Aristotle and his "Meteorologica"

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Abstract

Aristotle was one of the forefathers in the history of the science of meteorology. His *Meteorologica* is the oldest comprehensive treatise on the subject of meteorology. This paper presents a brief summary of some of the interesting facets of this important work by Aristotle.

For Athens politically, the fourth century B.C. could hardly have been more dismal. The Peloponnesian Wars had ended in 404 with the surrender of Athens to Sparta. The next half century saw many little wars break out between the Greek city-states. Political intrigues were rampant, alliances were made and broken, and what little hope of national unity among the Greeks quickly evaporated. To the east, the ominous shadow of the growing Macedonian power steadily moved over the Greek cities, heralding the approaching end to Greek independence. Despite this background of political disintegration, however, Greek culture continued to flourish, and Athens remained the center of Greek culture. One of the most famous Athenian intellects during this period was Aristotle (384–322 B.C.).

Aristotle (Fig. 1) was born at Stagira, a Greek colony, a few miles from the present monastic settlement of Mount Athos. He moved to Athens and at the age of seventeen became a pupil of Plato. Following his master's death in 347 B.C. Aristotle crossed the Aegean Sea and settled in Lesbos, an island off the coast of Asia Minor. His rising reputation as a scholar resulted in his being appointed tutor to the young prince Alexander of Macedon, who later became Alexander the Great. Another probable contributing factor to this honored appointment was the fact that Aristotle's father was physician to the monarch of Macedon. Aristotle remained in Macedon till 336 B.C. when Alexander began his extraordinary career of conquest. Returning to Athens, Aristotle became one of the most noted public teachers, writers, and philosophers of his time. Included in his many works in the treatise *Meteorologica* which became the cornerstone of the growth of meteorology into a science (1).

Written around 340 B.C., Aristotle's *Meteorologica* is the oldest comprehensive treatise on the subject of meteorology (2). The work is in four books of which the first three deal with what we now consider meteorology, and the fourth book is mainly chemistry (3). The following table of contents of the first three books provides a good indication of the great breadth of this treatise:

Book I Ch. 1 Introduction: the place of meteorology in the natural sciences and summary of topics to be discussed.

Ch. 2 General principles and basic elements of the terrestrial world. The relation of the terrestrial world to the rest of the universe.

Ch. 3 Arrangement and nature of the four basic elements, air, earth, fire, and

Fig. 1. Aristotle

water. Anaxagoras' opinion concerning the aether. The special nature of the bodies which fill the space between the earth and the stars. The double nature of exhalation. The formation of clouds and their height. Concerning the upper regions of the air.

Ch. 4 Shooting stars.
Ch. 5 The Aurora Borealis and its cause.
Ch. 6 The comets. Opinions and explanations of Anaxagoras, Democritus, the Pythagoreans. Hippocrates of Chios, and Aeschylus. Refutation of these opinions.
Ch. 7 The nature and cause of comets.
Ch. 8 The milky way, different opinions and Aristotle's new theory.
Ch. 9 The formation of rain, clouds and mist.
Ch. 10 Concerning dew and hoar-frost.
Ch. 11 Concerning rain, snow, hail and their relation to hoar-frost.
Ch. 12 Hail. Why it occurs in summer, views of Anaxagoras refuted by the "facts."
Ch. 13 Winds. Erroneous opinions on its cause. The formation of rivers; other theories and their refutation.
Ch. 14 Climatic changes, coast erosion and silting.

Book II Ch. 1 The sea and its nature.
Ch. 2, 3 The origin and saltness of the sea.
Ch. 4 Winds. The cause of winds.
Ch. 5 Winds (continued). Effect of heat and cold on winds. Prevailing winds of different climatic zones.
Ch. 6 Winds (continued). Enumeration of different winds and their directions.
Ch. 7 Earthquakes. Views of Anaxagoras, Democritus, and Anaximenes given and criticized.
Ch. 8 Earthquakes (continued). The causes of earthquakes.
Ch. 9 Thunder and lightning. Its cause explained. Theories of Empedocles and Anaxagoras refuted.

Book III Ch. 1 Hurricanes, typhoons, firewinds and thunderbolts. All products of the dry exhalation.
Ch. 2 Haloes and rainbows. All caused by reflection.
Ch. 3 Haloes (continued). Geometrical explanation of its shape.
Ch. 4 Rainbows. The physical basis of reflection. How rainbows are formed.
Ch. 5 Rainbows (continued).
Ch. 6 Mock suns and rods. Results of reflection.

The foundation of *Meteorologica* was based on two basic theories. First, Aristotle believed the universe was spherical in form. He accepted the system of Eudoxus which accounted for the movements of the stars and planets by a system of concentric spheres whose combined motions produced the apparent movements of the heavenly bodies (4). The earth was the inner core of these concentric spheres which were formed by the orbits of the heavenly bodies. Aristotle divided the universe into two major regions: the celestial region—the region beyond the orbit of the moon, and the terrestrial or sublunar region-sphere of the moon's orbit about the earth. Thus, he made a precise distinction between the real of astronomy and that of his new subject, meteorology. The former was restricted to the celestial region (including the orbit of the moon), and the latter was restricted to phenomena of the terrestrial region.

The second basic theory on which this treatise was founded was the "Four-element Theory" of Empedocles (5). Aristotle pictured the terrestrial region as being made up of four elements—earth, water, air, and fire, arranged in concentric spherical strata with the earth at the center (Fig. 2). This stratification, however, was

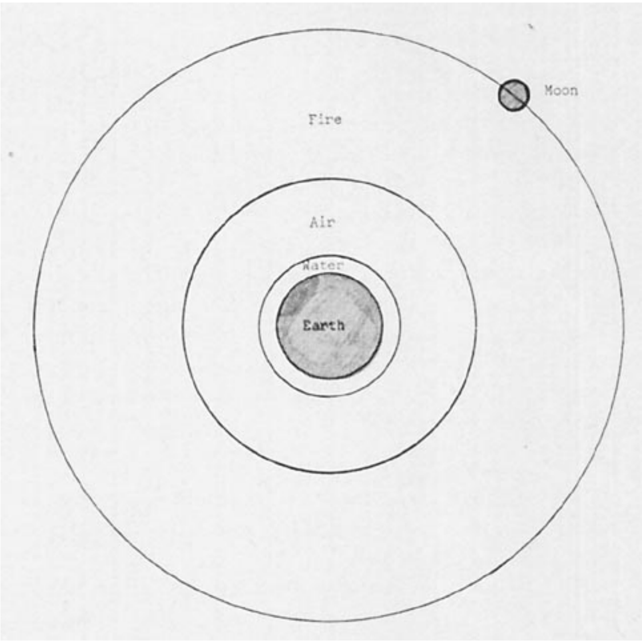

Fig. 2. Aristotle's concept of the universe.

not rigid. Dry land rose above water, and fire often burned on the earth. Also, all elements were thought to be in constant processes of interchange, one into the other (6). When the heat of the sun reached the earth's surface, it was believed to mix with the cold and moist water to form a new substance, warm and moist, essentially like air. The sun's heat similarly acted upon the cold and dry earth to produce another substance, warm and dry, essentially like fire.

Thus, we see that the sun was thought to draw up two kinds of "evaporations." One was the wet and generally warm vapors, which resulted in such phenomena as clouds, rain, etc. The other was the hot and dry vapors which provided source material for such phenomena as wind, thunder, etc.

There were thus two main strata in Aristotle's atmosphere, air and fire. But within the sphere of air, there were certain further differentiations. Aristotle theorized clouds could not form beyond the tops of the highest mountains because the air above the mountains contained "fire" and was carried round with the celestial motion. Also, clouds could not form close to the earth because the heat reflected from the earth also prevented cloud formation. Thus, there was a strata in the atmosphere between the height of the highest mountains and the earth's surface where clouds could form. (Fig. 3) (7).

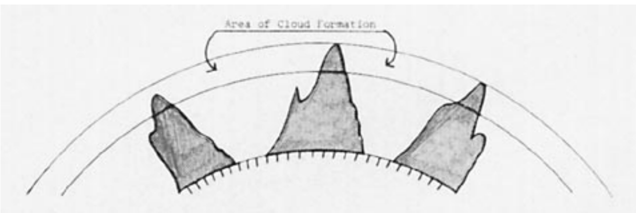

FIG. 3. Area of cloud formation was limited by tops of highest mountains, according to Aristotle.

Meteorologica not only represents Aristotle's theories, but also an accumulation of facts collected from former natural philosophers, historians, poets, and common experience (8). A number of weather prognostications in this work are derived from the Egyptians (9). Also much of the work is of definite Babylonian origin, especially in Aristotle's classification of the winds (10). Hence, *Meteorologica* could be regarded as representing the state of meteorological knowledge in the time of Aristotle. An excellent example of Aristotle's development of a meteorological theory from known facts is his discussion of hail which is presented below.

> In considering the process by which hail is produced, we must take into account both facts whose interpretation is straightforward and those which appear to be inexplicable.
>
> Hail is ice, and water freezes in the winter: yet hailstorms are commonest in spring and autumn, rather less common at the end of the summer, and rare in winter when they only occur when it is not very cold. And, in general, hailstorms occur in milder districts, snowstorms in colder.
>
> It is also odd that water should freeze in the upper region; for it cannot freeze before it becomes water, and yet having become water it cannot remain suspended in the air for any length of time. Nor can we maintain that just as drops of water ride aloft because of their minuteness and rest on the air, like minute particles of earth or gold that often float on water, so here the water floats on the air till a number of the small drops coalesce to form the large drops that fall. This cannot take place in the case of hail, because frozen drops cannot coalesce like liquid ones. Clearly then drops of water of the requisite size must have been suspended in the air: otherwise their size when frozen could not have been so large.
>
> Some then think that the cause of the origin of hail is as follows: when a cloud is forced up into the upper region where the temperature is lower because reflection of the sun's rays from the earth does not reach it, the water when it gets there is frozen: and so hailstorms occur more often in summer and in warm districts because the heat forces the clouds up farther from the earth (11). But in the very high places hail falls very infrequently; but on their theory this should not be so, for we can see that snow falls mostly in high places. Clouds have often been seen swept along with a great noise close to the earth, and have struck fear into those that heard and saw them as portents of some greater catastrophe. But sometimes, when such clouds have been seen without any accompanying noise, hail falls in great quantities and the stones are of an incredible size, and irregular in shape; the reason being that they have not had long to fall because they were frozen close to the earth, and not, as the theory we are criticizing maintains, far above it. Moreover, large hailstones must be formed by an intense cause of freezing; for it is obvious to everyone that hail is ice. But hailstones that are not rounded in shape are large in size, which is a proof that they have frozen close to the earth: for stones which fall farther are worn down in the course of their fall and so become round in shape and smaller in size.
>
> It is clear then that the freezing does not take place because the cloud is forced up into the cold upper region.
>
> Now we know that hot and cold have a mutual reaction on one another (which is the reason why subterranean places are cold in hot weather and warm in frosty weather). This reaction we must suppose takes place in the upper region, so that in warmer seasons the cold is concentrated within by the surrounding heat. This sometimes causes a rapid formation of water from cloud. And for this reason you get larger raindrops on warm days than in winter and more violent rainfall—rainfall is said to be more violent when it is heavier, and a heavier rainfall is caused by rapidity of condensation. (The process is just the opposite of what Anaxagoras says it is. He says it takes place when clouds rise into the cold air: we say it takes place when clouds descend into the warm air and is most violent when the cloud descends farthest.) Sometimes, one the other hand, the cold is even more concentrated within by the heat outside it, and freezes the water which it has produced, so forming hail. This happens when the water freezes before it has time to fall. For if it takes a given time to fall,

but the cold being intense freezes it in a lesser time, there is nothing to prevent it freezing in the air, if the time taken to freeze it is shorter than the time of its fall. The nearer the earth and the more intense the freezing, the more violent the rainfall and the larger the drops or the hailstones because of the shortness of their fall. For the same reason large raindrops do not fall thickly. Hail is rarer in the summer than in spring or autumn, though commoner than in winter, because in summer the air is drier: but in spring it is still moist, because in summer the air is drier: but in spring it is still moist, in autumn it is beginning to become so. For the same reason hailstones do sometimes occur in late summer, as we have said. If the water has been previously heated, this contributes to the rapidity with which it freezes: for it cools more quickly. (Thus so many people when they want to cool water quickly first stand it in the sun: and the inhabitants of Pontus when they encamp on the ice to fish—they catch fish through a hole which they make in the ice—pour hot water on their rods because it freezes quicker, using the ice like solder to fix their rods.) And water that condenses in the air in warm districts and seasons gets hot quickly.

For the same reason in Arabia and Aethiopia rain falls in the summer and not in the winter, and falls with violence and many times on the same day: for the clouds cooled quickly by the reaction due to the great heat of the country.

So much then for our account of the causes and nature of rain, dew, snow, hoar frost and hail. (Book I, Ch. 12.)

This discussion on hail illustrates the method used by Aristotle throughout his treatise. He is very fond of introducing his theories by first presenting the theories of others, and then refuting them. The differing opinions between Anaxagoras and Aristotle on the formation of hail illustrate a basic difference between Aristotle's method of developing a meteorological theory, and that of his predecessors.

Anaxagoras and the other earlier natural philosophers were largely inductive in their approach to their speculations on weather phenomena. Their theories were strongly based on their observations. Aristotle, however, employed a more deductive approach to the formation of his meteorological theories, in that he had preconceived meteorological theories and explained various weather phenomena on the basis of these theories. Instead of using weather observations to develop his theories, Aristotle very often interpreted these observations in such a way as to support his preconceived beliefs. This was often accomplished by employing arguments by analogies where the analogies were assumed rather than demonstrated (for example Aristotle's analogy concerning the temperature in subterranean places, in his discussion of hail). The great extent to which Aristotle applied this deductive reasoning was very evident in his discussion of winds.

As usual, Aristotle began his discussion by strongly refuting the opinion of Anaximander and others that wind was simply a moving current of air. Recalling his theory that the sun drew up two types of exhalations from the earth, Aristotle claimed that the origin of wind was the dry, hot exhalation. He explained the cause of wind on the analogy of rivers which represent the gradually accumulated flow of water from the mountains downwards. In the same way wind was due to the gradual accumulation of the dry, hot exhalation from the earth. Thus, Aristotle stated that:

> The facts also make it clear that winds are formed by the gradual collection of small quantities of exhalation, in the same way that rivers form when the earth is wet. For they are all least strong at their place of origin, but blow strongly as they travel farther from it. Besides, the north, that is the region immediately about the pole, is calm and windless in winter; but the wind which blows so gently there that it passes unnoticed, becomes strong as it moves farther afield. (Book I, Ch. 4.)

The fact that the winds blow horizontally, although the exhalation rises vertically, was explained thus by Aristotle: "because the whole body of air surrounding the earth follows the motion of the heavens" (12).

According to Aristotle, there were two main winds, those from the north and from the south. The north winds emanated from the cold regions under the Great Bear, the northern limit of the habitable world, and thus were cold. Those from the south came, not from the South Pole, but from the tropic of Cancer, which was the southern limit of the habitable world, since beyond it the heat was believed too great for life. Because of the region from which they emanated, the south winds were hot winds.

The Aristotelian classification of winds was based on Aristotle's meteorological theory of their connection with the sun. The Greeks of the time of Aristotle had very limited means of expressing directions. As a consequence, Aristotle employed such astronomical directions as equinoctial sunrise, winter sunset, midday sun, etc., to indicate the directions of the various winds. Dividing the compass-card into twelve equal sectors, he enumerated the different winds and their directions (Fig. 4). This duodecimal division was very suggestive of Babylonian origin. Aristotle noted there was not opposite wind to the wind Meses (K), nor to the wind Thrascias (I), "except perhaps a local wind called by the inhabitants Phoenicias." He explained the greater number of northerly winds than southerly winds as follows:

> First, our inhabited region lies towards the north; second, far more rain and snow is pushed up into this region because the other lies beneath the sun and its course. These melt and are absorbed by the earth and when subsequently heated by the sun and

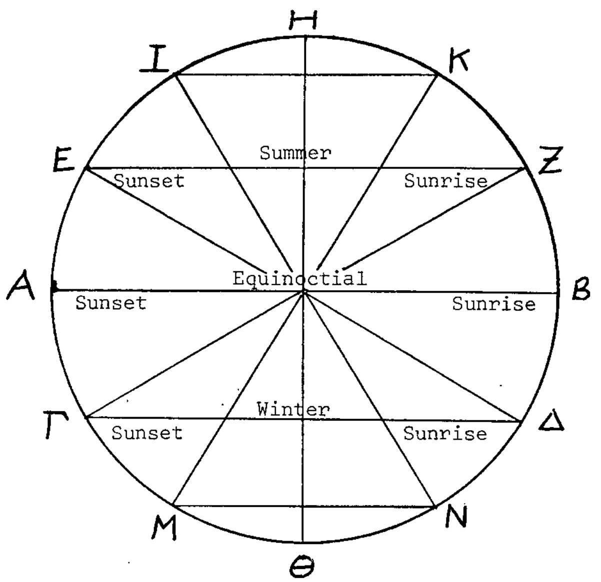

Fig. 4. Aristotle's wind rose.

the earth's own heat cause a greater and more extensive exhalation. (Book II, Ch. 6).

Thunder and lightning, the ever popular phenomena for speculation, was also attributed, by Aristotle, to the dry exhalation in the atmosphere. He claimed that thunder was the noise caused by some dry exhalation that was trapped in clouds, then forcibly ejected from the clouds as they condensed, and lastly striking the surrounding clouds. Different kinds of sound were produced because of the lack of uniformity in the composition of clouds. This ejected "wind" then burned with a "fine and gentle fire, and it is then what we call lightning" (13). Contrary to earlier opinion, Aristotle claimed that lightning followed thunder.

As has been seen, Aristotle based his explanations concerning weather phenomena on the theory there were two kinds of exhalation, moist and dry; and their combination (air) contained both potentially. Clouds also, contained both exhalations. He applied this theory to explain yet another weather phenomenon, hurricanes, in the following interesting way:

> The windy exhalation causes thunder and lightning when it is produced in small quantities, widely dispersed, and at frequent intervals, and when it spreads quickly and is of extreme rarity. But when it is produced in a compact mass and is denser, the result is a hurricane, which owes its violence to the force which the speed of its separation gives it. (Book III, Ch. 1.)

Here Aristotle was explaining the violent winds associated with a hurricane, not its accompanying rain which was due to the moist exhalation.

This has been a brief summary of some of the interesting facets of Aristotle's *Meteorologica.* This treatise provides an excellent example of the many errors made by the Greeks in natural science due to their comparative failure to develop experimental science; a major reason for this of course was the absence of precision instruments. Previously developed theory or philosophy outweighed experimental evidence. *Meteorologica* was the product of the natural philosopher, not the natural scientist. Neverthless, its importance in the history of meteorology is great. It is the earliest known effort at a systematic discussion of meteorology, and was the unquestioned authority on weather theory for over two thousand years (14). In fact, all text-books on meteorology in the Western Civilization up to the end of the seventeenth century were based exclusively on Aristotle's *Meteorologica* (15).

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