ARTICLE

The Science and Art of Meteorology

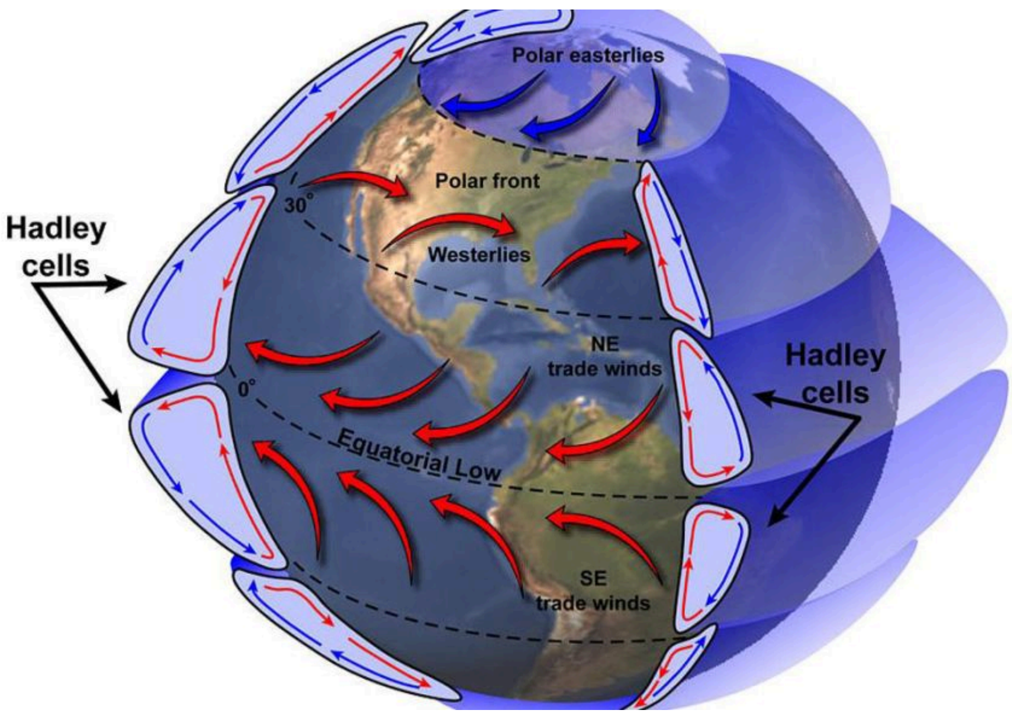
Meteorology is the study of the atmosphere.

GRADES

9 - 12+

SUBJECTS

Earth Science, Astronomy, Meteorology, Geography, Physical Geography



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PHOTOGRAPH

Convection

To understand weather, meteorologists study atmospheric patterns. The most familiar atmospheric pattern that drives weather and climate is convection, the process of warmer air rising, and colder, denser air sinking. Convection results in a transfer of energy, heat, and moisture—the basic building blocks of weather. Global convection is largely driven by Hadley cells. Hadley cells are tropical and equatorial convection patterns.

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ARTICLE VOCABULARY

Meteorology is the study of the atmosphere, atmospheric phenomena, and atmospheric effects on our weather. The atmosphere is the gaseous layer of the physical environment that surrounds a planet. Earth's atmosphere is roughly 100 to 125 kilometers (65-75 miles) thick. Gravity keeps the atmosphere from expanding much farther.

Meteorology is a subdiscipline of the atmospheric sciences, a term that covers all studies of the atmosphere. A subdiscipline is a specialized field of study within a broader subject or discipline. Climatology and aeronomy are also subdisciplines of the atmospheric sciences. Climatology focuses on how atmospheric changes define and alter the world's climates. Aeronomy is the study of the upper parts of the atmosphere, where unique chemical and physical processes occur. Meteorology focuses on the lower parts of the atmosphere, primarily the troposphere, where most weather takes place.

Meteorologists use scientific principles to observe, explain, and forecast our weather. They often focus on atmospheric research or operational weather forecasting. Research meteorologists cover several subdisciplines of meteorology to include: climate modeling, remote sensing, air quality, atmospheric physics, and climate change. They also research the relationship between the atmosphere and Earth's climates, oceans, and biological life.

Forecasters use that research, along with atmospheric data, to scientifically assess the current state of the atmosphere and make predictions of its future state. Atmospheric conditions both at Earth's surface and above are measured from a variety of sources: weather stations, ships, buoys, aircraft, radar, weather balloons, and satellites. This data is transmitted to centers throughout the world that produce computer analyses of global weather. The analyses are passed on to national and regional weather centers, which feed this data into computers that model the future state of the atmosphere. This transfer of information demonstrates how weather and the study of it take place in multiple, interconnected ways.

Scales of Meteorology

Weather occurs at different scales of space and time. The four meteorological scales are: microscale, mesoscale, synoptic scale, and global scale. Meteorologists often focus on a specific scale in their work.

Microscale Meteorology

Microscale meteorology focuses on phenomena that range in size from a few centimeters to a few kilometers, and that have short life spans (less than a day). These phenomena affect very small geographic areas, and the temperatures and terrains of those areas.

Microscale meteorologists often study the processes that occur between soil, vegetation, and surface water near ground level. They measure the transfer of heat, gas, and liquid between these surfaces. Microscale meteorology often involves the study of chemistry.

Tracking air pollutants is an example of microscale meteorology. MIRAGE-Mexico is a collaboration between meteorologists in the United States and Mexico. The program studies the chemical and physical transformations of gases and aerosols in the pollution surrounding Mexico City. MIRAGE-Mexico uses observations from ground stations, aircraft, and satellites to track pollutants.

Mesoscale Meteorology

Mesoscale phenomena range in size from a few kilometers to roughly 1,000 kilometers (620 miles). Two important phenomena are mesoscale convective complexes (MCC) and mesoscale convective systems (MCS). Both are caused by convection, an important meteorological principle.

Convection is a process of circulation. Warmer, less-dense fluid rises, and colder, denser fluid sinks. The fluid that most meteorologists study is air. (Any substance that flows is considered a fluid.) Convection results in a transfer of energy, heat, and moisture—the basic building blocks of weather.

In both an MCC and MCS, a large area of air and moisture is warmed during the middle of the day—when the sun angle is at its highest. As this warm air mass rises into the colder atmosphere, it condenses into clouds, turning water vapor into precipitation.

An MCC is a single system of clouds that can reach the size of the state of Ohio and produce heavy rainfall and flooding. An MCS is a smaller cluster of thunderstorms that lasts for several hours. Both react to unique transfers of energy, heat, and moisture caused by convection.

The Deep Convective Clouds and Chemistry (DC3) field campaign is a program that will study storms and thunderclouds in Colorado, Alabama, and Oklahoma. This project will consider how convection influences the formation and movement of storms, including the development of lightning. It will also study their impact on aircraft and flight patterns. The DC3 program will use data gathered from research aircraft able to fly over the tops of storms.

Synoptic Scale Meteorology
Synoptic-scale phenomena cover an area of several hundred or even thousands of kilometers. High- and low-pressure systems seen on local weather forecasts, are synoptic in scale. Pressure, much like convection, is an important meteorological principle that is at the root of large-scale weather systems as diverse as hurricanes and bitter cold outbreaks.

Low-pressure systems occur where the atmospheric pressure at the surface of Earth is less than its surrounding environment. Wind and moisture from areas with higher pressure seek low-pressure systems. This movement, in conjunction with the Coriolis force and friction, causes the system to rotate counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere, creating a cyclone. Cyclones have a tendency for upward vertical motion. This allows moist air from the surrounding area to rise, expand and condense into water vapor, forming clouds. This movement of moisture and air causes the majority of our weather events.

Hurricanes are a result of low-pressure systems (cyclones) developing over tropical waters in the Western Hemisphere. The system sucks up massive amounts of warm moisture from the sea, causing convection to take place, which in turn causes wind speeds to increase and pressure to fall. When these winds reach speeds over 119 kilometers per hour (74 miles per hour), the cyclone is classified as a hurricane.

Hurricanes can be one of the most devastating natural disasters in the Western Hemisphere. The National Hurricane Center, in Miami, Florida, regularly issues forecasts and reports on all tropical weather systems. During hurricane season, hurricane specialists issue forecasts and warnings for every tropical storm in the western tropical Atlantic and eastern tropical Pacific. Businesses and government officials from the United States, the Caribbean, Central America, and South America rely on forecasts from the National Hurricane Center.

High-pressure systems occur where the atmospheric pressure at the surface of Earth is greater than its surrounding environment. This pressure has a tendency for downward vertical motion, allowing for dry air and clear skies.

Extremely cold temperatures are a result of high-pressure systems that develop over the Arctic and move over the Northern Hemisphere. Arctic air is very cold because it develops over ice and snow-covered ground. This cold air is so dense that it pushes against Earth's surface with extreme pressure, preventing any moisture or heat from staying within the system.

Meteorologists have identified many semi-permanent areas of high-pressure. The Azores high, for instance, is a relatively stable region of high pressure around the Azores, an archipelago in the mid-Atlantic Ocean. The Azores high is responsible for arid temperatures of the Mediterranean basin, as well as summer heat waves in Western Europe.

Global Scale Meteorology

Global scale phenomena are weather patterns related to the transport of heat, wind, and moisture from the tropics to the poles. An important pattern is global atmospheric circulation, the large-scale movement of air that helps distribute thermal energy (heat) across the surface of the Earth.

Global atmospheric circulation is the fairly constant movement of winds across the globe. Winds develop as air masses move from areas of high pressure to areas of low pressure. Global atmospheric circulation is largely driven by Hadley cells. Hadley cells are tropical and equatorial convection patterns. Convection drives warm air high in the atmosphere, while cool, dense air pushes lower in a constant loop. Each loop is a Hadley cell.

Hadley cells determine the flow of trade winds, which meteorologists forecast. Businesses, especially those exporting products across oceans, pay close attention to the strength of trade winds because they help ships travel faster. Westerlies are winds that blow from the west in the midlatitudes. Closer to the Equator, trade winds blow from the northeast (north of the Equator) and the southeast (south of the Equator).

Meteorologists study long-term climate patterns that disrupt global atmospheric circulation. Meteorologists discovered the pattern of El Nino, for instance. El Niño involves ocean currents and trade winds across the Pacific Ocean. El Niño occurs roughly every five years, disrupting global atmospheric circulation and affecting local weather and economies from Australia to Peru.

El Niño is linked with changes in air pressure in the Pacific Ocean known as the Southern Oscillation. Air pressure drops over the eastern Pacific, near the coast of the Americas, while air pressure rises over the western Pacific, near the coasts of Australia and Indonesia. Trade winds weaken. Eastern Pacific nations experience extreme rainfall. Warm ocean currents reduce fish stocks, which depend on nutrient-rich upwelling of cold water to thrive. Western Pacific nations experience drought, devastating agricultural production.

Understanding the meteorological processes of El Niño helps farmers, fishers, and coastal residents prepare for the climate pattern.

History of 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 B.C.E. 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.

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.

Meteorology Today

Today's meteorologists have a variety of tools that help them examine, describe, model, and predict weather systems. These technologies are being applied at different meteorological scales, improving forecast accuracy and efficiency.

Radar is an important remote sensing technology used in forecasting. A radar dish is an active sensor in that it sends out radio waves that bounce off particles in the atmosphere and return to the dish. A computer processes these pulses and determines the horizontal dimension of clouds and precipitation, and the speed and direction in which these clouds are moving.

A new technology, known as dual-polarization radar, transmits both horizontal and vertical radio wave pulses. With this additional pulse, dual-polarization radar is better able to estimate precipitation. It is also better able to differentiate types of precipitation—rain, snow, sleet, or hail. Dual-polarization radar will greatly improve flash-flood and winter-weather forecasts.

Tornado research is another important component of meteorology. Starting in 2009, the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation conducted the largest tornado research project in history, known as VORTEX2. The VORTEX2 team, consisting of about 200 people and more than 80 weather instruments, traveled more than 16,000 kilometers (10,000 miles) across the Great Plains of the United States to collect data on how, when, and why tornadoes form. The team made history by collecting extremely detailed data before, during, and after a specific tornado. This tornado is the most intensely examined in history and will provide key insights into tornado dynamics.

Satellites are extremely important to our understanding of global scale weather phenomena. The National Aeronautics and Space Administration (NASA) and NOAA operate three Geostationary Operational Environmental

Satellites (GOES) that provide weather observations for more than 50 percent of Earth's surface.

GOES-15, launched in 2010, includes a solar X-ray imager that monitors the sun's X-rays for the early detection of solar phenomena, such as solar flares. Solar flares can affect military and commercial satellite communications around the globe. A highly accurate imager produces visible and infrared images of Earth's surface, oceans, cloud cover, and severe storm developments. Infrared imagery detects the movement and transfer of heat, improving our understanding of the global energy balance and processes such as global warming, convection, and severe weather.

FAST FACT

Humid Curls
Horace Benedict de Saussure was an amateur alpine climber, physicist, and meteorologist. In 1783, he constructed the first hygrometer, an instrument that measures humidity. The medium he used to measure the amount of moisture in the air: human hair. The hair Sassure tested relaxed, or lengthened, in moist weather. It tensed, or curled, in dry weather.

FAST FACT

Seal of Approval
Since 1982, the National Weather Association has promoted

quality weather broadcasting by issuing a Weathercaster Seal of Approval to qualified broadcasters. The seal exam is difficult, and only 918 people in the U.S. are certified. Find out if your local weather forecaster has made the list!

FAST FACT

Storm Synchronicity

"Unlike history, meteorology does repeat itself."

Dr. Mel Goldstein, meteorologist

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Arizona State University and the World Meteorological Organization: Climate Extremes Archive

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