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Meteorology and Environment in Islamic Scientific Tradition (4th/10th–6th/12th Century)

Abstract Meteorology in the Islamic scientific tradition covers ample ground. Under this umbrella may fall astronomical *anwāʾ*, historical meteorology, and scientific understanding of several phenomena. This article will present on overview of meteorological contributions by fundamental authors of the later centuries of the so-called golden age of Islamic scientific tradition—namely, al-Bīrūnī, Ibn Sīnā, Abū l-Barakāt, and Ibn Rušd—focusing on the origin of clouds, precipitations, and rivers and climatic differences across regions. Building on their understanding of meteorological phenomena and atmospheric structures, it is possible to draw broader conclusions about their views of the (created) natural world and what we understand today in terms of the environment. The varied multiplicity of their approaches and conclusions features a shared prominence of experience as a fundamental tool of inquiry.

Keywords Climate; Clouds; Meteorology; Rain; Water

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Meteorology within the Islamic scientific tradition encompasses a wide range of topics. This includes the study of astronomical phenomena, historical meteorology, and scientific understanding of various natural occurrences such as rainbows, clouds,

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and rainfall. In this article,[1] I aim to provide an overview of meteorological thought in the Arabic-Islamic philosophical and scientific tradition through the analysis of four authors: Ibn Sīnā (Avicenna, d. 428/1037), Ibn Rušd (Averroes, d. 595/1198), al-Bīrūnī (d. c. 440/1048), and Abū l-Barakāt al-Baġdādī (d. c. 560/1165).[2] Given the extensive and diverse nature of the subject matter, even when focusing solely on these authors, this article will concentrate on certain general aspects. Specifically, it will explore the topics of clouds, the origin of water on land, and the climatic aspects of meteorology, particularly in relation to the habitability of tropical and equatorial regions. The four scholars discussed in this article are just a few of many who have written about these subjects in Arabic.[3] As will be seen, two of them, Ibn Sīnā and Ibn Rušd, closely follow Aristotle's ideas, though not slavishly or without introducing novel elements, while the other two scholars, al-Bīrūnī and Abū l-Barakāt, offer more original approaches to these meteorological subjects.

The three topics selected for this article were chosen from the broad range of medieval meteorology. They are phenomena that have a continuous impact on a large scale, fundamentally shaping how we inhabit and perceive our environment, regardless of the historical period. As we will see, this allows for a significant appreciation of the role of experience in our authors' development of their meteorological phenomena and the overall mechanisms of the created world.[4] This experience is coupled with theoretical reflection, enabling them to connect visible phenomena with the realm of the unseen, which is beyond sensory experience.

1 Ibn Sīnā

Ibn Sīnā, also known as Avicenna, is a pivotal figure in the history of Islamic philosophy who left a profound and long-lasting influence in the subsequent philosophical tradition. His philosophical tenets became the benchmark for understanding the highest and most comprehensive knowledge in the Islamic world.[5]

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1 The research on which this article is based was supported by the PON Research and Innovation 2014–2020 Axis IV 'Education and Research for Recovery—REACT-EU'.

2 On the meteorological thought of the earlier al-Kindī, see Daiber 2020.

3 See also the encompassing lists provided in Sezgin 1979.

4 Regarding the particular place held by meteorology at the crossroads of theoretical speculation and empirical experience, I refer to the article by Hullmeine in the same volume.

5 For an updated and accessible introduction to Ibn Sīnā's thought and work, see Adamson 2023.

1.1 The Origin of Clouds and Precipitations

The meteorological reflections of Ibn Sīnā are based on Aristotle's distinction between two exhalations: the moist one, called vapour, which is the cause of precipitation as well as haloes and mock suns; and the dry one, also known as smoke, which is the cause of winds and lightning.[6] Both exhalations are produced by the sun's action on the Earth's surface, and most of the time, they are coexistent, with one component dominating over the other. In this regard, Ibn Sīnā reports his personal observation, having witnessed the separation of the two exhalations beyond a certain altitude:

> But vapour ends as it rises to a certain point, and if the smoke is strong, it separates from it, ascending higher toward the fire. We have witnessed the separation of smoke from the clouds while being on top of towering mountains. We observed the separated smoke leaving a layer on top of the accumulated clouds below, and it accelerates upwards, emitting a smell of fire.[7]

In Ibn Sīnā's conception, vapour is an ambiguous state of water "taking up airy image",[8] which can arise from the former through condensation as well as from the latter through evaporation. Clouds can form from this substance due to various causes, all of which can be attributed to the influence of cold or pressure, particularly in mountainous regions. Furthermore, wind plays a role in this process and induces the appearance of clouds when it is particularly cold, causing the vapour to condense or compressing it and preventing its ascent to the upper layers of the atmosphere.[9] Another mechanism by which the wind acts upon vapour is by compression against the mountains, explaining why a warm region like Ethiopia may experience abundant rainfall.[10]

It should be emphasised that, according to Ibn Sīnā, the effect of wind on precipitation does not necessarily result in rain. On the contrary, if the wind is warm, it can lead to a rarefaction of the matter that constitutes the clouds and, thus, to their dispersion. Interestingly, Ibn Sīnā identifies a significant regional variability, which leads him to briefly discuss specific types of winds in relation to certain regions.[11] As we will also see in the case of al-Bīrūnī, the discussion

6 On this aspect of Aristotelian thought, see Wilson 2013, pp. 51–72.

7 Ibn Sīnā: Kitāb al-Šifā', p. 39. The translation is mine.

8 al-Bīrūnī and Ibn Sīnā: al-As'ila wa-l-ağwiba, p. 147.

9 Ibn Sīnā: Kitāb al-Šifā', p. 35.

10 Ibid., p. 36.

11 Ibid., pp. 59–61.

of regional climates is one of the ways through which experience, even indirect, contributes to making the consideration of climate more complex and concrete.

1.2 The Origin of Water on Land

However, in accordance with Aristotelian doctrine, this cycle of precipitation and evaporation is not considered sufficient in itself. In contrast to the perspectives of thinkers like al-Bīrūnī, Ibn Sīnā assigns a lesser significance to the sea. He posits that its salty water generates a dense vapour which quickly condenses into rain.[12] Completing the cycle of evaporation and precipitation is its underground analogue, where the air permeating the ground becomes vapour under the influence of pressure and the coolness of the earth before being distilled in the mountains, where it further condenses into water through simple accumulation.[13] In this instance, we observe the role of direct experience subtly emerging, this time through an analogy between the distillation processes used in medicine and pharmacology at the time and the phenomenon of water formation deep within the Earth. As is clearly seen here, the analogous explanation allows Ibn Sīnā to bridge the gap between what can be observed and the unseen, explaining both the mechanism in general and the role of different soils in determining the effectiveness of the process:

> It is possible for mountains to be filled with water, similar to a mountain retaining vapour and channelling it towards the emergence of springs, like a solid distillation vessel made of iron, glass, or any other material suitable for distillation. If it is made of weak and porous wood or ceramic, it will not retain much vapour, nor will anything significant condense from it. However, if it is made of a solid substance, it will not allow any vapour to escape and dissipate.[14]

This very mechanism, which is analogous to the one that leads to the formation of metals, explains the greater presence of springs near mountains. The transformation of elements into one another lies at the core of Ibn Sīnā's understanding of the natural world, envisioned as a natural environment that is animated and shaped by a continuous struggle between the elements.[15]

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12 Ibid., p. 207.

13 Ibid., p. 10.

14 Ibid., p. 11.

15 Di Martino 2008, p. 36.

1.3 Climate

The same transformation of elements also explains the irregularity of the Earth's sphere, which is due to the transformation of land into other elements under the influence of celestial bodies.[16] This phenomenon aligns with the evidence of divine wisdom, as argued by various authors, not necessarily Muslims. The 4th-/10th-century Sabean scholar Ṯābit ibn Qurra, for instance, shares this perspective, as it allows for the survival of terrestrial life.[17] This irregularity plays a significant role in defining the climatic characteristics of different regions. Ibn Sīnā identifies four aspects that influence this phenomenon: the position of the sun, namely, the angle at which its rays strike the surface; altitude; the effect of the orography on the reflection of solar rays; and proximity to the sea.[18]

Ibn Sīnā also takes into consideration the latitude, based on the assumption that the sun's rays heat the Earth's surface more intensely when they are more vertical. However, this does not lead him to argue that subtropical and equatorial regions are uninhabitable. Ibn Sīnā reports that trustworthy travellers have informed him that these regions are indeed inhabited. This can be explained by the fact that, on one hand, the closer one is to the equator, the more quickly the sun reaches and departs from the zenith; and on the other hand, the duration of days and nights remains constant, eliminating the conditions that lead to the alternation of summer heat and winter cold in more northern climates. The result is that the equatorial region must experience the most constant and moderate climate.

Then, in addition to the effect of altitude, which results in lower temperatures in the higher atmospheric layers, mountains also impact the climate of surrounding regions by reflecting solar rays. The influence of seas is more complex, as they can both cool and warm a region. In the former case, it is simply a consequence of the inherent cold nature of water. In the latter case, it is the vapour, or moist exhalation, rising from the sea that intercepts the solar rays, thus experiencing a warming effect.

It is worth noting an interesting medical observation that connects the climatic characteristics of regions to the adaptation of the populations inhabiting them. Ibn Sīnā, as he frequently does,[19] draws upon his own direct experience in this regard,

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16 Ibn Sīnā: Kitāb al-Šifāʾ, pp. 24 f. The Earth's spheroidal imperfection is evidently crucial for the appearance of dry land. Ibn Sīnā's naturalistic rationale for this had the advantage of aligning with the Genesis narrative, and it was embraced by Jewish thinkers; see Freudenthal 2018.

17 Rashed 2009. This author is significant and influential, as evidenced by his substantial inclusion in the Ayasofya 4832 collection, which Hullmeine discusses in his contribution to this volume.

18 Ibn Sīnā: Kitāb al-Šifāʾ, pp. 26–29.

19 Janssens 2004.

inviting the reader to consider how Turks tolerate their land's cold and Abyssinians its heat and how he saw Bedouins and people from Ḫōrasān complain about the cold and the heat, respectively, despite experiencing the very same climate.[20]

2 Ibn Rušd

Ibn Rušd presents his meteorological thoughts in the 'Short Commentary' ('Kitāb al-Āṯār al-ʿulwiyya') and the 'Middle Commentary' ('Talḫīṣ al-Āṯār al-ʿulwiyya'). As noted by Paul Lettinck, these two texts do not entirely agree with each other and are based on the Arabic version of the 'Meteorology' by Ibn al-Biṭrīq (d. c. 215/830), with insertions from the Commentaries of Alexander of Aphrodisias (fl. c. 200), Ps.-Olympiodorus, and Ibn Sīnā. Where these sources diverge, Ibn Rušd tends to present a solution that encompasses both perspectives rather than favouring one over the other or, at least, provides both points of view.[21]

2.1 The Origin of Clouds and Precipitation

The most fundamental difference between the 'Short Commentary' and the 'Middle Commentary' lies in the theory of exhalations. In the first text, Ibn Rušd—following Ibn al-Biṭrīq's version of the Aristotelian 'Meteorology'—mentions *three* different exhalations, referring to hot and moist exhalation, cold and moist exhalation, and, finally, hot and dry exhalation.[22] In the 'Middle Commentary', however, the three exhalations are reduced, as it seems, to the opposition between a fiery exhalation (hot and dry) and a cold and moist exhalation, which is then referred to as vapour. Nevertheless, in one point, Ibn Rušd declares again that the earth gives off three exhalations.[23] Nevertheless, it is interesting here to note that, in the 'Middle Commentary', vapour is considered to be of the same substance as water.[24]

In this regard, given the importance of the transformation of elements in Ibn Sīnā's meteorology, it is worth noting, as Lettinck also points out, that although Ibn Rušd follows Ibn al-Biṭrīq, he "omits the statement that moist exhalation becomes air when nothing further occurs to it".[25] Nevertheless, the fate of the

20 Ibn Sīnā: Kitāb al-Šifāʾ, pp. 29 f.

21 Lettinck 1999, pp. 12–14.

22 Ibn Rušd: Talḫīs al-Āṯār al-ʿulwiyya, pp. 6–9, 20; see also Lettinck 1999, p. 62.

23 Ibn Rušd: Kitāb al-Āṯār al-ʿulwiyya, pp. 35 f.; see also Lettinck 1999, p. 63.

24 Ibn Rušd: Kitāb al-Āṯār al-ʿulwiyya, p. 25.

25 Lettinck 1999, p. 63.

two exhalations is otherwise similar to that outlined by Ibn Sīnā. After the earth releases the two exhalations under the influence of the sun, the moist exhalation rises but only to a certain point, where it begins to form clouds, while the dry exhalation separates from it and continues to ascend. Precipitation occurs through further cooling and condensation, a process that Ibn Rušd explains is entirely analogous to what is observed in steam-filled bath houses.[26]

2.2 The Origin of Water on Land

When it comes to the contribution of precipitation to the water that flows in rivers, Ibn Rušd's perspective appears to be varied. Water can exist in both flowing and stagnant forms, whether beneath or above the earth's surface. Stagnant water is often the result of rainwater being collected in areas where the soil is impermeable. However, it can also occur due to the underground transformation of air into water, a process analogous to the formation of rain in Ibn Sīnā.[27]

In the case of running water, Ibn Rušd assigns a predominant role to mountains, although it appears to be slightly different from Ibn Sīnā's view. Mountains, in fact, are considered particularly cold and humid because they are closer to the atmospheric zones where rain forms. Additionally, mountains are capable of retaining this moisture in their depths and maintain heat within themselves. This warmth evaporates moisture and then brings up vapour to the higher regions of the mountains, where the cold causes its condensation into water.

Once a sufficient quantity of water is reached, it can erupt and eventually merge with water coming from rainfall, forming rivers. The process described here by Ibn Rušd seems to reconcile the Aristotelian idea of water generation through the transformation of air within the depths of the earth with an almost entirely atmospheric cycle. In fact, Ibn Rušd briefly revisits the issue when discussing the sea and its connection to the water element. There, Ibn Rušd openly states, "the water of all rivers originate from it [i.e. the sea]".[28]

Upon closer examination, the generation of water from air seems to contribute only to the formation of stagnant water bodies rather than rivers. In the 'Short Commentary', he suggests that river water originates from atmospheric rain and follows an underground route, similar to yet distinct from the strictly Aristotelian water cycle model proposed by Ibn Sīnā. However, all of this is then contradicted

26 Ibn Rušd: Talḫīs al-Āṯār al-ʿulwiyya, p. 21.

27 Ibid., pp. 25 f.

28 Ibid., p. 28.

in the 'Middle Commentary', where the dual origin of river waters is presented instead: from rainfall or from the underground transformation of air.[29]

2.3 Climate

Regarding the habitability of the globe, Ibn Rušd substantially disagrees with Ibn Sīnā. Ibn Rušd observes that the summer heat persists on the Iberian Peninsula for three months following the solstice, while in regions located at a similar latitude, this period of heat lasts twice as long. Consequently, equatorial regions experience an extended, scorching summer that is incompatible with human, animal, and plant life, which relies on a cycle of hot and cold throughout the year. Even in the tropics, as seen in the case of Ethiopia, Ibn Rušd explains that life is only possible under very harsh conditions. This fact also serves the need for symmetry, considering the presence of uninhabitable regions due to extreme cold.[30]

3 Al-Bīrūnī

Al-Bīrūnī's meteorological approach displays several unique aspects, apparent both in the content and in the method of its presentation. Significantly, the scholar from Ḫōrazm addresses meteorological topics in a broad variety of works. It should be mentioned that al-Bīrūnī's only text with an assumed meteorological–astronomical character, the 'Book of the *anwāʾ*', is lost;[31] nonetheless, what can be gleaned from a comprehensive review of al-Bīrūnī's diverse body of work is helpful in forming an accurate understanding of his meteorological ideas on various subjects.[32]

Al-Bīrūnī seems to maintain a loose connection with the Aristotelian tradition;[33] however, this should not lead us to think that al-Bīrūnī's thought is entirely divorced from engagement with the great Greek thinker. A couple of examples that shed light on this matter can be found in the 'Coordinates' ('Kitāb Taḥdīd al-Amākin'),[34] as well as in the correspondence between al-Bīrūnī and Ibn Sīnā, collated by one of the latter's students.[35]

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29 Ibn Rušd: Kitāb al-Āṯār al-ʿulwiyya, pp. 73 f.

30 Ibn Rušd: Talḫīs al-Āṯār al-ʿulwiyya, pp. 45–49.

31 See Schmidl's contribution to this volume for a useful introduction to *anwāʾ* literature.

32 For a bibliography of al-Bīrūnī's works, see Pingree 2000a.

33 On al-Bīrūnī's meteorology, see the preliminary articles Wiedemann 1922 and Hasanov 1962.

34 An English translation is available in al-Bīrūnī: The Determination of the Coordinates of Positions.

35 Hullmeine 2019.

In terms of climatology, al-Bīrūnī exposes a few systems of global subdivision into climates.[36] In various works, al-Bīrūnī presents the Indian, Persian, and Greek systems. The Persian system divides the known world into climatic areas organised around a circle, with Iran as its centre. For this reason, al-Bīrūnī considers it more of a political division than a scientific one. Furthermore, the Indian system, in al-Bīrūnī's view, appears less precise and sophisticated in its calculations compared to the analogous Greek system, which envisages a division into seven parallel climatic zones.

3.1 The Origin of Clouds, Precipitation, and Water on Land

The 'Coordinates' is a work on astronomical geography. Its primary objective is to educate the reader on the correct method for determining the direction towards Mecca, thereby ensuring the ritual validity of their prayers, but it contains a few comments related to water in its introduction:

> It is also known from observation that the natural position of dry land is below that of the water, for soil precipitates in water. The penetration of water, when falling vertically into soil or earth, is due to the rarefaction of the air and the natural tendency of the water to settle below the air, which permeates the space between the aggregated particles of the soil.[37]

Here, al-Bīrūnī adheres rather closely to the Aristotelian tradition in describing the process through which water percolates and infiltrates deep into the earth. However, shortly afterwards, he addresses sea salinity, stating his alignment with Ṯābit ibn Qurra, who significantly influenced al-Bīrūnī's meteorological ideas:

> [God] commanded the winds to drive water vapour, in the form of clouds, to desolate and waterless lands, [...] its rain on the mountains will penetrate and accumulate deep inside them, or will remain on their tops in the form of snow. Further, the accumulated water will form rivers which will carry it back to the sea.[38]

36 Pingree 2000b.

37 al-Bīrūnī: Kitāb Taḥdīd nihāyat al-amākin, pp. 33 f.; translation from al-Bīrūnī: The Determination of the Coordinates of Positions, p. 23.

38 al-Bīrūnī: Kitāb Taḥdīd nihāyat al-amākin, pp. 34 f.; al-Bīrūnī: The Determination of the Coordinates of Positions, pp. 24 f.

As can be observed, al-Bīrūnī makes no mention of the second exhalation—smoke—central to the meteorological thought derived from Aristotle. Moreover, the vapour that forms clouds and will become rain for the emerged lands originates entirely from the sea and seems to be the sole source of water, thus forming a cycle that is not reliant on subterranean water generation. This is roughly analogous to the cycle we know today and, therefore, lacks the generation of water in the earth's depths that is characteristic of the Aristotelian tradition following the latter's 'Meteorology'. A potential influence, whether direct or indirect, might be traced here to the lost 'Meteorology' of Theophrastus and the Ps.-Aristotelian 'On the Cosmos'.[39]

It is worth noting how this divergence from the Aristotelian and Avicennian dictum is grounded in a differing conception of the nature of vapour. For al-Bīrūnī, vapour is a dispersion of water happening in the realm of the unseen—in this case, the outright invisible—as suggested in one of the questions he poses to Ibn Sīnā in their correspondence:

> Let us take the example of air and water: when water transforms into air, does it become air in reality, or is it because its particles spread out until they become invisible to the sight so that one cannot see these separate particles?[40]

Ibn Sīnā's response, of course, opposes al-Bīrūnī's proposition, on the empirical grounds that a sealed flask filled with water will crack when exposed to heat, which means that the content has expanded. If evaporation is due to dispersion, this would mean that the distance between particles of water has increased, thus leading to a void between them; and void, says Ibn Sīnā, is an impossibility.[41] However, the response must not have deterred him at all, as in one of his later works, al-Bīrūnī repeats the same description of vapour as an established fact: "[Water] becomes mixed with air, and as a result of the intimate contact becomes suspended in the air".[42]

This growing conviction can also be found in relation to the origin of the water we see on land. While in the 'Chronology' ('Kitāb al-Āṯār al-bāqiya') and later in the 'Coordinates', al-Bīrūnī discusses the issue leaning on the authority

39 Baksa 2020, pp. 123–126; Daiber 2021, pp. 300–302, 496–512.

40 al-Bīrūnī and Ibn Sīnā: al-Asʾila wa-l-ağwiba, pp. 146 f.; the exchange has been translated by Berjak and Iqbal 2003–2007; a German translation of this passage is also available in Strohmaier 1988, pp. 58–60.

41 Hullmeine 2019.

42 Arabic and English text in 'al-Bīrūnī: The Book of Instruction on the Elements of the Art of Astrology', p. 124.

of Ṯābit ibn Qurra, in the later 'Precious Stones' ('Kitāb al-ǧamāhir'), al-Bīrūnī opens his eclectic introduction leading to the discussion of gems and stones—the focus of the work—with an unequivocal description of an exogenous cycle. In this cycle, all water ultimately derives from a process of evaporation, precipitation, and potentially percolation, but not subterranean generation:

> All praise is for the Sustainer of the world, [...] has made the Sun and the Moon as the actors that uplift water towards the heaven. So, when the clouds are filled and laden with rain, winds drive them towards dry land and flood it with the blessing of water. [...] This very same water returns to the slopes and the oceans.[43]

Despite the lack of a subterranean generation of water, mountains play an important role. Al-Bīrūnī, drawing once again upon the insights of Ṯābit ibn Qurra, as illustrated in his lost 'On the Benefits of the Mountains' ('Risāla fī Manāfiʿ al-ǧibāl'), postulated that mountainous regions receive the highest amount of rainfall, as reliefs obstruct winds and clouds.[44] This obstruction leads to their compression and cooling, resulting in precipitation as snow or rain. This process enables mountains to conserve a substantial proportion of the precipitation, either as snow or as water infiltrating their cavities. This stored water is then released during dry periods, contingent on the latitude and structural features of the mountain ranges.

Again in the 'Precious Stones', al-Bīrūnī denies the usefulness of rain stones.[45] Sharing a story where a Turk offered him a rain stone, which is said to have the ability to summon rain, al-Bīrūnī—true to his empiricism—insists on testing the stone's supposed abilities, but the stone fails to trigger any rainfall, leaving its owner in a state of embarrassment. Al-Bīrūnī emphasises that the diverse climatic conditions across various regions should not be ascribed to distinct rituals. Instead, they should be linked to "the situation of the mountains, their structure, the blowing of the winds, and the passage of sea clouds".[46] This assertion aligns closely with al-Bīrūnī's understanding of the hydrologic cycle, demonstrating how the unique orographic formations of each area significantly shape their respective climate and meteorological outcomes.

43 al-Bīrūnī: 'al-Ǧamāher fī l-ǧavāher', p. 75.

44 A summary is available in 'al-Tawḥīdī: Kitāb al-Hawāmil wa al-šawāmil', pp. 354–356.

45 al-Bīrūnī: 'al-Ǧamāher fī l-ǧavāher', pp. 357–360.

46 Ibid., p. 360.

3.2 Climate

This leads us to discuss, more broadly, al-Bīrūnī's approach to the issue of differences between climates, which will bring us to the topic of habitability.

Despite al-Bīrūnī's adherence to the Greek theory of climes, he emphasises in both the 'Chronology' and the 'Instruction' ('Kitāb al-Tafhīm li-awāʾil ṣināʿat al-tanǧīm') that the unique orographic and geographical characteristics of each region play a significant role. Al-Bīrūnī attributes climatic specificities to the proximity of mountains, deserts or seas, altitude and latitude.[47] His understanding of climatology, which shares the regionalism dictated by personal experience of Ibn Sīnā, is also revealed in his treatment of weather forecasting.

Al-Bīrūnī's view of weather forecasting, a knowledge he acquired from the work of Sīnān ibn Ṯābit, son of the previously mentioned Ṯābit ibn Qurra, incorporates two main methodologies for anticipating future weather conditions such as rainfall and wind patterns.[48] Firstly, he considers the well-established lunar *anwāʾ* tradition; this system correlates the lunar stations with the rise and set of certain star pairs. Secondly, he acknowledges the use of the solar calendar, which records historically observed weather patterns for each day.[49]

These calendar-based predictions, as al-Bīrūnī clarifies, should be treated as broad trends for each day. He cites several such trends in the chapter on the Byzantine calendar, also known as the Julian solar calendar, in the 'Chronology'.

Al-Bīrūnī contends that both these methods have their merits. If both methods can be applied, he suggests that they should be, because a matching result from the two methods would provide greater certainty. Conversely, differing results would indicate the inherent uncertainty of the prediction. However, more generally, al-Bīrūnī stresses the importance of considering the origins of these predictions, as each will be most accurate, if not exclusive, for the regions where they were developed. The regionality of weather forecasting is thus closely tied with the empirical nature of meteorology, as al-Bīrūnī understands these notions to be closely tied to the immediate experience of any given region's weather and to originate from it.

4 Abū l-Barakāt al-Baġdādī

Abū l-Barakāt is a key figure in the evolution of Arabic-Islamic philosophical tradition, following the critique of Ibn Sīnā and the Arabic-Islamic philosophers (*falāsifa*)

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47 al-Bīrūnī: 'Kitāb al-āṯār al-bāqiya', p. 246; al-Bīrūnī: 'The Book of Instruction on the Elements of the Art of Astrology', p. 215.

48 al-Bīrūnī: 'Kitāb al-āṯār al-bāqiya', pp. 242 f.

49 See Schmidl's contribution to this volume for a useful introduction to *anwāʾ* literature.

by al-Ġazālī (d. 505/1111).[50] His most significant work is undoubtedly the 'Personal Reflection' ('Kitāb al-Muʿtabar'), which he likely wrote and revised over a rather extended period. This fact contributes to the uncertainty of whether the composition of 'Personal Reflection' predates or postdates what Arabic sources consider the central event of his biography: his conversion from Judaism, his birth religion, to Islam.

This conversion, which also involved two other significant intellectuals of the time, certainly happened in the latter part of his life. However, as Frank Griffel has shown, it likely did not occur towards the very end of his life, as Ibn Ḫallikān and others would suggest.[51] The 'Personal Reflection' offers both clues pointing to its composition before the conversion and others suggesting it was composed afterward. The issue remains unresolved.

What is undoubtedly established, however, is the highly original nature of the work.[52] From the outset, even with its title, the 'Personal Reflection' aims to present the product of the author's personal reflection and experiences, as we will see. This intent is programmatically reaffirmed by Abū l-Barakāt himself, who declares his intent to exclude concepts that elude his comprehension or lack empirical validation, even if they originate from esteemed scholars.[53]

4.1 The Origin of Clouds, Precipitation, and Water on Land

Contrary to what we have observed with al-Bīrūnī, the meteorological content of the 'Personal Reflection' is closely related to Aristotelian tradition. Like Ibn Sīnā, Abū l-Barakāt follows the theory of double exhalation. According to this, the earth and the sea (which is salty due to the wind bringing earth particles and the heat of the sun) emit a moist exhalation, or vapour, when warmed by the sun's rays. This vapour rises to the colder layers of the atmosphere, where it condenses into clouds.

The prevailing view among philosophers of the time was that the sun's rays could not directly heat the air of the atmosphere but instead warmed the seas and the earth. These, in turn, would spread the heat to the surrounding air, creating a warm lower layer and a point beyond which this heat did not spread. Furthermore, according to Abū l-Barakāt, the lack of rainfall in the summer is due to the increased heat emanating from the Earth's surface. This heat reaches the upper layers during

50 Griffel 2011; see also relevant chapters in Griffel 2021.

51 E.g. Ibn Ḫallikān: 'Wafayāt al-aʿyān wa-anbāʾ abnāʾ al-zamān', vol. 6, p. 74; Griffel 2021, pp. 208 f.

52 Street 2021; Benevich 2020; McGinnis 2018.

53 al-Baġdādī: 'Kitāb al-Muʿtabar fī l-ḥikma', vol. 2, pp. 4–7; For a translation of the passage, see Griffel 2011, p. 66.

these months, thus preventing the formation of clouds. Furthermore, the presence of clouds is not sufficient to bring rain, which requires sufficient coldness:

> As individuals enter the clouds, they can only see what is visible on a rainy or foggy day. […] And there is nothing that carries water, as the ignorant believes, but rather the clouds are rain itself. The cloud that does not rain is formed from vapour, which has become dense and has not cooled. If it had cooled, it would rain.[54]

What is, once again, evident here is the prominent role played by direct experience in shaping a thinker's meteorological system. In the case of Abū l-Barakāt, his programmatic reliance on personal experience and reasoning leads him to challenge what he sees as a mistaken, but common, conception about the role of wind in the generation of rain.[55] From Abū l-Barakāt's perspective, clouds and wind play crucial roles in the natural precipitation process. Unlike Ibn Sīnā, he views the wind as moving air.[56] The wind not only prevents clouds (and, therefore, rain) from spontaneously moving downwards but also carries the clouds to the point where, when the wind stops, precipitation can finally occur. [57]

This precipitation, according to Abū l-Barakāt, is the only source of fresh water on land. Some streams flow only when it rains, particularly in high areas and mountains, and stop once the rain does. Others flow from melting snow on mountain tops, their flow remaining steady as long as the snow is there and changing with the snowmelt rate. Some rivers start from rain or snow that falls into low spots and depressions, gradually accumulating until it forms a continuous stream. This water can seep into the ground and eventually spring up. The water flow from these sources can change based on rainfall and snow conditions.

Furthermore, Abū l-Barakāt took time to refute the idea that some of the river water comes from the transformation of air deep in the earth, and he does so on empirical grounds:

> People say and many ancient and modern philosophers believe that the air trapped inside the mountains cools down and changes into water that flows. […] The answer to them is that springs dry up, and wells desiccate, and rivers and valleys cease to flow when snow or rain become too little and why they increase when the latter increases, and

54 al-Baġdādī: 'Kitāb al-Muʿtabar fī l-ḥikma', vol. 2, p. 215.

55 Ibid.

56 Ibid., pp. 217–219.

57 Ibid., p. 215.

> why they decrease when the latter decreases. The intensity of the cold is not helpful against the lack of rain and snow to increase the water in springs and wells and its persistence.[58]

Abū l-Barakāt provides additional evidence against the idea of subterranean water production. He refers to wells that dry up in the summer, despite their bottom being colder in the winter than in the summer.[59] This probably suggests that the temperature difference between the air and the bottom of the well is more noticeable in summer, so the condensation effect should be stronger. As in the case of Ibn Sīnā, it is worth noting that this is not the only time this thinker challenges a widely accepted theory of natural philosophy based on his own experience.[60]

4.2 Climate

Abū l-Barakāt's examination of climate characteristics is considerably more theoretical.[61] While his formulation differs from Ibn Sīnā's treatment of the subject, the general picture that emerges from the 'Personal Reflection' is still close to Ibn Sīnā's teachings. Abū l-Barakāt's main statement, which is expressed later in his discussion, is that while heat is caused by the action of sunlight on dense bodies such as earth and water, cold does not require a cause to be produced in these two elements, as it is their natural state. Therefore, the length of the day is the main determinant of whether a region is hot or cold during a particular period.

This brings up a problem: how to explain why the northern regions, where summer days are longer than in the southern regions, are less hot even in summer? The answer lies in the aforementioned principle. The increased cold accumulated in the earth and snow of the northern regions during winter counteracts the effect of sunlight during the day. Furthermore, since heat lasts only as long as the sun's rays are active, while cold does not require a constant cause, the relationship between the two is not symmetrical, allowing cold to prevail, so to speak.

An additional correlation between a region's latitude and its climate is found in the position of the sun. When the sun is at its zenith, the earth receives the central, warmer portion of the sunray, as opposed to the colder, lateral portion. This is precisely when the shadows are at their minimum, meaning the warming

58 Ibid., p. 210.

59 Ibid., p. 212.

60 See, for instance, Abū l-Barakāt's rejection of the idea that mercury is the basis of malleable substances, and his refutation of astrology; al-Baġdādī: 'Kitāb al-Muʿtabar fī l-ḥikma', vol. 2, pp. 232–236.

61 Ibid., pp. 202–207.

effect of the rays is maximised. Also, when the sun is low, it reaches the earth's surface after a longer path through the atmosphere, during which it encounters more terrestrial exhalations. This consideration also explains why sunlight is more intense at noon than at dawn or dusk.

Therefore, given the key role of latitude in determining a region's climate in the ways we have outlined here, Abū l-Barakāt has no issue agreeing with Ibn Sīnā that equatorial regions are perfectly habitable. In fact, given the constant, perfect symmetry of day and night, equatorial regions enjoy a perpetual spring, with monthly rather than annual harvests.

While latitude plays a crucial role in determining a region's climate, Abū l-Barakāt does not completely rule out the influence of topography. In particular, altitude matters because the higher layers of the air are colder, but also because depressions receive reflected solar rays from the surrounding surfaces.

Winds, too, which can take on varying characteristics depending on their origin, play a role.[62] Due to the significance of winds, or what we would currently refer to as prevailing winds, in shaping the climate of a specific region, Abū l-Barakāt seems to limit the role of orography in determining a region's climate to the aforementioned effects of elevation and the function of mountains as barriers in the path of these currents.[63] Surprisingly, Abū l-Barakāt's approach to climatology seems the least based on direct observation among the authors discussed here, and, despite his frequent reliance on practical experience in other instances, his examination of climate is mostly theoretical. This approach may be why he shows only limited awareness of regional climatic variations.

5 Concluding Remarks

The broader perspective found in this last passage reveals a composite contribution of various geographical factors to the overall climate of a specific region. Similarly, the passages we have presented in these pages demonstrate how meteorological reflection between the 4th/10th and 6th/12th centuries emerged from a constant dialogue between theoretical speculation and empirical data, often acquired through personal experience, experiments, or just anyone's daily experience. This embryonic experimental approach is evident not only in renowned empiricist authors like al-Bīrūnī but also in others more inclined towards theoretical speculation, such as Ibn Sīnā, Ibn Rušd, and Abū l-Barakāt. Speculation, on the other hand, serves a fundamental purpose to expand the knowledge provided

62 Ibid., p. 207.

63 Ibid.

by observation towards the realm of the unseen that all these authors invariably touch. In the passages discussed here, the unseen is constantly and at times explicitly mentioned, whether we are talking about the invisibility of water particles in vapour, water generation beneath the mountains, or the distant causes of regional climates. It is through this intellectual tradition that the exploration of the natural environment takes place, resulting in a rich diversity of opinions that, hopefully, these pages have conveyed at least to some extent.

Bibliography

Sources

al-Baġdādī, Abū l-Barakāt: Kitāb al-Muʿtabar fī l-ḥikma. Ed. by Şerefettin Yaltakaya. Hyderabad 1939.

al-Bīrūnī, Abū Rayḥān Muḥammad and Abū ʿAlī ibn Sīnā: al-Asʾila wa-l-ağwiba. Including the Further Answers of al-Bīrūnī and al-Maʿsūmī's Defense of Ibn Sīnā. Ed. by Seyyed Hossein Nasr. Paris 1995.

al-Bīrūnī, Abū Rayḥān Muḥammad: The Book of Instruction on the Elements of the Art of Astrology. Ed. and transl. by R. Ramsay Wright. London 1933.

al-Bīrūnī, Abū Rayḥān Muḥammad: The Determination of the Coordinates of Positions for the Correction of Distances between Cities. Transl. by Jamil Ali. Beirut 1967.

al-Bīrūnī, Abū Rayḥān Muḥammad: al-Ğamāher fī l-ğavāher. Ed. by Yusof Al-Hadi. Tehran 1995.

al-Bīrūnī, Abū Rayḥān Muḥammad: Kitāb al-āṯār al-bāqiya ʿan qurūn al-ḫāliya. Ed. by Eduard Sachau. Leipzig 1923.

al-Bīrūnī, Abū Rayḥān Muḥammad: Kitāb Taḥdīd nihāyat al-amākin li-taṣḥīḥ masāfāt al-masākin. Ed. by Pavel G. Bulgakov and Ibrahim Ahmad. Frankfurt 1962.

Ibn Ḫallikān, Šams al-Dīn: Wafayāt al-aʿyān wa-anbāʾ abnāʾ al-zamān. Ed. by ʾIḥsān ʿAbbās. Beirut 1968.

Ibn Rušd, Abū Walīd Muḥammad: Kitāb al-Āṯār al-ʿulwiyya. In: Rasāʾil Ibn Rušd. Vol. 4. Hyderabad 1366/1947.

Ibn Rušd, Abū Walīd Muḥammad: Talḫīs al-Āṯār al-ʿulwiyya. Ed. by Jamāl A. Al-Alawī. Beirut 1947.

Ibn Sīnā, Abū ʿAlī: Kitāb al-Šifāʾ, al-Ṭabīʿiyyāt 5: al-Maʿādin wa-l-Āṯhār al-ʿulwiyya. Ed. by ʿAbd al-Ḥalīm Muntaṣir, Saʿīd Zāyid and ʿAbd Allāh Ismāʿīl. Cairo 1964.

al-Tawḥīdī, Abū Ḥayyān: Kitāb al-Hawāmil wa al-šawāmil. Ed. by Aḥmad Amīn and Aḥmad Saqr. Cairo 1951.

Secondary Literature

Adamson, Peter: Ibn Sīnā (Avicenna). A Very Short Introduction. Oxford 2023.

Baksa, István: Meteorology (Chapter 4). In: Pavel Gregorić (ed.): Pseudo-Aristotle, De Mundo (On the Cosmos). A Commentary. Cambridge 2020, pp. 121–148.

Benevich, Fedor: Perceiving Things in Themselves. Abū l-Barakāt al-Baġdādī's

Critique of Representationalism. In: Arabic Science and Philosophy 30 (2020), pp. 229–264.

Berjak, Rafik and Muzaffar Iqbal: Ibn Sīnā—al-Bīrūnī Correspondence. In: Islam and Science 1 (2003), pp. 91–98, pp. 253–260; 2 (2004), pp. 57–62, pp. 181–186; 3 (2005), pp. 57–62, pp. 166–171; 4 (2006), pp. 165–173; 5 (2007), pp. 53–60.

Daiber, Hans: Meteorology. In: Kate Fleet, Gudrun Krämer, Denis Matringe et al. (eds.): Encyclopedia of Islam, THREE. 2020. http://dx.doi.org/10.1163/1573-3912_ei3_COM_36400 (accessed: 28/12/2023).

Daiber, Hans: From the Greeks to the Arabs and Beyond. Vol. I: Graeco-Syriaca and Arabica. Leiden 2021.

Di Martino, Carla: I «Meteorologica» di Avicenna. In: Concetto Martello, Chiara Militello and Andrea Vella (eds.): Cosmogonie e cosmologie nel medioevo. Louvain-la-Neuve 2008, pp. 35–46.

Freudenthal, Gad: The Medieval Hebrew Reception of Avicenna's Account of the Formation and Perseverance of Dry Land. Between Bold Naturalism and Fideist Literalism. In: Dag Nikolaus Hasse and Amos Bertolacci (eds.): The Arabic, Hebrew and Latin Reception of Avicenna's Physics and Cosmology. Berlin, Boston 2008, pp. 269–312.

Griffel, Frank: Between al-Ghazālī and Abū l-Barakāt al-Baġdādī. The Dialectical Turn in the Philosophy of Iraq and Iran during the Sixth/Twelfth Century. In: Peter Adamson (ed.): In the Age of Averroes. Arabic Philosophy in the Sixth/Twelfth Century. Turin 2011, pp. 45–75.

Griffel, Frank: The Formation of Post-Classical Philosophy in Islam. New York 2021.

Hasanov, Hamidullah H.: O "Meteorologii i klimatologii" Beruni. In: Nauch. Tr. Tashkentskogo gosudarstvennogo universiteta im. V.I. Lenina 193 (1962), pp. 11–14.

Hullmeine, Paul: Al-Bīrūnī and Avicenna on the Existence of Void and the Plurality of Worlds. In: Oriens 47 (2019), pp. 114–144.

Janssens, Jules L.: "Experience" (*tajriba*) in Classical Arabic Philosophy (al-Fārābī – Avicenna). In: Quaestio 4 (2004), pp. 45–62.

Lettinck, Paul: Aristotle's Meteorology and Its Reception in the Arab World, with an Edition and Translation of Ibn Suwār's Treatise on Meteorological Phenomena and of Ibn Bājja's Commentary on the Meteorology. Leiden 1999.

McGinnis, Jon: Mind the Gap. The Reception of Avicenna's New Argument against Actually Infinite Space. In: Ahmed Alwishah, Ali Gheissari and John Walbridge (eds.): Illuminationist Texts and Textual Studies. Essays in Memory of Hossein Ziai. Leiden 2018, pp. 272–305.

Pingree, David: Bīrūnī, Abū Rayḥān II. Bibliography. In: Encyclopædia Iranica, Online Edition. 2000a. https://iranicaonline.org/articles/biruni-abu-rayhan-ii (accessed: 09/01/2024).

Pingree, David: Bīrūnī, Abū Rayḥān IV. Geography. In: Encyclopædia Iranica, Online Edition. 2000b. https://iranicaonline.org/articles/biruni-abu-rayhan-iv (accessed: 09/01/2024).

Rashed, Marwan: Thābit ibn Qurra, la Physique d'Aristote et le meilleur des mondes. In: Roshdi Rashed (ed.): Thābit ibn Qurra. Science and Philosophy in Ninth-Century Baghdad. New York, Berlin 2009, pp. 675–714.

Sezgin, Fuat: Geschichte des arabischen Schrifttums. Vol. 7: Astrologie, Meteorologie und Verwandtes. Leiden 1979.

Street, Tony: Abū l-Barakāt al-Baġdādī and the Traditions of Arabic Logic. In: Studia Graeco-Arabica 11 (2021), pp. 41–66.

Strohmaier, Gotthard: Al-Bīrūnī: In den Gärten der Wissenschaft. Ausgewählte Texte aus den Werken des muslimischen Universalgelehrten. Leipzig 1988.

Wiedemann, Eilhard: Meteorologisches aus der Chronologie von al Bîrûnî. In: Meteorologische Zeitschrift 39 (1922), pp. 199–203.

Wilson, Malcom: Structure and Method in Aristotle's Meteorologica. A More Disorderly Nature. Cambridge 2013.