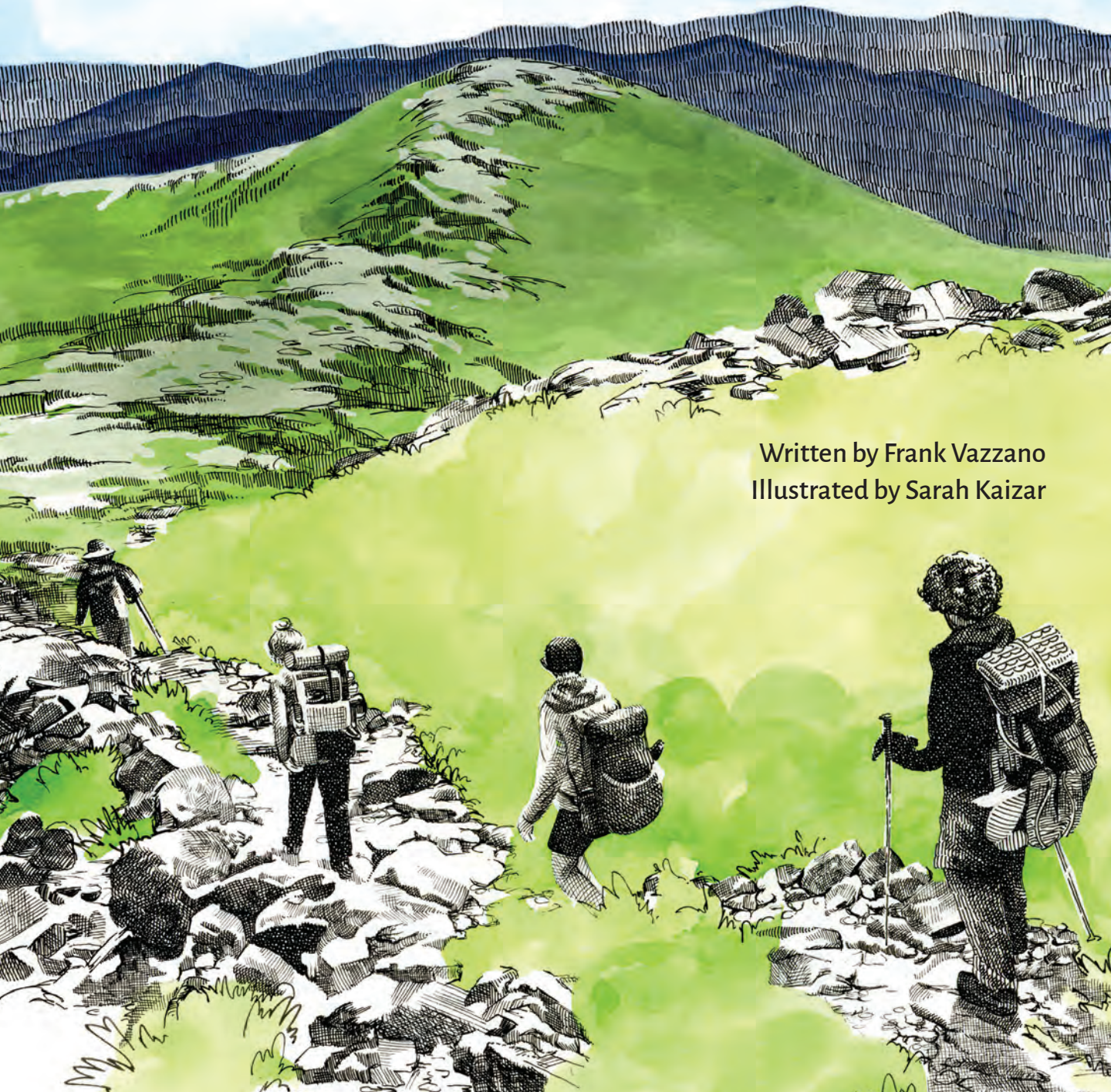
VOL. 1, FALL 2025

HUBBARD BROOK RESEARCH FOUNDATION

MWOBS MOUNT WASHINGTON OBSERVATORY

The White Mountains Almanac



Written by Frank Vazzano
Illustrated by Sarah Kaizar



About the publication

The White Mountains Almanac is a publication produced in collaboration by the Mount Washington Observatory, Appalachian Mountain Club, and Hubbard Brook Research Foundation, offering a comprehensive year-in-review exploration of ecological and climatological changes observed in the White Mountains region. Merging scientific findings with visual storytelling, the publication serves as both a resource for researchers and a guide for outdoor and nature enthusiasts, educators, policymakers, and the general public.

The Hubbard Brook Experimental Forest is one of the longest running and most comprehensive ecosystem study sites in the world. Operated and maintained by the U.S. Department of Agriculture, Forest Service since 1955, this 7,800-acre research site is located just north of Plymouth, NH, in the White Mountains. Long-term ecological research at Hubbard Brook is supported by the National Science Foundation along with other agencies and partners. The Hubbard Brook Research Foundation leads outreach and education programs to strengthen connections between science and society. Learn more and donate at ***hubbardbrook.org***.

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Administrative Offices
234 Mirror Lake Road
North Woodstock, NH 03262

The Appalachian Mountain Club is the nation's oldest conservation and recreation organization, committed to fostering the protection, enjoyment, and understanding of the outdoors. Since 1876, AMC has encouraged generations to deepen their passions for the outdoors and helped protect some of the most critical natural environments in the Northeast and Mid-Atlantic regions. Learn more and join at ***outdoors.org***.

Appalachian Mountain Club
10 City Square
Boston, MA 02129

Mount Washington Observatory is a private, non-profit, member-supported institution dating back to 1932 with a mission to advance understanding of the natural systems that create earth's weather and climate. It serves this mission by maintaining a weather station on the summit of Mount Washington, performing weather and climate research, conducting innovative science education programs, and interpreting the heritage of the Mount Washington region. Learn more and donate at ***mountwashington.org***.

Mount Washington Observatory
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Please email us at info@mountwashington.org with your feedback, suggestions for topics, and any other questions/comments.

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Preface

Hi, my name is Frank Vazzano, and I am the intern guest author of the 2025 White Mountains Almanac. Throughout this book, I'll introduce you to the climatological character of these wonderful mountains, how and where this is changing, and how these changes interact with spheres ranging from ecology to economy, and severe weather to outdoor recreation. Much like a normal almanac, monthly averages of temperature, precipitation, snowfall, and wind are included for various sites around the White Mountains. Perhaps unlike a normal almanac, the primary purpose of this publication is to delve deeper with the data as we explore a unique topic for each month of the year. For example, you'll be learning about how winter recreation is changing in March, but you'll understand how tropical cyclones influence the White Mountains in September (It is probably more than you think!).

As the first of its kind, this almanac represents the culmination of hundreds of hours of work from dozens of individuals, not just myself. I was given the opportunity to produce this work through a collaborative internship with three outstanding organizations based in the White Mountains; these are the Mount Washington Observatory, the Appalachian Mountain Club, and the Hubbard Brook Experimental Forest. The almanac truly wouldn't be possible without the mentorship, guidance, and resources from these organizations, and to that extent, the funding from their generous donors.

Having grown up in Colorado Springs, Colorado, I was instilled with a deep love and appreciation for the Rocky Mountains. This influenced my decision to study physical geography, physics, and meteorology at my undergraduate institution. Although I had not been to New England (let alone New Hampshire) before this opportunity, I found myself falling in love with the White Mountains upon arrival. I spent more than five months immersed in the valleys and summits of the Whites working on this project. While I can't say I became an expert in every aspect of them, through this immersion I feel I gained a similar level of love and appreciation for the Whites as I have for the Rockies. Although I am not staying in the White Mountains as I continue on in my education, a part of me will always stay here.

From the vast expanses of wilderness, to the unique flora and fauna, and the warm and inviting communities that call these mountains home, it is clear to me that the White Mountains must be preserved, protected, and researched so future generations can continue to enjoy their gifts. Whether you're a recreator, a nature enthusiast, a resident, a frequent visitor, a researcher, or if you've never been to the White Mountains at all, you will gain something from this publication. I hope you will join me throughout this almanac to understand how something as simple as daily temperature or rain can actually have extensive influence on all aspects of nature and human life.

If you enjoy this almanac, please consider becoming a member or donating to the three organizations that have collaborated on this piece so future works like this can become a reality.

Sincerely,
Frank Vazzano

Acknowlegments

Thanks to Karl Philippoff and Jay Broccolo from Mount Washington Observatory and Georgia Murray and Sarah Nelson from the Appalachian Mountain Club for their mentorship and contributions to the Almanac. Kind thanks to Jordon Tourville and Sarah Garlick for their reviews, as well as Nina Lany for data preparation. Thanks to all the past observers and data collectors. Without their work, we could not review such a high quality and robust set of data. Thank you to our generous funders, including the Cabot Family Charitable Trust, The Nature Conservancy of NH, Stephen Walker and Diane DeLuca, and the Hartford Foundation for Public Giving.

Personal thanks to fellow MWOBS observers and interns on my shift, as well as friends at AMC Pinkham Notch for keeping me motivated and all the fun we had while playing cards and skiing. Thanks to my family back in Colorado for the unwavering moral and emotional support during this project. I wouldn't have been able to do any of this without you!

— Frank Vazzano

Land Acknowledgment

Our research sites are located on the traditional lands of the Abenaki (W8banakiak), an Algonquin-speaking people and part of the Wabanaki Confederacy. Long before this land was colonized, it was home to these Indigenous people, who had a relationship with this land for generations, and continue to today. We acknowledge the violence perpetrated against the Abenaki people by colonizers, and the systems of colonization that continue today, particularly recognizing harm done in the name of conservation and present-day erasure of Indigenous people through our systems of environmental protection. We honor the members of Abenaki Nation past, present, and future by holding our organizations accountable and implementing systemic change. To learn more about the Abenaki communities or how you can contribute please visit: www.caodanak.com, www.dawnlandreturn.org, www.wabanakialliance.com.

About the Author/Illustrator

About the Author

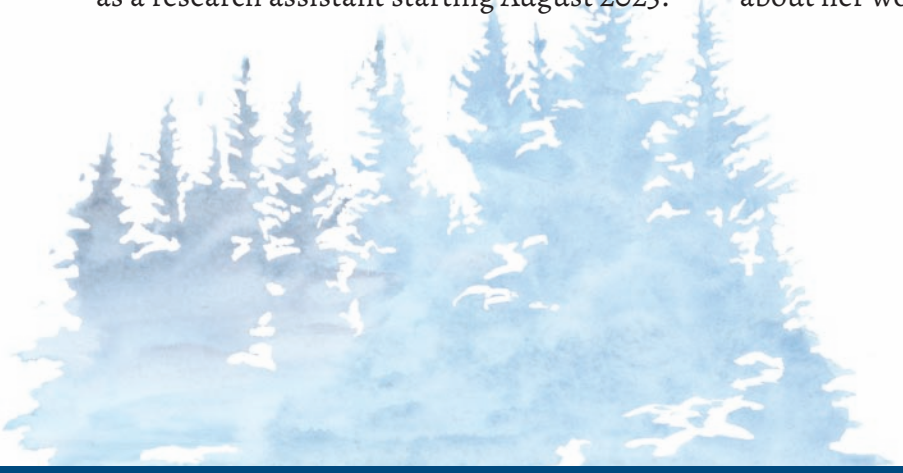
Frank Vazzano is the guest author of the first ever White Mountains Almanac through his joint internship with the Mount Washington Observatory, Appalachian Mountain Club, and Hubbard Brook Research Foundation. He was born in Oklahoma to a military family which eventually settled in Colorado Springs, Colorado, where he was raised. He gained a deep appreciation for natural processes and the mountains while growing up at the base of the Rockies.

Frank attended the University of Colorado at Colorado Springs, where he studied Physical Geography, Meteorology, and Physics. In his MWOBS internship, he spent most of his time on the summit researching and writing the almanac, but also gained experience in forecasting, weather observations, equipment, and science communication. In his free time, he enjoys skiing, hiking, cartography, and rock music. Frank will be continuing his education journey at the University of Oklahoma, where he will be completing an M.S. in Atmospheric Science as a research assistant starting August 2025.

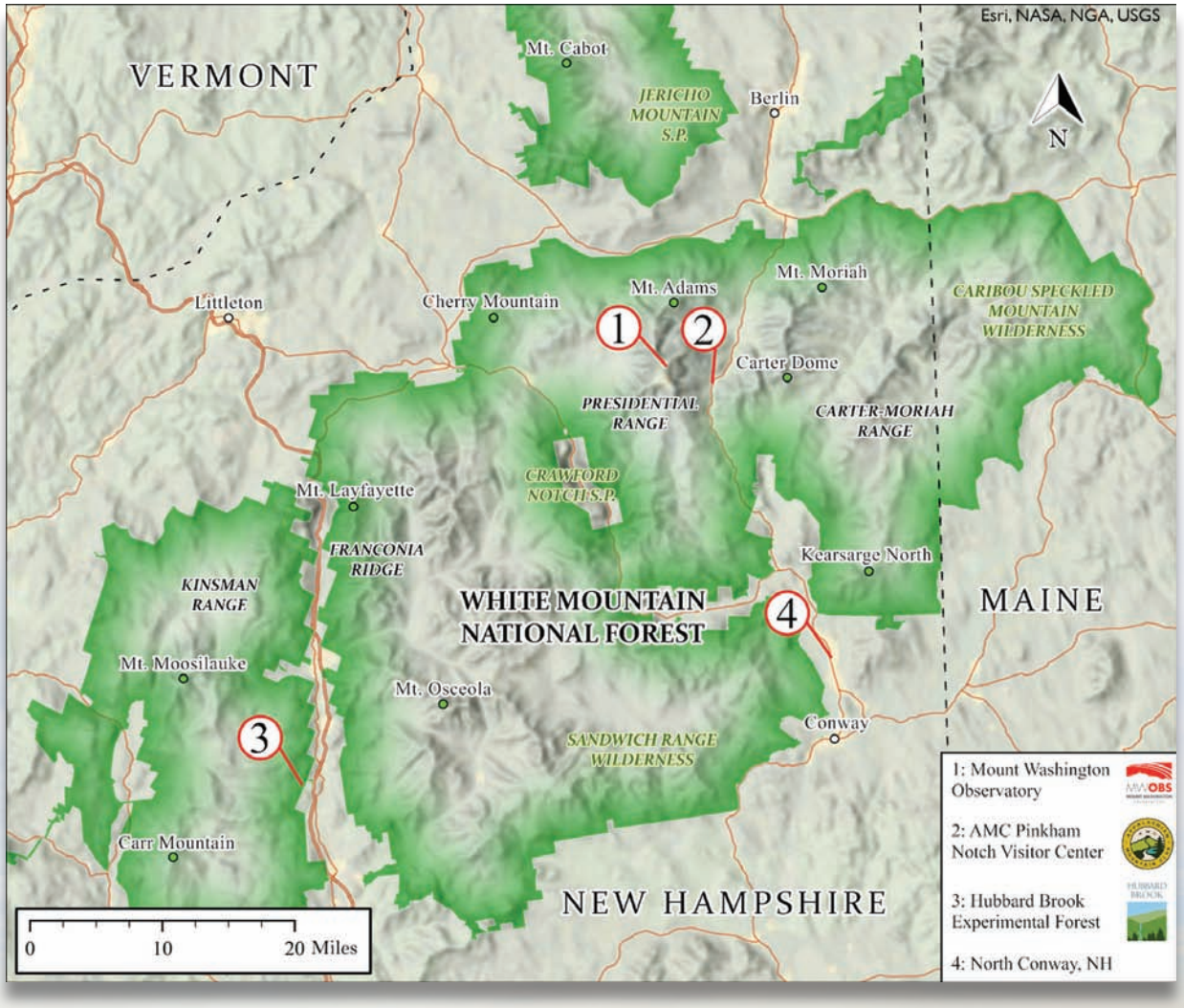
About the Illustrator

Sarah Kaizar is an illustrator and designer based in Philadelphia. Her work has been exhibited nationally in galleries and museums including the Burke Museum of Natural History and Culture at the University of Washington, the James A. Michener Art Museum, the Great Plains Art Museum at the University of Nebraska-Lincoln, the Catalina Museum of Art & History, the Woodmere Art Museum, and Delaware Contemporary.

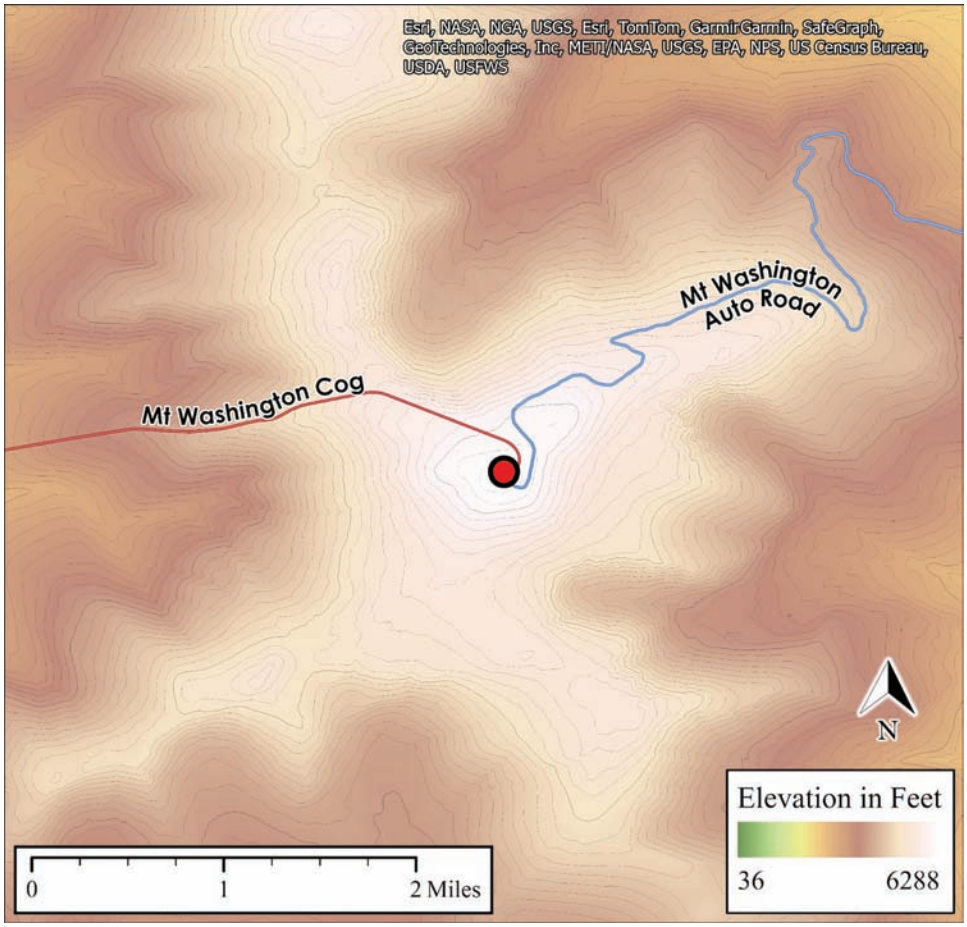
Sarah is the author of two books. HIKER TRASH: Notes, Sketches + Other Detritus on the Appalachian Trail is an illustrated work about long-distance backpacking culture (Mountaineers Books, 2019). Her second book illustrates stories about North American bird conservation and citizen science and is titled RARE AIR: Endangered Birds, Bats, Butterflies and Bees (Mountaineers Books, 2023). This title was recognized as a finalist for Foreword's INDIES 2023 Book of the Year in the Ecology and Environment category. To learn more about her work, visit sarahkaizar.com.



Regional Map



Mount Washington Observatory (MWOBS)

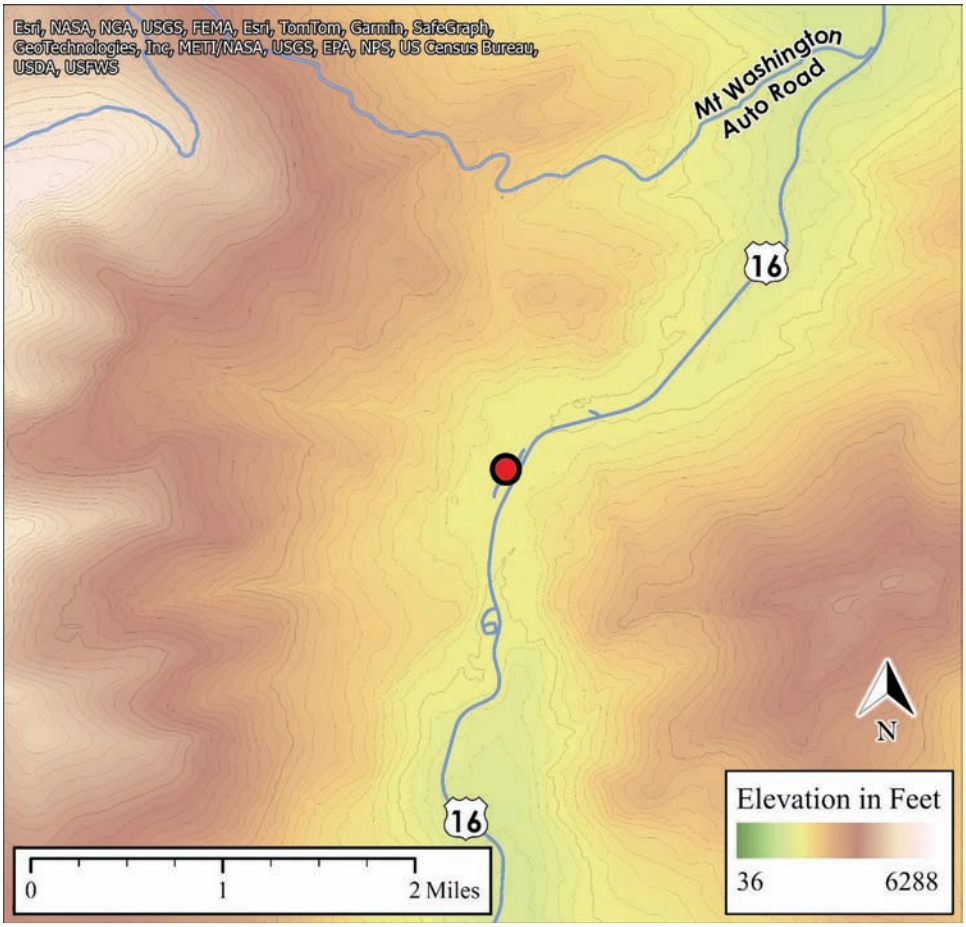


MWOBS MOUNT WASHINGTON OBSERVATORY

Elevation	**6,280 feet a.s.l.**
Established	**October 15, 1932**

Mount Washington Observatory is a private, non-profit, member-supported institution dating back to 1932 with a mission to advance understanding of the natural systems that create Earth's weather and climate. It serves this mission by maintaining a weather station on the summit of Mount Washington, performing weather and climate research, conducting innovative science education programs, and interpreting the heritage of the Mount Washington region. Learn more at mountwashington.org.

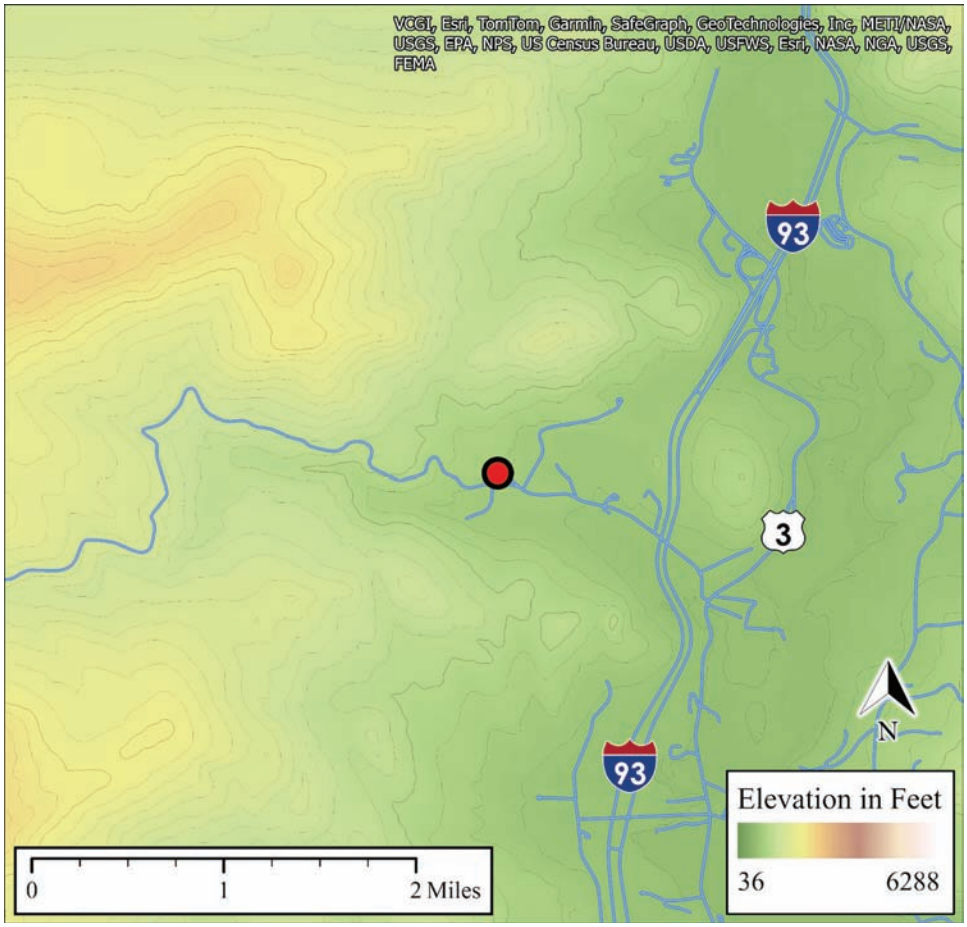
Appalachian Mountain Club Pinkham Notch (AMC PN)



Elevation	**2,032 feet a.s.l.**
Established	**Summer, 1920**

The Appalachian Mountain Club is the nation's oldest conservation and recreation organization, committed to fostering the protection, enjoyment, and understanding of the outdoors. Since 1876, AMC has encouraged generations to deepen their passions for the outdoors and helped study and protect some of the most critical natural environments in the Northeast and Mid-Atlantic regions. Learn more at www.outdoors.org.

Hubbard Brook Experimental Forest (HBEF)



HUBBARD BROOK



Elevation	**825 feet a.s.l.**
Established	**May 17, 1955**

The Hubbard Brook Experimental Forest is one of the longest running and most comprehensive ecosystem study sites in the world. Operated and maintained by the U.S. Department of Agriculture, Forest Service since 1955, this 7,800-acre research site is located just north of Plymouth, NH, in the White Mountains. Long- term ecological research at Hubbard Brook is supported by the National Science Foundation, along with other agencies and partners. The Hubbard Brook Research Foundation leads outreach and education programs to strengthen connections between science and society. Learn more at **hubbardbrook.org**.

Winter Temperatures



Winters in the White Mountains maintain a distinct balance between frigid conditions and picturesque scenery. The cold, short, and occasionally ferocious days of January contrast with beautiful scenes of snow-capped mountains and tranquil hinterland. Many living things retreat for the winter via hibernation, dormancy, or migration, potentially giving the mountains an eerie or lifeless atmosphere. This time of year is, however, critically important for the plant and animal residents of the White Mountains. These wild inhabitants are finely tuned to the clock of nature and rely on the cold as a reset to rest, ultimately to repair cells and produce sap.

Alongside the ecological importance of cold winter temperatures, the indirect effects on recreation, water resources, and the economy make something as innocuous as the daily temperature on your weather app deeply consequential. Thus, in the face of shifting global weather patterns, this chapter will focus on how winter temperatures in the White Mountains have changed in comparison to adjacent regions, and what this change means for some of the life and activities previously mentioned that rely on cold winters. In ecology, locations that provide sanctuary for wildlife (especially during periods of



Sugar maples (Acer saccharum) rely on sustained winter cold to reset cellular processes. This prepares them for the sap flow that occurs during sugaring season in March (Stinson & Morelli, 2018). Nationwide, the maple syrup industry was valued at over $172 million USD in 2022 (USDA, Maple syrup production 2023), with New Hampshire producing 3% of the nation's supply (ranked 6th by total statewide production) (Gokee, 2022).

environmental stress) are called 'refugia'. While the White Mountains are considered to be 'refugium' (and thus resistant to regional changes in weather patterns) this does not make them immune to changes in weather patterns. In this chapter and throughout the almanac, we will be investigating how resistant the White Mountains really are to environmental stress, and what this means for its refugium status.

For this almanac, we use meteorological data from four sites in the White Mountains of New Hampshire. These sites are the Mount Washington Observatory (MWOBS) on the summit of Mount Washington, the Appalachian Mountain Club's Pinkham Notch (AMC PN) visitor center, the Hubbard Brook Experimental Forest (HBEF) headquarters, and North Conway (NCON), New Hampshire (see maps on pages 6-9). These sites represent a diverse range of elevations and climate types in the White Mountains, from the temperate foothills to the subarctic alpine mountaintops.

For the first month of the year, we investigate meteorological winter (December, January, and February) temperatures as a whole. We start with the daily maximum (T_{max}) and minimum (T_{min}) temperatures, which are the highest and lowest temperatures recorded each calendar day. This is illustrated by Figure 1.1, which shows how temperatures typically fluctuate daily, or 'diurnally', usually peaking right before sunset, (shown as 'Tmax', short for 'maximum temperature') and bottoming out before sunrise (shown as 'Tmin', short for 'minimum temperature'). In reality, this pattern is much less cut-and-dry and depends on a lot more than just time of day, but this is the general pattern.

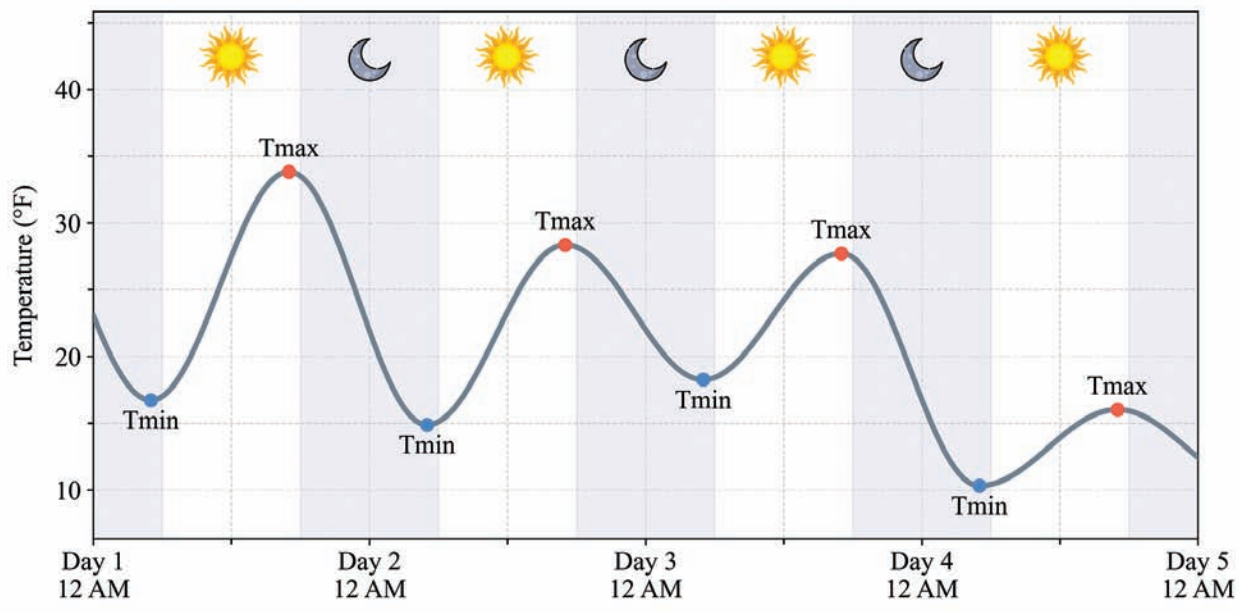


Figure 1.1. Graph of typical diurnal variations of temperature, where Tmax is an example of a daily maximum and Tmin is a daily minimum. Note that this general pattern can vary with geographic location and changing weather conditions.

The daily average temperature (T_{mean}) is calculated by adding the daily maximum and minimum temperatures together and then dividing by 2. Then, we find the entire winter average ($T_{seasonal\ mean}$) for every year by adding each daily T_{mean} value and dividing by the number of days*. In our case, the total number of days in December, January, and February is 91 days, except during leap years when it is 92. We use the average temperature of the entire winter season because it is a good, condensed indicator of the coldness or warmth of the entire winter season. As a note for the figures below, the year associated with the 'winter season' refers to the year of January of that meteorological winter (e.g. 1980 refers to the winter season of December of 1979, January 1980, and February 1980).

We plot the $T_{seasonal\ mean}$ for each season, as shown in Figure 1.2. Since we're interested in the trend in winter seasonal temperatures over time, we overlay a linear fit to the data to make it easier to discern. The line provides an estimate of the rate of change over time, or the slope, with the units degrees Fahrenheit (°F) per winter season. Refer to Appendix A - *What is a Trend Line?* (pp. 92) for more information on how to interpret trend lines and significance.
We complete a similar analysis in Figure 1.3, except instead of taking the seasonal average of daily means, we only take the daily lows for the month of January each winter season. This is to highlight how the coldest temperatures in the coldest month are changing.

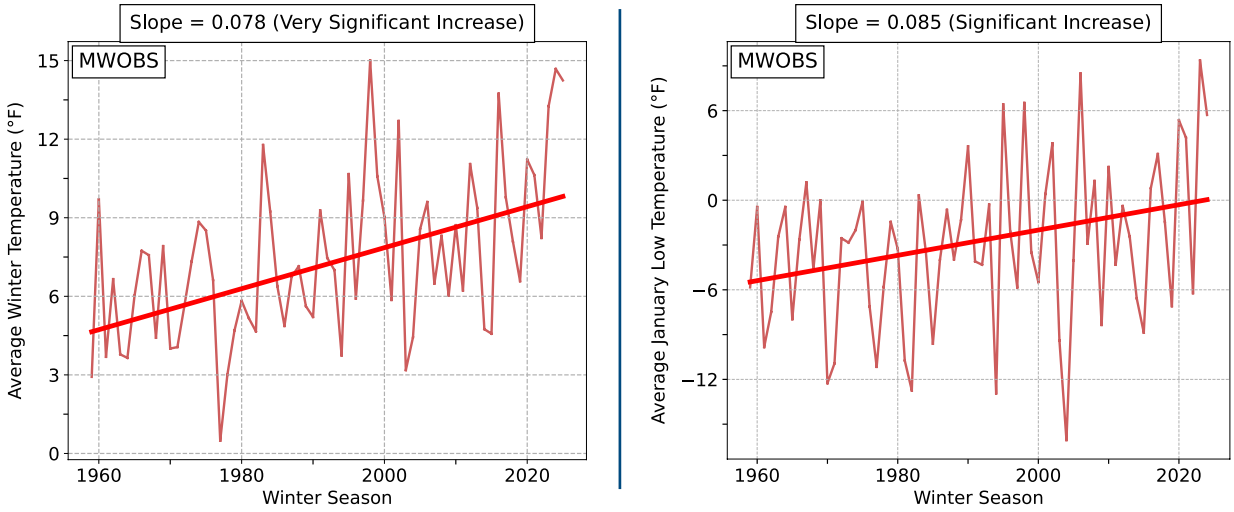
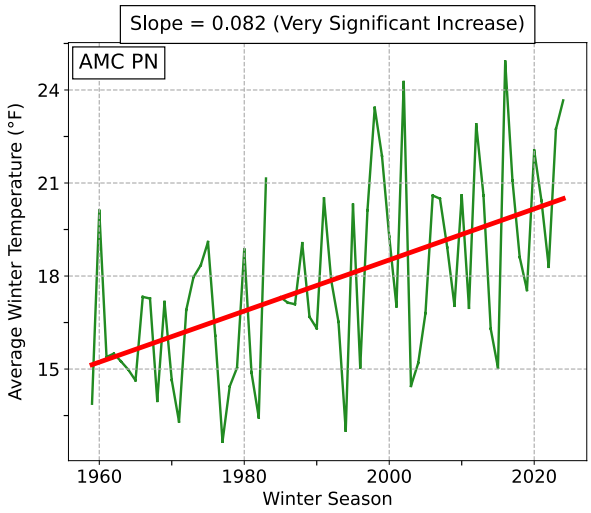


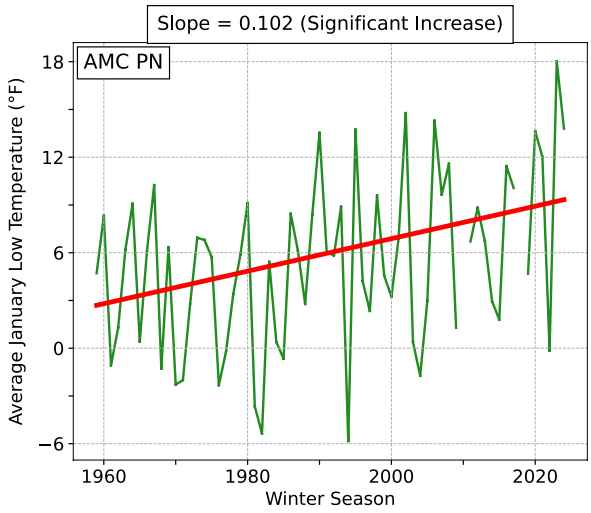
Figure 1.2 (left). Daily temperatures averaged across December, January, and February in °F for for MWOBS (above) and AMC PN, HBEF, and NCON (next page).

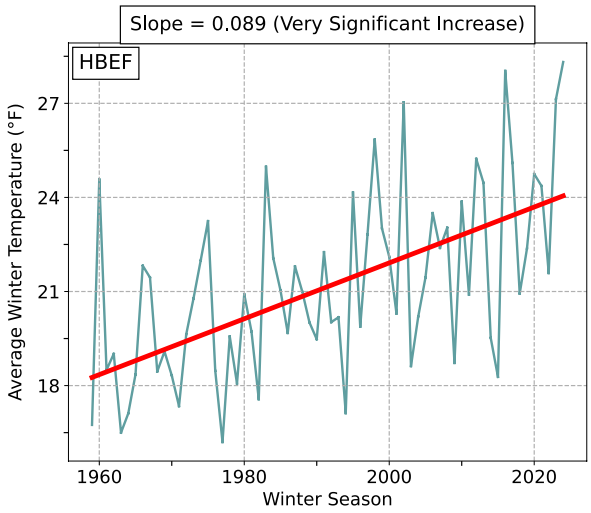
Figure 1.3 (right). Mean January daily low temperatures in °F for MWOBS, AMC PN, HBEF, and NCON.

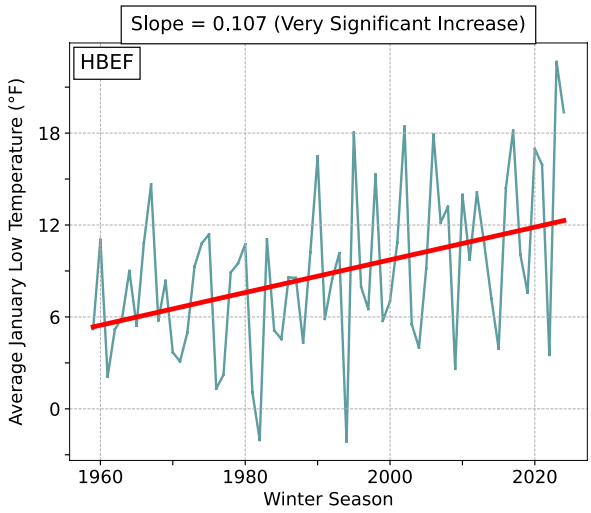
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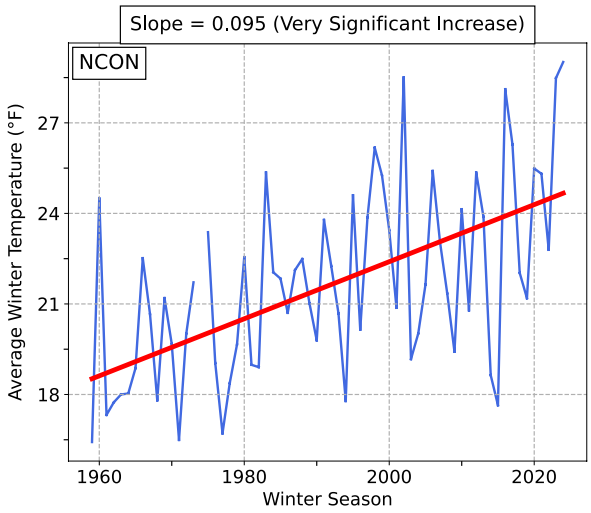
Equations for T_{mean} and $T_{seasonal\ mean}$ can be found in the Endnotes for January (pp. 97).

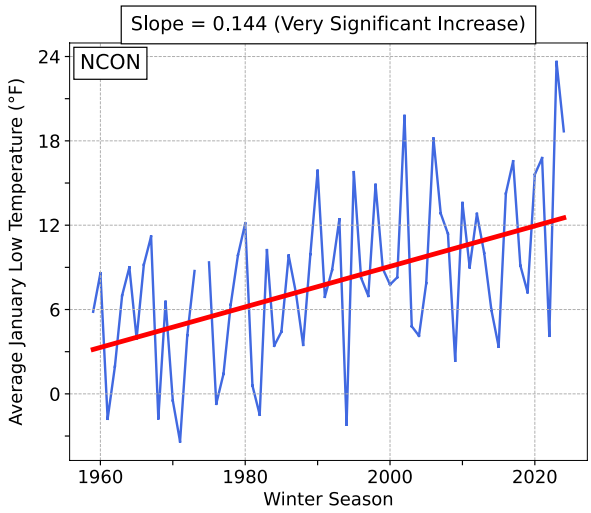

Slope = 0.082 (Very Significant Increase)
AMC PN
Average Winter Temperature (°F)
Winter Season


Slope = 0.102 (Significant Increase)
AMC PN
Average January Low Temperature (°F)
Winter Season


Slope = 0.089 (Very Significant Increase)
HBEF
Average Winter Temperature (°F)
Winter Season


Slope = 0.107 (Very Significant Increase)
HBEF
Average January Low Temperature (°F)
Winter Season


Slope = 0.095 (Very Significant Increase)
NCON
Average Winter Temperature (°F)
Winter Season


Slope = 0.144 (Very Significant Increase)
NCON
Average January Low Temperature (°F)
Winter Season

These temperature trends mean that, although not warming as quickly as adjacent regions, winters in the White Mountains are changing, dampening its aforementioned refugium status. All four locations (MWOBS, Pinkham Notch, Hubbard Brook, and North Conway) have experienced significant increases in average winter temperatures since the 1950s. In the Mount Washington Valley (represented by the site in North Conway) average winter temperatures are increasing by 0.95°F per decade and January daily lows are increasing by 1.44°F per decade. In the mid to lower elevations of the White Mountains, both Pinkham Notch and Hubbard Brook are seeing significant increasing trends in temperature. Average winter temperatures at Pinkham Notch and Hubbard Brook are increasing by 0.82°F and 0.89°F per decade respectively, while January daily lows are increasing by 1.02°F and 1.07°F per decade respectively. Even the highest, coldest reaches of the White Mountains are warming significantly, with winter temperatures at the summit of Mount Washington (represented by MWOBS) increasing by 0.78°F and January daily lows increasing by 0.85°F per decade. Overall, this means that at the lower elevations, winter temperatures have increased by about 6°F since the 1950s while the mid to higher elevations have seen winter temperatures rise by about 5°F.

Throughout the rest of this almanac, the data we share underscore the importance of temperature in the changes that are being identified in the White Mountains and elsewhere. We will also introduce other drivers of changes in high elevation systems such as precipitation, wind, and ice and their impacts on nature and humans. Weather and climate have the potential to ripple out and affect all facets of nature and life, starting with ecology and natural resources, but inevitably influencing infrastructure, the economy, public health, and beyond. In the next chapter, we explore rising winter temperature in relation to snowpack, and what this means for roads and avalanches.



Photo by NH State Parks

January Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	48°F	-	-	-
Average High	14°F	14°F	15°F	1°F
Average	**6°F**	**6°F**	**7°F**	**1°F**
Average Low	-3°F	-3°F	-1°F	2°F
Record Low	-46°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	63.1°F	-	-	-
Average High	25.2°F	25.5°F	26.0°F	0.5°F
Average	**15.2°F**	**15.1°F**	**16.7°F**	**1.6°F**
Average Low	5.2°F	4.6°F	7.5°F	2.9°F
Record Low	-32.8°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	55°F	-	-	-
Average High	28°F	27°F	29°F	2°F
Average	**18°F**	**17°F**	**20°F**	**3°F**
Average Low	9°F	7°F	11°F	4°F
Record Low	-31°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	61°F	-	-	-
Average High	30°F	29°F	30°F	1°F
Average	**19°F**	**17°F**	**21°F**	**4°F**
Average Low	8°F	5°F	11°F	6°F
Record Low	-34°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

The Delta Degrees Fahrenheit notation (Δ°F) refers to the overall change in temperature within a timeframe.



Mount Washington summit sign, cairn, and instrument tower coated in rime at sunset. Photo by MWOBS.

Thaw Events

By February, winter has long established itself in the White Mountains. Although February is neither the coldest nor snowiest month by most metrics (those titles belong to January and March, respectively), this middle child of the winter months is an important period. This month sees the deepest snowpack accumulations of the entire winter, on average. As such, February is a critical month for water resources, winter recreation, and ecology. Generally, a healthy snowpack in February will indicate a robust winter on the whole with a thick insulating blanket providing winter habitat and keeping soils from freezing.

As identified in *January* (pp. 10), winters have been warming in the White Mountains during the past 90+ years. Warming winters are bad for building and maintaining snowpacks for several reasons, but mostly because temperatures above 32°F (freezing temperature of water) will lessen snowpack through melting. Warm temperatures also open up the possibility of making liquid precipitation (rain) more common. Rain-on-snow events, which are increasing in frequency, are particularly destructive for snowpack because the relatively warm droplets soak in and disperse energy deep into the snowpack, while warm air will only interact with its surface (Krouse, 2024). Warming snow through air and rain can, in turn, increase the chances of certain types of avalanches.

Temperatures oscillating above and below 32°F over the course of a day are also bad news for infrastructure, especially roads. Melted snowpack will trickle down to the lowest and flattest surfaces (usually roads and parking lots) during the daytime. Then at night, when temperatures dip below freezing, the pooled water will freeze solid, potentially creating sheets of ice that make driving hazardous and damaging roads when the water expands as it freezes. This damage to roads is attributed to the 'freeze-thaw cycle,' which creates potholes and frost heaves.

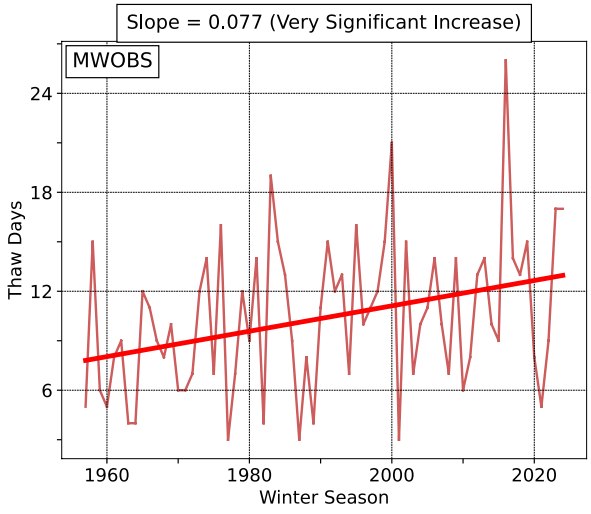
Although the cost of repairing specific instances of road damage


WHITE MOUNTAIN National Forest
AVALANCHE INFORMATION
TODAY'S ADVISORY
A GENERAL ADVISORY IS ISSUED
LION HEAD TRAIL
WINTER ROUTE
TUCKERMAN

are difficult to calculate, it can cost upwards of $50,000 to resurface a "stretch of road" and over $1 million to completely replace a single mile of road according to the New Hampshire Department of Transportation (Paradis, 2018). These costs will increase as more freeze-thaw cycles occur. As winters warm, community members and municipalities in the White Mountains will have to adapt to these changes and take action to protect life and infrastructure.

It is clear that thawing in winter is unfavorable for both snowpack and infrastructure, but just how much are thaw days changing? A 'thaw day', as defined by Kelsey & Cinquino (2021), is defined as any day in which the maximum temperature rises above the freezing threshold of 32°F, regardless of how high above freezing it rises. Another way to investigate winter thaws is by incorporating 'thaw intensity', which takes into account how much the maximum temperature exceeds 32°F on a thaw day. The thaw intensity (ΔT) for any given day is simply the daily maximum temperature in °F (T_{max}) minus 32°F (T_{freeze})*. Thus, a day when the temperature rises to 60°F has a greater thaw intensity than a day that only reaches 40°F. By summing winter thaw days and thaw intensities for each winter season, we can see how both are changing over time in the White Mountains at all elevations.

We used daily maximum temperature observations between December 1st and February 28th of each winter season recorded at MWOBS, AMC PN, and HBEF back to the 1950s for this analysis. The results of this analysis are displayed in Figure 2.1 and 2.2.



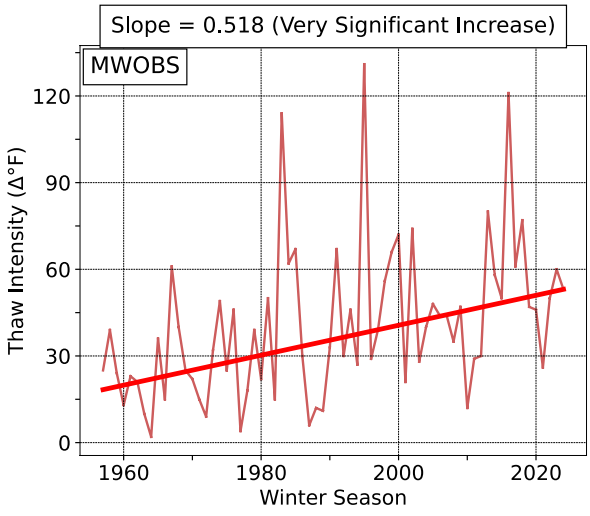
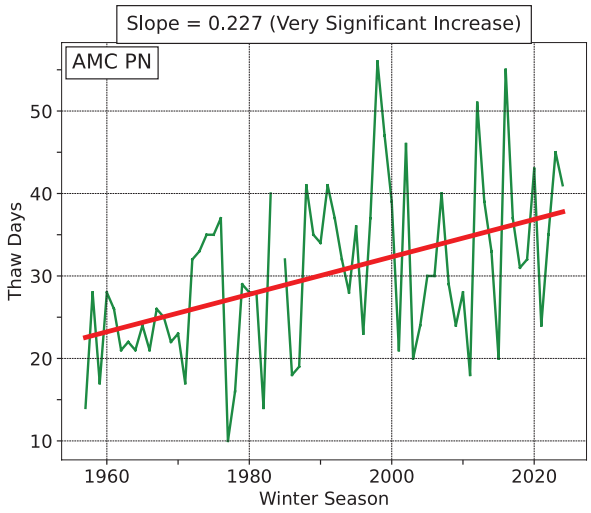
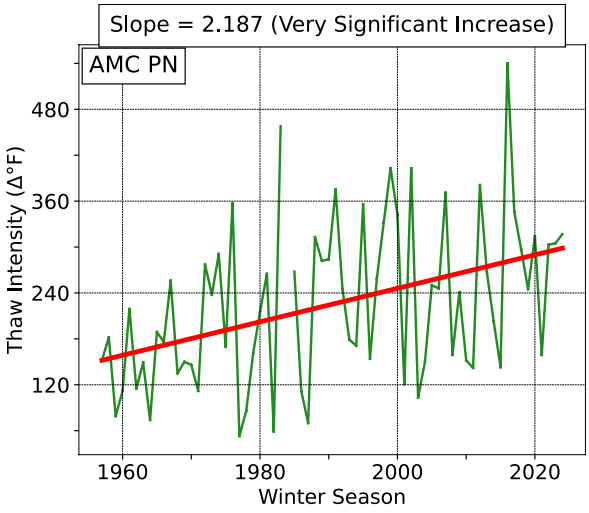


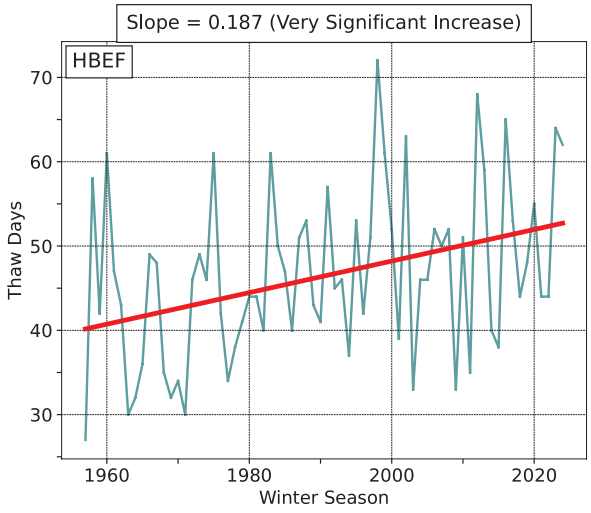
Figure 2.1 (left). Winter (December 1st to February 28th) thaw days for MWOBS, AMC PN, and HBEF.

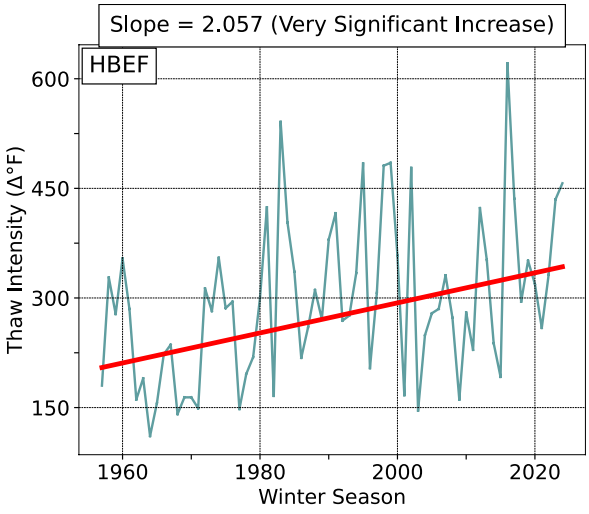
Figure 2.2 (right). Cumulative winter thaw intensity for MWOBS, AMC PN, and HBEF.

*$If\ T_{freeze} \geq T_{max}\ then\ \Delta T = 0$









Hubbard Brook is experiencing a very significant increase in thaw days, gaining 1.9 per decade, and a very significant increase in thaw intensity, gaining 20.6 Δ°F per decade. There are an average of 16 more winter thaw days at Hubbard Brook in the 2020s than the 1950s, while total thaw intensity has almost doubled over the same period. Pinkham Notch's increases in thaw days and thaw events are also both very significant. Thaw days there are increasing by 2.3 per decade, and thaw intensity is increasing by 21.9 Δ°F per decade.

Indeed, even high-elevation locations are witnessing more thaw days, with MWOBS seeing very significant increases in both thaw days and thaw intensity. At the summit, thaw days are increasing by 0.8 per decade and thaw intensity is increasing by 5.2 Δ°F per decade. This means there are about five more thaw days per winter in the 2020s than in the

1950s. Although this may not sound like a lot spread out across the whole winter, consider that this means thaw days are almost twice as common in the 2020s as they were in the 1950s for the summit. This change has broad implications for winters in the White Mountains, principally that winters with shallow and weak snowpack will become more common which is unfavorable for winter recreation and ecology. Snow may begin to accumulate later and melt earlier, indicating that winter as we know it is receding.

Avalanches are a hazardous and potentially fatal natural event that occur when large volumes of snow or ice fall away from a slope, usually on the sides of mountains. Although avalanches are not as common in the White Mountains as they are in other ranges (like the Rocky Mountains), do not be fooled into complacency while traversing alpine terrain in the Whites during winter and spring. According to the Mount Washington Avalanche Center (MWAC), an average of 25 recreators per year require rescue assistance in the White Mountains, with a vast majority



Unofficial Networks Photo



Snowpack analysis. Mount Washington Avalanche Center photo.

of those cases occurring in winter and spring (MacDonald, *DANGER ZONES MT. WASHINGTON*). "Nearly 95 percent of the incidents we tracked occurred from January to May, with more than half of the total in March and April" (MacDonald, *DANGER ZONES MT. WASHINGTON*). Moreover, since the winter of 1950, 17 people have died from avalanche-related incidents in New Hampshire (CAIC, 2024). Avalanche terrain may look exactly like the kind of terrain found at a ski resort, but the instability is hidden, making the danger avalanches pose more deceiving than other weather events like loud and flashy thunderstorms.

Since data on the amount and intensity of avalanches over time are sparse, we can't say for sure how avalanches and ice falls are changing in the face of warming winters, increasing thaw days, and decreasing snowfall (as will be discussed more next chapter, *March* (pp. 26). We do know, however, that warmer air can hold more moisture than colder air while also allowing the chance for rain to fall rather than snow. According to Jeffrey Fongemie, the current director of MWAC, the effects of rain on avalanches are complex, but in general, rain can increase the chances of types of avalanches (like 'wet snow' avalanches) while decreasing the chances of others (like 'persistent slab' avalanches) (Vazzano & Fongemie, 2025). This is because rain can create instability in the short-term, but can ultimately establish stability in snowpack in the long-term.

According to Fongemie, a few degrees difference in temperature and a few less inches of snowfall will likely not extensively impact avalanche conditions or forecasting in higher elevations (Vazzano & Fongemie, 2025). Many varieties of avalanches will still be a possibility during the whole winter. What could make a difference, however, is warming temperatures and decreasing snow totals at lower elevations, which are already seeing cold winters and snow disappear. As ski resorts become more dependent on snow making and backcountry glades at lower elevations get less snow every year, recreators may be forced to ascend to higher, snowier, and possibly more dangerous terrain to 'earn their turns'. The National Weather Service says that 90% of avalanches are caused by humans (directly or indirectly), so with increasing crowds on higher terrain, the chances of human-caused avalanches will also increase (NWS, *Avalanche Safety*).

For more information about avalanches in the White Mountains, visit the Mount Washington Avalanche Center at https://www.mountwashingtonavalanchecenter.org, and for general information and training about avalanches, visit "Know Before You Go" (a national avalanche awareness program) at https://www.kbyg.org.

February Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	48°F	-	-	-
Average High	14°F	14°F	15°F	1°F
Average	**6°F**	**6°F**	**7°F**	**1°F**
Average Low	-2°F	-3°F	-1°F	2°F
Record Low	-47°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	72.0°F	-	-	-
Average High	27.4°F	26.8°F	28.7°F	1.9°F
Average	**17.0°F**	**16.3°F**	**18.6°F**	**2.3°F**
Average Low	6.6°F	5.7°F	8.6°F	2.9°F
Record Low	-33.7°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	63°F	-	-	-
Average High	31°F	31°F	32°F	1°F
Average	**21°F**	**20°F**	**22°F**	**2°F**
Average Low	11°F	9°F	13°F	4°F
Record Low	-26°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	71°F	-	-	-
Average High	33°F	33°F	33°F	0°F
Average	**21°F**	**20°F**	**23°F**	**3°F**
Average Low	10°F	8°F	12°F	4°F
Record Low	-34°F	-	-	-

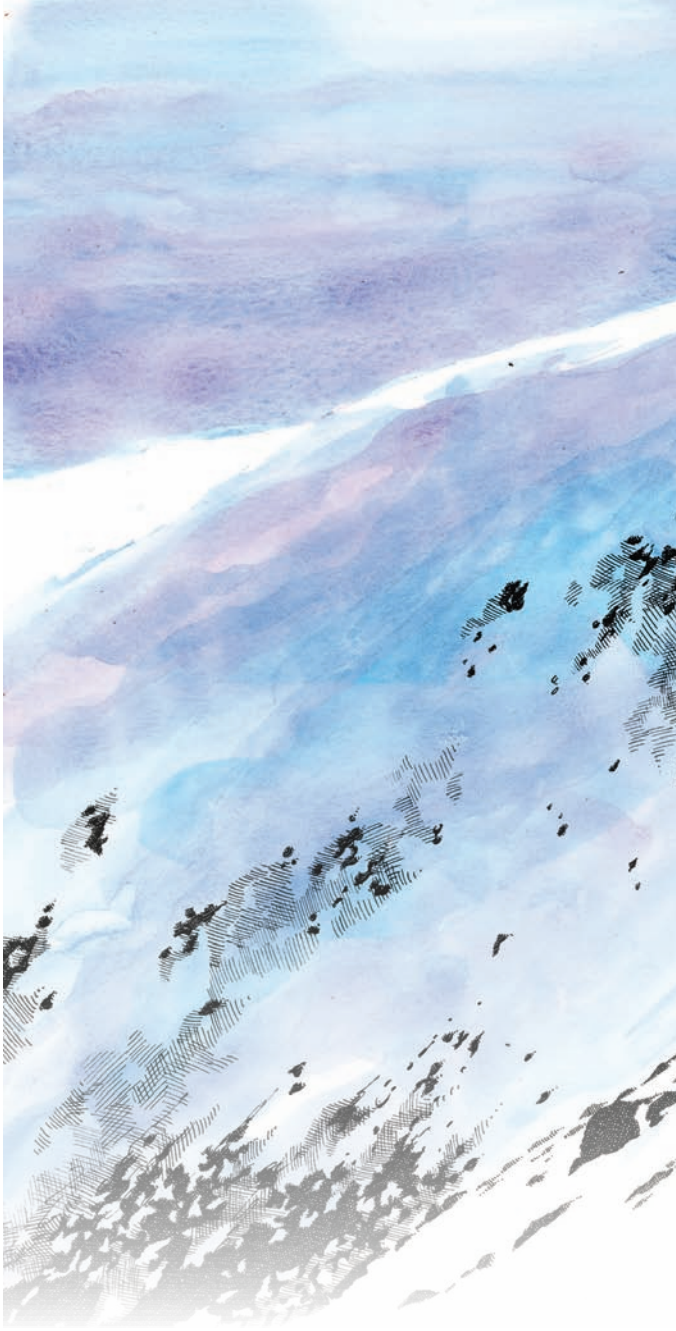
North Conway temperatures are rounded to the nearest integer.



Last light on Mahoosuc Notch and Old Speck Mountain, ME.
Photo by MWOBS.

Winter Recreation Days

The White Mountains are famous for the variety of outdoor activities that can be enjoyed year-round, but March is a special time of year in this regard. Although March 21st or 22nd marks the beginning of astronomical spring, winter recreational opportunities still abound in the White Mountains through the end of March and beyond. This month is generally the snowiest for the mountains; it's warm enough to allow for lots of moisture in the air, but cold enough for precipitation to still fall as snow. Visitors flock to the region to enjoy skiing and snowboarding at one of the many resorts or backcountry areas that call the White Mountains home. Mount Washington and the Presidential Range feature renowned backcountry basins and trails like Tuckerman Ravine and the Sherburne Ski Trail. Mountainous terrain, especially higher elevations, allow for unique microclimates and conditions that can change quickly over short distances and time intervals. This can result in ideal recreation conditions swiftly deteriorating into whiteout conditions within hours or less.



As established in January (pp. 10) and February (pp. 18), winters in the White Mountains are changing. Snowfall and snowpack characteristics are closely correlated with air temperature fluctuations, and in the face of rising winter temperatures and intensifying thaw events, these changes pose a threat to cherished winter recreation days in the White



Mountains. Other studies have found that snowpack across New England as a whole is decreasing over time due to it accumulating more slowly and melting out earlier (Contosta et al., 2019). So, how are winter recreation days in the White Mountains being impacted by changes in temperature, snowfall, and snowpack?

To answer this question, we have to define what makes a good winter recreation day. Berghammer and Schmude attempted to calculate how 'optimal ski days' have changed over time for resorts in the European Alps (2014). The formulas and methods described here were inspired in part from their work. While individuals can define optimal recreation days subjectively in different ways, we developed scientific metrics to gauge optimal winter recreation weather. One of the most important factors for a winter recreation day is snow. A day where

lots of fluffy snow falls is often considered a powder (or 'pow') day. Although there are several factors that contribute to snow formation, the 'sweet spot' to maximize snow amounts and fluffiness is when cloud temperatures are between 14°F and -4°F, which we call the dendritic growth zone.

The reason for this seemingly arbitrary temperature range comes in two parts and involves a bit of science. First, *snow crystals grow faster when the air is colder* (Libbrecht, 2022). This is because water in the air will more readily freeze onto suspended snowflakes in the air when it's cold. So, why not just say the best snow falls at 0°F, or -50°F, or even colder? The reason is that *cold air can hold less moisture* (Libbrecht, 2022). So, the colder the air is, the less water could be available to form snowflakes. It turns out that these two variables are maximized from 14°F to -4°F (Fig. 3.1). Within this temperature range (and assuming some other conditions are fulfilled), special types of fluffy snowflakes called stellar dendrites will form (hence the term "dendritic" growth zone).

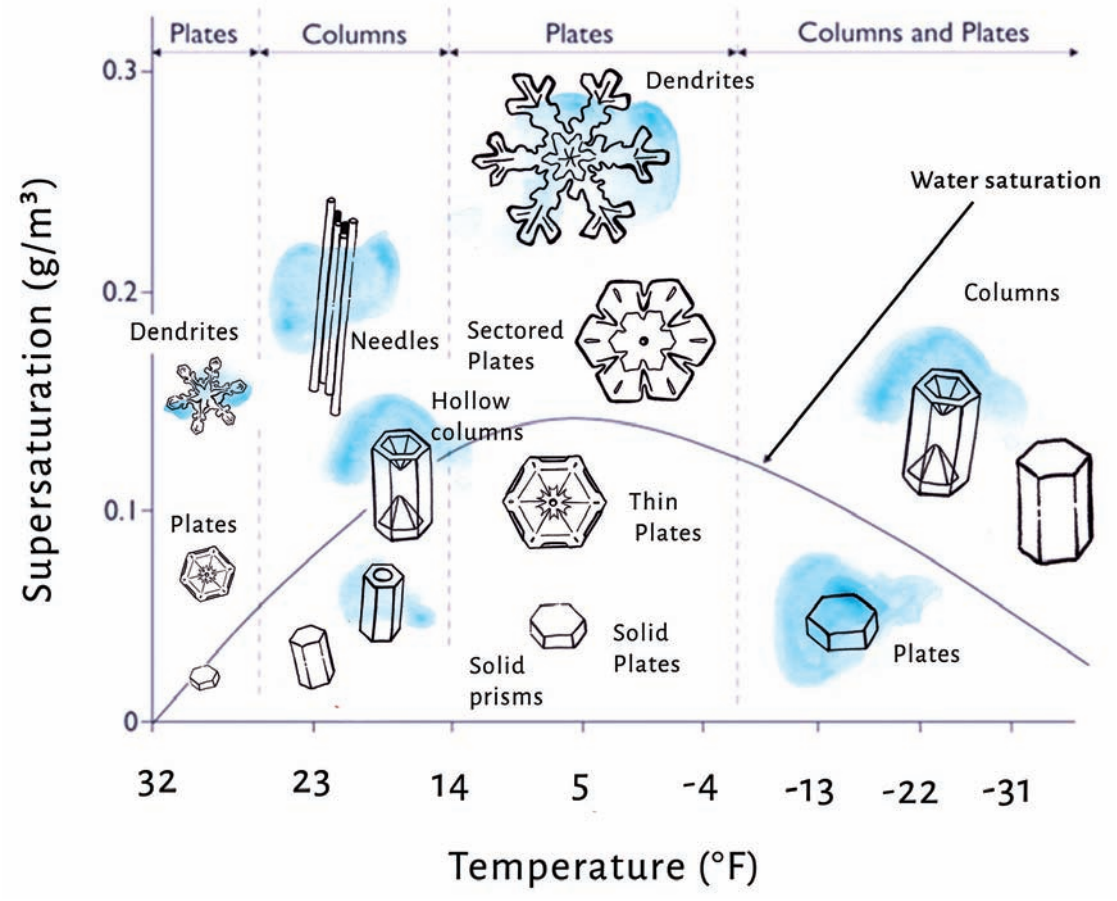


Figure 3.1. Snowflakes come in different shapes and sizes depending on the air temperature and moisture, represented here by Supersaturation in g/m3, present in the air. *(Diagram adapted from Libbrecht's "The Formation of Snow Crystals," originally created by Ukichiro Nakaya in the 1930's and termed "Nakaya snow crystal morphology diagram").*

Moreover, a deep base (the depth of accumulated snow on the ground, i.e. snowpack) can improve winter recreation conditions. If these three daily measurements (temperature, snowfall, and snow depth) are available, a 'winter recreation score' (WRS) can be calculated for any given day. A perfect recreation day will be scored '1' if it's around 20°F, has at least 1 inch of new snowfall, and has at least an 8-inch base (Table 3.1).** However, if a day is much warmer or colder than 20°F, has had no new snowfall, and no existing snowpack, it would have a '0' recreation score*. Most days will fall somewhere in between.

Individual Metric	*Scoring*
Daily Average Temperature Score	1 Point for T_{mean} around 20°F Drops off to 0 Points either direction
Daily New Snowfall Score	1 Point if ≥ 1 Inch Drops off to 0 Points at 0 Inches
Snow Depth Score	1 Point if ≥ 8 Inches Drops off to 0 Point at 0 Inches
Winter Recreation Score (WRS)	(Σ Metric Scores) / 3

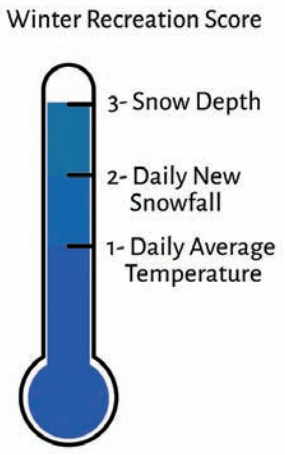


Table 3.1. Winter recreation scoring metrics.

Daily temperature and snow observations between December 1st and April 30th each winter season recorded at Pinkham Notch back to 1938 were used for this analysis. Pinkham Notch is used here because it can act as a proxy representation of the middle elevations of the White Mountains (where a large measure of winter recreation happens) while also having a long and thorough dataset. Applying this scoring rubric to every day with observations and then taking the average score of each winter season, we determined how ideal winter recreation days have changed over time. The results are displayed in Figure 3.2.

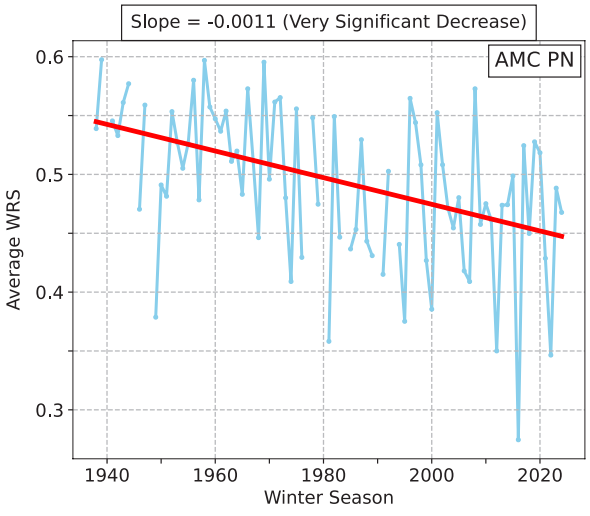


Figure 3.2. Average Winter Recreation Score by winter season between December 1st and April 30th at Pinkham Notch. Scores closer to 1 are more ideal recreation days, scores closer to 0 are less ideal recreation days.

** The full details of this methodology can be found in the Endnotes section for March (pp. 97)*

***We use 20°F here for a few reasons; one of them being its relative comfort as a below freezing temperature in relation to other environmental factors.*

Using a linear trend line, we can see that winter recreation days in the White Mountains are experiencing a very significant decrease over time. While WRS is only decreasing by a seemingly small amount of change at 0.011 per decade, this means that since the beginning of the period of record, the average winter recreation day has become 18% less optimal. Recreation days in the 1940s were closer to an average score of 0.55 while in the 2020s they are closer to 0.45. In other terms, the White Mountains have an average of 17 less ideal recreation days per winter season in the 2020s than the 1940s. According to this scoring system, the season that had the best combination of temperature, snowfall, and base depth was the legendary winter of 1969, while the worst occurred within the last decade in 2016.

We can divide the data in different ways to pinpoint when changes are occurring, such as by month and decade. The biggest changes are happening in the 'shoulder' season of the winter, especially December, March, and April. In the 1940s, the typical March had an average WRS of 0.58. In the 2020s the average score had fallen to 0.51. April has seen an even more dramatic drop with average WRS scores falling from 0.39 in the 1940s to 0.20 in the 2020s. This decrease can be attributed specifically to diminishing snowfall and snow depth, which are partly dependent on air temperature.

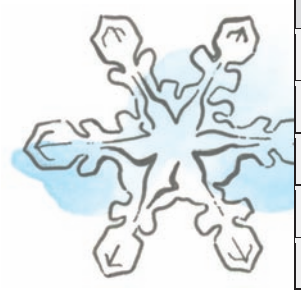
As shown in previous chapters, warming winters and advancing spring onset have already influenced the winter identity of the White Mountains. This has wide-ranging repercussions, particularly for the winter industry, with it becoming increasingly difficult for ski resorts to remain open into April. As this trend continues, the winter recreation industry and the economy of the White Mountains as a whole will have to adapt to shorter, warmer winters.

Still, recreators in the White Mountains should expect to have many "pow days" ahead of them. Our findings indicate that the best time to go recreating in the winter in the White Mountains has shifted earlier in the season. While the best days for recreating used to be deep within the middle of March, late February now holds that title. In Table 3.2, we list the ten statistically best weeks for winter recreation based on the last three decades.

Best Winter Recreation Weeks
Feb 15 – Feb 21
Mar 01 – Mar 07
Feb 22 – Feb 28
Feb 08 – Feb 14
Mar 08 – Mar 14
Mar 15 - Mar 21
Feb 01 – Feb 07
Dec 27 – Jan 02
Jan 25 – Jan 31
Jan 18 – Jan 24

Table 3.2. Statistically best average winter recreation weeks 1994-2023 at Pinkham Notch.

March Average and Record Temperatures Across Sites

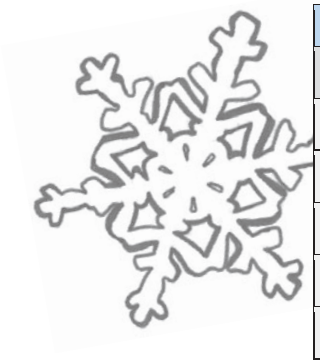


MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	54°F	-	-	-
Average High	20°F	19°F	21°F	2°F
Average	**13°F**	**12°F**	**13°F**	**1°F**
Average Low	5°F	4°F	6°F	2°F
Record Low	-38°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	78.1°F	-	-	-
Average High	35.0°F	34.2°F	36.4°F	2.2°F
Average	**25.2°F**	**24.5°F**	**26.2°F**	**1.7°F**
Average Low	15.3°F	14.8°F	16.0°F	1.2°F
Record Low	-22.9°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

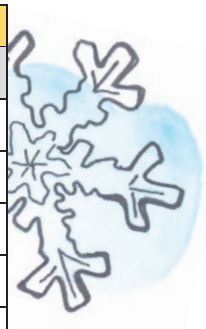


Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	82°F	-	-	-
Average High	39°F	37°F	39°F	2°F
Average	**29°F**	**28°F**	**30°F**	**2°F**
Average Low	19°F	18°F	20°F	2°F
Record Low	-17°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	85°F	-	-	-
Average High	42°F	42°F	42°F	0°F
Average	**31°F**	**31°F**	**31°F**	**0°F**
Average Low	20°F	19°F	21°F	2°F
Record Low	-22°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

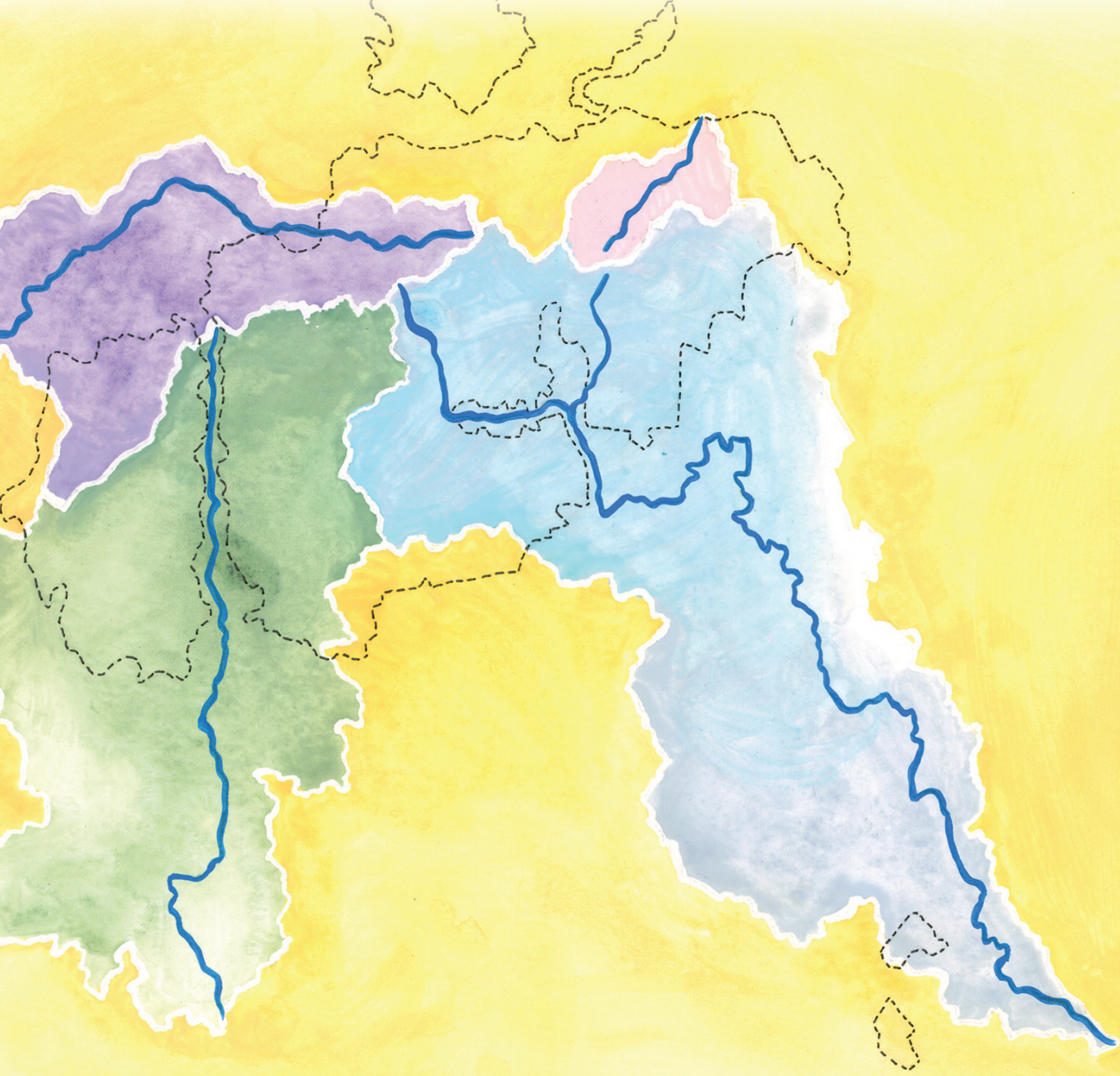


Streamflow and Spring Precipitation

In the valleys and notches of the White Mountains, it often takes several cycles of warming and chilling in a year for winter to (finally) give way to spring, despite spring's astronomical start date, otherwise known as the vernal equinox, occurring in late March. During the early vernal (spring) period, it is common to see sequences of warm days well above freezing that inspire thoughts of summertime, only for those dreams to be dashed by an arctic cold front. If these temporary periods of unseasonably warm weather (called "false springs") are long and warm enough, they can trick plants and animals into awakening from hibernation early. Once winter weather returns, the rapid swing in temperatures – winter weather whiplash – can damage plants and disrupt the activities of animals (Casson et al. 2019; Tourville et al. 2024).

As the transition to spring progresses, the snowpack that has built up over the course of the winter season starts to erode and melt away, filling up creeks, streams, rivers, and lakes. These water resources are essential for various ecological, commercial, recreational, agricultural, and municipal uses. The U.S. Forest Service estimates more than 150,000 people rely on water resources derived from the White Mountains for their drinking water (USDA, At a Glance Report: White Mountain National Forest 2018). Dependable water resources are also crucial for fishing and swimming in New Hampshire waterways. According to a BusinessNH article, tourists spent $250 million on these activities in 2023 (Merrill, 2023). Water originating as precipitation within the White Mountains likely plays a considerable role in the success of these recreational industries, and therefore a substantial portion of these economic benefits.

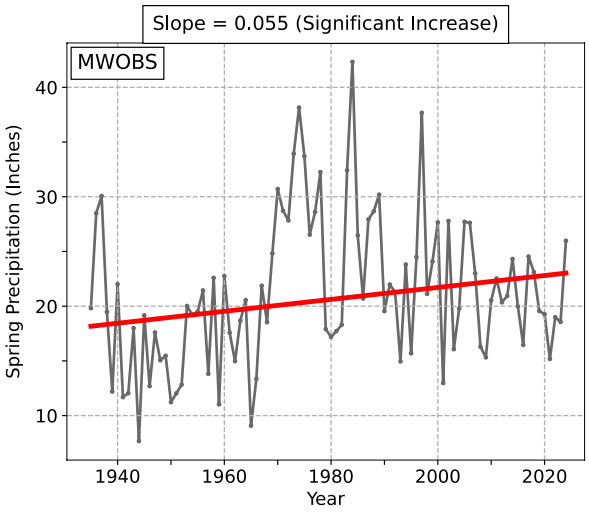
The amount and timing of peak spring streamflow is closely related to the amount of water stored within the snowpack at the end of the winter and the speed at which it melts. As discussed in previous chapters, winters are shrinking and springs are advancing earlier. While not directly related to this seasonal shift, the White Mountains are also seeing increases in overall springtime precipitation between March

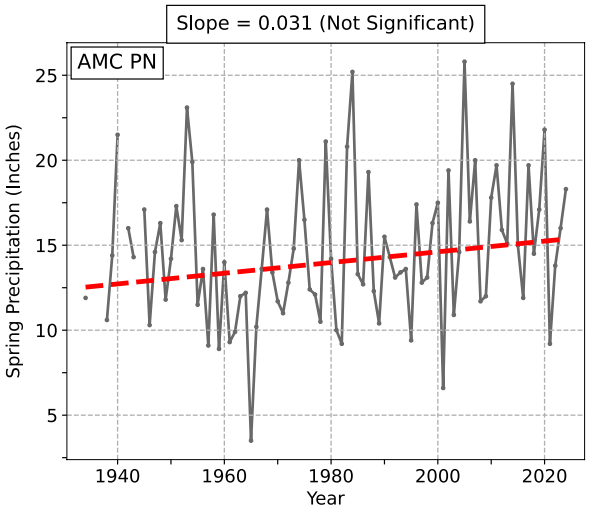


Artistic interpretation; not intended as factual representation.

Four major rivers originating in the White Mountains represent major channels for snowmelt and rain to be transported away from the mountains. Do you know what rivers these are?

1st and May 31st. We use daily precipitation observations from our three sites since the 1930s for MWOBS and Pinkham Notch and since the 1950s for Hubbard Brook. These observations include both liquid and frozen precipitation. The results are displayed in Figure 4.1.





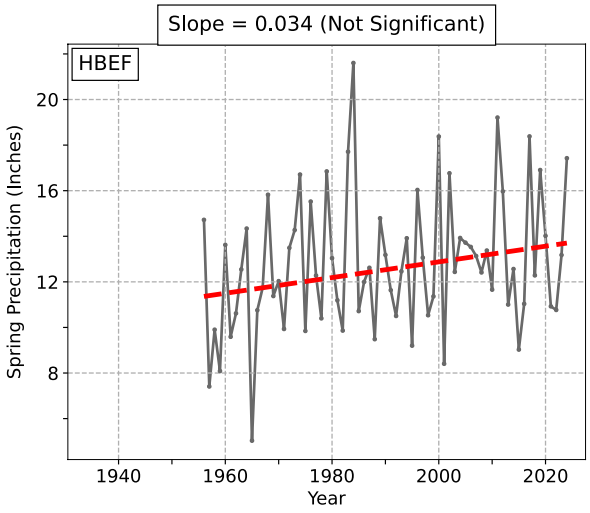


Figure 4.1. Total precipitation in inches for March 1st through May 31st by year, which includes rain and snow water equivalent, for MWOBS, Pinkham Notch, and Hubbard Brook.

The results show that MWOBS is experiencing a significant increase in spring precipitation, receiving over ½ an inch more per decade. Overall, the higher-elevations of the White Mountains are receiving about 4 more inches of spring precipitation in the 2020s than the 1940s. Hubbard Brook and Pinkham notch have marginally/less significant increases, both seeing about 1/3 of an inch more spring precipitation per decade over their respective periods of record. That means low-elevations are getting 2 to 3 inches more spring precipitation than they were 80 years ago, with an increasing proportion of this precipitation falling as rain rather than snow as established in previous chapters.

How do these changes affect streamflow amount and timing? To investigate this, we analyzed daily streamflow data from the United States Geological Survey (USGS), back to as early as the 1930s, for four major rivers (the Ammonoosuc, Pemigewasset, Saco, and Wild rivers) originating in the White Mountains (Fig. 4.2). These rivers represent major channels for snowmelt and rain to be transported away from the mountains. In general, the larger the watershed, the larger the river will be. Crucially, the locations of the stream gauges (devices or structures that measure water flow) for these rivers are situated upstream of any dams. Dams allow humans to

control streamflow for their own purposes. This makes it hard to directly compare streamflow on dammed streams to their undammed counterparts, as well as stream gauge data before and after a dam is built upstream of it.

To compare how streamflow has changed over time, we graphed and smoothed the average daily streamflow with a 9-day centered running average across the first and last 15 years of the period of record, then filled in the area in between the curves to show how it has changed over time. The results are shown in Figures 4.3 and 4.4. Red lines represent the older average, and green lines are the newer average. If red is filled in, that means the streamflow in the past was higher than the streamflow now on that day of the year, and the reverse is true if green is filled in.

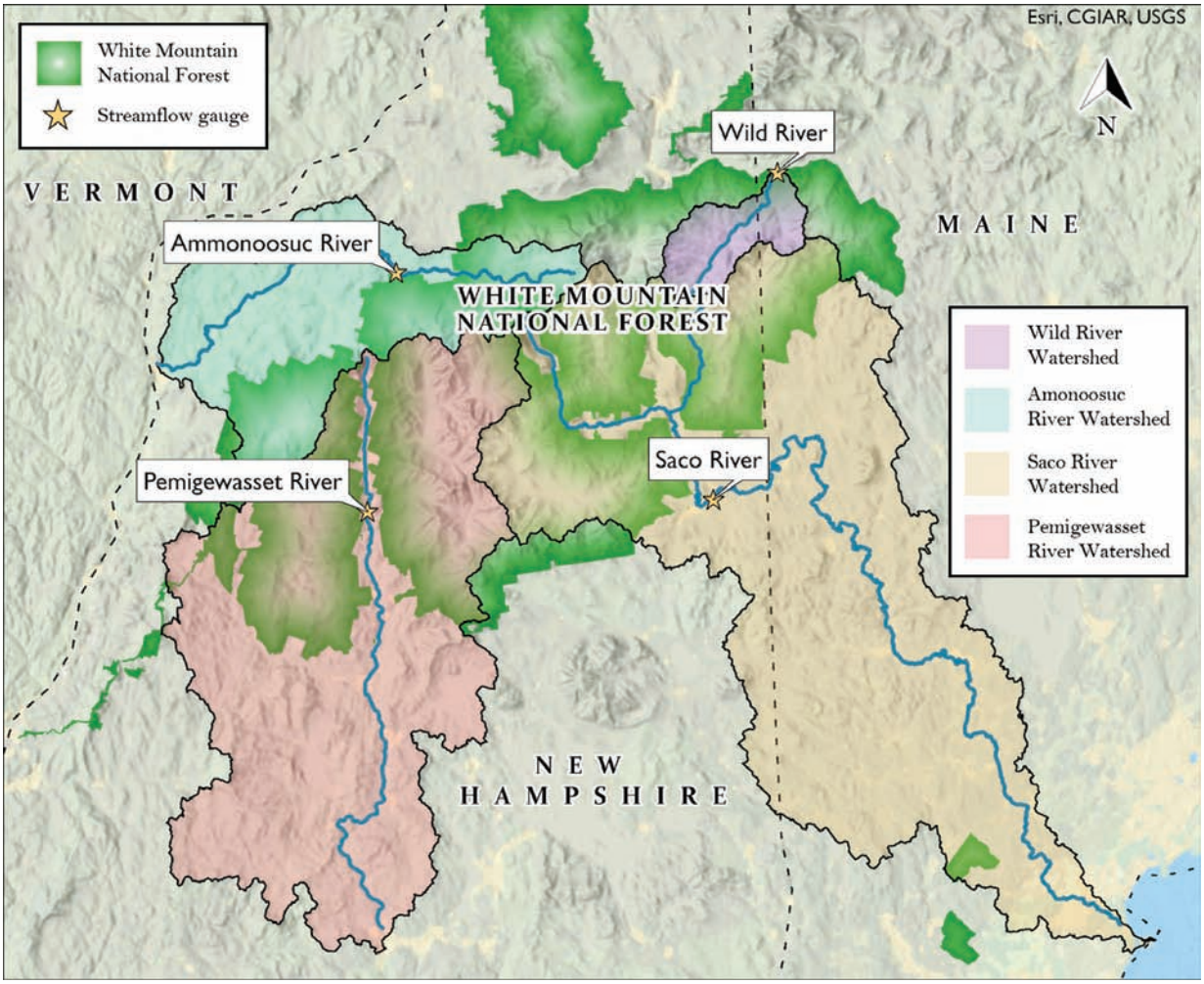
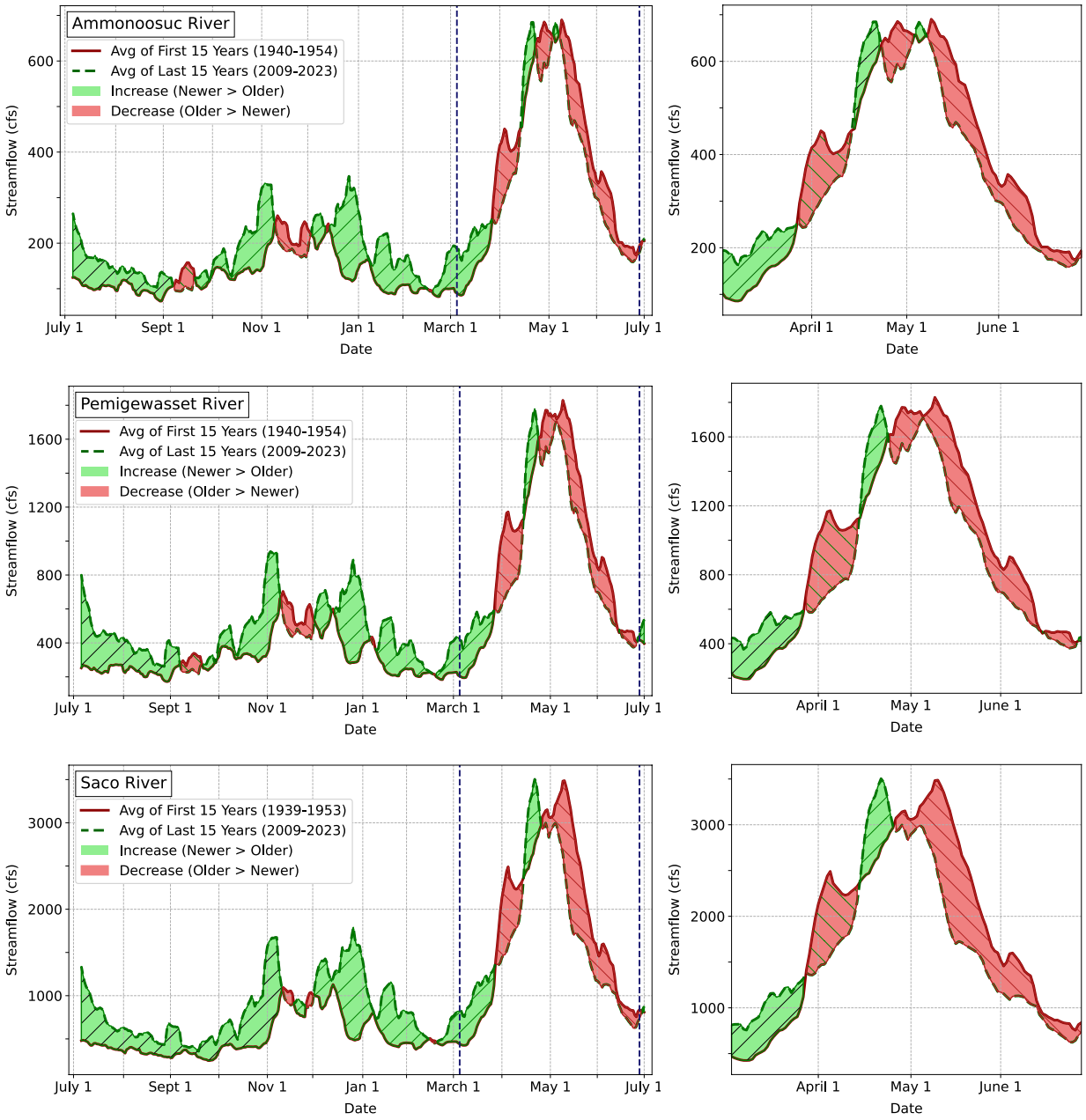


Figure 4.2. Four major rivers originating in the White Mountains (the Ammonoosuc, Pemigewasset, Wild, and Saco Rivers) their watershed boundaries, and the locations of USGS streamflow gauges (stars).

There are many interesting trends that emerge from the results, but there are two major ones that can be discerned at a glance. Across all the streams, we're seeing overall increased streamflow between July and March, and we're also seeing a shift in the timing and/or size of peak streamflow in spring. Specifically, the peak date of streamflow is occurring earlier in the spring. As shown in Figures 4.3 and 4.4, while streamflow used to peak in early May for most rivers, peak streamflow



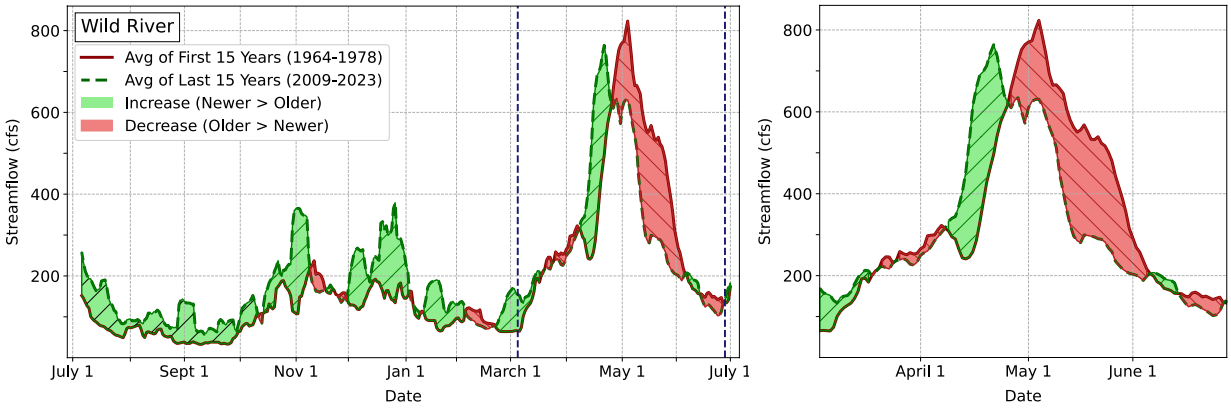


Figure 4.3 (left). Average daily streamflow (in cubic feet per second (cfs)) for the first and last 15 years of the period of record with a 9-day centered running average for four rivers originating in the White Mountains. Dashed vertical black lines indicate zoom range for Figure 4.4.

Figure 4.4 (right). Streamflow graphs from Figure 4.3 zoomed to peak streamflow season (March through June).

now happens in mid-late April. We're also missing an earlier, secondary peak that used to occur in the beginning of April.

These trends are consequential because they mean the seasonal changes in temperature and precipitation being observed in the White Mountains are directly influencing streamflow. An earlier peak date of stream-flow has both upstream and down-stream consequences. For example, water recreators, the fishing industry, and municipal drinking water companies rely on a certain amount and timing of water. Some potential good news for these parties is that annual total streamflow is increasing. This means rivers and streams have plentiful water, though the implications of how it is spread out over the year are not yet clear. Contrary to the growing number of regions in the United States (especially in the western US) that are facing water shortages, the White Mountains and regions downstream have yet to (seriously) worry about rationing water resources. As will be discussed more in *September* (pp. 68), while streamflow as a whole may be increasing, how the intensity of short-term extreme extreme wet or dry conditions are changing over time is not well understood for this region.

Still, increased precipitation and changing streamflow also present some downsides. There is anecdotal evidence, for example, that flooding is a growing concern for recreators and residents of the White Mountains. The April 2007 flooding event led to widespread damage across New Hampshire and Vermont, racking up $30.5 million in damages (Tuohy, 2017). As a result of this flooding, a Presidential Disaster Declaration was issued for some counties downstream of the White Mountains. This is not just an issue in the spring, as there have been several consequential flooding events in recent decades that have occurred other times of year. The flooding events of summer 2023 and December 18th, 2023 loom large



Weather Observers on Mount Washington collect and swap out the summit's precipitation can every six hours, as pictured here. They then bring it inside to measure liquid and mixed accumulation totals. Photo by MWOBS.

in the memories of locals. The latter event led to washed-out roads and far-reaching damage, with floodwaters up to 6 feet deep at some points on Route 175A in the western White Mountains (Hoplamazian & Allee, 2023).

Moreover, while additional precipitation may seem like an automatic benefit for the ecological health of the White Mountains, the impacts are not clear yet on how damp soil could promote growth of harmful fungi and negatively impact processes like nutrient transfer. While plants, animals, and microorganisms require water for a variety of biological processes, too much water for too long can be unhealthy. Waterlogged soils pose a particular threat to plants because they uptake air and nutrients through their roots and leaves (Akhtar and Nazir, 2013). Contrary to popular belief, plants require oxygen for cellular respiration, and if soil is waterlogged for too long, the plant may experience hypoxia (oxygen deficiency) since "oxygen transfer through water is 104-fold times slower than in air" (Akhtar and Nazir, 2013). Other studies have found that waterlogged soils and oxygen deficiency reduce the capability of roots to absorb critical nutrients like potassium ions and sodium ions (Drew and Armstrong, 2002), as well as nitrogen, phosphorus, potassium, magnesium and calcium (Smethurst et al., 2005).

There are many severe impacts of flooding, including:

- Soil erosion and sedimentation
- Infrastructure and property damage
- Loss of life and serious injury
- Crop destruction
- Habitat loss
- Waterborne diseases and contamination
- Displacement and psychological distress

April Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	60°F	-	-	-
Average High	30°F	29°F	30°F	1°F
Average	**23°F**	**23°F**	**24°F**	**1°F**
Average Low	16°F	16°F	17°F	1°F
Record Low	-20°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	86.0°F	-	-	-
Average High	47.0°F	45.9°F	48.5°F	2.6°F
Average	**37.2°F**	**36.5°F**	**38.2°F**	**1.7°F**
Average Low	27.4°F	27.0°F	27.8°F	0.8°F
Record Low	-6.2°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	91°F	-	-	-
Average High	53°F	51°F	54°F	3°F
Average	**42°F**	**41°F**	**42°F**	**1°F**
Average Low	31°F	30°F	31°F	1°F
Record Low	-2°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	92°F	-	-	-
Average High	54°F	54°F	55°F	1°F
Average	**43°F**	**42°F**	**43°F**	**1°F**
Average Low	31°F	30°F	32°F	2°F
Record Low	0°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Woodland Growing Degree Days and Phenology



In the fifth month of the year, the lower elevations of the White Mountains have thoroughly shed their icy shell and a beautiful metamorphosis occurs. True to the old adage, March winds and April showers do indeed bring May flowers. Flower enthusiasts and recreationists alike explore valleys and notches in search of blossoming buds like the Red trillium, Hobblebush, Bloodroot, and Yellow trout lily that call the region home (Fig. 5.1). So why is May the time in which flowers begin to emerge in the middle- to lower-elevations of the White Mountains? Although the question may seem to have a simple answer (i.e. it's simply warm enough), the timing of plant leaf-out and flowering is, in reality, a precarious gamble for understory plants.





Figure 5.1a - 5.1d. Woodland plants in the White Mountains. Opposite page top [right] Red trillium (*Trillium erectum*). [Opposite page bottom left] Bloodroot (*Sanguinaria canadensis*). [Above] Hobblebush (*Viburnum lantanoides*). [Left] Yellow trout Lily (*Erythronium americanum*).

May is the first month in which the average night-time lows rise above freezing in the valleys, though sporadic cold snaps still threaten to wreak havoc on delicate leaves and flowers. As described briefly in *April* (pp. 32), these false springs are common and damaging enough to pressure plants to blossom as late as necessary. Still, this is not the only environmental pressure that ground-level plants contend with: trees and large shrubs are also hungry for sunlight. These plants, after unfurling full leaves on their soaring branches, can easily choke out light to understory flowers. Thus, the low plants also have pressure to spring out earlier to maximize their window of sunlight, maximize carbon gain, and minimize competition for pollinators. Indeed, many understory plants bloom before trees do, even at the risk of severe damage from occasional cold snaps (Tourville et al., 2024).

This begs the question, how do plants know when to begin blossoming? We call

this study of the stages of plant growth 'phenology,' and growth stages themselves 'phenophases'. Seasonal changes, such as daylength, moisture, and temperature, serve as cues to plants to switch or progress through new phenophase stages.. When plants are emerging from winter dormancy (the plant equivalent of hibernation), a metric known as 'Growing Degree Days' (GDD) approximates temperature's role. The greater the accumulation of GDD, the more likely plants will begin to grow, though not all species will respond at the same rate. For many plants, this temperature threshold is freezing or 32°F, but this threshold can be higher or lower depending on the species and environmental pressures.

Knowing that springtime in the middle- to lower-elevations of the White Mountains is warming, how are accumulated GDD (aGDD) changing over time? To understand this, we used daily temperature data from Pinkham Notch dating back to the 1930s. Pinkham Notch, which sits at 2,032 feet a.s.l., can be a proxy representation of the woodland elevations of the White Mountains. Specifically, it is only slightly lower than the transition between the 'Mixed Northern Forest' zone (sea level - 3,000 feet a.s.l.) and the 'Montane Spruce-Fir' zone (3,000 - 4,000 feet a.s.l.). A sum of the GDD (aka accumulated GDD = aGDD) between February 1st and May 31st is used to encapsulate the full springtime growing season. The results are shown in Figure 5.2. The trend line shows a very significant increase, with Pinkham Notch gaining +17.2 aGDD per decade. This exact value of increasing aGDD cannot be extrapolated to all similar elevations of the White Mountains because factors like microclimate and aspect add variability to local aGDD, but it is probably safe to say that similar elevations are experiencing increasing aGDD of some magnitude. This means that woodland plants are experiencing more warmth early in their growing season than they were in the past, and thus we could see a change in spring emergence or rate of growth.

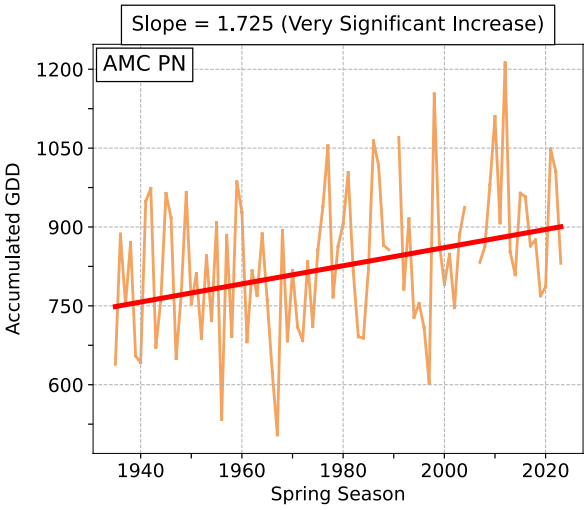
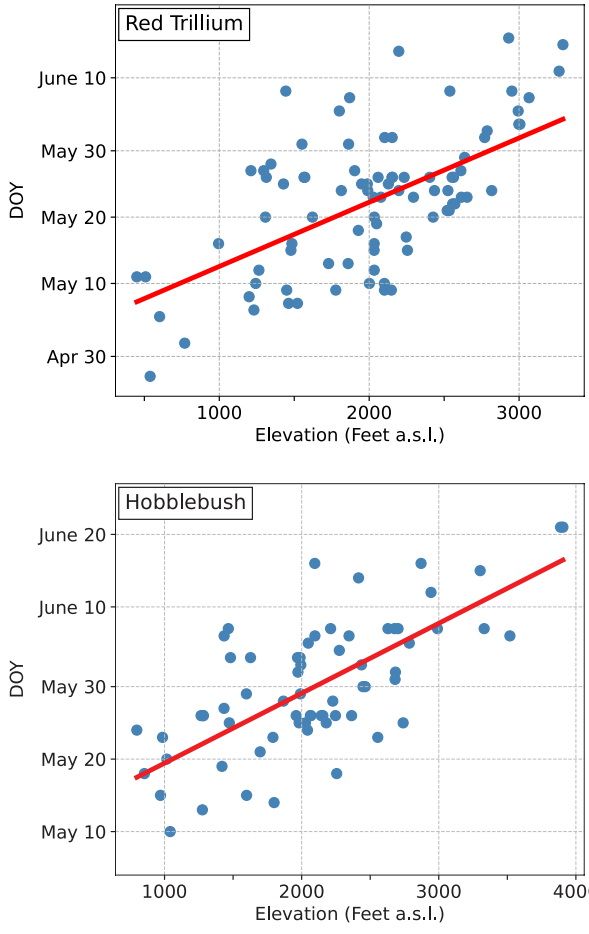


Figure 5.2. Springtime accumulated Growing Degree Days (aGDD) at Pinkham Notch using a 32F threshold.

Thanks to community-driven ecological datasets like the National Phenology Network (NPN) and iNaturalist (iNat), we also have access to information about specific stages of growth and maturity for a large assortment of plants and animals. Within these databases, there exists thousands of observations of plant phenophases ranging from spring blossoming to autumn leaf shedding. Although data from NPN and iNat do not extend far enough into the past in this region to make conclusions about how plant phenology is responding to climatological changes

(2007 and 2008 at the oldest, respectively), these data are still helpful to understand the current timing of certain phenophases, like flowering.

For this chapter, thus far, all plants growing at lower elevations in the White Mountains have been presumed to respond similarly to increasing temperatures during springtime. On the contrary, when we zoom in, plant flowering time varies substantially even at similar elevations. Using the aforementioned phenology datasets for two understory plants in the White Mountains, Red trillium and Hobblebush, we take the elevation of any given flower site and plot it against the observed day of flowering ($DOY_{flowering}$) each year. The results are shown in Figure 5.3 for the two species of interest. On average, Red trillium flowers 11.6 days later per 1000 feet (of elevation gain) and Hobblebush flowers 10.5 days later per 1000 feet in the White



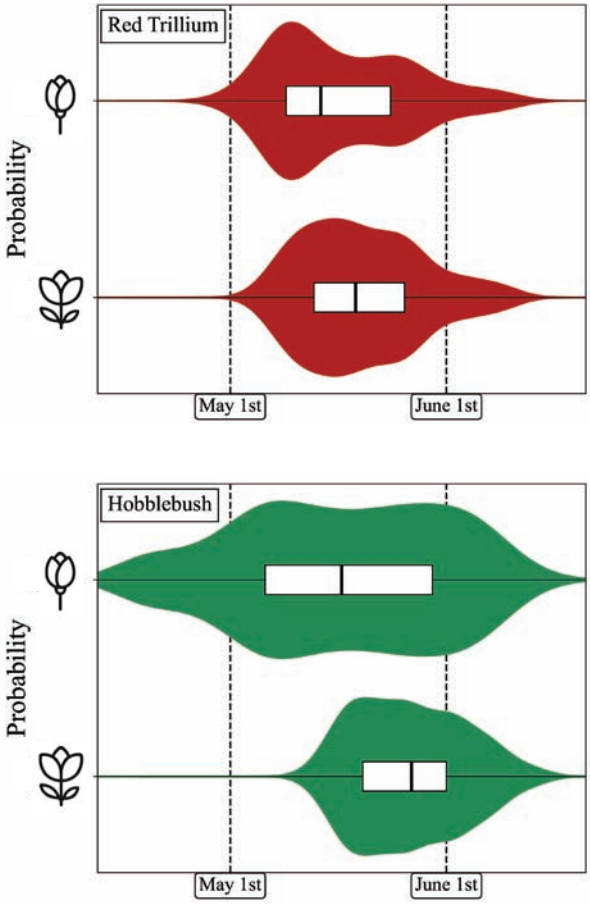


Figure 5.3 (left). Elevation vs $DOY_{flowering}$ for Red trillium and Hobblebush.

Figure 5.4 (right). Probability density and distribution of phenophases for Red trillium and Hobblebush by DOY across all elevations. Boxplots show median values for DOY (with First and Third Quartiles).

Mountains.

We also graph the probability distribution of phenophases in Figure 5.4. By taking the probability of a phenophase to occur on any day of the year, we find the distribution of budding and flowering timing. For more information on probability distribution graphs, refer to *Appendix B: Probability, Median Values and Box Plots* (pp. 94).

Mountains provide an elongated unfolding of spring, so the median date of flowering for woodland plants is highly dependent on elevation as shown in Figure 5.3. The variation in spring temperatures is also an influence. Other factors not accounted for in this data but expected to influence flowering times are snowmelt timing, aspect, soil moisture, and drainage. Still, we can find the median dates of flowering by species, as shown in Table 5.1. Half of all flowering will take place between the first and third quartile at all elevations, with dates likely a bit earlier than the median at lower elevations and a bit later than the median at higher elevations. Once again, for more information on medians and quartiles, refer to *Appendix B* (pp. 94-96).

	Red trillium		
	First Quartile	Second Quartile (Median)	Third Quartile
$DOY_{Budding}$ (Flower Buds)	May 9	May 14	May 24
$DOY_{Flowering}$ (Open Flowers)	May 13	May 19	May 26
	Hobblebush		
	First Quartile	Second Quartile (Median)	Third Quartile
$DOY_{Budding}$ (Flower Buds)	May 6	May 17	May 30
$DOY_{Flowering}$ (Open Flowers)	May 20	May 27	June 1

Table 5.1. First, Second, and Third Quartile day of year (DOY) of flowering phenophases for two woodland understory plant species (non-leap year).

May Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	66°F	-	-	-
Average High	42°F	41°F	42°F	1°F
Average	**35°F**	**35°F**	**36°F**	**1°F**
Average Low	29°F	28°F	30°F	2°F
Record Low	-2°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	90.0°F	-	-	-
Average High	61.0°F	60.3°F	62.3°F	2.0°F
Average	**49.9°F**	**49.4°F**	**50.8°F**	**1.4°F**
Average Low	38.9°F	38.5°F	39.3°F	0.8°F
Record Low	17.6°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	97°F	-	-	-
Average High	66°F	65°F	67°F	2°F
Average	**54°F**	**52°F**	**54°F**	**2°F**
Average Low	41°F	40°F	42°F	2°F
Record Low	23°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	98°F	-	-	-
Average High	68°F	68°F	67°F	-1°F
Average	**55°F**	**55°F**	**55°F**	**0°F**
Average Low	42°F	41°F	43°F	2°F
Record Low	18°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Alpine Growing Degree Days and Phenology

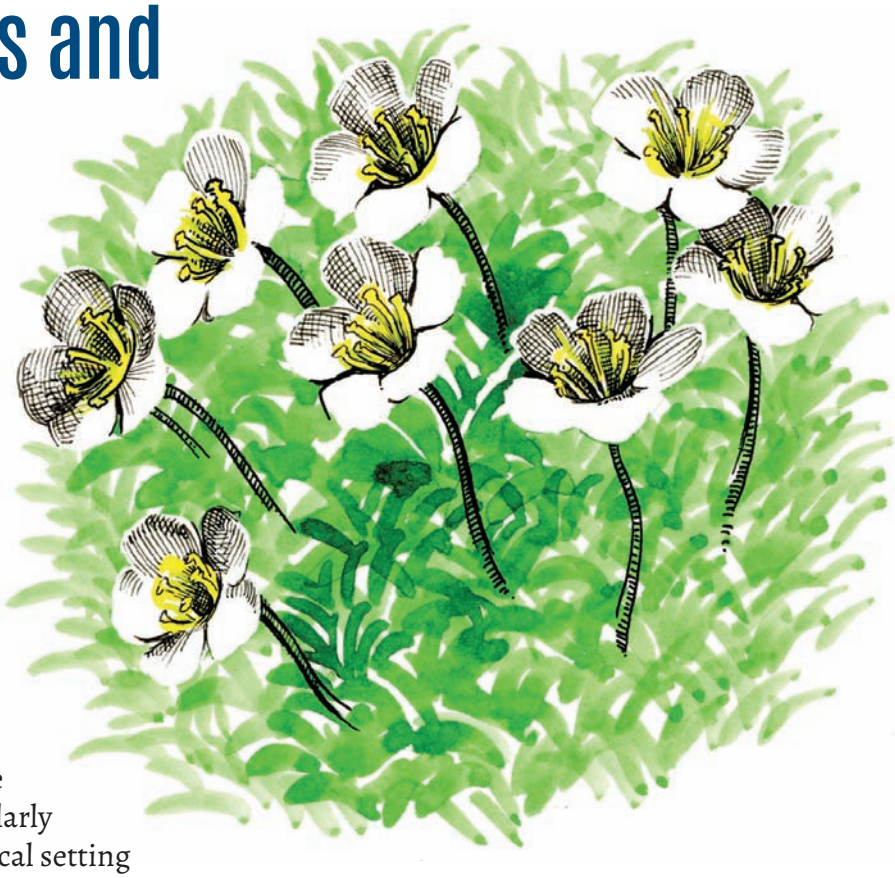


Figure 6.1a. Alpine plants in the White Mountains. Pincushion plant (*Diapensia lapponica*).

The month of June is a special time in the White Mountains, and not only because the days are long and the weather temperate. The Presidential Range is home to the largest swath of alpine tundra in the United States east of the Mississippi River (Jones et al., 2012). This makes the higher elevations a particularly unique, but fragile, ecological setting where rare plants and animals flourish. This includes specimens like the Pincushion plant (diapensia), the Alpine blueberry, Bog Labrador tea, Eastern Mountain Avens, and Moss Campion (Fig. 6.1). The latter two are extremely rare in New England and would potentially already be regionally extinct if not for the White Mountains.

While these plants don't have to compete with towering trees and shrubs above treeline, they have a shorter, colder growing season and have adapted to possess a small profile and flexible, less rigid structure compared to normal plants (Chardon et al., 2023). This means that while they can survive months covered in snow and strong winds, alpine plants are unfortunately highly susceptible to trampling. This is the reason it's important to only walk on marked

trails while exploring alpine areas in order to protect these delicate plants.

Similarly to *May: Woodland Growing Degree Days and Phenology* (pp. 40), in this chapter we investigate how the overall growing season is changing and the characteristics of phenophases for certain species. This time, it's for the higher-elevations of the White Mountains which can be called the 'Mixed Northern Forest' zone where trees are gnarled and stunted (4,000 - 4,400 feet a.s.l.) and the 'Montane Spruce-Fir' zone (4,400+ feet a.s.l.) where bare rock and low-lying plants dominate. To understand how accumulated Growing Degree Days (aGDD) are changing here, we analyzed MWOBS daily temperature data dating back to the 1930s. Since MWOBS is located adjacent to the highest point of the entire White Mountains (6,288 feet a.s.l.), the temperatures recorded at the station are not usually directly representative of those experienced at the more moderate elevations we are interested in. This is because the summit is going to generally be the coldest and windiest location on the mountain, with temperatures likely a few degrees below those measured in the majority of the alpine zone, including the Alpine Garden. Thus a threshold of 28°F was used rather than 32°F to account for the tendency of temperatures to



Figure 6.1b. Alpine blueberry (Vaccinium uliginosum).

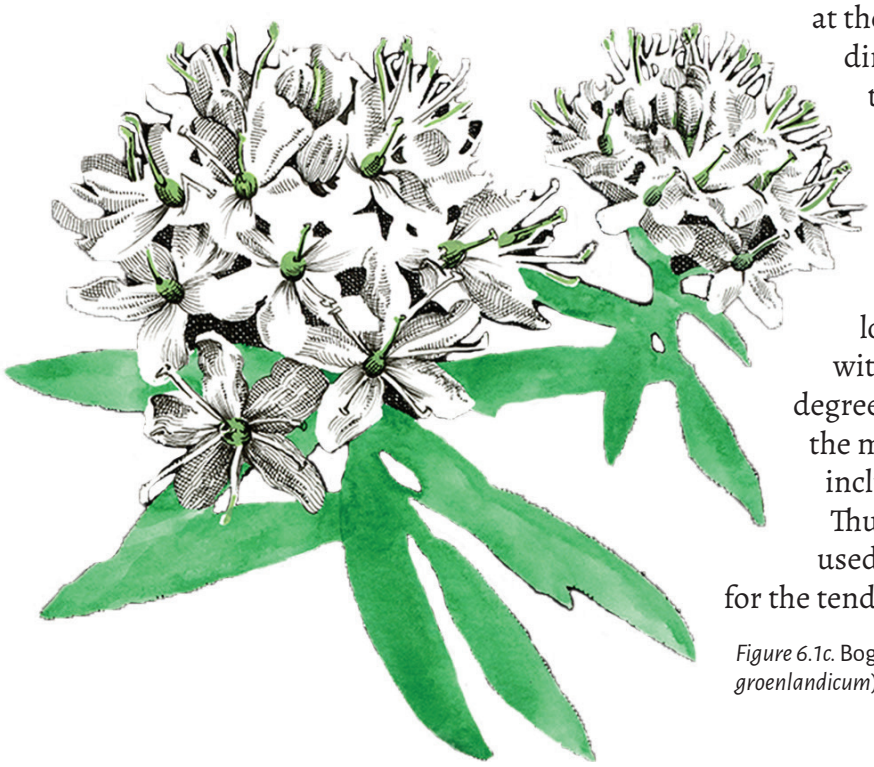


Figure 6.1c. Bog Labrador tea (*Rhododendron groenlandicum*)

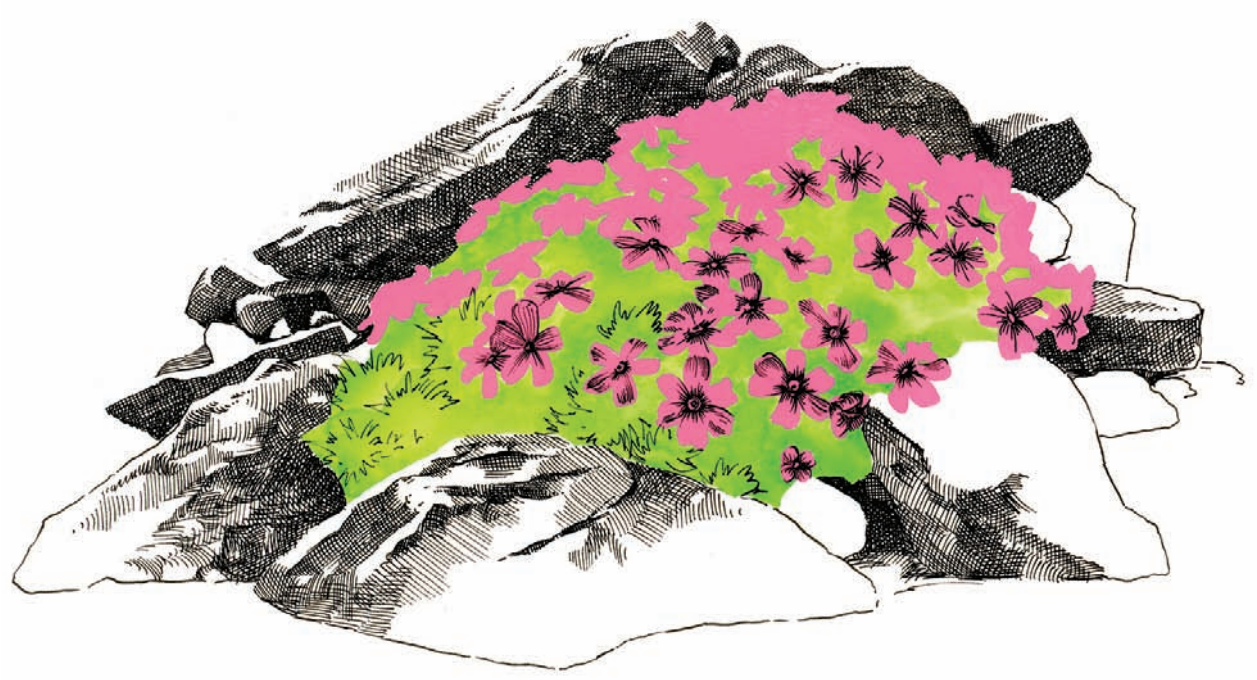


Figure 6.1d. Moss Campion (*Silene acaulis*).

decrease with increasing elevation, which is called the 'environmental lapse rate'. While the average global environmental lapse rate is considered to be 3.6°F per 1000 feet, research conducted on Mount Washington by MWOBS shows that the local lapse rate in the late spring and summer is actually closer to 6.0°C per kilometer or ~3.3°F per 1000 feet (Hawkins et al., 2024). We use the Alpine Garden as the representative elevation we're interested in, and since it's around 5,000 feet a.s.l., the summit is about 4°F colder on average than the Alpine Garden. We calculated the aGDD between April 1st and June 30th to encapsulate the entire springtime growing season.

The results are shown in Figure 6.2. The trend here is also very significant, and it is similar to increases seen at lower elevations; aGDD is increasing at a rate of +13.7 per decade. While on the surface this may seem beneficial for alpine plants because it allows them a potentially longer growing season, this is likely detrimental in the long run. This is because these plants are specially adapted to cool alpine zones, and rapid increases in temperature may change the environment too quickly to allow adaptation. To this end, as aGDD continues to increase, all ecological zones could move upwards in elevation, such that the Mixed Northern Forest and Montane Spruce-Fir Zones would shrink. Other species adapted to the newly warmer temperatures would out compete native alpine plants, further threatening their existence in the White Mountains.

Community-driven ecology datasets like NPN and iNat also have observations for

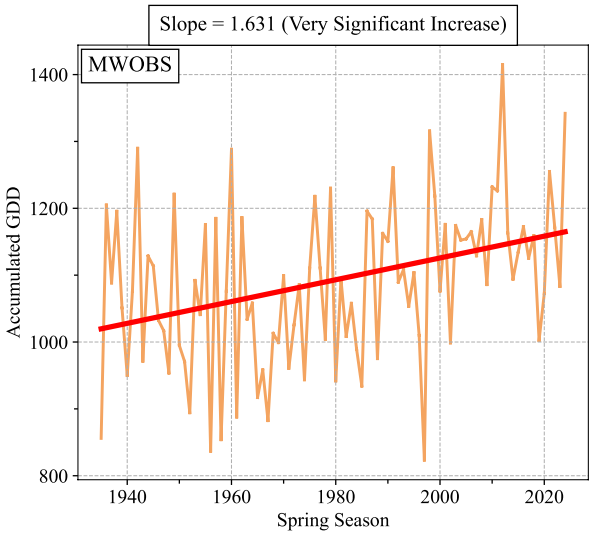


Figure 6.2. Springtime accumulated Growing Degree Days at MWOBS using a 28°F threshold.

alpine vegetation in the White Mountains. The phenophases of three alpine species (Pincushion plant, Alpine blueberry, and Bog Labrador tea) are analyzed using analogous methods described in the previous chapter. In Figure 6.2, the elevation of vegetation sites is plotted against the observed day of flowering ($DOY_{Flowering}$). In contrast to the lower-elevation plants, there is a very weak relationship between increasing elevation and $DOY_{Flowering}$ for alpine plants (aside from Bog Labrador tea which grows at an extensive range of elevations).

We plot the probability distribution of alpine flowers in Figure 6.3. For more information on probability distribution graphs, refer to *Appendix B* (pp. 96). It can also be seen that, dissimilar to lower-elevation plants, alpine budding and flowering occurs in a large temporal window.

Although slightly dependent on species, the



Rhododendron (purple) and Diapensia (white) blooming by Ball Crag with undercast in the background. Photo by MWOBS.

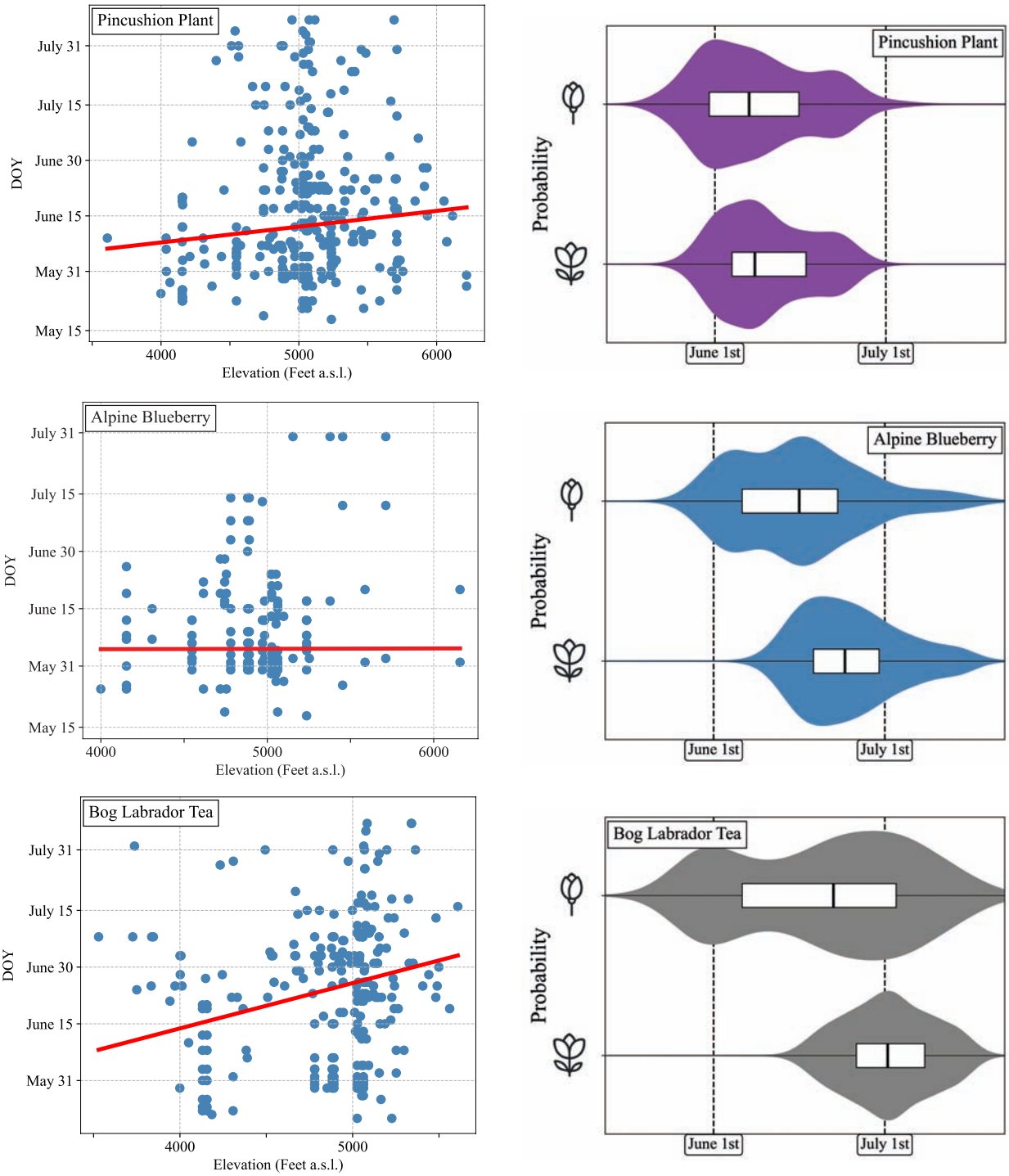


Figure 6.3 (left). Elevation vs $DOY_{Flowering}$ for Pincushion plant, Alpine blueberry, and Bog Labrador tea.

Figure 6.4 (right). Probability density and distribution of phenophases for Pincushion plant, Alpine blueberry, and Bog Labrador tea by DOY (elevation 3500 feet a.s.l.). Boxplots show median values for DOY (with First and Third Quartiles).

	Pincushion plant (diapensia)		
	First Quartile	Second Quartile (Median)	Third Quartile
$DOY_{Budding}$ (Flower Buds)	May 31	June 7	June 16
$DOY_{Flowering}$ (Open Flowers)	June 4	June 8	June 17
	Alpine blueberry		
	First Quartile	Second Quartile (Median)	Third Quartile
$DOY_{Budding}$ (Flower Buds)	June 6	June 16	June 23
$DOY_{Flowering}$ (Open Flowers)	June 19	June 24	June 30
	Bog Labrador tea		
	First Quartile	Second Quartile (Median)	Third Quartile
$DOY_{Budding}$ (Flower Buds)	June 6	June 22	July 3
$DOY_{Flowering}$ (Open Flowers)	June 26	July 1	July 8

Table 6.1. First, Second, and Third Quartile DOY of flowering phenophases for three alpine plant species (non-leap year).

	Red trillium		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Fruit} (Ripe Fruit/Seeds)	July 21	Aug 6	Aug 12
DOY_{Drop} (Fruit/Seed Dispersal)	Aug 18	Aug 23	Aug 24
	Hobblebush		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Fruit} (Ripe Fruit/Seeds)	Aug 3	Aug 29	Sept 14
DOY_{Drop} (Fruit/Seed Dispersal)	Aug 12	Sept 13	Sept 21

Table 6.2. First, Second, and Third Quartile DOY of fruit/seed phenophases for two woodland understory plant species (non-leap year).

date of flowering spans mid-June to early July. The exact median dates can be found in Table 6.1. Once again, for more information on medians and quartiles, refer to Appendix B (pp. 94-96).

On the previous page and below, we also include information regarding fruit-related phenophases for both woodland (Table 6.2) and alpine plants (Table 6.3). Ripe fruit is present and seeds are dropped around August for most understory plants in the White Mountains: Take particular note of phenophases for species like the Alpine blueberry, which produce berries that recreators appreciate as a quick and nutritious snack in the higher elevations.

	Pincushion plant (diapensia)		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Fruit} (Ripe Fruit/Seeds)	June 24	July 21	Aug 3
DOY_{Drop} (Fruit/Seed Dispersal)	July 25	Aug 2	Aug 19
	Alpine blueberry		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Fruit} (Ripe Fruit/Seeds)	Aug 1	Aug 11	Aug 22
DOY_{Drop} (Fruit/Seed Dispersal)	Aug 12	Aug 24	Sept 3
	Bog Labrador tea		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Fruit} (Ripe Fruit/Seeds)	July 20	July 31	Aug 13
DOY_{Drop} (Fruit/Seed Dispersal)	July 18	July 31	Aug 17

Table 6.3. First, Second, and Third Quartile DOY of fruit/seed phenophases for three alpine plant species (non-leap year).

June Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	72°F	-	-	-
Average High	51°F	51°F	51°F	0°F
Average	**45°F**	**45°F**	**46°F**	**1°F**
Average Low	39°F	38°F	40°F	2°F
Record Low	8°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	91.0°F	-	-	-
Average High	69.2°F	69.0°F	70.2°F	1.2°F
Average	**58.7°F**	**58.4°F**	**59.5°F**	**1.1°F**
Average Low	48.3°F	47.8°F	48.7°F	0.9°F
Record Low	26.1°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

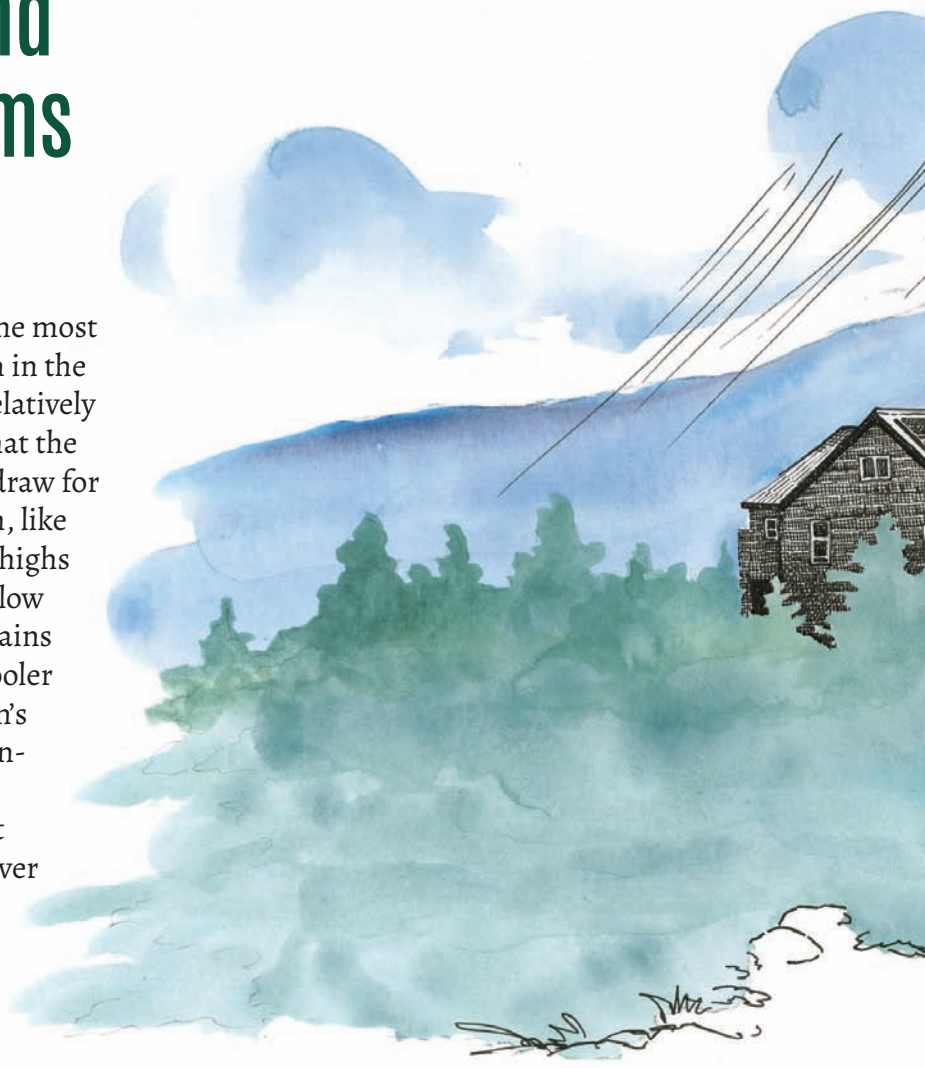
Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	99°F	-	-	-
Average High	74°F	73°F	75°F	2°F
Average	**62°F**	**61°F**	**63°F**	**2°F**
Average Low	50°F	48°F	51°F	3°F
Record Low	27°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	102°F	-	-	-
Average High	76°F	77°F	76°F	-1°F
Average	**64°F**	**63°F**	**64°F**	**1°F**
Average Low	52°F	50°F	53°F	3°F
Record Low	29°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Rain, Hail, and Thunderstorms



Summer is far and away the most popular time for tourism in the White Mountains. The relatively mild summer weather that the region is known for is a draw for many. While cities to the south, like Boston, soar to balmy average highs of 82°F in July, the middle and low elevations of the White Mountains will be between 5°F and 10°F cooler on average. Mount Washington's summit is even cooler, experiencing average highs of only 55°F in July. In fact, the highest temperature the summit has ever recorded is 72°F, which was initially reached on August 2, 1975 and was then tied on June 26, 2003. For more information on average and extreme temperatures, see *Appendix C: Averages and Extremes (pp.96)*.

Visitors come from far and wide to escape the summer heat while enjoying recreation ranging from hiking to swimming and more. One often overlooked aspect of summer, however, is that it opens the door to severe storms which can result in heavy rainfall, hail, and frequent lightning. This is especially pertinent to keep in mind while in alpine terrain because mountainous terrain presents more risk to severe weather (especially lightning).



Why should you be more aware of lightning while in mountainous terrain? Mountains can alter the airflow around them in such a way to force it to rise or serve as triggers to initiate thunderstorms. Moreover, mountains, especially mountaintops, are located closer to the bottom of the cloud layer, meaning mountains can act as giant lightning rods. In general, there are a few tips that you should keep in mind while in mountainous terrain during thunderstorm season:

Always check the weather forecast before you go.

This will give you a good idea if severe weather like thunderstorms are likely or possible. Always know where the nearest safe structure is and how long it may take you to get there.

If you want to hike within the alpine zone and storms are forecasted, try to plan to be below the treeline by noon.

Mountaintops, especially those reaching above treeline, are among the most dangerous places to be when lightning is possible because you are closest to the cloud layer. Electricity takes the path of least resistance, and air is generally more resistant than rocks, trees, and people. In general, thunderstorms are much more likely to form in the afternoon but this is not always the case, so always stay vigilant.

Nowhere outside is completely safe when thunderstorms are in the area.

That being said, even though being below treeline is better than being on bare peaks, nowhere outside is completely safe when lightning is possible.

If you hear thunder, take immediate precautions to avoid lightning strikes.

Lightning can strike more than three miles from the core of the thunderstorm. "Bolts from the blue", while rare, can strike areas > 25 miles away from the thunderstorm, much greater than the roughly 10 mile distance at which thunder can be heard from a nearby lightning strike. When you hear thunder, immediately move to safe shelter: a substantial building with electricity or plumbing or an enclosed, metal-topped vehicle with windows up. Stay in the shelter at least 30 minutes after you hear the last sound of thunder.

If you cannot make it to a shelter, there are still steps you can take to mitigate your risk.

- Immediately get off elevated and exposed areas such as hills, mountain ridges, or peaks
- Never lie flat on the ground
- Never shelter under an isolated tree or rocky overhang/cliff
- If you are boating or swimming, get to land immediately
- Stay away from objects that conduct electricity (barbed wire fences, power lines, windmills, etc.)
- Still, seeking shelter is the best way ensure your safety

If someone with you is struck, check if they have a pulse and call 9-1-1 or find help.

Cardiac arrest is the primary cause of death from lightning. Begin CPR if you are trained. If possible, move yourself and the victim to a safer place. Lightning can strike more than once in the same place.

Infographic Citations: (NWS Blacksburg, VA, Outdoor Activities: Lightning Safety and Preparedness) (NWS, Lightning tips 2025) (NWS, Lightning safety)

An unfortunate trend that has appeared in the White Mountains is that certain kinds of severe weather events are becoming more common, lasting longer, or becoming more intense. The Mount Washington Observatory has been noting the presence and duration of weather events, like thunderstorms, down to the minute since 1935. To be recorded as a thunderstorm, either the observer on duty must have heard thunder, or lightning was detected or otherwise observed within 10 miles of the station. A thunderstorm is defined to have ended 15 minutes after the last peal of thunder, or the last lightning flash meeting the above criteria occurred. Hail and rain events are similarly recorded, although with less emphasis on sound-based observations.

Using this data, subsetted between June 1st and September 30th, we investigated how the frequency and duration of severe weather events is changing. We use two metrics to consider thunderstorm trends: thunderstorm days and event durations. A day is categorized as a 'thunderstorm day' if thunder is reported any time during the 24-hour period between sunrises which were calculated specifically for the latitude of Mount Washington. 'Thunderstorm event duration' is the total number of minutes thunderstorms were observed on the summit in accordance with the above criteria. Thunderstorm days and minutes were then summed for each summer season and graphed over time (Fig. 7.1).

Both thunderstorm days and minutes are increasing very significantly. Thunderstorm days are increasing by 0.58 days per decade and the duration of thunderstorms are increasing by 45 minutes per decade. This means that there are four to five more days with thunder in summer in the 2020s than



Lightning to the southeast over the Stage Office. Photo by MWOBS.

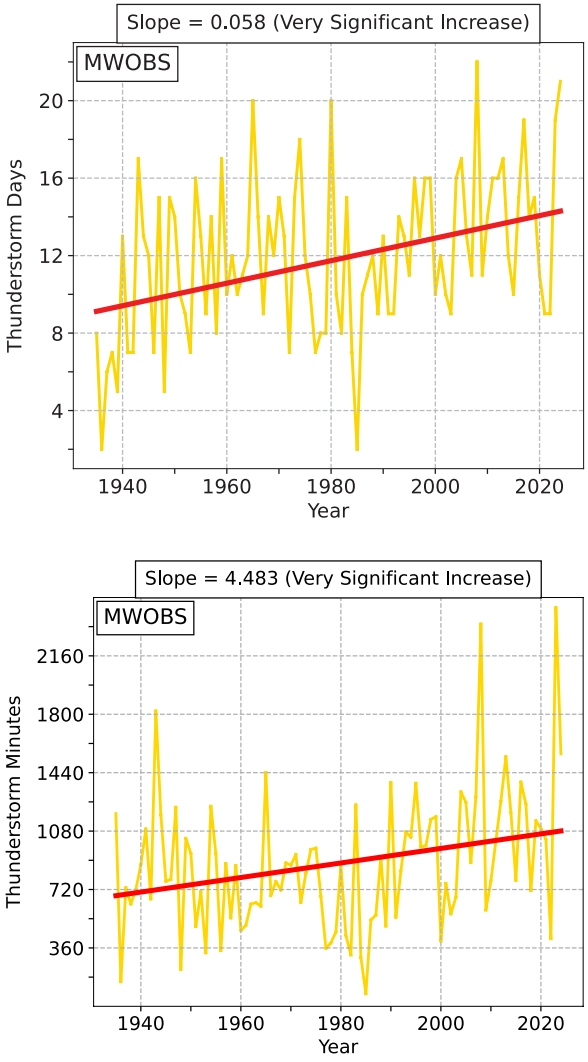


Figure 7.1. Summer days (June 1st through September 30th) with reported thunderstorms (top) and summer thunderstorm minutes (bottom) at MWOBS.

there were in the 1930s, and there are over 400 more summer thunderstorm minutes (over 6.5 hours) in the 2020s than there were in the 1930s. The summer of 2008 had the highest number of thunderstorm days on record since 1938, with thunder being reported on 19% of its days (or one thunderstorm every five days).

Luckily, there appears to be no significant increase in hail days or hail minutes in the higher elevations of the White Mountains (Fig. 7.2). Since, however, hail is usually a more localized type of weather event, it is plausible hail event frequency could be changing at lower elevations, but there was not enough data to know for sure. Rain days and minutes were also not significantly changing.

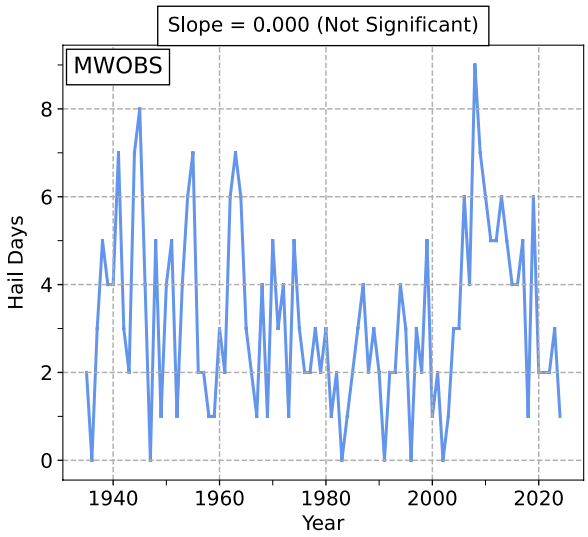
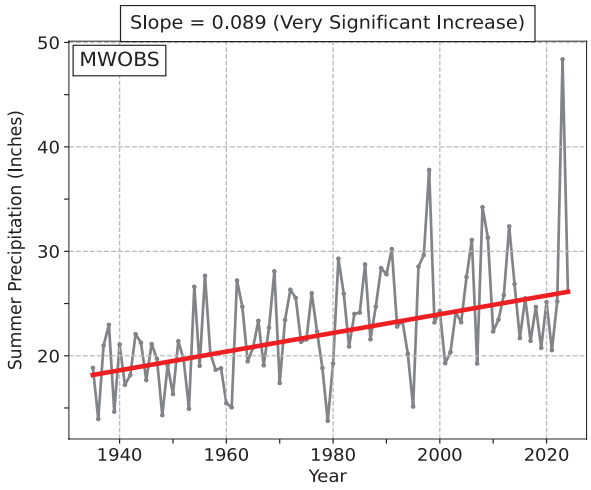
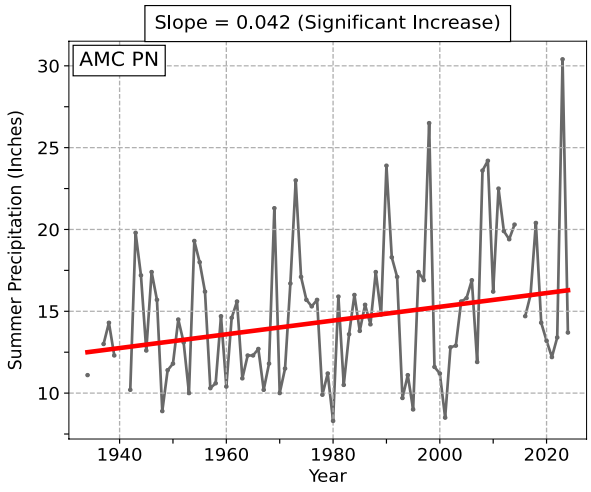
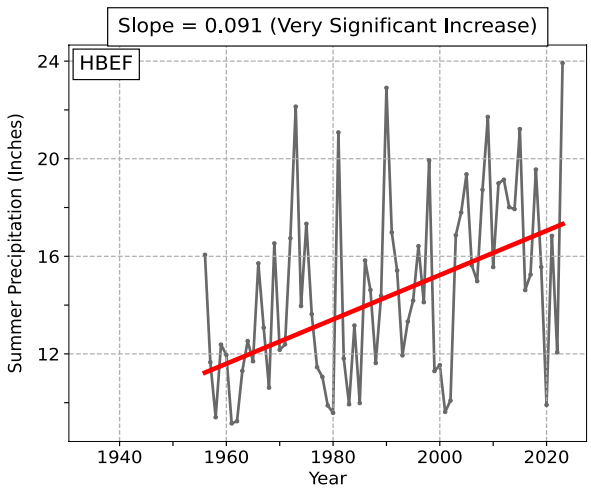


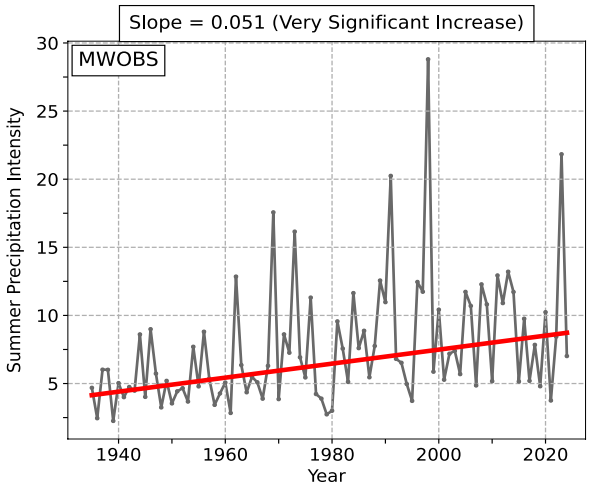
Figure 7.2. Summer days (June 1st through September 30th) with reported hail at MWOBS.

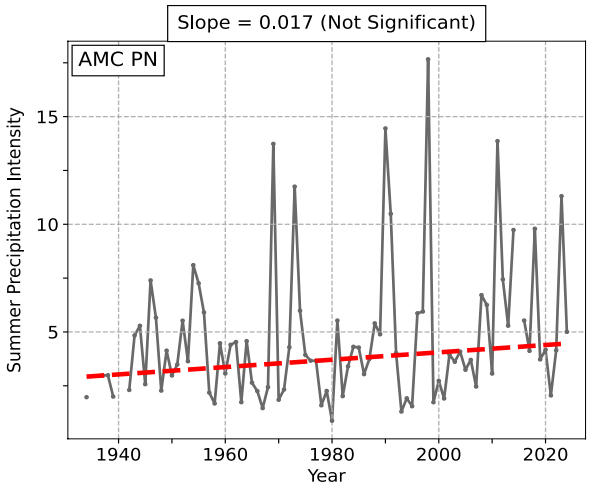
Summers are definitively becoming rainier in other ways, though. Although the number of days with rain is not increasing significantly, more total summer precipicipitation is falling (Fig. 7.3). Another way to measure how precipitation is changing is to look at event "intensity". This is similar to the precipitation amount, but it takes into account how much precipitation falls per day. Storms that amount to less than 6 inches of precipitation were given a lower











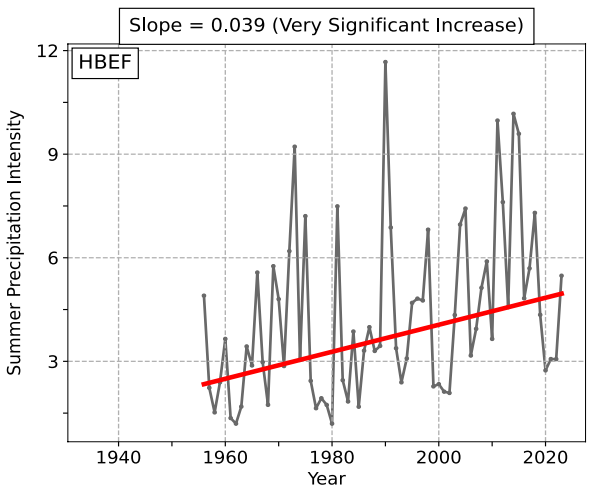


Figure 7.3. (left). Summer days (June 1st through September 30th) with reported hail at MWOBS.
Figure 7.4. (right). Summer precipitation intensity for MWOBS, Pinkham Notch, and Hubbard Brook.



Lightning on Wildcat B

score, while events larger than 6 inches are given a maximum score*. The data used for this analysis are daily liquid precipitation totals from MWOBS and Pinkham Notch back to the 1930s, and Hubbard Brook back to the 1950s between June 1st and September 30th. Plotting this for each summer season, we show how summer precipitation is changing in the White Mountains (Fig. 7.4).

In contrast to previous patterns between sites, MWOBS and Hubbard Brook are the sites experiencing very significant increases in both precipitation and intensity while Pinkham Notch is only seeing a significant increase in precipitation and no significant change in intensity. MWOBS, Pinkham Notch, and Hubbard Brook are receiving an additional 1.2 inches, 0.5 inches, and 1.0 inches of precipitation each decade respectively. The increases in intensity at these sites mean that more summer precipitation is falling within the same timespan, so although precipitation days aren't becoming significantly more common, days with rain are rainier.

Equations for precipitation intensity calculations can be found in the Endnotes for July (pp. 98).

July Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	71°F	-	-	-
Average High	55°F	55°F	55°F	0°F
Average	**49°F**	**49°F**	**50°F**	**1°F**
Average Low	44°F	43°F	45°F	2°F
Record Low	24°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	92.1°F	-	-	-
Average High	74.0°F	73.7°F	75.2°F	1.5°F
Average	**63.6°F**	**63.2°F**	**64.5°F**	**1.3°F**
Average Low	53.2°F	52.6°F	53.9°F	1.3°F
Record Low	33.1°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	99°F	-	-	-
Average High	79°F	78°F	79°F	1°F
Average	**67°F**	**66°F**	**68°F**	**2°F**
Average Low	55°F	53°F	56°F	3°F
Record Low	36°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	100°F	-	-	-
Average High	81°F	81°F	81°F	0°F
Average	**69°F**	**68°F**	**70°F**	**2°F**
Average Low	57°F	55°F	58°F	3°F
Record Low	33°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Summer Recreation Days



The White Mountains offer a plethora of outdoor activities in the summertime. One can look forward to hiking, camping, biking, ziplining, and countless other activities on land. Several more can be found in the water, including tubing, kayaking, swimming, and fishing. Within the nearly 148,000 acres of territory in the White Mountain National Forest there are over 1,200 miles of hiking trails (Forest Service, *White Mountain National Forest - Recreation Opportunities*), AMC's High Mountain Huts (AMC, *High Mountain Huts of the White Mountains* 2025), numerous frontcountry and backcountry campsites including (23 NH State Park campgrounds), and hundreds of lakes, rivers, and creeks. The possibilities are almost boundless.

As noted in *July: Rain, Hail and Thunderstorms* (pp. 54), summers in the White Mountains are changing. Although the White Mountains aren't warming up as much as adjacent lower elevation regions, temperatures in the summer are still increasing across the board. One way to show this is to compare a station's mean temperature over its first 30 years against its most recent 30 years. For example, AMC's Pinkham Notch Visitor Center has seen temperatures rise 1°F in early summer



and 3°F in late summer over its 90-year history. For more information on annual temperature changes, see the *Appendix C* (pp. 96). Combined with more thunderstorm days and increasing precipitation amounts, these changes imperil the precious recreation days that so many enjoy during the summer. So, how are summer recreation days evolving in response to these changes in weather patterns?

Just like in *March: Winter Recreation Days* (pp. 26), we will be defining what makes a good summer recreation day. Unlike recreation days in winter, however, summer recreation days are more challenging to define because there are many disparate types of activities that may stipulate contrary weather conditions. For example, while hiking in 100°F temperatures would be categorically terrible and pose an increased risk of heatstroke, most would agree swimming in the same temperature would be fitting (assuming you wear sunblock). Here, we will be considering recreation days that align more with the former, i.e. hiking, biking, camping, and other pastimes that have an upper threshold for temperature and would be adversely affected by or canceled due to thunder, hail, and rain*.

Excessively high temperatures are not just uncomfortable, they can quickly become dangerous. The National Weather Service recommends caution be taken outdoors any time the temperature is above 80°F, and that extreme caution should be taken when temperatures rise above 90°F (NWS, *What is the Heat Index?* 2023). The heat you feel from hot air is compounded by how much water is in the air, which we call humidity. A high

Individual Metric	*Scoring*
Daily Max Temperature Score	1 Point for 45°F≤ T_{max}≤75°F Drops off to 0 Points at 32°F and 103°F
Inclement Weather (IW) Score	Score based on amount of daytime in which unfavorable weather is present Weight* [Duration of weather/Total day time] Thunder Event Weight = 2.0 Hail Event Weight = 1.5 Rain Event Weight = 1.0
Summer Recreation Score (SRS)	Temperature Score - IW Score***

Table 8.1. Summer recreation scoring metrics.



** The reader should keep in mind that the definitions here are only generalized parameters, and a more complete picture of how recreation days are changing in the summer may also take into account other types of severe weather and wind.*

*** The full details of this methodology can be found in the Endnotes section for August (pp. 99)*

****Minimum of SRS of 0*

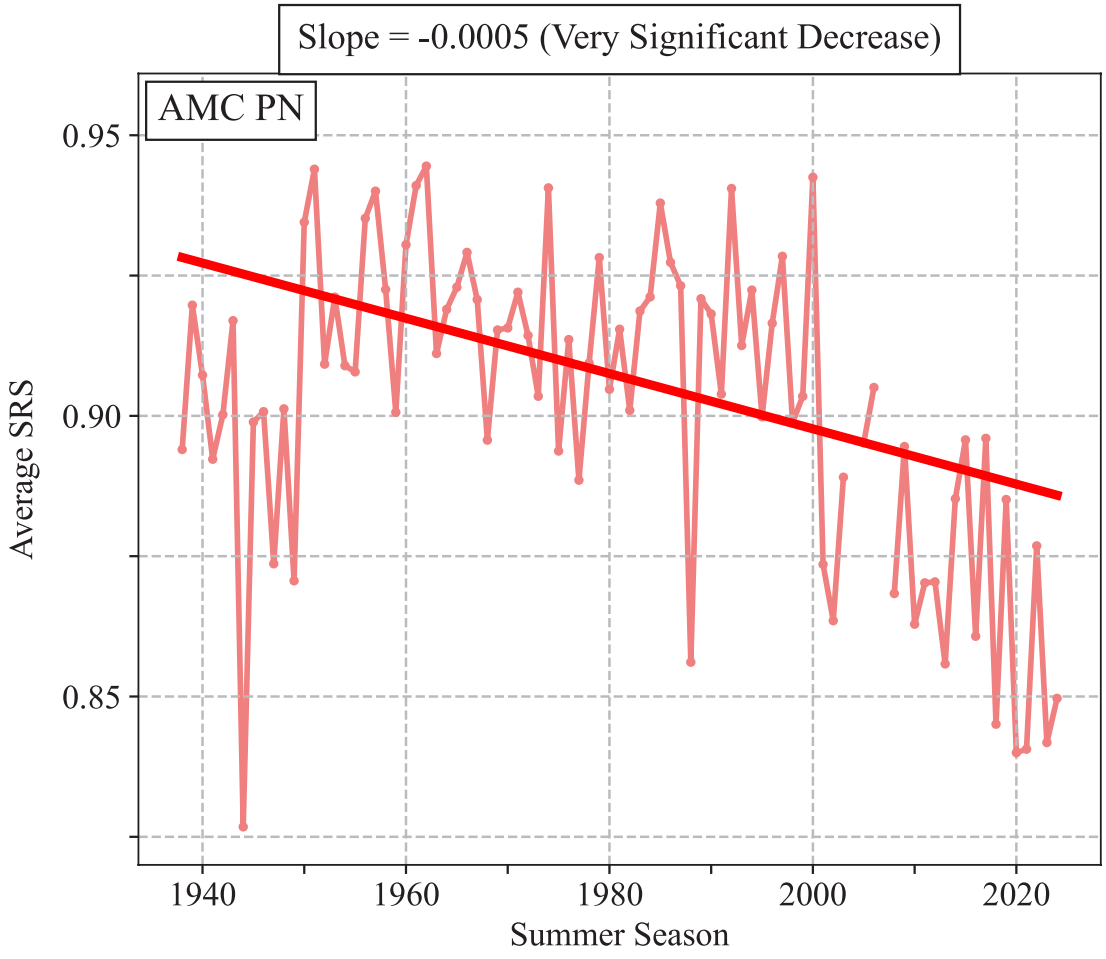


Figure 8.1. Average SRS between June 1st and September 10th by year at AMC PN. Scores close to 1 indicate near-ideal conditions for outdoor recreation, while scores closer to 0 indicate much more unfavorable weather conditions.

humidity day will feel much hotter than a low humidity day. Humidity data for the lower-elevations of the White Mountains is unfortunately meager, so it was not considered. Without taking into account humidity, we can still grade summer recreation days.

We will give a day a summer recreation score (SRS) of '1', the highest possible score, if the daily maximum temperature is below 75°F and does not experience thunder, hail, or rain (Table 8.1)**. SRS scores are reduced if the temperature is too hot or cold and based on the proportion of day time which experiences adverse weather conditions. This is done using similar methods used in *July* (pp. 46) by dynamically calculating day length and weighing more dangerous weather events (like thunder) to be more detrimental. Most days will have an SRS less than 1, but scores will generally be higher in this chapter compared to those in *March* (pp. 26). Daily temperature observations since

1938 between June 1st and September 10th recorded at Pinkham Notch and weather observations from MWOBS taken every minute were used for this analysis. As for winter recreation days, Pinkham Notch data is used because it represents a broad variety of elevations in the White Mountains and the data is robust. When this scoring system is applied to every day with observations, we calculate long-term trends in summer recreation days (Fig. 8.2).

The trendline shows a very significant decrease. While the change of SRS seems small (only -0.0049 per decade), the White Mountains have lost 0.04 average SRS over the period of record, a 4.9% drop. This is much less than the 18% decrease that winter recreation days have experienced, but it equates to five less days of ideal recreation days over the course of the summer. The year with the highest average SRS was 1962, and the years with the lowest average SRS in recent years were 2020 and 2021, noted for being especially warm and rainy summers. In the summer of 2020, 57% of days (or every other day) had rain and 11% (or once every ten days) had lightning. Take note of the 1940s as well; the earlier part of this decade was characterized by particularly hot and rainy conditions, a noticeable departure from the immediately following decades. The summer of 1944 was likely particularly unpleasant as that summer had the lowest average SRS for the whole record, with 49% of days that summer experiencing rain and 21% of days having high temperatures above 80°F.

Best Summer Recreation Weeks
Aug 24 - Aug 30
Aug 31 - Sept 6
June 1 - June 7
Sept 7 - Sept 13
Aug 17 - Aug 23
June 15 - June 21
Aug 10 - Aug 16
July 27 - Aug 2
July 8 - July 14
Aug 3 - Aug 9

Table 8.2. Statistically best average summer recreation weeks 1994-2023 at AMC PN.

August Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	72°F	-	-	-
Average High	53°F	53°F	54°F	1°F
Average	**48°F**	**47°F**	**49°F**	**2°F**
Average Low	42°F	42°F	44°F	2°F
Record Low	20°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	92.3°F	-	-	-
Average High	72.6°F	72.0°F	74.0°F	2.0°F
Average	**62.0°F**	**61.2°F**	**63.2°F**	**2.0°F**
Average Low	51.4°F	50.4°F	52.3°F	1.9°F
Record Low	30.9°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	97°F	-	-	-
Average High	77°F	76°F	78°F	2°F
Average	**65°F**	**64°F**	**66°F**	**2°F**
Average Low	53°F	52°F	55°F	3°F
Record Low	32°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	103°F	-	-	-
Average High	79°F	79°F	79°F	0°F
Average	**67°F**	**66°F**	**68°F**	**2°F**
Average Low	55°F	53°F	56°F	3°F
Record Low	26°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Drought and Tropical Cyclones



Coming off the heels of summer in the White Mountains, September represents the mirror to the spring shoulder months. This means that while September is still warm and wet like other summer months, the evolution to autumn has begun. For New England, one of the main concerns related to this transition is drought. Droughts are typically characterized by higher than normal temperatures and lower than normal precipitation amounts over an extended period of time. In other words, drought occurs when it's hot and dry for a long time. Late summer can be particularly ripe for drought conditions in the Northeast because it comes at the end of months of warm summer conditions, and water stored within the winter snowpack is but a memory.

Based on the trend that can be found in *Appendix C: Averages and Extremes (pp.96)* (that summer temperatures are increasing at all elevations), it is possible that drought conditions in late summer could be worsening. Other trends, however, may suggest otherwise. According to *July* (pp. 54), we know summer precipitation is increasing. In addition, in *April* (pp. 32), we know that streamflow has increased in late summer and fall. So, how are droughts in the White Mountains changing during this critical seasonal transition month given these conflicting indications?

There are a variety of indices that have been developed to determine the severity of droughts, some incorporating convoluted indicators like soil moisture and plant health. For this assessment, we used the Palmer Drought Severity Index (PDSI) because it requires measurements of only two variables: temperature and precipitation (Aiguo, 2023). Because these observations are relatively common, PDSI is readily accessible, with monthly mean values for northern New Hampshire available back to


MIDNIGHT
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
INCHES WATER
JUN 29 2025
Mt. Washington Observatory
HS 309

1895 (NCEI, *Divisional Mapping*). PDSI gauges drought conditions between -10 and 10, where -10 is extremely dry and 10 is extremely moist, with real values usually falling between -4 and 4. By averaging the PDSI values for August, September, and October by year, we can plot the data and apply a Theil-Sen trend line. The results are shown in Figure 9.1.

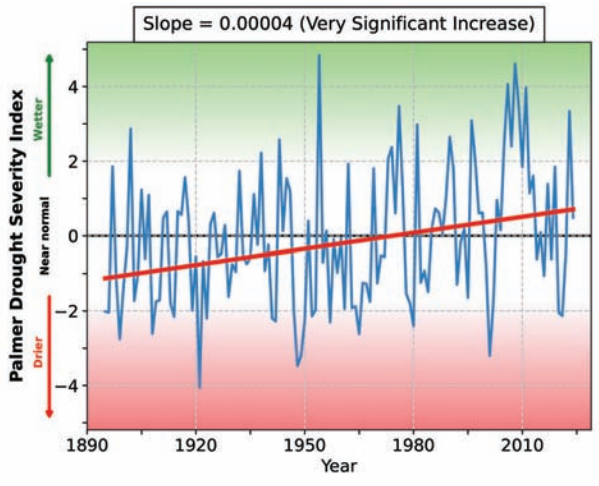


Figure 9.1. Palmer Drought Severity Index (PDSI) averaged between August and October for Northern New Hampshire.

The results indicate that drought conditions are becoming less common in the White Mountains, even during the time of year most prone to them. PDSI conditions have increased very significantly since the 1890s. NOAA denotes scores of -2 to 2 as 'near normal' conditions (NWS, *US Climate and Data Maps* 2025). While it's true some recent years do cross the -2 threshold, this is much less common than it was in the past. In some aspects, this is great news. For example, improving late summer drought conditions generally mean wildfires start less often, and if they are initiated, they will spread more slowly. Water resources for municipal and agricultural use also benefit from these conditions. In other aspects, decreasing drought conditions is more nuanced. Too much precipitation, for example, can increase risk of flooding. Overall moister conditions can also potentially cause harm to plants because soil that stays wet and cool for too long is prime real estate for pests like *Phytophthora spp.* fungi, which damage plant roots.

What's more, this graph may not be capturing the whole story. According to NOAA's National Integrated Drought Information System (NIDIS), New England is prone to experiencing "flash" droughts wherein strong drought conditions appear after periods of above-average precipitation, but only for a few weeks or months (NIDIS, *Northeast Drought Early Warning System (DEWS) Strategic Action Plan* 2022). By averaging PDSI over several months, these short, intense droughts may be lost. So while long-term drought conditions are becoming less common, flash droughts in New England are still a credible hazard.

At the same time of year that droughts most commonly occur in the White Mountains, late summer into early fall, the influence of tropical cyclones also tends to peak. When you think of the White Mountains (over 50 miles away from the ocean and characterized by alpine terrain), you probably don't think of tropical storms. Yet, the region has felt the effects of numerous tropical cyclones and hurricanes over its observational record. In fact, the highest

wind speed ever recorded in September on Mount Washington was due to a tropical storm.

The tropical depression (area of low pressure) formed in the Atlantic Ocean on August 25th, 1979. As the storm intensified and headed west, it was given the name 'David' and quickly reached category 5 status, the most powerful category on the Saffir-Simpson scale. Its central pressure, a measure of the overall strength of a hurricane, fell to 924 millibars. David plowed into the Caribbean, wreaking havoc on the Lesser Antilles, the Dominican Republic, and Puerto Rico on August 31st, killing over 2,000 people and inflicting over $1.5 billion in damages (1979 USD) (NOAA, *35th anniversary of Hurricane David's Florida Landfall* 2014). David regained its strength over the Bahamas and skimmed Florida, causing millions of dollars more in damage, before heading north along the East Coast. Despite weakening to a tropical storm, while tracking over New Hampshire, David produced fierce winds on the summit of Mount Washington, with a peak gust of 174 mph on September 6th, 1979 (Fig. 9.2). This set a new September wind record (previously 136 mph) that has not been seriously challenged since.

On the summit of Mount Washington, the hays chart receives data from nearby instruments collecting wind speed information and marks a rotating, 24-hour chart with a needle and ink. The further out from the center the marks are, the higher the wind speed.

(Fun fact: the ink is checked and topped off daily by the night observer).

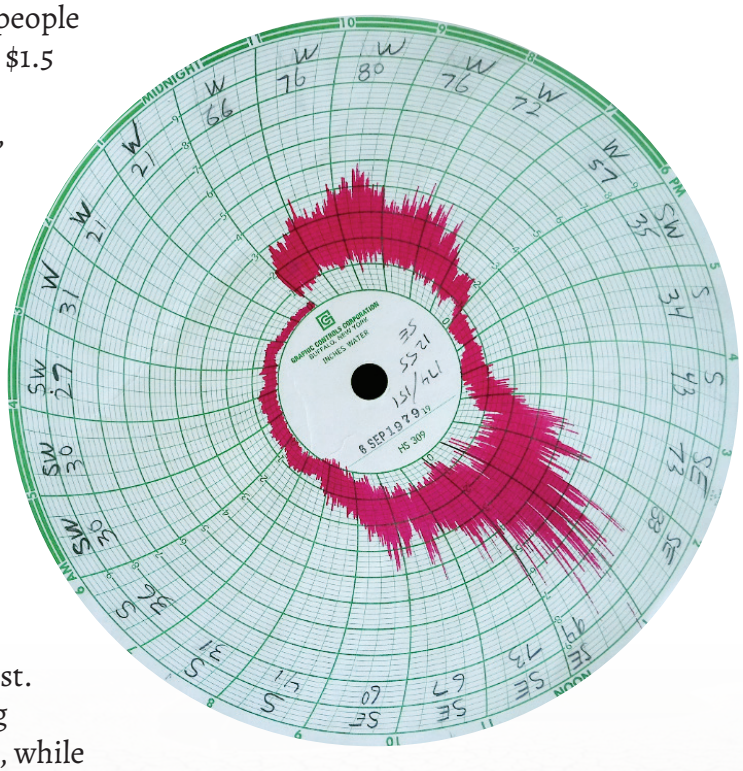


Figure 9.2. MWOBS Hays Wind Chart for September 6th, 1979 showing wind speeds from Tropical Storm David with a maximum gust of 174 mph at 12:55 PM.



MWOBS interns watch the Hays Chart for gusts over 100mph on a particularly windy day. Photo by MWOBS.

By some measures, tropical cyclones commonly influence the White Mountains, and September is the most common month for them to do so. While these impacts are small most of the time, these storms can deliver powerful winds and heavy rainfall on occasion, as exemplified by David. Since 1935, tropical cyclones (TCs) have passed within 100 nautical miles (nm) of Mount Washington every three years or so (0.32 TCs / year) and have passed within 200 nm in roughly three out of every four years (0.78 TCs / year) (Philippoff & Tarasiewicz, 2023).

Out of the 70 tropical systems which have tracked within 200 nm of the summit since 1935, however, only 17 produced winds over 100 mph, an average of one every five years. This is slightly less impressive considering the summit experiences wind gusts above 100 mph every three to four days in the winter.

TC Type	Within 200 nm since 1935	Within 100 nm since 1935
Extratropical Storm	30	10
Tropical Depression	4	-
Tropical Storm	24	12
Category 1 Hurricane	7	3
Cat. 2 Hurricane	1	1
Cat. 3 Hurricane	4	2
Total	70	28
TCs / Year	0.78	0.32

Table 9.1. TC types within 200 nm and 100 nm since 1935 (Philippoff & Tarasiewicz, 2023).

	All TCs (200 nm)		Hurricanes (200 nm)	
	Since 1850	Since 1935	Since 1850	Since 1935
February	1	1	-	-
May	4	1	-	-
June	9	5	-	-
July	10	8	2	1
August	29	17	6	3
September	55	32	16	10
October	29	6	3	-
November	4	0	1	-
Total	141	70	28	14

Table 9.2. TCs and hurricanes within 200 nm since 1850 and 1935 by month (Philippoff & Tarasiewicz, 2023).

Rank	Name	Year	Peak Gust (mph)	Top Category within 200 nm of Mount Washington	Wind Direction
1	David	1979	174	Tropical Storm	SE
2	Unnamed*	1938	160	Category 3	SE
3	Isaias	2020	147	Tropical Storm	SE
4	Carol	1954	142	Category 3	ENE
5	Sandy**	2012	140	-	E
6	Floyd	1999	128	Tropical Storm	NW
7	Gloria	1985	127	Category 1	SE
8	Irene	2011	120	Tropical Storm	W
9	Frederic	1979	119	Extratropical Storm	SW
10	Bob	1991	115	Category 2	N

Table 9.3. Top ten wind gusts produced by TCs at MWOBS (Philippoff & Tarasiewicz, 2023).

Still, the fact that storms that form thousands of miles away can affect the White Mountains is remarkable. Some tables are provided below that further describe the TCs that have passed by the region.

**The United States did not start officially naming hurricanes until 1953.*
***Hurricane Sandy did not track within 200 nm of Mount Washington.*

September Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	69°F	-	-	-
Average High	47°F	47°F	49°F	2°F
Average	**41°F**	**41°F**	**44°F**	**3°F**
Average Low	36°F	35°F	38°F	3°F
Record Low	9°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	91.9°F	-	-	-
Average High	65.2°F	64.4°F	67.9°F	3.5°F
Average	**54.9°F**	**54.0°F**	**57.0°F**	**3.0°F**
Average Low	44.5°F	43.5°F	46.1°F	2.6°F
Record Low	21.4°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	99°F	-	-	-
Average High	69°F	68°F	70°F	2°F
Average	**57°F**	**56°F**	**59°F**	**3°F**
Average Low	46°F	44°F	47°F	3°F
Record Low	23°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	98°F	-	-	-
Average High	71°F	71°F	72°F	1°F
Average	**59°F**	**58°F**	**60°F**	**2°F**
Average Low	46°F	44°F	48°F	4°F
Record Low	20°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Tree Leaf Phenology



Autumn in the White Mountains can be nothing short of wondrous. Although September technically marks the end of summer, October is the month in which it will really begin to feel the part. Days grow continually shorter, slowly at first, but more noticeably throughout the month. October may also be the first month in which you could see considerably colder temperatures, even at lower elevations. Daily low temperatures, especially towards the end of the month, trend towards freezing. While their departure date varies by species and seasonal conditions, the peak season for bird migration in the White Mountains typically happens around October as well (NH Audubon, *Birds in Migration & Winter* 2023).

The most celebrated aspect of autumn in the White Mountains, however, has to be tree "senescence" (a.k.a. trees changing the colors of their leaves). In late summer and early fall, lush green tree leaves will begin to turn vibrant shades of red, orange, and yellow. "Leaf-peepers" come from near and far to catch a glimpse of the brilliant colors of deciduous species like Red maples, American beeches, Yellow birches, and more (Fig. 10.1). This short period of leaf coloration is one of the most popular times to visit the region. Although we can only



get information based on seasonal travel, according to the Dean Runyan Associates travel dashboard for New Hampshire, fall has been second place both in terms of number of visitors and visitor spending in the White Mountains every year since 2017 (second only to summer) (Dean Runyan Associates, 2025).



Figure 10.1a - 10.1c. Autumn foliage in the White Mountains. [Above] Red maple (*Acer rubrum*). [Top right] American beech (*Fagus grandifolia*). [Below right] Yellow birch (*Betula alleghaniensis*).

Oftentimes the one question on the mind of every visitor hoping to see some of this vivid foliage is "when is the peak?". However, there is no straightforward answer. Much like the timing of bird migration, the timing of leaf coloration depends on many factors such as seasonal circumstances, species, and elevation. If you recall from the May chapter (pp. 40), plants 'keep track' of something we call Growing Degree Days to know when to come out of winter dormancy. It just so happens plants use similar information to know when to go into dormancy, as well. Once again, changing day length is an important cue; plants will also observe how much time they experience below a temperature threshold and begin to enter dormancy when a certain amount of chill accumulates, although other variables can also act as dormancy catalysts or inhibitors. We present an indicator of this transition time as 'cooling degree hours,' in which plants need to spend a certain amount of time below a temperature threshold. For now, all we need to know is that by autumn, deciduous trees in the White Mountains have usually reached cool enough nighttime temperatures to begin the process of senescence. So, when can you expect trees in the White Mountains to begin changing color en masse? We can use one of the same datasets as used in previous phenology chapters, namely NPN, to try to get a better understanding of this. Contained within these records are observations of when tree leaves begin to change color. By taking the median instance of when leaf coloration for individual trees exceeds 75% for each year, we can plot the distribution of these events (Fig. 10.2). The exact quartile dates with data between 2014 and 2024 can be found in Table 10.1.

While the results show that leaves will typically begin to change color in September and peak coloration occurs in October, the reader should keep in mind this is a generalization and leaf coloration is dependent on elevation, species, and local microclimate. A remote sensing approach (the process of detecting and monitoring the physical characteristics of an area) combined with phenological and elevation data would likely be a stronger candidate to answer this question at scale.

	Red maple		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Color} (Colored Leaves)	Sept 25	Oct 5	Oct 12
	American beech		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Color} (Colored Leaves)	Oct 7	Oct 12	Oct 19
	Yellow birch		
	First Quartile	Second Quartile (Median)	Third Quartile
DOY_{Color} (Colored Leaves)	Sept 29	Oct 8	Oct 16

Table 10.1. First, Second, and Third Quartile DOY of colored leaves (>75%) for three deciduous tree species (non-leap year).

As has been discussed throughout this almanac, changes in weather patterns in the White Mountains have a high likelihood of affecting the timing and progression of phenophases like flowering and the maturing of fruit. Likewise, studies have found that environmental changes across the entire year do have notable consequences for the timing of leaf senescence in trees.

Using satellite imagery of temperate and boreal forests in the northern hemisphere between 2001 and 2018, Zohner et al. (2023) found that warming during the summer and fall leads to an earlier onset and later end of leaf senescence for most forests

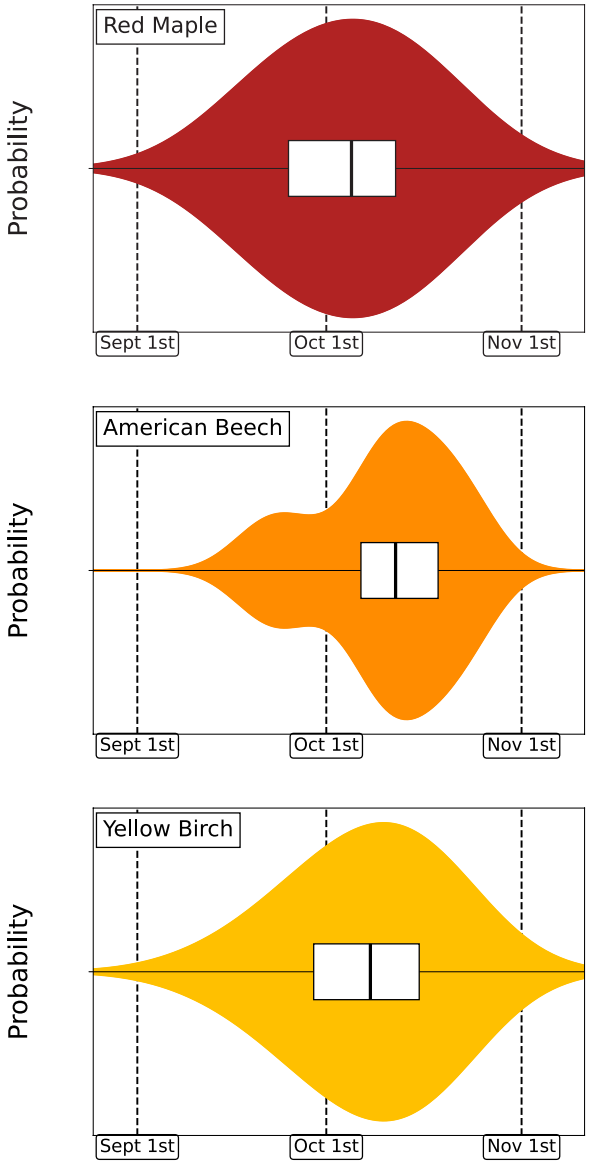


Figure 10.2. Probability density and distribution of leaf coloration (> 75% coloration) for Red maple, American beech, and Yellow birch by DOY. Boxplots show median values for DOY (with First and Third Quartiles).

in the study area, meaning leaves change color earlier and stay on the tree for longer. Specifically, warming before the summer solstice (usually June 20th or 21st) advances senescence onset by 1.9 ± 0.1 days per °C (~1.06 days per °F) and warming after the summer solstice slows senescence by 2.6 ± 0.1 days per °C (~1.44 days per °F) (Zohner. et al., 2023). This may seem counter-intuitive considering that warmer falls would mean a longer growing season, and thus the onset of senescence should be retreating.

Other research provides insight into what may be happening here. Studies by Chen et al. (2020) and Wu et al. (2022) found that while increasing temperatures alone do indeed typically correlate with a later onset of leaf senescence, secondary impacts of increasing temperature, notably drought, lead to senescence onset advancing. This means that, for regions that are prone to drought in late summer and fall, the extension to growing season from higher temperatures may be counteracted by the effects of drought (Chen et al., 2020). Another study by Calinger and Curtis (2023) also found that precipitation plays a large role in senescence, but they emphasized that the impacts of environmental changes on leaf senescence varied heavily across species and regions. It may even be the case that the timing of senescence is actually most strongly correlated with the timing of leaf budburst onset in the spring (Calinger and Curtis, 2023). The implications are even less clear for alpine and sub-alpine environments like ones found in the White Mountains. How leaf senescence timing and progression has changed as a result of increasing temperatures and other factors (like precipitation amounts and spring budburst timing) in the White Mountains is a very suitable topic for future research.



Why do deciduous plants shed their leaves?

In locations where winters get cold enough to freeze, certain kinds of plants ('deciduous' plants) have evolved to shed their leaves in autumn. Why is this the case? Surely, having to expel leaves in the fall and start all over again growing them in the spring is not worth the energy. The truth is that this process actually gives these plants an advantage, and permits them to live in regions they wouldn't be able to without shedding their leaves.

Almost all plants require some amount of sunlight to produce energy. They collect *red* and *blue* sunlight and reflect green light using chlorophyll molecules in their leaves to make energy via photosynthesis. In latitudes far from the equator, being a plant is great in the summer because there are long days with high intensity sunlight. The winter, characterized by short days with low intensity sunlight, is a different story. The amount of energy a plant can make in the summer is much higher than in the winter, but this alone shouldn't necessarily be enough for plants to completely banish their leaves.

The other variable in the equation relates to freezing temperatures in winter. Leaves on deciduous plants are typically thin, flimsy structures that maximize sunlight absorption and nutrient transport, so they're also full of water. When water freezes, it expands. This would cause severe damage to the tree's veins if it were to freeze, making it bleed nutrients and leaving it prone to infection. Moreover, leaves have large surface areas that collect snow. Snow is very heavy and can easily snap branches if too much accumulates, so dropping leaves physically reduces snow loads and structural stress on trees. Shedding leaves before it gets too cold (abscission) is a trade-off that allows plants to survive in regions with cold winters.

Many plants don't shed their leaves, though. Called 'coniferous' plants, these plants have evolved other strategies to thrive in winter without shedding their leaves. Pine trees, for example, wield leaves called needles. The small, narrow structure of needles coated with a special waxy coating collects less snow while also making them much more resistant to cold, allowing these plants to soak up sunlight year-round *(Poimiroo, 2022)*.

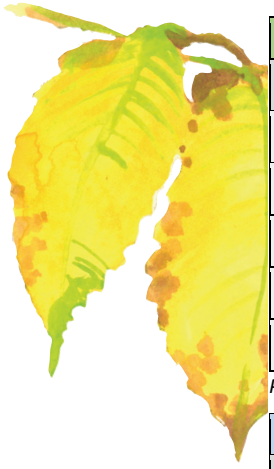


Photo by MWOBS.

October Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	62°F	-	-	-
Average High	37°F	38°F	38°F	0°F
Average	**31°F**	**31°F**	**32°F**	**1°F**
Average Low	25°F	25°F	26°F	1°F
Record Low	-5°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.



AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	85.3°F	-	-	-
Average High	54.1°F	54.9°F	54.7°F	-0.2°F
Average	**44.3°F**	**44.4°F**	**45.3°F**	**0.9°F**
Average Low	34.5°F	33.9°F	36.0°F	2.1°F
Record Low	5.5°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

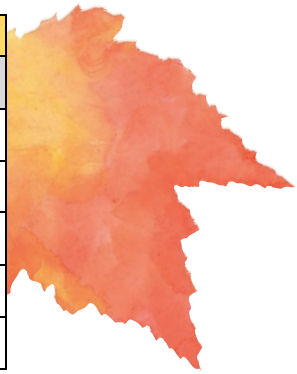
Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	86°F	-	-	-
Average High	57°F	57°F	57°F	0°F
Average	**46°F**	**46°F**	**47°F**	**1°F**
Average Low	36°F	35°F	37°F	2°F
Record Low	12°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.



North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	88°F	-	-	-
Average High	59°F	59°F	59°F	0°F
Average	**47°F**	**47°F**	**48°F**	**1°F**
Average Low	36°F	34°F	38°F	4°F
Record Low	10°F	-	-	-

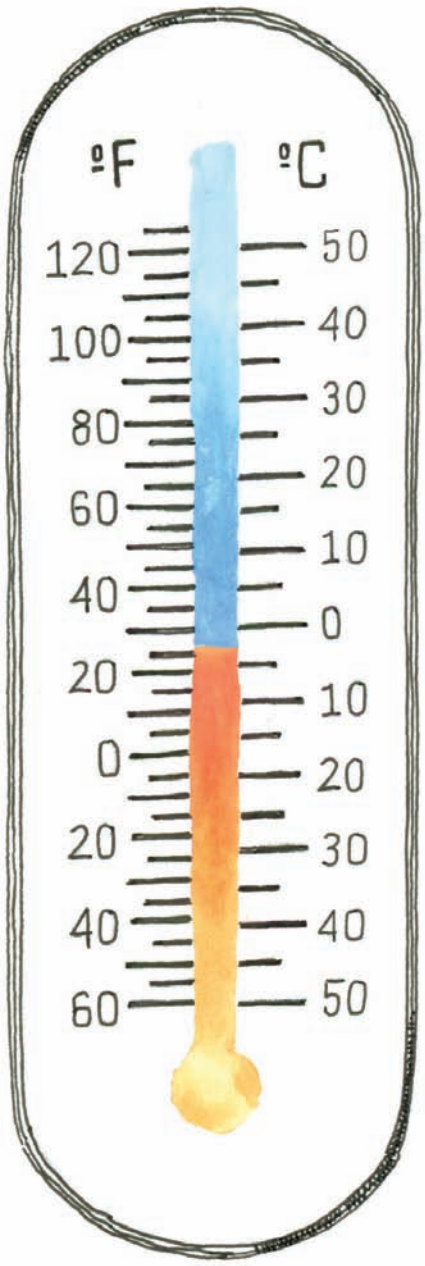
North Conway temperatures are rounded to the nearest integer.



Chilling Degree Days

By the eleventh hour of the yearly clock, winter begins to slowly exert its bitter grip on the White Mountains in full. While the freezing curtain has long since descended on alpine terrain by the beginning of November, the notches and valleys swiftly catch-up as they see their daily average temperatures dip below freezing this month. As will be discussed more in *December* (pp. 86), the lower-elevations will, on average, see their first noteworthy snowfall event this month. If they have not already fallen, brown and gold tree leaves will flutter to the ground, and some animals will enter hibernation.

The carefully tuned ecosystem and its individual organisms keep close track of these changes. While some animals may also pay attention to diminishing food sources, plants and animals alike will respond to decreasing sunlight and falling temperatures. One vital aspect of winter, however, is that many organisms actually rely on long, uninterrupted periods of cold temperatures in order to produce buds and leaves in the springtime, oftentimes the colder the better (to an extent). You can think of this rather counterintuitive concept as low temperatures 'setting the clocks' for subsequent spring activity in plants. If plants don't experience a certain amount of chilling during the winter, it may delay their emergence in the spring.





Iced mountain aster. Photo by MWOBS.

Chilling requirements vary by species, and usually if these temperatures are not reached in the environment, plants will not blossom completely. Although this is especially important for agriculture, as farmers rely on cool winters so their trees will produce lots of fruit, it also applies just as much to plants in the White Mountains. Here we define the time accumulated below a certain threshold temperature as chilling degree days (CDD), providing a descriptive index for winter conditions. While we don't know the CDD temperature threshold for every plant species in the White Mountains, we use a general threshold of 45°F for this analysis. This is because most plants require winter temperatures between 32°F and 45°F, and by using the upper threshold we can make assumptions about lower thresholds as well (Estrella & Menzel, 2006).

Given trends in warming winters as discussed in chapters like *January* (pp. 10), understanding how accumulated CDD (aCDD) is changing can give insight into how changing temperatures are affecting the ecosystem of the White Mountains. Studies suggest that some plants, through a complex process of biochemical reactions (called epigenetic changes), retain a 'memory' of the past (Abdulraheem et al., 2024). In practical terms, this means that some plants can 'understand' changing environmental patterns and react accordingly. For example, some plants have evolved to postpone sprouting right away during warm periods because a short period of thawing in February can give the illusion of spring. Similarly, some plants may have the ability to extend or contract their individual 'growing seasons' to better reflect warmer or colder seasonal temperatures. For example, if autumns have been getting warmer, such a plant would respond by staying green longer to take advantage of the longer frost-free period.

Therefore, how and when are chilling degree days changing in the White Mountains? For this analysis, daily maximum and minimum temperature observations from MWOBS, Pinkham Notch, and Hubbard Brook were used. We used a similar methodology as in the chapters that focused on aGDD, except rather than having a lower threshold we used an upper threshold. For lower elevations, this



Photo by MWOBS.

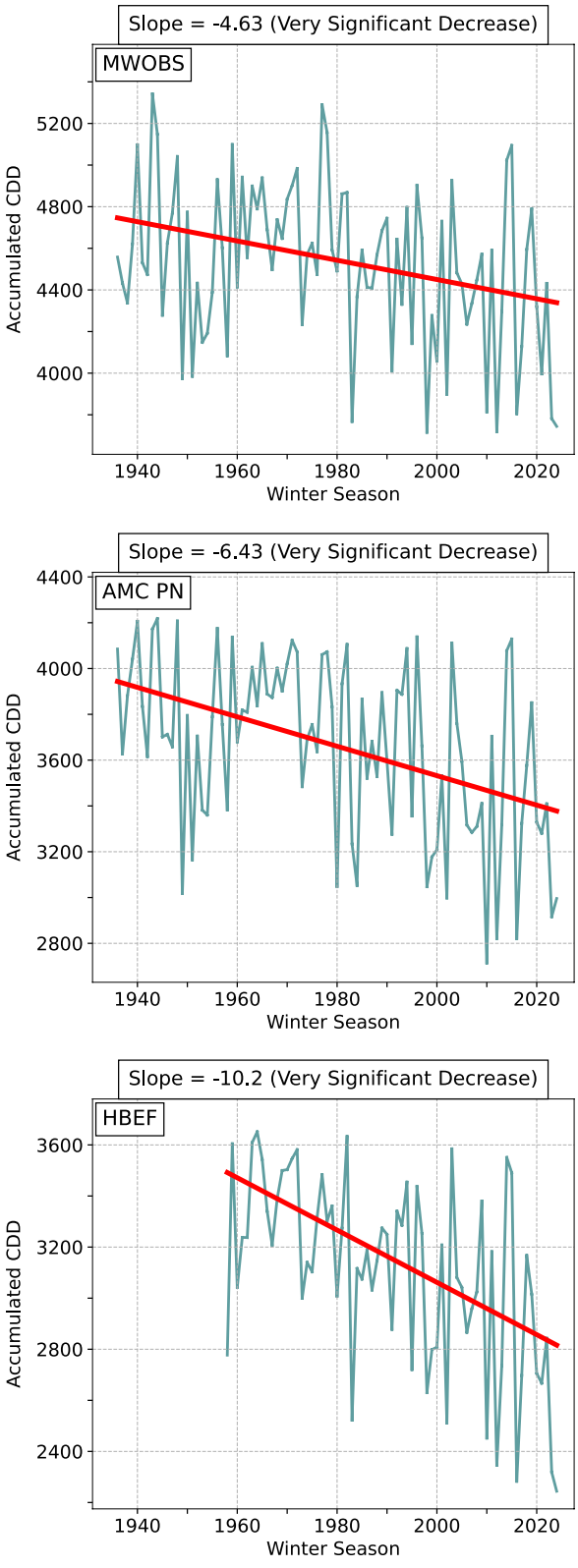


Figure 11.1. Wintertime accumulated Chilling Degree Days (aGDD) MWOBS (42°F threshold), Pinkham Notch (45°F threshold), and Hubbard Brook (45°F threshold) between November 1st and April 30th.

threshold is 45°F. For the alpine zone this threshold was set at 42°F because, as mentioned in *June* (pp. 46), temperatures at the summit of Mount Washington are colder on average than elevations we're interested in. This is attributed to the environmental lapse rate, which is the decrease in temperature with increasing elevation. On Mount Washington, in the fall and winter, the average lapse rate is closer to 5°C per kilometer or ~2.74°F per 1000 feet (Philippoff et al., 2024). Since aCDD can be important from the onset of winter all the way to spring, this analysis used data between November 1st and April 30th. The results are shown in Figure 11.1.

Overall, at all elevations, aCDDs are decreasing very significantly. Higher terrain is losing 46.6 aCDD per decade, while middle- and lower-elevations are losing between 63.7 and 105.5 aCDD per decade. This means that winters are warmer, and plants that rely on long periods of cold temperatures in winter may produce less fruit and leaf-out later/less efficiently. As mentioned previously, this is especially pertinent for parties that rely on bloom in the spring, and that's not just farmers. From the smallest sweat bee collecting pollen to a Rhodora flower (*Rhododendron canadense*) to the moose eating bunches of berries off the Bunchberry (*Cornus canadensis*), decreasing winter CDD has the potential to have wide-ranging impacts.

November Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	52°F	-	-	-
Average High	27°F	27°F	28°F	1°F
Average	**21°F**	**20°F**	**21°F**	**1°F**
Average Low	14°F	14°F	14°F	0°F
Record Low	-26°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.

AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	75.0°F	-	-	-
Average High	40.9°F	41.1°F	41.6°F	0.5°F
Average	**32.7°F**	**32.7°F**	**33.2°F**	**0.5°F**
Average Low	24.5°F	24.3°F	24.9°F	0.6°F
Record Low	-7.4°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.

Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	75°F	-	-	-
Average High	44°F	44°F	44°F	0°F
Average	**36°F**	**35°F**	**36°F**	**1°F**
Average Low	27°F	27°F	27°F	0°F
Record Low	-2°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.

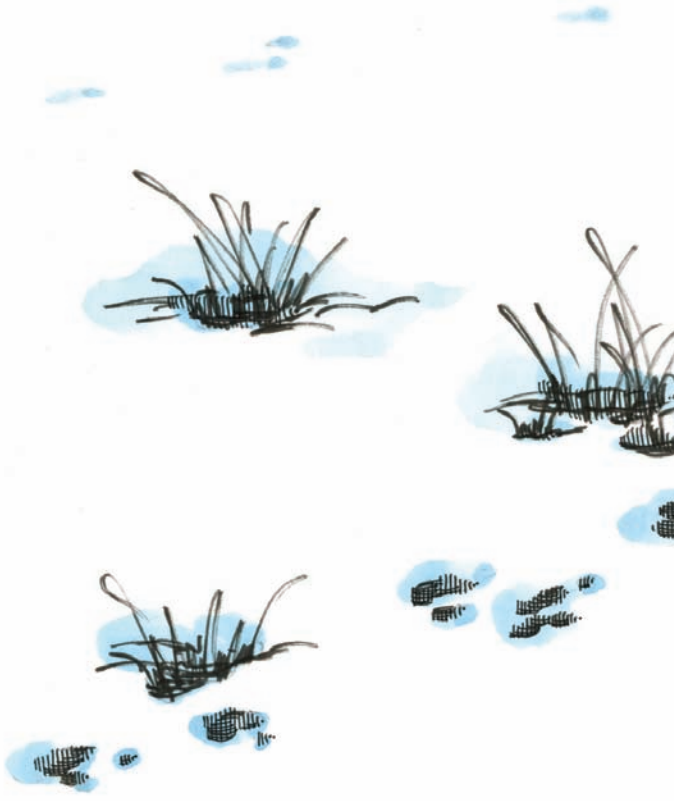
North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	78°F	-	-	-
Average High	46°F	46°F	46°F	0°F
Average	**36°F**	**36°F**	**37°F**	**1°F**
Average Low	27°F	26°F	28°F	2°F
Record Low	-4°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Snow Days Before the Holidays

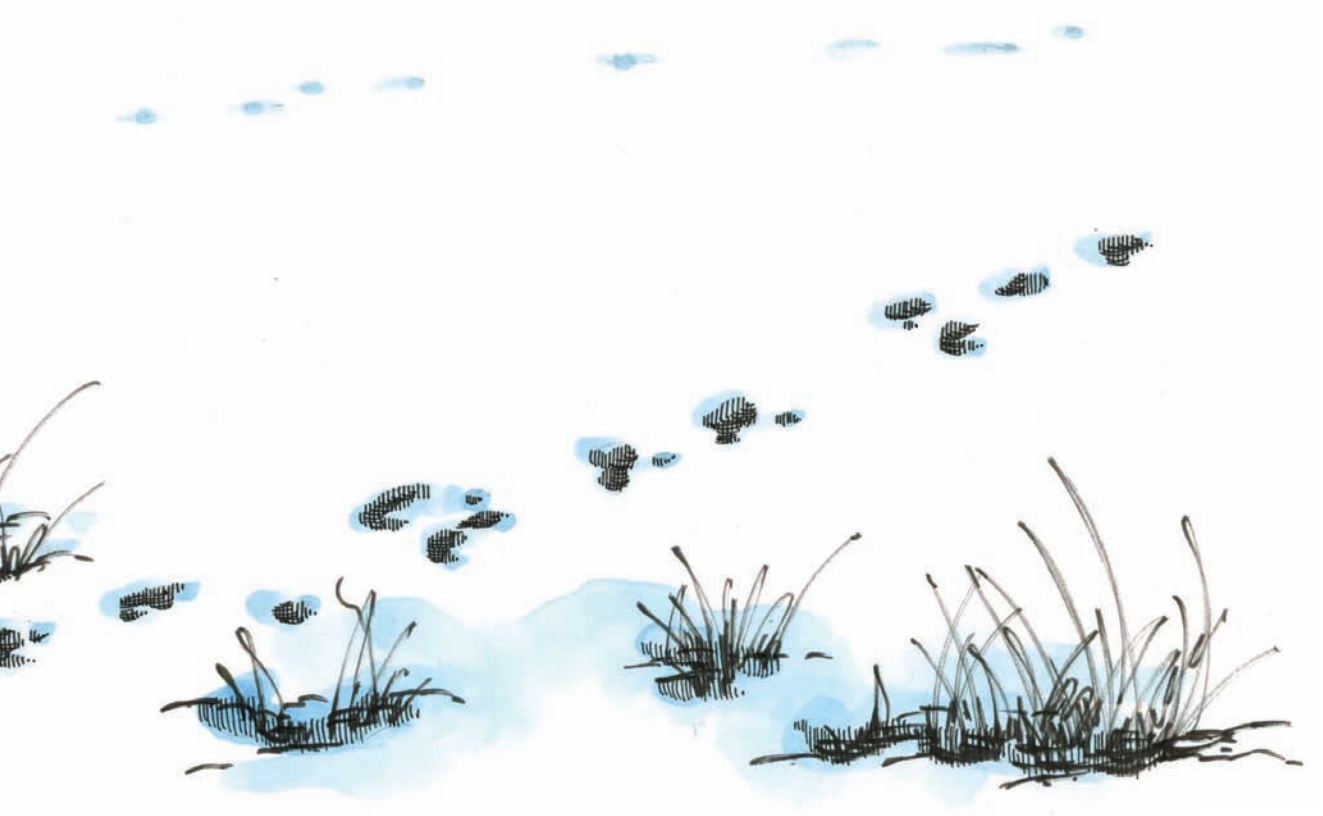
The final month of the year serves as a time of great transition. The 21st or 22nd of December is the Winter Solstice: this special day is the shortest of the entire year and it marks the beginning of astronomical winter for the northern hemisphere, although it begins to feel like winter in the White Mountains long before this. Due to it being the shortest day of the year, the Winter Solstice has acted as inspiration for a variety of holidays and celebrations around the world. In the United States, it is common for people to receive time off work and school to enjoy these traditions, spend time with family, and ring in the new year (often called the 'holiday season').

For regions that are no stranger to snow, a popular pastime is to eagerly hope that snow will fall on or before the holidays. Indeed, a layer of fluffy, white snow can turn the otherwise cold and gloomy environment into a winter wonderland. The geographical location and topography of the White Mountains make them likely to receive snow before the holidays, even at the lowest elevations. This makes the region a popular holiday destination for people that live in places that may not see much, if any, snow by the end of December. Given the changes in weather patterns that have been investigated throughout this almanac, this raises the question: how are snow days before the holidays changing in the White Mountains?



First, we have to define what "before the holidays" means. For this analysis, we will be using data between October 1st and December 31st. This is because the chance of snow falling at lower elevations before October is nearly zero, and the latter date is used because it marks New Years Eve for the Gregorian calendar. Although New Year's Eve is not the end of the holiday season, this date range encapsulates many holidays in which people wish for snow. We used Pinkham Notch daily snowfall data and Hubbard Brook daily precipitation and temperature data. For the latter, although daily snowfall data isn't available, we can make an approximation of snowfall totals using a methodology similar to how GDD is calculated, first introduced in *May* (pp. 40). The full details of this methodology can be found in the *Endnotes* section for *December* (pp. 100), but the main idea is that we are estimating the amount of snow that has fallen using daily precipitation, maximum and minimum temperature, and some other assumptions.

Using the data from these two sites, we take a broad look at chances of snow events leading up to the holidays. For any given day of the year, we can calculate the "daily probability" of a snow event occurring on or before that date by dividing the number of years that did receive snow by the total number of years (probability).



$$Snow\ Chance\ for\ dd/MM\ = \left(\frac{\#\ of\ dd/MM/YY\ that\ did\ receive\ snow}{Total\ \#\ of\ dd/MM/YY}\right) * 100\%$$

In other words, daily probability is the chance that a snow event of a given amount has occurred *on* that day. We plot daily probability of snow events for four snow amount thresholds: one, two, six, and twelve inches for the climate period (~30 years) (Fig. 12.1). We also calculate and plot the "cumulative probability", which is the chance that a snow event of a given amount has occurred *on or before* the date (Fig. 12.2). Probabilities in both figures 12.1 and 12.2 are smoothed using a 5-day centered running average for visual presentation. Pay attention to the y-axis for both of these graphs: while the *daily* chance for any 1 inch snow event is always less than 40% (Fig. 12.1), the *cumulative* chance rises to nearly 100% by the beginning of December for both sites (Fig. 12.2).

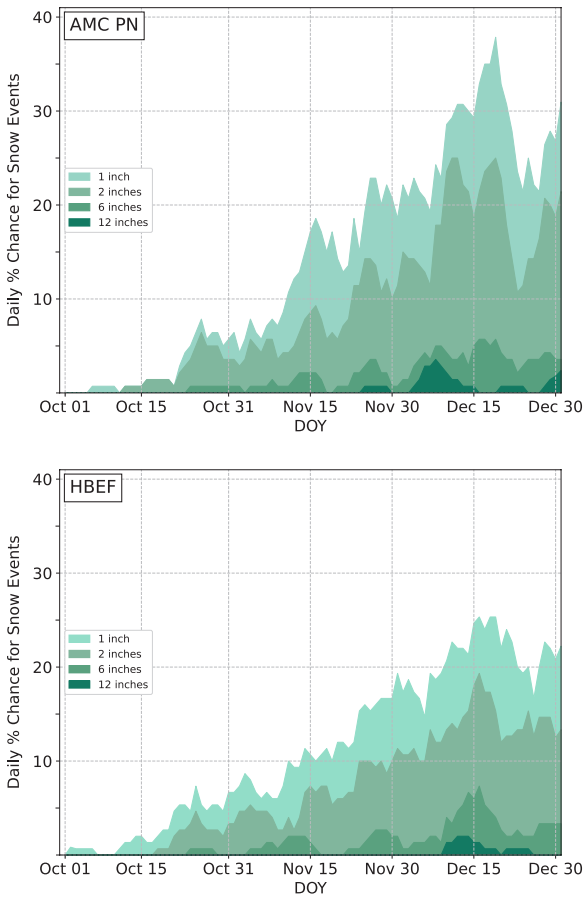


Figure 12.1. Smoothed daily chance of snow events from October 1st to December 31st for Pinkham Notch (top) and Hubbard Brook (bottom) between 1994 and 2023.

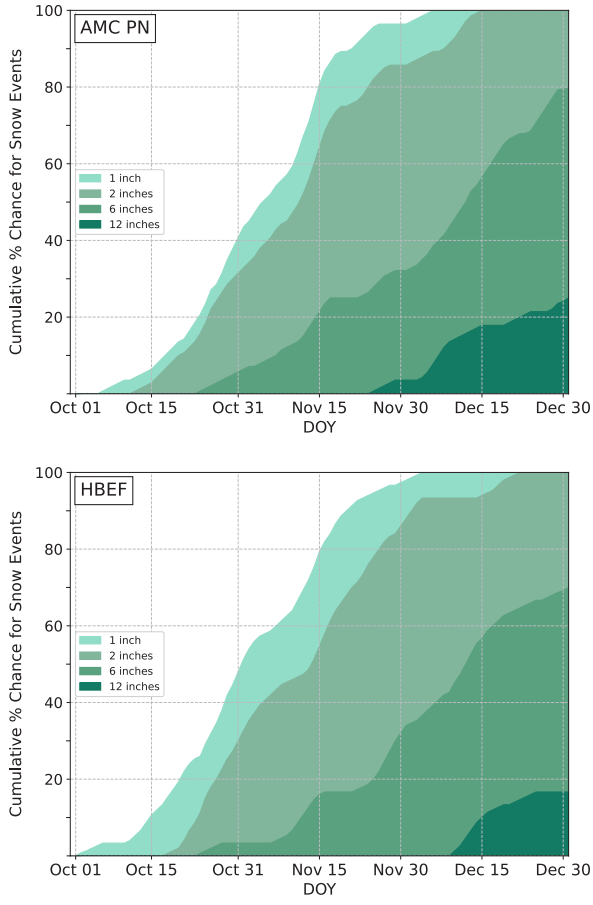


Figure 12.2. Smoothed cumulative chance of snow events from October 1st to December 31st for Pinkham Notch (top) and Hubbard Brook (bottom) between 1994 and 2023.

We can also break down the results by decade to visualize change over time and compare the sites. In Figure 12.3, we take the average total accumulated snowfall by decade (top) and the first average DOY with a 2-inch snow event by decade (bottom) for both sites. These results reinforce the idea that snow totals and timing before the holidays vary broadly between decades. An additional interesting find from these graphs is that the 1960s and 1970s have some of the highest average snowfall totals before the holidays, with Hubbard Brook averaging almost 44 inches in the 1970s. This agrees with some of the findings in *March* (pp. 26) relating to snow during those years. These decades were characterized by above average snowfall at all times of year.

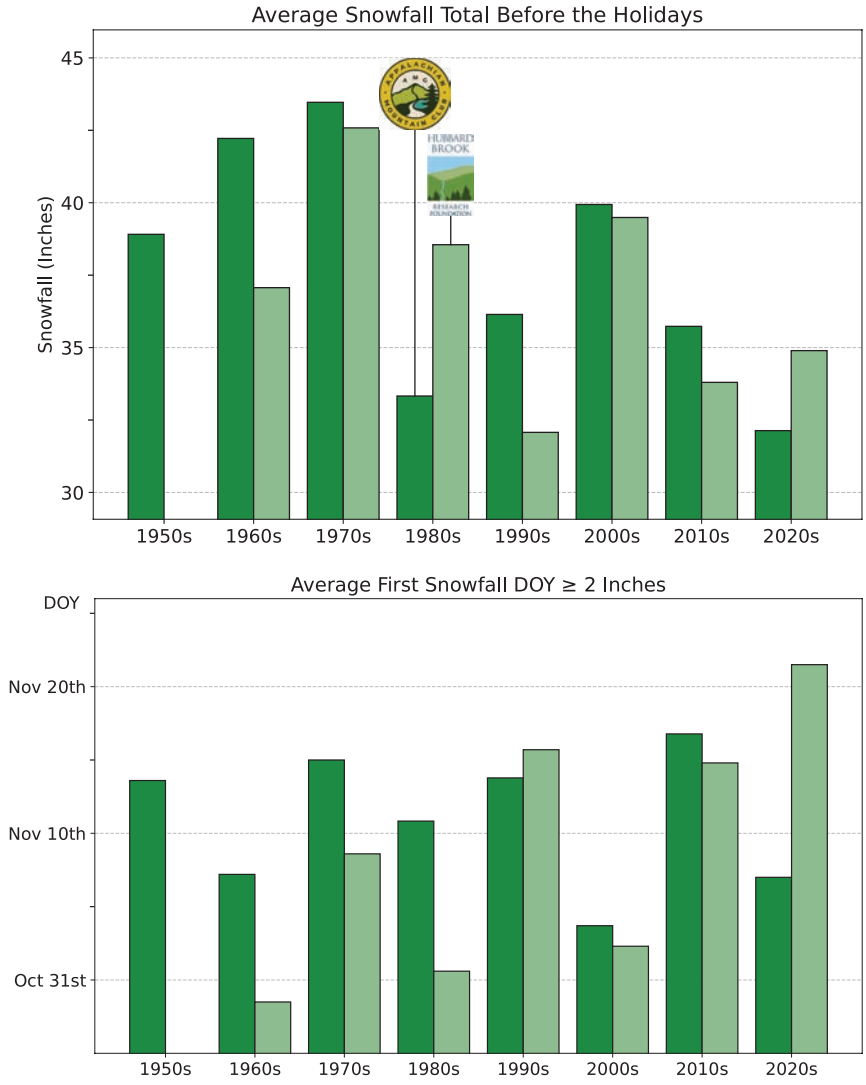


Figure 12.3. Average snowfall total in inches (top) and average DOY of first snowfall event ≥ 2 inches (bottom) at Pinkham Notch and Hubbard Brook between October 1st and December 31st by decade.

Something else to note in the bottom graph of Figure 12.2, is while Pinkham Notch has a fairly consistent first date of 2-inch events, Hubbard Brook's first snow event date varies considerably. For example, while the average first date for 2-inch event was in mid-November for the 2010s and 2020s, the average first date in the 1960s was before October 31st. While interesting, this could be a side-effect of interpolating snowfall amounts for Hubbard Brook.

In Table 12.1, some reference statistics are provided regarding snow before the holidays

in the White Mountains using data between 1994 and 2023.

1994 - 2023	*AMC PN*	*HBEF*
Average First DOY to get _ …		
≥ 1 Inch	November 5th	November 3rd
≥ 2 Inches	November 11th	November 13th
≥ 6 Inches	November 26th	December 6th
≥ 12 Inches	December 9th	December 16th
Percent Chance to get _ before the holidays …		
≥ 1 Inch	100.0%	100.0%
≥ 2 Inches	100.0%	100.0%
≥ 6 Inches	53.6%	66.7%
≥ 12 Inches	17.9%	16.7%

Table 12.1. Snow before the holidays reference statistics for the 1994-2023 record.



December Average and Record Temperatures Across Sites

MWOBS				
Values	P.O.R.	*1935-1964*	*1995-2024*	*Δ°F*
Record High	47°F	-	-	-
Average High	18°F	17°F	20°F	3°F
Average	**10°F**	**9°F**	**13°F**	**4°F**
Average Low	3°F	1°F	5°F	4°F
Record Low	-46°F	-	-	-

MWOBS temperatures are rounded to the nearest integer.



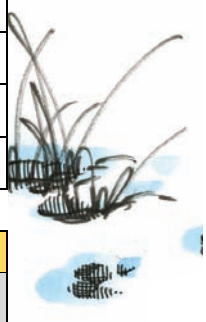
AMC Pinkham Notch				
Values	*P.O.R.*	*1935-1964*	*1995-2024*	*Δ°F*
Record High	66.9°F	-	-	-
Average High	29.5°F	28.3°F	31.4°F	3.1°F
Average	**20.7°F**	**19.2°F**	**23.2°F**	**4.0°F**
Average Low	12.0°F	10.2°F	14.8°F	4.6°F
Record Low	-28.7°F	-	-	-

Pinkham Notch temperatures are rounded to the nearest tenths place.



Hubbard Brook EF				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	64°F	-	-	-
Average High	33°F	32°F	34°F	2°F
Average	**24°F**	**22°F**	**26°F**	**4°F**
Average Low	15°F	13°F	18°F	5°F
Record Low	-24°F	-	-	-

Hubbard Brook temperatures are rounded to the nearest integer.



North Conway				
Values	*P.O.R.*	*1957-1986*	*1995-2024*	*Δ°F*
Record High	71°F	-	-	-
Average High	34°F	33°F	35°F	2°F
Average	**25°F**	**23°F**	**27°F**	**4°F**
Average Low	15°F	13°F	18°F	5°F
Record Low	-24°F	-	-	-

North Conway temperatures are rounded to the nearest integer.

Appendix A - What is a Trend Line?

What is a Trend Line?

When plotting data, it is often difficult to discern if there is a pattern in it using your eyes alone. Trend lines are |linear| lines that pass through data points; their slope and position are determined through statistical tests called "regression". They make trends in data easier to see (if any trends are present).

There are many types of trend calculations that exist, each with its own applications and strengths. For this almanac, we will be applying Theil-Sen's estimator, which typically does a better job of accounting for outliers than other trend calculations like *Ordinary Least Squares*. Outliers are extreme data points that differ significantly from other points, which can erroneously skew trend lines.

Theil-Sen Regression

Theil-Sen trend line is given by ...

$$y = mx + b$$

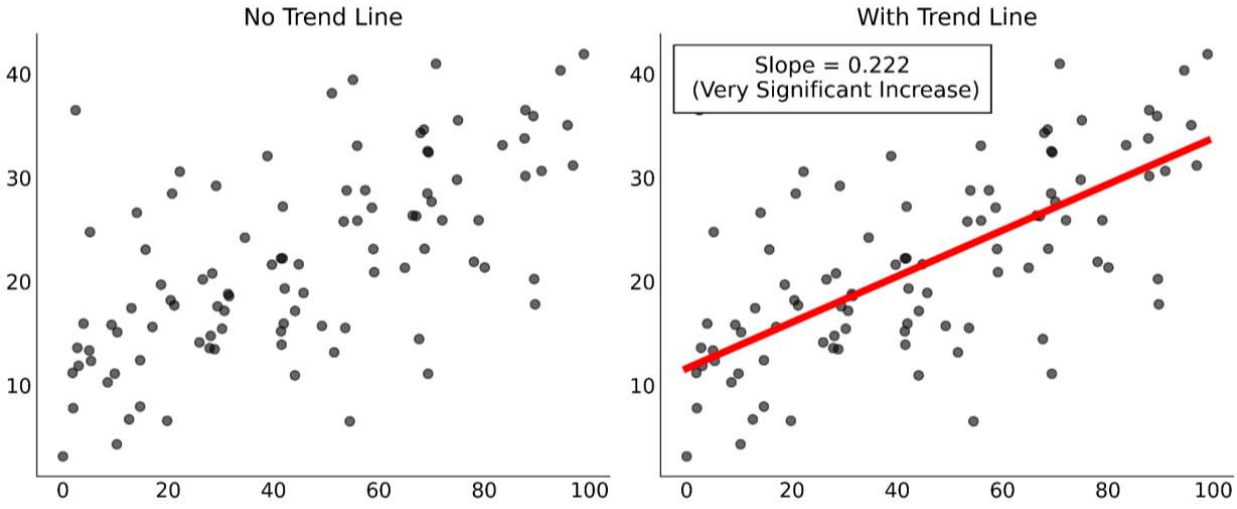
$$m = med\left[\frac{(y_j - y_i)}{(x_j - x_i)}\right]$$

Where m (slope) is the median of slopes between every point (x , y) ...

Trend Significance

Using the Mann-Kendall Test, we can test for monotonic *trend line significance*. Specifically, we will be using the *p-value*. Without going into too much detail, significance asks whether the trend line that is estimated to fit the data is from an underlying pattern or random chance, either by accepting or rejecting the 'null hypothesis' for significance levels. If we accept the null hypothesis, that means that there is no trend within the data and the slope is not different from zero, while if we reject the null hypothesis then there is a significant trend in the data and the slope is different from zero. The slope of the linear fit represents the rate of change with a positive slope being an increase and a negative slope being a decrease in the trend. The p-value ranges from 0 to 1, with values close to 0 being more significant. For this almanac, we will use three shorthand specifications to refer to the significance of results. Alongside slope, p-value specification will be included with all scatter and line plots in this almanac.

Significance Level	*Confidence Interval*	*Specification*
p > 0.05	< 95.0%	Not Significant
p ≤ 0.05	≥ 95.0%	Significant
p ≤ 0.01	≥ 99.0%	Very Significant



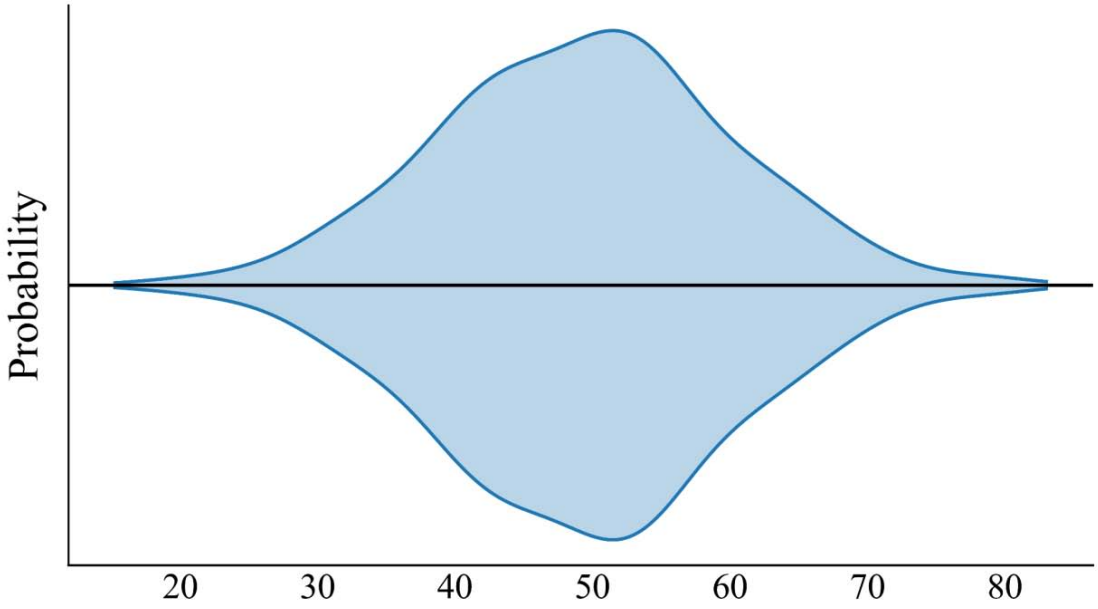
In the first graph, simulated data points are plotted. While you might be able to see a trend, the exact numerical relationship is hard to discern. With Theil-Sen regression, the increasing trend becomes clearer. |A p-value of < 0.01| means there is more than a 99.9% chance that there is an underlying trend in the data.

Appendix B - Probability, Median Values and Box Plots

What is a Probability Density Function?

Not all data are best represented as a scatter plot: sometimes, other kinds of graphs are required to understand the data. *Probability density functions* (PDF) are a common way to show how the data are distributed across all possible values. In other words, instead of plotting an independent variable (X) against a dependent variable (Y), we are plotting an independent value (X) against how many data points have that value.

In the PDF graph below, we graph random simulated values in the distribution of their probabilities against the x-axis. The values of the y-axis are not important because these probabilities are relative to each other. Another way to think about this is that, if you were to pick a random point from the dataset, you would have a *high chance* of picking a point with x-value around 50, and a *low chance* of picking a data point around 20 or 80. The curve is above and below the x-axis for visual presentation. This special type of PDF is called a *violin plot* or *kernel density plot*.



Median Values and Box Plots

In order to identify where the most values fall within the aforementioned PDF, we use 'median values' and 'box plots'. Median values are a type of average that represent the most 'middle' value in the entire dataset. As opposed to the 'mean' value (which adds all values together and divides by the number of values), the median orders the values by their size and takes the one in the middle. In the list below, we have seven values (odd set). The median of this list is 6 because it is the most middle value. 50% of values are below 6, and 50% are above 6.

Median for odd set

1	3	4	6	7	7	9	Median = 6

In the case there is an even number of values in the set like the list below, the median is found by adding the two middle values and dividing by two. So, 4 plus 6 equals 10, and 10 divided by 2 equals 5.

Median for even set

1	3	4	6	7	9	Median = 5

Box plots are a useful addition to distribution graphs that show how bunched up or spread out the data is. The ends of the box encompass the range from the *first quartile* (Q1) to the *third quartile* (Q3). The first quartile is the median of data points left of the overall median, and the third quartile is the median of the data points right of the overall median. The overall median can also be called the *second quartile* (Q2).

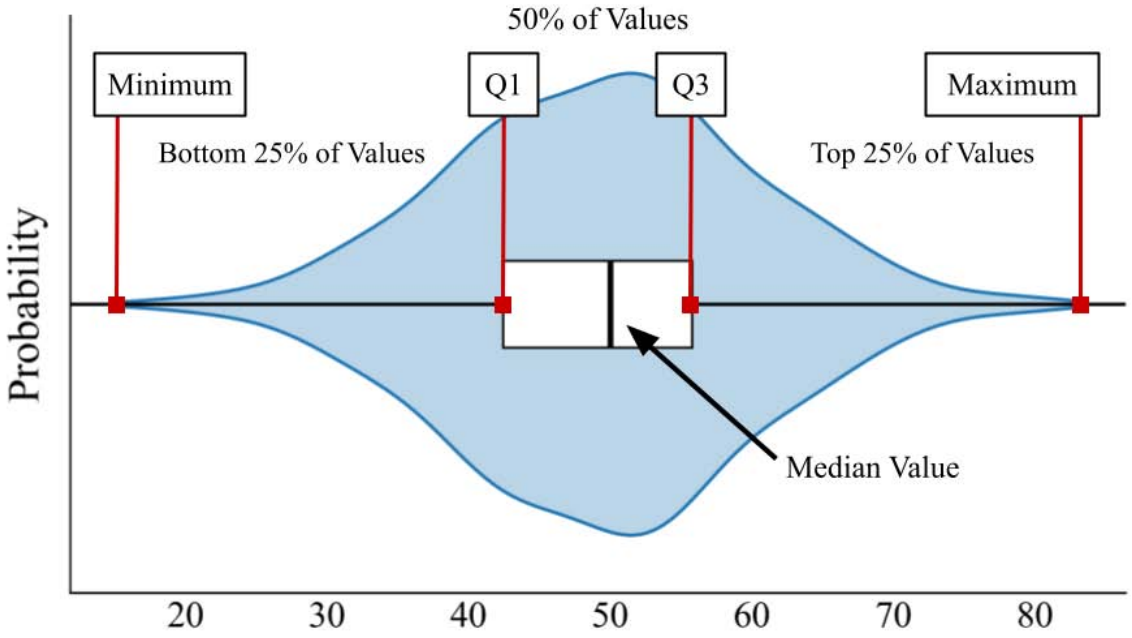
First Quartile

1	3	4	6	7	7	9	Q1 = 3

Third Quartile

1	3	4	6	7	7	9	Q3 = 7

The median value and box plot is added to our violin plot in the graph below. This should help illustrate why box plots and median values are helpful. We can see that 50% of values fall between Q1 and Q3. The rest of the values are in the top and bottom 25% of the curve. So, if you randomly pick a point from the dataset, there's a 50% chance you land between Q1 and Q3, and a 50% chance you land elsewhere. If the box plot is very wide, it means values are spread out far from the median. If the box plot is very thin, it means values are bunched up close to the median. All PDF graphs in this almanac will have a median value table and a box plot.



Appendix C - Averages and Extremes

For an extensive look at temperature, precipitation, snowfall, and other data across sites, visit ***https://mountwashington.org/wp-content/uploads/2025/10/Appendix-C_Averages-and-Extremes.pdf***

Notes

January

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \qquad T_{seasonal\ mean} = \frac{\Sigma\, T_{mean}}{\#\ of\ days}$$

Equations E.1.1

March

$T_{Ideal} = 20°F$	S_T = Temperature Score
$Dev_T = T_{mean} - T_{Ideal}$	S_{SF} = Snowfall Score
P_S = Snowfall (Inches)	S_{SD} = Snow Depth Score
$D_{S[1]}$ = Snow Depth from Today (In.)	WRS = Winter Recreation Score
$D_{S[2]}$ = Snow Depth from Yesterday (In.)	
$D_{S[3]}$ = Snow Depth from Ereyesterday (In.)	
$D_{S[4]}$ = Snow Depth from Erereyesterday (In.)	

Equations E.3.1.

Temperature Score	
If $T_{avg} > 20°F$ and $T_{avg} \leq 40°F$	If $T_{avg} < 20°F$ and $T_{avg} \geq \frac{-14\pi}{3}°F$
$S_T = sin(\frac{\pi Dev_T}{40} - \frac{3\pi}{2})$	$S_T = \frac{1}{2*arctan(\frac{7\pi}{3})} * arctan(Dev_T + \frac{7\pi}{3}) + 0.5$
If $T_{avg} = 20°F$	If $T_{avg} < \frac{-14\pi}{3}°F$ or $T_{avg} \geq 40°F$

Continued on next page

$S_T = 1$	$S_T = 0$

Table E.3.1.

Snowfall Score		
If $P_S \geq 8$	If $8 > P_S > 0$	If $P_S = 0$
$S_{SF} = 1$	$S_{SF} = \frac{(P_S)^2}{64}$	$S_{SF} = 0$

Table E.3.2.

Snow Depth Score	
If $D_{S[1]} \geq 8$	If $8 > D_{S[1]} \geq 0$
$S_{SD} = 1$	$S_{SD} = \frac{(D_{S[1]})^2}{64} + (\frac{3}{4} * \frac{(D_{S[2]})^2}{64}) + (\frac{2}{4} * \frac{(D_{S[3]})^2}{64}) + (\frac{1}{4} * \frac{(D_{S[3]})^2}{64})$

Table E.3.3.

Final Winter Recreation Day Score
$WRS = (\frac{1}{3} * S_T) + (\frac{1}{3} * S_{SF}) + (\frac{1}{3} * S_{SD})$

Table E.3.4.

July

P = Daily Precipitation (Inches)	S_P = Precipitation Intensity Score

Equation E.7.1.

Precipitation Intensity Score		
If $P \geq 6$	If $6 > P > 0$	If $P = 0$
$S_P = 10$	$S_P = \frac{(P)^2}{3.6}$	$S_P = 0$

Table E.7.2.

August

$T_{day} = (0.9 * T_{max}) - (0.1 * T_{mean})$	S_T = Temperature Score
M_{TS} = Minutes of daytime taken up by thunderstorms	IW_{TS} = Thunderstorm Score
M_{HS} = Minutes of daytime taken up by hailstorms	IW_{HS} = Hailstorm Score
M_{RS} = Minutes of daytime taken up by rainstorms	IW_{RS} = Rainstorm Score
	IW = Inclement Weather Score
	SRS = Summer Recreation Score

Equations E.8.1.

Temperature Score	
If $T_{day} \geq 75°F$	If $T_{day} < 45°F$ and $T_{day} \geq 32°F$
$S_T = \frac{1.022}{1 + exp[0.4 * (-80 + (0.94 * T_{day}))]}$	$S_T = \frac{log(T_{day} - 31)}{2.639058}$
If $T_{day} < 75°F$ and $T_{day} \geq 45°F$	If $T_{day} < 32°F$

Continued on next page

$S_T = 1$	$S_T = 0$

Table E.8.1.

Inclement Weather Score
$IW_{TS} = \frac{2.0 * [M_{TS}]}{Total\ daytime\ minutes}$ $IW_{HS} = \frac{1.5 * [M_{HS}]}{Total\ daytime\ minutes} - IW_{TS}$ $IW_{RS} = \frac{1.0 * [M_{RS}]}{Total\ daytime\ minutes} - (IW_{TS} + IW_{HS})$ $IW = IW_{TS} + IW_{HS} + IW_{RS}$

Table E.8.2.

Final Summer Recreation Day Score
$SRS = S_T - IW$

Table E.8.3.

December

When trying to estimate snow from temperature and precipitation, there are only three possible cases: two are simple, and the last is more complex. If the maximum temperature (T_{max}) recorded that day is below 32°F, then all the precipitation is assumed to be snow*. This is shown in table E.12.1A and E.12.2A. In this case, we simply multiply the precipitation amount by 9 because we are assuming a 9:1 snow-to-liquid ratio (SLR, or the amount of snow per unit precipitation). The assumption for a 9:1 SLR is explained at the end of this endnotes section. The other easy scenario is when the minimum temperature (T_{min}) is above 32°F, all precipitation is assumed to be liquid (i.e. no snowfall). This is shown in table E.12.1B and E.12.2B.

In the last case, T_{max} is greater than or equal to 32°F but T_{min} is less than 32°F. This may mean that some precipitation that falls on this day will be frozen and some will be liquid**. We use a sinusoidal curve to model daily temperature, assuming T_{max} occurs at 6 P.M. and T_{min} occurs at 6 A.M. (the actual timing of T_{max} and T_{min} doesn't affect the snow calculation

because we assume precipitation is spread evenly through the entire 24 hours). This is shown in Table E.12.1C.

Then, we want to figure out what percent of the 24 hours is spent below freezing. The derivation of the first equation in table E.12.2C is a bit complicated, but the main takeaway for this is that we have a sinusoidal curve that represents temperature which passes through the midpoint T_{mean} and has an amplitude T_{amp}. Then, f finds the fraction of the day that is below freezing for the two below-freezing segments by dividing by 2π (24 hours). Finally, we multiply precipitation by the fraction f and 9 to get the daily snowfall, again assuming a 9:1 SLR. This gives us a daily snowfall amount for any day with a Tm_{ax},T_{min}, and precipitation observation.

T_{max} = Maximum Daily Temperature	T_{min} = Minimum Daily Temperature
$T_{mean} = \frac{T_{max} + T_{min}}{2}$	$T_{amp} = \frac{T_{max} - T_{min}}{2}$
P = Daily Precipitation (Inches)	S = Estimated Daily Snowfall (Inches)

Equations E.12.1.

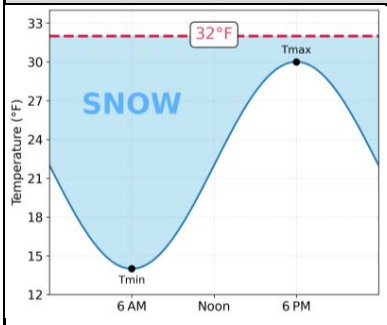
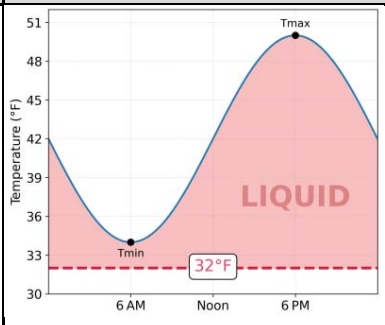
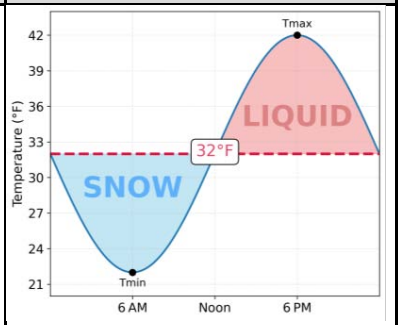
If $T_{max} < 32°F$	If $T_{min} \geq 32°F$	If $T_{max} \geq 32°F > T_{min}$
		
A.	B.	C.

Table E.12.1. Three temperature possibilities, and times in which precipitation will be liquid or frozen.

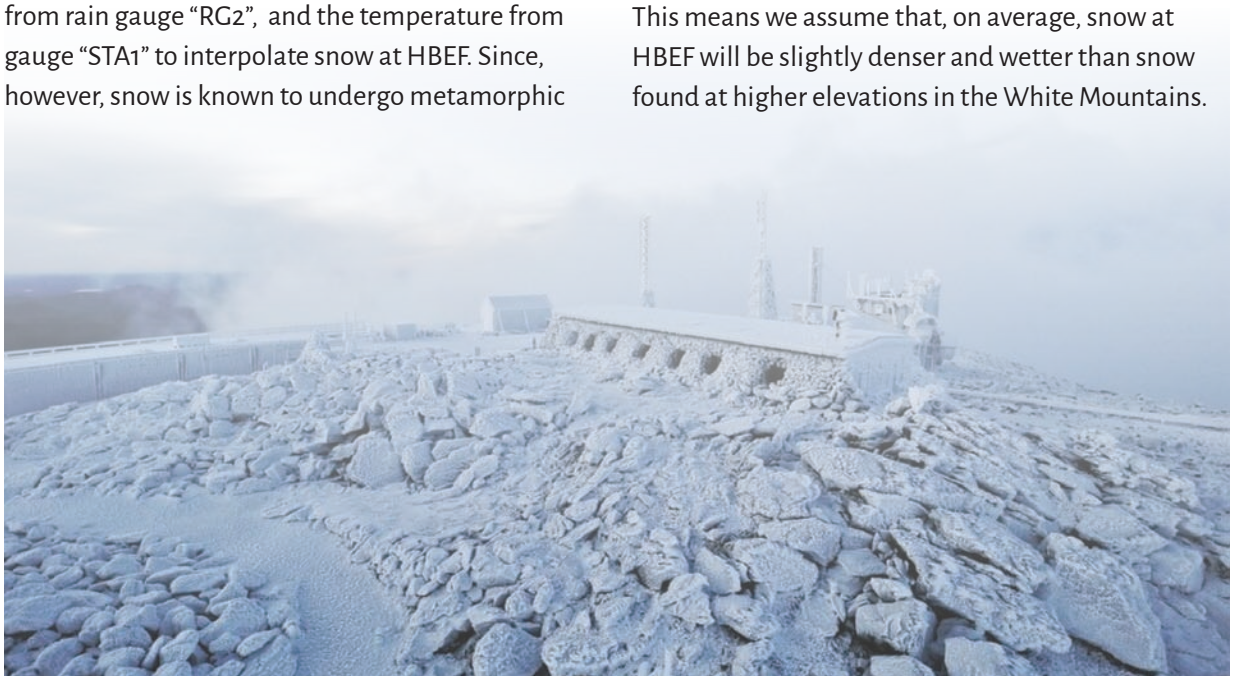
** This assumption does not hold when there is a mismatch between air temperature and precipitation type (i.e. snow can fall when air temperature is above freezing and vice versa during freezing rain events). In general, however, the temperature at the ground is an appropriate approximate indicator of precipitation type for our purposes.*

*** With the assumption being that precipitation will be equally distributed throughout the day.*

If $T_{max} < 32°F$	If $T_{min} \geq 32°F$	If $T_{max} \geq 32°F > T_{min}$
$S = P * 9$	$S = 0$	$f = \frac{\pi + 2\left[arcsin\left(\frac{32 - T_{mean}}{T_{amp}}\right)\right]}{2\pi}$ $S = P * f * 9$
A.	B.	C.

Table E.12.2. Three temperature possibilities in relation to estimating snowfall and the snowfall calculation.

The 9:1 SLR assumption comes from an attempt to normalize our snowfall assumptions with HBEF snow course data. These snow depth observations are taken weekly at the HBEF headquarters. To find the average SLR, we summed up the liquid-equivalent precipitation for an entire week that was below freezing, multiplied by different SLR modifiers, and compared it to the snow course value at the end of the week. We used precipitation data from rain gauge "RG2", and the temperature from gauge "STA1" to interpolate snow at HBEF. Since, however, snow is known to undergo metamorphic processes at all temperatures, this was a flawed methodology because it resulted in very low SLR (about 6:1) being the best fit. Thus, to account for snow metamorphology, sublimation, and other effects that may reduce liquid-precipitation caught in the rain gauge, we include a correction of about 15% - 30%. This brings SLR to between 8:1 and 9:1, so it is rounded up to 9:1 to agree better with the 10:1 average used by most NWS stations in New England. This means we assume that, on average, snow at HBEF will be slightly denser and wetter than snow found at higher elevations in the White Mountains.



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Lakes of the Clouds hut from Mount Washington.
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