ITHACATION

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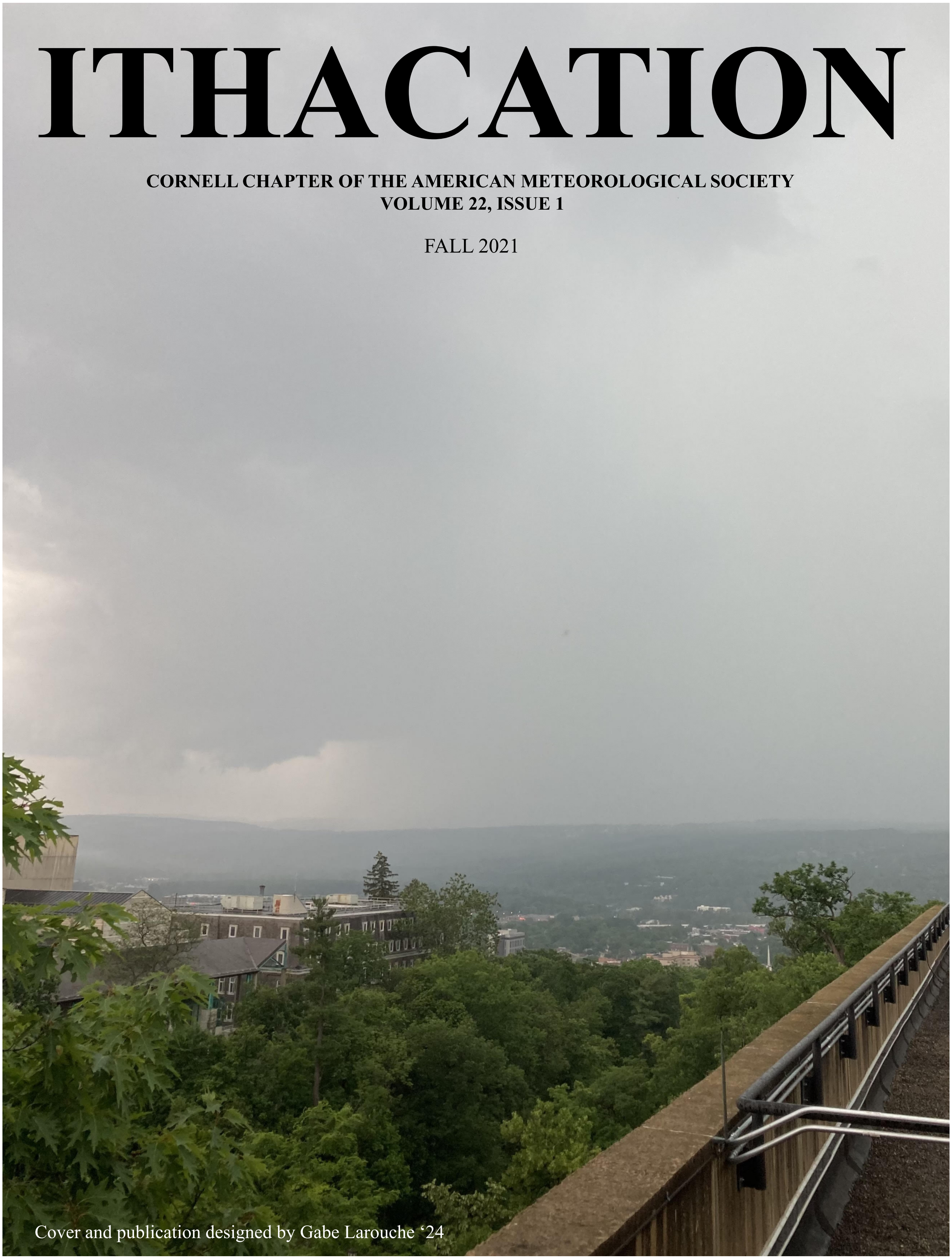


Cover and publication designed by Gabe Larouche '24

From the Editor

It is my pleasure to present the latest edition of Ithacation in which members of the Cornell Chapter of the American Meteorological Society (CCAMS) showcase their passion for the weather.

In this edition, CCAMS members kick their winter weather knowledge into high gear as Ithaca braces for snow and blustery winds. Many in the community are wondering what the coming months have in store, and if this applies to you, look no further than Rohan Shroff's comprehensive 2021-2022 winter outlook for the lower 48.

Additionally, past events such as the 2011 Groundhog Day blizzard and the Texas Valentine's Day snowstorm resulted in first years Erik Andersen and Henning Schade pursuing careers in atmospheric science. Ben Moose, another first year student, discusses the complexities that made Alabama's 2014 winter storm difficult to forecast. Jacob Feuerstein's case study of the November 2011 nor'easter provides a stark reminder of the New England power grid's frailty. Samuel Jurado investigates a mysterious cold blob anomaly off the coast of southern Greenland that suggests arctic warming is freshening our oceans.

This edition of Ithacation is further headlined by Joshua Pan's call for transparency and trust for machine learning in Atmospheric Science, and by Harrison Tran's experience interning with the Weather Prediction Center through the William M. Lapenta NOAA student internship program. Take a moment to try Kinen Kao's 2021 weather word search filled with exciting weather terminology and CCAMS references. Finally, check out page 20 for an ephemeral surprise prepared by senior Harrison Tran.

Simply put, Ithacation has something for everyone. It provides the Cornell weather community with a platform to demonstrate their passion, hard work, and experiences. It enlightens readers with well informed and illuminating discussions regarding our fascinating atmosphere. For me, it was truly an honor to compile, package, and deliver the following information prepared by today's emerging weather voices.

Sincerely,

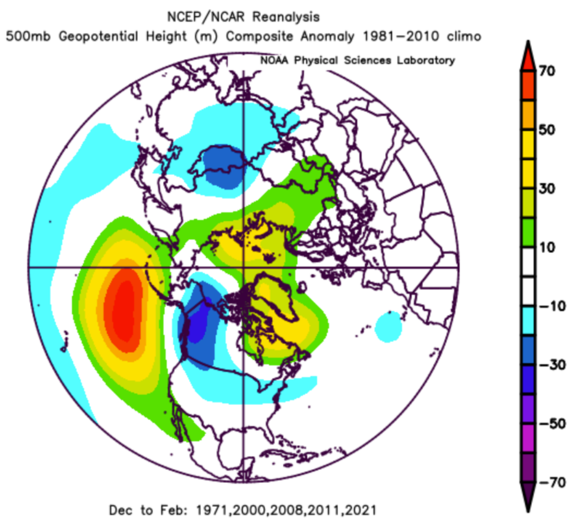
Gabe Larouche [*Editor-in-Chief]*

In this issue:

2021-2022 Winter Forecast

Rohan Shroff '24

Every year, the months right before winter present an opportunity for weather enthusiasts and meteorologists to roll up their sleeves and try to predict what the upcoming winter season has in store. Luckily, there are indicators provided by the Earth that help to give us some clues. One of the most important is the state of ENSO, the oscillation that governs the waters off the west coast of South America. This year looks to feature a weak to moderate La Niña that will be hybrid or "mixed" with the coldest waters being centered further west than normal, but also east of 180 degrees longitude. The position of the coldest waters can have large impacts on winter weather over the eastern U.S., with eastern-based La Niñas tending to support milder winters and western-based La Niñas promoting colder conditions for the northeast. Below is the composite for all mixed or hybrid La Niña winters during the December – February timeframe.



500mb Geopotential Height Composite Anomaly. Credit: *NCEP/NCAR.*

As you can see, mixed La Niña winters tend to feature high latitude blocking (- NAO) and below normal heights originating in northwest Canada that extend into the Pacific Northwest, Midwest, and Northeast. The dreaded southeast ridge that is present in many La Niña winters is also not depicted by the analogs. Overall, the analog composite paints a relatively active and dare I say wintry outlook for the Ithaca area. However, there are also many other factors that impact our winter, which I go through below.

Another factor that plays an important role is the Quasi-Biennial Oscillation (QBO). The QBO is currently in the easterly phase and is descending. Research has shown that the easterly phase of the QBO tends to promote high latitude blocking, which makes it easier in the mid-latitudes to experience colder than normal conditions. The easterly QBO phase also makes it easier to allow warming events to occur in the stratosphere, which disrupts and weakens the polar vortex, and when that happens, cold air often spills down into the mid-latitudes (where we are).

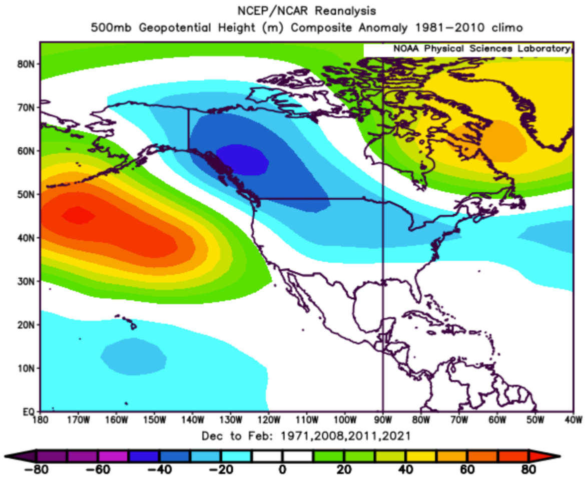
Next up is the NAO or North Atlantic Oscillation. The NAO looks to be neutral to negative this year. One tell-tale sign that can help predict the overall state of the NAO is by looking at sea surface temperatures during the month of May. If there is a warm – cool – warm tripole in May over the Atlantic Ocean, there is an increased probability that the NAO will be negative during the winter, while a cool – warm – cool tripole indicates a positive NAO for the upcoming winter. For May of 2021, we saw a clear warm – cool – warm tripole, increasing my confidence that the NAO will be predominantly neutral to negative this winter.

Now we switch gears to the pacific. The Pacific Decadal Oscillation (PDO) has been remarkably negative over the past few months and displays the classic horseshoe signature with cooler waters wrapping around a band of warmer waters. In fact, the averaged PDO value for last month was -1.94! Negative PDO values tend to promote above average heights and warmer weather over the eastern United States.

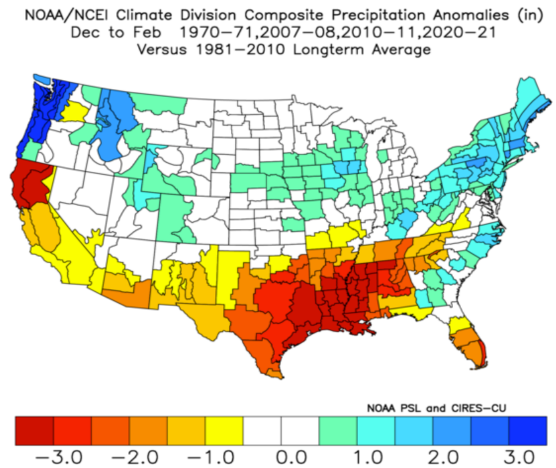
So to summarize for this winter, a mixed weak to near moderate La Niña looks to be the best bet. The QBO is descending and is easterly, the NAO looks to be neutral to negative, and the PDO will be strongly negative. What years most closely match this (analog years with at least 2 out of 3 matches were selected from the mixed La Niña dataset)?

The closest years are: 1970-1971, 2007-2008, 2010-2011, 2020-2021

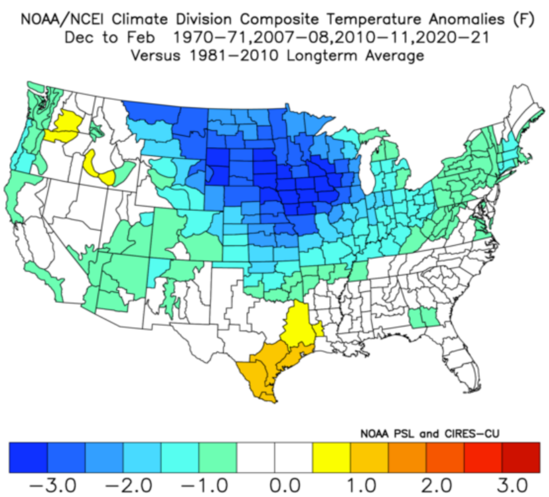
What were the outcomes for those winters averaged together?



500mb Height Anomaly. Credit: *NCEP/NCAR.*



Precipitation Anomaly. Credit: *NOAA/NCEI.*



Temperature Anomaly. Credit: *NOAA/NCEI.*

The outcome depicts an active winter season for Ithaca. There is an above average precipitation and below average temperature signal. The 500 mb geopotential height anomaly has blocking just west of Greenland (-NAO), and below average heights cover almost the entire United States. When looking at the analogs on a month-by-month basis, December and especially February look to have the most snow potential for the northeast, while January could have the greatest below average temperature anomalies. Winter should end quickly, however, with warmer conditions rapidly arriving at the start of March.

Now that we have our analog sample, what about the polar vortex (PV)? There has been an unusually strong signal this year from models that the polar vortex will be weaker this year, especially in the early stages of winter. If this were to occur, this would promote high latitude blocking and in general a colder and snowier outlook, especially for the first half of winter, since this is when the PV is forecast to be weakest. Unfortunately, while it is too soon right now to have high or even medium confidence on the behavior of the polar vortex this winter, this picture should become clearer by the end of October when we can look at Siberian snowfall cover and the extent of blocking present and forecast to take place in the Urals. However, as of now, I am leaning towards a slightly weaker than normal polar vortex due to the unusually strong and consistent signal from long-range modeling. This will skew the analogs to be slightly warm biased in December, and a little cold biased for the month of February.

Overall, the winter of 2021-2022 looks to be an interesting one, and to be honest, this is a year that winter enthusiasts should get excited about. I also believe snowfall will be above average for the Ithaca region. This is supported by looking at snowfall totals for all 4 analog years.

1970-1971: 86.5 2007-2008: 55.4 2010-2011: 84.4 2020-2021: 73.2

Average of Analogs = 74.9 / Ithaca 30 Year Average Total Snowfall (Nov 1 – March 30) = 60.9

3 out of the 4 years had above average snowfall, and the one year that was below the long-term average was only slightly below average. This increases confidence that snowfall this winter in Ithaca will be above average.

Ithaca, NY Winter Forecast:

December:

Temperature: Below Average
Snowfall: Above Average

Precipitation: Average to Slightly Above Average

January:

Temperature: Below Average
Snowfall: Average

Precipitation: Below Average

February:

Temperature: Average
Snowfall: Above Average

Precipitation: Above Average

Overall:

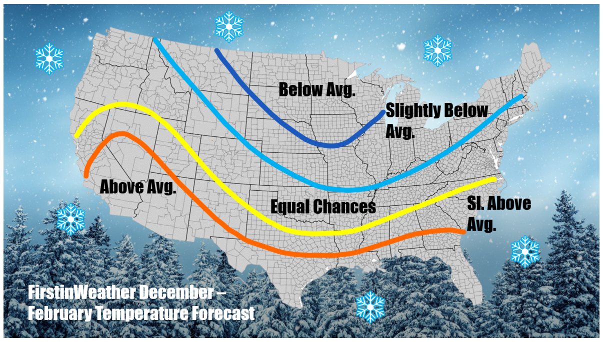
Temperature: Slightly Below Average
Snowfall: Above Average

Precipitation: Slightly Above Average

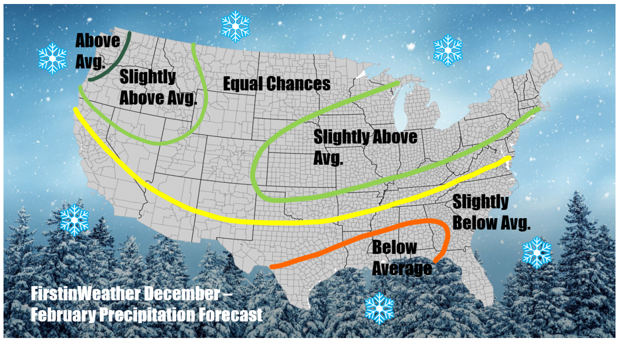
To recap, winter should arrive quickly this year and get into full gear as early as mid to late November, a stark contrast to the past few years where December has been mostly mild and quiet. With the analogs showing some potential for the southeast ridge to reappear in February, this should push the storm track right over the northeast, increasing our chances for significant snows in February. On the other hand, while January is the month with the best shot at seeing average to maybe even slightly below average snowfall, it should also see the strongest below average temperature anomalies. Luckily, for any winter weary folks, spring should arrive early with a warm March for the eastern United States. If you haven't invested in a durable winter jacket yet, do so before it becomes too late!

Well, that concludes my 2021-2022 winter forecast. I hope you enjoyed it! Below are my temperature and precipitation forecast maps for the lower 48.

Temperature Forecast:



Precipitation Forecast:



Machine Learning in Atmospheric Science: The Need for Transparency and Trust

Joshua Pan ‘23

A lot of buzz has come to surround artificial intelligence in atmospheric science. In 2020, the NSF established the AI Institute for Research on Trustworthy AI in Weather, Climate, and Coastal Oceanography, commonly referred to as AI2ES. This past summer, I conducted research on camera-based visibility estimation under AI2ES as a part of the University of Oklahoma Research Experiences for Undergraduates (REU) program. Other student projects in AI2ES included nowcasting hail, improving forecasts of various convective hazards, and automating surface front detection. This small sample of research topics hints at a wide range of machine learning (ML) applications to atmospheric science. I do believe ML has great potential to increase our skill in parameterizing atmospheric processes and finding patterns in atmospheric data. Nonetheless, I side with the experts who say that ML can’t replace an actual first-principles understanding of chaotic dynamical systems. For us, this means our dynamical atmospheric models are here to stay.

To better analyze the capabilities and limitations of ML, I think it would be helpful to qualitatively explain what ML models do. According to Wikipedia, “Machine learning involves computers discovering how they can perform tasks without being explicitly programmed to do so.” What does it mean for ML models to “perform tasks”? From my limited experience with ML, I find it most helpful to think of ML models as mathematical functions that are shaped by training data. Training data typically consist of sets of inputs to the function (model) that are labeled with the desired outputs. Regression models, support vector machines, decision trees, and neural networks can all essentially be conceptualized as trainable math functions. For example, say we want to predict whether a supercell will produce a tornado. Some possible inputs to our function (model) might include the size of the cell, the maximum wind speed in the cell, the mean radar reflectivity of the cell, and environmental parameters such as storm relative helicity. From a set of training examples, our model learns the relationship between these inputs and the presence or absence of a tornado. When our model is eventually fed a set of inputs it has never seen before, the goal is for the model to output an accurate prediction (e.g., probability or yes/no) as to whether a tornado will form. One experiment in my REU project demonstrates a neural network learning to estimate visibility distance from three photo-based parameters (scores; see Figure 1). Of course, it is possible to use dozens of predictor variables and multiple output variables, which makes visualization much harder.

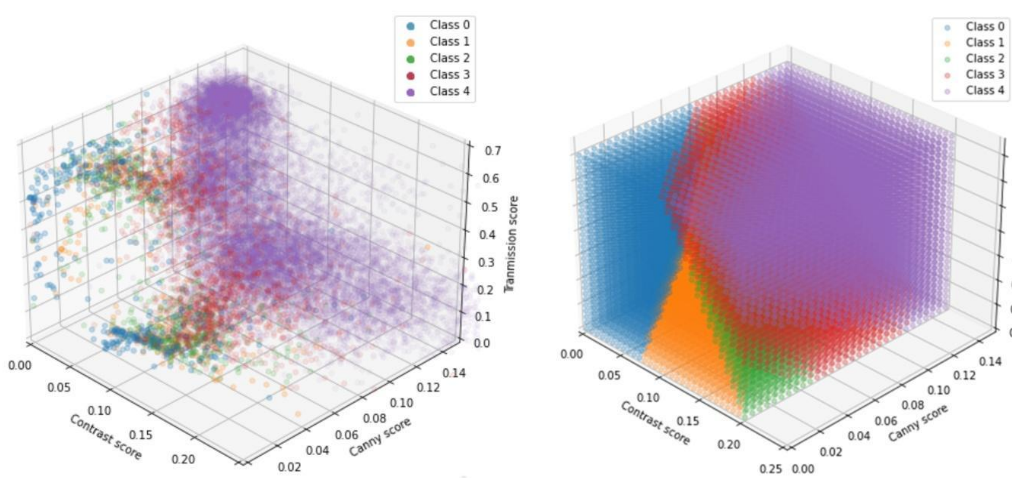


Figure 1. Three scores were computed for each image in a training dataset from the New York State Mesonet photo archive. The contrast score represents visual contrast along the horizon. The Canny score comes from the Canny edge detection algorithm. The transmission score approximates the proportion of light that is directly transmitted from objects in the frame (as opposed to light that reaches the camera via scattering). The class number represents visibility, where Classes 0-4 are ordered from poor to excellent visibility. Using the training dataset (left), a simple neural network learned to estimate visibility from the three scores (right). Notice how for any combination of scores, the neural network’s prediction of visibility resembles the training dataset.

Deep learning models like convolutional neural networks (CNNs) take the adaptability and generalizability of ML a step further. In my earlier examples, researchers define and compute the input variables that go into the ML model. In deep learning, the model itself can learn “features” (often spatiotemporal correlations) from raw data fields. For instance, when creating surface analyses, a human looks for wind shifts and sharp temperature gradients to locate fronts. A CNN performing the same task might learn to find similar wind and temperature patterns and associate them with fronts. In reality, CNNs usually learn to pick out features that are much more abstract and less physically interpretable (Figure 2).

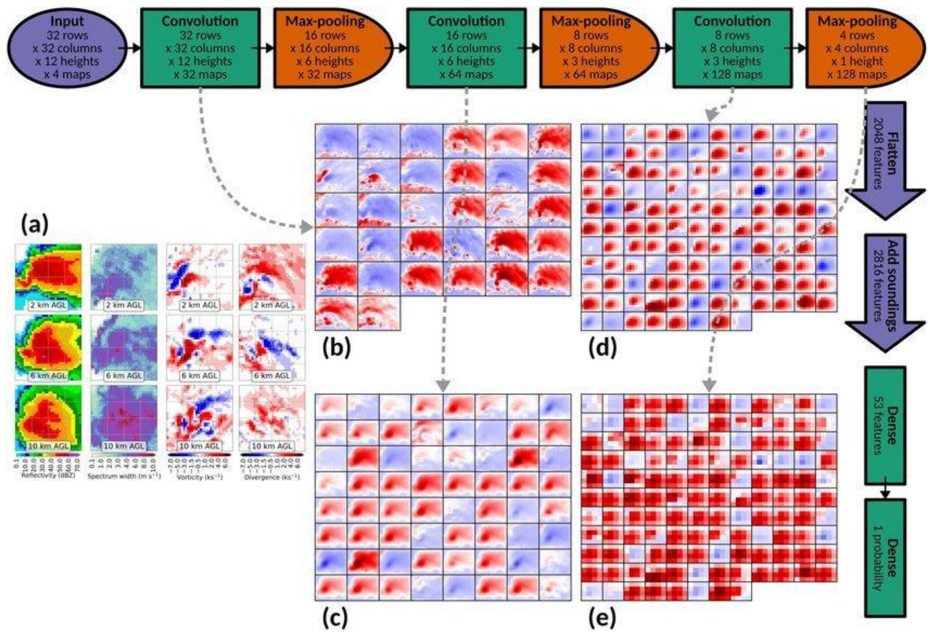
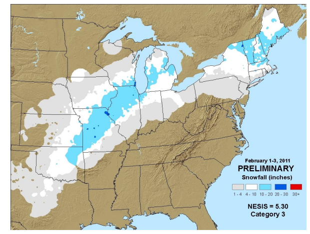


Figure 2. Lagerquist et al. 2020[4] developed a CNN to predict next-hour tornado probabilities from 3D radar data (a). Panels (b)-(e) show feature maps generated by progressively deeper layers within the CNN. One may naively be convinced that some feature maps directly correlate to a physical variable such as the shape of the storm cell. In practice, it is difficult to even guess the physical meaning of these feature maps, especially by the time we get to (e).

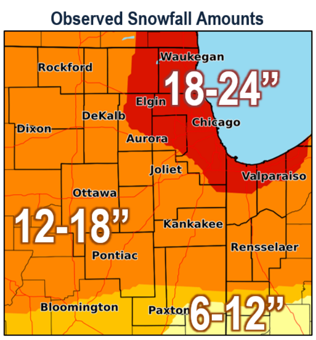
This brings us to a huge caveat of deep learning and ML: the most complex and *seemingly* powerful models are black boxes. We don’t truly understand what happens in the model between the input and output. In other words, the model lacks interpretability. We must go to great lengths to explain their behavior post hoc and make them trustworthy, hence the full name of the AI2ES institute. When hazardous weather puts lives and property at stake, we can’t afford to use untrustworthy models. Particularly with black box models, it can be too easy to overlook spurious correlations or noisy data that lead to a poor forecast. The more opaque behavior of deep learning sometimes outweighs the benefits of any marginal performance gains over a simpler ML model. In fact, in this area of active research, some argue that any assumed tradeoff between model accuracy and interpretability is overblown—we should develop ML algorithms with an interpretability-first mindset. I would add to this by asserting that most existing (non-ML) numerical atmospheric models provide invaluable interpretability that ML can’t conceivably rival.

I hope this brief discussion of ML, its potential, and its limitations has made you consider your expectations for ML in atmospheric science. From quality control to data assimilation and filling gaps in observations, ML is revolutionizing the ways in which we sift through vast amounts of data. Research on ML-based model physics and interpretable nowcasting also shows promise. However, human expertise on the physical world remains indispensable in solving the open problems in our field.

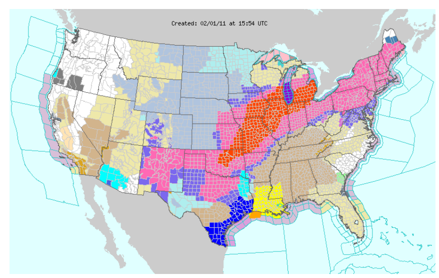
The 2011 Groundhog Day Blizzard
By: Erik Anderson '25
All figures courtesy of the National Weather Service



The historic 2011 Groundhog Day Blizzard from January 31 to February 2, 2011, brought heavy snow, strong winds, lightning, thunder, and even some small hail. This fast-moving storm was most intense in the Chicago area, beginning in the afternoon of February 1st and ending in the early morning hours of February 2nd. Wind gusts peaked at around 50 to 60 mph and drifts ranged from 2 to 10 feet. 21.2 inches of snow fell at Chicago's O'Hare Airport. The 2011 Blizzard was the third biggest snowstorm in Chicago history. Compared to all recorded Chicago winter storms, this storm brought the most intense winds and the greatest amount of lightning. The addition of lake effect enhancement helped to bring widespread 18 to 24-inch snowfall totals in counties bordering the southwest end of Lake Michigan. At O'Hare Airport, visibility was around ¼ mile for 11 straight hours. The storm trapped cars on Lake Shore Drive on the night of February 1st.

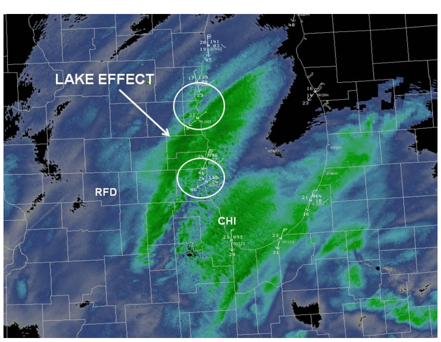


The historic 2011 Blizzard did not seem like much of a strong storm system during the week of January 24th. However, as the week progressed, computer models began to pick up on the disturbance. Even then, the track of the system was unclear. The weekend before the storm hit the Chicago area, models began to conclude that Chicago, along with northern Illinois and northwest Indiana, was in line for a potent winter storm capable of bringing heavy snow and strong winds. The storm tracked up from the Southwest, which favored extreme moisture content and heavy snow. As the surface low moved out of the southern Plains, precipitation began to fall around the mid-Mississippi valley. Lake effect snow began to fall early Tuesday morning in the Chicago area.



As the day pressed on, the strengthening storm system made its way up to northern Illinois and northwest Indiana. At the time, the area of low pressure tracked over southern Illinois and southern Missouri. The low kept strengthening as it moved northwards. The system, classified as an upper-level trough, increased its negative tilt, which caused greater pressure falls and rises. Along with this atmospheric setup, as the strong low pressure moved through east-central Illinois, a heavy snow band set up over northern Illinois, bringing 1-2 inches of snow per hour in that region. This heavy rate of snowfall kept up for many hours.

This was a fast-moving system that brought intense snow to Chicago from the afternoon of February 1st until the early morning hours of February 2nd. As the system moved east, wrap-around winds caused moderate snowfall to continue across northern Illinois and northwest Indiana. The flow of the system as it moved east allowed winds to blow from the northeast. The combination of high winds that continued to reach gusts of 50 mph and lots of surface convergence created lake effect snowfall in the Chicago metro area and in southern Wisconsin.



One of the most fascinating parts of the storm was the amount of lightning recorded during the storm. The storm system brought a copious amount of instability, moisture, lift, and forcing. There was forcing through the storm's intense upper-level trough and mid-level frontogenesis. The storm's origin near the Southwestern United States allowed it to pick up a large amount of moisture as it headed northeast. The instability from late February 1st into February 2nd allowed for increased snowfall rates and charge separation, which caused lightning to occur in a region from central Illinois to Chicago.

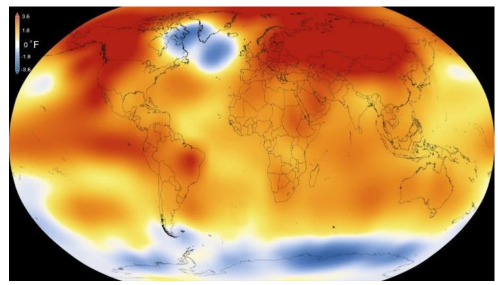
Another characteristic of this system was the sustained high winds. The instability in the upper-level trough caused the surface low to deepen as it moved northeast across the Midwest. The combination of a strengthening and deepening low along with a strong high-pressure ridge to the north allowed for a strong pressure gradient to set up across the Midwest. The increased flow that occurred throughout levels of the atmosphere along with a well-integrated thermal and moisture profile allowed winds a few thousand feet off the ground to come down to the surface. Places near Lake Michigan even reached stronger wind gusts because of the low friction. Unsurprisingly, the strongest winds were 70, 67, and 63 mph at the Chicago Lakefront, Burns Harbor, and Waukegan Harbor, respectively. Winds remained steady at around 35 mph for the entirety of the storm.

The 2011 Blizzard will long be remembered by Midwesterners, and especially Chicagoans. The fast-moving nature of the storm along with the heavy snowfall rates, high winds, lightning, and lake effect snow make the 2011 Blizzard an unforgettable meteorological phenomenon.

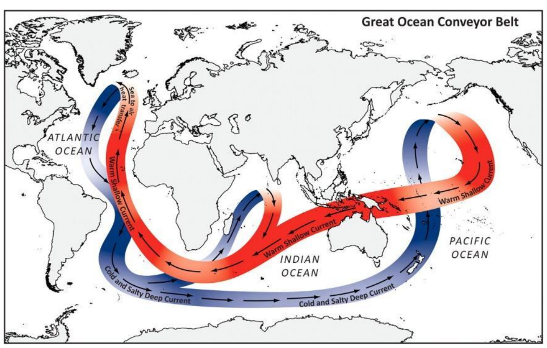
The Greenlandic Cold Blob Anomaly

By Samuel Jurado ‘25

It is no secret that the climate is warming. According to the National Oceanic and Atmospheric Administration’s (NOAA) 2020 Annual Climate Report, the land and ocean surface temperature has increased by 0.13 degrees Fahrenheit (0.08 degrees Celsius) per decade since the 1880’s. Since 1981, however, that rate has doubled to 0.32 degrees Fahrenheit (0.018 degrees Celsius) per decade. The Arctic circle, bearing the brunt of this heated onslaught, warms at twice the average global rate. If so, how could it be true that the Arctic is also home to one of the fastest cooling areas on Earth?



The cold blob is markedly visible just south of Greenland; a blue anomaly in a rapidly warming sea. *Credit: NASA/NOAA.*



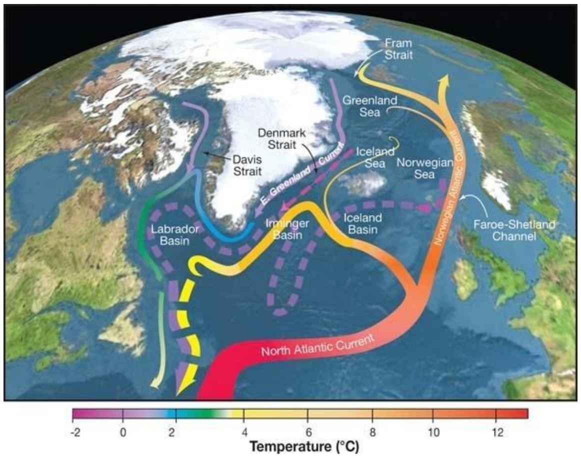
The Great Ocean Conveyor Belt extends across the entire globe. It plays a vital role in the health of both marine and terrestrial ecosystems. It also impacts weather systems and acts as a climate mitigator. Credit: *Broecker (1987).*

The Greenlandic Cold Blob describes a cold temperature anomaly in the ocean surface waters just south of – as the name suggests - Greenland. While global surface waters have warmed by approximately 1 degree Celsius, this area has cooled by 0.9 degrees Celsius over the same period. These temperature trends, however, are not permanent. By the time summer arrives to once again warm the waters of the Arctic the cold blob disappears. How can this be? The answer is contested, but climate scientists have reached a general consensus that the culprit behind the cooling is the introduction of freshly melted glacial waters to the Irminger Basin and Labrador Sea directly south of Greenland.

Greenland currently holds enough ice to raise global sea levels by over 7 meters if fully melted. While this will not occur anytime soon, the exploding rates at which Greenland is currently losing ice is concerning. Greenland now loses 234 billion tons of ice every year; a rate seven times faster than that of the 1990’s. While the ice loss does contribute to sea-level rise, the physical consequences of this phenomena extend beyond volume. The more ice Greenland loses, the lower the area’s albedo becomes. The lower the albedo, the more sunlight the area absorbs. This fuels a positive feedback loop, in which the effects of melting ice reinforce the continued melting of ice. As glacial waters pour into the North Atlantic, another dangerous phenomenon develops: the local freshening of water.

To understand why the freshening of the North Atlantic bodes such bad news, we must first understand the importance of salinity in ocean circulation patterns. While wind drives the currents of the upper 100 meters of the ocean, water density dominates the deep. Deep ocean currents are governed by the water’s density, which in turn is determined both by temperature (thermo) and salinity (haline).

Altogether, ocean currents are propelled by a thermohaline circulation pattern. As water ventures northwards, the water becomes colder and denser. When water begins to freeze in the arctic circle, excess salt is pushed into the oceans, making the local cold water saltier, and very dense. This water begins to sink, pulling in fresher and warmer waters from the south. As the cold-water seeps southwards across the abyssal plains, it eventually becomes rewarmed, and rises to the surface to begin the circulation anew.



The AMOC is integral to the functioning of the Great Ocean Conveyor Belt. The warm waters its brings helps maintain the warmer temperatures and mild weather of Western Europe. Without it, there would be unpredictable climatological consequences for the entire Northern hemisphere. Credit: *O'Malley, Isabella (2020).*

The Great Ocean Conveyor Belt can be subdivided into sections. Directly south of Greenland lies a zone called the Atlantic Meridional Overturning Current (AMOC). This is the area where northbound warm waters become cold and salty, whereupon they sink and become southbound. Herein lies the problem in Greenland's deglaciation: the water is no longer as salty as it once was. The water becomes less dense as it is freshened by glacial runoff. This water does not sink as efficiently as it did prior to deglaciation. As a result, less water bathes the abyssal ocean so less water is pulled from the equator. This disruption in the AMOC threatens to weaken the flow of the global circulation and impact weather patterns in the entire northern hemisphere.

We are already beginning to see the effects of the freshening of the AMOC. Exceptional AMOC weakening during the winter of 2009 has been implicated in a 13 cm sea-level rise along the New York Coastline. Additionally, the AMOC has slowed by 15 % since the 1950's. This unprecedented weakening of the ocean conveyor belt threatens to destabilize ecosystems, weather in the northern hemisphere, the climate, and severely impact coastal regions. Stegan Rahmstorf, a coauthor of the *Nature Geoscience* publication reporting these startling developments predicted that "in 20 to 30 years [the AMOC] is likely to weaken further […] we would see an increase in storms and heatwaves in Europe, and sea level rises on the east coast of the US".

The Greenlandic Cold Blob Anomaly is a representation of the extent to which Greenland is losing ice cover as the climate warms. The cold spot is composed of fresh glacial waters, which reduces the salinity of the area. As a result, the circulations of the area have been disrupted, possibly with global consequences. The continued existence of the cold blob is another cherry on the large, rapidly melting sundae of reasons to address climate change as a global community.

A Recap of the Texas Valentine's Day Winter Storm

Henning Schade '25

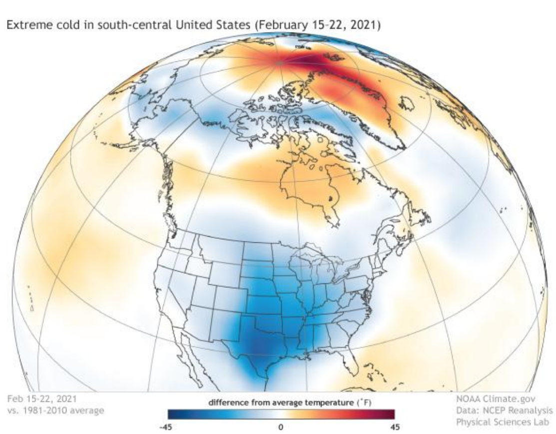
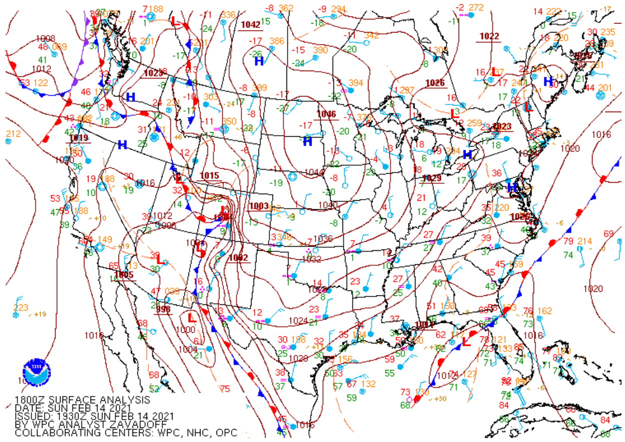


Figure 1: A strong ridge of high pressure disrupted the polar vortex and forced cold air from the poles into the mid-latitudes, such as the US. Credit: *NOAA*.

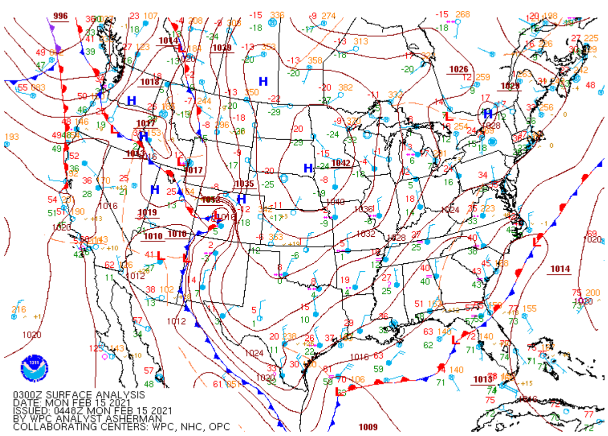
Coming from Texas, one might say I am not prepared for Ithaca's winters, which is a pretty reasonable assumption. However, I already got a taste of a harsh winter earlier this year, and I did not have to leave Texas to find it. The Valentine's Day winter storm smashed records all across Texas and surrounding areas of the South, causing the entire state to shut down. In my hometown of College Station, school closed for the entire week of 2/15 to 2/19 and our neighborhood had rolling blackouts for most of that time. We recorded a high of 20°F on the 15th and a low of 5°F the following night, a time of year when the average high and low temperatures are 65°F and 45°F respectively. As of now, it is the most significant weather event of my life.

This year has displayed several episodes of weird weather, from wildfires and drought in the west to floods and hurricanes in the east, all indicators of a warming world. But a freak winter storm is certainly not something most people think of when global warming comes to mind. How could this winter weather outbreak happen if we are growing warmer every year? Well, when one part of the world is cold, meteorologists know that somewhere else must be warm. And on the week of February 14th, the Arctic was indeed very warm. This is because the polar vortex, which usually keeps cold air confined to the areas around the poles, went into a weak phase. When the polar vortex becomes weak, instead of there being a well-defined jet stream which separates warmer air in the mid-latitudes and cold air over the poles, the jet stream becomes wavy. This allows huge intrusions of cold, polar air into the mid-latitudes while the Arctic warms. This past February, Arctic air effectively slid off the pole and migrated southward into the central US, as seen in figure 1.



A surface analysis at 18Z on Sunday February 14th 2021. A strong ridge of surface high pressure dominates the central US, bringing cold, Arctic air in from Canada. Credit: *National Weather Service.*

These cold temperatures set the stage for wintry weather. All that was needed for snow in Texas was a lifting mechanism which could use moisture from the Gulf of Mexico. Right on cue, a wave of low pressure formed along a stationary front in the gulf on Sunday afternoon, bringing moist air into Texas. With extremely cold air at the surface, areas of snow and sleet formed and intensified Sunday afternoon into Sunday night. The entire state experienced some form of wintry precipitation from Saturday into Sunday night. This was reflected in the winter storm warnings, which for the first time in history covered the entire state.



A surface analysis at 0300Z on Monday, February 15 2021. A wave of low pressure forms along a front in the Gulf of Mexico. Credit: *National Weather Service.*

The winter storm did not just affect Texas, but rather a swath of the country from Texas through the lower Mississippi Valley, Ohio Valley and Northeast. However, the brunt of serious effects were in Texas. Due to Texas being on its own power grid and this grid not being weatherized against winter weather, much of the state experienced blackouts. Governor Greg Abbott wrongly put the blame on renewable energy sources such as solar panels and wind turbines, when in reality most of the malfunctions came from natural gas facilities. In our community, my family and many others also had to shut off our water supply because the pipes could not handle water freezing inside them. My family filled up every pot and our bathtub with water before the storm hit, so we were able to handle the situation. But without power for so many Texans, the situation quickly became bleak. Some had to use snow for water, and others lost power for multiple days. At the beginning of the crisis before rolling blackouts were implemented, the power grid was only minutes away from a complete failure. Even though the worst was averted, the situation became disastrous for some. 223 people lost their lives in the US with 210 of those in Texas. This winter storm was more deadly than any single hurricane season since 2005.

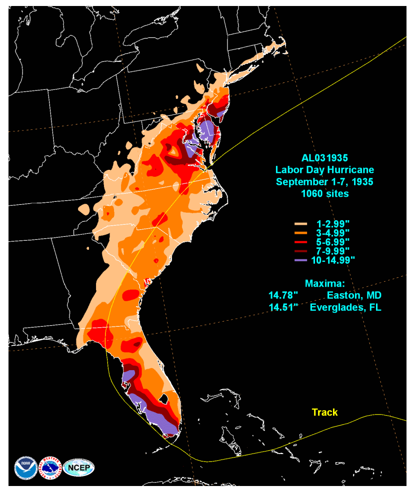
Relief did not come quickly for Texas. The deadly winter storm was followed by another just a few days later. Thankfully, this one was not as impactful, though it did bring significant ice to much of east Texas. There was a slow warming trend after this storm, with highs in my hometown climbing above freezing on the 17th and returning closer to normal by the next week. Power was back on line for most people by the end of the week.

Surprisingly enough, this snowstorm was not the only one in College Station this past winter. A second snowstorm in January brought the snowfall total for the season to 7.5 inches, which is tied for the second highest with 1930. 1973 holds the highest record with 8 inches. To have two separate snow events this far south in Texas is extremely unusual, and a reminder that even with global warming, significant winter weather events are still possible, and maybe even more likely. These next few winters will be key in determining whether cold snaps like this are truly a once in a century event, or if they are the new normal.

Interning with the Weather Prediction Center Through the Lapenta Program

By Harrison Tran '22

I had a great experience in summer 2021 interning with the Weather Prediction Center (WPC) as part of the Lapenta NOAA Student Internship Program. Although COVID-19 meant that the internship would be remote, it was nonetheless an enriching and rewarding experience. As part of the program, students are paired with mentors from a select NOAA office and are given the opportunity to work on impactful projects with real-world applications. These projects were wide-ranging, and included everything from statistical studies to product evaluation and from research to software development. There were also showcases of the various offices in the National Oceanic and Atmospheric Administration on almost every weekday, providing an illuminating inside look at the agency's large breadth. Staff from each respective office would either give a tour of their workplace or provide a thorough presentation discussing their day-to-day operations and responsibilities. My mentors over the summer were WPC Science and Operations Officer Mark Klein and Senior Branch Forecaster David Roth, who helped me along the way and were greatly supportive.



My project over the summer was to automate and improve the agency's CLImatology-based Quantitative Rainfall (CLIQR) system. The system was created in 2008 and was intended to identify historical rainfall analogs to currently active tropical cyclones. This would help give forecasters historical references and plausible outcomes when predicting tropical rainfall. However, changes in the system's data source in 2017 caused CLIQR to fall out of operation. I wrote new backend code for CLIQR to both update its data assimilation and identify storms not only with their current positions but also incorporating their entire forecast track from the National Hurricane Center where possible. CLIQR was also originally written in Fortran, so to bring it more in-line with the agency's other tools, I rewrote the code—around 2,000 lines—in Python. It was a fun experience getting gritty with the code and adding code documentation to breathe new life into the code, ensuring that it could be readily maintained and operated by future forecasters. The experience I've gained from taking computer science classes here at Cornell was tremendously helpful in guiding my programming and revitalization of CLIQR. My mentors Mark and David offered amazing support, and despite their busy schedules at the WPC, always made sure to provide some time during the week to check in on my progress and guide me through the project. Astonishingly, this new CLIQR went operational in mid-July, within weeks of my code modifications. CLIQR was used to aid forecasters in predicting Hurricane Ida's rainswath as it tracked across the Southern and Eastern US in August 2021.

In addition to working on CLIQR, I put together new rainfall maps of significant tropical cyclones affecting the contiguous United States between 1900 and 1949, augmenting the WPC's tropical cyclone rainfall database with data from this era for the first time. This expanded dataset now includes storms like the 1900 Galveston hurricane and the 1935 Labor Day hurricane (pictured above).

I greatly recommend the Lapenta Student Internship Program to my fellow students here at Cornell. There are a wide variety of agencies and projects offered through the Lapenta program, covering a wide spectrum of topics and interests. Even if you're unfamiliar with programming, your mentors will give you the resources you need to develop your project to its fullest potential, and there are also many projects that don't involve computer programming at all!

Ten years ago, a reminder of the New England power grid's frailty

(This article originally appeared in the Washington Post, a newspaper the author contributes to)

Jacob Feuerstein '23

The violent snapping and crashing of tree limbs echoed off a deep blanket of snow all night, like gunshots ringing through the forests of Southern New England. Those trees still standing were forced into precarious slouches by the weight of wet, heavy snow pressed against foliage. An unusual atmosphere had met a regional time bomb, and each tree's resignation to gravity ticked destruction higher.

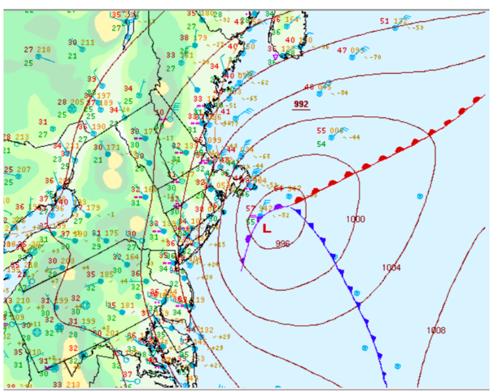
The Northeast is no stranger to winter weather. But when a perfect confluence of record-breaking early season cold and a powerful storm system brought feet of October snow to New England, a precarious power grid that services millions was brought to its knees. This month marks ten years since that terrible storm, a disastrous event that also serves as a warning about the region's unusual power grid vulnerability.

The Storm

Warm temperatures can delay the process by which leaves change and fall. 2011's Autumn was especially hot, and foliage remained remarkably intact through late October in southern New England. By the 27th of that month, as a strong cold front slid across the Northeast, leaves had yet to fully fall across much of Connecticut, Massachusetts, and New York.

As the late October cold front swept through New England, an unusual disturbance pattern rocked the upper atmosphere. The jet stream, which separates cold air from warm air thousands of feet above ground, was shuffled between an impulse over Oklahoma and one over the Great Lakes. As the latter outran the former, an immense ball of cold high pressure spilled south into the central US. The seasonably frigid airmass built behind the cold front, plunging New England's nighttime temperatures into the 20s F. Meanwhile, the jet was still forced south over the north-central US in a pattern that simultaneously kept cold air entrenched over New England and opened a path for energetic storms from central Canada to slide towards the Northeast.

One of these storms, enthusiastic but moisture-starved, leapt towards the Atlantic coast from Alberta late on the 28th. As it approached the Northeast, so too did a broad surface low stretched from Florida to the North Carolina coast. A perfect match to create a perfect storm, the former knocked a slug of cold air south, while the latter pulled deep Atlantic moisture north. When the two collided off the Delaware coast on the morning of the 29th, a formidable nor'easter was born.

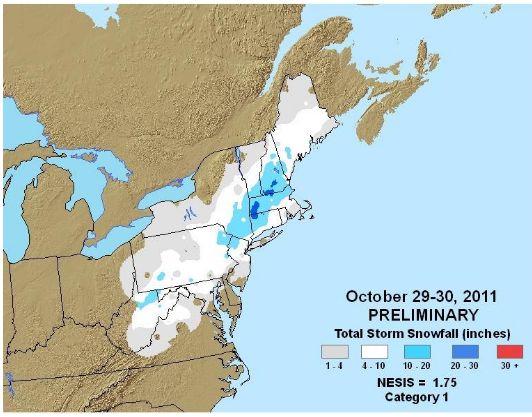


A confluence of unusual atmospheric events brought a remarkable early-season nor'easter to New England. Credit: National Weather Service.

It took an improbable combination of an odd jet stream orientation, an intense Canadian low, and a moisture-rich Atlantic storm, but snowflakes had started to fall in the October air. At first they melted long before they hit the ground, a testament to the resolute sun angle, and a cold rain pattered the surface. But as this melting process cooled the air, and the slug of Albertan atmosphere pulled ever closer to the coast, the rain slowly changed to snow.

The flakes were fat, wet, and dense, a product of the warm temperatures at which they formed and fell. In the cities where a few inches managed to accumulate amidst urban warmth, they would prove a pain to shovel. Further north and west, across a stripe of the interior Northeast, the cement snow fell on vast swaths of forest. Where leaves remained on trees, the stress of the heavy snow on limbs and trunks grew immense.

Through the night, inches turned to feet as band after band of snow rotated through New England. In the corridor from Northeast Pennsylvania through east-central Massachusetts, where the densest snow fell in greatest amounts amidst the most trees with the most leaves, limb after limb shattered amidst the weight of snow and plummeted to the ground. '



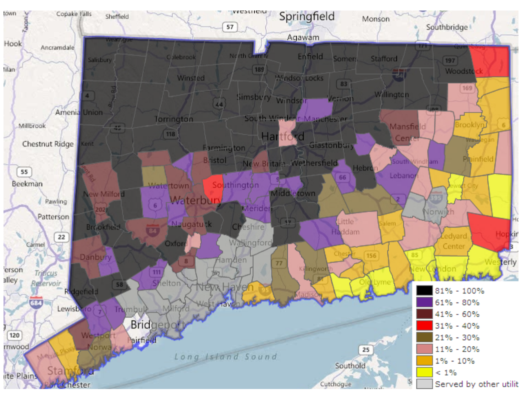
More than 10" of snow fell across a wide swath of the Northeast. Where this substantial accumulation overlapped relatively warm temperatures, the stress on trees was tremendous. Credit: National Weather Service.

The Grid

Trees fall often in the expansive forests of the Northeast. But as more and more people have made these forests their home, and as the woods themselves rebound from centuries of logging, treefall events have increasingly wrecked societal havoc. This is largely a function of the trust placed in trees to not fall by a power grid that snakes millions of wires through roadsides packed with limbs. All it takes is one instance of this trust being betrayed to plunge a neighborhood into darkness, a fact that combines with tumultuous regional weather to make New England's grid unusually vulnerable.

As the night of the 29th wore on, every one of the constant snaps that echoed across New England indicated a limb or tree losing the fight against the snow. Many also represented a battle lost between the power grid and the environment it was built within, as these falling trees severed countless electric lines.

The extent of power loss was tremendous and, for many, unprecedented. More than three million lost electricity during the nor'easter, with nearly one million in Connecticut alone- the worst power outage on record for the state, breaking a record set only two months earlier in tropical storm Irene.



The nor'easter wrought an incredible degree of damage to trees and the electrical grid, especially in Connecticut. A vast majority of the Northwest half of the state lost power. Credit: Ryan Hanrahan

For hundreds of thousands of the region's residents, tree destruction- and resulting power failure- was so complete that it took over a week for the lights to turn back on.

A storm slamming snow, dense and unseasonable, into canopies of leaves may be a fairly unusual and dramatic way to get catastrophic power grid damage. But when thousands of miles of snaking power lines rely upon trees not falling to the extent that New England's does, such disaster is hardly as unique as an October snowstorm.

Ryan Hanrahan, a weekday meteorologist at NBC Hartford who writes frequently about Connecticut storms and weather history, says the power grid vulnerabilities exploited by the October Nor'easter are still present. He notes that, while companies are somewhat better prepared than they were in 2011, recent storms have demonstrated a still-fragile electrical distribution system.

“The power grid in New England remains uniquely vulnerable to extreme weather events,” Hanrahan says. “As we saw in the October Snowstorm of 2011 and even more recently during Tropical Storm Isaias, the power grid is quite vulnerable given how many trees line every mile of distribution line in the state.”

In Connecticut, Isaias was one of three tropical cyclones in the last decade that have produced power outages nearly as numerous and long-lasting as the 2011 snowstorm, alongside Sandy and Irene. While all three brought winds no stronger than tropical storm force, gusts were sufficient to snap enough tree limbs to cripple a vulnerable grid. The region’s abysmal track record with relatively weak systems is enough to worry experts, like Ryan Hanrahan.

“I’m worried about what happens when a significant hurricane hits,” Hanrahan explains. The region is currently experiencing an unusual ‘hurricane drought’, but storms far stronger than Isaias have impacted New England in the last century. When the next one does eventually strike, Hanrahan fears, results could be catastrophic. “The outages would last for months.”

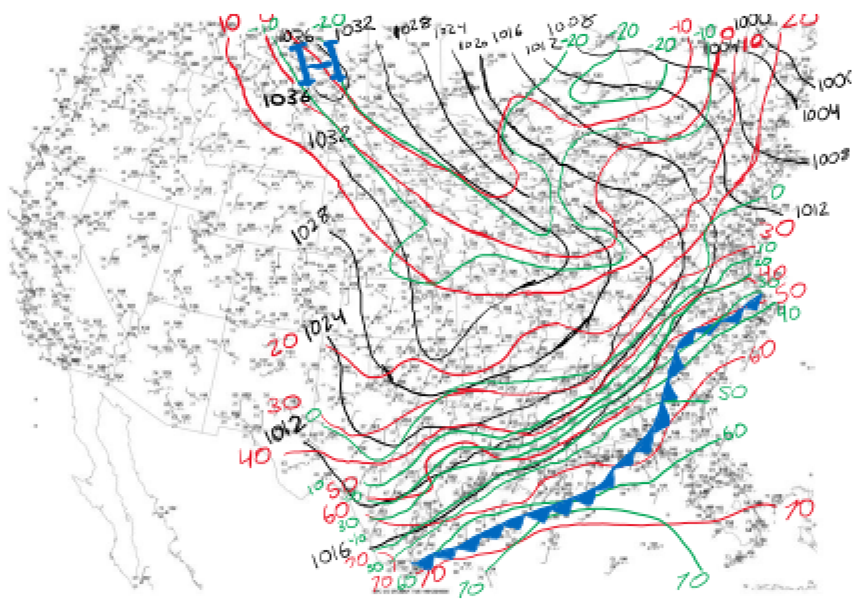
***A Complex Disaster* – Alabama’s 2014 Winter Storm**

Benjamin Moose ‘25

On January 28, 2014, just a couple inches of snow caused one of the most significant winter weather events of the decade for central Alabama. Forecasts originally predicted an insignificant amount of snow, with the NWS noting the improbability of significant snowfalls in the area. However, these forecasts were incorrect. Travel became nearly impossible as snow accumulated, creating what local meteorologist James Spann called “conditions you would expect from a crippling ice storm,” and a “humanitarian disaster,” and civil emergency messages were issued for much of central Alabama.

In a post-event report, the NWS explains the setup of the winter storm:

> *“As we went into Monday, a major change was taking place as yet another arctic front was headed south across the area… In fact, several dew points registered in the negative digits… The issue of just how far north the winter precipitation would fall was also a huge concern considering the extremely low dew points that were in place across portions of the area.”*



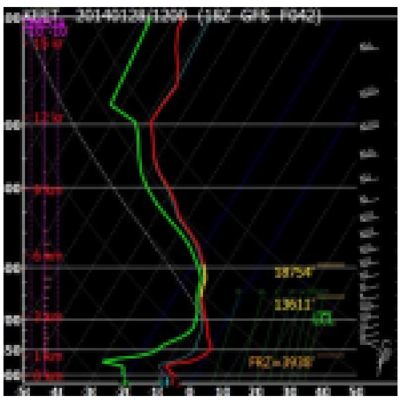
This setup is illustrated in the surface map (with estimated isobars, isotherms, and isodrosotherms) from 00Z on 01/27/2014 (6:00 PM local time). An elongated region of high pressure guided a continental arctic air mass to the southeastern United States. In fact, this air mass had already made its way into central Alabama, since the shift in wind direction accompanying the surface cold front had reached the Gulf of Mexico and southern East Coast. As shown by the sharp gradient in isodrosotherms, dew points were significantly lower over central Alabama than the coastal regions of the state, with a 51-degree dew point difference between Dothan (southeast AL) and Birmingham (central AL).

The NWS continues its event description:

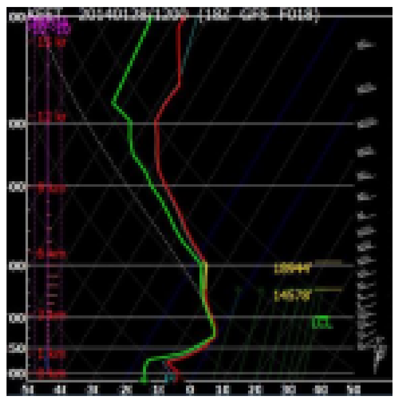
"By early Tuesday, it was apparent that a lot of moisture was moving into the area... Meanwhile, the surface temperatures were dropping in conjunction with the heavy precipitation…The atmosphere had moistened so quickly that snow up north and sleet and freezing rain south were already beginning to reach the ground several hours earlier than anticipated."

The NWS noted the day before the storm that a "dusting" of snow in the Birmingham area could occur only if "precipitation could fall through the ever-increasing dry air coming in from the north," when, in fact, significant moistening occurred and precipitation was able to fall for multiple hours.

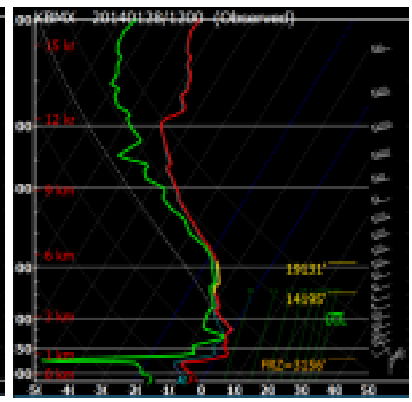
According to these National Weather Service forecast discussions, models had shown significant variability leading up to the event. The following soundings (from the *SHARPpy* tool) show the GFS's forecast at 42 hours and 18 hours before 6:00 AM local time on the 28th (the forecast location was the Shelby County Airport, near the Birmingham metro). The actual conditions at 6:00 AM ended up in between the two predictions (the column was not as moist as the 18-hour forecast suggested, but the actual 850-mb level was moister than the 42-hour forecast predicted, although a much dryer near-surface layer was present). The variation in model output, though not unusual, could have played a role in unreliable forecasts before the event.



Shelby Co. Airport 42-hour GFS forecast sounding for 6:00 AM local time on January 28th.
All soundings are from the *SHARPpy tool.*

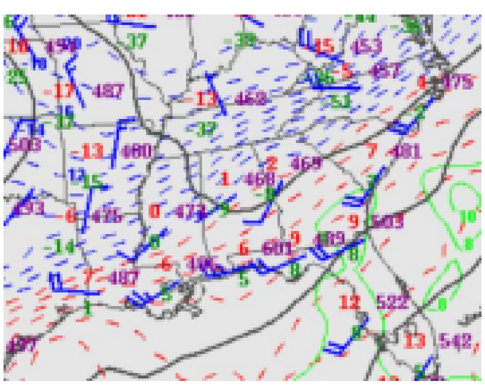


Shelby Co. Airport 18-hour GFS forecast sounding for 6:00 AM local time on January 28th.

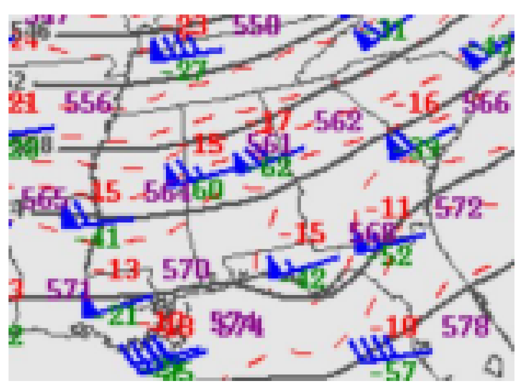


Shelby Co. Airport observed sounding for 6:00 AM local time on January 28th.

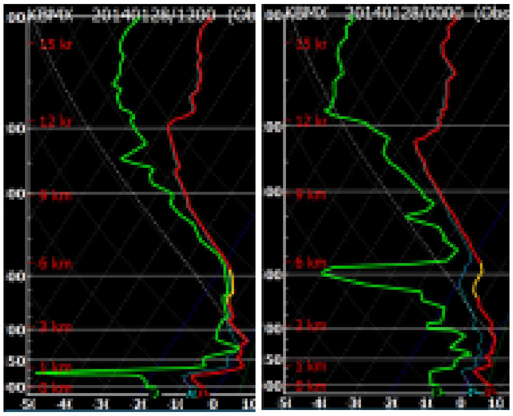
Layers of the atmosphere leading up to the snowfall can be partially explained by the flow aloft. The 850mb map from 12Z shows southwesterly flow, bringing moist air from southern Mississippi into central Alabama. However, this flow was quite slow, ranging from 5-10 knots in central Alabama, so perhaps it is more accurate to state that the *lack* of northerly flow (and therefore dry air advection) was more impactful with respect to the moisture content of the 850mb layer in the hours leading up to the snowfall event. 700mb and 500mb maps indicate moist-air advection from stronger southwesterly flow which eliminated the significant dry layers between 700 and 500mb seen in the comparison of observed soundings on the left. The map on the right shows *significant* moist air advection occurring with a southwesterly 500mb flow at 00Z on January 27th, setting the stage for the snow event about 18 hours later by providing upper-level moisture.



850mb map from 01/28/14 at 12Z (6:00 AM local time).
Credit: *Storm Prediction Center.*

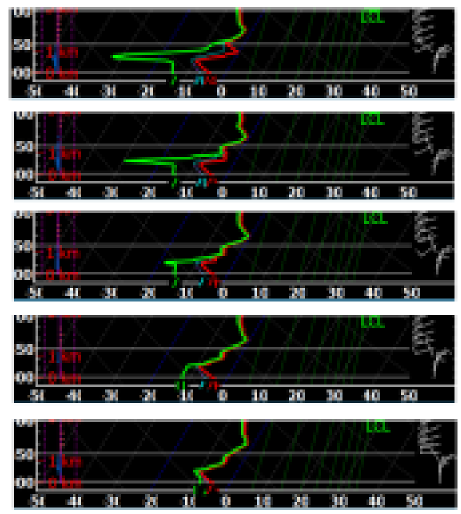


500mb map from 01/27/14 at 00Z (6:00 PM local time).
Credit: *Storm Prediction Center.*



Observed 00Z (6:00 PM 01/27/14) and 12Z (6:00 AM 01/28/14) soundings from the Shelby Co. Airport on 01/28/2014. Credit: *SHARPpy Tool*.

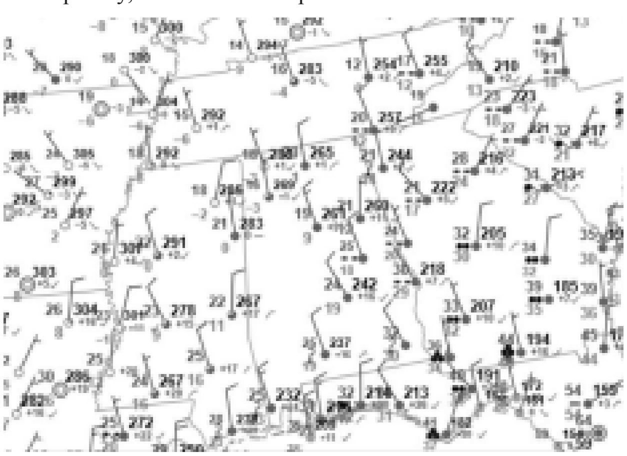
Since little moist air advection could have occurred in the lower levels (850mb and below) given the weak winds, what could have caused such a shift in the dewpoint in these lower levels? Most likely, precipitation falling from higher levels caused lower levels to moisten, as referenced in NWS forecast discussions. As precipitation fell, some of it likely evaporated into the dryer atmospheric layers closer to the surface, subsequently increasing the moisture of the surface layer and those just above it. A more complete view of this phenomenon can be seen by looking at the lower levels of the atmosphere according to the 18Z 01/27 NAM model soundings. The images below show the 14Z-18Z 01/28/14 forecast soundings, which, although not perfectly representative of the actual event, do not seem wildly inaccurate. As indicated by the wind barbs, advection at levels below around 875mb appears to be primarily from the north-northeast, moving in air that is cold, and, assuming the NAM's model run was fairly representative of actual conditions, not significantly moister than the existing air in place. Therefore, the change in the moisture of the air appears to be a result of evaporation of precipitation, and this phenomenon was forecast to, and did, occur quite rapidly on the morning of the 28th. As the NWS considered in earlier forecast discussions, the column of air did in fact "moisten from the top down."



Lower levels of 01/27/14 Shelby Co. Apt. 18Z NAM forecast soundings for hours 20-24 (8:00AM-12:00PM local time on January 28th). Credit: *SHARPpy Tool*.

In addition, we can look at the 01/29/14 00Z (6:00 PM local time, after the snowfall) surface observation map, which shows significantly lower magnitude dew point depressions (more moisture) than the 01/28/14 12Z map for central Alabama, but lower temperatures as well, indicating that the surface layer had moistened by the process described above while also cooling due to persistent north-north westerly flow and cold-air surface advection, in addition to any potential evaporative cooling.

In retrospect, forecasts from a few days before the winter storm could have underestimated the northward extent and/or magnitude of what the NWS called "overrunning" of moist air or, perhaps more evidently from model soundings from a few days out, the rapid moistening from sublimation. Moist-air advection likely resulted in condensation of moisture aloft as slightly unstable air rose and, subsequently, led to the development of clouds. As condensed moisture (in the form of frozen precipitation) fell through the atmosphere, it likely sublimated in the presence of dry air below the 850 mb level, subsequently decreasing lower-level and surface temperatures (allowing for more accumulation, in conjunction with cold air surface advection) and increasing the moisture of the lower levels of the atmosphere. As the surface and lower levels became more moist by this process, precipitation was able to reach the ground as accumulating snow, notably farther north than originally forecasted.



Surface map of the southeast from 01/29/2014 at 00Z (6:00 PM local time on 01/28/2014). Credit: *Storm Prediction Center*.

WEATHER WORD SEARCH 2021

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METEOROLOGY	**SATELLITE**	**SUPERCELL**	**FORECAST-NIGHT**
HURRICANE	**RADAR**	**CONVECTION**	**ITHACATION**
TORNADO	**SKEWT**	**UPDRAFT**	**CCAMS**
HAIL	**CAPE**	**LAPSE-RATE**	**SNEE**
CLOUD	**SHEAR**	**LATENT**	**ATMOS-SCI**
CUMULUS	**VORTICITY**	**DROPLET**	**JACOB**
WAVE	**GEOSTROPHIC**	**DENDRITE**	**JULIE**

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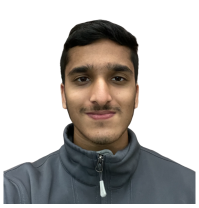
New faces of Fall 2021

My name is **Austin Ping**. I grew up in Beijing, China, and moved to Albany, New York during high school. My career goal is to study air pollution and clouds so far, but I'm also really passionate about chasing tornadoes and learning everything in the atmosphere. Movie *The Day after Tomorrow* and the fog conditions in Beijing ignited my passion for studying atmospheric science.

My name is **Nicole Collins** and I am from Boonton Township, NJ. I don't quite know what I want to concentrate on within meteorology yet because I find all of it so fascinating! One of the reasons I am passionate about the weather is because I saw a building get struck by lightning when I was four, which gave me a phobia of thunder and lightning throughout my childhood. However, that phobia eventually morphed into a passion and now I can't get enough of the weather.

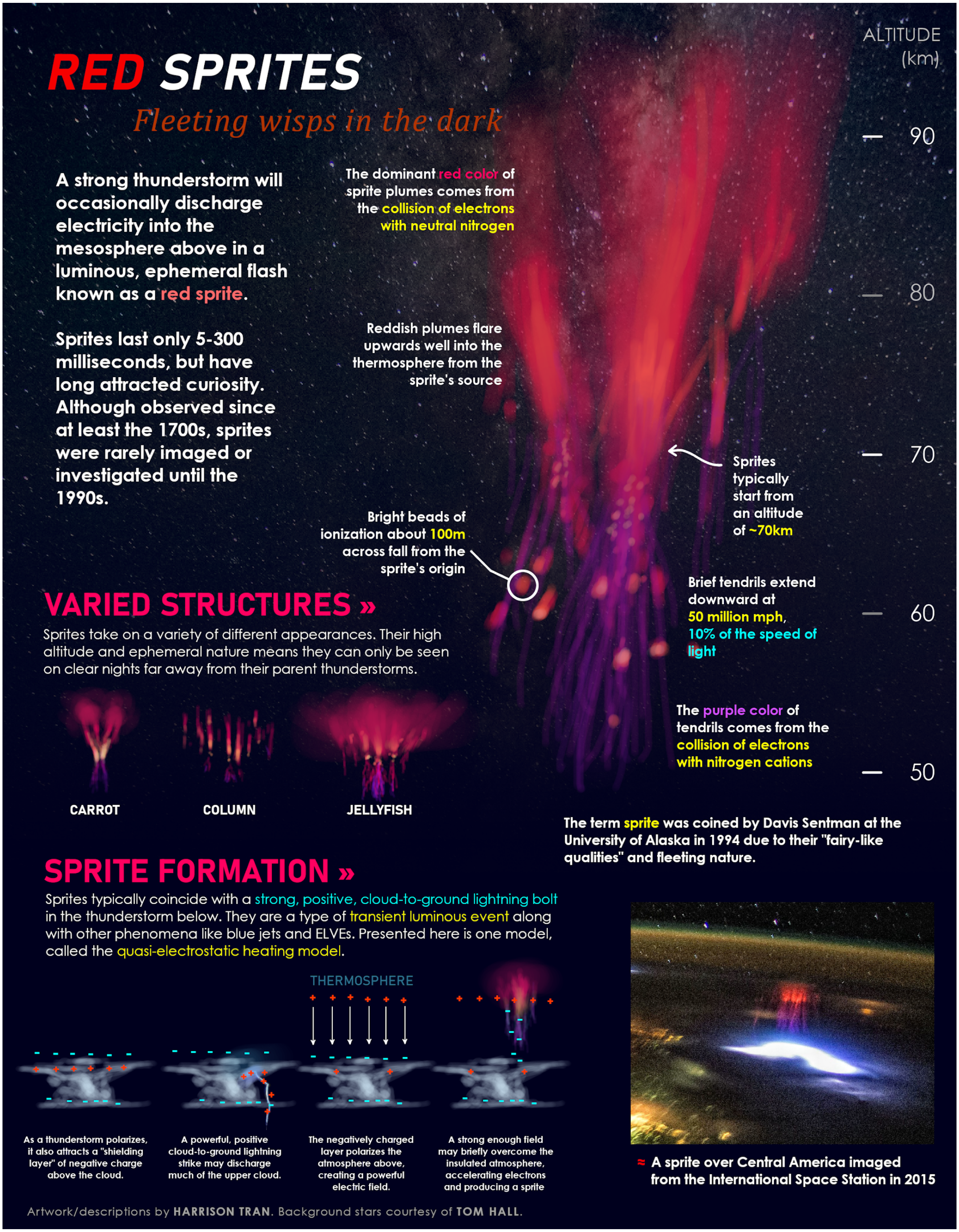
My name is **Samuel Jurado**, and I am from El Paso, Texas. I am interested in continuing to research boundary layer meteorology and developing atmospheric instrumentation. One phenomena that ignited my passion for atmospheric science was El Paso's near complete lack of interesting weather beyond the annual heat wave. This prompted me to try to learn why the Sun City was so boring, and the ensuing never-ending Googling spiral led me to where I am today.



My name is **Rohan Shroff** and I am from Richmond, Virginia. I'm particularly interested in winter weather, seasonal forecasting, and climate science, and I hope to conduct research in those fields. My favorite weather event is the Jan. 22-23, 2016 snowstorm, which dumped 18 inches of snow over Richmond.

My name is **Erik Anderson**, and I am from Chicago, Illinois. I have always been fascinated by the weather. I used to spend some of my free time running down to Lake Michigan to observe the cloud formations. My favorite weather event was the 2011 Groundhog Day blizzard.

My name is **Ben Moose**, and I am a freshman from Birmingham, Alabama. I plan to pursue a career in operational meteorology or research, working to develop or improve weather forecasts. I have witnessed the effects of historic tornadoes, in addition to a variety of impactful flooding, thunderstorm, and winter weather - related events back in Alabama, and I am interested in studying the conditions that cause such significant weather to occur, whether from a purely scientific or operational perspective.



Thanks for reading. See you again this spring!