scriptural geologists. This movement has been led by Americans, though a small but growing number of geologists in other countries also favor this creationist view.

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The Revolution in Meteorology

At the turn of the twentieth century, meteorology in America was beginning to emerge as a modern scientific discipline based not only on observation and empiricism but on theory as well. Although systematic weather observations had been made since the colonial period, it was not until the mid-nineteenth century, with the invention and widespread use of the telegraph, that scientists realized the practical application of simultaneous weather observations from various locations, which paved the way for more accurate weather forecasts.

Weather Bureau

In 1900, the U.S. Weather Bureau (the predecessor to the National Weather Service) began its second decade as a civilian agency under the Department of Agriculture, having been transferred from the War Department by act of Congress in 1890. Early weather forecasts issued by the Weather Bureau relied solely on observations taken at surface weather stations around the country. These reports were sent by telegraph to the Weather Bureau's central office in Washington, D.C., where a small group of forecasters plotted and analyzed the variations in temperature and air pressure and tracked the progress of storms. Forecasts were based more on rules of thumb and comparisons of the current weather map with similar past situations than on scientific or mathematic principles.

The advent of aviation gave rise to the need for observations of upper-air conditions, and, in 1909, the Weather Bureau began launching free-rising balloons with instruments attached to measure the temperature, humidity, and air pressure at various levels of the atmosphere. Though useful for local aviation forecasts, the full practical use of these upper-air observations, like their early surface counterparts, required advances in technology and the understanding of the physical processes that controlled them.

A major breakthrough in the understanding of how weather systems evolve and, subsequently, how to predict them, came after World War I from a small group of scientists working at the Geophysical Institute in Bergen, Norway. The "Bergen School" of meteorology, led by Vilhelm Bjerknes (and including his son, Jacob), developed a theory that weather systems evolve from differences between contrasting air masses. They called the boundaries where these tropical and polar air masses meet "fronts," in reference to the battlefronts of World War I. Bjerknes's "polar front theory" further explained that interactions between air masses led to the development of mid-latitude, or extratropical, wave cyclones. These are the weather systems that march across the continents of North America and Europe and bring most of the unsettled weather, particularly during winter. Although slow to receive widespread recognition, especially in the United States, Bjerknes's ideas served as a turning point in modern meteorology.

One of Bjerknes's students in Bergen was the Swedish-born Carl-Gustaf Rossby, who immigrated to the United States in 1926 and founded the department of meteorology at the Massachusetts Institute of Technology (MIT). In 1940, Rossby became chair of the Department of Meteorology at the University of Chicago, where he did pioneering work in dynamic meteorology, including the large-scale circulation of the atmosphere and jet streams. Building on the concepts developed by his predecessors, Rossby's ideas helped refine a three-dimensional model of the atmosphere that was essential in the development of long-range weather forecasting.

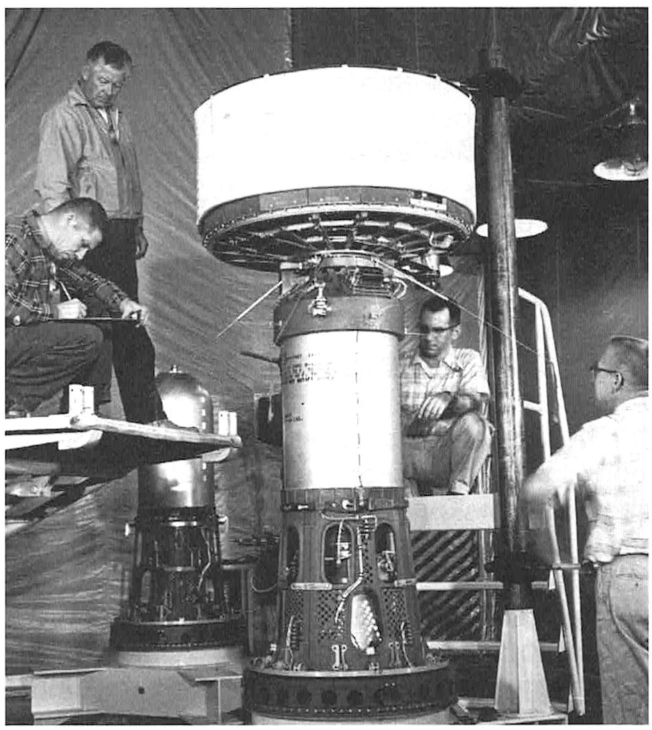
As early as 1904, Bjerknes theorized that weather could be predicted through the solution of complex mathematical equations that governed the physics of the atmosphere. During World War I, the English mathematician Lewis Fry Richardson attempted to devise a practical scheme to translate the theory of the atmosphere into the prediction of the weather. Since electronic computers did not exist in Richardson's time, his plan relied on human computing power to carry out the necessary calculations. In his 1922 book *Weather Prediction by Numerical Process*, Richardson described an elaborate "forecast factory" that involved 64,000 people working around the clock to produce a forecast for twenty-four hours into the future.

As the physical understanding of weather continued to develop, so did the technology that would help put forecasting it into practical use. In 1945, the world's first electronic computer, the Electronic Numerical Integrator and Computer (ENIAC), began operation. It was originally used by the U.S. Army for ballistics calculations, but mathematician John von Neumann successfully campaigned for ENIAC to be used for weather predictions. Von Neumann employed a small team at the Institute for Advanced Study at Princeton University, including Rossby's protégé Jule Charney, who simplified the set of equations used by Richardson for use by the computer. In April 1950, the first successful numeric weather prediction was made by Charney and his colleagues using ENIAC.

Although advances in computing ability and refinement of numeric models have led to increased accuracy of medium- and long-range forecasts, the most accurate forecasts continue to be those made for the shortest time periods in the future. These limitations were first expressed in the 1960s by meteorologist Edward Lorenz as an application of chaos theory. Chaos theory suggests that certain dynamical systems, known as nonlinear systems, are sensitive to their initial conditions such that small changes in these conditions can result in large variations as the system evolves over time. What may seem like miniscule differences in the data actually can produce significant differences in a computer model of a nonlinear system.

Since the atmosphere is a nonlinear dynamic system, small variations in the initial weather observations that go into a computer forecast model can produce large changes in the conditions that are predicted over time. It is impossible to input data detailing the precise state of the atmosphere everywhere on Earth into computer models. As a result, actual weather conditions will differ slightly from the data in the computer model, and weather phenomena will not exactly match predictions.

Lorenz's theory has been popularized as "the butterfly effect." This label was inspired by Lorenz's 1972 paper "Predictability: Does the Flap of a Butterfly's Wings in Brazil Set Off a Tornado in Texas?"



Engineers and technicians make final checks on NASA's TIROS I, the world's first successful weather satellite, before launch on April 1, 1960. TIROS I marked the beginning of a new era in atmospheric observation and data collection. *(NASA/Time & Life Pictures/Getty Images)*

Radar and Satellites

The second half of the twentieth century saw other important technological advancements applied to the study and forecasting of weather. During World War II, radar systems—originally used to detect aircraft and ships—began to be applied to the study of weather systems. Because radar could detect areas of precipitation (such as rain, snow, and hail) of varying intensities, it became an invaluable tool for forecasters. For the first time, they could see inside storms approaching from a distance. This ability to detect the circulation inside a storm is critical in identifying severe weather, such as tornado development. Improvements in radar technology eventually led to the implementation of a national network of Doppler radars, which are capable of detecting not only the location of precipitation within a storm but also whether it is moving toward or away from the radar.

On April 1, 1960, meteorology entered the space age when the world's first successful weather satellite, TIROS I (Television and Infrared Observation Satellite I), was launched by the United States. During its seventy-eight-day life span, TIROS I sent back nearly 23,000 images of cloud cover from its orbit of about 370 miles (600 kilometers) above Earth's surface. Although the early images were crude by current standards, they gave researchers and forecasters a new perspective on clouds and storm systems and demonstrated the usefulness of space-based observations.

As the technology of satellites improved, so did the quality of the images and usefulness of the data. Today, in addition to visible and infrared images of clouds, weather and environmental satellites collect a wide variety of data, including water vapor content, sea surface temperatures, stratospheric ozone concentrations, ice fields, and snow cover.

During the 1990s, the National Weather Service completed a major modernization program designed to improve the efficiency and accuracy with which the agency provides weather and climate data and services to the public. The modernization resulted in the implementation of new technologies, including Doppler-based Next Generation Weather Radar (NEXRAD), the Automated Surface Observing System (ASOS), and the Advanced Weather Interactive Processing System (AWIPS), an interactive computer workstation that allows forecasters to overlay radar, satellite imagery with real-time observation data, and forecast model output on a single screen to better assess current conditions and predict future weather. Other observational tools, such as LIDAR (Light Detection and Ranging), wind profilers, and radiometers have given researchers and forecasters new ways of looking at various components of the atmosphere.

Meteorology in the twenty-first century is focusing on improving our understanding of the complex interactions among Earth's systems to better predict changes in weather and climate on various scales. Issues such as El Niño and La Niña (the periodic warming and cooling of the surface waters of the eastern and central Pacific near the equator, which causes shifts in regional climate patterns), global climate change, atmospheric pollution, predictability and tracking of tropical storms and hurricanes, as well as basic forecasting of weather systems for a growing population, economy, and global infrastructure, will drive the demand for new technologies, improved computer models, and further research in the ever evolving science of meteorology.

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