8 Meteorology

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Greco-Roman meteorology will be described in four overlapping developments. In the archaic period, astro-meteorological calendars were written down, and one appears in Hesiod's *Works and Days*; such calendars or almanacs originated thousands of years earlier in Mesopotamia.[1] In the second development, also in the archaic period, the pioneers of prose writing began writing speculative naturalistic explanations of meteorological phenomena: Anaximander, followed by Heraclitus, Anaxagoras, and others. When Aristotle in the fourth century BCE mentions the 'inquiry that all our predecessors have been calling meteorology' (338a26), he is referring to these writers. In the third development, the first two enterprises were combined: empirical data collection about meteorological phenomena began to be married to naturalistic theoretical explanation. This innovation was prompted by Democritus and synthesised in its most influential form by Aristotle. At this point more sophisticated techniques of both short-term weather forecasting and long-term speculation about global climate change were also developed. In the fourth development, the wider implications of the naturalistic explanation of meteorological phenomena were contested. The views of 'meteorologists' had been controversial since the archaic period because they were perceived, and sometimes intended, to displace the divine prerogatives and undermine traditional religion. These controversies intensified throughout the classical and Hellenistic periods.

Aristotle established meteorology as a science. Whereas his predecessors had discussed meteorology in all-encompassing cosmological works, he conducted a systematic investigation devoted entirely to meteorological phenomena, entitled *Meteorology* (*Meteôrologikôn*).[2] Although he agreed that 'meteorology'[3] was continuous with natural inquiry, and although some of his contemporaries used the term interchangeably with 'astronomy', Aristotle carefully differentiated the subject from related ones,[4] and described its unique methodological features. He specified in his logical works how the practical-empirical and theoretical-explanatory parts of meteorological inquiry could be related to one another as sub-alternate sciences so as to produce scientific demonstrations (*apodexeis*) and causal explanations (*aitiai*). And in the *Meteorology* he offered mathematical explanations of optical meteorological phenomena such as halos and rainbows that conform to his methodological standards. Aristotle also methodically collected the meteorological views of his predecessors; meteorology comprises a significant part of doxographical literature.[5] Finally, Aristotle's meteorology was immensely influential on the subsequent development of the science, beginning in the Hellenistic era, when his views were adapted even by competing schools of Epicureans and Stoics. Later meteorology was mostly written as commentary on Aristotle's *Meteorology* well into the early modern period.[6] As an influential historian of meteorology stated: 'the system established by Aristotle remained for nearly two thousand years the standard textbook of our science'.[7]

ASTRO-METEOROLOGY AND WEATHER SIGNS

In the astro-meteorological almanac in *Works and Days*, Hesiod structures his advice on farming and sailing according to risings and settings of prominent heavenly bodies throughout the solar year, beginning with the harvest at the Pleiades' rising (in early May); ploughing is supposed to begin when the Pleiades set (in early November). In between is 'the season of toilsome summer … men are weakest, for Sirius parches their head and knees, and their skin is dry from the heat'.[8] Hesiod here refers to the position (in mid-July) of Sirius, the brightest star in the night sky, also known as the Dog-star.[9] He recommends cutting wood around early October: 'when the strength of the sharp sun ceases from its sweaty heat, as mighty Zeus sends the autumn rain, and a mortal's skin changes with great relief – for that is when the star Sirius goes during the day only briefly above the heads of death-nurtured humans'.[10] Under Sirius, the weather is hot and dry – Hesiod almost seems to imply that the position of the star is the cause of the dryness and heat. When Sirius changes position, the heat dies down, then Zeus causes rain.

More prosaic calendars, called *parapêgmata*, were originally inscribed on stones and erected as monuments in public places as instruments for tracking cyclical phenomena by means of a movable peg; specimens dating back to the fifth century BCE survive.[11] Literary *parapêgmata* were written on paper. The following excerpts are from the *parapêgma* attributed to Geminus.[12]

> The Sun traverses *Cancer* in thirty-one days. The 1st day: According to Callippus Cancer begins to rise, summer solstice, and there is a change in the weather … 27th: … According to Eudoxus Sirius rises in the morning, and for the next fifty-five days the Etesian winds blow …
>
> The Sun traverses *Leo* in thirty-one days. On the 1st day: According to Euctemon Sirius is visible, stifling heat follows, there is a change in the weather …
>
> The Sun traverses *Scorpio* in thirty days … On the 4th day: According to Democritus, the Pleides set at the same time as daybreak, wintery winds for the most part, and cold, there is now frost, it tends to be wintery, trees really begin to lose their leaves.

As in Hesiod, the rising of Sirius is associated with summer and hot, dry weather. But the accounting is more specific and detailed, and covers a greater variety of phenomena, and authorities are cited, like in a modern scientific paper.

Democritus is one of the most frequently cited authors in literary *parapêgmata*.[13] His predictions are usually accompanied by the qualifying expressions 'for the most part' (*hôs ta polla*) and 'tends to' (*philei*) (as in the above quotation), whereas the other authorities simply assert (as Hesiod did) that storms, winds, etc. do occur at the indicated time. These qualifiers indicate awareness of variation from the annual norm, and thus represent a more advanced concept of meteorology than is evident in the astro-meteorological *parapêgmata* based on fixed points in the solar year.

Pliny the Elder in general follows Hesiod in structuring recommendations for farmers according to the solar year, but he noted that 'Democritus thinks that the weather through the winter will be the same as it was on the shortest day and the three days that surround it, and he thinks so too in regard to the summer and the weather at the summer solstice.'[14] Democritus developed techniques of short-term weather forecasting, even for the weather of the next few days or hours,[15] and was reputed to have been successful.[16] Pliny reports that 'Democritus urged his brother Damasios, who was reaping his harvest on a very hot day, to stop harvesting and to gather what he had already cut and put it under cover. A few hours later his forecast was confirmed by a fierce rainstorm.'[17] Although his interest in these phenomena may have been largely theoretical, it may also have had other practical applications in addition to farming,[18] including medicine.[19]

These developments influenced later literature on weather signs. The work *On Signs*,[20] usually attributed to Theophrastus, was probably based on a work by Aristotle of the same title, which was in turn probably based on a lost work of Democritus.[21] In it certain meteorological phenomena are described as indicated by various signs (stars, sun, moon, comets, thunder, lightning, rainbows, halos, insects, birds, spiders, worms, frogs, and mammals). Within each section (in the order: rain, wind, storms, fair weather), the signs are given as in the following: 'Often (*hôs epi to polu*), an iridescent halo shining either around or through a lamp is a sign of rain from the south'; 'If it is not rainy at <the rising of> Sirius or Arktouros, there will be, for the most part (*hôs epi to polu*), rain or wind at the time of the <autumnal> equinox'.[22] The general formula is:

> If there is A <sign>, then ('for the most part') there will be B <signified>.

It is notable that *On Signs* is arranged according to event signified, not according to sign, which would be more useful for weather forecasting. This indicates a more theoretical purpose for collecting data on correlated meteorological phenomena than is evident in the astro-meteorology of Hesiod and the *parapêgmata*.[23]

METEOROLOGY AND THE INQUIRY INTO NATURE

Hesiod frequently describes meteorological events as intentional acts of the gods.

> Sailing is in good season … for fifty days after the solstice, when the summer goes to its end … You will not wreck your boat then nor will the sea drown your men – so long as Poseidon, the earth-shaker, or Zeus, king of the immortals, does not wish to destroy them; for in these gods is the fulfillment, both of good and evil alike. That is when breezes are easy to distinguish and the sea is painless: at that time entrust your swift boat confidently to the winds, drag it down to the sea and put all your cargo into it. But make haste to sail back home again as quickly as possible, and do not wait for the new wine and autumn rain and the approaching winter and the terrible blasts of Notus, which stirs up the sea, accompanying Zeus' heavy autumn rain, and makes the sea difficult.[24]

Homer too had held the gods responsible for meteorological events.[25] About a century after Hesiod, in the first prose books written in Greek, Anaximander began offering naturalistic explanations of the same meteorological phenomena. For example:

> Winds occur when the finest vapors of the air are separated off and when they are set in motion by congregation. Rain occurs from the exhalation that issues upwards from the things beneath the sun, and lightning whenever wind breaks out and cleaves the clouds.[26]

Anaximander held that the earth was originally covered by water; the sun caused most of the moisture to evaporate away; the remaining salty part is the sea. The evaporation causes winds; winds enclosed and compressed by clouds eventually tear out, causing explosions, thunder and lightning. The model of the sun acting on the moist surface of the earth so as to cause a 'vapour' (*atmis*) or 'exhalation' (*anathumiasis*) was immediately developed by Anaximenes[27] and Heraclitus as the basis for explanation of all meteorological phenomena.[28] Heraclitus distinguished two exhalations, relating them to a series of elemental transmutations of fire, a view later adapted by Aristotle.[29]

By the mid-sixth century BCE Ionians were investigating every variety of meteorological phenomena mentioned in the epics, and had already developed competing explanations. Anaximander was also 'the first to depict the inhabited earth on a chart'.[30] He conceived not only of the shape of the entire earth, but also its relation to the stars, sun, and moon, and realised that earth has antipodes. His outlook was global and he offered his explanations in the context of a comprehensive cosmogony, zoogony, and anthropogony. The resulting 'naturalising' picture is as different from the 'theologising' one of Homer and Hesiod as prose is different from poetry.[31] Nowhere is this difference more vivid than with respect to meteorological phenomena.

Against the background of astro-meteorology and *parapêgmata*, what stands out most in Anaximander and his successors is the concern to explain the phenomena. Against the background of Homer and Hesiod, what stands out is the naturalistic and non-theological perspective of the explanations.[32]

There is little evidence about Anaximander's, Anaximenes', or Heraclitus' knowledge of astro-meteorology or practical interests in weather signs. It is only with Democritus that we have clear evidence of interest in both the empirical-practical and explanatory-theoretical dimensions of meteorology.[33] It is also with Democritus that the replacement of intentional actions of the gods with natural causal explanations becomes an explicit programme.

Democritus also expanded the reach of meteorology to include both shorter- and longer-term phenomena. We already saw that Democritus developed techniques of short-term weather forecasting. He also speculated about changes in the global environment, asserting that the earth is warming up and drying out, causing overall sea levels to decrease.[34] Such speculation was related to Democritus' all-embracing physical theory. A papyrus records his view on how the sea came into existence:

> in liquids, as in the universe as a whole, like is sorted out together with like as a residue of putrification and it is by this process of congregation of like elements that the sea and other salty substances are formed … Democritus says that the most astonishing and paradoxical works of nature come about in the same way, as there are not many differences among the elements composing the earth.[35]

We see a similar employment of explanatory analogy in his explanation of wind:

> Democritus says that when there are many particles, which he calls atoms, in a confined empty space, the result is wind; on the other hand, the air is in a peaceful, still state when there are few particles in a large empty space. In a marketplace or street, so long as there are few people, one can walk without interference, but when a crowd converges in a confined area, there is quarrelling as people bump into each other. In exactly the same way, in the space surrounding us, when many particles have filled a small region, inevitably they bump into each other, push forward and get pushed back, become entwined and get forced together.[36]

It is characteristic of Democritus to explain large-scale phenomena by analogy to small-scale ones. He also pioneered giving multiple explanations of meteorological phenomena, for example, earthquakes.[37] Such explanations were designed to remove the terror of natural phenomena caused by the belief that gods inflict them on humans as punishment.[38] Democritus claimed that astonishment at meteorological phenomena caused belief in gods:

> Some people think that we arrived at the idea of gods from the remarkable things that happen in the world. Democritus … says that the people of ancient times were frightened by happenings in the heavens such as thunder, lightning, thunderbolts, conjunctions of stars, and eclipses of the sun and moon, and thought that they were caused by the gods.[39]

Democritus offered to remove their astonishment and fear by explaining all such phenomena according to naturalistic explanations, thus obviating the perception of divine intervention.

THE BACKLASH AGAINST METEOROLOGY

In a lost play by Euripides, the trickster Sisyphus claims that a 'shrewd and clever man invented for mortals a fear of the gods' and

> placed them where they might make the greatest impression upon human beings … where he knew that fears come to mortals … from the vault on high, where they beheld the shafts of lightning and fearful blows of thunder and star-filled gleam of heaven … parade-ground for the brilliant mass of the sun and source of rainfall moistening the earth below.[40]

The speech evidently represents the views not of Euripides himself, but of naturalists like Anaximander and Democritus. Popular depictions of 'meteorologists' conflated them with healers and itinerant priests who claimed possession of wisdom unavailable through traditional state religion.[41] Aristophanes' *Clouds*, performed in 423 BCE, capitalises on this conflation in a hilarious way. Strepsiades, desperate to relieve himself of debt, visits the 'Thinkery' where 'meteoro-sophists' offer to teach how to make the worse argument defeat the better; he encounters 'Socrates' suspended up high in a basket making 'accurate discoveries about meteorological phenomena'.[42] 'Socrates' is portrayed worshipping meteorological phenomena as if they were gods: 'O Lord and Master; measureless Air, who hold the earth aloft, and you, shining Empyrean, and ye Clouds, awesome goddesses of thunder and lightning.'[43] He is even portrayed denying the existence of traditional gods, 'disproving' their existence by replacing Zeus' rain and thunder with naturalistic explanations.[44]

Plato worked to deflect such views from Socrates. In his *Apology*, Socrates is portrayed refuting the accusation that he is 'a student of all the meteors and things below the earth' (18b7–8). Negative attitudes about 'meteorologists' persisted throughout antiquity.[45] Plato was sensitive to how they affected the perception of philosophy; his Socrates complains that 'they mention accusations available against all philosophers, about the meteors and things below the earth, about not believing in the gods, and about making the worse argument the stronger' (23d5–7). In the *Phaedo* Socrates claims that only in his youth did he dabble in meteorology, a passing interest he lost when disappointed by Anaxagoras' failure to explain how the phenomena are caused by an intelligent mind (*Phd.* 96a–e). Aristotle too reports that Socrates (in contrast to Democritus) turned his attention away from natural phenomena and towards political affairs (*Parts of Animals* 642a24–31; *Metaphysics* 1078b17–23).

Aristophanes falsely portrayed Socrates as a naturalistic philosopher to brilliant comedic effect, but the meteorological explanations and characters he devised are closely modelled on the kind of explanations found in the doxography of early Greek meteorology, for example in 'Socrates'' explanation of how clouds cause thunder: 'when they fill up with lots of water and are forced to drift by necessity (*di' anagkên*) sagging down with rain, then run into one another, and become sodden, they explode and crash' (376–8). Diogenes of Apollonia (ca. 425 BCE), a contemporary of Aristophanes, had made 'air' a leading cosmological principle, and apparently wrote a work dedicated to meteorology.[46] Anaxagoras and Empedocles were even more famous philosophers of this ilk, reputed for their ability to predict the weather.[47]

Plato mocks 'meteorologists' like Anaxagoras, and politicians who associate with them, like Pericles, in the *Phaedrus* (270a). In the *Timaeus*, he elaborates intelligent-design creationism, but conspicuously leaves out central meteorological topics such as thunder and lightning, treating only hail and frost extremely briefly (59de), in a 'diversion' from 'the things that always are, deriving instead a carefree pleasure from surveying likely accounts about becoming'.[48] Later, he harshly condemns 'meteorologists', describing their devolution in his comedic reincarnation scheme: 'Birds as a kind are the products of a transformation … They descended from innocent but simpleminded men, men who were meteorologists (*meteôrologikôn*), and who in their naivety believed that the most reliable demonstrations concerning those things could be based upon visual observation.'[49] Plato's antipathy to meteorology was thus caused not only by the longstanding association of meteorology with irreligious naturalism, but more specifically by the necessary dependence of meteorology on empirical methods.

ARISTOTLE'S *METEOROLOGY*

Plato's antipathy towards empirical science in general and meteorology specifically stands in stark contrast to Aristotle. In the *Posterior*

Analytics Aristotle points out that the phenomena identified by the empirical sciences can be explained by mathematical sciences.

> It is for the empirical scientists to know the fact, and for the mathematical scientists to know the reason why; for the latter have the demonstrations of the causes (*tôn aitiôn tas apodeixis*), and often the mathematical scientists do not know the fact, just as those who study universals often do not know some of the particulars because of lack of observation … Related to optics as this is related to geometry, there is another science, that of the Iris. Here it is for the natural scientists to know the fact, and for the students of optics (either of optics *simpliciter* or of mathematical optics) to know the reason why.[50]

'Empirical scientists', then, state facts about Iris phenomena (e.g. halo or rainbow),[51] while 'mathematical scientists' provide the explanations. This expression 'empirical scientists' is interesting because earlier in the same work Aristotle lays down stringent regulations for demonstration according to which mere observations of empirical facts would be considered insufficient for scientific knowledge. In 1.3 he holds that scientific knowledge can be expressed in the form of syllogisms which can be expressed in the following generic form:

> If (1) A <major term> of every B <middle term>, [Major Premise] and if (2) B of every C <minor term>, [Minor Premise] then (3) A of every C. [Conclusion]

Aristotle's explanatory syllogisms are more complex than the simple weather sign formula: 'If there is A, then (for the most part) there will be B.' With Aristotle's syllogisms we are dealing with not one but two conditional propositions, as well as a third proposition (the conclusion) necessitated by them; and the propositions include three terms, not just two.

In the context of demonstrations involving mixed 'empirical' and 'theoretical' sciences, the empirical sciences are placed 'under' the theoretical ones in the technical sense of explanatory sub-alternation. The conclusion, which is the proposition stating a fact observed by an empirical science, is demonstrated by means of propositions from explanatory mathematical sciences.

For example, consider Aristotle's explanation of the halo. Empirical meteorology identifies the fact that the halo always appears as a full circle around a luminous body like the sun or moon. Another science, which turns out to be a mixed mathematical-physical science called 'mathematical optics', in turn explains these facts by supplying the cause for the phenomena. The explanation of the halo phenomenon is that in the clouds 'tiny and uniform' particles (ice crystals) are suspended and act as mirrors which reflect (prisms which refract, actually) sight-stream to (light from, actually) a heavenly body at a constant angle from a viewer, so that every particle at a certain angular distance (e.g. 22°) becomes illuminated, producing the *appearance* of a complete circle around the moon or sun. Optics thus provides the reason for the phenomena observed in the empirical science of meteorology. Optics is in turn sub-alternate to geometry, which supplies the immediate principle on which explanations in meteorological optics ultimately depend. Consider the following syllogism.

> If (1) a circle is attributable to every figure with limits all equidistant from a single point; and if (2) a figure with limits all equidistant from a single point is attributable to every light reflected by tiny, uniform mirrors; then (3) a circle is attributable to every light reflected by tiny, uniform mirrors.

The major premise is a geometric definition of a circle. The syllogism gives a geometric explanation of the optical theorem stated in the conclusion. This conclusion can in turn be used as the major premise in another syllogism explaining an empirical fact.

> If (3) a circle is attributable to every light reflected by tiny, uniform mirrors; and if (4) a light reflected by tiny, uniform mirrors is attributable to every halo; then (5) a circle is attributable to every halo.

Thus the empirical fact about the halo, that it is circular, is explained on the basis of material and moving causes (reflection of sight-streams by mirrors), and a formal cause (the geometrical definition of a circle). Aristotle's explanation of the halo in *Meteorology* 3.2–3 thus conforms to his strict account of scientific demonstration in the *Posterior Analytics* (where, as we saw, geometry, optics, and Iris phenomena were instanced as a paradigm of scientific sub-alternation).[52]

As the example shows, true observations of 'empirical' meteorology are necessary but not sufficient for scientific knowledge, and can only contribute to knowledge when subordinated to theoretical and explanatory sciences. At the same time, mere theoretical statements about the causes of meteorological phenomena (such as those that survive in our doxography of Anaximander) do not constitute scientific knowledge in Aristotle's technical sense, since causal explanations must be wedded to empirical observations which produce the less well-known, posterior, and mediated conclusions. Otherwise the explanations would not be better known than, prior to, and explanatory of anything, that is, they would not have any subject matter for which they provide the demonstrations. Only the marriage of causal explanations to empirical data produces viable scientific knowledge. Democritus seems to have been the first to recognise this in practice; Aristotle, however, is to be credited with working it out in theory, indicating the logical form that meteorological arguments must take if they are to be scientific.

Aristotle recognises several kinds of causes as middle terms in scientific demonstrations, and in *Posterior Analytics* 2.11 he offers a meteorological example: 'if it thunders, when the fire is extinguished, it is necessary for it to sizzle and make a noise, and also (if things are as the Pythagoreans say) it has the aim of threatening those in Hades in order to make them afraid' (94b32–4). Thunder is noise in the clouds, and this is explained by recognising it in the class of 'fire-extinguishment'. Fire extinguishment in general causes a sizzling noise. Thunder can thus be explained as having a certain form, resulting in a 'formal' explanation.

What about the final cause explanation of thunder? The bizarre 'Pythagorean' explanation embodies the archaic theology of Hesiod. Both the formal and final explanations could easily be formulated as syllogisms, but are both explanatory? Aristotle does not, of course, actually hold that thunder is caused by Zeus for the purpose of terrorising sinners in Hades. What the example shows is that the one kind of explanation (the 'Pythagorean') can be replaced with another (the 'formal' explanation). It is not appropriate to explain every phenomenon by reference to every kind of cause, and many kinds of phenomena, such as eclipses, should not be explained by a final cause.[53] Cases of multiple explanation involving material and moving and formal and final causes occur regularly and as a rule in his biological writings, but in the *Meteorology* Aristotle does not offer *any* final cause explanations – the absence of teleology is conspicuous and noteworthy.[54] And in the *Physics*, Aristotle raises a famous *aporia* about such final cause explanations.

> There is an *aporia*. What prevents nature from acting neither for the sake of something nor for the better, but just as Zeus makes

> rain (*huei ho Zeus*) not in order to make the crop grow, but out of necessity? For what rises up must be cooled, and what has been cooled, having become water, falls down. This having occurred, it incidentally happens that the crop grows. And similarly, if the crop is destroyed on the threshing-floor, it does not rain for the sake of this (in order to destroy the crop), but this happened incidentally.[55]

Aristotle argues that the kind of explanation given here (and elsewhere[56]) for rainfall, which refers only to material and moving causes (in describing a kind of evaporative cycle through elemental transmutation), is not sufficient in the case of biological explanations, a point he reiterates in a methodological preface to the biological works (*Parts of Animals* 1.1). For example, absolute necessity cannot explain why teeth grow sharp in the front and broad in the back, thus reliably serving a clear purpose (biting and chewing). But rainfall is different: crops may either be helped or hurt by rain if not removed from the threshing floor when a storm happens to come, as Democritus reportedly pointed out to his brother Damasios.[57] Absolute necessity is the cause of the evaporative cycle and thus of rainfall, but its effects may be beneficial or harmful, depending on application or failure of human art. In the case of teeth, the same kind of absolute necessity cannot explain the inherent usefulness of the result, and so a different kind of necessity must be at work, which Aristotle in *Physics* 2.9 calls 'hypothetical necessity', comparing it to the kind of 'necessity' employed in art. In neither case, however, can luck be the cause:

> for teeth and all other natural things either invariably or for the most part (*hôs epi to polu*) occur in a given way, but of none of the results of luck or spontaneity is this true. And we do not think that it is the outcome of luck or concomitance that there is a lot of rain in winter, but only if there is a lot of rain under the Dog-star (*hupo kuna*); nor that that there are heat-waves under the Dog-star, but only if there is a heat-wave in winter.
>
> (Arist. *Ph.* 198b36–199a3)

In this second meteorological example in the *aporia*, Aristotle refers to the 'empirical science' of astro-meteorology which, as we saw, observes the fact that Sirius is accompanied by heatwaves. The question of how to explain such regularities is the subject of the *Meteorology*.

In the opening of *Meteorology*, Aristotle makes reference to his discussion of causes in the *Physics* when describing where meteorology fits into the overall scheme of natural science: 'We have previously spoken about the primary causes of nature, and about all natural motion … There remains a part of our investigation that all our predecessors have been calling meteorology.'[58]

> Meteorology is concerned with those incidents that are natural, though more disorderly (*ataktoteran*) than that of the first of the elements of bodies. They take place in the region nearest to the motion of the stars. Such are the Milky Way, and comets, and the movements of meteors. It studies also all the affections we may call common to air and water, and the kinds and parts of the earth and the affections of its parts. These throw light on the causes of winds and earthquakes and all the consequences the motions of these kinds and parts involve. Some of these things we are puzzled about, while others we can touch on in a way. Further, the inquiry is concerned with the falling of thunderbolts and with whirlwinds and fire-winds, and further, the recurrent affections produced in these same bodies by concretion.

By 'more disorderly than that of the first of the elements', Aristotle is referring to the motions of the stars in the 'upper' region (including the outermost 'fixed' stars, planets, sun, and the innermost celestial body, the moon), all which he takes to be composed of a special element ('ether'), the natural motion of which is circular.[59] The categorical differentiation of the area beyond the moon as immutable, eternal, and perfect stems from Pythagoreanism, and the idea that phenomena close to the earth involve 'more disordered' things is present in Plato's distinction between accounts of 'the things that always are' and 'likely accounts about becoming' (*Timaeus* 59c–e).

In the region below the moon, Aristotle holds that things are composed of four different elements and do not move in orderly circles but rather in two 'more disorderly' ways: (1) they move rectilinearly, fire and air naturally upwards away from earth as a result of their relative lightness, and water and earth downwards, towards earth, thanks to their relative heaviness; and (2) they transmute, as with air and water in the evaporative cycle. Aristotle stressed that the entire lower region is composed of these four elements, and it is 'their incidental affections' (*ta sumbainonta pathê*) that is the subject of meteorology (339a20–1). This strict differentiation between the heavenly and meteorological spheres precludes the earlier view, held by Anaximander, Heraclitus, and others, that the exhalations from the earth 'feed' the heavenly bodies, and it allowed Aristotle to envision a completely terrestrial evaporative cycle.[60]

The elements are the *material* cause of all meteorological phenomena. The motions and changes in the terrestrial region are continuous with those in the celestial, 'which therefore steer every potentiality of it' (339a22–3); in this way the movement of the celestial element is the primary *moving* cause for all motion in both regions. Most important is the movement of the sun, which melts the uppermost terrestrial region, also called the 'tinder' region (340b10–15). In this way, heat is communicated downwards to the water and earth, giving rise to two different kinds of 'exhalation' (*anathumiasis*): one arising from the water, which is 'more vaporous' and wetter; and another from the air, which is 'more windy' and drier, like smoke. The moist (*hugra*) and dry (*xera*) exhalations never exist in pure forms but are always mixed, and we name a particular exhalation on the basis of which quality predominates (2.4.359b28–32). The moist exhalation is heavier and so naturally falls below the drier and lighter, and the result is two stratified regions we identify with the regions of air and fire. The 'tinder' region, being hot and dry, frequently bursts into flame, causing several kinds of meteorological phenomena which differ according to the position and quantity of inflammable material: 'shooting stars' (1.4), aurorae (1.5),[61] comets (1.6–7), the Milky Way (1.8). The lower regions include a great intermixture of air and water, and are also affected by the sun: as the sun approaches and recedes from earth, its heat produces dissolution and composition of materials, resulting in the generation and destruction of terrestrial things, meteorological, mineralogical, and biological. The sun causes water near the surface of the earth to be heated and thus become lighter and to rise upwards, turning into air, at which point it rises further until it cools and condenses, turning back into water, becoming heavy, and falling to earth as rain (1.9.346a). The same moist exhalation causes clouds and mist (1.9), and, under certain circumstances, dew and frost (1.10), snow and hail (1.11–12). The dry exhalation is the cause of wind (2.4), and when trapped inside the earth, earthquakes (2.8), and when trapped inside a cloud, thunder (2.9); extremely large quantities of dry exhalation cause hurricanes, typhoons, fire-winds, and thunderbolts (3.1).

Aristotle insists that the exhalations are twofold (341b8). The Ionians explained meteorological phenomena by a single exhalation undergoing a linear and unidirectional transformation. Aristotle updates the theory to fit with his doctrine of elements. Although the result might not fully cohere with the theory of elements in other works, Aristotle can be interpreted as virtuously developing an independent science of meteorology with its own appropriate principles, combining the doctrine of elements and the doctrine of exhalations in a creative and influential way.[62] The fact that in so doing he elaborates his views largely by way of criticising his predecessors shows us a lot about his scientific method in general.[63] Aristotle invokes several new kinds of information to defend his views over earlier theories. For example, he brings in the results of recent astronomical research to support his view of the structure of the cosmos and the nature of the exhalations. He also brings new empirical observations, including some of his own, to support his own theories and refute those of his predecessors.[64] He also brings in recent geographical researches to support his account of rivers and terrestrial waters (1.13) and of the size and shape of the inhabited world (2.5).

The result is an astonishingly ambitious attempt to comprehend the meteorological situation of every region of the terrestrial globe and the universal history of its climatic and geographic changes (1.14). Aristotle for the first time divided the globe into five zones by reference to the heavenly sphere, a fruitful methodology for scientific climatology.[65] The term *clima*, which means 'slope', referred originally to the inclination of the earth's axis with respect to the plane of the local horizon,[66] and later to one of the zones defined by two lines of latitude of the earth, beginning with the five zones of Aristotle. The term 'climate' has become identified with the meteorological conditions prevailing in any zone of earth over a long period of time. Aristotle used his division of the earth into zones to speculate about the global climate, including the north and south poles, and he also discussed differences in climate on the basis of longitude, speculating about the extreme east or west of the 'habitable zone'. To reason about these far-off places, he employs both 'demonstrative calculation' (*logos deiknusin*), meaning mathematical techniques, and empirical 'facts known to us from journeys by sea and land' (362b15–20).

Aristotle asserts that 'one area does not remain earth, another sea, for all time, but sea replaces what was once dry land, and where there is now sea there is at another time land'.[67] The process, he insists, occurs in accordance with an order (*taxis*) and a cycle (*periodon*). He explains why the changes escape our notice: 'because the whole natural process of the earth's growth takes place by slow degrees and over periods of time which are vast compared to the lengths of our life, and whole peoples are destroyed and perish before they can record the process from beginning to end'.[68] War, disease, and famine destroy civilisations, and break others up by forcing migrations; environmental changes cause catastrophic agricultural failures that make people move or die out. People tend to settle in places that are wet and do not perceive the gradual change of the place to marsh and then desert: 'the advance is gradual and takes a long time, so that there is no record of who the first settlers were or when they came or in what state they found the land'.[69] He goes into a fair amount of detail about Egypt and Greece.

Up to this point Aristotle seems to be adapting Democritus' account, according to which the whole earth is in a process of warming and drying up, causing lowered sea levels that will eventually result in the drying up of the whole sea (352a; cf. 356b10), a view that Aristotle contemptuously dismisses in giving his own account of the origin, saltiness, and future of the sea (2.1–3). Aristotle criticises the unidirectional picture of 'global drying': 'it is true that there is an increase in the number of places that have become dry land and were formerly submerged; but the opposite is also true, for if they look they will find many places where the sea has encroached'.[70] New empirical evidence is used to confirm the existence of both desertification and sea-level rise. Again, these processes are cyclical and 'just as there is a winter among the yearly seasons, so at fixed intervals in some great period of time there is a great winter and excess of rains. This does not always happen in the same region of the earth.'[71] This is clear evidence that the ancients comprehended the reality of global and cyclical climate change (one is tempted to translate 'great winter' as 'ice age'), and the threat it poses to human civilisations through desertification and soil erosion, rising sea levels and cataclysmic flooding.

Like Democritus, Aristotle discusses long-term climate change in addition to regular seasonal variation of weather. The dry and moist exhalations cause wind and rain respectively. The sun approaching the earth draws up the moist exhalation with its heat, and receding condenses the vapour due to cold; being cold, the vapour falls downwards as rain; this, Aristotle explains, is why there is more rain in the winter than summer, and during night than daytime (359b34–360a3). A parallel process working through the dry exhalation is the cause of winds. Variation in weather (especially rain and wind) is to be explained on the basis of which exhalation predominates, the moist or the dry, and so this is also the basis of explaining drought (360a34–b5). For example, calm weather around the rise of Orion (early July) is due to the fact that the heat of the sun has scorched up and dispersed both the moist and dry exhalations, so that it neither rains nor is windy (2.5.361b14–30). Similarly,

> the Etesian winds blow after the summer solstice and the rise of the Dog-star <i.e. Sirius>; they do not blow when the sun is at its nearest nor when it is far off. They blow in the daytime and drop at night. The reason for this is that when the sun is closer it dries the earth too quickly for the exhalation to form.[72]

Here we have the official moving and material cause explanations of the data contained in astro-meteorological *parapêgmata*, and specifically of the phenomena used as an example in *Physics* 2.8. Notice that in accordance with his solution to the *aporia* about final cause explanations, Aristotle refers only to material and moving cause explanations of rainfall and heatwaves in the *Meteorology*.

All phenomena explained by exhalations are real products of the action of the sun's heat on elemental materials, but Aristotle also identifies meteorological phenomena that are actually optical illusions, including halos (3.2–3) and rainbows (3.4–5).[73] This is one of the most innovative aspects of his meteorology.[74] The explanation of the halo, discussed above, is particularly fascinating because it is a sublunary object that appears to be perfectly circular, like the objects in the celestial realm. Such phenomena were treated in archaic thought as prerogatives of the gods, as were rain, thunder, etc. Xenophanes asserted that 'Iris' (i.e. the cause of rainbows and halos) was actually a cloud.[75] Anaxagoras is credited with first recognising 'reflection' of the sight-stream as from a mirror (what turns out to be refraction of light from a prism) to be the cause of such phenomena.[76] Aristotle continues in this tradition by classifying the phenomena, outlining the outstanding problems and alternative explanations, bringing new empirical observations and new explanatory theories to bear, and by applying geometry and optics. His explanations are the earliest ones we have to be accompanied by lettered geometric diagrams, diagrams that were utilised throughout the Renaissance and early modern science, and are still utilised (though with some important modifications) in contemporary textbooks of meteorological optics.[77]

By contrast, less successful aspects of Aristotle's meteorology show him classifying two kinds of phenomena as meteorological which today we regard differently: the first are geological, namely metals and minerals; the second are astronomical. The second kind of conflation is not very surprising, given the meaning of the word 'meteor', but it is more problematic because the alternative theories available to Aristotle seem better. Aristotle was compelled by his assumptions to posit that rectilinear shooting stars (what we now call 'meteors', using the name of the genus for this species) were not celestial but rather sublunary phenomena. Aristotle was partially right about this: although meteors originate from outer space, they only become visible when falling through the earth's atmosphere where they burn up. But in the case of comets and the Milky Way the same assumptions led Aristotle astray. The Pythagoreans and others held that comets were planets that only appear at long intervals (342b29–343a1). Aristotle dismisses these views and offers two explanations of his own, recognising two different kinds of comets.[78] The explanations may cohere with the principles of Aristotle's meteorological theory, but they involve him in many absurdities, as ancient commentators pointed out.[79] Theoretical convictions about the unchanging celestial region may also have clouded Aristotle's observations (and those of other Greeks), leading to a failure to recognise astronomical phenomena like novae and supernovae.[80] The methodological remark with which Aristotle prefaces his account of comets was thus very appropriate: 'We think that we have adequately explained things unapparent to sensation if we have referred them to what is possible' (344a5–7). This remark has had considerable resonance in the philosophy of science.[81]

HELLENISTIC METEOROLOGY

Given Aristotle's statement of caution about meteorological explanation, and living in our own age of 'climate scepticism', we might expect that ancient sceptics showcased meteorology as a subject of ever-clashing dogmatisms, filled with doubts which call for suspension of judgement. In fact, we do not find them casting any doubt on astro-meteorology or meteorology whatsoever. Even the Pyrrhonian sceptic Sextus Empiricus seems to accept astro-meteorology as a valid science, contrasting it with the pseudo-science of astrology.[82]

In accordance with Aristotle's statement that we must accept 'adequate explanations' that refer to 'what is possible', meteorology ended up one of the least dogmatic and contentious areas of Hellenistic physics, at least with respect to individual explanations (not, however, in the interpretation of the theological implications of the explanations). Consider Theophrastus' treatise *Meteorology* (or *Metarsiology*).[83] Theophrastus briefly lists multiple causes for several phenomena: of thunder seven, of lightning four, of clouds two, etc. Theophrastus seems to enumerate every *possible* explanation for a given phenomenon.[84] Some have interpreted Theophrastus' work as a collection of earlier opinions (a doxography), but Theophrastus may endorse each multiple cause, either because he identifies several species of thunder, lightning, etc., or because he acknowledges an inability to demonstrate the definite cause, so that each of the explanations remains possible, none necessary.

Although for early stoicism we have only a summary of their meteorological views, Aristotle's influence is evident.[85] The fragments of Posidonius' work on meteorology indicate that his views, which were decisive for later Stoicism, were also heavily influenced by Aristotle.[86] Seneca's *Natural Questions* frequently references Aristotle, usually in agreement. This was the longest and most detailed investigation of meteorological topics surviving antiquity after Aristotle's *Meteorology*, and was the main source for meteorology in the Latin Middle Ages.[87] Seneca's explanations of particular phenomena are consistent with the foregoing tradition in being naturalistic.[88] But his overarching goal is to support a Stoical conception of the relationship between humans and gods, and to demonstrate the importance of god in creating and maintaining the cosmos.[89] Seneca thus interweaves his meteorology with theological and moralistic digressions completely alien to Aristotle.[90] Following Posidonius and earlier Stoics, Seneca accepted the validity of divination by comets and lightning.[91] These are not just vestiges of archaic views about meteorology, but a concentrated attempt to revive a theological view of the world. Whatever its other merits, however, Seneca's work did not advance meteorological science much beyond Aristotle.[92]

But advancing meteorological science was unlikely to have been the point. Like the Pseudo-Aristotelian *On the Cosmos*,[93] which may have in part been a response to Epicurus' *Letter to Pythocles*, Seneca's *Natural Questions* is probably best interpreted as a literary 'riposte' to Lucretius' Epicureanism.[94] Lucretius' didactic epic *On the Nature of Things* represents a thoroughgoing Epicurean naturalistic account of cosmology and meteorology designed to liberate us from the fear that the gods control nature. According to Epicurus, we undertake natural inquiry only to free ourselves from fear. In a letter to a disciple, he advises:[95]

> Do not suppose that there is any purpose to knowledge of meteorological phenomena (*ta meteôra*), whether considered in conjunction with other things or in their own right, other than tranquility (*ataraxia*) and firm conviction, just as with everything else … Everything goes smoothly and in conformity with the

> phenomena as long as everything is accounted for according to the multiple method, as long as we accept, reasonably, what is said with plausibility about them. But whenever one accepts one theory and rejects another that is equally consonant with the phenomena, it is clear that he deserts all genuine science and falls into myth.

For Epicurus, giving naturalistic explanations is all that is required of meteorology, so long as they are plausible enough to displace fears about the gods.[96] Furthermore, we need not (and should not) arrive at a single definitive explanation, rather we should enumerate as many explanations as are plausible and fit with our naturalistic assumptions; 'exclusion of myth is the sole condition necessary'.[97]

For Aristotle, by contrast, meteorological inquiry is undertaken not primarily for a practical purpose but for the sake of theoretical knowledge. Just because an explanation can dispel fear does not qualify it as a good explanation; Aristotle criticises both mythic accounts and naturalistic accounts that he thinks are implausible. Responding to Democritus' multiple explanations for earthquakes, Aristotle offers his own unified account in 2.8. While Aristotle explains multiple species of phenomena, e.g. several kinds of comet, and allows that there may be multiple causal factors involved in a single explanation (e.g. material and a moving causes), he does not allow multiple independent explanations of the very same phenomenon: he offers exactly one explanation for every meteorological species that he identifies, even while acknowledging that we may only find 'adequate' explanations that refer to 'what is possible'.

Epicurus, however, berates those who insist on a single explanation: 'to supply one cause for these facts, when the phenomena suggest that there are several different explanations, is the lunatic and inappropriate behavior of those who are obsessed with a pointless astronomy and of certain others who supply vain explanations, since they do not in any way liberate the divine nature from burdensome service'.[98] So, for example, Epicurus offers multiple possible explanations of comets,[99] including the Aristotelian one (that comets are an inflammation in the upper atmosphere), and one Aristotle rejects (that they are planetary phenomena, connected with the heavenly bodies). Both are offered as plausible explanations in an extremely non-committal way. Since Epicurus does not accept that the celestial and terrestrial regions are composed of fundamentally different kinds of matter, he is not constrained by Aristotle's presuppositions. In a contrasting case, Epicurus offers multiple explanations of the halo but not the (correct) one given by Aristotle, presumably because it would conflict with his own assumptions about the nature of sensation.[100] But Epicurus accepts any and every naturalistic explanation that can be adapted to his own principles.

What he does exclude are any theological or mythological explanations. Epicurus' naturalistic meteorology stands at an opposite extreme from the theology of the early archaic period, according to which gods cause meteorological phenomena in order to benefit or harm humans. In the centuries after Anaximander, both the empirical inquiry into weather signs and the theoretical explanation of meteorological phenomena were developed, and eventually integrated by Democritus. Aristotle embraced meteorology in his own physics and put the long-developing inquiry on a basis of scientific methodology. Whatever role the divine plays in his wider cosmology and metaphysics, Aristotle's meteorological explanations are purely naturalistic, and involve no teleology whatsoever. The Epicureans had merely to extend this philosophical tradition and did not feel the need to refute alternative explanations. Thus Epicurus seems to have borrowed directly from Theophrastus' work and to some extent may be following his practice of offering multiple explanations,[101] and he could also rehabilitate some earlier explanations rejected by Aristotle, beginning, of course, with those of Democritus. Some of his explanations of meteorological phenomena are unique and pioneering,[102] but Epicurus does not harp on these dogmatically.

The main purpose of Epicurean meteorology was to use naturalistic explanations to obviate the need for traditional theology. This is exactly what Lucretius aims to do in *On the Nature of Things*, and this in turn is what Seneca tried to counteract in his *Natural Questions*. The story about the origin of meteorology as a science (though perhaps not as philosophy) ends here, but the legacy of ancient meteorology continues in the fact that we still conceive of meteorology as an integrated empirical and explanatory science, and in many ways a mathematical science, one with both theoretical and practical aspects and implications. With the recent controversies over global climate change, something ancient scientists had already acknowledged as fact, we also see that the ideological controversies connected with meteorology remain an important part of the story.

NOTES

1 See Graßhoff 2010, 2012.

2 A likely date of around 341–330 BCE can be inferred from the fact that the *Meteorology* was circulated prior to certain geographical facts which suddenly became apparent during the expedition of Alexander into Asia (see Bunbury 1883, I: 401 n. 1).

3 The abstract noun '*meteorologia*' at 338a26 means 'discussion of meteors' (*ta meteôra*), and the title *Meteôrologikôn* means '<Books> of discussions of meteors'; the exact title may be due to an editor; one manuscript has just *Meteôrôn*: *Of Meteors*. The term *meteôra* (*met-êor-ôs*) is compounded from *meta-* (amid or among) + *aer-* (from *aeirô*, meaning to lift, raise, or be suspended); *ta meteôra* are literally, then, 'lofty or uplifted things'. Capelle 1912 details the gradual distinction of meteorology and atmospheric phenomena from astronomy, astrology, astrophysics, and sidereal phenomena.

4 Aristotle included many phenomena as meteorological that are now considered astronomical, such as comets, and others now considered geoscience, such as earthquakes. Aspects of meteorology eventually developed into independent specialised sciences including geography, geology, geophysics, geodesy, hydrology, oceanography, mineralogy, seismology, climatology, and atmospheric chemistry. These sciences, including meteorology, are now collectively referred to as geoscience.

5 Mansfeld 2010a, 239–41, 38–49. See also Taub 2003, 117.

6 Greek commentaries on Aristotle's *Meteorology* were written in the second century CE by Alexander of Aphrodisias, and in the sixth century by two pupils of Ammonius, Olympiodorus of Alexandria and John Philoponus. (The remains of Philoponus' commentary have recently been translated by Kupreeva 2011, 2012; Kupreeva's introductions contain excellent overviews of Aristotelian meteorology.) Syriac, Arabic, Persian, Hebrew, and Latin traditions eventually developed: Arabic translations and commentaries from the eighth to the fourteenth century CE (Lettinck 1999); Greek commentaries on the work resumed in tenth-century Byzantium, and by the eleventh century Aristotelian meteorology was transmitted into pre-modern Europe (Telelis 2012, 9–12). Translations of Aristotle's *Meteorology* and of Alexander's commentary were studied and commented on throughout the Renaissance and early modern period. See also Fritscher 2008, 536–8.

7 Hellmann 1908, 228; more recently, Mourelatos 2005, 285; Fritscher 2006, 799.

8 Hes. *Op.* 584–8, trans. Most 2007.

9 Holberg 2007.

10 Hes. *Op.* 414–19, trans. Most 2007.

11 Lehoux 2007, 12, 22.

12 Appended to his *Isagoge*, a first-century CE work; the *parapêgma* cites no author later than the third century and probably antedates the late second (Lehoux 2007, 157–8). The translation is by Lehoux 2007, 233–5.

13 Such as those of Geminus, Pliny, Ptolemy, and the Byzantine work *Geoponika*. See Lehoux 2007, 493.

14 Plin. *HN* 18.231, trans. Rackham 1950.

15 Sider 2002, 292–3, citing evidence from the Byzantine work *Geoponika*, which is ignored or mishandled by the standard collections of Democritus' fragments.

16 See also Plin. *HN* 18.273–4; a virtually identical story is told by Aristotle of Thales profiting from meteorological forecasting (*Pol*. 1.11.1259a6f; cf. Diog. Laert. 1.26; Cic., *Div*. 1.49.111.

17 Plin. *HN* 18.341, trans. Sider 2002, 296, adapted.

18 Sider 2002, 300–1.

19 Democritus' lost work *On Things Unseasonable and Seasonable* probably discussed the interplay between climate and medicine. The same topic was treated extensively in the Hippocratic treatise *On Airs, Waters, and Places*, in which it is argued that medicine has an important connection to meteorology: 'If

someone supposes all these things to belong to meteorology (*meteôrologa einai*) he will change his mind, learning that astronomy contributes no small part to medicine, but a very great part. For along with the seasons changes the diseases and the digestive organs' (2.21–26, trans. Jones 1923). Democritus very likely influenced the author of this text. See now Liewert 2015, 41–2, who presents a comprehensive study of the history of meteorological medicine.

20 Sider 2002, 293–7.

21 Sider and Brunschön 2007, 42. According to a gloss in the list of Democritus' writing, the work entitled *The Great Year, or Astronomy* included a *parapêgma*. The text reads *Megas eniautos ê Astronomiês parapêgma* (Diog. Laert. 9.48). Sider 2002, 298–9 convincingly argues that the term *parapêgma* was inserted as an editorial comment and was not part of the original title.

22 From sections 13 and 23 of *On Signs*, trans. Sider and Brunschön 2007; on the formula, see 34–5.

23 Sider and Brunschön 2007, 30, 37.

24 Hes. *Op.* 663–70, trans. Most 2007.

25 E.g. *Il.* 16.385–8; *Od.* 14.300–5.

26 Hippol. *Haer.* 1.6.7, trans. KRS. See also Aëtius 3.3.1–2; Sen. *QNat.* 2.18.

27 Arist. *Mete*. 365b6; Theophr. apud Simpl. *in Phys.* 24.22; Aëtius 3.3.2.

28 Clem. Al. *Strom*. 5.104.1–3; Diog. Laert. 9.9–10.

29 Kahn 1960, 99, 109, has thus argued that meteorology was a remarkably conservative line of inquiry stemming from the tradition of Anaximander. See also Taub 2003, 9–10; Mourelatos 2005, 285. See Wilson 2013, 54–60, for an interesting and more nuanced view of the influence of Heraclitus on Aristotle.

30 Agathemerus 1.1, trans. Kahn 1960, 82.

31 The concept of nature is absent from Homer and Hesiod. Aristotle distinguishes between those who frame accounts of the gods (*theologeô*, 983b29), like Hesiod (984b27–9), and those who frame accounts about nature (*phusiologeô*, 988b27), called 'naturalists' (*phusiologoi*, 986b14, 989b30, 990a3, 992b4). See Kahn 1960, 4 n. 1.

32 It is possible that Anaximander imbedded his naturalistic accounts in a larger cosmological framework in which justice plays a role; see the 'fragment' preserved by Simpl. *in Phys*. 24.17; Kahn 1960, 35–9.

33 On the empirical side are Democritus' contributions to the *parapêgmata* literature, mentioned above. On the explanatory side, he wrote a work *On Nature*, as well as works on 'causal explanations' (*aitiai*) of things in the 'heavens', of 'airs' (*aerioi*), of 'surfaces' (*epipedoi*, sc. of the earth), and of 'fire and things in fire'.

34 Arist., *Mete.* 356b; cf. 353b.

35 DK68A99a = *Hibeh Papyrus* 16.62, trans. Taylor 1999, 102–3.

36 Sen. *QNat* 5[4].1.2, trans. Hine 2010.

37 Arist., *Mete.* 365b1–6; Sen. *QNat* 6.20.1–4.

38 Democritus described the end of natural science as 'removal of astonishment or wonder' (*athaumastia*) and 'not being shocked' (*athambia*), not being disturbed (*ataraxia*), and not being upset (*anekplêktos*). See Cic., *Fin.* 5.8.23; Strabo 1.61; Stob. 3.5.74; Euseb., *Praep. evang.* 14.27.4.

39 DK68A75 = Sex. Emp., *Math.* 9.24, trans. Taylor, 140. See also Philodemus, *On Piety*, P.Herc. 1428, fr.16.2–11; Lucr. *DRN* 5.1186–94; Clem. Al., *Protr*. 68.5, *Strom*. 5.102.

40 The translation is by Kahn 1997, 247–8.

41 Marciano 2006.

42 Ar. *Nub*. 228, trans. Henderson 1998.
43 Ibid., 264–6, trans. Henderson 1998.
44 Ibid., 366–71.
45 For example, Lucian offers the following advice: 'The common way of life is the best, and you will act more wisely if you stop doing meteorology (*meteôrologein*) and examining ends and origins, and repudiate those wise syllogisms and consider that sort of thing nonsense' (*Menippus* 21, trans. Harmon 1961).
46 Diogenes of Apollonia is credited with a work on meteorology by Simplicius, *In Phys.* 151.20. Jones 1923 goes too far in saying that the Hippocratic *On Airs, Waters and Places* is 'derived' from Diogenes.
47 Anaxagoras (510–428) had famously demonstrated weather prediction abilities by wearing a raincoat to a public event on a sunny day during which the weather indeed turned to rain (see Sider 2002, 287–8). Empedocles (493–433) reportedly claimed to be able to control the weather, and Gorgias supposedly witnessed him doing so. Gorgias remarks on 'the meteorologists who, by removing one belief and replacing it with another belief, make things that are uncertain and unclear appear before the eyes of belief' (*Encomium to Helen* 13 = DK82B11).
48 Pl. *Ti.* 59d, trans. Zeyl 1997.
49 Pl. *Ti.* 91d6–e1, trans. Zeyl 1997, adapted.
50 *An. Post.* 1.13.78b34–79a13.
51 Iris was Zeus' messenger in the *Iliad*; rainbows and halos are her prerogative (e.g. 17.546–552, 23.198–211). Aristotle discusses Iris phenomena in *Mete.* 3.
52 See further Johnson 2009.
53 *Metaph*. 8.4.1044b8–12; see further Johnson 2005, 156.
54 Johnson 2005; Wilson 2013.
55 Arist. *Ph.* 2.8.198b16–23.
56 *An. post.* 2.12.96a2–7; Arist., *De insomniis* 3.457b31–538a1; *Mete.* 1.9.346b16–31; *Part. an*. 2.7.653a2–8; cf. *Metaph*. 6.2.1026b27–35; Johnson 2005, 150–6.
57 See above n. 17.
58 338a2–26, trans. Webster 1931, adapted. The following inset quotation continues to 339a5.
59 For an enlightening discussion of this distinction and the issues related to it, see Falcon 2005, 2–13.
60 Fritscher 2006, 798.
61 On Aristotle's successes in classifying ancient aurorae, see Stothers 1979.
62 Wilson 2013, 37–8.
63 Freeland 1990.
64 As has been shown with respect to comets and hail by Freeland 1990. Wilson 2013 builds on Freeland's point and shows this with respect to several other kinds of meteorological phenomena.
65 The theory of zones may have originated earlier, with Parmenides. According to Strabo, 'Posidonius says that Parmenides took the lead in dividing the earth into five zones' (Strabo 94). The authoritative Bunbury 1883 states: 'the division of the terrestrial globe into zones … [is] said to have originated with Parmenides, but … was developed in a more systematic form by Aristotle. It was the latter who first defined them in the sense in which they are understood by modern geographers' (Bunbury 1883, II: 227); and Tozer 1964 concurs: 'Aristotle is the first writer in whom we find an attempt to determine these limits on scientific principles' (179).

66 Neugebauer quoted in Taub 1993, 67–8.
67 351a22–5, trans. Lee 1952, adapted.
68 351b8–13, trans. Lee 1952.
69 351b25–7, trans. Lee 1952.
70 352a21–5, trans. Lee 1952.
71 352a28–32, trans. Lee 1952.
72 361b35–362a3, trans. Lee 1952.
73 See Boyer 1987; a magisterial history of the explanation of the rainbow. His discussion of Aristotle's contribution is on 41–65.
74 Taub 2003; Johnson 2009; Stothers 2009.
75 Aëtius 2.20.3.
76 Aëtius 3.5.11.
77 Johnson 2009.
78 See Freeland 1990; Wilson 2013.
79 E.g. Philoponus, *In Meteorologia* 97,22–98,13, 113,34–117,7 (citing Damascius).
80 Lloyd 1996, 164.
81 Hankinson 2013, 77–8.
82 Sext. Emp. *Math*. 5.1–2.
83 The work survives in Syriac and Arabic translation. For text, translation, and commentary, see Daiber 1992.
84 For example, he remarks that 'these are the causes by which lightning *can* occur' (2.17, trans. Daiber 1992, 262).
85 Diog. Laert. 7.151–4.
86 Kidd 1988, 84–5; 1992, 294–5; Fritscher 2008, 536. Alexander, *In Mete.* 3.3 explicitly says that Posidonius followed Aristotle's explanation of the halo.
87 Fritscher 2006, 798; 2008, 536.
88 Hine 2010, 8, 139.
89 Thom 2014, 1, 107–19.
90 Inwood 2005.
91 E.g. Sen. *QNat.* 2.32.
92 Graver 1999, 52–4; Hine 2010, 7–8. As Hine points out, the most important exception is his vigorous defence of the view that comets are planetary and not sublunary phenomena. Seneca's work remains crucial for its preservation of earlier views, and is fascinating from the literary and philosophical standpoint, as Taub 2003 (141–61), Inwood 2005, and Williams 2012 bring out well.
93 See Thom 2014.
94 Graver 1999, 51; Hine 2010, 5; Williams 2012, 9.
95 *Ep. Pyth.* 85–7, trans. Hankinson, 79–80, adapted. See also *RS* 9.
96 Taub 2009, 121.
97 *Ep. Pyth.* 104.
98 *Ep. Pyth,* 113, trans. Inwood.
99 *Ep. Pyth.* 111.
100 Namely, that sensations do not present illusions but reliable impressions that emanate directly from the surfaces of aggregate bodies such as clouds (see Johnson 2009).
101 Sedley 1998a, 125–6.
102 E.g. the formation of ice (*Ep. Pyth.* 109).

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