Introduction

Ancient Meteorology and the Transition to the Middle Ages

It is a truth universally acknowledged (at least among non-medievalists) that classical scientific knowledge died with the Roman Empire, and had to be disinterred once the Middle Ages were over. However, the history of meteorology provides an immediate challenge to this view – so much so that it was possible for an historian of ancient meteorology to write that the tradition of meteorological scholarship 'survived through late antiquity and was developed further in the medieval period, in both the Arabic and Latin traditions'.[1] This book is an attempt to fill in the missing history of meteorological discoveries and practices during the long period from the eighth century to the sixteenth. Within that, special emphasis will be placed upon the central period of the twelfth and thirteenth centuries, which saw the crystallisation of a distinctively medieval form of meteorology. This medieval meteorology was built upon foundations provided by the classical past; but it was also the beneficiary of radical and extensive advances made in the Arab Empire, and in the Islamicate world more broadly.[2] The importance of these discoveries is so great that four chapters of the book, from Chapters 3 to 6 inclusive, are dedicated to tracing their nature and impact up to ca. 1300. However, if the scale of the breakthrough represented by the new, scientific models for understanding and forecasting weather is to be understood, the state of meteorological knowledge in the early Middle Ages must also be examined; this is the task of Chapters 1 and 2. Equally, a major argument of this book will be that the demand for weather forecasts

[1] L. Taub, *Ancient Meteorology,* London & New York, Routledge, 2003, at p. 8.
[2] The term 'Islamicate' performs the valuable function of designating the diverse cultural heritage and products of the Arab Empire. As the editors of the journal *Intellectual History of the Islamicate World* (Leiden and Boston: Brill, ISSN: 2212-943X), state: 'In the medieval, late medieval and pre-modern world of Islam, Muslims, Jews and Christians constituted a unique cultural and intellectual commonality. They shared a language, Arabic (and at times Persian) … . Moreover, they often read the same books, so that a continuous, multidimensional exchange of ideas, texts, and forms of discourse was the norm'. https://brill.com/view/journals/ihiw/ihiw-overview.xml (accessed 1 November 2018).

and meteorological expertise remained high in the early modern period, even as the scientific basis on which medieval meteorology rested was falling from favour. Thus, the concluding chapters will show that no new method for producing trusted forecasts was found until the nineteenth century, and that 'medieval' meteorology had an extremely long afterlife.

As is clear from this outline, the book will necessarily take a chronological approach, tracing both the key discoveries and the scientists, astronomers, mathematicians and astrologers who made and built upon those discoveries. At first this is a story, at least in western and northern, Christian Europe, of isolated individuals who often conformed to the heroic stereotype of the lonely, marginalised or even persecuted, seeker after scientific truth. Most crossed boundaries, either political or cultural (or both) in their search for new, accurate knowledge of how the universe worked. Some undertook long travels, lasting for years, in order to gain access to texts, teachers and knowledge not available in their homelands. Others, usually Jewish scholars, were already expert in both medicine and the science of the stars, and offered this knowledge to new audiences. In many cases, however, key texts are either anonymous or clearly pseudonymous, and focusing the discussion on supposed authors would be misleading and unhelpful. Partly for that reason it is important to look also at how the new ideas and techniques were received, modified and further spread into northern Europe. Thus this book, whilst attempting to tell a clear and coherent story, will necessarily shift its focus from individuals to groups and institutions, according to the nature of the evidence and the numbers of important players involved. The discoveries of any individual, no matter how heroic, are of little long-term significance if they remain locked in isolated, unread manuscripts. Readers, users, followers and teachers are also needed if discoveries are to be accepted and put into practice; and for this to happen in medieval Europe, patrons were needed. In this regard, meteorology in the sense of scientific modelling and predicting of the weather occupied a privileged position, since access to specialist weather forecasts was highly desired by the elite – and was much less open to criticism than the desire for access to knowledge of future human actions.

Central to this new and compound, medieval meteorology, was the role played by the planets and stars in transmitting rays and influences from the higher levels of the universe down to the surface of the Earth. The effects of these celestial forces upon the actions of individual human beings was a matter of often-heated debate; but it was accepted as scientific fact that they could and did affect the material world. This material world included not only the Earth but the atmosphere surrounding it, up to the sphere occupied by the Moon. In other words, the region within which the interplay of these celestial forces produced the constantly modulating phenomena experienced on Earth as weather. It was an important part of the theory that these crucial rays and influences were conceived of as susceptible to mutual interaction and modification, depending upon the ever-changing spatial and geometrical relationships between the bodies emitting them. The complexity of the resulting model had the satisfying effect of providing a convincing explanation for the changeable and complex patterns of weather on the surface of the Earth. It followed from this that accurate knowledge of the courses of the planets and the positions of the stars would make true understanding of weather a real possibility. In this way, medieval meteorologists appeared to have made a highly significant, scientific advance upon classical meteorologists. The work of the latter could produce three-dimensional models of the zones of the Earth, in relation to the perceived path of the Sun around it, and could thus define concepts such as the Equator and the Tropics of Cancer and Capricorn, as well as the climatic conditions and the seasonal variations to be experienced in each zone. However, it could not produce a satisfactory means of producing detailed weather forecasts for specific dates and places. For these, only the time-honoured method of observing and interpreting weather signs, could be called upon. The importance of this breakthrough, illusory as it may have turned out to be, is hard to exaggerate.

However, the patrons of this new, medieval meteorology, were not necessarily interested in scientific knowledge for its own sake. One obvious reason for the ongoing interest of the rich and powerful was that knowledge of coming weather was especially important in what were essentially agrarian societies. As was frequently stated, for instance by Virgil in his widely copied *Georgics,* the fundamental activity of farming and food-production benefits greatly from knowledge about the weather, as also does fishing. Other areas exposed to meteorological phenomena, and of considerable political importance, were naval and military actions. The ability of societies to feed their citizens, to manage resources, and to be successful in relations with neighbours was crucially dependent upon the weather. This gave knowledge of coming weather a strong, and complex, relationship to power; and this was especially the case since the weather was held to be sometimes determined by, and always open to, divine intervention. There was inevitably a complex debate as to when extreme weather was to be understood as the result of purely natural factors, and when it should be accepted as a direct result of divine intervention. However, these two possible causes of weather events were not mutually exclusive. It was part of the theory of planetary influence upon the weather that certain combinations of planetary positions, and consequent influences, could directly produce devastating meteorological effects. What was crucial was the issue of predictability. If tempests and floods could be predicted from coming planetary interactions, then it would be a sign of ignorance, and even of superstition, to attribute them to a wrathful God. On the other hand, there was no attempt to deny that God certainly could, and sometimes did, cause meteorological events.

For Christian society, the Bible provided both clear evidence of God's role in meteorological events, and examples of ways in which knowledge of future weather could be obtained through naturally occurring signs. Extreme weather events were sometimes stated to be caused by divine anger or favour, with the punitive rains that produced Noah's Flood being a well-known example. However, God was always just, and therefore gave fair warnings. Thus, both the possibility of foreknowledge through such warnings, and the value of the accurate interpretation of signs and warnings, were equally stressed. This had the effect of making foreknowledge of unusual weather a matter of religious, as well as economic and political, significance. An example is provided by the story of Pharaoh's dreams in Genesis, chapter 41. In this sequence of dreams, visions of well-fed and then starved cattle were followed by visions of good grain followed by grain blasted by the east wind. Pharaoh and his courtiers were unable to interpret this, but Joseph understood that God was sending warning of a coming sequence of seven good years for agriculture, to be followed by seven disastrous years. The warning was heeded, preparations were made, and the land of Egypt was saved from a potentially disastrous famine. Joseph's status as intermediary between earthly and divine rulers was also confirmed.

Of course, not everyone could expect such warnings; but more ordinary knowledge and use of weather signs was confirmed in the Gospels by no less a figure than Christ.[3] Such signs gave information only for the short term, and for a restricted area; but they attested to two fundamental ideas. The first was that there is a close link between the appearance of the sky, in terms of the level and colour of light and the patterns of clouds, and weather for the coming day. The second, which follows from the first, was that the weather is governed by a system that links conditions on Earth to phenomena in the atmosphere in observable and comprehensible ways. A great, poetic statement of the extent to which God's Creation constituted a vast and interactive system was delivered in

[3] See, for instance, Matthew, 16, 2–3.

God's message to Job and his interlocutors, recounted in the Book of Job, chapters 38 and 39. This emphasised that the universe is ordered by measure, and that it operates according to divinely established rules, which keep the heavens, the stars, the Earth and the seas in their places, as well as maintaining regular units of time. Rain, snow, hail, thunder and wind are all parts of this system, and operate entirely independently of humanity. Complex but divinely governed connections between the heavens and the Earth are touched upon. Warm rains bring growth and green grass while frost brings ice, and all these phenomena are associated with the risings of the stars of the Pleiades, the movements of Arcturus, the regular appearances of the day star and evening star, and the whole order of heaven (*ordinem caeli*). This is further emphasised a little later, when questions about clouds, waters and lightning are followed by emphasis on the wisdom needed in order to know the order and harmony of heaven.

Meteorology thus had scriptural authority, even if the triumph of Christianity entailed the rejection of those classical theories that contradicted the concepts of a divine creation and a coming end of time. A sequence of patristic writers, including almost all the great founding figures, wrote exegeses of Genesis' account of the Creation, drawing upon established information from meteorology and natural philosophy in their commentaries. St Augustine wrote no fewer than five commentaries on the Creation story. Some were simply intended to disprove specific heretical arguments; but others effectively established that pagan knowledge of cosmology and meteorology, when based upon rational study of the universe, had value. Indeed, it could clearly be brought into the new, philosophical arena of biblical exposition. Meteorological knowledge is brought into play, for instance, in Book Three of Augustine's work *On the Literal Meaning of Genesis,* where information about the spheres and courses of the planets and the phases of the moon is brought together with discussion of the origins of clouds and earthly waters.[4]

This reuse and reinterpretation of classical theories and models entailed some technical problems. An important example was the much-disputed issue of how to distinguish between legitimate enquiry into celestial phenomena and their effects on Earth, on the one hand, and illegitimate claims to knowledge of future human actions, on the other. A usefully encyclopaedic, and much-consulted, source of information on the observable workings of the natural world was provided by the *Natural History* of Pliny the Elder. Pliny himself was a highly experienced veteran

[4] See *St Augustine; On Genesis,* Ed. J.E. Rotelle, Trans. E. Hill, New York, New City Press, 2002, pp. 215–250.

officer, scholar, and member of the upper echelons of Roman government and provincial administration, who had travelled widely. He died whilst attempting to observe the eruption of Vesuvius in 79 CE, and to bring some rescue to those fleeing the destruction. His survey was able to cover much of the Roman Empire, and to combine personal observations with information from witnesses and learned sources; he was still working on it at his death. It was very much wider in its range than works on theoretical meteorology. Nevertheless, it offered a store of useful quotations, from both Greek and Roman works, together with authoritative accounts of natural phenomena. In accordance with the established approach, given high status by the influential works of Aristotle and his successors, Pliny separated discussion of the celestial phenomena themselves from description of their practical effects and applications on Earth. It was also established that the celestial phenomena, being higher both literally and in their essential nature, should be dealt with first. Thus, astronomy and associated questions on the air, the winds, and the atmosphere are dealt with in Book Two of Pliny's work.[5] Significantly, more earthbound, and more localised, experiences of actual weather are dealt with together with agriculture, in Book Eighteen. Pliny is also aware of, and accepts, the Aristotelian concept of 'exhalations' as causes of mutability in material phenomena. These were held by Aristotle to play a major role in bringing about physical processes, and also had a role in causing developments in the weather.[6]

In accordance with their lower position in this hierarchical model of the workings of the universe, Pliny deals with the earthbound topics of agriculture and the farming year in the later part of his work. It is thus a section of Book Eighteen, which provides a long (and very influential) list of weather signs.[7] These are arranged in calendrical sequence and linked, as was customary in Greek as well as Roman works on the topic, to the risings and settings of named stars. Pliny is also informative as to the variations and disagreements amongst his sources of knowledge on the timings of these occurrences, in a way that both confirmed the complexity of the topic and passed on a range of ancient views to later readers.

[5] For discussion see L. Taub, *Science Writing in Greco-Roman Antiquity,* Cambridge, Cambridge University Press, 2017, and the analysis there of Pliny's work as an 'Encyclopaedia' (especially pp. 77–80).

[6] Ibid., p. 80. See also M. Wilson, *Structure and Method in Aristotle's* Meteorologica; *A More Disorderly Nature,* Cambridge, Cambridge University Press, 2013 (esp. Part 1, chapter 3, 'The exhalations' pp. 51–72).

[7] See: Pliny, *Natural History, Volume V: Books 17-19,* Trans. H. Rackham, Loeb Classical Library 371, Cambridge, Harvard University Press, 1950. Helpful context is provided by J. Healy, *Pliny the Elder on Science and Technology,* Oxford, Oxford University Press, 1999.

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Once again the Pleiades and their phases are important, something that was noted by later readers of the work, as will be seen in Chapter 1. Pliny also points out that, whilst Hesiod is clear that crops should be sown at the time of the setting of the Pleiades, and it is well-known that this is close to the autumn equinox, dates given by different authorities vary by twenty-three days.[8] Pliny theorises that the dates preferred by different writers relate to their geographical locations, but it is left to the reader to interpret the information provided. Related to this is his assertion in chapter 56 that food production, as much as navigation, depends upon knowledge of the interrelationship between the heavens and the weather. As often, Virgil is cited as authority for this.

It is also in Book Eighteen, and for the same reasons, that Pliny moves on to another complex phenomenon with a fundamental relationship to weather – that of the winds. He gives detailed discussion of the names, locations, and effects of identifiable winds, together with practical instructions for constructing a wind rose in order to make use of all this information.[9] A key topic linking the various meteorological discussions is that of the solar solstices and equinoxes.[10] As Pliny sets out in chapter 59 of Book Eighteen, these are dated both by the Roman calendar and by the Sun's position in the zodiac. Pliny gives irregular intervals between them, ranging from eighty-eight days and three hours between the autumn equinox and the winter solstice to ninety-four days and twelve hours between the spring equinox and the summer solstice. Nevertheless, he says that the seasons that they initiate each begin when the sun reaches the eighth degree of the relevant zodiac sign. These are Libra, Capricorn, Aries and Cancer. Pliny is slightly vague as to the actual dates of the solstices and equinoxes, though he provides the information that the winter solstice is 'usually' eight days before the kalends of January. He is naturally aware of the dominant Roman system of time measurement, which regarded every period from sunrise to sunset as containing twelve hours, and thus produced hours of frequently changing actual duration. However, for scientific accuracy, Pliny gives his time measurements in equal, equinoctial hours. Pliny's complete assemblage of meteorological knowledge exceeds the scope of this book, whose main subject is medieval meteorology; nevertheless, his work requires discussion here since it played a crucial role in the transition from classical to medieval meteorology. It was well known in the early centuries of the Middle Ages, at least in partial versions, and was held in high regard.

[8] Pliny, pp. 316–317 and 324–325. [9] Chapters 76–77; ibid., pp. 394–403.
[10] Pliny's bringing together in his work of both philosophical meteorology and practical weather signs is emphasised by Taub in *Science Writing in Greco-Roman Antiquity*, p. 79.

Ironically, it was in turn to be treated rather as Pliny had treated his own early sources. In other words it became a repository and quarry of information, both practical and theoretical, to be applied within new parameters.

Pliny's own attitudes in relation to meteorological study may be demonstrated by a few examples. Most striking, perhaps, is that whilst he shows knowledge of Aristotle's fundamental *Meteorology* he displays no desire to follow it in detail. Indeed, as others have noted, Pliny tends to emphasise Roman experience over Greek 'writings'.[11] Pliny's tendency to point out disagreements between his authorities also works to undermine any idea of there being a clearly authoritative reference work on these matters. Thus, practical experience and recorded observations (adapted to varying conditions across diverse territories of the Roman Empire) emerge as the fundamental factors in the creation of meteorological knowledge. It has further been suggested that Pliny's attitude to Greek authors in general reflected a Roman sense of superiority and distinctiveness, and this does emerge at least at certain points.[12] Whether this also helps to explain the relative lack of interest in Aristotle's *Meteorology* displayed by the Fathers of the western Christian Church is unclear. However, it does seem to have been predominantly in centres such as Alexandrea and Caesarea that knowledge and study of the work continued in the Christian period.[13]

What can be observed is that Pliny's emphasis on practical expertise and direct observation fitted well with the emerging early medieval, Christian understanding of weather. Both gave attention to techniques for forecasting the weather in a way that Aristotle did not. Aristotle's work was calculated to deliver a rigorously logical, internally consistent model of the workings of the universe and its component parts. Ephemeral phenomena such as local variations in weather were not integral to this. Thus Pliny's attention to methods of weather prediction provided an important basis for taking meteorological study in a new direction. Even so, the type of meteorological knowledge that was transmitted in this transitional period took for granted the assumption that forecasts, as opposed to theoretical modelling of climatic norms, could only be very local and very short term. This was because, as both the Bible and the information amassed by Pliny illustrate, forecasting was seen as being

[11] Ibid., p. 79.

[12] This argument is made in particular by T. Morgan Murphy, *Pliny the Elder's Natural History: The Empire in the Encyclopedia,* Oxford, Oxford University Press, 2004.

[13] For discussion see G. Karamanolis, 'Early Christian Philosophers on Aristotle' in A. Falcon, Ed., *Brill's Companion to the Reception of Aristotle in Antiquity,* Leiden, Brill, 2016, at pp. 460–461.

necessarily based on the observation of 'signs' in the changing appearances of the sky or the current behaviour of birds and animals. It was only in the central medieval period that a new model of meteorology took shape, which combined theoretical models with practical techniques for weather forecasting. This is the medieval meteorology with which this book is concerned.

Nevertheless, it is important to consider the question of whether any significant quantity of meteorological knowledge was rejected or mislaid when direct access to Aristotle's work dwindled in the western part of the Roman Empire. This is also necessary if the argument that medieval meteorology was an essentially new, hybrid creation is to be evaluated. Therefore, both to prepare for later chapters and to illustrate the difference between Aristotle's approach and Pliny's, a brief account of the former's central arguments will be given here. Aristotle's theories on the skies, the movements of the heavens and the planetary bodies, and the effects of all this upon the Earth below, were spread across several of his works. This in itself led to complications, since the terms in which Aristotle discussed key concepts were not necessarily identical across these works themselves, and they were subject to further variation in the processes of translation. The treatises concerned are *On the Heavens*; *On Generation and Corruption*; *On the Soul*; and *Meteorology*. Aristotle offered a wide-ranging coverage of the nature of the Earth and its waters (both fresh and salt), as well as hypothesising that the Sun evaporates water, and causes the vapour to be carried up to the upper part of the sky, where it is affected by cold and so falls to Earth again. This fits into the more general model of the processes of 'change and becoming and decay', which the heat and motion of the Sun set in train on Earth. Both earthquakes, as the result of pressures caused by underground winds, and aerial phenomena such as thunder, lightning and rainbows, are covered by the model. Rather less satisfyingly, it is necessary for meteors, comets and even the Milky Way to be atmospheric phenomena, since they are parts of the processes of change rather than purely external causes. A further step in the argument is that all change is perceived as cyclical, although many of the processes posited take place over very long periods of time, far exceeding any human life.[14] Thus 'these changes are

[14] See M. Scharle, '"And these things follow": teleology, necessity and explanation in Aristotle's *Meteorologica*' in D. Ebrey, Ed., *Theory and Practice in Aristotle's Natural Science,* Cambridge, Cambridge University Press, 2015, pp. 79–99.

not observed, and before their course can be recorded from beginning to end whole nations perish'.[15]

The topics to be covered in the *Meteorology* are set out in the introduction to Book 1, where Aristotle says that the 'natural changes', which come under the heading of meteorology 'take place in the region nearest to the motion of the stars. Such are the Milky Way, and comets, and the movements of meteors'. Meteorology in this sense also covers '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'. Affection is being used here as a technical term to cover the processes of interactive change under discussion, and Aristotle states clearly that he does not have a full explanation for all the phenomena that come under his definitions. Indeed, the more extreme elements of meteorology, including thunderbolts, whirlwinds and fire winds, are handled separately, since by definition they are not regular or cyclical in their patterns and occurrence. Book 1 itself goes on to outline the elements and bodies that are the component and dynamic parts of meteorology, conceived as a complex set of systems and processes of change taking place across the zones from the spheres of the stars down to the Earth. The emphasis here is on clarifying the processes involved, and the range of phenomena for which they can account. Reports of geological, geographical and climatic data and observations are considered carefully for the data they contribute to the model, which is intended to be fully comprehensive as well as internally coherent. There is no attempt to deal with the possibility of, or methods for, prediction of local weather events.

In Book 2 attention turns first to the sea, its origins and its relationship to the various bodies of fresh water. This is where the theory of the drawing up of water from the sea, and its return to Earth as fresh water, is set out. However, the emphasis is again on setting out a theory that will account for all known phenomena (and do so more effectively than previous ones) rather than on discussing the practical prediction of rain. A long discussion of the winds, conducted in a similar manner, follows and this leads in turn to the subject of earthquakes. The connection is, as mentioned above, that wind is argued to have a causative relationship to earthquakes, although the full model set out is considerably more complex in the phenomena included. The theory is summed up thus: 'Water

15 *Meteorologica,* Book I, chapter 14, Trans. E. Webster, in *The Works of Aristotle Translated Into English,* Oxford, Clarendon Press, 1923, sections 351a and 351b. All quotations are from this translation.