Aristotle’s legacy in meteorology

Abstract
Aristotle's *Meteorologica* dominated the development of the science of meteorology during the nearly 2000-year period from antiquity up to the seventeenth century. This paper presents a survey of the history of meteorology during this often called “Era of Speculation.”

Aristotle wrote his famous treatise *Meteorologica* about 340 B.C. This important work became the unquestioned authority on weather theory until the birth of scientific meteorology in the seventeenth century. During this two thousand year period, very little advance took place in meteorology. Most of the little attention devoted to this science consisted of commentaries on Aristotle’s treatise. Consequently, most of the successors of Aristotle added little to the perfection of his weather system. There were a few, however, who expanded the meteorological theories of Aristotle, especially in those areas in which slight attention was given by Aristotle. One such successor was a pupil of Aristotle, Theophrastus of Eresos (ca 372 B.C.-ca 288 B.C.).

The practice of weather prognostication by means of empirical rules dates back to two works by Theophrastus; *De ventis* (on winds), and *De signis tempestatum* (on weather signs). These two treatises contain some eighty different signs of rain, forty-five of wind, fifty of storm, twenty-four of fair weather, and seven signs of weather for periods of a year or less. In looking at the overall weather picture, Theophrastus advocates the following general principle:

Now the first point to be seized is that the various periods are all divided in half, so that one’s study of the year the month or the day should take account of these divisions. The year is divided in half by the setting and rising of the Pleiad; for from the setting to the rising is a half year. So that to begin with the whole period is divided into halves; and a like division is effected by the solstices and equinoxes. From which it follows that, whatever is the condition of the atmosphere when the Pleiad sets, that it continues in general to be till the winter solstice, and, if it does change, the change only takes place after the solstice; while, if it does not change, it continues the same till the spring equinox: the same principle holds good from that time to the rising of the Pleiad, from that again to the summer solstice, from that to the setting of the Pleiad.

So too is it with each month; the full moon and the eighth and the fourth days make divisions into halves, so that one should make the new moon the starting-point of one’s survey. A change most often takes place on the fourth day, or, failing that, on the eighth, or, failing that, at the full moon; after that the periods are from the full moon to the eighth day from the end of the month, from that to the fourth day from the end, and from that to the new moon.

The divisions of the day follow in general the same principle: there is the sunrise, the mid-morning, noon, mid-afternoon, and sunset; and the corresponding divisions of the night have like effects in the matter of winds, storms and fair weather; that is to say, if there is a change, it will generally occur at one of these divisions.

Applying the above principle and the principle of a general balance in the yearly weather, Theophrastus comes up with such general forecasts as “If a great deal of rains falls in winter, the spring is usually dry; if the winter has been dry, the spring is usually wet,” and “If the autumn is unusually fine, the succeeding spring is generally cold.”

The unusual actions of animals and birds have for centuries been observed as indications of future weather. The still popular empirical rules, based on the actions of animals and birds, are enumerated in this treatise of Theophrastus. Such rules as “It is a sign of storm or rain when the ox licks his fore-hoof,” “A dog rolling on the ground is a sign of violent storm,” and “It indicates an early winter when the breeding season of sheep begins early” are quite familiar to many a present day farmer.

The rules for forecasting from observation of certain astronomical and atmospheric phenomena also appear in Theophrastus’s work on weather signs. Many shooting stars are considered a sign of rain or wind. Observing the moon is also important; i.e., “If the moon looks fiery, it indicates breezy weather for that month, if dusky, wet weather.” It is interesting to observe that
nearly all of the still popular empirical rules for weather forecasts, for example, that a reddish sky at sunrise foretells rain, come from this short work by Theophrastus.

Theophrastus made no attempt to explain the different atmospheric phenomena, but referred all such consideration to the Aristotelian method. Thus, while Aristotle’s work was largely theoretical, Theophrastus’ short treatise was completely practical. It is the oldest collection of weather signs to have survived to the present, and the later collections of weather signs were based on this work.

A demonstration of the public use of weather signs survives in the Tower of the Winds at Athens (Fig. 1), erected during the first or second century B.C. and not later than 35 B.C. The sculptures on the frieze of the octagonal, marble tower represent in symbolic form the character of the weather attributed to each of the winds of an eight-point compass.

Speculation as to the cause of the annual flooding of the Nile River was temporarily put to rest by the famous mathematician and geographer Eratosthenes (ca. 274 B.C.–ca. 194 B.C.). According to Proclus, Eratosthenes declared that it was no longer necessary to inquire as to the cause of the overflow of the Nile, as it was definitely known that man had gone to the sources of the Nile, and had observed the rains there. According to Eratosthenes, this cause of the Nile flooding had been given by Aristotle. Although the real cause of this annual phenomenon was now determined, interest in its meteorological implications has continued up to the twentieth century.

The Golden Age of Greek science drew to an end during the second and first centuries B.C. Imperial Rome established her protectorate throughout the eastern Mediterranean soon after 200 B.C. The Romans displayed a very negative attitude toward pure science, which to them always remained somewhat of an exotic endeavor. Science was important to the Romans only in so far as it had practical applications. Consequently, the several areas of the physical and natural sciences declined radically during this period. One of the few noted natural scientists of this period was Posidonius (ca. 185 B.C.–ca. 50 B.C.).

Posidonius prosecuted physical investigations with a great deal of zeal, and was quite interested in meteorological speculations. In these speculations, he followed closely the theories of Aristotle. Thus, Posidonius theorized that thunder was the bursting of the dry exhalation that had become trapped in the clouds. Although most natural philosophers in antiquity held that the maximum cloud and wind height extended up to 111 miles, Posidonius claimed that winds and clouds only reached up to a height of around five miles, beyond which the air was clear and liquid and perfectly luminous. Aristotelian influence was clearly evident.

By the end of the second century B.C. the center of scientific activity was not Athens, but the city of Alexandria, which Alexander the Great had founded in the Nile Delta. Upon the death of this famous conqueror (323 B.C.), his vast empire was broken up and eventually fell into three parts. Alexander’s friend and counselor, Ptolemy Soter, came into possession of Egypt. Under Ptolemy’s benevolent reign (323–283 B.C.) Alexandria became one of the leading cities of the eastern Mediterranean, both in commerce and in scientific activity. The greatest of the ancient world libraries and the first international university was established in Alexandria. Today, however, there is no remaining trace of these two features which Cardinal Newman describes thus: “... as the first was the embalming of dead genius, so the second was the endowment of the living.”

One of the many scientists whose name is connected with Alexandria was Claudius Ptolemy, or Ptolemy the Astronomer (ca. 85 A.D.–ca. 165 A.D.). Very little is known about this man, except that his greatest activity was from about 140–160. What Euclid did for plane geometry in his Elements, Ptolemy did for astronomy. In one treatise, now known as the Almagest, he systematically developed the knowledge of astronomy known up to that time. His application of mathematics to astronomy represented an early beginning to the development of trigonometry. Since in antiquity meteorology was...
generally considered a branch of astronomy, it is not surprising that Ptolemy displayed interest in weather phenomena and forecasting.

In one of his treatises, *Tetrabiblos*, Ptolemy gave several astrological rules for the forecasting of weather. Other weather predictors given by Ptolemy were shooting stars, fixed stars, and comets. An example of Ptolemy's astrological weather prognostications is the following one based on the appearance of the moon:

We must observe the moon in its course three days before or three days after new moon, full moon, and the quarters. For when it appears thin and clear and has nothing around it, it signifies clear weather. If it is thin and red, and the whole disk of the unlighted portion is visible and somewhat disturbed, it indicates winds, in that direction in which it is particularly inclined. If it is observed to be dark, or pale, and thick, it signifies storms and rains.13

For the next 1,000 years, this treatise of Ptolemy's was the basic authority for astrological weather prediction.14

Ptolemy was also a noted geographer, and constructed a map of the world (Fig. 2). Ptolemy divided the world into climatic zones. These zones were classified solely with reference to the conditions of illumination which these several zones received. The climates of Ptolemy were zones in which the length of the longest day increased successively by half an hour between the equator and the arctic circle. These zones were therefore of very different widths. The first climate, on the equator, embraced eight and one-half degrees of latitude; while the twenty-fourth climatic zone, at the Arctic circle, embraced only three minutes of latitude. Ptolemy discussed the general temperature variations between these zones.15

Ptolemy's division of the earth into climatic zones was purely on an astronomical basis. As temperature is a principal element in any climatic classification, and as temperature depends on a large extent on the incoming solar radiation, there was some justification for such a division. Within such a climatic zone, however, other important "climatic elements" such as precipitation vary a great deal. Hence, the astronomical method of classifying climates has been refined in recent years. Remnants of the old division still appear, however, in such classification as the Equatorial Zone and the Polar Zone; two places, incidentally, where temperature is the principal climatic element.

The next 1000 years was a period of general inactivity for meteorology. With the fall of the Roman Empire in the middle of the fifth century, began what is known as the Dark Ages in Europe. This period in which western civilization reached a very low ebb extended into the eleventh century. Most of the ancient knowledge of the Greeks and others was lost. Violence and fervent religious faith marked this period, and a new feudal and ecclesiastical society arose out of the chaos. Hence, it is not surprising that during this period interest in meteorology was scattered and fragmentary. This long pause in the development of meteorology was shared to varying degrees by the other sciences.

The study of meteorology during the period from 400-1000 never, however, completely ceased. A slender thread of scientific activity, as well as Greek and Latin learning, was preserved largely by the monks and clergy of the Catholic Church. One of the greatest of these medieval church scholars was Bede the Venerable (ca. 673-735).16

Bede was the first Englishman to write on the weather; he is called by Botley "a founder of English meteorology." 17 Among his scientific works was De Natura Rerum, written around 703. In this treatise are chapters devoted to the atmosphere, wind, thunder, lightning, clouds, and snow.18 These meteorological chapters consisted of a summary of the knowledge then available, obtained chiefly from classical sources. There is a familiar classical "ring" to such theories as wind being "air disturbed or in motion; as may be proved with a fan," and "thunder is generated by the clashings of clouds, driven by the winds which are conceived among them."19 Throughout his meteorological discussions Bede made no reference to the theories of Aristotle, the reason being that Aristotle's works were not known in Western Europe until the twelfth century. Bede's meteorological discussions were not always free of superstition, as, for example, his claim that thunder with a west wind signified "a very bad pestilence."20 On the whole, however, Bede's De Natura Rerum represented a slowly growing tendency to treat meteorology in a less philosophical, and more scientific light. For this reason, his work did contribute in the development of meteorology.

Bede was not the only medieval scholar to display an interest in meteorology. At the beginning of the seventh century, there was no abler prelate in Christendom than Isidore, Bishop of Seville (ca. 570-636).21 In such works as *Etymologiae, De ordine Creaturarum*, and *De Natura Rerum*, this noted Spanish scholar devoted a considerable amount of attention to meteorological questions.22 Like Bede, Isidore's thinking was hampered by the theological views of science which were prevalent.

Fig. 2. Ptolemy's map of the world.
throughout the early Middle Ages. However, he displayed considerable power of thought; indeed, at times, when he discussed such weather phenomena as frost, rain, hail, and snow, his theories were rational and gave evidence that, if he could have broken away from his strict adherence to the letter of Scripture, he might have given a great impetus to the evolution of the science of meteorology.

Two hundred years after the fall of the Roman Empire, the mercurial rise of the Moslem empire occurred. Within a century following Mohammed's flight from Mecca to Medina in 622, the scattered and disunited Arabian tribes had united and formed a powerful empire extending throughout the Mediterranean area; reaching from India into Spain. The Moslem's major contribution to the history of science was their role as the "caretakers" of ancient cultures. They translated many Hindu and Greek works, including Aristotle's *Meteorologica*, into Arabic, later to be retranslated into Latin by Western scholars.

The greatest Moslem physicist and one of the most noted students of optics of all times was Ibn Al-Haitham (Alhazen) (ca. 965-1039). Alhazen is credited with the first correct definition of the twilight. The Latin translation of his main work, *Optica thesaurus*, exerted a great influence upon Western science, and represented considerable progress in the science of meteorology. In this work, Alhazen discusses atmospheric refraction, and gives an important result concerning twilight. He shows that twilight only begins when the sun is nineteen degrees below the horizon. Using this result, Alhazen attempts to measure the height of the atmosphere. In a very complicated geometric demonstration, drawing often upon Euclid, he arrives at a maximum of 52,000 "passuum"—about 49 miles.

The decline of the Moslem empire occurred in the eleventh and twelfth centuries, and was followed by an influx of Christian scholars to such cultural centers in the western part of the Moslem empire as Toledo in Spain. These Christian scholars translated the Hindu and Greek works from the Arabic into Latin. Thus, the writings of Aristotle, including his *Meteorologica*, became known to Western Europe by these Latin translations. One of the earliest of these translators was the English monk, Adelard of Bath (ca. 1120).

Adelard was quite interested in meteorological speculation. These speculations, which appeared in his *Quaestiones Naturales*, are novel, as they are not just paraphrases of earlier Greek theories. For example, in his discussions of winds, Adelard applied a theory which had as its basis the conjecture that the forms of all things were the cause of passive effects. Thus, air, which itself was not in a state of movement, produced movement which was the wind. In Adelard's words: "Wind then is air in a state of motion, and dense enough to have propulsive force; for I think that wind is a species of air." He then considered such questions as why winds traveled around the earth, and how they gained their tremendous power.

Among the other meteorological speculations in Adelard's *Quaestiones Naturales* is a discussion on the ever popular phenomena, thunder and lightning. Again, his theory is different from any previous ones proposed. He introduced his discussion of the cause of thunder and lightning in the following interesting manner:

Nephew: Is, then, your science bold enough to give the cause and origin of thunder, or is it unable to solve this most difficult problem, for in face of thunder the philosopher is no braver than the rest?

Adelard: Nothing is difficult, unless one loses heart. Hope on, and you will find the right road: so far as I can, I will explain this phenomenon.

With these inspiring words, Adelard then explained that thunder in the winter was due to the breaking of ice colliding in clouds; in the summer, it was caused by the melting of the colliding ice. As for lightning, Adelard observed that in all violent collisions of bodies, the lightest thing in them was the first to be separated from them. The fire-like aether in the air was the lightest substance in the air, and the violent collisions of ice in clouds forced this aether out of the air, causing the lightning.

The thirteenth century saw the authority of Aristotle completely reestablished in meteorology. The systematically developed theories of Aristotle were infinitely superior to those existing during that period, and consequently were immediately adopted. For the next four centuries these theories enjoyed almost uncontested acceptance. As a result, the meteorological work during this period simply consisted of commentaries on the meteorological theories of Aristotle. The number of such commentaries between the beginning of the thirteenth century and the middle of the seventeenth century was prodigious. It has been estimated that well over 156 commentaries on Aristotle's *Meteorologica* appeared before 1650. In the thirteenth century some of the better known commentators were St. Thomas Aquinas (1224-1274), the Franciscan monk, Bartholomaeus Anglicus (fl. 1220-1250), and Robert Grosseteste (1168-1253) in England, Thomas of Cantimpre (ca. 1200-1270) in Belgium, Vincent de Beauvais (ca. 1190-1264) in France, and the German Albertus Magnus (1206-1280).

Medieval research remained very largely research in books. This was especially true in meteorology. Whenever, in a problem, the choice arose between going out to nature or back to the books, this choice was settled by the cloistered scholar who retreated back to the books. Thus, in meteorology and other sciences, authoritative evidence ruled supreme over experimental evidence. Before any further advance could be made in the development of meteorology, this supremacy had to be broken. While this was slow in occurring, a definite beginning was made by the most prominent scholar in
England in the thirteenth century, Roger Bacon (1214–1294).

The great Franciscan scientist (Fig. 3), who is often said to have heralded the dawn of modern science in Europe, energetically advocated the importance of experimentation in scientific study. He also stressed the importance of mathematics, and the mathematical approach, in all other areas of science, including meteorology. In his noted work *Opus Majus*, his meteorological discussions occurred in the section devoted to mathematics.

In his discussion of meteorology, Bacon follows Aristotle’s version of the constitution of the atmosphere, being made up of water, air, and fire which surrounds the earth concentrically. His work in optics made it clear to him that the atmosphere was of varying density. He gives a geometrical proof of Aristotle’s hypothesis that the surface of the air must be spherical within and without. Bacon also discusses the topic of climates, referring to the work of Ptolemy. He notes that Ptolemy’s general climatic zones must be adjusted to account for different topographies such as mountains which are high enough to “exclude the cold from the north,” and thus effect the climate of the area.

Fig. 3. Roger Bacon, 1214–1294.

Bacon also joined the army of commentators on Aristotle’s *Meteorologica*, writing a work, *In meteora*. It was, however, his stress on the importance of experimentation in science, of meteorological speculation based on close observation of atmospheric phenomena, rather than on the authority of ancient writers, which was Bacon’s prime contribution to the development of meteorology. He made the first step in freeing meteorology from the bonds of Aristotelian theories—the culmination of such steps occurring in the seventeenth century.

The next four hundred years was the lull before the seventeenth century storm in the development of meteorology. By the middle of the sixteenth century, meteorology had developed along two divergent lines: the theoretical pure science based on Aristotle’s *Meteorologica*, and the applied pseudo science of weather prognostications carried on by the astrologers. The forecasting of the weather by natural signs became very popular during this period. Astro-meteorology enjoyed the protection of the church and princes. The fact that the astrologers who published weather prognostications included such noted persons in Europe’s cultural and scientific world as Johann Muller (Regiomontanus) (1436–1476), Leonard Digges (ca. 1550), and Johann Kepler (1571–1630), helped to establish accreditation for this pseudo science. Typical examples of sixteenth century astrological weather forecasts appeared in Digges’ *A Prognostication of Right Good Effect* (1555). Scattered throughout this work are the following typical prognostications:

The Sunne in the Horizon, on ryfynge, clear and bright, fheweth a pleafant day: but thinlie overcaft wyth a cloude, betokeneth foule weather.

If thyck clowdes refemblying flockes, or rather great heapes of wall, be gatherid in many places, they fhewe rayne.

Thundres in the morning fheweth wynd: about noone, rayn: in the evenygn great tempeft.

By no means all of the scientists between the thirteenth and the seventeenth centuries were convinced of the validity of astrological weather prognostications. One such doubter was the noted fourteenth-century mathematician, Nicole Oresme (1323–1382). Oresme, who also wrote a commentary on Aristotle’s *Meteorologica*, was one of the first to indicate an appreciation of the great problems involved in weather prediction. Holding low regard toward the astrologers of his time, Oresme believed that weather forecasting was possible, but thought that the proper rules for it were still unknown. Despite such dissenters as Oresme, however, the success of the astrologers did not diminish until the beginning of the eighteenth century, weather forecasting by then having lost all remnants of a science.

As has been seen, the long period from antiquity up to the seventeenth century was an era of speculation in the development of the science of meteorology. The Meteo-
orologica of Aristotle dominated this period. However, the sixteenth century saw a gradual breaking away from Aristotle’s influence. The crack in Aristotle’s authority, made a few centuries earlier by Bacon, was sufficiently widened by the noted sixteenth century algebrast, Girolamo Cardano (1501–1576).45

In his noted treatise De Subtilitate (1550), Cardano (Fig. 4) devoted considerable attention to meteorological speculation.46 His discussions of such atmospheric phenomena as winds, clouds, rain, and lightning reflected the strong Aristotelian influence still prevalent in Western Europe. In his discussions of air, however, Cardano took issue with several basic theories of Aristotle. For one thing, he maintained there were three, not four, basic elements; earth, air, and water.47 Fire was not a basic element since it required food to exist, moved about, and nothing was produced from it. Like Aristotle, Cardano separated air into two parts, but in a different way. He explained there were two kinds of air; “free air,” which destroyed inanimate things and preserved animate things, and “inclosed air,” which had the opposite effect as free air.48

Cardano’s De Subtilitate heralded the end of the 2000 year reign of the Meteorologica as the prime authority for theoretical meteorology. This end took place in the seventeenth century. In science, the seventeenth century was the “insurgent century.”49 Scientists no longer accepted without question the classical theories of Aristotle and his contemporaries. As they became unshackled from classical authority, these scientists increasingly turned to the experimental method, heralded by Roger Bacon, in their search for knowledge. This spirit was reflected in the works of such noted seventeenth century savants as Galileo (1564–1642), Huygens (1629–1695), and Pascal (1623–1662), who all made significant contributions to the development of meteorology—René Descartes (1596–1650).50 Thus, the long “Era of Speculation” for meteorology, dominated so completely by Aristotle and his Meteorologica, came to a conclusion in the seventeenth century.

Notes and references
3 Theophrastus was born at Eresos around 372 B.C. He came to Athens as a pupil of Plato, and it was during that period that he probably first became acquainted with Aristotle. The two philosophers became close friends. Like Aristotle, the interests of Theophrastus were widespread, and included botany (he is sometimes called the father of botany), mathematics, meteorology, anatomy, philosophy, physics, poetry, and politics. He was a prodigious writer with over 227 treatises ascribed to him.
6 Ibid.
7 For a detailed discussion on the historical development of theories on the causes of the Nile floods see H. Howard Frisinger, “Early theories on the Nile floods,” Weather, 29, 206–208.
10 Posidonius was born at Apameia, in Syria. He was a distinguished Stoic philosopher, and president of that school. For several years a teacher in Rhodes, Posidonius acquired a high reputation as a cosmographer and geometer. Among his many students were Cicero and Pompey.
16 Often called the father of English learning, Bede was mainly known for his diligent compilation of knowledge of earlier writers. His life was devoted to the church and to
learning. In his own words: “I have spent my whole life in the same monastery, and while attentive to the rules of my order and the service of the Church, my constant pleasure lay in learning, or teaching, or writing.”


19 Ibid., 115.

20 Ibid.

21 For a discussion of Isidore’s role in medieval science, see Floyd S. Lear, “St. Isidore and Medieval Science,” The Rice Institute Pamphlet, XXIII (1956), 75–105.

22 Heninger, op. cit., 721.


25 Sarton, op. cit., 721.


27 Ibid., 288.

28 Little is known about Adelard except that he studied in Spain and traveled extensively throughout Egypt, Greece, and Syria. Although he is credited with one of the first Latin translations of Euclid’s Elements, there is no evidence that he was one of the translators responsible for making the works of Aristotle known in Western Europe.


31 The format of Adelard’s Quaestiones Naturales consist of questions by a nephew, followed by the answers from the uncle (Adelard).

32 Adelard of Bath, op. cit., 149.


37 Ibid., 153.

38 Ibid., 178.

39 Ibid., 154–158.

40 Ibid., 155.


43 Ibid.


45 Cardano’s life was full of paradoxes. He was at the same time a genius and a scoundrel. Educated at the universities of Pavia and Padua, he first practiced as a doctor, only to later devote his attention to mathematics and science. In his Ars Magna, published in 1545, appeared the first solution of the general cubic equation, which was reported stolen from his one-time friend Tartaglia. His debauchery was the scandal of Italy. He was a notorious gambler and perhaps a murderer. Once, in a fit of rage, Cardano cut off the ears of his youngest son for committing some offense. Cardano developed an interest in astrology, and became the most distinguished Italian astrologer of his time. His astrological frame enabled him to obtain the position of astrologer to the papal court, but also led to his death. As the story runs, Cardano foretold that he would die on a particular day. In order to keep up his reputation, he committed suicide on the appointed day of his death. The thin line between his genius and his madness was at times imperceptible.


47 Ibid., 375.

48 Ibid., 396.


50 For a discussion of the important role played by Descartes in the history of meteorology, see H. Howard Frisinger, “René Descartes: The Last of the Old and the First of the New Meteorologists,” Weather, XXI (December, 1966), 443–446.

(More announcements on page 227)