



Full Length Article

Volumising territorial sovereignty: Atmospheric sciences, climate, and the vertical dimension in 20th century China

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A B S T R A C T

Works in Political Geography have focused on the exercise of territorial sovereignty beyond land, emphasising the voluminousness and dynamism of material forces that condition how territory is governed. In comparison, works on modern territorial statehood in IR have generally overlooked the question of materiality. By combining the attentiveness to more-than-human materiality in Political Geography with IR's focus on the role of epistemic transformations in the history of the modern international system, this article proposes a more comprehensive understanding of territorial sovereignty and modern statehood as constituted by the technoscientific management of the territory's materiality. Using the development of atmospheric sciences in the 19th century as an example of science-state entanglement in the emergence of the modern international system, this article shows that the integration of atmospheric knowledge production with state and international governance produced the vertical dimension as a realm of governmental concern. Through a detailed case study of the development of atmospheric sciences in early 20th-century China and scientific ideas about China's climate, this article demonstrates how the scientific discovery of the vertical dimension reconfigures territorial sovereignty as sovereignty over volume.

1. Introduction

The modernist conception of territory has long been critiqued for its Eurocentric, ahistorical, and statist understanding of political-geographical relations based on the 'Westphalian model of territorial sovereignty' (Halvorsen, 2019; Usher, 2020, p. 1022). Scholars in Geography and International Relations (IR) have generally viewed the notion of territorial sovereignty and its conceptual bundling of territory with statehood to be a historically specific arrangement that first emerged in Renaissance Europe (Elden, 2013b; Kratochwil, 1986; Ruggie, 1993). What is less clear is how the historical peculiar arrangement of territorial sovereignty and an international system of territorial states that are purportedly sovereign over their respective territories rather than each other, became a global phenomenon. Moreover, the territorial state continues to be the dominant form of political authority in the international system and territorial sovereignty remains the object of contestation to national liberation movements, border disputes, and backlash against the transnational governance framework (Antonsich, 2009; Murphy, 2013).

When we move away from *de jure* territorial sovereignty to see how a state's territorial governance functions 'on the ground', it appears that territorial sovereignty entails a great deal more than two-dimensional claims represented on maps and requires the control of three-dimensional environmental and cyberspace (Billé, 2020; Wirth, 2023; C. Zhang & Morris, 2023). Recent works in Political Geography have

increasingly engaged with the material aspects of territorial statehood and conceptualised territorial sovereignty as the control of 'volume' rather than flat earth divided by linear borders (Billé, 2020; Peters et al., 2018). In doing so, territorial governance is viewed as the quotidian effect of the interactions between anthropogenic political orderings and the more-than-human materiality of environmental, technological, and biological entanglements (McNeill, 2019; Squire & Dodds, 2020; Zee, 2022). The discipline of International Relations, owing to its epistemic starting point 'the international' remains focused on intellectual and conceptual histories of spatial practices that naturalised the modernist conception of territory (Lambach, 2022, p. 285; Shah, 2012). In doing so, IR has neglected the material dimensions of the modern territorial state.

This article argues that there are productive synergies between Political Geography works on the politics of territory and materiality with IR works on the historical entanglement between technoscience and the modern international system. The globalisation of technoscience and its entanglement with territorial statehood, offers an important clue to the emergence of territorial states around the world. In the first section of the article, I argue that by turning to 'volume' (Elden, 2013a), extant works in Political Geography on materiality and territory create two further questions that require further engagement: 1) The tension between socially constructed environmental knowledge and more-than-human materiality; 2) the historical entanglement between the globality of technoscience and the territorial state. Building on the

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insights of recent IR works the epistemic transformations that produced functionally similar territorial states and the international system at large (Allan, 2018), as well as science and the control of nature as prerequisites of international status and statehood (Yao, 2022), I argue that there is an endogenous historical relationship between the understanding of state territories as ‘demarcated nature’ and sociotechnical imaginaries of territorial sovereignty at large. The historical relationship between the two not only renders the materiality of territory ‘calculative’ using certain metrics to represent terrain (Elden, 2021) but also produces environmental objects that can be measured and governed in the first place (Allan, 2017b; Braun, 2000).

Using the 19th century development of atmospheric sciences in Europe and its colonial territories as an example of science-state entanglement, I argue in the second section that the territorial state’s technoscientific infrastructure and bureaucratic organisation, alongside international prestige and political influence of science made atmospheric sciences global. In return, the standardisation, bureaucratisation, and international collaboration enabled by the science-state entanglement allowed atmospheric sciences to produce the vertical dimension as a realm of governmental interventions. Finally, to separate analytically the productive power of technoscience from modern territorial logics of enclosure and exclusivity, I use the development of atmospheric sciences in the Republic of China (1912–1949) as an example of how technoscience can not only naturalise the territory as a pre-social physical environment but also configures how the territory and population are governed. The discovery of large-scale atmospheric circulations and their impacts on climatic variations within China in the 1930s by Chinese scientists with the aid of new infrastructure and data, I argue, helped to produce a three-dimensional understanding of Chinese territory as engulfed in the voluminousness of a distinctively ‘Chinese’ climate. The acclimatised territory of China, naturalised through the dynamic interplays between seasonal atmospheric circulations, and oceanographic, and topographic features beyond China, gave rise to a conception of Chinese territory as a mostly arid and overpopulated environment in need of governmental interventions.

2. Technoscience, international order, and materiality of the modern state: What IR and Political Geography can learn from each other

The modern international system is made up of states that are purportedly sovereign over two objects: the physical territory and the population within that territory (Bartelson, 1995, p. 23). Through processes of decolonisation after the Second World War, the modern international system became the domain of functionally identical units: the territorial state (Barkawi, 2017). Over the past few decades, scholars in the discipline of International Relations (IR) have been deconstructing and historicising the territorial state and the modern international system based on the notion of territorial sovereignty (Bartelson, 1995; Krasner, 1999; Ruggie, 1993; Walker, 1993). IR scholars have generally agreed that the so-called ‘modern territoriality’,¹ which defines the modern international system, refers to the geographical compartmentalisation of legitimate political authority (Goettlich, 2019, p. 204). The entanglement between territory with notions of sovereignty and statehood, however, appears to have messy and complex historical origins that are partly explained by European expansion (Craven & Parfitt, 2018; Geertz, 2004). More recent works by IR scholars have traced the universalisation of the territorial state to historical and contemporary

¹ Compared to IR scholars who conceive territoriality in Robert Sack’s conception as the deliberate strategy to create bounded space for control (Ruggie, 1993; Sack, 1983), geographers tend to operate with a looser understanding of territoriality and see the production of territories as being embedded in a wider set of relations that are neither geographically bounded nor confined to a specific political authority (Murphy, 2012; Raffestin, 2012).

territorialising efforts made by non-Western actors with diverse epistemic origins (Getachew, 2019; Li, 2022; Mukoyama, 2023; Shadian, 2010; C. Zhang & Morris, 2023).

Despite highlighting the diverse conceptual and technological foundations required for the universalisation of territorial states, IR scholars have generally taken the materiality or environmental qualities of state territories as self-evident attributes of physical space and focus instead on abstract spatial concepts such as the ‘international’ (Lambach, 2022, p. 284). In doing so, IR scholars largely perpetuate the modernist understanding of state territories as the physical substratum for politics (Shah, 2012, p. 68). In this regard, there are considerable synergies between IR’s historicisation of the modern international system and Political Geography’s attentiveness to the complex interplays between materiality and spatiality in the control and governance of a state’s territory.

As scholars in IR delve further into the historicity of the spatial logics that underpin the modern international system, many political geographers have shifted their attention away from spatiality towards materiality. Political geographers have become critical of taking the materiality of state territories for granted as either fixed or self-evident (Usher, 2020, p. 1023). Following the more-than-human turn (Whatmore, 2006) and older works on socionatural entanglements (Haraway, 1990; Latour, 1993; Swyngedouw, 1999), Political Geography has developed the conceptual and methodological toolkit required for studying how material forces configure the spatiality of territorial governance (Billé, 2020; Elden, 2013a, 2017, 2021; Squire, 2016; Squire & Dodds, 2020; Steinberg, 2009). Returning to the discipline’s earlier concern with the role of biological, geological, and other environmental forces in anthropogenic political histories (Barua, 2018), scholars are seeking to de-centre the ‘state ontology’ of static, geometric conceptions of territories and foreground the dynamic physical properties of environmental features (Peters et al., 2018; Peters & Steinberg, 2019; Steinberg & Peters, 2015). The move towards materiality has not only highlighted how the terrain is prefigured in the contestation and control of a state’s territory (Elden, 2013a) but also that *de facto* territorial sovereignty is often manifested as the control of ‘volume’ through technoscientific means and governance through ‘volumetrics’ (J. Clark & Jones, 2017; McNeill, 2019; Squire & Dodds, 2020).

Foregrounding the materiality of state territories requires us to pay attention to the ‘spatial relation between humans and nonhumans (re) produced materially and symbolically through daily practices’ (Marston & Himley, 2021, p. 3). Political geographers have favoured quotidian practices and micropolitics of territorial governance in part because the politics of materiality often exceeds and escapes what can be captured by cartographic and statist representations, as environmental forces tend to unfold in unexpected, dynamic, and visceral manners (Billé, 2020; Boyce, 2016; Squire, 2016). The physical world upon which territorialisation takes place, as Steinberg and Peters argue, is neither flat nor divided into ‘fixed hierarchical strata and scales’ (Steinberg & Peters, 2015, p. 248). Moreover, bodily-environmental entanglements mean that territorial governance often requires material practices that bring together biopolitics and geopolitics (Adey, 2009). State interventions in the environment through regulatory and infrastructural means are necessary to produce spaces that can be inhabited, controlled, and ultimately territorialised by a political authority (McNeill, 2019). By delving further empirically and conceptually into processes of territorialisation as ongoing encounters between the anthropogenic political orders, scientific knowledge, and technologies, with socionatural entanglements, the territorial state looks increasingly like a technoscientific state as the so-called ‘modern territoriality’ in IR is made possible by techno-territorial interventions to produce a physical environment that can be controlled by the state (Carroll, 2006; McNeill, 2019).

Nevertheless, there are two critical aspects that require further theoretical engagements in the turn to materiality through conceptual vocabularies such as volume, depth, verticality, and fluidity (Billé, 2020;

Elden, 2013a; Peters et al., 2018; Steinberg & Peters, 2015). The first aspect concerns the relationship between environmental knowledge and the materiality of the physical environment. Even though the role of environmental knowledge and technologies have often been used by political geographers to explain how environmental forces are understood and governed by political authorities (J. Clark & Jones, 2017; McNeill, 2019). The analytical focus of existing works on territorial knowledge production and materiality tends to emphasise the calculative rationalities which enable the quantification, management, and division of environmental features and resources. In the seminal work on the voluminous nature of territory, Elden stopped short of identifying 'calculation and metrics' and 'biometrics and geo-metrics' that bring together biopolitics and geopolitics themselves as objects of political contestation (Elden, 2013a, p. 49). The three-dimensional view of territories is enabled by the use of volumetrics by state authorities (Billé, 2020, p. 5). However, existing scholarships on materiality tend to overlook the conceptual and intellectual history of the environmental phenomena that are made visible using specific metrics.

Seen in this light, we need to examine the politics and historical origins of the environmental knowledge that allowed territories to be conceived as 'volume'. Environmental phenomena are not revealed to us through ready-made natural categories but are construed and communicated through concepts that are used to organise knowledge about properties and processes (Bocking, 2015). More importantly, the scholarly ability to speak for materiality is also dependent on the production of environmental knowledge and concepts. For instance, Steinberg and Peters' proactive call for a 'political ontology' centred on flows and circulations is undergirded by modern scientific knowledge about the molecular, physical, and geophysical properties of liquid particles and the sea against a mainstream flat terrestrial cartographic imagination (Peters & Steinberg, 2019). It is not possible to talk about the volume and fluid properties or write about a 'wet ontology' without specific forms of environmental knowledge, scientific concepts, and technologies that are approximated to physical realities. Therefore, there is a productive tension between the use of environmental knowledge to invoke materiality and the critique of environmental knowledge production's complicity in the territorialisation of volume and reproduction of social hierarchies (Bakker & Bridge, 2006; Braun, 2000; Bridge, 2013). Notably, the tension between the social construction of knowledge and the more-than-human materiality has prompted some political geographers to produce their own knowledge of materiality through immersive research methods or to recover underprivileged forms of environmental knowledge from the micropolitics of everyday territorialisation (Squire & Dodds, 2020). Compared to bodily knowledge and indigenous cosmologies that are potentially emancipatory, calculative conceptions of territory and terrain are directly imbricated with the imperial, military, and economic logics of control (Jackman et al., 2020).

The forms of authoritative knowledge that are often held in opposition to knowledge produced by marginalised and colonial subjects are typically labelled as 'scientific' (Braun, 2000; Hommes et al., 2022, p. 4; S. A. Marston et al., 2005, p. 3). The emphasis on the use of 'calculative technologies' in existing works on territorial knowledge production in different historical and geographical contexts, for instance, seem to be undergirded by the Eurocentric historiographical narrative of the triumph of (European) rationality, technological advancement, and the globalisation of modern science (MacLeod, 1992). Nevertheless, while the 'scientific' status and production of environmental knowledge are admittedly context-dependent and sociological, they cannot be explained away through anthropocentric politics (Latour, 2000). By bringing into view the existence and operation of the 'natural' environment that is also beholden to socially intelligible laws and rationales, scientific knowledge production wields productive and epistemic forms of power that are derived from its ability to 'speak for nature' (Demeritt, 2002, p. 778; Latour, 2000; Pedynowski, 2003, p. 739). The role of environmental knowledge production, specifically ones that assumed

authoritative and scientific status, is not simply calculative or technical. Instead, they appear to have productive power over the socio-natural configuration of a state's territory (Demeritt, 2002, p. 781). In other words, we do not simply see the voluminousness of a territory's materiality through our own bodily or cultural registers, but also through a socio-natural assemblage that also involves technological, infra-structural, and scientific apparatuses which bring specific material properties into being (N. Clark, 2017, p. 221).

More importantly, the multi-scalar nature of scientific knowledge production cannot be dismissed through the situated and context-dependent nature of scientific knowledge production (Pedynowski, 2003). Although the scientific status of knowledge is derived from the claim to universality, the production of knowledge is hinged on site and scale-specific dynamics that are not necessarily salient at other scales nor contradictory to the presumed universality and globality of the said knowledge (Jordheim & Shaw, 2020, p. 8; Livingstone, 2003; Pedynowski, 2003, p. 745). Seen in this light, when delimiting the relations between environmental knowledge production and the (re)production of state territories, we need to distinguish between territorially organised environmental knowledge production and the embeddedness of modernist territorial logics in environmental knowledge production in general. Whereas the former has the potential to reconfigure the governmental rationalities of territorial sovereignty over materiality and volume, the latter might simply be a derivative of the 'allure of territory' as the dominant form of political geographical imagination in general (Murphy, 2013). It is unlikely that all scientific knowledge about the environment (re)configures governmental rationalities and territorial sovereignty or that all scientific knowledge can be explained through the territorialising impetus of actors acting in the name of the state.

The distinction between territorially organised knowledge production and the territorial logics of knowledge production brings us to the second aspect that calls for further theorisation in the turn to volume in Political Geography, which is the under-explored global historical connections between the emergence of the modern territorial state and modern environmental sciences. Political geographers have observed the historical coincidence between specialist environmental knowledge production and state-building through geological surveying and resource exploitation (Bakker & Bridge, 2006; Bridge, 2013, p. 56; Squire & Dodds, 2020, p. 4). Nevertheless, existing works tend to focus on how the materiality and the volumetric dimensions of territories challenge the static terrestrial imaginary of territorial sovereignty conceptually, materially, and in everyday governance (Billé, 2020; Peters et al., 2018; Usher, 2020, p. 1035). The focus on more-than-human materiality and the methodological approach that centres on the everyday, bodily micropolitics of territorialisation in volumetric spaces can inadvertently conceal a larger global historical process towards voluminous territorial sovereignty.

The intertwined developments of modern environmental sciences and the modern territorial states, alongside the overlaps between environmental and territorial knowledge production, can help explain why efforts to manage depth, volume, subterranean and vertical dimensions often accompany *de facto* territorial sovereignty. In this regard, there are productive synergies between the focus on the politics of materiality in Political Geography and IR's focus on the globality of the modern territorial state and scientific knowledge. Despite IR's limited engagement with materiality, its scholars can provide the global historical context and systematic explanation of the territorial state's privileged position in socio-natural governance. Recent IR studies on scientific knowledge, hierarchy, and international order provide a useful blueprint for understanding the integration between territorial sovereignty and environmental governance (Allan, 2017a, 2017b, 2018; Yao, 2019, 2021, 2022). Overall, IR's macro-level insights remind us that the effective management of the natural environment through scientific knowledge and technology has been construed as a marker of effective statehood and territorial sovereignty from the inception of the modern

international system.

For instance, bridging the history of science and the history of international relations, Allan has argued that modern sciences have reshaped the normative foundations of state governance and the international system at large by normalising the idea of progress and social improvements (Allan, 2018, p. 20). Through the unit-level transformation and top-down systematic pressure, scientific and technological developments reshaped international system at large by the late 19th and early 20th century (ibid). Allan's observations are supported by Bartelson's conceptual history of sovereignty in the European context (Bartelson, 1995). Bartelson connects the idea of territorial sovereignty to epistemic shifts that coalesced political authorities with knowledge about the constitutive elements that make up the state (ibid:190). Modern government is necessitated by the production of specific governance objects such as the climate or the economy (Allan, 2017a, 2017b; Mitchell, 2002). Starting from the subject-centred approach, Yao's research complements the object-centred historiography of the modern international system by exploring how states' commitment to scientific knowledge and governance objects are enforced through the 'Standard of Civilisation' which privileges the 'taming of nature' and construes science as a status symbol (Yao, 2019, 2022). States are driven by external and internal forces in their attempts to gain status and recognition for their statehood. Indeed, from the denial of nationhood to indigenous peoples owing to their situational proximity to the state of nature (Connolly, 1994, p. 24) to alleged environmental mismanagement by the so-called failed state (Brooks, 2005, p. 1160), the control of nature has operated as a benchmark for effective statehood in the modern international system.

To summarise this section, Political Geography literature on the politics of materiality and state territories needs to reconsider its existing perspective on territorial knowledge production as a political-technical activity that converts volume to metrics (Bridge, 2013, p. 57; Elden, 2013). It is essential to recognise that prior to the use of statistical and mathematical rationalities, environmental forces and physical characteristics must be translated into legible environmental objects for political intervention (Braun, 2000, p. 28). Additionally, the enduring appeal of territorial sovereignty, remains evident across different geographical scales even as the analytical focus is shifted to the bodily, the everyday, and geophysical and dynamic prosperities. Thus, the next step is to move beyond pointing out how material forces defy or traverse the spatial logics of the territorial state, and instead delve into the historical roots of modern territorial sovereignty as the technoscientific management of materiality.

3. 19th century atmospheric sciences and the discovery of the vertical dimension

From aerial bombardments, and air pollution, to the planetary climate system, the vertical dimension is a crucial site wherein more-than-human forces are constitutive of the modern international system (Allan, 2017b; Asher, 2021; Brandimarte, 2023). The vertical dimension is characterised by physical properties and environmental forces operating at various scales, including the physical and chemical properties of aerosols, the airspace itself, and atmospheric phenomena. These elements, once made visible and conceptualised, can become the targets for military, technoscientific, legal and regulatory interventions by territorial political authorities (Lin, 2018). This section outlines the historical intertwining of atmospheric sciences and the territorial states in the 19th century, thereby demonstrating how the interactions between political and scientific concerns at different levels transformed weather and climate into governmental concerns for territorial settler-colonial, national, and imperial authority by the late 19th century.

The concept of a unified planetary climate system contrasts sharply with the anthropocentric conception of the world divided into national territories. However, before the present era of Earth System Science, computer modelling, and global climate, the concept of climate itself in

the 19th century was geographically bounded. In the *Handbook of Climatology* written by the founder of modern meteorology Julius von Hann, climate is said to be distinguished from weather, as the 'sum total of the meteorological phenomena that characterise the average condition of the atmosphere at any one place on the earth's surface' whereas weather is 'only one phase in the succession of phenomena' (Hann & Ward, 1903, p. 1). Atmospheric sciences were therefore characterised by the division of labour between Meteorology, whose task was to uncover the physical laws governing atmospheric happenings, and Climatology, which focused on describing long-term weather patterns' impact on life, economy, and nature at a specific location (Heymann, 2019, p. 1551). Nevertheless, by the 19th century, climate has emerged as a distinctive environmental force that needs to be taken into consideration by political authorities (Fleming & Jankovic, 2011).

The emergence of climate as a standalone environmental force was inseparable from the histories of European colonial expansion during the 17th and 18th centuries. During this period, climate transformed from its original Greek meaning as latitudinal distribution of solar heat to encompass geophysical and biological characteristics with socio-economic implications for maritime trade and plantation economies (Jankovic, 2010, p. 203). This conceptual transformation framed climate as an active force, setting the stage for its later recognition as an object of scientific research, and governmental interventions in agricultural and social planning. The conceptual history of climate reminds us that climate was first imagined as a 'force' and only then became a statistical index (Fleming & Jankovic, 2011, p. 2) during the professionalisation of naturalists as environmental scientists across the European colonial world (Grove, 1997, p. 310).

In the early 19th century, Alexander von Humboldt's works established the paradigm that climatic variations across different scales can be aggregated to reveal larger planetary forces (Jackson, 2009). The awareness of larger atmospheric forces gathered from maritime travels and colonial explorations made atmospheric scientists increasingly aware of the lack of instrument data as well as the discrepant and idiosyncratic nature of data collected by different actors (Edwards, 2013, p. 36). To resolve the challenge of data idiosyncrasy and relative scarcity, and to smooth out data sharing, atmospheric scientists saw political authorities in Europe and the colonies as a useful ally. The creation of national weather services across Europe, the United States, and settler colonies by the mid to late 19th century marked the start of the integration of atmospheric sciences into the framework of territorial governance (Baker, 2018; Coen, 2011, 2018; Edwards, 2006; Kerr, 2017; Mahony, 2021; Mahony & Randalls, 2020). Moreover, the 19th century saw the insertion of atmospheric sciences into the technological infrastructure of the modern territorial state through the former's use of telegraph, national standard time, and cartographic surveys (Hom, 2010). In return, by becoming a part of the technoscientific apparatus, the bureaucratisation of atmospheric sciences enabled the standardisation of observational practices and the construction of weather maps that allowed one to 'see' the weather across geographical space on a given time and day (Nebeker, 1995, p. 4).

At the international level, the establishment of the International Meteorological Organisation in 1873 exemplified efforts by the trans-national network of atmospheric scientists to transcend territorial boundaries through what Paul Edwards calls 'Infrastructural Globalism' (Edwards, 2006, pp. 231, 2013:50). The international scientific, technological, and bureaucratic networks enabled territorial authorities to issue synoptic weather forecasts using data from other countries that are transmitted through international telegraph networks (Edwards, 2006). By the end of the 19th century, these developments, alongside the systematic collection of meteorological data, and the use of statistical analysis, laid the groundwork for climatology to emerge as a distinctive subfield of atmospheric sciences (Nebeker, 1995, p. 22-3). Embodying the state-science entanglement, key figures of modern atmospheric sciences such as Julius Hann and Wladimir Köppen also served as the head of governmental weather services of Austria and Germany, respectively.

Despite the scientific focus on the extraterritorial and vertical dimensions of atmospheric forces, the work of meteorologists and climatologists was deeply entrenched in the personal, professional, and institutional contexts that were shaped by concerns with territorial control, nationalism, and the international politics of imperialism and colonial hierarchies. The use of scientific knowledge and international cooperation in the realm of socioeconomic improvements in terms of agriculture, health, and communication was a marker of civility and sovereign statehood in the European-dominated international system (Allan, 2018, p. 155). The development of atmospheric sciences, too, reflected the status symbolism of science and the control of nature as a marker of civilisation and effective statehood in the 19th-century international system (Mahony, 2016, 2021; Mahony & Endfield, 2018). This international scientific hierarchy was evident in the context of the first International Meteorological Congress in Vienna. The only non-European country that was invited to attend was Qing-China, which was represented by the semi-colonial Chinese Maritime Customs Service run by foreign management and staff (the Meteorological Committee of the Royal Society, 1874, p. 4).

At the national level, ideological and practical concerns of national political authorities and scientific communities also shaped atmospheric knowledge production. The logic of territorial consolidation through 'naturalisation' and the narrative of control was common across various colonial and national contexts. In colonial Asia for instance, European and Japanese authorities competed to assert 'control' over the weather through the issuance of forecasts (Williamson & Janković, 2020; Williamson & Wilkinson, 2017; M. Zhu, 2020). In Habsburg Austria, climatology emerged not only as a scientific and technical endeavour aimed at improving agriculture and economic conditions but was also a part of the imperial efforts to fend off the challenge of nationalism to the multifarious empire through the naturalisation of climatic diversity within the empire (Coen, 2010, 2018). British meteorologists, on the other hand, had a particular interest in studying the atmosphere as a global, interconnected system compared to their Continental counterparts thanks to the British Empire as an empire of 'all types of climates' (Coen, 2011; Mahony, 2016). In expanding settler-colonial states such as the U.S. and Argentina, the collection of weather data and the study of local climates in the 19th century were directly incentivised by the efforts to gain control over new territories by agents acting in the name of the state (Baker, 2018; Dimas, 2022). As Ghertner reminds us, atmospheric knowledge production remains inseparable from the 19th-century legacies of racialised geographies (Asher, 2021). The establishment of the India Meteorological Office by the colonial Government of India reflected the public health, economic, and trade interests and concern with tropical atmospheric happenings epitomised by 'the monsoon' (Carson, 2021, p. 310; Cullen & Geros, 2020).

The production of 'climate' as an environmental object and the institutionalisation of atmospheric sciences by territorial states made visible the materiality of the vertical dimension. This historical process of science-state entanglement can be partially explained by the opportunistic and strategic convergence between scientific and political rationalities (Mahony & Calioti, 2017). However, the visibility of planetary atmospheric circulations and the land-atmosphere nexus cannot be reduced to pre-existing political concerns. Both atmospheric forces and the atmospheric sciences are global in their outreach, and both cut across the scalar hierarchy of the modern international system. Neither the site of atmospheric knowledge production nor its political influence is confined to a specific geographical scale and political context. In this regard, Coen's concept of 'seeing across scales' encapsulates the process of integrating atmospheric phenomena into a coherent environmental object that is meaningful in the context of anthropogenic political orders (Coen, 2011, p. 47). Scientists working for national weather services assembled the climates of their respective states from meteorological data across different spatial and temporal scales (Coen, 2018; Williamson & Janković, 2020). Their efforts made scientific knowledge about the climate both socially relevant and

politically potent. With the support of national and international institutions, and technoscientific infrastructures, 19th-century atmospheric scientists allowed the vertical dimension of state territories to be conceived as volume, measured using metrics such as temperature, air pressure, and precipitation.

4. Acclimatising the nation-state: Territorial sovereignty, atmospheric sciences, and climate with Chinese characteristics

The dominance of Euro-American empires in 19th-century atmospheric knowledge production raises the question of whether atmospheric sciences only shaped territorial governance in colonial and imperial contexts. Therefore, it is worth looking beyond European nation-states and their colonial territories to better understand the dynamics between environmental knowledge and territorial knowledge production. As a weak, modernising territorial state in the early 20th century, the Republic of China (1912–1949) can be used as an empirical case study to better understand how environmental science prefigures in nation and state-building efforts and how technoscience configures the political rationalities of territorial governance beyond the contexts of European nation-states and colonial empires. The remainder of this article demonstrates how atmospheric knowledge production in early 20th-century China largely resembles the state-science entanglement pattern in mid to late 19th-century Western territorial states and colonial territories. Moreover, I argue that the establishment of a national weather service, the expansion of meteorological infrastructure, and new scientific ideas about atmospheric circulation, coupled with existing political concerns with territorial cohesion and population governance gave rise to a volumetric conception of Chinese territory. The visibility of the territory's vertical dimension, enabled by the environmental object known as 'climate' (氣候) allowed environmental scientists to configure the political rationalities used in territorial and population governance.

The contemporary PRC is the world's foremost power in terms of its use of technoscientific means to assert its voluminous sovereignty in challenging environmental conditions (Billé, 2020; Harris, 2020; Rodenbiker, 2023a; Wirth, 2023). In the realm of atmospheric governance, China uses geo-engineering and weather manipulation to remedy the 'natural' constraints to its socioeconomic development (Chien et al., 2017; Rodenbiker, 2022; Yeh, 2022). The attempt to intervene in social and environmental processes at selective locales to govern atmospheric happenings elsewhere in the country has been referred to by Zee as the 'machine sky' (Zee, 2022, p. 50). The combination of technoscientific and bureaucratic apparatus with sociotechnical imaginaries of 'civilisation' (Hansen et al., 2018; Rodenbiker, 2022) shows that Chinese territory is governed as socionatural entanglements rather than a flat social space. The governance of volume is enabled by scientific knowledge, calculative metrics, and governance techniques that attend to the multi-scalar dynamism of environmental processes such as dust storms (Zee, 2022). Nevertheless, the logic of territorial governance based on the territory's verticality and voluminousness is not simply a recent outcome of China's present-day material and technological prowess. As scholars have shown through the case of multiple environmental scientific disciplines such as Ecology, Geology, and Agriculture Science, the science-state entanglement can be traced back to the earlier days of China as a modern territorial state (Rodenbiker, 2023b; Shen, 2013; Wu, 2023).

Modern science and the territorial state emerged at an identical historical juncture in China. The weak modernising state and the challenges of establishing *de facto* territorial sovereignty provided a crucial historical opportunity for scientists to gain political power by leveraging their expertise and transnational connections (F. Fan, 2022; Z. Wang, 2002). Amidst the collapse of the empire and the absence of *de facto* territorial sovereignty, science itself became a means to national salvation as epitomised by the May Fourth Movement in 1919 (Z. Wang, 2002, p. 295). Moreover, the ability to produce scientific knowledge and

the control of scientific data was seen as an essential part of functional statehood by Chinese scientists. In the 1920s, Chinese scientists convinced the new Nationalist (Kuomintang) Party government to limit access to historical and cultural artefacts, biological specimens, and other forms of scientific data on Chinese territories to foreign researchers (S. Chen, 1998, p. 117). The collection of meteorological data, too, became a concern for territorial sovereignty. By the time the new Republic was established, German, British, and French colonial authorities operated their own observatories. Whereas the foreign-run Chinese Maritime Customs Service did operate an extensive network of weather stations dotted around China's coastal and riverine locations, its activities were geared for the needs of international maritime trade (Bickers, 2016). Given the clear connection between foreign-controlled meteorological infrastructure and defeats by colonial powers, the nascent community of Chinese meteorologists framed the collection of data and the ability to forecast as a demonstration of Chinese sovereignty (X. Liu, 2023). Moreover, the idiosyncratic nature of meteorological activities carried out by educational, military, and commercial actors led to the call by Chinese atmospheric scientists for standardisation and institutionalisation at the national level (X. Zhang & Jiao, 2016).

The politics of atmospheric knowledge production, however, is not reducible to the territorial logic of enclosure and control. Works in the global history of science have long recognised the mutability of globally circulating knowledge and the power of individuals and institutions to translate and adapt scientific knowledge to specific political contexts (F. T. Fan, 2012; Feichtinger, 2020; Raj, 2013). To illustrate how atmospheric knowledge production operated in the political contexts of Republican-era China, I follow the intellectual and professional trajectories of Zhu Kezhen (竺可桢), also known as Chu Choching, to excavate the mutability of scientific knowledge and its power to reshape perspectives in its specific context (Feichtinger, 2020). Zhu is arguably the foremost important figure in translating international atmospheric sciences into the political and scientific contexts of 20th-century China (Amelung, 2021; Frank, 2023; D. Wang & Ding, 2014). He was not only a pioneer of modern climatology in China but also a leading figure in the scientific nationalist movement who wielded an outsized influence on the Chinese state's scientific policies (Z. Wang, 2002). Zhu's scholarly interest in climate was owed to his training in the United States where he was mentored by figures such as Robert D Ward – the first professor of climatology in the United States and the English translator of Julius Hann's canonical handbook of climatology (Amelung, 2021; Ward, 1928, p. 94). Much like his Western contemporaries, Zhu subscribed to the environmental determinism of Friedrich Ratzel, and specifically the climate determinism of Ellsworth Huntington – a fellow student of Ward who also shared Zhu's interests in historical climates in China.

In the early days of Zhu's scientific career, following the late 19th-century European view of the climate, he saw climate as a two-dimensional affair that can be explained mainly through long-term weather patterns' socioeconomic impacts. The discipline of climatology, according to Zhu, is aimed at describing the geographical characteristics and distribution of atmospheric phenomena such as temperature, precipitation, air pressure, and wind speed (K. Zhu, 1920 in K. Zhu, 2004a, p. 161). More importantly, he was extremely concerned with the question of population and the connection between arability and population growth in rural China (K. Zhu, 1926 in K. Zhu, 2004a, p. 503). Even as his conception of the climate shifted from a two-dimensional to a three-dimensional dynamic understanding, the climate continued to be a proxy for Zhu to understand whether China was overpopulated.

Concerns for Chinese territorial sovereignty were evident in his scientific works. His 1929 paper, the '*Climatic Provinces of China*' 1929 was the first scholarly attempt to devise a climatic subdivision specifically for China '*from a purely meteorological point of view*' (K. Zhu, 1929 in K. Zhu, 2005, p. 161). Yet, Zhu's categorisation of climatic variations in China corresponded with traditional cultural geographical divides such

as the north-south divide, and ethnocultural geographical units such as the Steppe and Tibet, even though he admits that the scarcity of data from Tibet, Mongolia, and Xinjiang means that the climates of these regions remain '*unknown*' (ibid:178). The motivation behind the categorisation, as Frank observes, appears to be territorially-motivated as Zhu seeks to subsume the internationally adopted Köppen system of classification within the political geographical context of 1920s China (Frank, 2023, pp. 11,2).

Before being appointed the head of the newly established Institute of Meteorology in 1928, Zhu had been advocating the establishment of a national weather service throughout the 1920s. His political advocacy often reproduced the Standard of Civilisation as well as the Eurocentric idea about science as a marker of competent statehood and territorial sovereignty in his advocacy for the political application of atmospheric sciences. In a 1921 article advocating for the establishment of a national meteorological network, he wrote:

'the superiority of various nations in the world today can be determined by the ability of their countrymen to control the natural environment' (K. Zhu, 1921 in K. Zhu, 2004a, p. 344)

He critiqued the Beijing government for neglecting the importance of meteorological knowledge for maritime transportation and then went on to lament: '*Europeans and Americans often view us as a semi-civilised nation, they cannot be blamed for holding such a view*' (ibid). After he was appointed as the head of the new meteorology institute, Zhu came up with an incredibly ambitious plan that envisioned over 1000 weather stations across China (Zhu, 1929 in K. Zhu, 2004b, p. 25). In his draft plan, he argued that all states, from the 'civilised and advanced' European and Japanese powers to 'latecomers' such as Brazil or Turkey all have 'excellent meteorological observatories' (ibid:24).

The production of atmospheric knowledge in the frontier regions was especially important for Zhu. He leveraged his political influence to embed Chinese meteorologists in the Sino-Swedish Scientific Expeditions in Chinese Central Asia, utilised data collected by European scientists, and even established weather stations in warlord-controlled Xinjiang and Gansu (X. Chen, 2012). Under his leadership, the Institute prioritised limited resources in the Northwest and Southwestern frontier regions and installed meteorological equipment on civilian aircraft to collect data from higher altitudes (F. Liu, 2018, p. 68). A highly symbolic observatory was established at the Government delegation quarters in Lhasa in 1934, and the Lhasa station became the first functioning central state institution in the Tibetan capital in 1912 (Nyima & Qin, 2022). A major motivation behind his scientific interest in the frontier regions was the possibility of settler colonialism as a solution to overpopulation and territorial defence. In a draft plan for researching the climate of Northwestern China, Zhu reasoned that the ability of meteorological data and improved knowledge about the climate can identify areas in the frontier area suitable for military agricultural settlements (K. Zhu, 1931 K. Zhu, 2012, p. 343) (Fig. 1).

The availability of new data and new scientific theories about the climate in the 1930s, however, overhauled Zhu's two-dimensional view of the climate and led to a new voluminous conception of Chinese territory. The application of thermodynamic principles to the earth's atmosphere and higher altitude data provided by the advancement in aeronautical technologies replaced the conception of climate from an earthbound geographical concept to a dynamic atmospheric phenomenon (Coen, 2020; Heymann & Achermann, 2018, p. 608). Zhu quickly caught up with the idea dynamic approach through his participation in international conferences and familiarity with the Polar Front Theory of extratropical cyclones. Drawing on observations of ocean and atmospheric currents made by U.S. and British military meteorologists, and new data from Northwestern China, Zhu attempted to explain the seasonal atmospheric circulations above China using the new dynamic approach to climatology in a paper presented at the Pacific Science Congress in Canada in 1933 (K. Zhu, 1934 in K. Zhu, 2005, p. 202). In this important scientific paper entitled *Circulation of Atmosphere Over*

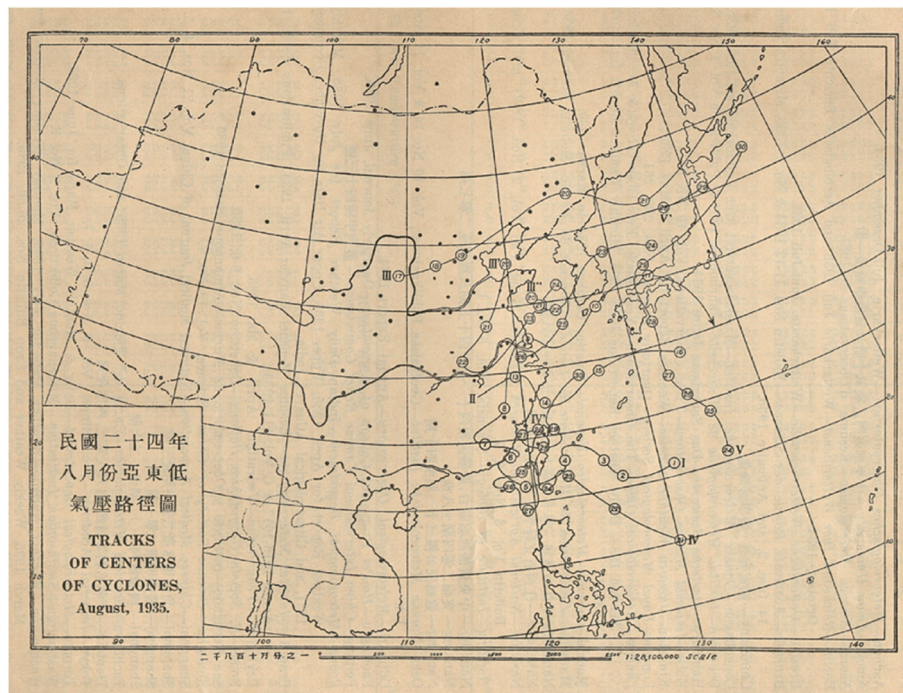


Fig. 1. 'Tracks of centres of cyclones'.

Source: Monthly Meteorological Bulletin, August 1935 (page VII) Academia Sinica, National Research Institute of Meteorology Nanjing, China

China, Zhu identified three main factors that determine how the East Asian Monsoon moves across China: the general pressure distribution in East Asia and the Western part of the North Pacific Ocean, the frequency and trajectories of cyclones, and the country's topography (ibid).

On the one hand, the new dynamic conception of climate as a holistic multi-scalar system wherein local variations can be explained by planetary atmospheric circulations naturalises the use of Chinese territory as a geographical scale of climatic analysis (K. Zhu & Lu, 1935). As Frank observed, by distinguishing the causes between the Monsoonal rains of India and Southern China, Zhu was able to naturalise the cultural geographies of Sinic and Indic climates (Frank, 2023, p. 26). On the other hand, technoscientific development also made visible the surface level impacts of extraterritorial and high-altitude atmospheric forces. The visibility of the climatic forces as the interactions between China's geographical positioning and interaction with larger atmospheric forces allowed Chinese territory to be reconceptualised in volumetric terms.

The new understanding of climate as the result of complex thermodynamic interplays of atmosphere, ocean, and land was not only a scientific breakthrough for Zhu. It was also going to serve a practical purpose: which is to evaluate whether China's population was indeed exceeding its sustainable limits. In his seminal 1934 paper on the 'Aridity of North China', Zhu compared China with areas of Canada and the United States at similar latitudes where annual rainfall is above 500 mm and concluded that most of northern parts of China are comparatively more arid, leading to a narrower belt of arable land concentrated at the coastal area (K. Zhu, 1934 see Fig. 2). To further his thesis of using annual rainfall as a proxy for agricultural and population sustainability, Zhu compared rainfall levels in similarly densely populated areas of the world and identified North China as an anomaly. More importantly, he triangulated the modern meteorological data with Chinese historical records of drought and famine and historicised the climate of North China as the cause for its reputation as an overpopulated 'land of famine' (K. Zhu, 1934, p. 107). By combining bio-metrics with geo-metrics and demonstrating that Chinese territory and its inhabitants are beholden to larger atmospheric forces and topographic features, Zhu politicised the climatic qualities of Chinese territory as a socio-natural phenomenon in need of governmental intervention.

Zhu's volumetric understanding of Chinese territory and his environmental determinist thesis of population-climate nexus backed by technoscience would be popularised by his student Hu Huanyong who was then serving as the Chair of Geography at the prestigious National Central University in the capital Nanjing. Building on Zhu's observation of North China's aridity, Hu tries to examine whether China's overall population level has become unsustainable. He followed Zhu's approach of using climatic variations and topographical features as a proxy for agricultural and population sustainability. He laboriously compiled census data from around the country, and triangulated cartographic representations of population density and topography with Zhu's map of precipitations (Hu, 1935, p. 43). He divided the country into eight different natural zones based on population density, topography, and climate. The least arable and populated parts of the country including all of Mongolia, Xinjiang, and Tibet, he observes, are roughly beyond the 500 ml isohyet drawn by Zhu (ibid:48). Based on this 'discovery', Hu identifies a straight line that overlaps with the 400 ml isohyet that runs from northeast to the southwest through the entirety of China. This environmental-cultural divide 'converges with the racial distribution within the country' between 'the world of the Han' in the Southeastern half and the 'the domain of Mongolians, Tibetans, and Muslims' in the Northwestern half (ibid:44).

The 'Hu Line', which the divide has come to be known, has gained canonical status in Chinese Geography discourse over the past century. It is included in contemporary China as a part of the secondary school's geography curriculum and used in scholarly discussions on ecology, urban planning, and economic development. Indeed, the environmental and climate determinist idea behind the Hu Line played an active role in China's Population control and planning policies. After his rehabilitation after the Cultural Revolution, Hu worked for the population policy unit of the National Population and Family Planning Commission – the administration for China's birth control policies. The objective and unchanging materiality of the territory manifested via the trio of rainfall, arability, and population density forms the basis of his policy recommendations. The trio has been quite adaptive to the state's various colonial, defence, and developmental objectives. For instance, in 1985 he recommended that minority groups too should be subjected to

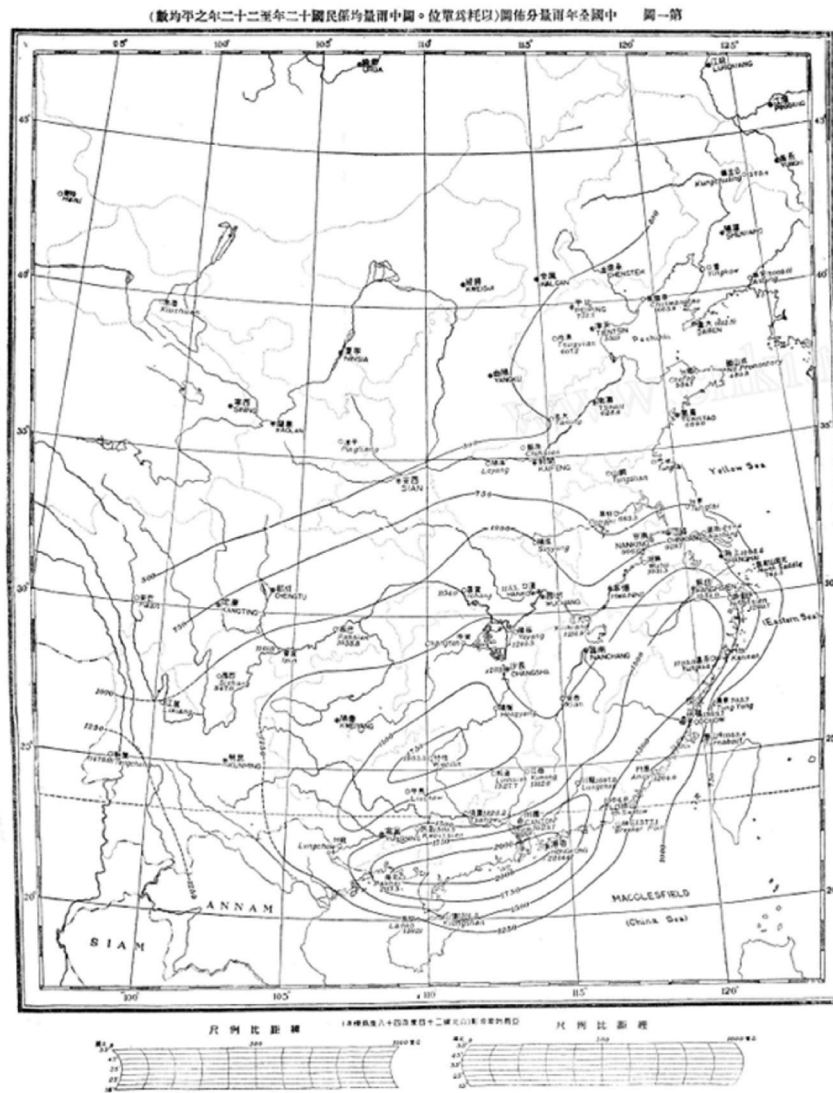


Fig. 2. The distribution of annual rainfall.
 Source: Zhu, K. (1934). 華北乾旱及前因後果 The Aridity of North China: its Causes&Consequences. *Acta Geographica Sinica* 地理學報, 1(2), 107

mandatory family planning policies because of the natural environmental constraints in Tibet, Xinjiang, and southwestern provinces (Hu, 1985, p. 23). Hu was also able to leverage climate as a multi-scalar environmental force to provide the scientific support for a more settler-colonial approach when needed. Notably, he suggested that hydraulic engineering project and the capture of high-altitude rainfall can allow areas in Xinjiang with more arable microclimates to support up to 50 million people (ibid:34–36).

5. Conclusion

Hu’s environmental determinist bent on the traditional cultural geographical divide is hardly innovative given the pre-existing distinction between ‘Chinese Tartary’ and ‘China Proper’ (Lattimore, 1937). Instead, the emergence of the Hu Line suggests that Chinese territory in the 1930s was conceived as a voluminous environment where demographic metrics could be explained through volumetrics such as precipitation and topography. The convergence between environmental knowledge production and politically useful knowledge shows that *de facto* territorial sovereignty is not imagined as sovereignty over land but also as sovereignty over volume. The main challenge facing the weak Chinese state, as scientists such as Hu and Zhu among others (Shen,

2013) highlighted, was that the state could not control nature effectively. Whereas the Qing Empire was held together by heterogeneous forms of political authority and the state’s ability to project its power along the frontiers was dependent on animal-human power (Bello, 2016), the modern Chinese state needed control of the physical environment itself to govern the population.

The need to control nature itself is not just due to the lack of legitimacy among frontier groups and polities but also the result of new forms of knowledge and technologies. As the entanglement between atmospheric sciences and the Republic of China state reveals, the state did not assert its voluminous sovereignty over environmental forces that are already known. Instead, the voluminous materiality of the territory is framed by technoscientific knowledge, infrastructure, and expertise that are simultaneously global and local. The historical and political contingency of technoscience-state entanglement means that the materiality of the territory, too, is contingent not only owed to the dynamism of ‘nature’ itself but also on the politics of environmental knowledge production (Braun, 2000). The production of the territory’s vertical dimension centred on the environmental object known as the climate by atmospheric sciences placed Chinese territory, nation, and history within the engulfing voluminousness of atmospheric forces. In doing so, not only did atmospheric circulations become a governmental concern

for the state (Zee, 2022) but knowledge about atmospheric forces also reconfigured ideas of how Chinese territory and population should be governed till this day. The Republican-era idea of China being arid and lacking sufficient arable land owing to larger planetary forces, for instance, laid the foundation for contemporary securitisation of water supply (Yeh, 2022) and legitimated use of weather manipulations to induce rain (Chien et al., 2017).

The Chinese state did not find itself in a vertical environment whose materiality is readily seen as political. The larger atmospheric forces that are responsible for the 'Chinese climate' such as the Asian Monsoon System was not known until scientists such as Zhu Kezhen translated them into the socially legible concept that can be measured and intervene through volumetrics. Similarly the equivalence between population-rainfall-topography and environmental carrying capacity is not 'natural' despite the naturalness of environmental phenomena such as climatic variation and arability. Instead, Zhu's conception of the Chinese climate and Hu's ecological-demographic bifurcation are imbued with political concerns with territorial sovereignty, population control, and the efficacy of governance. Nevertheless, they also point to more-than-human forces that are not reducible to the political concerns that undergird their scientific activities.

By foregrounding the technoscience-state entanglement and the technoscience as a part of the Standard of Civilisation during the expansion of the modern international system (Yao, 2022), we can better understand how specific claims to scientific knowledge acquire political and governmental importance in the context of state-building. The equivalence between a state's territory and the natural environment, is bundled with a second-order conception of the modern state as the guardian of the natural environment (Whitehead et al., 2007, p. 35). Indeed, the idea that the natural environment is a separate realm that is managed and retrieved by technoscience is a defining feature of modern and anthropocentric conception of politics (Latour, 1993). Moreover, the case of atmospheric sciences in Republican-era China shows that non-Western states are not necessarily latecomers to the technoscience-state entanglement but coeval participants in the global transformation towards the modern international system.

CRedit authorship contribution statement

Andy Hanlun Li: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

There are no conflicts of interest.

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