How Accurate Are Weather Forecasts?

Comparing the Most Popular Weather Forecasting Services

Earth & Space Sciences

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9th Grade

Abstract

The concept for this project arose from pure curiosity. Almost everyone relies on weather forecasts to schedule their daily activities. In the world of business, many companies, whether corporate or small and family-owned are dependent on accurate forecasts. Agriculture-based companies are especially so. Knowing how much rain their fields will receive, how hot it will get and other factors help influence decision making and ultimately lead to an improved crop yield. However, forecasts are never spot on. How much can farmers rely on forecasts to assist them in their businesses? How often do they miss the mark, and to what extent? To put it simply, how accurate are weather forecasts? These are the questions that this project was created to answer. Three companies were chosen to evaluate based on their popularity and alleged accuracy: AccuWeather, The Weather Channel, and Dark Sky. It was hypothesized that The Weather Channel would be the most accurate. For a period of fifty-eight days, data was collected from all three companies regarding temperature, humidity, and wind speed. After analyzing the data, it was concluded that AccuWeather produced the most accurate weather forecasts. This partially disproved the hypothesis. The Weather Channel was not as accurate as AccuWeather, but it was more accurate than Dark Sky. Certainly, this process could be improved. However, the project still met its predetermined objectives. Most importantly, it determined how accurate weather forecasts are. It also left some questions unanswered. To study the topic further and answer those questions, the data collection process could be automated and extended over a longer period of time.

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Background Research

You know that picnic you planned? You've got the date marked on the calendar, you've contacted your buddies, and you've even checked the weather in advance to make sure your much-anticipated vacation won't be rudely interrupted by an uninvited guest. Thunderstorms, freezing cold weather, and boiling hot temperatures are just a few of the contenders on the long, long list of unwelcome visitors that are intent on laying waste to your plans. However, you're determined to have the best picnic possible, and so naturally you've checked the weather, which has comfortingly reassured you that the weather will be perfect. "Why, with a light cloud cover, a gentle breeze, and a beautiful 72-degree weather forecast for the day, what on earth could go wrong?" you ask yourself. Well, for one thing, that prediction could be completely bogus. How many times have you relied on a heavenly weather forecast, only to have the actual results turn out at least askew, if not completely off target? Most people have experienced at least one such annoying situation, and sometimes, it can be a source of extreme emotional trauma. "In Israel, a weathercaster was sued by a viewer who claimed a surprise shower messed up her hair, gave her the flu, made her miss four days of work, and caused mental anguish" (Goldstein, 2002). The truth is, weather predictions aren't 100% accurate, although they are much more so than they were a millennium or even a century ago. Humans have been attempting to master the seemingly magical science of meteorology since the dawn of time. Tracing the origins, history, and improvements of meteorology is not only fascinating, but it will provide some insight into the meteorological dilemmas that we face today.

The art of predicting the weather has been carefully researched, documented, and explained since ancient times. According to Mel Goldstein, “From the earliest of times, hunters, farmers, warriors, shepherds, and sailors learned the importance of being able to tell what the weather might be up to next” (2002). The first scientific meteorologists are considered to be the Greeks, the most notable being Aristotle. Amazingly, “For 2000 years, no one added anything significant to his findings” (Farrand, 1991). However, the curiosity in weather was not only due to a desire to further scientific discovery. Although ancient civilizations valued meteorology, they did so for different reasons than we do today. Frequently, the weather and it’s often catastrophic, magnitudinous effects caused people to believe that it was the work of omnipotent deities. They fearfully served these gods, trying to appease them in the hopes that they would not send them undesirable weather. Some of the most powerful of these were Zeus and Thor, esteemed by the Greeks and the Norse, respectively. From those beliefs came the numerous myths and legends that readers and listeners enjoy today, many of which have been made into major motion pictures, such as Marvel’s Thor movies. Even more intriguing are the rituals and ceremonies that were practiced by thousands of ancient humans around the world, specifically the ones concerned with the weather. A ceremony called rainmaking was very common. In the well-respected blog *Brewminate*, Azriel ReShel remarks, “Shamanic rainmaking ceremonies are thousands of years old and were once practiced all around the world” (2017). She goes on to describe numerous examples in different ethnic groups, such as the San, Igbo, Aboriginal Australian, Native American, and Chinese. Unfortunately, although these

rituals would have been fascinating to watch, they did not actually help in influencing and predicting the weather, as their purposes were more cultural and sacramental than empirical. Even Aristotle's highly advanced theories about weather, that were used for thousands of years, had numerous errors and false assumptions. Humankind was still very far away from accurately predicting the weather. It would be several centuries until the advancement of meteorology would really start to accelerate.

Like most of science, the dramatic improvement of meteorological accuracy and development was the work of a copious quantity of eccentric, ingenious inventors and other contributors. One of the first, officially recognized weather instruments was designed by Nicholas de Cusa in the 15th century. According to Farrand, he simply "hung out some wool and noticed that it was heavier when moisture condensed on it" (1991). It was towards the end of the century when the renowned Galileo Galilei started to dabble in meteorology. The result was one of the most useful tools ever invented in the field - the thermometer. The name quite literally means "heat measurer." Galileo also noticed during his study of thermodynamics that gases and liquids expand when exposed to heat. It was around this time that yet another important invention, the barometer, was designed. Later, "In 1768, John Heinrich Lambert developed the hygrometer" (Farrand, 1991). This instrument measured the humidity of the surrounding air. Today, advanced models of his hygrometer are crucial in gathering data about the weather. The numerous inventions, theories, laws, and breakthroughs in meteorology that were created at this time are almost mind-blowing. The tools and instruments that were created then are still used today, and they are used to formulate more accurate

weather forecasts than ever before. That doesn't mean that there aren't exceptions, though. Meet *The Old Farmer's Almanac* and *The Farmers' Almanac,* with the former being founded in 1792, and the latter being founded in 1812. Both publications claim to accurately predict 16-18 months of weather in advance. According to their website, *The Old Farmer's Almanac* claims that it is "useful, with a pleasant degree of humor" (2016). Humor, indeed. Their boasted 80 percent accuracy rate is often scoffed at by meteorologists, who struggle to deliver accurate forecasts past ten days. Remarkably, the publication is still a relative success. In fact, you can buy the latest, 2019 edition on their website "www.almanac.com." However, though there were certainly some outliers, this time period and the instruments made during it proved to be essential in the furthering of meteorology.

Today, meteorologists use all that equipment and more to create a weather forecast. That forecast is then broadcasted by the media, on many different channels throughout the day. Millions of people everywhere rely on these forecasts to regiment, sculpt, and plan out their daily lives. So, one might wonder, how exactly do scientists predict the weather? Well, thanks to the technology that we have today, scientists can delegate more of the monotonous, basic tasks to advanced computers, who crunch numbers on an unbelievable scale. First, "Thousands of weather stations throughout the world communicate weather observations and data to international weather centers every three hours where the information is analyzed by meteorologists" (Nelson, 2010). These weather stations have all the equipment necessary to provide the computers with data on which they make their predictions. Besides the simple measurements discussed

earlier, such as temperature, humidity, and air pressure; weather elements like precipitation, cloud cover, and types of clouds are recorded. Finally, all this information is plugged into a supercomputer, which knows how all the factors might affect each other and the weather based on previous data. A weather forecast is then produced for the next few days or even a week. The forecast is often assisted or supplemented by high-tech radars and satellites, which work to graphically represent the data. The American Meteorological Society proudly announced that “Guided by numerical weather prediction models, operational forecasters at NOAA provided outstanding forecasts of Harvey's future path and potential for record flooding days in advance” (2019). This was largely thanks to one of their satellites, GOES-16. Because of the sheer computing power of these machines, forecasts are incredibly accurate, compared to older methods. However, even today, they aren’t perfect, especially long-range forecasts. Shockingly, the weathermen in other countries aren’t always held blameless for their inaccuracy. “In Taiwan, the head of the weather service was jailed for not warning of an approaching typhoon” (Goldstein, 2002). Thankfully, technology is still rapidly improving, so predictions can only get better.

The key measurements that will be discussed are temperature, humidity, air pressure, and wind speed, most of which will be used and quantified during this experiment. To get a better understanding of the procedures and results, they will be explained individually. Temperature is a highly useful measurement and is typically expressed in either Celsius or Fahrenheit. It is measured with a thermometer, which determines the average amount of kinetic energy of the particles in a system. Humidity

is another crucial quantity to understand, and it is measured by the hygrometer. Some aspects of humidity are somewhat complicated, but simply put, humidity "...is a measure of the amount of water vapor in the air" (Lerner, 2014). There are two important measurements of humidity to understand, the first being relative humidity. It is the most commonly used measurement, as it is usually more intuitive and relevant to the general population. Again, Lerner expertly explains the term at hand, stating that relative humidity is "a comparison of the amount of water vapor in the air with the maximum amount [of] water vapor that—at a given temperature—represents saturation" (Lerner, 2014). Essentially, relative humidity compares how much water there is in the air to the maximum amount there could be in the air. Absolute humidity, a different but related quantity, is a direct measurement of how much water vapor there is in the air. Finally, air pressure is measured by the barometer. In the U.S, it is typically expressed with the psi unit, although the pascal is also accepted. The air pressure of an area or location simply states how many air molecules are pressing down on that given area. Interestingly, Aristotle was yet again one of the first thinkers on a meteorological concept. "Aristotle, whose teachings sometimes inhibited the advancement of science, was right on target in his belief that the atmosphere surrounding the Earth had weight" (World of Scientific Discovery, 2007). Air pressure greatly influences the patterns of weather, movements of fronts, and other meteorological processes. Because particles tend to move from an area of high pressure to an area of low pressure (a phenomena known as wind), the speed of wind in a given area is greatly affected by the air pressure of that given area. All of these measurements are vital in the prediction of weather today.

Meteorology has certainly changed a lot over the years. From Aristotle and Thor, to Galileo and thermodynamics, to finally the supercomputers of today and tomorrow, the progression of science in the field has been exponential. Every scientist, entrepreneur, and engineer worked tirelessly over the centuries to increase the knowledge of the general population, and to make our lives easier. Leaving weather aside, it is simply remarkable how quickly science and innovation have overtaken civilization and dramatically improved it. Today, weather forecasts are more accurate than they have ever been before, but there is certainly room for improvement. Considering the leaps that science has made over the years, it is not unlikely that another major improvement in weather prediction accuracy is on the horizon. So the next time the weather ruins your special day out, remember that there is still much to be discovered and improved. And maybe take a moment to appreciate the tremendous amount of work that went into producing what you have right in front of you.

Materials & Procedures

QUESTION: How accurate are weather forecasts?

HYPOTHESIS: The weather forecasts produced by The Weather Channel will be more accurate than the forecasts produced by AccuWeather and Dark Sky.

MATERIALS:

- Computer
- Fast internet connection
- Access to G Suite
    - Google Scripts
    - Google Sheets
- Basic programming knowledge
- Access to common weather websites
- Notebook to report progress and take notes

PROCEDURE:

1. Pick 2 or more weather forecasting sites.
2. Create a new Google spreadsheet.
3. Name the spreadsheet.
4. At the bottom menu, click “+” and add a sheet for every weather forecasting site.
5. Name each sheet whichever forecasting site it corresponds to.
6. Label the columns on every sheet as follows:

    (1) Temperature Actual
    (2) Humidity Actual
    (3) Wind Speed Actual
    (4) Temperature 1-Day
    (5) Humidity 1-Day
    (6) Wind Speed 1-Day
    (7) Temperature 5-Day
    (8) Humidity 5-Day
    (9) Wind Speed 5-Day
    (10) Temperature 10-Day
    (11) Humidity 10-Day
    (12) Wind Speed 10-Day

7. Every day for the number of days that you desire, retrieve the data shown above and put it in the appropriate column on every sheet (for every weather forecasting site). Each row is a new day.
    a. To make it easier, you can retrieve the data automatically via Google Scripts (if the weather forecasting site has an API).
8. You can then create some charts using Google Sheets based on your data to visualize it.
    a. Try graphing the predicted measurements along with the actual measurements to see how close the weather predictor was.
9. Create an algorithm using Google Scripts that calculates the accuracy of all the forecasts (using percent difference). This is done by comparing the actual unit measured of a day (temperature, humidity, etc.) to the prediction.
    a. 1-Day signifies a prediction for the next day, 5-Day signifies a prediction for five days in advance, and so on.
10. By using both the charts and the data you just generated, you can now easily visualize each weather predictor's accuracy. If you'd like, you can compare them and see who came out on top.

Results and Data Analysis

The general purpose of this experiment was to determine how accurate weather forecasts are. My hypothesis was that the weather forecasts produced by The Weather Channel would be more accurate than the forecasts produced by AccuWeather and Dark Sky. First, I had to make sure that I had plenty of data to crunch in order to get the most accurate results possible, as weather is highly variable. Using three separate weather forecasting services (AccuWeather, The Weather Channel, and Dark Sky) and three different measurements (temperature, humidity, and wind speed), I started to gather data. Every single day for fifty-eight days, I collected a one-day, a five-day, and a ten-day prediction for each measurement and from each weather forecasting service. I also collected actual measurements of those quantities every day, which were later used to compare against the predictions. All these measurements were recorded for the weather in Delaware, Ohio. I intended to continue this process for sixty days. Due to minor complications, this was only carried out for a total of fifty-eight days.

A couple of days in, I realized that this process was going to be very time consuming. On average, I spent about twenty minutes a day gathering data. Although the amount of time I spent gathering data every day lessened as I became more experienced, it was still incredibly tedious. For this reason, I developed a program in Google Scripts that automated ⅓ of the process. This program involved automatically retrieving data from Dark Sky every day at a specific time. A screenshot of the code can be found in the appendix.

Another problem I encountered was the fact that this process was completely inflexible. If one day of data collection was missed, then the data hole would have to be compensated for or else other valuable data would be lost. I forgot to collect data three times during this fifty-eight day period. I filled in the data holes with “dummy” data based on previous forecasts. Although this did not significantly affect the end results of my project, it should be taken into consideration.

Yet another challenge I faced was deciding what formula to use to analyze my data. I wrote another program in Google Scripts to analyze the data automatically. This program was designed to comb through the entire Google spreadsheet and compare the prediction of a measurement to the actual value. However, I had to revise the code multiple times because it was spitting out strange values. Eventually, I realized that I was using percent difference when I should have been using percent error. This was fixed, although it took a considerable amount of time to do so.

Once I was finished collecting data, I was presented with the challenge of graphically representing it. This was very difficult, simply because I had a very large quantity of data to represent. However, once I was finished, I began to see some very interesting trends. First, that AccuWeather appeared to be the most accurate in every category except humidity. This seemed strange to me. It is possible that the humidity-specific technology AccuWeather utilizes is less superior to the technology of the other two companies. Another interesting trend was that the further out a prediction was, the more inaccurate it was. An illustration of this observation can be seen in the appendix. Yet another interesting trend was the complete inaccuracy of all weather

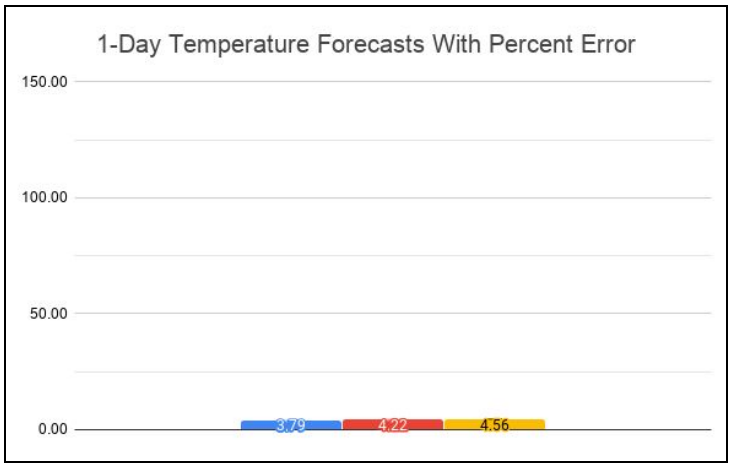
forecasting services regarding wind speed. Compared to temperature forecasts, wind speed forecasts were highly inaccurate. For example, Dark Sky predicted wind speed ten days away with an accuracy of about 32%. Again, the technology in the field could be less developed. And wind speed is much more variable than temperature, making it considerably harder to predict.

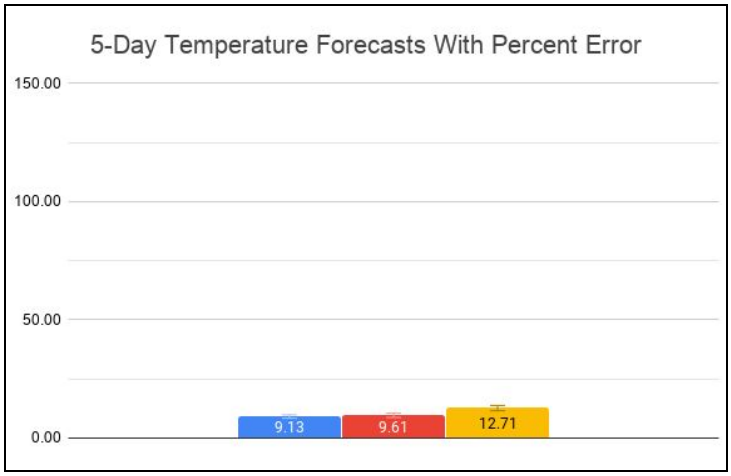
To analyze my data, I used a few different statistical formulas. To actually calculate the accuracy of each individual prediction, I used percent error. For example, because I recorded data for fifty-eight days, there were fifty-eight individual predictions to compare (for one-day predictions). Thankfully, I was able to create a program in Google Scripts to do this for me. The percent errors of all these predictions were then averaged together to create one mean accuracy for each kind of forecast. (There are nine in total.) I did this for each weather forecasting service, for each measurement, and for each forecast length. **The lower the number is on the data bars, the more accurate the forecast is.** This is because I used percent error to evaluate the data. For example, AccuWeather predicted the temperature one day away with an average percent error of 3.79%. This means that, on average, AccuWeather was “off” by 3.79%. It is important to understand that this measurement is purely relative, meaning it is solely based on the numbers being compared. In any case, that is incredibly accurate - 96.21%, actually. On the other hand, AccuWeather predicted the temperature ten days away with a percentage error of 17.62%. This means that AccuWeather’s ten day temperature forecasts were 82.38% accurate. The bar graphs below compare the average percent errors of all three weather forecasting services regarding different

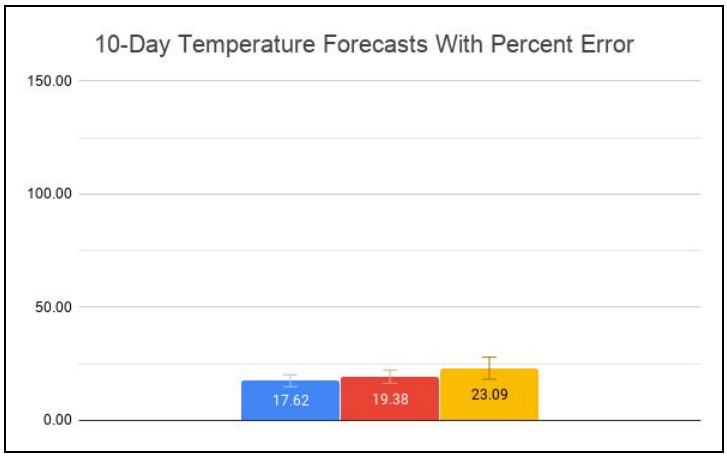
measurements and different forecast lengths. The standard deviation bars signify how inconsistent the data is. Notice that on the wind speed bar graphs, the standard deviation bars are enormous. **I have changed the graphs here so that they all have the same scale and they are easier to compare. On my poster, the graphs have different scales, so they will look different.**

Temperature Forecasts

AccuWeather The Weather Channel Dark Sky

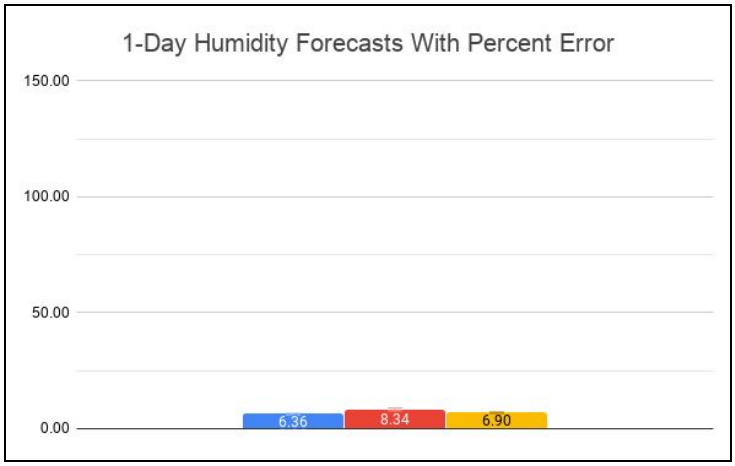


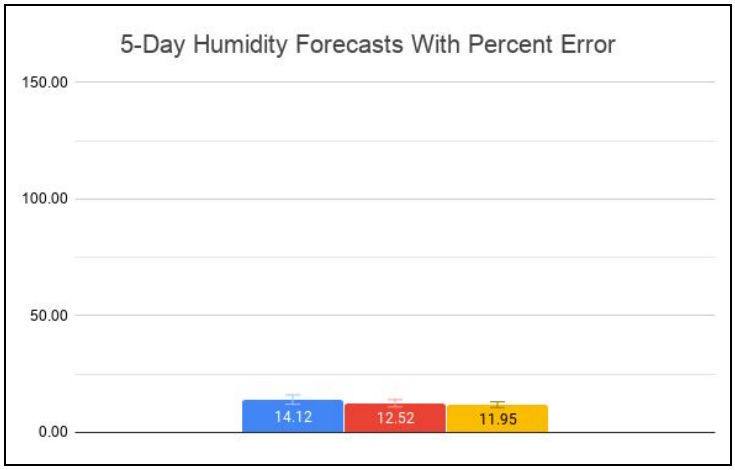


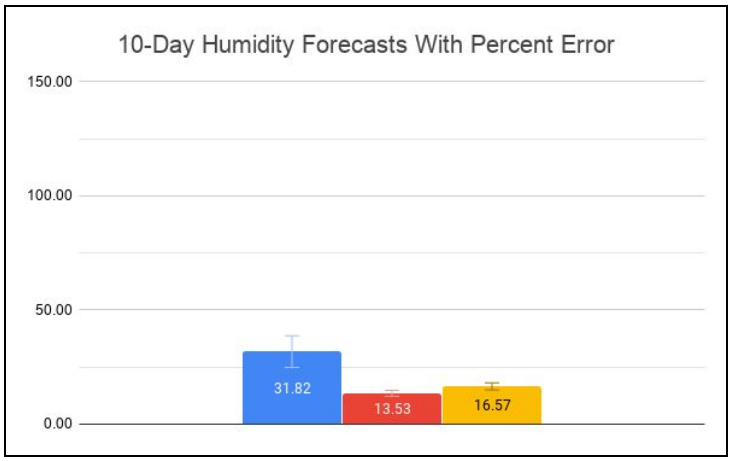


Humidity Forecasts

AccuWeather The Weather Channel Dark Sky

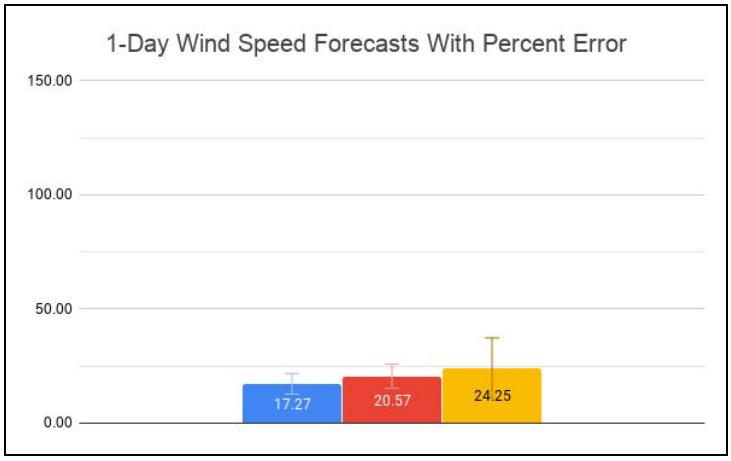


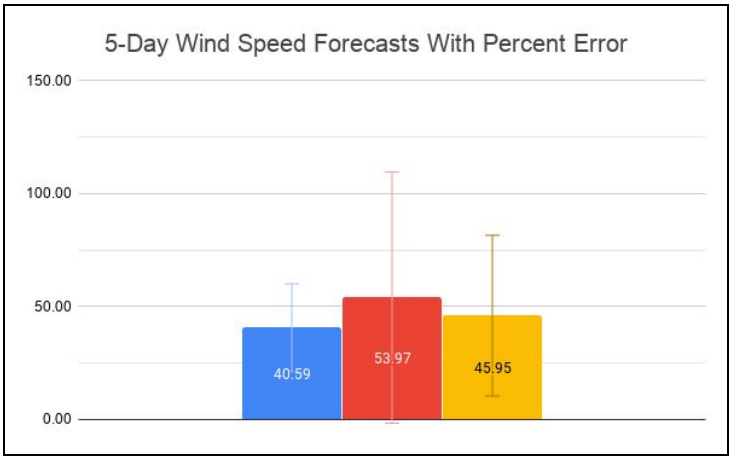


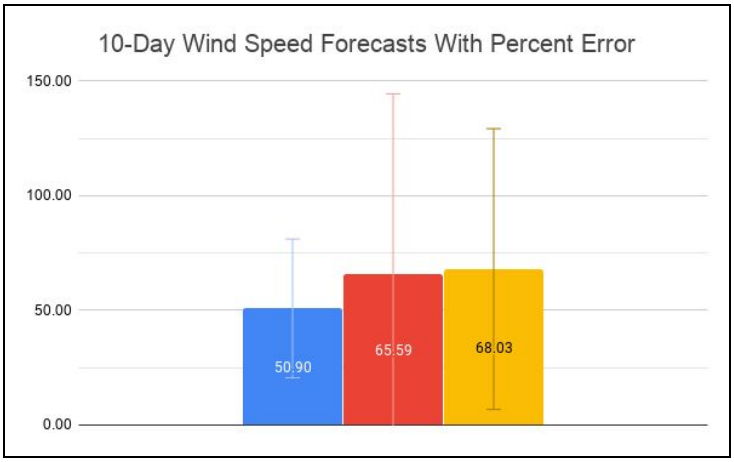


Wind Speed Forecasts

AccuWeather The Weather Channel Dark Sky







Conclusions

My original hypothesis was that the weather data produced by The Weather Channel was going to be the most accurate because of the high level of technology it utilizes (Sibley, 2019). Not only does The Weather Channel use extremely advanced machine learning algorithms, but the data that it uses is supposedly more rich and diverse than the data that other weather forecasting services use (IBM News Room, 2019). My data partially supports my hypothesis. Although The Weather Channel was very accurate, more so than Dark Sky, it was not as accurate as AccuWeather in most forecasts. Once analyzed and interpreted, the data that I collected leads me to believe that AccuWeather is the most accurate weather forecasting service. Out of the nine kinds of forecasts, or trials, AccuWeather was the most accurate in seven. This means that AccuWeather was the most accurate forecaster about 78% of the time.

However, it should be noted that my conclusions are by no means 100% accurate. Not only did I have to fill multiple data holes, but my data-collection period was shorter than I would have liked it to be. I was also concerned that the standard deviation bars overlapped in some of the graphs. It is possible that the differences in accuracy between the three companies are a result of coincidence and therefore negligible. However, I am confident that this is not so. The fact that AccuWeather data closely followed a trend of being the most accurate throughout the experiment suggests that even though the margin between the three data sets is small (sometimes ~1%) it is still significant. Another concerning aspect of the data that I mentioned before was AccuWeather's poor humidity forecast accuracy. I checked the code in my GS program

to make sure it was not the reason for this anomaly. After conducting some tests, I determined it was not. I would like to conduct another experiment to determine the cause of this inaccuracy.

If I were to do my experiment again, there are a few things I would do differently. First of all, I would like to automate the process completely. This would take a lot of work, but it would ensure that I would never have to fill in any data holes. It would also give me the opportunity to analyze the weather forecasts much more extensively. First, I could extend the data-collection period or even gather data at multiple points in a day. I could also more easily analyze multiple different measurements such as precipitation, cloud cover, and air pressure. And instead of only analyzing one, five, and ten-day forecasts, I could very easily gather data for every single consecutive day leading up to the tenth day. As a more comedic experiment, I would also like to analyze The Old Farmer's Almanac to see if their boasted 80% accuracy can be scientifically proven.

In the end, the results did not support my hypothesis. But the results of the experiment are still useful, and I feel that they do not detract from the original purpose of the experiment. First, I believe that it has given deeper meaning to the numbers in weather forecasts. My even greater hope is that one day I can use my conclusions as an initiative to improve weather forecasting. I would love to research the technology that helps create weather forecasts, especially machine learning. Who knows - I might even become a meteorologist one day.

Acknowledgements

I wish to acknowledge the contributions of the following people and companies to my project. First, I would like to thank my mother and father who provided encouragement and support throughout this project. I am also thankful for both of my grandmas' advice and support throughout this project. And it would not have been possible without the amazing capability and power of G Suite. I utilized much of the software, especially Google Scripts and Google Sheets. Finally, I would like to thank the several companies that I tested for accuracy and the many services that they graciously offered for free.

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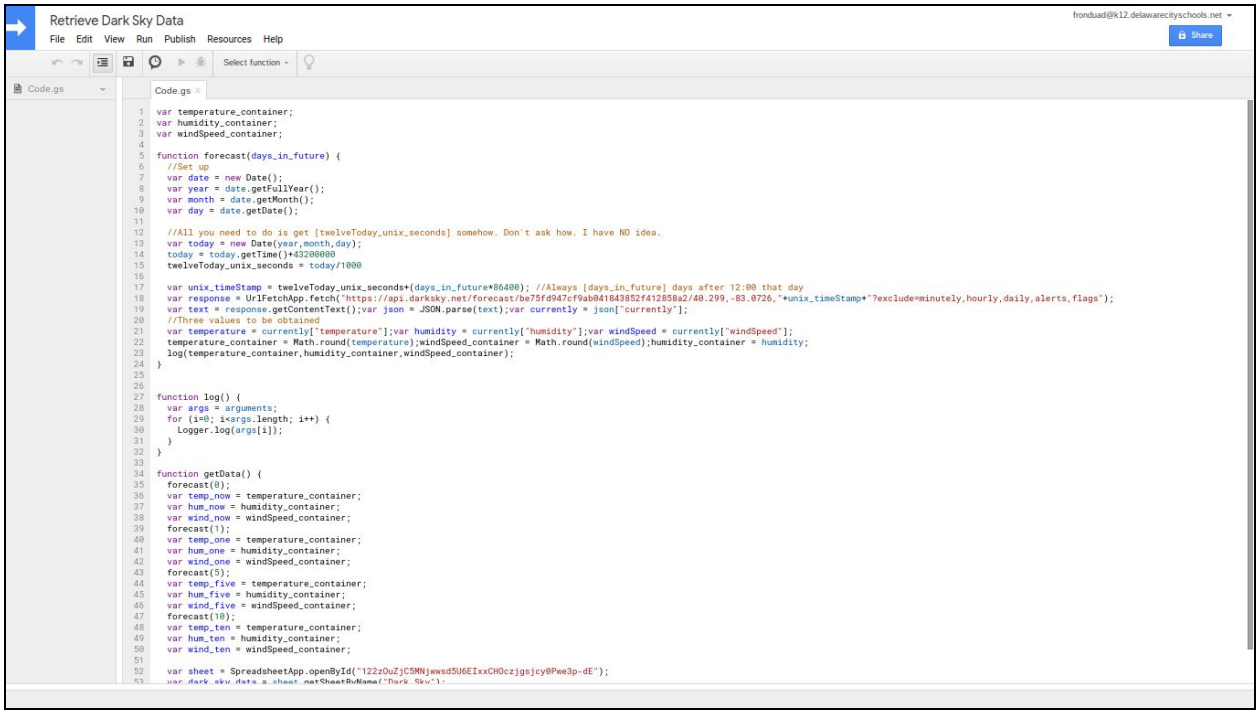
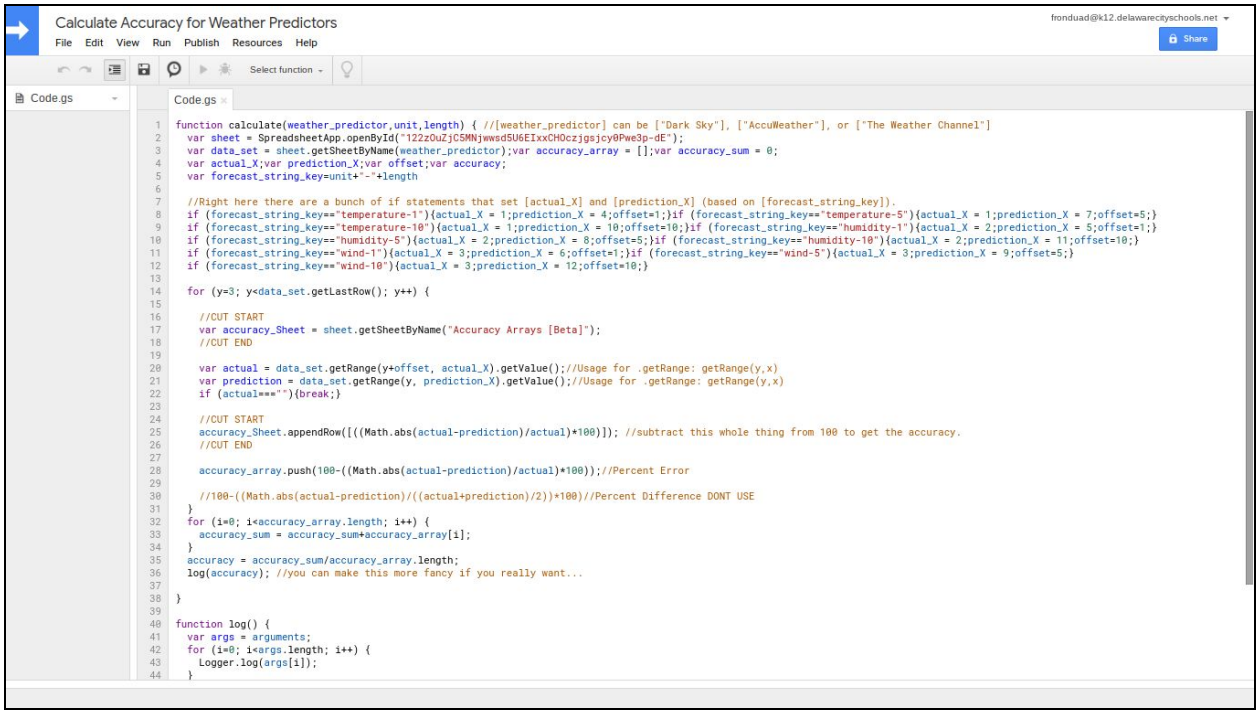
Appendix



Above: This code was set to fetch Dark Sky data every day at 12:00 via Dark Sky's API which was offered to me free of charge.



Above: This code is what combed through my spreadsheet and calculated the accuracy of the weather forecasts.

Below are graphs of **AccuWeather's** data for 1, 5, and 10-day **temperature** forecasts. This illustrates my observation that companies were more inaccurate the further out they predicted. The red lines represent the predictions, and the blue lines represent the actual values. Notice that the gaps between them are much more numerous in the 10-day prediction graph than in the 1-day prediction graph.