Book review

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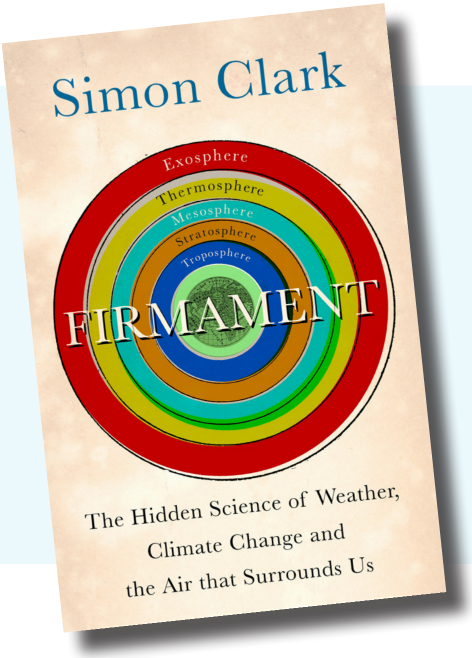

Simon Clark. 2023.

Firmament: The Hidden Science of Weather, Climate Change, and the Air that Surrounds Us

London: Hodder & Stoughton.

253 pp. 12 illustrations.

ISBN 978 1 5293 6231 2 (paperback) £10.99.

Part history of science, part science communication, *Firmament* is a fascinating survey of atmospheric science from antiquity to the present day.

Simon Clark holds a PhD in atmospheric physics from the University of Exeter; his research examined stratosphere-troposphere coupling over the Arctic. He started a YouTube channel in 2010, which initially focused on giving advice to students from disadvantaged backgrounds on the application process for Oxford and Cambridge (Clark completed a master's degree at University of Oxford). Upon moving to Exeter his YouTube output shifted to videos about science, mostly focused on physics of the atmosphere. Since finishing his PhD he has worked full-time as a science communicator. His YouTube channel has accrued 460,000 subscribers and over 40 million views.[1]

The first chapter, "Idea," charts the shifting conceptualisations of the atmosphere from antiquity through the invention of the thermometer and barometer in the early modern period to present-day knowledge of the troposphere's lapse rate. The chapter contains the extraordinary story of James Glaisher, a pioneering meteorologist who, in 1862, assisted by aeronaut Henry Coxwell, undertook manned balloon flights to determine the characteristics of the upper atmosphere, on behalf of the British Association for the Advancement of Science. A tangled valve line caused the balloon to rise uncontrollably; Glaisher lost consciousness during the ascent, while Coxwell just managed to avert disaster by releasing the valve, causing the balloon to begin descent, before he too lost consciousness. It is believed the pair may have reached as high as 37,000ft – without oxygen or any kind of heating beyond thick clothing.[2]

The second chapter, "Birth," expands on the previous discussion by describing the structure of the stratosphere, mesosphere, thermosphere, and exosphere. First, however, Clark describes how ice core samples are used to map the past climate; he establishes for the reader that the atmosphere has varied greatly in chemical composition

[1] https://www.youtube.com/@SimonClark.

[2] This flight was the subject of the 2019 film *The Aeronauts,* although Coxwell is replaced by a fictional character.

and temperature over the course of its history. Clark then describes the technological advances that made it possible for upper reaches of the atmosphere to be studied – weather balloons could only rise so high (the current record is 53 km), so it took the invention of liquid-fuelled rockets in the 1920s to penetrate the mesosphere and above.

Chapter three, "Wind," takes us on a journey through debates about the nature and origin of storms. The view handed down from antiquity was that weather developed in situ. Daniel Defoe's *The Storm* (1704), which recognised that stormy weather reported across Europe in late November 1703 was attributable to a single storm that moved across the region, was one of the first works to challenge this notion of in situ development. The discussion then takes us from Benjamin Franklin's investigation of a storm in 1743 through William Redfield's recognition of the cyclonic nature of lows in 1831 to William Ferrel's formulation of the equations of motion in 1858.

Chapter four, "Fields," introduces the notion of a meteorological field. Having discussed in the previous chapter how Ferrel connected changes in pressure to wind, Clark highlights how the ideal gas law links pressure changes to temperature variations. To explain the origin of temperature changes he describes the radiative balance of the earth and in turn accounts for the troposphere's lapse rate. He concludes with a discussion of air parcel theory and static stability. He points out the contrast between the often unstable troposphere and the highly stable stratosphere – vertical motion is a common feature of the former, but almost entirely inhibited in the latter.

In chapter five, "Trade," Clark gives an account of how the trade winds have been understood over the course of history. He discusses Edmond Halley's remarkably accurate description of the global wind circulation, which was published in 1686. Halley attributed the cause of the trade winds to the movement of the sun across the sky: the sun would heat up a section of the atmosphere, causing the pressure to fall and air to rush in from the east towards the area of low pressure. In 1735, George Hadley challenged Halley's theory of the trade winds, instead arguing that air in the tropics, owing to an excess of heat, is forced to rise, which causes air to converge from the north and south to replace the rising air. Hadley also got part of the way to accounting for the Coriolis effect. Clark finishes the chapter by explaining how Gaspard-Gustave Coriolis' contribution in 1835 addressed the shortcomings in Hadley's theory.

Chapter six, "Distance," explains the role of the subtropical and polar jet streams in the genesis of weather systems. Clark rightly attributes the discovery of the mid-latitude jet stream to Japanese meteorologist Wasaburo Ooishi, whose upper air studies in the 1920s documented the phenomenon long before the winds were "discovered" by Allied aviators during the Second World War – Ooishi's trouble was that he published his results in Esperanto, which limited the circulation of his work amongst the meteorological community. He also explores Gilbert Walker's early 20th century statistical investigations of the monsoon in India, which led Walker to recognise a connection between El Niño Southern Oscillation (ENSO) and the monsoon. Clark then segues Walker's observations into a discussion of Jacob Bjerknes' articulation in 1969 of the physical processes that drive ENSO.

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In chapter seven, "Forecast," Clark details the progress in weather forecasting from Robert Fitzroy in the UK during the 1860s, Cleveland Abbe in the US during the late 19th century, Vilhelm Bjerknes and the Bergen School of Meteorology in Norway during the early 20th century, through to Lewis Fry Richardson's attempt at numerical weather prediction (NWP) in 1922 and its ultimate realisation by electronic computer with the work of Jule Charney and John von Neumann during the 1950s. In the course of this discussion Clark explains concepts like pressure gradient force, geostrophic flow, air masses/fronts, the primitive equations, and chaos theory.

Chapter eight, "Vortex," focuses on the stratospheric polar vortex and its effects on surface weather. Through an account of Richard Scherhag's investigations in 1952, Clark explains the process of sudden stratospheric warming and details its effects on the behaviour of the polar vortex.

Finally, in chapter nine, "Change," Clark describes how we came to recognise that climate change was possible. He identifies Chinese scholar Shen Kuo, who wrote in the late 11th century, as one of the first to recognise the possibility of climate change, and then explains James Hutton's late 18th century thesis of glacier retreat and Louis Agassiz's mid 19th century postulation of past ice ages. Clark details James Croll's 1864 theory that ice ages are caused by changes in the Earth's orbit, and the more successful variant of the theory developed by Milutin Milanković during the 1920s and 30s. Noting, however, that Croll-Milanković orbital cycles only explain temperature variation on timescales of tens of thousands of years, Clark goes on to account for temperature changes over tens or hundreds of millions of years by tracing the evolution of the idea that the

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atmosphere acts as an insulator from Jean-Baptiste Fourier in the 1820s, through to Eunice Newton Foote in 1856 and John Tyndall in 1859, who demonstrated the greenhouse effect experimentally. He explains how the global carbon cycle accounts for temperature variation on geological time scales, and then discusses Charles Keeling's discovery in the late 1950s of increasing carbon dioxide concentration in the atmosphere. Finally, Clark describes the emergence of a global scientific consensus on the problem of anthropogenic climate change and offers a short summary of the predicted consequences of climate change.

I enjoyed this book. It is a great demonstration of how the history of science can serve as a tool of science communication. The characters and historical episodes Clark selected are entertaining and instructive and he deftly (at times, even poetically) weaves the historical narrative in and out of the discussion of scientific concepts. At points along the way I worried the book was suffering from poor organisation – reading over the chapter summary above one might feel that the topics were jumbled together with little logical structure. By the time I had got to the end of the book, however, these doubts had fallen away: Clark brings the historical and scientific stories together nicely in the end.

Most of the cast of historical characters will be familiar to historically inclined atmospheric scientists or historians with an interest in the history of meteorology. But Clark is not claiming to have produced an original work of history of science. Nevertheless, I was impressed by his sensitivity to the way in which women, people of colour, and other historically marginalised groups were excluded (or if not excluded, written out) of the history of atmospheric science in the 19th and 20th centuries. I was also glad to see him acknowledge the ways in which meteorology benefited from the expansion of the European empires – both in money and data. Furthermore, although much of his historical narrative focuses on the contribution of individual scientists, he is clear that these achievements need to be understood in their broader social context:

> While individuals may make remarkable accomplishments, propelling our understanding of the natural world forward, these accomplishments are enabled only by circumstance. The wealth of a nation, the availability of particular materials, the quality of education given to the general populace – broader societal factors position and enable their contributions … James Croll and William Ferrel, in particular, [benefited from] scientific textbooks and journals being made widely available in the nineteenth century. Any history of science is truthfully a history of these societal factors (p. 173).

These issues are often neglected by scientist-historians in their accounts of the development of their fields. These facets ought to endear Clark's book to historians of science.

Firmament is an entertaining, informative read. I don't know if atmospheric science is all that "hidden" these days, but those still in the dark will find themselves enlightened by the end of this book. It ought to be accessible to a motivated lay reader, yet it also contains historical anecdotes and context that atmospheric scientists will find of interest. Clark's book is also an excellent introduction to the problem of anthropogenic climate change. His book ends with an urgent plea for societal action: the "atmospheric giant" has been "happy to keep us safe and warm, fed and watered. In return, we must now use the collected knowledge of the past 500 years to keep it on our side" (p. 196).