WIREs CLIMATE CHANGE

Article type: **Advanced Review**

Article title: Contributions and perspectives from geography to the study of climate

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Abstract

Geographers have played an important and sometimes controversial role in the study of climate during the 20th century. This review traces the historical contributions of geographical scholarship to the study of climate in two primary areas: statistical, descriptive climatology and research in climate and society. It draws out the specifically geographical nature of climatological work in the first part of the 20th century, looking at the role of maps, classifications and historical statistics in describing and potentially explaining climatic cycles, patterns and processes. Geographers were keen to demonstrate the broader linkages between climate and the physical environment and humankind, such that applications of climatological expertise were crucial to economic development, imperialism and local scales, particularly the urban scale. This led geographers into insightful interdisciplinary applications, but also rather more awkward themes such as climatic determinism.

The review draws out both the positive and negative aspects of geographer's contribution to understandings of climate.

Introduction

Climate has rarely been far from the core of geographical enquiry, yet studies of climate have had a sometimes controversial role within geography as a discipline. Frequently shamed for climatic determinism, the spectre of characters like Griffith Taylor and Ellsworth Huntington cast a shadow across geographical contributions to work on climate and society[1]. Even attempts at researching climate systems and processes have had a variegated history as geography has competed with other disciplines, particularly atmospheric physics, for credibility and value. Whether in constructing a classification of the world's climatological regions, using past climate cycles for weather prediction or attempting to explain society's (racial, economic, cultural) relationship with climate, geographers have nonetheless created insights and developed ways of thinking that are still relevant and inspire contemporary research on climate change.

Despite the conviction of (some) geographers in their mission to place geographical knowledge at the heart of academic enterprise with claims such as that "Ever since the dimmest antiquity the spirit of man has felt the need for geographical i.e. earth-describing, knowledge"[2] (Reference 2, p1.); if we fast-forward to the 1960s and 1970s, such an ambition appeared to be in crisis. Geography textbooks became replete with disclaimers about the stale nature of a purely descriptive, regional climatology[3]. This was particularly unfortunate since, as the eminent geographer and climatologist Gordon Manley suggested, climatology had become the next big field of research after having for so long been "something we took for granted as a rather depressing part of school geography"[4] (Reference 4, p360). It is the purpose of this review paper to outline geography's contributions to understanding climate through the 20th century, incorporating the disconcerting (climatic determinism) and the perceived old-fashioned (descriptive climatology), while also emphasizing how geographers reclaimed relevance in climate research through alternative interventions particularly in applied climatology and new forms of integrated climate and society research.

This paper is not meant to be a lament for geography (there are plenty of these already) nor a celebration of geography (as such). In setting out the contributions of geographers, the aim is neither to draw a boundary around what counts as geography nor to make bold statements about the (ir)-relevance of the subject. Such inward-looking might lead to the kind of 'mania' an editorial in the July 1958 edition of the meteorological magazine *Weather* warned of: "Two excellent prize essays on 'The place of meteorology in liberal education' were published in 1957. It occurs to one of the editors that these, together with the current 'Geographer as a Scientist' controversy, may inspire contributions with a bias toward introspection. Heaven forbid that budding meteorologists should develop 'Geogramania' and spend (too much) time justifying their existence"[5] (Reference 5, p214). It is by no means a coincidence that it was geography that was chosen to highlight this phenomena. Indeed Manley worried about the stifling effect such introspective work (or 'Geogramania') would create and promoted good scientific work, rather than following fads or fashions in which geographers tried to draw boundaries around 'appropriate' geographical work[6]. Thus, the aim in this

paper is to present some of the contributions that geographers made to the study of climate in the periods in which they were writing and the ways in which these approaches have inspired later studies of climate.

It would of course be impossible to list all the various contributions geographers have made to the subject of climate (change) in one short paper, let alone do justice to the diversity of traditions in different parts of the world. Instead the paper presents two core areas where geographers have made distinctive contributions to the field of climate studies: 'descriptive climatology' and 'climate and society'. The former is used to indicate a series of work embracing climatological cartography, climate cycles, and regional climate classification schemes. The latter is used to discuss work ranging from applied climatology through to climatic determinism, as well as more recent debates about climate and society. In each of these two core fields, I show how ideas emerged, what prompted their emergence, how they opened up space for geographical contributions and how they waxed and waned in importance over time. I argue that while the descriptive climatology tradition has largely disappeared from the majority of academic work on climate (though note it maintains a continued importance in the public imagination of what geographers do), climate and society research has maintained and perhaps even increased its visibility and importance as climate change research has (and still needs to) become more interdisciplinary and holistic.

There are a few important caveats about the scope and ambition of this paper. First, while there are geographically-inspired approaches to climate prior to the formal establishment of geography as an academic discipline, I direct readers to the article by Heymann for this[7]. Second, the choice of authors or sub-fields is not to delimit the scope of other contributions within geography. This is an indicative, rather than a holistic historical paper. Third, there is insufficient space in this paper to trace the interventions that scientists based in geography departments have made within contemporary atmospheric physics, paleoclimatology and climate modelling. Fourth, while in places I indicate the importance of non-Anglophone geographies, this paper is primarily focused on the Anglophone traditions. Fifth, while the atmospheric sciences were largely male-dominated particularly with the post-World War II influx of military trained meteorologists into the discipline[8], future research will need to explore in more depth the contributions of women in this field. With these caveats in place, the first major area of the paper is to explore descriptive climatology.

DESCRIPTIVE CLIMATOLOGY

Descriptive climatology has been a core part of geographers' historical contributions to understandings of climate, with maps, statistics of average climate and classifications a central part of enquiry[7], particularly since the early 20th century[9]. This approach used descriptions of the climates of different places, regions or the globe to anticipate patterns, cycles and changes. Frequency data were thus central to a geographical study of climate[10]. Geographical work on climate, however, was not solely concerned with description for the sake of description, but rather geographers frequently allied description to explanations too. For example, the work of W.M. Davis aimed to explore the laws of nature that gave rise to particular climates and their relation to the peoples living under these climates[9]. Robert DeCourcy Ward similarly wished to explain as much as describe[11]. While descriptive approaches have subsequently been largely superseded by numerical modelling (indeed

this has come to dominate over researchers using other traditions)[12], descriptive climatology played an important role in setting out the parameters of, expectations for and realisation of economic, social and political activities in various parts of the world. In other words, descriptive climatology was useful, not least for imperial ambition.

Climate maps played an important role in the development of an understanding of how observations over a geographical area might be connected together. The drawing of isotherms, isolines and trade winds were central in the formation of maps in the first half of the 19th century by authors such as Heinrich Wilhelm Brandes, Julius Hann, Wladimir Köppen and most prominently Alexander von Humboldt[13]. Humboldt advocated for isolines rather than latitude as an understanding of climate that would be both geographically relevant and reflect the experiences of travellers and settlers in different climes[14]. Humboldt was likewise convinced that humans were responsible for environmental changes, particularly caused by European colonialism[15]. For the Austrian imperial cartographer Hann, climatography was the description of regional climates in their correlation to plant cover and the organization of human life[16]. Köppen advocated for a systematic collection of data and methodology of interpretation, such as is evident in the production of Köppen's climate maps in the 1860s and the formation of the Köppen classification scheme that continued to play a significant role in geography climate textbooks through the 20th century[7]. Köppen, it is worth noting, contributed to debates about the quality of Eurasian steppes which were central to questions of the likely success of European colonization within central Asia[16]. Within later Soviet climatology, one of the most sophisticated of these classifications was the radiation index of aridity produced by A.A. Grigor'ev and M.I. Budyko that enabled a closer correlation to vegetation and soils deriving from their climate classifications[17]. This was of particular importance given the centrality of agroclimatology within Soviet climate research.

Maps therefore did not serve a merely descriptive purpose. They were to enable an understanding of the broader environment and human life, and act as tools to advocate for or against the impacts of colonial activity. Likewise mapping was considered to be good for science in general, indeed Francis Galton in the 1860s advocated for accurate, visually appealing synoptic maps to help take observational data and make it useful for science[13]. Classifications of climatic zones were thus important particularly at a regional macroclimatic level in geographical enquiry[18]. Classificatory maps like Köppen's were used to show how the climates of the world translated into particular kinds of ecosystems.

There were several challenges with climate maps and classifications however, not least the scale and diversity of climates around the world tempered by local factors, such that considerable work went into improving the Köppen system. The scale of the climatic zones was a particular challenge and it was not difficult to point out, for example, that New Zealand had multiple regions with markedly different climates even as the whole country (except for two stations) would, after Köppen, be classified as Cfb[19]. C. Warren Thornthwaite developed a significant reworking of the Köppen classification system that aimed for what he called a more rational approach to classification based not just on temperature and precipitation but what these figures actually meant in terms of experienced warmth or moisture, key ingredients for shaping the natural environment[20,21,22]. With Thornthwaite, the New Zealand classification showed an almost complete variation of different world climates[19]. This confirmed the need for geographical specificity for users and a striving for accurate description. Another challenge was that regions were not easily disentangled given that a

mobile atmosphere would have to be represented on a *static* map to provide a world map of climatic types or zones. This mapping, however, enabled the factors that caused climate gradients that created regional climates to be inferred, which enabled an explanatory value to be located in maps. This overcame some of the criticism that the classic Köppen or Thornthwaite classifications had little research value[23].

In addition to classifying 'average climates' of places, geographers were interested in the regular and irregular climate cycles and patterns that the statistics represented. Eduard Brückner, the German geographer and geoscientist who taught physical geography 1906-1927 in Vienna, pioneered a series of studies into climatic oscillations[13,24,25]. Concerned with changes in climate, he reflected on the connections between those changes and society. Indeed Brückner wrote in his dissertation about the ways in which states might gain or lose from climate change[26]. It is perhaps interesting to note that the Eduard Brückner prize issued by the GKSS is given to an expert in interdisciplinary climate science. Climate cycles might be used to predict and manage future climate changes.

In an address to the Royal Meteorological Society Sir Richard Gregory[27] explained the value of testing hypotheses about weather cycles, collating facts and confirming through experience the search for periodicities. Gregory asserted that the value of the Brückner cycle is less in its predictive capability, which was next to useless given that only a fifth of cycles arrived within 30 months of the 35 year periodicity (indeed Brückner noted its mathematical inexactness[26]), but that it did have value in tracing out the ground water cycles that marked out stronger or weaker years for agricultural production and therefore emigration patterns. Gregory claimed that meteorologists would welcome reliable cycles for forecasting, even if they could be little understood[27]. Leslie Curry though cautioned of the need to give due account to the importance of random variations in ascertaining climate periodicities, but noted that exploring the dynamic processes behind indeterminate processes of climate cycles and changes should be of central importance and interest to the geography student[28]. P.R. Crowe speculated that, within geography, climatology's "devoted adherents are few and forward progress during the last Brückner cycle has not been noteworthy. Indeed, it could be said that climatologists have abandoned their cycles before equipping themselves with an attractive bandwagon"[29] (Reference 29, p1).

Climate fluctuations were also of interest to geographers whose interest was in rather longer timescales. To provide just a few examples. Hans Wilhelmsson Ahlmann, professor of geography at the University of Stockholm and later a scientific and political ambassador (Sweden's ambassador to Norway in the 1950s), was concerned with a trend of polar warming[30]. Using datasets to establish a curve of 30-year overlapping means from 1710 to 1940, Ahlmann speculated on the reasons for the climate fluctuation in the polar North, concluding that if polar trends were equally seen in other parts of the world, then a likely explanation would be a change in solar activity[31]. Ahlmann's contribution was perceived to be particularly distinctive in geography and ambassadorial in its ambition to bring together the international science community for Anglo-Scandinavian cooperation[32]. We can name others work here too including Anders Ångström on the causes of climate fluctuations in prehistoric times[33], Karl Butzer on climate change in the Pleistocene[34] and Manley too who used Ahlmann's work in his own exploration of changes to the snow line in the U.K.[35] Climatological science in geography was international in ambition and reach.

Geography was, however, facing an increasing challenge to its approach through the emergence of numerical modelling and more physics-based dynamic understandings. Heymann argues that the descriptive 'average climate' style of work that formed the basis for a geographical approach to climate was superseded with the emergence of physical, dynamic understandings towards the mid-20th century[7]. Indeed the German climatologist Hermann Flohn attempted to reconcile classical and newly emerging dynamic climatology in the 1950s, but with only limited success, in part as Heymann suggests[7], because the dynamic conception of climate was irreconcilable with the statistical, geographical conception. But Flohn was not alone in maintaining the relevance of a classical approach. In British climatology, there was no better exemplar of this than Hubert Lamb, who advocated for looking for past climate patterns to predict the future[12]. Lamb continued the geographers' interest in taking weather observations and maps of past weather and using these as the basis for understanding[36], hopefully in the long run even predicting weather patterns.

Lamb was particularly concerned to explore how climate patterns shifted over time, a topic that bridged the educational shift he experienced from the early-20th century descriptions of regional climate as static entities to the dynamic work that showed how climates changed[12]. A stable climate suggested that calculating averages for the temperature or precipitation of particular places would suffice to be called 'the climate of that place'. But Lamb was concerned that these "Tables of climate statistics could no longer be used with confidence as a guide to the future" (cited in Reference 12, p.469). Unstable climates demanded more complex explanations about how climates changed and why cycles and patterns were irregular. But this instability did not automatically mean the end of a descriptive as opposed to a numerical modelling approach to understanding climatic changes. Lamb published *The Changing Climate* in 1968[37] and demonstrated that geographers in the spirit of classification and description, were not beholden to descriptive statistics in a way that denied the possibilities of climatic changes. Lamb was convinced that historical statistics could still answer many of the questions about the changing climate; and he was convinced that making quick political decisions based on the output of numerical models (rapidly gaining domination) was unwise.

Within the universities, the place and relevance of geographical expertise in understanding and explaining climate during the 20th century was also under threat. The turn-of-the-20th century American university more commonly placed meteorology with physical geographers and geologists. While Cleveland Abbe, for instance, was appointed to Columbia University in 1893 offering a Master's programme in atmospheric physics, in both Harvard and Johns Hopkins, meteorology was sited in geography (aiding observatories like the Blue Hill)[38]. Charles Brooks, editor of Monthly Weather Review (and founder of the American Meteorological Society), was taught at Harvard and maintained that meteorology should be co-located with other outdoor sciences[11,38]. While meteorology was considered to have little theoretical rigour[8] this situation continued, but by the 1930s, there was a clear institutional split in the atmospheric sciences: meteorology increasingly went with physics following the mathematics of the Norwegian school and the increasing interest in aeronautics, while climatology went with geography[38]. This left climatology viewed as a soft, descriptive topic and with limited theoretical content, a view that secured (and was re-enforced by) its placement within geography, the descriptive science[39]. The location of climatology within geography significantly shaped and potentially tarnished the reputation of climatology due in particular to the propensity of geographers to also focus on cultural aspects in the spirit of Huntingtonian environmental determinism[8]. In other words, meteorology (for physicists) needed to be clearly insulated from what geographers did in climatology.

This distinction, significant as it may have been in later warding off human geographers from working on climate for fears of determinism[40], was challenged in the 1950s and 1960s as physical geographical work moved from descriptive regional climatology to approaches more focussed on processes and a search for universal laws[39]. The search for physical laws, however, did not mean that geography would simply become the same as atmospheric physics. Kenneth Hare argued that the approach to climatology should not be limited to atmospheric physical processes, but should embrace a broader understanding of soils and vegetation too, an enterprise that would necessarily embrace a wider range of scientists, including geographers[41]. Hare also argued that geographers could make a unique contribution to emerging concerns about climate change with this holistic approach[39].

These changes in geographical approaches to climate were also reflected in the educational books through which the subject was taught. Geography climatology textbooks particularly in the 1950s to 1970s were concerned with descriptions of climates especially regional climates of the world[42,43,44,45]. At the same time there was a concern that unlike meteorologists, geographers were interested in relating weather and climate to the broader physical and human environment.

Trewertha, for instance, produced several iterations of his introductory climate textbook, titled most succinctly from the 3rd edition in 1954 as *An Introduction to Climate*[42], which displayed the systematic aspects of climatology and then regional climates. A geographer needed training in the genesis and the explanation of atmospheric phenomena and Trewertha's text classified regional climates with a modified Köppen system. But description alone would be insufficient for disciplines with an anthropocentric focus, a theme that emerged in other geography textbooks. Lockwood's 1974 textbook, for instance, aimed at situating the environments of the world in relation to their climates (echoing Hare's call) rather than focusing explicitly on the physics of the atmosphere[44]. Lockwood was concerned that a statistical approach should not be just about averages, but of "…relevance to the natural environment experienced by man" (Reference 44, p3).

Koeppe and De Long's 1958 textbook again allied physical understanding with practical application, noting the geographer's keen interest in seeing climate as a factor in the physical environment[43]. The book explicitly did not include anything requiring more detailed knowledge of maths and physics, to prevent those with an interest being "discouraged because of an inadequate technical background" (Reference 43, p v). The book again uses the Köppen system recognising that it is not necessarily the best system, but is widely known – indeed Koeppe's own climate maps are relegated to an appendix. Boucher's 1975 book likewise introduced students to a synoptic climatological approach using a modified Köppen system to review regional climates (and with more coverage of the Southern hemisphere than some other textbooks)[45].

Trewertha's 1961 book *The Earth's Problem Climates* in a title synthesises a concern to identify those climates that appear anomalous from a general climate classification (Köppen or Thornthwaite) viewpoint[46]. It argues for a need to move beyond description and through careful exploration show that "some climates which at present appear to be anomalous will… lose much of their unusual or enigmatic character and seem to be more a part of the normal climate pattern" (Reference 46, p5). This is accomplished by adding in 'perturbations' and 'the unique', with 'large-scale synoptic situations' and 'weather types' to the usual array of description i.e. it introduced a more dynamic element.

The emphasis on dynamism and moving beyond merely descriptive climatology was a recurring theme of textbooks in the 1970s. Mather's 1974 *Climatology: Foundations and Applications* set out to address what he perceived to be the major stumbling block with previous climatology textbooks: that they were 'dry as dust.'[3] Instead he suggested a need to focus on dynamic climatology and a use of statistics that focused as much on application for operational purposes as on mere description. Mather aimed to provide a basic understanding of weather and climate processes but encouraged thought on the interrelation between humans and their environment.[3] Mather's legacy has been expounded in a special issue of *Physical Geography* that notes in particular his contribution to the climate water budget and his applied work at the Thornthwaite Laboratory of Climate[47].

If there is one continual feature of these textbooks it is that while the method changed, from more statistical and descriptive to more synoptic, dynamic and physical, a core concern was that geographers wanted to situate atmospheric science within a broader environmental and human context. Geographers advocated holistic and societally relevant approaches. It is to this broader context that I turn next in the second half of the paper, exploring how geographers have contributed to understandings of climate and society.

CLIMATE AND SOCIETY

Geographers have made significant interventions in discussions of the relationship between climate and society. Indeed given the aspiration for geography to be seen as an integrative discipline, it is probably in this area that geographers have had the most potential to mark out important and distinctive contributions. Here I focus on three main areas: climatic determinism; applied climatology; and cultural climatology. I show that geographical work on climate and society, particularly once removed from a legacy of climatic determinism, can make a critical contribution to contemporary concerns about climate change.

Climatic determinism and geography's legacy

Geographical enquiry has long considered the relationship between human society and the climate, but this has been a field of enquiry that has led to much embarrassment for geographers. Climatic determinism drew from a longer tradition of environmental determinism usually cited to a range of authors from Hippocrates to Baron de Montesquieu[48]. This understanding of the climates of the world stemmed in part from imperial interest and ambition as colonizers attempted to settle, manage and extract economically productive goods from the land[1]. But in its uptake in geography in the late 19th and early 20th century it is figures like Ellen Churchill Semple, Griffith Taylor and, most particularly, Ellsworth Huntington who have drawn the most commentary.

Huntington was particularly influential in shaping ideas of climate and society, to the point that it has been suggested that one reason social science has been relatively reluctant to engage with climate (change) again is a fear of a return to his determinism[40,49]. While Huntington wrote in an academic style, he was in many ways a failure as an academic[48]. Despite this he had an influence on geography and on students even if his ambitious conclusions were regularly reigned in with the critical reviews of his work[48]. Huntington's *Climate and Civilization*[50] purported to show how climate

influenced the world's civilizations, producing some to be productive and enterprising, and others to be consigned to backwardness. New Zealanders were just more productive than Indians as high climatic energy translated into high civilization defined through his own scale of advancement based on 'expert' advice. Huntington was particularly concerned with the productivity of workers, conducting experiments in the early 1920s on optimal efficiency rates[48], which he believed would also be instructive regarding the development of civilization more broadly.

To briefly list others work. Ellen Churchill Semple was also important in establishing a case for the environment's influence on humankind with geography a key explanadum though with race as the backup answer[51]. Australian geographer Griffith Taylor (1880-1963) used cartographics from William Diller Matthew's *Climate and Evolution* article (published 1915, later as a book 1939)[52] to discuss how climatic cycles led to human migrations to different parts of the world and how the climates of these places shaped these inhabitants[53]. The Harvard geographer Robert DeCourcy Ward, who had worked with Köppen[54], advanced views of the tropics as debilitating and with superstitious persons that could only be improved through an absentee outsider administration. Koeppe and De Long's textbook replicated this determinism too, quoting a poem (uncited) that they considered to "summarize the truth, namely, that the activities and destinies of human beings are partially determined by the weather and climate of the region in which they live" (Reference 43, p8) and that makes reference to the weather as the moulder of 'the life of man' and that makes Zulus live in trees.

Climatic determinism provided one answer to the geographical concern with human-land/nature relationships and the view of tropics as unsuited for civilization persisted even until the 1950s[51]. This civilizing spirit, however, draws attention to the fact that climatic determinism was never the realm of purely scholastic enquiry; rather, imperial and political decisions were central to the field. The Russian climatologist Alexander Voiekov argued that rational use of water would enable the improvement of unfavourable climates, but Huntington disagreed considering the determinism of the environment to outweigh the prospect of imperial ambition to improve the environment[16]. The question was debated in relation to the desiccation of steppe landscapes and civilizations of central Asia with Huntington's view that it was unstoppable echoing Kropotkin's work, but which was challenged by Voeikov who argued that nature could be modernized and improved for the benefit of the empire[16]. This contrast between humans as passive subjects of nature and humans as active actors in shaping nature was to dominate the geographical literature on human-land relationships and in its way shape the contributions geographers made to our understanding of the climate. In other words, geographers were rarely interested solely in the climatic processes, but rather had a holistic concern with plant, animal and human lives.

It is also important to remember that geographer's contributions to determinism came as much from an interest in medicine as climate, in particular a medical geography that associated climate (especially a tropical climate) as one that would not be conducive for the white, European body. In part, the geographical maps of climate risk within this literature were built on an ideal of a stable climate. This derived as much from medical research as from specifically geographical research, but nonetheless geographers took a keen interest in medical research about the consequences of living in or travelling through 'non-native' climates[55]. Research on climate and health was also seen as an opportunity to demonstrate a scientific approach to the discipline[55].

The visibility given to the climatic determinists should not overlook the many geographers that made significant and serious criticisms of their work. Carl Sauer, Isaiah Bowman and Preston James were all geographers critical of Huntington[40]. More broadly, Spate argued that without humans, there would be no 'environment', and thereby cut against determinist accounts that failed to sufficiently align history and geography, art and science[56]. But, there was such a fear that mentioning 'environmental influence' would be sufficient to get oneself tarnished with the brush of determinism, that (for some) human and physical geographers split apart rather than talked to each other about climate and society[57,58]. Manley was perhaps one of the few who dared to continue to explore climate-society relationships in the face of this backlash. Indeed he praised Huntington for outlining the ways in which climate and society were inter-linked not least in the, for him, vigorous British climate that led to industrious citizens[6]. But he argued against Huntington's less specific general conclusions and instead prioritised a locally, geographically-specific articulation of the climate-society relationship[6]. Local specificity was something acknowledged for example in the use of hill stations in India and in medical climatological research including the promotion of particular kinds of climatic health tourism. Geographers in Peru, for example Luis Carranza who founded the Geographical Society of Lima in 1888, advocated Jauja as a health tourism capital away from the coastal plains[59]. Terjung, likewise, developed an interest in a bioclimatic classification i.e. how human comfort was influenced by climate, in his aspiration to construct an index of comfort[60]. Terjung recognised, however, that comfort was as much psychological and individual, though he thought the value of trying to derive an index regardless would be of value to retirees, tourists, and the military. Others such as JW Gregory in Melbourne argued that the risk to the white body was more from the diseases carried by natives than the climate anyway[55].

In practice, climatic determinist arguments were deployed and re-negotiated as it suited the colonists or governors of particular districts. In Northern Australia, Pacific island labourers were considered to be better able to withstand the diseases of the tropical climate than the European body, despite statistics suggesting the islanders were dying in larger number than the Europeans[55]. It was nonetheless a convenient argument to enable the continued use of this labour. Similarly, if a 'white man' could not safely reside in Queensland, Australia, for example, then what would be the purpose of establishing a white colony? Acclimatization must be possible if colonization is also plausible. Indeed Johns Hopkins geographer Isadore Dordick argued that lowland New Guinea, for example, was a satisfactory climate for acclimatized white men to perform their mental and physical activities, except that on occasions atmospheric tolerance limits might be exceeded for short periods[61]. European colonization would render tropical climates as safe.

Arguments about climate and society, therefore, were rarely simply floating free of the imperial ambitions and context in which they were formulated. It is also important to remember that many geographers critiqued those advancing climatic determinism. But nonetheless this legacy haunts geographical enquiry.

Applied climatology

Given the awkward politics of climatic determinism, social scientists in general[49] and geographers in particular[40] shied away from talking too much about climate-society interactions. Climate and society never died out as a research area, but the research was more carefully delineated. Physical

geography would contribute to understandings of climate with some thought given to potential impacts, while human geographers largely sidestepped questions of environmental influence. As such, applied climate and society research in the U.S. came to be dominated by technical topics such as weather modification[40]. This pitted elite scientists against applied ones, as the former fought to encourage research funding for basic research rather than applied research, seeing basic research as being in competition with expensive weather modification operations[62]. Despite this, basic and applied research were rarely self-contained entities. Geographers were particularly important to crossing boundaries between science and concerns with policy impact and economic development, and they did so at a variety of scales.

Geographers had a keen interest in seeing the policy and political implications of their research recognized. In an interesting turnaround from accusations that geographical work was merely descriptive, the Canadian geography professor William H. Parker, for example, was concerned with the impact of atomic testing on weather patterns[63]. Parker's expertise was particularly in political geography and especially geographies of Russia. In writing to the *Times*, Parker suggested that the causation between 'lurid skies and thunderstorms in Canada' and bomb tests in Nevada was clearly evident, even if meteorologists were too buried in their charts and isobars for these kinds of policy relevant questions[63]. Gordon Manley (along with other meteorologists and geographers) were less than amused by Parker's swipe at meteorological introspection and argued that these changes in weather were consistent with normal variations (of over 300 years of data), suggesting to Parker that perhaps lurid clouds followed fallout like cricket preceded rain[63]. This somewhat quirky incident demonstrates that geographers were engaged in public issues of the day in ways that went beyond mere description.

In the Soviet era, Russian geographers made strong claims for the relevance of an applied climatology as a science that would enhance economic development strategies[64]. Using climate knowledge for transforming the natural environment for the benefit of society was an approach borne out of both a sense of scientific progress and prestige within physical geography as well as being borne along by the need to enhance Socialist economic development. As I.P. Gerasimov put it[65](note that Gerasimov replaced A.A. Grigor'ev as Head of the Institute of Geography at least in part for his greater focus on this), environmental science would need to help with the process of moving from haphazard transformation of the environment to a positive, planned transformation that would deliver on Soviet economic goals[64]. Soviet research had particular strengths and interest in agroclimatology, the use of climatology in alliance with understandings of soil and vegetation (recall Grigor'ev and Budyko's classifications mentioned earlier) to understand and promote better agricultural development [17,64]. Likewise the possibility of climate control to enhance agricultural productivity was important[17], as it was in the U.S. context too[66]. Geographers were enrolled into the economic development challenges of the period.

Climate was not just in the realm of major governmental politics either. Gordon Manley was keen to see the topic of climate discussed much more frequently in media and society circles[6], while other applied climatologists interested in corporate, urban or human scales advocated for more attention to be paid to local climates. Indeed one area that geographers particularly developed was a sense of the importance of the 'human scales' of climate that was lived in and experienced on an everyday level. In other words, geographers took an interest in the different scales of climate (change), which of necessity meant bringing humans back into research on climate.

The field of urban climatology is especially important for any review of the applied work of geographers, and since it is a subject more extensively reviewed elsewhere[67,68,69], I will only briefly review the key components here. Albert Kratzer published a landmark review in 1937 *Stadtklima* which assembled the pre-existing literature into a synthesis that became valued internationally, particularly after its publication in English in 1956[68]; from Luke Howards work on the climate of London through the extensive German research that looked to an urban climatology to aid urban planning, these were frequently conducted through a descriptive physical geography of the climate of particular places. For grand theories of atmospheric processes, urban climates had less to commend them since they were significantly humanly modified, but geographers (along with meteorologists) helped establish the importance of research that would aim to understand and manage climates at human scales, particularly the climates of the towns and cities.

Gordon Manley is considered the founder of the term 'urban heat island' and he played a significant role in the development of an urban climatology that explored the changes of city climates as humans shaped the world around them[68]. But it was especially Tony Chandler's (University of Manchester and University College London) establishment of a network of observers in London that enabled the production of isothermal maps of the city and a better understanding of the specific spatialities of urban climates[68]. Chandler, for instance, sought to understand the way in which city morphology was shaping the experience of urban climates[70]. He also led the call for urban climatology to move beyond maps and engage with a much more detailed understanding of processes using physical models where required[68]. Other research including by Terjung further developed the understanding of the energy urban balance of cities and the comfort for inhabitants in these spaces[68].

Later, geographers like Tim Oke established the importance of understanding chemistry and physics as part of studies of air pollution. Oke was central to establishing how the urban boundary layer worked[68], the topic of his well-known and well used textbook *Boundary Layer Climates*[71]. Oke, himself, is an excellent example of the way in which a geographical inspired tradition of urban climatology was also adopting the tools and expertise of physics in a more sophisticated analytical approach within physical geography. Equally, though, Oke was no closet scientist; rather, and in collaboration with former PhD students like Sue Grimmond, Oke established the importance of urban climatological research within discussions of global climatic change more broadly[68]. A geographical sensitivity to space and scale, and a willingness to focus on human modified landscapes as much as theoretical ones, enabled geographers to advance studies of the kinds of climatic changes that were and would be experienced at the human scales.

The business or industry scale was also of particular interest to geographers, beyond the economic development angle mentioned previously. Indeed Helmut Landsberg had come up with a term *technoclimatology* to capture work exploring climate's role in industry and commerce (though it did not catch on)[3, 71]. The works of people like W. John Maunder, John E. Hobbs, Martin L. Parry, James A. Taylor and John E. Thornes were all important in technoclimatology.

In writing in the preface to the 1974 volume *Climatic Resources and Economic Activity* University of Aberystwyth based Taylor suggested that "Academic geography has by tradition afforded some successful communication between scientific and humanitarian studies. Currently, however, increasingly narrow specialisation in individual branches of either physical or human geography has

not only seriously impeded this communication, but has also created problems of internal communication between physical and human geographers who now frequently find themselves aligned to the research priorities of adjacent fields e.g. Quaternary studies, Sociology, etc"[73] (Reference 73, p15). He bemoaned the decline of regional geography too, but noted the advantages of the kinds of statistics and modelling that built precision and enriched the philosophy of the subject. Not least, these demonstrated the vitality of geographical work on climate. The use of terms like climatic resources, in his estimation, helped bring back both halves of the discipline and this was evident at the 1972 workshop the book emanated from, which featured contributions from, for example, John Maunder, Asit K. Biswas and Ian Burton. The book was "*not* a prescription for the revival of any crude type of climatic determinism" but rather "it presents an alternative and more sophisticated, interdisciplinary approach to the problem" with "the ultimate rewards are sound prescriptions for environmental management and sound planning" (all Reference 73, p17). This could not just be about better science. The 1971 symposia on agricultural climatology at Aberystwyth (which had held these annual symposia since 1958) focused on weather forecasting related to agriculture and industry, with 100 delegates present including Hubert Lamb[74]. One crucial lesson that emerged from this symposium was that forecasting would need to be oriented to user needs and there was a clear need to better understand how users actually did use these forecasts. More science would not necessarily advance the cause of better environmental management.

Taylor and Parry had particular interests in agriculture, continuing a theme from earlier geographical contributions that situated atmospheric processes as one part of understanding soils and vegetation, and it is in agriculture and food that some of the most complete interdisciplinary work by geographers can be found. These approaches often deployed the kinds of integrated systems thinking that had been laid out by Terjung for integrating human and physical geography[75]. Parry, for example, led collaborative research into understanding the food security challenges that climate change would present[76]. He was also appointed to co-chair the second working group of the 2008 Intergovernmental Panel on Climate Change report and won the Peek award of the Royal Geographical Society in 1991 for contributions to understanding climate change and agriculture. Likewise Diana Liverman helped pioneer the study of climate and food systems through enhanced integrated modelling[77]. Liverman subsequently has become world-renowned as a leading interdisciplinary geographer who has established the relevance and importance of the discipline in contributing to global environmental change research, and she was awarded the Founder's medal of the Royal Geographical Society in 2010 for this achievement. Geographers have made significant contributions to developing interdisciplinary understandings for the betterment of society.

Other applied climatologists likewise pursued research that aimed at better environmental management. Allen Perry provided several contributions including for example the relevance of understanding the importance of changing climate conditions on the Scottish skiing industry[78]. John E. Thornes provided analyses of the effects of weather on sport[79], but became best known for his work on the effects of weather on transportation particularly road icing[80]. Indeed, Thornes base at the University of Birmingham is a good example of an institutional embrace of the field of applied climatology. Birmingham's geography department had established an MSc in 1963 in Applied Meteorology and Climatology, and saw this as a rival to Reading and Imperial College London whose meteorology Masters programmes were much more straightforwardly scientific. The Birmingham MSc would provide a keenly applied physical geography focus with a good basis in science, but a real appreciation for application and integration (pers.comm. Brian Giles). Indeed Ted Stringer, the

original promoter of this MSc and a keen supporter of climatology as a science, published a book *Foundations of Climatology*[81] in which he stated its aim "to discover, explain and exploit for the benefit of man the normal behaviour of atmospheric phenomena" (Reference 81, p vii). In other words, Stringer clearly identified the commercial possibilities of climatological information, a prospect he took up with his solar panel business, but is perhaps best illustrated by Thornes commercialisation of road ice prediction. Influential applied climatology textbooks of the period included Mather[3], Barry and Chorley[82], and Hobbs[83] (for a fuller list see reference 84).

Likewise the University of Birmingham showed clear ambition in relation to identifying relevant societal aspects of the emerging debates about climate change. The Atmospheric Impacts Research Group at Birmingham produced a short publication in 1988[85] collating evidence for and research gaps in estimating the impact that climatic variability had on British industries, exploring water, construction, energy supply, transport and insurance. At a more international level, the Scope 27 climate impacts report edited by Robert W. Kates[86] contained contributions from a few geographers including William Riebsame, Jennifer Robinson and Martin Parry. The report sketched out the need for better information and conceptualization of the interactions between climate and society and bemoaned disciplinary fragmentation in research that prevented a more integrated assessment[84]. Likewise it established the importance of exploring the 1970s work on climate as hazard in a fresh light in the context of climate change[87]. Indeed, geographers such as Liverman, Parry, and Richard Warrick contributed to international assessments of the impacts from global climate change in the late 1980s and into the 1990s[88].

Applied climatology, as illustrated through the examples of urban climatology, agro-climatology and technoclimatology, is an area where geographers have marked out a frequently quantitative and policy-oriented contribution. This has gone beyond the dominant global scale modelling to equally appreciate the value of understanding and managing climates at the scales in which humans live and work[87].

Cultures of climate

Geographical scholarship has further developed qualitative research on climate and society and this research needs to go beyond applications of climatology to consider the production of knowledge about climate and the way this is translated through cultural context. Geographers have reminded us that knowledge emerges from particular places and is situated within the terms and concepts of those places. Geographers have been frequently skeptical of the claim for necessarily globalized environmental discourse and interventions[88]. As DeCourcy Ward's claims for the need for strong external management of the people of the tropics was legitimated through a deterministic view of the dangers of the tropical climate, so climate change science needs to be critically interrogated for its assumptions and political implications. Geographers have played an increasingly significant role in situating the knowledge of the global change community by exploring the geographies of its production and circulation[89,90]. By reminding scientists that science is produced in particular places, geographers highlight the way in which science legitimates or delegitimizes forms of explanation, democracy and power relations[88,90,91]. At a national scale, Akiko Yamane for example has identified how in the mapping of vulnerability in Sri Lanka, the 'climatically vulnerable subject' is produced in a way that legitimates interventions to steer subsistence farmers into adopting export-oriented

agriculture[92]. Justice and equity issues are therefore at the heart of claims for expertise on the climate and its impacts.

Geographers have further considered expertise and suggested that the incorporation of local knowledge has to be more than as an adjunct to authoritative global change science[90]. Political ecology, in particular, has inspired significant geographical scholarship about the knowledge and practices of climate change adaptation[91]. This has drawn attention to issues of justice and inequality that shape the production, circulation and use of climate knowledge for adaptation. Political ecologists have particularly emphasized the value of local knowledge. Drought in Tanzania, for instance, has been recognised as multiple rather than a universally agreed term, as the scientific definitions are insufficient to account for or replace indigenous understandings of the nature, causes and scale of droughts[93]. Geographers have therefore stressed the need to embrace knowledge and ideas from the Global South rather than simply downscaling knowledge from the Global North[89,90]. This will and should become a significant field of enquiry for future geographical research reminding scientists and policymakers that climate (change) is not just a subject for Global North led science and policy initiatives, but a field that is produced and practiced throughout the world.

This challenge necessarily also embraces a cultural approach to climate as well as a scientific one, something geographers are already well versed in. The term 'cultural climatology' was put forward by McGregor and Thornes as a way of bringing back this genuinely interdisciplinary concern with the climate within geography[94]. Thornes own work on art and climate, combining the reconstruction of meteorological data from art while remaining alive to artistic modes of representation is a good example of this kind of cultural climatology in practice[95] and can be developed further to consider the politics of representation.

It is probably the disciplinary-crossing Mike Hulme that has done most to deliver on these aspirations and has stressed in numerous publications in recent years the centrality of understanding climate as a cultural idea and thereby developing a cultural approach to climate[96,97,98,99,100].. To understand disagreement about climate change necessarily requires attention to the imaginations, ideas, and beliefs that shape our relations with the climate. Geographers are making contributions that enable a more complex and varied understanding of the icons and imaginations of climate change to emerge, and to situate these within locally produced practices and understandings[101]. For example, O'Neill and Nicholson-Cole have identified that the images that make climate change seem important are the same ones that make participants feel unable to do anything about it[102], which raises significant questions for scientists and science communicators. Geographers have argued, however, that the importance of culture goes beyond icons and images to equally stress the lived, everyday cultural practices that shape behaviours and lifestyles that may be more or less consistent with seasons or climate (change)[103]. Geographers have therefore argued that climate change researchers need to explore knowledge and culture from art through to lived practice as a way of deepening and expanding understanding climate and society relations.

Conclusion

The previous parts of this paper have sketched out some historical ways in which geographers have contributed to understandings of climate. One perennial feature of this literature is a regard for a scientific approach to understanding climate, and climate and society interactions, but what counted as scientific has changed over time. In other words, the epistemologies of climate research in geography significantly altered through the 20th century, not least in the move from descriptive climatology to numerical modelling, and in the move from determinism (in general) to more specific work on the impacts of weather and climate on particular urban spaces or businesses. In this final, necessarily brief, concluding section, I explore how these geographical insights may inform future research on climate change and society.

To first turn to a less positive corner of past research, climatic determinism is a topic that geographers still need to engage with. As Livingstone has noted, climatic determinism debates have made a steady reappearance on the academic scene[53]. Whether reflecting on the causes of conflicts that some associate with climate change[104,105,], or whether looking at the correlations of religion and ecology[106] (somewhat reprising Huntington's 1945 *Mainsprings of Civilization*[107]) or whether considering the role that climate might play in future human evolution[53], geographers need to play a significant role in forcing a careful analysis of these claims. As a discipline well-versed in the trauma of climatic determinism, geographers should be particularly careful in assessing and advancing these kinds of claims, and should be actively reminding members of the global change research community about why they are so cautious[53].

Second, for all that climate change seems to have drawn attention away from local scales to global scale research (even if it may be subsequently downscaled), geographers interested in industry and urban environments have played a crucial role in reminding the global change research community of the importance of the scale of lived experiences with climate. The kinds of climate changes that are most readily apparent and visible are rarely ones that can be immediately correlated to global climate change[68]; rather it is at the urban scale, for instance, that geographers continue to remind climate scientists more broadly of the relevance of interdisciplinary and geographically particular contributions to our understanding of climates in ways that can make a difference to human lives today. This work, for instance, has establishedthe experimental nature of much of urban climate governance[108]. Geographers are also reminding scientists of the crucial importance of culture and the geographies of knowledge such that climate should be understood as multiply constituted by different actors in different ways. Indigenous expertise of climate, for instance, cannot be merely reduced to a comparison to 'global' science, but rather must be respected in its own terms.

How to translate these contributions into new policy frames is a particular future challenge and as Luke notes, little of the critical work that has gone into interrogating climate change imaginaries seems to have influenced the grand regulatory policy regimes[109]. To this day there are competing claims about the extent to which human geographical, and more broadly social scientific, contributions to global environmental change research are being valued even within the environmental change community[110,111,112]. In outlining some of the areas in which geographers have contributed to our understanding of climate, this paper has established the importance of geographical ways of thinking to past climate research. Hopefully this article has avoided becoming merely a dose of 'Geogramania' and rather has set out a series of approaches and pathways that are still relevant to this day and should shape future research on climate (change). Given the rapidly expanding corpus of work dealing with the Anthropocene, the continuing expansion of global

environmental change research and repeated calls for interdisciplinarity, there are plenty of lessons to be learnt from geography's past contributions to the field that can help shape geography's distinctive contributions in the future.

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