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Aristotle's Μετεωρολογικά*: Meteorology Then and Now* by Anastasios A. Tsonis and Christos Zerefos

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Aristotle's *Meteorologica* is one of the least studied of Aristotle's major works, and scholars who do study it often concentrate on its logical and theoretical aspects rather than on the empirical science contained in it. The two authors of this study are professional meteorologists from Greece: Anastasios Tsonis, emeritus distinguished professor in the Department of Mathematical Sciences at the University of Wisconsin-Milwaukee, and Christos Zerefos, head of the Research Centre for Atmospheric Physics and Climatology at the Academy of Athens and professor of atmospheric physics at the Universities of Athens and Thessaloniki. They are interested in Aristotle's work as a contribution to science and not just as an essay in the logic of scientific inquiry. This book thus fills a gap in the resources available for the study of Aristotle's *Meteorologica*. I shall provide an overview of the book and then offer a critical assessment of it.

In a brief prolegomenon, the authors give an overview of the contents of the *Meteorologica*, which includes subjects distinct from what we would call meteorology today, including discussions of geology, oceanography, astronomy, and chemistry. They promise to limit themselves to meteorological topics, appropriately. They note that they have consulted one English translation, the revised Oxford translation [Barnes 1984], and one modern Greek translation; they offer their own translation of passages to be discussed, which they apologize for in case the rendering seems too "exotic", in keeping with

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the style of Aristotle. They then offer a brief discussion of the life of Aristotle and the transmission of his works. They turn to the *Meteorologica* itself, going through the four component books of the treatise (originally papyrus rolls) one by one. (They designate the books A, B, C, and D rather than, as would be more conventional, using either the first four letters of the Greek alphabet or roman numerals.) The book concludes with three appendices and a brief index.

In the body of the book, the authors begin by providing an overview of the topics that Aristotle covers in the given book, then talk about "Meteorology Now, Part *N*" (i.e., in 21st-century science), and then go back to compare and assess Aristotle's views in light of modern science (under the heading "Back to Aristotle's *Meteorologica*"). This tripartite scheme is a bit formulaic, but it does make it easy to keep track of which theory we are dealing with and in what capacity. In the first chapter, on book A, the authors spend some time explaining Aristotle's cosmology [9–19], which forms the framework within which his theory of atmospheric phenomena occurs, as is appropriate to provide the necessary background for his theorizing. Throughout, the text is amply illustrated with figures representing everything from cloud formation to cosmography. The sections of overview of a given book of the *Meteorologica*, the relevant modern science on the subject, and the comparison of Aristotelian and modern explanations typically conclude with a numbered list of points summarizing the results.

In this exposition, the "Meteorology Now" sections are often lengthy and detailed, providing a reliable and informative presentation of the state of the art of modern weather theory. The treatments of Aristotle sometimes include lengthy translations by the authors of passages from the relevant books of the *Meteorologica* and generally follow the order of Aristotle's exposition in each given book. At times, however, the amount of material on Aristotle is dwarfed by the scientific exposition so that we get more of how the atmosphere works than about how Aristotle understands it. In principle, the structure of the work makes sense: we need to know what Aristotle says about different aspects of the weather; we need to know what modern science has to say about the relevant phenomena; and we need to reconcile the two, at which point the modern science provides a commentary and basis of assessment of Aristotle's science. Unlike physics and chemistry, especially in the theories of modern science, meteorology deals with phenomena that are observable, even if they are sometimes distant from human observers,

in a realm, the atmosphere, where people actually live. In this way, meteorology can provide a kind of test case for the application of more recondite principles of physics and chemistry.

One area in which modern science is especially helpful is in explaining the movement of air around the planet, discussed in a limited way by Aristotle in his account of winds. Hot air expands and tends to rise, while cold air contracts and tends to fall. Hot air from the tropics rises and moves to replace descending cold air at the poles, creating a northward migration of warm air in the upper troposphere (the portion of the atmosphere closest to the Earth) in the northern hemisphere, and a corresponding migration of cold air southward along the surface. This process, called Hadley circulation [28–29], which is driven by the rotation of the Earth, further breaks up into three cells producing zones of prevailing winds, roughly corresponding to the tropics, the temperate zone, and the polar zone. There is a corresponding circulation in the southern hemisphere [67–68].

The present work provides the reader with the tools of modern science for evaluating Aristotle's ancient science. These tools are too often neglected in historical and philosophical studies of Aristotle's meteorology. How successful is the application of modern science to ancient theory? I have some worries here, based not on the modern science but on the ancient theory and how it is handled. First, a quibble about the passages from Aristotle. Virtually every scholarly translation and commentary on Aristotle makes use of Bekker pages, the system of citing passages by the page, column, and lines of the corresponding passage in the edition of 1831 by Immanuel Bekker (as I shall in this review). In the present work, however, passages are identified as coming from a given book and chapter of the *Meteorologica* only. This is disappointing.

Another small worry: at times the authors' reliance on modern Greek seems to get in the way. Some Aristotelian technical terms are given in modern rather than ancient Greek, which most scholarly readers are likely to take as misprints (e.g., «αναθυμιαση» [no accent] for «ἀναθυμίασις» [1]), while some etymologies of Greek words are misleading rather than helpful (e.g., "troposphere" from «τρόπος», allegedly in the sense of "behavior" [20]).[1]

[1] This 20th-century coinage is usually said by lexicographers to derive from «τρόπος», which is taken to mean "turning", but «τρόπος» does not occur in this sense. It seems better to take it from the cognate «τροπή» (turning). The rules of Greek word formation allow this lexeme to be represented by the stem «τρόπ-». Cf. «δικόγραφος» from «δίκη».

Furthermore, some phonetic transcriptions will be confusing, based as they are on modern, not ancient, Greek pronunciation (e.g., "trepome" for «τρέπομαι» [59]). One wonders, too, at the wisdom of giving the second word of the book's title in Greek, instead of using the Latin "Meteorologica". In a book that is fairly obviously addressed to a nonspecialist audience—after translating a passage of Aristotle, the authors say, "If this passage sounds like ancient Greek, you are not alone!" [11]—it seems odd to use Greek in the title. What is the lay reader to make of this?

More worrisome are some questions of interpretation. The authors spend considerable time expounding the water cycle (or "hydrological cycle"), whereby water evaporates into the atmosphere, condenses back into water droplets, and falls to Earth as rain or some other precipitation. The authors' account of the cycle as understood by modern meteorology is impeccable. But what about Aristotle's interpretation of the phenomena in question? For Aristotle, water does not just undergo a change of state from liquid water to gaseous water vapor: it turns into a new substance, namely, air. There are four elements: earth, water, air, and fire, each of which has its own essence (earth is cold and dry; water, cold and moist; air, warm and moist; and fire, warm and dry [12]). But these stuffs are not permanent existences: if you heat water, the water goes from cold to warm, and thus perishes and is reborn as a new "substance" or entity, air, with a different essence. (Perhaps it would be best not to call these four basic or "simple" substances "elements", as Aristotle is aware, sometimes referring to them as "so-called elements";[2] in any case, even the term "element" proves to be ambiguous and potentially misleading.) Thus for Aristotle, evaporation is not a mere change of state of the same substance[3] but a substantial or, if you

[2] See «τὰ καλούμενα στοιχεῖα» in *De gen. et corr*. 328b31, 329a26, *et passim*. The four elements really are unchanging elements for Empedocles, who first identified them as the basic components of reality: Diels and Kranz 1951, frr. 6; 8; 9; 17.16–20, 27–35. On the changeability of the so-called elements for Aristotle, see *De caelo* 3.6, *De gen. et corr*. 2.4.

[3] In contemporary science, there are four states or phases of matter: solid, liquid, gas, and plasma. Thus, ice is solid, water is liquid, water vapor gaseous, and so on. It would be interesting to consider Aristotle's four primary substances as phases (earth is solid, water liquid,....), but this is decidedly not Aristotle's conception. For him, the change from earth to water to air to fire is not a phase transition of the same substance but a substantial change, involving the perishing of the previous substance and a coming-to-be of the new substance.

will, chemical, change to a new entity. Condensation is similarly a chemical change in the opposite direction.

Tsonis and Zerefos understand the Aristotelian "chemistry" perfectly well: "Water and air are interchangeable [in the cycle] and one is produced from another" [13]. But when they come to expound Aristotle's water cycle, they tend to ignore the fact that for him evaporated water is no longer water. They translate the term «ἀτμίς» as "water vapour" [e.g., 16, 37], unlike most translators, who omit "water", presumably because that term would beg the question as to what ἀτμίς is. Aristotle says this about vapor:

> The moisture about it [the Earth] is evaporated by the sun's rays and the other heat from above and rises upwards…[until] the vapour (ἀτμίς) cools and condenses again as a result of the loss of heat and the height and *turns from air into water*: and having become water falls again onto the earth. The exhalation (ἀναθυμίασις) from water is vapour. [*Mete*. 1.9.346b24–32, trans. Lee 1952, 68–71, emphasis added: cf. Tsonis and Zerefos, 16]

The implication of this account is that vapor is air seen as the product of a process of exhalation or evaporation; it comes *from* water but is not itself water. Air and water are distinct substances for Aristotle, even if they are readily intertransformable; there is no such thing as water vapor (although there is a kind of in-between stuff, mist (ὁμίχλη), mentioned following the passage just cited [b33–35], complicating the picture further).

The point is that, however similar Aristotle's view of the phenomena is to our modern view, with evaporation, updraft, cloud formation, and rain, the theoretical basis is fundamentally different so that if we want to remain true to Aristotle, we had better not be too quick to apply modern scientific concepts and terminology to his account. Aristotle has a water cycle like ours, but it has a significantly different theoretical basis than our cycle. It is, as philosopher of science Thomas Kuhn would say, *incommensurable* with our cycle.

And, while we are at it, Aristotle's atmosphere is not our atmosphere. His atmosphere is a mixture of ἀήρ, a chemical element or primary constituent of the world, and the dry exhalation, also known as fire, another primary constituent, while in modern theory our atmosphere is a mixture of 78% nitrogen, 21% oxygen (N_2 and O_2, respectively), that is, molecules composed of atoms, and other trace gases that include water vapor and carbon dioxide (H_2O and CO_2, respectively), both compounds [21].

Another major point that Tsonis and Zerefos make is that Aristotle already has a theory of climate change as part of his meteorology and cosmology. They say:

> Chapter 14 [of book 1] touches peripherally on what today we call climate change. Very few know that Aristotle acted not only as a philosopher but at

> the same time he went far away from supernatural explanations and beyond superstition. In fact, he was among the first scientists to try to present and hint on climate change both from a global and a regional perspective. His insights on this subject, we believe[,] are stunning. [56]

The authors provide a lengthy excerpt from the *Meteorologica*, indeed almost the whole of book 1, chapter 14 [351a19–353a26] as evidence of Aristotle's views on climate change [56–59]. They point out the similarity of cycles posited by Aristotle to the "geological cycles" proposed by some modern climatologists [60]. Much of this material, including the long excerpt, is repeated in appendix 2 [111–117], with some expansion and emphasis on Aristotle's relevance to modern concerns.

It is indeed important to recognize Aristotle's views on climate change and his potential relevance to modern concerns about global warming. But we should not overlook the context in which Aristotle presents his theory of climate change. He recognizes periods of catastrophic changes in weather patterns, including great floods and conflagrations [see Rose 1886, fr. 25]. According to Aristotle, these disasters and others in the prehistoric past led to the collapse of civilization and extended dark ages, after which humans had to reinvent civilization, which is only now (in Aristotle's time) reaching its acme (with some help from Aristotle's enlightened theories).[4] No matter how grim the results of past climate changes, he did not see humans as responsible for those changes. And, since for him the cosmos was everlasting, along with the heavenly bodies, the Earth, and every biological species on Earth, there have been no extinctions and no emergence of new species.[5] The species, presumably, were stressed by the disasters, but they have rebounded every time. Aristotle has a cyclical climatology and anthropology but a static cosmology and biology. None of this is mentioned by the authors, who are keen to present Aristotle as a forerunner of contemporary theories of climate change.

In evaluating Aristotle's meteorology, the authors say:

> Had Aristotle come up with the concept of atmospheric pressure, and if he had any evidence that the Earth is not the centre of the Universe, but it spins on itself while it revolves around the Sun, the state of science would have been advanced much earlier. [69: cf. 107]

[4] *Meta*. 1074b1–14; *Pol*. 1329b25–33; Rose 1886, fr. 53. Cf. also Plato *Tim*. 21e–23b, mentioning the flood of Deucalion, the Greek Noah, and the fire of Phaethon; *Legg*. 3.677a–678b.

[5] *De gen. et corr*. 731b24–732a1, with Lennox 1985.

This is no doubt true, but the statement seems naïve in light of decades of studies in the history of science that show how difficult it is for even the most brilliant minds of a given era to see things from a new perspective, especially if that involves grasping a whole new worldview [see esp. Kuhn 1962]. Aristotle's perspective is firmly anchored in a central and immoveable Earth, in a cosmos made up of five fundamental constituents, two of which are heavy, two of which are light, and one of which moves in a circle. He offers a powerful and mostly self-consistent physics and "chemistry" that provide elegant accounts of meteorological phenomena in the absence of modern conceptions, such as those of thermodynamics and electricity. There are, I believe, some less obvious issues in Aristotle's meteorological theory, such as, How does the Sun, which obviously generates heat, do so in the sphere of the fifth element, which has nothing to do with fire? Why is there a water cycle of the moist vapor and a parallel fire cycle of the dry exhalation, given that the two bodies are intertransformable?

The science of this book is stimulating. But the work suffers from a lack of competent proofreading. There are numerous typographical errors and solecisms that make the text difficult to follow in places. The authors, whose native language is not English, can be excused for lapses of idiom; but a good copy editor is still needed. Those of us who have prepared publications in foreign languages know that we need the services of a good native speaker to fix our mistakes. Moreover, the appendices are odd: appendix 1 is an English translation of Aristotle's *Ode to Virtue*; appendix 2 provides a translation of most of book 1, chapter 14 of the *Meteorologica*; and appendix 3 provides the ancient Greek text and a modern Greek translation of the *Ode to Virtue*. Aristotle's poetic composition is of dubious relevance and, in any case, should occupy only one appendix. The translation in appendix 2 is redundant, given that it has already been quoted in the body of the book. It would have been better to offer an abbreviated version or paraphrase in the body and to refer the reader to an appendix if that was desired. Again, the book seems to want editorial intervention.

Despite some problems, the present book does provide a firm foundation in contemporary meteorological science for the student of Aristotle's *Meteorologica*. This book fulfills a definite need and offers an authoritative scientific background for the study of Aristotle's weather theory.

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