Logical and illogical exegeses of hydrometeorological phenomena in ancient Greece

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Abstract Technological applications aiming at the exploitation of the natural sources appear in all ancient civilizations. The unique phenomenon in the ancient Greek civilization is that technological needs triggered physical explanations of natural phenomena, thus enabling the foundation of philosophy and science. Among these, the study of hydrometeorological phenomena had a major role. This study begins with the Ionian philosophers in the seventh century BC, continues in classical Athens in the fifth and fourth centuries BC, and advances and expands through the entire Greek world up to the end of Hellenistic period. Many of the theories developed by ancient Greeks are erroneous according to modern views. However, many elements in Greek exegeses of hydrometeorological processes, such as evaporation and condensation of vapour, creation of clouds, hail, snow and rainfall, and evolution of hydrological cycle, are impressive even today.
Keywords Science, Technology, Ancient Greece, Hydrology, Meteorology

INTRODUCTION

It is a common belief that the most fundamental hydrological and meteorological concepts were formulated not before the 16th century (by Palissy, Perrault, Mariotte, Halley and others) and that ancients, including Greeks, had a serious misconception about hydrometeorological phenomena. It is very common in modern literature to read assertions such as:

> *"As late as the seventeenth century it was generally assumed that water emerging from springs could not be derived from rainfall … Early Greek philosophers … hypothesized that springs were formed by the sea water conducted through subterranean channels below the mountains … Aristotle suggested that air enters into cold dark caverns under the mountains where it condenses into water and contributes to springs." (Todd, 1959)*
>
> *"… in the early 17th century many workers were still in essence following the Greeks in believing that sea water was drawn into vast caverns in the interior of the Earth, and raised up to the level of the mountains by fanciful processes" (Price, 1985).*
>
> *"In fact, the birth of meteorology as a genuine natural science did not take place until the invention of weather instruments … at the end of the sixteenth century …" (Ahrens, 1993).*

These, however, may provide and inaccurate picture of the development of science (given for instance that even the term 'meteorology' is at least as ancient as Plato (Phaedrus, 270a). On the other hand, the scientific community agrees that history of science is important to know and that it should trace the evolution faithfully, giving appropriate credits. Modern scientific theories are advanced (even though several phenomena are not fully understood until today) but are not independent of the ancient scientific views. The study of the ancient science is useful because it reveals that thinking and reasoning, which were the main tools of ancient philosophers (in contrast to modern modelling tools and computers), can establish consistent views of the world, whose precision in some cases is admirable even today (even though in some other cases the views are illogical according to modern knowledge). And also because it enlightens the continuity of the development of science as it is known that the ancient Greek ideas had a major contribution in the beginnings of modern science (after the Renaissance).

In all ancient civilizations the exploitation of the natural sources, such as sun, wind and water, was a major activity triggering cultural progress through inventions and technological advances. These achievements helped ancient communities to manage the wind for sailing, to exploit the water for drinking and irrigation and to take advantages of the solar energy by appropriate orientation of buildings. Such technological applications certainly imply some understanding of nature. However, at the first stages the related explanations were hyperphysical, i.e. mythological. In ancient Greece, the struggle of humans to control nature has been imprinted in a rich mythology which was survived in texts and artefacts. For example several myths about the hero Hercules (Heracles), symbolize the struggle against the destructive power of water. The myth depicted in Fig. 1 is related to the duel between Achelous (or Acheloos) and Hercules. Achelous, the greatest (in discharge) river of Greece, in mythology was deified as the son of Poseidon, the god of the sea. Achelous was eventually defeated by Hercules. As demystified later by the historian Diodoros Siculus (IV 35) and the geographer Strabo (X 458–459), the meaning of the victory is related to the channel excavation and the construction of dikes to confine the shifting bed of Achelous.

Figure 1. The battle of Hercules against Achelous (depiction based on an Attic red figure vase, 6th century BC, kept in the British Museum).

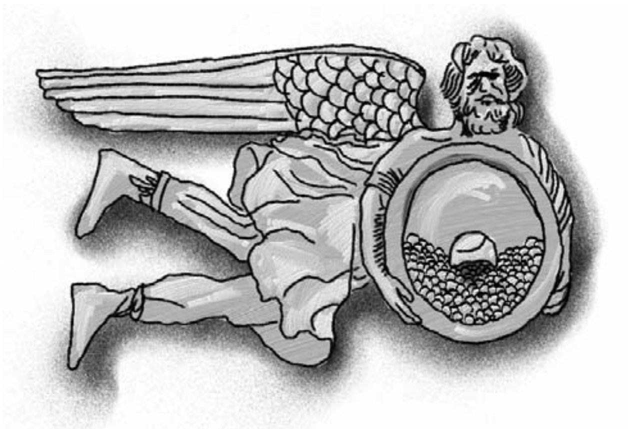

Figure 2. Kaikias, the northeast wind holding a shield with hail-stones (depiction based on sculpture in the Wind Tower a monument built in Athens in the 2nd or 1st century BC).

With the advancement of technology, a new need arose, the physical exegesis of hydrometeorological phenomena that govern the natural sources. In ancient Greece, several theories were proposed in an environment that lasted for more than six centuries (roughly from Archaic to Roman Period), in which mental activities flourished. This environment has been credited as the birthplace of philosophy and science as both appeared there for first time in history (Krutwig Sagredo, 2006). Reviewing the original texts of this period, the researcher meets a great variety of views, mythical, poetical, religious, symbolical, philosophical and scientific. Interestingly, the mythological and symbolical views have been popular (and particularly inspiring in arts) even in the late stages of this period, even thought scientific theories had already been developed (Fig. 2).

Although the modern world inherited many original texts of the ancient Greek civilization, the majority of them have been lost. In what follows we focus on the views on hydrometeorological phenomena that come from original texts or from other classical Greek and Roman authors who must have accessed the original texts. The next three sections cover three phases of the ancient Greek philosophy: archaic, with focus on Ionia, classical, with focus on Athens, and Hellenistic.

IONIA AND THE BIRTH OF SCIENCE

Although the technological application in water resources started in Greece before 2000 BC, in the Minoan and Mycenaean civilizations (Koutsoyiannis and Angelakis, 2003), the first scientific views of phenomena were formulated only around 600 BC. Greek philosophers from Ionia (Fig. 3), rejected the hyperphysical approaches that were reflected in epic poems (mostly in Homer's Iliad and Odyssey), and explained many physical phenomena in a scientific manner.

Figure 3. Ionian philosophers (from left to right: Anaximander, Anaxagoras, Xenophanes, Thales, Anaximenes – a depiction based on known sculptures).

Thales of Miletus (640-546 BC), one of the Seven Sages of Greece, was the founder of the Ionic philosophy (and according to many, the father of philosophy and of science). Thales formulated the theory that water is the fundamental substance of the world. Interestingly, his record includes some engineering achievements thus emphasising the link of technology and philosophy in the genesis of the latter. According to the historian Herodotus (480-430 BC; Histories, Cleo, 75) he accomplished the diversion of Ales river to help the army of Croesus (king of Lydia) in a conflict against the army of Cyrus (king of Persia). Also, Thales tried to explain the hydrological "paradox" of the floods of the Nile River. The fact that the Nile floods occur at the summertime when rainfall in Egypt is minimal, puzzled the ancient Greek world even before Thales, and mythical exegeses (e.g. by Homer, that the Nile originates from the Ocean, a mythical river located in the Sky) had been given. Thales put this puzzle as a scientific problem proposing that the northern wind that prevails in the region in wintertime does not permit the river to flood. During summertime, because of the attenuation of the winds, the river outflows (Herodotus, Histories, Euterpe, 20). Obviously, the explanation is incorrect (Greeks were not aware of the tropical storms in summertime). But what is more important than a correct explanation is the fact that the question is put and studied on physical grounds. In this respect, Thales can be thought of as the first hydrologist in history. This story emphasizes the importance of hydrology at the beginnings of science.

Anaximander (c. 610 BC – c. 547 BC) from Miletus, successor of Thales, is the first who dared write a book "About Nature" not based on mythology or religion (Themistius, or. 36, p. 317) which however has been lost. He understood the relationship of rainfall and evaporation:

> *"Rains are generated from the evaporation [atmis] that is sent up from the earth toward under the sun" (Hippolytus Ref. I 6, 1-7 – D. 559 W. 10).*

He also attempted explanation of winds and thunders (Seneca, Nat. Qu, II 18). Anaximenes (585-525 BC) of Miletus, a student of Anaximander, devised logical explanations for the formation of clouds, rain and hail. According to him

> *"hail is produced when precipitating water from clouds freezes; snow is produced when the water in the more wet clouds freezes" (Hippolytus Ref. I 7, 1 – D. 560 W. 11).*

Also, he attempted to explain the formation of the rainbow and lightning. Of particular importance is the explanation of Anaximenes for the creation of winds:

> *"they are caused when the air density is decreased, so the air becomes light and then starts to move" (ibid.).*

Xenophanes of Colophon (570-480 BC), a philosopher, poet, and traveler (perhaps the founder of Eleatic philosophy) seems to be the first who integrated the concept of hydrological cycle:

> *"The sea is the source of water and of wind/ For without the great sea, there would be no wind/ Nor streams of rivers, nor rainwater from on high/ But the great sea is the begetter of clouds, winds, and rivers" (Xenophanes, B30; quoted from the Stanford Encyclopedia of Philosophy, http://plato.stanford.edu/entries/xenophanes/).*

The philosopher Anaxagoras of Clazomenae (500-428 BC) has been very influential; as he lived mostly in Athens, he transplanted the ideas of Ionian philosophers to Athenians including the great politician Pericles, who was his student, the dramatists Euripides and Sophocles, and the historian Herodotus. As a natural philosopher and founder of experimental research, he clarified the concept of the hydrological cycle and studied various meteorological phenomena (winds, storms) generally accepting and completing the explanations of Anaximenes. Specifically, he considered that the differences in the air density, caused by the solar heat, were responsible for the creation of winds (Georgoulis, 1957). Also, he explained the rainbow (iris, which earlier was personified in a deity):

> *"Iris is the reflection of the solar light incident to the clouds" (from Georgoulis, 1957).*

Finally, he tried to explain the paradox of the floods of the Nile River, proposing that the snow melting in the mountains of Ethiopia in spring causes summer floods in the regions of Delta of the Nile, with time delay. Herodotus (Histories, Euterpe) who relates this and earlier explanations seems not to adopt any of these explanations; in addition, he appears to have good understanding of hydrological processes.

CLASSICAL ATHENS

As mentioned above, Anaxagoras is regarded as the link between the Ionian and Athenian philosophers (Fig. 4). The founder of Athenian philosophy is regarded to be Socrates (c. 470–399 BC). Socrates did not write anything himself; however, his student Plato (c. 427–c. 347 BC) has conveyed some of his teacher's views in his Dialogues, in which Socrates is often a character.

Plato was one of the most influential philosophers and the founder of the Academy in Athens. Plato's contribution in metaphysics, epistemology, politics and ethics is more important than that in natural philosophy. Perhaps the following passage (attributed by Plato to Socrates and influenced by Homer's epics) from his dialogue Phaedo has been responsible for the misleading modern views of the ancient scientific approaches, as discussed in the Introduction:

> *"One of the chasms of the earth is greater than the rest, and is bored right through the whole earth; this is the one which Homer means when he says 'Far off, the lowest abyss beneath the earth' and which elsewhere he and many other poets have called Tartarus. For all the rivers flow together into this chasm and flow out of it again, and they have each the nature of the earth through which they flow … And when the water retires to the region which we call the lower, it flows into the rivers there and fills them up, as if it were pumped into them; and when it leaves that region and comes back to this side, it fills the rivers here; … Thence they go down again under the earth …and flow again into Tartarus" (Phaedo 14.112; transl. H.N. Fowler).*

However, we should be aware that Plato's central theme in Phaedo is the immortality of the soul, i.e. irrelevant to natural phenomena, and therefore the discussion may have a symbolic meaning. Other Plato's texts may provide more consistent hydrological views, for instance Critias:

> *" the land reaped the benefit of the annual rainfall, not as now losing the water which flows off the bare earth into the sea, but, having an abundant supply in all places, and receiving it into herself and treasuring it up in the close clay soil, … providing everywhere abundant fountains and rivers" (Critias, 111d; transl. B. Jowett).*

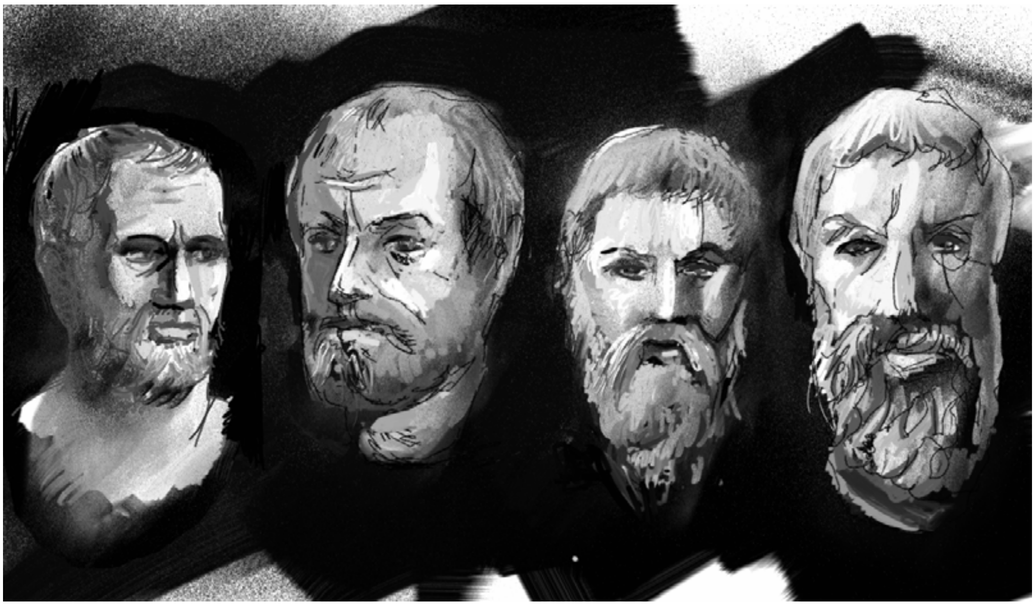

Figure 4. Athenian philosophers (from left to right: Theophrastus, Aristotle, Plato, Epicurus – a depiction based on known sculptures).

Aristotle (384-328 BC) was a student of Plato but his theories were also influenced by Ionian philosophers. His famous treatise 'Meteorologica' was a great contribution to hydrometeorogy. Although many of his views are erroneous, Aristotle formulated correctly the hydrological cycle. He understood the phase change of water and the energy exchange required for this:

> *"… the sun causes the moisture to rise; this is similar to what happens when water is heated by fire" (Meteorologica, II.2, 355a 15).*
>
> *"… the vapour that is cooled, because of lack of heat in the area where it lies, condenses and turns from air into water; and after the water has formed in this way it falls down again to the earth" (ibid., I.9, 346b 30).*

He also recognized the principle of mass conservation within hydrological cycle:

> *"Thus, the sea will never dry up; for the water that has gone up beforehand will return to it; and if this has happened once we must admit its recurrence" (ibid., II.3, 356b 26).*
>
> *"Even if the same amount does not come back every year or in a given place, yet in a certain period all quantity that has been abstracted is returned" (ibid., II.2, 355a 26).*

An impressive perception for the world transformation is also included in Aristotle's texts. Specifically, he puts the question whether the extent of land is decreased, compared with that of the sea. Aristotle believes that, on large time scales, all changes:

> *"The same parts of the earth are not always wet or dry, but they change depending on the formation or disappearance of rivers. And so the relation of land to sea changes and a place does not always remain land or sea throughout all time, but where there was dry land there comes to be sea, and where there is now sea, there one day comes to be dry land" (ibid., I.14, 351a 19).*
>
> *"… neither the Tanais [River Don in Russia] nor the Nile has always been flowing, but the region in which they flow now was once dry: for their life has a bound, but time has not… But if*

rivers are formed and disappear and the same places were not always covered by water, the sea must change correspondingly. And if the sea is receding in one place and advancing in another it is clear that the same parts of the whole earth are not always either sea or land, but that all changes in course of time (ibid., I.14, 353a 16).

The successor of Aristotle in his Peripatetic school, the philosopher Theophrastus (372-287 BC), adopted and advanced or even corrected his teacher's theories on the formation of precipitation from condensation and freezing of water vapour. He also understood the nature of wind:

"The movement of air is wind" (quoted from Brutsaert, 1982, p. 16).

and its relation with cloud formation as well as the role of the orography on the latter. Furthermore he understood the mechanisms of evaporation and particularly the influence of wind:

"The reason that winds, which are cold, dry more quickly than the sun, which is warm, and the coldest winds most of all, must be that they create a vapour and remove it […] while the sun leaves the vapour"(ibid.).

The above examples indicate the importance of the understanding of meteorological and hydrological processes in classical Athens. We can imagine that the discussions of these issues would be strong and affected by superstition. These are vividly expressed in the theatre play Clouds (Nefelae) by the comic dramatist Aristophanes (c. 448 - c. 385 BC). The central character of the play, Strepsiades, a citizen of Athens, becomes a student of Socrates. The following passage, a dialogue between the two, reveals that Athenians had difficulties to accept the physical principles as causes of phenomena and were ready to transform the physical principles into a new type of deities:

Soc.: What Jupiter? Do not trifle. There is no Jupiter.
Strep.: What do you say? Who rains then? For first of all explain this to me.
Soc.: These to be sure. I will teach you it by powerful evidence. Come, where have you ever seen him raining at any time without Clouds? And yet he ought to rain in fine weather, and these be absent.
Strep.: By Apollo, of a truth you have rightly confirmed this by your present argument. And yet, before this, I really thought that Jupiter caused the rain. But tell me who is it that thunders. This makes me tremble.
Soc.: These, as they roll, thunder.
Strep.: In what way? you all-daring man!
Soc. :When they are full of much water, and are compelled to be borne along, being necessarily precipitated when full of rain, then they fall heavily upon each other and burst and clap.
Strep.: Who is it that compels them to borne along? Is it not Jupiter?
Soc.: By no means, but aethereal Vortex.
Strep.: Vortex? It had escaped my notice that Jupiter did not exist, and that Vortex now reigned in his stead (Clouds, 356, English ed. by W.J. Hickie).

HELLENISTIC PERIOD

In the Hellenistic period, many different schools of thought were developed in the Greek world, among which the most notable were the Sceptics, Stoics and Epicureans. The latter school, which for the first time admitted women and slaves into it, was the one that mostly explored nature and natural phenomena. Its founder Epicurus (341-270 BC), who too lived in Athens, represented a departure from the other major Greek thinkers of this and earlier periods. However, he kept several ideas of earlier philosophers. Like Leucippus (first half of 5th century BC) and Democritus (c. 450 - c. 370 BC), he was an atomist, believing that the fundamental constituents of the world are atoms flying and colliding through empty space (void). These movements he considered random rather than ordered, thus expressing a view different from the determinism of Leucippus and Democritus and more consistent with the indeterminism of Heraclitus (c. 535 - 475 BC). This view allowed the development of notion of free will; according to Epicurus, Gods exist but they do not intervene in natural phenomena or human affairs. His advanced ideas were subsequently (and are even today) misunderstood by many; the most characteristic example is his idea of hedonism, which today has a negative meaning, different from that taught by Epicurus.

His epistemological views are remarkable and could stand in a modern discussion, as shown for instance in the following passage (cf. the modern notion of the Theory of Everything):

> *"It is not good to desire what is impossible, and to endeavour to enunciate a uniform theory about everything; accordingly, we ought not here to adopt the method, which we have followed in our researches into ethics, or in the solution of problems of natural philosophy … Besides, it is not here a question about reasoning on new principles, and of laying down, a priori, rules for the interpretation of nature; the only guides for us to follow are the appearances themselves" (Letter to Pythocles, reproduced by Diogenes Laertius, English translation by C.D. Yonge).*

Some of his views on the hydrometeorological phenomena and presented in his letter to Pythocles:

> *"The clouds may be formed either by the air condensed under the pressure of the winds, or by the agency of atoms set apart for the end, or by emanations from the earth and waters, or by other causes …" (ibid.)*

He also studied, and attempted to explain hurricanes, hail, snow, dew, hoarfrost, rainbow, lightning and thunder; for the time lag between the last two he says:

> *"… perhaps, the two phenomena being simultaneous, the lightning arrives among us more rapidly than the noise of the thunder-bolt, as is in fact remarked in other cases when we see at an instance the clash of two objects" (ibid.).*

From the school of stoics, the philosopher who is known to have studied meteorological phenomena is Posidonius (c. 135 - 51 BC). Among his writings, all of which are lost except a few fragments, are the treatises "On meteorology" and "On meteors". It is known that he studied clouds, mist, wind, rain, frost, hail, rainbow and lightning, closely following the teachings of Aristotle.

The Hellenistic period signifies the transformation of science to a more rigorous basis, closer to its modern sense. Thus, in this period one can trace the foundation of modern mathematics by Euclid (c. 325 - 265 BC), Archimedes (287 - 212 BC) and Apollonius (c. 262 - c. 190 BC), and the modern astronomy by Aristarchus of Samos (310-230 BC) and Eratosthenes (276 BC - 194 BC). Archimedes is also considered as a physicist and engineer and the founder hydrostatics. He introduced the principle, named after him, that a body immersed in a fluid is subject to an upward force (buoyancy) equal in magnitude to the weight of fluid it displaces.

Another famous mathematician, physicist and engineer of the late Hellenistic period is Hero (Heron) of Alexandria (he lived around 150 BC or, according to others, during 10-70 AD). In his treatise Pneumatica he founded several physical concepts with their modern meanings such as pressure (air pressure, water pressure, and the connection of the two), flow velocity and discharge. His views are impressive and his experimental method very modern, as revealed from the following passage:

> *"Vessels which seem to most men empty are not empty, as they suppose, but full of air. Now the air, as those who have treated of physics are agreed, is composed of particles minute and light, and for the most part invisible. If, then, we pour water into an apparently empty vessel, air will leave the vessel proportioned in quantity to the water which enters it. This may be seen from the following experiment. Let the vessel which seems to be empty be inverted, and, being carefully kept upright, pressed down into water; the water will not enter it even though it be entirely immersed: so that it is manifest that the air, being matter, and having itself filled all the space in the vessel, does not allow the water to enter. Now, if we bore the bottom of the vessel, the water will enter through the mouth, but the air will escape through the hole … Hence it must be*

assumed that the air is matter. The air when set in motion becomes wind (for wind is nothing else but air in motion), and if, when the bottom of the vessel has been pierced and the water is entering, we place the hand over the hole, we shall feel the wind escaping from the vessel … This movement of the air, however, is not everywhere of uniform velocity: it is more violent in the neighbourhood of the exhalation, where the motion began" (Pneumatica, Treatise, transl. B. Woodcroft).

Hero was able to convert his theoretical knowledge to technological inventions. Thus, he describes in his writings numerous devices and mechanisms he invented, among which the simplest is the siphon and the most famous is the steam engine (or turbine), the first recorded engine exploiting the steam power, which was created almost two millennia before the industrial revolution.

CONCLUSION

Technological applications aiming at the exploitation of the natural sources appear in all ancient civilizations. The unique phenomenon in the ancient Greek civilization is that technological needs triggered physical explanations of natural phenomena, thus enabling the foundation of philosophy and science. Among these, the study of hydrometeorological phenomena had a major role. Many of the theories developed in the course of ancient Greek civilization are erroneous according to modern knowledge. However, there are many impressive elements in Greek exegeses and interpretations of various hydrometeorological processes, such as the evaporation and condensation of vapour, the creation of clouds, hail, snow and rainfall and the evolution of hydrological cycle. Naturally, at the latest stage of this civilization, the Hellenistic period, the theories were more advanced, closer to the modern sense of science, and reveal better understanding of physics.

Similar to modern times, the formulation of scientific theories needed courage in the antiquity, too. As pointed out by Plutarch (c. 46- 127):

> *"Anaxagoras was the first to put in writing, most clearly and most courageously of all men, the explanation of the moon's illumination and darkness ... For in those days they refused to tolerate the physicists and stargazers, as they were called, who presumed to fritter away the deity into unreasoning causes, blind forces, and necessary properties. Thus Protagoras was exiled, and Anaxagoras was imprisoned and with difficulty saved by Pericles" (Plutarch, De Placitis Philosophorum; quoted from I. Velikovsky, Anaxagoras, http://www.varchive.org/ce/).*

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