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ADVANCED REVIEW

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Imperialism, colonialism, and climate change science

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Abstract

Historical studies of the influence of imperialism and colonialism on climate science have yet to be brought together into a critical synthesis. This advanced review offers a critical overview of the key themes of this literature with the primary intention of enabling historians and other scholars to recognize, specify, and acknowledge the roles of imperial and colonial processes in shaping scientific framings of climate. Following a brief overview of debates in older literature over the significance of imperialism and colonialism in climate sciences, the article investigates the wealth of recent scholarship that demonstrates specific and diverse connections between empires and climate science. Major features of this scholarship include: the role and the erasure of Indigenous and local knowledge; imperial climate infrastructures and visions; and climate data and theories in land empires as well as in informal empires and neocolonial settings. Through critically engaging these themes, the article seeks to help historians identify avenues for future research.

This article is categorized under:

Climate, History, Society, Culture > World Historical Perspectives
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empire, history, indigenous knowledge, local knowledge, scientific infrastructures

1 | INTRODUCTION

Over the last decade, it has become a truism for historians that the modern field of climate science emerged out of processes of imperial and colonial expansion. Historians working across diverse contexts from the Habsburg to the British Empires have shown the many and varied ways in which imperialism and colonialism shaped the study of "the structures and dynamics of the earth's climate system" as well as "the processes by which they change over time"—that is, climate science (Parker, 2018). Although studies of the influence of imperialism and colonialism on climate science have flourished in recent years, they have yet to be brought together into a critical synthesis. In this article, we offer a critical overview of this literature and its key themes with the intentions of: (1) enabling historians and other scholars

to recognize, specify, and acknowledge the roles of imperial and colonial processes in shaping scientific framings of climate; and (2) helping historians to identify avenues for future research.

What do we mean by imperialism and colonialism? Whether because of historical accuracy or pragmatic brevity, it has become common to refer to "climate change and colonialism" (Bhambra & Newell, 2022; Pörtner et al., 2022; Reibold, 2022; Sultana, 2022). Yet in this article, we deliberately use the categories of both imperialism and colonialism because they were and are different things (Burbank & Cooper, 2010). *Imperialism* is the wider of the two categories. Broadly stated, it is about the effort of one group of people to assert control over another whether through direct or indirect forms of rule. As historians Jane Burbank and Frederick Cooper have argued, "imperialism is not a singular kind of domination"; there have been "a multiplicity of ways that different empires worked" (Burbank & Cooper, 2010, p. xii). One such way was through *colonialism*, which saw imperial powers try to both occupy and control other people's territories.

In what follows, we review the latest historical scholarship to trace five key areas where efforts to assert imperial or colonial control influenced climate science, and vice versa. This scholarship has itself developed out of the broader field of the history of science and empire, which since at least the 1990s has shown how "science and empire grew together" (Goss, 2021, p. 1). The wider insights of this field—from the role of science in exploiting the natural resources of other people's lands to its dependence on imperial networks of exchange—have inspired much of the more focused work on climate science and empire. Yet, compared with the history of disciplines such as botany and biology, studies of how climate science grew with and out of empire have been fewer and more recent. To contextualize and elucidate the stakes of this recent shift, we use the following section of this review essay to offer an overview of the emergence of historiography of climate sciences and associated debates over the importance of imperialism and colonialism.

2 | HISTORIANS AND AN "OFFICIAL GENEALOGY" OF CLIMATE SCIENCE

Against a backdrop of growing public awareness of, and interest in, anthropogenic climate change, the 1990s and early 2000s saw a profusion of work on the history of climate knowledge. We divide these studies into two subcategories, differentiated by disciplinary and historiographic traditions, the framing of their subjects, and the aim of their analyses. One category, which we call "cultural climate histories," was practiced by historical geographers (e.g., Endfield & Nash, 2002a, 2002b; Livingstone, 1991), environmental historians (e.g., Davis, 2001; Grove, 1995), and historians of medicine (e.g., Anderson, 1992; Harrison, 1996; Osborne, 2000). It developed already established lines of investigation in these disciplines analyzing past understandings of "environment," "climate," and related concepts (e.g., Glacken, 1967; Merchant, 1980; Stepan, 1982). Across a wide range of specific case studies, these works focused on historical actors' diverse understandings of the mechanisms and consequences of climate. They also foregrounded the role of modern European empires as key drivers of climate knowledge throughout the early modern and modern eras (encompassing the 16th–20th centuries).

The other category, which we call "biographical climate histories," is smaller and more homogeneous. It is typified by two books by historians of physical sciences: James Rodger Fleming's *Historical Perspectives on Climate Change* (Fleming, 1998); and Spencer Weart's *The Discovery of Global Warming* (Weart, 2003). These studies are concerned specifically with knowledge of climate *change*—and even more specifically with establishing the historical roots of contemporary climate science. Fleming and Weart's books differ in their temporal range. Fleming covers late-17th- and 18th-century climate theorizing and only deals briefly with mid- and late-20th century developments, which is Weart's primary focus. Fleming is also more concerned than Weart to avoid positioning scientists of the 19th and early 20th centuries as "direct forerunners or prophets of contemporary climate concerns" (Fleming, 1998, p. 65; compare Weart, 2003, pp. 1–18).

Both Weart and Spencer's accounts, however, focus on the ideas of a largely shared cast of influential European and North American men, including Joseph Fourier, John Tyndall, Svante Arrhenius, and Guy Callendar. They thereby construct the history of climate science as a canon of those scientists whose laboratory and calculation work established the climatic agency of humans and of carbon dioxide molecules. The precursors to this framing lie less in work by historians, than in the scientists' own accounts of their predecessors (e.g., Arrhenius, 1906; Callendar, 1938, p. 223; Ekholm, 1901, p. 19; Plass, 1956, pp. 140–141; Tyndall, 1861, p. 1). Imperialism and colonialism are insignificant in these accounts, dropping out of Fleming's analysis after American Independence with the partial exception of a chapter on Ellsworth Huntington's "categorical errors" in theorizing race and climate change during the early 20th century (Fleming, 1998, pp. 95–106).

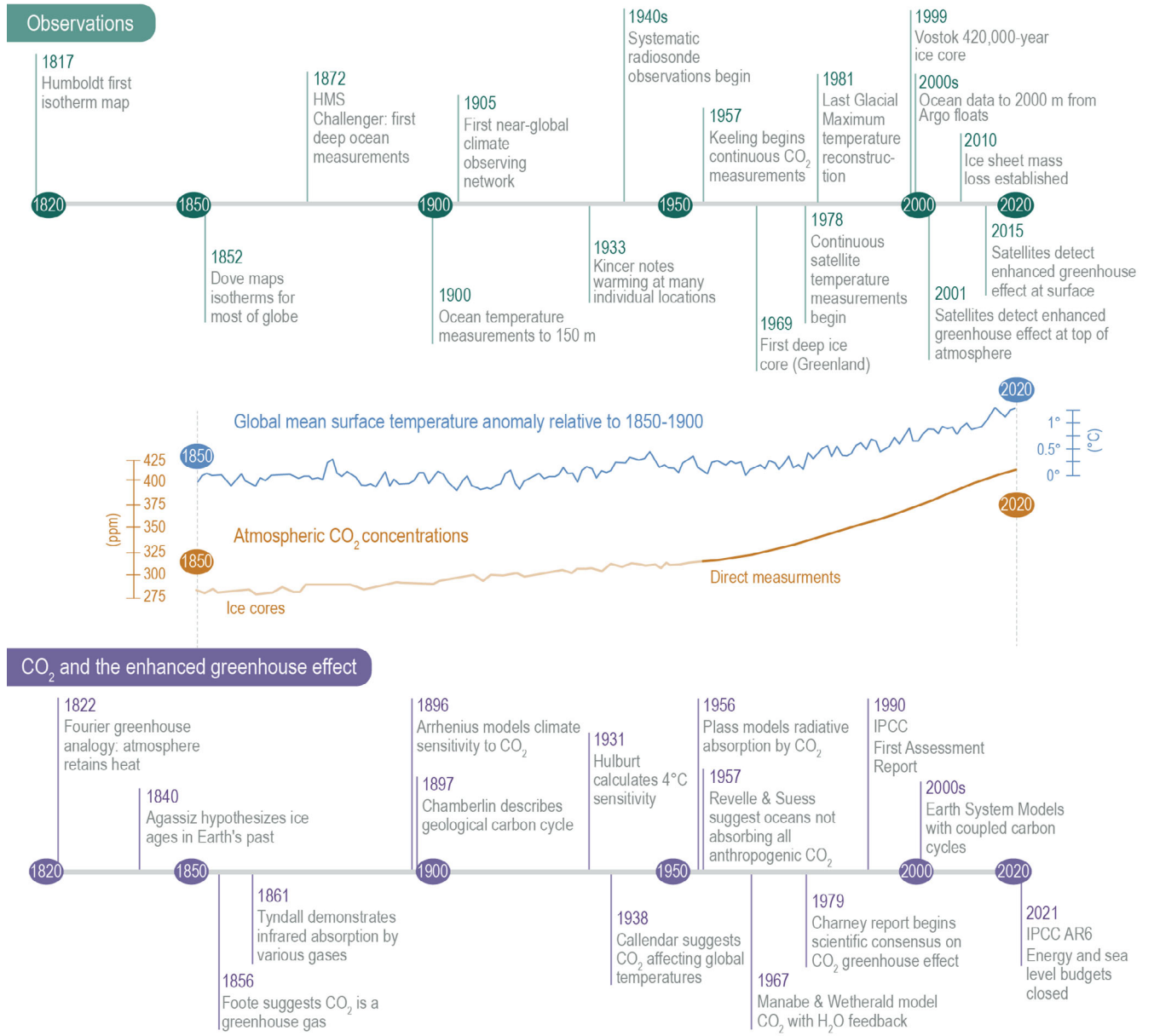

FIGURE 1 IPCC Sixth Assessment Report, 2021, Working Group I. Original caption: "Climate science milestones, between 1817 and 2021. Top: Milestones in Observations. Middle: Curves of global surface air temperature ... Bottom: Milestones in scientific understanding of the CO_2-enhanced greenhouse effect" (Chen et al., 2021, p. 174).

The narrative of the history of climate science as a Euro-American story of individual savants working in labs or at desks and focusing on physical mechanisms of climate remains influential. This is especially the case in publications aimed beyond historians and humanities scholars, and instead at climate data users, policymakers, and a wider public audience. Prime examples are the two accounts of the history of climate science that have appeared in the contributions of Working Group I to IPCC Assessment Reports (Chen et al., 2021; Le Treut et al., 2007). The opening chapter of the most recent Sixth Assessment Report of 2021 couches the advent of "national and colonial weather services in the 19th century" as a significant development in the progress of instrumental observation. It also states that "indigenous and local knowledge has played an increasing role in historical climatology" and acts as "a complement to sparse observational records" in some regions (Chen et al., 2021, pp. 175–178). Yet these references notwithstanding, the chapter does not substantively engage with themes of imperialism and colonialism. Instead, the history of climate science is rendered in textual and visual form (Figure 1) as timelines populated by a few scientists and infrastructural and intellectual developments.

Giving the history of climate science a shared temporal x-axis with curves of the climate metrics that are supposed to be its principal focus epitomizes a historical framing that a growing number of historians have recently called into question. Fressoz and Locher (2020, pp. 221–222) critically term this accumulation of names and discoveries pertaining to the Greenhouse Effect and global mean surface temperature, the "official genealogy" of climate science. They and others argue that such an approach is excessively narrow, anachronistic, and prone to overlooking the political and social contexts and impacts of climate theorizing and data production. One of the key omissions of the "official genealogy" is the imperial and colonial settings in which key features of climate science developed. Each of the following five subsections draw out these contexts by identifying a topic within the burgeoning scholarship on climate science and empire. Our intention is to complement an important earlier overview of "Climate and Colonialism" in this journal (Mahony & Endfield, 2018) by prioritizing studies published in subsequent years and by focusing on the ideas and infrastructures crucial to perceiving climate as something that can and does change over time.

3 | ROLE OF INDIGENOUS AND LOCAL KNOWLEDGE

There has been a recent trend in climate science literature toward seeking out and acknowledging the value of Indigenous and local people's climate-related knowledge (Ford et al., 2016; Green & Raygorodetsky, 2010; Lemi, 2019; Parry et al., 2007; Salick & Ross, 2009). Within this literature there has been a tendency to make two inter-related assumptions, both of which historians of climate science and empire have started to problematize. One is that a scientific interest in Indigenous and local climate knowledge is a relatively new, 21st-century development. The other is that it is always and in all contexts possible to separate what counts as "Indigenous," "local," and "scientific" climate knowledge. In theory, Indigenous and local knowledge, often also referred to as Traditional Ecological Knowledge (TEK), is broadly defined as "a complex knowledge system grounded in generations of place-based observations and experiences" (Ford et al., 2016, p. 350). In practice, historians of climate science and empire are showing that the distinction between different climate knowledges can at times become muddied given their overlapping histories.

In the context of the Habsburg Empire during the mid- to late-19th century, Deborah Coen (2018) demonstrates the deep and indeed often celebrated intellectual debt that imperial scientists owed to local knowledge. The Habsburg Empire's ideological program of seeing unity in diversity—of uniting a diverse group of peoples and places under a common imperial structure—helped to foster this appreciation of local knowledge. Coen writes, for example, of how imperial scientists such as Anton Joseph Kerner relied on the knowledge of local Hungarians to appreciate the diversity of plant life in that part of the Empire. It was by reading and listening to Hungarian poetry and folk songs that Kerner learnt to see what he originally viewed as a monotonous landscape as a botanically rich one. This lesson proved fundamental to the development of Kerner's idea that plants could be used to interpret climates of the past—that spatial changes in vegetation were linked to temporal environmental changes and in particular climatic change over time (Coen, 2018, pp. 171–204, 274–311).

Scientists attached to other European imperial and colonial powers were likewise reliant on the knowledge and assistance of local guides that their expansionist ambitions brought them into contact with. Philipp Lehmann (2022) shows that it was because of local North African guides, for example, that the 19th-century German scientist and explorer Heinrich Barth was able to view and interpret a series of rock engravings in the Libyan Desert which provided clues about climatic change. The engravings went on to become an important part of the evidence base used by European scientists to debate the nature and causes of past—and possible future—climatic change in the region (Lehmann, 2022, pp. 1–37). In the high and icy borderlands of British India, Thomas Simpson (2022, pp. 216–217) reveals that British scientists were similarly reliant on local guides to help them locate and interpret evidence of past climatic change. British surveyor Henry Godwin-Austen's studies of glaciers—which are still used by climate scientists today—were only made possible by the oral transmission of knowledge by local guides, traders, and farmers. The repeated visits to particular glaciers by these traveling and semi-nomadic individuals were critical to Godwin-Austen reading them as markers of recent and ongoing climatic change.

The work of Coen, Lehmann, and Simpson indicates that the influence of Indigenous and local knowledge identified in earlier research by Sverker Sörlin and Gregory Cushman on, respectively, early 19th-century South America and the mid-20th-century Arctic were by no means outlier cases. Sörlin (2011) and Cushman (2011) demonstrate the profound indebtedness of influential Western scientists to local knowledge. Sörlin's study of the climate change theories of Swedish geographer Hans Ahlmann demonstrates how crucial indigenous and other non-elite collaborators in the Arctic were to garnering climatological data in complex cryospheric field sites. Between the 1920s and 1940s, Ahlmann

worked with a range of local people as field assistants—Lapland Sami, Greenland Inuit, Norwegian trappers and hunters, and Icelandic farmers—and had a sincere "passion for local knowledge." However, Sörlin also emphasizes that these relationships were "hierarchical and quite asymmetric," marked by Ahlmann's "commandeering behavior" which served to reproduce class- and race-based inequalities (Sörlin, 2011, p. 78). Cushman, meanwhile, demonstrates that Alexander von Humboldt drew deep inspiration from the ideas of South American creole scientists to make his arguments about the relationship between local weather and regional ocean currents. It was the creole physician Hipólito Unanue—himself influenced by Indigenous knowledge—who formulated crucial insights in the early 19th century about the reasons why the Peruvian coast received such little rainfall. For Unanue, the peculiarities of Peru's coastal climate was linked to a cold ocean current in the Pacific that originated in the Antarctic. Humboldt, Cushman shows, never gave any credit to Unanue with whose work he was intimately familiar (Cushman, 2011). What is today often known as the "Humboldt Current" is, therefore, in many ways a misnomer.

In the case of the term originally used to describe the seasonal reversal of the Humboldt current, "El Niño," the dynamics between local knowledge and Euro-Western science were somewhat different. Richard Grove and George Adamson (2018, pp. 107–137) trace the history of the term from a descriptor borrowed from Peruvian sailors by Lima-based intellectuals, to its coopted in the 1920s by American, Dutch, and German meteorologists. These scientists expanded its meaning to refer to a Pacific Ocean-spanning occurrence of warm waters and connected it to an atmospheric concept with imperial pedigree: the Southern Oscillation identified by the British imperial meteorological network centered in colonial India. Although the local label stuck, a set of actors with colonial and neocolonial interests in the Pacific Ocean World affixed it to a very different climatic object.

Examining the British Empire's influence in east Asia, Fiona Williamson (2021) shows that it was not only the ideas, but also the labor of Indigenous and local peoples that underpinned the development of climate sciences. Williamson focuses on work produced at the Hong Kong observatory in the 19th century and early 20th centuries. There, London's Greenwich observatory maintained control of recruiting senior staff and exclusively chose Europeans for these positions. Yet Williamson shows that these senior staff members looked to Indigenous and local workers for support. It was a man named Mahomed Alarakia who undertook the majority of the Hong Kong observatory's meteorological work, which later fed into broader studies of spatial and temporal climatic change. Someone recorded in colonial archives as "Mr Lau-Shau," meanwhile, was in charge of communicating the all-important storm warnings to the colony (Williamson, 2021). In the context of early-20th century French Indochina, Giuditta Parolini has likewise demonstrated that agro-meteorological stations connected to the International Meteorological Organization were reliant on local staff, even though the most senior positions were reserved for Europeans. The agro-meteorological service, Parolini argues, "could not have existed without the native staff manning meteorological, climatological, and pluviometric stations" (Parolini, 2020, p. 15).

The recruitment of Indigenous and local peoples into meteorological observatories was not a pattern that was repeated across all colonial contexts. In the British settler colonies in Australia, for instance, observatories were typically reserved as spaces for white men. Yet Harriet Mercer demonstrates that these official attempts to create racially segregated spaces of knowledge-making did not stop colonists from seeking out Indigenous people's knowledge in other contexts, especially when the information coming out of the observatories was seen as inaccurate or unreliable. Mercer shows that in the British colony of Tasmania in Australia's southeast, colonists turned to the knowledge of Indigenous people, and most likely Palawa women, to help them understand and preempt changes in the weather. There, place-based knowledge of the sensitivity of certain plants such as the lightwood tree to atmospheric changes were used by Palawa people to understand and anticipate broader environmental changes (Mercer, 2021). Similarly, Ruth Morgan (2020) draws attention to the way colonists in mainland Australia valued Indigenous people's long-held intergenerational knowledge to help them interpret the temporal variability of the climate and especially its changing precipitation patterns over time.

As some of these examples suggest, the diverse roles Indigenous and local knowledge played in the development of climate science is a burgeoning rather than a fully-fledged sub-field of research. To date, most of the research on this topic forms small parts of broader studies of the development of climate knowledge in specific places and times. Some histories of climate science such as that of Sarah Dry (2019) contain helpful clues for further research. Dry shows that the Irish scientist John Tyndall is often credited with taking a novel interest in the question of whether ice moves. But this was something that the shepherds who lived and worked around the glaciers that became Tyndall's field sites had long known. Just how much this local knowledge and insights influenced Tyndall's now famous physics of heat and ice remains to be investigated. Moreover, as historians of science and empire often argue (Beattie & Morgan, 2021), different knowledge systems hold the potential to influence each other. In what contexts and to what extent Indigenous and

local knowledge of climate were themselves influenced by what would eventually become known as the distinctive discipline of climate science is in need of further research.

4 | ERASURE OF INDIGENOUS AND LOCAL KNOWLEDGE

New research is starting to show that it is not an accident that the roles played by Indigenous and local knowledge in climate science have gone largely unacknowledged until recently. One risk of assuming that the scientific interest in Indigenous and local climate knowledge is a novel, 21st-century phenomenon is that the role this knowledge played in the early development of climate science gets overlooked. Another risk is that the *reasons why* the role of Indigenous and local knowledge were later erased from or devalued in the scientific literature also go unnoticed. As Coen observes, impact and erasure could be two sides of the same coin: "the modern science of climate [...] has simultaneously appropriated and undermined traditional and indigenous forms of climate knowledge" (Coen, 2020, n.p.). This section examines recent studies which demonstrate that the omission or devaluation of climate-related Indigenous and local knowledge by scientific elites was at times deliberate and part of wider programs of conquest and control. These studies are also suggestive of the ways in which asserting the separability of the homogenizing categories of Indigenous, local, and scientific climate knowledge can come with political agendas.

Scientists in the Habsburg Empire may have valued and celebrated the role of local knowledge in the formation of their own ideas about climate and climatic change (Coen, 2018), but such acknowledgment did not suit the ideological foundations or practical ambitions of all imperial powers. Examining the chronologies of drought and deluge assembled by British scientists in 19th-century India, Morgan finds a tendency to simultaneously utilize and devalue local peoples' knowledge. One British colonial scientist drew on oral history testimonies of the Bengal famine of 1770 as part of his evidence base of climatic change in the region, while simultaneously casting the people who provided the testimony as a people without any record of the past. "By temporally distancing colonized spaces and peoples from the historical present," Morgan surmises, the scientist "denies the 'coevalness' of colonizers and colonized that would undermine the linear narrative of progress that legitimated enlightened British rule" (Morgan, 2020).

The French, in their efforts to colonize North Africa, likewise found it difficult to accommodate any overt appreciation of Indigenous and local peoples' climate knowledge into their imperial ideology and ambitions (D. K. Davis, 2016a, pp. 94–99). Lehmann (2022) shows that this was likely part of the reason why French and German scientists could reach different conclusions about the nature and causes of climatic change in the region. French scientists and colonial officials, Lehmann demonstrates, were more likely to take the declensionist view that human actions were causing North Africa to get progressively drier because it allowed them to justify placing strict controls over the Indigenous peoples of the area. The colonists enforced harsh policies of economic and social control over the communities whom they argued had caused the desertification of North Africa through such practices as neglecting irrigation works or cutting down trees. By contrast, Lehmann shows that scientists trained at German language universities were more likely to investigate and consider *natural* causes of climatic changes in historical times in part because they were less politically invested in the region (Lehmann, 2022, pp. 28–30).

In another part of the continent, the British colony of South Africa, government-aligned scientists and officials were also inclined to disparage Indigenous and local peoples' climate knowledge because of its perceived incompatibility with colonial goals. Meredith McKittrick (2020) has researched attitudes to climate engineering endeavors—or attempts to create "artificial rain" as it was known—in early 20th-century South Africa. McKittrick shows that in the effort to add credibility to government-aligned projects to engineer rain, white investigators devalued Africans' climate knowledge. The government-backed efforts to alter the climate using human intervention threatened to dissolve the distinction that white South Africans had drawn between European "science" and African "superstition." In South Africa, McKittrick argues, "'artificial rainmaking' became a means not just to fight drought but also to assert a white identity grounded in modernity, scientific rationality, and mastery of technology" (McKittrick, 2020, p. 154). The denigration of Indigenous rainmaking knowledge and veneration of colonists' knowledge was part of the politics of race-based segregation in South Africa.

Lehmann argues that the late 19th and early 20th centuries saw a general trend toward European climate scientists devaluing Indigenous and local peoples' knowledge (Lehmann, 2022). He suggests that two reasons help explain the trend in North Africa. One was a heightened perception of racial and cultural difference which developed at this time and which tried to draw sharper distinctions between "civilized" Europeans and "uncultured" Africans. The other was the scientists' frustrations at their own shortcomings. Exasperated that they could not locate the kind of quantifiable

data that they longed for, European climate scientists would blame and criticize local informants for their alleged inability to find or keep such data (Lehmann, 2022). These insights align with Williamson's research (Williamson, 2021) on the observatory in the British colony of Hong Kong, which shows that ideas of European racial superiority led British scientists and officials to openly disparage and sometimes exclude the knowledge of the observatory's Chinese workers.

Williamson's work is also suggestive of a theme that deserves further exploration in the study of the entangled histories of imperialism, colonialism, and climate change science. She observes that in the archive of the Hong Kong observatory the voices of Indigenous and local peoples are heard mainly in the form of complaints. For Williamson, this makes it difficult both to reconstruct the full contribution Indigenous and local people made to the work of the observatory and to avoid presenting a negative picture of their engagement with meteorological and climate science (Williamson, 2021). Yet these sorts of archival evidence can also be used to trace the ways that Indigenous and local peoples used their climate knowledge as a form of resistance against imperial and colonial encroachments. The evidence Williamson found in the archive suggests, for example, that at times Indigenous and local peoples might have shared knowledge as a means of asserting their claims to a region, or that they might have withheld it as a means of negotiating better conditions or resisting coercive regimes.

Thus, a related topic in need of more attention within the history of climate science and empire is the issue of how decolonization movements of the mid- to late 20th century impacted, and were in turn impacted by, efforts to understand the climate system. One promising direction is the "decolonial approaches to studying climatic phenomena" that Sarah Carson highlights in relation to South Asia (Carson, 2020, p. 8). Such approaches emphasize that major colonial projects of meteorology and climatology prompted often competing responses from, inter alia, "Indian merchants, fishing communities, public works managers, district officers, rural landlords, small farmers, and 'learned' pandits." "Professional meteorologists," Carson reminds us, were "one trusted group ... [but] not the only available weather authorities" (Carson, 2020, pp. 6–8).

5 | IMPERIAL CLIMATE INFRASTRUCTURES AND VISIONS

Systems of atmospheric observation critical to 19th- and 20th-century climate knowledge often emerged as part of efforts to pursue imperial goals of control over people and territory, resource extraction, and profit making. In this section, we first examine recent scholarship that covers various dimensions of the co-constitution of climate infrastructures and imperial power. These networks, which were produced partly for purposes of coercion and exploitation, still form critical parts of present-day efforts to reconstruct past climate. In particular, they provide many of the baselines from which scientists measure the extent of anthropogenic change. We also consider work that demonstrates how imperial meteorological and climatological observation networks were essential to envisioning climate as a dynamic global system (see Mahony & Caglioti, 2017). Again, this artifact of empire remains a potent presence in contemporary climate science.

Although the entanglement of climate measurement infrastructures and European imperial power is now well established, recent work adds the important nuance that meteorology and climatology were not "simply diffused from the metropole," but were instead "produced by a diverse cast of actors with complicated relationships to colonial states and subjects" (Mahony & Randalls, 2020). Just because the history of climate sciences cannot be told without the history of imperialism, it does not follow that imperial climate data and theories were uniform or simple. Coen (2020, n.p.) captures this duality in her claims that "climate science grew out of the political context of 19th-century empire-building" but also that "climate science was constructed out of a panoply of different ways of knowing." On the one hand, European empires, especially the two most powerful empires of the 19th and 20th centuries—the British and French—"consolidated what had been a loose network of intermittent weather informants into a modern meteorological network." On the other, dominant conceptions of climate "emerged from exchanges across cultures and disciplines: between physicians and geographers, collectors and travelers, scholars and peasants, European writers and translators around the world" (Coen, 2020, n.p.).

Grove's book *Green Imperialism* (Grove, 1995) remains a reference point for many historians who in recent years have provided rich case studies of how atmospheric and oceanic observations bolstered European empires and yet remained fragile and disparate enterprises (e.g., Mahony & Caglioti, 2017, pp. 6–7). A major theme within this body of scholarship, directly developing the work of Grove and others (e.g., Davis, 2001; Endfield & Nash, 2002a), is desiccation theorizing across multiple empires and colonies (D. K. Davis, 2016a; Duffy, 2019; Williamson & Wilkinson, 2017, p. 160). During the 19th and 20th centuries Europeans attempted to measure, comprehend, and ameliorate aridification

in colonial locales across Africa (Caglioti, 2022; D. K. Davis, 2016a; Lehmann, 2016, 2022; McKittrick, 2017, 2018), the Americas (McKittrick, 2017), Central Asia (M. Davis, 2016b; Keating, 2022), and Australia (Morgan, 2020).

Many of these attempts to know and to remake climate appear from present-day perspectives to be discredited "dead ends" driven by settler colonial priorities to expand agriculture and suppress indigenous and nomadic forms of environmental engagement (Mahony, 2021, p. 50; McKittrick, 2017, p. 75). Nonetheless, the influence they had on where and what kind of climatic data were collected and collated shapes the historical records available to climate scientists today. For instance, fears of progressively dwindling precipitation prompted German colonial authorities in Southwest Africa during the early 20th century to create a dense network of stations, many equipped with only a simple rain gauge rather than a full array of meteorological instruments (Lehmann, 2018, p. 40). Supposed causes of, and solutions to, desiccation were also engaged with by figures and institutions that are still widely considered major players in the development of meteorology and climatology, and thereby significantly shaped the development of these fields (e.g., McKittrick, 2017, pp. 76–77).

Just as desiccation debates in continental interiors involved unstable amalgams of knowledge from professional meteorologists, European settlers, and indigenous communities (McKittrick, 2018; Morgan, 2020), in oceanic and island arenas multiple actors brought into contact by imperialism contributed to new ways of recording and framing climate. The importance of maritime insurance markets in climate knowledge-making from the mid-19th century onwards has come to light in recent scholarship (Kneale & Randalls, 2020). Debjani Bhattacharyya (2022), for example, shows how the concept of cyclones first emerged in British colonial courts in Calcutta tasked with adjudicating responsibilities for financial losses in ships wrecked by storms in the Indian Ocean. The President of the Marine Court, Henry Piddington, devised the term "cyclone" in the 1840s with reference to accounts of storms from colonizers and settlers in the Americas as well as sailors and harbormasters in the Indian Ocean world. He also created tools such as "storm cards" in an attempt to bring these phenomena within the realms of the observable and predictable, requiring an "epistemic switch" from a ship-borne perspective of "contrary wind patterns to the bird's-eye view of [a] neat and cycloidal representation" (Bhattacharyya, 2022, p. 178). As Sunil Amrith (2018, pp. 61–63) points out, this "fully three-dimensional" perspective on maritime storms at once prompted and was reinforced by the creation over the later 19th century of a British network of telegraph-linked meteorological observations across the Indian Ocean littoral and islands. This expansive infrastructure was bound up with the (still-prevalent) vision of "the Indian Ocean … [as] a weather factory: the source of India's climate" (Amrith, 2018, p. 63).

Although the cyclone started out as an atmospheric object shaped by imperial schemes of maritime insurance, it was soon put to work in different colonial contexts. British meteorologists on Mauritius in the western Indian Ocean shifted away from a search for causes of cyclones and toward assessing their impacts, especially on the sugar industry that was the centerpiece of imperial profit on the island. Robert Rouphail (2019) details how this reconception inaugurated the field of agrometeorology around the turn of the 20th century, concerned less with the formation of cyclones at sea and more their manifestation over land. Although the particular imperatives of colonial capital in Mauritius were crucial to this development, agrometeorology became widespread as European empires expanded rapidly at this juncture. It was spread in part by personnel circulating between colonies: Albert Walter, who had been at the forefront of its emergence in Mauritius, sought to apply its core principles to expand the agriculturally productive area in East Africa following the Second World War (Mahony, 2020). Its manifestations also followed the exigencies of each colony's particular systems of extraction and production. As Aitor Anduaga shows, Jesuit meteorologists became crucial actors in cyclone prediction across far-flung locations thanks to a number of shared features, including epistemic values, instrumental apparatuses, and recording practices. However, Jesuit cyclone recording and forecasting took diverse forms across distinct locales, with observatory staff adapting to "local needs and conditions" (Anduaga, 2022, p. 525). Meanwhile, in French Indochina there was a "proliferation of … pluviometric stations" because "rainfall data were extremely precious for planters," providing "indications of the best times to sow and harvest." Climatological stations in this colony also gathered data on the air temperature above the soil, "a crucial factor in microclimatological studies on the correlation between plant growth and weather conditions" (Parolini, 2020, pp. 13–14).

Precipitation was likewise the key metric in perhaps the most widely discussed instance of the intersection of weather and climate data with imperial and colonial exigencies: monsoon observation and prediction by the British-run Indian Meteorological Department (IMD, founded in 1875; for an institutional history, see Sikka, 2011). Recent work builds on the foundations laid by Mike Davis's *Late Victorian Holocausts* (Davis, 2001) and Katherine Anderson's *Predicting the Weather* (Anderson, 2005). There is particular attention to developing and nuancing the central claim of these books that atmospheric observation marched in lockstep with the disciplining agenda of the colonial state, memorably expressed in Anderson's (2005, p. 284) claim that "meteorological research, it seemed, could control the anarchy of the weather just as the Raj controlled its chaotic and immense possessions."

Carson (2020, p. 7) identifies how recent historical work on colonial climate knowledge in South Asia instead tends to "highlight the messiness of implementation, contestation, and maintenance." Carson's own research suggests that British imperial monsoon observations and forecasts emerged in opposition to existing forms of "weather reasoning" in the subcontinent yet were sometimes interpreted through South Asian concepts, such as when journalists "portrayed professional scientists as equivalent to Hindu *jyotisis* (Sanskrit astrologers)" (Carson, 2021, pp. 322–323; see also Carson, 2020, pp. 8–9). Overall, she judges that British monsoon measurement "did not successfully project state authority," but still held significance as "symbols of responsible modern government" (Carson, 2021, p. 307; see also Cullen & Geros, 2020, pp. 15–17). Although this particular mode of forecasting was "a defensive strategy by minority rulers against a landscape perceived as irredeemably hostile and foreign," it instantiated key elements of monsoon meteorology and climatology—such as "the association between monsoon and economy" and the "centrality of agriculture"—that remain vital long after decolonization in 1947 (Carson, 2021, p. 314).

This scholarship on colonial India fits with the wider trend to emphasize how imperial meteorological networks were simultaneously haphazard and riddled with shortcomings, but nevertheless essential to what Martin Mahony (2016, p. 30) terms "an emerging globalism" in the framing of climate. Despite the increasing density of observatories and new communication systems, especially the telegraph, allowing for coordination between them, many of the quotidian difficulties that stymied imperial scientific networks in earlier decades remained in existence in the late 19th and early 20th centuries (Naylor & Schaffer, 2019). Damaged instruments, hastily retrofitted observatory buildings, and social and political tensions all demanded modifications and improvisations to original plans (e.g., Mahony, 2021, pp. 49–50; Naylor & Goodman, 2020; Parolini, 2020, pp. 16–19; Schaffer, 2010; Williamson, 2015). New technologies created not only opportunities but also new weaknesses: telegraphic cables, for instance, were "materially and politically fragile" (Williamson & Wilkinson, 2017, p. 176). There is a need for future scholarship focused on the mid- to late 20th century to similarly attend to imperial infrastructural "states of disrepair" (Schaffer, 2011) in climate sciences.

Despite these practical limitations, the increasing density and vertical depth of atmospheric and oceanic observations by European imperial institutions embedded understandings of climate as a unified global system (Mahony, 2016; Reidy, 2018; Wille, 2017). New techniques of data analysis and representation were also essential elements of this story. In the era of high imperialism, even doubtful, patchy, or heterogeneous data was often assembled into tables and maps, enabling what Lehmann (2018, p. 46) terms "the appearance of globality." Atmospheric teleconnections linking weather and climatic phenomena in far-flung locales were, quite literally, unimaginable without the sharing of meteorological series between distant observers and the application of innovative statistical tools (Grove & Adamson, 2018, pp. 107–137). Thanks to laboriously constructed postal and telegraphic communications, the Director of the IMD credited with uncovering the Southern Oscillation, Gilbert Walker, had "the greatest distances available" to him (Dry, 2019, p. 128). All 26 locations providing data for his Southern Oscillation index were in current or former colonies. Furthermore, as Adamson (2020, p. 62) points out, "it was only through the availability of large amounts of cheap Indian labor that Walker was able to undertake the mass of calculations required to uncover the oscillation."

This work in colonial South Asia gave rise to a notable shift in not only British but also international meteorology, away from practical empiricism and toward the identification and theorization of worldwide "centers of action" that dictated climatic patterns (Mahony, 2016, pp. 30–31). The British Empire's instrument networks and colonized workforce enabled the identification of teleconnections, just as the Habsburg principle of "unity in diversity" allowed imperial scientists in Austria-Hungary to conceive of climate as "a concept applicable at multiple scales, from the local up to the planetary" (Coen, 2018, p. 235). As the following section shows, Austria-Hungary was just one of many continental land empires that influenced the development of climate theories and the production of climate data with widespread and enduring effects.

6 | CLIMATE DATA AND CLIMATE SCIENCES IN LAND EMPIRES

As the previous section discussed, western European empires composed of far-flung colonies sustained by maritime connections enabled particular forms of climate science to develop. A body of scholarship that has grown substantially in recent years demonstrates the central role of another distinct type of imperial formation in the evolution of climate science: large land empires consisting of contiguous territory spread across environmentally, culturally, and politically diverse regions. In contrast to colonial enterprises based on maritime dominance established during the early modern period, many of these polities had longer histories or positioned themselves as successors to earlier empires (Burbank & Cooper, 2010; Lieven, 2002).

In the case of the longest-established land empire of all, China, meteorological record-keeping and prediction extended back millennia (see Williamson, 2020, p. 3). Pei and Forêt (2018, pp. 863–864) detail how Confucian philosopher Dong Zhongshu (ca. 185–110 BCE) "elaborated a cosmological theory that connected public policy to 'wind and rain', to prosperity or collapse, and, eventually, to natural phenomena that his contemporaries considered desirable or undesirable." Such practices of what Mark Elvin (1998) terms "moral meteorology" persisted into the last imperial dynasty, the Qing (1644–1911), during which court savants incorporated an increasing emphasis on empirical verification. There was also a parallel trend to specify regional climates in gazetteers produced by local imperial officials during the Qing dynasty (Agøy, 2023). Pei and Fôret point out that the imperial purposes of weather observation in China set them apart from modern meteorological series, making them complex if potentially valuable sources for present-day climate scientists. In keeping with the "desire to grant climate events and trends a metaphysical meaning that would have practical consequences for society and should therefore generate a political response," extreme events and patterns were prioritized over regular observations. Quantified records were rare, especially before the Qing dynasty, with a simple typology of cold, hot, wet, and dry the most common descriptors. Written for the emperor with the primary aim of bolstering his political authority, these records tend to read to modern climate data users as "vague and inconsistent" (Pei & Forêt, 2018, pp. 866–868).

Empire did not end in China with the downfall of the Qing dynasty and establishment of the Republican regime in 1911–1912, and imperial dynamics continued to inflect meteorology and climatology in the region throughout the 20th century. Republican China established meteorological stations across portions of the Tibetan plateau colonized during the 1910s and 1920s, in keeping with administrators' conviction that studying "atmospheric phenomena" (*qixiang*) was economically important. However, as Mark E. Frank shows, the young Han settlers dispatched to staff these outposts were "at once ... accessor[ies] to empire and victims thereof." Facing "illness, poverty, and isolation" and being equipped with defective instruments, the data that they produced were deemed mostly inadequate by their superiors at the Central Institute of Meteorology (Frank, 2021, pp. 363–364). As Williamson and Jankovic (2020, p. 2) point out, "modern meteorology was the sole property neither of Western actors nor of colonial needs. Asian interest and demands, public opinion, and Asia-based scientists and scientific networks were crucial." And Asian weather and climate data could be every bit as modified by imperial imperatives as those produced under the auspices of western European colonial powers.

Another important intersection between imperial priorities and the production of climate data in the continental interior of China was the network of Russian Magnetic-Meteorological Observatories dotted across Qing territory from 1848 to 1888. As Tatiana Feklova (2019) reveals, the priorities and limitations of the Russian Empire during its rapid eastward and southward expansion into Central and East Asia shaped this infrastructure. The Russians made particular efforts to establish regular observations in the desert and steppe regions at the northwestern outskirts of the Qing Empire, as these were understood to be important in understanding the weather and climate of Russian imperial territory in nearby central and eastern Siberia. These stations were nonetheless reliant on a range of non-state and non-Russian subjects to operate. The observatory in Inner Mongolia, for instance, used Belgian Catholic missionaries supplied with Russian instruments to produce data. The range of phenomena recorded in these regions—including soil temperature, never previously recorded in China (Feklova, 2019)—was shaped by the dominant Russian imperial framing of climate in terms of agricultural productivity. David Moon's book *The American Steppes* (Moon, 2020) shows how Russian migrants also exported to the Great Plains of the United States this definition of climate that included soil along with atmospheric conditions, with enduring consequences on agricultural practices and climate knowledge in the region.

Moon's earlier scholarship (Moon, 2010, 2013) provides crucial insights into how Russian imperial expansion into the dry steppe region beyond the moister, forested heartland of European Russia, was the essential setting for the development of this distinctive brand of climate theorizing and measurement. The focus on soil partially distinguished these debates in continental interiors from the forest-focused desiccation debates that emerged in locales around the Mediterranean basin (discussed in Section 4; Duffy, 2019). In Russia, discussions about the existence and mechanisms of climate change flared up in the wake of serious droughts leading to crop failure first in the early 1830s, and again in the early 1890s (Moon, 2010, p. 251). The latter episode prompted the development of the substantially new discipline of soil science as well as related developments in Russian climatology. The leading soil scientist Vasilii Dokuchaev insisted, contrary to the interpretation dominant in the aftermath of the 1830s drought, that climate was stable but that over-cultivation was leading the steppes to dry out. This was a major influence on the most prominent Russian climatologist of the era, Aleksandr Voeikov, who downplayed human influence on climate and theories of progressive change, instead claiming that climate changed according to natural cycles (Moon, 2010, pp. 252–257; Coen, 2011, pp. 51–55).

Recent work by environmental historians and historical geographers also reveals the importance of Russian expansion into arid Central Asia during the later 19th century in shaping the thinking of Voeikov and his near-contemporaries on the inextricability of air, earth, and water when defining climate and its influences (Bichsel, 2022; Keating, 2019, 2022; Oldfield, 2020; Peterson, 2019). Voeikov was a leading voice calling for modern meteorological instruments to be located throughout the empire to adjudicate between competing theories of climate change (Moon, 2010, pp. 267–268). He was thereby a key player in the narrowing of whose evidence counted in Russian climatology and the initiation of what present-day climate scientists recognize as useable data sets from large swathes of Russia's southern and eastern imperial territories. This framing of climate and associated shifts in recording techniques had enduring effects, influencing the likes of Mikhail Budyko, a major contributor to climate science within and beyond the Soviet Union in the second half of the 20th century (Oldfield, 2016, pp. 683–685).

This section has focused on two long-lasting land empires in Eurasia—China and Russia—highlighting overlaps and resonances, but also differences, between imperial priorities and climate knowledge in each. Deborah Coen claims that during the 19th century, continental polities extending over substantial contiguous territories developed a distinctive shared type of climatology marked by "'regionalization' with a global vision" (Coen, 2011, p. 45). Encouraged by the notion of empire as an integrated unit in which people and goods circulated, scientists tended to be concerned with determining climatic regions while also "follow[ing] atmospheric phenomena" that crossed continents (Coen, 2011, pp. 46–48). These core features of multiscalar climatology can also be found in a polity whose status as a continental empire is easily overlooked: the United States. Zeke Baker argues that understandings and measurements of weather and climate followed settler colonial priorities. Racial stratification and militaristic expansion, Baker (2018) suggests, underpinned a shift during the first half of the 19th century away from the notion that human activities substantially changed climate. The spread of industry and settler agriculture during the second half of the 19th century across the continental expanse reinforced a twin concern with defining stable climatic regions and tracking atmospheric phenomena across large distances (Baker, 2021). The kinds of climate data produced and the frameworks within which they were understood shared striking similarities in the United States, Russia, and Austria-Hungary during the 19th century, suggesting that there was indeed a continental-empire type of climatology. Future research might attend to how such continental imaginaries influenced conceptions of climate (and inter-imperial networks of observation) across colonial and postcolonial political boundaries in continental and subcontinental regions such as Africa, the Middle East, and even Antarctica.

7 | INFORMAL EMPIRES AND NEOCOLONIALISM

In meteorology and climatology as in many other field and survey sciences, Euro-Western knowledge production extended far beyond the official boundaries of imperial sovereignty. As well as the settler colonial imperatives that shaped climate data production within its national territory, the United States also obtained atmospheric and oceanic data as part of overseas commercial and military activities that can be labeled "informal imperialism" (Immerwahr, 2019). Jamie Pietruska (2016) demonstrates how the U.S. Weather Bureau expanded its instrumental infrastructure into the Caribbean in the 1890s, initially with the limited aim of protecting American ships from hurricanes. However, there quickly emerged another intention: to facilitate external investment in agriculture in the region. The American military's concern during the late 19th century to secure safe passage for military and trade vessels also extended westwards across the Pacific, as far as Japan. A station located at the U.S. Naval Hospital in Yokohama was supplied with American-manufactured instruments and incorporated into the Smithsonian Meteorological Network, managed by the War Department of the Federal Government (Takarabe, 2020).

The complexities of imperialism in East Asia in the 19th and 20th centuries crucially inflected meteorological observations and climate knowledge-making across the East China Sea as well. French Jesuit missionaries had long played important roles in meteorological recording in coastal China, operating an observatory in Shanghai. From the mid-19th century, the Qing Empire faced increasingly intensive interference from numerous European empires. The enforced opening of China to European trade led to a new meteorological observatory system headed by the British mercantile community. It was based in Shanghai and Hong Kong and connected by telegraph to stations beyond Qing borders, including the Russian port city of Vladivostok, Nagasaki in Japan, and British-governed Malaya (Bickers, 2016; Williamson & Wilkinson, 2017; Zhu, 2020). The Deutsche Seewarte (German Naval Meteorological Research Observatory) also constructed an extensive network of stations through its power bases in China and the western Pacific (von Storch & Gräbel, 2018, p. 4).

EMPIRES …
… relied on the knowledge and labour of Indigenous and local peoples in efforts to understand climatic change over time and space **(section 3)**
… actively erased or devalued the contributions of Indigenous and local peoples' knowledge if it did not suit their ideologies and ambitions **(section 4)**
… built infrastructures for measuring and conceptualising a global climate system as part of their efforts to expand their strength, wealth, and influence **(section 5)**
… made particularly deep investments in climatic research when they sought to expand across contiguous land masses **(section 6)**
… laid the foundations for enduring unequal power dynamics in the collection, analysis, and presentation of climate science data **(section 7)**

FIGURE 2 Five areas of influence between imperialism, colonialism, and climate science.

Despite the scale of these communication networks, recent scholarship on weather and climate knowledge in East Asia during this period foregrounds the fragility and contingency of data production and dissemination in European-run observatories and field sites. In the wake of its violent seizure of the port city of Qingdao in 1898, German plans to train Chinese meteorological observers to staff a projected China-wide network came to little (von Storch & Gräbel, 2018, pp. 6–7). And despite imperial governments' reliance on Jesuit meteorology in many locations (Anduaga, 2022), in places such as Hong Kong, observatories run by European colonial governments and those operated by the Jesuits issued directly competing forecasts and data sets (Zhu, 2020, pp. 6–13). In other cases, Europeans collaborated more closely on transnational or transimperial projects of climate knowledge. For example, the British colonial state in India employed the German Schlagintweit brothers in the 1850s to garner data in the Himalaya and Central Asia across a range of geophysical fields, including meteorology and climatology. Their extensive publications drew on measurements at 250 stations and constituted "the first comprehensive survey of weather conditions in both India and High Asia" (von Brescius, 2018, p. 304). They were also among the key advocates of the establishment of an Indian Meteorological Department (discussed in Section 4).

Transimperial collaboration was a feature of the expansion of meteorological measurement into the upper atmosphere around the turn of the 20th century as well. At the forefront of this vertical extension was the Deutsche Seewarte, grounded in the imperialist aspirations of the newly unified German state despite the internationalist leanings of its Russian-born director Wladimir Köppen. In Robert-Jan Wille's words, the Seewarte "serviced the whole of the German Empire with gathering data and doing scientific studies benefiting maritime meteorology, meteorological instruments, and storm warnings" (Wille, 2017, p. 109). German naval vessels took upper atmosphere measurements far beyond continents and into remote reaches of the South Atlantic, Pacific, and Indian Oceans. International connections also mattered, however: the expansionist powers of the United States, France, and Russia were all deeply engaged in intersecting projects to regularize upper atmosphere observations. The shift to understanding and measuring weather and climate in three dimensions was, then, a profoundly imperial undertaking (Achermann, 2020; Wille, 2017, p. 116).

The move "from climatology to climate science" during the 20th century was predicated on Euro-Western powers' penetration of high latitudes as well as high altitudes (Heymann & Achermann, 2018). Colonial dynamics persisted into the later 20th century at crucial sites of climate knowledge production such as ice coring stations. Recent scholarship highlights cases such as Danish paleoclimatologist Willi Dansgaard's work during the 1960s at the American military research base Camp Century in northwest Greenland (Doel et al., 2016; Dry, 2019, pp. 231–270). Dansgaard's earlier

research had made use of the remnants of Danish colonial enterprise, employing materials collected across the world at outposts of the East Asiatic Company (Dry, 2019, p. 234). His subsequent access to Greenlandic ice was enabled by Danish neocolonial power following Greenland's formal shift from a colony to a county of Denmark in 1953, and also by Denmark's Cold War alliance with the United States (Nielsen & Nielsen, 2016). Such instances are indicative of how key aspects of the advent of modern climate science during the Cold War were predicated on the continuation of colonial power dynamics and geopolitics beyond the formal conclusion of imperial rule. A great deal more work remains to be done to explore how these neocolonial structures inflected climate data production and theorizing during an era that existing histories of climate science tend to characterize as one defined solely by the ideological struggle between communism and capitalism.

Colonialism not only underpinned vital infrastructures of climate science in the later 20th century; it also continued to shape whose knowledge counts in climate science. Antonello and Carey (2017, pp. 189–190) explain this phenomenon in the case of ice cores, suggesting that "only certain societies have been enrolled" into discussions of what ice cores can tell us about climate history. Jen Rose Smith and Klaus Dodds take this contention further, arguing that global stories of past and present climate change told from ice cores can risk assisting efforts to dispossess Indigenous peoples of their lands and livelihoods in the Arctic (Dodds & Smith, 2022; Smith, 2020). This is an apposite point at which to hand over from an overview of how imperialism and colonialism have shaped climate change science historically to the burgeoning literature exploring the relationship between Indigenous knowledge and climate science today (Smith & Sharp, 2012; van Bavel et al., 2022).

8 | CONCLUSION

In the five years since the publication of Mahony and Endfield's important overview of historical literature on climate and colonialism (2018), the number of works of history dealing with these themes has exploded as has the diversity of their sites of study. Yet the scientific literature still tends to assume that imperialism, colonialism, and climate science share their most intimate relationship in terms of the *physical* and *structural* legacies left by the imperial and colonial projects of earlier centuries. Historic and ongoing forms of imperialism and colonialism, it is often stated, are a key cause of the unequal impacts of climate change that are felt across the world, making some peoples more vulnerable to the effects of a warming planet than others (Pörtner et al., 2022). In this article, we have shown that there are also crucial *intellectual* legacies. Drawing on each of the five core sections of this article, we can identify five key ways that imperialism and colonialism have influenced the development of climate science, and vice versa (see Figure 2).

There is also more work for historians to do in examining the intertwined histories of imperialism, colonialism, and climate science. This review identifies that further research is still essential to better understand the roles played by Indigenous and local peoples in the development of the modern field of climate science, both in the realm of ideas and labor. Relatedly, the range of motivations that shaped Indigenous and local peoples' historic engagement or disengagement with practitioners of the fledgling field of climate science in the 19th and 20th centuries remains under-examined. Research in these areas would help to historicize more recent efforts by climate scientists to engage with and Indigenous and local climate knowledge, and even help guide future exchanges.

Notwithstanding the rapid expansion during the past five years of histories of climate sciences, coverage remains uneven across different empires and colonies. While the British and French empires—especially in India and northern Africa respectively—have well-established climate science historiographies, climate theorizing and data production in the Ottoman and Iberian (Spanish and Portuguese) empires are notably under-researched. Although their preponderance peaked in the early modern rather than modern era, these empires continued to have substantial sway over large territories and populations throughout the 19th and into the 20th centuries. Comparative studies that directly compare the development of climate science under different imperial and colonial regimes are another promising area of future research and would help to give the field a more rigorous theoretical foundation.

Finally, research on the influence of mid- to late-20th century decolonization movements on the development of national and international climate science agendas is a promising area of inquiry, as is the influence of the interaction of Cold War politics with neocolonial projects in sites deemed crucial to climate science research. As historians turn their attention to these topics, they can help to highlight the imperial and colonial power dynamics that still shape climate science, as well as neocolonial dynamics that continue to inflect new climate data and theories.

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Harriet Mercer: Conceptualization (equal); investigation (equal); writing – original draft (equal); writing – review and editing (equal). **Thomas Simpson:** Conceptualization (equal); investigation (equal); writing – original draft (equal); writing – review and editing (equal).

CONFLICT OF INTEREST STATEMENT

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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