

Epistemic geographies of climate change: science, space and politics

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Abstract

Anthropogenic climate change has been presented as the archetypal global problem, identified by the slow work of assembling a global knowledge infrastructure, and demanding a concerted global political response. But this 'global' knowledge has distinctive geographies, shaped by histories of exploration and colonialism, by diverse epistemic and material cultures of knowledge-making, and by the often messy processes of linking scientific knowledge to decision-making within different polities. We suggest that understanding of the knowledge politics of climate change may benefit from engagement with literature on the geographies of science. We review work from across the social sciences which resonates with geographers' interests in the spatialities of scientific knowledge, to build a picture of what we call the epistemic geographies of climate change. Moving from the field site and the computer model to the conference room and international political negotiations, we examine the spatialities of the interactional co-production of knowledge and social order. In so doing, we aim to proffer a new approach to the intersections of space, knowledge and power which can enrich geography's engagements with the politics of a changing climate.

I Introduction

Global climate change is arguably the greatest contemporary geographical challenge. As a composite, synecdochical 'matter of concern' (Latour 2004) through which a seemingly infinite variety of values, discourses and imaginaries are being refracted (Hulme 2009), it raises anew a number of questions which have long troubled geographers. Among these we might cite questions concerning different conceptualisations of 'nature' (Castree 2005), the nature of the 'global' and the 'local' (Randalls 2016), modernity and difference (Head & Gibson 2012), distribution and justice (Fisher 2014), agency and temporality (Yusoff 2013), and about the place of technical expertise in democratic debate (Owens 2005; Demeritt 2006; Whatmore 2009). In this essay we examine work which contributes to a more recent concern of geographical scholarship – largely of the historical variety – but a concern which has not yet been fully integrated into human geographers' engagements with climate change – the geographies of science (e.g. Livingstone 2003; Powell 2007a; Meusburger et al. 2010).

Much attention to the geographies of climate change knowledges has been devoted to capturing differences between scientific and more 'local', 'traditional' or 'indigenous' narratives and conceptualisations of climate, often taking for granted a distinction between a disembodied global science and local, embodied knowledge. This article aims to do something different – to examine the geographies of climate science itself. We review scholarship from across the social sciences on the geographies of the sites, practices, discourses and imaginations through which climate science is produced and put to work, arguing that a geographic sensitivity can enrich our understanding of climate knowledge politics. Geographers have been urged to join colleagues across science & technology studies (STS) in examining the specific spaces of climate change knowledge production, and to follow the transformations, antagonisms, agreements and disagreements which coalesce

around the paths of this knowledge's circulation (Hulme 2008). We use the term 'epistemic geographies' to denote the spatialities of the technoscientific knowledges which underpin understandings of human-induced climate change. This term is informed both by Foucault's later use of the notion of *episteme* as an apparatus for determining the 'scientificity' of a truth claim (Foucault 1980, 197), and by Peter Haas's notion of an *epistemic community* as a network of authoritative experts on a given topic (such as climate change) united by shared beliefs regarding mechanisms of causality, standards of validity and ameliorative prescriptions (Haas 1992). As such, attention to the epistemic geographies of climate change means attention to the uneven geographies of scientific authority, the spatialities of the boundaries drawn between the scientific and the political, and the situated co-production of epistemic and normative commitments. In Section II, we briefly introduce recent arguments about the historical geographies of science and the role of place in shaping the production of scientific knowledge. We then examine in Section III how scholars from various disciplinary backgrounds have engaged with the constitutive spaces and sites (Whitehead 2011, 213) of climate knowledge-making, examining particularly the field, the scientific assessment, and the conference. In later sections we extend this interest in the constitutive spaces of climate knowledge-making by engaging with contemporary debates in STS about the co-production of scientific knowledge and social order.

Reviewing the development of STS, Jasanoff (2004) positions co-production as a key conceptual concern, approximately dividing a continental, ANT-inspired school and a more political and humanist North American school into 'constitutive' and 'interactional' co-production, respectively. Inquiry into constitutive co-production – into the attainment of particular forms of ontological or metaphysical order at distinct sites (Jasanoff 2004, 19; e.g. Latour 1993) – has been hugely influential in geography, motivating important work on the more-than-human geographies of knowledge production and political controversy (Hinchliffe 2001; Whatmore 2002; Barry 2013a; Lorimer 2012; Braun & Whatmore 2010; Davies 2013a; 2013b). While mindful of the dynamism of this work and its potential to inform understanding of the ontological politics of climate change (Blok 2010; Knox 2015), we want to expand the field by turning here to questions of interactional co-production, which have been less prominent in geographers' engagements with environmental politics. 'If constitutive analysis focuses in the main on the emergence of new facts, things and systems of thought, then the interactional strain concerns itself more with knowledge conflicts within worlds that have already been demarcated, for practical purposes, into the natural and the social' (Jasanoff 2004, 19). This is an approach to understanding science and social order which can be traced to the 'Edinburgh School' and the 'Strong Programme' in the Sociology of Scientific Knowledge (e.g. Bloor 1976; Barnes 1977; Shapin & Schaffer 1985), and is thus part of the same intellectual lineage of much work on the historical geographies of science (see section II). We seek to offer an approach to the epistemic geographies of climate change which takes seriously contestations over the distribution of authority and power on the cultural checkerboard of late modernity. In section IV we examine the simulation model as another key site of climate knowledge-making, and position the notion of interactional co-production as a useful heuristic with which to comprehend the mutual construction of space as an epistemological category and space as a form and object of governmental rationality. The ontological politics of constitutive co-production are therefore never far from view. Focusing

on the role of climate models at the intersections of science and politics, we explore how particular spatial constructions have emerged which reflect, but also serve to challenge, existing forms of scientific and political order.

II Geographies of science

Space, place and locality are now canonical concepts across science studies (e.g. Barry 1993; Shapin 1998; Secord 2004; Henke & Gieryn 2008). This 'embracing of the spatial' (Turnbull 2002, 273) builds upon constructivist epistemologies which regard scientific knowledge 'primarily as a human product, made with locally situated cultural and material resources, rather than as simply the revelation of a pre-given order of nature' (Golinski 2005, xvii; see also Demeritt 2001; 2006). STS scholars have posed a number of answers to Simon Schaffer's (1991, 190) question of how to address the distinction 'between the processes of 'localization', through which local techniques get to work at sites like labs via the concentration of widely distributed resources', and 'spatialization', through which 'techniques which are efficacious within the lab. manage to travel beyond it' (quoted in Powell 2007a, 313).

As Powell shows in a wide-ranging review (2007a), answers to these questions have drawn on varied conceptions of spatiality. A 'socio-spatial' school of historical sociologists, inspired by the Strong Programme and focused in the main on what Finnegan (2008, 374) calls 'science *in situ*', has revealed how solutions to epistemological problems of warrant, credibility and attribution are to be found in local socio-spatial arrangements, through practices of social exclusion and inclusion of the 'geographically privileged' (Shapin 1988, 375), which in turn reflect broader forms of social hierarchy and order (Shapin & Schaffer 1985; Shapin 1984; 1998). Relatedly, students of the architectures of science have developed the argument that 'spatial arrangements determine the degrees of visibility and social interaction within architectural structures' (Powell 2007a, 315), thus connecting concerns with the rhetorical boundaries of science (Gieryn 1983) with an interest in the architectural materialisation of science's socio-cultural boundaries (Galison & Thompson 1991; Gieryn 2000; 2008). Ethnographic studies of laboratory spaces have provided insights into distinctive 'epistemic cultures' constituted by different social, symbolic and technical machineries of knowledge production (Knorr-Cetina 1999; see also Traweek 1988; Collins 1992; Pickering 1995; Mol 2002). They have also informed influential posthumanist theories of scientific practice and constitutive co-production such as actor-network theory (ANT), which extend Bloor's (1976) symmetry principle to the analytical distribution of agency across human and nonhuman actors (Latour & Woolgar 1979; Latour 1987; 1999; 2005; Law & Mol 2001).

This focus on the constitutive spaces of scientific practice has been complemented by work concerned with what Naylor (2005) terms the spatial contexts of science, which stresses how scientific endeavours have been shaped by particular urban (Inkster & Morrell 1983; Elliott 2000; Withers et al. 2008), regional (Livingstone 2003; Lorimer 2003; Naylor 2010) or national cultures (Nye 1993; Withers 2007; Golinski 2010; Walker 2012), or by processes of imperialism and globalisation (MacLeod 2000; Bennett & Hodge 2011; Jasanoff 2006). Geographers of science, so far, have taken much of their inspiration from the socio-spatial school of thought (Finnegan 2008), seeking to develop 'social geographies of both warranted assertibility in general, and of

science in particular, in ways sensitive to the context-dependent nature of meaning *and* to the negotiated transfer and movement of ideas between sites' (Withers & Livingstone 1999, 16, emphasis in original). As well as the social and material spaces of knowledge-making and the 'performance spaces of science' then (Livingstone 2005a, 97; Wainwright & Williams 2008), historical geographers have analysed the range of social, literary and communicative technologies which must be mobilised to enable scientific knowledge to travel (e.g. Naylor 2006; Keighren 2010; Ogborn & Withers 2010; Withers & Keighren 2011). Questions of knowledge 'reception' have also risen to prominence with David Livingstone, for example, producing a number of influential arguments about the regional, national and transnational geographies of textual interpretation and 'hermeneutic encounters', which see ideas and knowledge interpreted in different ways in different places according to a contingent range of cultural, political and historical conditions (Livingstone 2005b; 2014; also Rupke 1999; Secord 2000; Daston 2004; Keighren 2010).

ANT has likewise been an influential approach to understanding 'science in motion' (Finnegan 2008, 378), addressing Schaffer's (1991) spatialization question by theorising the expansion of material-semiotic networks of heterogeneous actors and associations, through which scientific products can travel as 'immutable mobiles' (Callon 1986; Law 1986; Latour 1987). But understanding science in motion is often less about standardisation and the secure transfer of ideas and artefacts, as about understanding more unstable geographies of encounter and hybridisation between different forms of knowledge and practice (Finnegan 2008). More recent moves to enhance ANT's ability to deal with questions of power and difference inside and outside of networks (e.g. Law & Mol 2001; Castree 2002; Blok 2010) have responded in part to postcolonial criticisms of how STS has dealt with relationships between 'scientific' knowledge and more marginalized epistemologies (Watson-Verran & Turnbull 1995; Verran 1998; Turnbull 1998; Chambers & Gillespie 2000; Anderson & Adams 2008). Here, 'the replacement of the dominant conception of universal rationality with notions of the *local* geographies of knowledge' (Powell 2007a, 319-20) has played out in studies of how 'indigenous' forms of knowledge are written-out both of postcolonial development programmes and of conventional historiographies of 'western' science (Chambers & Gillespie 2000; Raj 2007). Important accounts of hybrid encounters between culturally different modes of knowledge-making have not only enhanced our understandings of colonial and postcolonial history, but have spawned new modes of critique of scientific, economic and cultural globalisation (Miller 2004a; Jasanoff 2006).

Livingstone (2002) and Wainwright (2012), following Gregory (1995) and Crang (1998), have urged geographers to put these conceptual tools to work on contemporary cultures of physical-geographical knowledge production, and recent debates about a 'critical physical geography' point towards innovative cross-disciplinary conversations about the nature of geographical knowledge (Lave et al. 2013; also Tadaki et al. 2012; Head & Gibson 2012). Others have argued for the tools of geography of science to be turned towards wider cultures of scientific knowledge making, including the epistemic communities shaping public discourses on climate change (Hulme 2008) and the Anthropocene (Castree 2015)ⁱ. The rest of this paper responds to this challenge, seeking to illustrate what a geographical focus on the knowledge politics of climate can tell us about the wider cultural politics of environmental change. In the next section we begin our consideration of the

epistemic geographies of climate change by exploring canonical and emerging work in STS, focusing on particular spaces of knowledge production and circulation – namely the field, the knowledge assessment and the international conference. In the subsequent section we turn to the climate model as perhaps the most powerful site of climatic knowledge production, but a site which helps us to advance an argument about the geographies of interactional co-production.

III Constitutive spaces of climate knowledge-making

1. Field

Geographers of science have taken a particular interest in the constitution and nature of ‘the field’ as a particular kind of scientific space (e.g Crang 1998; Naylor 2002; Powell 2002, 2007b, 2008; Lorimer & Spedding 2005; Matless & Cameron 2006; Richards 2011; Forsyth 2013). The field, as Kohler (2002) argues, occupies a curious position between laboratory and landscape (e.g. Melillo et al. 2011). It is in some senses a controlled space – selected perhaps for its representativeness or its boundedness, or its amenity for total surveillance. But it also evades control. It is inherently a part of much wider human or nonhuman systems, and thus resists attempts at segregation and insulation (Finnegan 2008, 380). The field can, however, be a marker of authority – of empirical authenticity against the fabrications and abstractions of the laboratory (Forsyth 2013; Latour & Woolgar 1979), and as a source of entwined sensory, experiential and technical knowledge (Powell 2007b; O’Reilly 2016). In climate science, the field often disappears from view as the *global* climate system dominates scientific and political discourses (see section IV). Yet despite the successful construction of a global atmosphere — through satellite imagery (Benson 2012) and computer models (Edwards 2010) — the field has offered resources for an empiricist streak in climate science, which sometimes conflicts with the hegemony of global, computerised simulation.

That the field is a contested source of epistemic authority is well illustrated by Sverker Sörlin's work on mid-20th century glaciology, meteorology and climate change discourse. For a figure like Swedish glaciologist Hans Ahlmann, the glacier, as an object and site of field science, was the key to authoritative empirical knowledge of potential swings in climate, whether natural or anthropogenic (Carey 2007; Carey et al. 2016). Ahlmann extended both the laboratory and the human body into the field, enacting a distinctly ‘Nordicist’ culture of field glaciology which integrated concerns for authoritative field observations with a form of scientific internationalism and a tentative receptiveness towards ‘local’ knowledges in Greenland and Iceland (Sörlin 2011). In anxiously seeking to establish the glacier as a truth-spot (Gieryn 2006), perhaps recognising that his knowledge ‘could not escape its embeddedness in the field site’, Ahlmann sought to transcend heroism and self-sacrifice in field expeditions (Hevly 1996; Carey et al. 2016) in favour of a ‘*long durée* of observation’ built upon heterogeneous assemblages of instrumental installations, bodily work, ‘local’ knowledge and laboratory-like practices of precision (Sörlin 2011, 84). Towards the end of World War II Ahlmann established a new ‘micro-geography of authority’ with an observatory in the Tarfala Valley in Swedish Lapland, which would become ‘the ultimate material manifestation of Ahlmann’s constant interest in the institutionalization of precision and data gathering in the field’ (Sörlin 2009, 241-242). As arguments about rising polar and global

temperatures emerged in the 1940s, Tarfala became a site of empirical dissent to theories of anthropogenic causation. While the theoretical and computational meteorologist Carl-Gustaf Rossby reportedly took pride in having ‘not collected one single empirical observation’ during his long career in Scandinavia and the US (quoted in *ibid*, 248)ⁱⁱ, Tarfala ‘became an internationally recognized field-based bulwark of climate scepticism’ (*ibid*, 247) which persisted among Stockholm glaciologists and geographers into the 1980s. Exercising no such ‘cult of local observations’ (*ibid*, 249), Rossby’s group, of which the first IPCC chair Bert Bolin was a part, turned their attentions instead to globally representative observations like those of the Mauna Loa CO₂ observatory, and to attempts to model the impacts of such observed changes on global climate (Bohn 2011; Fleming 2016). Myanna Lahsen (2013) makes related observations about the cultural histories of empirical, theoretical and computational climatology and their shaping of climate scepticism among US atmospheric scientists.

Sörlin’s history points to how the different geographies of field, laboratory and computer science have been shaped by different epistemic cultures – conflicting standards of evidence, sources of authority, and ways of relating theory to empirical data (Sundberg 2006; Guillemot 2010; Lahsen 2015; see also Heymann 2010; Rudiak-Gould 2013) – thus illustrating a broader tension in 20th century meteorology between ‘those who crunch the numbers, but never look outside’, and those ‘who are unimpressed by equations, but read the sky’ (Harper 2003, 689). In these conflictual borderlands of field and computer lab, observation and theory, we can see how particular field sites exercise a hold over scientific ambition and imagination. Lahsen (2009) shows how the production of the Amazon rainforest as a workable field site has been shaped by conflicting epistemic and institutional cultures. Janet Martin-Nielsen’s history of scientific engagements with Eismitte – Greenland’s central point – illustrates how narratives of exploration, epistemic authority, political sovereignty and military strategy converge on a particular place, generating a unique ‘ecology’ of social and physical relations which has shaped the evolution of Arctic glaciology and meteorology (Martin-Nielsen 2013). A comparable ecology can be observed on Antarctica, albeit one shaped by different geopolitical, epistemic and cultural trajectories (Yusoff 2005; Turchetti et al. 2008; Howkins 2011; O’Reilly 2016). Emerging work is examining the material constitution and practices of field sites in sub-disciplines such as dendroclimatology, from where tree samples are transported along an extended chain of reference (Latour 1999, 70) from ecological locality, through the laboratory, to indices of regional or hemispheric change (e.g. Ramírez-i-Ollé 2015; also Schinkel 2016). Martin Skrydstrup uses Sloterdijk’s spherology (see van Tuinen 2009) to examine the architectural grammars of ice core drilling sites, interpreting Greenland’s NEEM station as ‘a modern micro-cosmos, anticipating and building within itself the very sense of a global ecumene to which its scientific work ultimately is addressed’ (Skrydstrup 2016, 14). The project of producing scalar correspondence between the field and the global is not just epistemological, but cosmo-political.

The broader production of scalar correspondence has proceeded through uneven economies of recognition. Anthropologist Ben Orlove and colleagues argue that biophysical ‘regions’ like the Arctic and small oceanic islands have become particularly prominent parts of the geographical imagination of climatic change, as opposed to arguably equally vulnerable mountain or desert environments. The ‘distribution of concern about climate change impacts is historically situated and constructed rather than solely a reflection of environmental

dynamics', Orlove et al. (2014, 249) argue. Long histories of selective 'recognition', shaped by historical geographies of exploration and scientific fieldwork, colonial exploitation and postcolonial geopolitics have all shaped this uneven geography of concern (cf. Carey 2007), while contemporary scientific assessments and research programmes reinforce the scientific promotion or neglect of certain regions and processes (also Ford et al. 2011; Ford et al. 2016).

A growing body of work has focused on practices of knowledge making around climate change adaptation, motivated by an interest in how the global claims of climate science are 're-localized' in relation to local specificities, knowledges and politics (e.g. Bravo 2009; Carey 2010; Popke 2016; Nightingale 2016).

Geographers have developed perspectives on 'adaptation' as a travelling idea. These have used concepts from STS and critical policy studies to examine the translation (or spatialization) of a certain ontology of adaptation and its enrolment into local political projects (Yamane 2009; Weisser et al. 2014), such as reforestation projects and the forced resettlement of farmers in Rwanda (Gebauer & Doevenspeck 2015; see also Bhatasara 2015) and 'best practice' adaptation to climate change in Pacific islands (Webber 2015).

'Adaptation science' (Moss et al. 2013) can be considered an epistemic 'trading zone' (Galison 1997), where global climate simulation intersects with field-based research on socio-ecological systems and human vulnerabilities. As Castree (2015, 306) notes, this 'grounded socio-environmental research' is married with a desire 'to transfer lessons about inquiry and intervention internationally'. It is a powerful site of co-production, where new knowledges are emerging and traveling alongside new political subjectivities and modes of governmental intervention (Eriksen et al. 2015). We might also consider adaptation science a 'translation zone' in Andrew Barry's (2013b) sense; a political space where certain knowledges and practices may resist enrolment, and where interventions may become unexpectedly politicised. Geographers working in postcolonial and political ecology traditions have critiqued strands of adaptation science for its depoliticisation of social vulnerabilities, for seeking to understand *who* rather than *why* and to develop strategies of intervention which bracket-out questions of power, inequality and social justice (e.g. Forsyth 2003; Ribot 2014). The notion of 'resilience' in particular has recently prompted lively debate across and beyond geography (Cote & Nightingale 2012; Brown 2013; Welsh 2013; Simon and Randalls 2016), while others have critically examined the epistemic construction of adaptation through linear, reductionist conceptions of climate-society relationships (e.g. Hulme 2011; Beck 2010; Nielsen & Sejersen 2012).

Further work which conjoins this concern for the discursive and cognitive aspects of adaptation science (Preston et al. 2015) with a critical engagement with the 'field sites' of adaptation research and practice (e.g. Popke 2016) would add necessary empirical detail to Orlove et al.'s (2014) broad-brush observations of the uneven spatialities of climate change knowledges. Emerging work on the intersection of climate change narratives with the cultural geographies of landscape offers a promising entry point into thinking about climate change in its guises as intellectual artefact, material phenomenon, and 'embodied and experiential process' (Brace & Geoghegan 2010, 296; also Leyshon & Geoghegan 2012; Matless 2014; 2016; Rice et al. 2015).

2. Assessment

Much scholarly attention to the politics of climate change knowledges has concerned practices of scientific assessment. The Intergovernmental Panel on Climate Change (IPCC) has been the pre-eminent focus (for an earlier review, see Hulme & Mahony 2010). Such institutions pose immediate challenges to the conventional vocabulary of geography of science. As its own website explains, the IPCC is 'a huge and yet very tiny organization' (IPCC 2013). It is nonetheless 'peopled and placed' (O'Reilly 2015, 108), consisting of government representatives, a small central staff, and hundreds of volunteer scientists who are convened for each sextennial assessment round, either in conference centre meeting rooms or in virtual, online spaces. But the IPCC also performs a form of 'cultural erasure' (ibid). Through stringent practices of review and even 'audit', the work of authors is made uniquely visible and scrutable. Knowledge claims are distilled to their global, consensus essences and re-circulated, with studious neutrality, as authoritative and global knowledge. Is it possible to study such an organisation using the terms, for example, of the 'socio-spatial' of historians and geographers whose concern is the mutual constitution of the physical and social boundaries of scientific sites (Powell 2007a, 313)?

We can at least begin by re-visiting the more geographically-sensitive work by students of the IPCC. Scholars have pointed for example to the continuing geographical imbalances in IPCC participation between countries (Kandlikar & Sagar 1999; Ho-Lem et al. 2011), to a lack of recognition of 'indigenous' knowledge claims about particular places like the high Arctic (Ford et al. 2011), to a lack of governmental interest in the process in certain cases (Biermann 2001), and to occasions of distrust on the part of certain scientific and political communities in the global South with regard to problem framings and arguments which do not sit comfortably with alternative epistemic and normative commitments (Lahsen 2004; 2007; 2009; Fogel 2004; 2005; Mahony 2014). The new knowledge claims and framings (Miller 2000) produced by IPCC assessment processes can be seen as products of particular, situated commitments to forms of epistemic and social order. Russill (2016) has recently argued that the dominance of geophysical modelling and 'trend detection' practices, as opposed to more ecological approaches to climate-society relations, can be traced to 1980s US energy politics (also Howe 2014). The dominance of 'top-down', global modelling strategies (Beck 2011a; Hulme 2011; Nielsen & Sejersen 2012) and of particular economic rationalities (Randalls 2011a) subsequently coloured the way issues like carbon sequestration have been presented in IPCC documents. As Fogel (2004; 2005) and Blok (2010) argue, areas of the global South have been presented as 'blank' spaces to be fed into the calculative regimes which underpin efforts to offset Northern emissions through mitigation projects in the South (see Bumpus & Liverman 2008; Lovell & Liverman 2010). New practices of carbon accounting are co-produced with re-territorialisations of the carbon cycle, creating 'a peculiar situation whereby a territorial substance...which contributes to a change in the operation of natural systems at a post-territoriality scale, is conceived, of, classified, and managed through its association with the persistent territorialities of nation-states' (Whitehead et al. 2007, 205; Lövbrand & Stripple 2006; Twyman et al. 2015)

These powerful co-productions of the epistemic and normative content of climate knowledges have offered foci of contestation 'among competing models of knowledge-making and governance' (Jasanoff 2010, 240). As if channelling Livingstone (2005b), Jasanoff (2010, 240) argues that 'scientific facts bearing on the global environment never take root in a neutral interpretive field; they are dropped into contexts that have already been conditioned to produce distinctive cultural responses to scientific claims'. Reactions to the 'climategate' controversy which swirled around the IPCC in 2009/10 offered STS scholars an opportunity to test these claims. Emails hacked from the University of East Anglia appeared to show questionable scientific practices being employed in the communication of results, while a series of errors uncovered in the IPCC's 2007 report added fuel to the media fire. Jasanoff (2011) argues that the uneven response to the controversy in different countries tells us something about how IPCC knowledge travels. While the IPCC and its scientist-authors came in for heavy criticism in the UK and the US, the episode received scant attention in German media (Beck 2012). Seeking to go beyond explanations of this which would appeal simply to particular mass media cultures and conservative lobbying activities, Jasanoff (2011) argues that distinct 'civic epistemologies' were at play.

The notion of civic epistemology emerged from studies of regulatory science in the interactional tradition of co-productionist inquiry, and builds on the observation that 'modern technoscientific cultures have developed tacit knowledge-ways through which they assess the rationality and robustness of claims that seek to order their lives; demonstrations or arguments that fail to meet these tests may be dismissed as illegitimate or irrational' (Jasanoff 2005, 255; see also Wynne 2003; Miller 2004b). These distinctive 'knowledge-ways' are embedded in apparently national cultures of public knowledge-making which are historically textured yet seemingly stable over time. An American tradition of pluralistic knowledge-making and ad-hoc decision-making in adversarial national institutions can be contrasted with more depoliticized regulatory practices in continental Western Europe. Jasanoff (2011) sees in German civic epistemology a form of risk aversion which disavows the kind of scepticism expressed, especially in UK and US contexts, towards predictions of catastrophic climate change. In these two Anglophone cultures such predictions rub up against respective commitments to 'common sense empiricism' and to a form of quantitative objectivity which historically came to prominence amid political efforts to unite a sceptical and divided polity (Porter 1995; see also Beck 2012). Although we should be wary of essentialising 'national cultures', the concept of civic epistemology offers a means of adding geographical texture to understandings of how and why the boundaries between science and non-science, objectivity and subjectivity, are drawn where they are.

Institutions like the IPCC nonetheless pose challenges to the concept. They are transnational, and involve the participation of government representatives who may bear with them distinctive political or civic-epistemological commitments (Mahony 2015). It is therefore important to attend to the agonistic processes by which knowledge framings are constructed within such institutional spaces. Peter Haas's 'epistemic communities' model of how shared scientific knowledge is transmitted to policy-makers (Haas 1992; 2004) arguably pays insufficient attention to the material and social processes by which 'shared' knowledge 'comes to be shared in the first place' (Miller 2001, 248). The IPCC provides an ideal setting to study the practices and politics of collective reasoning (e.g. Adler & Hirsch Hadorn 2014), and of how disputes between different

modes of public knowledge-making are played-out. Following the fate of individual knowledge claims, such as particular predictions (O'Reilly et al. 2012; O'Reilly 2015) or visual representations (Mahony 2015), has proven a useful methodological opening. However, ethnographic work within organisations like the IPCC is challenging, due both to questions of access and to the dispersed, largely virtual nature of the organisation. Few have been welcomed into relationships of 'ethnographic complicity' (Marcus 1998, 105) – O'Reilly (2015) in collaborative relationships with IPCC authors, Petersen (2006) attached to a government delegation are two exceptions. Significantly however, the IPCC has recently adopted a formal process for granting ethnographic access to social researchers (IPCC 2015). Important opportunities are therefore arising for social scientists to study the epistemic and political complexities of climate knowledge-making inside the IPCC through close, multi-sited ethnographic engagement (Marcus 1995; Krauss 2009; Braun 2006).

3. *Conference*

A wide range of literature on the production and circulation of climate science on public stages has been emerging (Yusoff & Gabrys 2011), examining for example the place of film (Svoboda 2016), print and online media (Carvalho & Burgess 2005; Boykoff 2011), the theatre (Bottoms 2012), the courts (Hulme 2010a; Peeters et al. 2016), museums (Cameron et al. 2013) and television satire (Brewer & McKnight 2015) in the public adjudication of climate science's facticity. In this section, we explore a particular type of stage in which geographers, along with political scientists, have recently shown growing interest as a particular site of social and political action – the conference (e.g. Craggs 2014; Craggs & Mahony 2014; Hodder 2015). Carl Death (2010; 2011) has explored the role of 'summit theatre' in contemporary forms of advanced liberal government. His Foucauldian lens takes him beyond the critique of high-profile conferences as mere rhetorical smokescreens which obscure true structures of power and authority. Instead, he positions the performative and theatrical politics of conferences as a key element in the government of conduct through a form of 'exemplary governmentality' (cf. Rose 1999). This perspective is instructive for new thinking on the role of the conference as a site of knowledge production and circulation.

Conferences, of both notionally scientific and political kinds, have long-loomed large in the politics of climate (see Brenton 1994; Agrawala 1998; Orlove et al 2015; Weisser & Müller-Mahn 2016). For example, a large scientific conference held in the run-up to the ill-fated climate negotiations in Copenhagen in 2009 offered opportunities to examine the situated production and synthesis of scientific knowledge (Skrydstrup 2009; Mahony 2013). As interdisciplinary exchanges proceeded, a scientific steering committee was tasked with synthesising the discussions before presenting them to the Danish Prime Minister on the final day. The conventional rhythms of conference talk and summary response were disrupted by an atmosphere of political urgency; a shared affective telos which structured the material practices of conferencing (Schatzki 2006; Weisser 2014). Snap conversations in corridors and email threads joined the gathered-together paper abstracts in shaping and informing the synthetic claims of the steering committee. The presentation of the findings to Prime Minister Rasmussen was a highly choreographed affair. But discursive disruption ensued when Rasmussen disavowed considerations of uncertainty and the apparent destabilisation of 2°C as a valid

threshold of 'dangerous' climate change. The exchanges, filmed for the internet and circulated in transcript form (Baer & Kammen 2009), were a public performance of, or contestation between, different idealisations of the relationship between science and politics (Skrydstrup 2009; Mahony 2013). Nervous laughs and supportive whoops emanated from the audience as Rasmussen pleaded for more certainty and 'fixed targets', interpreted by some as justified impatience with scientific reticence, but anathema to more cautious interpreters of climatic indeterminacies and science's reach. This performance illustrates how at conferences, as at other sites of scientific speech and performance, 'the setting sets limits on what can be spoken; the social space conditions what is heard' (Livingstone 2007, 75). The meeting at this particular conference of ostensibly different 'social worlds' (Clarke & Star 2008) – science and politics – created ruptures in these tacit expectations of speech and discourse. Farbotko & McGregor (2010) make similar arguments about the ruptured divide between spaces of rationality and emotion at the subsequent climate negotiations in December of that year (COP15; see also Weisser & Müller-Mahn 2016).

A focus on the contested and mutable meanings which become attached to climate science, pursued through textual analyses of scientific and political documents mined for implicit framings and normative commitments (Fløttum & Gjerstad 2016), would be enhanced through conversation with Florian Weisser's work on the documentality (Ferraris 2013) of international environmental negotiations (Weisser 2014). Documents can be considered as both effects and drivers of particular practices, material arrangements and political contestations, and thus as performative agents in the spatial practices of international diplomacy (see also Kuus 2014; Craggs 2014; Dittmer & McConnell 2016; Dittmer 2016). This would be to move beyond a conception of documents as mere vehicles of meaning (Riles 2006; Asdal 2015). Focusing on the materiality of documentary practices (cf. Schatzki 2005; 2006) opens new questions about the spatialities of sites like international conferences (Phadke 2015) and of the meetings, negotiations and performances which constitute organisations like the IPCC (e.g. Hollin & Pearce 2015). Innovative methodologies such as 'collaborative event ethnography' (Campbell & Brosiusa 2010; Davies et al. 2014) offer guidance on how to bridge the demands of detailed ethnographic attention and the sheer size and complexity of the high-profile 'performance spaces' (Livingstone 2005a, 97; Wainwright & Williams 2008) of public reasoning about climate change (cf. the digital methods of Venturini et al. (2014)).

IV Co-production in the model spaces of climate

Geographers of science have emphasised, with varying explicitness, that the task of understanding the geographies of scientific practice and culture is inseparable from the task of understanding the wider geographical agency of science itself (Naylor 2005; Finnegan 2008; Livingstone 2010). This agency may manifest in new imaginations of spatial order, material relationships or spatial rationalities. Turnbull (2000) uses the notion of 'knowledge space' to describe the dialectical co-production of knowledge and social space through the assemblage of heterogeneous components both within the laboratory, and in the wider spatialization of laboratory artefacts and practices (cf. Powell & Vasudevan 2007). In critical geography, such considerations have been most immediately apparent in the history of cartography where the political effects

of particular spatial representations have been at the forefront of critical inquiry (Crampton 2001; Harley 2002; Pickles 2004; Cosgrove 2008; see also Donovan et al. 2012). However, we would suggest that geographers can do more to consider the links between the constitutive spaces of science and the spaces which science constructs as epistemic categories. STS scholars have made important contributions to our understanding of how space as an epistemic construct is co-produced with new configurations of political order and rationality. The territorialisation of the carbon cycle, for example, through new calculative means is one process which has caught the attention of critical social scientists and geographers (Whitehead et al. 2007; Lövbrand et al. 2009; Doyle & Chaturvedi 2010; Blok 2010; Lövbrand & Stripple 2011; Randalls 2011b). We seek to bring these overlapping modes of thought into closer conversation, firstly by focusing on one particular site, tool, and object of climate change knowledges, the general circulation model (GCM).

1. *Locating the global*

...these models - which predict global climate changes, man's [sic] imminent decline or, at least, his uncomfortable future - fit conveniently into my pocket: A complete ocean with fishes, the atmosphere with clouds and the ability for turbulent behaviour, countrysides with vegetation, lakes, land and sea ice, the anthroposphere and a lot more existed in my handbag when I left the institute of meteorology (Gramelsberger 2006, 78)

Complex scientific models of the climate system have long occupied a prominent place in the cultural politics of climate change. Models have offered numbers and visions of putative futures, which have been woven into narratives oscillating between the certainty of impending crisis and the hazy, disarming uncertainty of innumerable possible outcomes of social and environmental change (Yusoff 2009). Epistemologically, climate models challenge the presumed independence of theory, observation and experiment (Helmreich 1998; Dowling 1999; Morrison 1999; Sismondo 2008; Guillemot 2010). Culturally, they unsettle conventional boundaries between fact and value, or logic and rhetoric (Shackley & Wynne 1996; Jasanoff & Wynne 1998; Ravetz 2003; Hulme 2011). And politically, models depict environmental change as a set of interlinked problems which can only be properly addressed at global scales (Ashley 1983; Demeritt 2001; Miller 2004c; Oels 2005; Dahan 2010; Hulme 2010b). Model representations of the 'earth system', with their fecundity of interrelated, human-nonhuman sub-systems, appear to offer societies a demanding totality which must be prudently managed within prescribed boundaries and limits (Knox 2014).

General circulation models of the atmosphere, ocean and other 'Earth system components' have become the dominant, perhaps hegemonic, way in which knowledge of future climates is constructed (Heymann et al, forthcoming). As Gramelsberger (2006) argues, climate models not only describe the world in a theoretical language of dynamical equations rendered in computer code, but also enact the world as an object of experimental research. As if in a Latourian laboratory, an abstract, purified climate system is coaxed into existence from a rarefied computer language and subjected to experimental manipulation, before difficult questions of evaluation, validation and credibility are explored in oftentimes very public 'trials of strength' (Latour 1987).

Scholars of interactional co-production have argued that global climate models have reinforced, and been reinforced by, increasingly globalist forms of politics and spatial imagination (Shackley et al. 1998; Demeritt 2001; Miller 2004a; Hulme 2010b; Gurevitch 2014). Global mean temperature (GMT) has been the key index of observed and simulated anthropogenic climate change, as opposed to alternatives like radiative forcing or ocean heat content. While estimates of the equilibrium response of the climate system to a doubling of atmospheric carbon dioxide have remained remarkably stable (and equally uncertain) over time (Van Der Sluijs et al. 1998; IPCC 2014), so too has GMT endured as the organising metric of international climate politics: the ‘story of global climate has in many senses become the story of global temperature’ (Hulme 2010b, 560). GMT has furnished an indexed storyline of change, become a focus of sceptical challenges, and become the locus of normative policy targets, such as the goal of limiting warming to 2°C (or 1.5°C) above pre-industrial temperatures (Randalls 2010a; Morseletto et al. 2016). The 2°C target has nonetheless faced challenges as both a feasible target (Geden 2015; Anderson 2015), and as an accurate, just representation of the threshold of ‘dangerous’ climate change (Shaw 2016) – challenges which were forcefully aired at the 2015 climate negotiations in Paris and related debates about whether integrated assessment models were smuggling-in impossible assumptions about carbon sequestration in order to retain the virtual feasibility and political authority of temperature targets (Geden 2015; Anderson & Peters 2016).

GMT is the product of the ‘panoptic gaze’ of global data and models (Barnett et al. 2009), the power of which lies in its making-visible of new, governable objects (Scott 1998; Oels 2005). It is a gaze which isolates and divides, separating global process from local experience (Head & Gibson 2012; Jasanoff 2010; Knox 2014) while privileging certain synoptic processes and variables over other, more locally-relevant changes (Stott & Thorne 2010; Bhatasara 2015; Russill 2016). Hulme (2014) cautions against the temptation to see GMT as a controllable variable to be purposefully manipulated, *in silico* or *in vivo*, with climate engineering technologies (see also Stilgoe 2015). Like the forests constructed as empty spaces for the disposal of the North’s carbon (Fogel 2005), a new imaginative geography of the global atmosphere (Doyle & Chaturvedi 2010) risks enframing it as a space to be colonised by new forms of technologically mediated intervention (Hulme 2014; Hamilton 2015).

The fact that climate models can fit into a philosopher’s pocket (Gramelsberger 2006) means that the mobility and (im)mutability of such tools has become a key element of the spatialization of climate science writ large, and of the physical and social environments of scientific practice (de Laet & Mol 2000). Climate modelling has a particular geography rooted in post-war scientific collaborations, Cold War computational geopolitics and patterns of government and military funding for science (Doel 2003; Masco 2009; Howe 2014). The global models which have so far entered the IPCC’s intercomparison programmes hail from the global North, principally the US and Europe. Indeed, Edwards’ (2010, 171) statement that ‘the elite world of global climate simulation still includes no members from South or Central America, Africa, the Middle East, or Southern Asia’ remains true, although groups in India and Brazil are increasingly active. As climate models have developed, sub-modules and parameterization schemes – chunks of code representing particular small-scale processes – have circulated between modelling centres (Gramelsberger 2006; 2010; Sundberg 2007; Masson & Knutti

2011; see also Jankovic 2004). This ‘interbreeding’ raises epistemological questions about pluralism (Betz 2009; Lenhard & Winsberg 2010) and even democracy (Knutti 2010) in the community of global climate models – are divergences in model projections a healthy sign of epistemic diversity? If so, which models should be trusted more? Models can be considered ‘boundary ordering devices’, regulating the flow of information and the management of uncertainty at the boundaries of different disciplines (Shackley et al. 1998; Lahsen 2005; Sundberg 2007), and of science, politics and decision-making more broadly (Shackley & Wynne 1996; Van Der Sluijs et al. 1998; Lane et al. 2011; Daipha 2015; Donovan & Oppenheimer 2015). They are emblematic cases not just of technical mutability and interpretive flexibility, but also of efforts to invest trust, credibility and authority in largely automated or ‘autonomous’ (Morrison 1999) technologies of knowledge production (van der Sluijs 2002; Fine 2009; Wynne 2010; Hulme 2013; Daipha 2015). As such, the social coordination of worldwide intercomparison programmes and of the resulting internationalisation of climate simulation is worthy of geographical study (cf. Sundberg 2010; Davies 2013c)

Comparative perspectives on the epistemic cultures (Knorr-Cetina 1999) of the elite climate modelling laboratories are in short supply. Simon Shackley’s 2001 study of climate modellers in the US and UK is a notable exception (see also Krueck & Borchers 1999). Shackley found the UK’s Met Office Hadley Centre to possess a ‘hybrid’ style of scientific work and policy engagement which was appreciably distinct from that of comparable US institutions (see e.g. Howe 2014). The UK Government had in the late 1980s resolved to focus funding for climate simulation on one single, authoritative institution which would be close to and answerable to political actors (Mahony & Hulme 2016). But climate modelling in the US developed in a number of relatively autonomous settings, with rival models, different research orientations and links to policymakers of variable strength (Shackley 2001; on the UK context see also Shackley & Wynne 1996; Shackley et al. 1998). The effects of these different ‘epistemic lifestyles’ (Shackley 2001) can still be detected, for example in the Hadley Centre’s central role in producing national climate projections (now considered a ‘climate service’) for the UK (Hulme & Dessai 2008; Tang & Dessai 2012) and its influence on such practices in other national settings (Mahony 2014).

In contrast, Howe (2014) recounts efforts at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado to inculcate a particularly collaborative, experimental research culture through architecture, with a building designed, like the NEEM station, to ease interpersonal interactions (Skrydstrup 2016). NCAR’s veritable revolving door of visiting scientists can be read as a response to an environment wherein atmospheric scientists were wary of co-optation into Cold War research structures, the institution’s relative autonomy and lively circulation of scientists a form of resistance to the increasingly centralizing tendencies of US science policy (see also Bassi 2015). Such institutional cultures are formed through the intersection of various geographies: national, perhaps in the form of distinct civic epistemologies (Mahony & Hulme 2016); regional, in the broader patterns of scientific exchange which constitute trans-local cultures of scientific practice (Livingstone 2003; Finnegan 2008; Naylor 2010; cf. Beck et al. 2013; Fleming 2016); and global, in the shape of infrastructural globalisms (Edwards 2006) and attendant moves towards new forms of global, universalizing scientific practice (Miller 2015).

2. *Assembling the region*

Questions remain on how to make sense of the links between such institutional geographies and the geographies which are the objects of institutional knowledge-making. Laborde (2015) uses Foucault's notion of heterotopia (Foucault 1986) for this purpose (Ophir & Shapin 1991; Smith & Agar 1998). Positioning the modelling laboratory as a heterotopic space, Laborde discusses the complex relationships between the physical, segregated spaces where modelling work is conducted and the physical spaces (in Laborde's case an Italian lake) which are the target of the modelling. Heterotopias are spaces set aside from the rest of society, albeit with multiple, overlapping relationships to other spaces and times (Johnson 2013) – in the case of modelling labs, these relationships are the representational and cognitive links between model and target system. Laborde's use of heterotopia encourages reflection on the practices that make these heterogeneous spatial assemblages 'hang together' to produce authoritative knowledge (cf. Turnbull 2000). Importantly, she encourages 'a conceptual shift away from cognitive and epistemological differences between communities of practice and instead towards differences between the physical and social environments that support these practices' (Laborde 2015, 278). Spaces like the modelling lab, or modelled lakes and Antarctic ice sheets (O'Reilly 2016), are polysemic, 'with overlapping layers of different spatial formations' (Livingstone 2002, 16), requiring a spatial vocabulary that goes beyond locality and socio-spatial constitution to embrace a more fluid (but not frictionless – cf. Edwards et al. 2011; Rose 2015) topology of circulating, mutable representations and virtual mediation between different sites and forms of expertise (Law & Mol 2001; Blok 2010; cf. Kinsley 2014; Leszczynski 2015; Ash et al. 2016).

The 'universalizing instinct' of climate science (Hulme 2010b) is increasingly being supplemented, if not yet superseded, by a new focus on local variations (Stott & Thorne 2010) and the development of new, locally-focused 'climate services' targeted at both public and private sector users (Krauss & von Storch 2012; Vaughan & Dessai 2014; Webber & Donner 2016). Following Rose (1993), we might say that climate science, as an assemblage of expertise, has moved from the identification and advocacy of new (global) problems to being institutionalised (and localised) as a form of government which acts through the regulated choices of citizens and 'stakeholders', and through increasingly marketised forms of substantive expertise (European Commission 2014; see also Randalls 2010b). We can therefore further our understanding of the co-production of modelling and modelled spaces by considering how climate models have participated in transforming the *episteme* of government at multiple scales (Dean 1999; Whitehead 2011, 229; Knox 2014).

For example, PRECIS, a highly mobile regional climate model produced by the Hadley Centre, has since the early 2000s been disseminated or marketed to research institutes around the world, particularly the global South (Jones et al 2004). The making-mobile of this complex scientific tool through the production of a distinctive physical and social assemblage (its packaging in an easy-to-use software interface and institutional relationships with bodies like DFID and UNDP) can be seen as an important instance of the spatialisation of the arcane practices and technologies of climate simulation (Schaffer 1991), leading to new forms of national, predictive knowledge being pursued in government science institutes (Mahony & Hulme 2012; Mahony 2014).

Regional models promise greater spatial realism through the 'dynamical downscaling' of global simulations, and we might identify a concurrent downscaling of political concentration. Although other mobile regional models exist (e.g. Pal et al. 2007), the Hadley Centre model is unique in its construction of an extensive network of national, governmental research sites. The spatialization of this model may thus be said to be not just reflective of particular 'national' cultures of knowledge-making (cf. Shackley 2001), but to be part of a broader epistemic transformation of modes of prediction and scenario planning (e.g. Hulme & Dessai 2008; Rickards et al. 2014) and of a broader regime of calculative and imaginative practices of anticipation (de Goede & Randalls 2009; Anderson 2010; Matthews & Barnes 2016; McQuillan 2016).

Practices of anticipation act through, and upon, present geographies (Anderson 2010). The circulation of regional models, for example, has brought new geographies of cross-national scientific cooperation into being, with organisations like the Caribbean Community Climate Change Centre in Belize acting as regional hubs for predictive information and policy advice (see also the geography outlined in Giorgi et al. 2006). As Barnes (2015) has suggested, the act of defining the 'region' to be modelled can be deeply political; something recognised by IPCC authors in guidelines for regional modelling: 'An important geo-political issue may be the importance of national representation in climate models in the context of international negotiations (i.e., it may matter if a country is or is not on the map)' (Mearns et al. 2003, 21). Existing studies of the role of models in politics have focused on how information and assumptions flow across social boundaries, or more simply on what kinds of information different decision-makers feel that they need.

What is needed now, however, is further work on the actual political effects of new modes of simulation. By this we mean we mean two things: the processes of constitutive and interactional co-production by which different spaces and scales (e.g. the nation, the region, the 'local') are jointly constituted as epistemic and political objects (Whitehead et al. 2007; Moore 2008; Rangan & Kull 2009); and the effects of this co-production on shifting societal engagements with climate change (Jónsdóttir 2013; also Ahlborg & Nightingale 2012; Beck et al. 2014). One debate to which geographers can contribute is about the role of simulation models in the ontological work of defining certain local weather events as anthropogenic or 'natural', and the implications of such distinctions for the social distribution of risk and responsibility (Hulme et al. 2011). Geographers can reflect on the extent to which simulation is a distinct practice of representation and of world-making, and how simulation becomes a site of heterogeneous engineering (Law 1987) of equivalences and differences between objects, artefacts, practices and places in the production of new climatic knowledge spaces (Turnbull 2000).

V Conclusion

We have offered an approach to making sense of climate politics which emphasises the diverse and contested spatialities of climate change knowledges. The notion of epistemic geographies emphasises the world-making powers of accredited scientific knowledges, but it also brings attention to the local and trans-local attainment of scientific authority, and to the indeterminate boundaries between science and its others. Investigating the

geographies of science 'implies more than an acknowledgement of the locational context of science' (Driver 1994, 338). It is rather a conceptually heterodox attempt to answer the question of how space matters in the production and circulation of authoritative scientific knowledges. In section II we introduced a number of approaches to this question, which can be broadly bracketed as constitutive and interactional understandings of the co-production of knowledge, space and power. We then reviewed existing empirical engagements with the epistemic geographies of climate change, relying, to a large extent, on work from outside geography, which nonetheless exhibits resonances with extant work on historical and contemporary geographies of science.

There is scope and need for greater theoretical reflection on the spatialities of scientific knowledge and on science's role in the ongoing (re)making of common cultural, political and material worlds (e.g. Carey et al. 2016). We have suggested the STS notion of co-production as one fruitful mode of thought which is largely absent from geographical work on climate change thus far. Co-production encourages analytical symmetry in its treatment of science and politics, knowledge and power, and is therefore an appropriate lens through which to view the complex cultural politics of climate change. For the epistemic geographies of climate change, co-production draws attention to how certain '[r]epresentations of the natural world attain stability and persuasive power' (Jasanoff 2010, 236). But this is achieved 'not through forcible detachment from context' as ANT modes of thought tend to suggest, 'but through constant, mutually sustaining interactions between our senses of the *is* and the *ought*: of how things are and how they should be' (ibid, 236).

Such a perspective has significant practical implications for how public policy and practice in response to climate change is shaped. Knowledge, of whatever sort, can never arise independently of culture, from human ways of doing things. And so knowledge of climate always carries with it beliefs and values about the world it is seeking to describe. The objective of the IPCC to make knowledge which is 'policy relevant, but policy neutral' is therefore a chimera and needs calling out. The ambition of Future Earth to 'co-produce knowledge' for transformation of society is more promising, but urgently needs the awareness of the knowledge politics of climate change which the geographical scholarship reviewed here can offer (see Castree et al. 2014). Acting in the world may be a corollary of knowing the world, but *how* one acts is already bound up with *how* one knows. Different knowledges lead to different actions.

An expanded notion of the epistemic geographies of climate change departs from an interest in geographies of circulating knowledges to examine the geographies of diverse ways of knowing; the spatialities of the sites, practices, discourses and imaginations through which climate is made known, whether these spatialities are dominant or marginal, authoritative or contested. As such it is an approach which articulates new questions about the nature of knowledge and possibilities for acting in the world (Arendt 2013). We have identified promising new areas of research, including the cultural geographies of the field and of adaptation science, the epistemic cultures of scientific assessment, public spaces of scientific performance, and the performativity of simulation at multiple scales. To this list we may add the public and private organisational spaces of climate work including emissions accounting (Asdal 2008, 2011; Lovell & Mackenzie 2011) and carbon trading (Callon

2009; Lovell & Ghaleigh 2013), the 'intermediary' networks of consultants, communicators and activists who 'play explicit roles in producing and circulating' climate knowledges (Larner 2011, 330), and the (largely virtual) spaces where the claims of mainstream climate science are being publicly contested (Sharman 2014; Pearce et al. 2014; Sharman & Howarth 2016). Such work would allow deeper exploration of the co-production of diverse, even dissident knowledges, practices and political imaginations (Demeritt 2006). The cultural geographies of all of these spaces may shed further light on how, in the case of climate change, 'science does not transcend our particularities; it discloses them' (Livingstone 2002, 10).

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ⁱ We don't have space here to comprehensively cover the burgeoning literature on the histories and historical geographies of meteorology and climatology, but see for example Naylor (2006), Jankovic (2000), Richards (2011b), Veale et al. (2014), Mahony (2016), Fleming (2016).

ⁱⁱ Fleming (2016, 80) disputes this point.