Summer 2022 Vol. 63 No. 2

WINDswept

The Bulletin of the Non-Profit Mount Washington Observatory

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WINDswept

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Mount Washington Observatory™ is a private, nonprofit, member-supported institution 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.

Membership in the Observatory is open to all. Members who donate at least $60/year or $5/month receive: Tours of our famous mountaintop weather station (generally mid-May through mid-October); a one-year subscription to *Windswept™: The Bulletin of the Mount Washington Observatory*; meteorology and climate research news from the summit of Mount Washington, straight to your inbox; free admission to *Extreme Mount Washington™* museum; advanced notice of special events; a 15% discount on all purchases in our museum and online shop; and free admission to more than 300 science centers through the ASTC Passport Program (restrictions apply, please see the ASTC website for details).

Members will receive the three issues of *Windswept: The Bulletin of the Mount Washington Observatory*, for the year following the quarter in which they join. Please make checks payable to the Mount Washington Observatory and send to Mount Washington Observatory, PO Box 2310, North Conway, NH 03860-2310, or join at mountwashington.org.

Windswept: The Bulletin of the Mount Washington Observatory (ISSN 1098-7215, USPS 330-710) is published three times a year (spring, summer, fall/winter) by the Mount Washington Observatory. Periodical postage paid at North Conway, NH, and additional mailing offices. Editorial office to which all correspondence and address changes should be mailed is PO Box 2310, North Conway, NH 03860-2310 or submit via email to cbuterbaugh@mountwashington.org

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WINDswept

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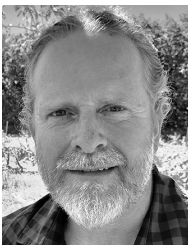
Humans Braving Extremes to Study our Weather and Climate



Charlie Buterbaugh

BY **CHARLIE BUTERBAUGH**, EDITOR

In April, as luck would have it, duty called for a two-night stay at our summit weather station. Our observers needed support during a staff transition.

The forecast warned of a storm. I was ready for a real Mount Washington challenge. The summit delivered.

A nor'easter arrived Monday night, April 18, sending forceful winds across the Whites. Gusts topped out at 142 mph Tuesday morning. As the temperature rose, glaze ice accumulated nonstop on the Observatory tower instruments, requiring frequent trips all day up the ladders and onto the parapet in extreme winds to de-ice anemometers, wind vanes, and antennas as gingerly as possible, using blunt hammers and crow bars to keep the weather data flowing.

Observer Jay Broccolo had to do this all night, alone, while assuring continuous data integrity during the storm. Observer Jackie Bellefontaine had to de-ice – while teaching me to hammer rock-hard glaze without breaking instruments – between hourly observations and appearing on camera, soaked head to toe, to lead educational programs.

On Tuesday night, they spent over an hour on the phone with our technology wiz Keith Garrett, trouble-shooting a data transmission problem so all observations could flow freely to the National Weather Service.

Wednesday's weekly shift change became less and less certain as snow piled up on the Mount Washington Auto Road. Long, bullet-proof sheets of ice were manageable with tire chains on the way up Monday before the storm – we could see them. Invisible, snow-covered ice on the steep road with no guard rails was a frightening prospect no one wanted to hazard.

There were other challenges, like dense fog. It was classic shoulder-season complexity that ultimately delayed shift change, adding an extra night to the tired yet resilient observers' week-long shift on the mountain.

My two nights turned into three. The mountain's hurricane-force winds, blinding snow, extreme cold, and icing lost their comfortable status as abstractions in my mind. I now know how stubborn glaze ice is compared to rime and what it feels like to brace against 140+ mph wind on the rooftop of New England.

Our observers level up to these harsh

Continued on page 6

Changing Seasons, Observed from the Summit

Donna Dunn

BY **DONNA DUNN,**
INTERIM EXECUTIVE DIRECTOR

It's that time when we look to summer activities. We think about vacations and make plans. We may complain that it is too hot. Or maybe we complain that the summer is too short.

In its 90th year, Mount Washington Observatory has a unique and valuable data record that is key to tracking climate in the White Mountains.

At the Observatory, summer means lots of visitors to the summit. People taking in *Extreme Mount Washington,* our museum in the State Park Sherman Adams Building. People scheduling and taking tours of our weather station. Our regular work continues while we add these summertime activities.

Yet somehow, it seems summer weather is a bit different. Is it warmer than we remember it being? Does it seem like it lasts longer? Are those summer storms more extreme than what we remember from years past? Do they have more rain or more wind or cause more damage than we expect?

Anyone who reads *Windswept* knows that the seasons don't seem to follow the patterns we expect, at least not in the past several years. Once upon a time here in many parts of New England, the expectation was no planting the garden until after Memorial Day because of frost. Can we really have guidelines like that anymore?

Here in North Conway, we had a colder than normal January. A warmer than average February. An average March. A colder than normal April and a warmer than normal May. Climate variability seems to be the hallmark of our changing seasons. Farmers and growers watch the weather concerned that really warm early spring days will cause fruit trees to blossom too early and be subject to frost. Planting of row crops happens a few days earlier each year.

Mount Washington Observatory is part of a group of organizations and individ-

uals contributing to a new exhibit at the Museum of the White Mountains on the Plymouth State University campus. "Watching the Seasons Change" is not about moving from spring to summer to fall. It is about what the environment may be like should the current trends in climate change continue.

What happens when sugar maples are no longer the dominant tree in northern New England? What might be the consequences of ponds and lakes no longer freezing? Mixing science and arts, the exhibit explores the changing environment in the mountains. Artists interpret the visible landscape; Abenaki basket-makers work with foresters to assure a supply of the brown ash they need; scientists record and study the changes to the climate and environment. This exhibit puts it all together – how people are understanding and adapting to climate changes in the White Mountains. I'm looking forward to exploring this exhibit and the broad approach to the science, culture and art impacts of our changing world.

It's pretty obvious why MWOBS is participating in this exhibition. In its 90th year, Mount Washington Observatory has a unique and valuable data record that is key to tracking climate in the White Mountains. We do watch the seasons change. We track key weather components over the decades to identify the changing climate. This is only possible because of the financial contributions that keep this nonprofit scientific organization going. Your continued support of the Observatory means that we will remain an integral part of tracking the weather and contributing to climate research for years to come.

In My View continued from page 4

conditions, working together (and frequently alone) to write mountain forecasts, maintain the 90-year data set, and research the atmosphere, all while communicating weather and climate insights widely to numerous audiences.

This edition of *Windswept* puts a focus on the critical weather instrumentation that enables the Observatory to inform search and rescue, aviation, and backcountry communities of current conditions and forecasts.

Alongside the technology are the brave people who engineer, maintain, and optimize how data are recorded, tracked, interpreted, and communicated, helping us understand the unique relationship between weather and high terrain in the White Mountains.

People sometimes ask why our weather station is staffed by people in this age of tech. I now know how to respond, convincingly, on behalf of our summit team.

Weather Station Tours Return this Summer

Guided tours of our mountaintop weather station are returning to the summit this summer. Mount Washington Observatory's supporting members can meet and interact with scientists, learn how they create forecasts, and see the instruments they use to measure weather conditions.

Guided tours of the station are a benefit provided to members to deepen understanding of our weather observers' work and daily experience at 6,288 feet. Tours are offered to members who make a donation of at least $60 a year or $5 a month per household. The weather station is located inside the Mt. Washington State Park Sherman Adams Visitor Center, so tours are only available when the visitor center is open (generally mid-May through mid-October).

There will be a few changes to how tours are offered this year. Reservations must be made at mountwashington.org (under the Visit Us tab) at least 24 hours ahead of time, so please plan ahead. This is to help our busy summit staff prepare each day. You will need your member ID to register for a tour. These IDs will be verified by staff.

Tours are available at 9:20 a.m., 11:20 a.m., and 1:20 p.m. every day except Wednesdays. Masks will be required for all tour guests while inside the weather station.

For more information, email *education@mountwashington.org*. If you have questions about your membership, please reach out to *membership@mountwashington.org*.

Observatory Introduces New Summit Museum Docent Volunteer Program

A new summit volunteer program will support critical operations with particular emphasis on the *Extreme Mount Washington* museum.

This summer and fall, seasonal museum docent volunteers will have the opportunity to provide educational programming for visitors and support daily tasks in our museum. Volunteers will act as ambassadors for MWOBS' work, history, and mission by engaging with guests and assisting our museum attendants in a busy atmosphere. They will work in pairs and have the opportunity to live with our summit crew for the week, supporting the weather station's operations.

Interested members are encouraged to read through the listed requirements, duties, and example schedule at mountwashington.org before submitting an application. Selected applicants will be asked to contribute a $10 application fee to cover the costs of a background check before volunteering on the summit.

Summit volunteer duties include:

- Acting as a key informational guide in the *Extreme Mount Washington* museum space by offering daily programs and demonstrations (training provided)
- Assisting museum attendants with duties that include cash register coverage, restocking of merchandise, and cleaning the museum space
- Providing dinner in the summit weather station for staff and assist with nightly clean-up duties in the living quarters

Warmer Season Means Opportunities for Mischief

TRANSLATED BY **SAM ROBINSON**

Meow again! When I sat down with Weather Observer Sam today, I noticed he was wearing less gear than usual. My fur coat is also starting to seem a little too thick. Could the warmer season really be starting up here?

If I am being honest, I am definitely ready to nap a little less and explore a little more. It feels like I have not ventured outside fur-ever!

The claw-some thing about springtime as the summit prepares to open is that I get to roam freely around the Sherman Adams Building where we live. There are so many purr-fect spots to explore, and I feel like I have barely scratched the surface, finding areas to play, mice to hunt down, and things to sharpen my claws on.

Nimbus warms himself in the late winter sun.

However, as some of you may know, my real fun will start when the building opens to visitors. That means more people are here to give me attention, and more opportunities arise to be mischievous. I can practically smell the hot dogs already!

I also very much look forward to getting outside again, as I have not been out there since the fall. Even though I have only ventured out a few times, it is always so fun to soak up the sun, feel the meow-tain rocks under my paws, and watch the ravens flying around the summit.

I recently did some climbing in the instrument tower to prepare myself for the outdoors. It felt a bit warmer in there, but it was still purr-etty chilly and wet.

Anyways, I think I just heard someone fill my food bowl up. I better go check. Until next time!

Growing Outdoor Community at the Heart of Seek the Peak

BY **CARRIE SLIFE**

Every July for the last 21 years, supporters of Mount Washington Observatory have come together for our annual *Seek the Peak* fundraiser.

Hikers make their way to the summit of Mount Washington in 2019. The 22nd annual Seek the Peak will take place Sat., July 16, 2022 from 12:00 noon to 6:00 p.m. at Great Glen Trails.

It's the Observatory's largest annual fundraiser, and staff have challenged this year's 22nd annual event participants to collectively raise $202,200. That's critically needed support making up a significant portion of the weather station's annual budget. All Observatory members are encouraged to join this peer-to-peer fundraiser. Once you register at seekthepeak.org, you'll receive a link to your personal fundraising page to share with friends and family, earning outdoor gear as you go. Seek the Peak has become a much-anticipated summer gathering and celebration of the outdoor community in New Hampshire. Participants come together year after year to reconnect with friends and support an organization they believe in and rely on for mountain forecasting.

Local businesses, nonprofit organizations, and outdoor gear vendors enthusiastically answered the call last year to be part of an expanded event that introduced the Mount Washington Adventure Expo, featuring food trucks and live music in a festival format at the base of Mount Washington.

The 2021 event welcomed a growing number of people seeking retreat from populated regions during the pandemic, while keeping a focus on how

A quiet moment before the opening of the inaugural 2021 Mount Washington Adventure Expo.

to responsibly recreate in the White Mountains amid expanding demands on cherished natural resources.

If there is anything that the past two years showed us, it is the importance of maintaining connections with friends and loved ones, and the outdoors have been deemed one of the safest places to do so. Throngs of people have taken to our public lands, many trying new activities for the first time, and the numbers continue to grow.

MWOBS staff have seen firsthand the impact that increased visitation can have in the backcountry. Like so many who have had to pivot during this time, the Observatory saw an opportunity, and a need, to reimagine *Seek the Peak* to respond to this increased demand for a diversity of outdoor recreation opportunities, and we have used the event's platform to provide resources that reinforce safe, thoughtful, and sustainable outdoor practices.

What has resulted is a re-imagined *Seek the Peak*, with multifaceted objectives and a mission that resonates with the broader role that the Observatory plays in the White Mountains and surrounding communities as the voice of Mount Washington. We hope to raise vital funds needed to sustain the valuable weather forecasting that so many recreating in the outdoors utilize and, with our Adventure Expo, provide a gathering space for a diverse array of community groups and outdoor recreation experts.

The inclusion of these groups is key to our goal of fostering an inclusive participant environment, as they provide valuable resources for first-time visitors to our public lands. We hope to encourage our *Seek the Peak* participants and the public as a whole to recreate on our trails, cliffs, and waterways in a safe and sustainable manner, not just for the purpose of our singular fundraising event, but in a way that enables our lands to sustain generations of future outdoor enthusiasts who will foster the same appreciation for the work of the Observatory that our current supporters do.

The Mount Washington Adventure Expo in full swing during the 2021 Seek the Peak.

While *Seek the Peak* will always carry with it the spirit of a classic hike-a-thon, we have maintained our expanded format with categories of hiking, mountain or road biking, paddling, trail running, fly fishing, or climbing as possible fundraising activities under which to register.

For a few years now, we have encouraged people to "Seek your Peak," and to further our goal of inclusion, this year also saw the addition of a "custom" registration category, which truly expands the field to all people of all ability levels.

Observatory enthusiasts comprise a diversity of backgrounds with people from urban and rural environments located across the country. We offer our forecasts and educational programs freely to the public, and we have set out to make our fundraiser just as inclusive.

If a walk around the block in your neighborhood is more your speed than a hike up Tuckerman Ravine—this is no matter. You are a part of the Observatory community regardless, and we want nothing more than to see you register, set a goal that is your very own, and join us on Saturday, July 16 to celebrate your accomplishment.

By supporting the Obs, you are not only helping to ensure that our vital weather and educational work on the summit of Mount Washington can continue; you're also helping to enrich and sustain the White Mountains community as a whole. I think we can all agree just how important that cause is.

Donate or register at *seekthepeak.org*.

Pitot 22 Approaching Designation as MWOBS' Primary Wind Instrument

BY **SAM ROBINSON**

At the Home of the World's Worst Weather™, we need to utilize extreme anemometers to accurately capture wind speed data.

The accuracy of that data is very important to our operation, informing our weather observations for aviation METAR reports, forecast models, and our own long-standing climate record.

The Pitot 22 features a large, strong aluminum body and a tail vane so big that it can internally house all pressure tubing and two separate pressure transducers.

Subzero temperatures, extreme icing, and heavy precipitation make measuring the often high wind speeds a unique scientific challenge. It would be nice if we could simply go out and purchase an anemometer designed to withstand Mount Washington's extreme weather, but nothing readily available on the market meets our requirements.

Over the years, Mount Washington Observatory staff have collaborated with outside support to develop custom pitot tube anemometers that accurately measure the wind while being robust enough to handle summit extremes. While our instrumentation is equal to the task, there is always room for continuous improvement as technology is always evolving.

Through a partnership with General Electric and the University of Massachusetts Lowell, we have recently been able to develop our latest and greatest next-generation anemometer, Pitot 22.

For over 75 years, MWOBS has utilized pitot tube technology to measure the winds on the summit. Pitot tubes are most commonly used on airplanes to measure speed as the plane flies through air; we use the technology to measure the speed of the air as it flies

Members of the Pitot 22 development team include, clockwise from upper-left, GE staff Eddie Walton and Joe Chaves and MWOBS staff Dr. Eric Kelsey, Pete Gagne, and Keith Garrett.

into our anemometer by force of the wind.

Pitot tubes are relatively simple instruments developed to measure velocity of a flowing fluid. With a hole at the tip and holes on both sides of the tube – perpendicular to the flow – a differential pressure is created, which is then measured and directly calculated according to the velocity of the flowing fluid.

Mid-20th century, MWOBS staff realized that attaching a pitot tube to a rotating vane was a great way to measure wind speed and allow instrument heating. That is the kicker. Other anemometers such as three-cup and propeller-driven anemometers are readily available, but these instruments are difficult to heat. With the extreme icing conditions that commonly occur on the summit, heat is required or else inaccurate wind data and/or mechanical failure will occur.

Back in 2013, it was becoming apparent that our primary anemometer at the time, Pitot 11 (now Pitot 19 in its most current form), was in need of improvement. In its basic design and function, it had remained mostly unchanged since 1946, consisting of a pitot static tube attached to a rotating vane to help direct into the wind.

The pitot tube was connected to two pressure lines, the total and static pressure lines, which traveled from the instrument down almost three stories in our tower to the Hays Chart, a familiar wind speed recording device. Over the years, small internal part and heating improvements were performed, as well as a more major improvement in 1992: the introduction of pressure transducers (sensors) and an electrical data logger. Prior to 1992, wind speed data was obtained solely from the Hays Chart, so the introduction of electrical sensors and components made it easier to instantly get and record data.

In 2013, it was theorized that the long length of tubing down to the weather room caused a loss of accuracy. In theory, this length, and thus volume of the system, led to dampening of pressure waves. The tubing travels from the instrument (one temperature) down through the tower (usually a slightly warmer temperature) and into the weather room (much warmer temperature). Differential pressure is calculated into wind velocity (speed) through the use of air density, and air density changes with temperature. It was clear that

these changes in temperature that the pressure system experienced could lead to a slight loss in accuracy. The tubing length had to be shortened.

Along with the overall length of the pressure tubing, other desired improvements entailed making the instrument easier to remove and install and upgrading the existing heating system. The first 10 feet of tubing coming out of Pitot 19 is actually stiff copper tubing that cannot be bent. This makes it a bear to take down and re-mount from the top of the instrument tower. Doing so requires optimal weather conditions, many sets of hands, and careful movements.

The Pitot 19 heating system is simply aged, outdated, and is also controlled from the cold room in the instrument tower. This means that our busy weather observers have to physically go up into the tower to monitor and change heater settings and frequently de-ice the instrument manually because the heaters are inadequate.

By 2015, the joint effort between MWOBS, GE employee volunteers, and senior engineering students from UMass-Lowell benefited all involved, providing the Observatory with funding and support, GE with regional public relations, and students with a senior capstone project. It was determined that this next-generation anemometer had to have minimized pressure tubing length; no unbendable, hard-to-install components; and the best heating system possible, resulting in greater accuracy, ease of use, and durability.

By 2017, the project had reached the manufacturing and testing stage, with a fully custom instrument that was built to incorporate all areas of improvement. The new pitot anemometer features a large, strong aluminum body that has a tail vane so big that it can internally house all of the pressure tubing and two separate pressure transducers (a 0-10" P-T for lower wind speeds [up to 156 mph], and a 0-70" P-T for higher, potentially record breaking speeds [up to 418 mph]).

The incorporation of the pressure system directly in the body of the anemometer took care of many improvements all at once. The tubing length was truly minimized (~6 inches vs 840+ inches in Pitot 11/19) as well as eliminating any large temperature swings in the system. The sensors simply use electrical wires to connect the instrument to our weather room, so when removal or installation is necessary, a few wires just need to be unplugged. No longer do we have to deal with that long, unbendable, and fragile section.

Finally, the new anemometer also features a fully custom heating system with robust, integrated heaters directly in the body. The controller for the heating system is still located in the cold room of the tower, but this new controller is connected to our network, meaning it can be remotely monitored and controlled.

The new instrument, named Pitot 22 this year, was first installed on the summit in 2018. Over the course of the next few years, it was removed and reinstalled multiple times as we worked out the bugs and further improved the design. Since the instrument was so unique and complicated to build, it was its own prototype. Initial testing was done on Pitot 22 before it made it to the summit, but as with most any products, the real world

testing is what really matters. Simulating the conditions that it would actually experience on the summit would be nearly impossible to achieve in a lab setting. So what better way to test it than to install it and run it alongside our other anemometers right here on the summit?

The heated Pitot 22, left, and Pitot 19 anemometers are shown in mid-April as heavy glaze icing covers the rest of the instrument tower.

Recently, Pitot 22 was sent to the University of New Hampshire for third-party wind tunnel testing as part of the journey to making it our primary anemometer. Before this designation, we want to be sure it is capturing and recording the most accurate wind speed data possible (remember, the wind data are used in multiple important ways, including informing aviation, search and rescue, and backcountry communities of current summit conditions).

Along with the physical anemometer itself, data sets from real wind events on the summit were also sent along to be analyzed. Multiple initial tests were performed to confirm the anemometer would operate correctly inside the wind tunnel.

Then it was tested in the tunnel alongside the reference pitot tube with a MWOBS-supplied transducer. Pitot 22 recorded slightly lower wind speeds than the reference pitot at the high end of the speed range, so a non-pitot tube, ultrasonic anemometer was added for a third dataset comparison. This also recorded slightly lower speeds, showing the accuracy of Pitot 22 is likely superior and that all anemometers are unique, differ in design, and can produce different measurements. It is also a reminder that lab tests are difficult to set up and complete perfectly, and that real-world testing is the best form.

As far as real historical wind data analyzation went, a slight discrepancy between Pitot 19 and Pitot 22 was found at speeds over 120 mph, but again, the difference was relatively minimal and mostly expected.

Pitot 22 is getting closer and closer to becoming the primary anemometer on the summit, and by the time of this publication, it may already be there. If visiting the summit sometime soon, be sure to look up at the top of the instrument tower to admire Pitot 22's sleek and shiny design against the sky over Mount Washington.

For more specifics on testing, view the April 12 *Science in the Mountains* program at mountwashington.org.

Mesonet Measures Weather across Mountainous Terrain, Despite Challenges

BY **BRIAN FITZGERALD**

Mount Washington Observatory is more than the summit weather station at 6,288 feet. A significant portion of the nonprofit organization's work involves operating remote weather monitoring stations throughout the White Mountains.

Known as the Mount Washington Regional Mesonet, the network of 18 remote stations, including the Auto Road Vertical Profile (ARVP), measures temperature and relative humidity, with additional variables at many locations. Data are transmitted continuously via radio links and available to the public at mountwashington.org.

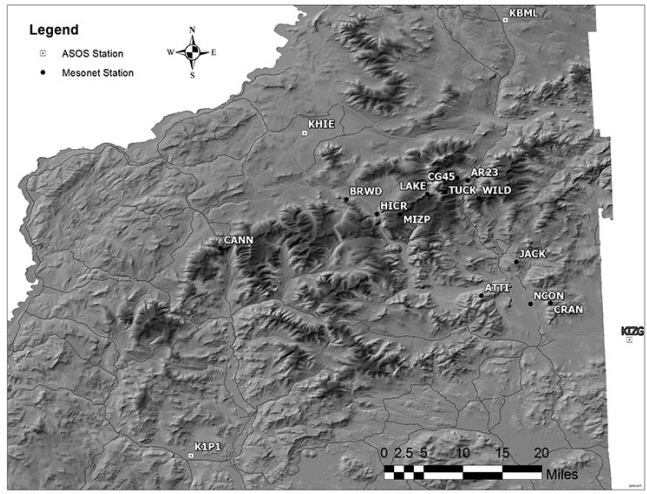
The Auto Road Vertical Profile 5,300 station is located along the Mt. Washington Auto Road. An RM Young Heavy-Duty Wind Monitor HD-Alpine anemometer is installed at this station in summer only due to heavy rime ice accumulations and high winds in the colder months.

All stations need to withstand the frequent combination of intense cold, high precipitation amounts, icing, and super-hurricane-force winds in a mountain environment. Due to these challenges, the mesonet employs rugged instrumentation, an innovative radio communications relay approach, and carefully selected sites that balance ideal measuring environments with station survivability.

Data collected from the mesonet are used by regional meteorologists including MWOBS staff to validate weather model guidance, recreationalists accessing conditions in the backcountry, groups operating on the mountain (Mount Washington State Park, Cog Railway, and Auto Road), and search and rescue groups conducting missions

in the region.

The mountain environment is not a uniform landscape, and interactions between the atmosphere and terrain can cause a wide variety of conditions across time, space, and elevation. A network of remote stations at varying elevations allows many different types of data users to understand just how much the weather varies from place to place across the mountain range, where conditions on higher peaks can be drastically and dangerously different.



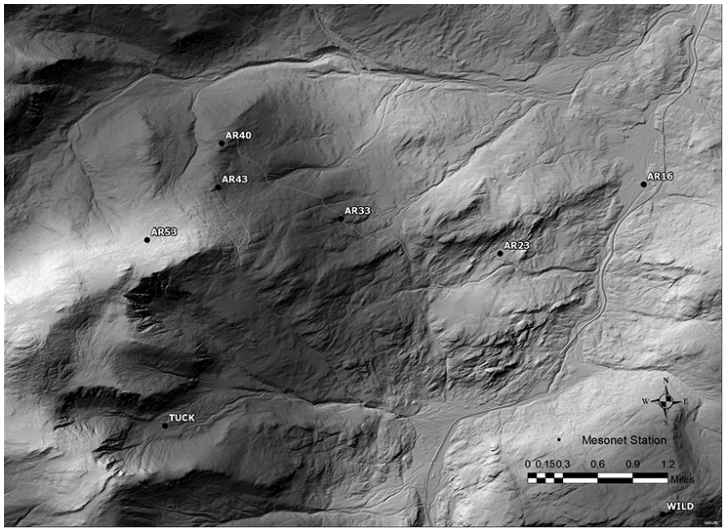
This map showing the Mount Washington Regional Mesonet station layout with approximate locations includes data from New Hampshire's Statewide GIS Clearinghouse, GRANIT. Not all ARVP sites are visible.

The White Mountains and particularly Mount Washington are known for extreme weather. Every type of frozen precipitation and a wide variety of weather phenomena ranging from extra-tropical cyclones (nor'easters, clippers, low-pressure systems), blizzards, heavy snows, upslope precipitation, snow squalls, ice storms, extreme riming and glazing conditions, whiteout conditions, extreme winds, severe thunderstorms, inland flooding, and extreme heat and cold are experienced with some frequency, and particularly in the colder months of the year.

On the summit of Mount Washington (6,288 ft), where MWOBS has continuously operated a mountaintop weather station with records dating back to 1932, extreme weather conditions are routinely recorded. Most notably, the highest gust ever recorded by a staffed weather station was recorded on Mount Washington at 231 mph in April of 1934.

Mount Washington experiences frozen precipitation every month of the year. From December to March, the summit receives an average 41.4 inches of frozen precipitation per month with a maximum monthly recording in February 1969 of 172.8 inches.

Aside from the MWOBS summit weather station, only four Automated Surface Observing System (ASOS) stations are established around the White Mountains region. These stations at Fryeburg, ME; Whitefield, NH; Berlin, NH; and Plymouth, NH are all at surface level presently. National Weather Service Cooperative Weather Stations (COOP) are present at Pinkham Notch Visitor Center at the eastern base of Mount Washington, and in North Conway Village.



Six stations along the auto road make up the ARVP (Mount Washington summit station not pictured). TUCK and WILD sites add two additional observing stations to the east of Mount Washington.

Located in the western White Mountains, the US Forest Service Hubbard Brook Experimental Forest has been monitoring meteorological conditions dating back to 1955. The location and elevation of most of these sites leave fairly large measurement gaps, making for an insufficient number of ground stations to adequately cover the complex terrain and diverse microclimates of the mountain region.

The region, including the White Mountain National Forest (WMNF), is a recreation and tourist hub throughout the year, with millions of people visiting annually. Due in part to the area's use and nature of usage, combined with unforgiving weather conditions, the New Hampshire Fish and Game Department, US Forest Service, and local volunteer rescue teams carry out in excess of 200 search and rescue missions annually for victims that include hikers, climbers, OHRV operators, and other backcountry visitors (New Hampshire Fish and Game, 2022).

While multiple backcountry forecasts for the higher terrain of the White Mountains are available, including those produced by MWOBS, knowledge of actual conditions at elevations between ASOS stations and the summit of Mount Washington was previously limited in nature prior to establishing the Mount Washington Regional Mesonet in 2003.

Before 2003, steps were underway at MWOBS to apply for a significant NOAA grant for a major "Research Instrumentation and Infrastructure Upgrade" (RIU) to replace and expand instrumentation and infrastructure both at the summit weather station and at two administrative/research sites in the Mount Washington Valley. The motivation for the mesonet was initially born out of conversations with regional National Weather Service (NWS) Weather Forecast Office (WFO) officials in early 2003 based specifically around what would best help them advance their mission of weather forecasting for the region.

Recommendations from this meeting included establishing "air temperature measurement stations with real-time data transmission at several elevations along one or more routes from the base of Mt. Washington to the summit," with intervals ideally every 500 or 1,000 feet to provide better definition and confirmation of predicted freezing levels during precipitation events (Pszenny 2003).

Additionally, NWS officials recommended establishing a wind measurement network on other nearby mountain summits. Finally, they noted a general interest in acquiring surface observation data from almost anywhere in the Mount Washington/White Mountains region.

Upon MWOBS' successful NOAA RIU grant, funds were used to first install the six ARVP stations along the Mt. Washington Auto Road in 2003, followed by an additional 14 stations over the span of several years.

As of early 2022, the mesonet records meteorological data around the clock from 18 automated stations in addition to the fully staffed MWOBS summit weather station and National Weather Service Cooperative Weather Station located in North Conway Village, New Hampshire.

Stations comprising the mesonet were laid out by MWOBS staff across multiple installation campaigns. The ARVP, along with the summit of Wildcat Ski Area to the east of Mount Washington, were installed first, starting in 2003, followed by most of the current stations by 2008. The most recent station installed was in 2015 (NCON).

Station Name	Elevation (ft.)
Administrative Office/North Conway (NCON)	538
ARVP 1600 (AR16)/ Maintenance Garage	1617
ARVP 2300 (AR23)	2,310
ARVP 3300 (AR33)	3,307
ARVP 4000 (AR40)	4,091
ARVP 4300 (AR43)	4,403
ARVP 5300 (AR53)	5,302
Attitash Mountain (ATTI)	2,274
Bretton Woods (BRWD)	2,992
Cannon Mountain (CANN)	4,078
Cog 4500 (CG45)	4,498
Cranmore Mountain (CRAN)	1,670
Highland Center (HICR)	1,926
Jackson/Tyrol Mountain (JACK)	2,671
Lakes of the Clouds Hut (LAKE)	5,030
Mizpah Hut (MIZP)	3,799
Tuckerman Ravine (TUCK)	4,003
Wildcat Mountain (WILD)	3,990

Mount Washington Regional Mesonet active station names and elevations as of 2022.

At its widest, the network stretches from Cannon Mountain in the west to Cranmore Mountain in the east at a distance of roughly 30.8 miles, and 18.8 miles from the southern-most point, Cranmore Mountain, to the northern-most point, the 4,000' ARVP site.

The network has the highest density of sites (13, not including the MWOBS summit weather station) clustered around Mount Washington and neigh-

boring peaks, ravines, and valleys across an area of 18.6 square miles, with an average of 1.4 miles between sites.

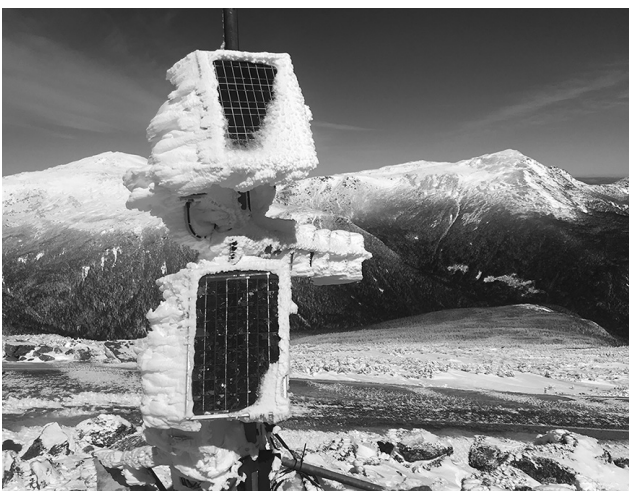
The vast majority of stations reside on private property and are owned by a variety of stakeholders, including ski areas, backcountry and roadside facilities operated by the nonprofit Appalachian Mountain Club (AMC), the Mt. Washington Auto Road, and the Mount Washington Cog Railway. Agreements at these locations provide free data access and current conditions information to landowners and their patrons. Additionally, MWOBS provides communication, real-time weather data services, or webcam access in trade at some stations.

The mesonet measures a variety of near-surface variables at different elevations with a limited number of stations recording surface and subsurface temperature. Regardless of location, each mesonet station was designed to provide the most accurate data possible with the least amount of data interruptions. To this end, design solutions were needed to overcome the challenges associated with bitter cold, high winds, heavy snow, and frequent icing in mountainous terrain. Rigid, small footprint stations were erected, rugged sensors were selected, and an innovative power management system was designed.

In rare cases of a total power failure, a direct in-person connection may be required to retrieve data. Each site is equipped with either a radio connection or antenna including a unidirectional antenna, pointing at the nearest receiver, and an omnidirectional antenna, which allows for alternative connections to be obtained should the primary connection be disabled.

Radio links are used across the mesonet due to limited cellular connectivity throughout the mountains, while also taking advantage of excellent line of sight from prominent mountains such as Mount Washington.

Data transmission may not always be possible if prolonged inclement weather (long-lived fog, rime ice on solar panels, snow-buried panels) has prevented sufficient power generation. When available power does not meet the consumption



Heavy rime and glaze ice accumulations, high wind exposure, and limited power generation at some stations, particularly AR53, limit the amount of equipment that can be operated with reduced power.

requirements of a specific station, a power-saving protocol is enacted that powers off communication services at a station-specific value. Once the power level rises above another station-specific value, communication and webcam services are restored in order to preserve recording of data during low power output.

All mesonet data are communicated through a variety of internet connections (DSL, fiber-optic, cable, point-to-point, point-to-multipoint microwave) and are polled directly by the summit weather station on Mount Washington. There, data are ingested, processed by multiple physical and virtual servers, and replicated to servers at both the MWOBS administrative offices in North Conway and in the cloud, creating near-real-time access to the data via the internet. Data are additionally backed up offsite in multiple locations.

Summit weather station weather observers maintain a 24/7/365 operations schedule that provides around the clock monitoring of data services. Summit staff regularly incorporate mesonet data as a key tool for the higher summits forecast, produced twice daily by MWOBS.

Rime and glaze ice, accumulated during prolonged periods of fog, likely impact temperature and humidity readings even after fog events end.

Financial support for the long-term operation on the mesonet remains a priority for the continued success of the network. Additional opportunities to potentially add meteorological monitoring capabilities such as barometric pressure, precipitation, wind speed, and direction at existing sites (where operationally possible) are one area of interest. Adding additional ecological monitoring equipment such as soil temperature and moisture probes, and air quality measurement sensors, represent another area of interest, with a hope of making stronger connections between monitoring the physical and natural world.

MWOBS has begun to regularly participate in professional working groups of mesonet operators through the American Association of State Climatologist (AASC) and the National Mesonet Program (NMP). Engaging with these groups and mesonet operators has been particularly valuable in learning from others in the community about shared challenges and solutions.

MWOBS Director of Technology Keith Garrett and Weather Observer/Meteorologist Jay Broccolo contributed to this article.

Jack Middleton Retiring as Trustee after 65 Years of Service

BY **CHARLIE BUTERBAUGH**

After 65 years as a Mount Washington Observatory trustee, Jack Middleton of Freedom, NH is planning to retire when the board holds its Annual Meeting in June.

Jack Middleton in 1988 at the summit of Imja Tse, elevation 20,252 feet, in the eastern Himalayas of Nepal.

An attorney and accomplished climber, Middleton served as the board secretary for many years, attending his first trustee meeting in that role in January 1957 at MIT.

He was recruited by Dr. Charles F. Brooks, director of MWOBS' meteorology program and a professor at Harvard, who knew Middleton from his work as a weather observer in 1952-53. They frequently talked on the radio when Dr. Brooks was working at the Blue Hill Observatory, south of Boston, and Middleton was on shift at MWOBS.

Before becoming a trustee, Middleton had earned his law degree at Boston University and started his career at McLane in Manchester, NH. The law firm is now known as McLane Middleton. Jack was named partner in 1962.

His connection to the White Mountains began long before as a child, when his parents would send him and his brother to summer camps in Maine to

Jack and his late wife Ann Dodge are shown during their last ski together in Tuckerman Ravine.

protect them from the polio epidemic in suburban Philadelphia. He climbed Mount Chocura at age 11 and Mount Washington at age 12.

Midway through college in 1947, he took a summer job working at the Tuckerman Ravine shelter.

"Unlike most of my peers, I liked climbing, so when the opportunity to get a job with the AMC came up, I took it," said Middleton during a recent visit to our office in North Conway. He worked three summers at the shelter, where he met Ann Dodge, daughter of AMC leader and Observatory co-founder Joe Dodge.

Jack and Ann's fondness for each other was immediate. They eventually married after Jack graduated from college and spent two years overseas with the Marine Corps during the Korean War in 1950-52, including service as part of a landing force with the 6th Fleet.

Middleton remembers his year as a weather observer on Mount Washington in 1952-53 fondly.

"The crew consisted of four of us. We worked 20 days up and 10 days down," he said.

The Signal Corp would take observers up to the Horn via snowcat. Jack and his co-workers then had to walk the remaining 3.5 miles up to the summit for a shift change.

His favorite memories on the summit were in spring time after the long winter. If the observers had a good weather day, between synoptic observations they would grab their white wooden Army surplus skis with "bear trap" bindings

Jack and Ann.

and head out for a run in the Ammonoosuc Ravine, Great Gulf or Tuckerman Ravine.

Middleton has seen many things change and helped steward the Observatory through major developments, including the construction of the Sherman Adams State Park building in 1980. Both of his sons, Peter, a civil engineer and current MWOBS trustee, and Jack, an architect, worked on the project.

"Ann would put together some food and climb the mountain to feed them," Middleton said. "It combined all of our interests in one place."

In addition to his role as secretary and trustee for MWOBS, Middleton has served on the Mount Washington Commission since its inception in 1968, at one time representing both the Mount Washington Cog Railway and the Mount Washington Auto Road on the commission.

Although he is retiring, Middleton plans to continue attending Observatory Board of Trustees and Mount Washington Commission meetings.

"All of us should be very proud that the Obs is still alive and doing well. It's a tough place to do anything up there, just to keep it going. I'm very proud of the fact that it is alive and well today," Middleton said.

"Mount Washington is New Hampshire's icon."

We thank Jack for his extraordinary dedication and more than six decades of service to Mount Washington Observatory.

Outlook for Summer Includes More In-Person Experiences

BY **BRIAN FITZGERALD**

We had another busy spring sharing the work of Mount Washington Observatory with a wide array of audiences. Since January, MWOBS staff have presented over 56 virtual programs (through May) to an audience totaling in the thousands who have tuned in for our virtual classroom series, *Science in the Mountains™*, *WeatherX,* and other distance connections.

As we look ahead to welcoming visitors back to the *Extreme Mount Washington* summit museum and our summit weather station, 2022 looks to be an exciting year.

If you haven't had the chance to join us online, Weather Observer/Education Specialists Jackie Bellefontaine and Stephen Durham have helped the *Home the World's Worst Weather™* Live virtual classroom series continue to be a big hit with students of all ages. Now in its third year, the program has been a reliable and engaging way for middle school-aged students to expand their content knowledge on topics in weather, climate, and climate change. Participating classrooms in New Hampshire, Maine, and New Jersey have been loyal followers, adding tough questions for our weather observers. If you missed any of our programming for this past school year, head over to mountwashington.org/classroom.

The *Science in the Mountains* lecture series is celebrating two years of virtual programming this July, with more than 5,000 participants viewing lectures on Zoom, Facebook, or after the fact on YouTube. The virtual series continues to be an outstanding way to connect current science and scientists with MWOBS' far-reaching audience. Highlights from this spring's programs include Dr. Baker Perry and "Reaching New Heights on Everest," Dr. Peter Crane's "19th Century Weather Observers on Mount Washington," and Pat Scanlan's "Avalanche Forecasting in the Presidential Range." Be sure to check out our upcoming list of topics and presenters, and don't forget to sign up over at mountwashington.org/sitm.

School is out for summer, but that doesn't mean learning at MWOBS has to end! In fact, the summit weather station and *Extreme Mount Washington* summit museum will open to the public this summer, increasing our capacity to engage in person once again. MWOBS is excited to launch a summit-based museum docent volunteer program for those looking to support the Observatory's mission to advance understanding of weather and climate

Weather Observer and Education Specialist Jackie Bellefontaine gets ready for a Chat with a Scientist program as part of WeatherX.

in the museum space. If you're interested in applying for the week-long volunteer experience, be sure to visit mountwashington.org and click "Get Involved" to learn more.

Finally, if it's been on your "bucket list," be on the lookout for more information later this year on the possible return of the Winter Overnight EduTrip program. A staple for well over two decades, the EduTrip program has been the ultimate way to learn about and experience the inner-working of MWOBS' summit weather station. Program dates and spaces are likely to be limited, but if you've had your eye on this program in the past, stay tuned for updates later this year.

As always, if you have any questions about educational programming at MWOBS, don't hesitate to drop me an email over at *education@mountwashington.org*. Happy learning!

Winter 2021/Spring 2022 Weather Data

	DEC	JAN	FEB	MAR
Temperature (°F)				
Average	14.7	2.2	8.1	14.1
Departure	+2.9	-3.6	+2.2	+1.2
Maximum	43	32	38	44
Date(s)	11th, 16th	1st	18th	31st
Minimum	-12	-31	-24	-18
Date(s)	23rd	11th	14th	3rd, 4th
Precipitation (inches)				
Monthly	5.70	4.52	4.65	6.59
Departure	-1.65	-1.22	-0.80	-0.13
24-hour Maximum	1.35	1.82	1.05	1.40
Date(s)	6th/7th	17th/18th	22nd/23rd	12th/13th
Snowfall (inches)				
Monthly	34.6	38.6	32.7	42.1
Departure	-13.1	-2.8	-10.6	-4.1
24-hour Maximum	5.8	11.7	7.7	12.8
Date(s)	18th/19th	17th/18th	25th	12th/13th
Season Total	96.5	135.1	167.8	209.9
Departure	-7.1	-9.9	-20.5	-23.8
Wind (mph)				
Average	47.2	44.9	45.4	44.8
Departure	+3.2	-0.7	+0.8	+5.0
Peak Gust/Direction	122 W	144 E	125 W	131 W
Date(s)	7th	17th	19th	7th
Days 73+	20	19	19	18
Days 100+	8	10	9	6
Other				
% Sunshine	29	42	36	27
Clear Days	0	7	1	0
Partly Cloudy Days	3	3	3	3
Cloudy Days	28	21	24	28
Days with Fog	30	26	26	30
Days with Rain	5	2	4	9
Days with Snow	28	20	20	27

Winter Whiplash a Defining Factor of the 2021-22 Season

BY **RYAN KNAPP**

During winter 2021-22, it felt like with every step forward on snowfall, we quickly fell two steps back as warmth and rain followed to melt out any gains. It was also quite windy with several days' worth of hurricane-force winds.

December 2021

A pair of fronts on the 1st provided snow. High pressure provided clearing overnight into the 2nd prior to a warm front providing a wintry mix. A cold front on the 3rd provided a return of snow and winds. Conditions improved briefly on the 4th prior to a passing low that returned fog, snow, and winds which would linger into the 5th. A warm front on the 6th provided a wintry mix turning to rain, then a cold front transitioned back to snow late in the day and into the 7th. Upslope snow showers lingered until the 8th. A low passed to our south on the 9th/10th providing snow. The 11th saw low pressure passing to our west resulting in a warm flow over the summits. Precipitation transitioned to rain as temperatures tied the daily record high and the summit lost two-thirds of its snow cover prior to a cold front overnight returned winter weather. In the wake of the cold front, snow lingered and winds boosted. Fair weather skies returned with high pressure on the 13th. A cold front on the 14th returned fog, snow, cold, and winds. Brief clearing on the 15th gave way to a warm front late. Temperatures soared to a new daily record high of 43F on the 16th resulting in a transition to rain once again. A trailing cold front passing on the 17th returned cold, snowy weather. Low pressure on the 18th provided nearly 6" of snow by the time it exited on the 19th. Fair weather conditions returned on the 20th with high pressure. The 21st saw a low clip the region providing mostly fog and winds. Low pressure in the Gulf of Maine on the 22nd provided fog, snow, and winds into the 23rd. Fair weather returned early on the 24th but eventually eroded to fog and wintry weather overnight and into the 25th. Upslope snow showers lingered on the 26th. A cold front on the 27th provided light snow showers. An upper level trough on the 28th/29th provided light to moderate snow. Fair weather returned early on the 30th prior to a warm front late in the day returning fog and snow. A warm front early and a cold front late on the 31st ended the year with a few inches of new snow.

January 2022

High pressure started the year with clear skies but a deepening low late in the day and into the 2nd returned fog and a wintry mix to the summits. High pressure on the 3rd/4th allowed for cold conditions despite fair weather skies overhead. A low from the west on the 5th provided light snow grains. A coast-

al low passed on the 6th/7th providing measurable snowfall. High pressure on the 8th provided improving conditions. Low pressure by Hudson Bay swung a warm front NE on the 9th followed by a cold front on the 10th. High pressure built in on the 11th with temperatures plummeting to 31F below, a new daily record low. A trough from the west on the 12th provided seasonal temperatures and light snow. A front stalled to our south on the 13th provided fog and light snow. The front lifted on the 14th as a low passed along the coast. While summits missed out on snowfall, a tight pressure gradient set up boosting winds to 110 mph by the 15th before things wound down through the day and into the 16th.

A strong coastal low moved north on the 17th boosting winds to 144mph and dumping over a foot of snow by the time it exited on the 18th. Upslope snow, cold air, and triple digit gusts continued on the 19th as the low slowly exited. A Clipper on the 19th provided additional snowfall and additional gusts over 100 mph. High pressure built in on the 20th allowing winds to decrease as a clearing trend set up late. Fair weather conditions continued on the 21st/22nd as the ridge crested and then slid offshore. A cold front on the 23rd provided snow then high pressure provided clearing on the 24th. A weak low late on the 24th lingered into the 25th providing light snowfall and cold temperatures. Arctic high pressure on the 26th provided clearing with temperatures remaining below 0F. A cold front on the 27th provided light snowfall that lingered into the 28th. A coastal low on the 29th provided winds, snow, and cold temperatures. Upslope snow showers and cold lingered on the 30th. Building high pressure ended the month.

February 2022

High pressure built over the region on the 1st then slide offshore on the 2nd. A cold front on the 3rd/4th provided over 8" of snow with an additional 1" of upslope snow falling early on the 5th. The 6th a ridge passed as a Clipper approached for the 7th providing light snow/sleet. A coastal low on the 8th provided a few inches of snow and an upper level trough provided upslope snow showers on the 9th. A weak low from the west passed on the 10th then high pressure provided clearing on the 11th. A low passed to the north overnight and into the 12th providing scattered snow showers and high winds. Low pressure passed offshore on the 13th/14th resulting in just a few flurries. High pressure on the 15th/16th provided clearing and high winds.

A warm front on the 17th provided mixed precipitation as temperatures soared and tied daily record highs for the 17th and 18th before a passing cold front plummeted temps below 0F and provided a return of winter weather. A Clipper on the 19th provided additional snowfall. High pressure provided fair weather skies on the 20th/21st then a weak trough overnight returned fog. A low from the west passed on the 22/23rd providing a wintry mix and high winds. High pressure provided improved conditions on the 24th. A strong low from the SW dumped 7.7" of snow on the 25th. High pressure provided clear but blustery conditions on the 26th. A cold front on the 27th/28th provided 6.5" of snow prior to high pressure providing clearing to end the month.

March 2022

A Clipper on the 1st provided nearly 5 inches with a trailing trough on the 2nd providing additional light accumulations. A cold front on the 3rd provided additional snow then tapered as high pressure built into the 4th. A weak trough overnight provided a few flurries then high pressure built for the 5th. A warm front lifted northeast on the 6th providing a wintry mix turning to rain as a new daily record high of 39F was met. The 7th saw the daily record high tied before temperatures plunged resulting in rain transitioning back to snow. Winds boosted to 131 mph as the low exited and high pressure built from the west for the 8th. Low pressure passed to the south with a few snow showers brushing the summit on the 9th. High pressure reigned on the 10th then exited on the 11th as a trough swung through with a few flurries. A low from the mid-Atlantic moved north on the 12th dumping 13" of snow by the time it exited on the 13th. Upslope snow showers lingered on the 14th/15th prior to tapering ahead of a frontal system late on the 15th, which provided additional snow.

The 16th/17th, the region was sandwiched between a low to the north and south but both only provided variable cloud cover overhead. A warm front lifted on the 18th/19th providing a wintry mix that turned to rain. A cold front on the 20th resulted in rain turning back to snow. Another cold front on the 21st then upslope conditions lingered into the 22nd prior to tapering as high pressure built in late. The ridge continued for the 23rd then exited on the 24th as a warm front lifted northeast providing a wintry mix turning to rain. A coastal low on the 25th transitioned precipitation back to snow. A weak low continued snowy weather on the 26th. A cold front on the 27th continued snowfall. An upper-level trough provided additional light snow showers on the 28th-30th then high pressure provided clearing. A warm front ended the month with a wintry mix that transitioned to rain.

The Observatory with rime ice at sunset on March 14.

COMPILED BY **JAY BROCCOLO**

This past winter saw a series of ups and downs in terms of temperature, precipitation, wind, and snow depth on the summit of Mount Washington. One of the first blog posts of the year was a review of the 2021 averages with showing what has happened thus far in 2022. Staff Meteorologist Ryan Knapp described 2021 as "warm, dry, foggy, and windy." To find out why these words were chosen, let's look back at some of the stats from last year.

Our average temperature for 2021 was 29.7°F (-1.3°C), which is 1.7°F above the 1991-2020 30-year normal for our station. This would make the annual average temperature of 2021 tied with 1938 for the third highest in our dataset, which started in 1932. Our warmest temperature recorded in 2021 was 67°F (19°C), which occurred on August 12 and again on August 13. Our coldest temperature recorded in 2021 was 28°F below (-28°F/-33°C), which occurred on March 2.

In terms of total liquid precipitation, from January to December of 2021, the summit received 77.41 inches, which was 13.82 inches below the 1991-2020 30-year normal for our location. From January to December of 2021, the summit received 222.3 inches of snow, which was 59.5 inches below the 1991-2020 30-year normal for our location.

In terms of winds, for 2021 our average was 34.9 mph, which was equal (+/- 0.0 mph) to the 1991-2020 30-year normal for our location. Our highest gust recorded for 2021 was 157 mph, which occurred on January 24th. From January to December, we had 135 days which had gusts of 73 mph or greater and of those days, 38 days had gusts that were 100 mph or greater.

As for our weather during 2021, we averaged 35% of the possible sunshine. The summit had 16 days that were noted as clear or mostly clear, and there were 44 partly sunny days, with the remaining 305 days being filed under mostly cloudy, cloudy, or obscured (fog). We had 321 days with at least some amount of fog recorded during a 24-hour period. We had 145 days with rain and 156 days with snow. If interested in additional weather data, please check out our F-6 page (updated nightly), our Normals, Means, and Extremes page, our Current Conditions Page, our 48-Hour Higher Summits Forecast, and our Annual Temperature Graph. These can all be found on our website under the Experience The Weather tab on our home page.

February saw the usual winter storms that brought strong frontal boundaries producing warm and cold snaps with some type 2 ice fun and a plethora of

Rime ice accumulates on rocks at the summit in early February.

amazing cloud photos from Weather Observer Sam Robinson. Back on February 18, a rapid drop in temperature behind a cold front caused melted snow and ice along with liquid precipitation to rapidly freeze. A more detailed description of event goes like this.

The temperature was holding steady at around 38°F on Friday, Feb. 18. The station had just tied the record high temperature for the day. Winds were out of the west/southwest with sustained winds in the 70 to 90 mph range, and it was raining out. The beautiful snowpack that took all winter to build... we watched a lot of it melt away. Jackie had to trudge through a foot or so of slush to get the precipitation can that morning. It was rather messy. Then, the winds suddenly relaxed and the temperature started to drop. We knew there was going to be a steep decline, given the synoptic set-up. The White Mountains seemed to be at the bottom of the Low's center as it crossed through the region, which aligned with the bottom of the trough aloft. As the cold front crossed through, wind direction shifted 20 degrees to the north, making it westerly. It took one hour for the temperature to drop 18 degrees.

At 0630 EST, the temperature was 38°F (rounded). Over the next hour, the warm front abated, and the pressure bottomed out at roughly 780 hPa, signifying the passage of the trough and that the cold front would be quickly approaching. The night prior, we looked at the weather prediction models to see if our forecast had changed, which it had not really, but we did see that the models were trending towards a stronger cold front. The strong cold front and frontogenesis were projected to pass between 0600 and 0700 EST, along with the bottom of the trough as depicted by the wind barbs.

The cold front actually began to sweep through, at summit level, at 0631 EST. Around 25 minutes later, the temperature dropped 16°F, then another 2 or 3°F over the next half hour. Behind the front, cold air advection was much less and presented as a more gradual slump in temperature rather than the plunge that occurred initially.

Sam's favorite clouds followed later in February where he discussed his favorite cloud types. "My personal favorite are cirrus, part of the cirri-form cloud classification, or high cloud family. These form at the highest parts of the atmosphere (usually 20k to +40k feet above ground level) and are made up completely of ice crystals, rather than water vapor, even in the summer. Cirrus clouds are usually the first sign of incoming moisture ahead of approaching systems, and are also usually the first and last clouds to be viewed at dawn and dusk. Because they are so high up in the atmosphere, the rising/setting sun illuminates them before/after it crests the horizon and this is usually what leads to magnificent sunrises and sunsets. During the day, cirrus clouds usually appear thin, fibrous, and mostly white in color except near the horizon line where they look slightly yellowed due to a greater distance and thickness of air between the clouds and viewer. They also tend to move slower across the sky than other cloud types due to their greater distance from the viewer.

My next favorite cloud is the cumulonimbus, part of the cumulus cloud classification, or low cloud family. These clouds tend to be thunderstorms and are formed when very strong upward motion grows the clouds very high into the atmosphere. The uppermost reaches of cumulonimbus clouds can actually spread out to form cirrus clouds, and when the cloud reaches this high, lightning and hail tend to form as well (because remember, cirrus clouds are ice crystals, and lightning and hail come from ice crystals).

Cumulonimbus tend to form only during the summer in our region because atmospheric conditions need to be just right with very warm air at the surface and cold air aloft. The warm air wants to rise and the greater the gradient, the faster and higher these clouds and storms will form. Sometimes these clouds can have a base only a few thousand feet off the ground but the height reaches over 60k feet up into the atmosphere!

Closing out the winter season was March, but that does not mean the summit stops experiencing winter. Former Weather Observer Matthew Addison presented a telling of icing on the summit with a series of photos that are sure to inspire wonder. Matt even goes on to say something as bold as "Rime ice and hoar frost are by far the most spectacular things I've witnessed on the summit. While hoar frost is not typically a hazard, rime ice can be extremely dangerous for aircraft. But as an observer, it's just absolutely stunning to watch ice form throughout the night." It's a bold statement I say, because Matthew has chased storms and forecasted weather all over the world!

These are only a short few posts from our Blog and encourage you to head on over to read more of them from the beginning of 2022.

Temperature Inversions, when Summit is Warmer than Valley

BY **JACKIE BELLEFONTAINE**

If you're familiar with our Current Summit Conditions page, you may have noticed the Auto Road Vertical Profile (ARVP) temperature section. It displays temperature data recorded by automated weather stations on a vertical transect along the Mount Washington Auto Road, as a part of the Mount Washington Regional Mesonet.

On a typical day, the ARVP looks like Figure 1, with temperatures dropping as elevation increases. The reason temperatures decrease with elevation in the troposphere is related to air pressure. Air at higher elevations is under less pressure than air at lower elevations, so air molecules at higher elevations spread out further, resulting in temperature decreases.

Temperature and pressure have a linear relationship; if there is a decrease in pressure, there must be a decrease in temperature.

We are also able to determine the rate at which temperature changes vertically in the atmosphere, known as a lapse rate. The environmental lapse rate, the rate at which temperature changes vertically in the troposphere, can change from day to day. Averaging lapse rates over time and large geographic regions have shown that in the troposphere, the standard (or average) lapse rate is approximately 3.0°F per 1,000 feet. Looking at the ARVP in Figure 1, we can observer this phenomenon.

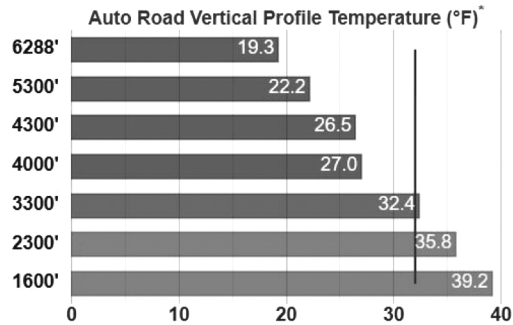


Figure 1. ARVP temperature found on the Current Summit Conditions page at mountwashington.org.

However, there are days when the ARVP shows the inverse of this behavior, where the summit is much warmer than lower elevations. This is called a temperature inversion.

Also known as a thermal inversion, this occurs when a warmer, less dense air mass overlays a colder, denser air mass. Inversions have an influence on visibility, precipitation, cloud formation, and air quality.

An inversion acts similarly to a cap on the upward movement of the air from the lower layers, therefore convection is

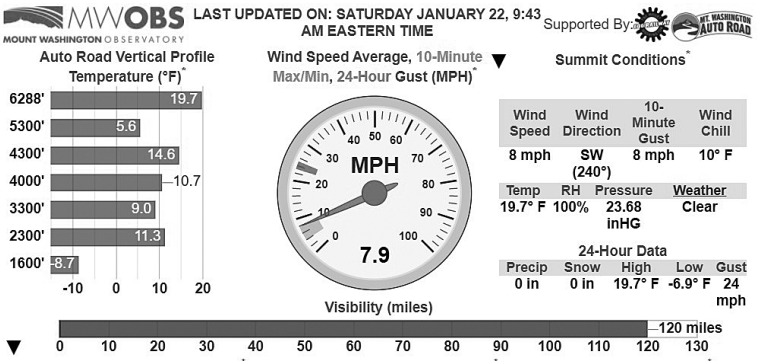


Figure 2. The ARVP on the morning of Jan. 22 shows an inversion as temperatures increased from 1600 to 6,288 feet..

limited to below the inversion. Instead of clouds growing vertically, they spread out horizontally.

When a low enough inversion is present, vertical growth of convective clouds is limited to the point where they are unable to produce precipitation (though rising air can begin above the inversion boundary, which can produce precipitation).

In addition to capping the vertical growth of clouds, temperature inversions are also able to trap air pollutants, which can affect the air quality of an area. Within the inversion layer, fog is likely to form and smoke and dust particles can be trapped, all helping to reduce visibility.

There are several types of inversions, including ground, frontal, and subsidence. To briefly describe each of these, a ground inversion is very common, occurring when air is cooled through contact with a colder surface. For example, at night when radiational cooling occurs, the air right above the surface begins to cool quickly. Air is a poor conductor of heat, and therefore the cooler temperatures near the surface are not transferred to the higher layers of the atmosphere without the aid of some wind. The lack of mixing allows for the atmosphere to become very striated with distinct temperature differences at each level.

A frontal inversion develops when the air mass associated with a shallow cold front undercuts a warmer mass, lifting it aloft. With a frontal inversion, humidity may be high and clouds may be present about the inversion.

Subsidence inversions form when a widespread layer of air descends. The descending air is warmed by compression resulting from the increase in atmospheric pressure, which results in a reduced lapse rate. If this descending air sinks low enough, the air at higher elevations becomes warmer than at lower elevations. When an upper layer warms at a greater rate, an inversion is formed.

Inversions can also cause some interesting optical phenomena. Inversions can distort how the sun appears around sunrise and sunset, sometimes making the sun appear compressed into a "pancake" on the horizon, as seen in Figure 3.

Inversions can also cause a phenomenon called a superior mirage. Mirages are a result of the refraction of light passing through layers of air with changing refractive indexes due to temperature differences, therefore density differences. With a superior mirage resulting from a temperature inversion, light is bent downwards towards the person observing. This makes distant objects appear higher than their actual positions.

So, if you're interested in thermal inversions, check out the Current Summits Conditions page, and you might catch one!

Figure 3. A "pancake" sun at sunrise (a) and a distorted sun at sunset (b). Both optical phenomena are the result of a temperature inversion.

Scholand Moves on after Three Years as Summit Ops Director

Rebecca Scholand gives a thumbs up while watching the Falcon-9 launch on May 3, 2020 from our summit weather station. The day marked the U.S. resuming sending people to space.

We bid a fond farewell to Summit Operations Director Rebecca Scholand in early April, so we thought it fitting to include an article in this space about her work at Mount Washington Observatory.

Scholand has written the Summit Operations column for the past three years, keeping members up-to-date on developments at our weather station while working through unprecedented challenges caused by the pandemic. Her history with the Obs actually began well before that time period.

She started as a summer intern on the summit in 2010 – between her junior and senior years of college studying applied meteorology at Embry-Riddle Aeronautical University – then returned for a winter internship to gain research experience working on the Observatory's Pitot 11 anemometer.

Asked what initially drew her to the Observatory, Scholand said, "When looking at your career ahead, the Observatory comes up in any meteorology textbook. The concept of the world's worst weather is very intriguing, and once I got here and learned more about the Obs, living and working on the summit, I found a mountain community that I connected with. That sealed the deal and I was all in."

After graduation, Scholand joined the Obs museum staff, followed by a move onto the Education team focusing on outreach in the valley. After that, she took a role working for past Summit Operations leader Ken Rancourt, a post that included research on rime ice accumulation.

This led to a longer-term role as a Weather Observer and Education Specialist where Scholand led daily programs and EduTrips while also serving as a shift leader for the summit team.

In May 2019, after some time away from the Obs to grow professionally and personally working as a brand ambassador for Backpacker Magazine, she rejoined the organization as Summit Operations Director.

"I learned a lot from Ken (Rancourt), living and working on the summit, and this was my opportunity to come back to manage the facility," Scholand said. "I have such a passion and respect for the work being done on the summit. Without the observers, we don't have an Observatory. It holds a very special place in my heart."

When she took the position, it was before the pandemic. Her aim was to grow the team and their potential, which held true throughout her tenure.

"We've just had to go about it in a very different way," Scholand said. "It's always a fight to keep the Obs going. This fight and drive is so unique to our organization. Maybe it's because you're battling the conditions at the summit. You can't just let things stop."

She led the weather station team of observers and interns through an ever-evolving era, full of uncertainty as summit volunteer and visitor programs changed and staff adopted wholly new processes to ensure their health in the face of COVID-19.

Looking back, one of her favorite parts of the job has been helping new summit staff learn how to observe the weather real-time and interpret it for the rest of the world. Playing an integral role in that work and watching her staff succeed in the process were very rewarding.

"They don't miss an observation. It's their hard work, and you're proud that has happened," she said. "They joke and call me the summit mom."

Referring to the Observatory's anniversary year in 2022, Scholand said, "90 years, that's an amazing part of history. Keeping that history going rides on our backs. Our observers take pride in that and you see their maturity shift as they understand that. Even when they leave, they go on to contribute, using skills they learned here."

Asked what she will miss about the job, she described the interaction with Mother Nature that you can't get anywhere else.

"I can always visit, but there is something special about observing the weather, recording it, and sharing it," she said.

Scholand will also miss the people she worked alongside. "They've not only been a family but have watched me grow up in some way, as I earned appreciation for the work I produced. The mountain has seen me grow up. Because I arrived here at 21 and am leaving at almost 34, the Observatory has been a huge piece of my life."

After giving so much to support the Observatory during the pandemic, Scholand is looking forward to spending more time with family and friends.

Studies to Investigate Alpine Zone's Future and Elevation's Influence on Weather

BY **BRIAN FITZGERALD**

As I write, the familiar expression "April showers bring May flowers" comes to mind during a wet and stormy April. However, atop Mount Washington, it won't be until June when miniature alpine plants – well-adapted to the harsh environment above tree line – begin blooming.

In a warming world, questions persist about just how tough these famously resilient species are, and whether the environmental factors that determine tree line, like high winds and icing, are changing.

Recent analyses of Mount Washington Observatory (MWOBS) summit records show warming temperatures at 6,288 feet and a changing condition of winter (Murray et al. 2021). Additionally, Kelsey and Cinquino (2021) have noted that winter thaw events are becoming more frequent over time on Mount Washington.

With this in mind, what might the future hold for this unique alpine ecosystem?

To explore this question, researchers at MWOBS and the Appalachian Mountain Club (AMC) will team up this summer to begin a deeper dive into climate trends on the summit, focusing on long-term wind and humidity records.

High wind speeds and moisture combine to create winter icing and riming events that mechanically damage trees at higher elevations, preventing significant tree growth, and thus allowing miniature alpine plants to thrive.

If temperatures are warming and the nature of winters are changing on the Rockpile, what does this mean for tree line and the rest of the alpine ecosystem? As researchers at MWOBS and AMC pursue answers to this question, staff at both organizations aim to improve modeling predictions and inform the public and natural resource managers.

While project work kicks off investigating climate trends, another project will get its start this summer establishing and clarifying something known as near-surface seasonal lapse rates (NSLR) on Mount Washington.

Lapse rates can generally be defined as the amount of change in a variable, like temperature, with the change in elevation. Many fans of MWOBS' Auto Road Vertical Profile (ARVP), which shows real-time temperatures at various elevations between 1,600 and 6,288 feet on our Current Summit Conditions page at mountwashington.org, have noted the typical occurrence that as you travel up the mountain, temperature decreases with height (see Weather 101 on p. 36 to learn about temperature inversions). Simply put, understanding how NSLR on Mount Washington compare with other locations will likely give ecologists, mete-

orologists, climatologists, and other researchers a key tool in determining a number of different ecological processes.

Tree line on Mount Jefferson is shown near the bottom of this image as blowing snow comes off the mountain's leeward side.

Forecasters at MWOBS are always cognizant of the relationship between temperature and elevation whenever a Higher Summits Forecast is produced. For starters, there are no other weather stations at 6,000 feet across the Northeast, meaning our weather observers must rely quite heavily on forecast models and theoretical lapse rates that are established for broader regions. This can be especially challenging when distinguishing things like precipitation type, snowpack, inversions, and cold-air pooling (Minder et al. 2010). It's also possible that NSLR affect precipitation convection lift processes (Shadbolt et al. 2019).

As work gets underway this summer, MWOBS staff and interns will be busy making full use of our weather station's "mountain of data" that AMC Staff Scientist Georgia Murray has frequently described. The Mount Washington Observatory Regional Mesonet (MWRM) will be a particularly important source of data for the lapse rate project, taking full advantage of the higher resolution that these remote sites provide in the complex terrain of the White Mountains. (See feature story about our mesonet on p. 18.) Be sure to stay tuned throughout the year and into 2023 for updates on both the lapse rate and climate trends projects.

Finally, MWOBS staff are looking forward to engaging peers in the science community through a number of professional conferences coming up this year. In late June, the University of New Hampshire will play host to the American Association of State Climatologists Annual Meeting, where our staff will look to connect with a number of different state climate offices that also support regional mesonets.

Also in June, MWOBS will send a representative to the American Meteorological Society's (AMS) Mountain Meteorology Conference hosted in Park City, Utah, where we will present our Pitot-22 next-generation pitot-static anemometer, launched this year, to this group of meteorology professionals. Last but not least, MWOBS staff are already looking forward to the AMS Annual Meeting in Denver, Colorado in January of 2023.

For any questions about research and product testing at MWOBS, be sure to reach out to *research@mountwashington.org*, and stay tuned for an enlightening summer of science!

New Tech on Mounts Washington and Everest

BY **KEITH GARRETT**

Three new live-streaming weather cameras at mountwashington.org allow our supporters and the public to watch Mount Washington's extreme weather and see incredible views using any Internet-connected device.

The new cameras include our tower weather cam (operating May-Oct), deck weather cam, and Wildcat weather cam. In addition to live views, the cameras also provide time lapses. We're excited about the opportunity to serve a wider audience in response to high demand for our weather cameras, a service maintained by MWOBS thanks to our members' ongoing support.

Another exciting technology update involves two new Observatory-built wind sensors that are now performing weather research on the world's highest weather monitoring stations.

The two pitot static tube anemometers, designed and custom-built by our team, were installed in May on Mount Everest. We were asked to work on the project in 2021 by a team of climate scientists, including Dr. Tom Matthews of King's College London and Dr. Baker Perry of Appalachian State University.

Perry and Matthews previously partnered with the Observatory in 2019 to test weather stations on Mount Washington for an earlier National Geographic expedition to Everest.

"The highest mountains in the world are a critical yet under-monitored cog in the Earth's climate system," Perry said. "Holding vast quantities of snow and ice, they act as water towers to over a billion people downstream. Yet we know little about how they are responding to climate warming because they are so hard to monitor, with their extreme cold and powerful winds challenging humans and sensors alike."

With 90 years of experience measuring extreme weather on Mount Washington, the Observatory specializes in instrumentation that can withstand the world's harshest weather conditions, with Mount Washington serving as an ideal testing ground. A subarctic environment on par with Antarctica and the polar regions, nowhere else in the contiguous United States is able to offer such readily accessible and consistently extreme conditions.

Look out for a more detailed story in the next edition of *Windswept*!

Looking forward, one of the projects I'm looking forward to working on this summer is attempting to repair and rebuild our two broken ceilometers. A great aspect of working with tech-

A view captured mid-May from our new tower weather camera.

nology at MWOBS is the vast array of technologies we employ every day. One minute you're setting up a new phone extension, or fixing some bad HTML code on the website, and the next you're taking apart some very expensive piece of equipment that has failed. Hey, it's already broken, so you can't make it worse!

A ceilometer uses lasers to measure cloud heights. I will leave it to the meteorologists to explain why ceilometers are important.

Until relatively recently, MWOBS maintained two ceilometers. One ceilometer at the base of the Mount Washington Cog Railway, and the other at the Mt. Washington Auto Road base.

The Vaisala CT25k unit on the west side of Mount Washington was capable of reading three different layers of clouds up to 25,000 feet above ground level. The Vaisala LD40 on the east side at the auto road is capable of measuring three cloud layers at heights up to 43,000 feet above ground level. Both units are circa 2002.

However due to their age, both have failed. These units are end of life, and no replacement parts are available. One has a suspect power supply, while in the other, the laser module has failed. At prices starting around 40,000 each, it is worth a little elbow grease to see if we can make them shine again.

Did I mention they use lasers!? I am fairly certain that some time with a multimeter and soldering station can bring the CT25k back to life, however the LD40 may be more difficult. The laser module in the LD40 was replaced once before, with great difficulty sourcing the part. I hope to find something with similar power ratings, and due to how they work, the frequency of the laser needs to be precise.

If I can get the units to power up, the next stage would be testing.

Gardens Come to Life as Busy Summer Begins

BY **HANK AND LINDA DRESCH**

With the beginning of spring, the gardens around the North Conway offices are coming to life. Once again, our dedicated volunteer gardeners Barbara Althen and Bill Ofsiany have begun their efforts to make the gardens a true show piece in North Conway. Please stop by and enjoy the display when you are in the area.

Bill Ofsiany loosening the soil around the shrubs.

We're waiting now for the bulbs, donated by our volunteers last fall, to show off their splendor. Bill also reports that he has started many annuals at his home in Connecticut for replanting in our gardens when there is no longer a danger from frost. Another challenge for our gardeners is the eradication of an invasion of yellow hawkweed in the front lawn, a project Barbara will work on with Peter Crane, who has already invested many hours.

Summer is the time for Seek the Peak once again, and we're all looking forward to this popular fundraising event. As always, it is scheduled on the third weekend in July (7/16/22). It will include an expanded reprise of the Mount Washington Adventure Expo. This same event was so well received last year that it will become a mainstay of the day. We are looking forward to receiving the list of volunteer positions needed.

We also want to take this opportunity to thank Kim Henry and Linda Denis for coordinating the March mailing while we supported our grandson in Minneapolis for the Junior National Nordic Ski Championships. (The New England team won the overall event.) Kim and Linda also stepped up for the April mailing, completing the job on their own.

As always, we couldn't accomplish the activities without support of our fabulous volunteers. The folks who have most recently given of their time include:

Barbara Althen
Kathy & Ed Boyle
Peter Crane
Linda Denis
Linda & Hank Dresch
Peter Fisk
Karen Franke
Kim Henry
Ava Honan
Bill Housum
Marie Kaspar
Joan & Sandy Kurtz
Bill Ofsiany
Jane & Ken Rancourt

UPCOMING EVENTS

ANNUAL MEETING - JUNE 25

The Mount Washington Observatory Annual Meeting is a recap of the prior fiscal year. It also gives a chance for Observatory members to meet the staff and trustees. This year, the meeting will be held on Saturday, June 25 at 11:00 a.m. at McAuliffe-Shepard Discovery Center in Concord, NH. Exhibits will be open and lunch will be served. Email membership@mountwashington.org to RSVP.

SEEK THE PEAK - JULY 16

Seek the Peak is Mount Washington Observatory's largest annual fundraiser. All outdoor enthusiasts are invited to raise funds, set goals, and earn gear – all in support of the observatory's work. In the expanded format introduced last year, new and returning participants are invited to select a self-led outdoor challenge of choice, set a fundraising goal, share their personalized fundraising page with friends and family, and ultimately celebrate on Saturday, July 16 at the observatory's Mount Washington Adventure Expo. The expo takes place at at Great Glen Trails at the base of Mount Washington and is open to all Seek the Peak participants, Observatory members, and the general public from 12:00 noon to 6:00 p.m. For more information, visit **seekthepeak.org.**

90TH ANNIVERSARY OF MWOBS OCTOBER 15

Four ambitious volunteers who loved the mountain environment carried equipment and supplies to the summit in Oct. 1932 to establish our mountaintop weather station. It was a Depression year, but with private funding, Alex McKenzie, Bob Monahan, Joe Dodge, and Sal Pagliuca were determined to improve forecasting methods. On Oct. 15, 2022, Mount Washington Observatory will celebrate 90 years of continuous moisture, wind, and temperature observations, data that have proved vital to researching longer-term climate trends. Stay tuned for details as we plan to celebrate the unique dedication of our supporters, staff, and trustees.

MEMBERSHIP MILESTONES

25 Years

Whitney A. Beals
Penny and Scott Bennington
Cathy Borsinger
Lloyd Cuttler
John Gutowski & June Rogier
Richard S. & Susan M. Jackson
Kenneth M. Johnson
Kenneth J. & Nancy Johnson
Patricia Kanouse
Richard E. Lewis Jr.
Eric Miller
David J. Payne
David Redman
Eric A. Richard
Acmena Schmid
Russell J. Spaight
Marvin and Arlene Swartz
William H. Tworek
Stanley C. Yutkins

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Science on the Fly
Settlers' Green Outlet Village
Ski The Whites
Smartwool
White Mountain Milers
White Mountain Oil & Propane
David J. MacKenzie
David Raizen
Mark Badger
Michael and Sue Zlogar

...Thank you

Tributes & Memorial Gifts

Deborah Clark	In Memory of Victor F. Clark
David Greer	In Memory of Charlie Humphreys
Jean Humphreys	In Memory of Charlie Humphreys
McLane Middleton, Professional Association	In Honor of Jack Middleton
The Edmund & Betsy Cabot Charitable Foundation	In Memory of Bradford & Barbara Washburn

GREEN FLASH

Mother's Day on the Summit

Weather Observer Sam Robinson talks on the phone with his mother while enjoying the sunset view from the observation tower after a day's work on Sunday, May 8.

CORPORATE SUPPORT