

Humans Among the Clouds

By

Saima Sidik

B.S. Biology
McGill University

M.S. Microbiology and Immunology
Dalhousie University

SUBMITTED TO THE PROGRAM IN COMPARATIVE MEDIA STUDIES/WRITING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTERS OF SCIENCE IN SCIENCE WRITING AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SEPTEMBER 2021

© 2021 Saima Sidik. All rights reserved.

The author hereby grants to MIT permission to reproduce and to distribute publicly paper and
electronic copies of this thesis document in whole or in part
in any medium now known or hereafter created

Signature of Author: _____

Graduate Program in Science Writing
May 19, 2021

Certified by: _____

Seth Mnookin
Professor of Science Writing
Director, Graduate Program in Science Writing

Accepted by: _____

Alan Lightman
Professor of Science Writing
Thesis Advisor

Humans Among the Clouds

Weather observers have meticulously documented Earth's climate for centuries, but with climatology turning toward automation, their way of life may become a relic of the past.

By

Saima Sidik

Submitted to the Department of Comparative Media Studies/Writing
On May 19, 2021 in Partial Fulfillment of the Requirements
For the Degree of Master of Science in Science Writing

ABSTRACT

For over 100 years, scientists have trekked to an observatory on top of Blue Hill in Milton, Massachusetts to observe and record the weather. When the Observatory was founded in 1885, scientists' understanding of Earth's atmosphere was still too limited for them to reliably predict the next day's weather. Today, a global network of satellites, weather balloons, airplanes, and ocean buoys makes Blue Hill's contribution to day-to-day weather prediction minimal, and yet the Observatory has found itself at the center of a looming crisis — climate change. Throughout the decades, Blue Hill scientists have stayed deeply committed to consistency. They continue to use thermometers, barometers, anemometers, and other equipment from as far back as the 1800s to avoid disrupting their record by changing their instrumentation. As a result, records from Blue Hill and similar sites are some of the most reliable indicators that the Earth's climate has shifted in a small, but meaningful, way. Old equipment is difficult to maintain, however, and justifying their seemingly-arcane methods to the lawmakers who control their budget can be challenging. As technology evolves, and automation sweeps through disciplines ranging from meteorology to medicine, will Blue Hill weather observers be able to maintain their way of life? And what will science lose if they can't?

Thesis Supervisor: Alan Lightman

Title: Professor of the Practice of Science Writing

ACKNOWLEDGEMENTS

Thank you to everyone who introduced me to the fascinating lives of weather observers. In particular, thank you to Elizabeth Suzedell at the Blue Hill Observatory for letting me spend a day peering into her routine.

Thank you to the Taylor/Blakeslee fund and the MIT Graduate Program in Science Writing for funding this work.

Thank you to my classmates Anna, Ali, Alice, Kelso, Elizabeth, Robert, and Nafisa, for being such good friends and colleagues. If we ever have to survive another pandemic, lets hunker down together again.

Thank you to all the GPSW faculty and staff, and to my alumni mentor, Josh Sokol, for their advice and encouragement. In particular, thank you to Alan Lightman, my thesis advisor.

Lastly, thank you to Jesse, my husband, best friend, and almost constant companion throughout this last year. Without you, I would not be me.

To find the ground truth, one has to rise early. Just after sunrise on a bitter December morning, Elizabeth Suzedell stood on the roof of a three-story tower in Milton, Massachusetts, about 10 miles south of Boston, taking in her surroundings. Pine trees covered the surrounding land with the snow from a nor'easter two days earlier still clinging to their branches. Lakes punctuated the foreground, with mountains in the distance. Boston's skyscrapers extended above the landscape, but they were a small interruption to the panorama of forests and snow-covered fields.

"I can see Mount Monadnock, so that's 70 miles," Suzedell said, assessing the visibility in the Northwest. "North-northeast to south-southeast, the visibility is a bit lower. Maybe 15 miles? I know Hull is over there, and you can barely see it."

Suzedell, a senior studying meteorology at the University of New York, Oswego, works as a weather observer at the Blue Hill Observatory whenever she's home from school. For 135 years, scientists have come to the top of this hill to take readings of atmospheric conditions, examine the sky, measure precipitation, and carefully document their observations. Because of their work, generations to come will know exactly what the weather was like at this east coast vantage point on any given day.

The pompom on Suzedell's hat shimmied in the light breeze as she made a slow 360-degree turn, taking in everything there was to see from the roof. As a Massachusetts native, she knows how to dress for cold weather. A heavy black coat with a fur-lined hood covered the athletic gear she wore to stay comfortable during her eight-hour shift at the Observatory. With an earth-toned mask covering her mouth and nose, her blue eyes and the tips of her two blond braids were all I could see sticking out of her winter clothing.

One hundred percent of the nearby pond was covered in ice, Suzedell noted. Not surprising on this 14° Fahrenheit morning when the sun had just crested the horizon. Wispy, innocuous stratus clouds streaked about one eighth of the sky. Working with quiet determination, she wrote everything down on the clipboard that dictated the flow of her workday.

On one side of the roof, there was a clear glass sphere, about the size of a grapefruit, held by a metal clamp, as if a globe had been replaced by a giant marble. This was the Observatory's Campbell Stokes Sunshine Recorder — a type of instrument that Blue Hill has used to record the number of hours of sunlight since the late 1800s. The glass ball acts like a magnifying glass that burns a strip of paper tucked between the ball and the clamp. As the sun rotates, the position of the burn travels across the paper.

These days, [pyranometers](#) can replace Campbell Stokes instruments. Like disc-shaped spaceships, about six inches in diameter, these instruments have glass bulges in their centers that capture sunlight and convert it to measurable electricity. Pyranometers are more convenient and precise than Campbell Stokes instruments, but it's not just nostalgia that drives Suzedell and her coworkers to keep doing things the old way — The Blue Hill Observatory is one of just a few sites around the country where weather observers do everything they can to keep their protocols consistent, using the same tools and techniques as the generations of scientists who came before them.

“It’s really important that we stick to the same exact way that we’ve been doing it,” Suzedell had told me earlier. While the slight variation that might result from switching to a new instrument, or moving an instrument to a new location, isn’t meaningful for day-to-day weather forecasting, the Observatory is in this for the long haul, she explained. Their climate record started almost a century before the environmental movement, and yet it’s one of the few reliable sources of information that climate scientists can turn to when they want to judge how atmospheric conditions have changed over the last century.

Despite their predisposition toward antiquity, the observers don’t shun scientific advances. Rather, when a new piece of equipment comes on the market, they add a new column to their spreadsheets and start running it alongside their older instruments, meaning that the Observatory houses a hodgepodge of equipment from many different eras. Observing climate change takes decades if not longer, so the data the Observatory collects today may be used to answer questions that won’t be asked for another hundred years. When you’re performing an experiment that might not be designed until you have great-great-grandchildren, you might as well collect as much data as possible.

Climatologist Zeke Hausfather from the Berkeley Earth project calls records like the one kept by Blue Hill, “a gift to modern scientists.” Many natural metrics help researchers discern what the climate was when the Earth was younger. The spacing between tree rings, fossils that reveal coral growth, and the ratios of isotopes found in ice cores, for example, all correlate with temperature and precipitation. But to make sense of the tools nature provides, scientists need to calibrate them against a climate record they can trust. Meticulous measurements like those kept by Blue Hill provide the ground truth on which much of climatology is based.

As Suzedell typed, a draft came through the observer’s room. The building had seen better days, and in addition to being chilly, the paint was peeling here and there. The vestibule linking the tower to the administrative area had an especially pernicious leak, and big sheets of paint were peeling off of its ceiling.

The Observatory is raising money to repair the building, but the old equipment that surrounded Suzedell has become hard to maintain as manufacturers have stopped making replacement parts. Change is inevitable, be it in weather monitoring, in medicine, or in our daily lives, but it comes with growing pains. In this age of increasing automation, as technological advances overshadow the work done at Blue Hill, will there remain a role for Suzedell and other weather observers? What will happen to climatology if their long-standing traditions come to an end?

It was 1884 when Abbott Lawrence Rotch went for a stroll on Blue Hill and came up with the idea of starting the United States’ [longest continuous weather record](#). Having recently finished a bachelor’s degree at MIT, Rotch was feeling at loose ends, and he hoped a walk up the small mountain would be calming. An inheritance from his late father meant Rotch didn’t need to work, so finishing school had left a void in his life that he hadn’t yet filled.

For weeks after his walk, Rotch kept thinking about the unobstructed view from the top of Blue Hill, and how easily he'd observed the weather from this vantage point. He had a long-standing interest in the weather, extending back at least to age 17, when he started recording weather observations in his diary. Although he'd studied mechanical engineering at MIT, he'd maintained his interest in weather throughout college, once even writing [an article for the Institute's newspaper](#) debunking his fellow students' claims that the previous winter had been unusually cold. (He did concede, however, that the winter had been quite dark and gloomy.) Two weeks after his trip up Blue Hill, Rotch's listlessness had faded as he wrote in his diary that he was considering constructing a weather observation station at the hill's summit. With it, he hoped to answer meteorological questions that had long occupied his mind, such as how elevation affects wind speed and precipitation.

Rotch consulted town officials and fellow scientists from his time at MIT, who encouraged him to follow through with his plan. Less than a year later, he constructed a two-bedroom living space where he'd live, attached to a turret atop which he'd observe the weather. On January 31, 1885, fireworks marked Blue Hill Observatory's official opening, and Rotch moved in along with an MIT student named [Willard Gerrish](#) whom Rotch had hired to help him. From that point forward, Rotch and Gerrish dutifully recorded information such as temperature, pressure, precipitation, and wind speed three times a day — a rhythm similar to the one Blue Hill weather observers abide by today.

Blue Hill's continuous weather record helps modern climatologists predict what weather will be like in the coming decades, but in the 1800s, predicting the next day's weather was still a lofty goal. Rotch built Blue Hill Observatory only about [forty years after telegraphs](#) first let meteorologists communicate quickly about conditions in disparate locations — a prerequisite for weather forecasting. British navy admiral [Robert Fitzroy had attempted](#) to use this new-found ability by issuing the world's first weather forecast in 1861, but his report was light on the details. The North and West of England would experience moderate wind, he said, while in the south the wind would be “fresh,” and over all the weather for the next two days would be “fine.”

Although predicting weather was an ambitious goal the late 1800s, Rotch wanted to reach beyond this practical problem and truly understand how the atmosphere worked. Perhaps he was motivated by a suspicion that humans would one day face a problem along the lines of the current climate crisis. The Swedish scientist Svante Arrhenius realized in the 1890s that [increasing atmospheric carbon dioxide levels were likely to warm the planet](#), even though the concept didn't become prevalent in the scientific zeitgeist until the 1960s. Arrhenius's work may have convinced Rotch that a consistent weather record would become important, or perhaps his scientific training had simply taught him that consistency is always the best policy. Whatever his rationale, he and his successors went to great lengths to ensure that measurements were taken the same way, every day, and that when changes to observing protocols were unavoidable, they were documented rigorously.

Decades before Rotch set up shop on Blue Hill, Smithsonian scientist [Joseph Henry](#) started a similar meteorological pursuit involving citizens across the United States. A physicist by training, Henry wanted to understand the chaotic nature of the atmosphere, as well as predict the weather. With both these goals in mind, Henry recruited a network of hundreds of volunteer

weather observers throughout North America. The volunteers recorded metrics like temperature, humidity, and precipitation, then reported back to the Smithsonian Institution once a month. Eventually, Henry also enlisted the help of telegraph operators who reported their local weather to him in real time.

Henry's forecasting endeavors were moderately successful in areas where his network provided good coverage, but collating the large amounts of data needed for wide-spread weather predictions became too big a job for the Smithsonian. In 1870, [Henry convinced the U.S. Army's Signal Service](#) to add weather forecasting to its portfolio of communication-related duties. When Rotch began recording the weather in 1885, he reported his findings to the army.

By the turn of the century, the Observatory's scientists had taken their atmospheric observations into the sky. In 1894, pioneering meteorologist William Eddy visited Blue Hill, where he and the Observatory's scientists strapped a [thermograph](#) to a kite and took their observations to the sky. The instrument was made of a metal arm that drew a line around a circular piece of parchment with the height of the line indicating the temperature. Drawing a squiggly line around the label on a coffee can would produce a similar looking graph. The apparatus rested on a board with wires that ran over it, providing a handle to attach the thermograph to the kite. Over four hours of flight, the thermograph provided the world's first continuous measurement of the temperature above ground level.

The Observatory's scientists probed the atmosphere with kites on many occasions over the next few decades, including one unfortunate day in 1913 when a kite broke free and became tangled in the wheel of a train in nearby Braintree. An estimated five kilometers of wire wound around the train's axel before it stopped. Today, weather balloons, airplanes, and satellites provide much easier ways for scientists to gather information from the higher reaches of the atmosphere, but a whole wall of the Observatory's gift shop is devoted to kites as a testament to their early importance.

As meteorology evolved throughout the early 1900s, [so did aviation](#). The Wright brothers made their historic first flight at Kitty Hawk in 1903, and by 1960, airport development was booming. Storms are dangerous during flight, so aviation officials had a vested interest in taking weather observations at airports. By their nature, airports are distributed in a way that's convenient for collecting weather data, so [a partnership](#) between the Federal Aviation Administration and the National Weather Service developed naturally. Airports are still among the primary sites where weather observations are recorded today.

Just as airports were providing wide-spread data collection venues, [advances in computer science](#) finally let scientists process data on the scale that's needed to make reliable daily weather predictions. As meteorologists took advantage of this modern technology, they also started wondering if airport employees really needed to spend their time taking weather observations. "It has been a slow and labor intensive process," [wrote U.S. Airforce Captain James A. Lindquist](#) in the a 1977 issue of *Bulletin of the American Meteorological Society*. "There are significant advantages that automation can provide to the taking and dissemination of a weather observation."

So scientists invented the Automated Surface Observing Station, or ASOS, to replace the humans who had diligently recorded observations for decades. When the first generation of these machines appeared at airports in the 1960s, they only reported temperature, wind speed and direction, and pressure, but they freed human observers to focus on subtle aspects of weather observation, like how cloudy the sky was, and whether it had rained recently.

By the 1990s, the second generation of the ASOS could do most of what humans could, and the U.S. government decided to install these machines at thousands of airports and other locations around the country. Today, the ASOS is the [primary way](#) that America's weather forecasters gather data, with humans stepping in less frequently.

Now that modern equipment gives meteorologists reams of data, some scientists have said that Blue Hill has fulfilled its purpose, and it's time to retire the Observatory. Blue Hill had become part of Harvard University in 1913, but in 1971, the University pulled its funding, saying that it was simply not worth the expense of keeping the building running. It was only because the local government agreed to serve as the organization's new landlord that Blue Hill's climate record remained unbroken. The National Park Service eventually designated the Observatory as a National Historic Landmark, and in 2002, the Observatory's former director, Richard Goody, [wrote that](#) becoming a historical monument was, "an appropriate retirement use for a world-famed institution of little use for modern investigations."

Yet the Observatory persists, and today a group of around 10 scientists and administrators keep it running as a scientific site and an education center. Funding is still difficult to come by, and every year the staff wait anxiously to see if the Massachusetts state budget will include a line granting them \$100,000. Approximately a third of their budget rests on whether lawmakers vote to include this one sentence.

It's easy to see why lawmakers hesitate to fund an outdated scientific outpost alone on top of a hill. "We have a wealth of Earth observational data for the present day," Zeke Hausfather from Berkeley Earth said. "We have satellites, we have robots floating around in the oceans all the time, we have airplanes doing measurements, we have somewhere upwards of 50,000 land stations that report automatically to archive databases."

Impressive as these upgrades are, they're also huge changes for a discipline in which even seemingly-innocent changes can "wreck havoc," in Hausfather's words. Switching from mercury thermometers to modern electronics, for example, caused many climate records to reflect about half a degree less warming than had actually occurred. The ASOS also [reads about 0.1°C warmer](#) than the thermometers used by most human observers — a small difference, but one that can make a difference. If the [Earth's average temperature increases](#) by just 1.5 more degrees, one in seven humans will regularly experience severe heat waves. Warming by two percent brings the number up to one in three.

Meteorologist Eric Kelsey from Plymouth State University said that having human eyes on weather stations can also avoid unexpected alterations. "There's always a little bit of uncertainty

as to just how good some of the data coming from remote automated weather stations are. Was there a — I don't know — a polar bear or something sleeping underneath the sensor, giving off some heat?" (An unlikely sounding situation, and yet polar bears [have been known to trap](#) observers in an arctic weather stations. Clearly, these animals are positioned to disrupt climate monitoring efforts!)

"We often play the role of detective," Hausfather said when he explained the work that climatologists put into accounting for all the changes weather observing stations have made over the decades. People like Suzedell who get up early in the morning, drive to the top of a hillside, and measure the weather the same way as their predecessors, give him a way to check his work, and make sure his inferences are sound.

But nothing lasts forever. This is why, a couple decades ago, the National Centers for Environmental Information began strategically placing [automated climate observing stations](#) in remote locations around the United States. Climatologists hope that these stations will stay in place and measure the climate in a consistent manner for hundreds of years. But unlike Blue Hill Observatory, they require minimal human involvement.

Each station is equipped with three separate thermometers that each take temperature readings every two seconds, while other instruments measure precipitation, wind speed, humidity, and soil moisture. Instead of using a Campbell Stokes instrument to burn a record of sunlight into paper, the stations have pyranometers, which convert solar radiation to measurable electricity. All the information automatically goes to a geostationary satellite, then to an online database.

"The fact that we've set up a new monitoring network that is purposefully unchanged is an implicit, if not explicit, recognition of the importance of these pristine, unchanged measurement sites," Hausfather said. Even with the automated system in place, Hausfather said he hopes Blue Hill and other manual weather stations continue operating as long as possible. Replacing one source of climate data with another requires a long period of overlap to act like a bridge between the two systems. Unless scientists can place an automated station in exactly the same place atop Blue Hill, and make it record all the same types of information that humans have been recording for over a century, the bridge would be rickety and the climate record would suffer.

The sky was just getting light when I pulled up to the Blue Hill Observatory at 6:45 AM, two days before the winter solstice. Suzedell was about to get started with the day's work, and we'd go up to the roof after taking some readings from instruments on the ground. She waved to me from the parking lot, where she was waiting with a disposable coffee cup in her gloved hands. It was approaching 12PM Greenwich Mean Time. Meteorologists all over the world were about to take synchronized weather readings, and she was ready to get started.

After making her way through the snow to the instrument pen, Suzedell used water from the cup to wet the cotton tip of the wet bulb thermometer. Combined with a reading from a typical dry-bulb thermometer, this instrument lets Suzedell calculate the dew point, or the temperature below

which dew can form. She stood on a bench to get the cup inside a wooden box raised about six feet off the ground, where the thermometers are mounted.

When the wet bulb reached the outdoor temperature, the thermometer would be ready to read. Suzedell turned on a fan to expedite the process before she closed up the box and headed into the observers room to read some of the Observatory's other instruments, starting with the oldest. After opening the glass case containing Rotch's original mercury barometer, she peered closely at its silver column of mercury before recording the atmospheric pressure on her clipboard — 1006.8 millibars. Low atmospheric pressure means a storm is on the way, but 1006.8 millibars is right around the average pressure at sea level, and only benign wisps of clouds streaked the sky.

Although the Observatory has been using this barometer since 1888, the observers moved it up a floor in the 1950s when a new director decided to reorganize, and they've been compensating ever since. Later, after Suzedell had finished her flurry of early morning measurements, she pulled out a three-ring binder and referenced a weathered, hand-drawn chart. A note on the chart marked with the date Oct. 1, 1952 indicated that the magnitude of the correction had been increased by 0.06 millibars to account for the move — six thousandths of a percent of Suzedell's initial reading.

The wet bulb thermometer still needed a bit more time to acclimate to the temperature outside, so Suzedell turned her attention to one of the Observatory's five other atmospheric pressure instruments: the microbarograph. Like the thermograph Rotch strapped to a kite a century before, this instrument consists of an arm with an ink-covered tip that varies in height when atmospheric pressure changes, combined with a paper chart wrapped around a slowly rotating cylinder. The Observatory recently found a printer willing to make customized charts for a similar instrument. The discovery came just in time, as they were running low on a batch that they'd ordered back in the 1960s when the design was in vogue.

Suzedell swapped out the previous day's chart for a new piece of paper and wound the base of the cylinder like an old-fashioned clock so that it would keep turning for another day. The pen began to progress around the chart at an almost imperceptible pace, as a shadow progresses around a sun dial. Looking at the old chart, Suzedell noticed that the microbarograph's readings varied quite a bit from the mercury barometer. "It could have been bumped," she said. But that's why she had five other ways to measure atmospheric pressure — so she could weed out the faulty instrument.

One of these other instruments is the ASOS, which reports atmospheric pressure to the National Weather Service every hour. But this instrument has only been at the Observatory since 1998. At 23 years old, it's a rookie compared to the mercury barometer and the microbarograph, so it will have to operate undisturbed for at least a few more decades before its record carries the same weight for climatologists as their older instruments.

We headed up to the roof so that Suzedell could observe the sky. Clouds are part of what attracted her to meteorology, and even when she was three years old, she loved to watch them roll and drift. "I like the basic summer day cumulus clouds, but thunderstorms in the summer really are what interested me," she said.

As a young kid, Suzedell had her own weather observer network made up of family members. She remembers a major snowstorm in the early 2000s that got her so excited that she called her relatives in surrounding towns to take a poll of how much snow they'd gotten. But it wasn't until the summer before her junior year in high school that she discovered the Blue Hill Observatory, where she decided that meteorology would form the basis for her career.

"They had this weather camp thing," she said. It's run by NBC Boston's meteorologist Tim Kelley, who takes pride in instilling a love of meteorology in younger generations.

"One of the first things I teach them to do is introduce themselves," Kelley told me over the phone. "That's one of the hardest things to do on TV." By asking the campers to repeat over and over, 'Hi, I'm future meteorologist so-and-so,' Kelley said, "not only am I teaching them weather, I'm putting an imprint in their mind that they're going to be meteorologists."

Suzedell isn't sure she wants to be a TV personality, and in fact she's considering becoming a science teacher herself. But the weather camp instilled a love for the Observatory in her, and the following summer, she asked if she could volunteer as a weather observer. By the time she graduated from high school, she'd become a trusted staff member.

A new anemometer had appeared on the roof while she'd been away for the semester, Suzedell mentioned. A half dozen of these instruments spun above our heads, each measuring wind speed and direction. Wind carries weather with it, and makes water evaporate more easily, so measuring wind helps predict storms. Most of the anemometers consisted of three cups, each resembling a hollowed-out half baseball, which caught the wind and caused the instruments to turn. "It's another back-up thing," she said, referring to the new one. She could compare it to the rest of the pack if their oldest anemometer started giving her suspicious readings.

Since the observers installed these anemometers on the Observatory's roof in 1960, a six-foot-tall machine in the observers room, a floor below the roof, has extruded long sheets of paper bearing wavy red lines, with their waverings proportional to wind speed. About an hour into Suzedell's morning routine, she turned her attention to the eight feet of paper that had begun to bunch up on the floor.

She cut off about six feet of the paper, representing the past 24 hours, laid it out on a wooden counter, and went about examining the thousands of tiny peaks drawn by the red pen, each indicating a gust of wind. Referencing the ASOS's wind data had given her a rough idea of when the peak gust had probably occurred, and now her goal was to examine the hundreds of red peaks on the print-out to see if the manual system agreed with the automated one. Working slowly and deliberately, she drew her fingers across the feet of paper until she was convinced that she'd found the highest red peak.

Observers need this type of quiet determination to do such precise work, but when they start talking about the storms they've been in, their calm exteriors usually give way to excitement. Suzedell, for example, chose to go to college in Oswego, New York partly because she gets to experience the lake effect brought on by nearby Lake Ontario. "Often [we'll get] complete

whiteout conditions, and then five minutes later, it'll be completely clear!" she told me. So when Blue Hill Observatory's chief observer Ben Turner showed up just before noon, Suzedell was eager for a report on the nor'easter that had dumped 16.5 inches of snow on the Observatory two days earlier.

"I was up all night. Still recovering from it today," Turner said as he adjusted his Blue Hill Observatory-branded facemask. He sounded more excited than irritated despite having spent about 16 hours, from 10PM to 2PM, measuring snowfall every hour. The storm had been the tenth biggest December snowstorm Blue Hill had seen since the observers started keeping track in 1886, and his data could help weather forecasters improve their models. Next time a major storm was on the horizon, they'd be able to look back to see if they'd predicted this one correctly and adjust accordingly.

"It looked like it was going to end around 3AM, or 5AM, but it kept ramping energy off the ocean, so it kept going until 2PM," he said, laughing. "It was enjoyable, but I don't want to do it too many more times this winter."

Like Suzedell, Turner has been interested in weather since he was young. As a five-year-old, he would regularly watch The Weather Channel, and one of the station's meteorologists, Jim Cantore, was his childhood idol. He landed an internship with Blue Hill Observatory during college, and he's been working there full-time since he graduated three years ago.

"I really care about the place," Turner said. But the deteriorating state of the building sometimes makes him wonder how long the Observatory will last. "When we get rain, it's literally raining half as hard as it is outside in that hallway," he said, pointing to the crumbling vestibule outside the observer's room.

After years of fundraising, Turner hopes that 2021 will be the year that the Observatory finally gets patched up, but as chief observer, he also has to think about keeping the Observatory's antique instruments running. Despite the Observatory's commitment to consistency, Turner said that as their old equipment becomes untenable, the Observatory will most likely make a slow switch to an automated way of doing things. "It's necessary," he said. "It's not that I completely like it, but it's necessary."

In some ways, the Observatory's data will benefit. Machines don't have human error, for example. Different human observers will always read instruments slightly differently, no matter how carefully they standardize their protocols. But Turner said it's the things that machines haven't been trained to recognize that make manual weather observation so valuable. "We're very detail oriented," he said. "There are little things that we do around here that make us very unique and special."

The snowstorm that kept him awake two days earlier is a good example. The ASOS measures snow by melting it down and measuring the resulting water, but this only gives a piece of the story. While it's a myth that the Inuit have 100 words for snow, meteorologists very well may have so many descriptions — the International Association of Cryospheric Sciences's [guide to classifying snow](#) is 80 pages long. Whether it's dry or wet, small-flaked or large, makes a big

difference in how it acts once it's on the ground. "We'll be here hour by hour, taking snow measurements, doing liquid to frozen ratios, and all that stuff. It makes for a long night, but it's all so we can get our data as accurate as possible," Turner said. All these subtle details help forecasters when they go to predict how future storms will shape up, and so far there's no machine that can report them as well as a human can.

Sky cover presents another challenge for machines, which have difficulty differentiating between the cloud shapes that humans can easily tell apart. Machines designed to measure visibility also have trouble at vantage points like Blue Hill, where the view is so vast. "A lot of automated systems go out to about 10 miles of visibility and that's it," Turner said. "We can see for 90!"

Although Turner worries about the future of the Observatory and his own job security, the fact that the Observatory has operated for 135 years gives him faith that it will continue. "There's been somebody up here every day," he said. "That's what makes it special."

Weather observation isn't the only field in which automation threatens to push out human perception, and perhaps nowhere is this trend more noteworthy than in medicine. It's a field my family knows well — for over five decades, my grandmother worked as a secretary in doctors' offices, and she'd often tell stories about her job. The doctors were brilliant, she said, but they were absent-minded. A surgeon she worked for treated prominent politicians and athletes, but couldn't find his car keys half the time. She and the other administrators were the ones who chatted with the patients, remembered their stories, comforted them when their health was poor, and kept them company when the doctors inevitably got behind schedule.

My doctor's office is trying to institute an online system for booking appointments, eliminating the need to call a secretary like my grandmother. At the moment, filling out an online form simply prompts a human to call me to set up an appointment. But it's only a matter of time until they cut out the middleman, leaving the computer to do the scheduling.

COVID-19 has revealed that even seeing a doctor in the flesh isn't as necessary as we once thought. Tele-medicine, where doctors meet with patients over the phone or by teleconference, [increased 154%](#) over the first month of the pandemic. While certain ailments require hands-on care from a doctor, tele-medicine has actually proven to be preferable for many minor problems. Patients don't have to spend time getting to the doctor's office or sitting in the waiting room, and doctors can get through patients more quickly when they don't have to shuffle them in and out of exam rooms. Not only is tele-medicine pandemic-safe, it saves time and money.

My personal record for pandemic-inspired contact-less medicine has been updating my eyeglasses prescription and purchasing a new pair without interacting directly with a human being. I downloaded an app that instructed me to place my computer a certain number of feet away from me before reading an eye exam off its screen. My kitchen is just long enough to meet the requirements, so I set my laptop on the butcher's block, then stood next to the fridge while I used my phone to indicate whether progressively smaller letter "c's" were upright, upside-down,

backwards, or forwards. A few weeks later, the pair of frames I selected online arrived in the mail, complete with updated prescription lenses.

As the trend toward automated medicine continues, computers are taking on more sophisticated tasks than booking appointments and updating prescriptions. Thanks to advances in artificial intelligence (AI), computers are starting to do work that was once the domain of seasoned specialists. Qiyuan Hu (who also goes by Isabelle) is one of the researchers pushing this trend along. As a graduate student at the University of Chicago, she's training computers to diagnose cancer.

Give a computer examples of what it means to be sick or healthy, along with corresponding diagnoses made by expert doctors. The examples could be [slides from biopsies](#), [brain scans](#), [recordings of coughs](#), or any number of other diagnostic tools. With a bit of careful programming, artificial intelligence (AI) algorithms let computers assimilate this knowledge and see the patterns as well as a seasoned specialist. Until recently, human perception was the only tool sensitive enough to reliably detect slightly dark areas on a CT scan that can indicate a stroke, or DNA clustered around the peripheries of nuclei, suggesting cancer. Thanks to AI, technology is catching up.

Despite recent progress in AI, Hu said she didn't see computers taking over for doctors in the near future, or perhaps ever. "Algorithms, so far, don't have common sense," she said.

Lacking common sense means lacking a last line of defense against silly mix-ups. If an AI algorithm is asked to diagnose a disease outside the set it's been trained to recognize, for example, it will force the ailment into a category it's been trained on. One of humans' strengths, Hu said, is that we're able to think outside rigid parameters and make new discoveries. Instead of replacing human doctors, Hu thinks expert pattern-recognition machines can give doctors more information to work with and free up their schedules, which could let them spend more time with their patients.

"AI definitely has the potential to make healthcare human again," she said.

Lodovica Illari is a meteorology instructor at MIT who said that, in a way, manual weather observatories fill a role in meteorology similar to the role that a compassionate doctor plays in health care. "They're used nowadays, not only for the data, but they've become a center for outreach to the public," she said. Blue Hill gives kids opportunities to interact with meteorology in a tangible way that an automated weather station, whirring and beeping alone in a field, could never replicate. Just as there's no substitute for a human caregiver when a patient is afraid, it's hard to beat a tower with a view from Boston to New Hampshire when you're trying to get kids excited about science.

As mid-afternoon approached, the frost had melted off the windows of the observers room, and the sunbeams that streamed in were starting to warm the space. When Suzedell went up to the roof to complete her last task of the day, she left her coat behind.

She hopped agilely over the railing surrounding the tower's roof and took a seat on a platform beside the Campbell Stokes sunshine recorder. Soon she'd swapped the paper strip for a new one, and a whisp of smoke rose as the new paper started burning.

The sun still shone on the Observatory, but a bank of cirrus clouds was rolling in from the southeast. Suzedell took one last look out over the fields, forests, cities, and smokestacks of eastern Massachusetts before heading back to the observers room to add another day of weather to the history books.

End Notes

Page 4

“I can see Mount Monadnock...” — Notes from Dec. 19, 2020, page 2

Suzedell, a senior... — Dec. 15, 2020 interview with Suzedell, 6:23 and 13:11

For 135 years... — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, (1990) John H. Conover, American Meteorological Society, 45 Beacon St., Boston, MA

The pompom on Suzedell’s hat... — Saima Sidik’s visit to Blue Hill Observatory, Dec. 19, 2020

One hundred percent of the nearby pond... — Daily Discussion, Dec. 19, 2020:

<https://www.bluehill.org/Data/2020/december/dec19.txt>

These days, pyranometers... — Campbell Scientific website:

<https://www.campbellsci.com/blog/pyranometers-need-to-know>

Page 5

“It’s really important...” — Dec. 15, 2020 interview with Suzedell, 21:57

The Observatory houses a hodgepodge of equipment — Blue Hill instruments:

<http://www.bluehill.org/handbook/Pages/Instruments.html>

“a gift to modern scientists” — Dec. 21, 2020 interview with Hausfather, 8:00, 21:00, 26:41

The building had seen better days — Dec. 19, 2020 Blue Hill visit recording 2, 1:44:40

Abbott Lawrence Rotch went for a stroll — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 15

An inheritance from his late father — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 6

Page 6

He had a long-standing interest in the weather, extending back to at least age 17 — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 4, 5

Once even writing an article for the Institute’s newspaper... — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 5; <http://tech.mit.edu/V3/PDF/V3-N13.pdf>

How elevation affects wind speed and precipitation — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 16

Two weeks after his trip up Blue Hill — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 15

Rotch consulted town officials — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 15

A two-bedroom living space where he'd live attached to a turret... — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 19

On January 31, 1885 — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 20

Rotch built Blue Hill Observatory only about forty years after telegraphs... — <https://www.loc.gov/collections/samuel-morse-papers/articles-and-essays/invention-of-the-telegraph/>

British navy admiral Robert Fitzroy — https://www.bbc.co.uk/blogs/23degrees/2011/08/150_years_since_the_first_uk_w.html

The Swedish scientist Svante Arrhenius — *Publication of the Astronomical Society of the Pacific* Vol 9 No. 54 (February 1, 1897) pp. 14-24

Joseph Henry started a similar meteorological pursuit — https://www.jstor.org/stable/40670917?seq=1#metadata_info_tab_contents

Page 7

Henry convinced the US Army's Signal Service — <https://siarchives.si.edu/history/featured-topics/henry/meteorology>

When Rotch began recording weather — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 6, 19

In 1894, pioneering meteorologist William Eddy — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 67-68

The Observatory's scientists strapped a thermograph to a kite — <http://waywiser.fas.harvard.edu/objects/10289/thermograph?ctx=472d295b-dc38-4e53-8329-79e14f80feaf&idx=64>

A kite broke free and became tangled in the axel of a train — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985*, pg. 136

Today, weather balloons, airplanes, and satellites — Nov. 23, 2020 interview with Lodovica Illari, 6:33 – 13:33

As meteorology evolved... so did aviation. — <https://public.wmo.int/en/bulletin/meteorological-services-aviation>

A partnership between the Federal Aviation Administration and the National Weather Service — https://www.faa.gov/documentLibrary/media/Order/Order_JO_7900.5E.pdf

Page 8

When the first generation of these machines appeared at airports in the 1960s... By the 1990s, the second generation of ASOS could do most of what humans could... — Automated Surface Observing System (ASOS) User's Guide: <https://www.weather.gov/media/asos/aum-toc.pdf>

Today, the ASOS is the primary way... — <https://www.weather.gov/asos/asostech>

Blue Hill had become part of Harvard University in 1913 — <https://bluehill.org/observatory/about-us/historical-timeline/>

Harvard pulled its funding — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985* pg. 344 – 351

Designated the Observatory as a National Historic Landmark... — <https://bluehill.org/observatory/about-us/historical-timeline/>

Richard Goody wrote that becoming a historical monument... — <https://www.annualreviews.org/doi/abs/10.1146/annurev.energy.27.122001.083412>

Today, a group of around 10 scientists and administrators keep it running... — <https://bluehill.org/observatory/leadership-key-staff-and-volunteers/>

Every year the staff wait anxiously to see if the Massachusetts state budget... — <https://bluehill.org/observatory/2016/07/governor-baker-vetoes-100000-b-h-o-your-support-is-needed/>
<https://bluehill.org/observatory/2019/05/senate-to-vote-on-100000-for-bho-your-immediate-help-is-needed-3/>
<https://bluehill.org/observatory/2018/05/senate-to-vote-on-100000-for-bho-your-immediate-help-is-needed-2/>
<https://bluehill.org/observatory/2017/05/senate-to-vote-on-100000-for-bho-your-immediate-help-is-needed/>

Approximately a third of their budget... — <https://projects.propublica.org/nonprofits/organizations/222517414>

“We have a wealth of Earth observational data...” — Dec. 21, 2020 interview with Zeke Hausfather, 1:22

Seemingly-innocent changes in observing protocols can “wreck havoc” — Dec. 21, 2020 interview with Zeke Hausfather, 6:50

Switching from mercury thermometers to modern electronics caused many climate records to reflect about half a degree less warming than had actually occurred — Dec. 21, 2020 interview with Zeke Hausfather, 6:14

The ASOS reads about 0.1°C warmer than the thermometers used by most human observers — <https://journals.ametsoc.org/view/journals/apme/58/12/jamc-d-19-0170.1.xml>

If the Earth’s average temperature increases... <https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/>

“There’s always a little bit of uncertainty...” — September 15, 2020 interview with Eric Kelsey, 47:24

Page 9

Polar bears have been known to trap observers... — <https://weather.com/news/news/polar-bears-trap-meteorologists-russia>

“We often play the role of detective” — Dec. 21, 2020 interview with Zeke Hausfather, 7:28, 7:51 – 8:04

Climatologists began strategically placing automated climate observing stations... — <https://www.ncdc.noaa.gov/crn/overview.html>

“The fact that we’ve set up a new monitoring network...” — Dec. 21, 2020 interview with Zeke Hausfather, 8:00, 32:45 – 33:58

We’d go up to the roof... — Dec. 19, 2020 notes, page 2

Wet the cotton tip of the wet bulb thermometer — Dec. 19, 2020 notes, page 2, <http://www.bluehill.org/handbook/Pages/Instruments.html>

Page 10

Headed into the observers room to read some of the Observatory’s other instruments, starting with the oldest — Dec. 19, 2020 notes, page 1

Right around the average pressure at sea level — <https://www.ndbc.noaa.gov/educate/pressure.shtml>

Only benign wisps of clouds streaked the sky — Blue Hill Daily Discussion, Dec. 19, 2020, <https://www.bluehill.org/Data/2020/december/dec19.txt>

The observers moved it up a floor in the 1950s... — *The Blue Hill Meteorological Observatory: The First 100 Years — 1885-1985* pg. 332

A printer willing to make customized charts — Dec. 19, 2020 Blue Hill visit recording 2, 1:38:24

“It could have been bumped” — Dec. 19, 2020 Blue Hill visit recording 1, 1:39:01
ASOS reports atmospheric pressure to the National Weather Service every hour — <http://www.bluehill.org/handbook/Pages/Instruments.html#ASOS>

This instrument has only been at the Observatory since 1998 — <https://bluehill.org/observatory/about-us/historical-timeline/>

“I like the basic summer day cumulus...” — Dec. 15, 2020 interview with Elizabeth Suzedell, 9:41

Page 11

Suzedell had her own weather observer network — Dec. 15, 2020 interview with Elizabeth Suzedell, 11:59

Summer before her junior year — Dec. 15, 2020 interview with Elizabeth Suzedell, 7:08

“They had this weather camp thing.” — Dec. 15, 2020 interview with Elizabeth Suzedell, 7:20

“One of the first things I teach them...” — Dec. 4, 2020 interview with Tim Kelley, 21:11

Suzedell isn’t sure she wants to be a TV personality — Dec. 15, 2020 interview with Elizabeth Suzedell, 7:52

Considering becoming a science teacher — Dec. 19, 2020 Blue Hill visit recording 1, 2:05:58

Asked if she could volunteer — Dec. 15, 2020 interview with Elizabeth Suzedell, 8:04

By the time she graduated from high school — Dec. 15, 2020 interview with Elizabeth Suzedell, 6:00

“It’s just another back-up thing...” — Dec. 19, 2020 Blue Hill visit notes, page 3; recording 1, 16:13

Since the observers installed these anemometers... — http://www.bluehill.org/handbook/Pages/Instruments.html#Wind_Gust_Chart_Recorder

She cut off about four feet of paper... — Dec. 19, 2020 Blue Hill visit notes, page 5;

“Often [we’ll get] complete whiteout...” Dec. 15, 2020 interview with Elizabeth Suzedell, 12:55

Page 12

Suzedell was eager for a report — Dec. 19, 2020 Blue Hill visit recording 2, 43:26

“I was up all night...” — Dec. 19, 2020 Blue Hill visit recording 2, 43:26

Tenth biggest December snowstorm — <https://www.bluehill.org/Data/2020/december/dec18.txt>

Improve their models — Dec. 19, 2020 Blue Hill visit recording 2, 1:30:52, 2:48:45

“It looked like it was going to end...” — Dec. 19, 2020 Blue Hill visit recording 2, 46:25

As a five-year-old, he would regularly watch The Weather Channel — Jan. 20, 2020 interview with Ben Turner, 1:04

Jim Cantore was his childhood idol — Jan. 20, 2020 interview with Ben Turner, 1:46

“I really care about the place” — Dec. 19, 2020 Blue Hill visit recording 2, 1:44:29

“When we get rain...” Dec. 19, 2020 Blue Hill visit recording 2, 1:45:06

2021 will be the year that the Observatory finally gets patched up — Jan. 20, 2020 interview with Ben Turner, 29:15

“It’s necessary. It’s not that I completely like it, but it’s necessary.” — Dec. 19, 2020 Blue Hill visit recording 2, 42:31

Different human observers will always read instruments slightly differently — Jan. 20, 2020 interview with Ben Turner, 27:37

“There are little things...” — Jan. 20, 2020 interview with Ben Turner, 25:43

The ASOS measures snow... — <https://www.weather.gov/media/asos/aum-toc.pdf>, pg. 29

It’s a myth that the Inuit have 100 words for snow — <https://www.buzzfeed.com/tomchivers/no-the-inuit-dont-have-100-words-for-snow>

The International Association of Cryospheric Sciences’s guide to classifying snow — <https://unesdoc.unesco.org/ark:/48223/pf0000186462?posInSet=1&queryId=7c665048-4e3f-464a-b282-66a33989ff00>

Page 13

“We’ll be here hour by hour...” — Jan. 20, 2020 interview with Ben Turner, 17:13

There’s no machine... — Jan. 20, 2020 interview with Ben Turner, 16:43

Sky cover presents another challenge — Jan. 20, 2020 interview with Ben Turner, 22:50

“A lot of automated systems...” — Jan. 20, 2020 interview with Ben Turner, 25:31

There’s been someone up here... — Jan. 20, 2020 interview with Ben Turner, 15:50

Tele-medicine, where doctors meet with patients... —
<https://www.cdc.gov/mmwr/volumes/69/wr/mm6943a3.htm>

Updating my eyeglasses prescription... — <https://www.warbyparker.com/prescription-check-app>

Page 14

Qiyuan Hu... is training computers to diagnose cancer —
<https://www.nature.com/articles/s41598-020-67441-4>

Slides from biopsies —
<https://www.sciencedirect.com/science/article/abs/pii/S1470204519307387>

Brain scans — <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5647643/>

Recordings of coughs — <https://ieeexplore.ieee.org/abstract/document/9208795/authors#authors>

“Algorithms, so far, don’t have common sense.” — Jan. 19, 2021 interview with Isabelle Hu, 29:10

One of humans’ strengths — Jan. 19, 2021 interview with Isabelle Hu, 32:34

“AI definitely has the potential...” — Jan. 19, 2021 interview with Isabelle Hu, 27:03

“They’re used nowadays...” — interview with Lodovica Illari, 58:37

Blue Hill gives kids opportunities... <https://bluehill.org/observatory/education/>;
<https://bluehill.org/observatory/2016/12/help-us-inspire-children-to-learn-about-the-weather/>