METEOROLOGY

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Meteorology is the study of the Earth's atmosphere and the variations in temperature and moisture patterns that produce different weather conditions. Some of the major subjects of study are such phenomena as precipitation (rain and snow), thunderstorms, tornadoes, and hurricanes and typhoons. The importance of meteorological events is felt in various ways. For example, a drought results in water shortages, crop damage, low river flow rates, and increased wildfire potential. In addition, these effects may lead to restricted river travel, saltwater infiltration in aquifers and coastal bays, stress on various plant and animal species, population shifts, economic hardship, and even political unrest. The critical impact of weather on human activity has led to the development of the uncertain science of weather forecasting.

The word *meteorology* derives from the Greek word *meteoron*, which refers to any phenomenon in the sky. Aristotle's *Meteorologica* (340 B.C.) concerned all phenomena above the ground. Astronomy, including the study of meteors, or "shooting stars," later became a separate discipline. The science of meteorology was restricted eventually to the study of the atmosphere. Various weather phenomena are still referred to as "meteors," such as hydrometeors (liquid or frozen water — rain, snow and snowflakes, clouds, fog), lithometeors (dry particles — sand, dust, or smoke), photometeors (optical phenomena — halos, mirages, rainbows, coronas), and electrometeors (electrical phenomena — lightning, Saint Elmo's fire).

Modern meteorology focuses primarily on the typical weather patterns observed, including thunderstorms, extratropical cyclones, fronts, hurricanes, typhoons, and various tropical water waves. Meteorology is usually considered to describe and study the physical basis for individual events. In contrast, climatology describes and studies the origin of atmospheric patterns observed over time. Several important phenomena, such as monsoons and the El NiÃ±o–Southern Oscillation, are considered in both meteorology and climatology because they exhibit large changes on seasonal time scales.

Scope

The effort to understand the atmosphere and its processes draws on many fields of science and engineering. The study of atmospheric motions is called dynamic meteorology. It makes use of equations describing the behavior of a compressible fluid (air) on a rotating sphere (the Earth). One important complication in this study is the fact that the water in the atmosphere changes back and forth between solid, liquid, and gas in a very complex fashion. These changes greatly modify the equations used in dynamic meteorology.

Physical meteorology, or atmospheric physics, deals with a number of specialized areas of study. For example, the study of clouds and of the various forms of hydrometeors involves investigations into the behavior of water in the atmosphere. The study of radiative transfer is concerned with the fundamental source of energy that drives atmospheric processes, namely solar radiation, and the ways in which radiant energy in general is employed and dissipated in the atmosphere. Other specialized disciplines deal with phenomena involving light (atmospheric optics) and sound (atmospheric acoustics). Some branches of meteorology are defined in terms of the size of the phenomena being studied. For example, micrometeorology is mainly the study of the small-scale interactions between the lowest level of the atmosphere and the surfaces with which it comes into contact. Mesoscale meteorology deals with phenomena of intermediate size — thunderstorms and mountain winds, for example. Synoptic meteorology is concerned with larger processes such as high- and low-pressure systems and their fronts, and so on up to the study of overall atmospheric circulation for time scales of a few days. Weather forecasting, the predictive aspect of meteorology, derives from these disciplines.

Other branches of meteorology focus on phenomena in specific locations, such as equatorial areas, the tropics, maritime regions, coastal areas, the poles, and mountains. The upper atmosphere is also studied separately. Other disciplines concentrate on taking observations with particular technologies, including radio, radar, and artificial satellite. Computer technology is applied extensively, including numerical weather prediction, interactive data analysis, and display systems.

The chemical behavior of the atmosphere, studied in atmospheric chemistry, has rapidly gained in importance due to inadvertent changes caused by humans in the molecular composition of the atmosphere. Changes in ozone (and the ozone layer) and carbon dioxide concentrations, and increased levels of acid rain, have gone beyond the status of local problems to become regional or global issues.

Meteorological studies are carried out in conjunction with several environmentally related fields. These include aeronautics, agriculture, architecture, ballistics, ecology, energy production, forestry, hydrology, medicine, and oceanography. Many of these related fields simply need to determine the weather's effects at a particular time and place, but some — hydrology and oceanography, for example — also affect meterological events by modifying atmospheric conditions at the Earth's surface.

Development of Modern Meteorology

The origins of meteorology lie in qualitative observations of the local weather and speculation. On the whole, Aristotle's work was the standard reference in the ancient and medieval periods, until RenÃ© Descartes, Galileo Galilei, and others began to replace speculation with instrumental observations in the early 17th century. The requisite instruments for carrying out these measurements — the barometer, hygrometer, and thermometer — were developed during the period from about 1650 to 1750. Corresponding theoretical and experimental work included Sir Isaac Newton's laws of motion, cooling, and refraction; the work of Blaise Pascal, Edme Marriotte, Robert Hooke, Edmund Halley, and others on hypsometry (precise measurement of altitudes); the work of Robert Boyle on gases; and that of Halley, George Hadley, and Jean Le Rond d'Alembert on atmospheric circulation. In the next century (1750 –1850), thermometers were standardized, Benjamin Franklin studied lightning, John Dalton laid the foundations for measuring evaporation and humidity, and Luke Howard classified clouds. After 1800, private individuals and public institutions began to collect weather observations.

After the French fleet was damaged by a storm during the Crimean War (1853–56), serious attempts were initiated in western Europe and North America to collect weather data from many locations simultaneously by means of the recently invented (1837) telegraph. The development of reliable clocks permitted continuous recording of observations. The cup and pressure anemometers were invented, and electricity was harnessed to record instrument readings. Later, balloons, kites, and airplanes were used to carry weather instruments through the troposphere, the lowest layer of the Earth's atmosphere, into the stratosphere, the second lowest atmospheric layer, which was discovered, named, and described shortly after 1900. Systematic upper-air observations began in the 1920s after the development of battery-powered radios light enough to be carried by balloons. The collection of upper-air reports over large areas provided a more complete description of the atmosphere, including such features as the jet stream.

Thermodynamics, developed from the mid-19th century onward, provided a major component in the set of formulas describing atmospheric motions and transformations. During the century from 1850 to 1950, synoptic meteorology was the dominant branch, with a body of more fundamental physical principles replacing scattered empirical rules. About 1920 the Bergen school, led by Vilhelm Bjerknes and his son Jacob, synthesized these ideas into the polar-front theory of cyclones, including key concepts such as fronts and air masses.

Modern dynamic meteorology was born in 1948, when Jule Charney succeeded in reducing the full dynamic equations (first stated by Vilhelm Bjerknes in 1904) to a simple yet useful form. The simultaneous development of the digital computer ensured that Charney's method had great practical impact, for it allowed weather forecasting to be based on an approximate solution to the dynamical equations as a function of time. Since 1948, technologies for remote sensing of the atmosphere have proliferated. By 1950, radar had been developed to the point where it could be used to delineate clouds by their suspended water droplets and thus indicate the internal structure of storms, especially thunderstorms. Starting in the mid-1960s, radar units that measure the Doppler shift were developed to provide velocity information as well. After 1960, satellites began providing detailed observations of the entire Earth.

The first sustained governmental activity in meteorology in the United States came in 1870, when Congress directed the army to organize a weather service to forecast storms over the Great Lakes and the coasts. After two decades under the Signal Corps, this activity was transferred to a new civilian Weather Bureau in the Department of Agriculture because farmers were particularly concerned with forecasts of upcoming weather and long-term climate trends. Half a century later the growing need of aviators for frequent observations and short-term forecasts led to the bureau's transfer to the Department of Commerce. In 1965 the Weather Bureau became part of the new Environmental Science Services Administration (ESSA), with climatology separated into the new Environmental Data Service (EDS); five years later ESSA was dropped and the bureau became the National Weather Service, a part of the National Oceanic and Atmospheric Administration (NOAA).

Contemporary Meteorology

The field of meteorology is increasingly becoming computerized and automated as scientists seek how best to use the flood of observations from a wide variety of traditional and new instruments. For example, rapid processing of Doppler radar data is crucial to maximize the warning time for tornadoes and other severe local weather phenomena. The preparation of observations for use in large numerical global forecast models, the "timestepping" of these models, and the processing of the resulting output are too laborious for any but the most powerful computers. Development of the World Wide Web has opened a whole new range of options for disseminating the resulting data and forecast information in ways that are still being explored.