History of Meteorology Readings

Each reading in this packet is followed by a short set of questions. Skim the passages and then answer the questions on a separate piece of paper using complete sentences.

History of Meteorology, © National Geographic Society

Early meteorology

The development of meteorology is deeply connected to developments in science, math, and technology. The Greek philosopher **Aristotle** wrote the first major study of the atmosphere around 340 BCE. Many of Aristotle's ideas were incorrect, however, because he did not believe it was necessary to make scientific observations.

A growing belief in the scientific method profoundly changed the study of meteorology in the 17th and 18th centuries. **Evangelista Torricelli**, an Italian physicist, observed that changes in air pressure were connected to changes in weather. In 1643, Torricelli invented the **barometer**, to accurately measure the pressure of air. The barometer is still a key instrument in understanding and forecasting weather systems. In 1714, Daniel Fahrenheit, a German physicist, developed the **mercury thermometer**. These instruments made it possible to accurately measure two important atmospheric variables.

There was no way to quickly transfer weather data until the invention of the **telegraph** by American inventor Samuel Morse in the mid-1800s. Using this new technology, meteorological offices were able to share information and produce the first modern weather maps. These maps combined and displayed more complex sets of information such as isobars (lines of equal air pressure) and isotherms (lines of equal temperature). With these large-scale weather maps, meteorologists could examine a broader geographic picture of weather and make more accurate forecasts.

Modern meteorology

In the 1920s, a group of Norwegian meteorologists developed the concepts of **air masses** and **fronts** that are the building blocks of modern weather forecasting. Using basic laws of physics, these meteorologists discovered that huge cold and warm air masses move and meet in patterns that are the root of many weather systems.

Military operations during World War I and World War II brought great advances to meteorology. The success of these operations was highly dependent on weather over vast regions of the globe. The military invested heavily in training, research, and new technologies to improve their understanding of weather. The most important of these new technologies was **radar**, which was developed to detect the presence, direction, and speed of aircraft and ships. Since the end of World War II, radar has been used and improved to detect the presence, direction, and speed of precipitation and wind patterns.

The technological developments of the 1950s and 1960s made it easier and faster for meteorologists to observe and predict weather systems on a massive scale. During the 1950s, computers created the first **models** of atmospheric conditions by running hundreds of data points through complex equations. These models were able to predict large-scale weather, such as the series of high- and low-pressure systems that circle our planet.

TIROS I, the first meteorological **satellite**, provided the first accurate weather forecast from space in 1962. The success of TIROS I prompted the creation of more sophisticated satellites. Their ability to collect and transmit data with extreme accuracy and speed has made them indispensable to meteorologists. Advanced satellites and the computers that process their data are the primary tools used in meteorology today.

Questions – answer with complete sentences!!

1) Aristotle was one of the greatest ancient philosophers. He wrote books on many subjects including several areas of science. However, he would not be considered a very good scientist today. Why?
2) What is a barometer?
3) Why was the invention of the telegraph important to weather forecasting?
4) How is radar used in meteorology?
5) Why are computers important to modern weather forecasting?

Weather Forecasting Through the Ages: Towards Numerical Prediction

By Steve Graham, Claire Parkinson, and Mous Chahine (NASA Earth Observatory)

Over the past few centuries, physical laws governing aspects of the atmosphere have been expressed and refined through mathematical equations. The idea of **numerical weather forecasting**—predicting the weather by solving mathematical equations—was formulated in 1904 by Vilhelm Bjerknes (1862-1951, Norwegian) and developed by British mathematician **Lewis Fry Richardson** (1881-1953, British). Despite the advances made by Richardson, it took him, working alone, several months to produce a wildly inaccurate six-hour forecast for an area near Munich, Germany. In fact, some of the changes predicted in Richardson's forecast could never occur under any known terrestrial conditions. Adding to the failure of this effort, a six-hour forecast is not particularly useful if it takes weeks to produce.

Courageously, Richardson reported his results in his book Weather Prediction by Numerical Process, published in 1922. In one of the chapters of this work, Richardson describes a scheme for predicting the weather before it actually happens, a scheme involving a roomful of people, each computing separate sections of the equations, and a system for transmitting the results as needed from one part of the room to another. Unfortunately, Richardson's estimated number of human calculators needed to keep pace with weather developments was 64,000, all located in one very large room.

Richardson's work highlighted the obvious fact that a large number of calculations had to be made very rapidly in order to produce a timely forecast. In the late 1940s, using one of the earliest modern computers, significant progress toward more practical numerical weather forecasts was made by a team of meteorologists and mathematicians at the Institute for Advanced Study (IAS) in Princeton, New Jersey. Mathematician John von Neumann (1903-1957, Hungarian-American) directed the construction of the computer and put together a team of scientists led by Jule Charney (1917-1981, American) to apply the computer to weather forecasting. Charney determined that the impracticality of Richardson's methods could be overcome by using the new computers and a revised set of equations, filtering out sound and gravity waves in order to simplify the calculations and focus on the phenomena of most importance to predicting the evolution of continent-scale weather systems. In April 1950, Charney's group made a series of successful 24-hour forecasts over North America, and by the mid-1950s, numerical forecasts were being made on a regular basis.

Questions – answer with complete sentences!!

6) What is "numerical weather forecasting"?
7) What problems did Richardson encounter in his first attempt at a weather forecast?
8) Why was Richardson's method not practical before the invention of the computer?
9) What research was conducted at the Institute for Advanced Study (IAS)?
10) How did scientists at the IAS improve on Richardson's methods?

Evolution of the National Weather Service, by the NWS

The National Weather Service has its beginning in the early history of the United States. Weather always has been important to the citizenry of this country, and this was especially true during the 17th and 18th centuries. Weather also was important to many of the Founding Fathers. Colonial leaders who formed the path to independence of our country also were avid weather observers. Thomas Jefferson purchased a thermometer from a local Philadelphia merchant while in town for the adoption of the Declaration of Independence. He also purchased a barometer — one of the only ones in America at the time — a few days later from the same merchant. Incidentally, he noted that the high temperature in Philadelphia, Pa., on July 4, 1776 was 76 degrees. Jefferson made regular observations at Monticello from 1772-78, and participated in taking the first known simultaneous weather observations in America. George Washington also took regular observations; his last weather entry was made the day before he died.

During the early and mid-1800's, weather observation networks began to grow and expand across the United States. Although most basic meteorological instruments had existed for over 100 years, it was the telegraph that was largely responsible for the advancement of meteorology during the 19th century. With the advent of the telegraph, weather observations from distant points could be "rapidly" collected, plotted and analyzed at one location.

- **1849**: **Smithsonian Institution** supplies weather instruments to telegraph companies and establishes extensive observation network. Observations submitted by telegraph to Smithsonian, where weather maps are created. By the end of 1849, 150 volunteers throughout the United States were regularly reporting weather observations. By 1860, 500 stations were furnishing daily telegraphic weather reports to the Washington Evening Star, and as the network grew, other existing systems were gradually absorbed, including several state weather services.
- **1860**: 500 stations are making regular observations, but work is interrupted by the Civil War.
- **1869**: Telegraph service, instituted in **Cincinnati**, began collecting weather data and producing weather charts. The ability to observe and display simultaneously observed weather data, through the use of the telegraph, quickly led to initial efforts toward the next logical advancement, the forecasting of weather. However, the ability to observe and forecast weather over much of the country, required considerable structure and organization, which could be provided through a government agency.
- **1870**: A Joint Congressional Resolution requiring the Secretary of War "to provide for taking meteorological observations at the military stations in the interior of the continent, and at other points in the States and Territories...and for giving notice on the northern lakes and on the seacoast, by magnetic telegraph and marine signals, of the approach and force of storms" was introduced. Congress passed the resolution and on February 9, 1870, President Ulysses S. Grant signed it into law. A new **national weather service** had been born.
- **1890**: President Benjamin Harrison passes an act transferring the meteorological responsibilities of the military's Signal Service to the newly-created U.S. Weather Bureau in the Department of Agriculture.
- **1891**: Weather Bureau becomes responsible for issuing flood warnings to the public.
- **1901**: Official three-day forecasts begin for the North Atlantic.
- **1935**: A hurricane warning service is established.
- **1955**: Regularly-scheduled operational computer forecasts begun by the Joint Numerical Forecast Unit. The Weather Bureau becomes a pioneer civilian user of computers along with the Census Bureau in Commerce; Bureau begins development of Barotropic model, a first for numerical predictions.
- **1970**: Weather Bureau transferred to the new National Oceanic and Atmospheric Administration (NOAA) and renamed the National Weather Service (NWS).
- **Today**: NWS processes over one million weather observations every day. Regardless of where we read or hear our weather forecast, almost all of the predictions originally come from the NWS.

Questions – answer with complete sentences!!

11) What weather observations were made by some of our nation's founders?
12) What organization collected weather observations from volunteers before the Civil War?
13) When and how did the US government get involved in collecting weather observations?
14) From where do the Weather Channel, Accuweather, and USA Today get their data and observations?

The Butterfly Effect, by Larry Bradley

Weather prediction is an extremely difficult problem. Meteorologists can predict the weather for short periods of time, a couple days at most, but beyond that predictions are generally poor.

Edward Lorenz was a mathematician and meteorologist at the Massachusetts Institute of Technology who loved the study of weather. With the advent of computers, Lorenz saw the chance to combine mathematics and meteorology. He set out to construct a mathematical model of the weather, namely a set of differential equations that represented changes in temperature, pressure, wind velocity, etc. In the end, Lorenz stripped the weather down to a crude model containing a set of 12 differential equations.

On a particular day in the winter of 1961, Lorenz wanted to re-examine a sequence of data coming from his model. Instead of restarting the entire run, he decided to save time and restart the run from somewhere in the middle. Using data printouts, he entered the conditions at some point near the middle of the previous run, and re-started the model calculation. What he found was very unusual and unexpected. The data from the second run should have exactly matched the data from the first run. While they matched at first, the runs eventually began to diverge dramatically — the second run losing all resemblance to the first within a few "model" months. A sample of the data from his two runs in shown here:

At first Lorenz thought that a vacuum tube had gone bad in his computer, a Royal McBee — an extremely slow and crude machine by today's standards. After discovering that there was no malfunction, Lorenz finally found the source of the problem. To save space, his printouts only showed three digits while the data in the computer's memory contained six digits. Lorenz had entered the rounded-off data from the printouts assuming that the difference was inconsequential. For example, even today temperature is not routinely measured within one part in a thousand.

This led Lorenz to realize that long-term weather forecasting was doomed. His simple model exhibits the phenomenon known as "sensitive dependence on initial conditions." This is sometimes referred to as the **butterfly effect**, e.g. a butterfly flapping its wings in South America can affect the weather in Central Park.

[This discovery led to the development of Chaos Theory in mathematics.]

Questions – answer with complete sentences!!

15) What did Lorenz write his computer model to do?
16) What happened when he tried to re-run the model after starting partway through the simulation?
17) Why didn't Lorenz think that rounding his numbers off would be a big deal?
18) The "butterfly effect" is an exaggerated analogy for the very sensitive behavior of chaotic systems. What conditions in the atmosphere might be changed – a very, very small amount! – by the flight of a butterfly?